Investigation of the Bitumen Impact on the Petrophysical Properties in the Carbonates*

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Search and Discovery Article #41421 (2014)**
Posted August 18, 2014

*Adapted from oral presentation given at 2014 AAPG Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014

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Abstract

The determination of petrophysical properties in carbonate rocks is strongly affected by heterogeneity at different scales. Complex depositional and diagenetic processes have led to systems with a very wide range of pore sizes involving many decades of length-scales (e.g. from sub-micron to cm) as in carbonates. In particular, the latest invasion of bitumen takes an important role in control of reservoir quality. Reservoir bitumen precipitates in pore systems from the alteration of trapped or migrating oil in carbonate. Reservoir bitumen is not readily identified on typical log suites, where it is read as open porosity. When present as a solid, it can be as influential on reservoir quality as carbonate, silica, or authigenic clay cements and should therefore be evaluated as part of the diagenetic evolution of any pore system whenever encountered. Calculations of flow parameters such as permeability, relative permeability and capillary pressure do require the representative multiscale pore system to get accurate prediction. Therefore, models of the pore space that include the full range of pore sizes and their connectivity are vital for this requirement in petrophysics and reservoir simulation.

In this work we explore the extension of this multiscale pore-reconstruction and image statistical description to include diagenetic processes. We present a study of cementation and dissolution processes on the diagenesis of carbonate rock, particularly with occurrence and distribution of bitumen. Using derived information from thin section images indicating various stages of diagenesis, a modeling of the process of cementation and dissolution as well as the occurrence and distribution, will be carried out to investigate the impact of bitumen on the pretrophysical properties in carbonate. The diagenetic processes are modeled using Pore Architecture model to explore the dissolution of grains and cementation of the inter-particle pores in the regions of the best connectivity estimated from reconstructed 3D images of carbonate samples. At last a further study of an integrated multi-scale pore-network is then generated and the petrophysical predictions would be performed on a pore-network flow simulator and petrophysical properties is investigated to better understand the bitumen controls of the pore system and transport properties.

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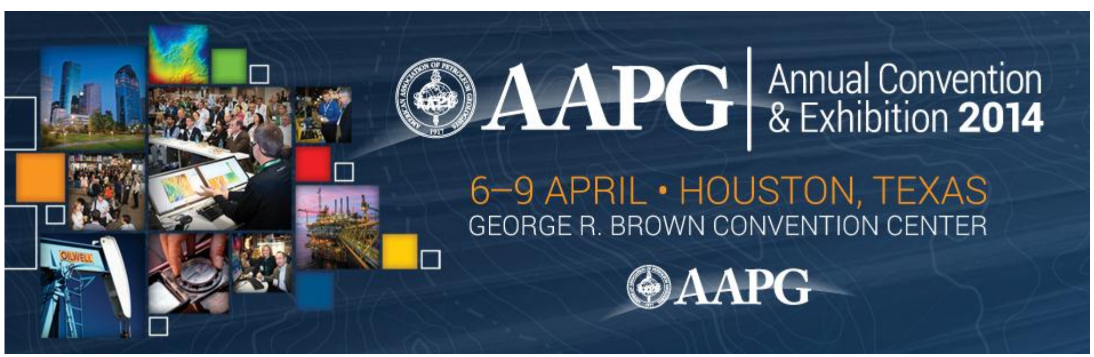


Outline

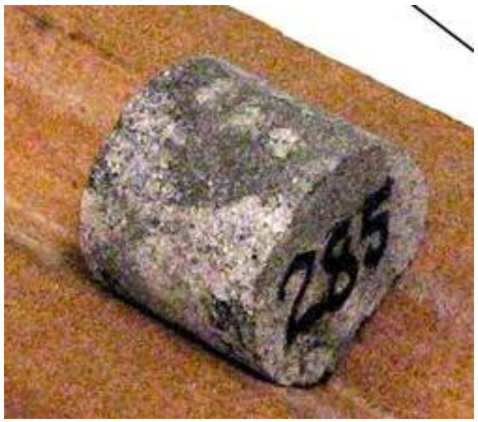
- Goals
- Images of Carbonates Samples
- Diagensis and End Points of Geological Scenario
- Pore Architecture Model
- Rock reconstruction based on Diagensis
- Conclusion

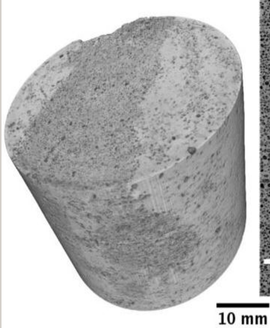
Goals

- Explore the evolution of rock properties for given a depositional setting and the typical diagenetic processes that modify them to create the final reservoir rock
- Identify a suite of characteristic textures inferring former states about cementation, dissolution burial cementation and bitumen (diagenetic backstripping)
- Reconstruct 3D pore structures using PAM determining their former flow properties and investigate bitumen impact on petrophysical properties
- Establish a quantitative way to link petrophysical properties to diagenetical modeling.

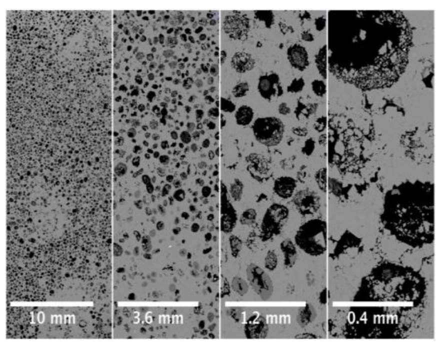
Various images from carbonate plug sample

Sample	Porosity (%)	K (mD)	Bitumen(%)
285	24.3	30.9	1.2

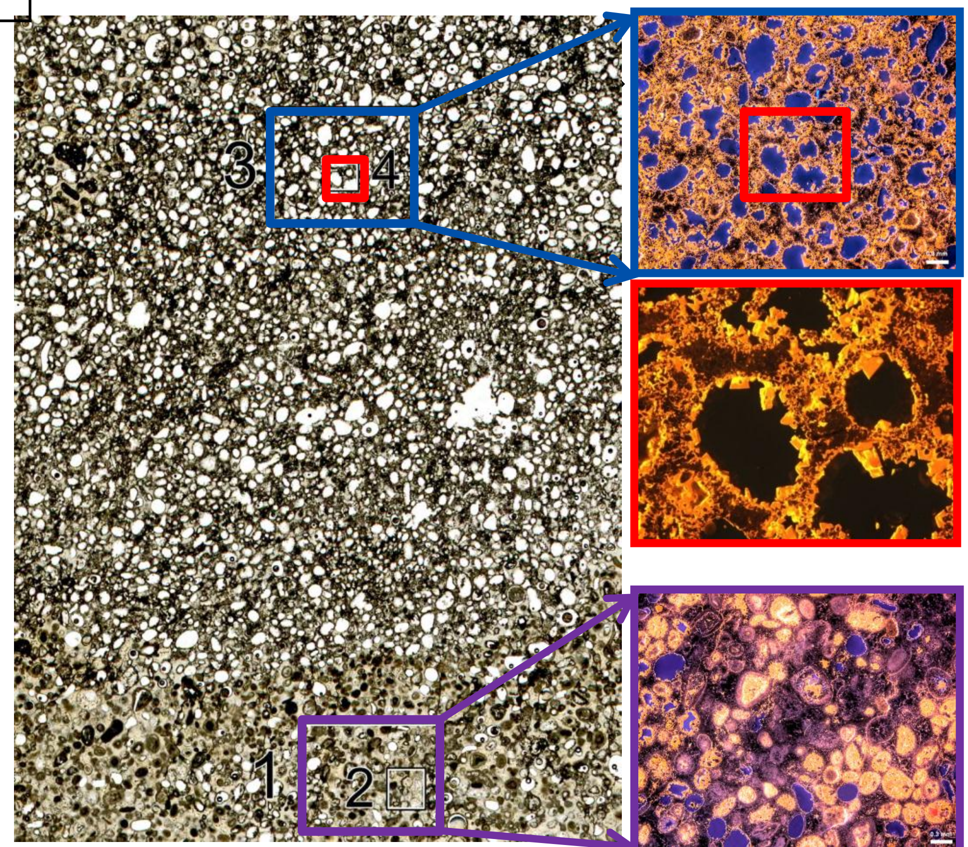




3D mCT image



SEM images



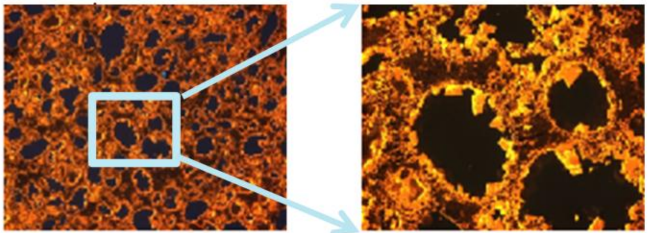
Thin Section image

Cathodoluminescent images

J. A. D. Dickson 2009

Methodology

- Cathodoluminescent images show the different time cementation at various luminance/brightness, The brighter the later
-



By J. A. D. Dickson

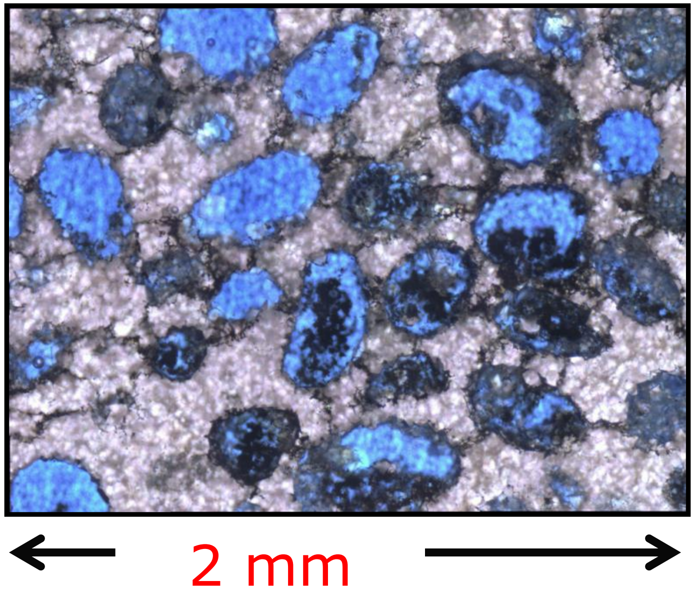
- By segmenting different time cementation give a direct input for the modeling of cementation and ooids dissolution.
- Investigating permeability changes in association with a given diagenetic processes

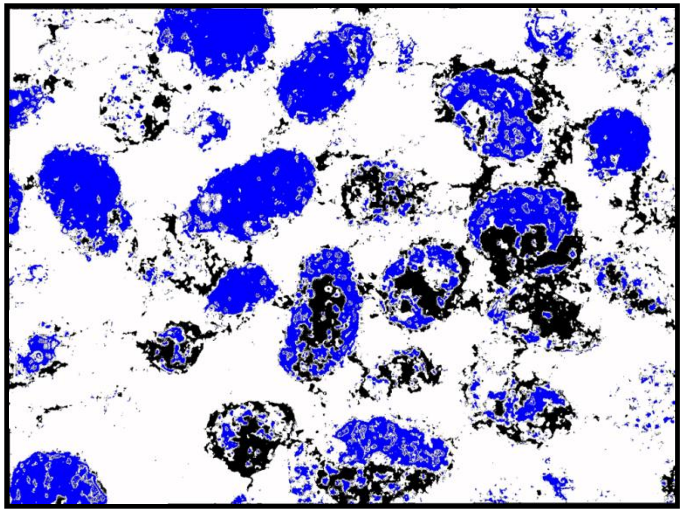
Presenter's notes: We selected one sample of an oolitic grainstone (Figure 1, sample 285) from the Bashkirian platform interval of Tengiz, a Paleozoic isolated carbonate platform located in the Pricaspian basin, Kazakhstan and currently buried to several thousand meters below sea level.

Bitumen Analysis

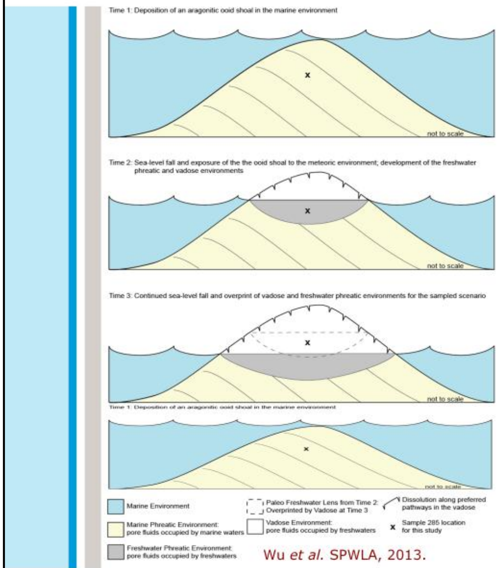
- Establish trends to illustrate the impact of flow properties for given a depositional setting and the typical bitumen occurring processes that modify them to create the final reservoir rock

Resolution: 0.294 micron

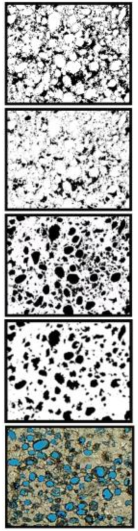




Several possible geological scenarios about mineralogy and texture



Wu *et al.* SPWLA, 2013.



Stage 1(Marine Environment):
Oooid sediment get lithified by marine (fibrous, bladed micritic) cement.

Stage 2(Meteoric Environment):
Partially meteoric cementing, non luminescent part.

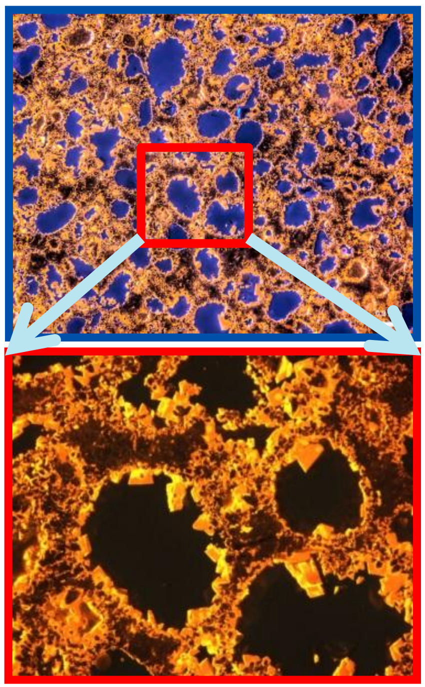
Stage 3(Meteoric Environment):
Partial dissolution of aragonite ooids and cementation of isopachous aragonite

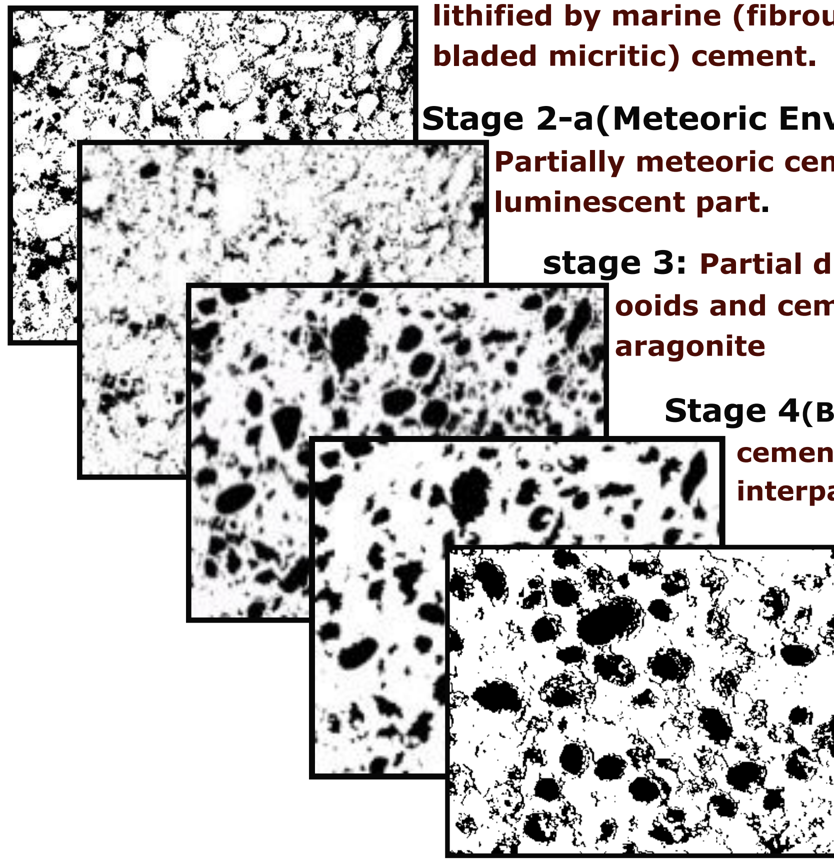
Stage 4(Burial Environment):
cement the remaining interparticle pore space and partial cementation by ooid molds (oomolds).

Stage 5(Latest Burial Environment):
after oil charge the bitumen precipitated in the outer modular pore space (oomolds), and partial interparticle pore space.

Presenter's notes: This particular sample was originally deposited in an interpreted high-energy shallow-subtidal open-platform to intertidal environment (Kenter et al., 2006) and was later exposed to both the meteoric (Figure 2) and burial diagenetic environments. Although the sample mineralogy has been stabilized to 100 % low-Mg calcite (LMC) the original ooids were deposited in Icehouse seas and were composed of metastable aragonite. For the purposes of computer modeling of the pore network evolution and its evolving porosity and permeability we are constrained to modeling the diagenetic evolution beginning in the marine to the meteoric and to the burial diagenetic environments by separate dissolution-cementation events. For example, the fresh water lens diagenetic environment is capable of dissolving aragonite while precipitating LMC (Budd, 1988; Budd and Land, 1990; Humphrey, 1997). The residence time and fluid saturation with respect to CaCO3 will ultimately dictate whether the pore fluids are biased towards corrosion or precipitation of calcium carbonate. Because of the constraints of the modeling we will assume that reactions in the fresh water phreatic environment result primarily in cementation and recrystallization by LMC and that dominant reactions in the vadose diagenetic environment limited primarily to dissolution. Over geological time these reactions are nearly instantaneous and thereby form a mineralogically stable framework for later diagenesis. Complete stabilization of metastable carbonate sediments by LMC can occur in the fresh water lens on the order of 10s of thousands of years (Evans and Ginsburg, 1987; Sare, 1998).

End point geological scenarios for modeling: Image processing





Stage 1: **Oooid sediment get lithified by marine (fibrous, bladed micritic) cement.**

Stage 2-a(Meteoric Environment): **Partially meteoric cementing, non luminescent part.**

stage 3: **Partial dissolution of aragonite ooids and cementation of isopachous aragonite**

Stage 4(Burial Environment): **cement the remaining interparticle pore space**

Stage 5(Latest Burial Environment): **after oil charge the bitumen precipitated in the outer modular pore space (oomolds), and partial interparticle pore space.**

Pore Architecture Model-PAM

- ## 3-D Markov Random field mode

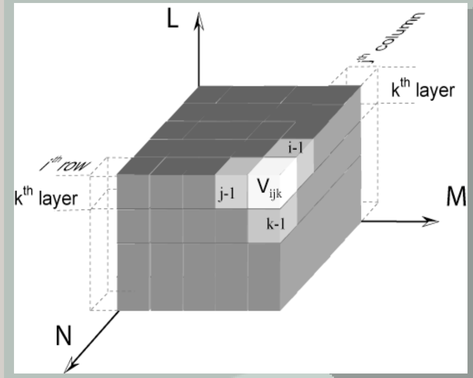
15 neighbourhood Method: use three orthogonal images

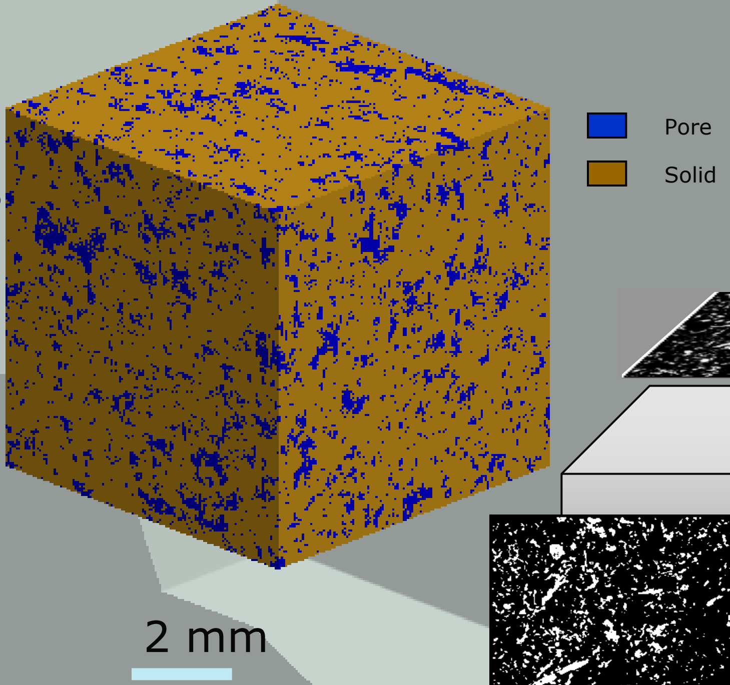
$$P[V_{ijk}] = \prod_{l=0}^{i}\prod_{m=0}^{j}\prod_{n=0}^{k} P\left[\lambda_{lmn} \mid \lambda_{l-1,m,n}, \lambda_{l,m-1,n}, \lambda_{l,m,n-1}\right]$$

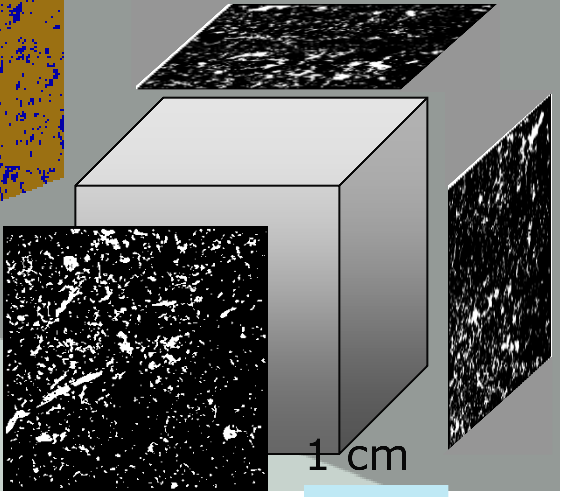
- **Advantage**:

Can use **any scale** 2D images ranging from nano scale to centimeter scale to build 3D structures

Fast and efficient



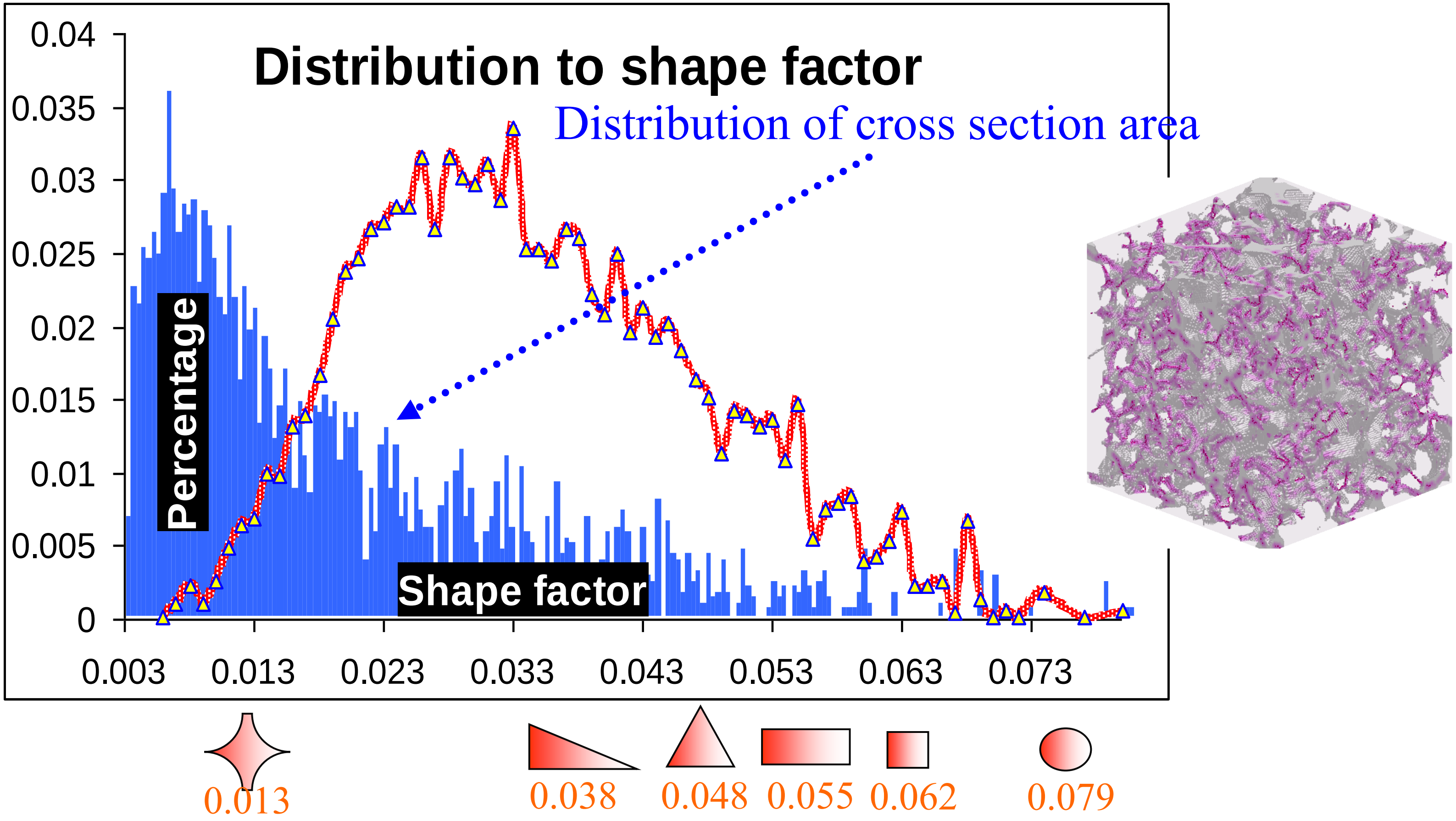




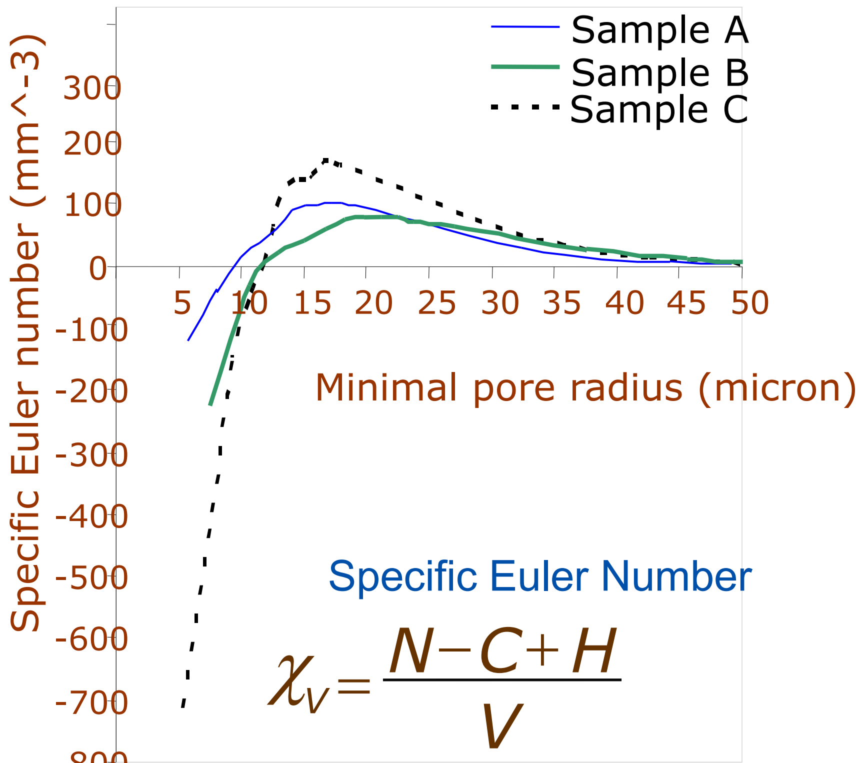
Wu *et al.* Transport in Porous media, 2006.

Characterization of Pore System

- Pore cross-section Geometry

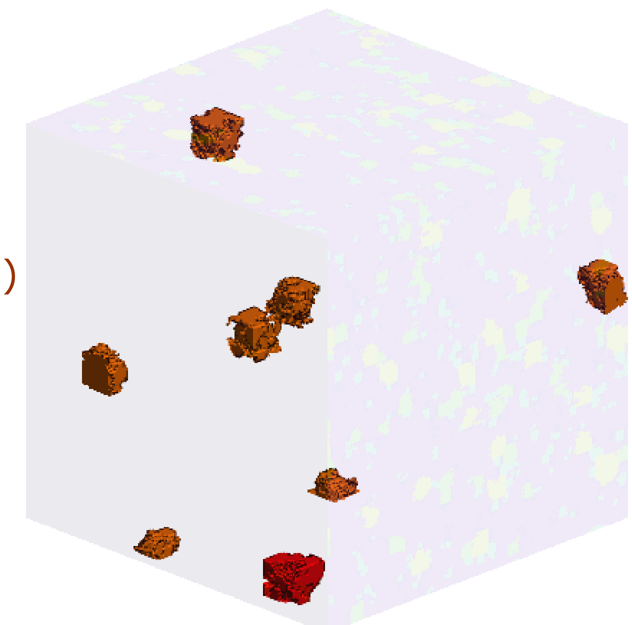


Quantification of pore connectivity system: Pore Size and Connectivity



Specific Euler Number

$$\chi_V = \frac{N - C + H}{V}$$

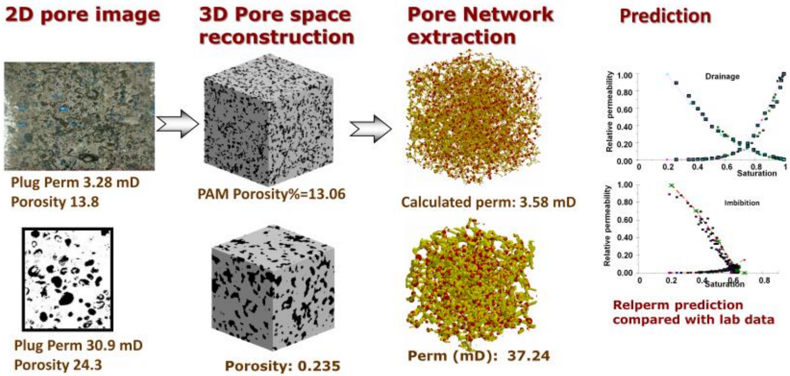


Connectivity Function Curve

From core sample to pore network

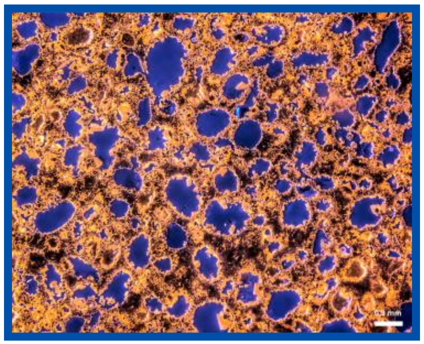
- ## Digital core technology

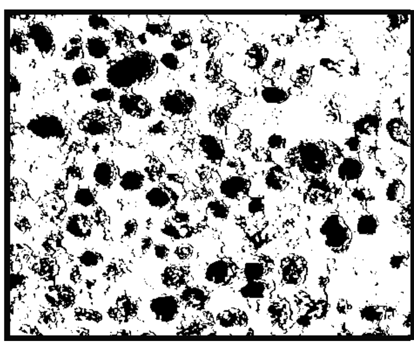
Tools: 3D pore space reconstruction techniques, pore network extraction and integration, pore network flow simulator.

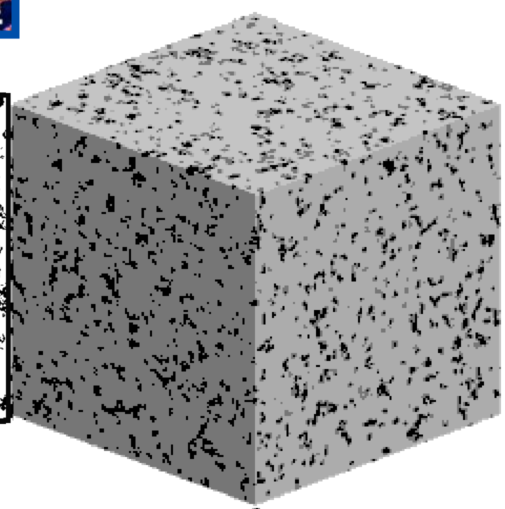


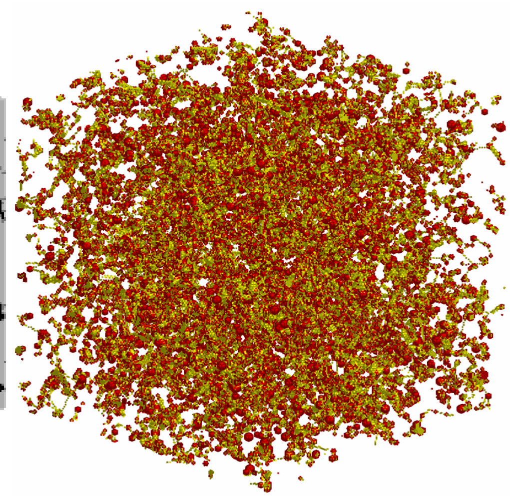
Presenter's notes: We have developed a series of tools such as 3D pore space reconstruction techniques, pore network extraction and integration, pore network flow simulator, and to derive physically informed effective relative permeability and capillary pressure functions for use in reservoir simulations.

Pore structure evolution and resultant petrophysical properties









Porosity: 0.28
Perm: 523.34 mD

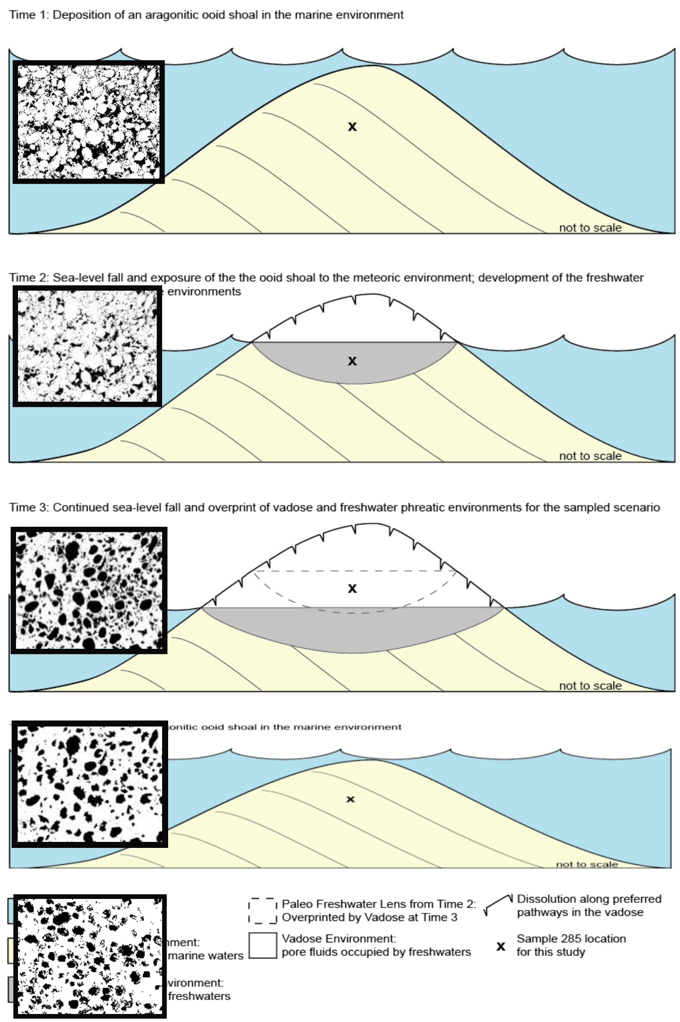
Porosity: 0.057
Perm: 0.28 mD

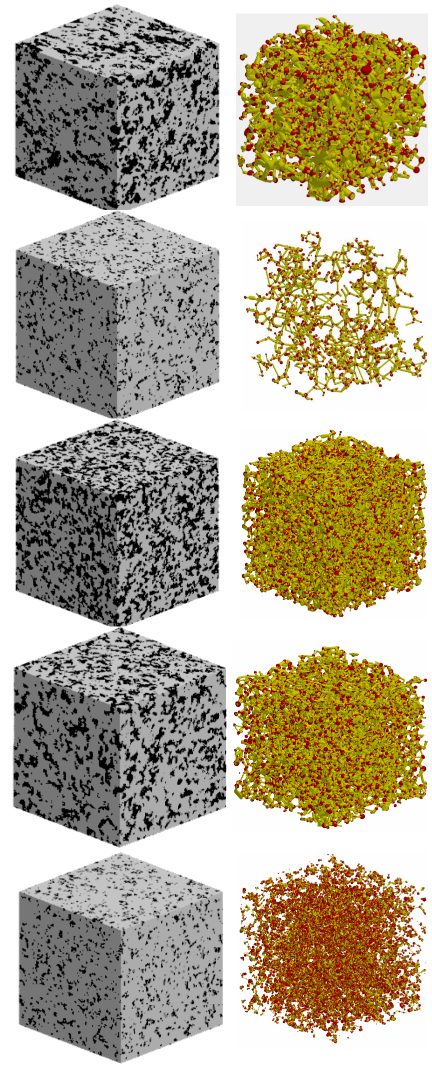
Porosity: 0.38
Perm: 318.84 mD

Porosity: 0.22
Perm: 133.34 mD

Porosity: 0.13
Perm: 0.67 mD

Pore structure evolution and resultant petrophysical properties





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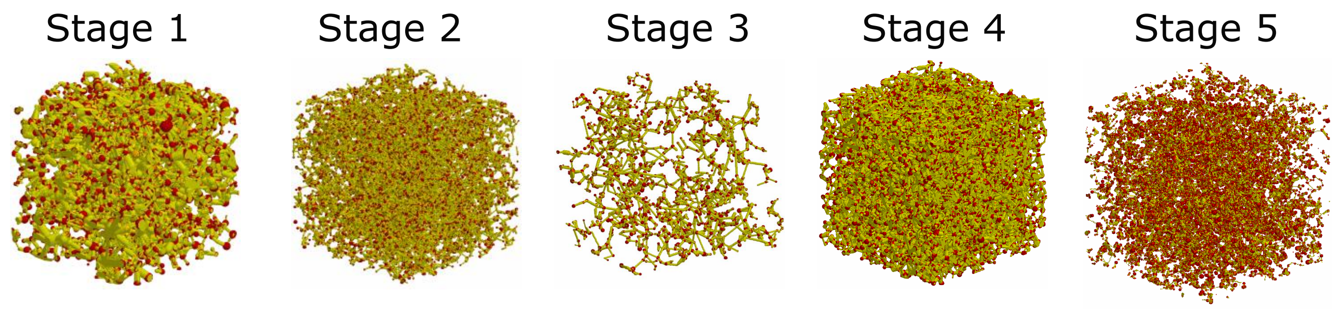
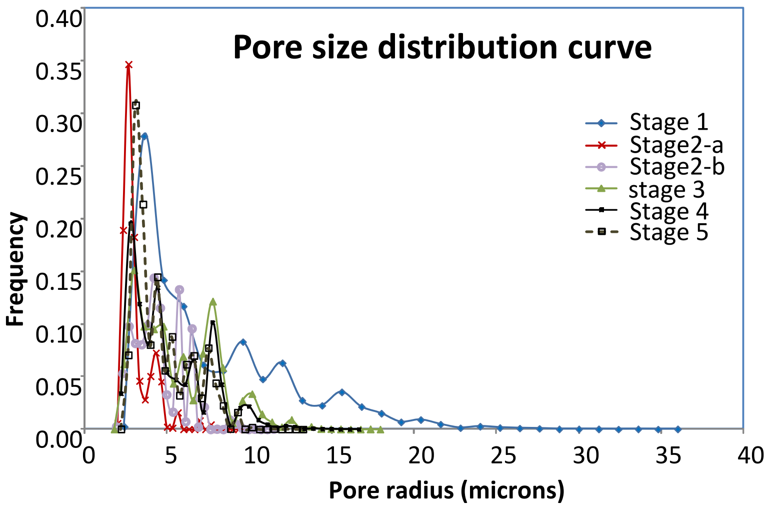
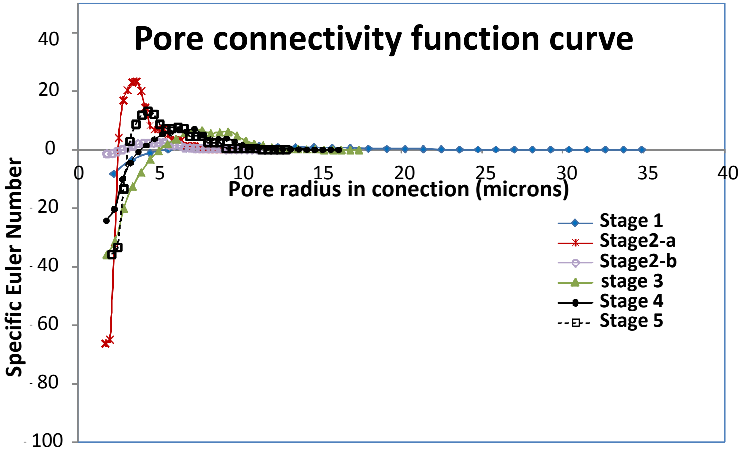
Evolution of pore system

-Pore size and connectivity





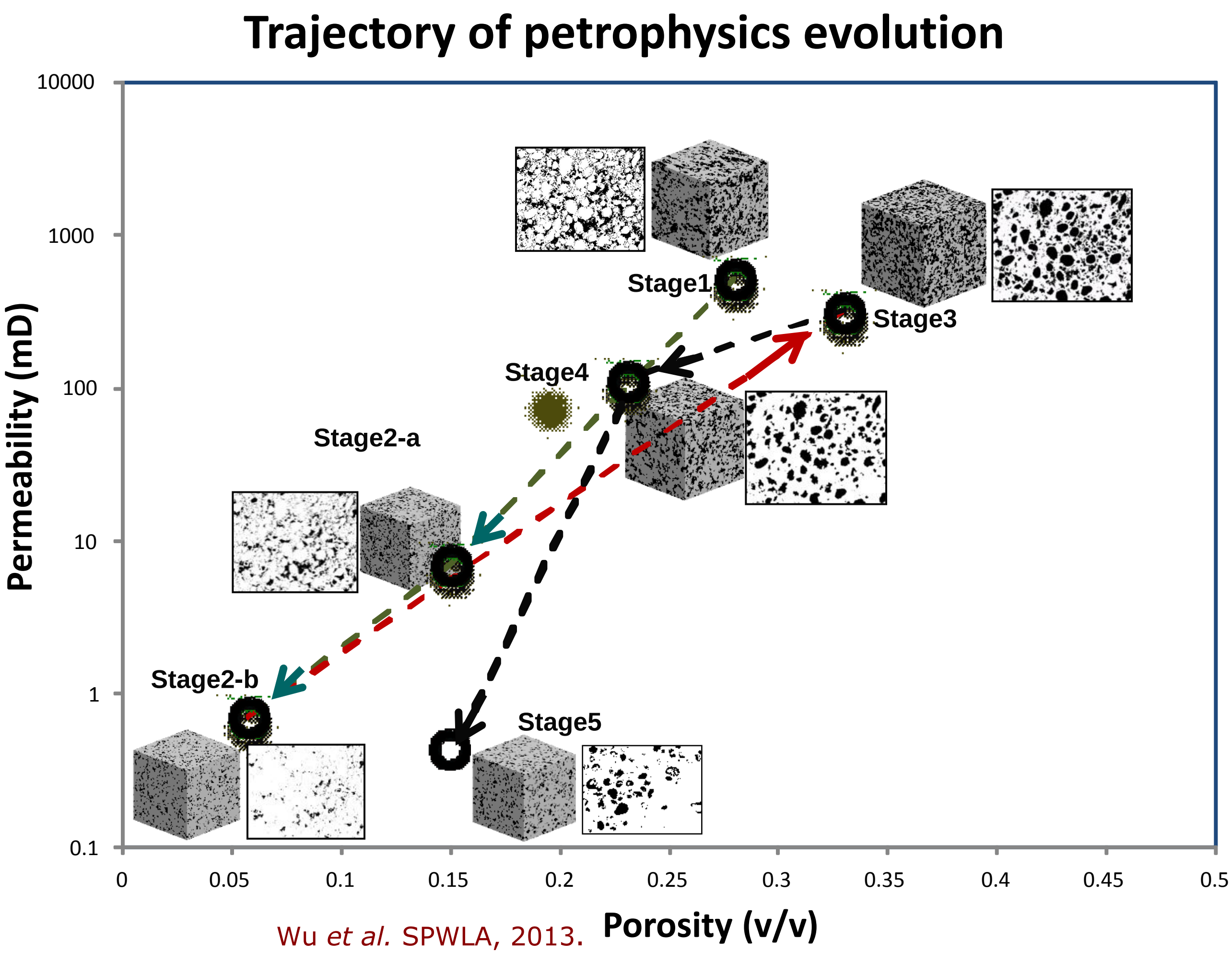


The evolution of pore spatial characteristics for all the diagenetical stages.

The pore connectivity shows the evolution of topology of pore system for all the diagenetical stages.

Wu *et al.* SPWLA, 2013.

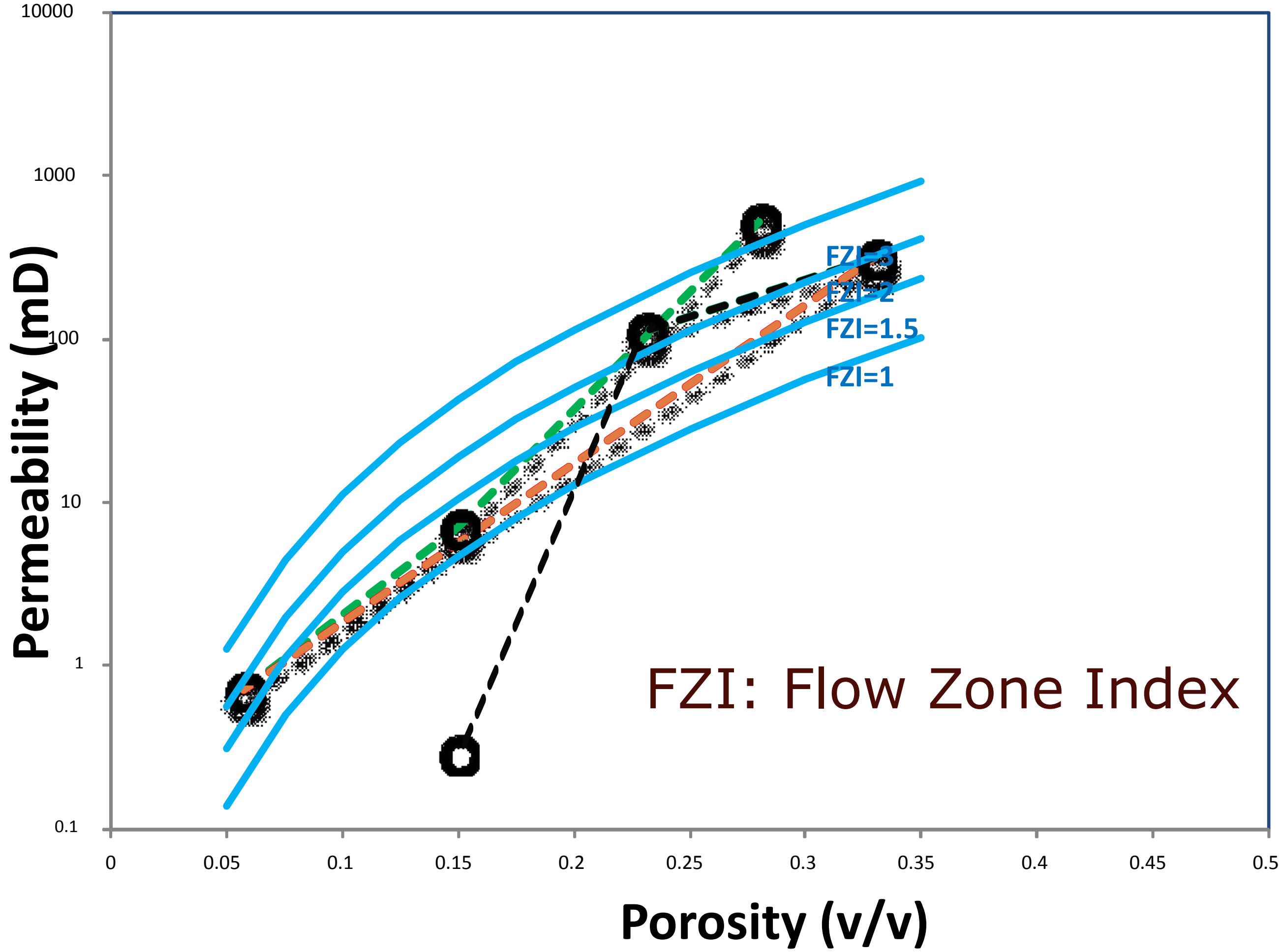
End points of recovered petrophisical properties



Wu *et al.* SPWLA, 2013.

Petrophysical “diagenetic trajectories”

Petrophysical “diagenetic trajectories” compared with FZI lines



Conclusion

- The diagenesis of carbonate takes a key part of role in controlling the petrophysical properties of carbonate, and the permeability can be at least four orders in change

- The predictions of petrophysical properties by PAM methods are in very good agreement with SCAL data

- The latest bitumen precipitation has a great impact on the petrophysical properties in the carbonate, reducing the permeability significantly

- By comparing the diagenetic modeling with FZI diagenetic trajectories are cross-cutting FZI lines. further work have to be done to assess its applicability/ limitations in carbonate reservoirs.