Petrophysical Rock Typing: Enhanced Permeability Prediction and Reservoir Descriptions*

Wanida Sritongthae[1]

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Abstract

One of the existing challenges for geoscientists and reservoir engineers is to improve an understanding of reservoir descriptions (i.e. fluid flow capacity). This is to define the best representative reservoir properties in a reservoir simulation model. Poorly described reservoir characteristics can lead to a significant impact in reservoir performance predictions and its future production behaviors. The field case studies are 1) Field A of the Jurassic sandstone of a fluvio-deltaic environment that has undergone multiple stages of diagenesis and 2) Field B of the Miocene fluvial-lacustrine thinned-bed sand shale reservoirs.

FZI rock typing technique provides an understanding of factors that controlled reservoir quality and fluid flow characteristics. Rock type prediction using the statistical MRGC model with conventional log provides a good matched with the core data. However, predicted rock type becomes less accurate when bed thickness is less than the well log vertical resolution, and mismatching often occurs at the shoulder bed boundaries. Furthermore, the appropriated sets of reservoir properties (permeability, relative permeability, capillary pressure, and irreducible water saturation) are well defined for each rock type. This will help to improve reservoir simulation studies for performance prediction and future field development decisions.

Selected References

Amaefule, J.O., M. Altunbay, D. Tiab, D.G. Kersey, and D.K. Keelan, 1993, Enhanced Reservoir Description: Using Core and Log Data to Identify Hydraulic (Flow) Units and Predict Permeability in Uncored Intervals/Wells: 68th Annual Technical Conference and Exhibit, Houston, TX, SPE 26435.

Sain, R., 2010, Numerical Simulation of Pore-Scale Heterogeneity and its Effects on Elastic, Electrical and Transport Properties: Ph.D. Dissertation, Stanford University, Stanford, CA, 198 p.

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Petrophysical Rock Typing:

Enhanced Permeability Prediction and Reservoir Descriptions

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“Characterization of Asian Hydrocarbon Resources”

Bangkok, Thailand

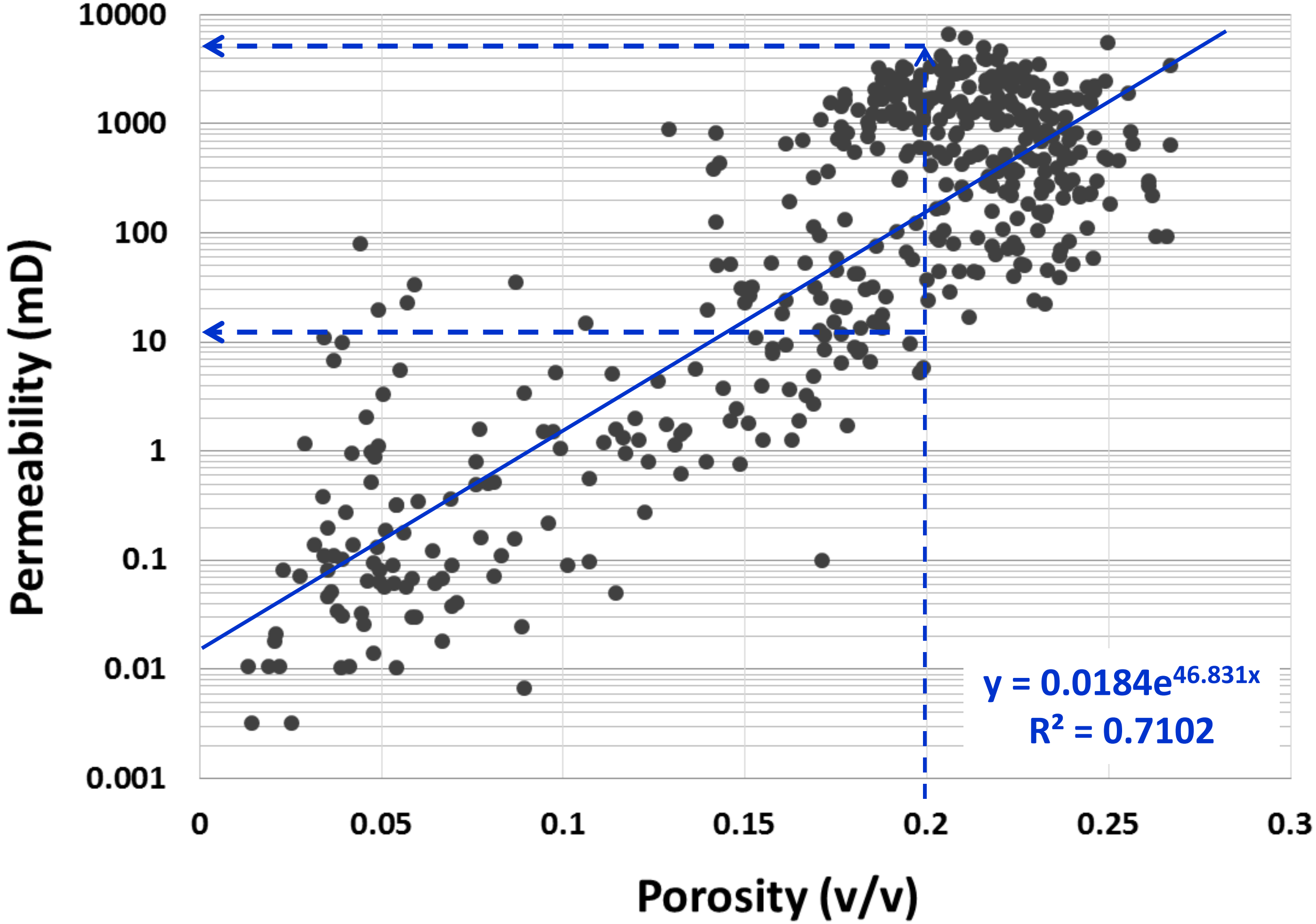
31 March – 1 April 2016

PTTEP

Outlines

- Introduction
- Core-log Integration for Rock Type Prediction and Permeability Estimation
- Case Studies
  - Field A: Diagenesis Sandstone
  - Field B: Thin Laminated Sandstone
- Observations
- Conclusions

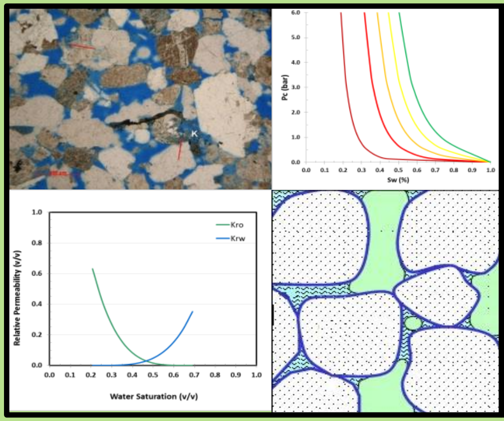
Challenges in Permeability Estimation



Field A: Fluvio-deltaic sediments

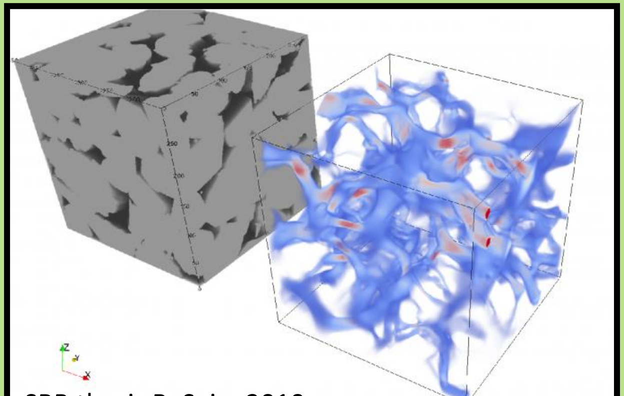
Petrophysical Rock Typing

Petrophysical Properties



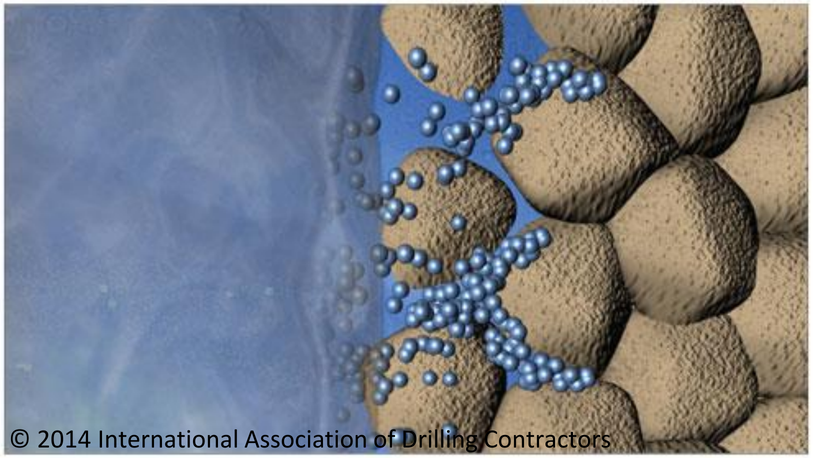
- Ø-K
- Pc
- Swi
- etc.

Pore Geometry



SRB thesis R. Sain, 2010

Fluid Flow Behaviors



Permeability of the Porous Media

Kozeny-Carman of capillary tube model

$$K = \frac{{\emptyset_e}^3}{(1-\emptyset_e)^2}\frac{1}{F_s\tau^2 {S_{gv}}^2}$$

Permeability (K) in µm

Effective porosity ($\emptyset_e$) in fraction

Shape faction (F_s)

Tortiosity (τ)

Surface area per unit pore volume (S_{gv}) in µm^{-1}

Concepts of Flow Zone Indicator(FZI)

Amaefule et al. (1993) presented method of Flow Zone Indicator (FZI) by modifying Kozeny-Carman equation;

$$K = \frac{{\emptyset_e}^3}{(1-\emptyset_e)^2}\frac{1}{F_s\tau^2{S_{gv}}^2}$$

Divide both sides with Q_e, and convert K to millidarcy

$$0.0314\sqrt{\frac{K}{\emptyset_e}} = \left(\frac{\emptyset_e}{1-\emptyset_e}\right)\left(\frac{1}{\sqrt{F_s}\tau S_{gv}}\right)$$

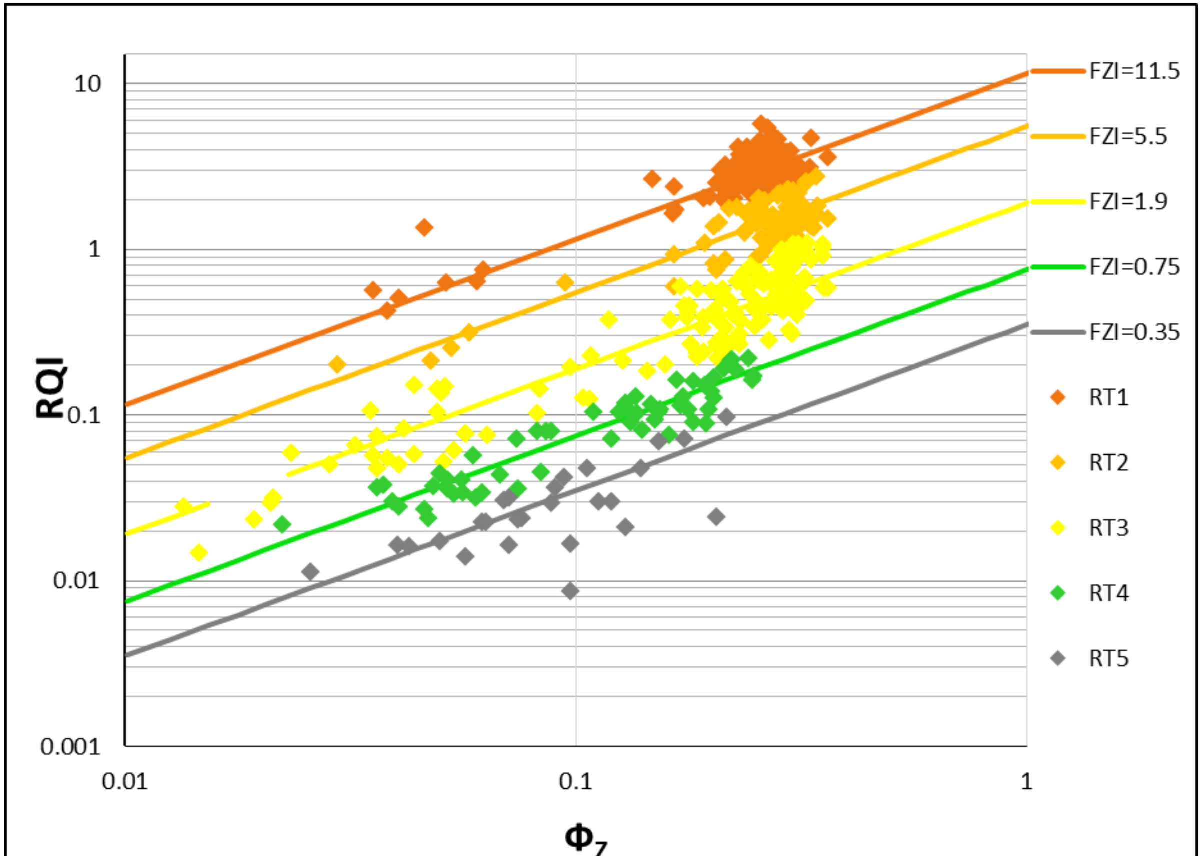
Reservoir Quality Indicator (RQI)

Normalize Porosity ($\emptyset_z$)

Flow Zone Indicator (FZI)

Flow Zone Indicator & Rocktype

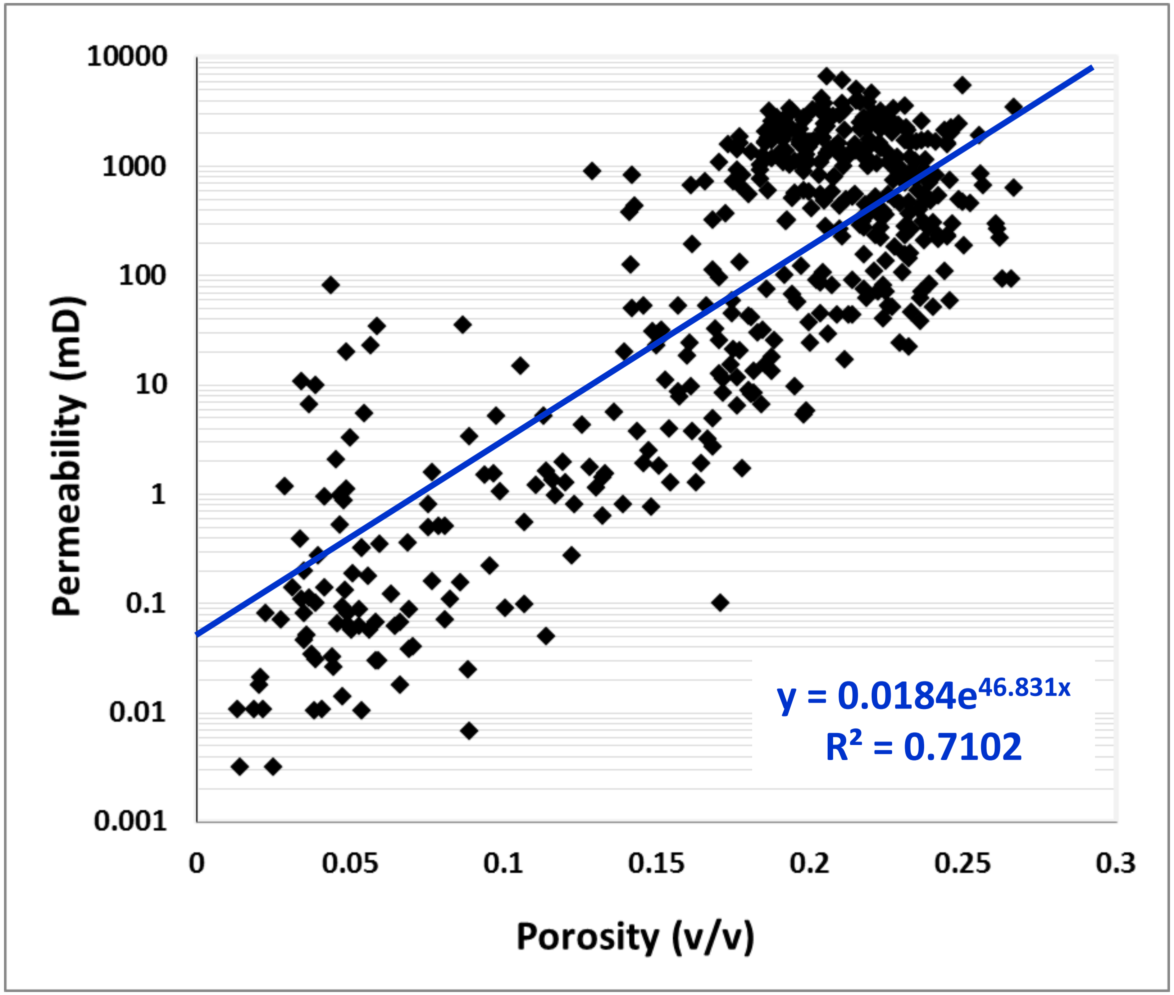
log (R(RQI = Q_z.FZI og (FZI)



Samples that have same **FZI** will be classified into the same Hydraulic Flow Unit **(HFU) or Rocktype**

Each unit has a similar **pore geometry and rock textures** (i.e. grainsize, sorting, diagenesis) which exhibiting a similar fluid flow characteristics

Flow Zone Indicator & Rocktype



Rocktype or HFU

RT1
RT2
RT3
RT4
RT5

Field A: Fluvio-deltaic sediments

Objectives

- Core-log integration for rock type analysis and permeability estimation using **FZI or HFU**
- Define a suitable **reservoir properties** in static and dynamic models; such as rock type, permeability (K), relative permeability (Kr), capillary pressure (Pc) and irreducible water saturation (Swi)

Outlines

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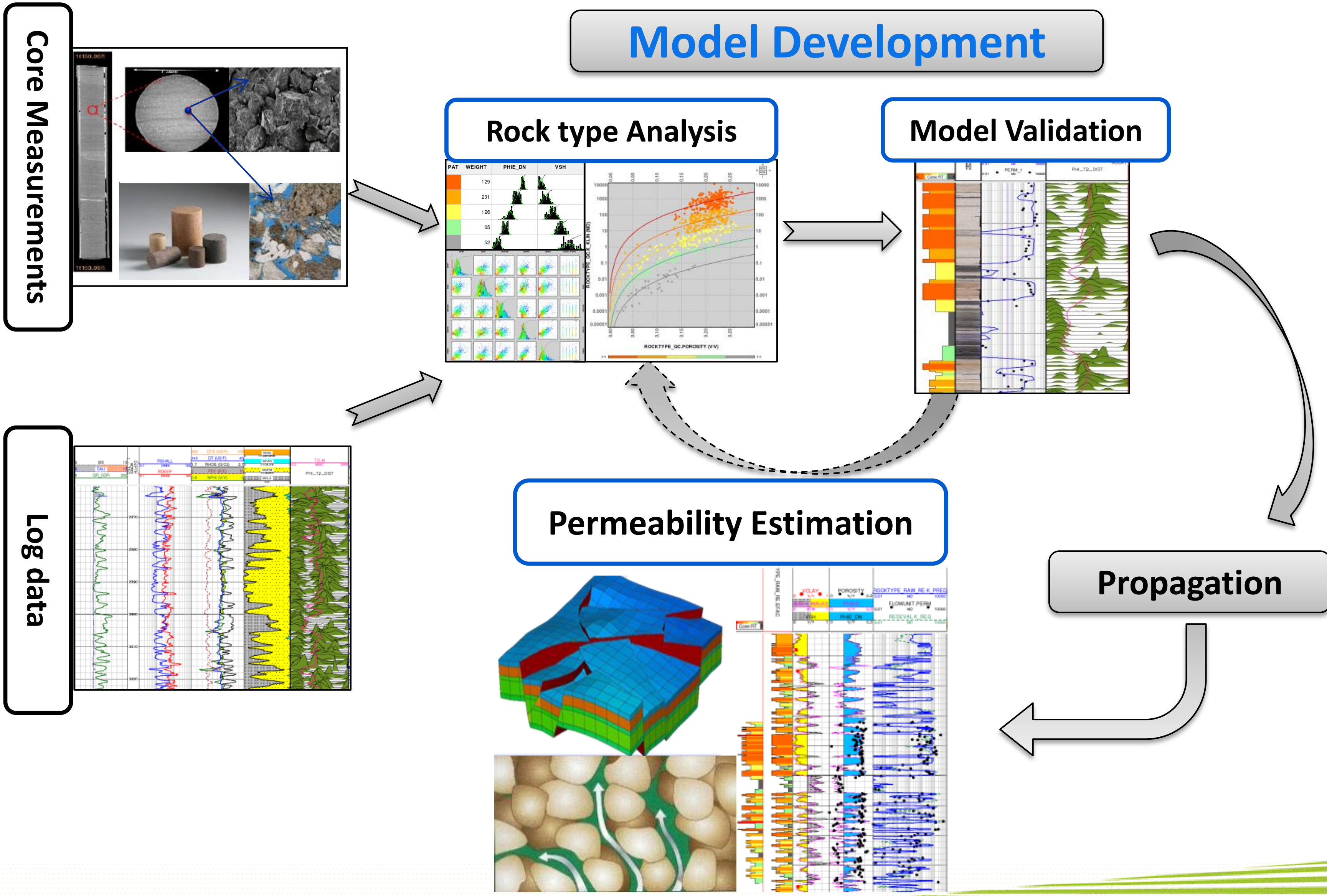
Workflow for Rocktype Prediction & K Estimation



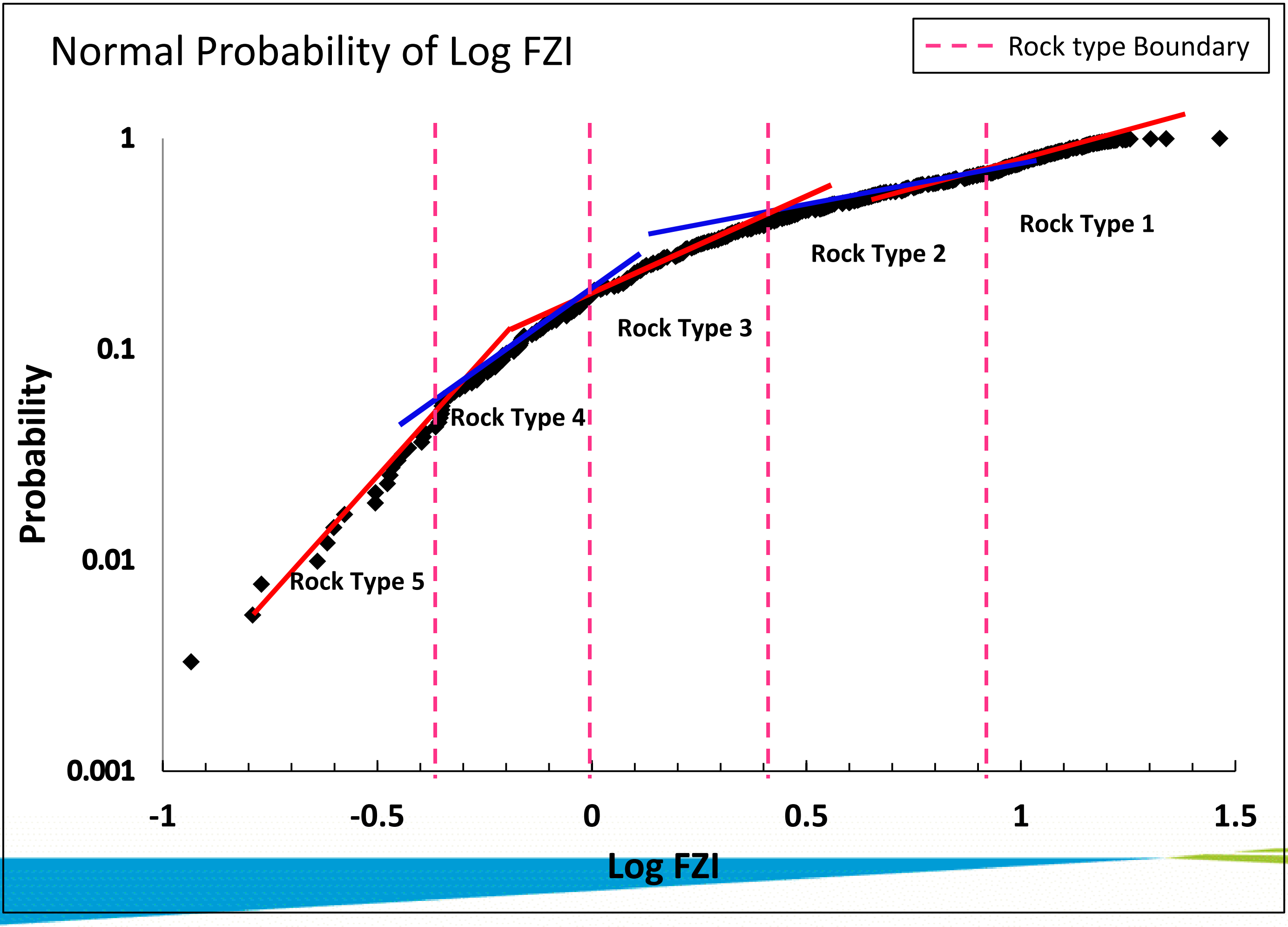
Data Requirements

- Core porosity and permeability at reservoir conditions
- Core descriptions and mineralogy analysis (thin-section, XRD, and SEM)

- Well log data and quality controlled
  - Recorded and calibrated in the same reference system
  - Borehole environmental correction
  - Log normalization
  - Identify badhole interval

Step 1: Core-Rock Typing Analysis

$$FZI = \frac{0.0314\sqrt{K/\emptyset_e}}{\frac{\emptyset_e}{1-\emptyset_e}}$$



RT	FZI Value
RT1	>8.0
RT2	3.5 < FZI ≤ 8.0
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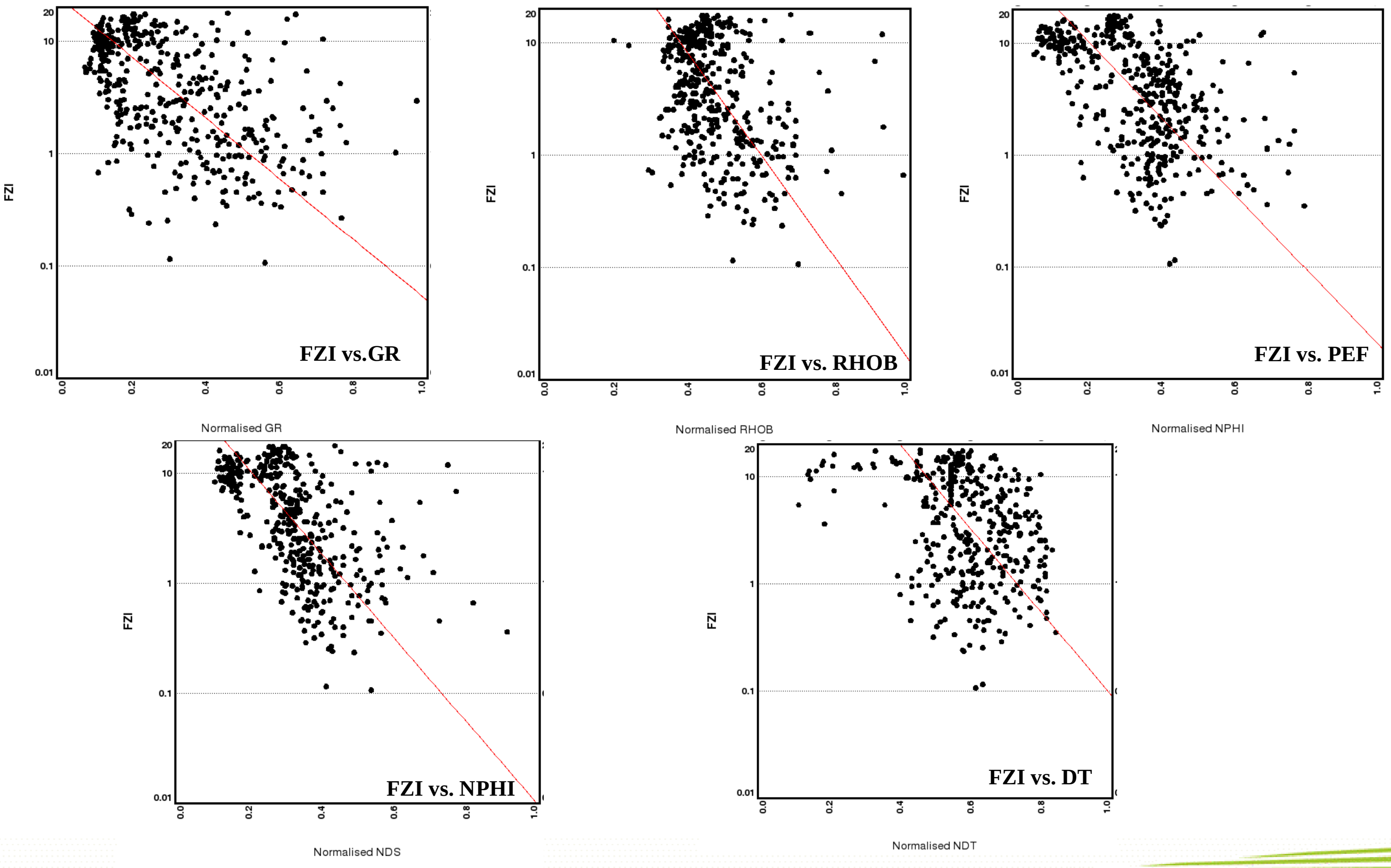
RT4	0.45 < FZI ≤ 1.0
RT5	≤ 0.45

Step 2: Core-Rocktype to Logs Correlation

- Correlations of core-rock type (FZI) and log measurements
- A representative dataset (Training data) for model construction

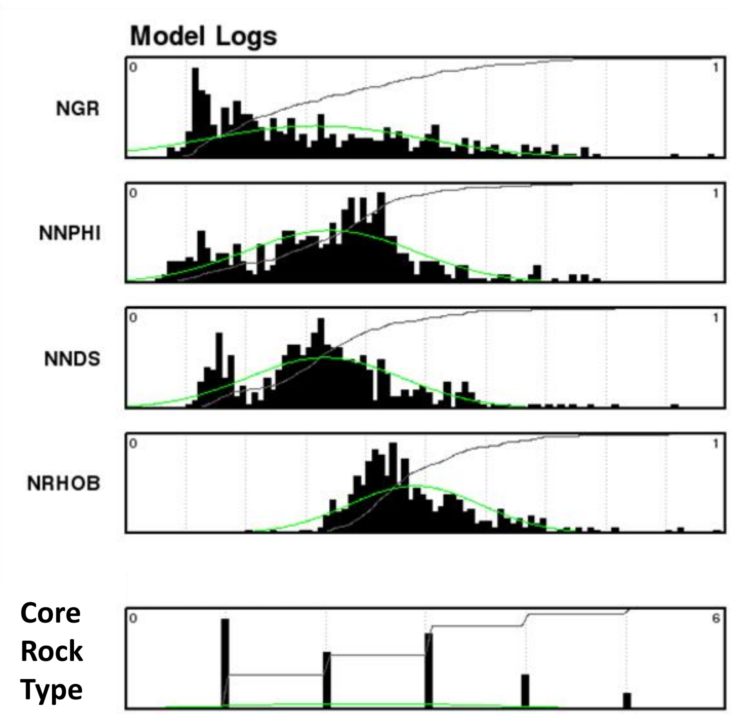


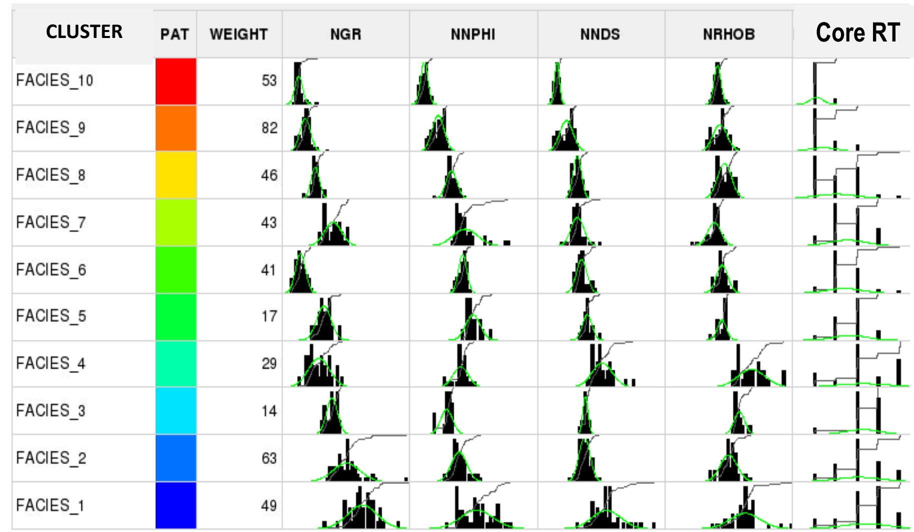
Step 3: Rocktype Model Development

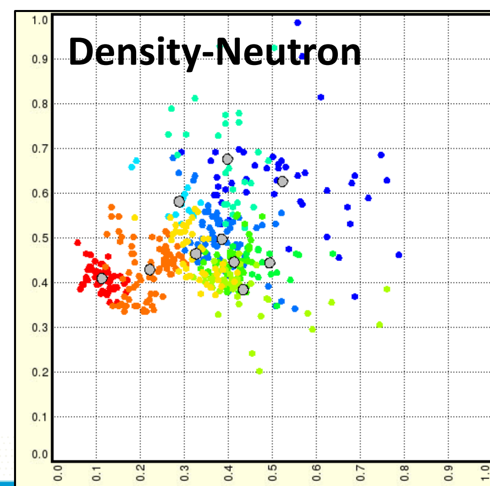
The Multi-Resolution Graph-Based Clustering or MRGC (Ye and Rabiller ,2000)

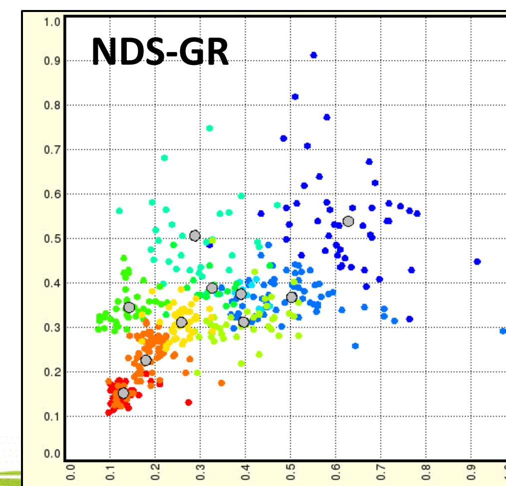
Statistically partitioning an input into specific range, with optimum cluster number

INPUT: Training Dataset





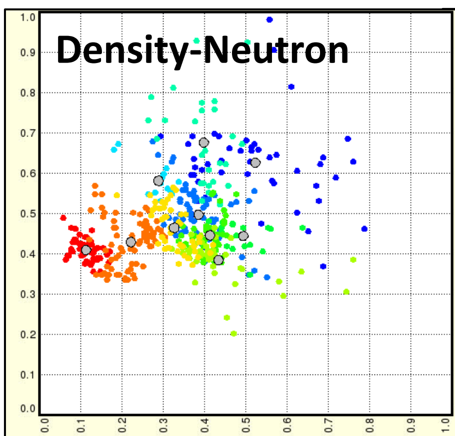


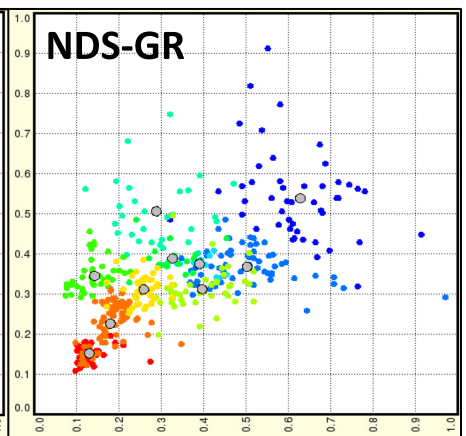


Step 3: Rocktype Model Development

Grouping the initial clustering model into the core-rock type using supervising probability table

CLUSTER	PAT	WEIGHT	NGR	NNPHI	NNDS	NRHOB
FACIES_10		53				
FACIES_9		82				
FACIES_8		46				
FACIES_7		43				
FACIES_6		41				
FACIES_5		17				
FACIES_4		29				
FACIES_3		14				
FACIES_2		63				
FACIES_1		49				





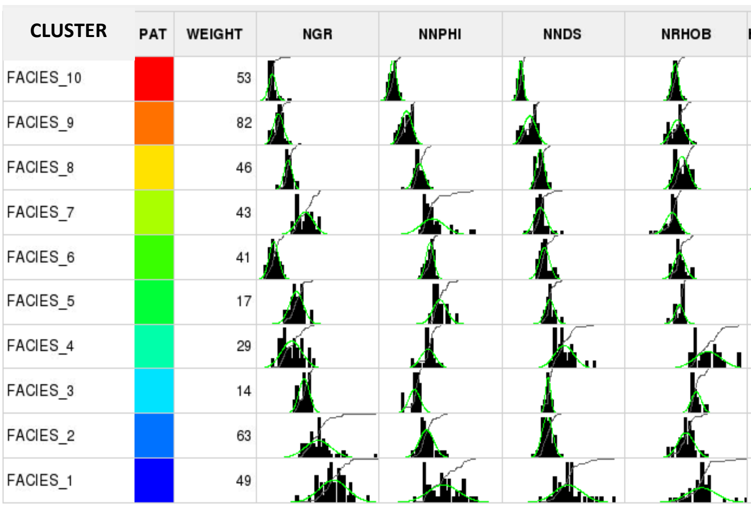
Initial MRGC Cluster

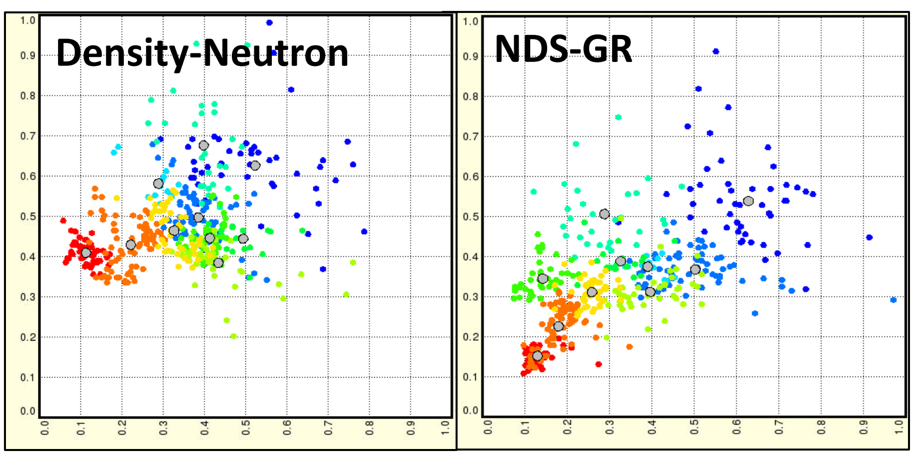
Defined Rock Type

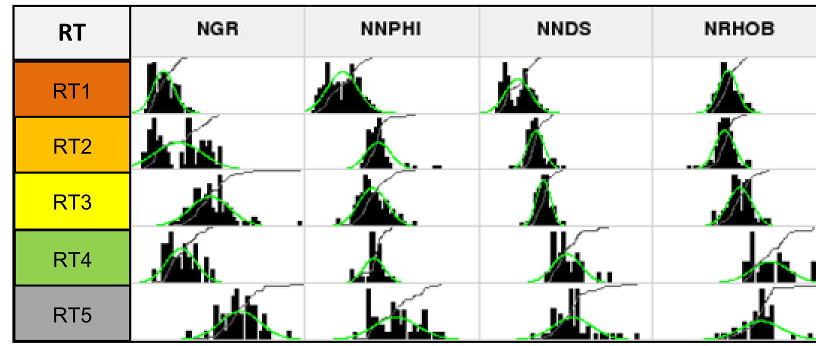
	1	2	3	4	5	6	7	8	9	10
RT1	8%	8%	7%	14%	6%	7%	9%	41%	71%	89%
RT2	8%	17%		7%	29%	54%	40%	22%	17%	11%
RT3	33%	43%	50%	41%	53%	32%	35%	30%	11%	
RT4	37%	21%	43%	10%	12%	5%	16%	4%	1%	
RT5	14%	11%		28%		2%		2%		
TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Step 3: Rocktype Model Development

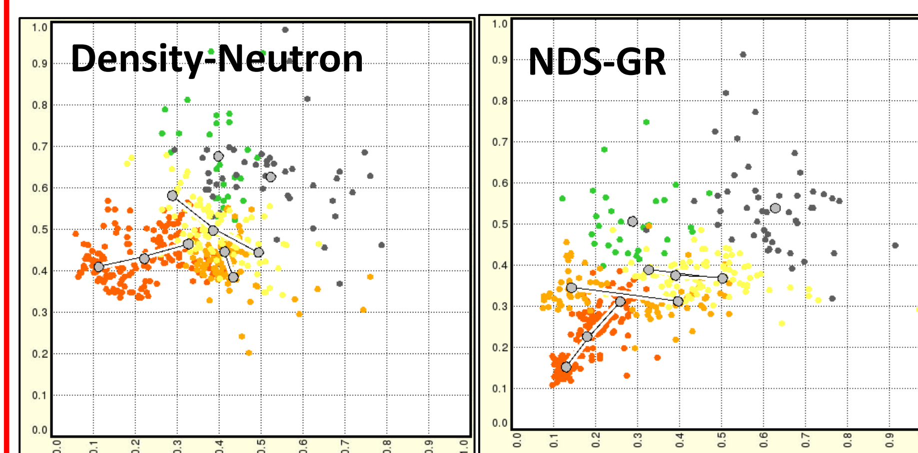
Grouping the initial clustering model into the core-rock type using supervising probability table







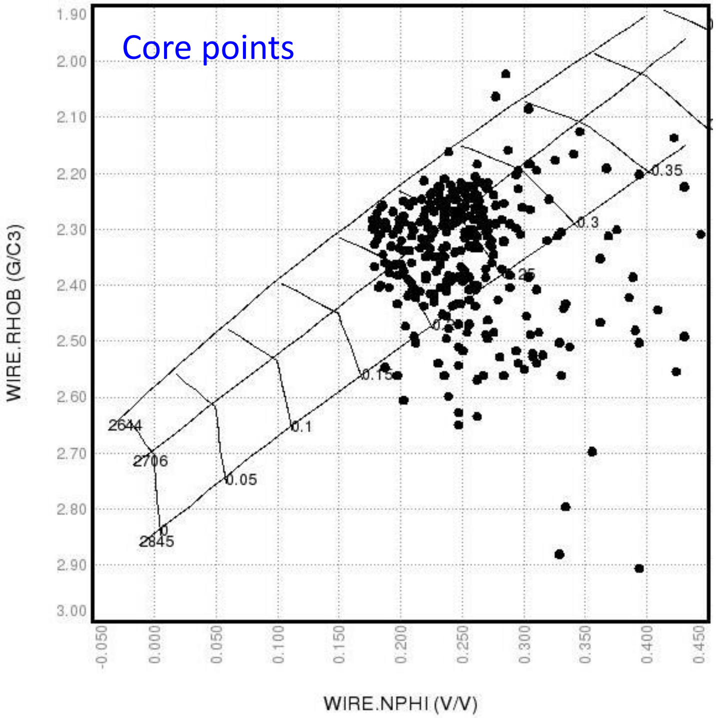
Rock Type Clustering Model



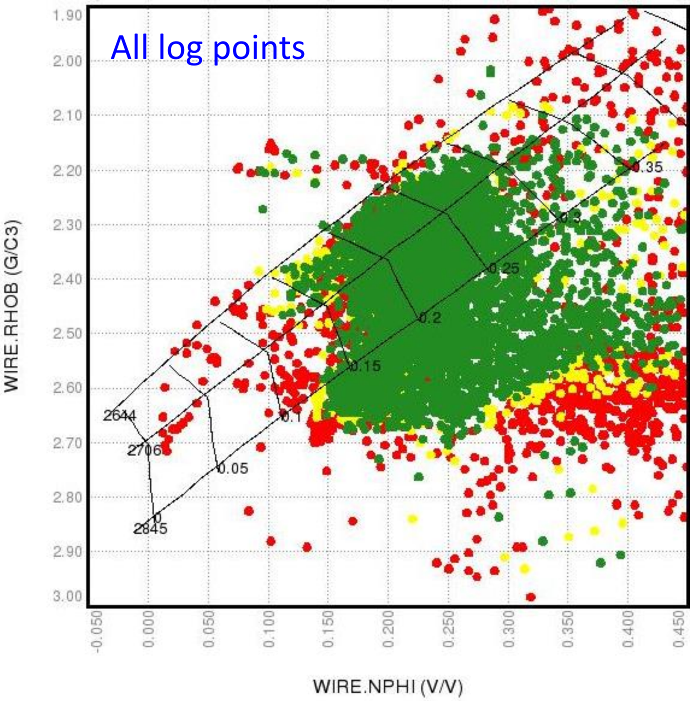
Step 4: Log Data-Training Data Validation

Similarity Model or Similarity Threshold Method (STM) is a technique used to determine the similarity of the application data (logs) to the training data

Training Data or Learning Region



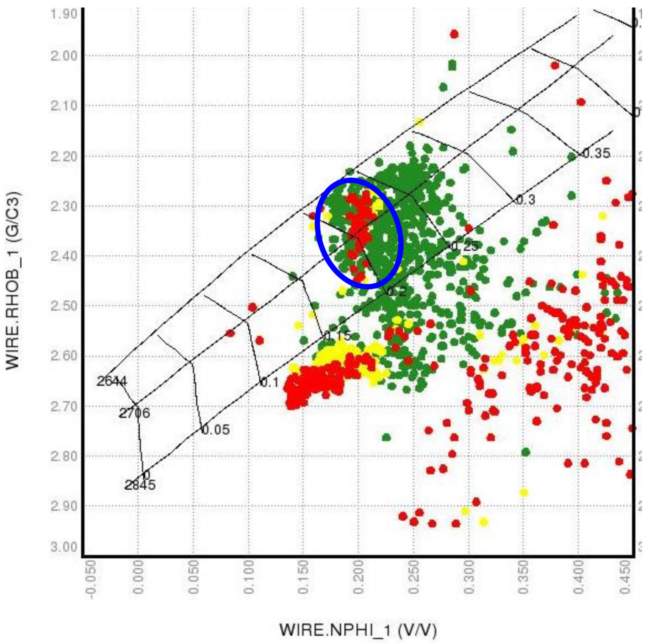
The Application Region

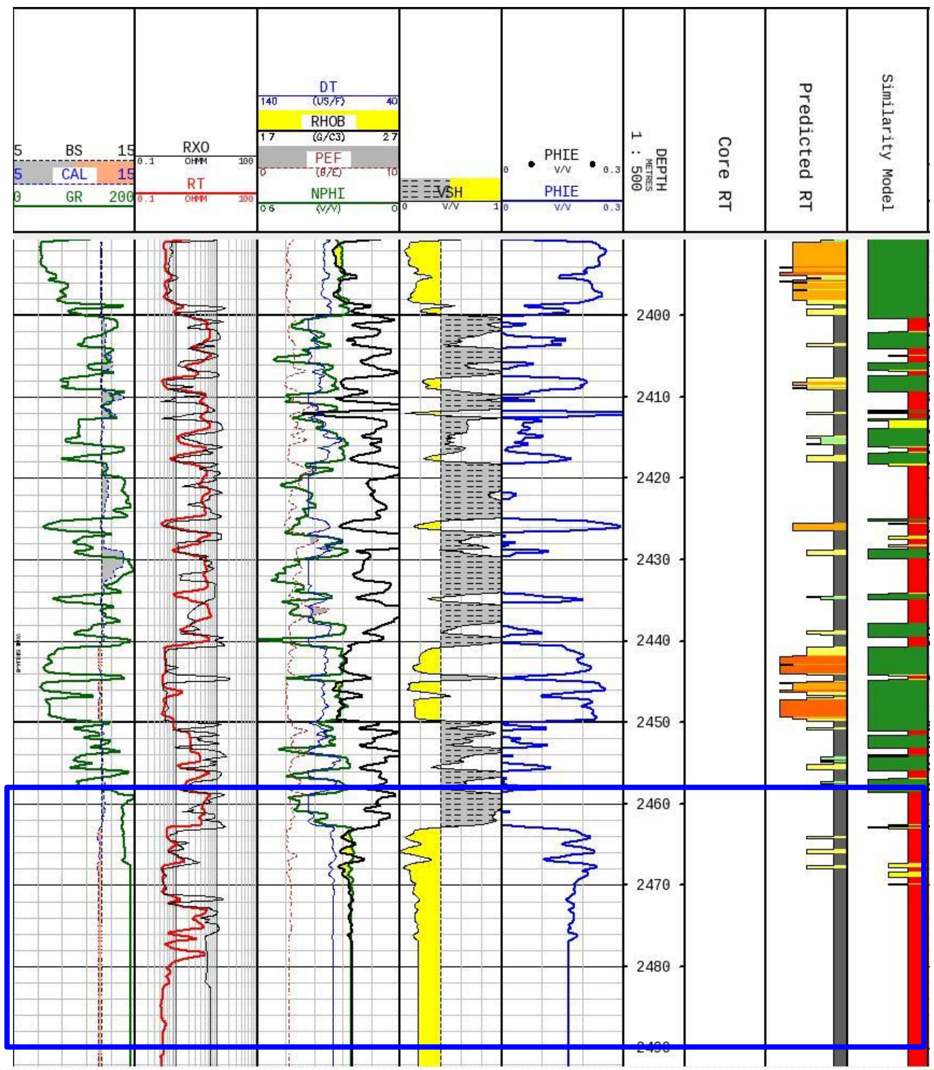


Green = Similar
Yellow = Inconclusive
Red = No similarity

Step 4: Log Data-Training Data Validation

a) Invalid log data





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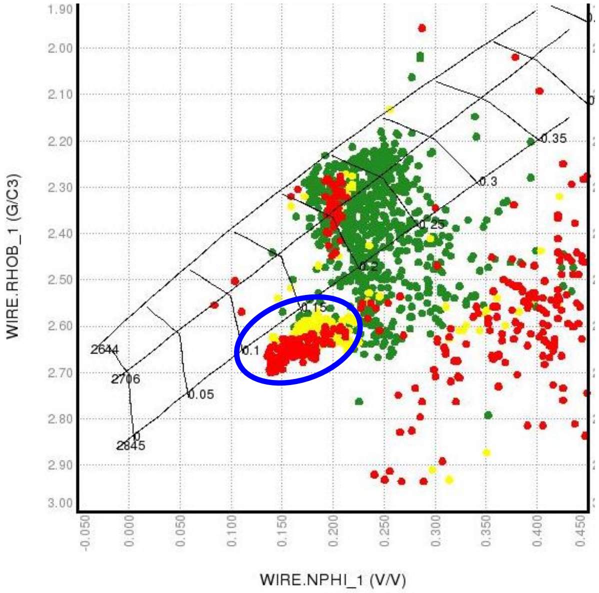
Step 4: Log Data-Training Data Validation

b) Different geological facies



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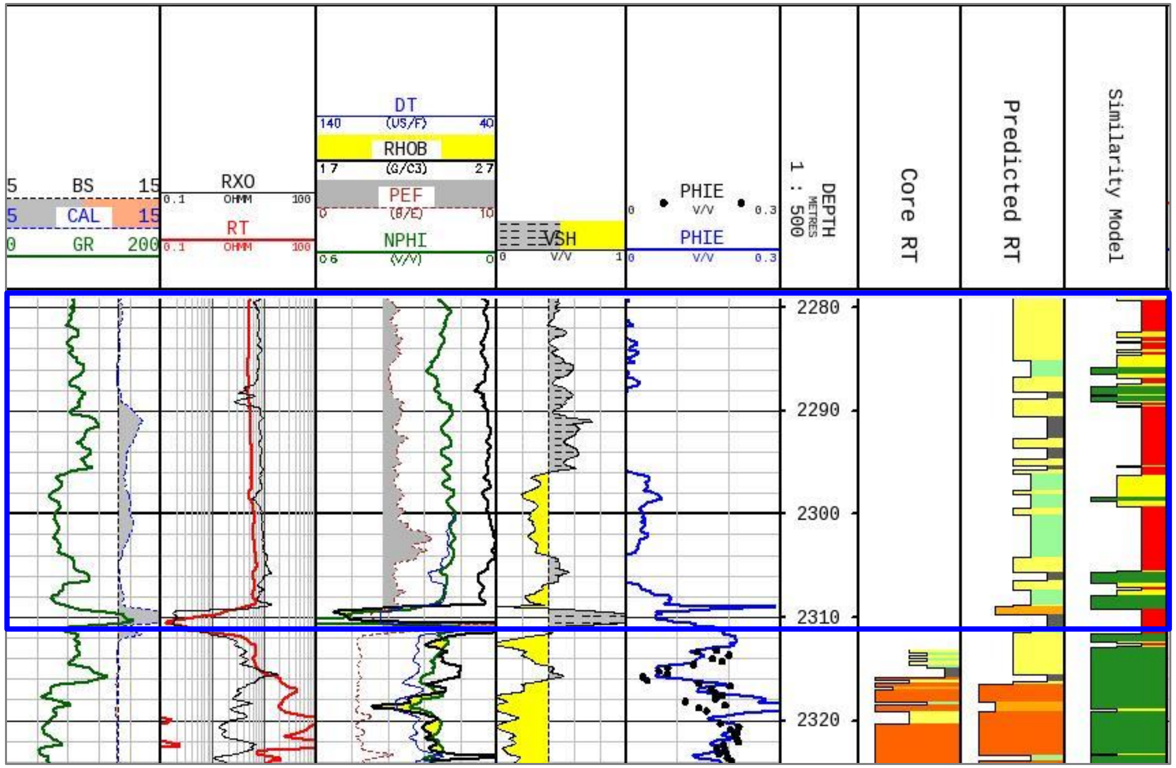
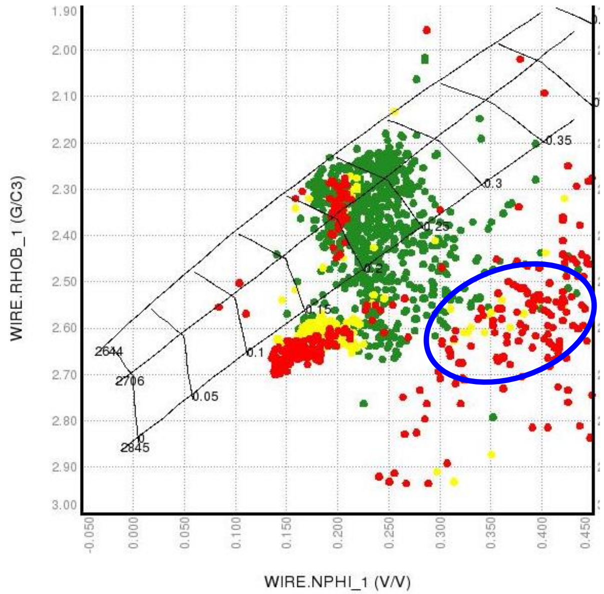


marl, calcareous claystone

Step 4: Log Data-Training Data Validation

b) Different geological facies



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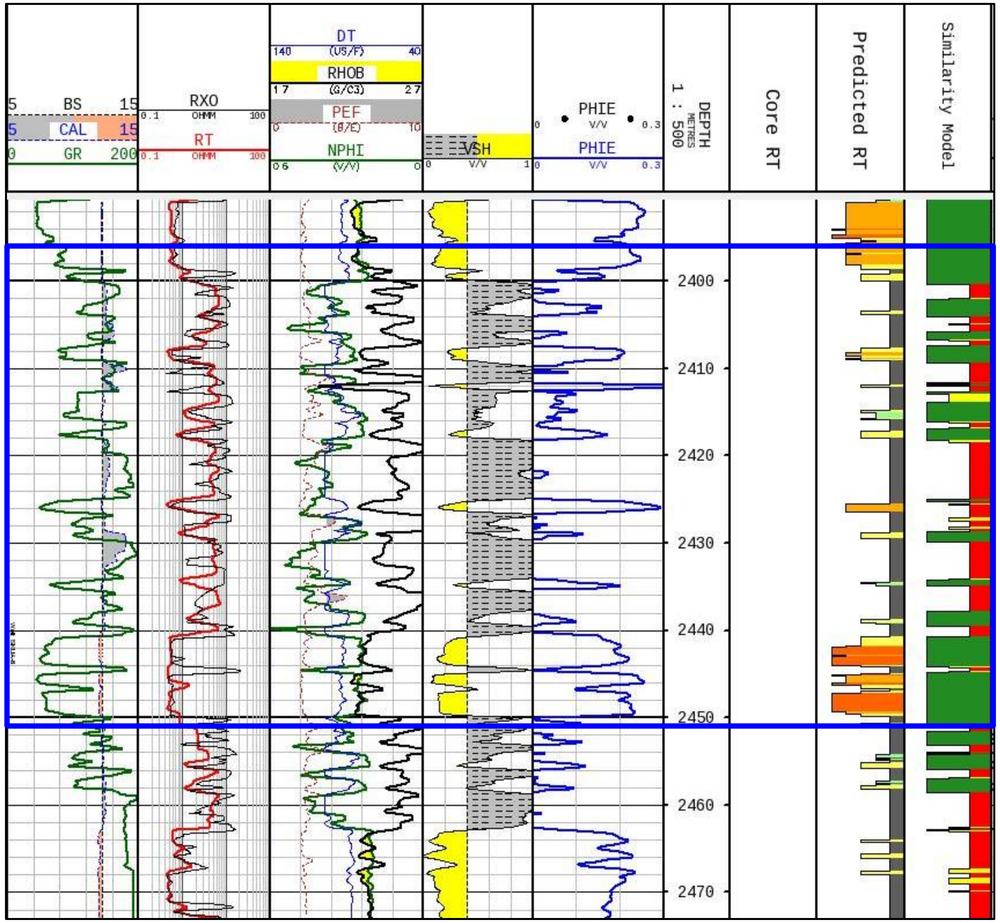
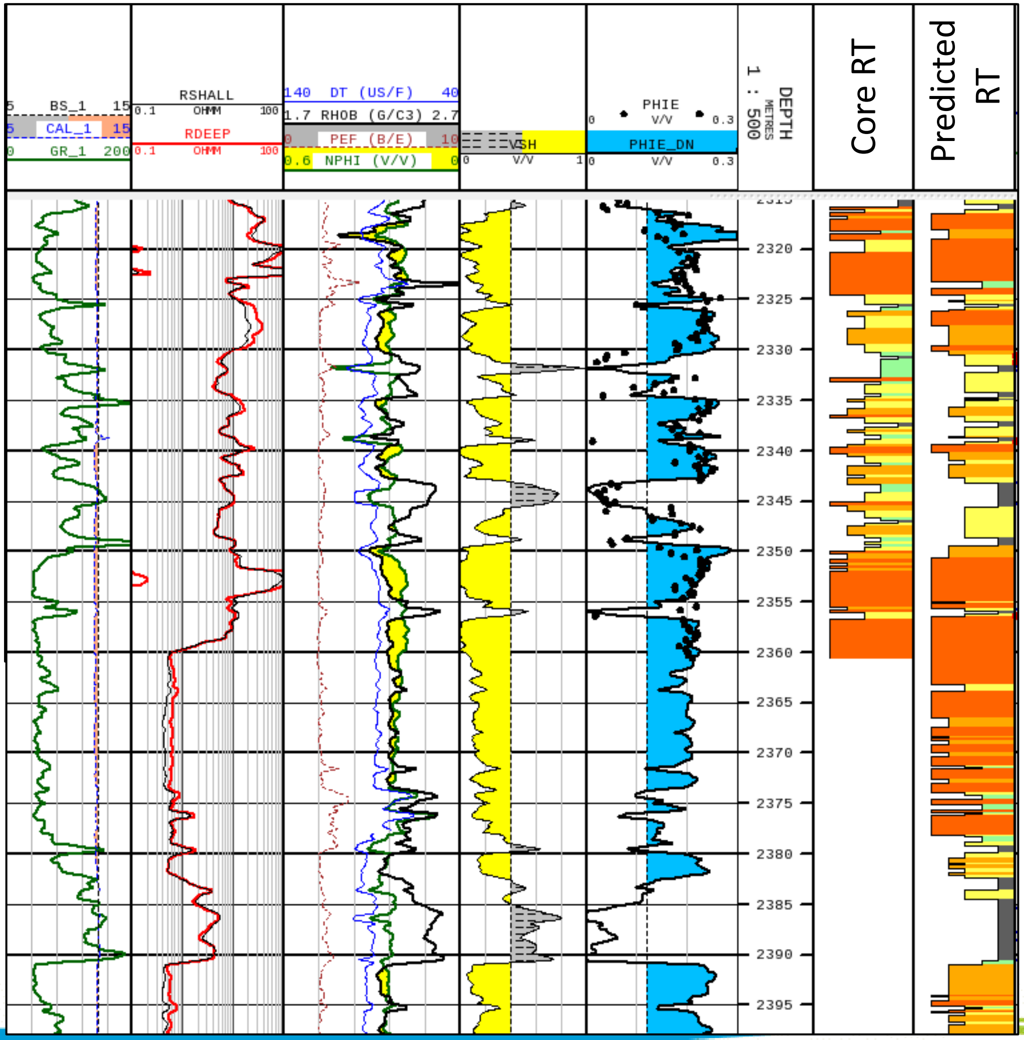


Different shale property

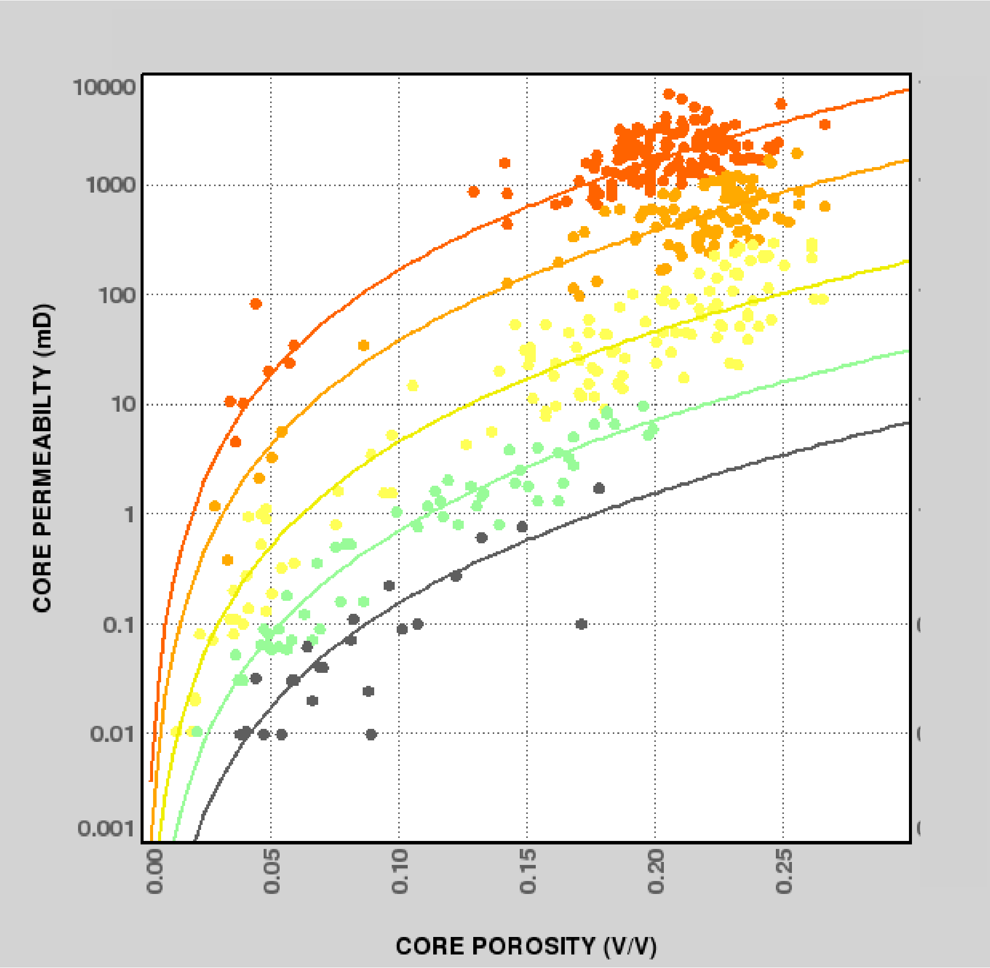
Step 5: Model Propagation

Validation by comparing the predicted rock type to core-rock type

Model propagation using the K-nearest neighbor algorithm (KNN)



Step 6: Permeability Estimation



$$K = 1014(MeanFZI)^2\left[\frac{\phi_e^{\,3}}{(1-\phi_e)^2}\right]$$

RT	FZI Value	Mean FZI	Reservoir Quality
RT1	>8.0	11.4	Very Good
RT2	3.5 < FZI ≤ 8.0	5.5	Good
RT3	1.0 < FZI ≤ 3.5	1.9	Medium
RT4	0.45 < FZI ≤ 1.0	0.75	Poor
RT5	≤ 0.45	0.35	Very Poor

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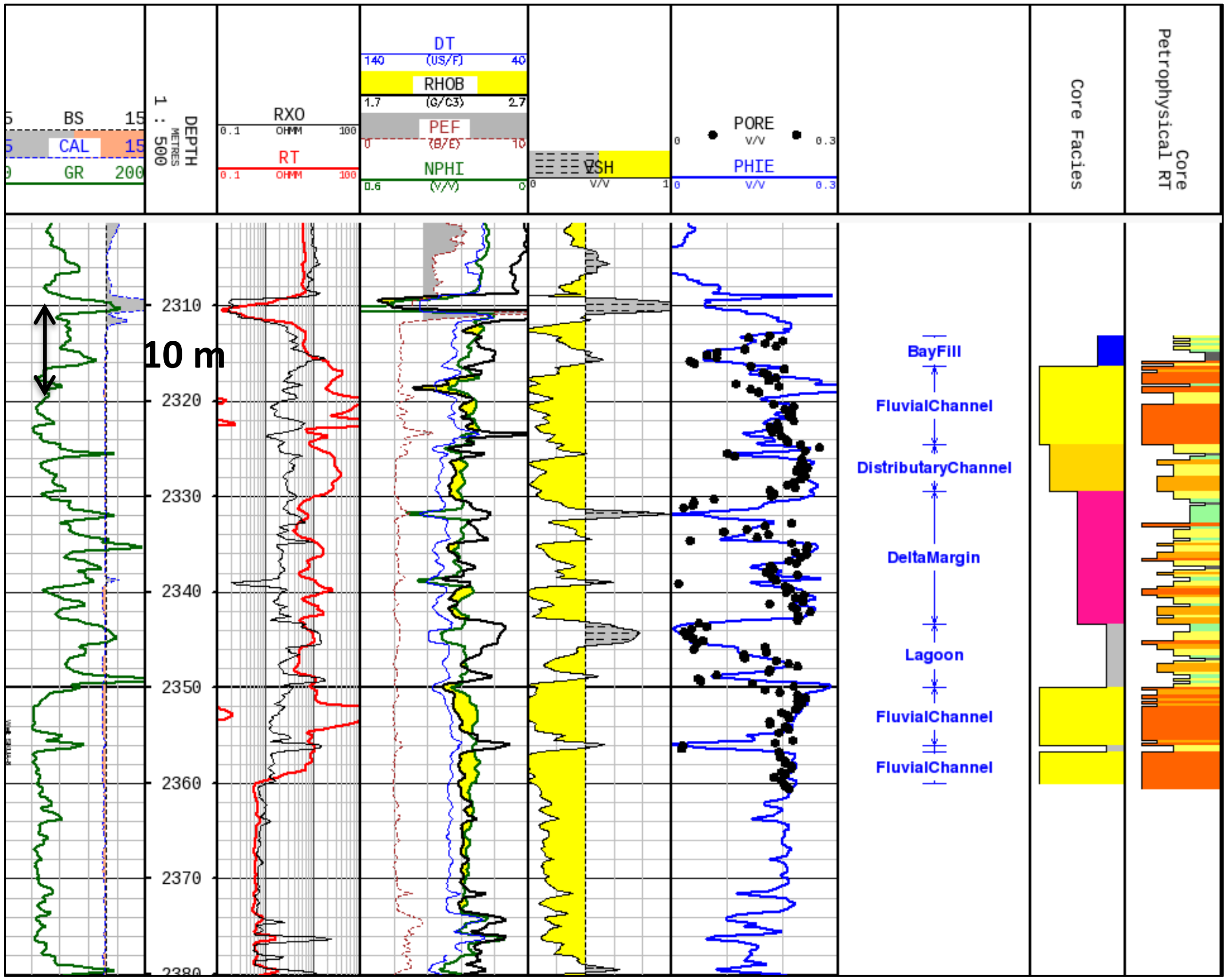
Field A: Diagenesis Sandstone

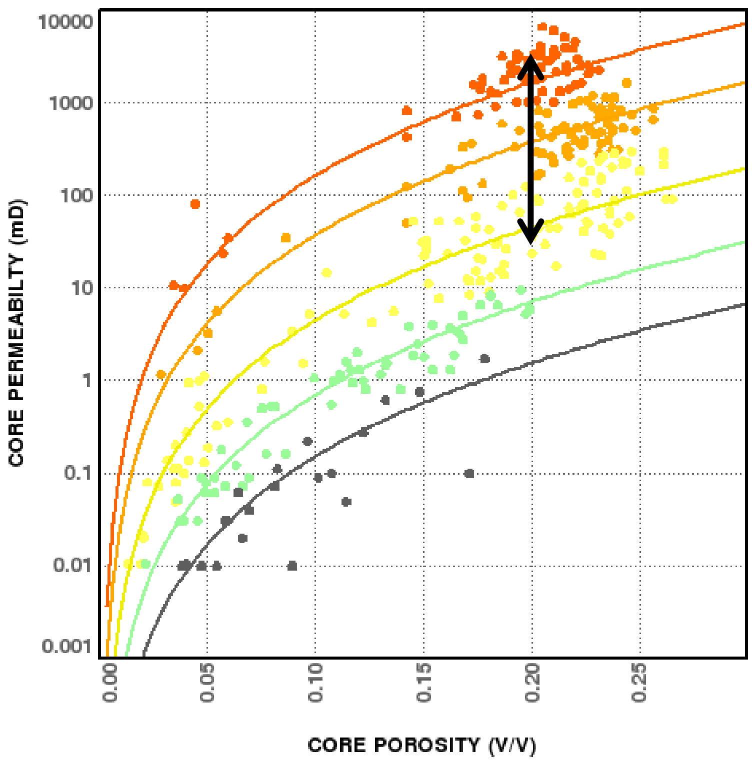
Fluvio-deltaic sediments of the Early Jurassic. Interbedded sandstone and shale

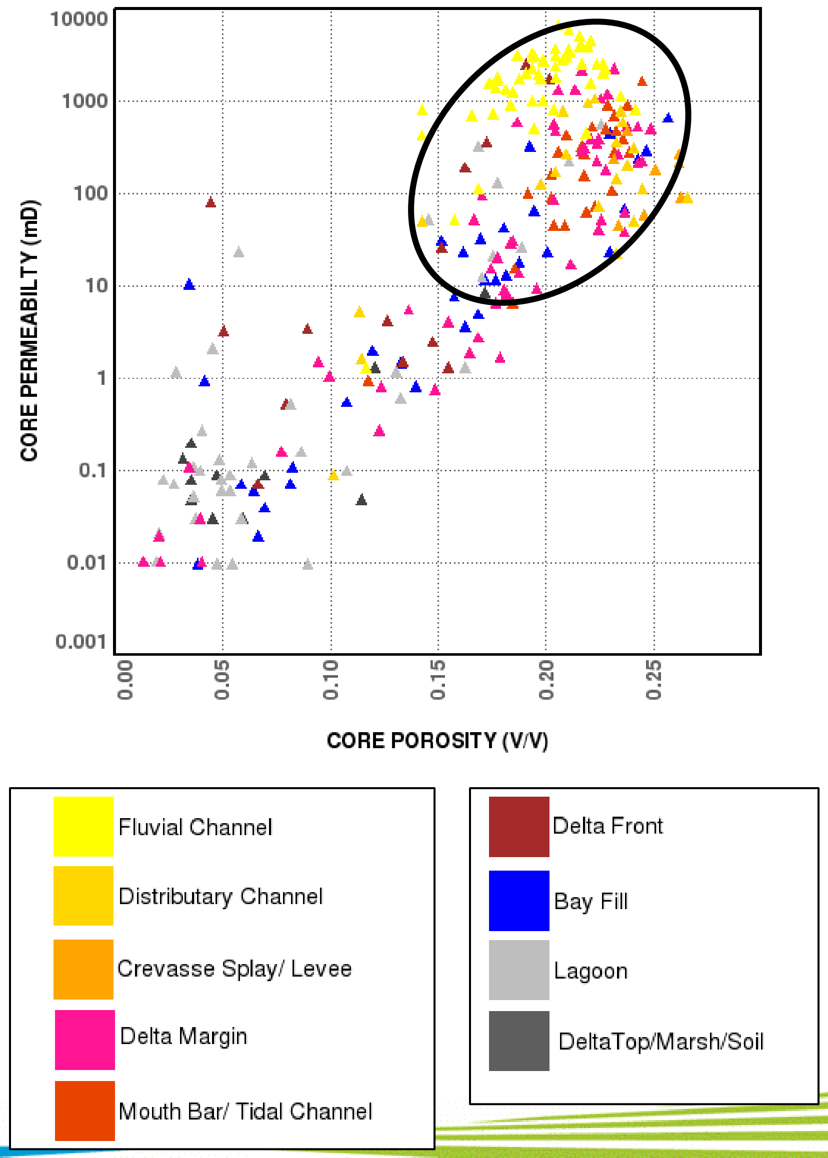


Diagenesis

- Matrix dissolution
- Cementation (pyrite, clays, etc.)
- Quartz overgrowth

Rocktype vs. Depositional Facies





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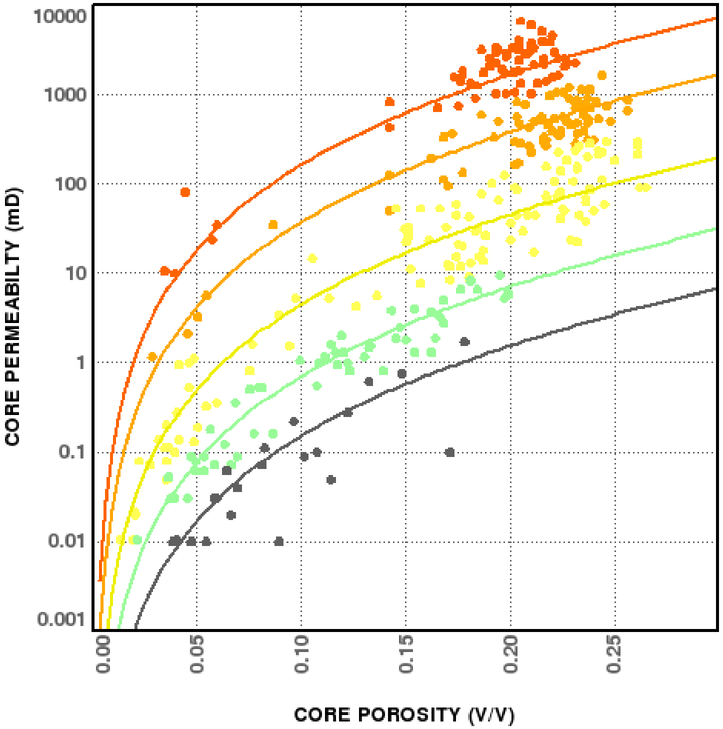
Rocktype and Properties



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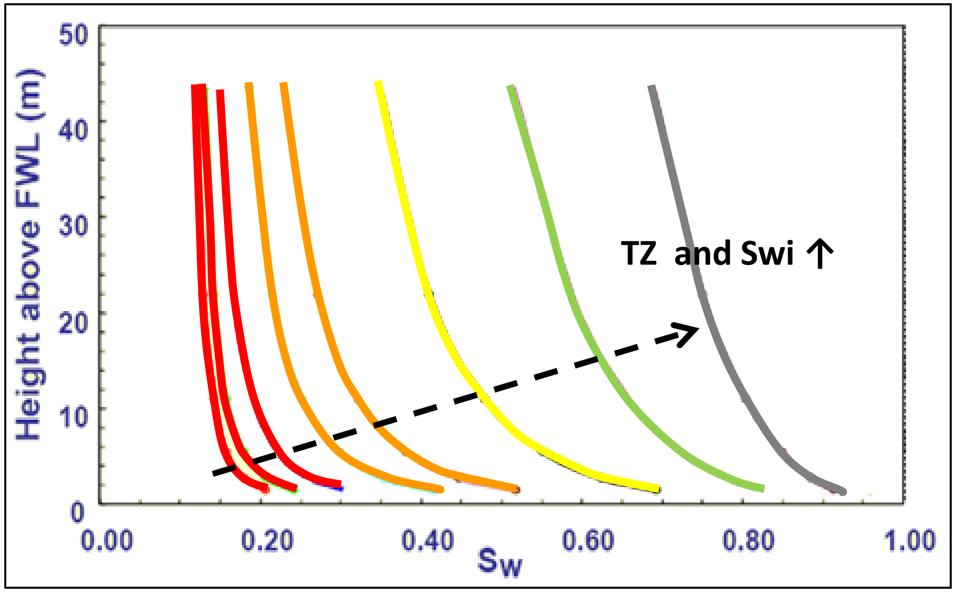
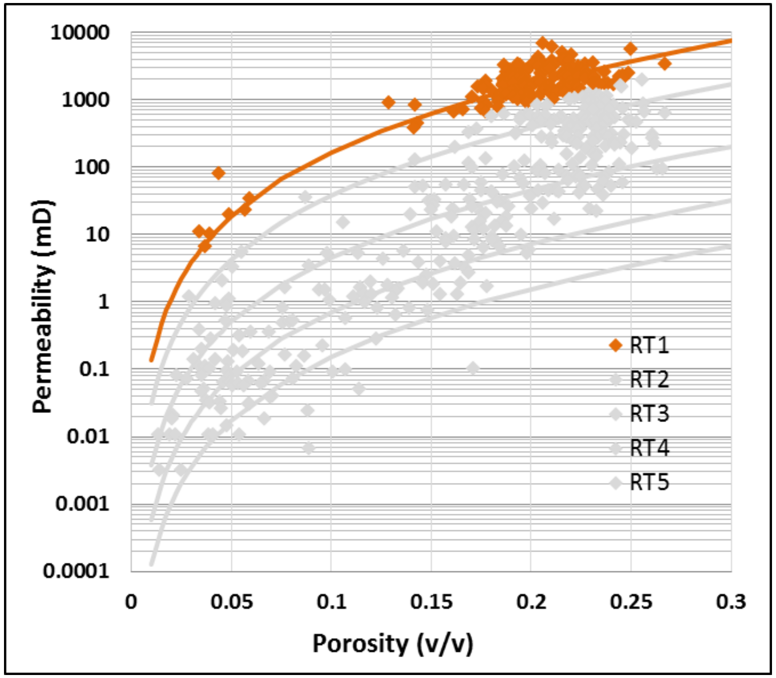
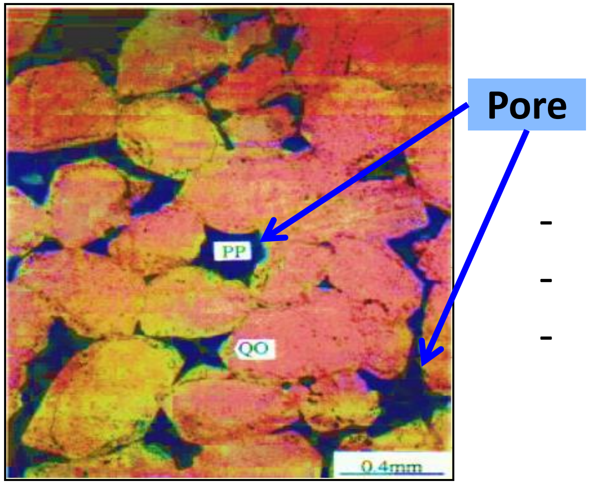
Pc HAFWL vs. Sw



Petrology, Capillary pressure (Pc) vs. S_w plot analog from Bonaparte Basin, Peter Behrenbruch,2013

Rocktype and Petrophysical Properties





- Coarse grained
- Well preserved pore
- Grain dissolution

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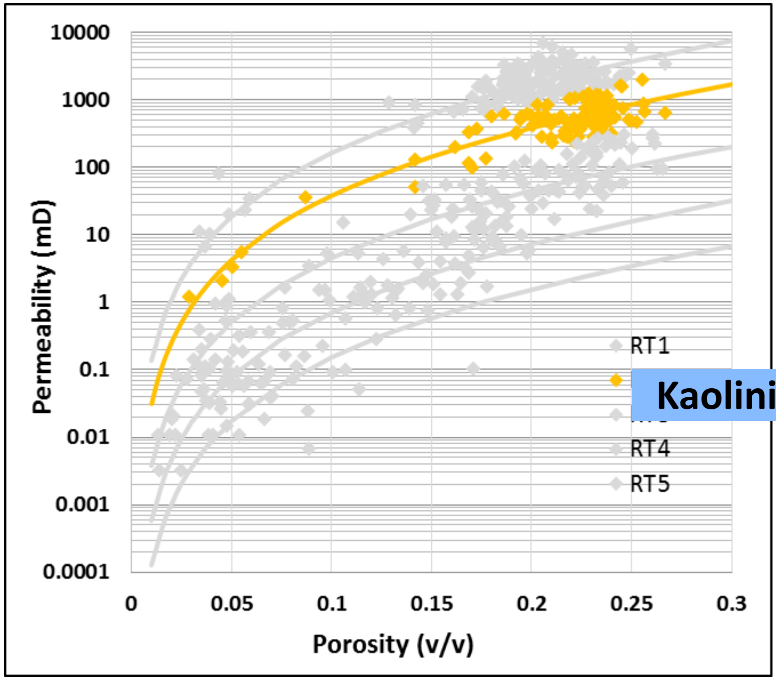
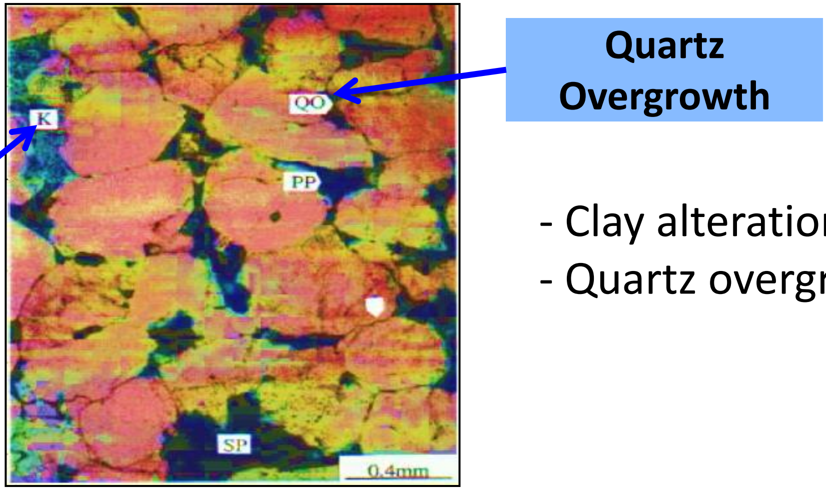
Rocktype and Petrophysical Properties





- Clay alteration
- Quartz overgrowth

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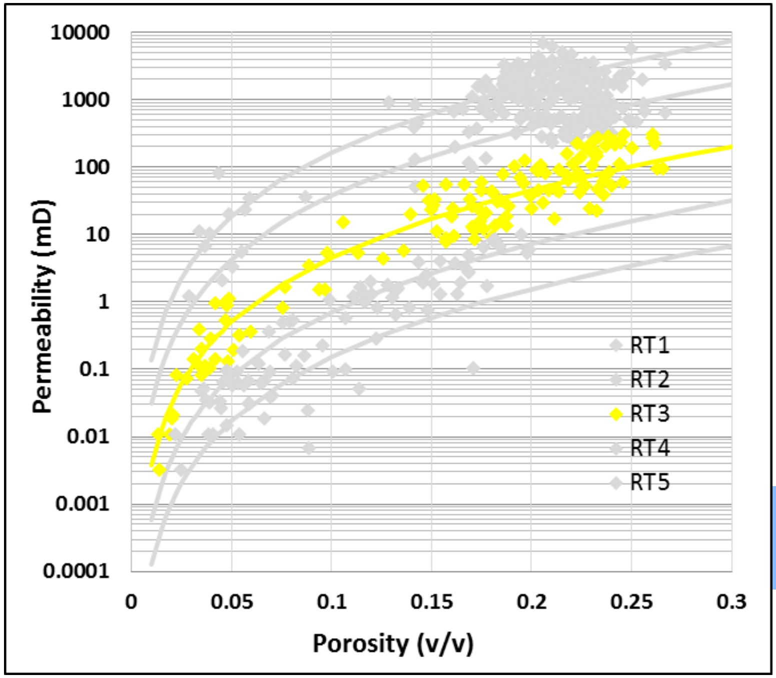
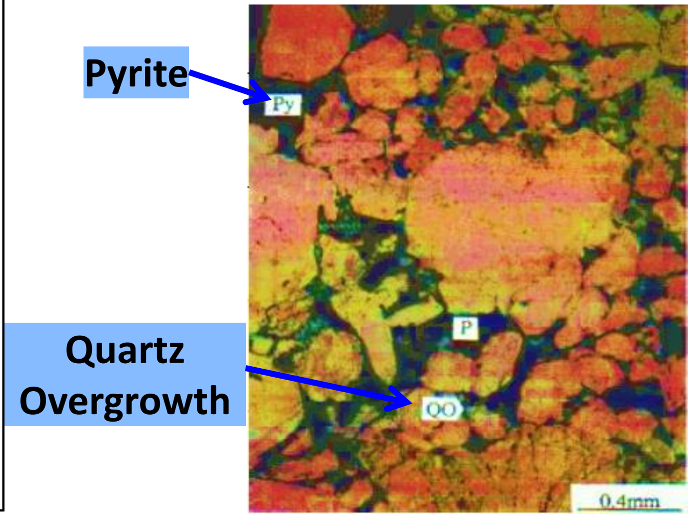
Rocktype and Petrophysical Properties





-Poor sorting
-High cementation

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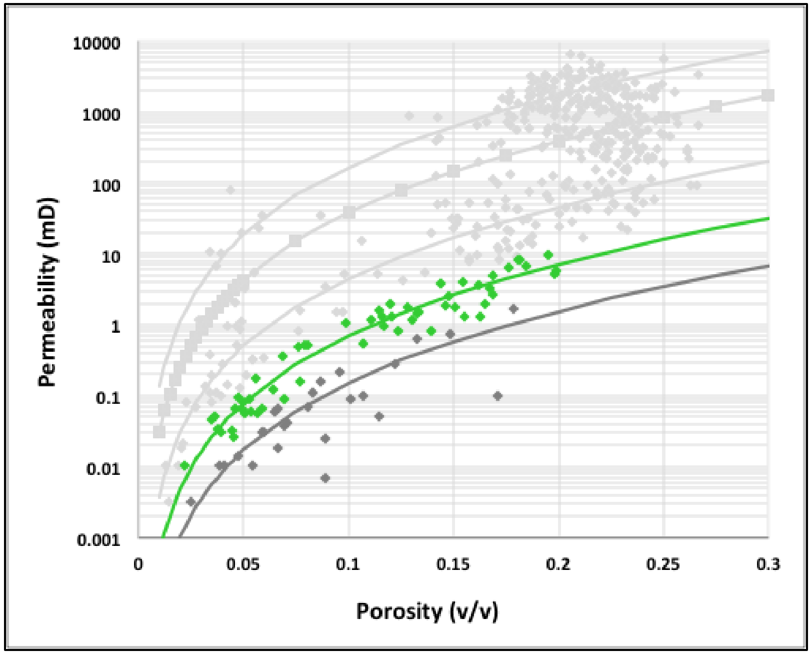
Rocktype and Petrophysical Properties



- Very fine grained sandstone and siltstone
- Contain high amount of clay minerals

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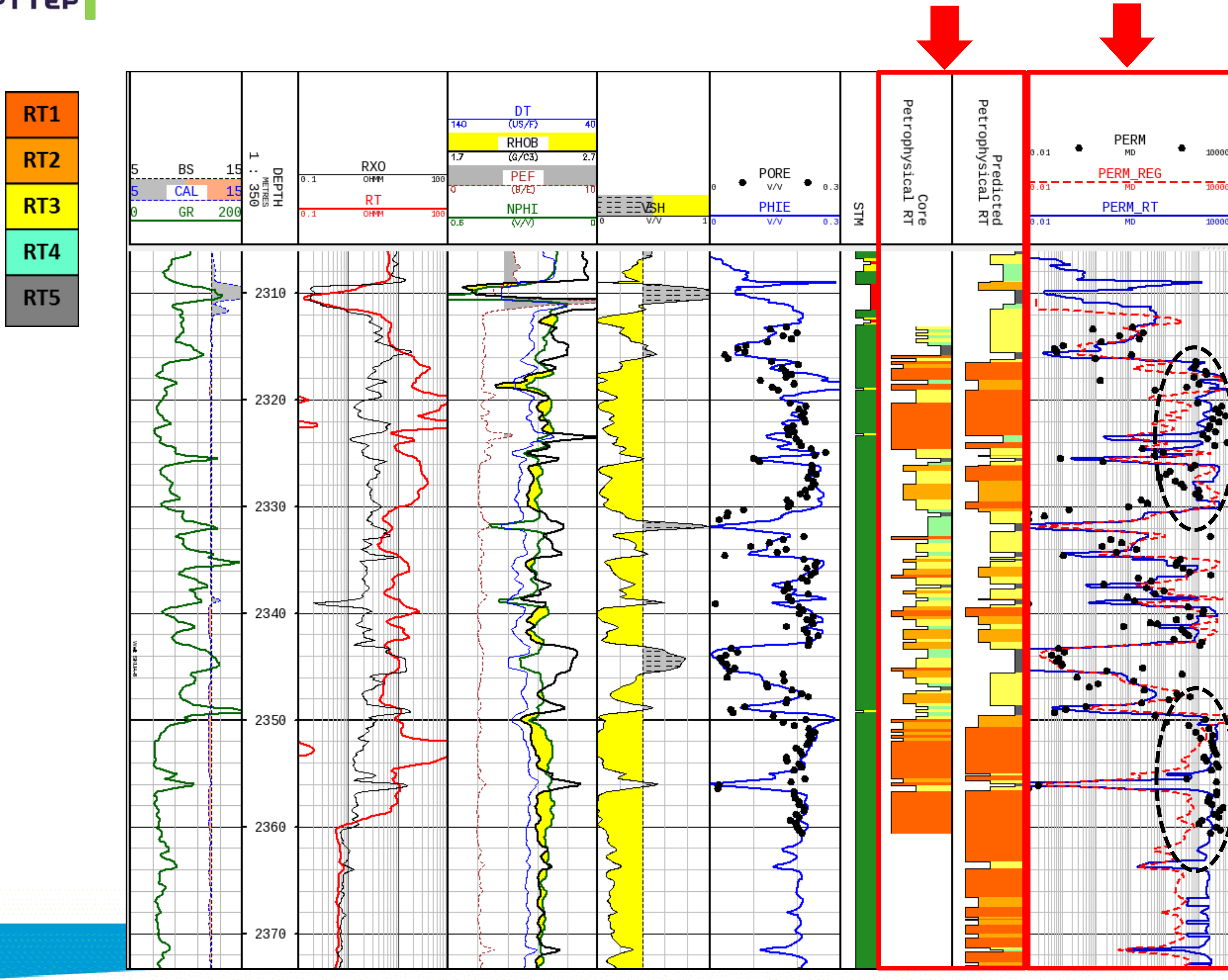
Rocktype Prediction and Permeability Estimation



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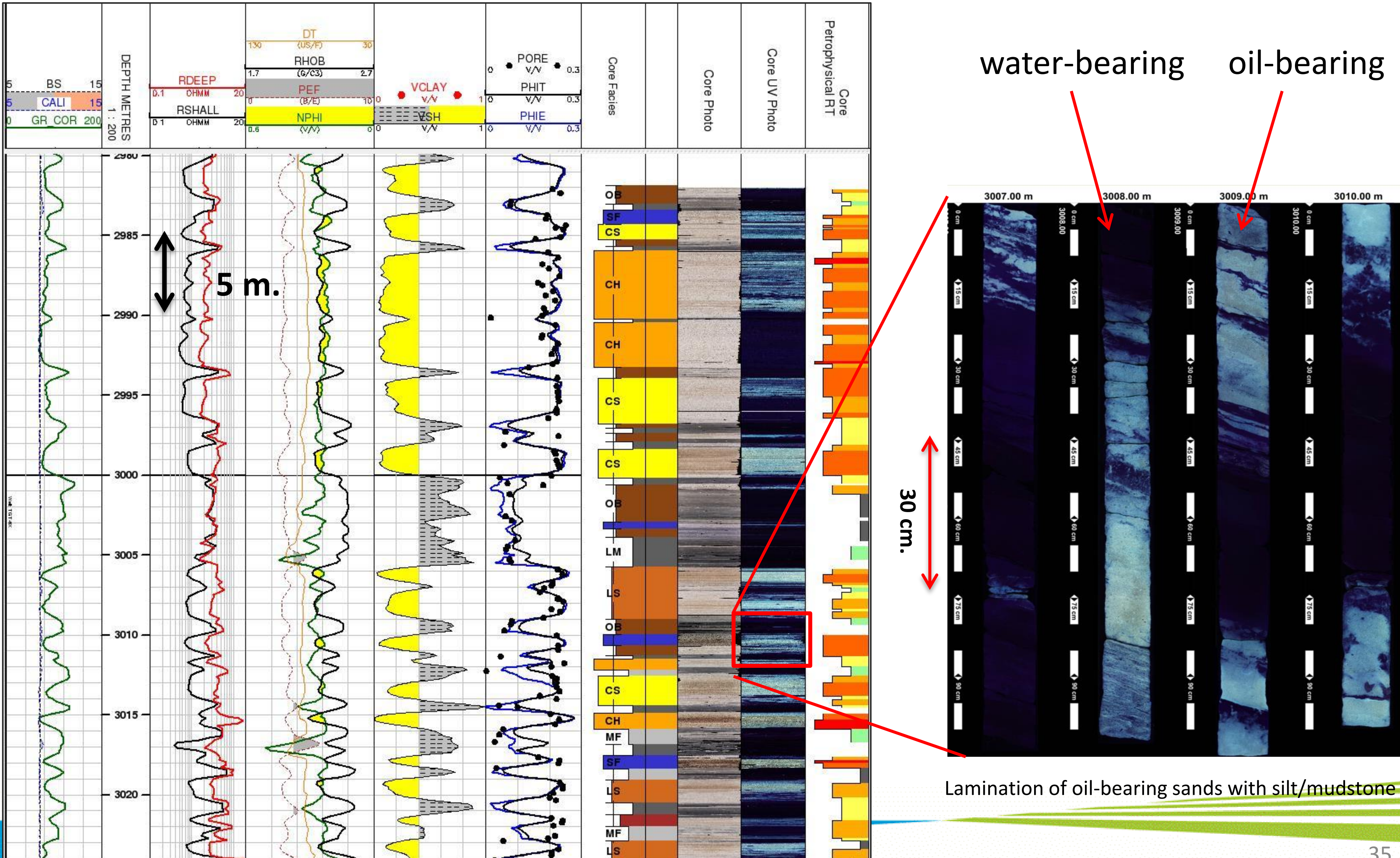
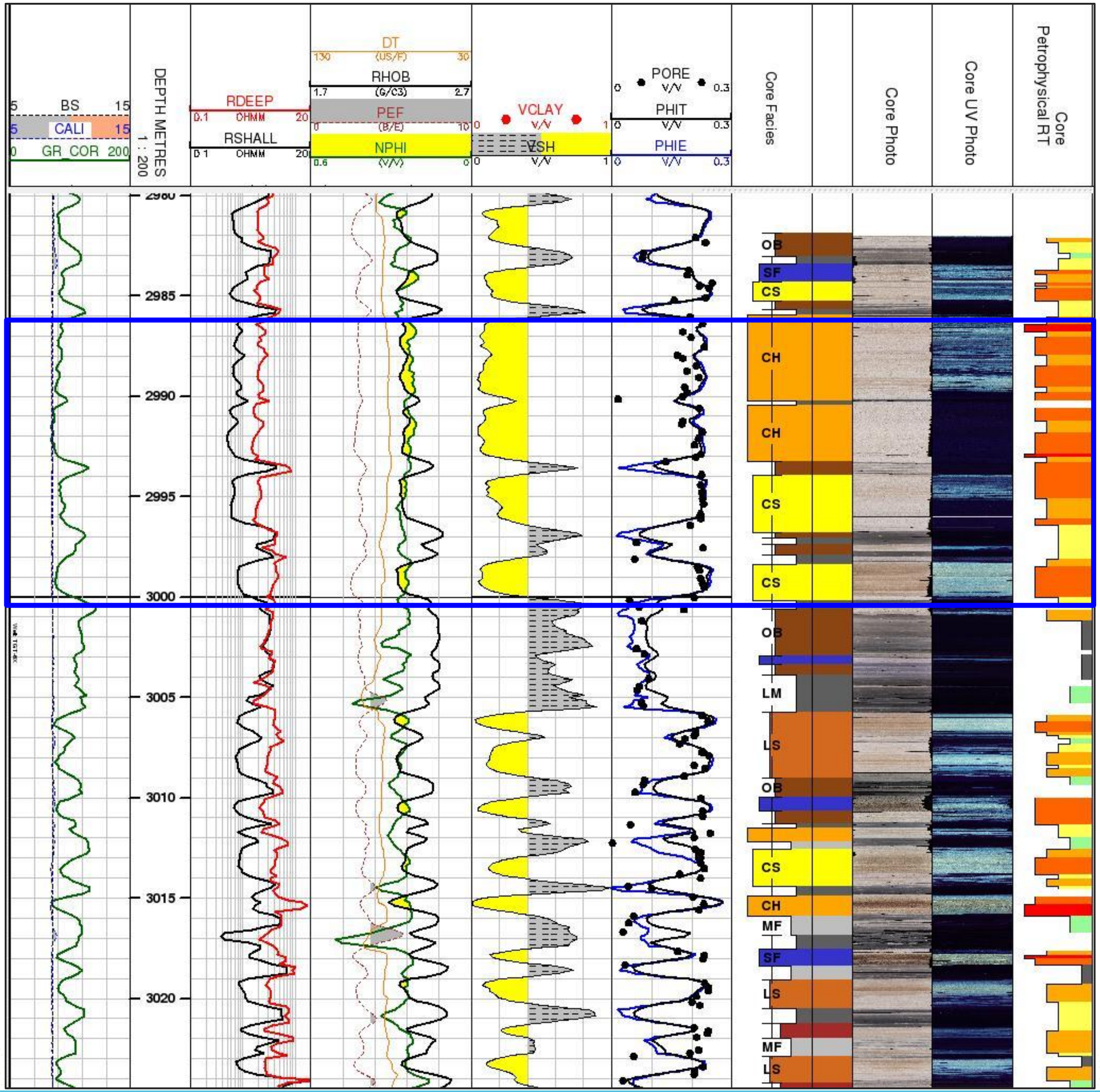
Field B: Thin Laminated Sandstone

Sands shale lamination deposited Miocene fluvio-lacustrine environment



Lamination of oil-bearing sands with silt/mudstone

Facies Description vs. Rocktype



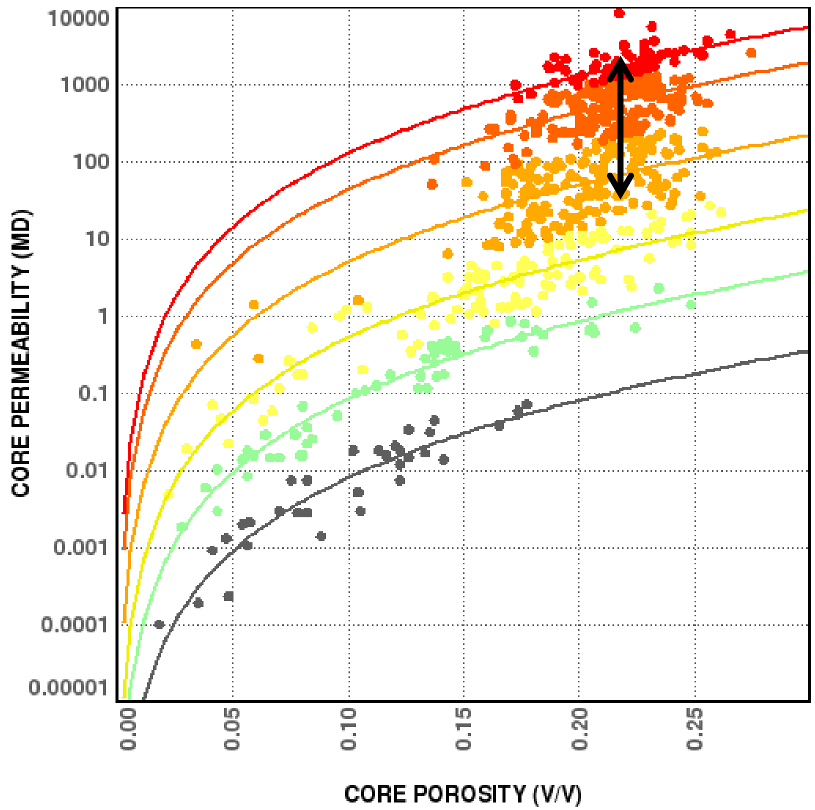
Rocktype

- RT1
- RT2
- RT3
- RT4
- RT5
- RT6

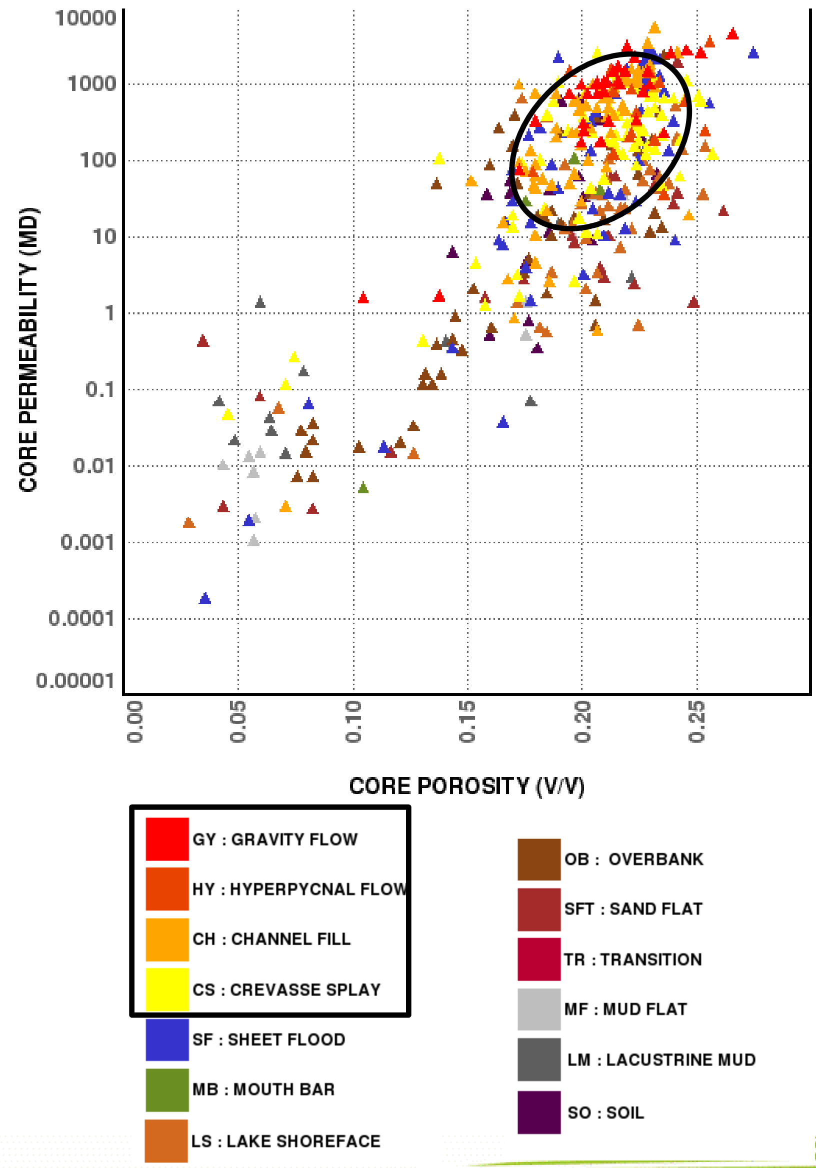
Facies

- GY : GRAVITY FLOW
- HY : HYPERPYCNAL FLOW
- CH : CHANNEL FILL
- CS : CREVASSE SPLAY
- SF : SHEET FLOOD
- MB : MOUTH BAR
- LS : LAKE SHOREFACE
- OB : OVERBANK
- SFT : SAND FLAT
- TR : TRANSITION
- MF : MUD FLAT
- LM : LACUSTRINE MUD
- SO : SOIL

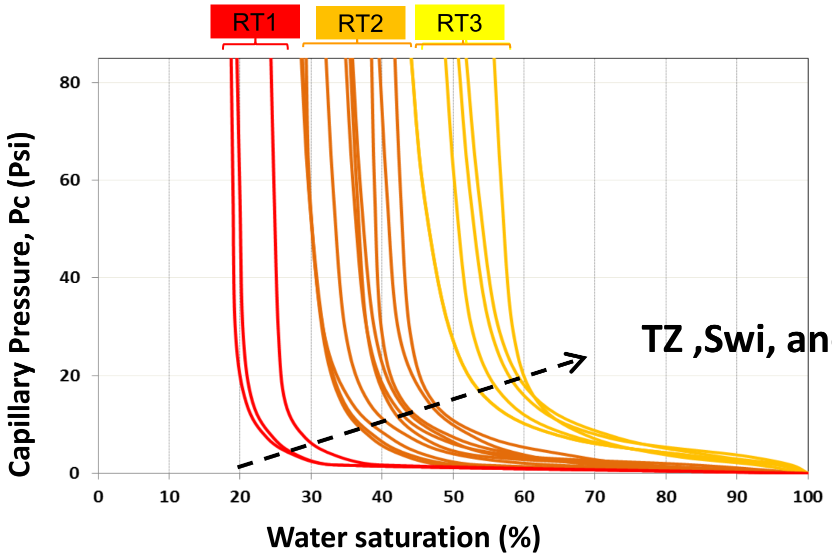
Rocktype vs. Depositional Facies

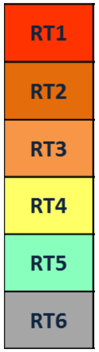


RT	FZI Value	Mean FZI	Reservoir Quality
RT1	>8.5	10.1	Extremely Good
RT2	1.0 < FZI ≤ 3.5	5.9	Good
RT3	0.35 < FZI ≤ 1.0	2.0	Medium
RT4	0.15 < FZI ≤ 0.35	0.65	Poor
RT5	0.15 < FZI ≤ 0.35	0.26	Non-Reservoir
RT6	≤ 0.15	0.08	Non-Reservoir

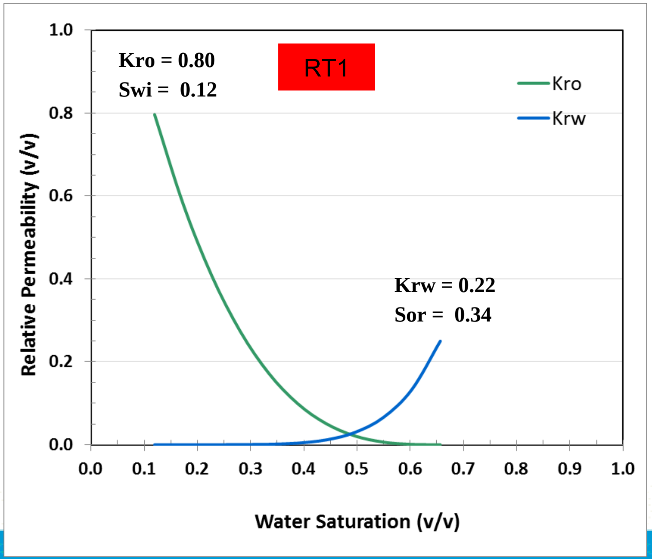


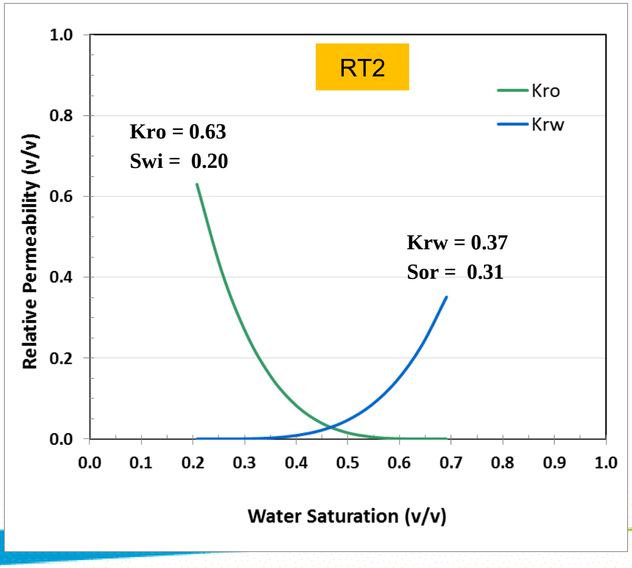
Capillary Pressure and Relative Permeability

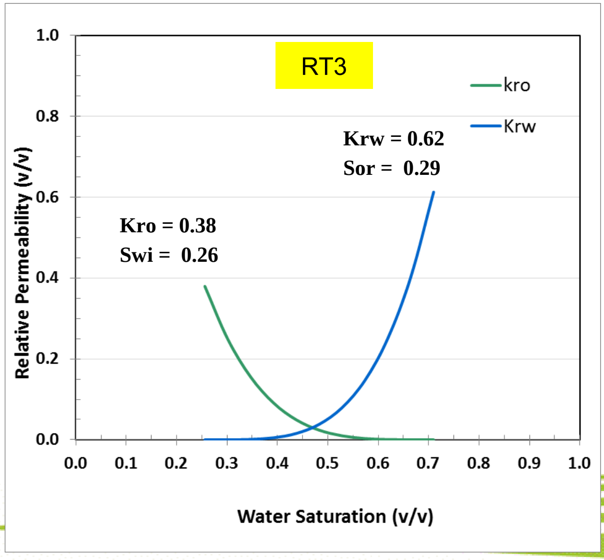




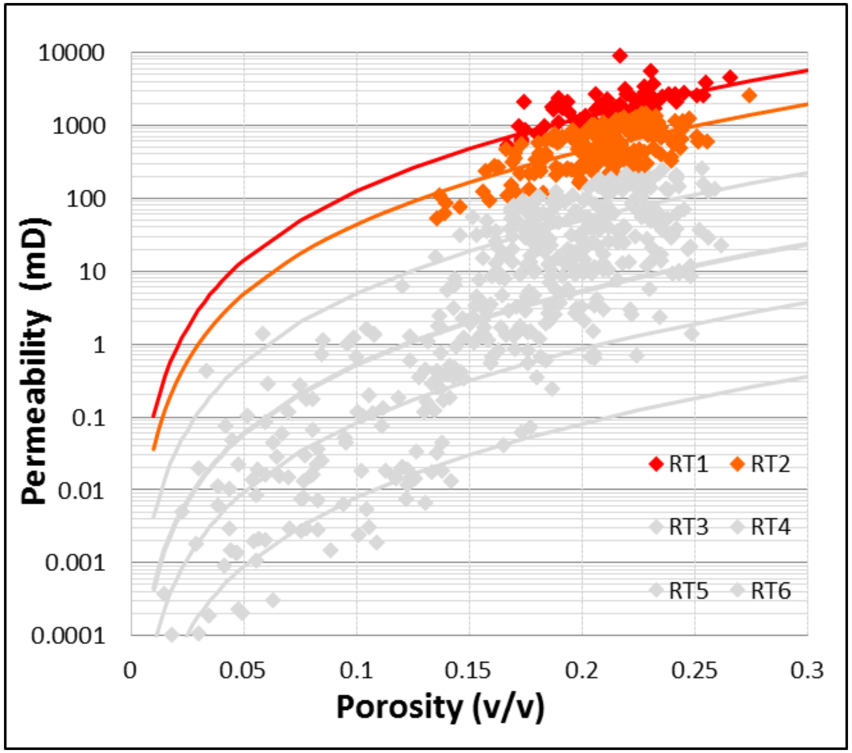
Krw ↑, Kro ↓



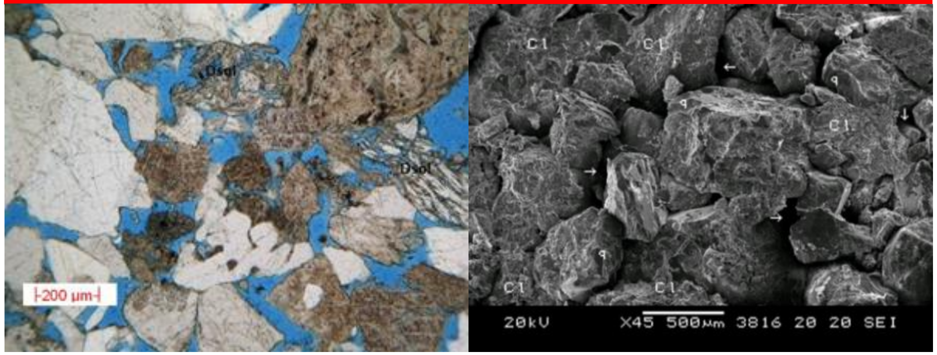




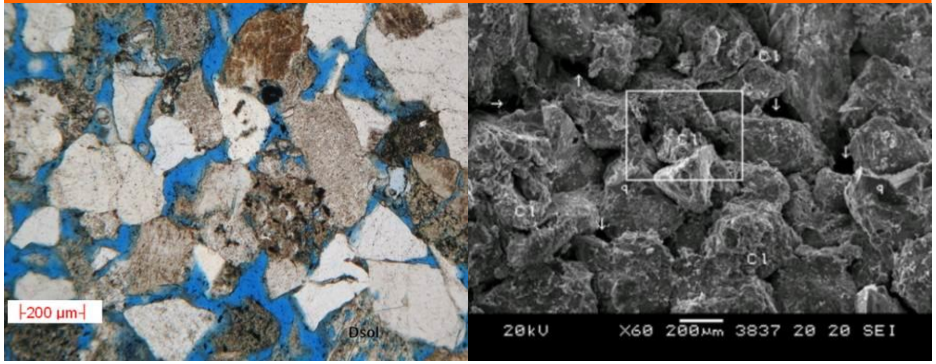
Rocktype and Petrophysical Properties



Rock Type 1: Ø = 21.5 %, K=1750 mD

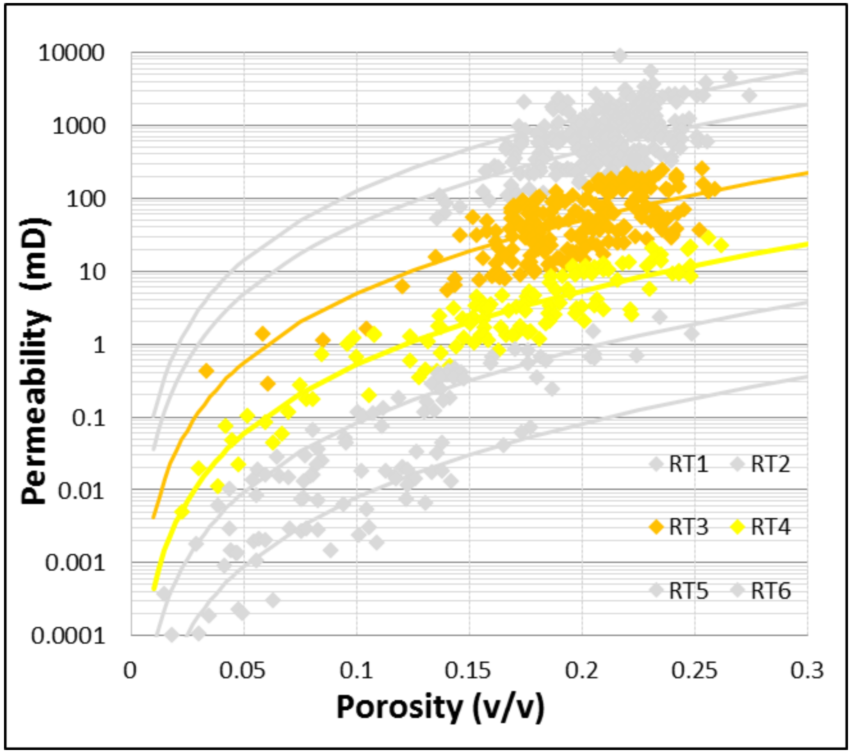


Rock Type 2: Ø = 21.5 %, K= 963 mD

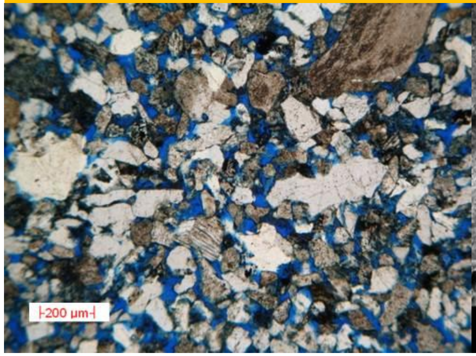


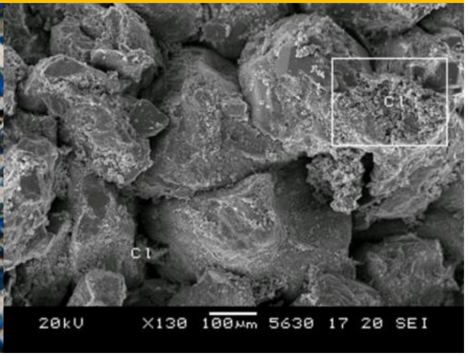
- Coarse to very coarse grained
- Low clay content
- Grain dissolution

Rocktype and Petrophysical Properties

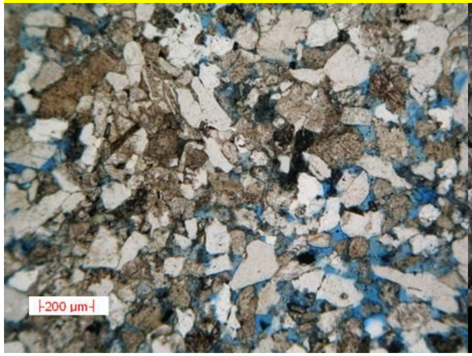


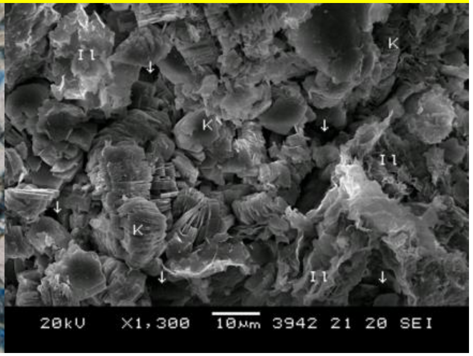
Rock Type 3: Ø = 20.0 %, K= 98 mD





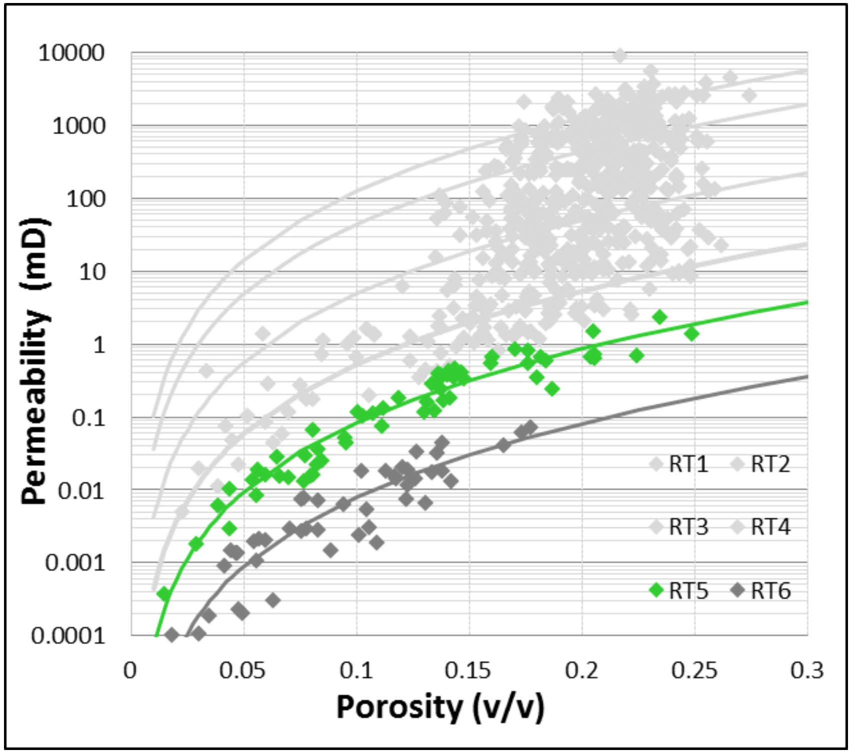
Rock Type 4: Ø = 17.0 %, K= 2.8 mD





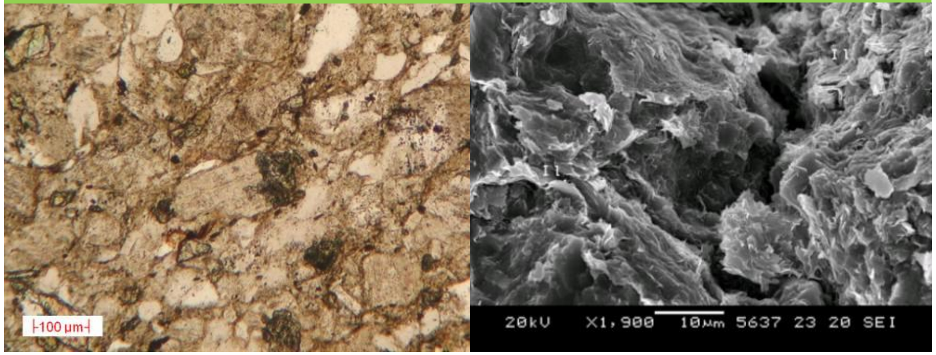
- Medium to fine grained
- Moderate clay content
- Poorer sorting

Rocktype and Petrophysical Properties

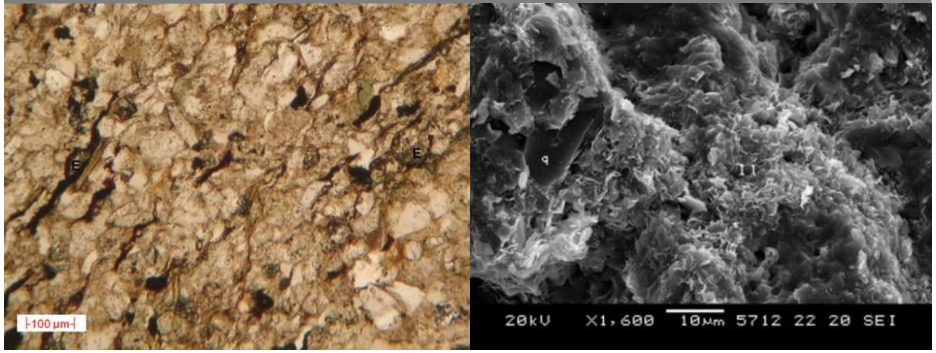


- Very fine grained sandstone
- Siltstone and mudstone
- High clay content

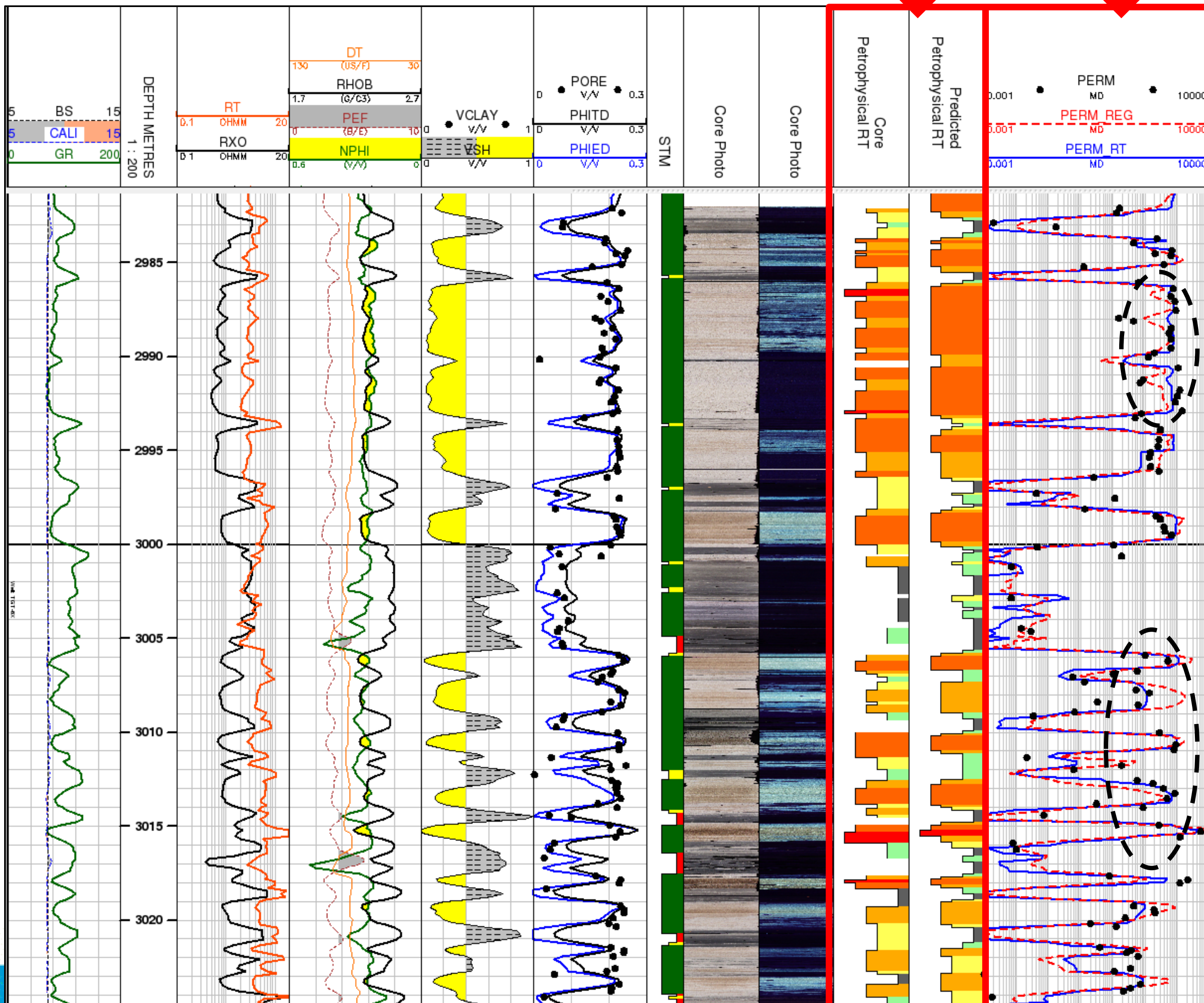
Rock Type 5: Ø = 13.8%, K= 0.2 mD

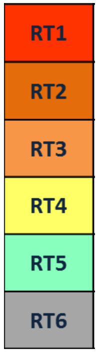


Rock Type 6: Ø = 7 % K= 0.002 mD



Rocktype Prediction and Permeability Estimation





Outlines

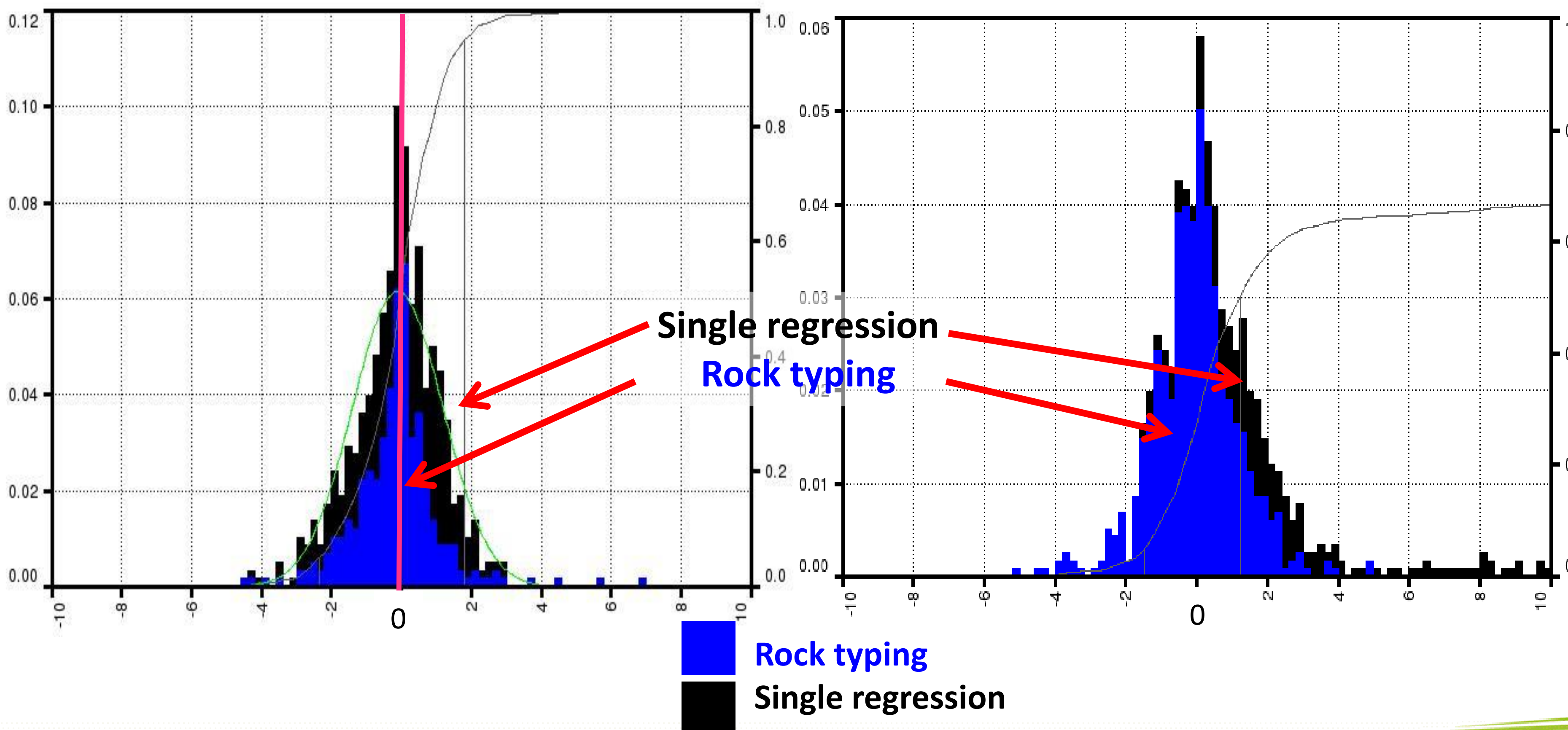
- Introduction
- Core-log Integration for Rock Type Prediction and Permeability Estimation
- Case Study
  - Field A: Diagenesis Sandstone
  - Field B: Thin Laminated Sandstone
- **Observations**
- Conclusions

Predicted Permeability vs. Core Permeability

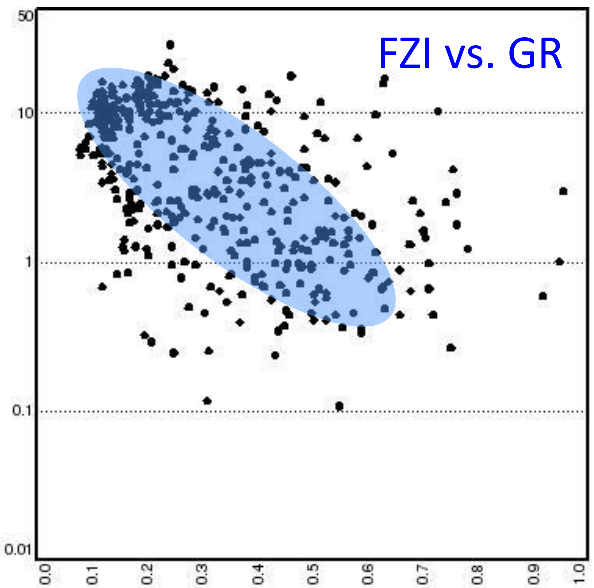
Distribution of the Log10 (Kcore/Kpred)

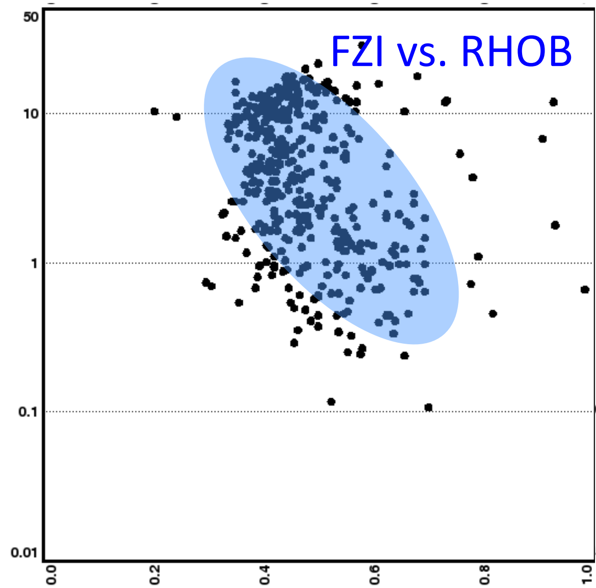
Field A: Diagenesis Sand

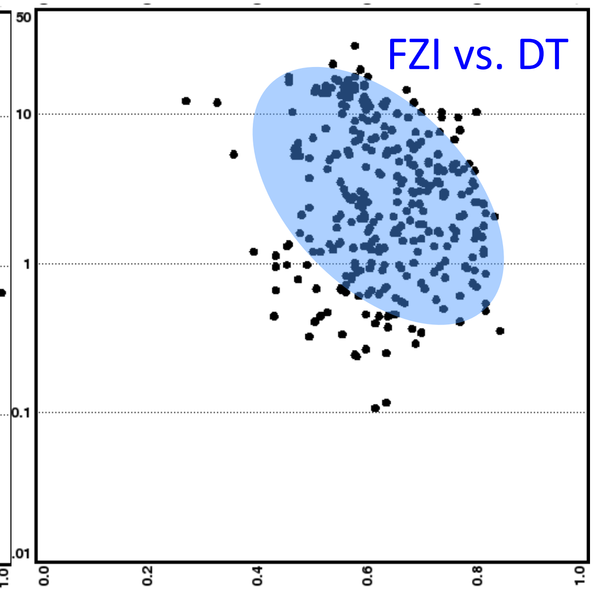
Field B: Thin Laminated Sand

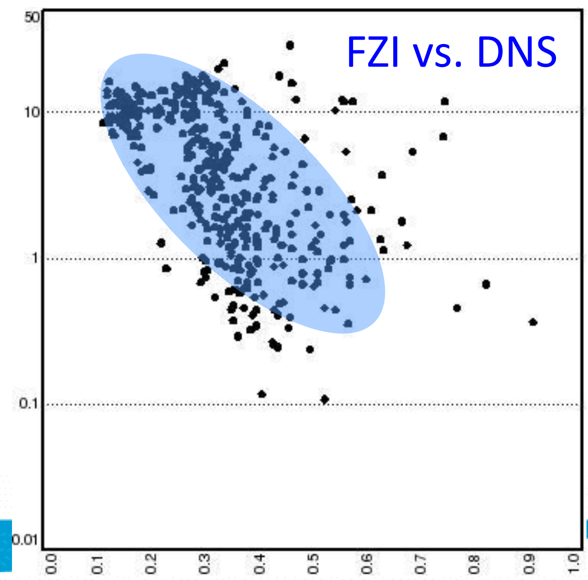


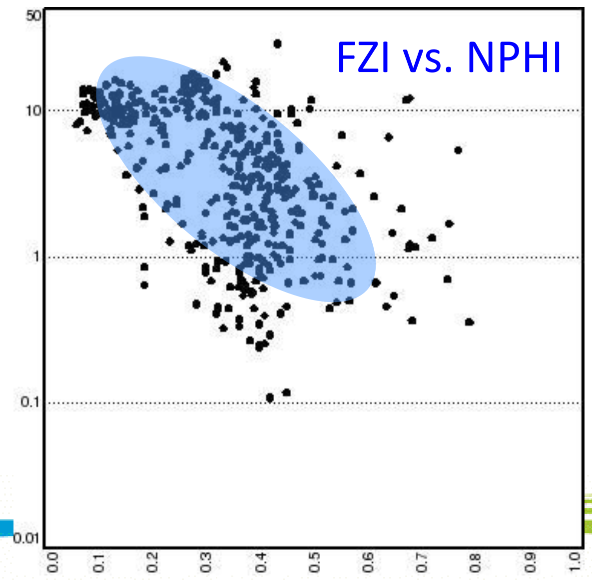
Field A Diagenesis Sandstone: FZI vs. Logs



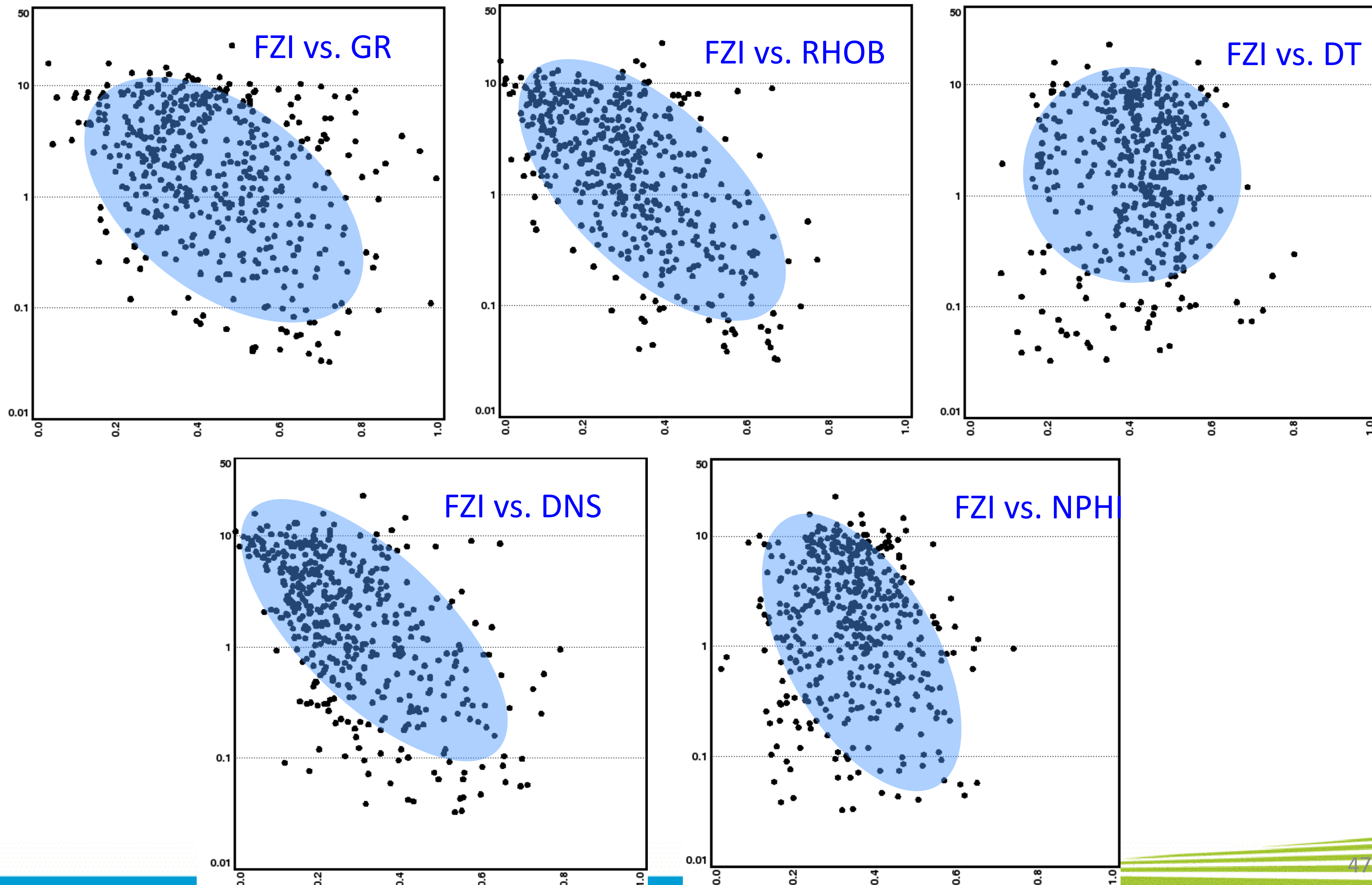




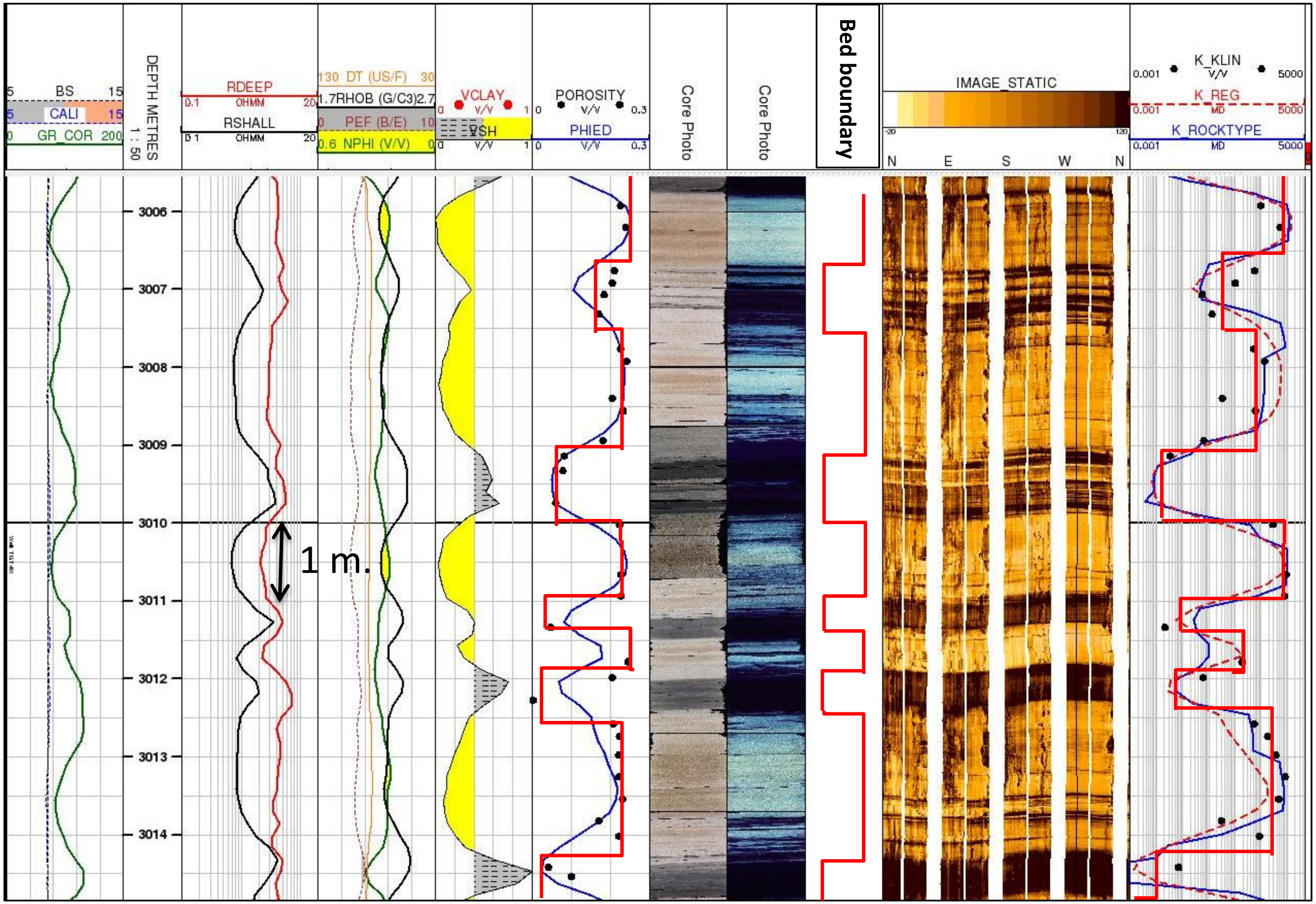




Field B Thin Laminated Sands: FZI vs. Logs



Potential Improvement



- Define the bed boundary from Borehole resistivity image
- De-convolution to solve for true formation properties
- Improve rock type and K prediction

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- **Introduction**
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Conclusions

- The rock typing using FZI/RQI approached provides an understanding of factors that controlled reservoir quality and fluid flow characteristics
- Rock type prediction gives a good result, especially where log data have a strong correlation with the FZI
- Predicted rock type becomes less accurate when bed thickness is less than well log resolution, and miss-matching occurs at the shoulder bed boundaries
- Field A (Diagenesis sandstone) shows good enhancement in permeability estimation. Field B (Thin Laminated Sandstone) shows slightly improvement. This is due to the conventional logs do not have a vertical resolution to give true formation properties
- Appropriated set of reservoir properties (K, Kr, Pc and Swi) are defined. Improved reservoir simulation studies for performance prediction and future field development decisions

However…

FZI doesn't always have a direct relationship to "Facies"

"Facies and Depositional" models are a major tool geologists use to describe what is happening between the wells

Petrophysicist need to find the relationship between the "Facies" and "Well Log" So the petrophysical properties are well described

Acknowledgements

- PTT Exploration and Production
- Petrophysics Section, Geology Department
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THANK YOU