Petroleum Prospectivity of the Strike Slip Fault Bounded Pishin Frontier Basin, Pakistan*

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Abstract

The Pishin Basin is a young sedimentary basin that has formed since early Tertiary times. It is located between Chaman transform fault in the west and Ghazaband fault in the east. Its extensions are Katawaz and Makran convergence zones in its northern and southern segments. Pishin Basin forms the boundary zone between Afghan Block and Indian Plate.

The Pishin Basin is filled with more than 6,000 m thick flysch-molasse including the Khojak Formation of Oligocene-Lower Miocene and Eocene limestones (Nisai/Nimargh/Wakabi). The Khojak Formation is subdivided into the Murgha Faqirzai Shale and Shaigalu Sandstone. The Murgha Faqirzai grades into the Shaigalu Sandstone mainly in the northern part of Pishin Basin. A similar sequence is termed the Turbat Group, which covers the Makran Ranges (convergence zone) between the Siahan and Nai Rud faults. The Chaman fault proper is marked by Paleocene through Miocene-Pliocene sediments of the Rakhshani Formation, ultramafic rocks, Kharan limestone and the Kamerod Formation. Generally, these sediments entered into the Chaman fault zone from the west with rare fragments of flysch.

Flysch sediments are exposed in the core of folded structures, which are bounded by longitudinal faults on both flanks. Splays of Chaman and Ghazaband fault systems dissect the earlier compressional structures and transpressional features related to northward movement of Indian Plate are overprinted on the previous structures.

Until the end of the last century, the Pishin Basin remained neglected, however, during the previous decade, a number of exploration blocks have been awarded to E & P companies. As a result, a substantial G & G database has been established including seismic and drilling an exploratory well. This paper discusses the issues related to basin fill history, structural setting, petroleum system, and application of modern exploration techniques coupled with conventional exploration methods, to highlight the efforts and direction to assess the hydrocarbon prospectivity of this frontier basin with special reference to its southern segment.

Selected References

Treloar, P.J., and C.N. Izatt, 1993, Tectonics of the Himalayan collision between the Indian Plate and the Afghan Block; a synthesis, *in* P.J. Treloar and M.P. Searle, (eds.), Himalayan tectonics: Geological Society of London, Special Publications, v. 74, p. 69-87.

Vestrum, R.W., V. Dolgov, G. Wittman, L. Csontos, and J. Gittins, 2011, 3D seismic imaging over two structurally complex seismic surveys in the foothills of Pakistan: First Break v. 29/4, p. 61-70.

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Prospectivity of the Strike-slip Fault Bounded Pishin Fold Belt Basin, Pakistan

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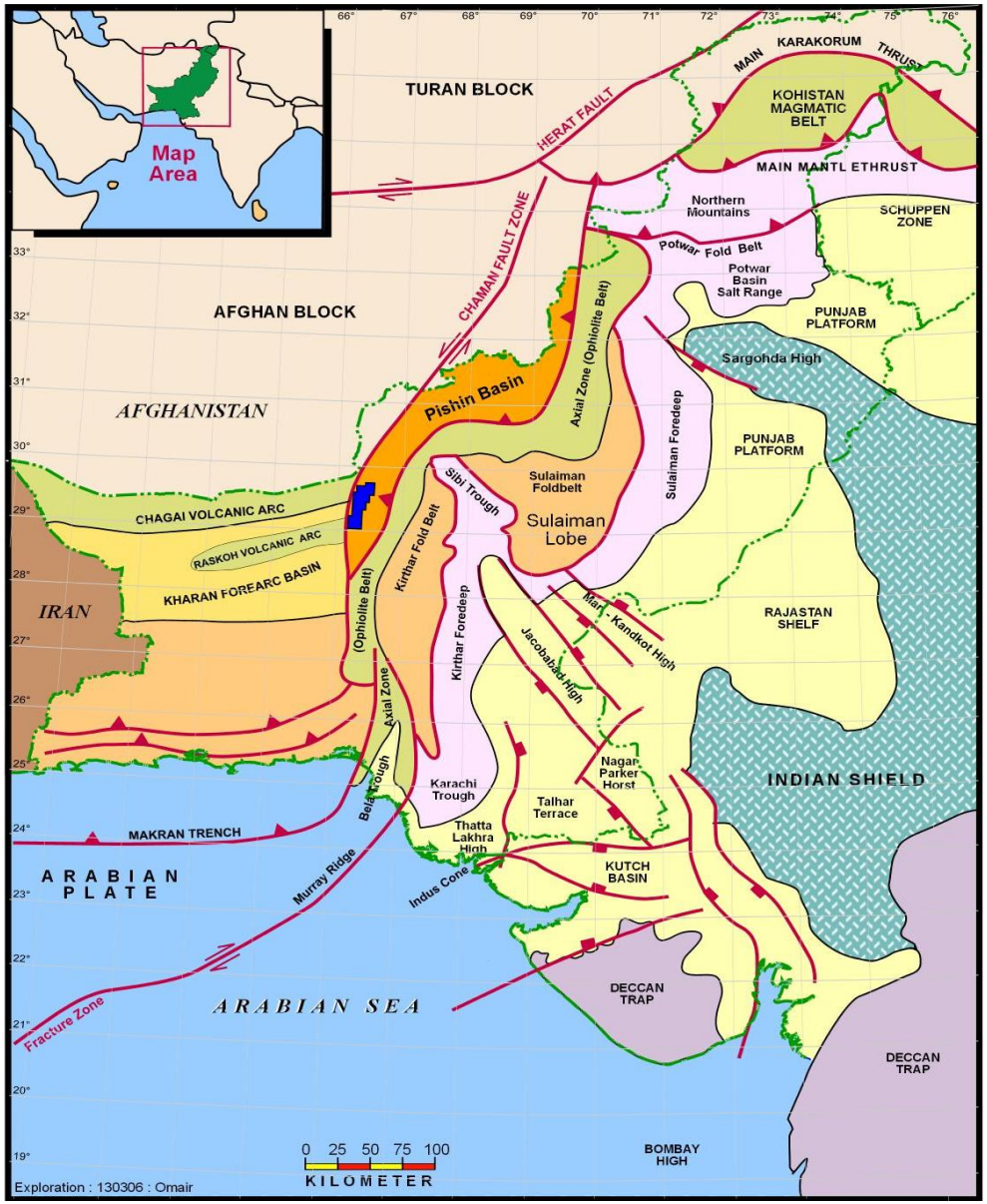
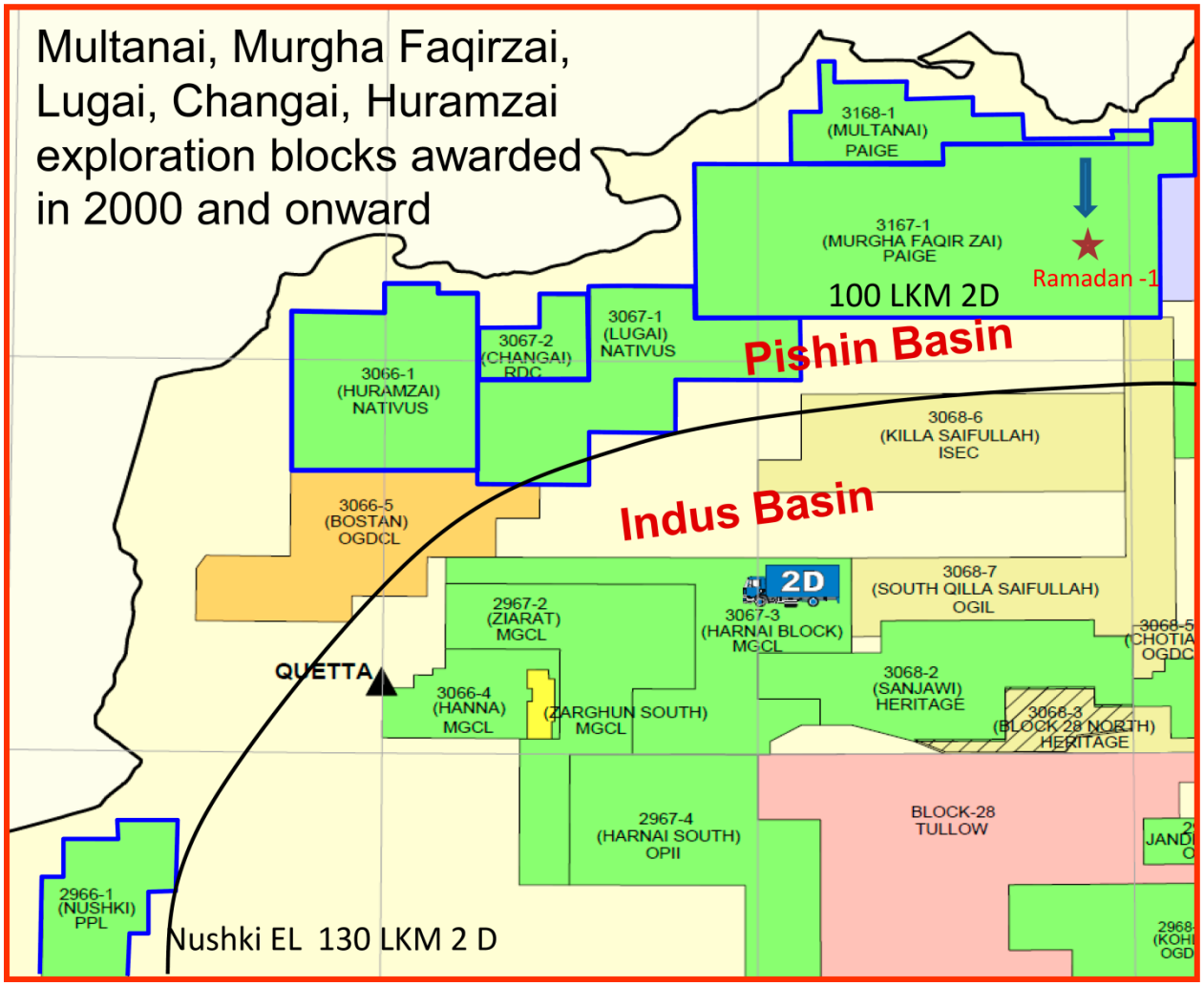
Location Map



- Pishin Basin constitutes the western margin of the Indo-Pakistan Plate in Pakistan
- Pishin Basin is more than 800 km long and 40 to 175 km wide between Khuzdar-Quetta and Zhob-Kabul regions
- It is bounded in the west and east by left lateral Chaman and Ghazaband transform faults, respectively
- Pishin Basin extends to Main Karakorum Thrust (MKT) in the north and Makran region in the south

Exploration Blocks



Ramadan -1 of Murgha Faqirzai Concession is the first exploration well in the basin which did not reach Primary target (Eocene Nisai Limestone) despite drilling 4528 m thick sequence

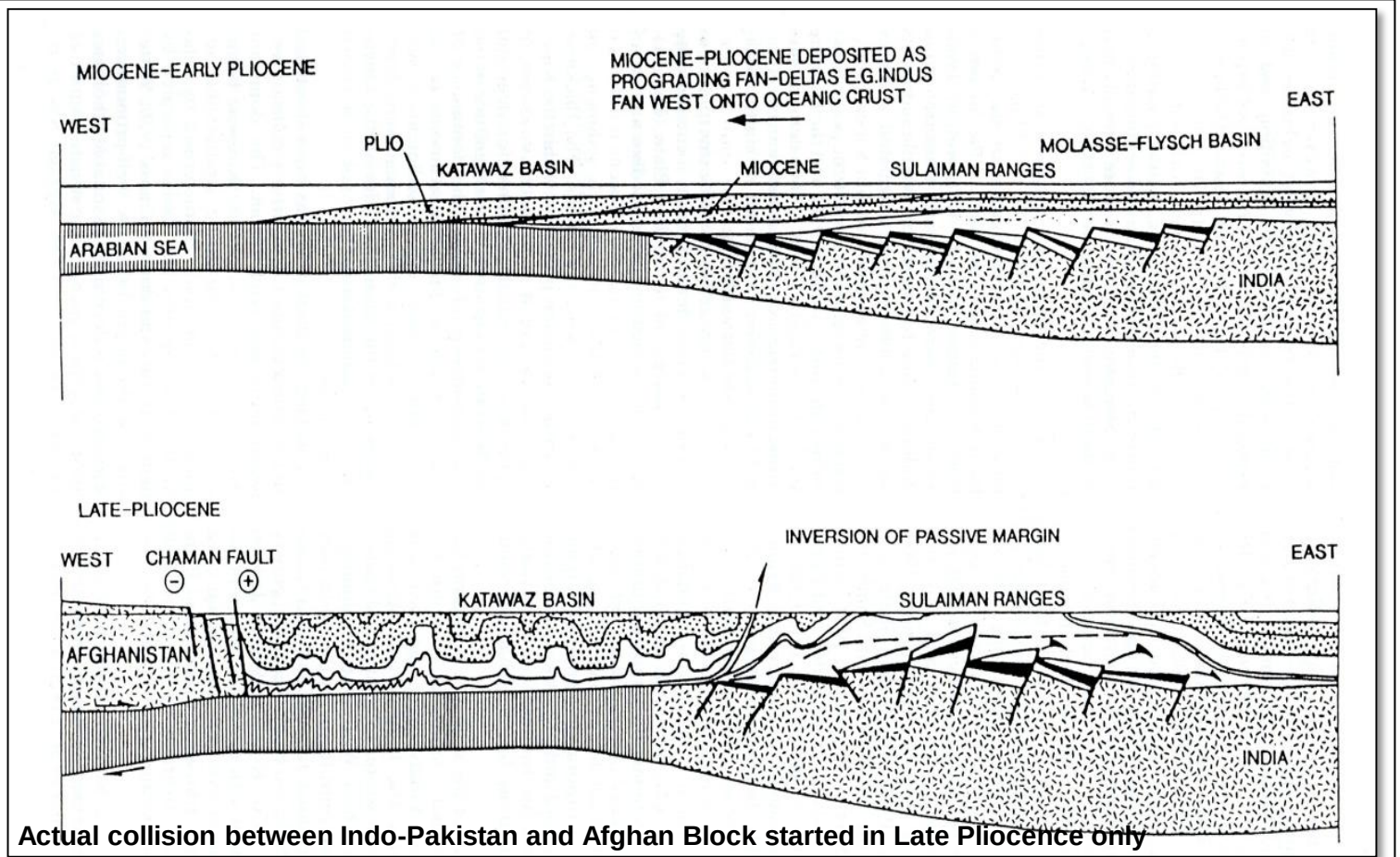
Govt. recently offered sixty exploration blocks for bidding, out of those six are in Pishin Basin

Objectives

Discussing petroleum prospectivity of the Pishin Basin, associated risks and exploration strategy; which include:

- Data Review
- Geological Fieldwork & Lab Analysis (HDIP & Sindh University, Jamshoro)
- Gravity-Magnetic Study (BGP-China)
- Remote Sensing Study (MDA Federal, USA,2006)
- Hydrocarbon Induced Spectral Survey (MDA Federal, USA,2008)
- Structural Modeling Study (Dr. Bannert, German Geologist,2009)
- Acquisition of 130 LKM Seismic (BGP, 2010)
- Processing / reprocessing of Seismic data (TBI, Canada, 2011)
- Seismic interpretation / mapping (In-house, 2011)
- Identification of possible Eocene Wakabi limestone reflector (Primary target)
- Advance Processing Techniques (RTM- 2011) through GRI China

Structural Evolution of Indo-Pakistan Plate



Actual collision between Indo-Pakistan and Afghan Block started in Late Pliocence only

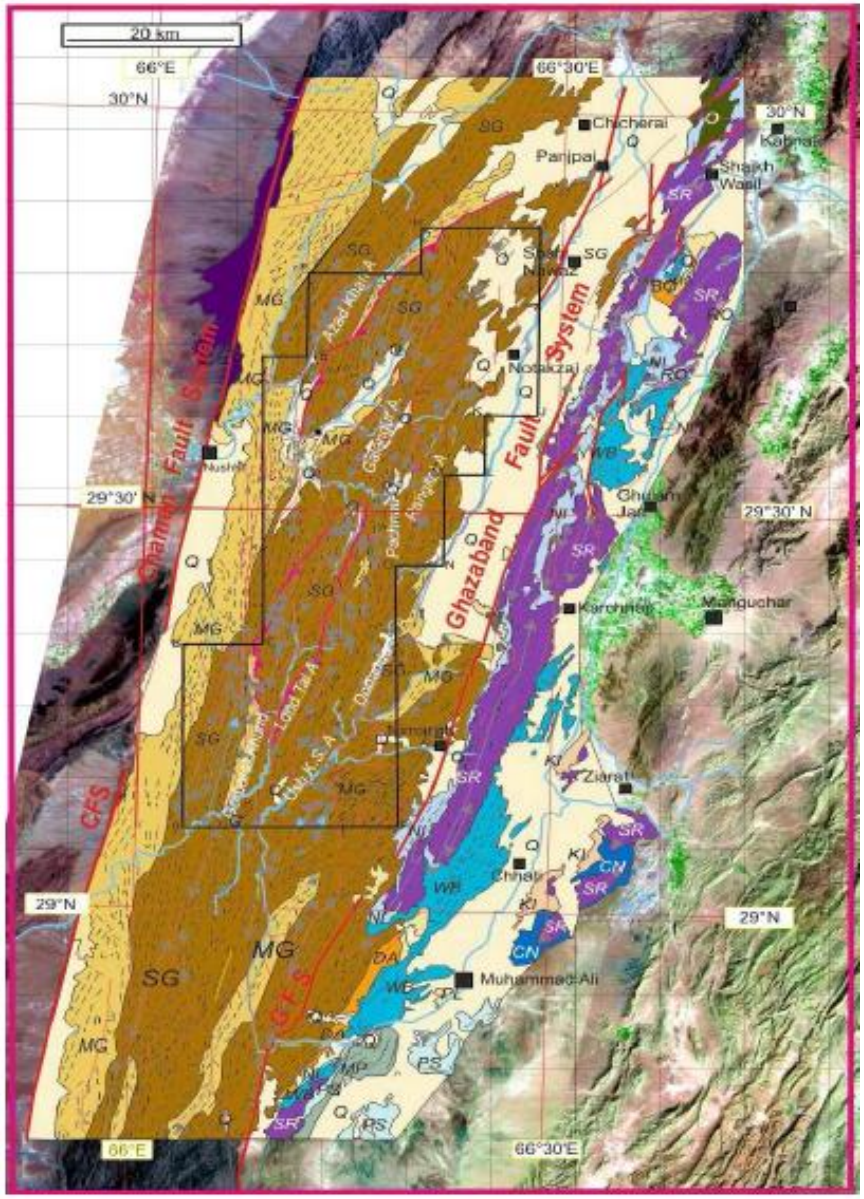
A cross-section across Afghan Block and Indus Basin suggests Mio-Pliocene and Late Pliocene deposition of clastic sediments of Katawaz and Indus Basin on extended Indo-Pakistan Plate continental and transitional crust, continued till the Early Pliocene that was followed by basin inversion in Late Pliocene (Treloar and Izatt, 1993)

Stratigraphy and Petroleum System

AGE	ZHOB SEGMENT					KHOJAK SEGMENT				
	FORMATION/ THICKNESS	LITHOLOGY	SOURCE	RESERVOIR	SEAL	FORMATION/ THICKNESS	LITHOLOGY	SOURCE	RESERVOIR	SEAL
Recent /Sub-recent						±200m				
Pliocene - Pleistocene										
Oligocene to Miocene	SHAIGALU 1300m ->3000m					SHAIGALU 1800-2000m				
	MURGHA FAQIRZAI 1200-2300m					MURGHA FAQIRZAI 500-700M				
Eocene	NISAI FORMATION 900-1200m					WAKABI FORMATION +1050m				
						NIMARGH LIMESTONE <500m				
Pre-Eocene	OPHIOLITES (CRETACEOUS)					SHIRINAB (JURASSIC) +1500m				

Stratigraphic succession in the northern (Zhob) and southern (Khojak) segments

Satellite Image Interpreted Geological Map



- Basin fill is more 8000 m thick flysch-molasse of Khojak Fm and limestone of Nisai / Nimargh / Wakabi
- In the east the flysch sediments of the basin thrust over shelf carbonate of Indo-Pakistan Plate
- The contact in the east is faulted
- Flysch wedge may host petroleum elements in the east

Shaigalu Formation

Murgha Faqirzai Fm

Wakabi Formation

Nimargh Formation

Shirinab Formation

Petroleum System

Source Rock

Wakabi Formation (Late Eocene)

- TOC (upto 0.74%); Tmax (upto 453 ^{o}C) and Vitrinite Reflectance (upto 1.3 %) indicate formation falls in wet to dry gas window

Nimargh Formation (Early Eocene)

- Good TOC (upto 3.98%), Tmax (average 480 ^{o}C) and Vitrinite Reflectance (1.3 - 1.6%) indicate formation falls in wet to dry gas window

Shirinab Formation (Jurassic)

- TOC values upto 0.3% indicate low or no-source potential

Petroleum System

Source Rocks

Sr.No	Formation	TOC %	Tmax (°C) / VR (%)	HI
Zhob Zone (1999)				
1	M. Murgha Faqirzai (Shale)	0.51	476 °C	12
2	L. Nisai Formation (Mud Slurry)	0.67	477 °C	52
3	M. Nisai Formation (Oil Shale)	**1.14**	445 °C	181
4	M. Nisai Formation (Shale)	0.80	442 °C	89
5	M. Nisai Formation (Limestone)	0.90	442 °C	197
Khojak Zone (GFW 2004)				
PPL-NK-1	Nimargh Limestone	**3.98**	480 °C / 1.5%	3
PPL-NK-23	-	0.94	491 °C / 1.6%	17
PPL-NK-24	-	0.45	480 °C	11
PPL-NK-27	-	**1.13**	484 °C	52
PPL-NK-31	-	**19.71**	507 °C / 1.3%	40
PPL-NK-7	Wakabi L.st	0.74	439 °C	6
PPL-NK-32	-	0.31	453 °C	9
Khojak Zone (GFW 2009)				
Geo-1	Nimargh (Shale)	0.34	1.02 %	
Geo-4	L .Paleocene – E. Eocene Flysch	0.41	1.10 %	
Geo-8A	Shirinab Formation (Jurassic)	0.30	1.11 %	
Geo-10b	L .Paleocene – E. Eocene Flysch	0.33	-	

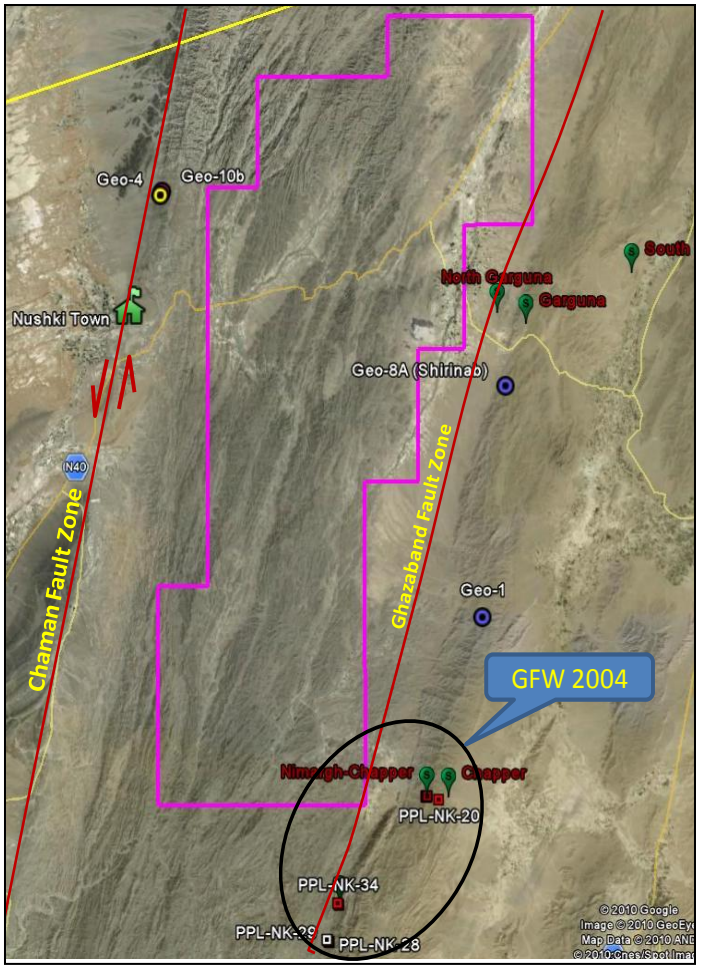
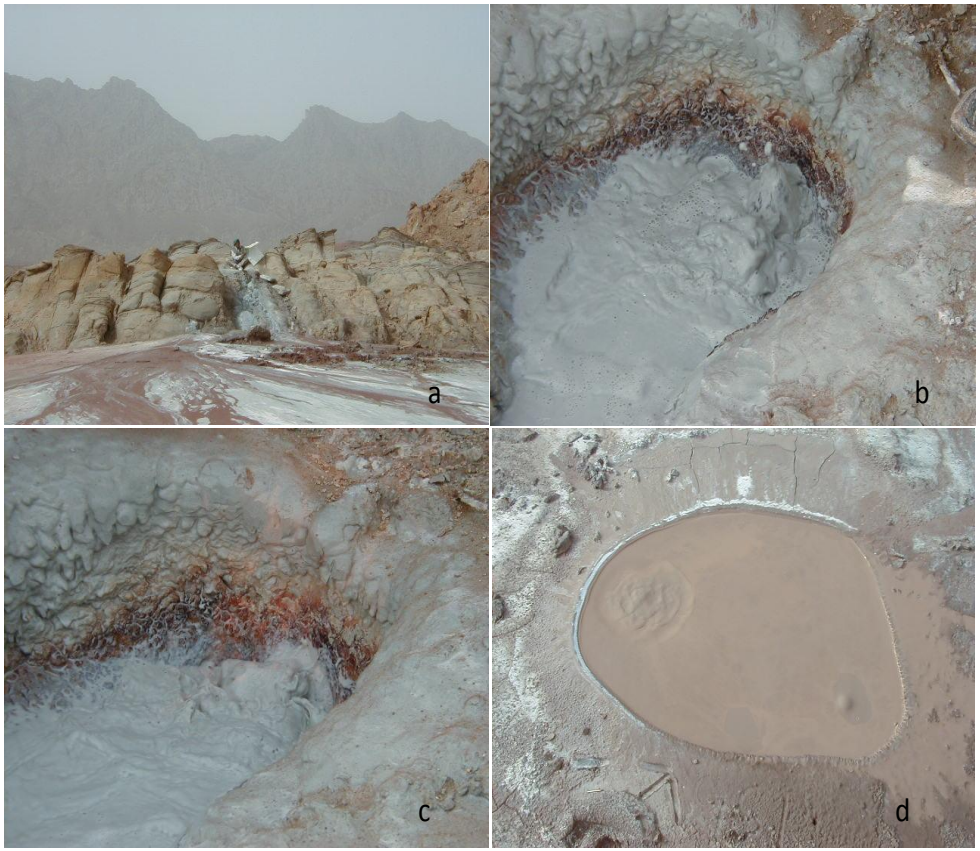


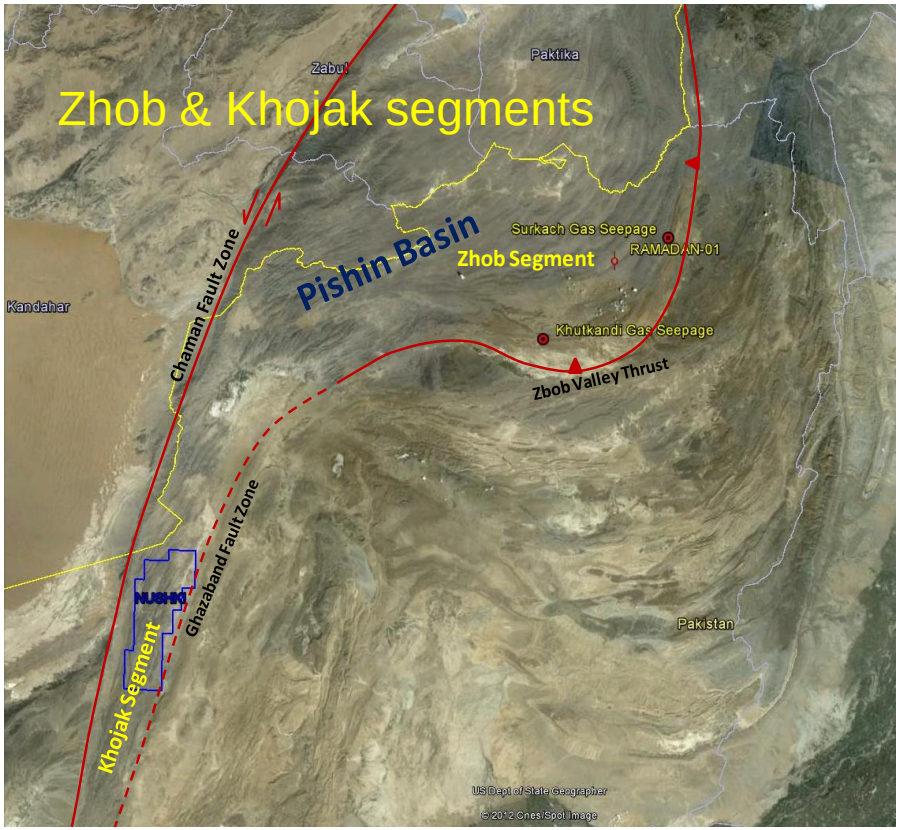
Image showing the location of source rock samples from Khojak Segment (GFW-2004 & 2009)

Petroleum System

Gas Seepages



a, b, c - Mud volcano and burning Methane (CH4) flares, d - Methane gas bubbles, Khutkandi gas seepage, Gardab Manda, north of Qila Saifullah (30o 53' 14'' N, 68o 28' 08'' E)



Google Earth image showing the location of gas seepages in Zhob Segment of Pishin Basin. Zuberi & Dubois, 1961 showed 5 seepages

Petroleum System

Potential Reservoirs Rocks

Murgha Faqirzai Formation (Oligocene)---Secondary Reservoir

- Reefoid limestone reported from northern Pishin basin is expected in Nushki Block

Wakabi Formation (Late Eocene - Early Oligocene) ---Primary Reservoir

- Mainly limestone with subordinating sandstone and shale in lower part. Limestone is thick bedded, highly fractured, locally reefoid with corals
- Lab analysis show sandstones of 21 - 25% porosity and good permeability

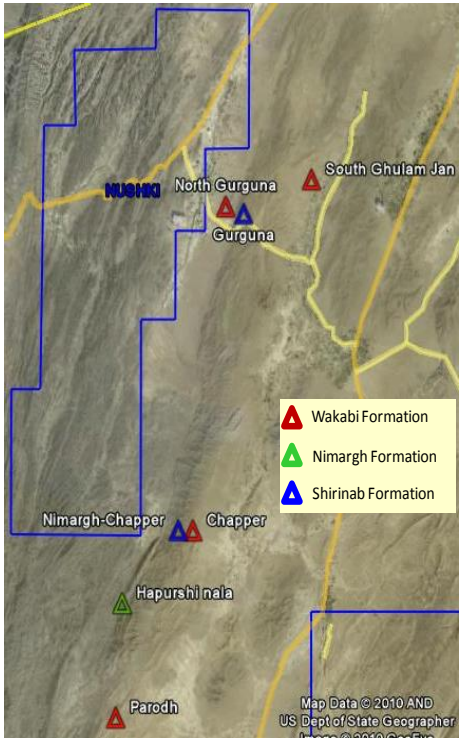
Nimargh Limestone (Early Eocene)

- Thick bedded limestone, rich in fossils with possibility of good intergranular porosity

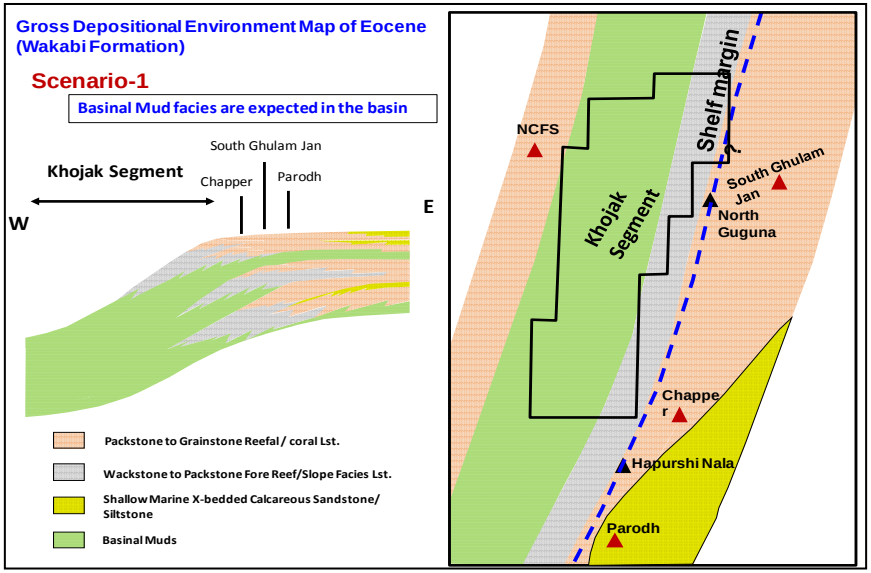
Shirinab Formation (Jurassic)

- Upper part mainly oolitic and may have reservoir potential

RESERVOIR ROCKS



Schematic depositional models of Eocene rocks on the eastern margin of Khojak Segment.
We consider scenario-2 for the Eocene Reservoirs in Khojak Segment in which limestone is expected to be deeper towards the basin



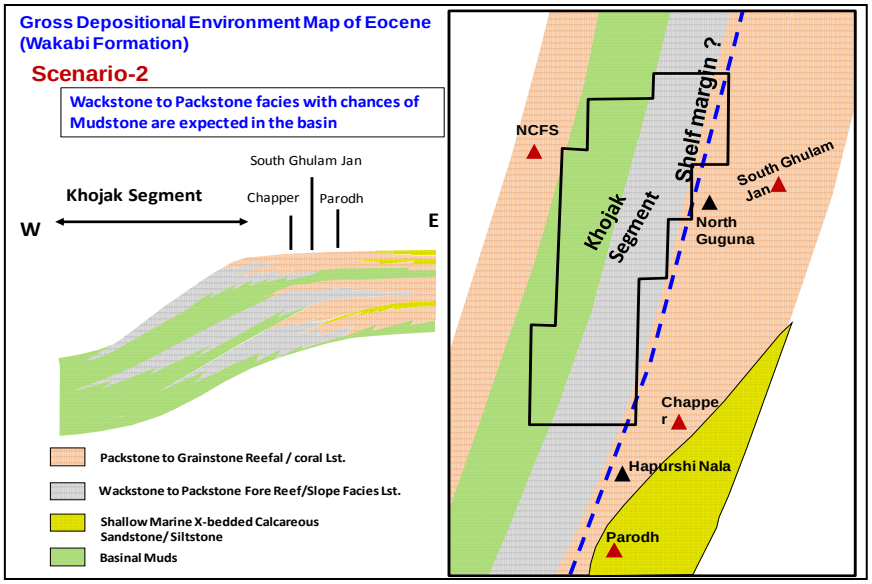


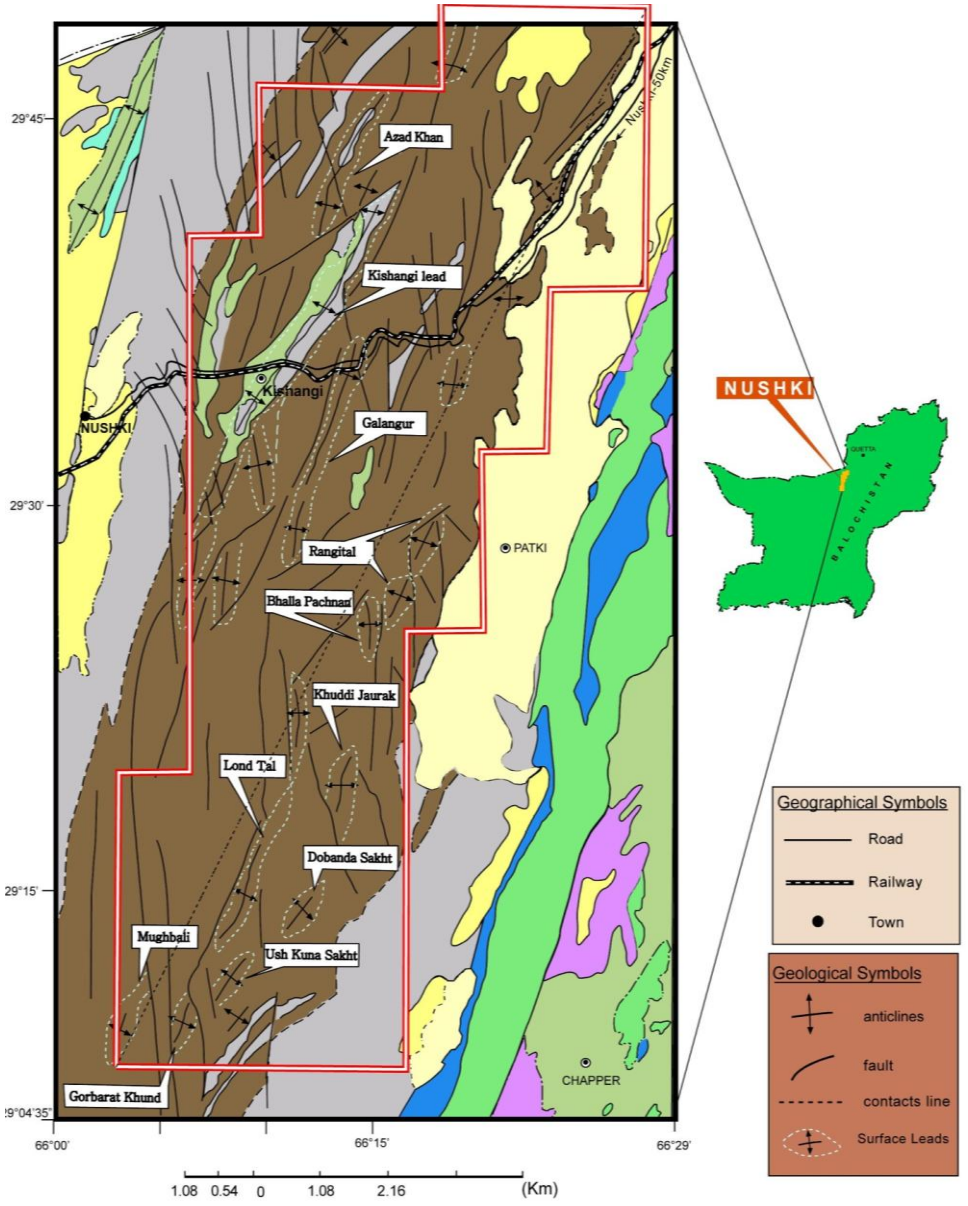
Image showing the location of measured stratigraphic sections in Khojak Segment

AGE		STRATIGRAPHY	LITHOLOGY	PPL						
				Parodh	Chapper	Hapurshi Nala	Gurguna	North Gurgana	Nimargh Chapper	Ghulam Jan
TERTIARY	HOLOCENE TO PLIESTOCENE		ALLUVIUM							
	OLIGOCENE TO EARLY MIOCENE		SHAIGALU MEMBER							
			MURGHA FAQIR ZAI MEMBER							
	EOCENE		WAKABI	473.8m+	968.5m+			247.5m+		1154m+
			NIMARGH			165m+				
	JURASSIC		SHIRINAB				430m+		311m+	

Showing thickness in various measured sections in the Khojak Segment.

TRAPS

Geological map of Nushki Block showing surface anticlines (leads)



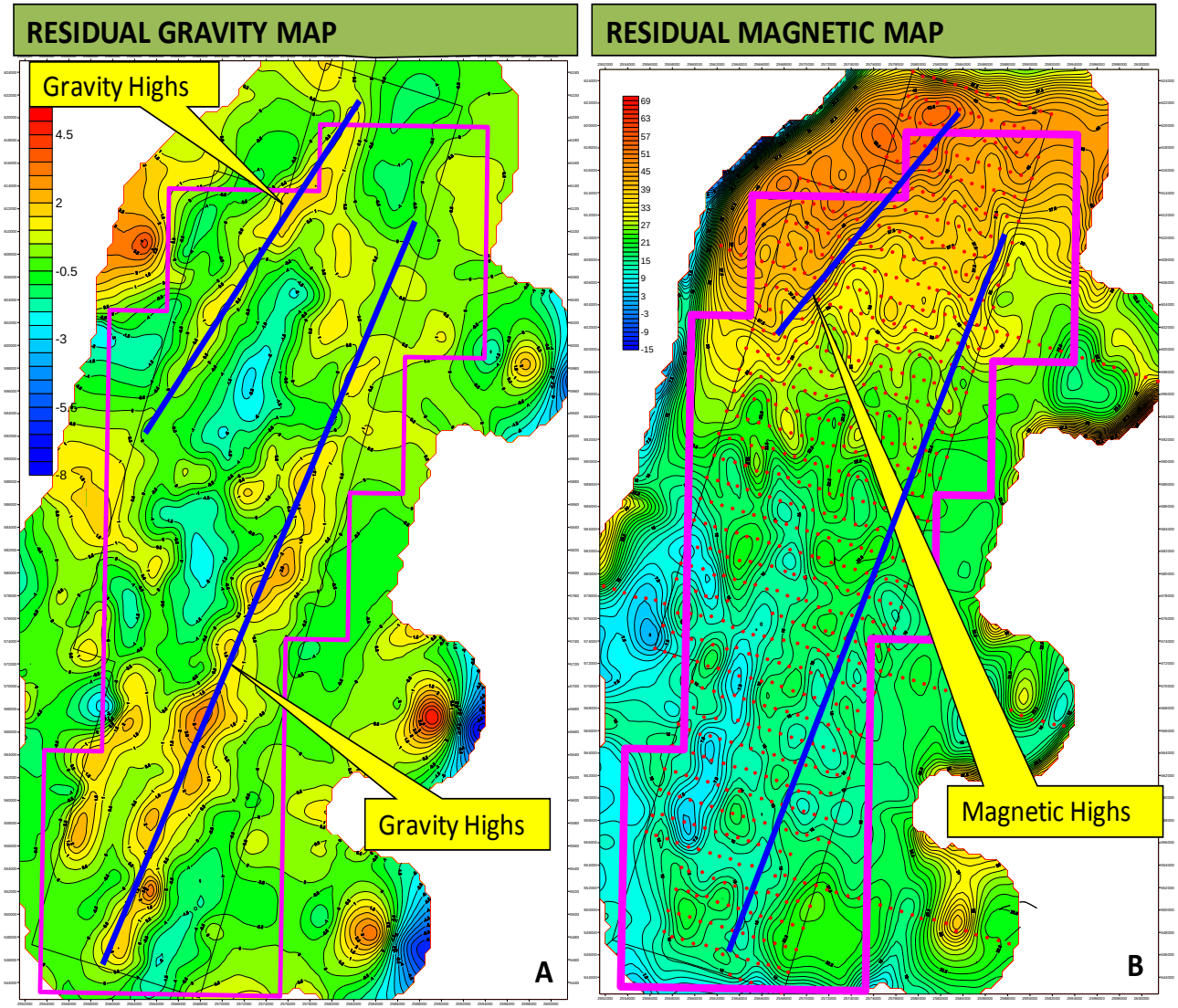
Legend

Shirinab Formation	Nimargh limestone
Wakabi Limestone	Shaigalu Sandstone
Recent deposit	Murgha Faqirzai shale
Subrecent deposit	

Gravity and Magnetic Survey

Pakistan Section

The basin is developed in E. Paleogene so surface folds were taken shallow i.e. did not involve deeper rocks but two identified gravity highs inferred highs and lows in the sub surface about 3km deep

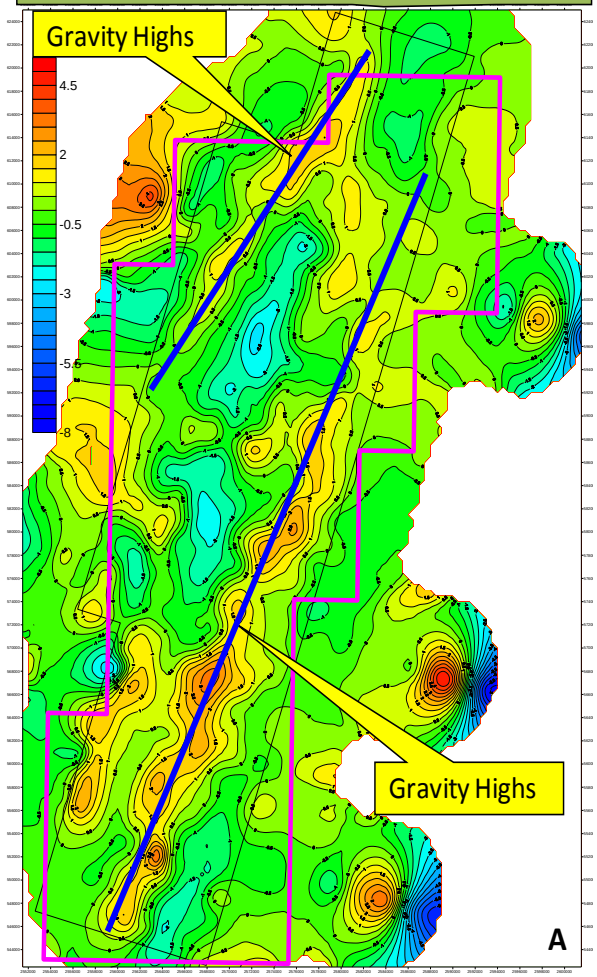


A) Bouguer gravity map, terrain corrected after BGP 2004, B) Magnetic residual anomaly map - after BGP 2004

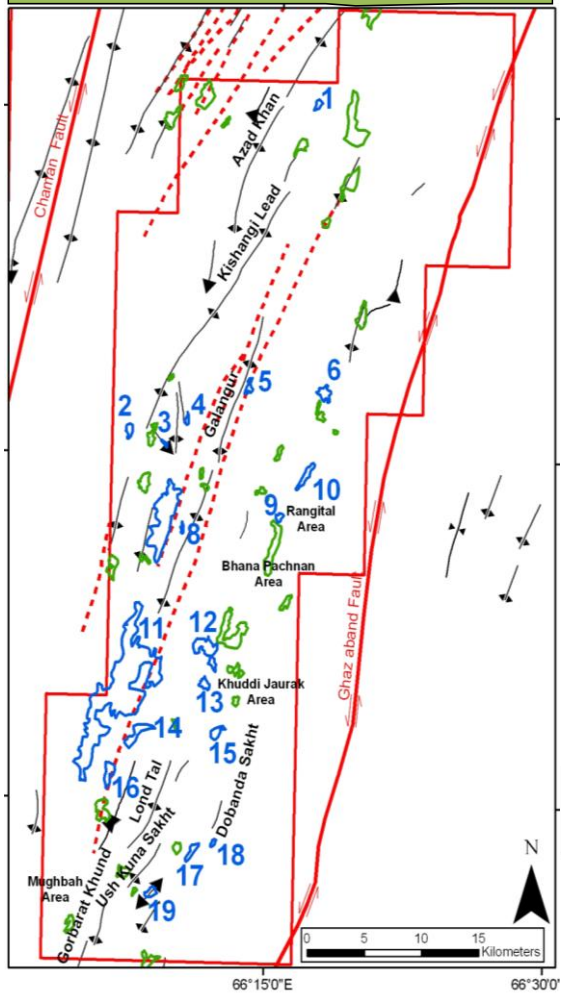
Correlation of Gravity & Spectral Anomalies

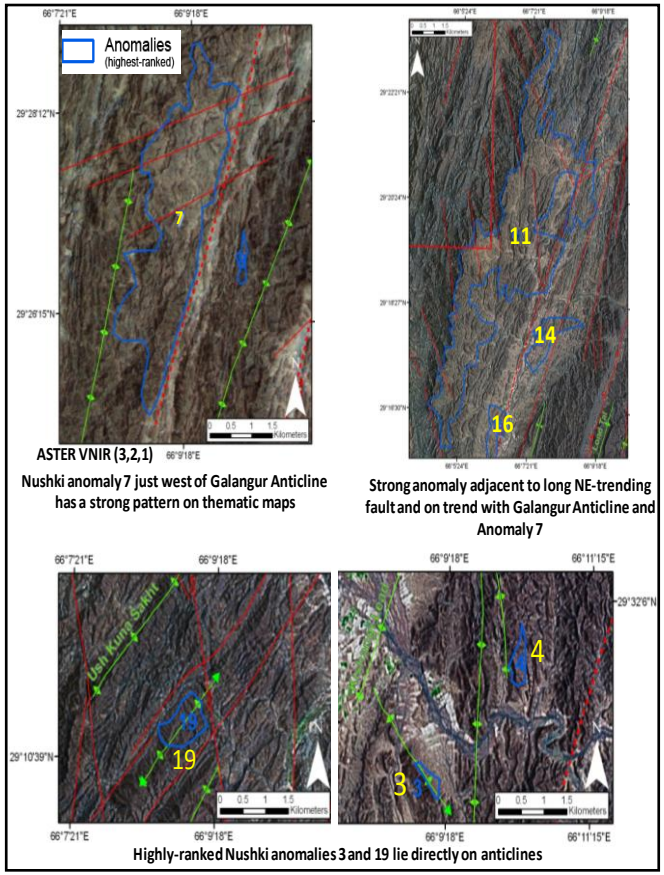
Pakistan Section

RESIDUAL GRAVITY MAP



Spectral Anomaly Map

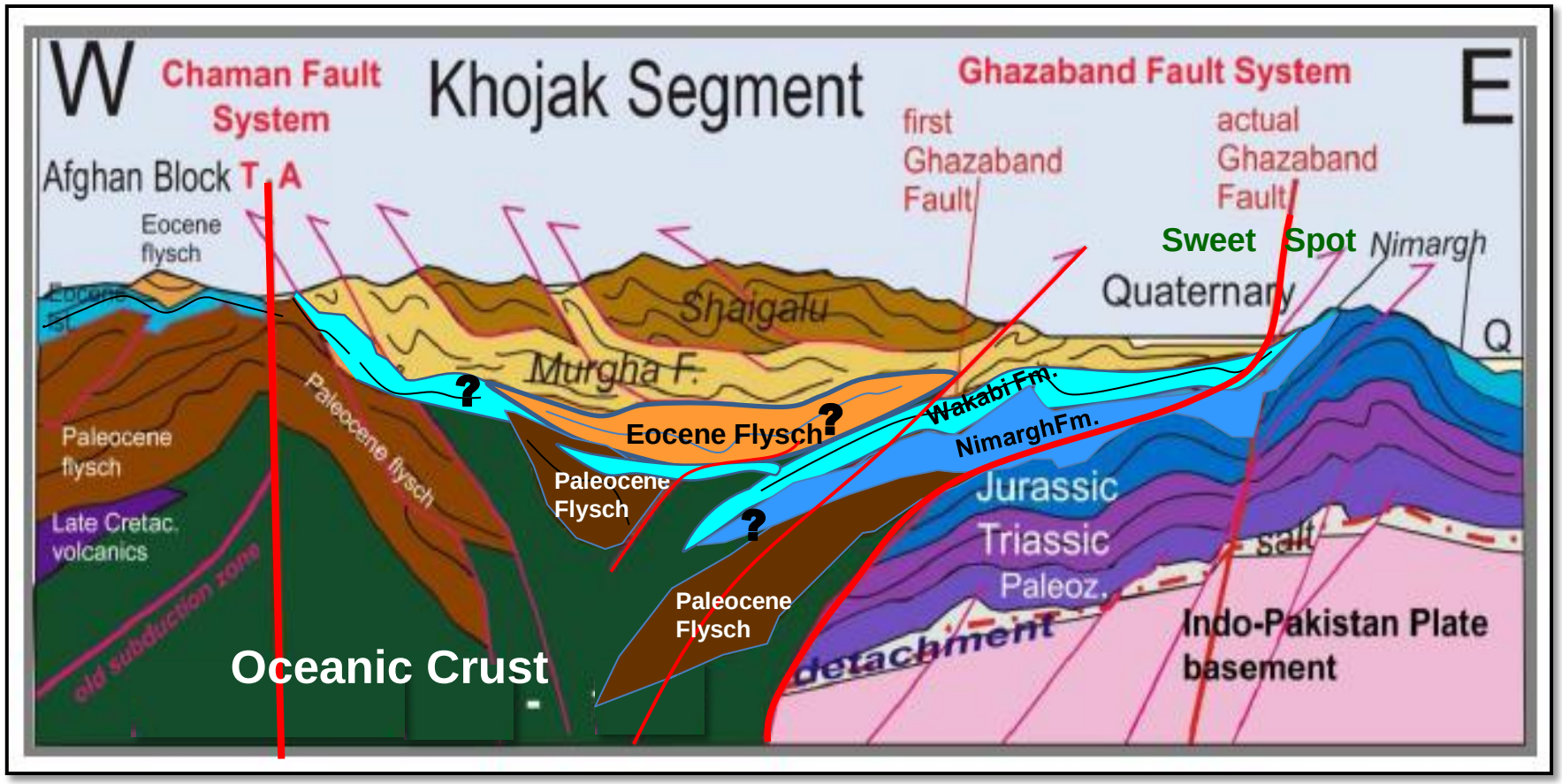




High ranked anomalies follow gravity highs. Spectral anomalies may indicate subsurface traps. Anomalies are aligned along highs

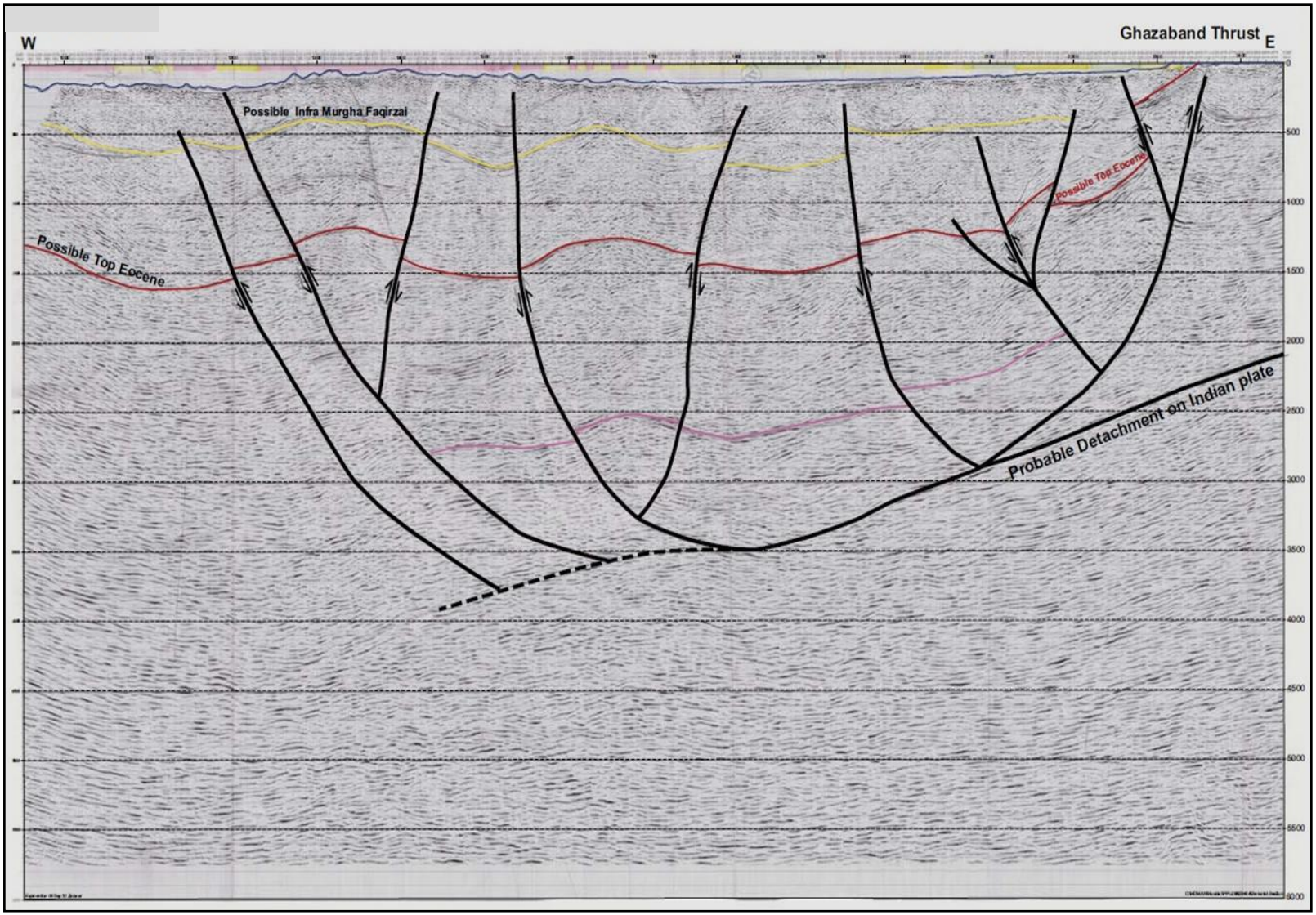
Showing 19 high ranked anomalies. Anomalies 7 & 11 are promising

Conceptual Structural Model



Flysch of Khojak segment thrusts on shelf sediments of Indo-Pakistan Plate in the E with a faulted contact. In the west shelf carbonate and flysch of Afghan Block are in contact with flysch sediments of Nushki Block (modified after Bannert, 2009). Paleozoic salt at the base of Indian Plate with detachment is projected from Salt Range in the north.

Seismic Survey



East-West interpreted seismic section (dip line) thorough Nushki Block (Khojak Segment)

Conclusion

Eocene limestone has good source and reservoir potential	Positive indicator
Gas shows on logs in Murgha Faqirzai sands in Ramdan-1 well and reported gas seepages	Positive indicator
Good TOC and high VR (due to thrusting) expected in subsurface	Positive indicator
Sweet spot along the east margin of the basin possible where flysch are lying on Mesozoic shelf carbonate of Indo-Pakistan Plate and may host HC elements at shallow depth	Positive indicator
Inferred Wakabi reflector may be a deceptive reflector in the overlying Murgha Faqirzai sands	Risk
Thick flysch, poor seismic quality ,wide spacing and no offset well	Risk
RTM on inferred Eocene reflector showed no significant results	Risk

Recommendations

- Pishin Basin is considered a potential candidate for exploration with improved technology
- Close space 2D seismic along the eastern part of the basin is recommended to investigate reservoir reflector and its extension beneath the basin
- Construction of a tectonic and Paleogene carbonate shelf model and possibility of Oligocene-Miocene clastic reservoirs play is recommended to understand that the basin is tectonically separated or covered with marginal facies
- Pishin basin deserves to be classified a special prospectivity zone wherein the enigmatic nature of flysch can be resolved only through drilling by a consortium of E & P companies

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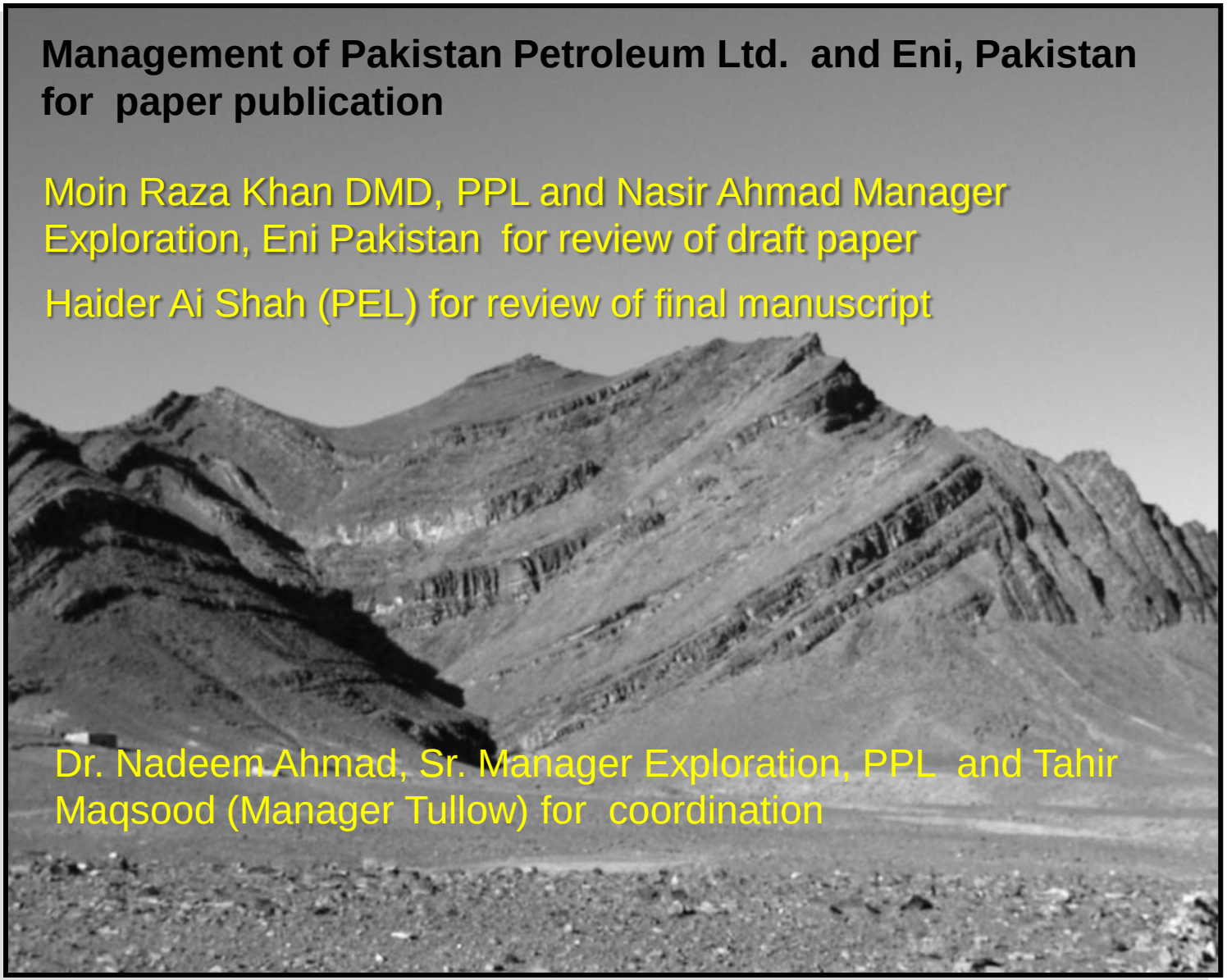

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Thanks