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Review of Petroleum Occurrence and Prospects of Pakistan with Special Reference to Adjoining Basins of India, Afghanistan and Iran

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ABSTRACT

Pakistan is endowed with three major sedimentary basins (covering more than 2/3 of its total area) namely, Indus in the east which extends east and south-eastward into India; Balochistan in the west which continues northward into Afghanistan and westward into Iran; and Pishin in the northwest which is spread into Afghanistan. The two basins, Indus and Balochistan are separated by a north-south trending Bela-Ornach-Chaman transform fault zone while the Pishin is perched in between this fault zone and the Indus basin. Indus is the only producing basin of Pakistan where 83 oil and gas fields have been discovered.

Review of data indicates that in Balochistan basin some speculated petroliferous plays could exist in Eocene-Plio-Pleistocene clastic/carbonate reservoirs which are probably filled with oil and gas charged from interbedded shales as well as from underlying formations. The oil and gas in southern part of the Indus basin had been mostly formed in Early Cretaceous shales deposited during rifting phase and generation probably took place as early as Paleocene. In the northern part of the Indus basin most of the oil was generated from Paleocene source rocks which were deposited in restricted marine conditions created by compression related to first episode of collision. The structural styles in Indus basin from its southern to northern areas change from fault traps associated with Cretaceous block faulting to inversion of extensional features and to younger compressive structures produced by collision, subduction and thrusting. Tertiary flysh thrown into complex structures in Pishin basin appears to have speculative potential for containing hydrocarbons as the basin has not yet been explored.

INTRODUCTION

The sedimentary basins of Pakistan and their sub-basins/fold belts, which developed as a result of diverse geodynamic conditions, embody different structural styles associated with varied tectonic environments, such as, rift-inverted extensional, convergent-divergent wrench, overthrust-compressional, remnant fore-arc-inter-arc subduction.

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The variety of structural patterns seen in sedimentary basins of Pakistan makes it essential to understand various entrapment systems of migrating oil and gas, in addition to defining organic rich source beds and porous accumulators through conventional laboratory techniques.

Hydrocarbon Development Institute of Pakistan (HDIP) has carried out a number of basin studies which include geological modelling. The results of these studies together with the available researches by others have been used in this paper to depict an updated petroleum geological picture of various sedimentary basins of Pakistan and their sub-basins/fold belts defined so far as distinct potentially hydrocarbon bearing sedimentary areas with recognizable producing analogs elsewhere in the world. Information on adjoining regions has also been incorporated to complete the picture, some of the significant sources of information are: Wadia (1957), Tainsh et al (1959), Hunting Survey Corporation (1961), Zuberi and Dubois (1962), Rehman (1963), Bakr and Jackson (1964), Movshovitch and Malik (1965), Wellman (1966), Bishop (1968), Voskresensky et al (1968), Rehman (1969), Abdel-Gawad (1971), Auden (1974), Farah (1976), Menke and Jacob (1976), Sylvester and Smith (1976), Nicolas et al (1977), Shah (1977), DeJong (1978), Chaudhry (1979), Abdullah (1979), Desio (1979), Kazmi (1979), Lawrence and Yeats (1979), Powell (1979), Quittmeyer et al (1979), Sarwar and DeJong (1979), Ahmed and Abbas (1979), Asrarullah et al (1979), Bordet (1980), Armbruster et al (1980), Boulin (1980), Gupta and Singh (1980), Lawrence et al (1980), Jackson (1980), Klemme (1980), Gansser (1981), Lawrence et al (1981a), Kazmi and Rana (1982), Kemal et al (1982), Abid and Siddiqi (1982), Biswas (1982), Ahmed and Ashten (1982), Balli (1983), Raza and Alam (1983), Farah et al (1984), Ali and Ahmed (1985), Ali (1985), Plat et al (1985), Khan and Raza (1986), Khan et al (1986), Banks and Warburton (1986), Seemann et al (1988), Soulsby and Kemal (1988), Ahmed et al (1988), Malik et al (1988), Ahmed and Ali (1988), Raza et al (1989, 2), Hiller and

Ahmad (1989), Bannert et al (1989), Hiller and Ahmed (1990), Lowell (1990), Humayon et al (1990), Iqbal (1990), Shafique and Daniels (1990), Ahmed and Alam (1990), Raza and Ahmed (1990), Ali et al (1991), Ahmed and Ali (1991), Ahmed and Ahmad (1991), Jadoon (1991), Hildebrand et al (1991), Ahmed (1991), Khan et al (1991), Ahmed et al (1992), Ahmad and Alam (1992), Raza et al(1992).

TECTONIC FRAMEWORK

Presently three main sedimentary basins occupy Pakistani territory (Figure 1). These are: Indus, Balochistan and Pishin. The Indus basin is located on the Indian plate and is a part of the Indian land-mass. The Balochistan basin owes its existence to subduction of an Arabian oceanic slab under a block of the Eurasian mega-plate. The Pishin basin developed in response to plate margin adjustments.

Indus Basin

The Indus basin is the largest and the only producing basin among the three Pakistani basins. Its sedimentary history is as old as Precambrian (Figure 2). The Precambrian to Permian shallow marine sediments exposed in the Salt Range were probably laid down in an intra-cratonic sag setting on the Indian plate which at that time was a part of the Gondwana.

The fragmentation of Gondwana was completed during Triassic to Early Cretaceous time when platform carbonates and restricted marine clastics with a plenty of source rock material were deposited specially in the areas close to the plate margin. The rifting away of the fragmented portions of the Gondwana onset an extensional regime near separating plate margins. Block faulting can be found buried in southern Indus basin. Transgressive deposits with more open marine conditions were laid down during drifting of the Indian plate in Middle and Late Cretaceous time covering the older restricted marine, organic rich sediments.

The northward drifting Indian plate finally collided with the Eurasian plate probably in Paleocene time. The impact of collision combined with large scale transform movement in the west is manifested in the form of fold and thrust belts, development of sub-basins and reactivation and inversion of Cretaceous block faults. Reefs and shoals producing good reservoirs developed on reactivated horsts during Late Paleocene to Middle Eocene time when the marine basins were being turned into land areas. Organic rich shales and coal were deposited during some restricted marine environmental cycles developed during Paleocene time due to initial collision in newly formed sub-basins.

Balochistan Basin

The Balochistan basin is a sedimentary basin of Cretaceous to Recent age (Figure 2). It is an active subduction basin produced by subduction of an oceanic slab of the Arabian plate beneath a block of the continental Eurasian plate. An island arc-trench system remained active during most of the Cenozoic, surrounded by active transform movement along continent-to-continent collision boundaries in the east and the west which also affected its geometry. The convergence has now totally closed the arc and the basin has reached a non-arc stage. The basin has been under explored.

Pishin Basin

The Pishin basin is developed as a Cenozoic clastic sedimentary basin (Figure 2) in the plate marginal area, deriving its clastic sediments from the rising areas in its surrounding. It has experienced compression as well as wrenching and as a result complex structural geology has developed. The basin is unexplored.

PAKISTAN AND ITS BORDERING SEDIMENTARY BASINS

Pakistan's three sedimentary basins extend into adjoining countries: Indus has its eastern part continuing into India (Jaiselmer, Punjab, Cambay-Bombay and Kutch basins of India are connected with Indus basin of Pakistan); Balochistan continues into Iranian Makran in the west and its Chagai arc extends in the north into Afghanistan where a back arc basin: Hirmand, is developed; and Pishin continues into Afghanistan in the north where it is known as Kundar- Urgan basin (Figure 1).

Afghanistan: Petroleum Summary

First oil discovery in Afghanistan was made in 1977 at Angot which was followed by another discovery at Ak-Darya the same year. The third and last discovery was made at Kashkar in 1979. The oil reserves discovered so far are very meagre and are located in northern Afghanistan (Figure 1).

Afghanistan has known gas reserves of about 5 trillion cubic feet. All the discoveries are located in northern Afghanistan (Figure 1). The two main fields are Hodja-Gugerdag and Djarkuduk. The transmission infrastructure leads to ex-U.S.S.R.

Prospects near Pakistan border.- The southern and southeastern Afghanistan is an unexplored area (Hirmand back-arc basin and Kundar-Urgan basin, Figure 1). Unfortunately, on the Pakistani side (in Pishin basin) also exploration has not been done. Based on the study of geology on Pakistani side, it can be said that modest oil and gas prospects exist in southern and southeastern Afghanistan.

India: Petroleum Summary

The oil reserves (proven and inferred) of India are about 6 billion barrels whereas its natural gas reserves stand at about 26 trillion cubic feet. The country remains an oil importer despite having adequate oil reserves. India needs better oil development plan and more utilization of its natural gas reserves in order to reduce liquid fuel imports and protect its environment. Both India and Pakistan shared a common petroleum industry till 1947. Since some petroleum basins are common between them, the two countries keenly follow each others progress in oil and gas exploration.

Prospects near Pakistan border.- A number of gas discoveries e.g. Tanot, Sadewala, Manhera Tibba etc. in Tertiary reservoirs and a Cambrian heavy oil discovery have been made in India near Pakistan border (Figure 1). The gas discoveries were inspired by the giant Mari discovery in Pakistan which is located close to the above mentioned area.

Oil and gas discoveries have also been made in Cambay basin and Bombay high areas which lie in line with Panno Aqil graben of Pakistan. Bombay high discovery is a giant. Some gas discoveries have also been made in the Indian Kutch basin which extends into Pakistan.

The exploration results on both sides of the border confirm prospectivity of all the remaining unexplored area in Sukkur rift-Jaiselmer-Cambay and Kutch areas. Prospects of Punjab platform, which are generally low in view of smaller sedimentary fill and low geothermal gradients have slightly been enhanced by the Cambrian oil discovery on Indian side. Similarly, Cretaceous stratigraphic trap gas discoveries of Kadanwari and Miano would draw attention to the area east of these discoveries.

Iran: Petroleum Summary

Since first discovery of oil in southwestern Iran in 1908, the country with all its ups and downs of the petroleum industry, has remained one of the major oil suppliers of the world. It has a distinction of having a number of super giant oil fields like, Agha Jari, Marun, Rag-e-Safid and Gach Saran. The oil and gas reserves of Iran are about 93 billion barrels and 700 trillion cubic feet respectively (British Petroleum, 1993).

Prospects near Pakistan border.- There is a continuity of sedimentary sequences across the western border of Pakistan into Iran (Balochistan basin). Unfortunately, the oil-rich Iran which has large reserves in the Gulf area has not seriously explored its part of the Balochistan basin.

The surface geological studies and laboratory analysis of samples carried out by HDIP indicate good oil and gas potential. Gas seepages are present on both sides of the border whereas an oil seepage is reported near Pak-Iran border which confirm occurrence of oil and gas in Balochistan basin.

Pakistan: Petroleum Summary

The first commercial discovery in Pakistan dates back to 1915 when Attock Oil Company discovered oil at Khaur in northern part of the Indus basin. Since then oil in small quantities has been discovered in two areas only: Potwar and Badin. The gas has been found at a number of places in Indus basin, including 3 giants at Sui, Mari and Qadirpur.

Pakistan despite discovery of some 83 oil and gas fields is able to meet only about 25 percent of its current oil demand, the reason being exploration in one basin only and non-discovery of any giant oil field. In our view the exploration in the past was not always based on proper geological understanding of the basin and as a result there were a number of unnecessary failures which discouraged large scale foreign participation. The hydrocarbon production, reserves and resource of Pakistan are shown in Table 1.

Table 1. Hydrocarbon production, reserves and resource of Pakistan (Source: HDIP).

	OIL	GAS
Current Production	60,000 BPD	1,600 MMCFD
Proven Reserves	480 Million bbl	31 TCF
Potential Resources	40-50 Billion bbl	200 TCF

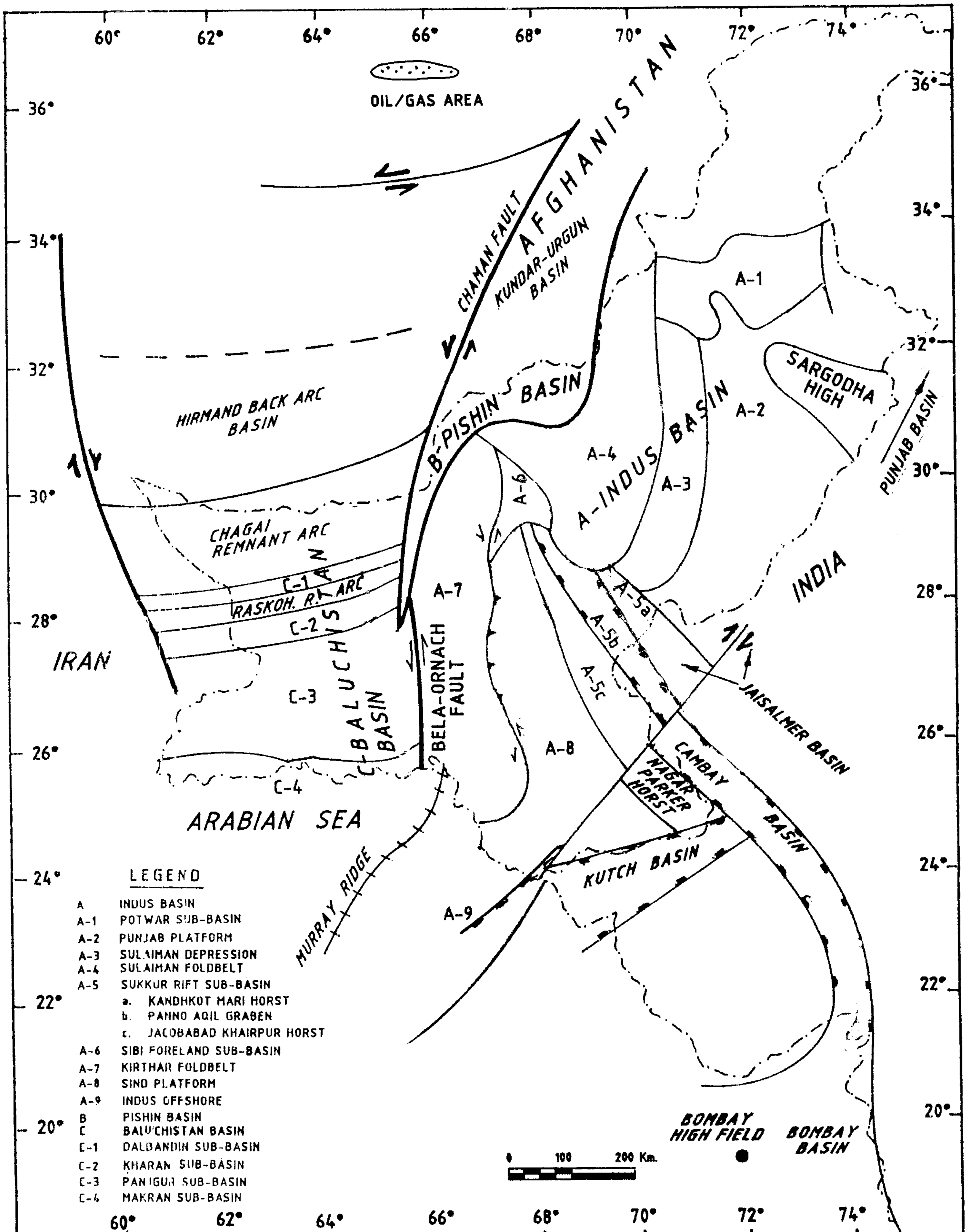

Figure 1– Basin map of Pakistan (Source: HDIP).

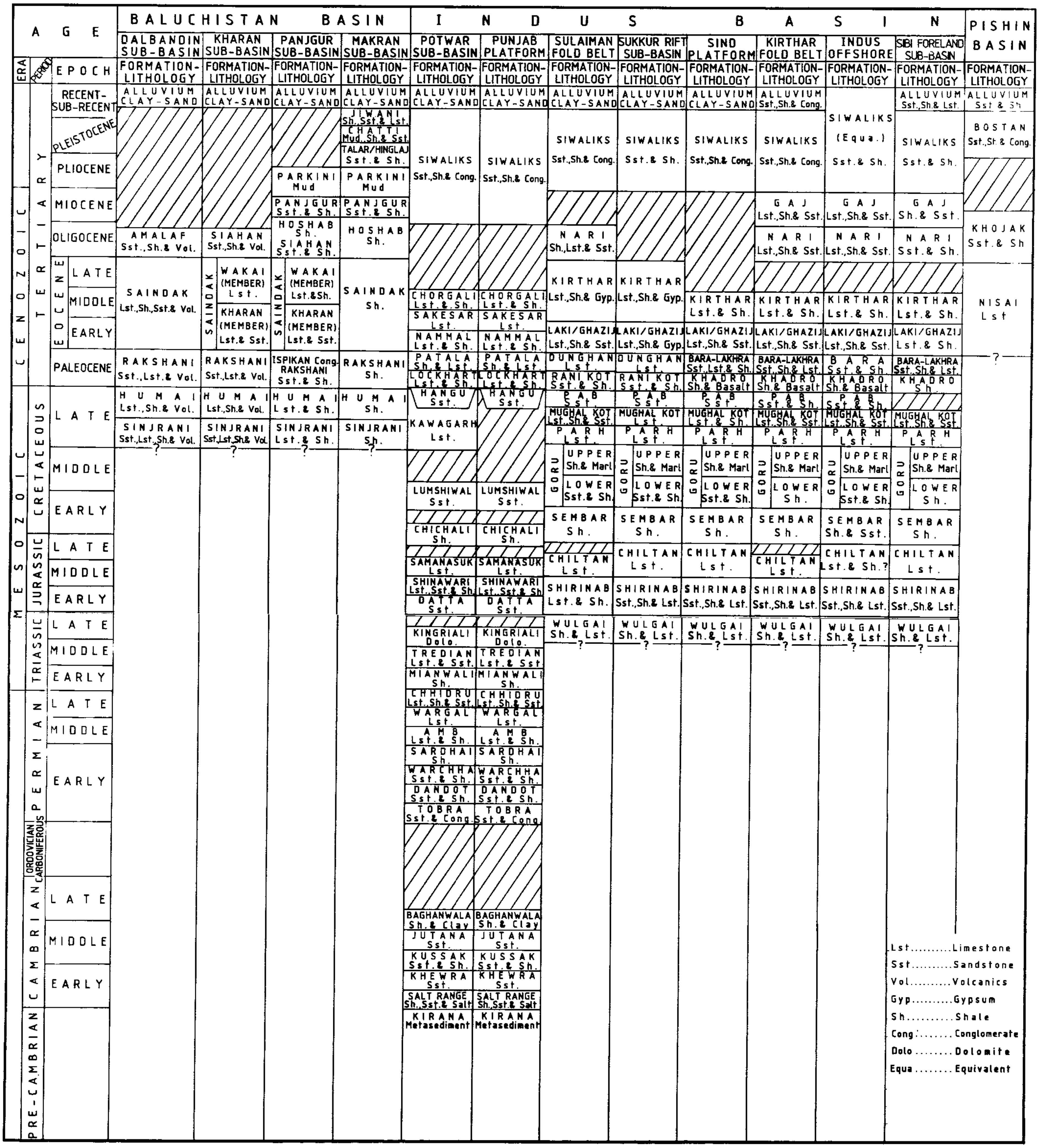

Figure 2– Stratigraphic succession in Pakistani basins.

PETROLEUM OCCURRENCE AND PROSPECTS OF PAKISTAN

Indus Basin

The basin belongs to the class of Producing Extra-continental Downwarp Basins. All known oil and gas reserves of Pakistan are located in this basin.

Tectonically, it exhibits complex features due to change from passive to active plate setting during its long history of sedimentation and configuration. The events, rifting of a passive Gondwana, drifting, collision and subduction of Indian plate fragment, coupled with large scale strike-slip movement are manifested by development of various types of facies and different structural regimes in a number of basinal elements.

The following overview is aimed at highlighting the prospectivity of potentially hydrocarbon-bearing areas of the basin by using key parameters like, source rocks (Table 2), reservoirs rocks, traps, etc. as prospectivity indicators.

Table 2. Key source rock formations of Indus, Balochstan and Pishin basins (Source: HDIP).

Basin	Source Rocks Formation	Age
North Indus basin	Jatta Gypsum	Eocene
	Patala*	Paleocene
	Salt Range	Precambrian
Centre and South Indus basin	Kirthar*	Eocene
	Laki/Ghazij	Eocene
	Sembar*	Cretaceous
	Anjira Member*	Jurassic
Balochistan basin	Parkini	Miocene-Pilocene
	Panjgur*	Miocene
	Hoshab*	Oligocene-Miocene
Pishin basin	Murgha Faqirzai*	Oligocene

*Main source rock.

Potwar sub-basin.- The Potwar sub-basin is located close to the northern margin of the Indian plate (Figure 1) and contains sedimentary rocks of Precambrian, Paleozoic and Mesozoic eras. It is the oldest and most prolific oil producing area of Pakistan. The size of discoveries, however, had been below 50 million barrels mark. Occidental, OGDC, POL and PPL are the major producers.

Potential source rocks are the shales of Precambrian, Permian, Jurassic and Paleocene-Eocene ages. Geochemical studies by HDIP-BGR of the surface and well samples, however, show that the oil accumulations discovered so far are mostly sourced from laminated organic rich calcarous black shales of Paleocene age (Patala shales) which were partly laid down in anoxic conditions prevailing during Paleocene due to buckling of the basin floor and reasons for some of the older accumulations might lie in tectonics.

A large number of sandstone and carbonate horizons qualify as potential reservoir rocks. The producing reservoirs are the porous sands of Cambrian, Permian and Jurassic ages and the fractured and diagenetised carbonates of Paleocene and Early Eocene ages. The productive traps are mostly anticlines produced as a result of compression.

Despite long and concentrated exploratory activity still a number of abandoned prospects and untested disguised structures remain in the sub-basin which could be explored using new seismic and drilling techniques. Delineation of stratigraphic traps specially related to major unconformities could also form interesting targets in southern part of the sub-basin. The northern and north eastern part with intense thrusting, and the western area with an Eocene salt cover over prospective reservoirs hold the key to future exploration.

Punjab platform and Sulaiman fold belt.- The Punjab platform and Sulaiman fold belt occupy central part of the Indus basin (Figure 1). The area has so far produced mainly gas with condensate at two places (Dhodak) and Savi Raga. The producing horizons are in Jurassic-Paleocene sandstones (Rodho, Dhodak, Pirkoh, Nandpur & Punjpir gas fields) and Eocene limestones (Sui, Loti, Zin and Uch gas fields). OGDC and PPL are the producing companies in the area.

The geochemical results indicate the presence of immature source rock material in Precambrian shales in Punjab platform. Locally prospects of Precambrian oil exist where sediment thickness is increased or some igneous activity had raised the paleotemperatures. Eocene shales/argillaceous limestones in Sulaiman fold belt according to various geochemical studies of HDIP-BGR are the best potential source rocks. The results of spot samples also indicate that source rock potential exists in Triassic-Eocene formations in various parts of fold belt.

Accumulations of migrated oil and gas are expected in anticlines related to salt diapirism and paleotopography, and stratigraphic traps in Punjab platform. In Sulaiman fold belt prospects may exist in compression-produced anticlines in the foreland areas and probable sub-thrust plays in Tertiary and older strata towards hinterland (Ali et al, 1991). The intervening depression (Sulaiman depression) is a hydrocarbon kitchen area, the oil and gas could have been trapped in its flanks along migration paths.

Sukkur rift sub-basin.- It is a reactivated rift feature. There are a number of gas discoveries in the area which also include the giant Mari field. Most of the discoveries are in Eocene limestones while two discoveries (Kadanwari and Miano) are in Cretaceous sandstone (L.Goru). The drilling has so far concentrated on horsts where gas discoveries have been made at shallow depth. The graben area has not been explored as yet which may produce oil as is the case in adjoining Indian area (Cambay graben). Discovery of some condensate with gas at Qadirpur field is also an indicator that the graben may contain liquid hydrocarbons. Mari, Lasmo and Premier/OGDC are the main producers in the sub-basin.

Sembar shales (Early Cretaceous) are the main source rocks which were deposited during rifting phase. Geochemical analysis of samples by HDIP-BGR from the nearby Sulaiman fold belt have revealed the presence of oil shales in Habib Rahi limestone (Middle Eocene).

The target reservoirs are the Eocene limestones/ sandstone, Cretaceous-Paleocene sands and Jurassic limestone. Additional prospects may also exist in Jurassic limestones if in contact with a fairway from a younger source or some source beds are developed within Jurassic sequence.

Recent work by authors indicates reactivation of Mesozoic rift features probably during Tertiary time.

Detailed investigations are underway to decode the subsurface fault patterns which hold key to future exploration in the area.

Sibi foreland sub-basin.- This small but distinct basinal area is dominated by fault-bounded trap-door structures in the north and northwest, and wrench associated structures in the west.

The area is still a frontier as the two wells (Bannh-1 and Sanni-1) drilled so far did not cross the Siwalik overburden. The prospects in the west lie at drillable depths in Paleocene-Eocene limestone and Paleocene sandstone reservoirs within wrench associated structures. In the north and northwest the exploratory targets should be the Jurassic-Eocene limestones and Paleocene sandstones which should occur at shallow depths within fault-bounded trap-door structures. Goru sandstone (producing reservoir in Badin area) and Pab sandstone are probably not developed in Sibi area.

The presence of oil seepages at Khattan (Sulaiman Range) and Gokurt (Kirthar Range) near the periphery of the sub-basin provides evidence for oil generation near the sub-basin. Existence of potential source rocks within Triassic-Eocene sediments in nearby Sulaiman and Kirthar ranges should further encourage exploration in the sub- basin.

Los Angles basin is a producing example of traps associated with wrenching. Keystone field of the Permian basin of foreland of the Marathon thrust-fold belt in West Texas and Grass Creek field of Big Horn basin are comparable examples of compressive block style with trap-door configuration (Lowell, 1990).

Kirthar fold belt.- Exploration of fold belts has become a state-of-the-art. New concepts have led explorationists to unfold structural development before prospecting for petroleum in fold belt areas.

Banks and Warburton (1986) proposed a passive roof duplex model for Northern Kirthar Range. Recent studies by HDIP (Ahmed and Ali, 1991) review that the feature is a product of collision and left lateral transform movement from west along Bela-Nal-Chaman fault zone to the eastern part of Kirthar fold belt, which has resulted in the development of two different structural styles in the eastern part of Kirthar fold belt: (i) Convergent wrench driven in the north, (ii) Divergent wrench associated in the south. Recent studies indicate that as a result of divergent wrenching a divergent wrench basin has been developed in the southern part of Kirthar fold belt.

Traps associated with en-echelon normal fault blocks and negative flower structures might have been developed in the subsurface within Mesozoic-Tertiary section which may form potential targets for hydrocarbon exploration in this basin. Such type of traps are common in divergent wrench regimes elsewhere e.g. New port-Inglewood Trend, California, Scipio-Albion Trend, Michigan and Cottage Groove Fault System.

Potential source rocks have been identified by HDIP-BGR in Cretaceous-Eocene section. Limestones of Jurassic, Paleocene and Eocene and sandstones of Cretaceous age can be the target reservoirs. Paleocene limestone is the proven productive horizon in the area.

Sindh platform.- The productive area on the Sindh platform (Badin) contains both oil and gas in the form of small pools accumulated in a network of small fault traps along tilted fault blocks associated with Mesozoic rifting. UTP and OGDC had been the successful producers.

Source rocks are mainly the Sembar shales (Early Cretaceous) which were deposited during rifting. The Goru sands which are the main producing reservoirs overlie the source beds.

Chiltan limestone could also hold prospects of accumulating oil/gas coming from Anjira Member or from its own source.

Indus Offshore

The Indus offshore is characterized by the presence of a large delta. The subsurface structures are related to normal faults in the east and listric normal faults and diapiric structures in the west.

Source rock material is expected in Cretaceous-Oilgocene section. Occurrence of hydrocarbons is confirmed (PakCan-1 well encountered gas in Miocene sands) but the drilling effort has so far been insignificant.

Cretaceous-Miocene sandstones and Eocene limestones can be targeted as potential reservoirs associated with fault traps. Probable reef build up in the southeast at Eocene level may also form potential target.

Balochistan Basin

Balochistan basin is of subduction non-arc category (Raza et al, 1991). Very little exploration has taken place in this large basin which extends westward into Iranian Makran. Sediments of Cretaceous to Recent ages are known to be filling the basin.

The evidence of gas accumulation can be derived from the chain of mud volcanoes which emit methane gas along with the mud discharge. This gas has been analyzed and found to be thermally mature. An oil seepage is also reported at Kwash near Pak-Iranian border. Gas shows were also encountered in Garkoh-2 in the coastal area.

Potential source (Table 2) and reservoir rocks are mainly confined to Tertiary section.

Four sub-basins namely, Dalbandin, Kharan, Panjgur and Makran have been briefly discussed for their prospectivity.

Dalbandin sub-basin.- The Dalbandin is a small sub-basin with limited petroleum prospects expected in Eocene limestone/sandstone and Oligocene sandstone at shallow depth in view of high geothermal gradient.

Kharan sub-basin.- Paleogene sediments are the main targets in this sub-basin which is filled by thick dominantly clastic sediments. Eocene limestones and Oligocene-Miocene sandstones form good target reservoirs. Good source beds in Paleogene, efficient migration system and possibility of traps developed along normal fault blocks make it as one of the prize area for exploration in Balochistan basin.

Panjgur sub-basin.- The Panjgur sub-basin which has probably been produced as a result of wrench tectonics has often been down-graded due to its complex surface geology but the new interpretation of HDIP indicates the presence of traps at drillable depths within Eocene-Miocene section associated with positive flower development (Raza et al, 1990). HDIP- BGR source rock studies show the presence of potential source rocks in Oligocene-Miocene section. Panjgur turbiditic sandstones with high porosity can serve as excellent accumulators. An oil seepage is also known to be present in western part of this sub-basin near Pak-Iran border which further lends support to its prospectivity. The area deserves to be seismically explored anticipating positive flower structuring for delineation of traps suitable for drilling.

Makran sub-basin.- The Makran sub-basin is an active area of subduction. It is filled with younger Tertiary sediments. Talar sands and Panjgur turbidites are the main targets in structural and stratigraphic traps developed in the area. HDIP has confirmed through its laboratory studies the presence of source beds in Oligocene-Miocene section.

Pishin Basin

The Pishin basin is a small Tertiary basin of Median class (Raza and Ahmed, 1990). There is absolutely no exploration history of the basin either in Pakistan (Pishin basin) or in Afghanistan (Kundur-Urgan basin, Figure 1). The only available information is about its dominantly clastic nature of sediments, occurrence of an oil seepage, surface structuring, and estimated sediment thickness through gravity data and surface geological mapping.

Potential source rocks are expected within Eocene-Miocene shales. Eocene carbonates and Eocene-Miocene sandstones may be the potential reservoir rocks.

Compression-produced anticlines associated with probable wrench tectonics can be the prospective targets.

ANALOGS OF PAKISTANI BASINS

Pakistani basins can be generally classified on the world basins classification scheme of Halbouty et al (1970) and subsequent modifications by others e.g. Riva (1983) and Klemme (1987).

Indus Basin

The large Indus basin with its asymmetric profile is located south of the great Himalayan Range on the Indian lithospheric plate. It was formed as a result of collision of the down-rushing Indian plate with the overriding Eurasian plate. Its genesis brackets it with Extra-continental downwarp basins (class IV of Halbouty et al, 1970), such basins are defined by their location along continental margins and downwarping into oceanic areas. The basic type in this class of basins is the open downwarp which opens into small ocean basins. Subsequent deformation depending upon severity of plate movement and collision modifies it to close and trough downwarp types.

The Extra-continental downwarp basins account for about 50 percent of the world's oil and gas reserves and include prolific producing basins viz., Arabian-Iranian (Middle East), Gulf Coast (USA) and Tempico and Reforma-Campeche (Mexico). The yield of producing basins of this class varies from 20 to 600 thousand barrels of oil and equivalent gas per cubic mile (Riva, 1983).

The Indus basin shares the following geological characteristics with other basins of its class: (i) substantial thickness of sedimentary fill which commonly comprises Paleozoic, Mesozoic and Tertiary deposits and is dominated by greater thickness of Mesozoic and Tertiary sedimentary sequences, (2) optimum geothermal regimes, (3) occurrence of thick organic-rich shales, (4) accumulation of thick carbonate reservoirs, (5) presence of evaporite sequences, and (6) formation of greater number of compression related anticlinal structures with additional salt-induced and combination traps.

A list of basins of Extra-continential downwarp class which can in a broader sense be taken as analogs of the Indus basin is given below for comparison of prospects.

1. Arabian Iranian basin,
2. Southern Soviet basins (ex-Soviet Union),
3. Eastern Venezuelan basins,
4. Some American basins, like Gulf Coast and North Slope,
5. Mexican basins,
6. North Borneo-Sarawak basin,
7. North Canadian basin (Sverdrup),
8. Rumanian basin (Ploesti),
9. Italian basin (Po Valley),
10. North Australian basin,
11. Assam-Bangladesh basin.

Since Indus basin is a very large basin and it contains fold and thrust belts at its margins in the north and west, depressions/troughs/foredeeps in the middle and sloping platform in the east with buried rifted features of Mesozoic age in its southern part, and oceanic area with attached deltaic features in the south, some of its parts can also be individually compared with other areas of the world, e.g. (1) rifted area of the Indus platform with Cambay-Bombay (India), Sirte (Libya)), Suez (Egypt). Tsaidam (China) and Gulf of Siam (Thailand); (2) the Sibi foreland sub-basin with Permian and Big Horn basins (USA); (3) Kirthar fold belt with Alborz (Iran) and Andes (Venezuela and Colombia); (4) Indus delta with Niger delta (Nigeria, and Mississippi delta (USA); and (5) Punjab platform with Oman platform.

Balochistan Basin

The basin is classified as Extra-continental subduction basin (class VI of Halbouty et al, 1970). Some researchers of Pakistani geology place it in the fore-arc sub-class, but the authors consider it a non-arc subduction basin. However, within this now modified non-arc basin, remnant fore-arc and inter-arc areas are recognizable.

The share of subduction basins to world petroleum reserves is about 7 percent. The yield per cubic mile of sediments is in the range of 20 to 300 thousand barrels.

Like most of the other non-arc subduction basins, Balochistan is Tertiary in age and contains mostly clastic sediments. Potential reservoirs are shallow marine porous sandy beds and turbidites. The traps have been formed by draping of sediments over fault blocks.

Its best source rocks are associated with turbiditic sequence. Geotherms are also expected to be high leading to easy generation and migration of hydrocarbons.

Since the basin is more or less unexplored, possibility of finding a giant field is very bright as subduction basins have a reputation of commonly containing a giant.

Some of the analog basins are listed below for comparison of prospects.

1. Talara (fore-arc),
2. Java-Sumatra basins (back-arc),
3. Los Angles, Ventura, San Jaquin, Sacramento, Salinas, Santa Maria (USA; non-arc),
4. Baku (non-arc),
5. Vienna (non-arc).

Pishin Basin

It has been classified as Extra-continental median basin (Raza and Ahmed, 1990 and Ahmed, 1991) due to its location in plate margins. Median basins which are equivalent of class VII of Halbouty et al (1970) are known to contain 20 to 300 thousand barrels of oil equivalent per cubic mile of sediments. Their contribution to the world reserves is only 2.5 percent and the best example is Maracaibo basin of Venezuela.

Pishin basin is a frontier basin but geologically it has many key factors common with other basins of its class, for example, small size, Tertiary age, predominantly clastic sediments, combination trap situations created due to wrenching over block uplifts and collapse structures.

Some of its analogs are: Gippsland (Australia), Kutei (Indonesia), Taranaki (New Zealand), Upper Magolena (Colombia) and Central Iran.

CONCLUSIONS

Pakistan's sedimentary basins account for approximately 2/3rd of its total area. Out of the 3 main basins namely, Indus, Balochistan and Pishin, only one (Indus) falls in the category of producing basins.

Complex and varying tectonic frames in Pakistan leave little room for sweeping general evaluations, and each basinal feature is unique and demands individual assessment of its prospectivity. The present study has, therefore clearly defined different structural regimes developed in relation to varying tectonic setting in various sub-basins in order to properly understand and delineate traps.

The key mature source rocks in Indus basin are organic rich argillaceous beds within Precambrian, Cretaceous and Paleocene-Eocene stratigraphic units. The identified source rocks of Balochistan basin are shales/ clays of Oligocene to Miocene age.

In Indus basin the stratigraphic column is so extensive that often multiple reservoirs are targeted for drilling. These accumulators are often well sealed by their own shales/clays or those of overlying formations.

Abandoned wells both in well explored as well as sparsely explored areas if re-evaluated through new seismic and in the background of new structural concepts discussed in this paper could result in discoveries.

Pishin basin which extends into Afghanistan and Balochistan basin which continues into Iranian Makran have good worldwide producing analogs. These basins should be geologically and seismically prepared before planning any drilling to save them from any further down-grading.

Reactivated rift and inverted extensional features within Indus basin merit more state-of-the art exploration for success. Already, a number of discoveries have been made in such features in Pakistan. Adjoining rift basins of India are also quite productive.

Possibilities of striking giant discoveries exist in those unexplored areas which do not lie too close to the collision front. Major discoveries are also possible in stratigraphic traps which are developed over large Indus and Balochistan basins under the influence of frequent facies and thickness changes. Kadanwari and Miano gas discoveries in Indus basin which are of stratigraphic type provide evidence of subtle entrapment in the Indus basin.

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