

Application of Borehole Imaging to Evaluate Porosity and Permeability in Carbonate Reservoirs: from Example from Permian Basin*

D.V. (Vivek) Chitale¹, Clive Johnson², Hunter Manley³, David Entzminger⁴, and Lyn Canter⁵

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¹Reservoir Evaluation Services, Halliburton, Houston, TX.

²Reservoir Evaluation Services, Halliburton, Ft Worth, TX. (clive.johnson@halliburton.com)

³Faskin Oil and Ranch, Ltd., Midland, TX.

⁴Permian Basin, Whiting O&G, Midland, TX.

⁵Exploration and Production, Whiting O&G, Denver, CO.

Abstract

This paper presents a case history of applying modern borehole image interpretation techniques to carbonate reservoir evaluation in a development well from the Permian Basin. The new borehole image interpretation technique was developed specifically to evaluate the porosity and permeability of carbonate reservoirs by integrating the high resolution data from an electrical borehole image log with the conventional wireline logs.

As shown in the paper, the Xtended Range Micro-Imager (XRMI) with improved signal to noise ratio and expanded dynamic range, was able to generate very high resolution borehole images showing millimeter size features in the fabric of carbonate beds. The micro-conductivity signal was then analyzed with the help of a newly developed software technique that first equates the total signal with total porosity that is then resolved into fractions correlatable with micro-, primary- and secondary porosity. The new technique of image interpretation uses published models to equate carbonate rock types and their porosity types with permeability.

Integrated analysis of XRMI and other logs from a well drilled in a Wolfcamp carbonate reservoir in the Permian Basin (USA) shows that the facies and layer boundaries, the internal fabric of the carbonates, and the estimates of different porosity fractions and permeability determined by using the new imager and the new interpretation technique closely follow the core descriptions and laboratory analysis of porosity and permeability. The results are encouraging as these correlations should be applicable to newly drilled wells in similar geological facies in this region where there is no core control.

Application of Borehole Imaging to Evaluate Porosity and Permeability in Carbonate Reservoirs: A Case Study From Permian Basin, USA.

D. V. (Vivek) Chitale and Clive Johnson
Reservoir Evaluation Services, Halliburton
Hunter Manley, Faskin Oil & Ranch

David Entzminger and Lyn Canter:
Whiting O&G Corp., USA

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Introduction

- Accurate estimation of petrophysical parameters in carbonates is essential
- Complex pore geometries in carbonate rocks governed by both depositional and diagenetic processes
- Full diameter core offers best solution but expensive
- Conventional resistivity and porosity logs not adequate by themselves
- Borehole imaging combined with other open hole logs help classify facies when calibrated to core analysis

To evaluate storage and flow of hydrocarbons

Core description expensive on a regular basis in field development

Introduction

- The software technique equates total image signal to total porosity (X-Plot or NMR)
- Helps resolve total porosity into micro, primary and secondary porosity fractions
- Estimate permeability based on models published by Jennings and Lucia, equating porosity to permeability via rock fabric typing.

Micro – Porosity filled by immovable wetting fluid

Interparticular - fluids that can flow

Secondary – Vugs and dissolution features that may or may not contribute to fluid flow – Dependant on connectivity

Helps incorporate a geological relationship. Important to have full core description to determine rock type. Rock types can then be used for other wells in the field with no core.

Carbonate pore space evaluation and borehole image logs: prior work

- Increased higher resolution of modern electrical imagers and increased computational power
- More focus on these issues including work from:
 - Newberry et al, 1996
 - Russell et al, 2002
 - Xu et al, 2005
 - Chitale et al, 2006
- Understanding of relationships between geological rock fabric in carbonates versus porosity and permeability:
 - Lucia, 1995
 - Wang et al, 1998
 - Jennings, 2000
 - Jennings and Lucia, 2003

Work aided by higher resolution and increased computational power.

Case Study

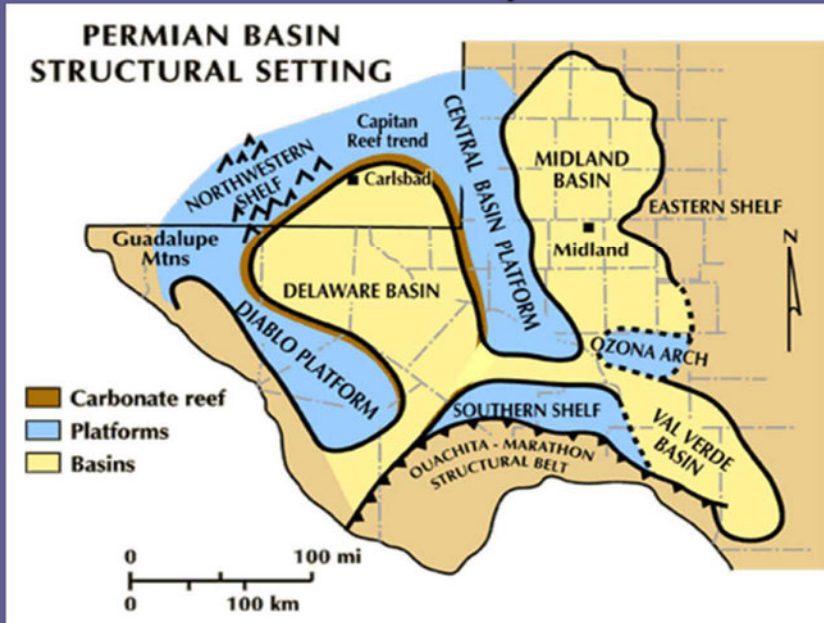
- Based on work by Vivek Chitale et al (2007) on a well drilled by Whiting Oil and gas Corp. in the Wolfcamp reservoir in Permian Basin
- Permian Basin "home" for carbonate reservoirs with complex textures and pore geometry
- Full suite of open hole wireline logs including sonic, NMR and electrical imager
- Extensive conventional core for log calibration.

Well was ideal because Permian with complex textures and geometries

Great thing about this well was the data obtained

Grateful to David and Lynn at Whiting Oil and Gas for releasing the data for publication. Hope you got a chance to see their great poster presentation on Monday.

Field Map



Several basins and uplifts

Case study well drilled on the Central Basin Platform

Borehole Image Logs

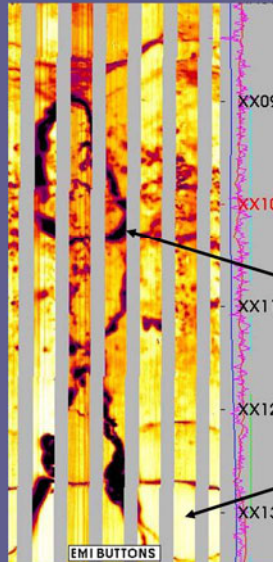


Image due to micro-resistivity contrast

Water Based Mud

Darker – Less resistive

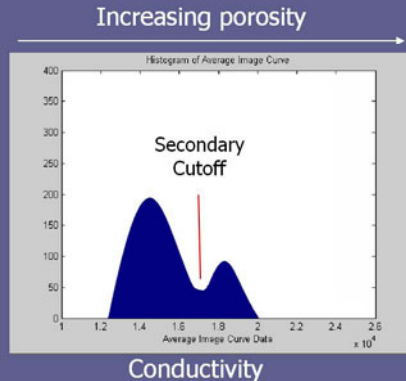
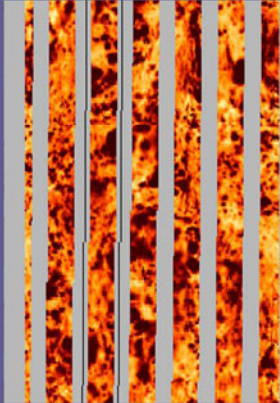
Lighter – More resistive

Conductive mud filtrate will fill pore space.

Solution enhanced fracture filled with conductive mud filtrate

Porosity versus Conductivity Histogram

In a clean carbonate, increasing porosity seen as a darkening of image coloration as pores are filled with conductive mud filtrate

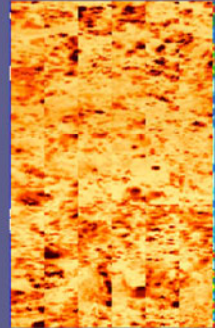
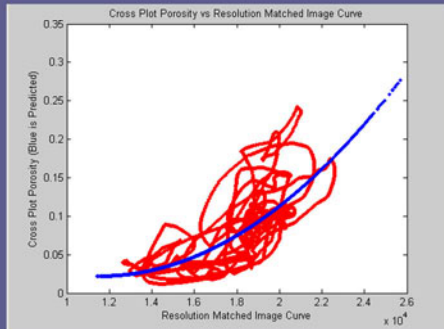


Need to eliminate effect of clay bound water on porosity calculation;
large pores typically generate a peak toward far right of the histogram

The histogram has been observed to be bi-modal which allows us to distinguish between primary and secondary porosity types

Porosity Estimation

- Plot the average image conductivity against the cross plot or NMR porosity
- Applying Linear, Quadratic or power law regression to best fit the data



Porosity map by
applying regression to
individual pixels

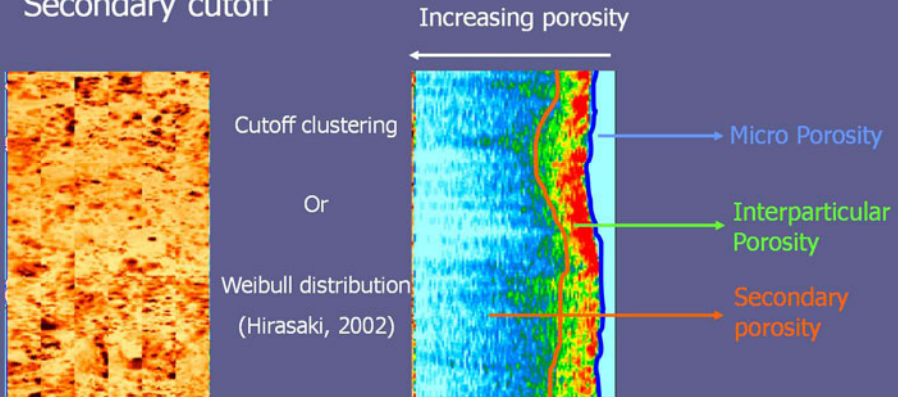
Take one depth point (120 SPF) and plot against corresponding cross plot or NMR

User defined Regression to best fit the data.

Apply regression to conductivity image pixels to give us a porosity map

Porosity Partitioning

Histogram analysis to determine Micro cutoff and Secondary cutoff

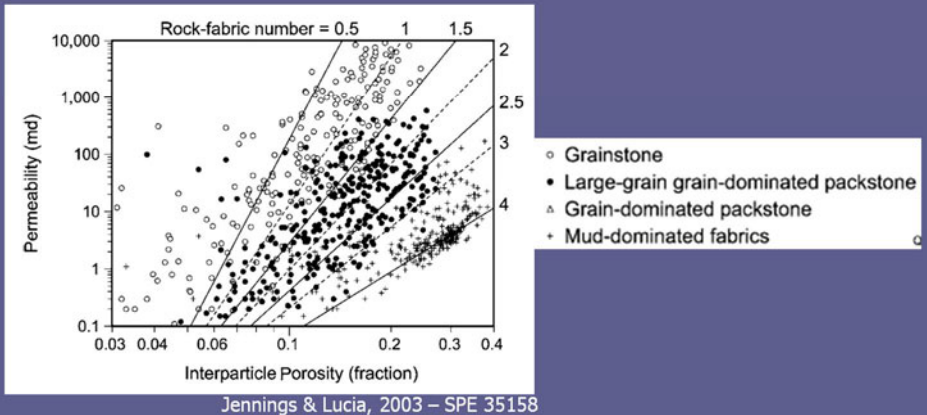


Perform histogram analysis on porosity map to determine Micro and Secondary cutoff

Allows us to estimate micro, interparticular and secondary porosity fractions

Permeability Estimation

- Input high resolution image porosity
- Determine rock fabric number, preferably from core analysis. Zone formation if necessary

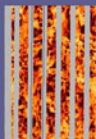


We have high resolution image porosity

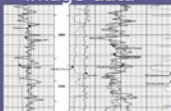
Need to determine rock fabric number, preferable from core analysis. So we can estimate permeability based on the Jennings & Lucia model.

This allows consideration of rock typing instead of relying on purely mathematical regressions

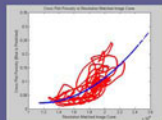
Workflow Summary



High Resolution
image data

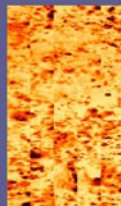


Conventional Cross-plot
or NMR Total porosity

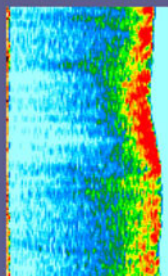


Filter to match
resolutions

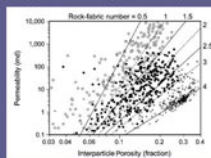
User defined
Regression to
porosity image map



Histogram analysis



Jennings-Lucia
permeability from rock
type and porosity



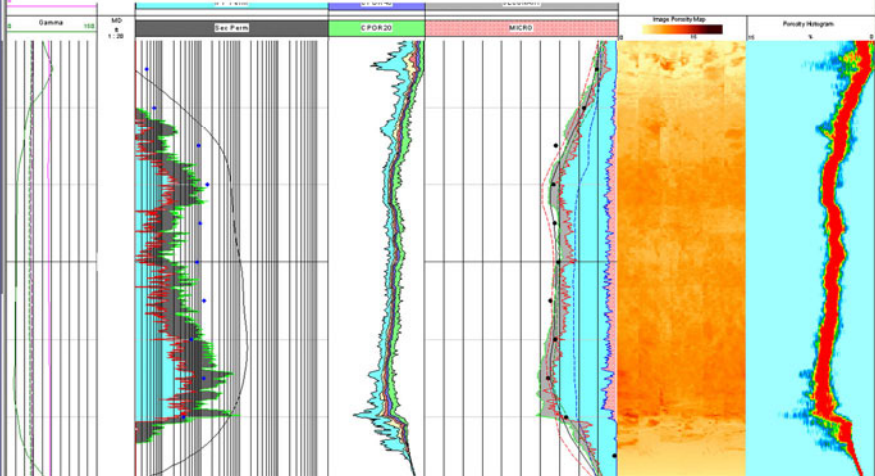
Predict Micro,
Primary and
Secondary
permeability
fractions

Predict Hi Res
Micro, Primary
and Secondary
porosity
fractions

Results

Now go onto results of the case study

- Main pay zones in upper part of Wolfcamp formation
- Well sorted, coarse grained packstones and grainstones
- Primary interparticular enhanced by secondary meteoric dissolution



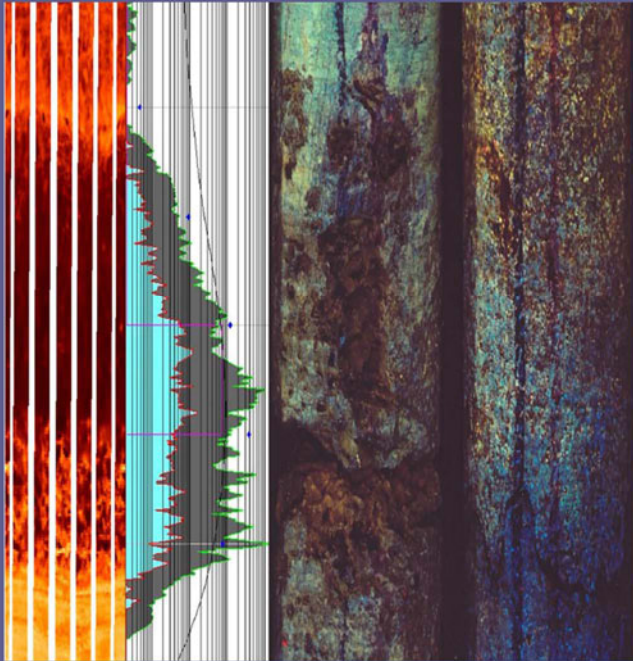
Concentrate on two main zones that are significant in the Wolfcamp formation

Here is the log from the Image Perm software showing the upper section. Explain log

Deposited as a series of stacked shoals along the platform margin primarily interparticular porosity enhanced by meteoric dissolution.

As this zone is primarily driven by interparticular porosity we do not see much variation on the histogram

Image to Core comparison

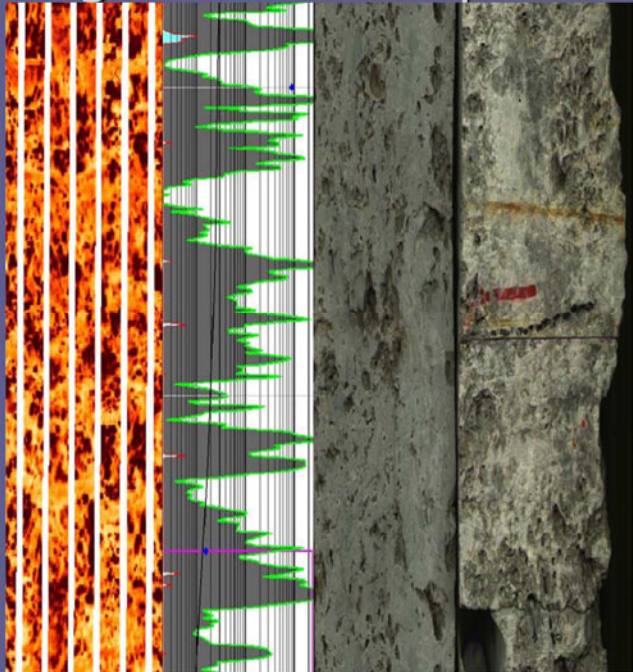


Great correlation between the image and the core in the well

Here we have the Image and permeability estimation against the core for the upper grainstones and packstones.

High permeability as expected from the Jennings – Lucia model

Image to Core comparison



Boundstone facies shown with the inner polished and outer rugged surfaces of the core.

Clearly see the corresponding vugs and cavities in both the image and core

Exhibited highest porosity >24% and permeability >4000 mD

Cross checks

- Image Primary and secondary porosity against sonic porosity
- Image Porosity and Permeability with Core Porosity and permeability
- Image micro porosity with NMR BVI (Bulk Volume Irreducible)

The cross checks we can make to validate the results are firstly to use the sonic porosity against image primary and secondary porosity

Image porosity and permeability with core porosity and permeability

Image micro porosity with NMR BVI porosity

Summary

- Image interpretation technique can provide reasonable predictions of micro, primary and secondary porosity
- Estimates of permeability can be derived from image porosity and rock type using Jennings-Lucia model
- Technique provides 'high resolution' porosity and permeability, important in characterizing complex carbonate reservoirs
- Applicable to field wide studies based on 'calibration' to core on select wells

Since we have a core calibration we apply it to field wide studies.

Selected References

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