[PS]Hydrocarbon Prospects of Balochistan Basin Revisited - Delineation of New Horizon for the Discovery of Hydrocarbons in Southwestern Part of Pakistan*

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Abstract

During the last five decades, several tectonic models were proposed by various researchers to explain the geologic setting viz-a-viz hydrocarbon potential of southwestern part of Pakistan, the Balochistan Basin, comprising Chagai Volcanic Arc, Kharan-Mashkhel-Panjgur Trough, and the Makran Flysch Basin. In the 1960s and then in the last decade or so, several exploratory wells were drilled focusing particularly in the offshore along the coastal areas of Makran accretionary prism. The wells drilled in the 1960s were abandoned due to abnormally very high pressures, while those drilled in the last decade did not find reservoirs. Simultaneously, most of the researchers proposed an active subduction of the Arabian oceanic plate beneath the Afghan Craton (block of continental landmass). The failure of exploratory drilling on the accretionary wedge in 1960s diverted the attention from further hydrocarbon exploratory activities in the region till late 1990s when exploration activities resumed in the same region, which again despite the drilling of three offshore wells did not yield positive results. However, Kharan-Mashkhel Trough (Forearc basin?) still remains unexplored. This calls for the reassessment of the exploration model for the Balochistan Basin. The results of the present research study reveal the conducive environments by delineating the new horizon for the discoveries of hydrocarbons in the region. Based on present integrated geophysical analyses supplemented with detailed geological data, it is identified that the exposed or near-surface geologic trends are camouflaging the deep-seated geologic trends, which are entirely different in their tectonic style and other geologic characteristics. Considerably larger sedimentary basins have been identified in Kharan-Mashkhel-Panjgur region based on the analysis of the satellite gravity anomalies. Moreover, the results of the fault-plane solutions indicate the rifting nature of these basins indicating the possibility of tilted fault block traps. The results of the aeromagnetic and detailed geological data analyses demonstrate the presence of significant geothermal environments, which may have provided sufficient maturity level to relatively younger source

rocks. However, the above needs to be confirmed by seismic survey results in the Kharan Basin region. By integrating all the above factors, it is inferred that if unraveled appropriately, these basins may be the excellent targets for the hydrocarbon exploration in Pakistan in the future.

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Introduction

During the last five decades, several tectonic models have been proposed by various researchers to explain the geologic setting viz-a-viz hydrocarbon potential of southwestern part of Pakistan, the Balochistan Basin, comprising Chagai Volcanic Arc, Kharan-Mashkhel Trough and the Makran Flysch Basin – part of the subduction association complex, i.e. Arabian Oceanic Plate underneath Makran Continental Margin. Most of the exploration has been focused in the accretionary prism part, both onshore and offshore, of the Balochistan Basin. However, Kharan-Mashkhel Trough / Fore Arc Basin (FAB), located between Raskoh Range and northern margin of Makran Accretionary Prism, still remains unexplored.

Kharan FAB covers an approximately 30,000 Km^2 area and is entirely obscured by superficial deposits of the Kharan Desert. Kharan FAB represents less deformed part of paleo fore-arc basin and it is about 150 km wide and 300 km long.

The area between the southern end of fore-arc basin and Makran coast is mainly occupied by flysch type sediments and is known as Makran Accretionary Prism (Jacob and Quittmeyer, 1979). It has many active mud volcanoes, emanating methane gas. This extraordinary thick and wide accretionary zone was formed by the continuous northward accretion of marine sediments from Eocene to Pleistocene and both the fore-arc basin and accretionary zone form one of the widest (450 km) arc-trench gap in the world.

The subsurface geophysical data (gravity, magnetic and seismic) has been evaluated to understand the structural geometry, which supports the presence of 5000 to 7000 meters of sedimentary column above basement in Kharan FAB. The seismic data show presence of high angle reverse faults.

Fig. 1: Generalized tectonic map of Pakistan showing location of the study

Geological History

- During Cretaceous, submarine eruption and deposition of Sinjrani – Kuchakki volcanic groups in the result of intra-oceanic subduction of Indian Plate along Zhob Valley Thrust (ZVT) and Bela Ophiolitic Mélange (Axial Belt). Multi cycles of basalt and deep marine sediments (micritic limestone and chert) accumulated in Chagai - Raskoh area.
- During Paleocene, development of a number of deltaic fans with provenance in ZVT and axial belt which resulted in deposition of Rakhshani Formation in eastern part of Raskoh Range and Kharan FAB.
- Eocene saw the development of Kharan Limestone in the southeastern part of Raskoh Range on the top of huge fan complex of Rakhshani Fm. This carbonate platform may be extended into Kharan FAB. Deep marine sediments are present in Siahan Range except in Plantak area where few interval of black shales of shallow marine setting are also present.
- Upper Eocene saw rejuvenation of clastic input and deposition of lower part of Nauroz Fm in Raskoh Range and probably in Kharan FAB.
- Oligocene is represented by deposition of upper part of Nauroz Fm and Nishi Group in Raskoh Range and northern part of Kharan FAB while Siahan and Panjgur formations in Siahan Range and southern part of Kharan FAB.
- A large delta with provenance in uplifted areas of Indian collision zone, developed during late Oligocene to Miocene, was source of thick sediments present in Makran Accretionary Zone. Convergence of Arabian Plate from south under pre-existing Chagai Island Arc system started and turned it into a magmatic arc.
- During Miocene, possible initiation of movement along Chaman Fault resulted in thrusting of ophiolites and Kuchakki Volcanics on Nauroz Formation in the north of Raskoh Range.
- Deformation shifted to the south in Siahan Range possibly in late Miocene. Deposition of Dalbandin Formation in Kharan FAB and Dalbandin Trough occurred during Pliocene.
- Ongoing deformation in Siahan Range progressed towards south and formed northern half of MAZ. This uplift become the source for deposition of Kamerod Formation within Kharan FAB.
- Culmination of geological history occurred with deposition of alluvial fan of recent times and subsequent wind action.

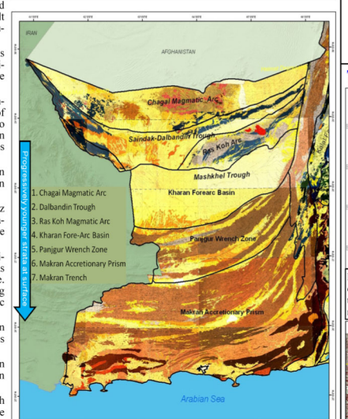


Fig. 2: Geological map (after HSC, 1961) and major tectonic zones of Balochistan Basin

Geodynamic Evolution

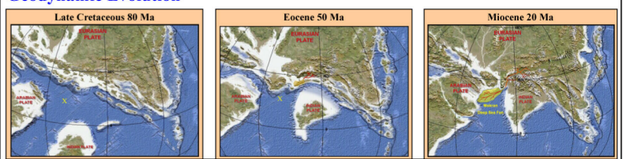


Fig.3: Paleogeographic reconstructions (after Blakey, R. C., 2003) showing the geodynamic evolution of Study Area and development of Makran Fan

Exploration History

- An early pioneering geological reconnaissance was made by the Geological Survey of India in 1900 (Vrendenburgh, 1901)
- Hunting Survey Corporation (HSC) conducted mapping of this area and established the lithostratigraphy (HCS, 1960)
- Two aeromagnetic surveys were conducted in 1962-63 and 1976-77 within the Kharan area
- In 1999, an airborne gravity/magnetic survey was carried out over the Kharan Basin: 7,359 line km gravity and 8,771 line km magnetic.
- OGDCL during 1993-96 acquired 507km of 2D seismic data in the NE part of Kharan FAB (Fore Arc Basin).
- Several geological field works and related studies have been conducted in this region since 1960s to date.
- Hydrocarbon exploration activity was focused in the Makran Accretionary Prism primarily due to presence of gas-emanating active mud-volcanoes. About 24,000 line km 2D and 4,000 sq. km 3D seismic data has been acquired.
- Nine exploratory wells were drilled in the region, mainly offshore, with no hydrocarbon discovery.
- It is suggested to focus the exploration efforts in the Kharan FAB where the systems appear likely to be effective based on current studies and analogy with Cook Inlet Basin (Alaska) and Salin Basin (Myanmar).

Table 1: Exploratory wells drilled in the Balochistan Basin and possible failure reason

Sr. No.	Well Name	Operator	Year	TD (m)	Results (All wells P&A)
1	Chandragup-01	BOC	1916	810	Mechanical Failure
2	Dhak-01	Hunt	1956	2561	Reservoir not encountered
3	Dhak-02	Hunt	1956	4454	Mechanical Failure
4	Kech Band-01	Tide Water	1962	3348	Reservoir not encountered
5	Garr Koh-01	Marathon	1975	3622	Reservoir not encountered
6	Jalpari-01	Marathon	1976	2007	High formation pressures
7	Pasni-01	OPC	1999	3368	Reservoir not encountered
8	Gwadar-01	OPC	2000	3810	Reservoir not encountered
9	Pasni-X2	PPL	2005	4000	Reservoir not encountered

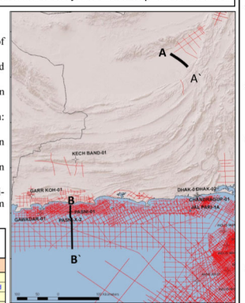


Fig. 4: Seismic coverage and wells drilled in the Balochistan Basin illustrating that the exploration was focused in the Makran Accretionary Prism. Lines AA` and BB` show the location of seismic lines in Fig. 8

Tectonic Models

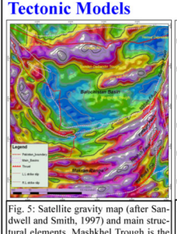


Fig. 5: Satellite gravity map (after Sandwell and Smith, 1997) and main structural elements. Mashkhel Trough is the maximum gravity-low in this region

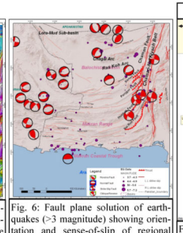


Fig. 6: Fault plane solution of earthquakes (>3 magnitude) showing orientation and sense-of-slip of regional faults in the basin and adjacent areas

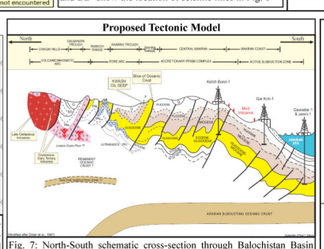


Fig. 7: North-South schematic cross-section through Balochistan Basin (after Dolan et al., 1987)

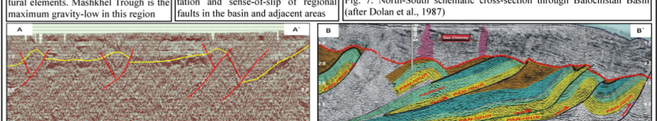


Fig. 8: Seismic dip-lines though the northeastern part of Kharan FAB (AA`) and southern part of Markran Accretionary Prism (BB`). For location see Fig. 4

Stratigraphy and Petroleum Play System

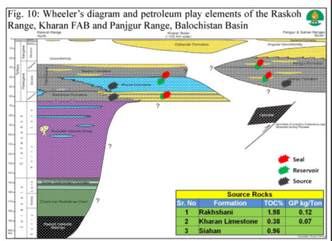
Two distinct petroleum systems have been identified in the outcrops, north and south of the Kharan FAB.

1. Rakhshani-Kharan (Paleocene-Eocene) Composite Petroleum System (Fig. 11)
2. Siahan (Eocene-Oligocene) Petroleum System (Fig.12)

In all, four petroleum plays are identified after recent geological fieldwork, as follows:

i. Kharan Limestone Play
ii. Rakhshani Sand Play
iii. Siahan Sand Play
iv. Panjgur Sand Play

Fig. 10: Wheeler's diagram and petroleum play elements of the Raskoh Range, Kharan FAB and Panjgur Range, Balochistan Basin



Source Rocks

Sr. No.	Formation	TOC%	GP bsTon
1	Rakhshani	1.98	6.12
2	Kharan Limestone	0.38	0.07
3	Siahan	0.96	

- Kharan Limestone Play: The most promising play in Kharan FAB. It can have indigenous charge system or form Rakhshani source. Nauroz Formation, mud dominant at its basal part, is sealing rock for this play. Entrapment could be large size four way dip and three way fault bonded closures.
- Rakhshani Sand Play: The sandstone bodies, sealed by interbedded shales, could be charged from Rakhshani shales. Entrapment is same as Kharan play and both of these plays can be tested through one well.
- Siahan Sand Play: Sandstone lenses were observed in Siahan Formation having thickness of about 30-50m and aerial extension of these channels are also reasonable. Charge system for these sands is from good quality source rock present within Siahan Formation. Channel sands are well encased in shale which could act as seal and similar settings are expected in southern part of Kharan FAB. Traps associated with faulted anticlines as well as stratigraphic entrapment are also envisaged based on field observations.
- Panjgur Sand Play: Sandstone is the dominant lithology of Panjgur Formation which might act as reservoir. The sandstone units are separated by equally thick shales which would provide seal. Charge system and entrapment mechanism would be the same as of Siahan Sand Play. This play is also expected to be present in southern part of Kharan FAB.

Fig. 11: Total Petroleum System of Northern Kharan

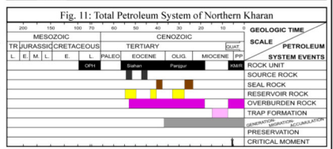
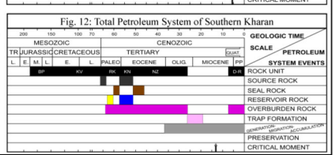


Fig. 12: Total Petroleum System of Southern Kharan



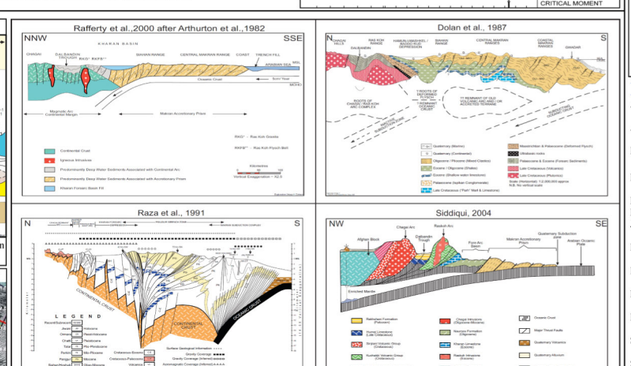


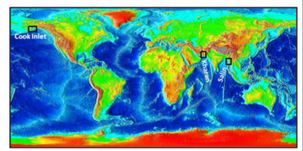
Fig. 9: Tectonic models of the Balochistan Basin by various researchers

Analogues

In a trench-arc system as that of the Balochistan Basin, fore-arc basins are considered to bear the best petroleum prospects. An example is the Cook Inlet Basin of Alaska with total oil and gas recoverable reserves of over 3 Bboe (25 oil and gas fields). Another analogy exists in the Salin Basin of Myanmar, which has about 850 MMboe discovered so far.

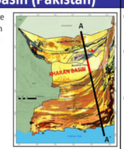
Kharan FAB is analogous to Cook Inlet Basin of Alaska, in terms of exponentially wide trench-arc gap, (250-300 km) and the relatively simple tectonic style. Cook Inlet Basin produces from Eocene, Oligocene and Miocene reservoirs and similar age equivalent reservoir are expected in Kharan FAB.

A comparison of timing of source rock maturation, structuration and migration has been made by developing petroleum system charts for Kharan FAB. Based on, the above Kharan FAB is quite analogous to Cook Inlet FAB, except that there is no Jurassic source rock known in this area. However, sedimentary cover being very thick, even the younger source rocks are expected to be mature to have generated hydrocarbons.



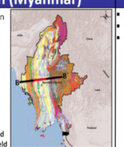
Kharan Basin (Pakistan)

- Geological settings are comparable with Salin Basin (Myanmar) and Cook Inlet Basin (Alaska).
- No hydrocarbon discovery
- Limited exploration activities



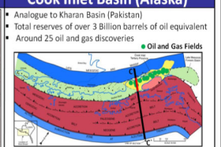
Salin Basin (Myanmar)

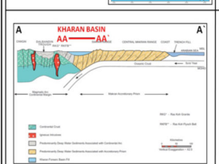
- Analogue to Kharan Basin (Pakistan)
- Total reserves of 850 Million barrels of oil equivalent
- Several oil and gas discoveries

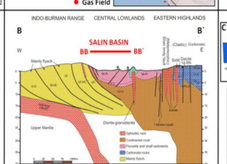


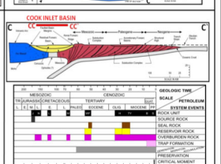
Cook Inlet Basin (Alaska)

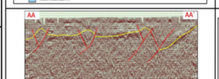
- Analogue to Kharan Basin (Pakistan)
- Total reserves of over 3 Billion barrels of oil equivalent
- Around 25 oil and gas discoveries

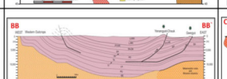


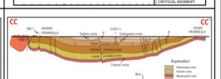












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