Evaluation of Mineralogical Composition and Reliable Petrophysical Parameters by Neutron Induced Gamma Ray Spectroscopy in Mineralogical Complex Reservoir of Lower Goru Formation, Middle Indus Basin – A Case Study*

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Abstract

Lower Goru Formation reservoirs sands (Lower Cretaceous) characterization in the Middle Indus Basin is challenging due to complex mineralogy of the rocks. The varying mineralogy characteristically makes the Petrophysical Evaluation difficult and cannot be resolved by using basic conventional log suites. To resolve this ambiguity in Lower Goru Formation evaluation, proper additional data sets are required.

Reservoir quality is defined by two main factors, porosity and permeability of a rock. The reservoir quality index or rock type is known to be an important input for field static and dynamic models. Core data analysis in Lower Goru Sands across the Middle Indus Basin reveals the presence of heavy minerals, calcareous cement, conductive mineral i.e. chlorite, chamosite etc. that effect the conventional wireline logs response i.e. reservoir porosity (storage capacity) and permeability (flow capacity). Hence, the quantification of the mineral contents becomes important in classifying the rock type.

However, estimation of complex mineralogy from conventional logs (density, neutron, and sonic) is also complicated by several factors such as barite mud effects, oil base mud filtrate invasion, sensitivity of the tools' measurements, as well as differences in the tools' vertical resolution and depth of investigation.

Developments in the neutron capture spectroscopy logs make it possible to estimate all matrix parameters which are significant for accurate formation evaluation. The number of parameters is dramatically reduced. Using the measured spectroscopy data as input to

multi-mineral solver software, provides more accurate mineralogy output, consequently yielding better porosity and water saturation calculation.

This paper describes the application of neutron capture spectroscopy data to formation evaluation and characterization of Middle Indus Lower Goru Sands. The formation evaluation result in the studied well is found to be validated with core data.

ANNUAL TECHNICAL CONFERENCE

2011

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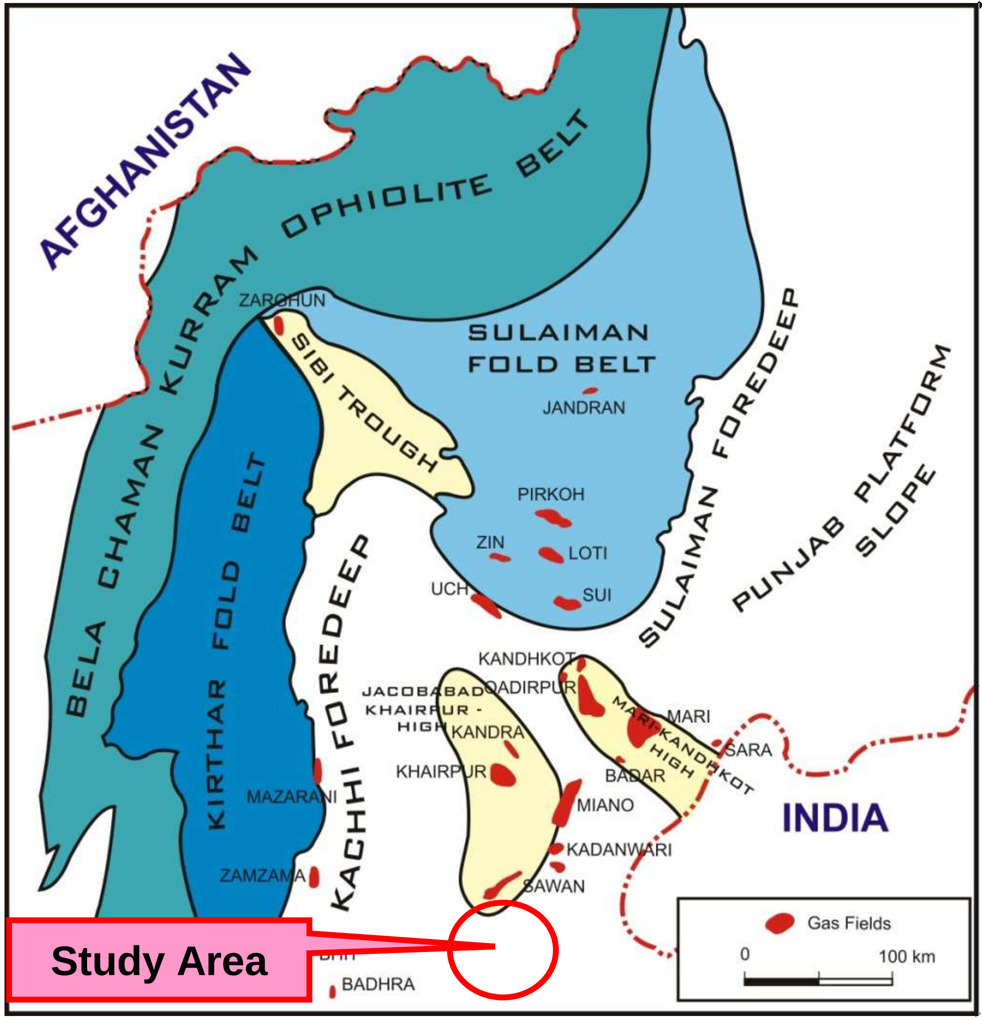
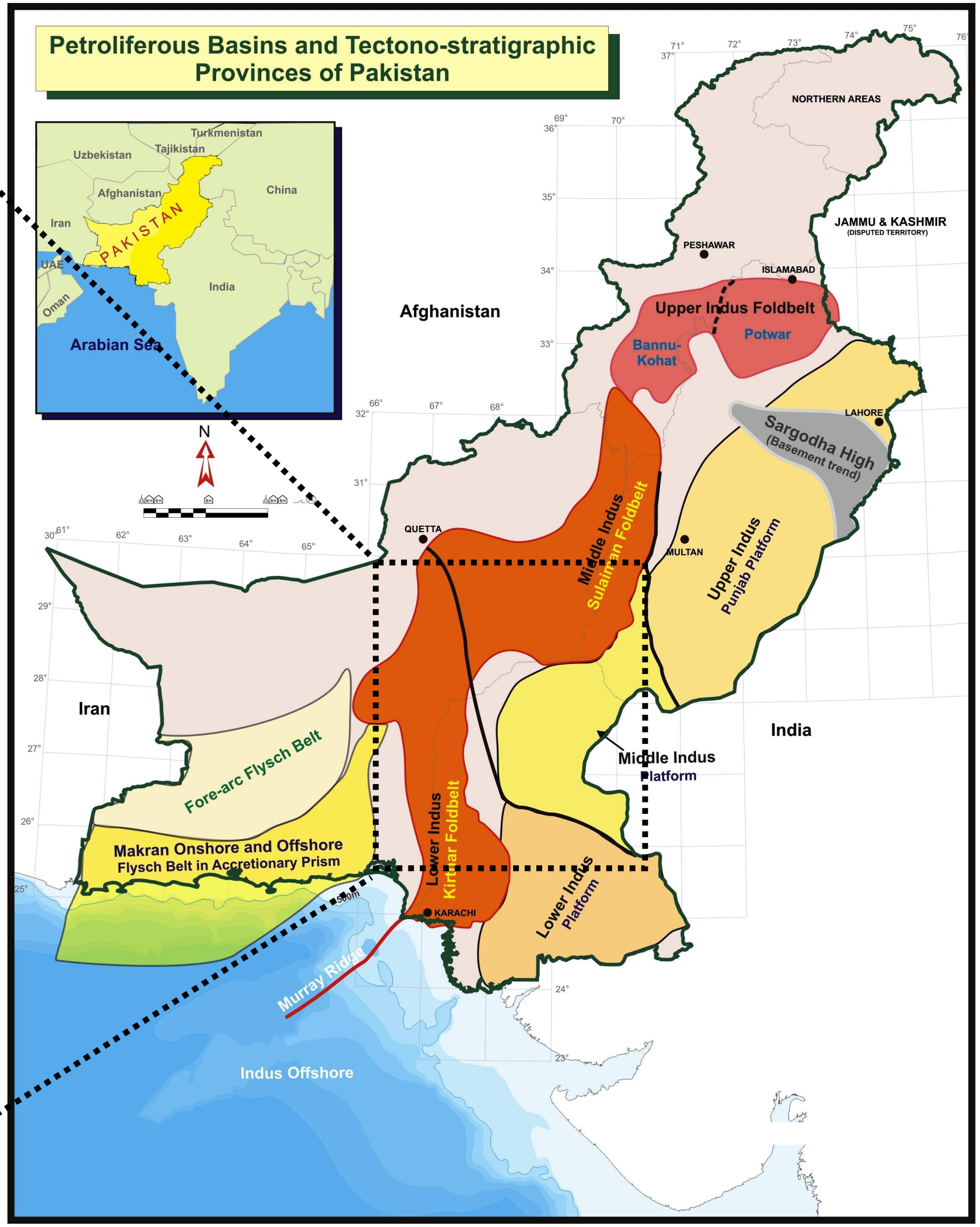
Pakistan Section

Outline

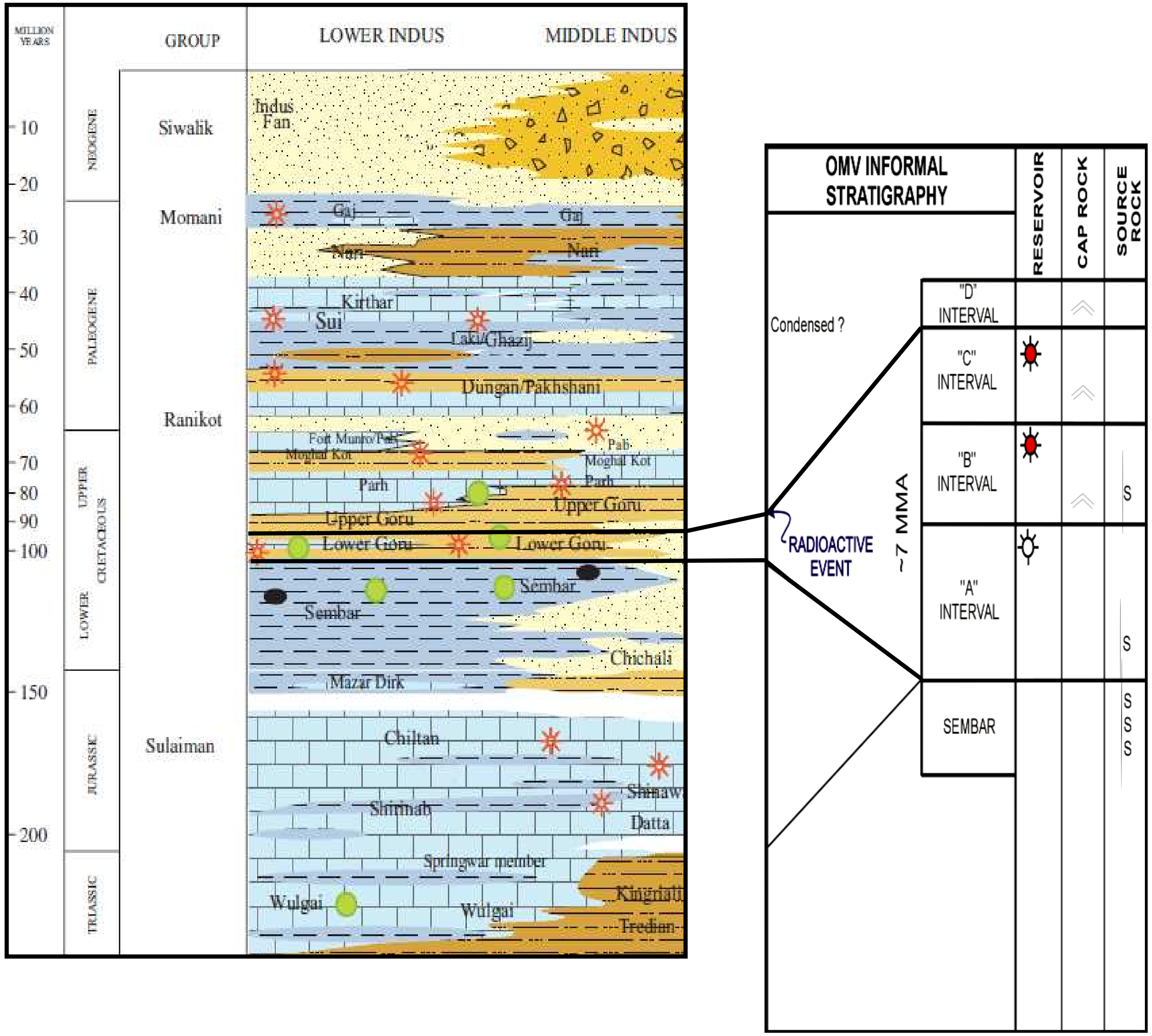
- Overview of area
- Problems faced in Lower Goru Sands – a complex and heterogeneous reservoir
- Elemental Capture Spectroscopy – A method to resolve mineralogical complex reservoirs
- Core to spectroscopy log integration
- Accurate petrophysical evaluation using spectroscopy data in multi-mineral model
- Results
- Conclusions
- Acknowledgement

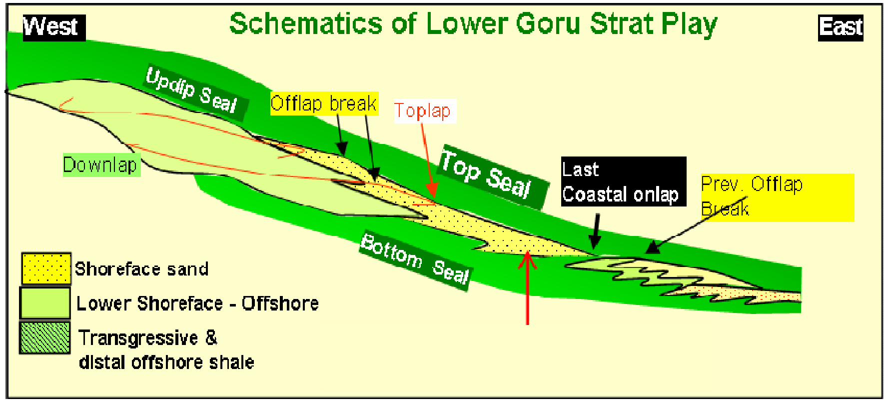
Regional Structural Framework

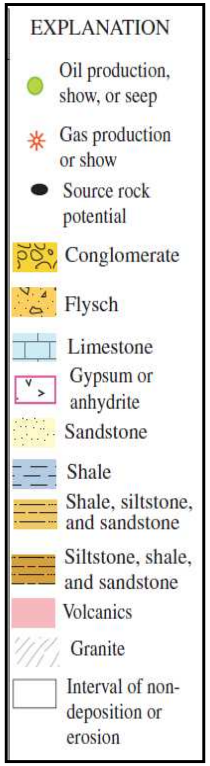




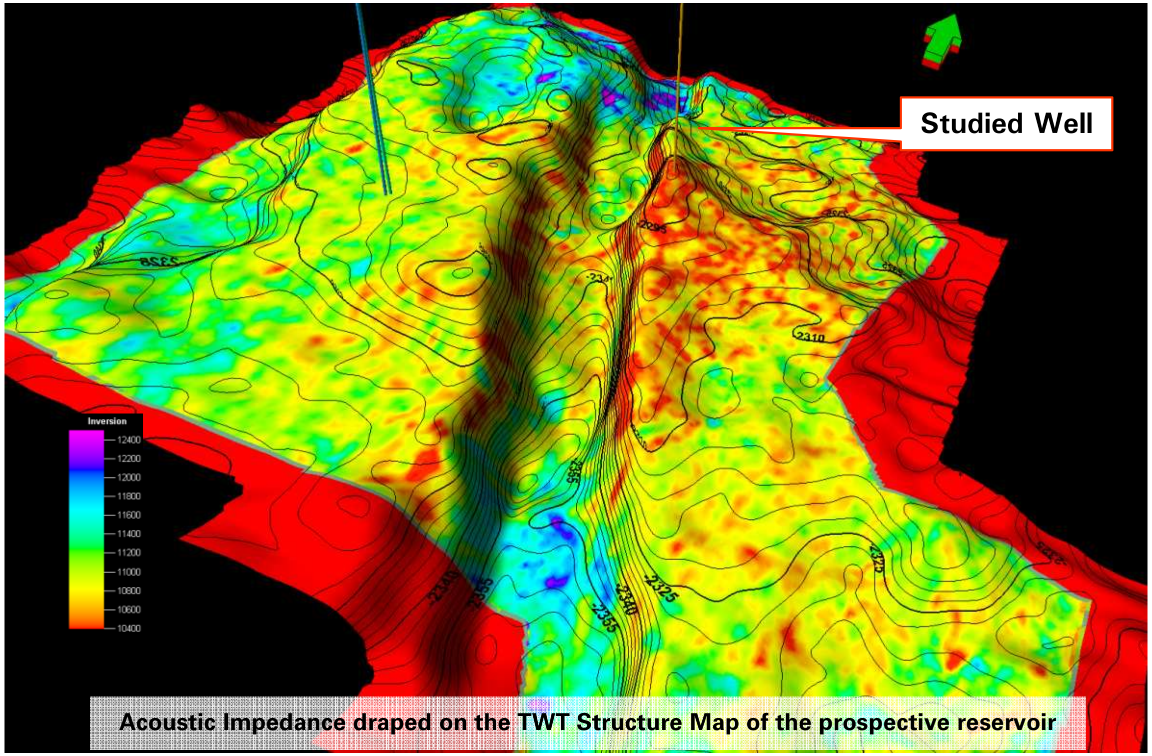
Stratigraphic Framework



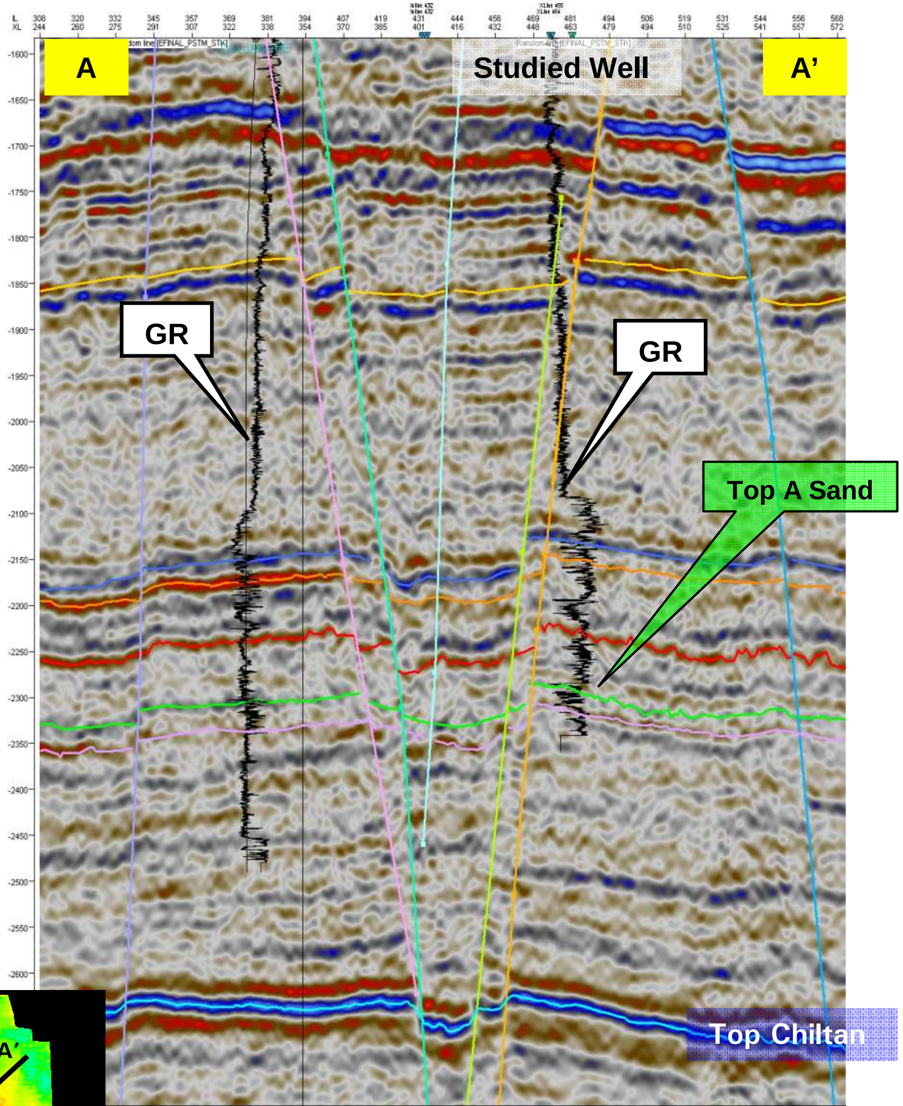


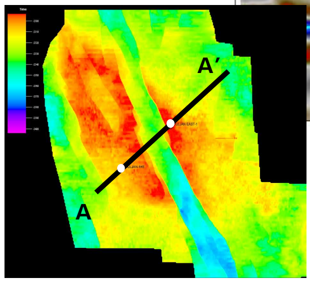


Field Description



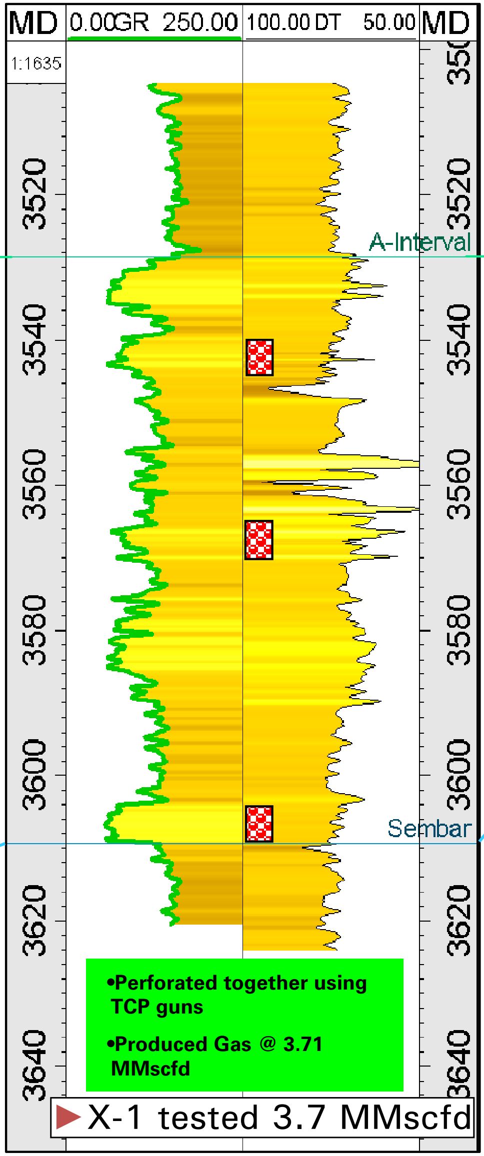
Acoustic Impedance draped on the TWT Structure Map of the prospective reservoir



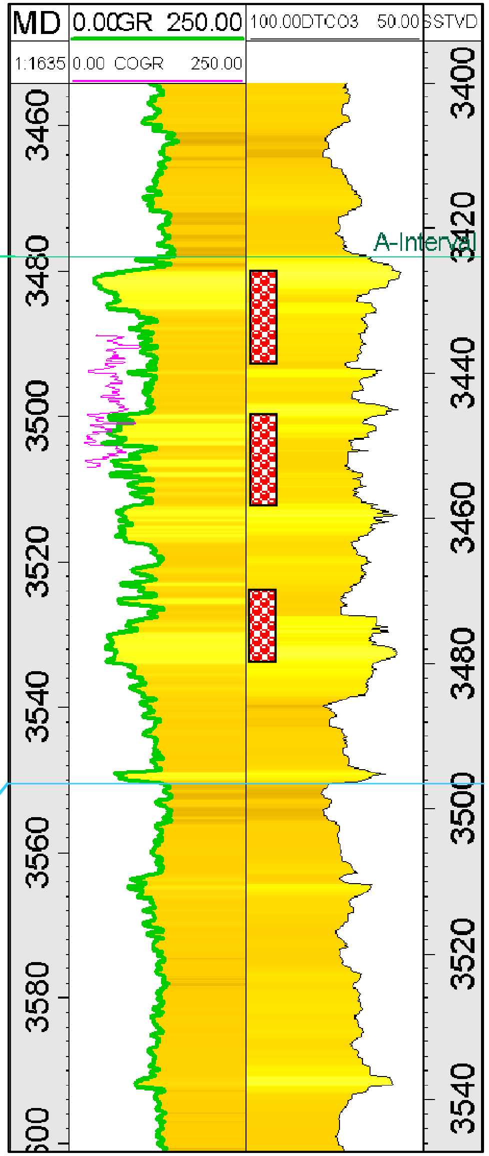


Well Results

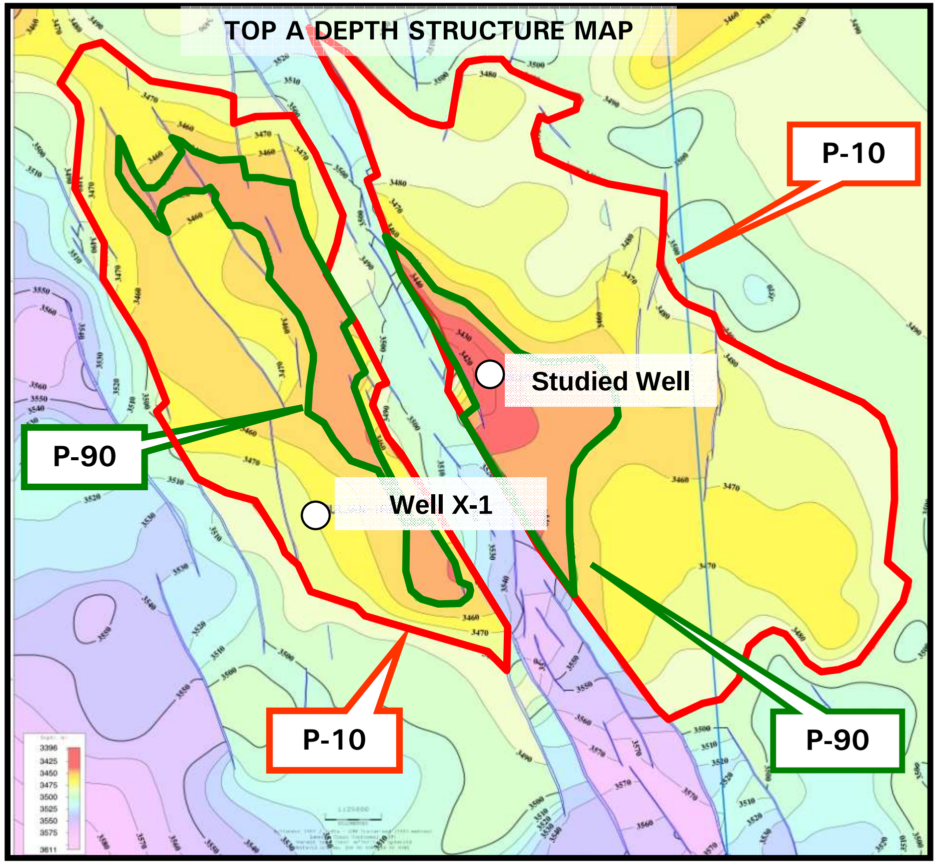
Well X-1



Studied Well



Average Core Permeability < 1mD



Petrophysical Evaluation		
Properties	**X-1**	**Studied Well**
Gross Interval	81 m	83 m
Net Sand	26.1 m	28 m
Net Pay	8.8 m	9 m
Avg. Porosity	9.00%	9.00%
Avg. Sw	26%	24%

Problems faced in Lower Goru Sands - Middle Indus

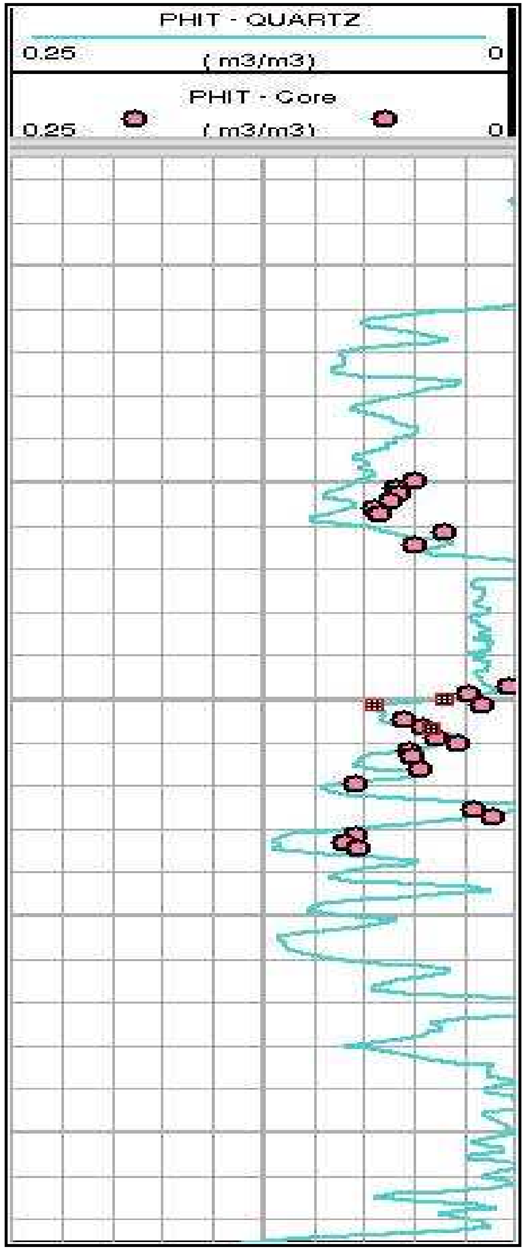
- Mismatch between calculated & core porosities
  - Actual grain density unknown
  - Fixed Density of matrix, $\boldsymbol{\rho}_{ma}$, used in porosity equation ;

$$\textbf{Ø} = (\rho_{ma} - \rho_b) / (\rho_{ma} - \rho_f),$$

Limestone	2.71 g/cc
Sandstone	2.65 g/cc
Dolomite	2.83 g/cc

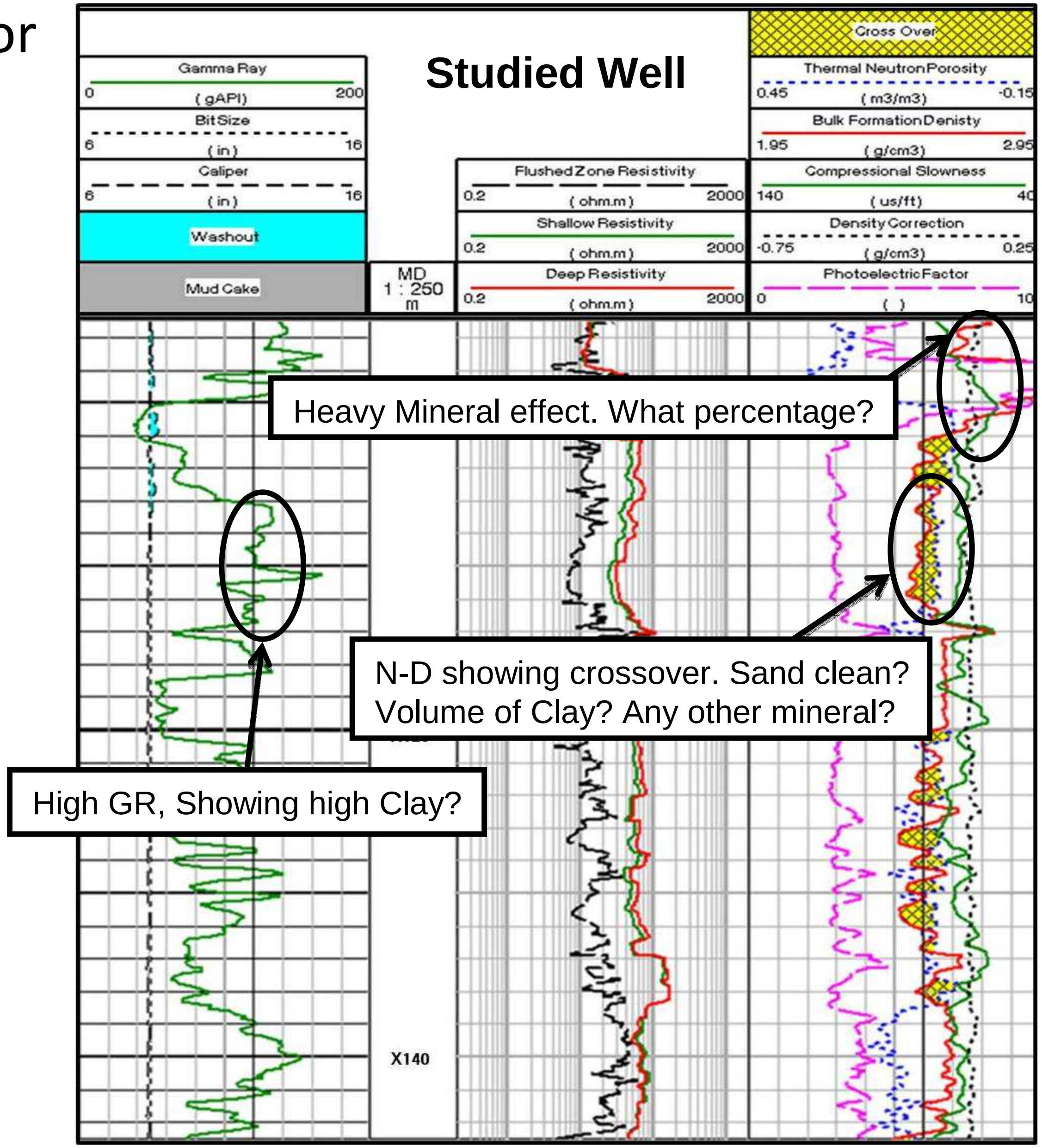
  - Core gives stationary measurement of grain density & permeability not entire spectrum
  - Accurate porosity & permeability essential for reservoir volumetric and reservoir flow potential

Studied Well



Problems faced in Lower Goru Sands of Middle Indus

- Need of Accurate Mineralogy for Reservoir Volumetric
  - High GR due to radioactive minerals or Clay?
  - Neutron-Density are effected by heavy minerals?
  - Difficult to predict accurate mineral volumes from conventional logs
  - Mud logs only provides basic information
  - SCAL / Core Sedimentology Results are time consuming

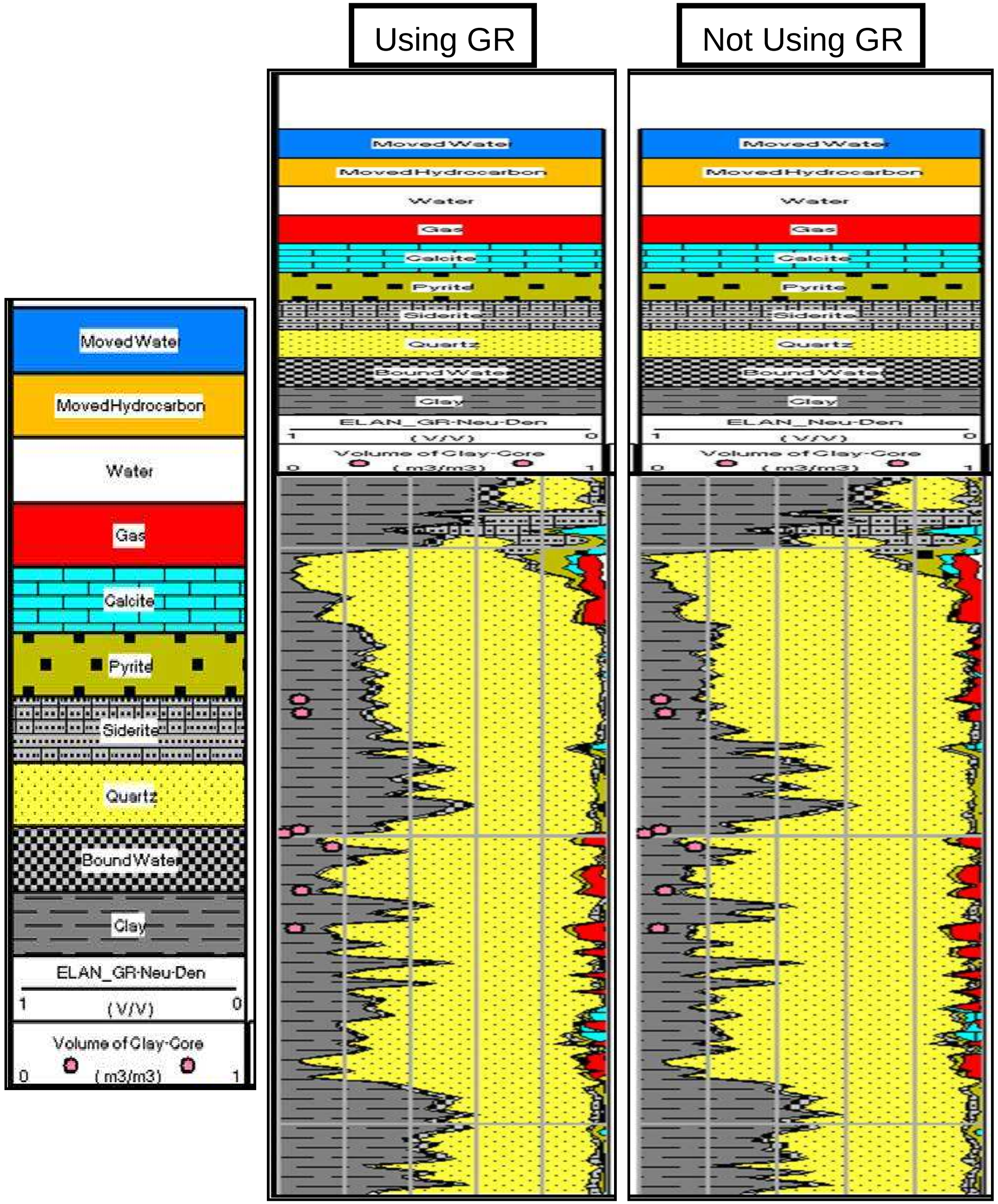


Problems faced in Lower Goru Sands of Middle Indus

- Conventional Petrophysical Evaluation - Basic Assumptions
  - Porosity (fixed grain density)
  - Vclay (GR, Neutron, Density)
  - Matrix/Mineral (Cross-plots)

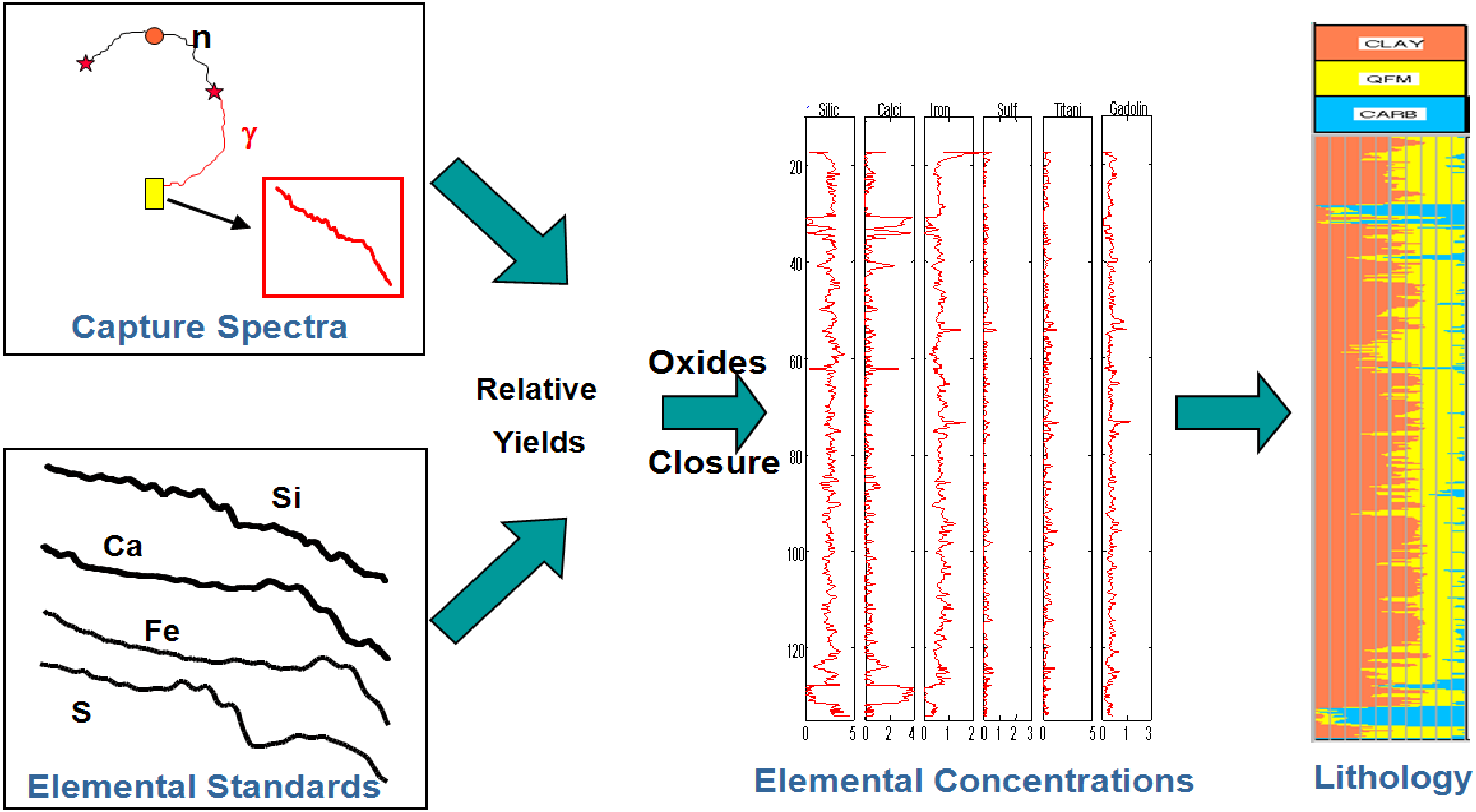
Ambiguities in Conventional Petrophysical Interpretation

- Do not estimate accurate mineralogy
- Over/under estimate porosity
- Over/Under estimate fluid saturations



Elemental Capture Spectroscopy - Methodology

- A single advance tool to resolve all petrophysical issues in one go



Elemental Capture Spectroscopy - Applications

- Identify carbonate ($CaCO_3$), gypsum ($CaSO_4.2H_2O$) and anhydrite (CaSO4); quartz (SiO_2), feldspar (Ca-Mg-K-Silicates) and mica; pyrite (FeS_2), siderite ($FeCO_3$), coal, and salt (NaCl) fractions for complex reservoir analysis
- Estimate exact amount of clay using aluminum
- Estimate most realistic total porosity using bulk density
- Estimate mineralogy-based permeability
- Determine well-to-well correlation from geochemical stratigraphy
- Determine sigma matrix for cased hole and openhole sigma saturation analysis
- Obligatory requirement for Shale Gas evaluation
- Estimate producibility and in situ reserves

Continuous Grain Density for Measuring Accurate Porosity

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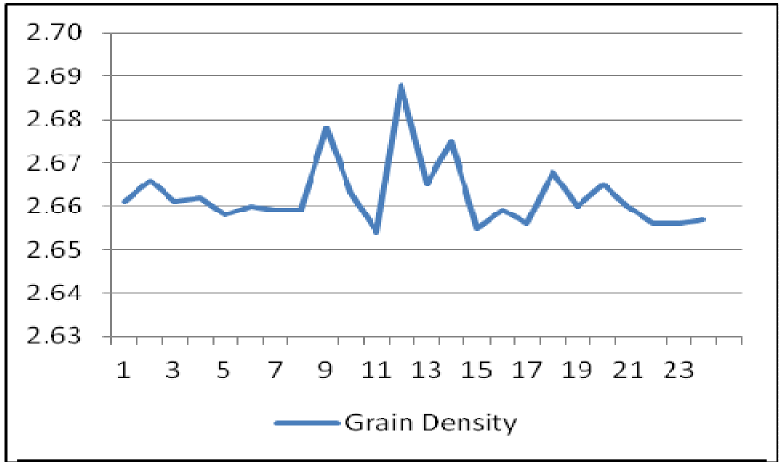
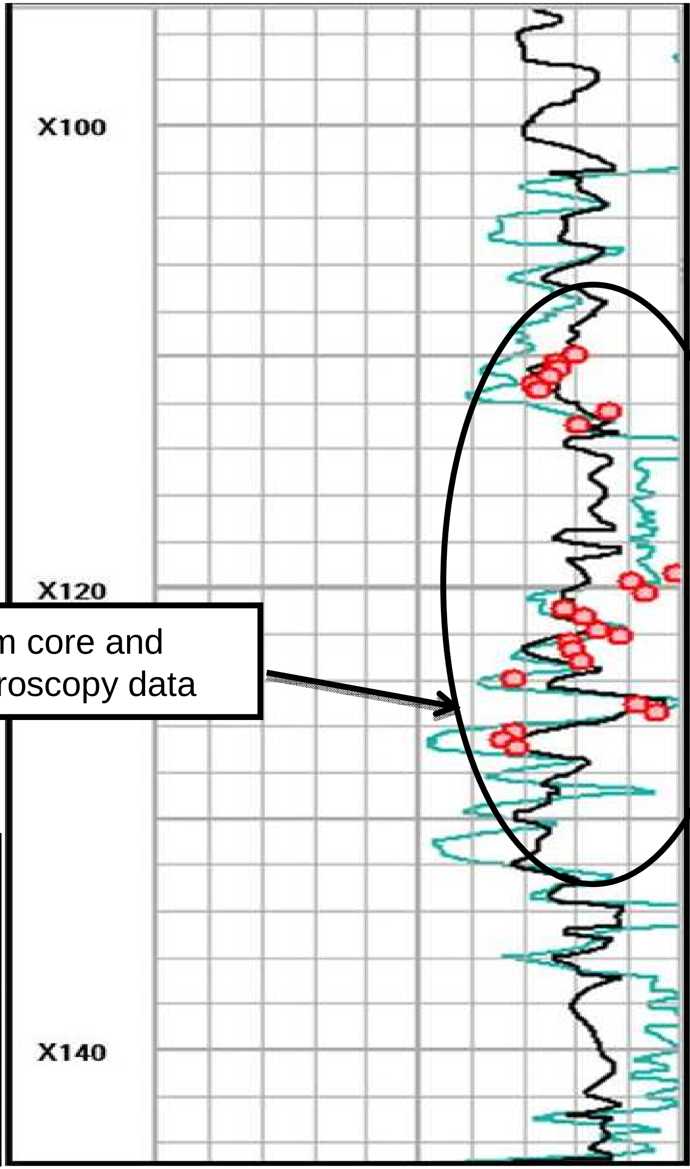
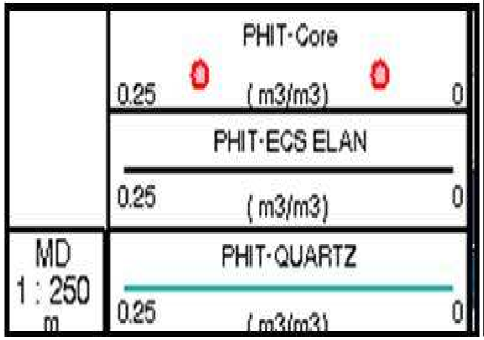


Core grain density varies from ~2.66 to 2.69

Very good match between porosity from core and porosity using grain density from spectroscopy data





Estimation of Continuous Permeability

- Permeability from spectroscopy data is called K-Lambda permeability as is derived using following equation:

$$k = \frac{Z \cdot \phi_t^{m^*+2}}{\rho_g^{\,2} \cdot (1.0 - \phi_t)^2 \cdot \left(\sum W_i \cdot S_{0i}\right)^2}$$

- Whereas:
  - k is the absolute permeability (mD)
  - Z is proportionality constant with a default value of 200000.0 (dimensionless)
  - Øt is the total porosity using spectroscopy grain density (v/v)
  - m is the cementation factor
  - ρ_g is the grain density from spectroscopy (g/m³)
  - W*i* is the weight fraction of mineral i (w/w)
  - So*i* is the specific surface area of mineral i (m^2/g)

Pakistan Section

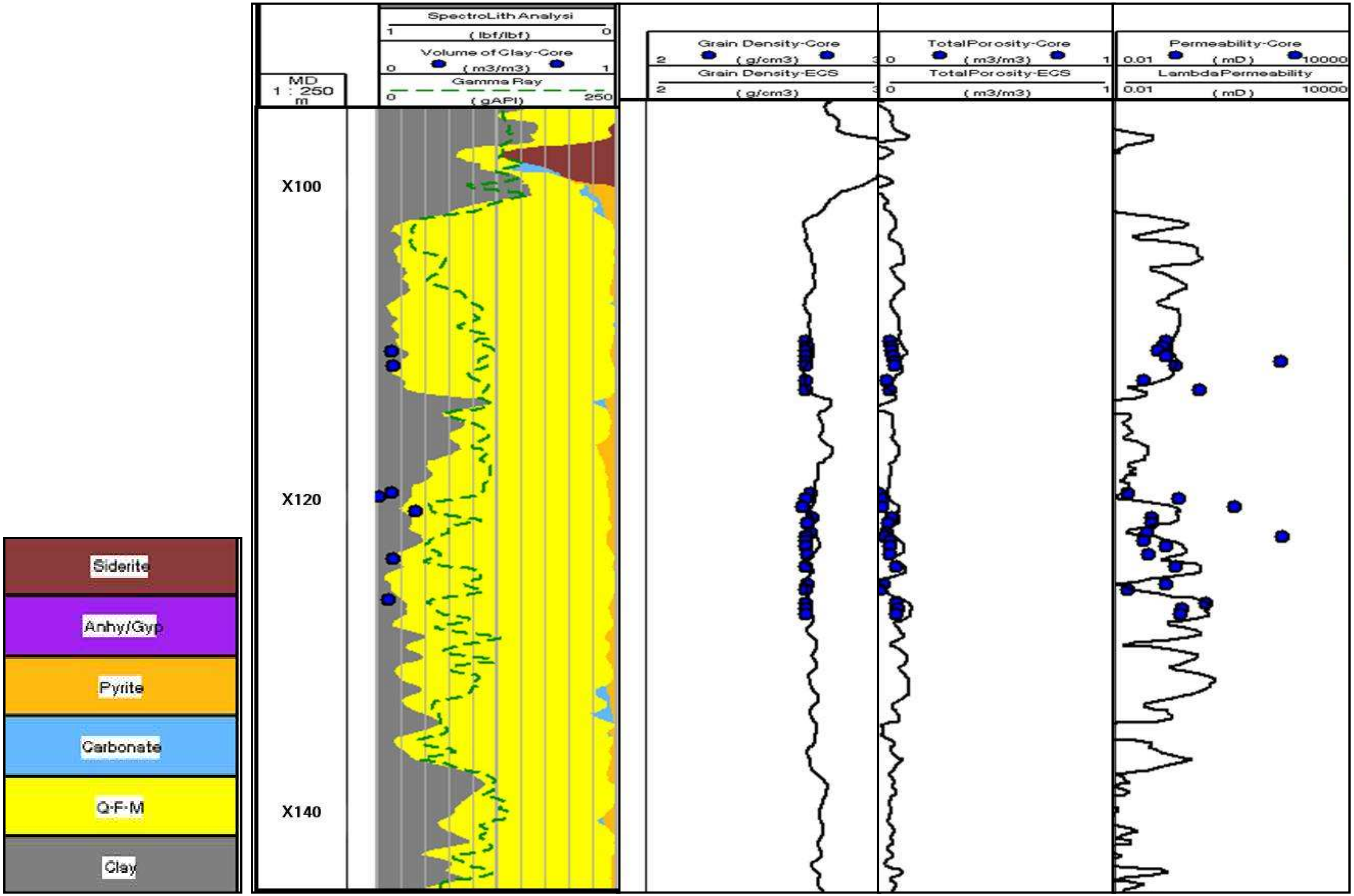
Estimation of Continuous Permeability

Mineral Group	S_0 (g/cm3)
Clay	6.0
Quartz-Feldspar-Mica	0.22
Carbon	2.0
Anhydrite	0.1
Pyrite	0.22
Siderite	0.22
Halite	0.22
Coal	0.22

- If the initial estimate of k is less than 100 mD, the calculated permeability is modified using the following expression:

$$\begin{aligned} &if\,(k < 100.0)\,then \\ &k = 0.037325 \cdot k^{1.714} \end{aligned}$$

Core Results Vs Spectroscopy Log - Perfect Match



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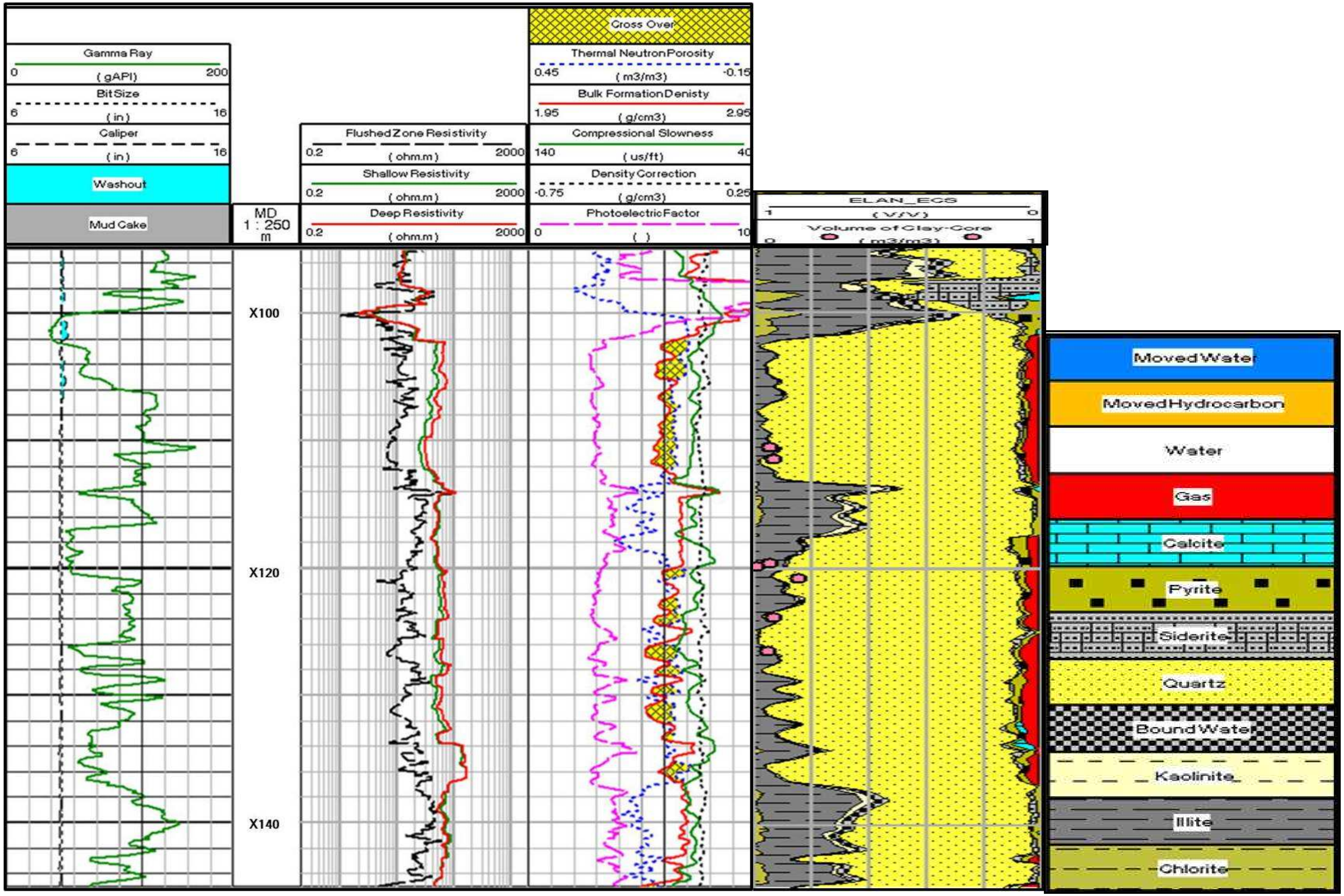
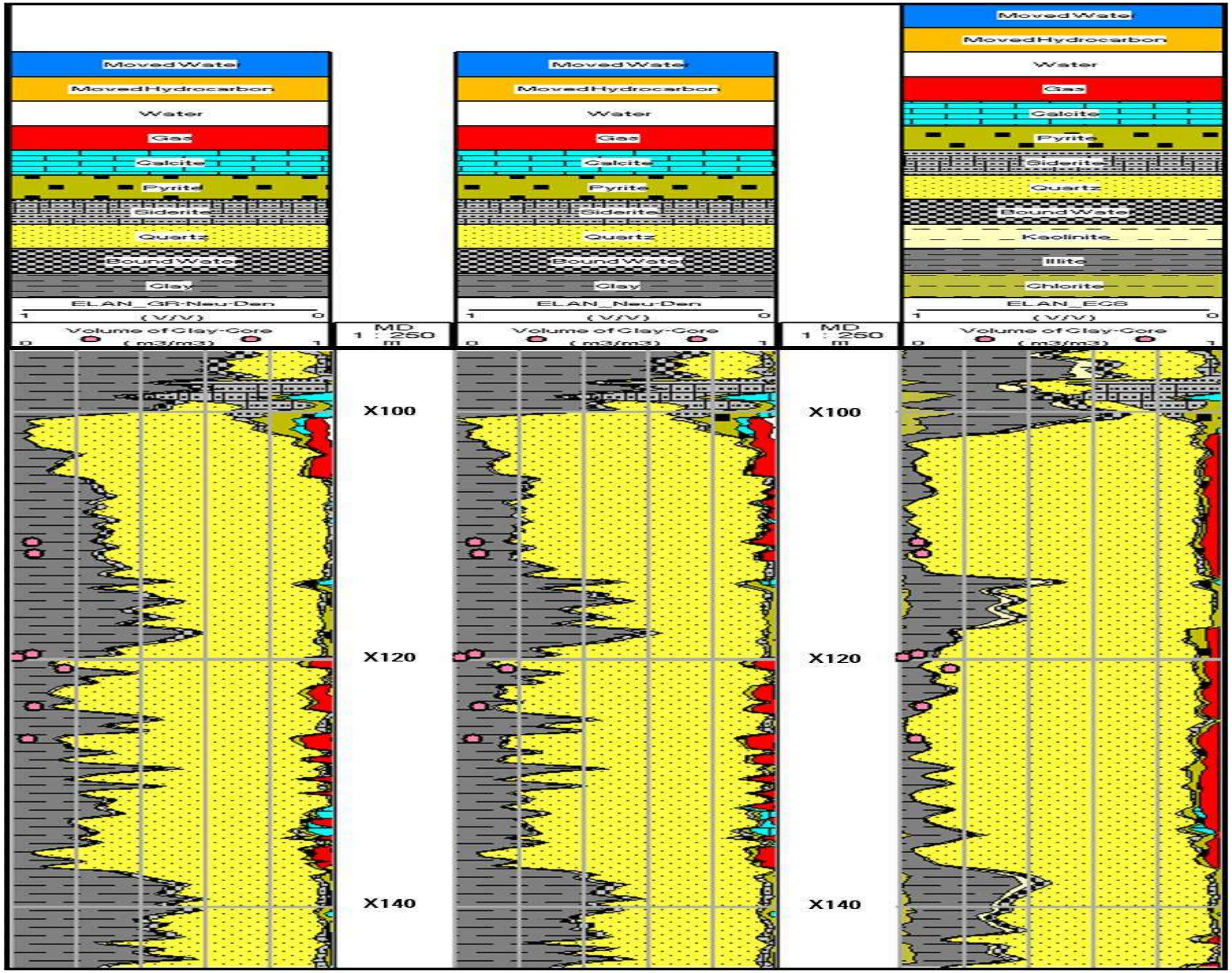
Accurate Petrophysical Evaluation using Spectroscopy Data in Multi-mineral Model

MODEL-3 USING SPECTROSCOPY DATA AND CONVENTIONAL LOGS			
Reservoir Model		**Shale Model**	
Equations	**Volumes**	**Equations**	**Volumes**
Rt (DWA)	Quartz	Bulk density	Quartz
Rxo (DWA)	Calcite	Neutron porosity	Calcite
Bulk density	Illite	DWAL	Illite
Neutron porosity	Kaolinite	DWSI	Kaolinite
DWAL	Chlorite	DWCA	Chlorite
DWSI	Siderite	DWFE	Siderite
DWCA	Pyrite	DWSU	Pyrite
DWFE	Water	WWTH	
DWSU	Gas	U	
WWTH			
U			

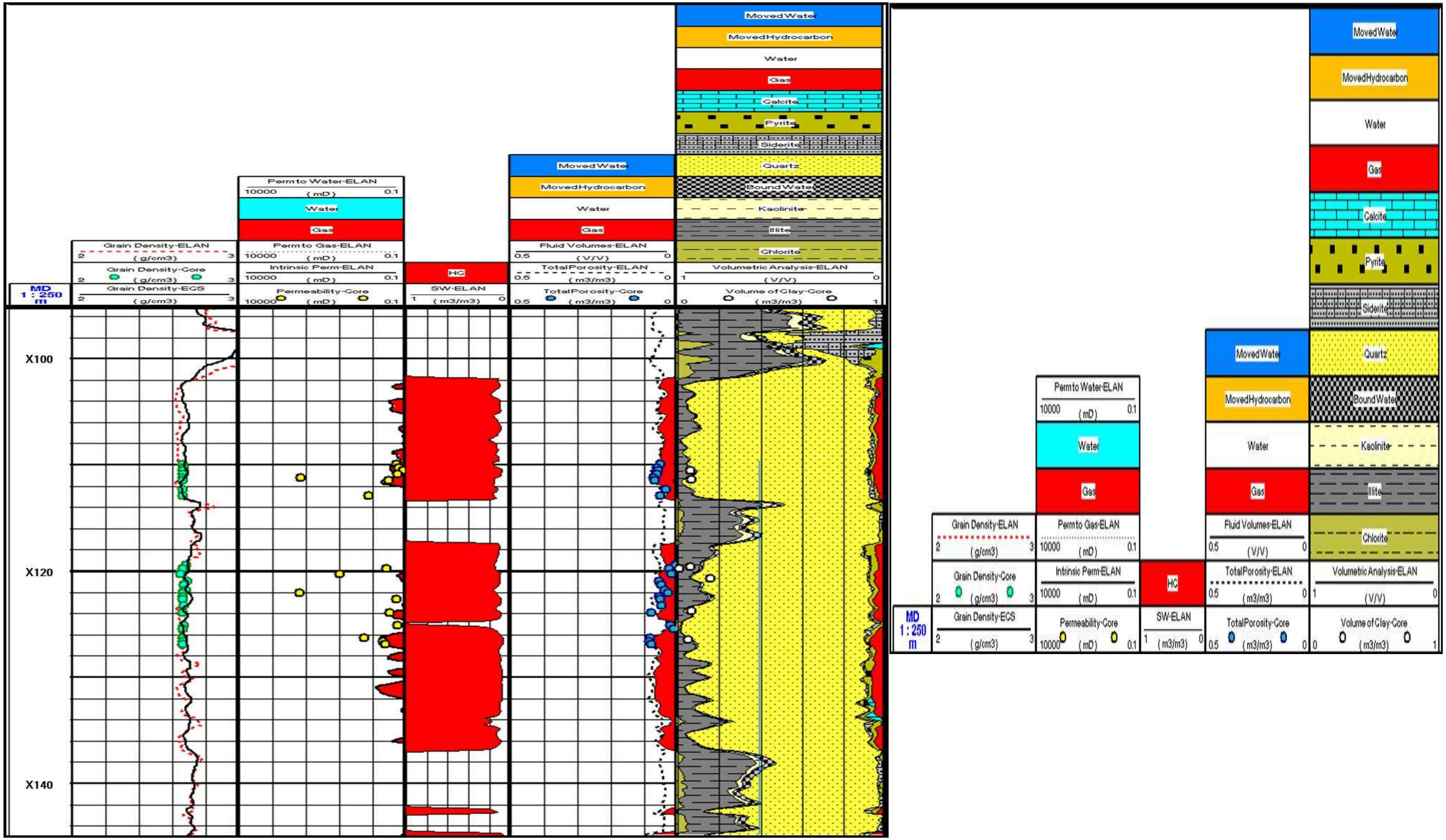
Accurate Petrophysical Evaluation using Spectroscopy Data in Multi-mineral Model



Comparison between Conventional Interpretation and Interpretation using Spectroscopy Data



Reliable Results with High Confidence Level



Conclusions & Recommendations

Conclusions

- Reliable amount of clay/types and other minerals
- Estimation of accurate porosity due to variable grain density measurements
- Estimation of reliable continuous permeability for understanding reservoir potential and making well testing decision
- Resolution of complex lithology/mineralogy throughout reservoir interval

Recommendations

- Elemental Spectroscopy provides reliable information in making timely/right decision for well testing
- Elemental Spectroscopy can replace expensive coring program in exploration as well as in development wells

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