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

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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.

References Cited

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**ABSTRACT:**

The presence of constant heterogeneity in carbonates poses a real challenge for the full characterization of each rock. Conventional logging technologies do not have the necessary resolution to address such variations in the identification of textural boundaries, within a carbonate body. It is of paramount importance to highlight possible intervals of diagenetically altered matrix, and to cover additional porosity hidden from the standard resolution measurements. Advanced techniques in the borehole image analysis have been applied to carbonate data 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 are additionally classified in reference to their connectivity and their interaction 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 vugs in a row connected: the identification and analysis of heterogeneities in carbonates, based on borehole images, is not a novelty (Delhomme, 1992; Newberry et al, 1996; Akbar et al, 2008) but a newly revised workflow (Yamada et al 2013) allows for a more detailed description of such texture.

The proposed workflow 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 of the background conductivity against matrix values or on the presence of vugs within the matrix. Fracture segments extraction (or manual dip picking) is carried out to identify porosity associated to fractures or to identify solution enhanced features associated to bed boundaries. We invite the reader to refer to Kherroubi, 2008 for more details on the automatic fracture extraction method which is outside the scope of the present poster. In this poster we are also presenting a case study conducted in a reservoir carbonate of West 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 West Texas and have been helpful for the operators in characterizing the full porosity distribution in the reservoir. 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 of the background conductivity against matrix values or on the presence of vugs within the matrix. Fracture segments extraction (or manual dip picking) is carried out to identify porosity associated to fractures or to identify solution enhanced features associated to bed boundaries. We invite the reader to refer to Kherroubi, 2008 for more details on the automatic fracture extraction method which is outside the scope of the present poster. In this poster we are also presenting a case study conducted in a reservoir carbonate of West Texas and have been helpful for the operators in characterizing the full porosity distribution in the reservoir. The workflow shown below was created to evaluate the potential of this workflow in characterizing the full porosity distribution in the reservoir. 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 was kind enough to provide the authors with the data acquired in its wells to be included in this poster. Schlumberger wishes to thank Trey Resources for the good cooperation in completing the case study from Oklahoma.

**INTRODUCTION:**

The first oil field study presented in this poster is taken from analysis performed on West Texas carbonates 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 the 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 latest Ocean. Shallow-water carbonates were deposited on the shelf, and deep-water shales and carbonates were deposited on the slope and in the basin (Lourdas R.). Restricted environments were present in the interior of the shelf while open-marine conditions were present in the outer shelf. Diagram 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) intercrystalline, (4) crakes-missel-mosaic fractures, or (5) tectonic-related fractures. In any carbonate reservoir, the strong diagenetic overprint produces a strong spatial heterogeneity within the reservoir system and it is important to gain as much information as possible about the distribution of such heterogeneities for a better understanding of the reservoir. The application of the advanced workflow shown in the present poster has greatly helped in better understanding pore distributions and heterogeneities variability within the reservoir.

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**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 microrosetica images have several pads to acquire images which refills missing strips between pads which compaile the heterogeneity definition. Texture analysis provides satisfactory results when the heterogeneity size is smaller than the pad, but becomes inaccurate when the size of the textural features extends the pad width. Gap-filled image overcomes this possible dipolarity in the results in FILTERSIM, a second multipoint statistics (MPS) algorithm (Zhang, 2006; Hurley and Zhang, 2011) 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 features associated to bed boundaries. We invite the reader to refer to Kherroubi, 2008 for more details on the automatic fracture extraction method which is outside the scope of the present 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, matrix, fracture segments.
5) Heterogeneity delineation: image characterization and interaction cutoff. Washed transform is used to segment the image and to characterize it. A gradient image is created of the rate of change in conductivity. Each pixel 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 washed transform, neighboring mosaic pieces are merged together to form a 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 (such as fractures and bed boundaries).
6) Image porosity analysis. The porosity map is created through the below equation (Newberry et al. 1996), where \( \phi_{\text{por}} \) and \( R_0 \) are the porosity and the shallow resistivity, respectively, and \( \phi_{\text{m}} \) is the value of the conductivity image.\[ \phi_{\text{por}} = \frac{\phi_{\text{m}}}{1 + \frac{R_0}{\phi_{\text{m}}}} \]

Histograms of such texture classes are created over vertical windows (along the borehole depth) and are stacked in the same track.
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Presenter: Dragan Andjelkovic, Schlumberger & Tim Hunt, Trey Resources

Ground indicative of tight matrix. Natural conductive fractures are present in discrete intervals. Presence of dissolution features is observed in the background, possibly caused by an overall increase in the matrix porosity.

Advanced image log analysis can be utilized to derived facies variations related to depositional environments. The general response in deep shelfal environments is abundance of heterogeneities along beddings and overall porosity from image low to medium. Facies 4 in the horizontal well is comparable to the shallow shelf facies in the vertical well.

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

1) High background resistivity with discrete fracture presence
2) Medium to High background resistivity with high presence of fractures
3) Medium background resistivity with vuggy texture
4) Low background resistivity with vuggy texture and fractures
5) Low background resistivity with vuggy texture and fractures and fractures

increased presence of heterogeneities of various nature.
Segmented fractures and heterogeneities equally present
Heterogeneities seem to be predominant along boundaries, connected or not.
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8185.1 ft: Minor bioclasts and a small brachiopod in the bioclastic wacke/mudstone.

8096.1 ft: Bioclastic wackstone with attached in situ bryozoan and stromatoporoid.

8189—8189.5 ft: Scan image shows nodular structured lime-wacke/mudstone. Black mud infillings are tightly compacted.

8005.55 ft: Green and brown mud inclusions are accompanied by crinoid fragments.

8100.35 ft: Fractures and pyrites beneath.

8198.5 ft: Irregularly lenticular/wavy-bedded Hard ground.

8010.8 ft: Fractures bioclastic packstone with bioclastic lime-wacke/mudstone with argillaceous wisps which are resulted from combination of initial mud and lime distribution and diagenetic compaction.

8108.35 ft: Bioclastic wackestone contains bryozoans, echinoderms, and other bioclasts.

8018.8 ft: Oil stained bioclastic grain/packstone with fracture and micro-fracture.

8204.7 ft: Irregularly wavy-bedded, argillaceous Lime-mudstone, bioclastic lime-mudstone. The "lenses" are as thin as 5-8 cm thick. Note also the black, shaly wisps.

8113.1 ft: Lenticular rudstone composed of mud and whole bryozoans. The stylolite follows the earlier fracture.

8211.5 ft: Irregularly wavy-bedded, argillaceous Lime-mudstone shows details of the muddy wisps.

8029.95 ft: Open fractures and micro-fractures.

8122.5 ft: Bioclastic wackestone shows an unknown fossil.

8219.3 ft: Irregularly wavy-bedded, argillaceous Lime-mudstone shows details of the muddy wisps.


8133.5 ft: Lenticular bioclastic wackestone & Mudstone with compaction horsetail wisps.

8046.4 ft: Light brown bioclastic packstone, crinoid predominated.

8152.7 ft: Fractured hard ground surfaces.

8230.6 ft: Contact of a thin bed of limey shale lays on an irregularly lenticular/wavy-bedded lime-mudstone.

8139.3 ft: Randomly oriented tiny shells dominated bioclasts.

8053.6 ft: A part of blocky bryozoan.

8254.6-8254.9 ft: Argillaceous lime-mudstone composed of gray, irregularly wavy and mottled lime-muds and dark argillaceous wisps. Above: Karst fillings breccias.

8072.75 ft: Bioclastic packstone shows skeletons of brachiopod and bryozoans.

8261.8 ft: Argillaceous lime-mudstone shows irregularly shaped lime-mudstone and argillaceous wisps.

8162.5—8163.3 ft: Scan image to show nodular structure, compaction wisps, stylolites and Hard ground surface.

8075.1 ft: Bioclastic skeleton of brachiopod and bryozoans.

8164.05 ft: Very thin shells of unknown fossil.

8273.3 ft: Mud-bearing, bioclastic lime-mudstone shows irregularly shaped lime-mudstone with bioclasts and argillaceous wisps.

8181.2 ft: Bryozoans in wacke/mudstone.

8277.7 ft: Limey mudstone (shale).

8183.3 ft: Bioclastic wacke/mudstone.

8282.3 ft: Wavy/lenticular bioclastic lime-mudstone with very shaly wispy laminas.