Rock Typing and Characterization of Carbonate Reservoirs: A Case Study from South East Kuwait*

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Abstract

Reservoir rock typing (RRT) is a process of up-scaling detailed geological and petrophysical information to provide more accurate input for 3D geological and flow simulation models. The reservoir rocks that correspond to a particular rock type should have similar rock fabric, pore types, and pore throat size distribution. The study integrated multi-scale data types to develop a robust and predictable rock type scheme. This consists of detailed sedimentological description of depositional environment and associated sedimentary features, detailed numerical petrographic analysis of rock texture, grain types, porosity types, and rock mineralogy and petrophysical data grouping using open hole log and core plugs porosity-permeability relationship and pore throat size distribution (MICP).

The main objective was to develop a reliable reservoir rock type scheme that captures the heterogeneity in Jurassic carbonate reservoir for the Middle Marrat Formation in South East Kuwait area and implementation of the RRT to the permeability prediction within the field. Integration of the thin sections, porosity-permeability, pore throat size and distribution has resulted in the identification of reservoir rock types. A total of 14 different rock types were identified within the reservoir interval in the cored wells, which is subsequently grouped into eight due to modelling limitation. The RRT up-scaling was done in a way to minimize the impact of grouping on permeability and saturation computations. The prediction success between the cored RRT and the predicted RRT using open hole data is more than 85%. As a result, the permeability computation success between core plugs and computed permeability using the RRT is more than 80%.

Discussion

This paper summarizes the findings and workflow involved in the static Reservoir Rock Typing (RRT) in the Lower Jurassic. The objective of the study is to predict RRT at wells scale, which subsequently will be used in the South East Kuwait area for full field RRT prediction and modelling.

Most of the carbonate reservoirs in the Arabian Gulf are characterized by complex textural heterogeneity that corresponds to extreme permeability variation which is the controlling factor in reservoir production. Therefore, the methodology implemented in this study describe a unique work flow that captures multiple scales of the grains, pores, and rock fabric/textural heterogeneity through integration of various data ranging from high resolution core measurements, high resolution and azimuthal borehole images, advance and conventional OH Logs data.

The key objectives of the study are to characterize the Middle Marrat carbonate reservoirs to develop a reservoir rock type (RRT) scheme that captures the heterogeneity in the reservoir and the changes in the water saturation and permeability properties within the field. This will ultimately improve geological model building, detailed characterization of reservoir properties which leads to accuracy of the well performance prediction by reservoir simulation and better well placement.

Methodology of RRT

Reservoir characterization is a key to the field development plan exercise, to minimize the uncertainties in the permeability and water saturation computation. The Reservoir Rock Typing (RRT) were used to achieve this by integration the core description, thin section, MICP, and open hole log data. The workflow used to establish a continuous RRT for this study were divided to five steps:

1. Core review
2. Thin section description
3. Geological facies - Candidate rock type (CRT)
4. Petrophysical grouping
5. Reservoir rock type (RRT)
6. Continuous RRT

1. Core Review

Three cored wells (XX-0201, XX-0210, and XX-0175) were reviewed. Areas of high-quality reservoir were identified as grainstones to packstones of shoal environment as previously described by Core Lab (Patrick Clews, 2007) in a brief report. New observations that were apparent are the presence of relatively lighter colored intervals that were identified by the Target Team as dolomitized intervals and the presences of a fault and some cemented fractures. There was a clear positive correlation between the dolomitized intervals and the oil stained intervals. Discussion with the Core Lab team supported with the combined staining solutions (Alizarin Red S + potassium ferry cyanide) that were applied to the core swiftly confirmed the dolomitized interval (Figure 1).

Furthermore, dolomitization is greater within *Thalassinodes* burrows compared to the non-burrowed intervals (Figure 1) reflecting a selective process that attacks first the more porous zones followed by less porous zones. Thin section has also supported this observation at the micron scale.

Based on the observed distribution of the dolomite zones and their replacive style (see section on petrographic analysis) it is tentatively interpreted to be the result of seepage-reflux dolomitization. A process of dolomitization downward and lateral displacement driven by denser fluid percolating through generally low energy sediments of wackestones and mudstones. Such a process when it takes place causes the partial and rarely complete replacement of the rock from limestone to dolomitic limestone or dolostone (dolomite). It has to be noted that Core Lab used the definition/classification scheme of Jones and Lucia (2003) where a rock with more than 80% dolomite is classified as dolostone otherwise it is limestone. This is the main reason dolomite is not clearly shown in the logs. However, the logs do show the dolomitized intervals in the lithologic accessories.

2. Thin Section Description

More than 300 thin sections were examined to understand the different rock types. An Excel spread sheet was specifically designed for the Middle Marrat Formation to capture numerically the different characteristics of each thin section (Figure 2). The description sheet is including the following different parameters:

1. Mineralogical components of each thin section petrographically based on visual estimation of the different mineral phases.
2. Classification of the carbonate texture based on the Dunham Classification into lime mudstone, wackestone, packstone, grainstone, floatstone, and rudstone.
3. Grouping and quantifying of grains systematically.
4. Identification of the different cement types e.g. fringing, sparite, syntaxial overgrowth etc.
5. Describing the different pore filling cements and whether they are primary or secondary.

3. Geological Facies - Candidate Rock Type (CRT)

Identification and classification of the CRT is based on three aspects:

- Depositional texture (descriptive).
- Grain size, sorting, effective pore type and diagenesis.
- Depositional environment (interpretive).

These CRT will be grouped and numbered to reflect their reservoir quality (Figure 3). Dolomite can be classified as an independent CRT if it has a major impact on reservoir characteristics. The numbering will be divided into two digits; the first digit reflects the rock type while the second digit (from 1 to 3) reflects reservoir quality. 3 is the highest reservoir quality while 1 is the lowest. If dolomite is given number 2 as a class, then 23 will be the highest in reservoir quality while 21 is the lowest in reservoir quality (Figure 3).

4. Petrophysical Grouping

Petrophysical grouping are units of rock with similar petrophysical correlations and common porosity and permeability bins in the domains. These can be classified by conventional core plug analysis and Mercury Injection Capillary Pressure (MICP).

The first attempt in this study was to apply porosity permeability ratio criteria from the routine core analysis to classify the reservoir rock type. Then these criteria were compared with visual porosity and rock fabric characterized from thin section analysis. MICP curves were analyzed to confirm validity of the reservoir rock type classification.

The petrophysical grouping is classified for a similar pore throat, similar capillary pressure, and one porosity-permeability trend (Figure 4).

5. Reservoir Rock Type (RRT)

Development of 3D model of Middle Marrat Formation will be carried out with the input data from the geological and petrophysical results. The results were applied to identify various reservoir rock types. A reservoir rock type is defined as an interval of rock with unique pore geometry, determined mineralogical composition, and is related to certain specific fluid-flow characteristics.

Candidate rock typing (CRT) classifications are purely geological grouping of reservoir rocks, which have similar texture, grain size, sorting etc. Each CRT indicates a certain depositional environment with a distribution trend and dimension. Petrophysical groups are classified by porosity, permeability, capillary pressure, and pore throat size distribution. A Rock Type (RRT) combines both these classifications by linking petrophysical properties and CRT as part of the reservoir rock type definition.

The different rock indicators will be computed for these plugs, which use the RRT classification and differentiation. Rock Quality Indicator (RQI) and Flow Zone Indicator (FZI) were computed for the MICP samples data. These indicators will be computed using the following equations:

$$RQI = 0.0314\sqrt{\frac{k}{\emptyset}} \qquad FZI = \frac{0.0314\sqrt{\frac{k}{\emptyset}}}{\left[\frac{\emptyset}{1-\emptyset}\right]}$$

Where, k is permeability in mD and $\emptyset$ is porosity in v/v .

Using the above workflow, fourteen RRT were identified for the Middle Marrat Formation in the South East Kuwait area based on the available data. Table 1 summaries the 14 RRTs for the Middle Marrat Formation. The RRT coding flow, the CRT scheme definition, the first digit from left represent the deposition environment, e.g. 3 for shoal and 2 for dolomite. The second digit represents the quality of the reservoir 1 is poor, 2 is intermediate, and 3 is good reservoir quality (high porosity and permeability). The letters in the RRT code represent the further sub-dividing the RRT base in the quality of the reservoir was a means higher reservoir quality than B.

The RRT scheme in the Middle Marrat Formation is based on the available data, some of the code numbers are not listed because the data do not suggest presents of these RRT. The scheme has the flexibility to add in the future if more data were acquired and suggests the presents of these RRT's. For example, RRT 23 is not present in the current scheme because the dolomite data do not show high permeability similar to what has been seen in the shoal RRT.

6. Continuous RRT over Core Interval

Once the RRT scheme was define using the MICP and thin section data, the other core data like core description, texture, depositional environment, thin section analysis, porosity, permeability, Flow Zone Indicator (FZI), and Reservoir Quality Indicator (RQI) were used to generate continuous RRT (from the discrete RRT). Table 2 list the criteria used to predict the continuous RRT for the cored intervals. Figure 5 shows the schematic diagram illustrating the methodology used to predict the continuous RRT. Figure 6 shows examples of Continuous RRT in cored wells.

The 14 RRTs were lumped to 8 RRTs, to be used for modeling purposes. The lumping processes developed to minimize the impact of the lumping to the permeability computation especially the high permeability values. Figure 7 shows the RRT before and after lumping.

RRT Prediction

1. RRT Prediction over Core Interval

The approach aims towards finding a relationship between RRT logs derived from core and log data and geological/seismic properties to generate full field continuous RRT models that can be used to predict RRT in undrilled locations and predicting blind wells. This approach uses a unique technology that integrates all data using artificial intelligence where a neural network is trained and tested using existing data. Multiple realizations are created, analyzed, and validated through blind well testing. The resulting RRT models can be used to constrain permeability models.

The RRT prediction approach honors all type of data and various scales to better integrate and extend the well-related observation across the field. The methodology can provide reasonable results through this technology on predicting RRT at the well scale. Three methods tried for the RRT prediction:

1. 1.Multi-linear Regression and Sequence Stratigraphy.
2. 2.Single-Multi Wells Neural Network Prediction.
3. 3.3D Fuzzy Neural Network Prediction.

The final RRT prediction is done using multi-linear regression and sequence stratigraphy.

The open hole (OH) logs raw and interpreted data were used to duplicate the cored continuous RRT. The objective of this process is to train, test, and validate a methodology to duplicate the RRT over the cored interval and implement the same process for the uncored interval to predicate the same RRT. The different open hole data (raw and interpreted) were crossploted to see the consistence of the data across the entire studied zone laterally and vertically, and if there is any relationship between the RRT, open hole logs, and or different reservoir layers. The sequence stratigraphy was used, as well, to constrain some high or low permeability values.

The continuous RRT was computed using the following conditions:

- Normalized logs were used to have consistence data across the entry reservoir, and to minimize the uncertainties of the RRT prediction.
- Shoal RRT assumed to be in certain geological unit, as seen from the core data and the sequence stratigraphy.
- RRT 31 has porosity < 12%, and RRT32 ≥ 12%, see Figure 8.
- Sequence stratigraphy used to separate between the RRT33 and RRT32. RRT33 is representing the high permeability streaks, which mostly occurred below or above the tight streaks in MM420 and MM450.
- It can be differentiated between RRT 2 and RRT 5 by applied porosity cut off.
- RRT 5 has porosity ≤ 15%, and RRT 2 > 15%, see Figure 9.
- Since supratidal and lagoon RRTs have almost same OH logs response and the supratidal RRT is non-reservoir rock, the RRT 61 was lumped to be part of RRT5. Supratidal RRT only seen in XX-0201 and XX-0210, see Figure 10.
- The shale RRT (11B) computed using the volume of clay curve with cut off 25% (VCL ≤ 25%).
- The anhydrite RRT (11C) computed using the volume of anhydrite curve (VANHY=100%).

Figure 11 shows example results using the above methodology to compute the continuous RRT and the comparison with the continuous RRT in the cored wells.

2. RRT Prediction over Uncored Interval

The continuous OH RRT methodology was implemented in the uncored wells for the Middle Marrat Formation. The results seem to be good, where XX-0126 is not a cored well, the production behavior support the permeability trends computed from the RRT, where the high production is associated with the high permeability streaks, see Figure 12.

Permeability Computation

Once the continuous RRT are defined over the cored interval an attempt will be made to predicate the permeability using these RRTs. Different approaches will be used to assess the best way to compute the permeability, e.g. FZI permeability, RQI permeability, simple line trend between porosity and permeability, Lucia Permeability method. If these methods fail to predict the permeability, the neural network method will be used to predict the core permeability. In the below example the FZI permeability found to be the best way to compute the permeability for the different RRT, where the average FZI value from the different RRT were used to re-compute the permeability.

Figure 13 shows the cross-plot of the core porosity versus core permeability against the computed permeability using the FZI equation. Figure 14 shows the core permeability against the computed permeability using the Coates equation (standard permeability equation with no RRT input) for the different RRTs. Using the FZI computed permeability for the different RRT, honors the core permeability better than Coates equation and reduces the uncertainties in the permeability computation especially in the high permeability values where the Coates permeability underestimate these permeabilities. These high permeabilities in the reservoir may have large impact to the production or injection during the water flooding processes. Figure 15 shows example of the continuous RRT with permeability computation using the RRT and Coates equation. The computed RRT permeability honors the high permeability better than the Coates equation.

Conclusions

- Dolomitization observing in the reservoir is more than what initially assumed.
- Dolomitization is enhancing lagoon reservoir quality due to an increase in porosity and permeability.
- Baffles are observed in the shoal in form of hard ground/cementation.
- Good match is observed between core and OH log RRT (more than 85% prediction success rate.
- Most of the high permeability streaks were captured by OH log RRT.
- OH log Permeability have more than 80% prediction success.
- High permeability streaks are in Shoal and associated with dissolution (secondary porosity) and rock texture.
- The OH log RRT approach is simple and robust which can be reproducible in future wells.

Reference Cited

Jones, R., and Lucia, F.J., 2003, Better Than a Porosity Cutoff: The Rock Fabric Approach to Understanding Porosity and Permeability in the Lower Clear Fork and Wichita, Fullerton field (abs.), *in* New Methods for Locating and Recovering Remaining Hydrocarbons in the Permian Basin: The University of Texas at Austin, Bureau of Economic Geology, Petroleum Technology Transfer Council and University Lands West Texas Operations, p. 10.

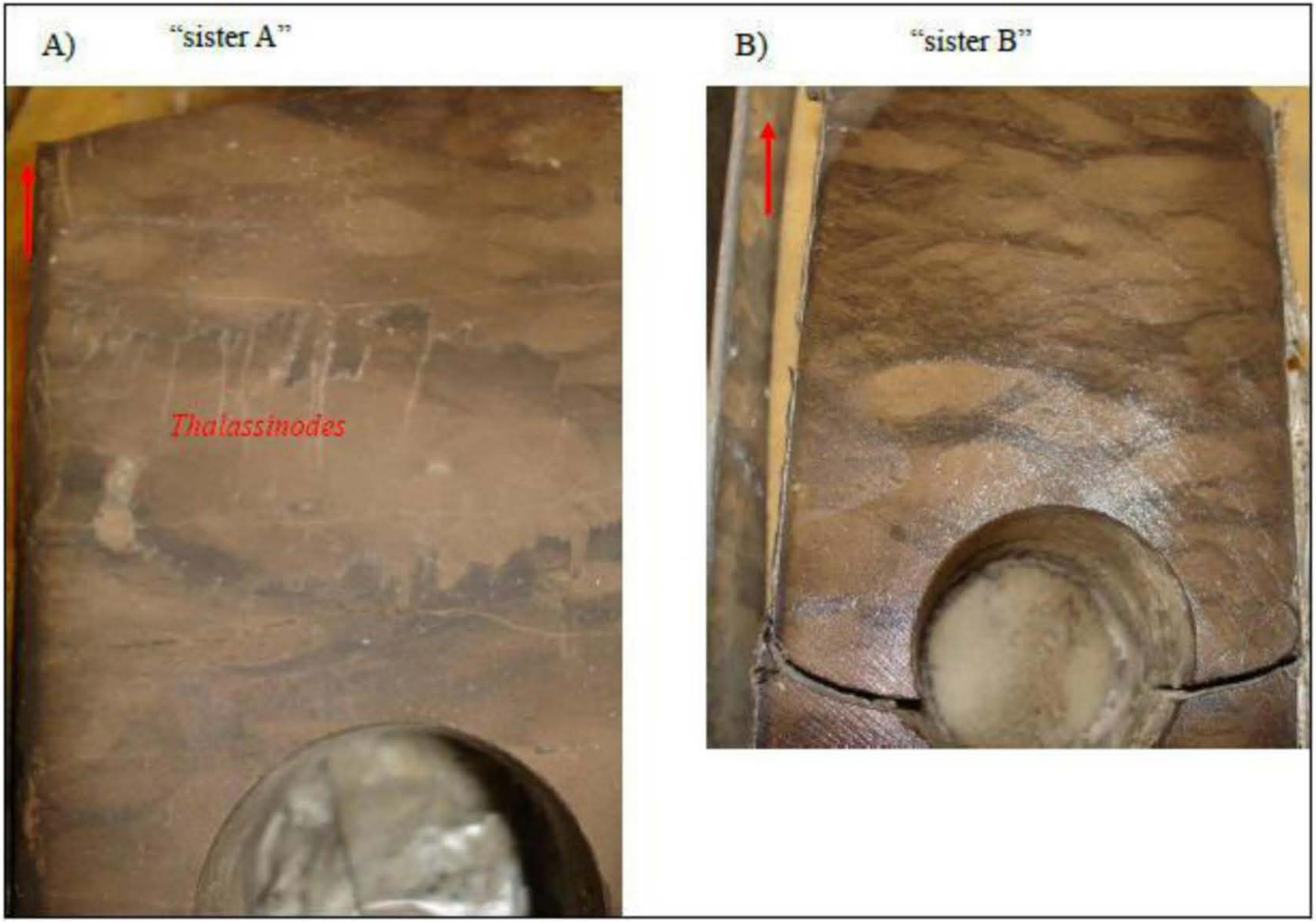


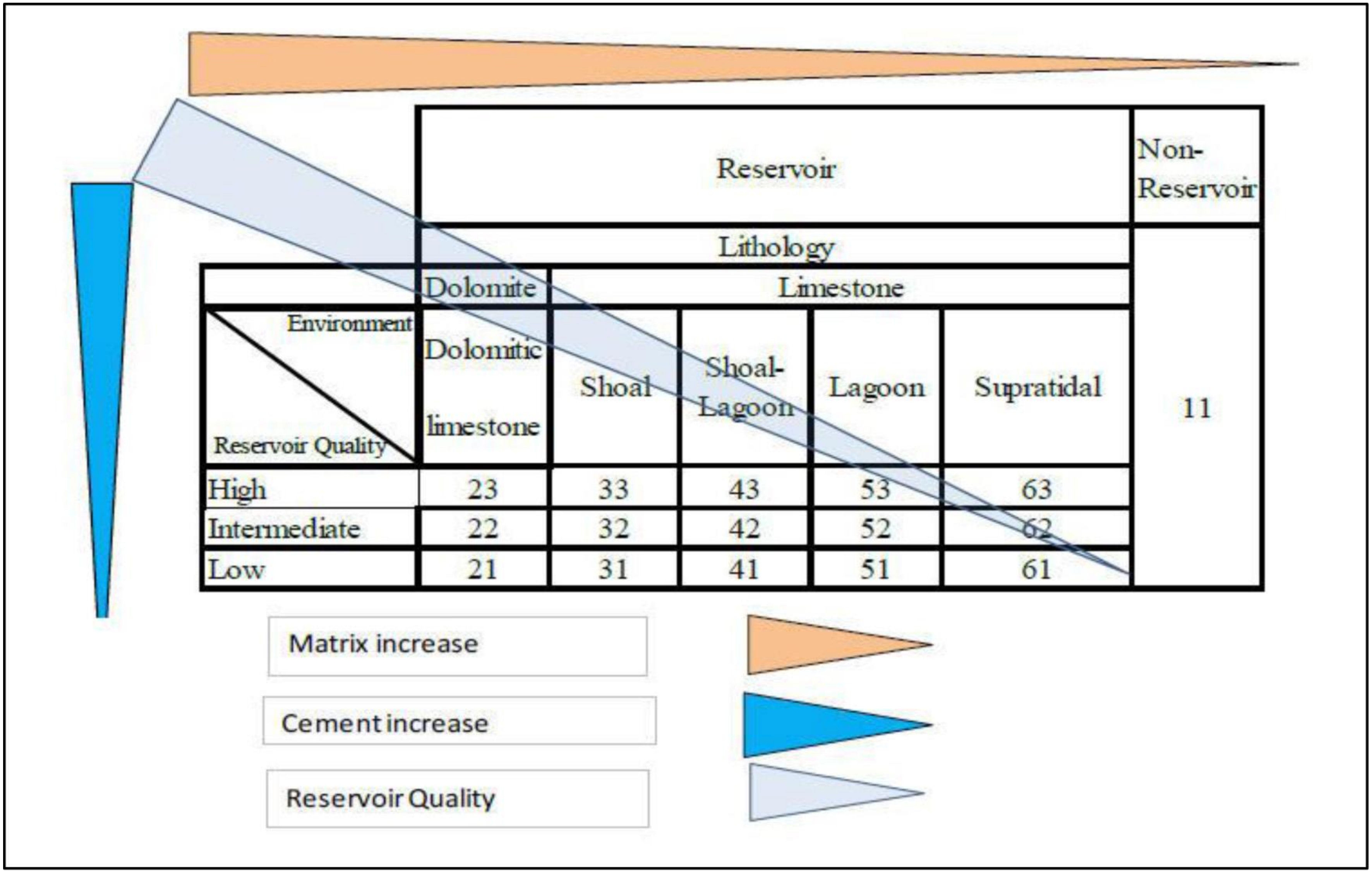
Figure 1. Core photographs of XX-0210 showing the lighter color zones that are selectively dolomitized. There are three intervals in the upper part of XX-0210 that are dolomitized and are known as sisters A, B, and C (not shown). Note that dolomitization is greater within *Thalassinodes* burrows because of their high porosity. Red arrows point towards the top of the core. A) Dolomitized *Thalassinodes* burrows from "Sister A" at depth XX479 ft. B) Dolomitized *Thalassinodes* burrows from "Sister B" at depth XX485 ft.

	LITHOLOGY (%)				ONLY GRS & PKS		TEXTURE						SKELETAL GRAIN									NON-SKELETAL GRAIN								Cement					
Core Depth (ft)	LIMESTONE	DOLOMITE	ANHYDRITE	SILICA	GRAIN SIZE	SORTING	Rudstone	Floatstone	GRAINSTONE	PACKSTONE	WACKESTONE	MUDSTONE	FORAM	ALGAE	Corals	Stromatoporids	Pelecypods	Echinoids	Sponge specules	Gastropods	Others	Peloids	Ooids	Intraclasts	Extraclasts	Oncoids	Blackened (pyritised) grai	Quartz	Compaction/Stylolites	Fringe cement (F=Fibrous	Microsparite	Sparite	Syntaxial overgrowths	Dolomite	Anhhydrite
30.25	20	70		10	3	3						3					1	1									1	3						2	
31.35	10	80		10	3	3						3					1	1									2	2							
34.25		80		20	3	3						3					1	1			1						2	2						1	
35.25		90		10	3	2					1	3					1	1			1						2	2						1	
36.25		90		10	3	3						3					1										2	2						1	
37.15		80		20	3	2					1	3					1	1				2					1	2	2						
38.25	90		10		4	1					3						2	2		1							2		1			2	1		1
39.2	90		10		4	1					3						2	1		1		1					2					2	1		1
40.15	90				3	1				1	3						2	1		1				2			1		2			1			
41.2	90		10		4	2					3						2	1		1		1					1		2			2			2
42.25	90	10			5	1			1		3		1				2			1		1		1	1		1		1			2	1	1	
46.45	100				3	1					3						2			1		1					1		1			2	2		
50.3	90	10			6	1			3		2						3			2	1		2	1			1					1	2	1	
54.45	80	20			3	2					3	1					2	1			1	2					1	1	2					3	
58.3	70	30			1	3						3															2	1							
62.4	90			10	2	1				3	2		1				2	1				2	2						2			1		2	
66.3	100				3	1				3	1		2				1	1				3					1				2	2			

	DOLOMITIZATION												PORE SPACE																		
	DOLOMITE										CEMENT		Dolomite			PRIMARY POROSITY						SECONDARY POROSITY									
	%	SHAPE			SIZE																										
Core Depth (ft)	%	Anhedral	Subhedral	Euhedral	Crypto < 16 Micron	Micro < 64 Micron	V. Fine < 125 Micron	Fine < 250 Micron	Medium < 500 Micron	Coarse > 500 Micron	% in Primary Porosity	% in Secondary Porosity	INTERCRYSTALLINE	Totally Cemented (1to 3)	VUGS	BETWEEN GRAINS	Totally Cemented (1 to 3)	WITHIN GRAINS	Totally Cemented (1 to 3)	MATRIX I	TOTAL	MATRIX II	MOLD or Pinpoint	Totally Cemented (1 to 3)	VUGS	Totally Cemented (1 to 3)	WITHIN GRAINS	Totally Cemented (1 to 3)	FRACTURES	Totally Cemented (1 to 3)	TOTAL
30.25	70	3	1		3																0										0
31.35	60	3			3																0										0
34.25	60	3			3																0										0
35.25	70	3			3																0										0
36.25	70	3			3																0										0
37.15	80	3			3																0										0
38.25																					0								3		3
39.2																					0										0
40.15																					0								3		3
41.2																					0								3		3
42.25	10	1	2						1	3				2		2					2		1	1			1	2	3		5
46.45																					0								3		3
50.3	10	1	3					2	2			20			4						0								3		7
54.45	10	1	2	1			2	1													0										0
58.3	30	2	2		3	1															0										0
62.4																					0										0
66.3																					0										0

	ROCK PROPERTIES				
Core Depth (ft)	Fluid Porosity %	H. Permeability (md)	Depositional Code	Depositional Environment	CRRT NAME
30.25	1.4	0.21	2	Lagoon	M21
31.35	1.6	4.5	2	Lagoon	M21
34.25	1.6	58	2	Lagoon	M21
35.25	1.9	0.69	2	Lagoon	M21
36.25	1.5	0.58	2	Lagoon	M21
37.15	1.4	0.19	5	Lagoon	M21
38.25	0.8	0.76	5	Lagoon	W51
39.2	0.4	0.04	5	Lagoon	W51
40.15	1.3	0.09	5	Lagoon	W51
41.2	2.2	0.04	5	Lagoon	W51
42.25	6.1	0.09	5	Lagoon	W51
46.45	0.8	0.36	5	Lagoon	W51
50.3	0.9	0.05	5	Lagoon	G51
54.45	0.5	0.04	5	Lagoon	W51
58.3	0.03	2	2	Lagoon	M21
62.4	0.7	0.74	5	Lagoon	P51
66.3	0.7	0.05	5	Lagoon	P51

Figure 2. Example of a template to register numerical petrographical data which will be used later to group the different reservoir units to candidates rock types.



	Reservoir					Non-Reservoir
	Lithology					
	Dolomite	Limestone				
Environment / Reservoir Quality	Dolomitic limestone	Shoal	Shoal-Lagoon	Lagoon	Supratidal	11
High	23	33	43	53	63	
Intermediate	22	32	42	52	62	
Low	21	31	41	51	61	

Figure 3. The Candidate Rock Types (CRT) were divided broadly into two categories: reservoir and non-reservoir. The non-reservoir rocks have been assigned the number 11 and include tight limestone, anhydrite, and shale. The potential reservoir rocks were assigned number 2 to 6. The best quality rock type from each group was followed by number 3 (23, 33, 43, 53, 63) while the least in quality due to cementation was followed by number 1 (21, 31, 41, 51, 61). The quality of rock groups also decreases with increasing amount of mud matrix.

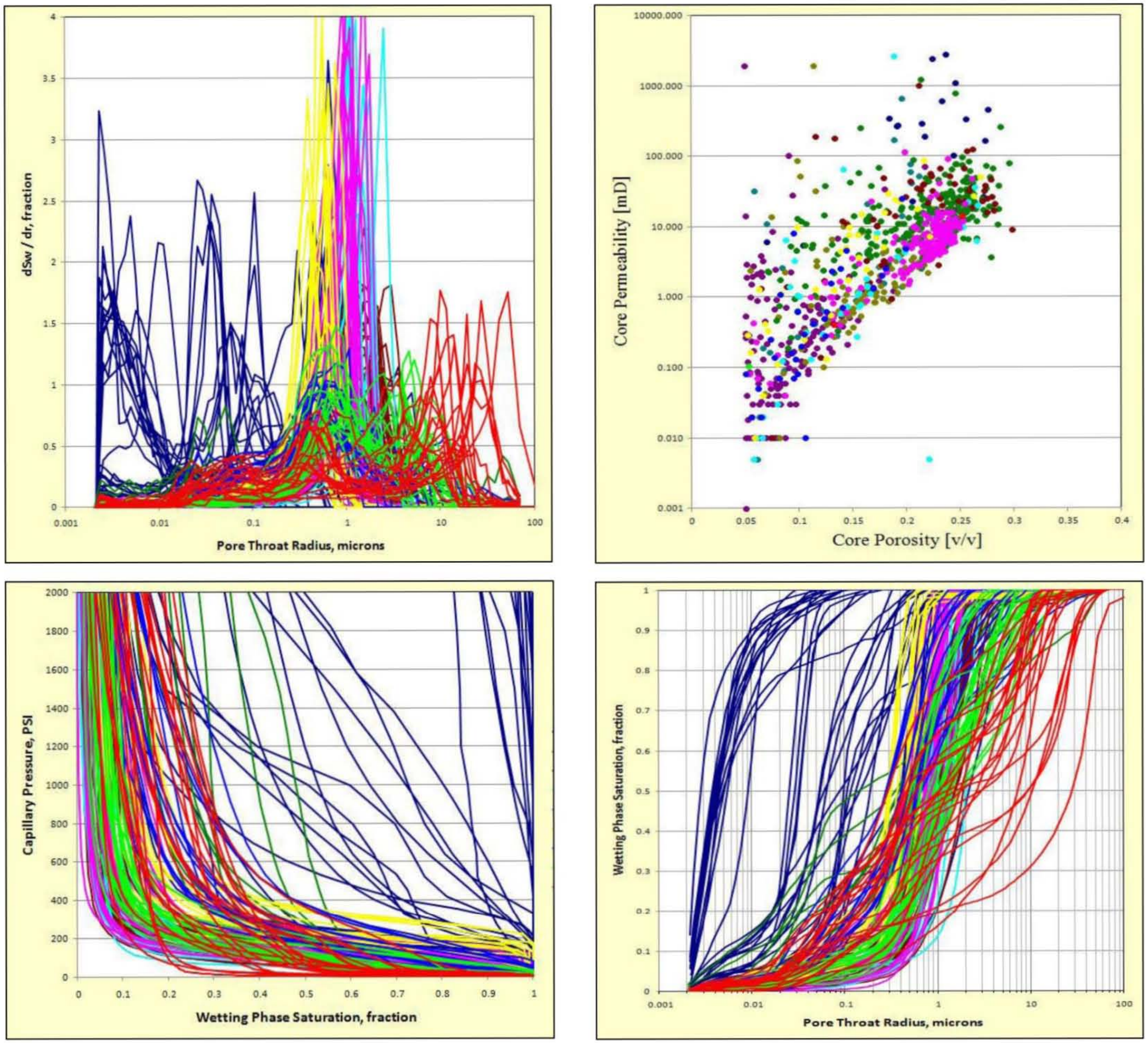


Figure 4. Petrophysical groups built from porosity-permeability relationship, pore throat size distribution, and capillary pressure curve.

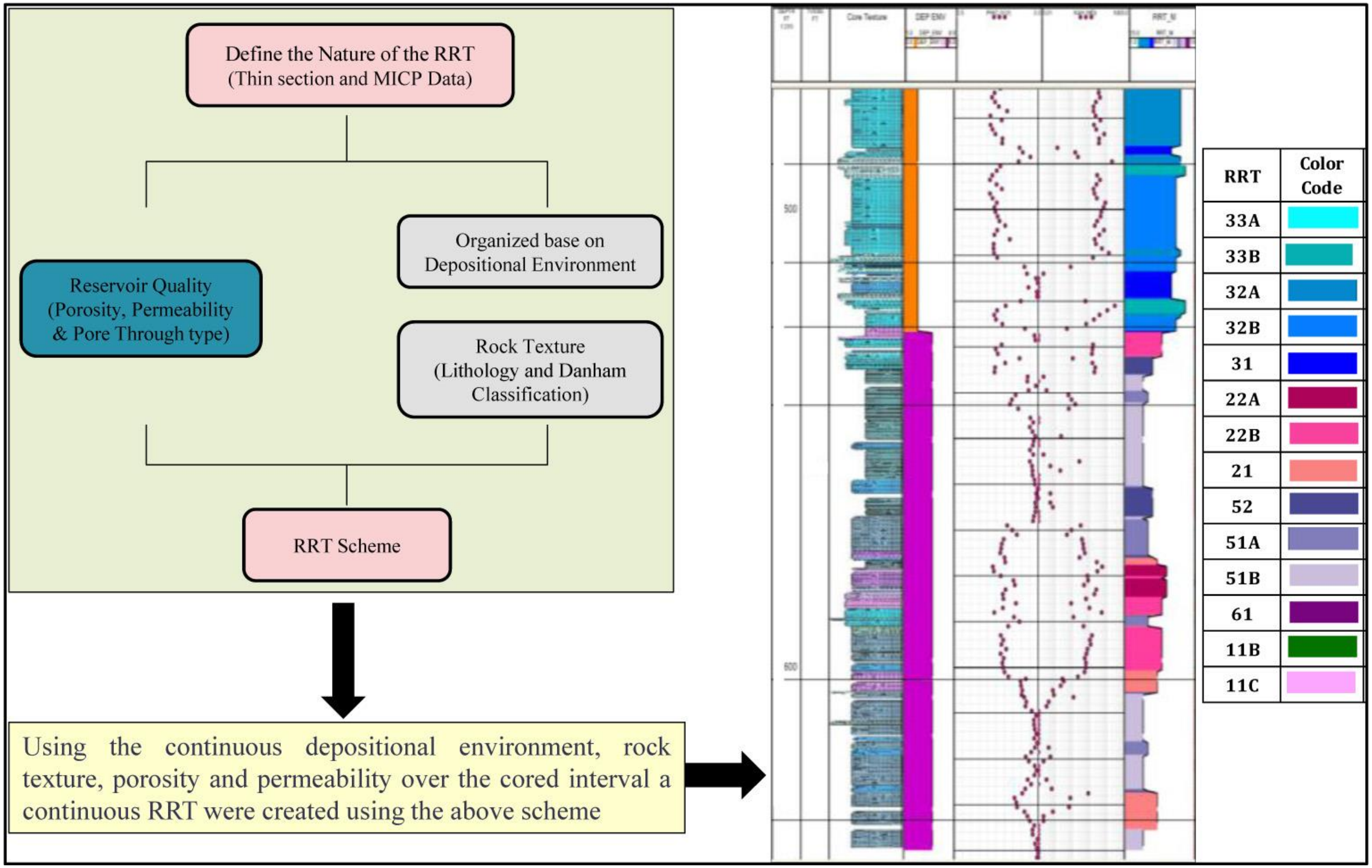


Figure 5. Schematic diagram illustrates the continuous RRT prediction over the cored interval.

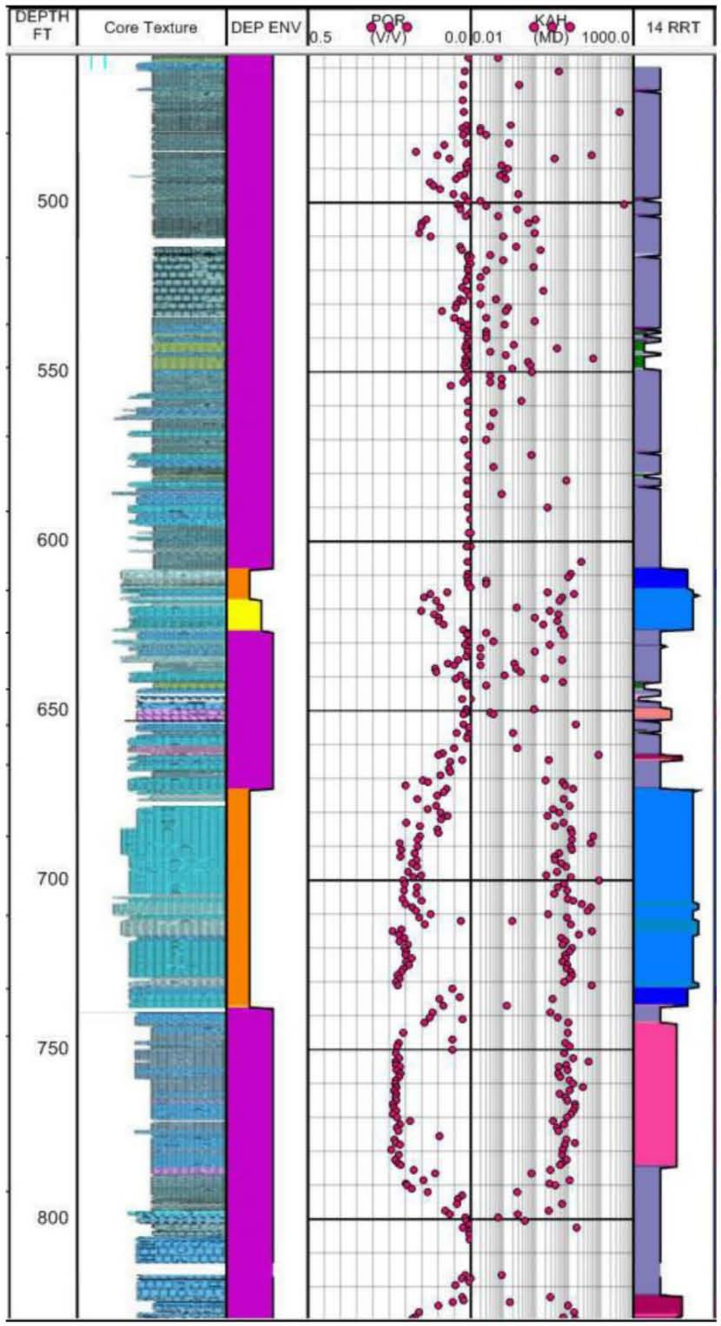


Figure 6. Continuous RRT prediction over the cored interval.

RRT		Color Code	FZI	Average
Shoal	33A		> 6.5	10
	33B		6.5 - 3	4.23
	32A		3 - 1.1	1.598
	32B		1.1 - 0.52	0.82
	31		< 0.52	0.375
Dolomite	22A		> 1	1.363
	22B		1 - 0.43	0.6297
	21		< 0.43	0.335
Lagoon	52		> = 1	2.39
	51A		0.4 =< < 1	0.6
	51B		< 0.4	0.3
Supratidal	61			
Shale	11B			
Anhydrite	11C			

RRT	Color Code	FZI	Average
33		3 - 6 <=	6.35
32		0.52 - 3	1
31		< 0.52	0.38
2			0.63
5			0.60
61			
11B			
11C			

Figure 7. RRT before and after lumping with average FZI values to be used for the permeability computation.

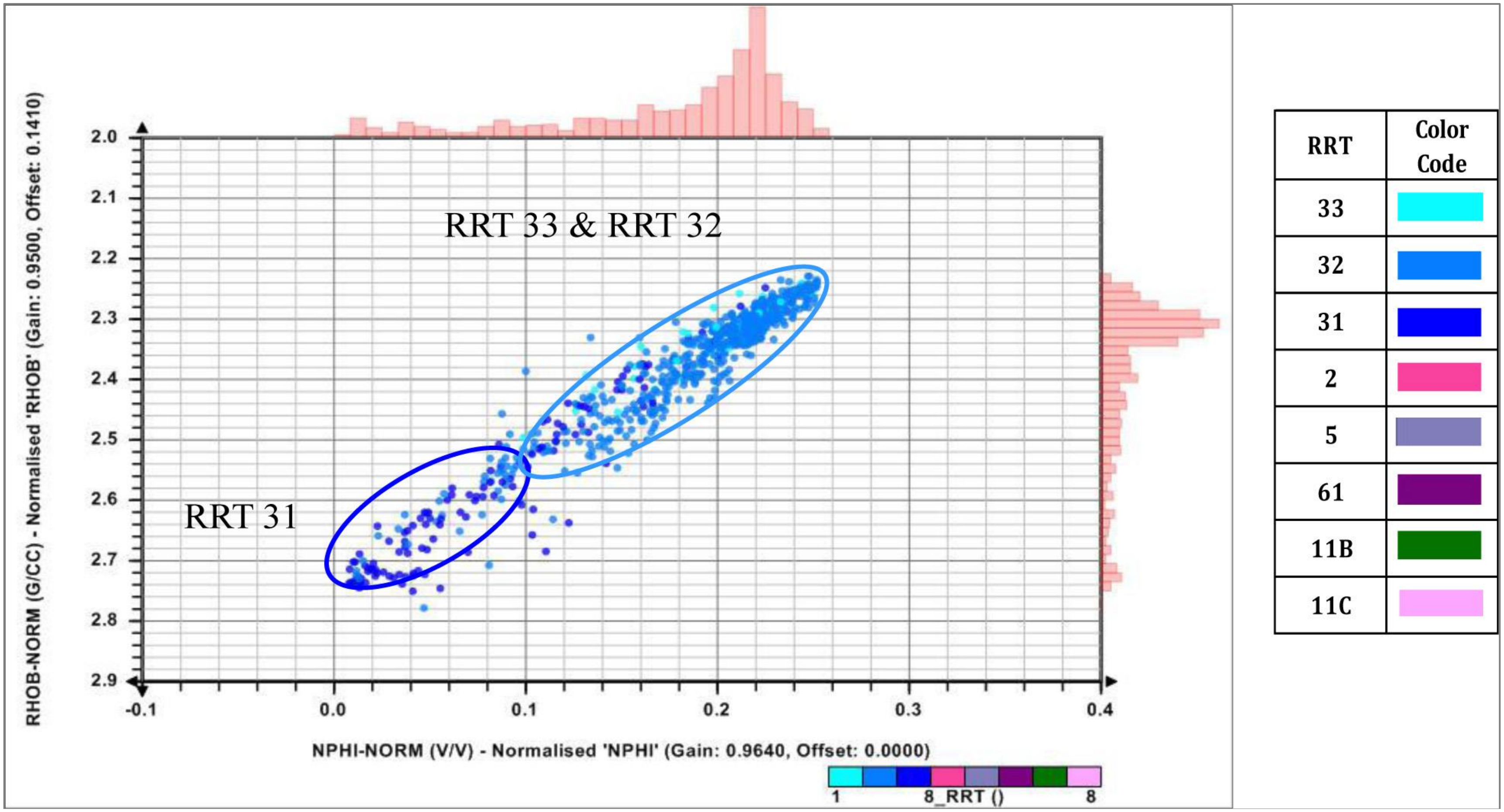
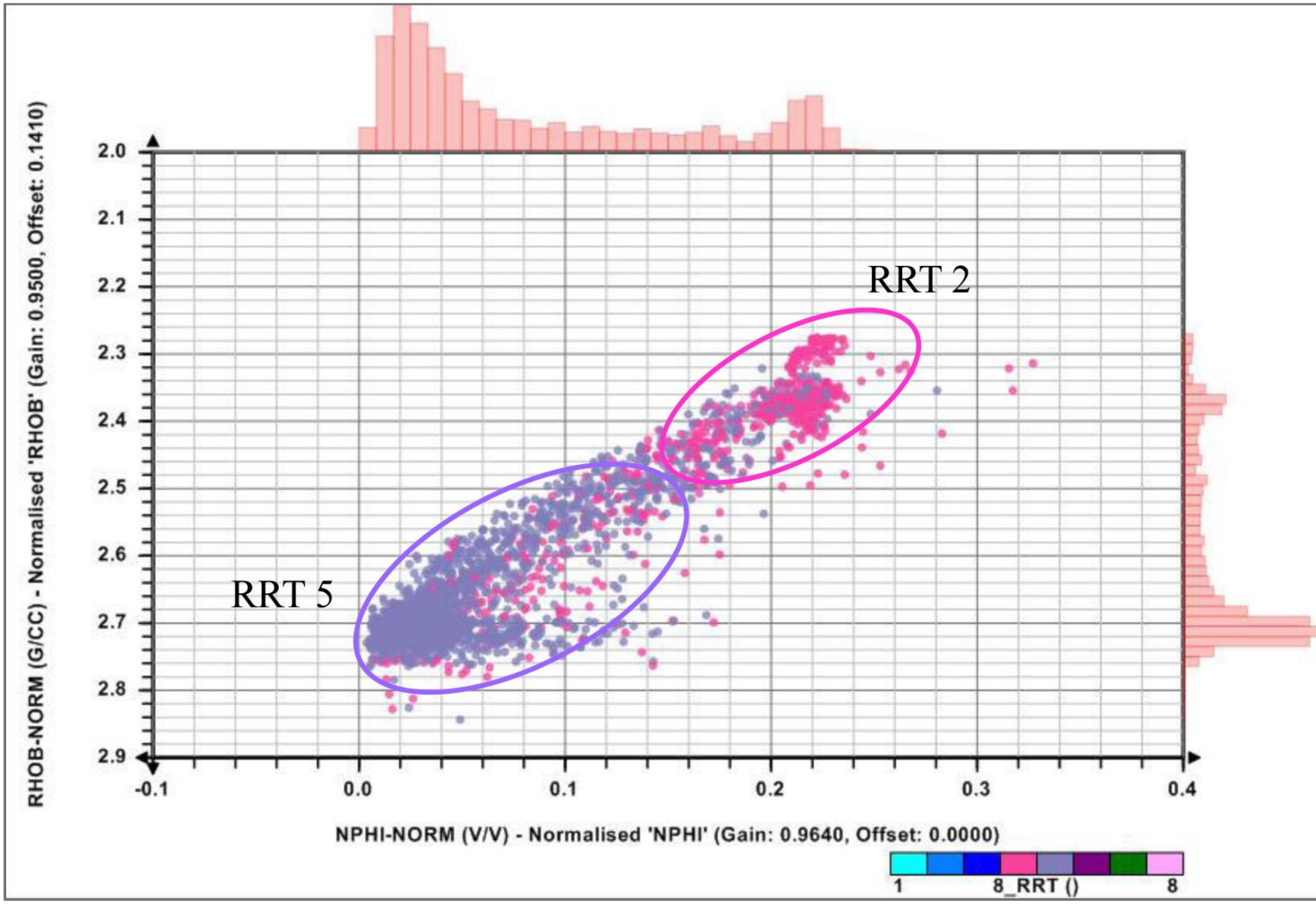


Figure 8. Normalized NPHI vs. RHOB for the cored wells over the cored interval, shaded with lumped shoal RRTs. Data clearly separate between the RRT31 and 32, with some mismatch and that because of the core to log resolution.



RRT	Color Code
33	
32	
31	
2	
5	
61	
11B	
11C	

Figure 9. Normalized NPHI vs. RHOB for the cored wells over the cored interval, shaded with lumped dolomite and lagoon RRTs. Data clearly separate between the RRT2 and 5, with some mismatch and that is because of the core to log resolution.

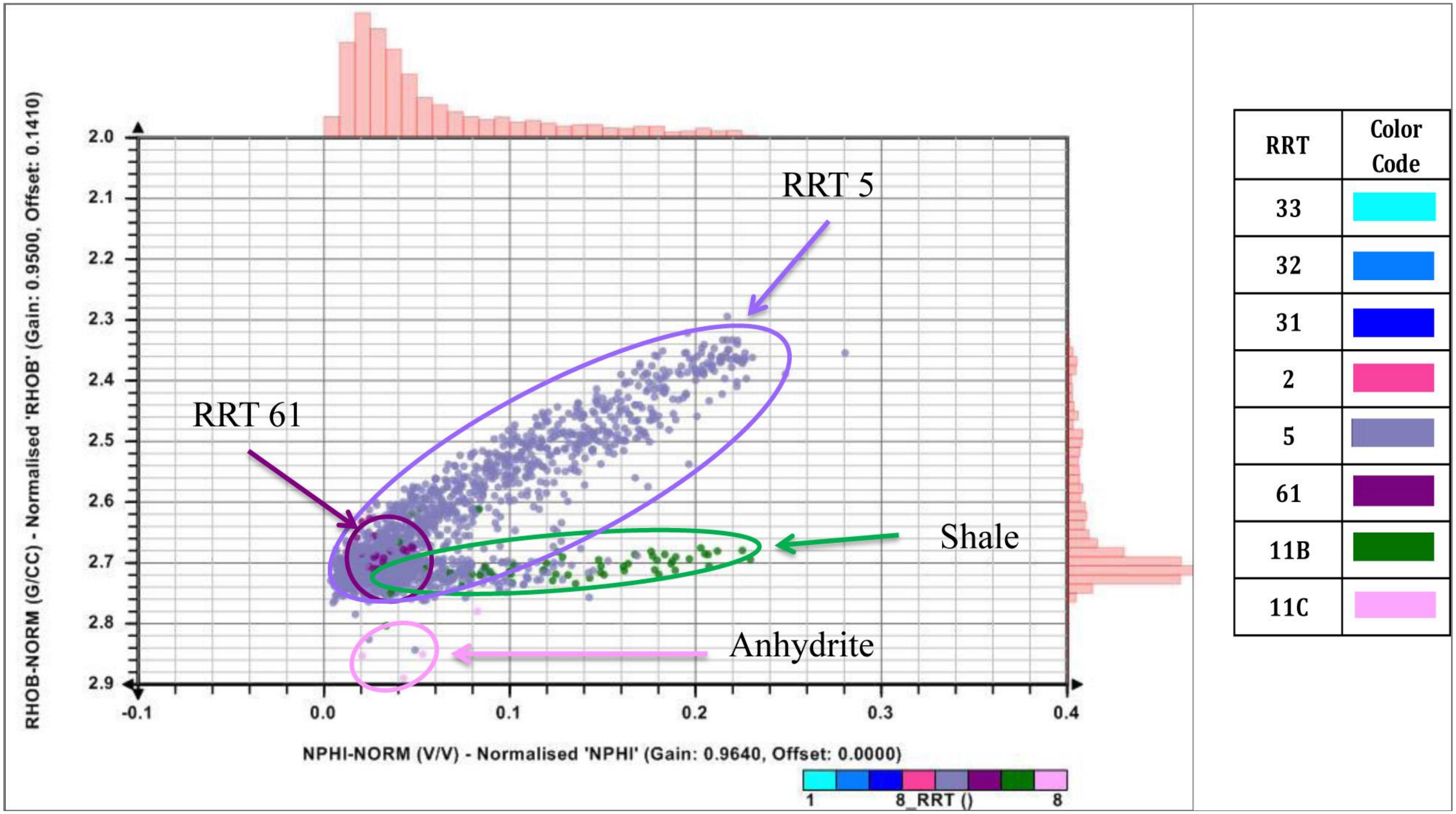


Figure 10. Normalized NPHI vs. RHOB for the cored wells over the cored interval, shaded with lumped lagoon, supratidal, shale, and anhydrite RRTs. Since Supratidal and Lagoon have almost same OH logs response and both of them are non-reservoir rock, we lumped RRT 61 to be part of RRT 5. Supratidal only present in XX-0201 and XX-0210.

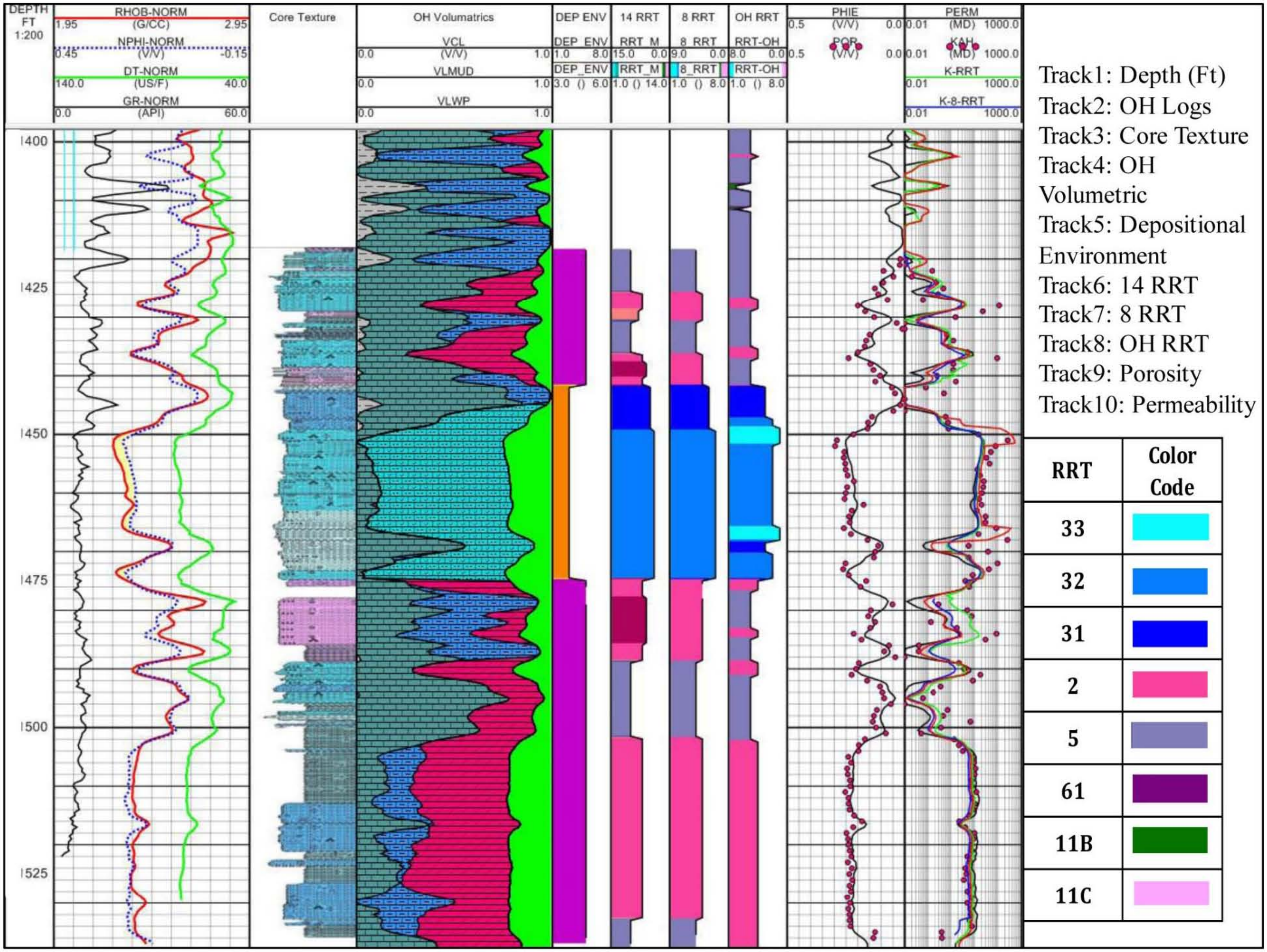


Figure 11. Comparison between the 14 and 8 cored RRTs and OH RRTs over the cored interval for XX-0142. Good match between the OH and 8 cored RRTs.

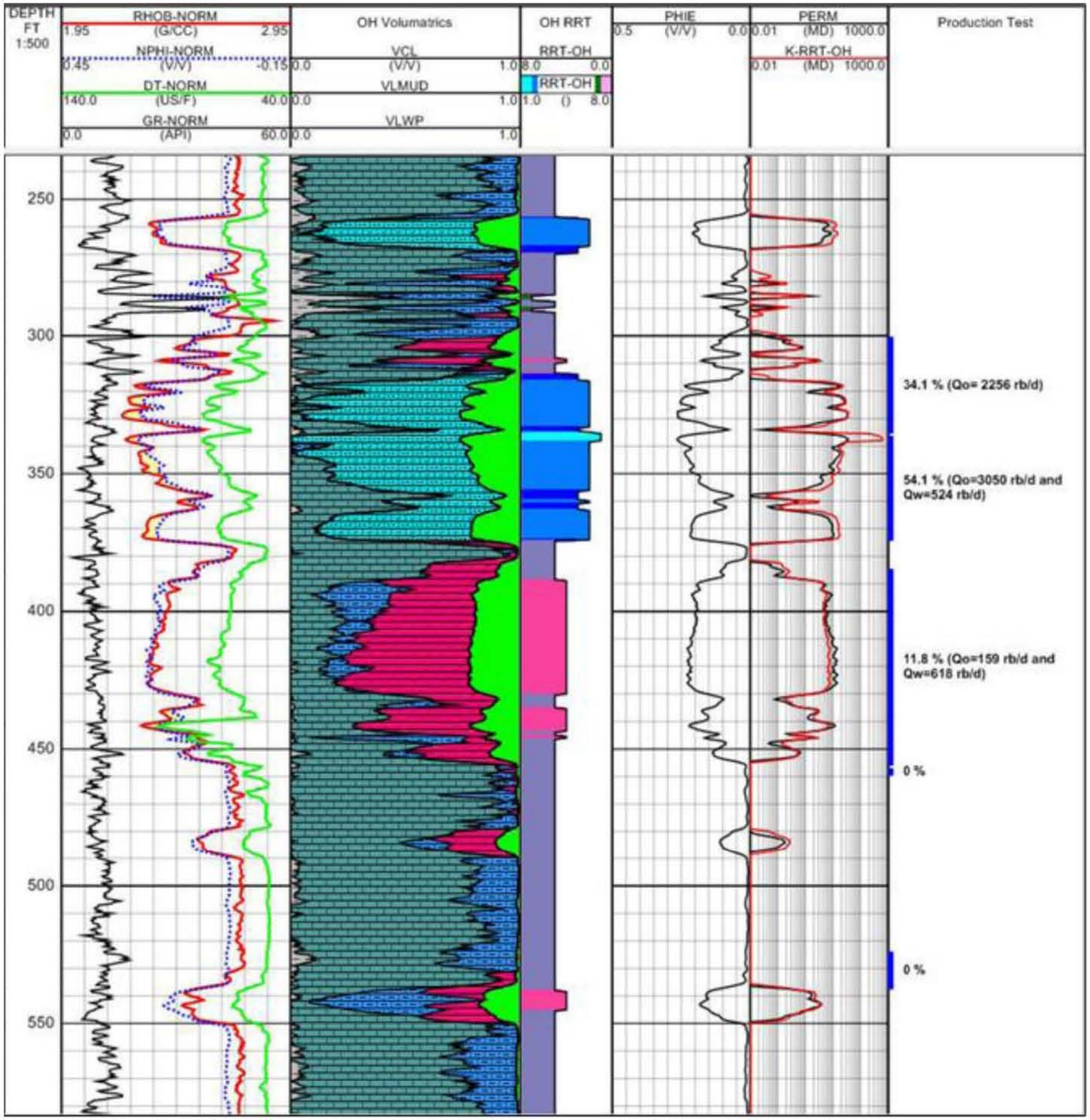


Figure 12. Continuous OH RRT and permeability results for XX-0126. The production behavior supports the permeability computation from the RRT, where the high production contributions are matched with the high permeability streaks.

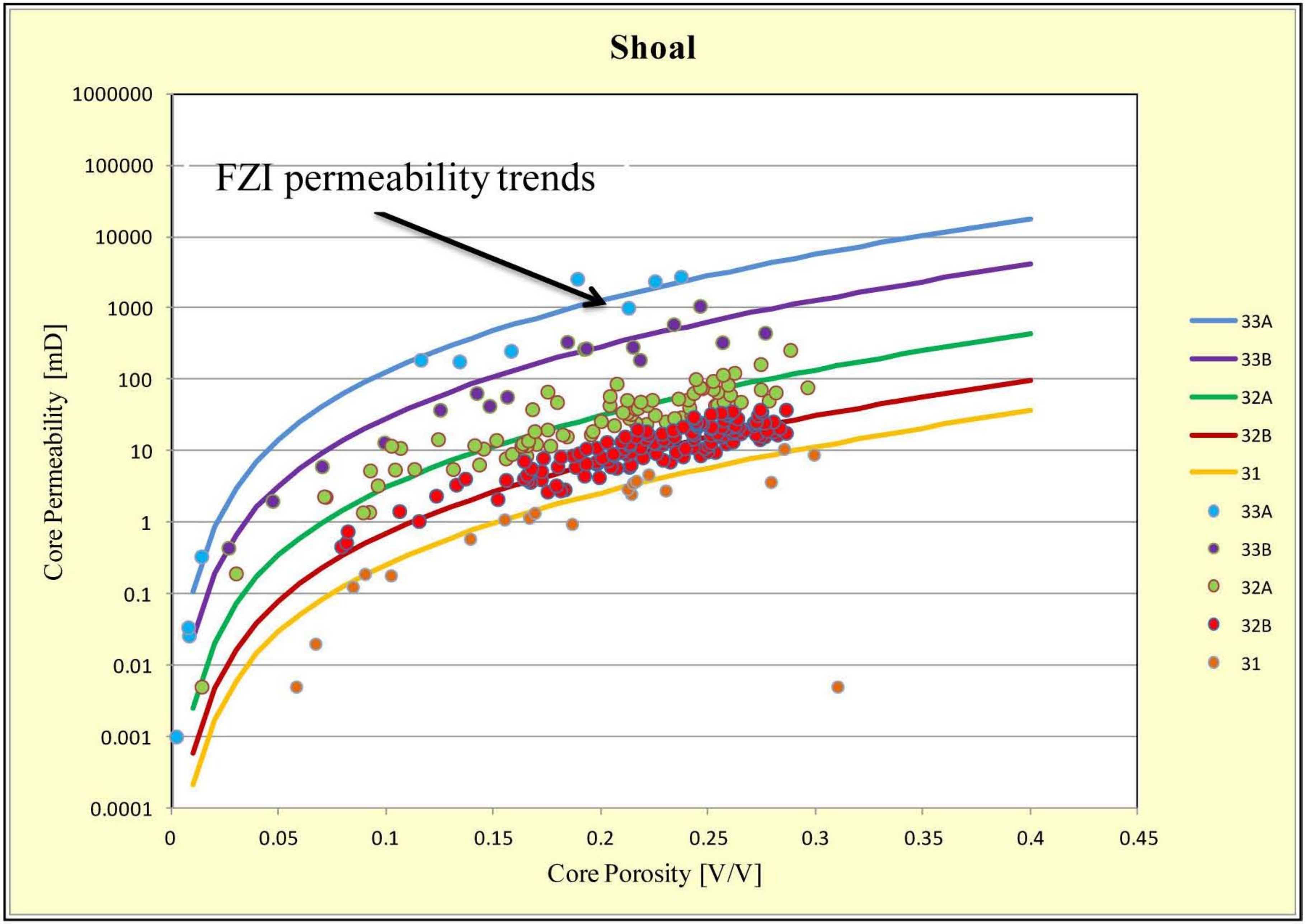


Figure 13. Core porosity vs. Permeability and the FZI permeability trend for the different shoal RRTs.

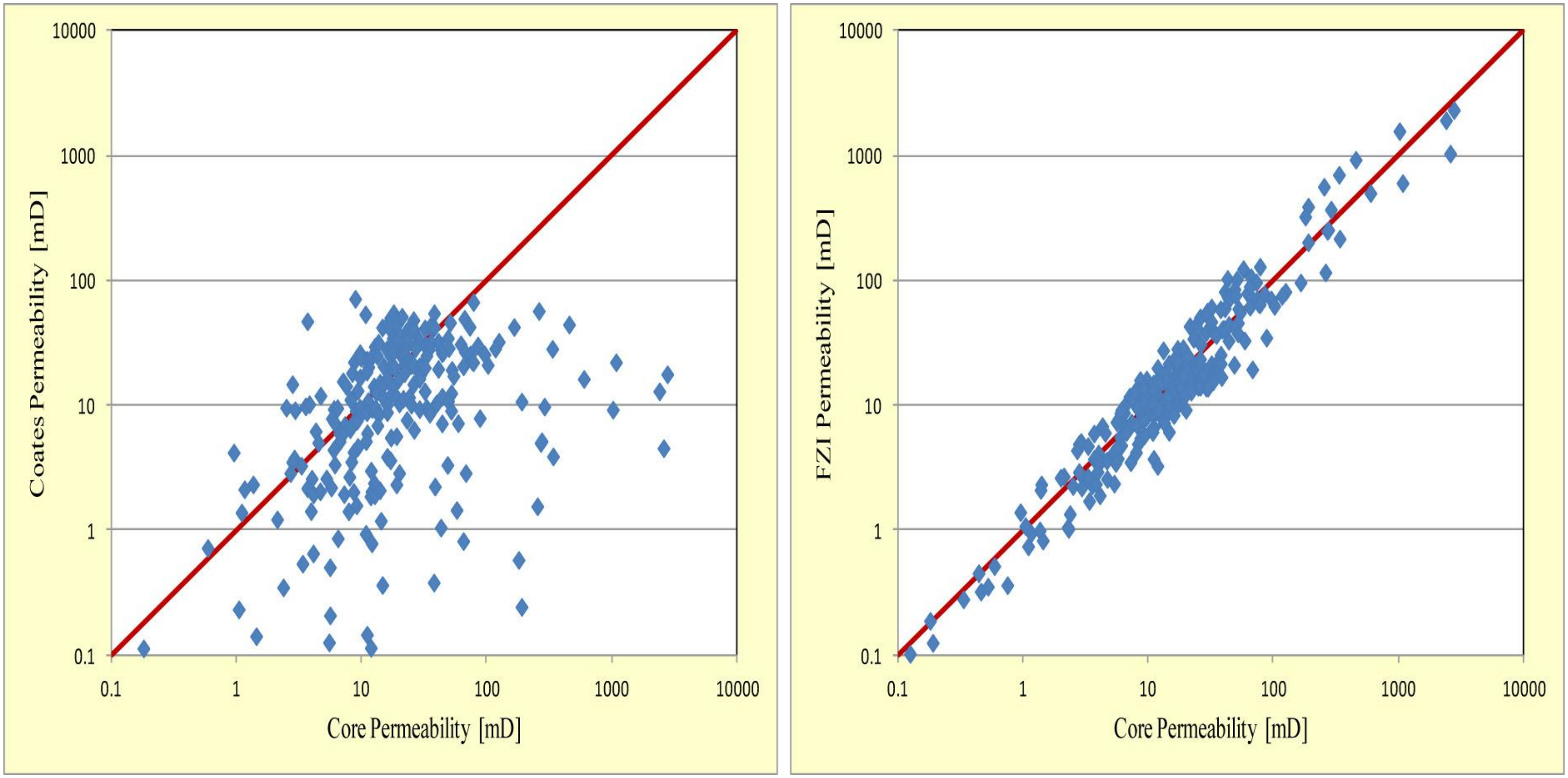


Figure 14. Core permeability vs. Coates permeability (left graph) and the Core permeability vs. FZI permeability comparison for the different shoal RRTs. The computed permeability using the FZI method honors the core data better then Coates equation.

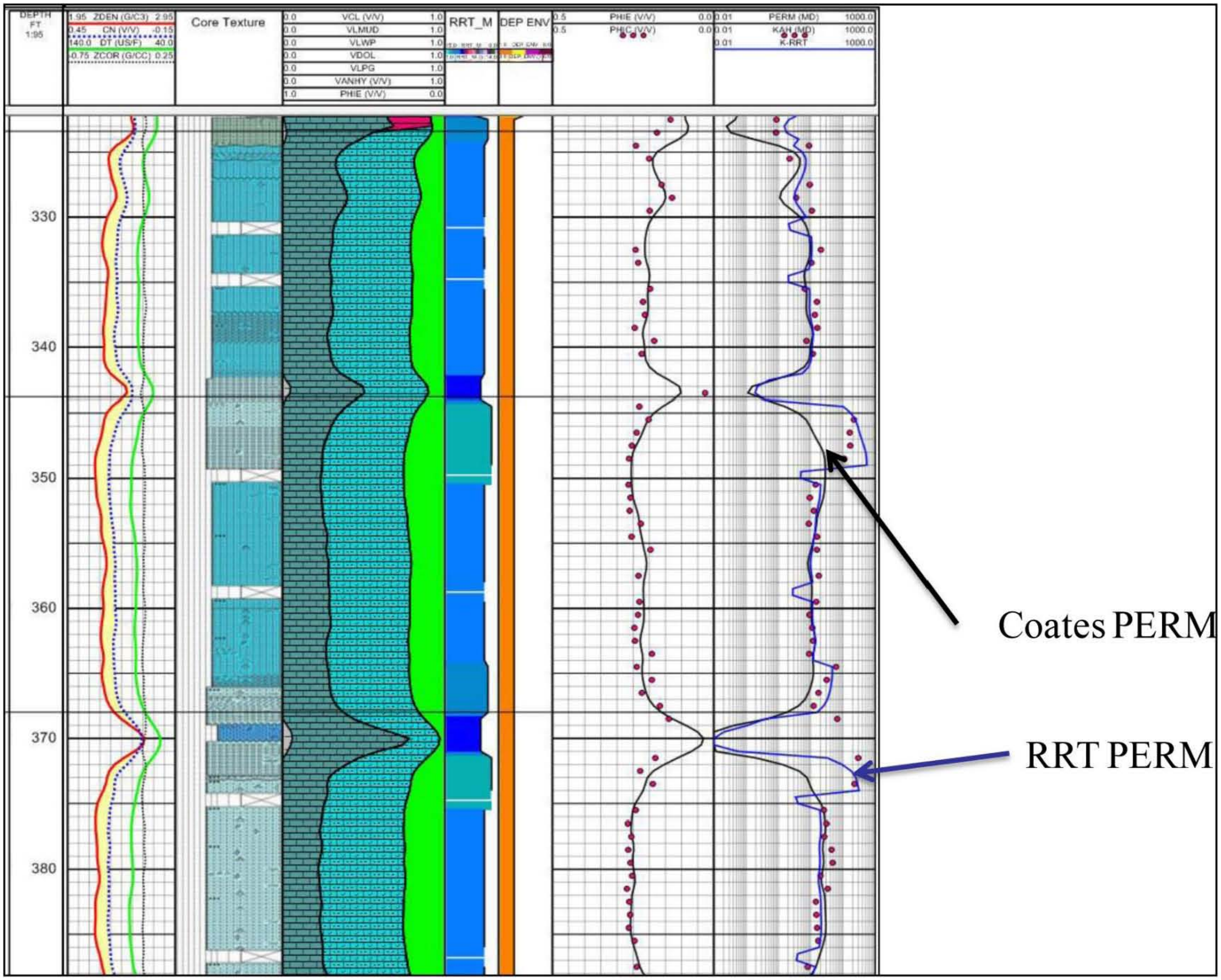


Figure 15. Example of the continuous Shoal RRT with permeability computation using the FZI and Coates equation. The computed FZI permeability honors the high permeability better than the Coates equation.

No.	RRT	Environment	Texture	Characteristics
1	33A	Shoal	Grainstone	• Primary porosity enhanced by secondary porosity • Good porosity, very good permeability
2	33B	Shoal	Grainstone	• Primary porosity with coarse to medium grain size • Good porosity, good permeability
3	32A	Shoal	Grainstone	• Primary porosity with relatively finer grain size • Moderate porosity, moderate permeability
4	32B	Shoal	Packstone	• Texturally of lower quality than grainstone due to the presence of mud matrix • Moderate porosity, moderate permeability
5	31	Shoal	Grainstone	• Originally good reservoir rock but degraded due to cementation • Poor porosity, poor permeability
6	22A	Lagoon (Dolomite)	Dolomite	• Intercrystalline porosity enhanced by vuggy porosity • Good porosity, good permeability
7	22B	Lagoon (Dolomite)	Dolomite	• Intercrystalline porosity typically with good porosity and low permeability • Good porosity, moderate permeability
8	21	Lagoon (Dolomite)	Dolomite	• Intercrystalline porosity partially cemented or dolomitization porosity not well-developed • Moderate porosity, poor permeability
9	52	Lagoon	Wackestone/ Lime Mudstone	• Primary intergranular porosity • Moderate porosity, moderate permeability
10	51A	Lagoon	Wackestone/ Lime Mudstone	• Primary intergranular porosity • Moderate porosity, poor permeability
11	51B	Lagoon	Wackestone/ Lime Mudstone	• Primary intergranular porosity • Poor porosity, poor permeability
12	61	Supratidal	Algal dolomite/ hetrolithics	• Primary porosity and permeability is variable and low
13	11A	Lagoon	Shale	• Non-reservoir
14	11B	Supratidal	Anhydrite	• Non-reservoir

Table 1. Criteria used to implement the continuous RRT for the core interval.

No.	RRT Code	Environment	Texture/lithology	FZI
1	33A	Shoal	Grainstone /Limestone	> 6.5
2	33B	Shoal	Grainstone/Limestone	6.5 - 3
3	32A	Shoal	Grainstone/Limestone	3 - 1.1
4	32B	Shoal	Packstone/Limestone	1.1 - 0.52
5	31	Shoal	Grainstone/Limestone	< 0.52
6	22A	Lagoon (Dolomite)	Dolomite	> 1
7	22B	Lagoon (Dolomite)	Dolomite	1 - 0.43
8	21	Lagoon (Dolomite)	Dolomite	< 0.43
9	52	Lagoon	Wackestone, Mudstone/Limestone	> = 1
10	51A	Lagoon	Wackestone, Mudstone/Limestone	0.4 =< < 1
11	51B	Lagoon	Wackestone, Mudstone/Limestone	< 0.4
12	61	Supratidal	Algal dolomite/ hetrolithics	
13	11A	Lagoon	Shale	
14	11B	Supratidal	Anhydrite	

Table 2. Criteria used to implement the continuous RRT for the core interval.