Carbonate Reservoir Characterization Using Electrical Borehole Image – Revisited Existing Methods Using Textural Analysis Workflow*

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Abstract

Carbonate formations provide the main reservoirs in the Middle East Region. Many productive carbonate formations have complex dual porosity system consisting of primary matrix porosity and secondary porosity. The secondary porosity may comprise vugs, molds, and fractures. Electrical borehole images provide both high resolution and azimuthal coverage to quantify the heterogeneous nature of the carbonate porosity.

Porosity Spectrum Analysis (PoroSpect) is a textural analysis technique that gives porosity distribution and vug fraction quantification from high-resolution electrical borehole images such as the Formation Micro-Imager (FMI).

The primary assumption for this technique is that the conductivity measurement from the electrical images is measured in the flushed zone of the borehole. After calibration with a shallow resistivity log, the conductivity images are transformed into a porosity map of the borehole using log porosity. The following equation is used to get such transformation (Akbar et al., 2000).

$$\phi_i = \phi_{log} [R_{LLS} * C_i]^{1/m}$$

Where C_i is conductivity of each image button, R_{LLS} is external shallow flushed zone resistivity curve, ϕ_{log} is external porosity curve, **m** is Archie cementation exponent and ϕ_i is derived porosity for each image button.

A histogram of porosities over a short depth window (typically 1.2”) is computed. Different methods are then used to compute a threshold between the primary and secondary porosity.

(1) In the Newberry method (Newberry et al., 1996), the standard deviation of the porosity distribution is computed and a threshold is obtained by adding a multiple of this standard deviation to the median porosity.
(2) The SDR or Fixed-Percentage method locates the threshold at a fixed percentage above the mean porosity.

(3) The TSR Discriminant method (Ramakrishna et al., 2001) does not require any user input to define the threshold. It involves decomposing a distribution using linear discriminant analysis (LDA). This method works by grouping the data into classes by minimizing within-class scatter and maximizing between-class scatter so that within a group data are "similar" while between groups they are "different". Simply stated, if the porosity data consists of two populations, then the best threshold should maximally separate the two means.

(4) The Gaussian Extraction Optimization-based method (Goswami et al., 2006) involves multimodal decomposition of a composite distribution, in this case applied to the porosity distribution. The porosity distribution can considered as a superposition of several distributions, each corresponding to some type of pore configuration. The method selects one of the identified Gaussian distributions, classifies it as secondary porosity and computes secondary porosity by integrating the distribution.

(5) The manual method which allows user to manually set a fixed threshold per zone.

The best threshold should separate the primary and secondary porosity.

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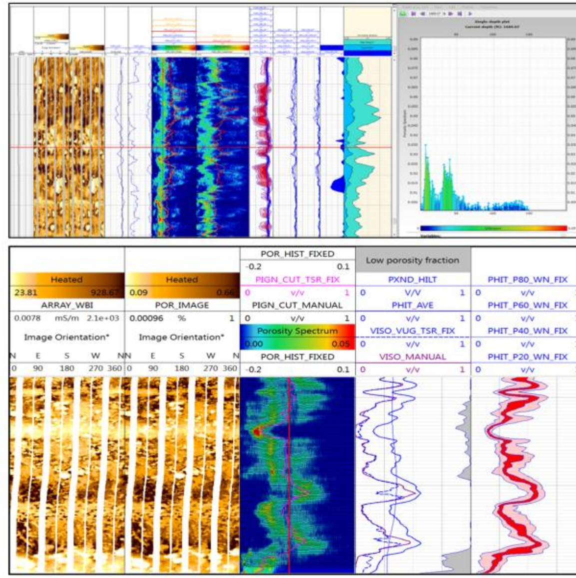
AGENDA

- Introduction
  - Porosity spectrum analysis
  - Facies analysis
- Methodology
- Define cutoff
- Example of homogeneity and heterogeneity with facies output
- Methods (WN, SDR, TSR, Gaussian and Manual)
- Electrical borehole image example
- Conclusion

Introduction

- Porosity spectrum analysis
  - Method provides porosity distribution and vug quantification
  - Valid for image acquired in WBM
  - Valid for conductive and resistive image



Presenter's notes: CARBONATE THEME (vuggy carbonate; Karst………… grain supported env. packstone, grainstone or mud supported env. mudstone or wackestone)

The PoroSpect (Porosity spectrum analysis) method provides porosity distribution and vug fraction quantification from high-resolution electrical wireline FMI borehole images or LWD GVR images . The technique is only valid for images acquired in conductive muds.

Many productive carbonate formations have complex dual porosity system consisting of matrix primary porosity and secondary porosity. The secondary porosity might contain vugs, molds and fractures. Borehole electrical conductivity and resistivity images provide both small scale resolution and azimuthal coverage to quantify the heterogeneous nature of the carbonate porosity component.

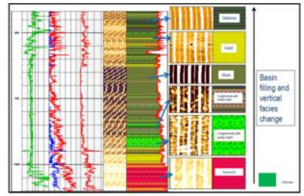
The implementation of PoroSpect in Techlog supports any calibrated borehole image scaled in conductivity or resistivity. The conductivity or resistivity data from the electrical images is measured in the flushed zone of the borehole. The calibrated electrical images are transformed into a porosity map of the borehole.

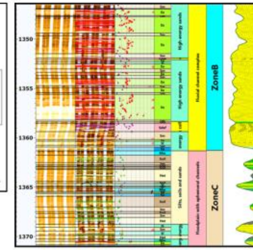
The external resistivity curve must be a shallow resistivity curve reading in the same part of the flushed zone as the image (for example: LLS or RLA3 for an FMI). If such an external curve is also used to calibrate the image, you can also use the average value of the image (for example: SRES from image calibration) smoothed to a resolution similar to that of the external porosity curve.

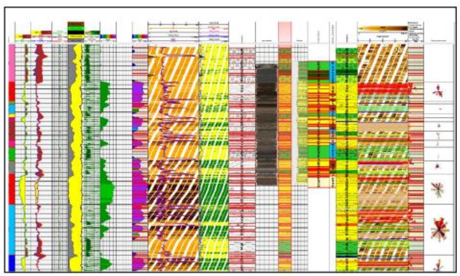
ADT data can be use for continuous Archie cementation exponential.

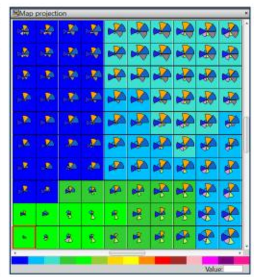
Introduction

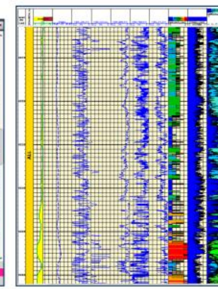
- Facies Analysis
  - Manual classification
  - Statistical analysis
  - Facies identification
  - Depositional environment





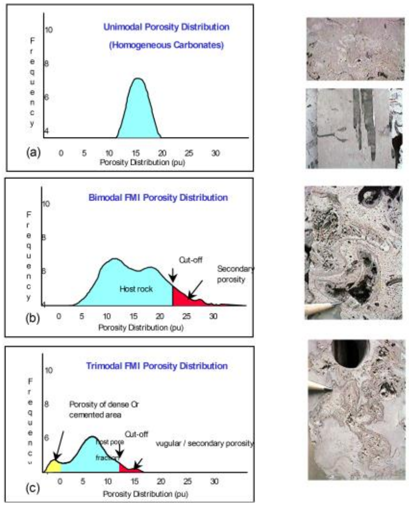


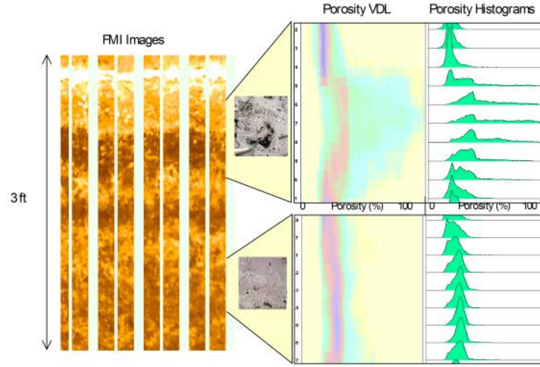




Presenter's notes: FACIES THEME (detail facies, depositional environment analysis, single and multi well correlation……)
Facies can be generate using Ipsom, MLP, HRA or manually (ex. With core description/photo reference)….
The Ipsom modules provides automatic classification solutions with both supervised and unsupervised methods. These methods are based on the neural network technology (The Kohonen algorithm). Ipsom is designed for geological interpretation of well log data and facies prediction.
The MLP (Multi Layer Perceptron) classifier tool allows you to model qualitative variables from one or several training dataset (GR, Neutron por., Density por., Sonic DT, SRES, SORT, VISO…). The module is based on the multi layer perceptron technology, a non-linear regression statistical method. This tool is very similar to K.mod but with a major difference: the variables that are modelled are qualitative and not quantitative.
Heterogeneous Rock Analysis (HRA) is a log-based rock classification method developed by TerraTek, a Schlumberger company, for the integration of core data and correlation of core data to logs in unconventional reservoirs. HRA defines rock classes based on their fundamental attributes of texture and composition as discriminated by log inputs. It is used to discriminate the material properties of the rocks.
Depositional environment is manually indentify by the user after considering all the information extract from the analysis.
Sand dispersal analysis can be integrated into the model for each reservoir zone for single and multi wells study.

Methodology





$$(\Phi)_{FMI} = (\Phi)_{LOG} * [LLS * Ci]^{1/m}$$

Ci is conductivity of each FMI electrodes, m is cementation factor, $(\Phi)_{LOG}$ is log porosity

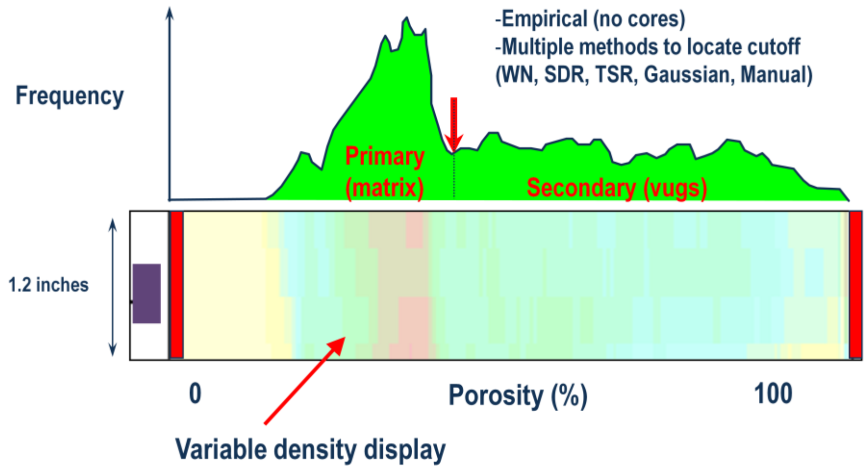
SPE 87297
Petrophysics, Vol. 50 No.1, 2009, p.67-78.

Presenter's notes: ***WN Threshold Method:*** In this method, first the standard deviation of the histogram below the median porosity is computed. Then the threshold value is obtained by adding a multiple of this standard deviation to the median porosity. Generally the value of the multiple is taken as 3; however this is not fixed. It can be increased or decreased based on the calibration of the porosity results with cores.
SDR or Fixed-Percentage Threshold Method: This is a variant of WN method. It locates the threshold at a fixed percentage (typically 15 %) above the mean porosity. The percentage value is not fixed. It may be greater or smaller than 15 %. Core observation / measurement provide a way to fix its value.
TSR or Discriminant Threshold: This method does not require any user input to define the threshold. It involves the use of Discriminant Threshold Selection Algorithm, which is based on the standard linear discriminant analysis used in the field of pattern recognition and statistics. This method works on the idea that if the porosity data consists of two populations, then the best threshold should maximally separate the two means.

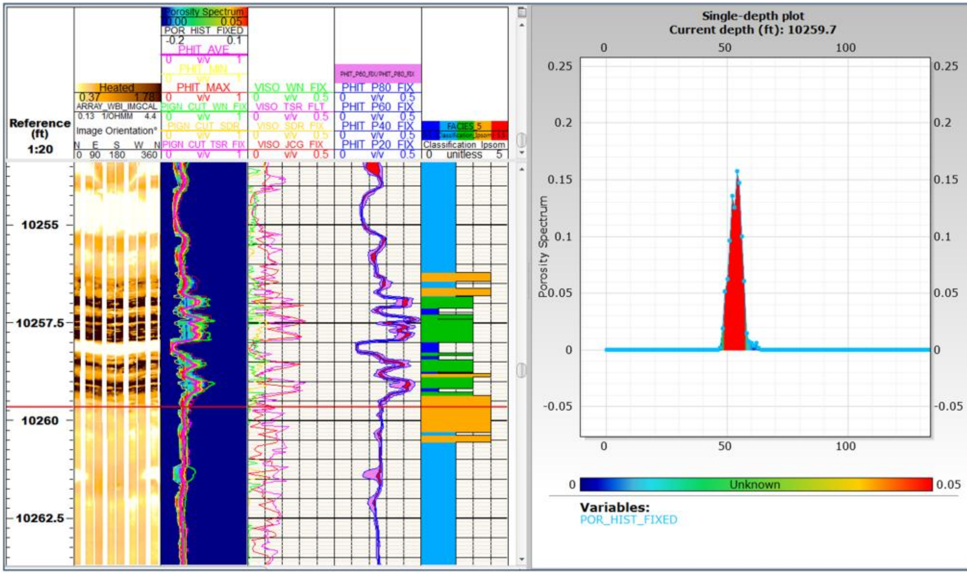
Define Cutoff

Total Porosity = Primary + Secondary

Cutoff separating two porosity type
-Calibrated with cores
-Empirical (no cores)
-Multiple methods to locate cutoff
(WN, SDR, TSR, Gaussian, Manual)

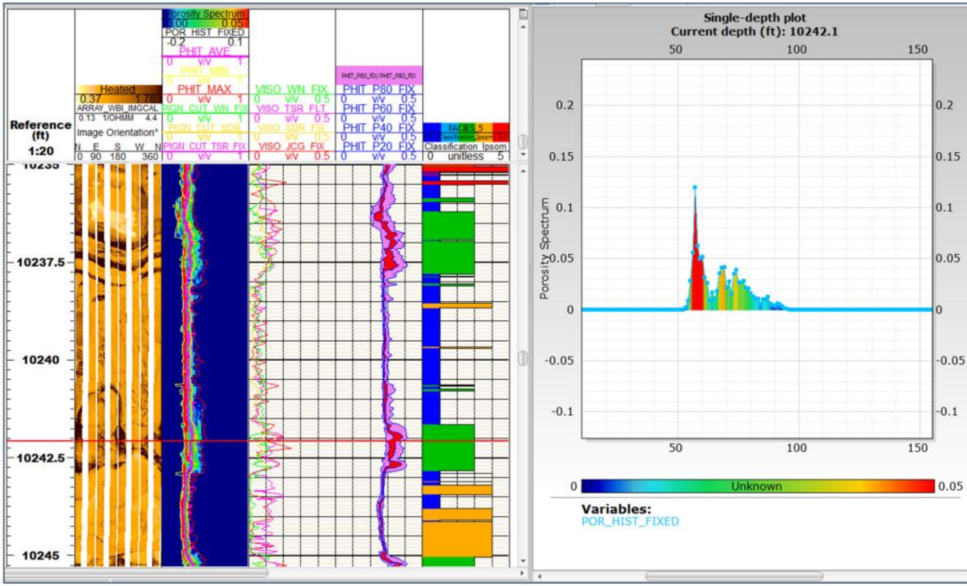


Example of Homogeneity & Heterogeneity with Facies



- Example of heterogeneity

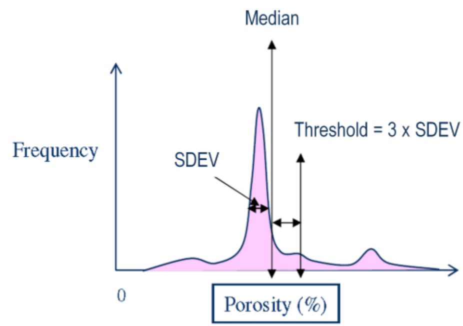
Example of Homogeneity & Heterogeneity with Facies



- Example of heterogeneity

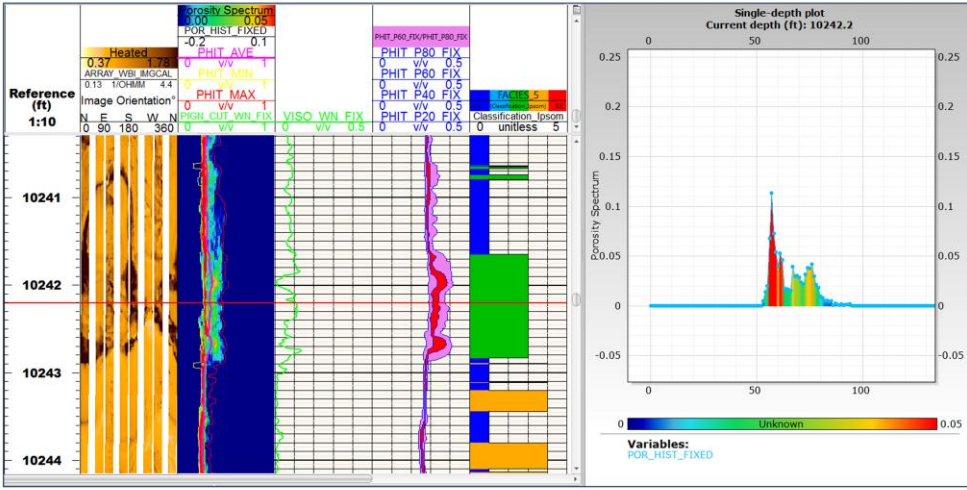
WN (William Newberry) Method

- Standard Deviation (SDEV) of the histogram below the median porosity is computed
- Threshold is obtained by adding a multiple of the SDEV to the median porosity
- Default value of the multiple is taken as 3 x SDEV
- Work well in low porosity West Texas carbonate



Presenter's notes: The threshold is obtained by adding a multiple of this standard deviation to the median porosity. Generally the value of the multiple is taken as 3 standard deviation.

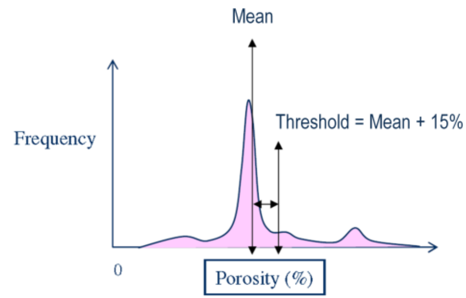
WN (William Newberry) Method



Presenter's notes: The threshold is obtained by adding a multiple of this standard deviation to the median porosity. Generally the value of the multiple is taken as 3 standard deviation.

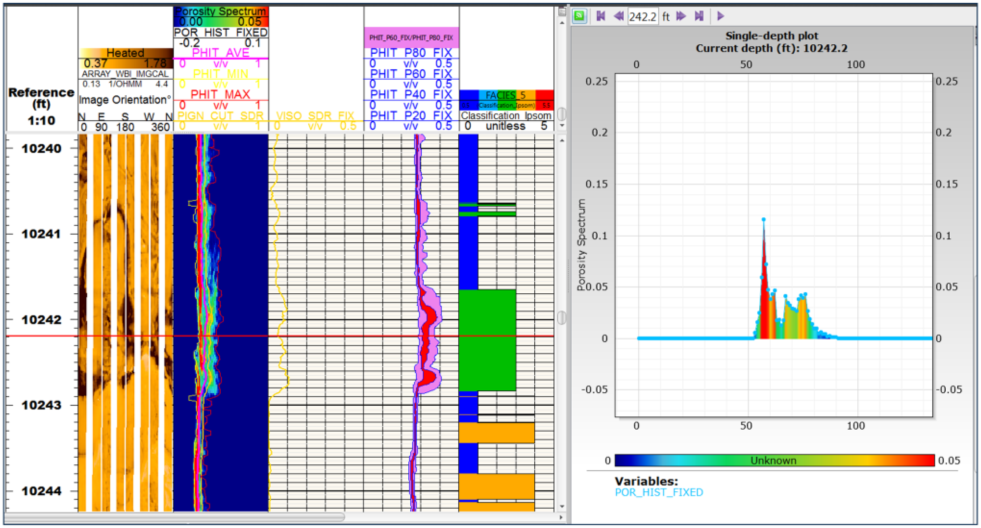
SDR or Fixed-Percentage Method

- Threshold locates at user-defined fixed percentage
- Default value is 15% above the mean porosity
- Work well in high porosity Middle East carbonate



Presenter's notes: It locates the threshold at a user defined fixed percentage (default value 15 %) above the mean porosity. Core observations and measurements provide a way to calibrate this value.

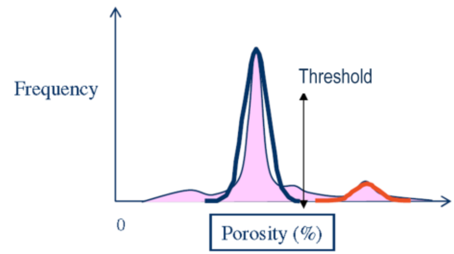
SDR or Fixed-Percentage Method



Presenter's notes: It locates the threshold at a user defined fixed percentage (default value 15 %) above the mean porosity. Core observations and measurements provide a way to calibrate this value.

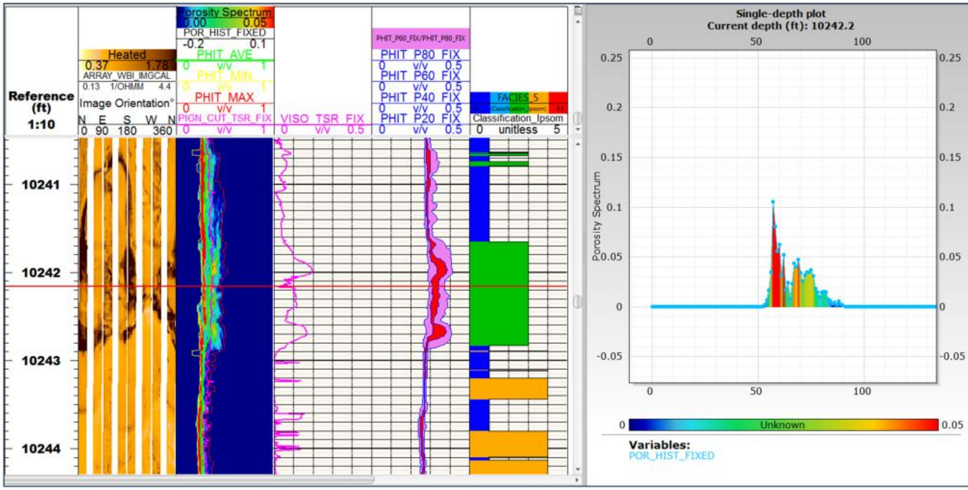
TSR (T. S. Ramakrishnan) Discriminant Method

- Decomposing a distribution on linear discriminant analysis (LDA)
- Data are grouped into classes by minimizing within-class scatter and maximizing between-class scatter
- Within a group data are similar
- Between groups data are different



Presenter's notes: This method works on the idea that the data are grouped into classes by minimizing within-class scatter and maximizing between-class scatter so that within a group data are "similar" while between groups they are "different". Simply stated, if the porosity data consists of two populations, then the best threshold should maximally separate the two means.

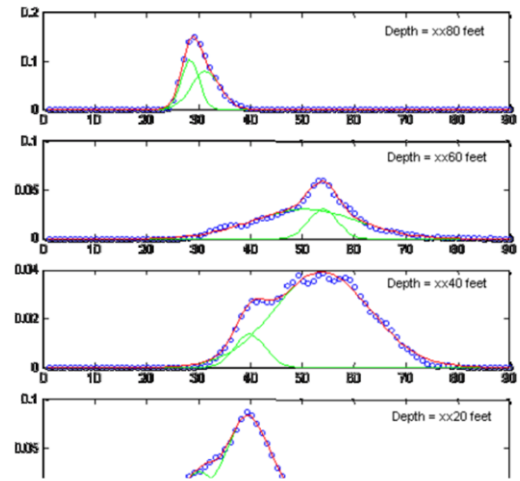
TSR (T. S. Ramakrishnan) Discriminant Method



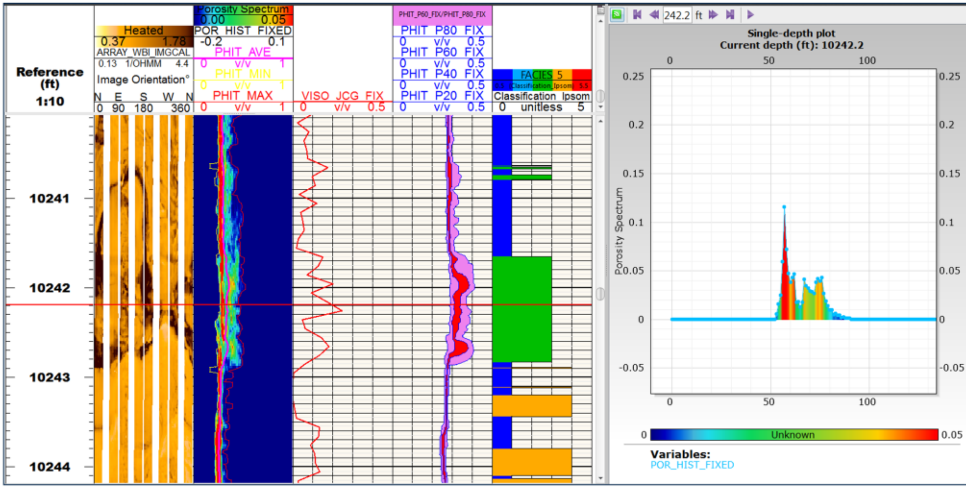
Presenter's notes: This method works on the idea that the data are grouped into classes by minimizing within-class scatter and maximizing between-class scatter so that within a group data are "similar" while between groups they are "different". Simply stated, if the porosity data consists of two populations, then the best threshold should maximally separate the two means.

Gaussian Extraction Optimization-based Method

- This optimization-based method is designated as JCG (Jaideva C. Goswami)
- Multi-modal decomposition of a composite distribution, applied to the porosity distribution which can be superposition of several distributions, each corresponding to some type of pore configuration
- The method identifies one of the gaussian distributions as secondary porosity and computes the secondary porosity by the integrating the individual

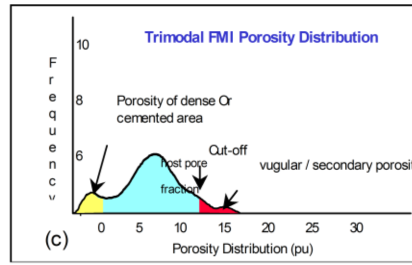


Gaussian Extraction Optimization-based Method

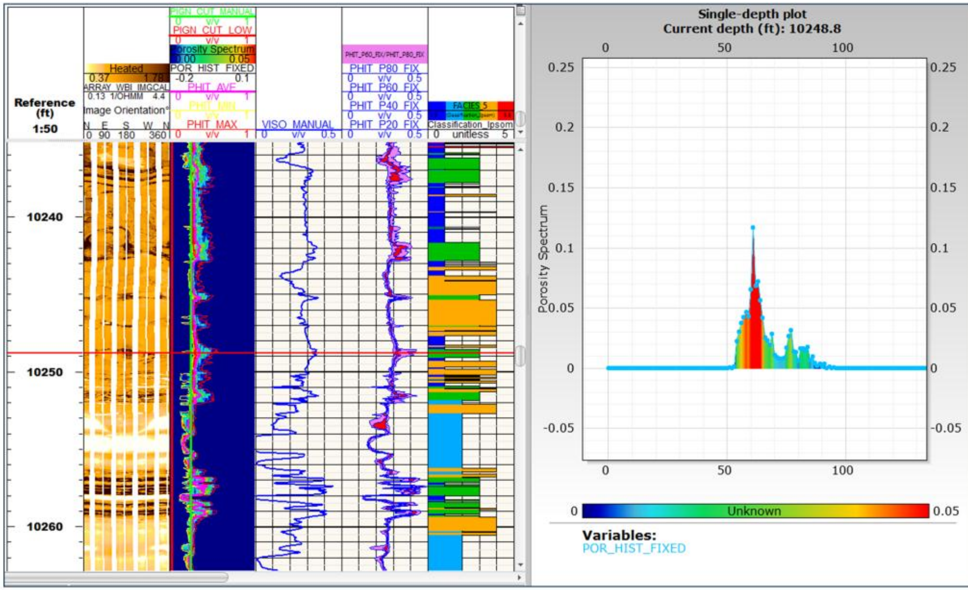


Manual Method

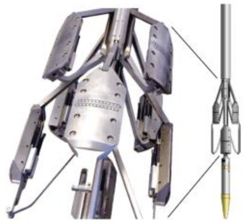
- Manually set a fixed threshold per zone
- Low porosity fraction threshold to exclude porosity of dense or cemented area

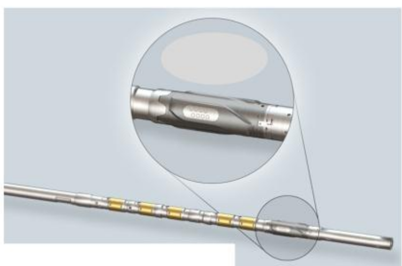
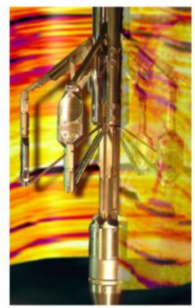


Manual Method



Electrical Borehole Image




Conclusion

- Applications:
  - Carbonate reservoir
  - Complex dual porosity system
  - Water base mud condition
  - Calibrated electrical borehole image scaled in conductivity and resistivity
- Benefits:
  - Porosity distribution
  - Vug fraction quantification
- Features:
  - Different cutoff methods
  - Vendor neutral
  - Combinable with other modules


ANY
QUESTIONS
?