

Shale Gas Potential of the Lower Goru Formation over the Lakhra High in Lower Indus Basin, Pakistan*

Fareed Iqbal Siddiqui¹, Asad Adhami¹, Afnan Asghar¹, Atif Hussain¹, and M. Wahaj Uddin Khan¹

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¹Pakistan Petroleum Limited, Karachi, Pakistan (s_fareed@ppl.com.pk, m_adhami@ppl.com.pk)

Abstract

Due to the continuous depleting nature of conventional reserves in Pakistan, the unconventional resources particularly shale gas has gained significant importance. Potential of shale gas in Lower Indus Basin remains largely unknown due to limited data in shales because wells are usually drilled at the highs targeting conventional reservoirs. On the other hand, mature source rocks are located in the lows or synclines. However, an attempt has been made to evaluate Shale Gas potential of Lower Goru Shales over Lakhra High in the Lower Indus Basin by using geochemical and geological data from seven wells.

Lakhra High is a north-south oriented, gentle fold between the Laki Range and the Indus River, and it appears to be the eastern most structure resulting from collisions of the Arabian, Eurasian, and Indian tectonic plates. To date only eight wells are drilled near the high targeting Early Cretaceous age Lower Goru Formation at structural traps. The conventional potential of these wells is unproductive due to poor quality reservoir. However, unconventional potential of Lower Goru Formation over the High still needs to be developed. The Lower Goru Formation was deposited in the deltaic settings over the westward dipping passive margin. The Formation is divided into seven members namely; Upper Sands (Youngest), Upper Shale, Middle Sands, Lower Shale, Upper Basal Sands, Talhar Shale and Lower Basal Sands (Oldest).

Results of the current study show that all shale units comprise of Type II and Type III Kerogen with a TOC in a range of 0.5-5.0%. All the shale units are more than 50m thick and are present at a depth of 2,700-3,500m. The Upper and Lower Shale units are considered as immature whereas Talhar Shale is in the wet gas to dry gas window based on the maturity data of surrounding wells. Talhar Shale possesses the required brittleness for hydraulic fracturing.

The study lead us to conduct 3-D basin modeling study, specialized core analysis and re-evaluation of available geochemical data in future to refine our results and establish prospects for shale gas.

SHALE GAS POTENTIAL OF THE LOWER GORU FORMATION OVER THE LAKHRA HIGH IN LOWER INDUS BASIN, PAKISTAN

Dr. Fareed Iqbal Siddiqui, Asad Adhami, Afnan Asghar,
Atif Hussain & M. Wahaj Uddin Khan

Pakistan Petroleum Limited

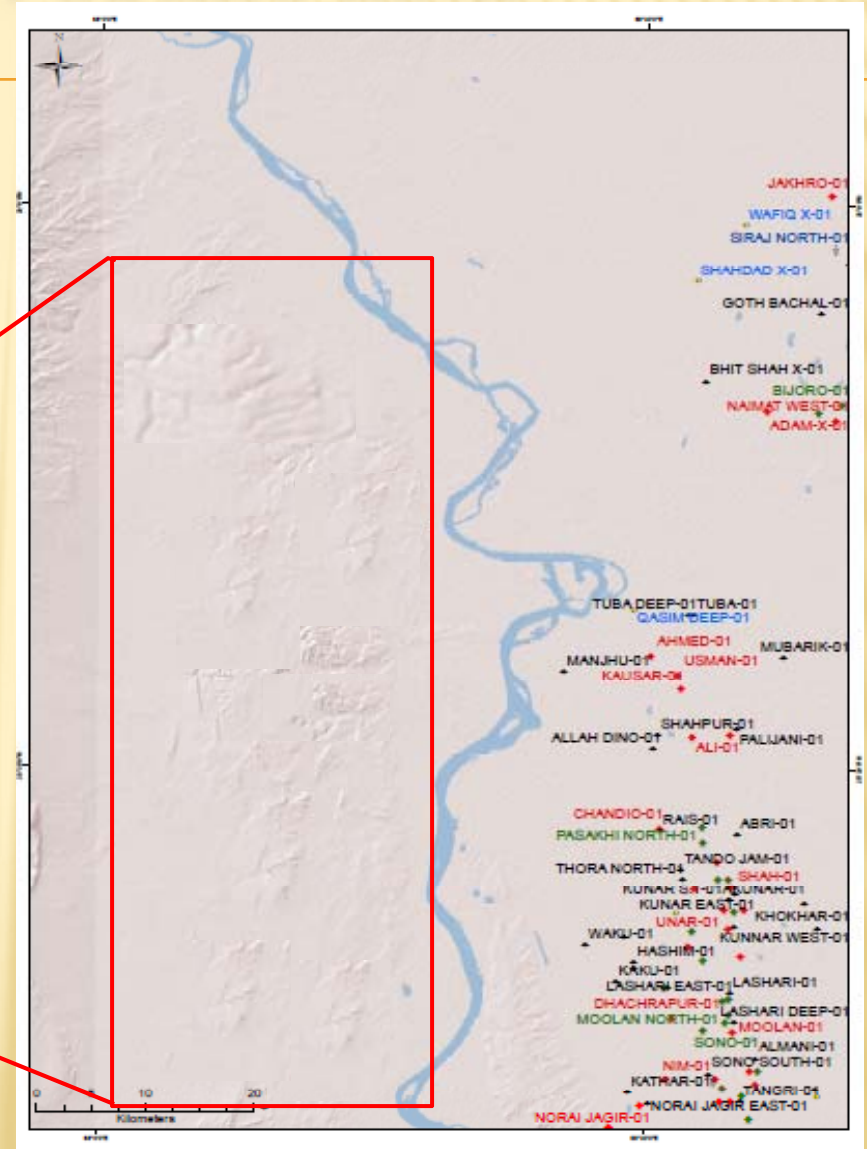
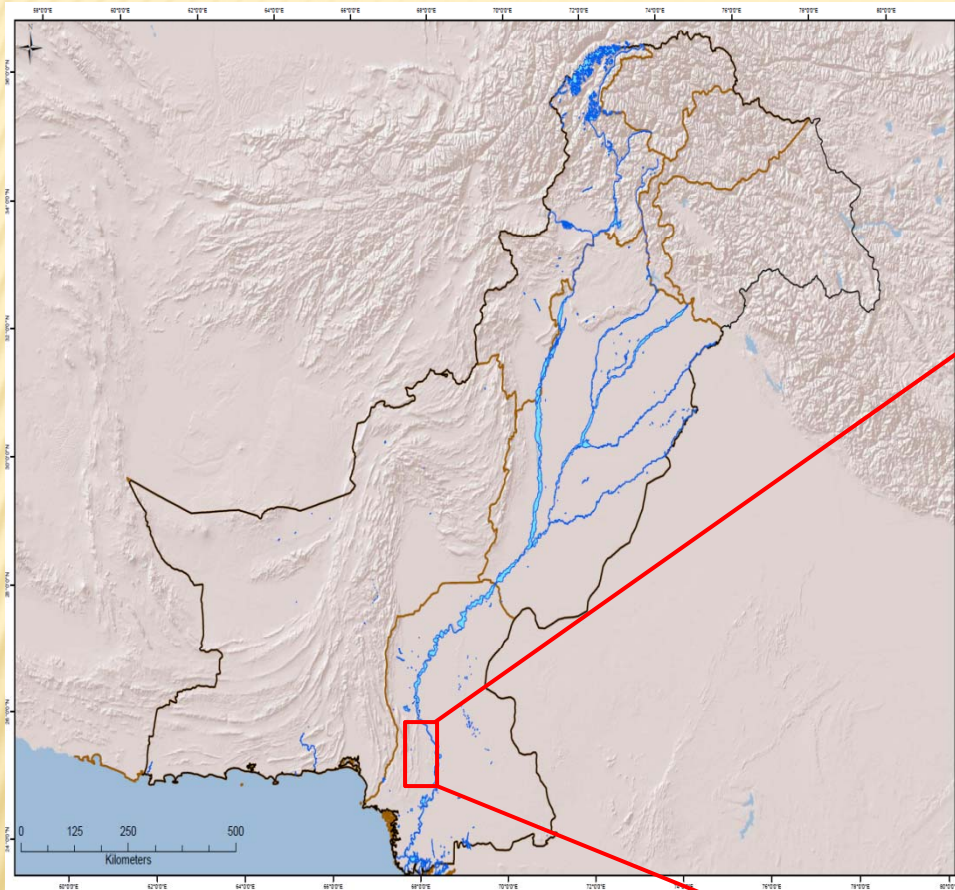
s_fareed@ppl.com.pk

m_adhami@ppl.com.pk

OUTLINE OF THE PRESENTATION

- ❖ General Description of the Area
- ❖ Available Data
- ❖ Geological & Geochemical Characteristics of Shale Units
- ❖ Comparison of Shale Potential
- ❖ Conclusion & Way Forward

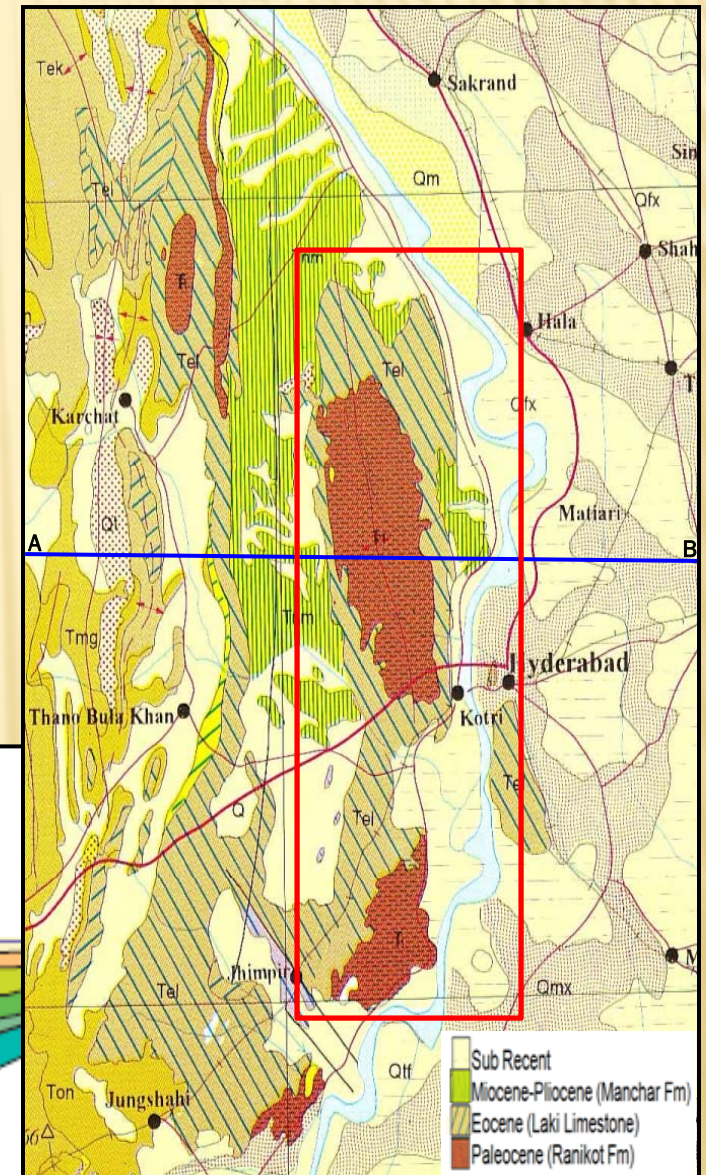
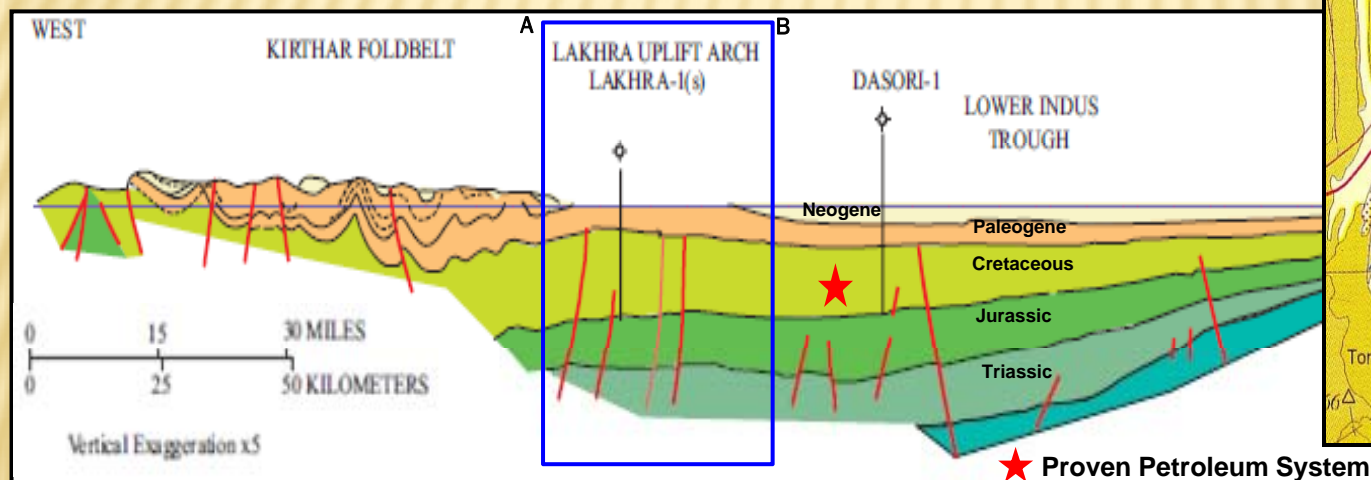
LOCATION MAP OF LAKHRA HIGH



- ❖ Area of 740 Sq Km available
- ❖ Sindh Province
- ❖ 50-130 m amsl
- ❖ Water resource
- ❖ Less populated
- ❖ Easily accessible

GEOLOGICAL MAP & REGIONAL CROSS SECTION

- ❖ North trending anticline
- ❖ Paleocene exposed in the core
- ❖ Located in the foothills of Kirthar Fold belt
- ❖ 30 Km wide & 100 Km long
- ❖ Cretaceous at shallow depth due to Paleocene Exposure but impacts the maturity
- ❖ Less deformed comparing to the West



Ref: GSP, 1993
Scale: 1:1000,000 4

STRATIGRAPHY & PETROLEUM SYSTEM ELEMENTS

A G E			FORMATION	LITHOLOGY	HYDROCARBON POTENTIAL				Conventional Discoveries	
SYSTEM	PERIOD	CONVENTIONAL			Un CONVENTIONAL					
		SOU- RCE			RESE- RVOIR	SEAL	SHALE GAS			
C R E T A C E O U S	PALEOGENE	PLIO-MIOCENE	SIWALIKS						EQUIVALENT TO SML & SUL IN CENTRAL INDUS BASIN; PRODUCING GAS IN SUI, ZIN, UCH, KANDHKOT, MAZARANI, QADIRPUR, SARA, SURI & ALL CENTRAL INDUS BASIN FIELDS	
		MIDDLE	BARTONIAN	LAKI						
	E O C E N E	EARLY	LUTETIAN	DUNGHAN					PIRKOH, SURI & HUNDI	
		LATE	YPRESIAN	RANIKOT						
	THANETIAN									
	DANIAN									
	LATE CRETACEOUS	SANTONIAN	KHADRO						MOST OF THE FIELDS LOCATED IN THE BASIN, NIM & TANDO ALLAH YAR BLOCK	
		CONIACIAN	PAB							
		TURONIAN	M.KOT / F.MUNRO							
		CENOMANIAN	PARH							
	ALB I A N	UPPRE GORU							TGA, ZAUR DEEP, S. MAZARI DEEP	
	Z A R T I A N	LOWER GORU							3	MARI DEEP, KADANWARI, SAWAN, MIANO, MITHARO, JAKHRO, PAINAR, CHACK-DIM, BOBI, ADIM X-1 ETC.
									1	
M E S O Z O I C	CRETACEOUS	VALANGINIAN	SEMBAR						MAJOR SOURCE ROCK	
		BERRIASIAN								
	JURASSIC	TITHONIAN	CHILTAN						ZARGHUN SOUTH #1	
		KIMMERIDGIAN								
		OXFORDIAN								
		CALLOVIAN								
		BATHONIAN								
		BAJOCCIAN								
	ALENIAN									

❖ Lower Goru Fm 1700m thick

- Inner – Middle Shelf fines (upper part)
- Outer Shelf fines (lower part)

❖ Based on Sand-Shale sequences, clearly divided into Seven (07) Members in the East;

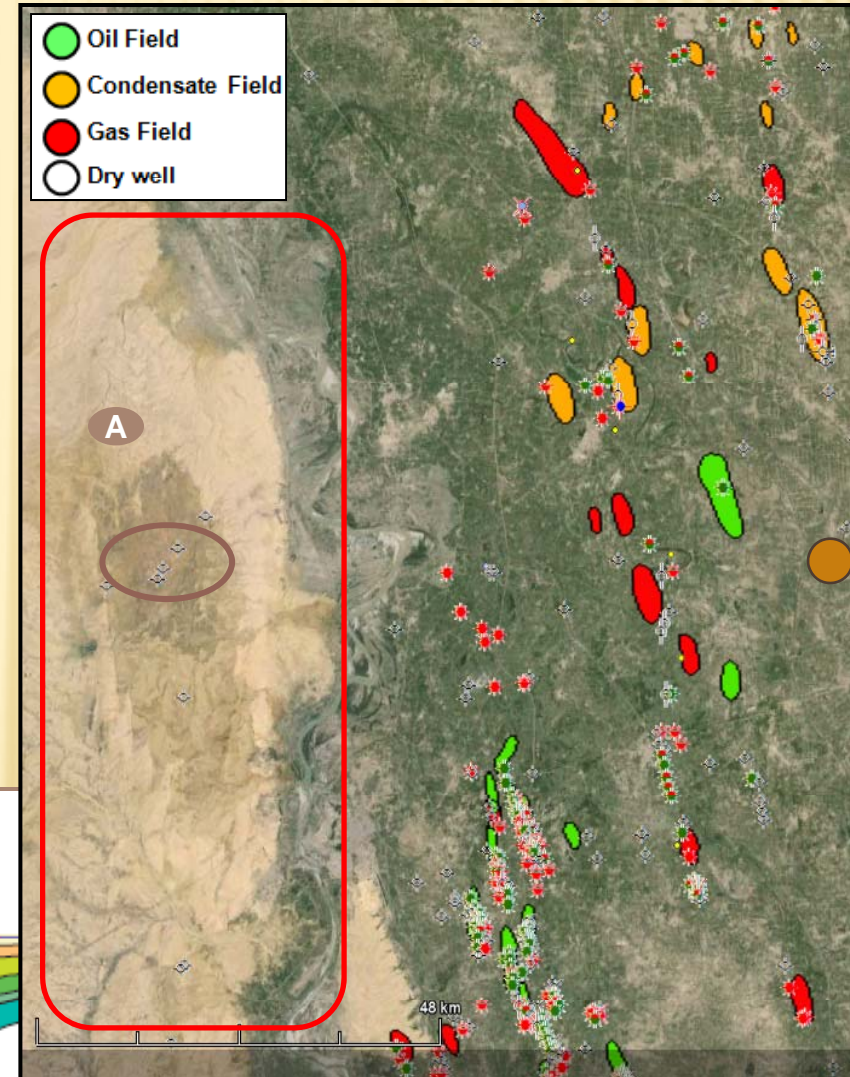
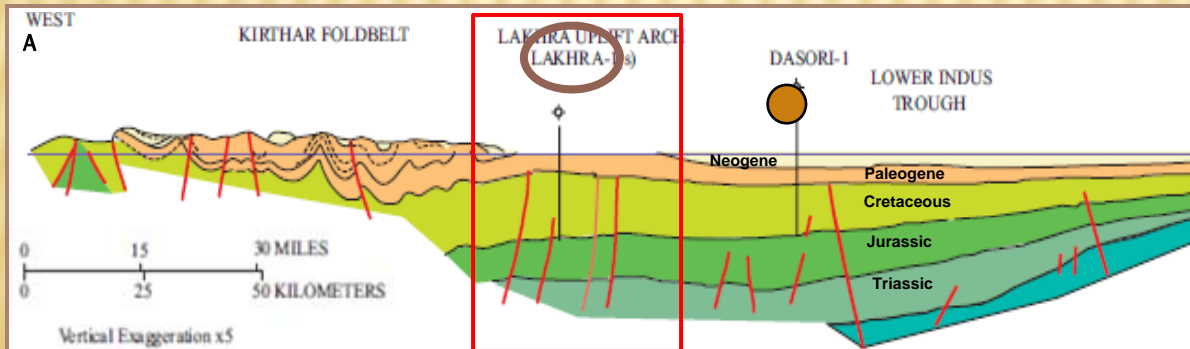
- Upper Sand (*Con. Reservoir*)
- **③ Upper Shale***
- Middle Sand (*Con. Reservoir*)
- **② Lower Shale***
- Basal Sand (*Con. Reservoir*)
- **① Talhar Shale*** (*Potential source*)
- Massive Sand (*Proven reservoir*)

❖ Proven reservoir units pinching out in the area, comprises siltstones & thinly bedded sandstones

*** Potential Shale Gas Candidates**

EXPLORATION HISTORY OF LAKHRA HIGH

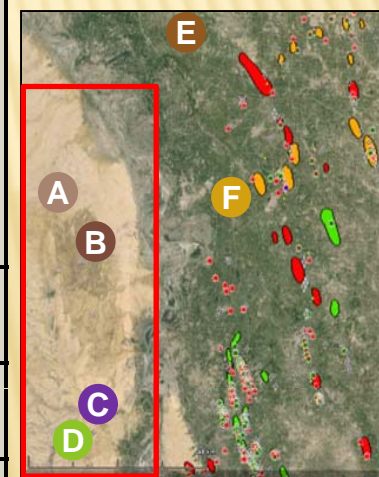
- ❖ Since 1957; 08 wells have been drilled (All Dry Holes)
- ❖ Targets were Conventional Reservoirs ;(i) Early Cretaceous, (ii) Late Cretaceous & (iii) Paleocene
- ❖ Several Oil and Gas Discoveries in the East
- ❖ Proven Source Rock: Sembar Shales (Late J - Early K)
- ❖ Potential source rock: Lower Goru Shales
- ❖ Reservoir Quality was key failure issue for Lower Goru
- ❖ Lower Goru Shales have high Gas shows in “ Well A”



Ref: Google Earth

DATABASE

Well	Wireline Logs						Mud Log	Geochemical data						Facies Log	XRD Data	Source of Geochemical data
	G R	D T	R E S	R H O B	N P H I	P E F		T O C	S 1	S 2	S 3	T m a x *	V R *			
<div></div> A																IEDS Study, 1995 PPL-ENI Joint Study, 2011
<div></div> B																Pakistan Regional Geo chemical Study, 1989
<div></div> C																
<div></div> D																
<div></div> E																OGDC Basin Study, 2007
<div></div> F																Weatherford Geochemical analysis, 2012



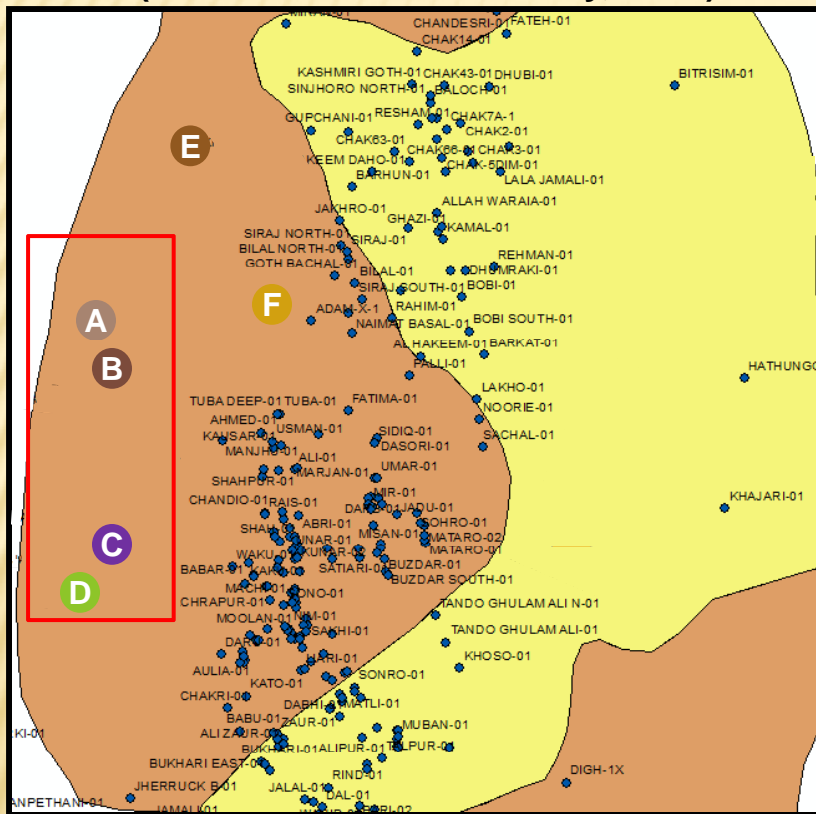
Available

Not Available

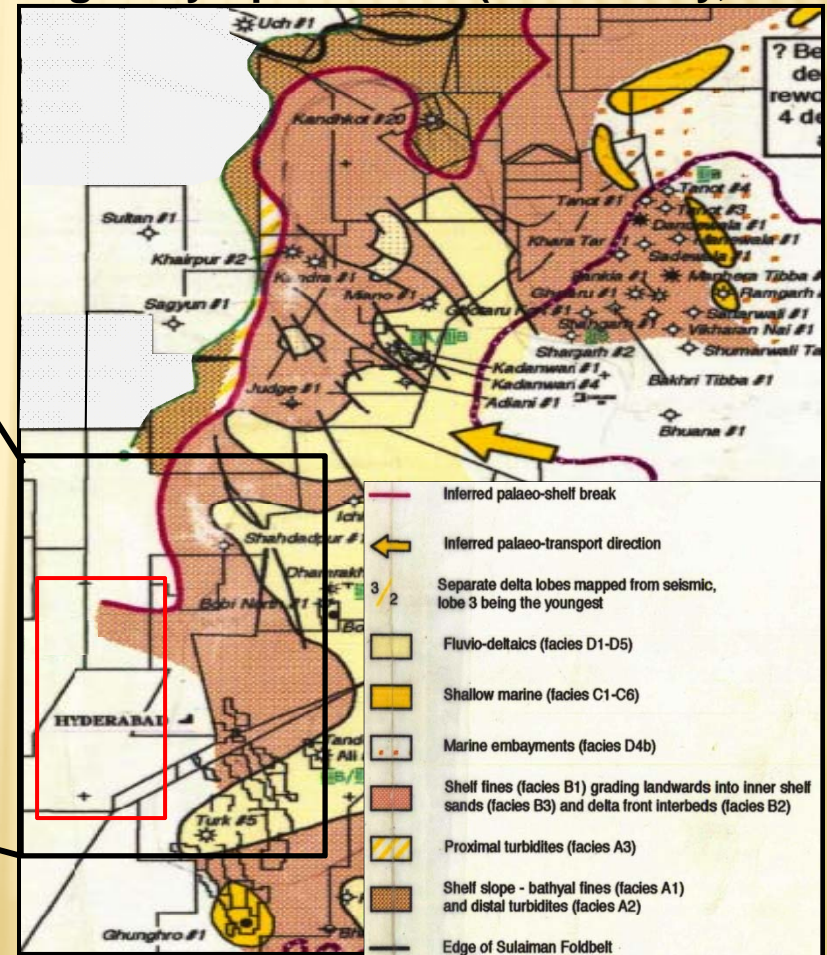
- ❖ 06 wells data available; 04 wells inside & 02 wells outside the study area
- ❖ Regional Studies in Lower & Middle Indus Basins by IEDS in 1995 & OGDCL in 2007
- ❖ Geochemical data based on well cuttings except “F well” (9m core in Talhar Shale)
- ❖ Facies Log available in only “ Well A” (IEDS Study, 1995)

PALEOGEOGRAPHIC MAP OF LOWER GORU FM

(Modified after IEDS Study, 1995)



Regional Paleogeographic Map of Lower Goru Fm during Early Aptian Time (IEDS Study, 1995)



- ❖ Facies Log modified / extrapolated to other wells after calibrating with GR & DT Log in "Well A"
- ❖ Prepared Regional Correlation Panels along and perpendicular to the Depositional Dip

Geological, Geochemical & Petrophysical Properties of Talhar Shale

GEOLOGICAL CHARACTERISTICS OF TALHAR SHALE

- ❖ Depth: **3000-3400m**
- ❖ Shallower in the North
- ❖ Thickness: **80- 140m**
- ❖ Thicker in the South
- ❖ Lithology:

Shale: Dark gray, fissile, pyritic, silty, occ highly carbonaceous, slightly to non calcareous

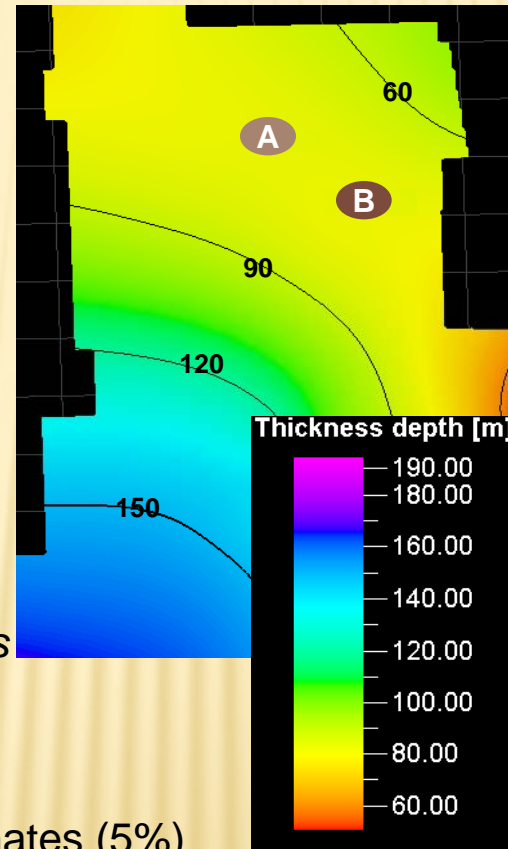
Siltstone: Light to medium gray, soft to moderately hard, blocky, sl. pyritic, non calcareous

Sandstone: Quartzitic, fine to med grained, friable

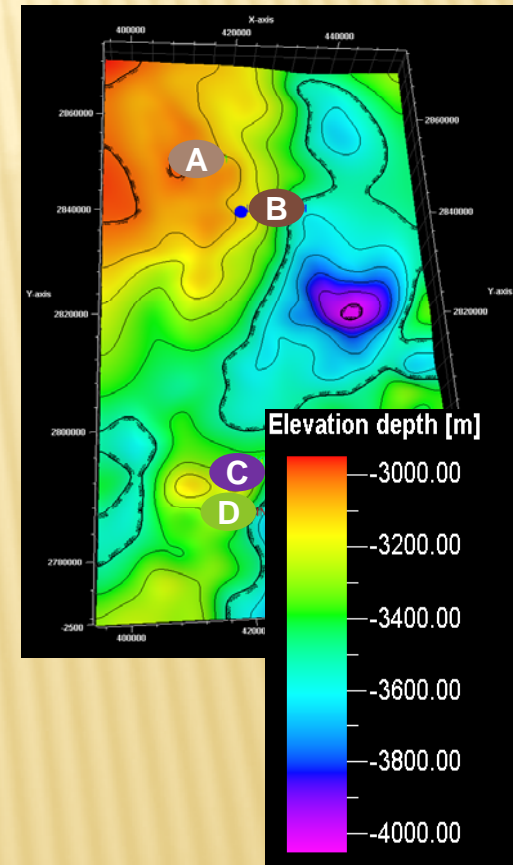
- ❖ **Mineralogy***: Clay (<30%), Silica (67%) & Carbonates (5%)

* XRD data of an offset well

ISOPACH MAP



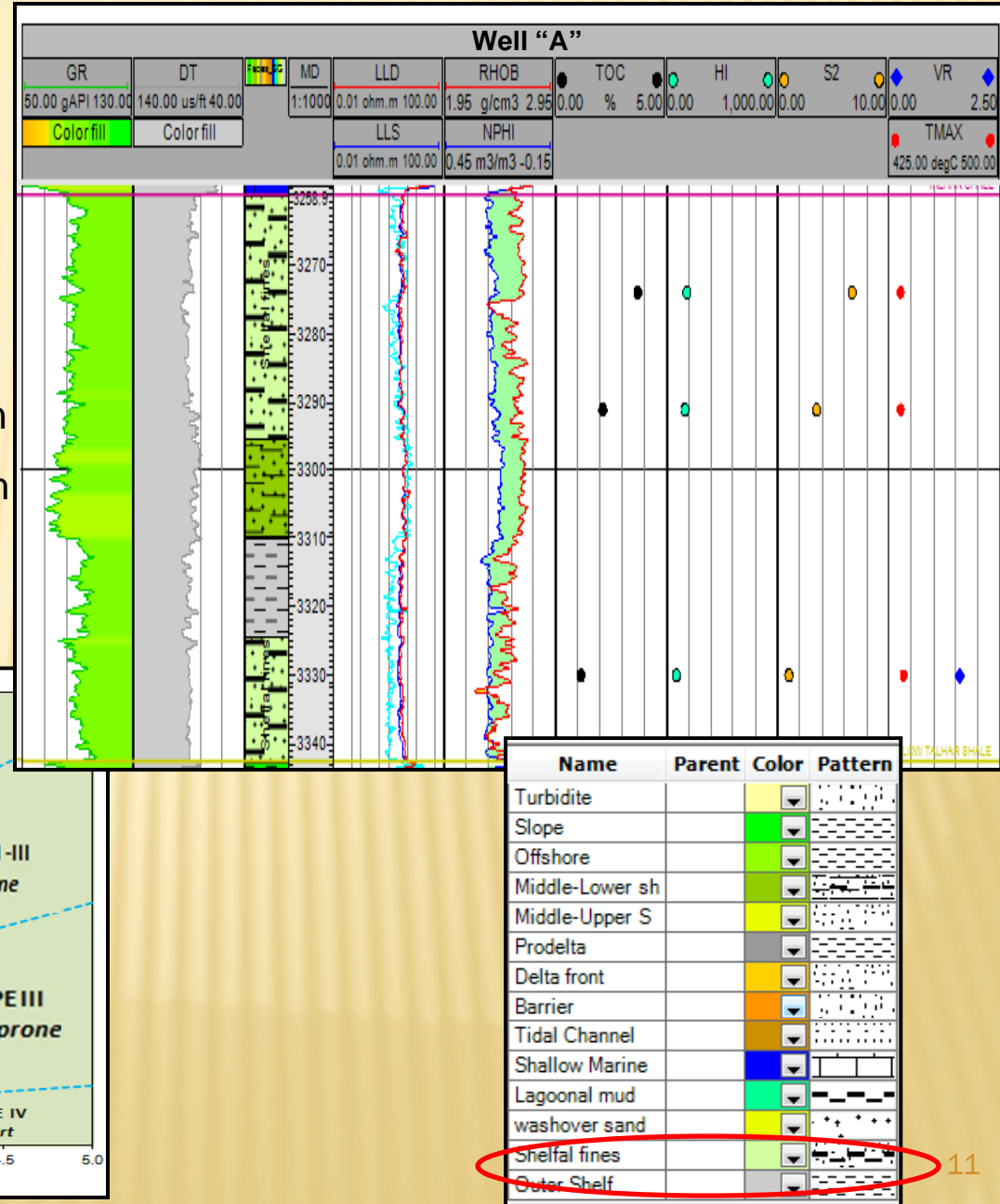
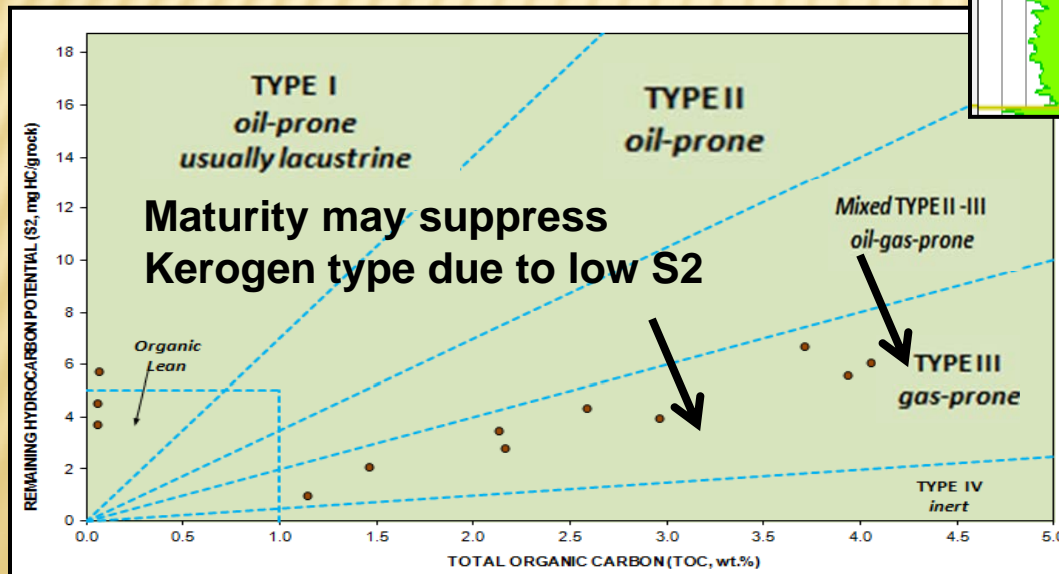
DEPTH MAP



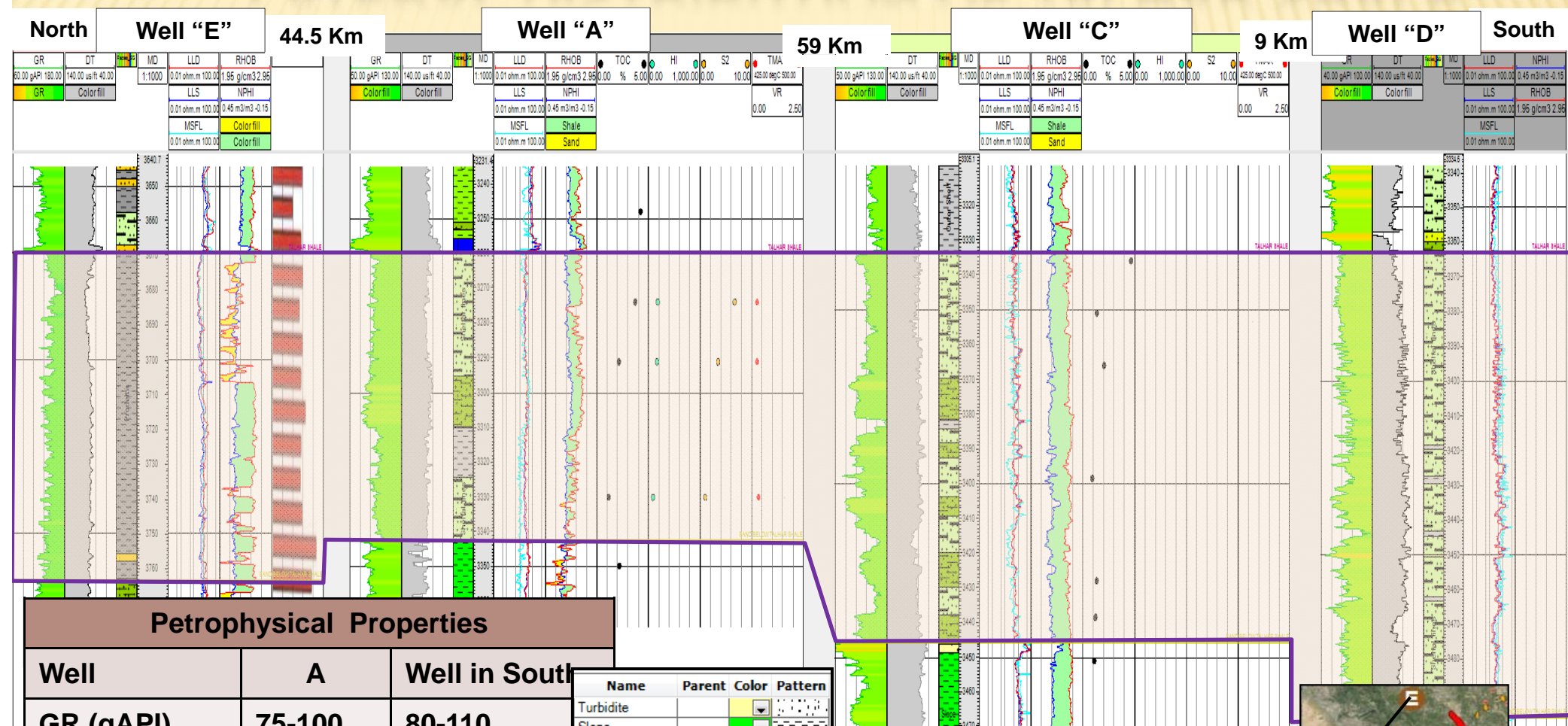
GEOCHEMICAL CHARACTERISTICS OF TALHAR SHALE

- ❖ Depositional Environment: Prodeltaic to outer Shelf
- ❖ TOC: 1.5-4.7%
- ❖ Visual Kerogen assessment suggests;
- ❖ Dominant Type II & Subordinate Type III Kerogen
- ❖ Maturity**: No reliable VR & Tmax data over High 3- TAI (equivalent to 1.2 % VR)

**Poor quality samples with mud additives



LATERAL DISTRIBUTION OF TALHAR SHALE

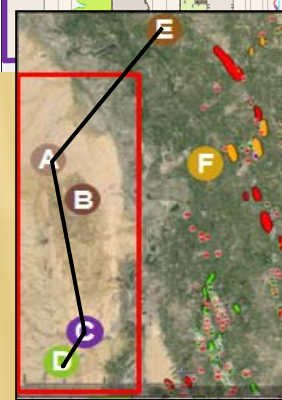


Petrophysical Properties

Well	A	Well in South
GR (gAPI)	75-100	80-110
DT (us/ft)	80-100	70-90
LLD (ohm.m)	2.4-3.8	5-10
RHOB (g/cm3)	2.46-2.66	2.60-2.72
NPHI (m3/m3)	0.14-0.23	0.16-0.28

Name	Parent	Color	Pattern
Turbidite			
Slope			
Offshore			
Middle-Lower sh			
Middle-Upper S			
Prodelta			
Delta front			
Barrier			
Tidal Channel			
Shallow Marine			
Lagoonal mud			
washover sand			
Shelfal fines			
Outer Shelf			

- ❖ Widely developed in the area
- ❖ Outer Shelf- Prodeltaic facies
- ❖ 2-3 % TOC in the area



Geological, Geochemical & Petrophysical **Properties of Lower Shale**

GEOLOGICAL CHARACTERISTICS OF LOWER SHALE

❖ Depth: **2200-3000m**

❖ Shallower in the North

❖ Thickness: **375- 640m**

❖ Thicker in the North

❖ Lithology:

Shales: Light to medium gray, fissile, pyritic, silty, slightly to non calcareous, rarely glauconitic in lower part

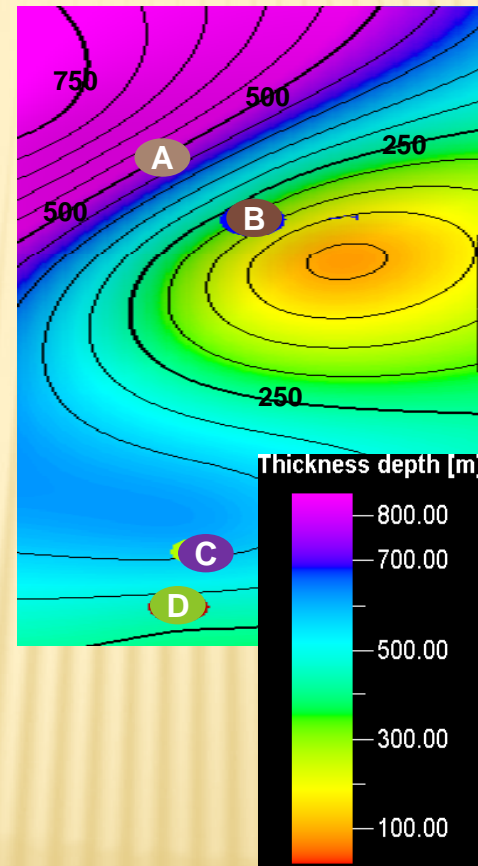
Siltstone: Light brnsh gray, moderately hard, micaceous, slightly to non calcareous, at places grading to v fn Sst

Sandstone: Quartzitic, fine to medium grained, moderately hard, pyritic, calcareous

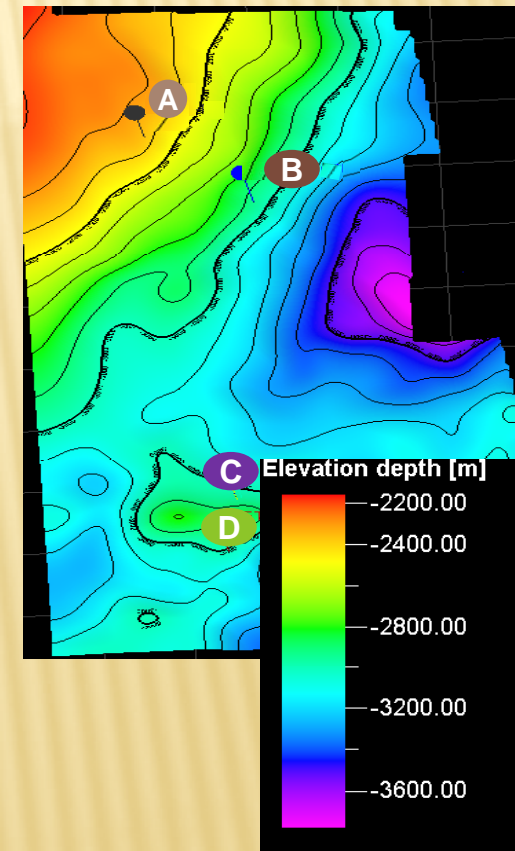
❖ Mineralogy*: Clay (45%), Silica (40-45%), Carbonates (8-10%)

* Based on XRD data of "Well A"

ISOPACH MAP



DEPTH MAP

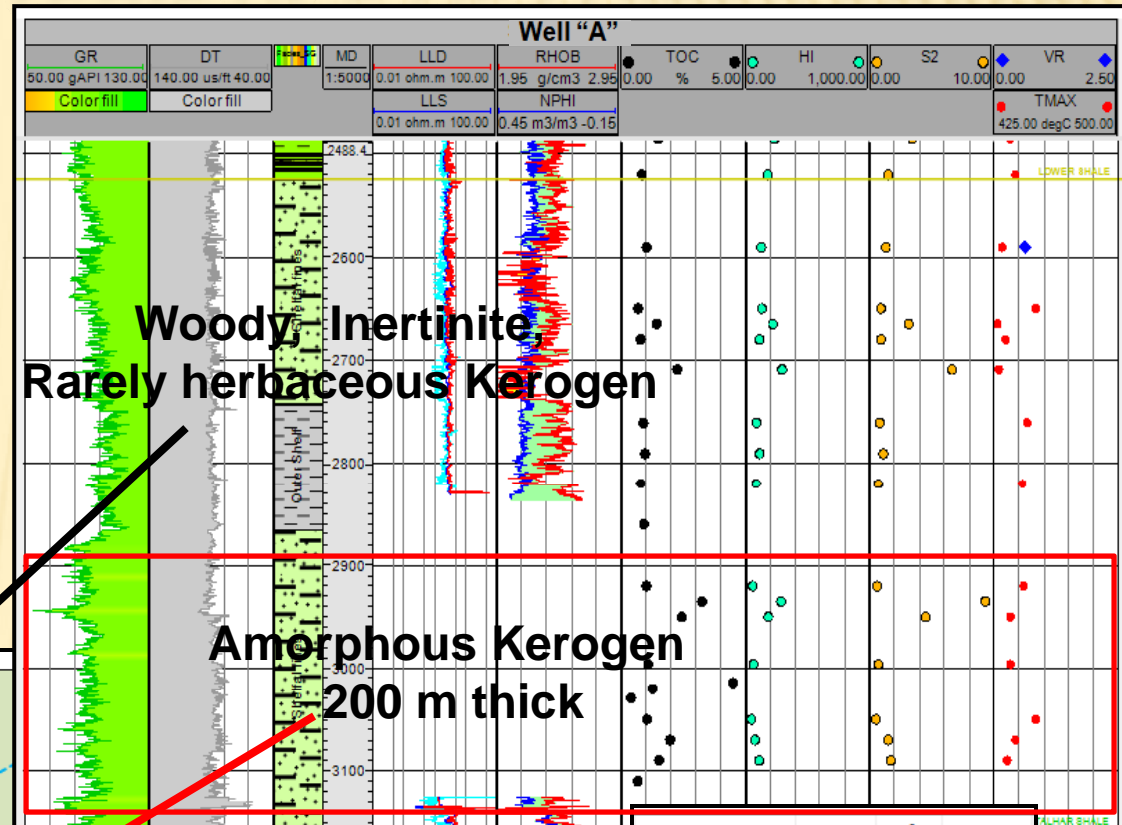
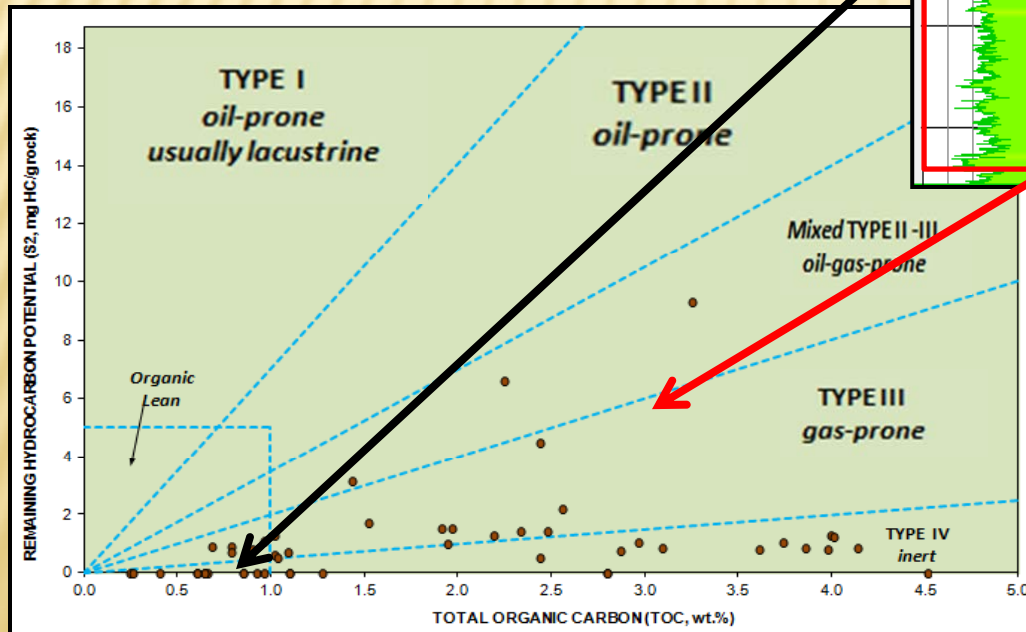


GEOCHEMICAL CHARACTERISTICS OF LOWER SHALE

- ❖ Depositional Environment: Prodeltaic to outer Shelf
- ❖ TOC: 0.6 – 4%
- ❖ Upper part has Type III & IV Kerogen
- ❖ Lower part has Type II-III Kerogen
- ❖ Maturity^{**}: Oil – Wet Gas Window

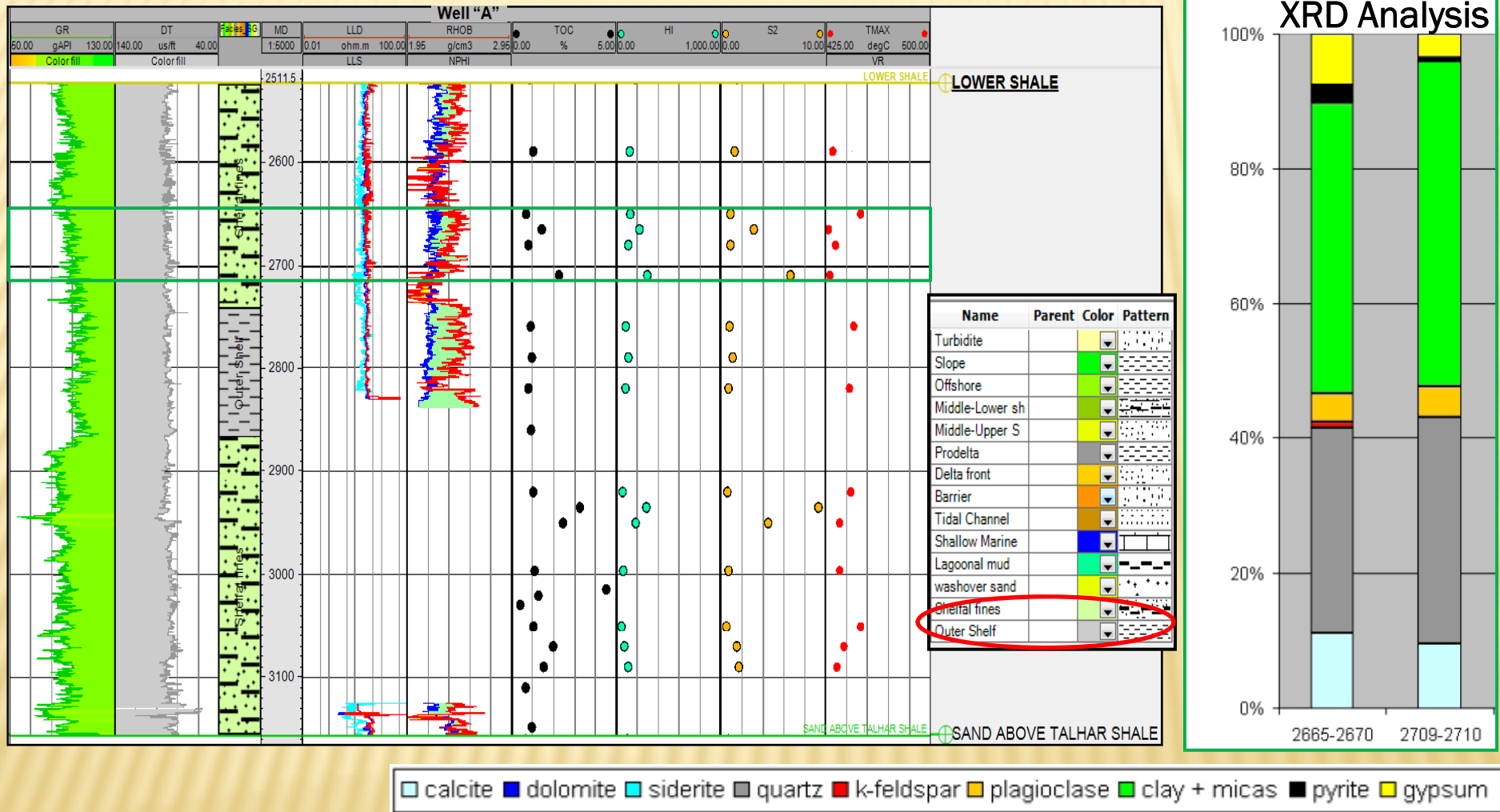
(Based on TAI 2+ to 3- values)

^{**} VR data is not reliable due to difficulty in differentiation b/w woody & inertinitic OM



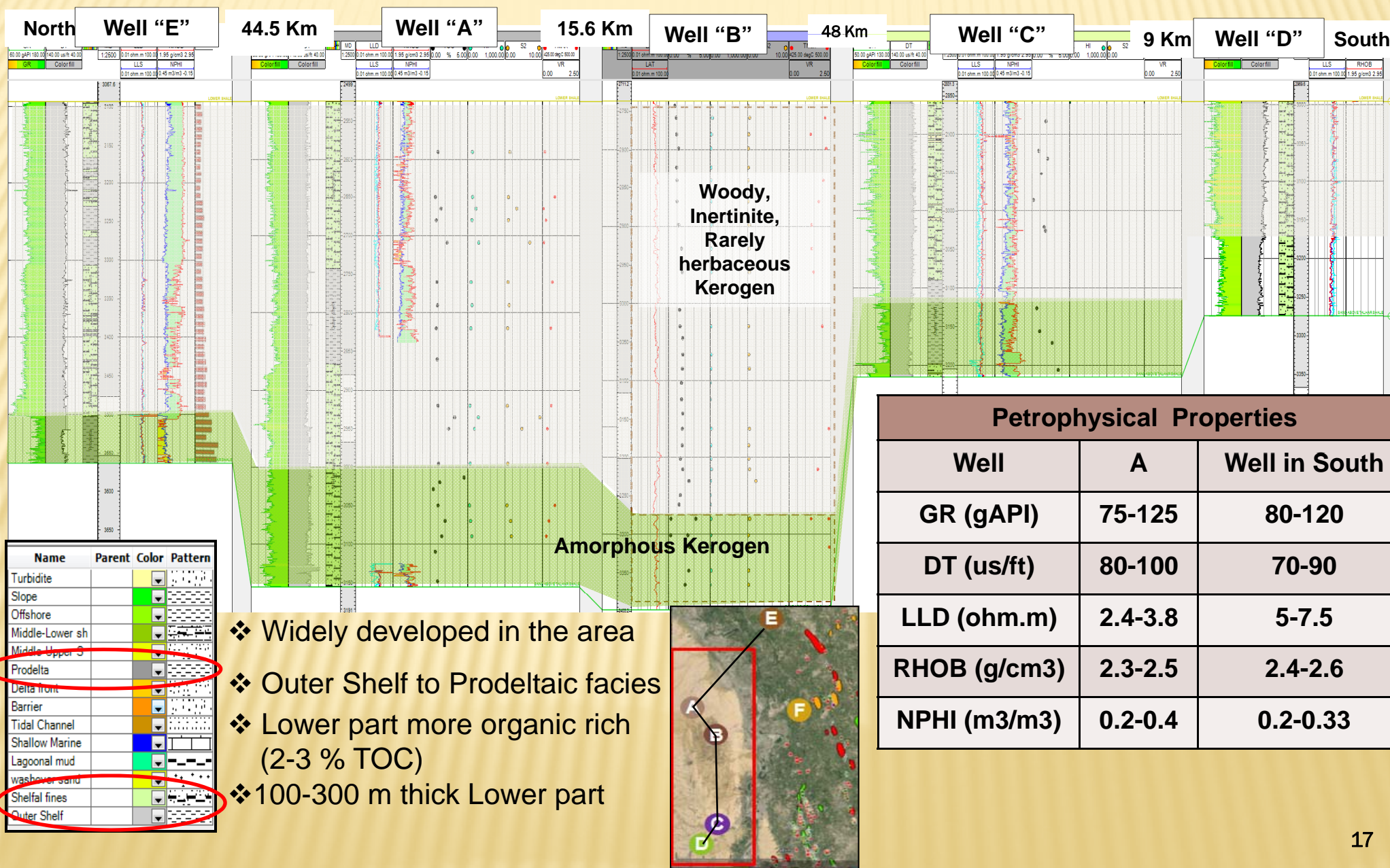
Name	Parent	Color	Pattern
Turbidite			
Slope			
Offshore			
Middle-Lower sh			
Middle-Upper S			
Predelta			
Delta front			
Barrier			
Tidal Channel			
Shallow Marine			
Lagoonal mud			
washover sand			
Shelfal fines			
Outer Shelf			

MINERALOGICAL CHARACTERISTICS OF LOWER SHALE



- ❖ Clay (45%), Silica (40-45%), Carbonates (8-10%)
- ❖ Considering GR response, lower part of Lower Shale may have low clay content as compare to highlighted part

LATERAL DISTRIBUTION OF LOWER SHALE



Geological, Geochemical & Petrophysical Properties of Upper Shale

GEOLOGICAL CHARACTERISTICS OF UPPER SHALE

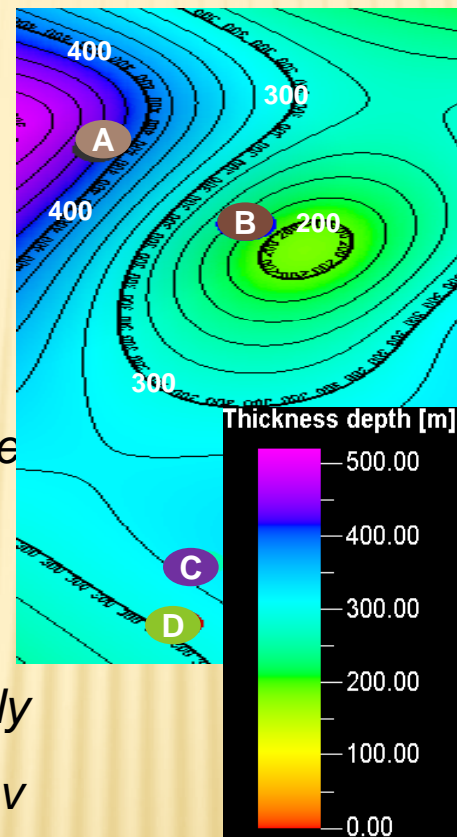
- ❖ Depth: **1800-2200m**
- ❖ Shallower in the North
- ❖ Thickness: **200-400m**
- ❖ Thicker in the North East
- ❖ Lithology:

Shales: Medium to dark gray, sub fissile - fissile
occ sl. Silty, slightly to non calcareous, iron
stained

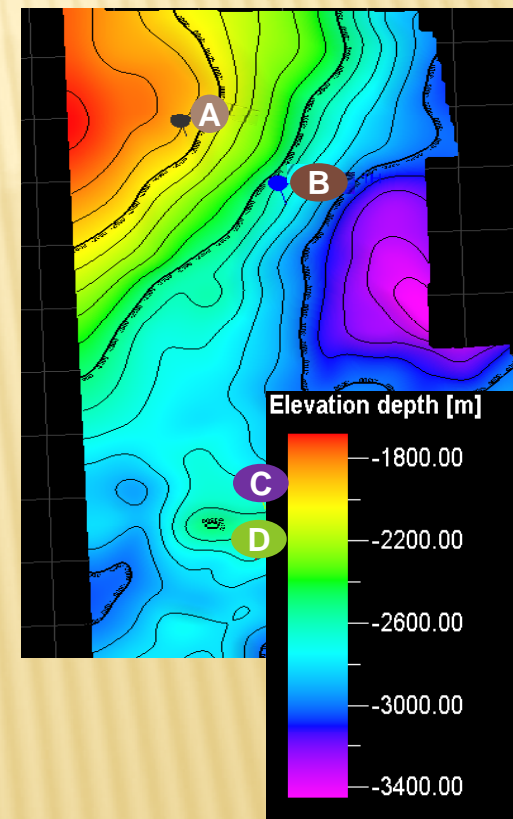
Siltstone: Lt. olive gray to olive grey, moderately
hard, blocky, calcareous, at places grading to v
fn-med grnd Sst

- ❖ Mineralogy: Not Available

ISOPACH MAP

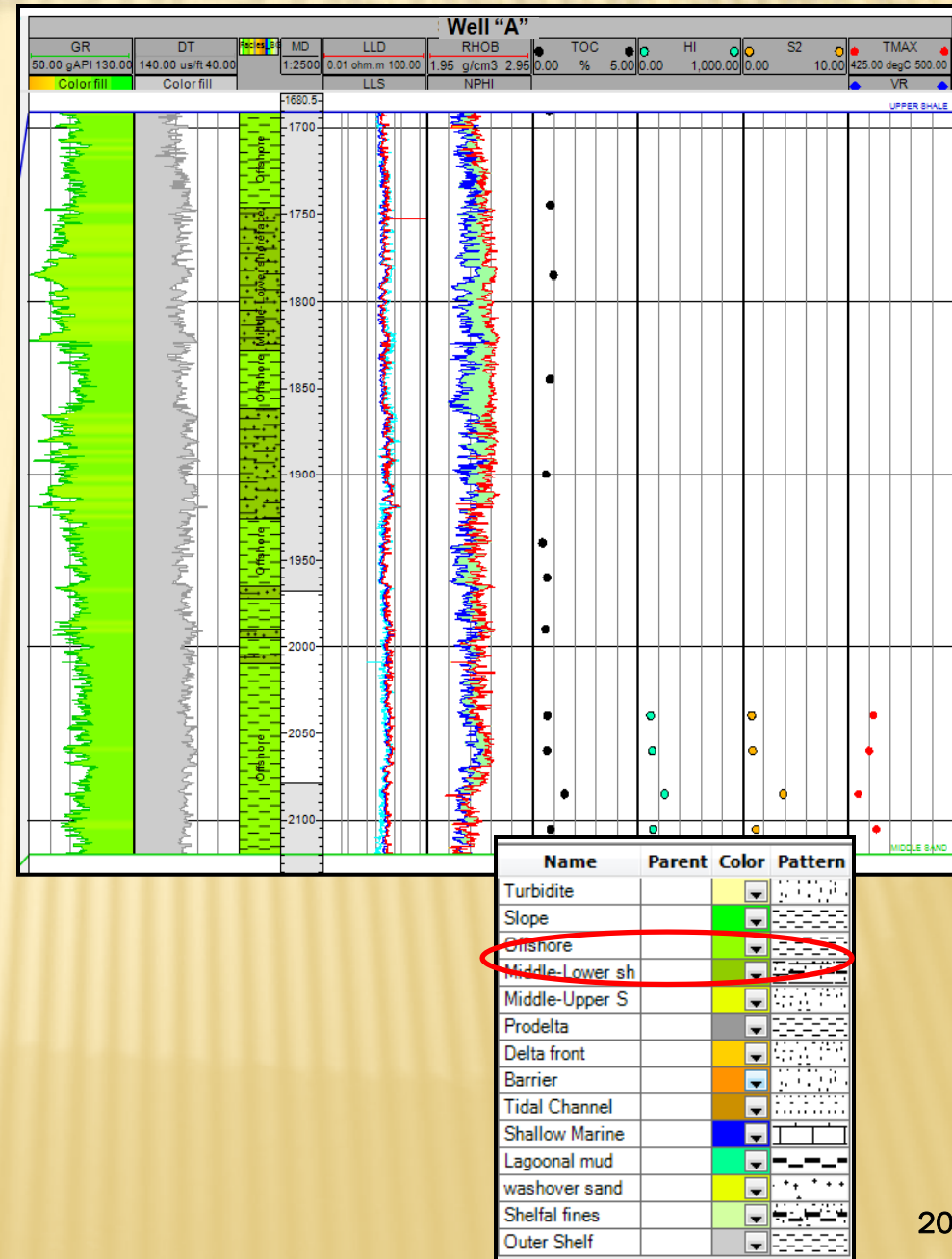
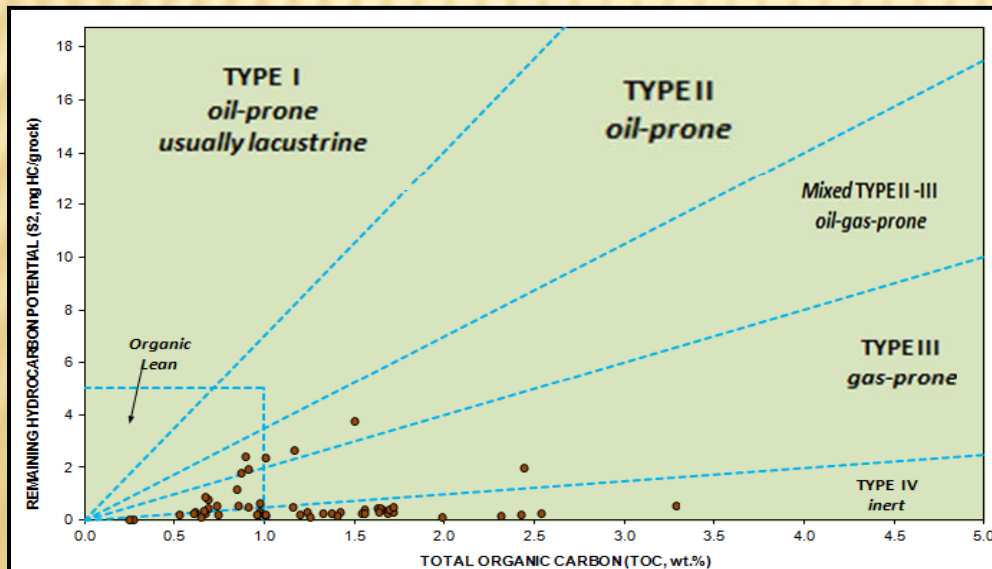


DEPTH MAP

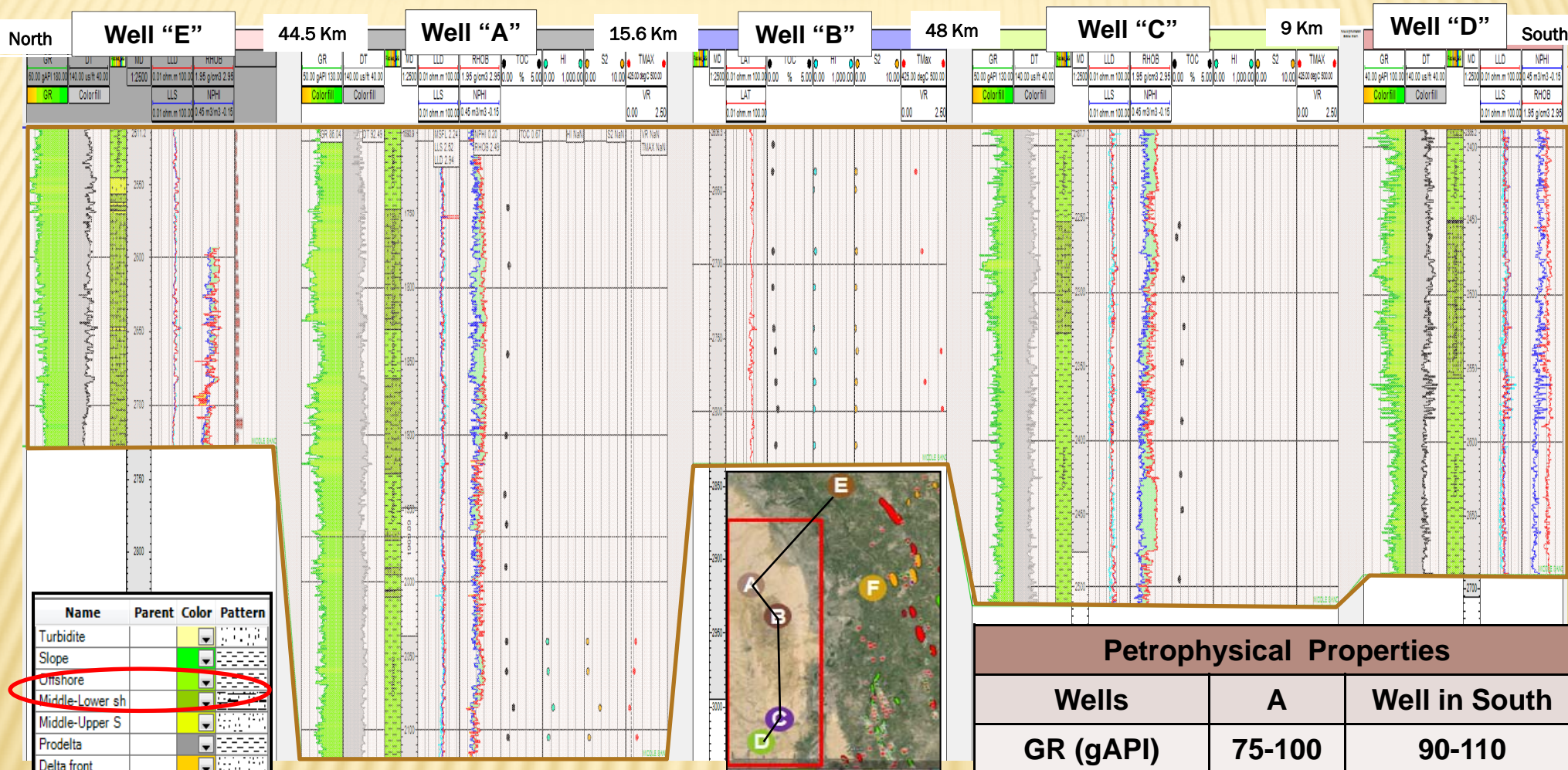


GEOCHEMICAL CHARACTERISTICS OF UPPER SHALE

- ❖ Dep. Environment: Offshore-Upper Shoreface
- ❖ TOC: 0.5 – 2.0%
- ❖ Type II-III, Type III & Type IV Kerogen
- ❖ Dominantly Woody & Inertinitic,
- ❖ Sub-ordinate Amorphous & Herbaceous
- ❖ Maturity: No reliable data available



LATERAL DISTRIBUTION OF UPPER SHALE



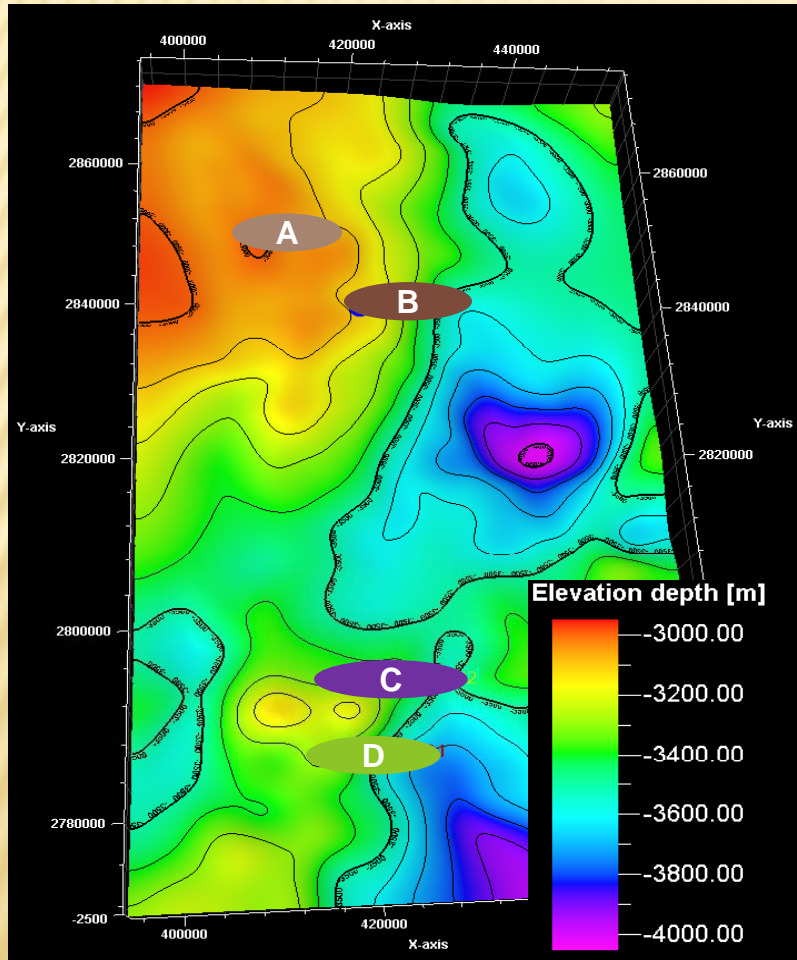
- ❖ Widely developed in the area
- ❖ Middle shoreface to Offshore facies
- ❖ 1-1.5% TOC in the area
- ❖ Variable thickness (200-400m)

Petrophysical Properties

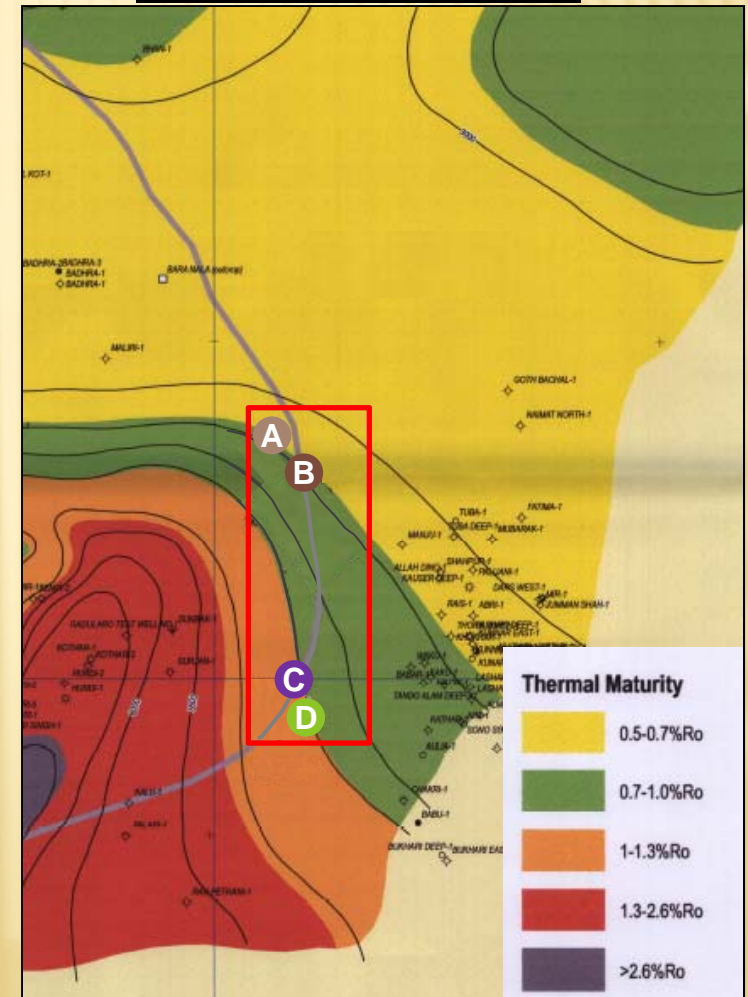
Wells	A	Well in South
GR (gAPI)	75-100	90-110
DT (us/ft)	80-100	90-110
LLD (ohm.m)	1.7-3.8	1-5
RHOB (g/cm3)	2.4-2.6	2.4-2.6
NPHI (m3/m3)	0.1-0.3	0.2-0.33

REGIONAL MATURITY OF LOWER GORU FORMATION

Depth Map of Talhar Shale



Thermal Maturity Map of Base Cretaceous at Top Lower Miocene



- ❖ Lower Goru is in Oil to Wet Gas window Over Lakhra High
- ❖ Talhar Shale being the deepest shale would have the highest maturity

Reference: OGDC Basin Study, 2007




N-S Structural Cross Section of the Lakhra High

- ❖ Based on microscopic parameters (TAI) Top of Wet Gas window is at 3100 m (?)
- ❖ Lower part of Lower Shales & Talhar Shale is expected to be in Wet Gas window (?)

COMPARISON OF LOWER GORU SHALE UNITS

Shale Unit	Upper Shale	Lower Shales		Talhar Shale
		Upper Part	Lower Part	
Thickness (m)	200-400	275-350	100-300	80-140
Depth (m)	1800-2200	2200-2700	2500-3000	3000-3400
TOC (%)	0.5-2.5	0.6-4.0	2-3	1.5-4.7
Kerogen type	II-III, III, IV	III, IV	II-III	II, III
Mineralogy	N/A	Clay (45%), Silica + Carbonate (48-65%)		Clay (<30%), Silica + Carbonate (72%)
Maturity	Early Oil	Oil-Wet gas	Oil-Wet Gas	Oil-Wet Gas
Depositional Environment	Shoreface to Offshore	Prodeltaic to outer Shelf	Outer Shelf	Prodeltaic to outer Shelf

❖ Considering (i) TOC, (ii) Kerogen type, (iii) Mineralogy & (iv) relatively higher depth for maturity in Wet Gas window; Talhar Shale & Lower part of lower shale seems better among other Lower Goru Shales

 Poor reservoir properties
 Marginal reservoir properties
 Good reservoir properties

CONCLUSION & WAY FORWARD

Conclusions

- ❖ All Lower Goru Shales are geologically thick, having depth of 2-3.5 Km and contain appropriate TOC.
- ❖ Lower part of Lower Shale & Talhar Shale posses required Shale reservoir properties
- ❖ Kerogen is mostly Type II with some Type III having maturity of Oil-Wet Gas (although uncertainty exists due to contaminated samples)

Way Forward

- ❖ Cut 30-40m cores in Lower Shale & Talhar Shale in Upcoming wells over the Lakhra High
- ❖ Carryout detailed laboratory analysis including (i) Organic Geochemistry, (ii) Adsorption Gas analysis, (ii) Geomechanical Test, (iii) Rock Physics & (iv) canister gas analysis at wellsite
- ❖ Acquire specialized logs (ECS, DSI etc) for mineralogical & geo-mechanical modeling
- ❖ Carryout 3D Basin Modeling to estimate GIIP & identify sweet spots for exploratory wells

ACKNOWLEDGEMENTS

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- ❖ Our Special Thanks to Dr. Nadeem Ahmed, Dr. Abrar Ahmed & Mr. Mohsin Ali for reviewing the work and providing valuable inputs

THANK YOU
(Q/A)