

Hydrocarbon Exploration Perspective in Middle Jurassic-Early Cretaceous Reservoirs in the Sulaiman Fold Belt, Pakistan*

Muhammad Iqbal¹, Adeel Nazeer¹, Hayat Ahmad¹, and Ghulam Murtaza¹

Search and Discovery Article #10394 (2012)

Posted March 12, 2012

*Adapted from oral presentation at PAPG/SPE Annual Technical Conference 2011, Islamabad, Pakistan, November 22-23, 2011

¹Petroleum Limited, Karachi, Pakistan (d_iqbal@ppl.com)

Abstract

The Sulaiman Foldbelt is a part of the western Himalayas in Pakistan and is covered with rocks of Triassic to recent age. The first commercial discovery of gas condensate at Dhodak-1 (1976) in the frontal part of the Sulaiman Foldbelt, in the Upper Cretaceous and Paleocene reservoirs, brought momentum in exploration activities. In 1975, Jandran-1 flowed gas from Late Cretaceous (Mughal Kot) and Middle Jurassic (Chiltan Limestone) with low BTU. Good quality gas was discovered in Zarghun South-1 (1998) in the western periphery of the Sulaiman Foldbelt. Dewan-1 and Dewan 5-A (2005 and 2007) encountered hydrocarbons in Sembar/ Lower Goru and Chiltan formations that prove the existence of an active petroleum system in the deeper Middle Jurassic-Early Cretaceous rocks. The deeper reservoir potential of the internal part of the Sulaiman Foldbelt is the focus of this paper.

Wide spread distribution of thick, massive bedded Chiltan limestone characterized by shoaling-upward cycles and grainstone facies indicate high energy environments. Outcrop geology suggests that its upper part contains laterite and karstification which indicates paleo exposure. Such features generally enhance the reservoir quality. The Early Cretaceous (Sembar-Goru) play consists of sand progrades, deposited in a fluvio-deltaic setting. The depositional environment varies from proximal to basinal facies from eastern to western part of the Sulaiman Foldbelt. Lowstand wedges consist of good quality sands acting as potential reservoirs.

Integrated well data, outcrop geology and history of hydrocarbon discoveries in the Sulaiman Foldbelt suggest an effective petroleum system comprising source, reservoir and seal trilogy in the Middle Jurassic-Early Cretaceous succession to form prospective hydrocarbon plays in the internal part of the Sulaiman Foldbelt.

Selected References

Sheikh, R.A., M.I. Saqi, and M.A. Jamil, 2002, Chiltan limestone and Ziarat Nala Section and its reservoir potential in Western Sulaiman and Kirthar Range – an elementary appraisal: SPE/PAPG, Annual Technical Conference Proceedings, Islamabad, Pakistan, p. 80-105.

Wandrey, C.J., B.E. Law, and H.A. Shah, 2004, Sembar Goru/Ghazij composite total petroleum system, Indus and Suliaman-Kirthar geologic provinces, Pakistan and India: U.S. Geological Survey Bulletin, Report #B 2208-C, 23 p.

Hydrocarbon Exploration Perspective In Middle Jurassic-Early Cretaceous Reservoirs in the Sulaiman Fold Belt, Pakistan



Muhammad Iqbal

Chief Geologist

Pakistan Petroleum Limited, Karachi

Co-authors: Hayat Ahmad, Adeel Nazeer and
Ghulam Murtaza



CONTENTS

- OBJECTIVES
- EXPLORATION HISTORY
- GEOLOGICAL HISTORY
- STRATIGRAPHY & PETROLEUM SYSTEM
 - Source Rocks
 - Sealing Mechanism and Traps
 - Reservoir Rocks
 - Chiltan Limestone
 - High Energy Carbonates
 - Karstification and Reservoir Quality
 - Depositional Model for Chiltan Limestone
 - Sembar / Lower Goru
 - Sequence Stratigraphy
 - Localized Tectonic Events
 - Depositional Model For Sembar-Lower Goru
- CONCLUSION
- ACKNOWLEDGEMENT

OBJECTIVES

The objectives of this presentation is to evaluate the reservoir quality of the Deeper horizons in western and central Sulaiman Fold Belt

In Sulaiman Fold Belt reservoir rocks can be categories into:

- Shallow Reservoirs: those include
 - Dunghan & Ranikot formations (Paleocene)
 - Pab, Mughalkot and Parh formations (Late Cretaceous)

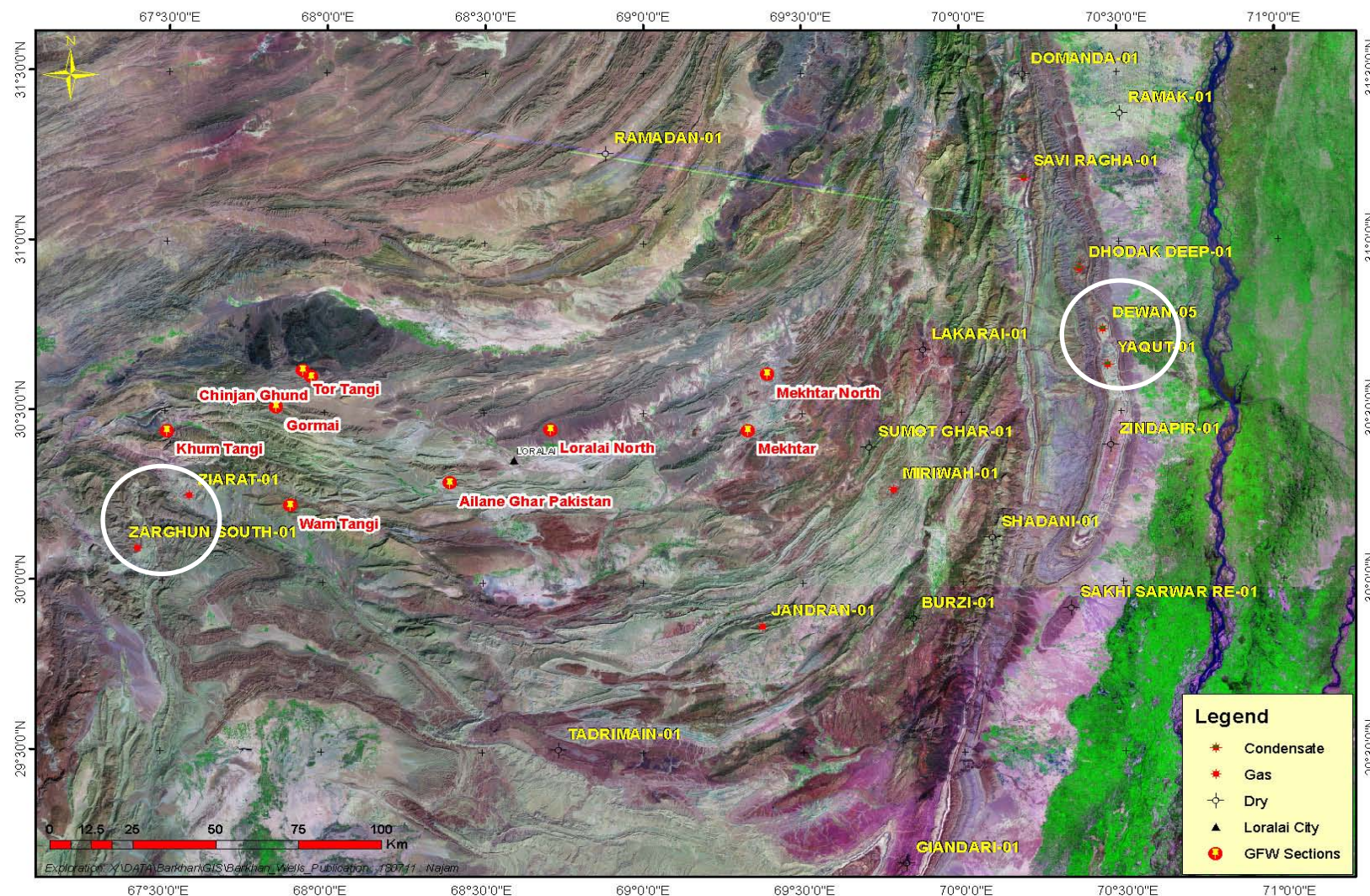
- Deeper Reservoirs: are those older formations which are not well established reservoirs though found to retain hydrocarbons. They include
 - Sembar / Lower Goru formations (Early Cretaceous)
 - Chiltan Formation (Middle Jurassic)

EXPLORATION HISTORY

Well	Year	Operator	TD	Formation at TD	Hydrocarbon Shows
Jandran-1	1975	AMOCO	2454m	Chiltan	Gas Discovery of 2.87 MMscfd in Chiltan
Zindapir-1	1986	OGDCL	4406m	Alozai	Minor Gas Shows in Allozai , Sembar/L Goru & Parh
Sumot Ghar-1	1997	OGDCL	1700m	Mughalkot	Minor Gas Shows
Miriwah-1	1997	BG	2005	Mughalkot	2.6 MMscfd of gas
Burzi-1	1999	OGDCL	2752m	Goru	Gas shows in Parh and Mughalkot
Zarghun South-1	1998	Premier	2025m	Chiltan	17.7 MMscfd gas from Chiltan
Shadani-1	2003	OGDCL	3606m	Alozai	Minor Gas Shows in Sembar/l. Goru
Ziarat-1	2005	MGCL	1050m	Chiltan	Gas discovery in Chiltan Limestone
Dewan-5A	2007	DPL	3305	Chiltan	Hydrocarbon discovery in Chiltan and Lower Goru formations
Yaqut-1	2009	DPL	3250	Chiltan	Hydrocarbon discovery in Chiltan and Lower Goru formations

Exploration history suggests that petroleum system exists and has charged Deeper reservoirs

MAP SHOWING WELLS AND SECTIONS VISITED



Scattered commercial discoveries in Deeper reservoirs show that a large part of the fold belt needs detailed exploration

GENERALIZED STRATIGRAPHY AND PETROLEUM SYSTEM

Age	Group	Formation/ Member	Lithology	Petroleum Geology		
				Source	Reservoir	Seal
Miocene to Recent	Siwaliks	Alluvium				
		Upper Middle Lower				
Oligocene		Chitterwatta /Nari				
Eocene	Kirthar	Drazinda				
		Pirkoh				
		Sirki				
		Habib Rahi Limestone				
	Ghazij	Baska				
		Drug / Rubbly L/S				
		Ghazij Shale				
Paleocene		Dunghan				
		Ranikot				
Cretaceous		Pab				
		Mughalkot				
		Parh				
		Upper Goru				
		L. Goru/ Sembar				
Jurassic		Chiltan				
		Loralai				
Triassic		Alozai				

PETROLEUM SYSTEM

SOURCE ROCK

- Shale of Sembar/Goru formations are considered as primary source with TOC upto 1.76% and both Kerogen type II and III, capable of generating oil and gas
- Carbonate of Chiltan (TOC up to 0.74% in Central Sulaiman Fold Belt) and shale of Mughalkot Formation (TOC up to 1.94% with kerogen Type-III) are additional source rocks
- Ghazij Shale and Habib Rahi Limestone are immature in eastern Sulaiman Fold Belt
- 1D basin modeling of Miriwah-1 shows that Sembar-Goru, Chiltan and Mughal Kot formations are in gas window

Formation	Average TOC (%)	Kerogen Type	Average Vitrinite Reflectance (%) / Tmax (°C)	Remarks
Mughalkot	1.94	III	> 1.2% / >450°C	Secondary Source
Sembar/ Lower Goru	1.76	III and mix type II-III	1.6 %	Primary Source
Chiltan	0.74	II and III	> 1.6 %	Secondary Source

PETROLEUM SYSTEM

SEALING MECHANISM

- The overlying marine shale observed in Zindapir-1 and Shadani-1 will provide top seal for the Chiltan reservoir
- The shale of the Upper Goru will provide top seal for the Lower Goru Sands

TRAP

- Thrusted anticlines, pop ups and positive flower geometry are possible traps, however, the possibility of stratigraphic traps also exists

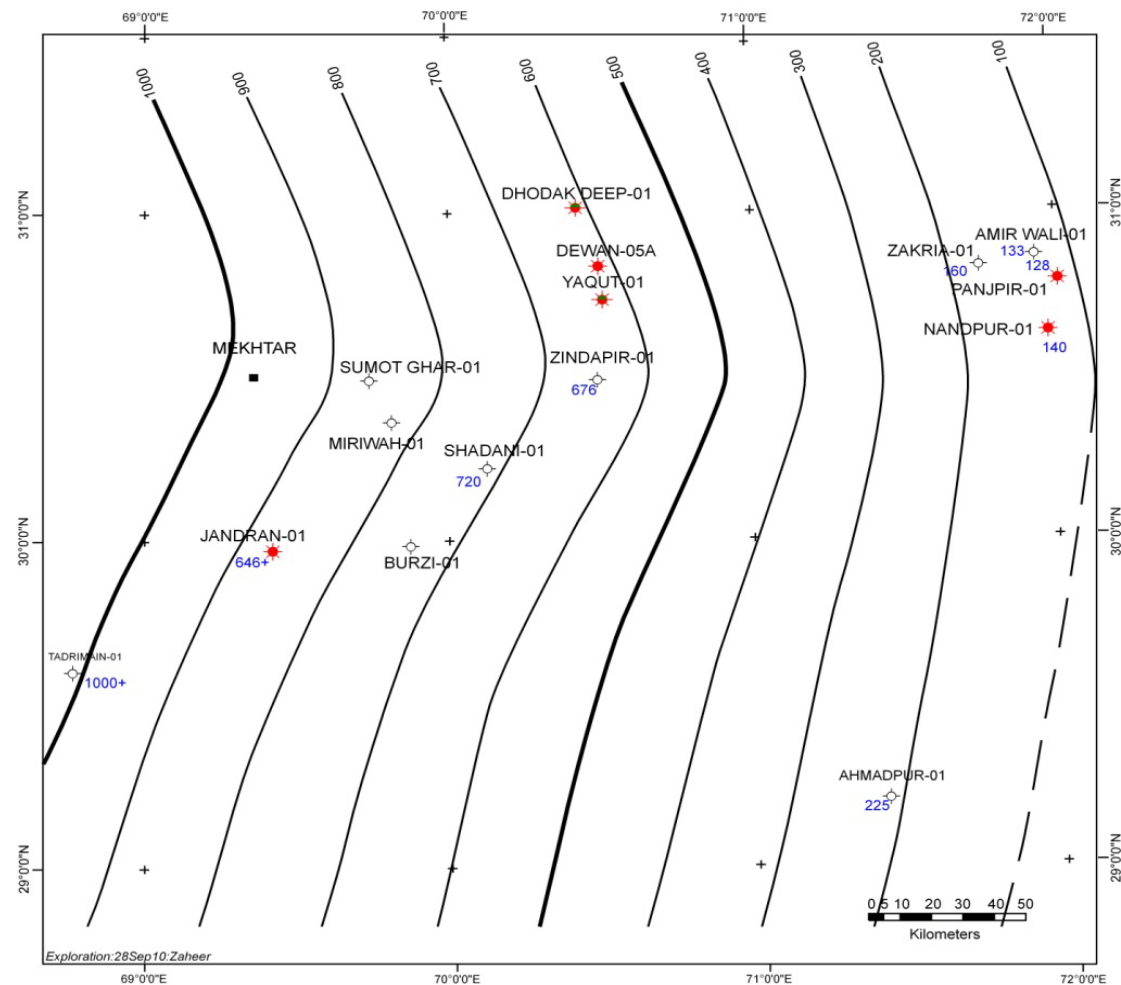
RESERVOIR ROCKS

CHILTAN LIMESTONE

- Generally Chiltan Limestone is massive to thick bedded and locally oolitic
- In the study area Chiltan Limestone is oolitic, packstone / grainstone (Jandran-1) with cavernous porosity at places
- High Energy carbonates and present day karstification observed
- Sheikh et al. [2002] reported vuggy and moldic porosity from Ziarat Nala
- Neutron Porosity trend shows shoaling up sequences
- These observations suggest that Chiltan Limestone is a shelf edge facies where leaching, winnowing and karstification processes are common. Such facies are generally coarse grained with quality reservoirs which can retain hydrocarbons

RESERVOIR ROCKS

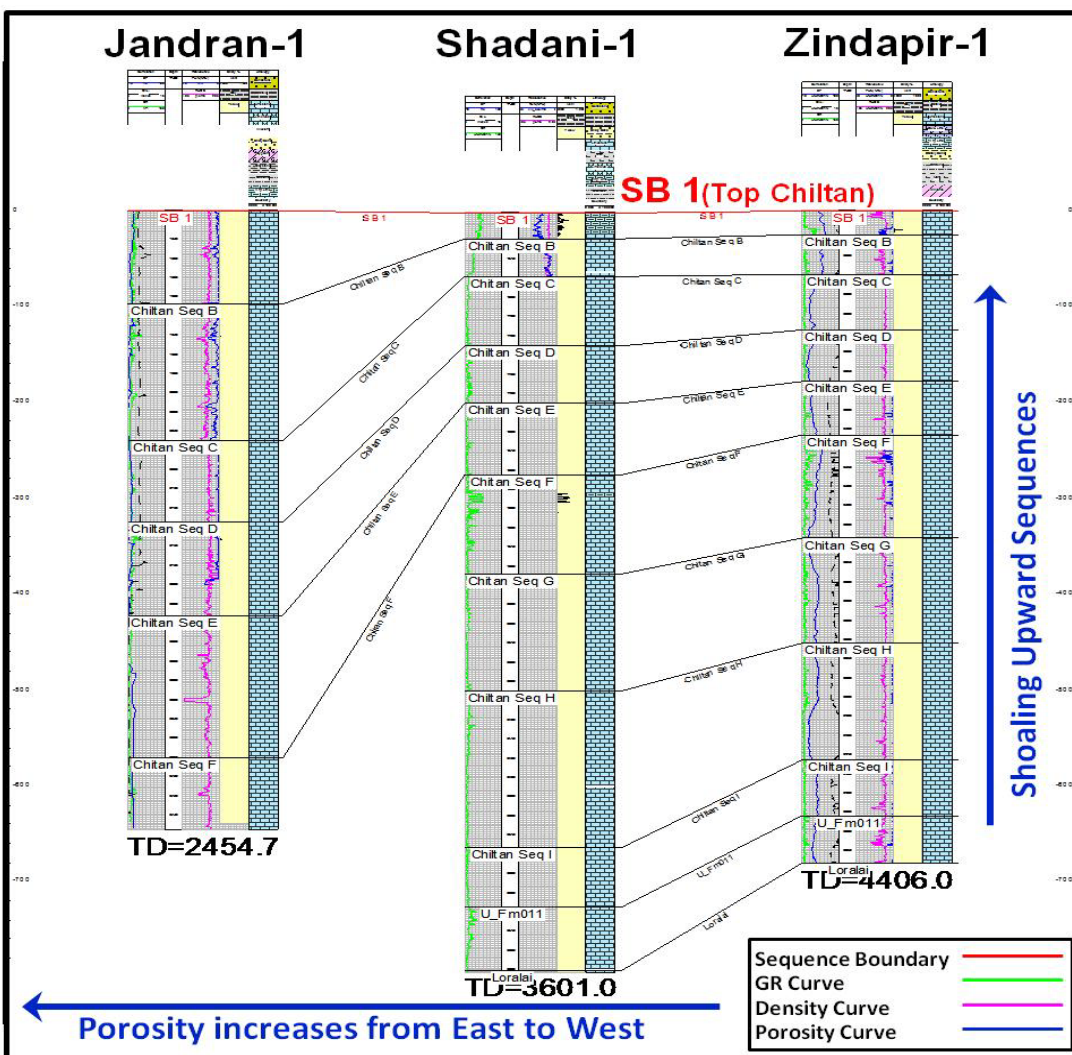
ISOPACH MAP OF CHILTAN LIMESTONE



Map shows westward increase in thickness. Reported thickness ranges from 750 to 1800 m in the Sulaiman Fold Belt

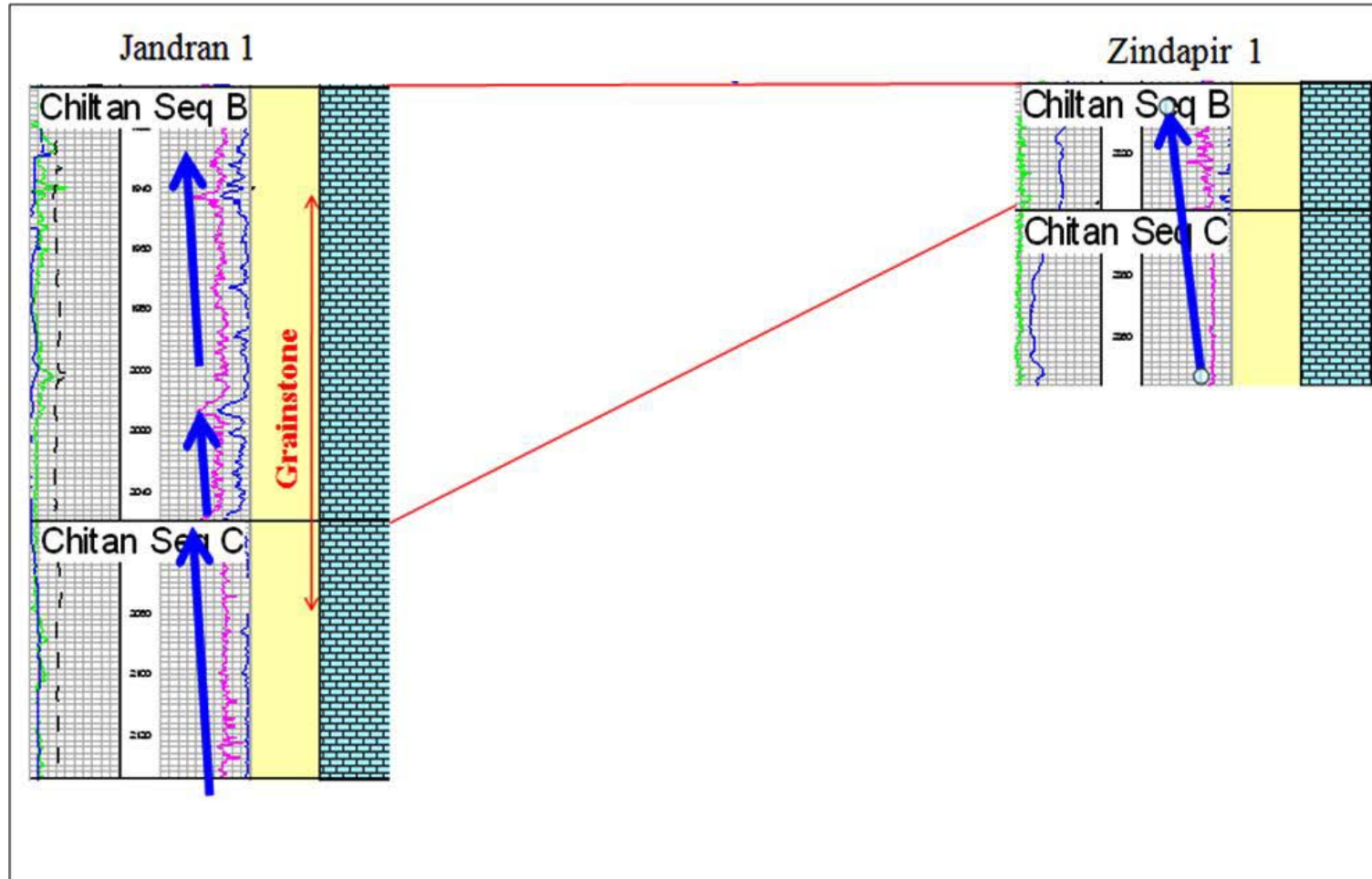
Correlation showing persistent lateral extent of Chiltan Limestone

Log derived porosities of Jandran-1 and Zindapir-1 showing lateral and vertical increase



Zindapir-1			Jandran-1		
Interval	Thickness	Porosity	Interval	Thickness	Porosity
2196.5-2207.5	11.1	3-7%	1808-1916	108	3-9%
2343.5-2354.6	11.3	3-7%	1970-2094.5	124.5	2-8%
2364.4-2369.8	5.4	2-4%	2141-2185	44	2-4%
2373.7-2402.1	28.4	2-8%	2268-2307	39	2-6%
2446-2453	7	3-4%	2329.6-2357	27.5	4-6%
2514-2582.6	68	2-6%			
2611.6-2627.9	16.3	2-3%			
2770-2777	7	2-4%			

SHOALING UP SEQUENCE IN CHILTAN LIMESTONE



Increase in Porosity reflects increase in grain size. Neutron Porosity trend shows Shoaling Up sequence in carbonate

DEVELOPMENT OF VUGGY POROSITY IN CHILTAN LIMESTONE

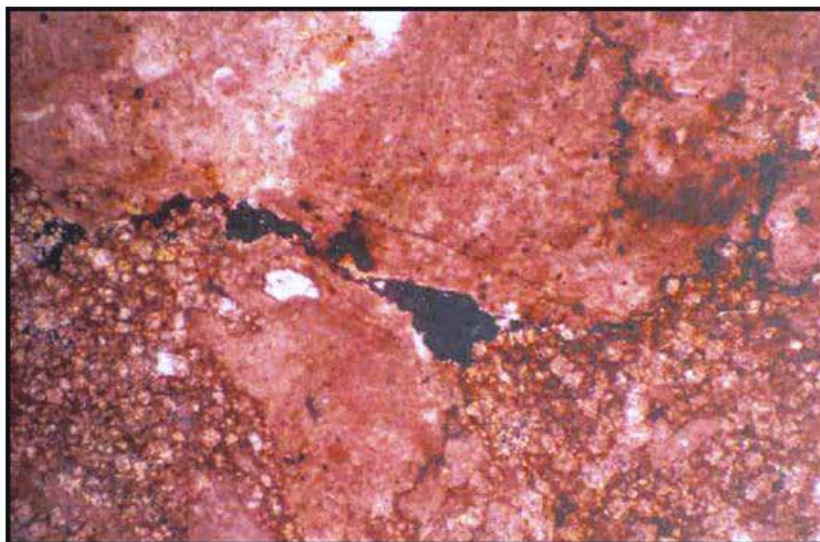


Plate-1a: Open vugs and matrix selective dolomitization.
(Magnification x 50).

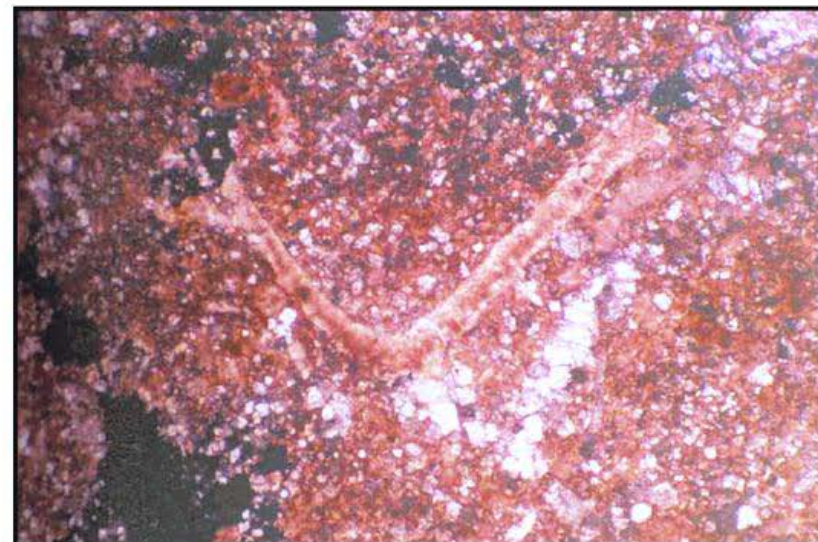
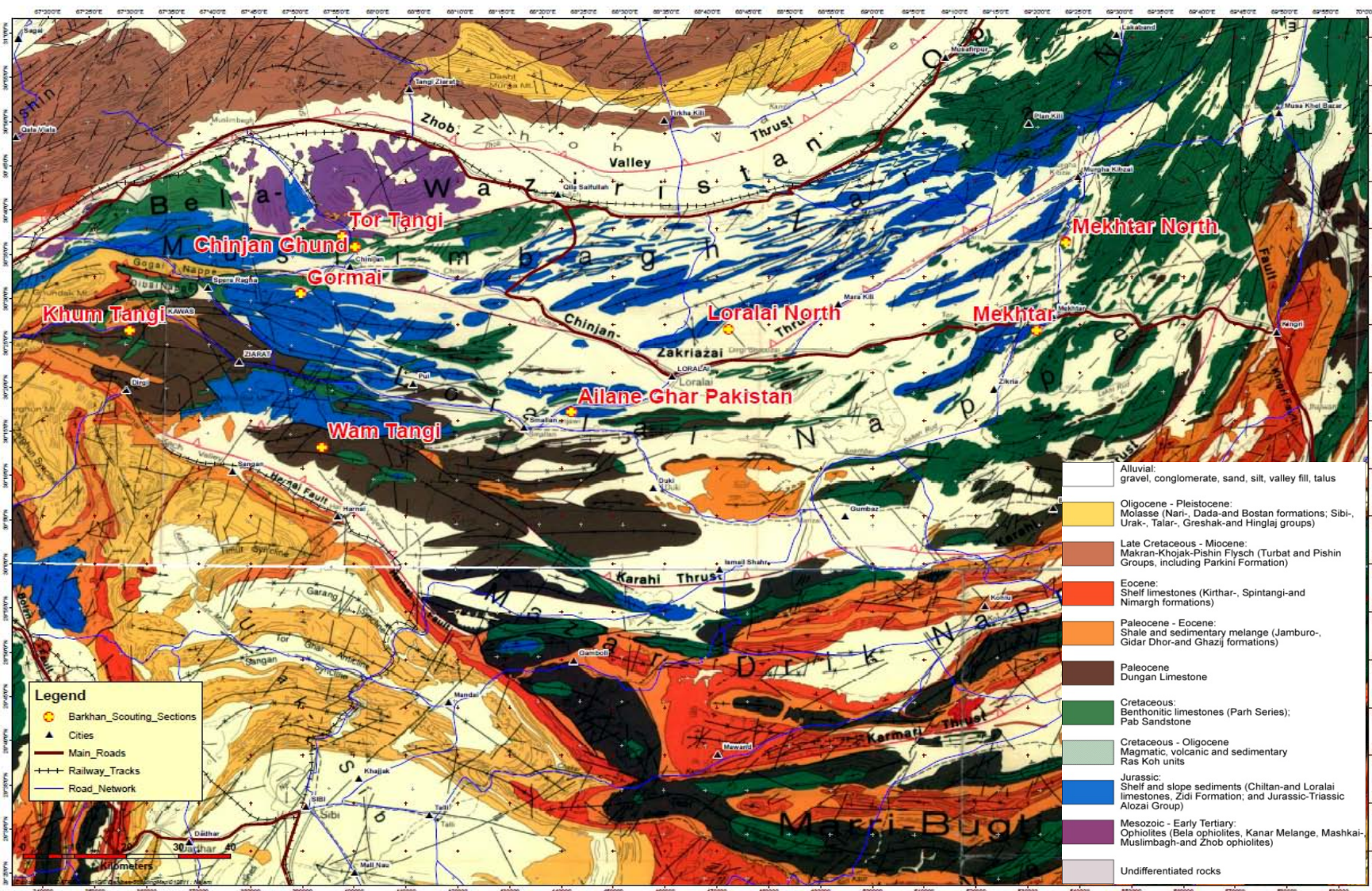


Plate-1B: Red Algae bearing dolomitized matrix and vuggy porosity.

Vuggy porosity in Chiltan carbonate at Ziarat Nala (Sheikh et al., 2002)

GEOLOGICAL FIELDWORK OF THE STUDY AREA



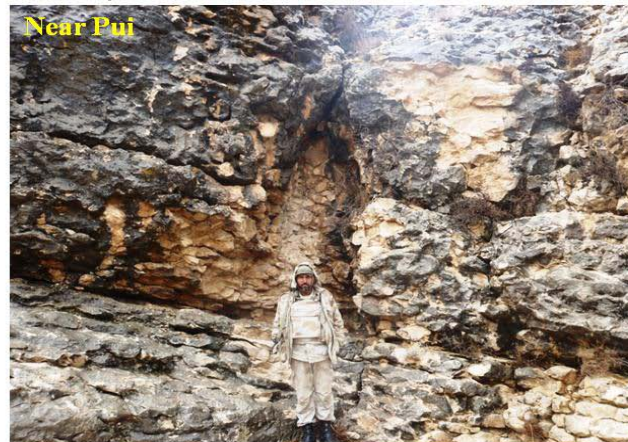
The study area is an ideal location for sampling Deeper reservoirs as they are buried in the adjacent area

HIGH ENERGY CARBONATE

Well developed fossils represent high energy shelf carbonate environment



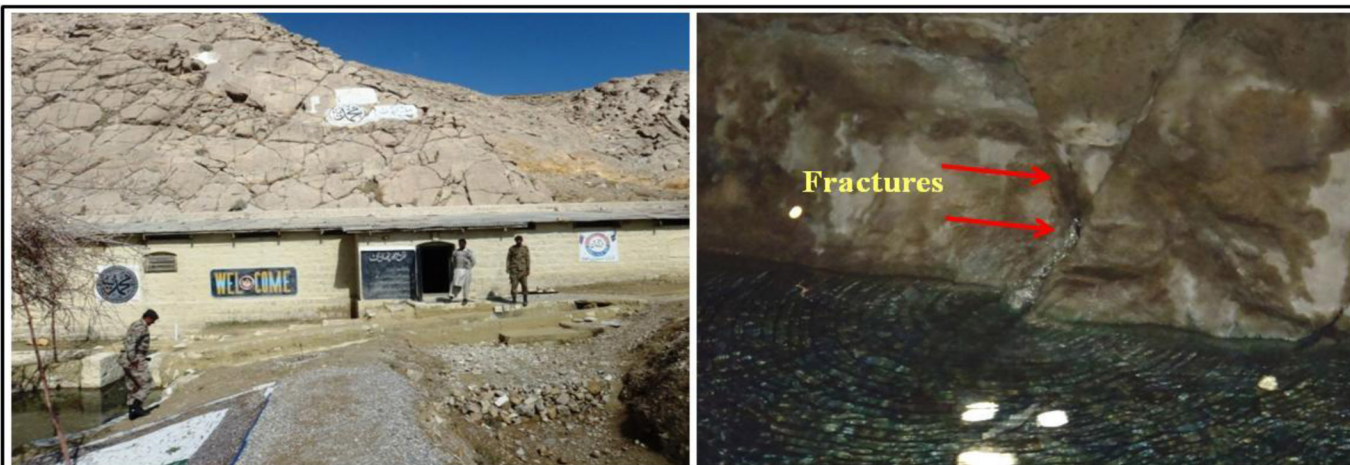
Basal part of Jurassic limestone with abundant fossils



**Jurassic nodular limestone
(Shallow marine)**

Well developed benthonic fossils and nodular limestone represent high energy shelf environment

PRESENT DAY KARSTIFICATION IN CHILTAN LIMESTONE



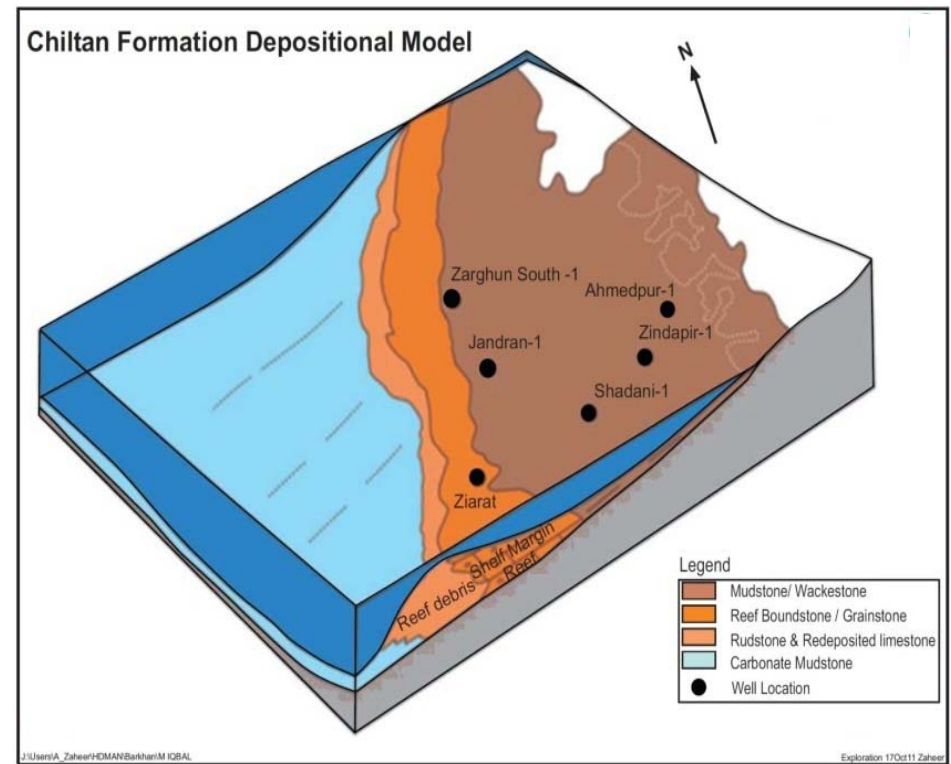
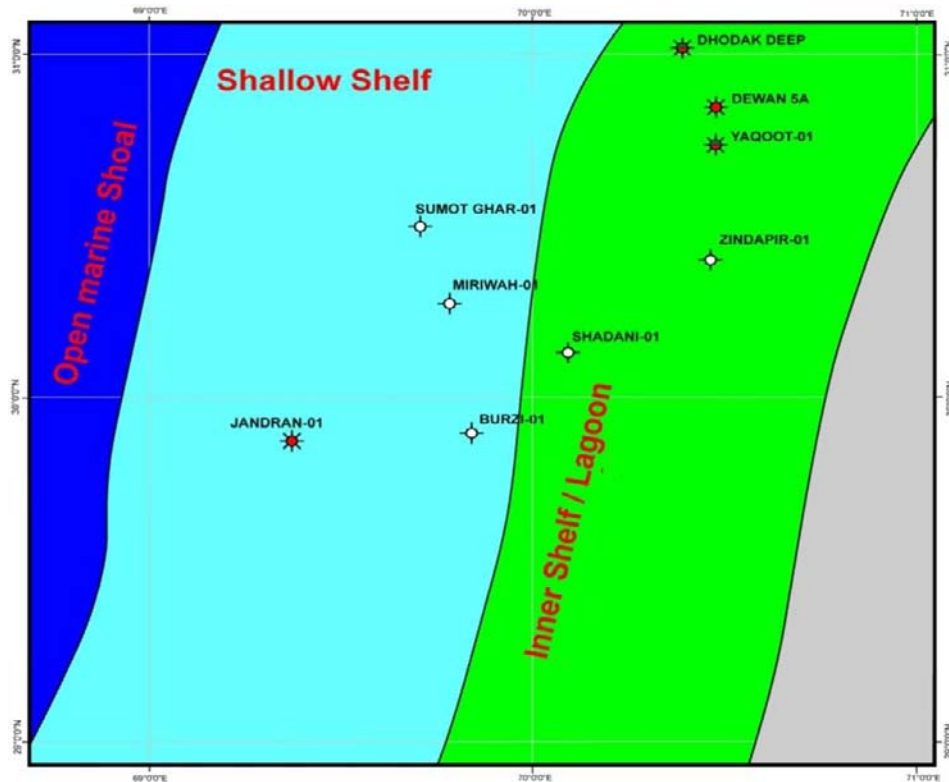
Surface fractures and seepages in Jurassic carbonates at Pathan Kot, Loralai



Present day karstification in Jurassic carbonates at Pui section

Fractures, water spring and present day karstification from solution weathering in Jurassic carbonate at Pathan Kot, Distt. Loralai, Balochistan indicate enhanced porosity

DEPOSITIONAL MODEL FOR CHILTAN LIMESTONE



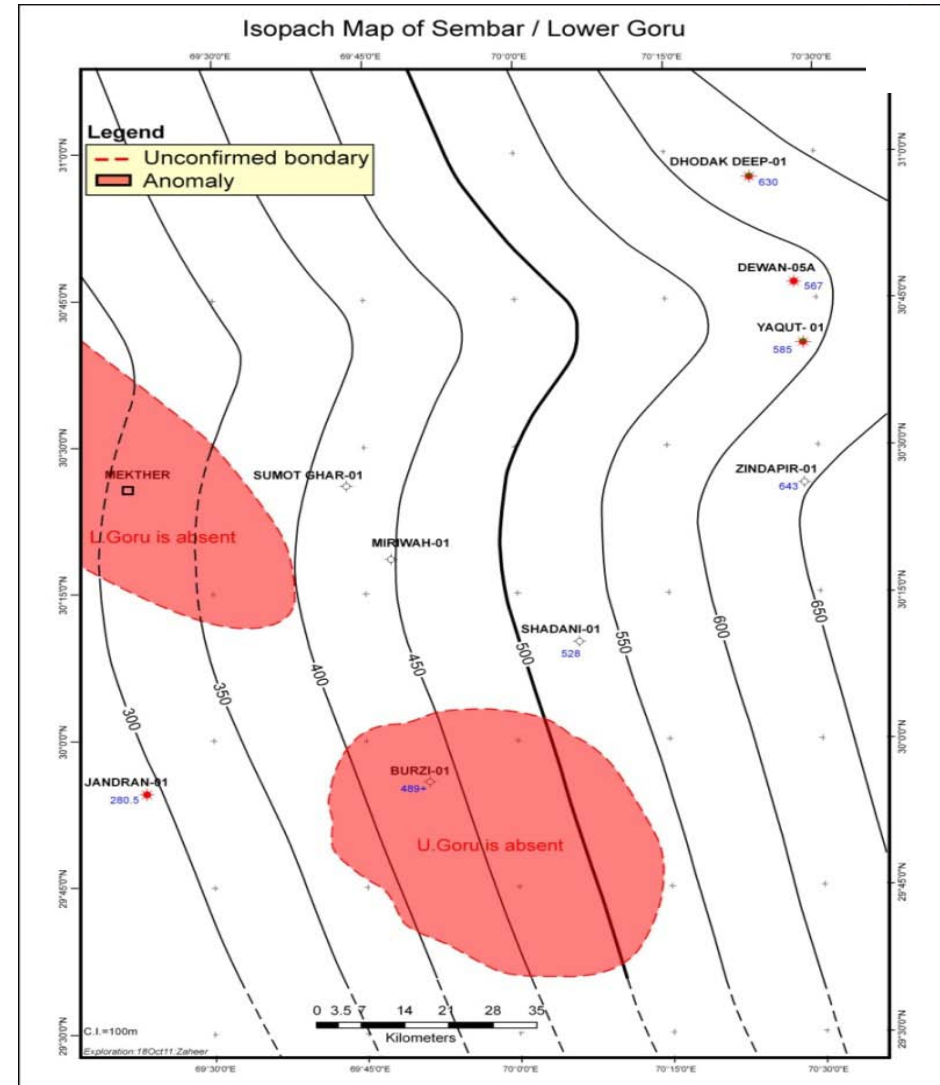
- In Zindapir & Shadani wells mudstone to wackestone facies (oolitic, cryptocrystalline to microcrystalline, argillaceous and rarely fossiliferous) occur
- Jandran-01 and Zarghun South-01 lie in shallow shelf environment and represent cycles of mudstone to grainstone facies. Grainstone contain oolites, pellets, and intraclasts
- Reefoid facies in Chiltan Limestone with good secondary porosity were reported at Ziarat Nala (Sheikh et al. 2002) and at Gurmai and Pui sections (GFW 2011)

RESERVOIR ROCKS

SEMBAR/ LOWER GORU

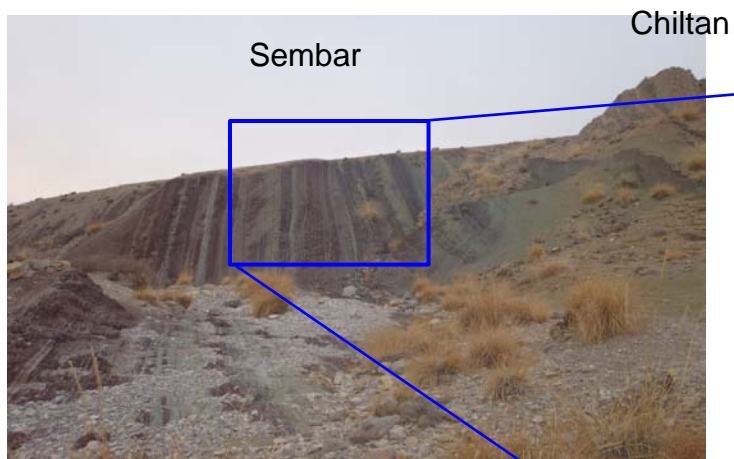
- Sembar Formation is organic-rich, silty shale sequence with subordinate sandstone. It shows eastward increase in thickness
- Lower Goru is mainly sandstone with interbedded shale. It conformably overlying Sembar and is overlain by thick shale and limestone of Upper Goru
- Sembar/Lower Goru sandstones hydrocarbon producers in Salsabil field
- Sembar/Goru formations divided into 9 sequences (IEDS). Sequences 1 to 3 correspond to different lithology of Sembar whereas 4 to 9 are for Lower & Upper Goru formations
- Beicip [2007] & Wandrey et al., [2004] considered that top Chiltan represents a basin wide hiatus of 24MY

Absence of IEDS 3, 4, 5 & 6 seqs. of Goru (at Mekhtar) may be due to local uplift

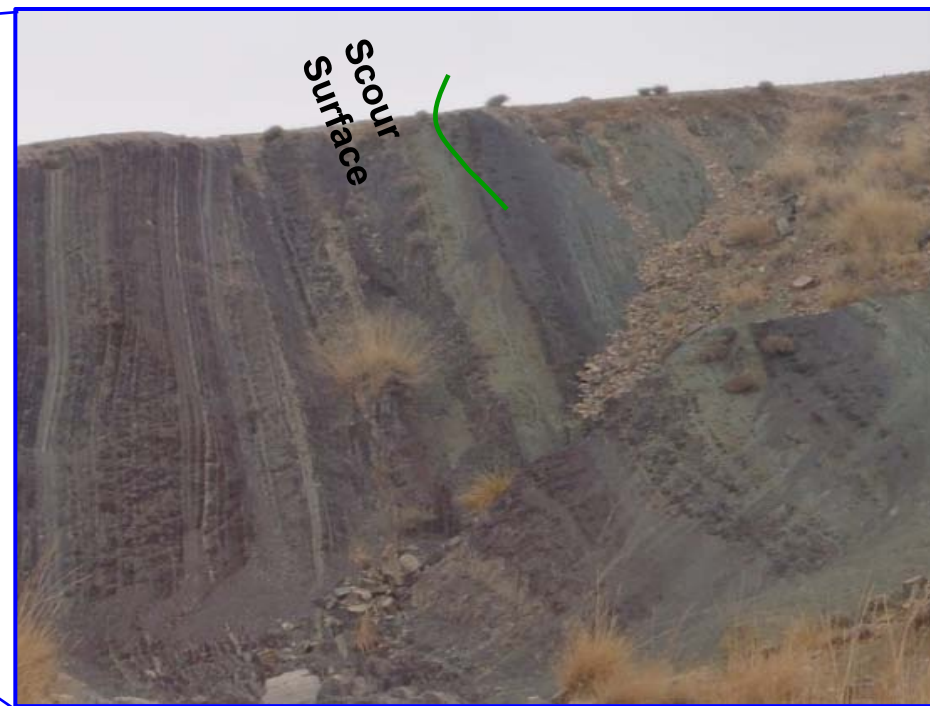


PALEOSOLS /SUB AERIAL EXPOSURE AT OUTCROPS

Sub Aerial Exposure at top Chiltan



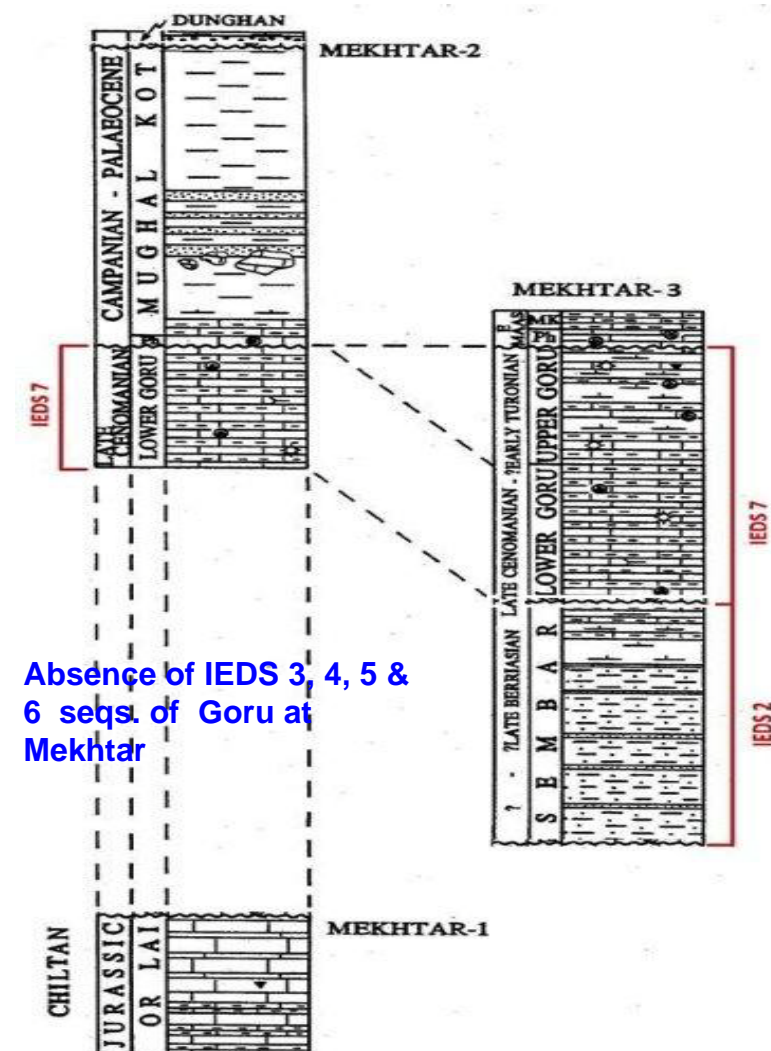
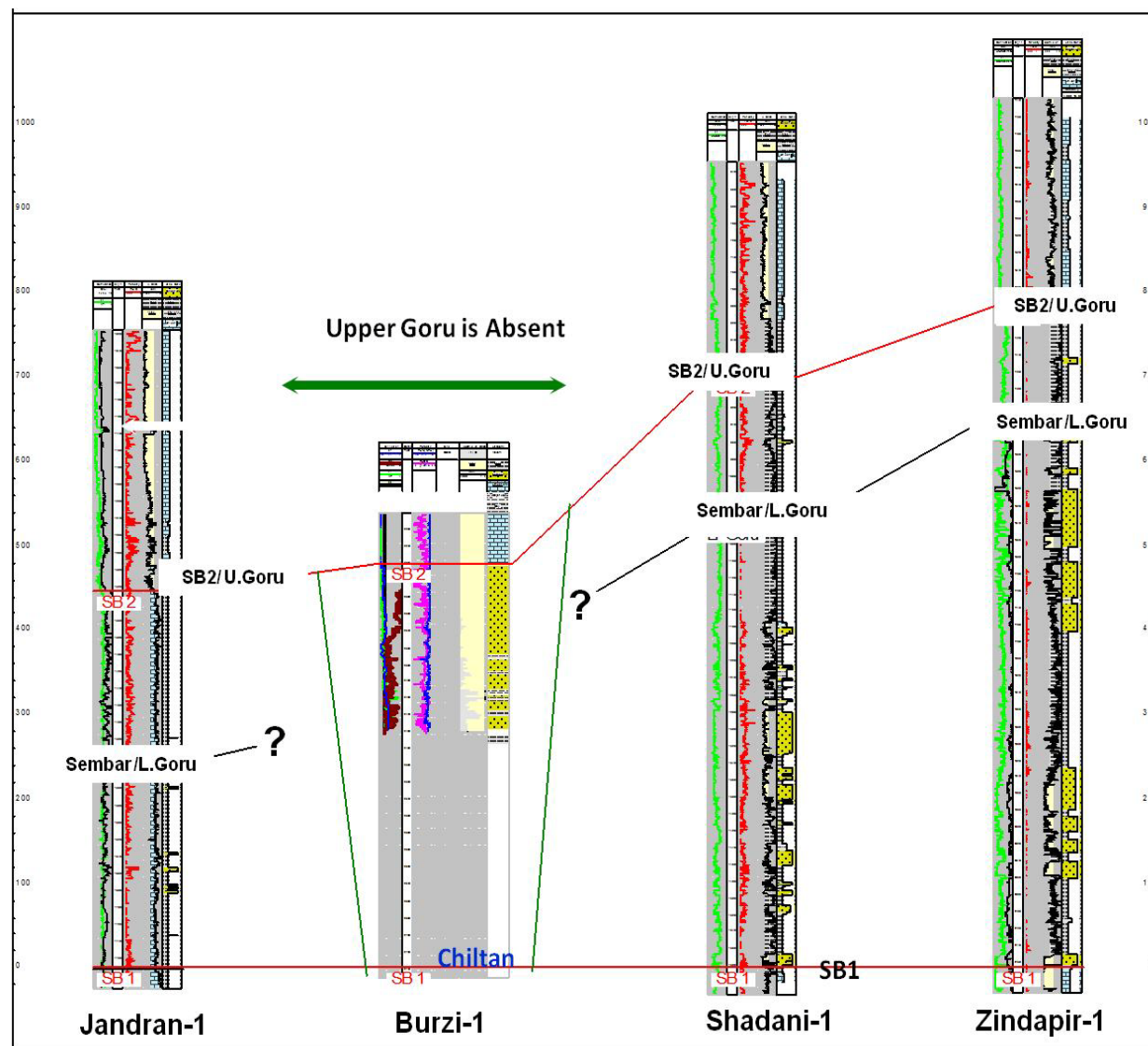
Reddish shale indicates sub aerial exposure



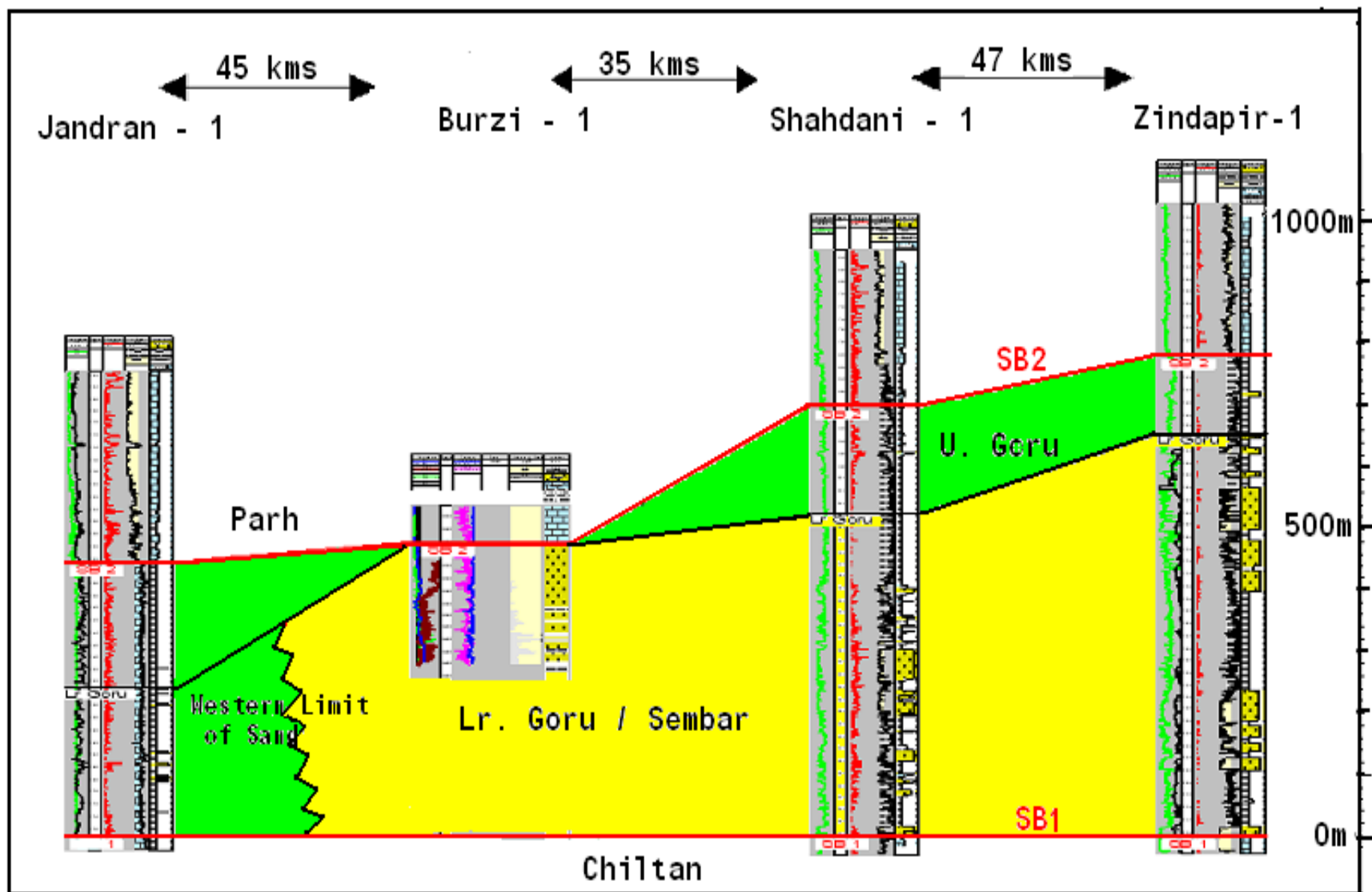
Basal part of Sembar (Mekhtar – Murgha Kibzai Road)

Laterite at the top of Chiltan

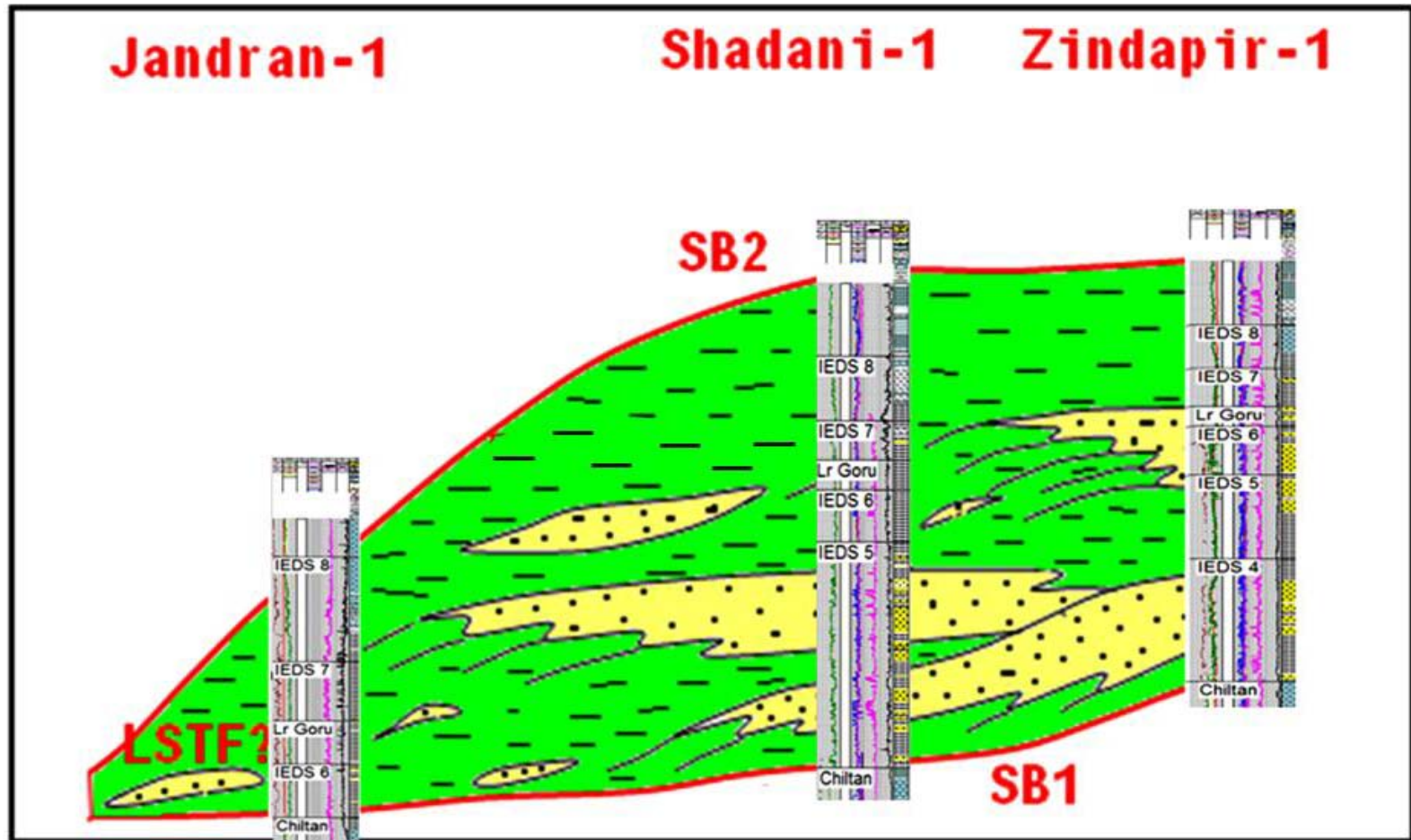
LOG CORRELATION OF SEMBAR / GORU INDICATING ABSENCE OF UPPER GORU



LOG CORRELATION OF SEMBAR / GORU INDICATING ABSENCE OF UPPER GORU



DEPOSITIONAL MODEL OF SEMBAR / GORU FORMATIONS



This model suggests that fluvio-deltaic sands in the east (Shadani-1 & Zindapir-1) pass westward into distal slope and basin mud (Jandran-1) across shelf edge. These distal facies may provide the possibility of low stand turbidite fan systems (Burzi-1)

CONCLUSION

- Chiltan Limestone is moderate to high energy, oolitic and grainstone facies with shoaling upward trend, localized cavernous, vuggy and moldic porosity
- Fractures, present day karstification, paleosols / and paleo-exposure surfaces at top part are common in outcrops
- Integration of well data, log and GFW suggest that Chiltan Limestone has good reservoir quality
- Limited stratigraphic data reveal that central and western fold belt is located in a depositional setting where westward prograding Early Cretaceous sands (Zindapir & Shadani) passing into slope to basin mud (Jandran)
- This facies change may provide a strong stratigraphic component with up dip pinch outs of the westward prograding fluvio-deltaic sands along structural noses, which can act as potential exploration target
- Overall, assessment of deeper horizons suggests presence of an effective petroleum system comprising source, reservoir and seal in Jurassic to Lower Cretaceous sediments with possibility of both conventional and unconventional traps. Deeper reservoirs of Chiltan Limestone and Sembar / Goru formations are, therefore, considered as prospective candidates for detailed exploration and drilling in the central and western Sulaiman Fold Belt





ACKNOWLEDGMENT

Pakistan Petroleum Limited Management is acknowledged for permission to present this paper.

Special thanks to Mr. Moin Raza Khan (General Manager Exploration), Dr. Nadeem Ahmad (Senior Manager Exploration) and Syed Haider Ali Shah (Ex-Consultant at PPL) for encouragement and guidance.

We are grateful to reviewers Mr. Shahid Hameed, Mr. S. Manshoor Ali (Spud Energy Pty Ltd.) and Jerome Kelly (Tullow Oil) for their valuable review and productive feedbacks.