PS Resistivity Indication of Reservoir Flow Potential in Carbonate Rocks: A Case Study of Little Cedar Creek Field, Onshore Alabama*

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Abstract

In carbonate reservoir characterization, permeability is one of the most difficult reservoir properties to estimate and it can be influenced by many factors such as pore structure and pore size, in addition to porosity. Pore structure can greatly affect both the electrical and the hydraulic behavior of the reservoir. The purpose of this study is to investigate the resistivity response of different pore structures in comparison with sonic velocity, for a better understanding of the relations between resistivity, velocity and permeability, in order to map the distribution of potential fluid flow zones. Cementation factor ‘m’ in Archie's law has been found to be related to carbonate pore structure and explains the electrical resistivity variations at a given porosity. In highly heterogeneous carbonates, simple assumption of a default value of m such as two for calculation of the hydrocarbon saturation in different pore systems can lead to inaccurate result. In this report, the variation of cementation factor derived from resistivity, density, velocity logs acquired in a carbonate formation onshore Alabama is taken into consideration and investigated to relate to diagenetically generated high permeable zones. Detailed petrophysical analysis of over eight wells and petrographic analysis of thin sections demonstrate that “m” could be a good indicator of pore structure.

Resistivity indication of reservoir flow potential in carbonate rocks: a case study of Little Cedar Creek Field, onshore Alabama

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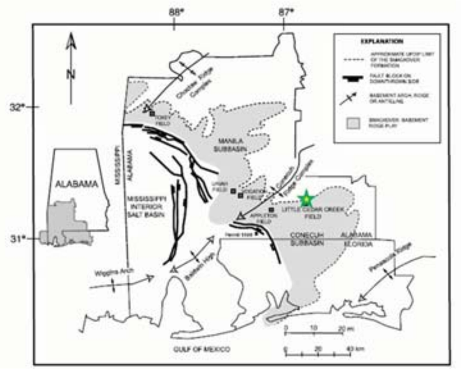
Summary

Cementation factor "m" in Archie's law has been found to be related to carbonate pore structure and explains the electrical resistivity variations at a given porosity. In highly heterogeneous carbonates, understanding the variation of the cementation factor in different pore systems is important for accurate estimation of both hydrocarbon saturation and permeability. In this report, we derive the cementation factor from resistivity and density logs from an onshore carbonate formation in Alabama. We investigate the large range in cementation factor and relate these values to high-permeability zones resulting from diagenesis. Detailed petrophysical analysis of over 8 wells reveals that "m" is a good indicator of pore structure. From log analysis, we find that for 1<m<1.9, the dominant pore type is micropores; for 1.9<m<2.1, the dominant pore types are intercrystalline and intergranular; and for 2.1<m<3, the dominant pore type is vuggy. It is also found that m deviation log relative to a value of 2 agrees well with the velocity deviation log relative to the velocity calculated using time -average equation. Both deviations have similar trends with permeability measured from cores, especially in high permeability zones which can be correlated to positive m and Vp deviation logs. In the studied field, the two high fluid flow zones can have m deviation as high as 0.9 with an average m deviation of 0.4 for the two zones.

Regional Geology

Regional map

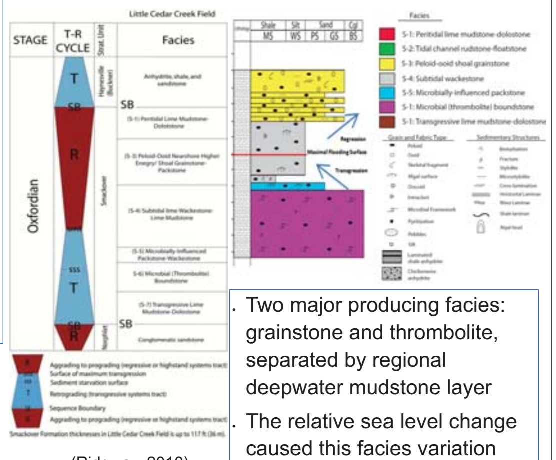


Field located at the upper limit of Smackover formation

Smackover Formation deposited on carbonate ramp on the northern rim of the Gulf of Mexico

(Mancini, 2008)

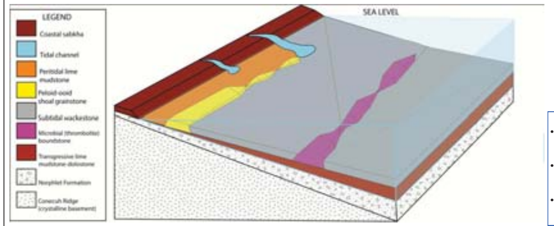
Sequence stratigraphy& Seimentary facies



(Ridgway, 2010)

- Two major producing facies: grainstone and thrombolite, separated by regional deepwater mudstone layer
- The relative sea level change caused this facies variation
- Little dolomitization

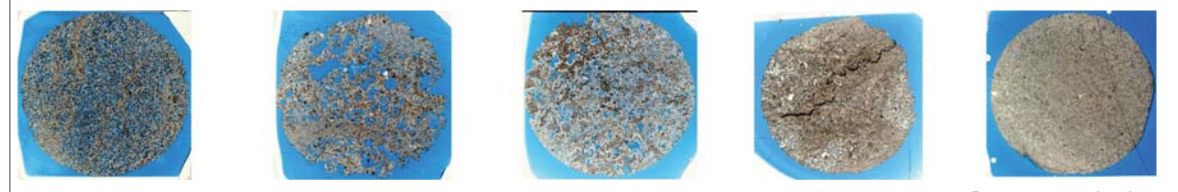
Depositional model



(Ridgway, 2010)

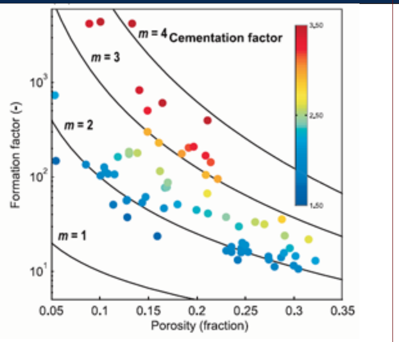
- *Grainstone*: high energy, near shore
- *Mudstone*: Low energy, basinal or peritidal
- *Thrombolite*: Patch reefs locally, on topographic highs

Pore type variation



Grainstone moldic pore | Thrombolite vuggy pores | Dolomitized thrombolite | Stylolite | Dense, cemented grainstone

Previous Laboratory work



(Verwer, Eberli, 2010)

Data used

- Resistivity log, RWA
- Density, Neutron and Sonic porosity
- Density-derived porosity (based on core measurement)
- Core porosity and permeability
- Sonic velocity

Basic Formula

Archie's law

$$FF = \frac{Rt}{RWA}$$

$$m = \frac{\log \frac{a}{FF}}{\log \phi}$$

Assumption: a= 1

m=2 for intergranular/intercrystalline pores (Dullien,1992)

Wyllie's equation(1956)

$$\frac{1}{Vw} = \frac{1-\phi}{Vm} + \frac{1}{Vf}$$

Velocity of matrix (Vm) =6530m/s

Velocity of water (Vf) =1500m/s

$$\triangle V = V - Vw$$

$$\triangle m = m - 2$$

High permeability zones

Rock physics model

$$V_p = \sqrt{\frac{k + \frac{4}{3}\mu}{\rho}} \quad V_s = \sqrt{\frac{\mu}{\rho}}$$

$$K_d = K_s(1-\phi)^{\gamma}$$

$$\mu_d = \mu_s(1-\phi)^{\gamma_u}$$

$$K = K_d$$

$$\mu = \mu_d$$

For gas reservoirs (Sun, 2004)

$$c = \frac{\gamma}{\gamma_u}$$

Assumption: $c = c_0 m$

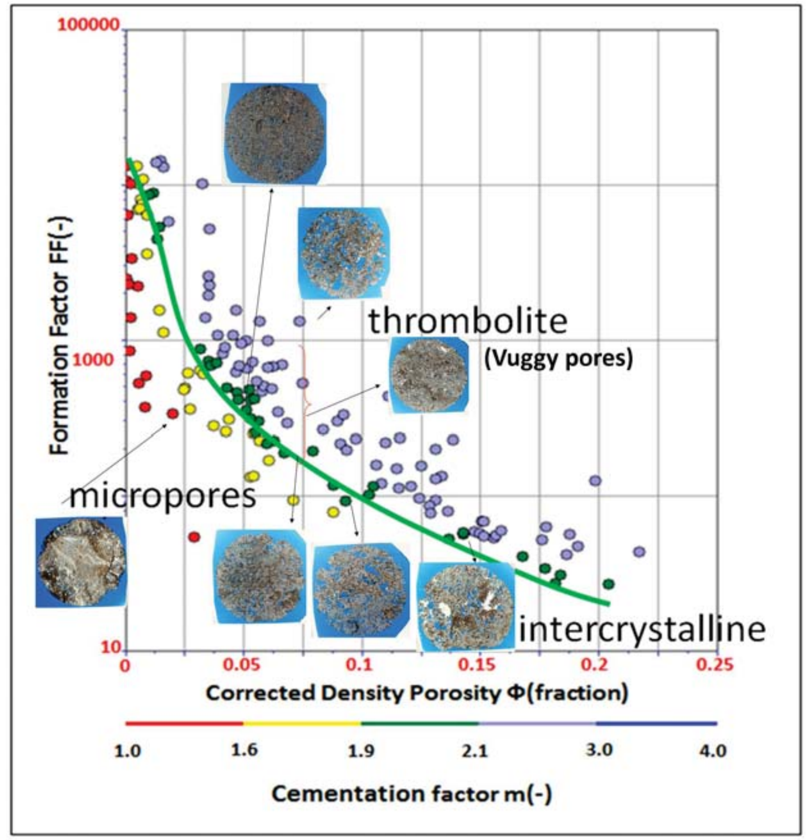
$$\frac{V_p}{V_s} \approx \sqrt{c_0 m * \frac{K_s}{\mu_s} + \frac{4}{3}}$$

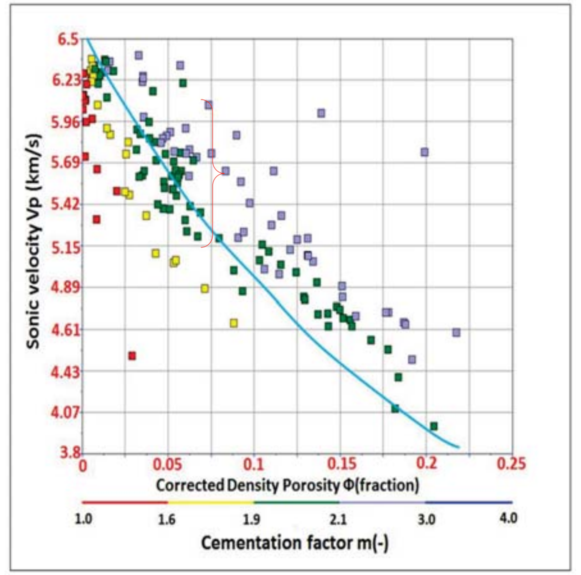
V_s

Apply the model again

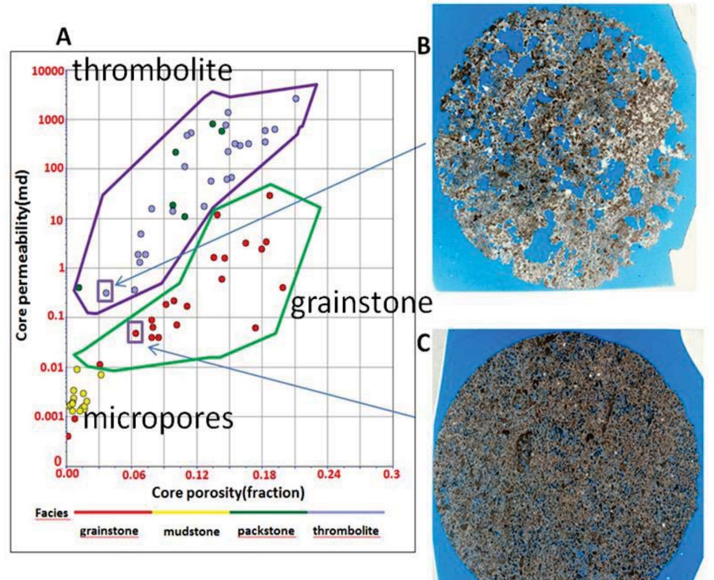
γ_u

Results

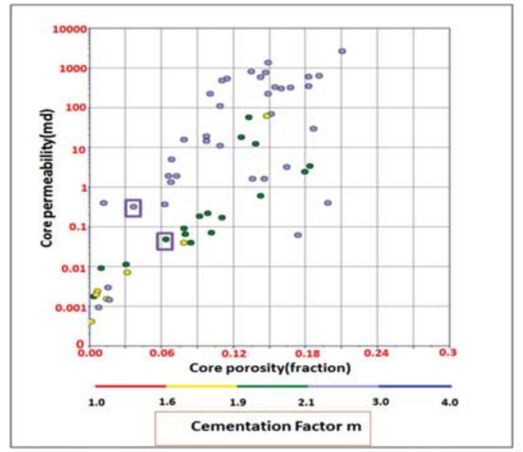




- Large variation of FF and Sonic Velocity at a constant porosity caused by changes in pore structures
- Interpretation based on core and well log analysis: At the same porosity, when m<1.9, FF and Vp are low, pore type is dominated by small microporosity; when 1.9<m<2.1, the dominant pore type is sucrosic intercrystalline caused by partial dolomitization; when 2.1<m<3, the pore type is vuggy pore in thrombolite; when m>3, it's highly cemented and rigid.
- Mudstone has low resistivity



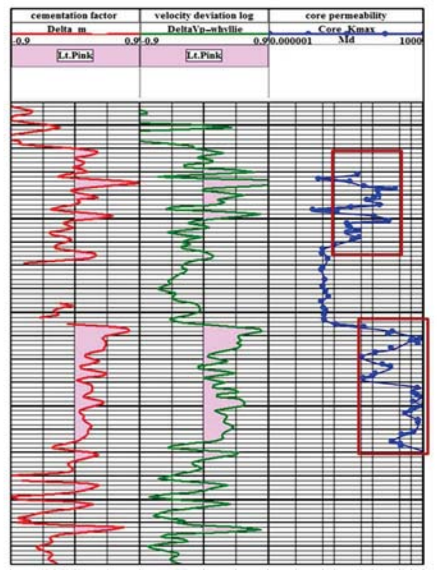
(Facies are shown in color)



- Moldic grainstone with a high cementation factor (m) exhibits lower permeability
- Thrombolites with a lower m exhibit higher permeability
- Mudstone and wackstone has lowest m and lowest permeability

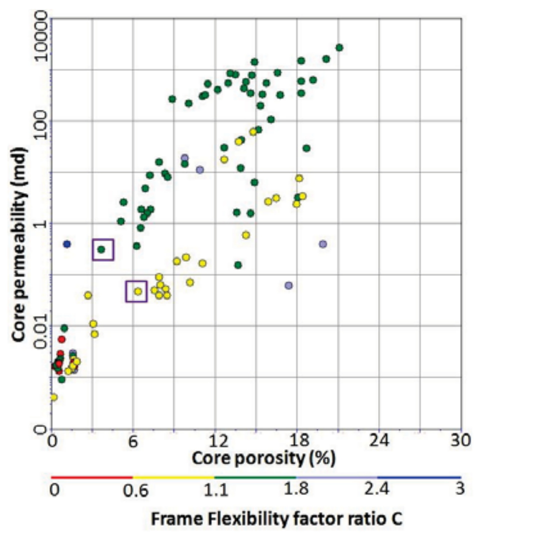
Application

Deviation logs



In addition to facies identification, velocity deviation and cementation deviation can be used to identify permeable zones, and both of them match with the core permeability

Derived shear information



By applying cementation factor in rock physics model, the shear wave velocity can be estimated and the derived pore structure parameters show the separation of high permeability scatters from low permeability scatters.

Conclusions

- Cementation factor (m) is a good indicator of pore structure based on both the laboratory measurement and log analysis
- Cementation factor deviation can be used to more accurately locate high permeable zones using the resistivity method, which agrees well with the velocity deviation. Both have a similar trend with permeability
- Synthetic shear wave velocity has been calculated by applying cementation factor m in Sun' rock physics

Acknowledgement

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