[PS]Characterization of Carbonates Through High Definition Borehole Images: Examples from Texas and Oklahoma*

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Search and Discovery Article #42210 (2018)**
Posted May 21, 2018

*Adapted from poster presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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Abstract

The presence of heterogeneity in carbonates, pose a challenge for the characterization of such rocks. Conventional logging technologies do not have the necessary resolution to address such variabilities and the identification of textural variations, within a carbonate body, is important to highlight intervals of diagenetically altered matrix, and discover additional porosity hidden from the standard resolution measurements. Advanced techniques in borehole image analysis have been applied to carbonate data sets from Permian aged rocks from Texas and have highlighted intervals characterized by various heterogeneities, which can be interpreted as developed vugs. Such heterogeneities can be additionally classified in reference to their connectivity and their intersection to fractures or to bed boundaries, always observed on the borehole image, finally exposing intervals differently characterized by vugs connected to fractures, vugs connected to bed boundaries, isolated vugs or vug to vug connected. The identification and analysis of heterogeneities in carbonates, based on borehole images, is not a novelty but a newly revisited workflow allows for an even more detailed description of such texture. The proposed workflows starts with the creation of a full borehole image generated using multipoint statistics, and providing a 360 degrees full borehole coverage image. From this image a matrix computation is performed on the calibrated image, allowing the extraction of the background conductivity utilized in the following step. Once the background conductivity is delineated, a series of cut offs are applied based either on the contrast or based on the resistivity values between matrix resistivity and heterogeneity resistivities. The output of this step is the delineation of conductive and resistive heterogeneities in respect to the background matrix. Superimposing the delineated heterogeneities, together with bed boundaries and natural fractures, allows the identification of vugs connected to fractures and/or vugs connected to bed boundaries or solution enlarge boundaries. A defined connectivness allows the identification of isolated vugs versus connected vugs. This methodology was applied to various carbonate data sets from the Permian succession of Texas and have been helpful for the operators in characterizing the full porosity distribution in the reservoir.

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Characterization of Carbonates Through High Definition Borehole Images: Examples from Texas & Oklahoma

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Presenter: Dragan Andjelkovic , Schlumberger & Tim Hunt, Trey Resources

ABSTRACT:

The presence of constant heterogeneity in carbonates, pose a real challenge for the full characterization of such rocks.

Conventional logging technologies do not have the necessary resolution to address such variabilities and the identification of textural variations, within a carbonate body, is of paramount importance to highlight possible intervals of diagenetically altered matrix, and discover additional porosity hidden from the standard resolution measurements.

Advanced techniques in the borehole image analysis have been applied to carbonate data sets from Permian aged rocks from Texas and have highlighted intervals characterized by various heterogeneities which in turn can be interpreted as developed vugs. Such heterogeneities can be additionally classified in reference to their connectivity and their intersection to fractures or to bed boundaries, always observed on the borehole image, finally exposing intervals differently characterized by vugs connected to fractures, vugs connected to bed boundaries, isolated vugs or vug to vug connected.

The identification and analysis of heterogeneities in carbonates, based on borehole images, is not a novelty (Delhomme, 1992; Newberry et all, 1996; Akbar et al, 2008;) but a newly revisited workflow (Yamada et al 2013) allows for even a more detailed description of such texture.

The proposed workflows allows for the creation of a full borehole image which is generated using multipoint statistics on the data and providing a 360 degrees full borehole coverage image.

From this image a matrix computation is performed on the calibrated image, allowing the extraction of the background conductivity utilized in the following step.

Once the background conductivity is delineated, a series of cut offs are applied based either on the contrast or based on the resistivity values between matrix resistivity and heterogeneity resistivities. The output of this step is the delineation of conductive and resistive heterogeneities in respect to the background matrix.

Superimposing the delineated heterogeneities, together with the previously analyzed image features, such as bed boundaries and natural fractures, allows the identification of vugs connected to fractures and/or vugs connected to bed boundaries or solution enlarge boundaries. A defined connectivness allows the identification of isolated vugs versus connected vugs.

This methodology was applied to various carbonate data set from the Permian succession of Texas and have been helpful for the operators in characterizing the full porosity distribution in the reservoir.

In this poster we are also presenting a case study conducted in a reservoir carbonate of Oklahoma in which the same methodology and workflow was conducted in the lateral well.

In this last mentioned case study, a conventional core was acquired in the pilot well and the comparison between facies from the core and facies from the image was possible.

This highlighted a good agreement between different facies and different responses from secondary porosity analysis based on borehole images.

INTRODUCTION:

The First case study presented in this poster is taken from analysis performed on West Texas carbonate and in particular on the Ellenburger formation. This formation is part of a Lower Ordovician carbonate platform sequence which covers a large area of the United States. During early Ordovician time, Texas was situated in a tropical to subtropical latitude, in a shallow-water shelf with deeper water condition to the south where it bordered the Iapetus Ocean.

Shallow-water carbonates were deposited on the shelf, and deep-water shales and carbonates were deposited on the slope and in the basin (Loucks R.). Restricted environments were present in the interior of the shelf while open-marine conditions were present in the outer shelf.

Diagenesis of the Ellenburger is considered very complex and can be summarized in three major diagenetic processes: 1) dolomitization 2) Karsting and 3) tectonic fracturing. These three major processes have contributed to the formation of a pore network which is very complex in this formation. Pore networks can be represented by the combination of any of the following pore types: (1) matrix, (2) cavernous, (3) interclast, (4) crackle-/mosaic-breccia fractures, or (5) tectonic-related fractures.

Like in any other carbonate reservoir, the strong diagenetic overprint produces a strong spatial heterogeneity within the reservoir system and it is important to gain as much information on the distribution of such heterogeneities for a better reservoir modelling, but also for short term decisions on favorable intervals for perforation.

The application of the advanced workflow shown in the present poster has greatly helped in better understanding pore distribution and heterogeneities variability within the reservoir.

POROTEX WORKFLOW (from Tetsushi et Al., 2013):

1) Borehole Image calibration using an external shallow resistivity curve. The image can now be treated as a conductivity map of the borehole wall.

2) Gap-filled image creation. Wireline microrelectrical imagers have several pads to acquire images which reflect in missing strips between pads which complicate the heterogeneity delineation. Texture analysis provides satisfactory results when the heterogeneity size is smaller than the pad, but becomes inaccurate when the size of the textural features exceeds the pad width. Gap– filled image overcome this possible inaccuracy in the results. FILTERSIM, a recent multipoint statistics (MPS) algorithm (Zhang, 2006; Hurley and Zhang, 2011) is used to fill gaps in the image.

3) Fracture segments extraction (or manual dip picking) is carried out to identify porosity associated to fractures or to identify solution enhanced featured associated to bed boundaries. We invite to refer to Kherroubi, 2008 for more details on the automatic segment extraction method which is outside the scope of this poster.

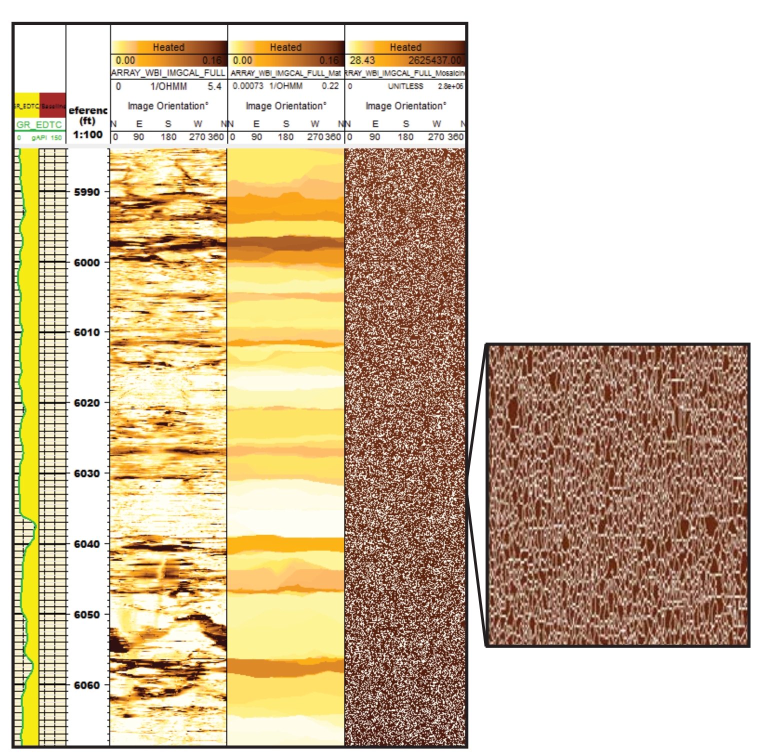
4) Matrix extraction. The background of the image, which corresponds to the geological term matrix, is computed by removing non-crossing features on the images such as vugs, molds, fracture segments.

5) Heterogeneity delineation: image characterization and interactive cutoff. Watershed transform it is used to segment the image and to characterize it. A gradient image is created of the rate of change in conductivity. Each mosaic piece is characterized by its attributes such as peak/valley value, contrast against matrix image, size and type. Two types of mosaic pieces are identified: conductive (the one with conductivity above matrix value) and resistive (the one with conductivity below matrix one). Using the crest line extracted from the watershed transform, neighboring mosaic pieces are merged together to form an heterogeneity feature (conductive or resistive). The conductive heterogeneities are then sub classified into connected, isolated, fractures and bed boundaries types depending on their relationship with manually picked features 9such as fractures and bed boundaries).

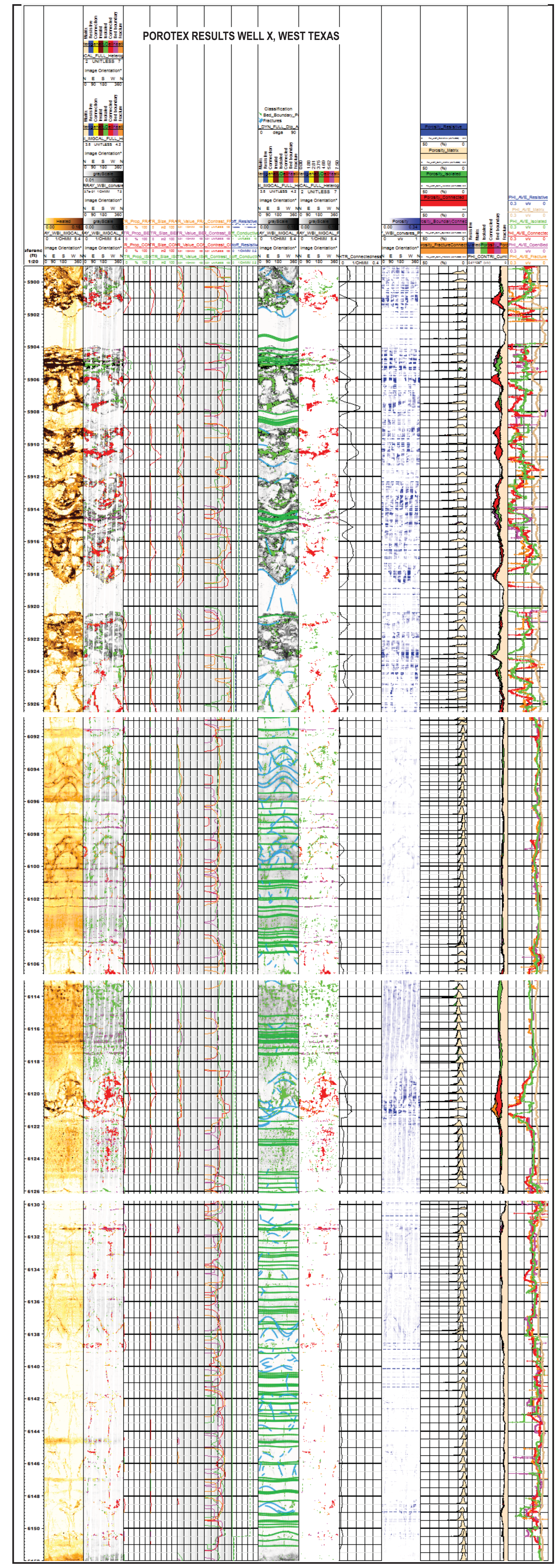
6) Image porosity analysis. The porosity map is generated through the below equation (Newberry et al. 1996), where ϕ_{ext} and R_{ext} are the porosity and the shallow resistivity, respectively, and C_i is the value of the conductivity image.

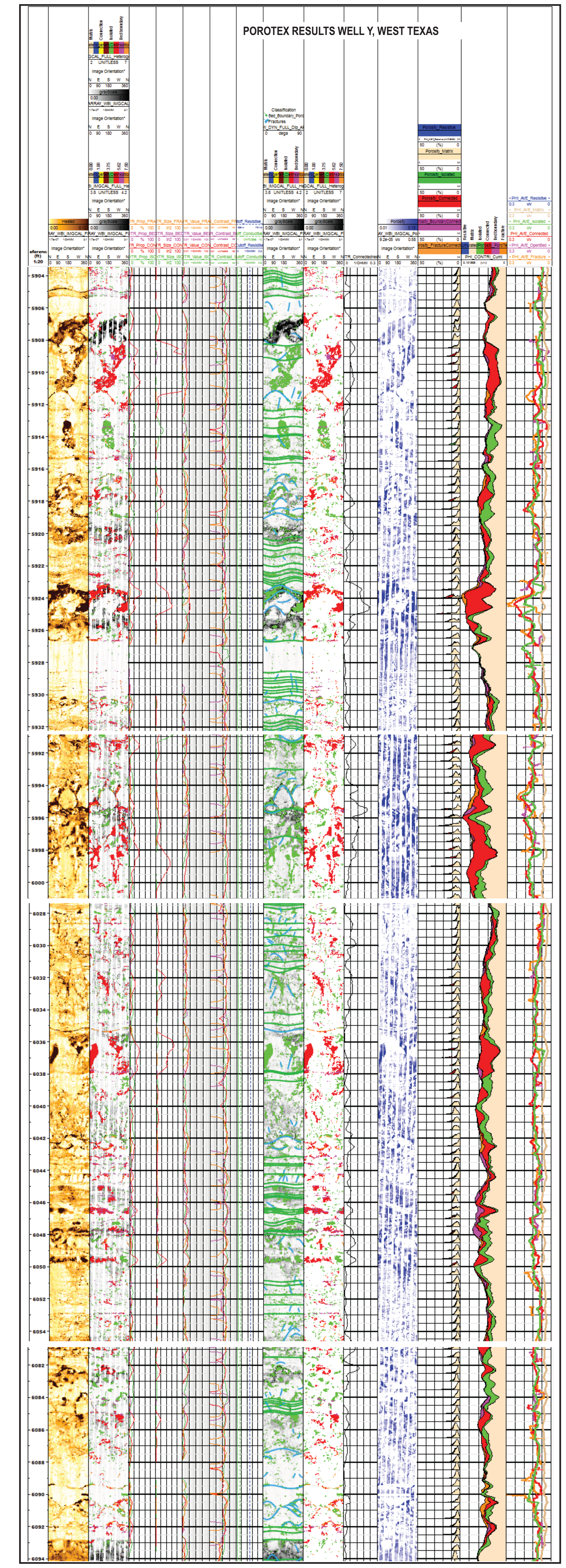
$$\phi_i = \phi_{\mathrm{ext}}(R_{\mathrm{ext}}C_i)^{1/m}$$

Histograms of each texture class are created over vertical windows (along the borehole depth) and are stacked in the same track.



ABOVE: Example of results for the step matrix extraction and on the right the results of the watershed transform on the image to divide it in mosaic pieces utilized in the next step of the workflow. Note the "layering" created in the matrix extraction, reflecting the vertical succession of different facies as seen from the image. In particular, some of the more conductive layers (example at 6057 ft and 6040 ft) occur together with an increase in the gr reading. Those interval could be related to cave collapse features and subsequent clay infill. While other more conductive layers (ex. 5998 ft) could be generated by dissolution features and creation of vugs or secondary porosity features.





ABOVE: Examples of final Porotex results for two offset wells, X and Y, about 5 miles from each others, from West Texas. It is interesting to observe the variation in the heterogeneity distribution between the two wells, but also along one single well. Also, there is a noticeable difference between the overall matrix porosity between the two wells.

With the utilization of borehole images, the operator was able to make decision on perforation in the intervals characterized by a more developed isolated and conductive heterogeneity and also the identification of hetwrogeneities connected to fractures was taken into consideration in the completion decisions.

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ACKNOWLEDGMENTS:

The authors would like to thank Dragan Andjelkovic for presenting this work in their behalf.

Additionally a good thank you goes to an Oil & Gas Operator from Texas, who wish to remain unknown, to allow Schlumberger the use the data acquired in its wells, to be included in this poster.

Schlumberger wish to thank Trey Resources for the good cooperation in compiling the case study from Oklahoma.

AAPG Annual Convention & Exhibition 2016

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CASE STUDY INTRODUCTION

Two Units comprise most of the Short Junction field, which produces from the Hunton group, located in northwest Cleveland County, Oklahoma. The units have produced approximately 22 million barrels of oil since 1948 of an estimated 250 million OOIP. The less than 9% recovery even after a secondary water flood leaves a sizable target for a revitalized field.

In 2008, the Well A, was recompleted as a horizontal lateral and included borehole imaging logs. Trey Resourses acquired the units in 2014 and drilled the Well B. The entire Hunton (Bois d'Arc to Chimneyhill) was cored as well as a full petrophysical suite including borehole imaging logs were acquired.

The core was oriented to determine principal stress direction and structural position. Additional whole core samples were analyzed for directional permeability and plugs were measured showing permeability in the East- West direction. Three plugs were selected for conventional CT scan analysis to help determine electrical properties.

Advanced interpretation techniques were applied on the acquired borehole images and correlated with the core results. The objective was to characterize the heterogeneities present in the formation. With the creation of full borehole images, covering the entire borehole surface, it was possible to better identify various heterogeneities (including vugs and fractures) and classify them as conductive or isolated vugs, fractures connecting vugs or heterogeneity developed along bed boundaries. Intervals where the matrix porosity was the predominant component to the overall porosity were highlighted, versus intervals where the vuggy porosity has an important contribution.

SIMPLIFIED STRATIGRAPHIC COLUMN

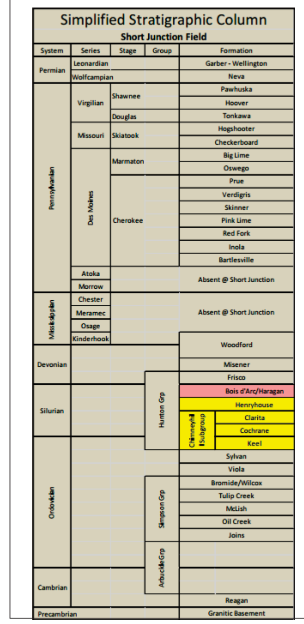


IMAGE POROSITY ANALYSIS WORKFLOW

This state of the art workflow includes textural analysis, image porosity analysis and fracture analysis to fully characterize the porosity distribution in the carbonate reservoir. This technology was applied in the Well B and Well A.

1) Full image creation: this step utilizes geostatistics to generate an image that represents full borehole coverage.

2) Conductive and Resistive heterogeneities are delineated utilizing thresholds on contrast and resistivity values. Changes in resistivities compared to the matrix corresponds to heterogeneities: highly resistive heterogeneities correspond to cemented zones, while low values of resistivities correspond to vugs or fractures (Delhomme, 1992;

3) Combining the detailed feature identification done in the manual dip picking phase, with the heterogeneity delineation, allow the classification of heterogeneities into different categories.

4) Porosity map from image is constructed utilizing a well established method. This method computes porosity utilizing a modified Archie's equation applicable to the flushed zone and has as input each conductivity curve measured by the Formation Micro Imager (Newberry et All, 1996).

OUTPUT DESCRIPTION

On the left, part of the PoroTex results, applied to the Well B.

Track 1: Depth Reference, scale 1:10

Track 2: Zonations highlighting different interval used for setting thresholds

Track 3: Full Calibrated image

Track 4: Calibrated FMI* Microresistivity curve with 0.2" vertical resolution

Track 5: Heterogeneity Image delineation. Refer to legend on top of the log to differentiate different colors heterogeneities.

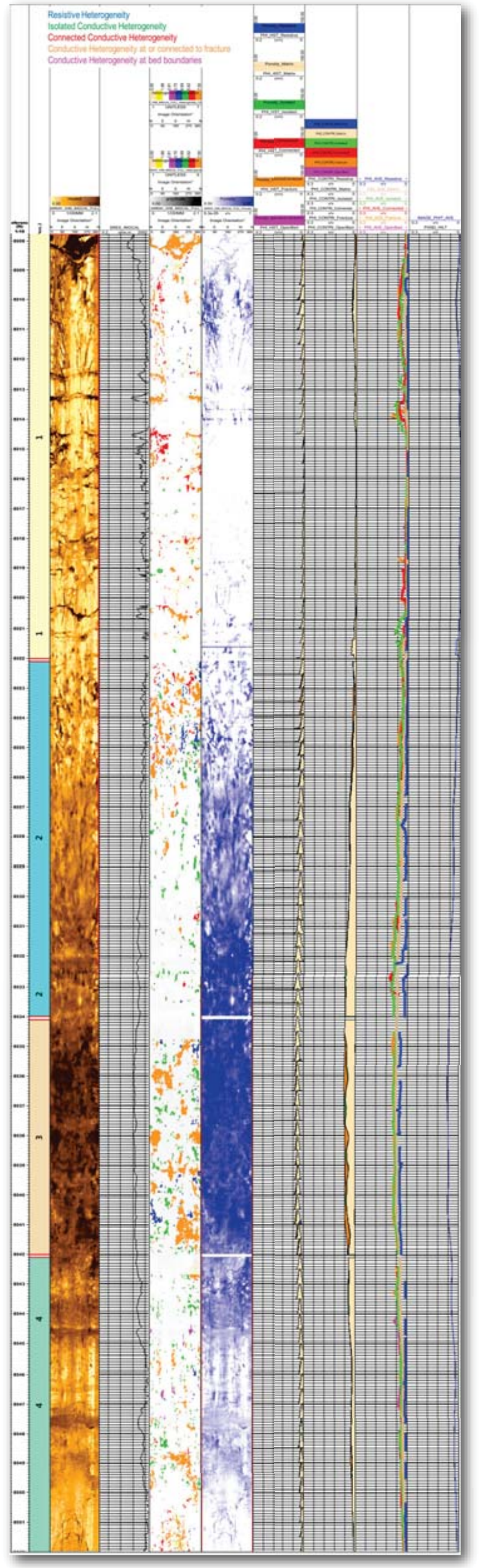
Track 6: Image Porosity Map – An increase in darkness of the color correspond to an increase in image porosity.

Track 7: Spectrum of Porosity distribution

Track 8: Cumulative Porosity Distribution

Track 9: Average Image Porosity at each heterogeneity type

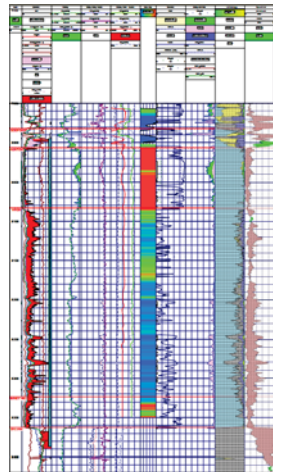
Track 10: Cross Plot porosity and total porosity computed from image porosity. The value corresponds to the average at each depth level of the image porosity curve.



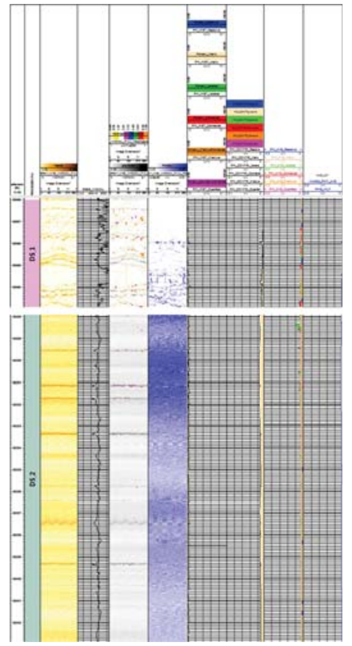
SHORT JUNCTION LOCATION MAP

★ Field Location

WELL B

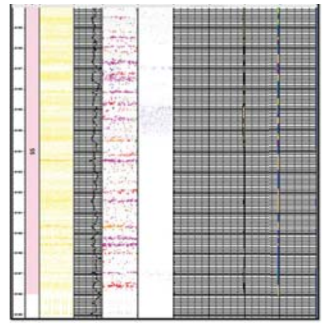


RESPONSE OF POROTEX IN DEEP SHELFAL ENVIRONMENT



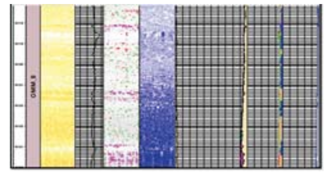
The general response in Deep shelfal environment is lack of heterogeneities and overall porosity from image from low to medium

RESPONSE OF POROTEX IN SHALLOW SHELF



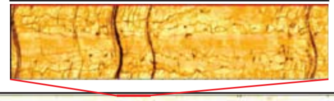
The general response in shallow shelf environment is abundance of heterogeneities along beddings and overall porosity from image low

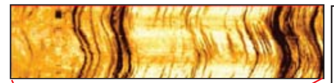
RESPONSE OF POROTEX IN ORGANIC MUD MOUND



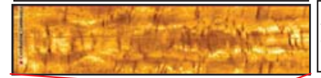
The general response in the organic mud mound is of presence of heterogeneities contributing to the overall medium image porosity. Heterogeneities are predominantly along beddings and isolated

Left and Below: Facies characterized by an overall high resistivity background indicative of tight matrix. Natural conductive fractures are present in discrete intervals. Presence of dissolution features is observed in the general direction of bed boundaries and can be associated to dissolution along beddings. Some longitudinal induced fractures might indicate deformation caused by overburden (Left and Below).



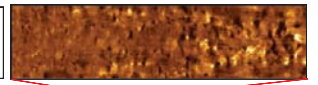


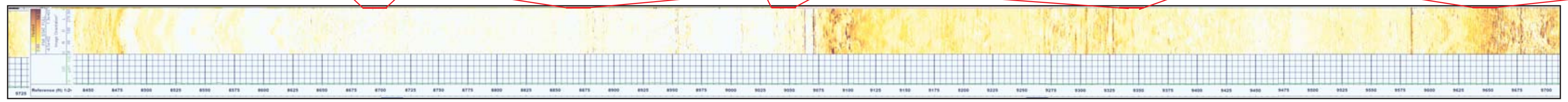
Left and Below: An intensely fractured interval is marking the transition to an image facies characterized overall by a more conductive background, possibly caused by an overall increase in the matrix porosity. The presence of discrete fully developed fracture continued to be observed, but the presence of short, segmented fractures is evident as well

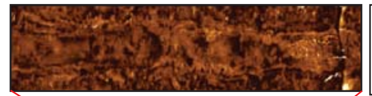


Sinusoidal features characterizing bed boundaries are visible in the compressed log scale. Looking at horizontal well, the bedding surfaces will show as high angle sinusoids and are better appreciated at a compressed scale.

Right: Bounding surfaces visible across 9600 ft, delineate the interval off a more conductive image facies characterized by an increased matrix porosity and a visible presence of vugs. Fractures presence seems drastically decreased.

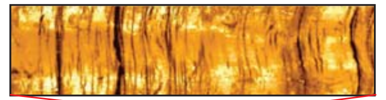


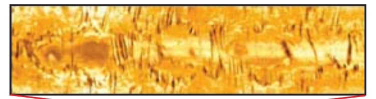


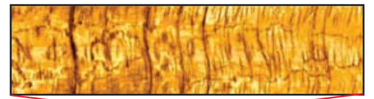


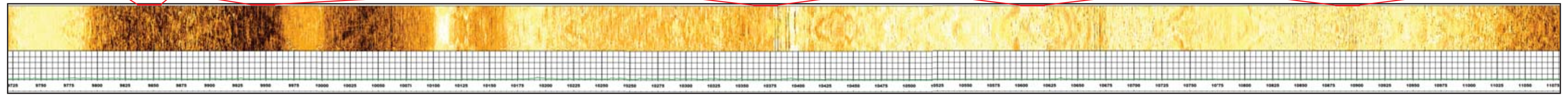
Left and Below: Facies characterized by an overall low resistivity background indicative of conductive matrix. Interesting textures are visible on images and identified with boundaries dissolution & precipitation features. Conductive features interpreted as vugs are visible on image and fractures are not predominant but present. In the figure below, the highest conductivity interval is bounded by a boundary feature.

Below: Facies characterized by an overall medium to low resistivity background indicating an overall low porosity. The predominant characteristic of this facies is the presence of fractures. They can vary in intensity: highly intensely fractured on the right, to less fractured in the middle. Fractures can vary also in the morphology: on the bottom left and bottom right, the fractures are fully intersecting the borehole, while in the middle examples, the fractures are limited in length and almost seem to be bounded to one specific interval, possibly developed along bedding. Vugs are not observed or at least not clearly visible on the image.

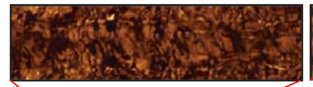


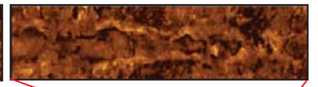


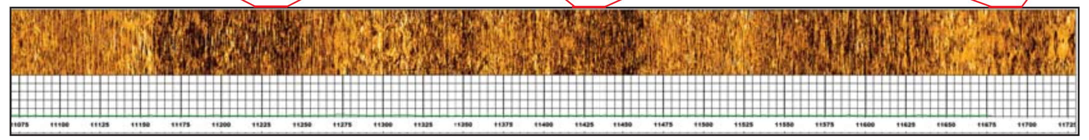




Below: The toe of the well is characterized by an overall lower background resistivity and presence of slightly different faciess. However, all of the facies are characterized by an increased presence of dissolution features. In the middle snapshot below, it is evident how some of this enlarged dissolution features are intersection features. From left snapshot to the right, we see an overall decrease in the vugs. Also observed were the differences in fracture intensity: left has a medium occurrence, middle has a high occurrence and right has a low occurrence. Looking at the compressed scale log, it gives a very good idea of the lateral facies variation, where the overall color change is indicative of tighter or more porous matrix. These variations can occur in a very short interval.







Conclusions

Advanced image log analysis can be utilized to derived facies variations related to depositional environments supported and consolidated by a detailed core description.

The facies variation can be observed equally across vertical and horizontal borehole.

The identification and classification of heterogeneities in the vertical and horizontal well shows somehow good matches allowing the identification of different facies along the horizontal well comparable to the vertical one: in particular

Facies 1 & 2 in the horizontal is comparable to the deep shelfal facies in the vertical well

Facies 4 in the horizontal well is comparable to the shallow shelf facies in the vertical well

Facies 5 in the horizontal well is comparable to the Shallow shelf bioclastic mud mound

These information can provide a valuable inside in the distribution of porosity in carbonate reservoir and help in identifying sweet spots for production.

Overall a total of 5 FMI image facies were identified and below is represented the output of the porosity classification analysis:

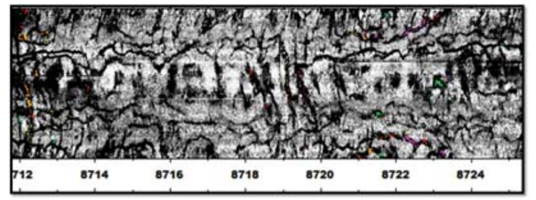
1)High background matrix resistivity with discrete fracture presence

2)Medium to High background resistivity with high presence of fractures

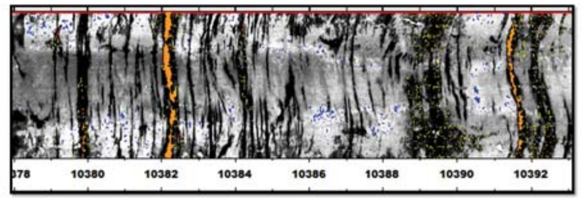
3)Medium background resistivity with segmented fractures

4)Low background resistivity with vuggy texture

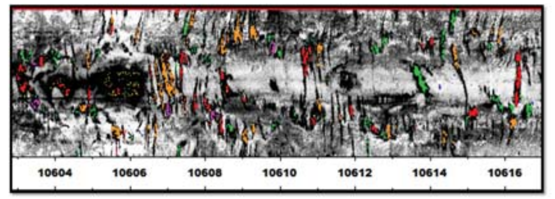
5)Low background resistivity with vuggy texture and fractures



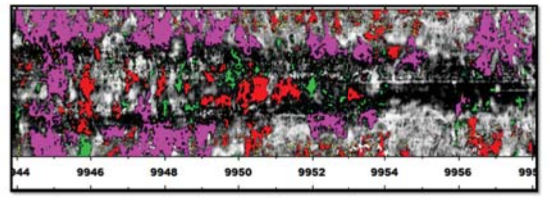
FACIES 1
Low presence of heterogeneities
Discrete fractures are the contributors to reservoir properties

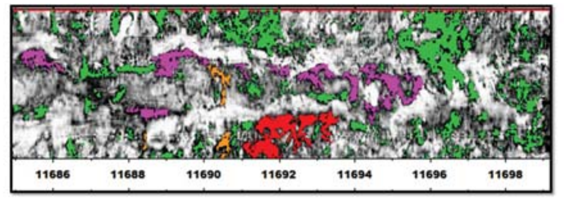


FACIES 2
Low presence of heterogeneities and if present connected to fractures
High presence of fractures is the contributor to reservoir properties

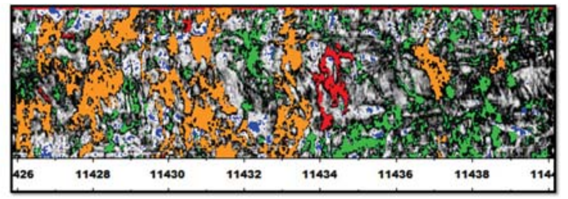


FACIES 3
Increased presence of heterogeneities of various nature.
Segmented fractures and heterogeneities equally present





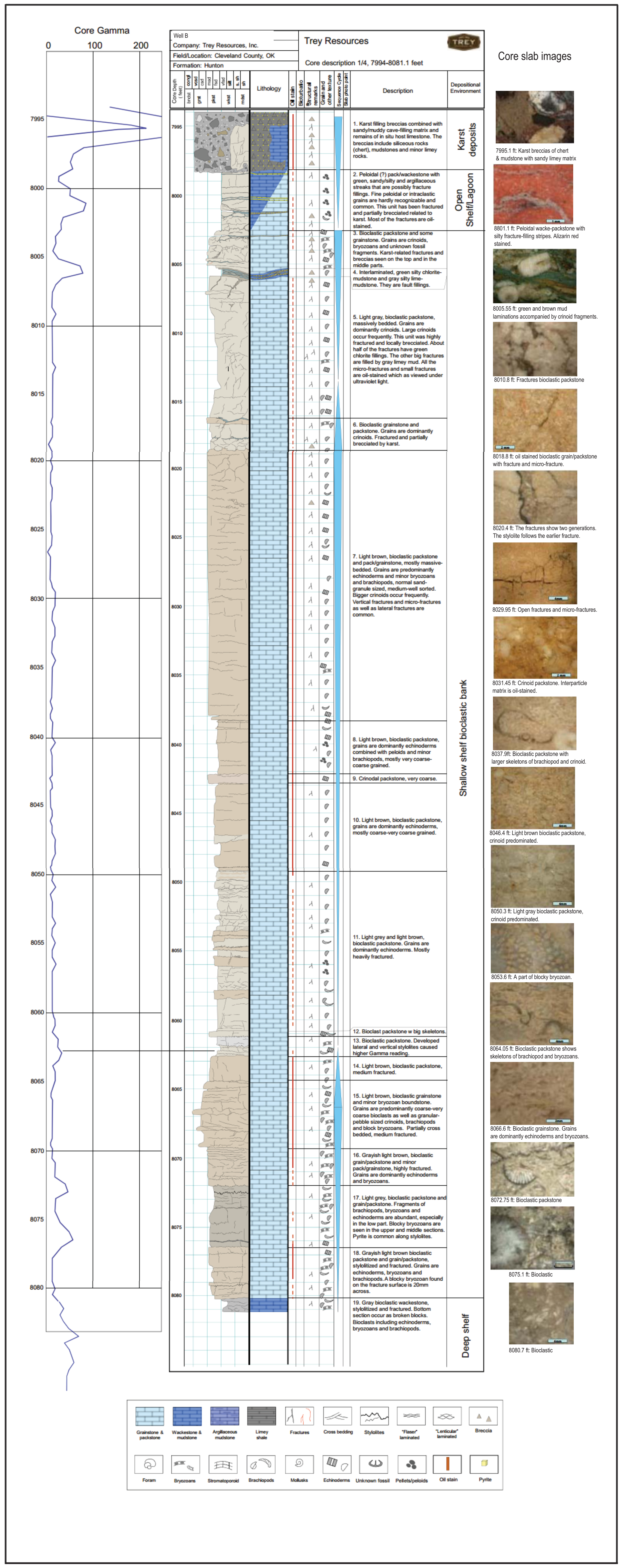
FACIES 4
Increased presence of heterogeneities and overall increased matrix porosity. Heterogeneities seem to be predominant along boundaries, connected or isolated.
Fractures do not represent a predominant feature

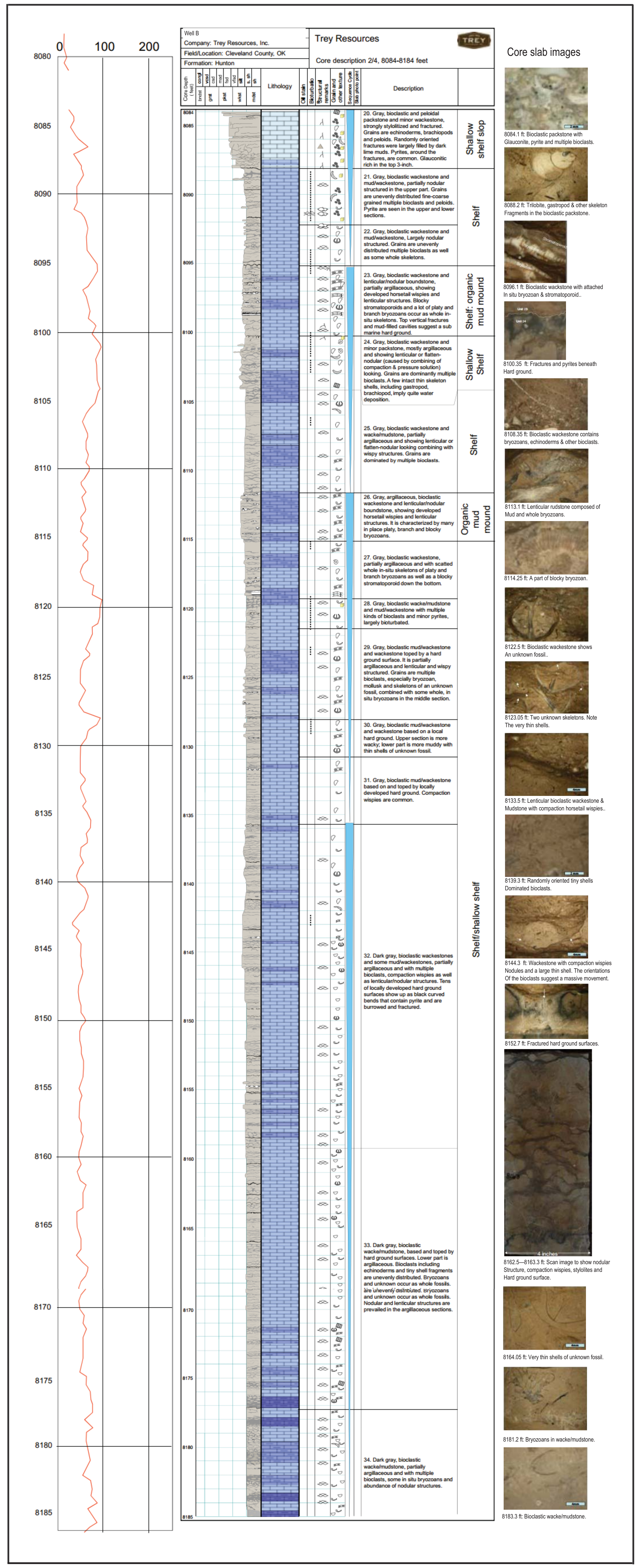


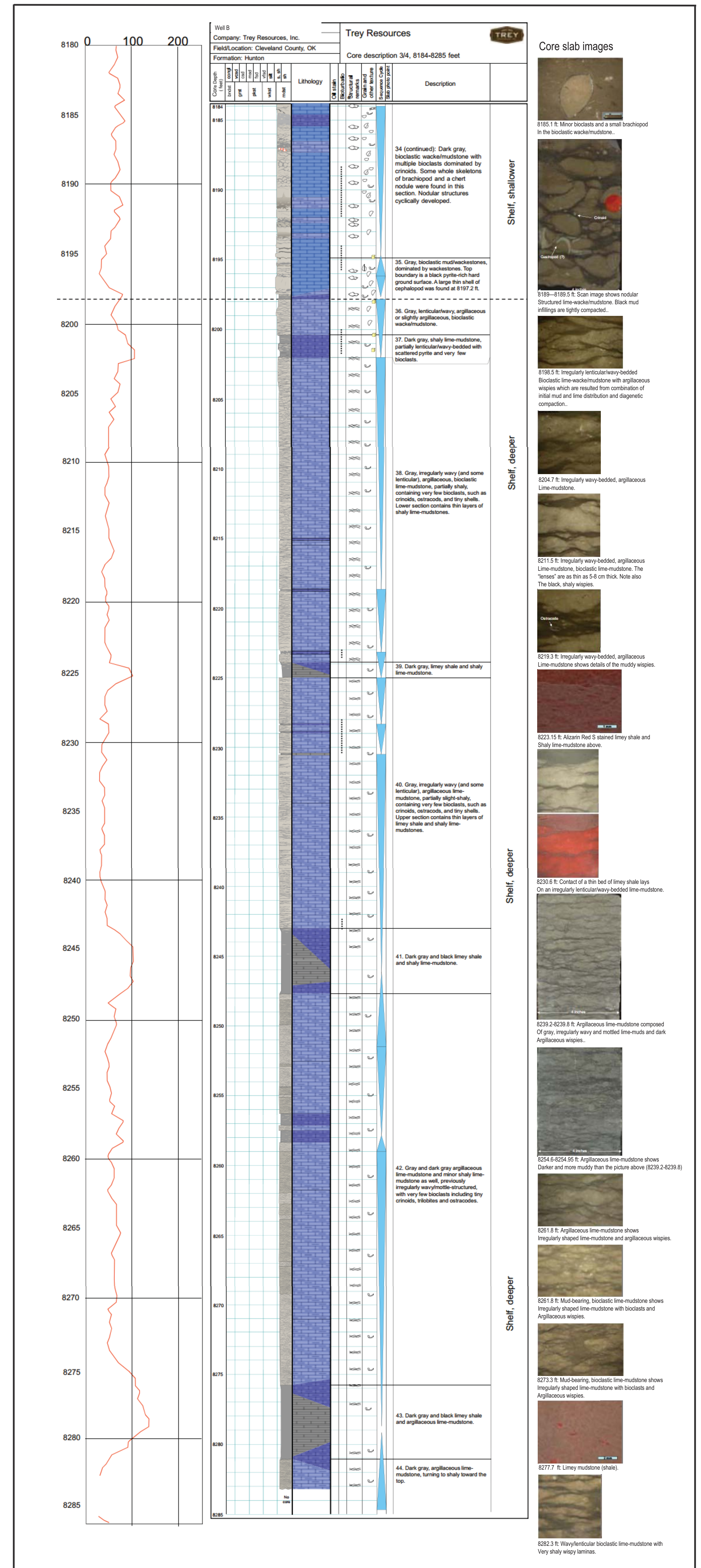
FACIES 5
Increased matrix porosity and increased heterogeneity presence. Vugs connected to fractures are the most predominant feature.
Fractures and vugs are equally highly contributing to increased reservoir properties

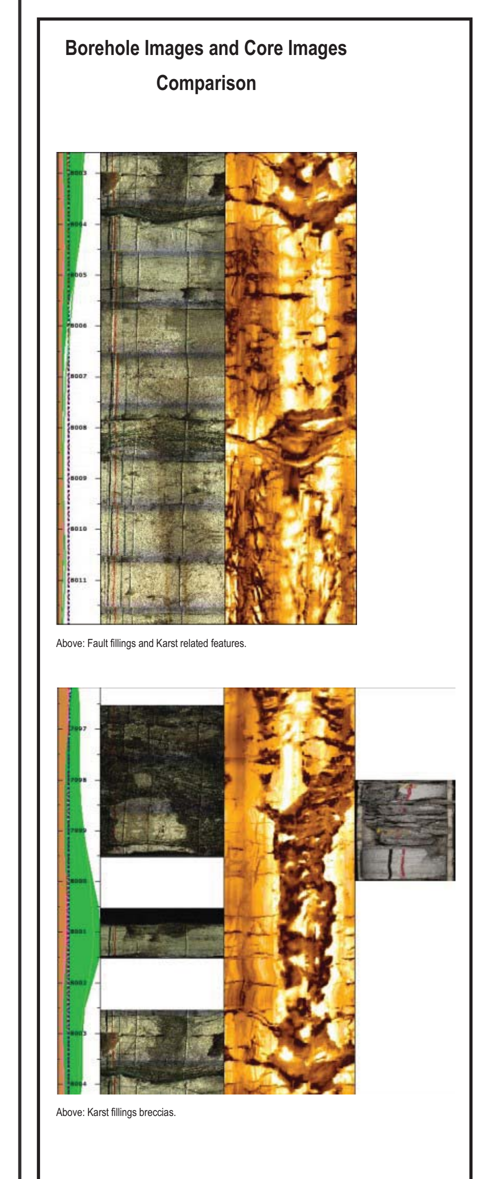
Characterization of Carbonates Through High Definition Borehole Images: Examples from Texas & Oklahoma

Tim Hunt[2], John Speight[2], Huabo Liu[2], Valentina Vallega[1], Don Christensen[1] - (1) Schlumberger, (2) Trey Resources Inc
Presenter: Dragan Andjelkovic , Schlumberger & Tim Hunt, Trey Resources









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