

أرامكو السعودية
Saudi Aramco



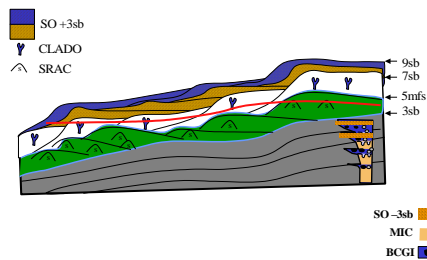
Rosetta Stone Project Overview

E. A. Clerke, Ph.D.

Rosetta Stone

Mile Scale
Depositional Rock Types

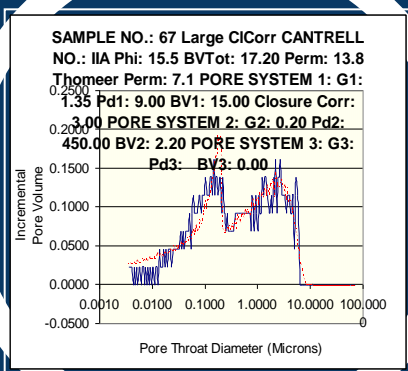
Arab D Facies Architecture



Micron Scale

Pore System Parameters

- Permeability
- Imbibition Rel Perm
- Ultimate Recovery



Centimeter Scale
Wireline Log Responses
• NMR



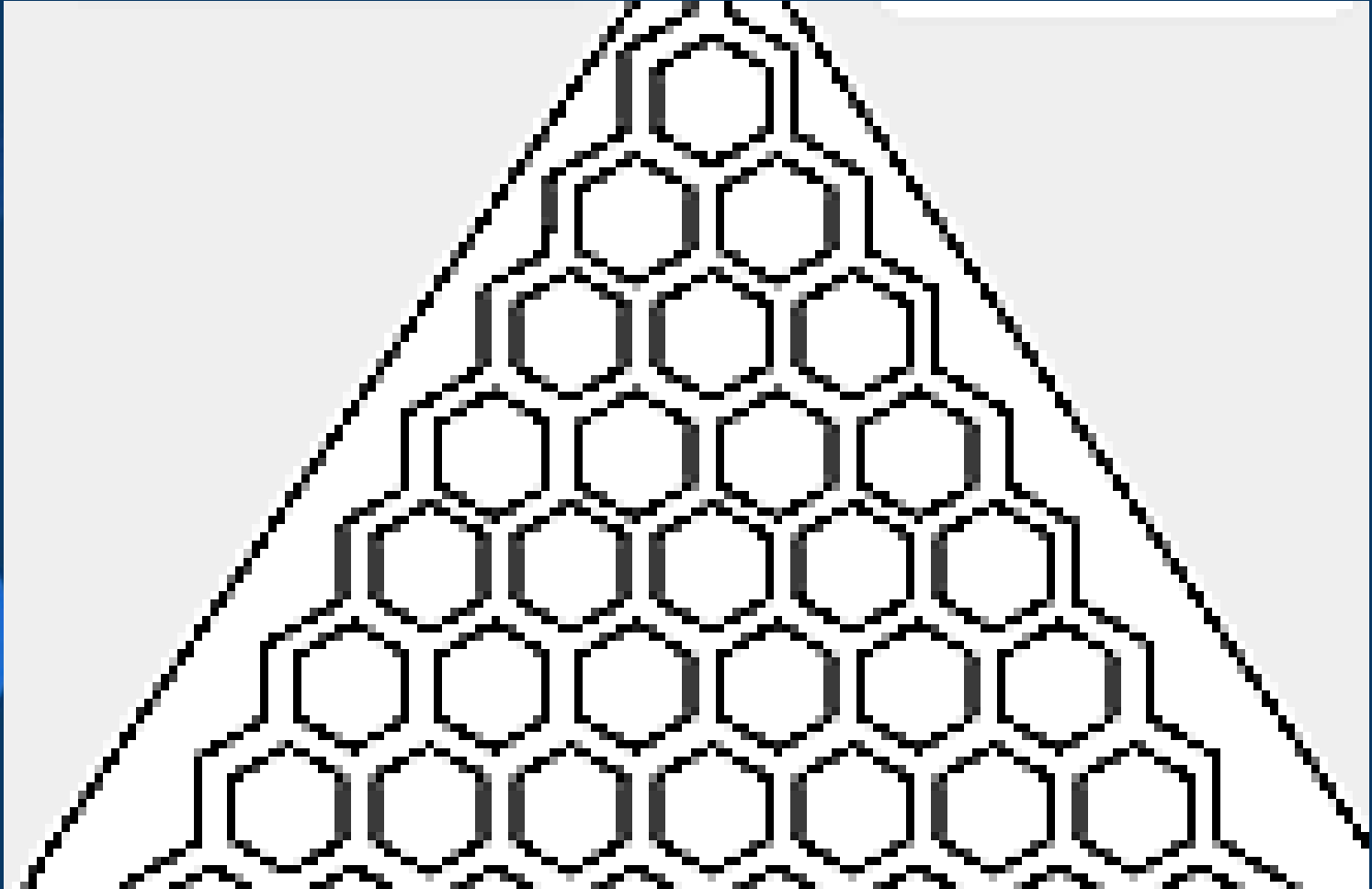
Arab D Limestone

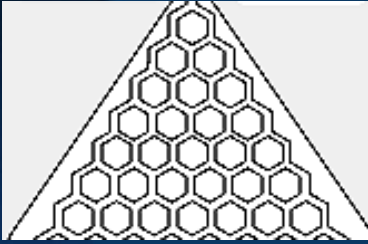
Porositons

Recurring Maximum Pore Throat Diameter Modes

Captured by the Thomeer Parameterization

Pore Network Game





Pore Network Game

A large number, n , of microscopic data recording devices are inserted at random locations into the pore network

The devices are programmed to move in the pore network but must always go through equal or larger pore throat diameters

The devices record the current maximum pore throat diameter that they have encountered

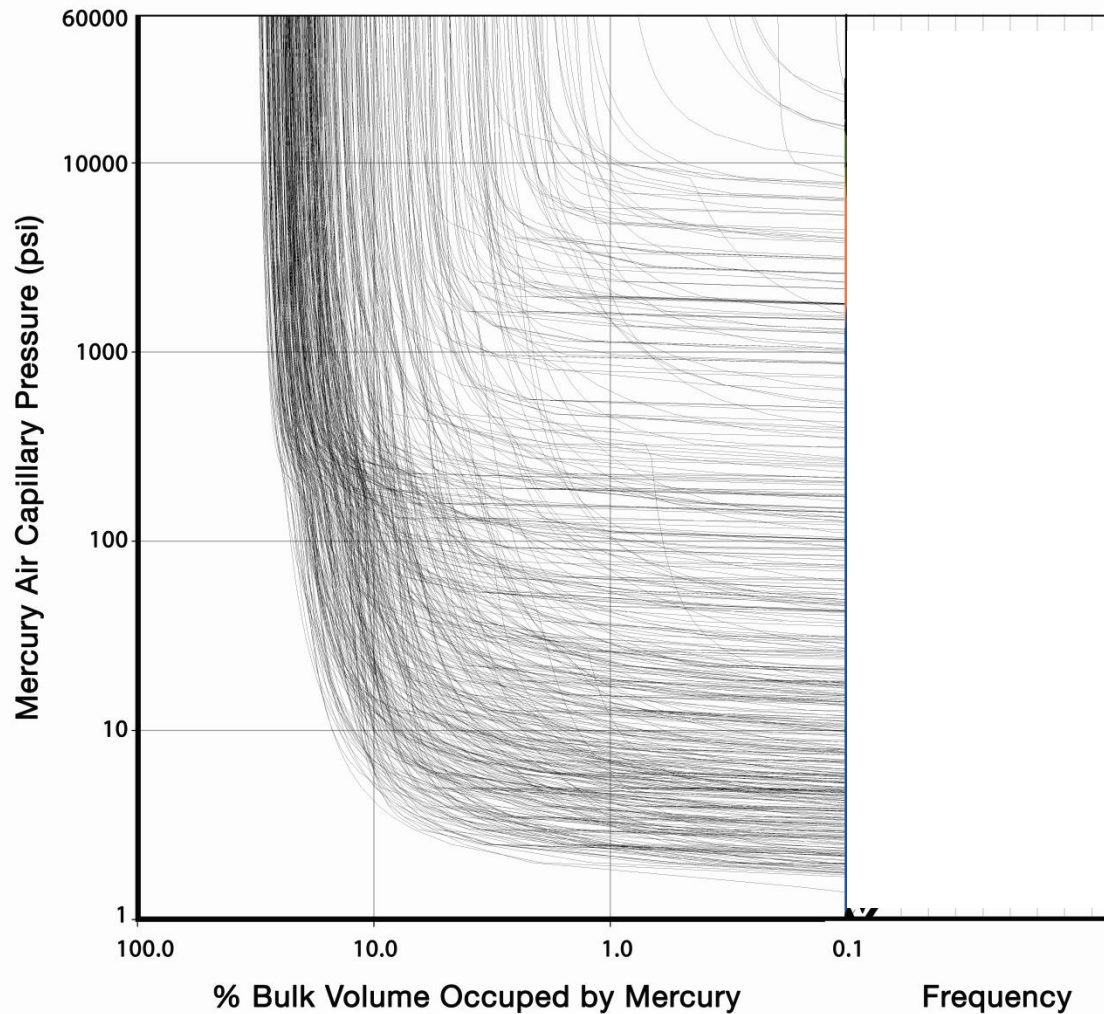
The devices are retrieved when they exit the pore system and interrogated

484 Rosetta Stone MICP curves, Thomeer analyzed and closure corrected

Rosetta Stone MICP Data Ghawar Arab D Limestones

(after closure correction and Thomeer type curve matching)

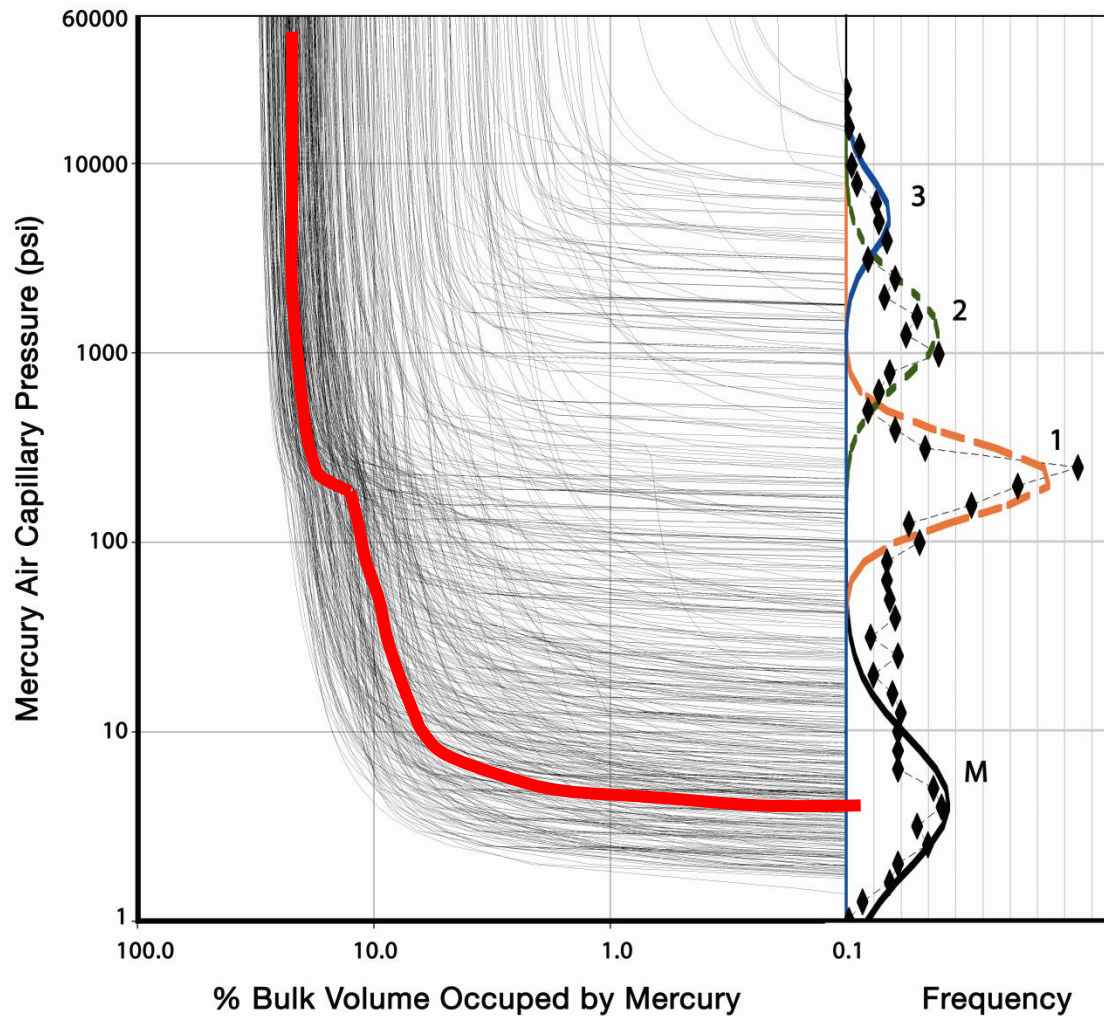
with P_d histogram showing 4 porositons



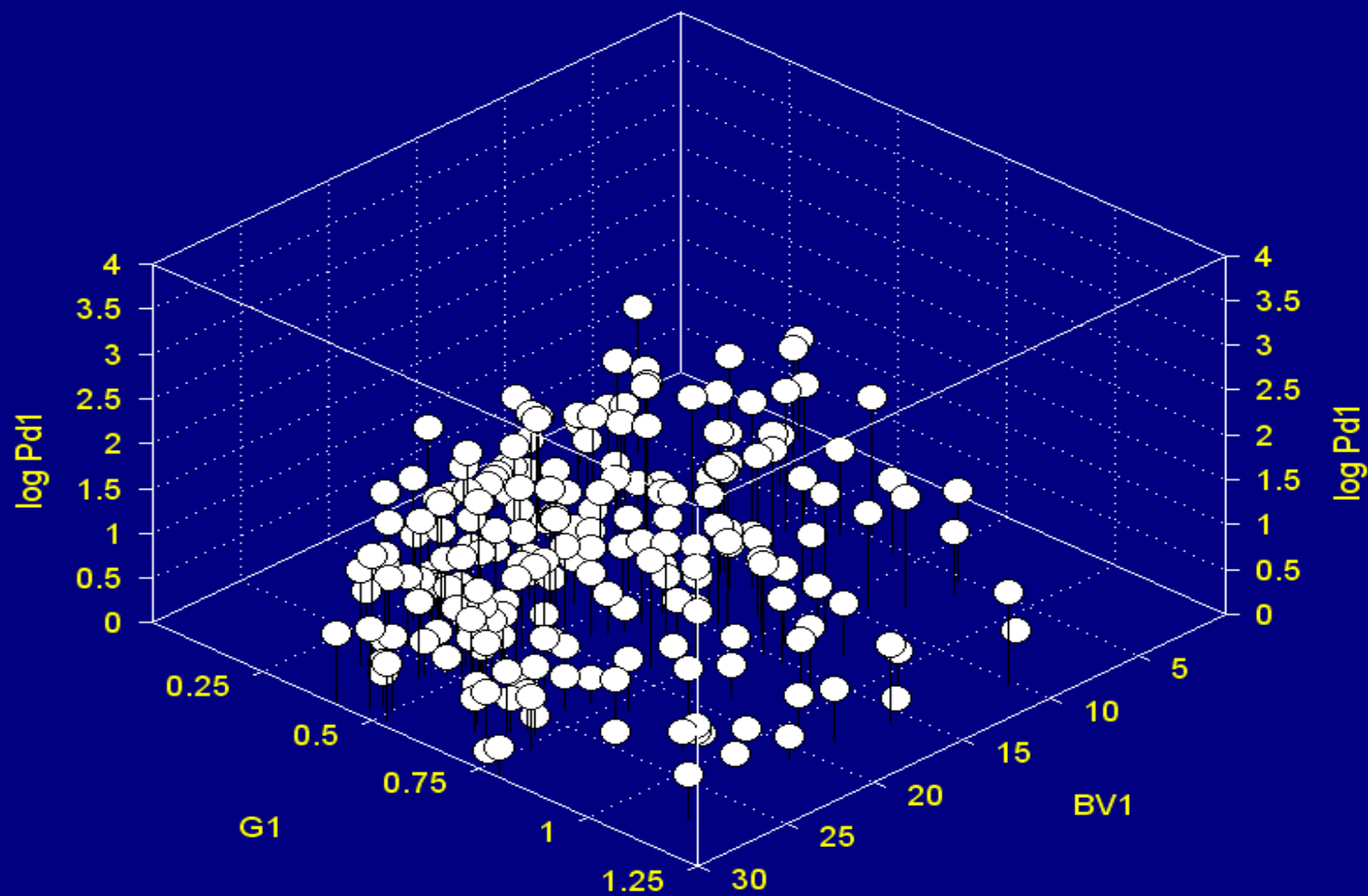
M_1 Emphasized

Rosetta Stone MICP Data Ghawar Arab D Limestones

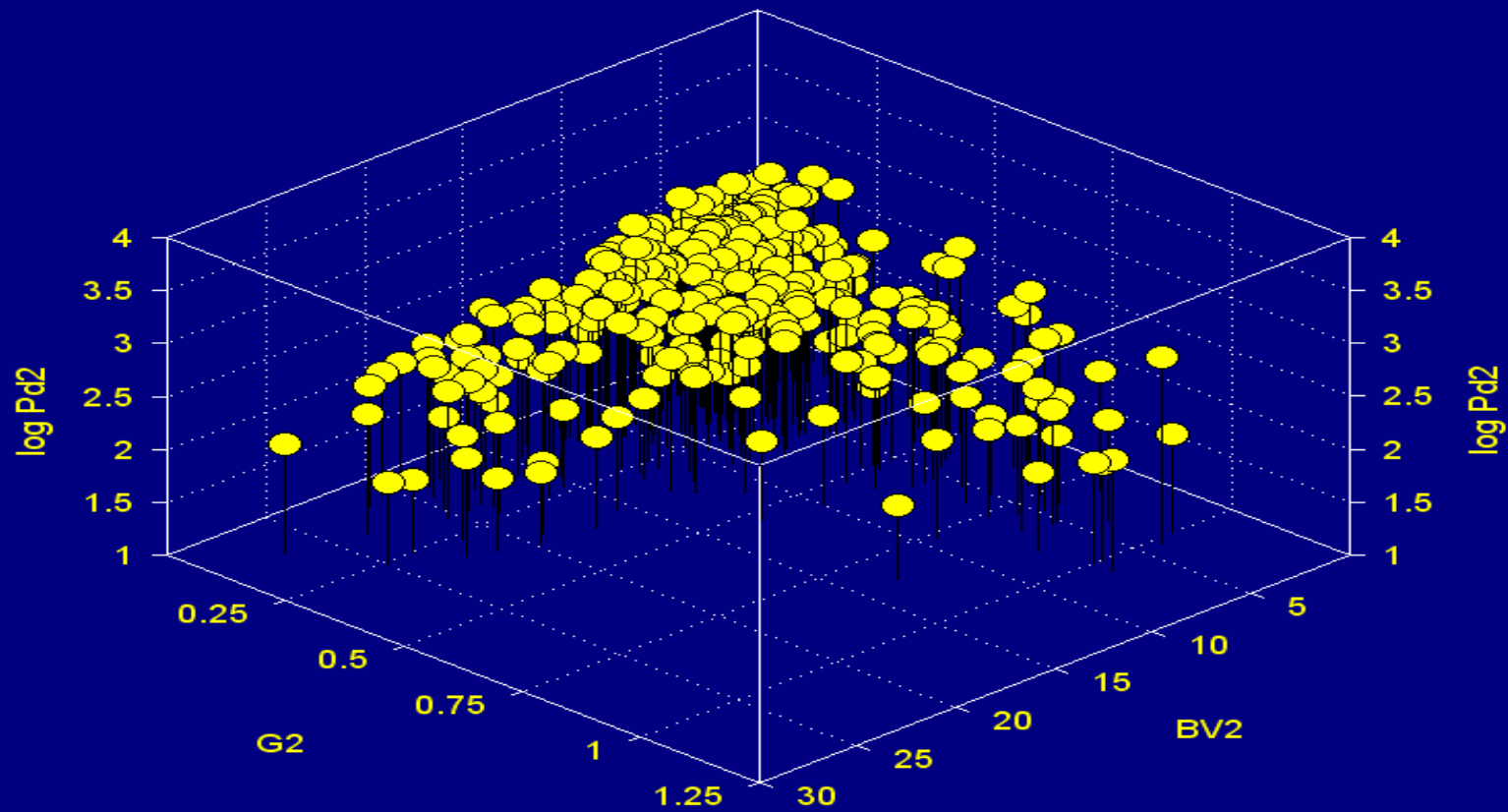
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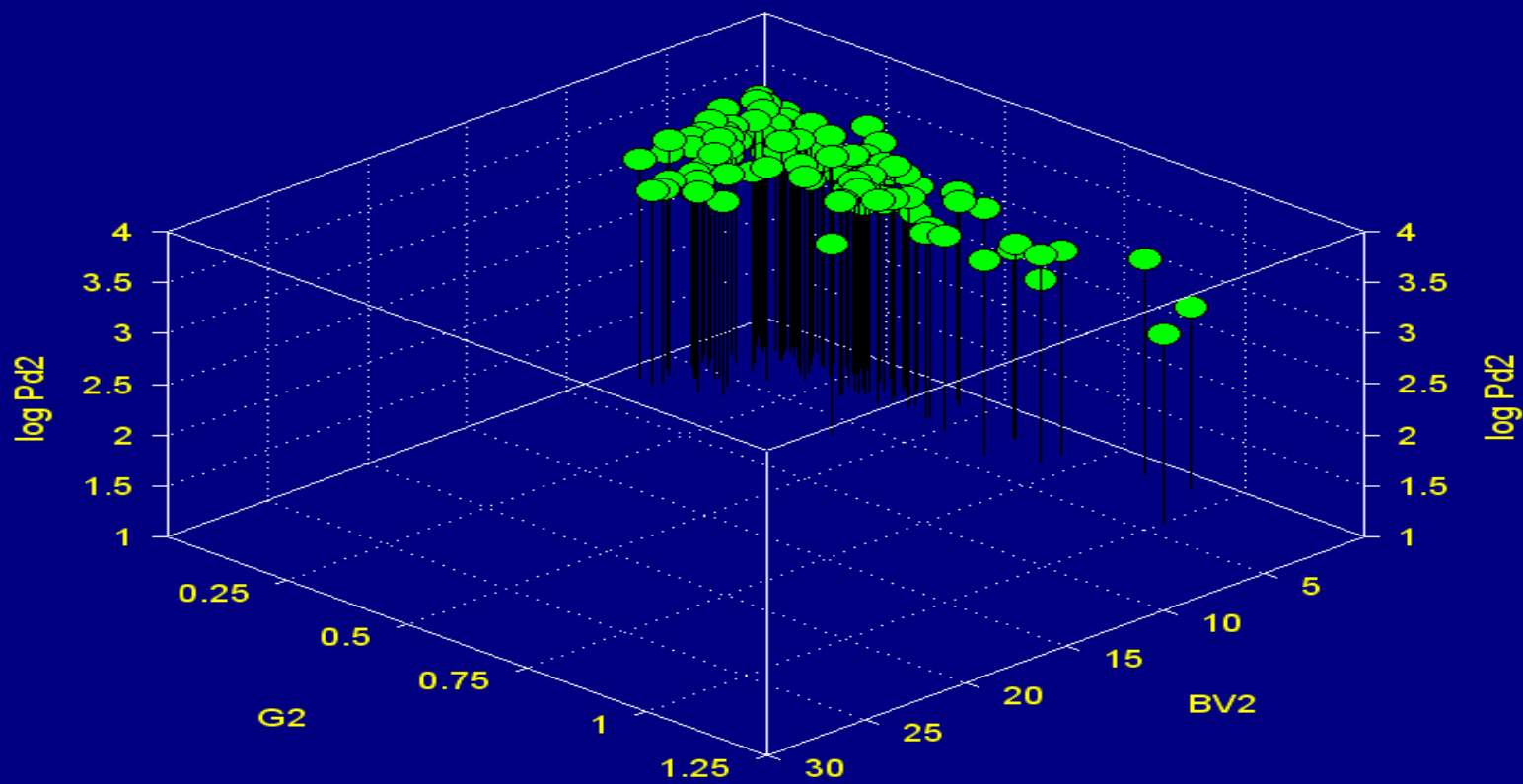
Rosetta Stone Porositon M



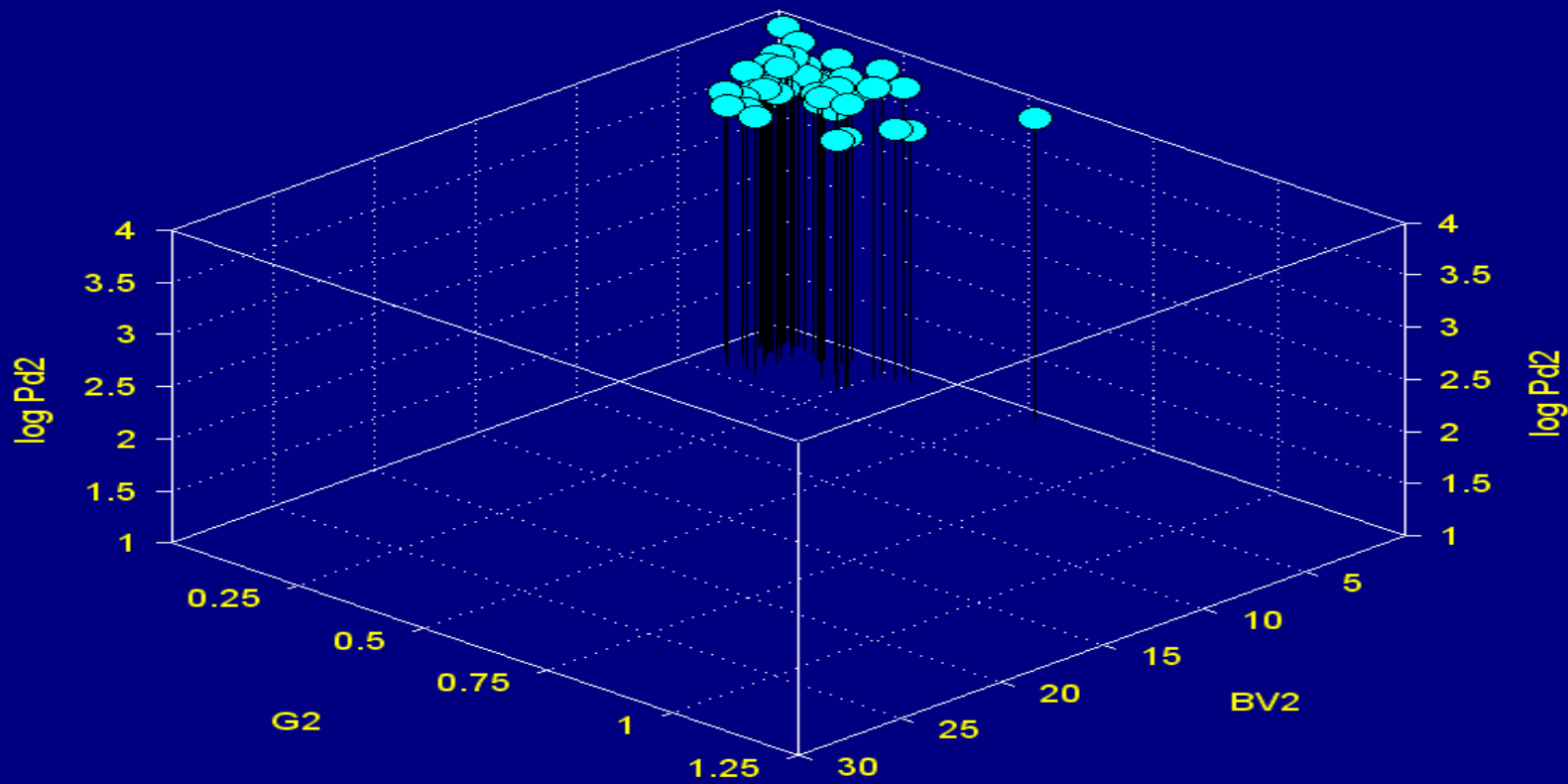
Rosetta Stone Porositon 1



Rosetta Stone Porositon 2



Rosetta Stone Porositon 3



Ghawar Arab D Rosetta Stone

Three Languages of the Subsurface



Uncertainty

Sequence Stratigraphy



Depositional Rock Types



**Petrophysical Rock Types
(Rosetta PRT)**



Rock Properties

By PRT:
ROS, Recovery,
Perm, Rel Perm
Exponents

Time



Arab D Limestone

Porositons

Recurring Maximum Pore Throat Diameter Modes

Captured by the Thomeer Parameterization

**A four character “alphabet” for the Arab D limestone
pore systems**

The Language of Arab D Limestone Pore Systems

The pore system words have at most three letters, commonly two

M and 1 are highly occurring as the M_1 word in the grainstone and packstone SO, SRAC, CLADO context

2, 3 occur most commonly in the Micrite context

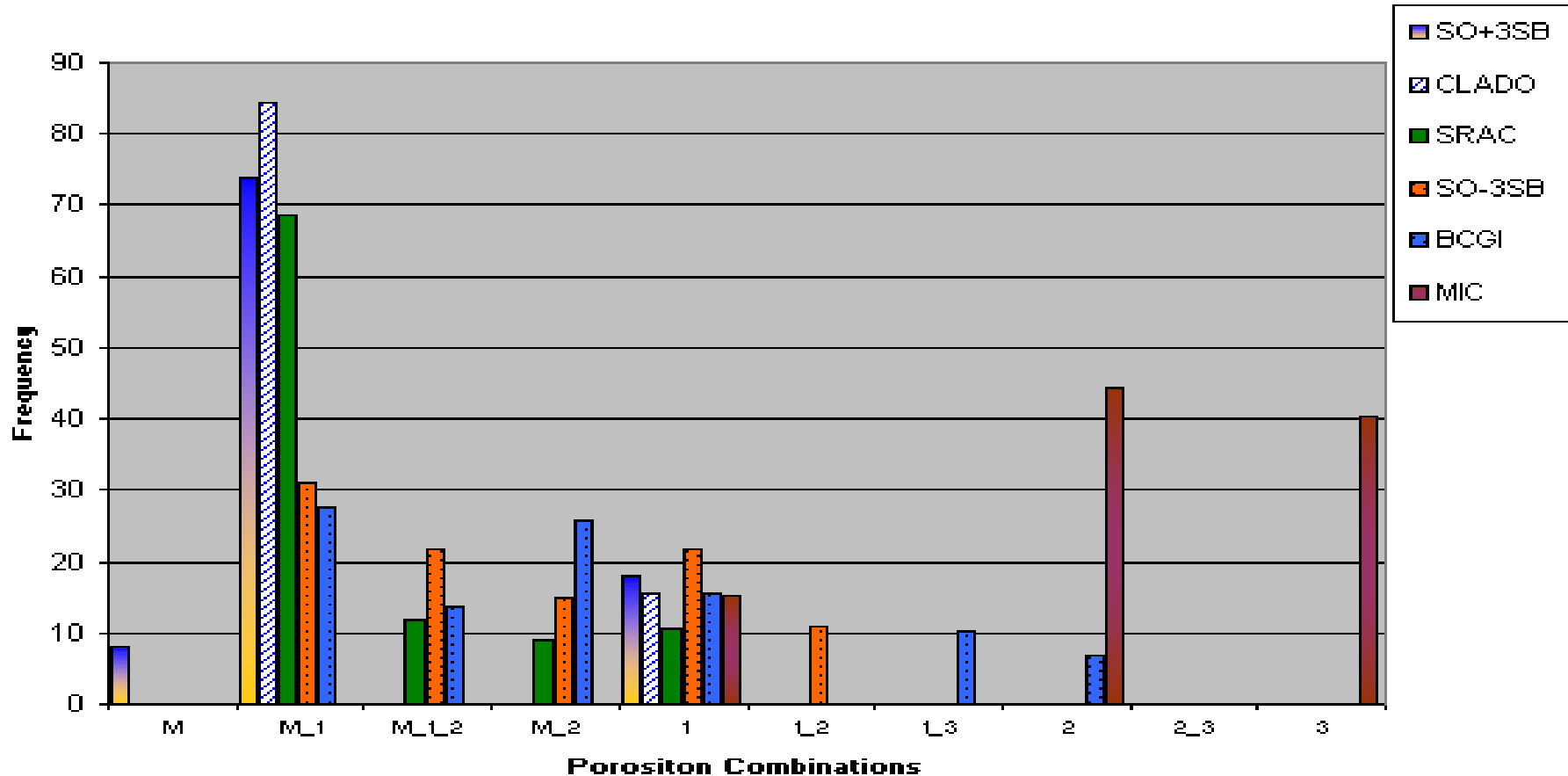
Maximum Pore Throat diameters have four distinct ranges of preferential values, modes, porosities

HWM-C Facies in terms of Porositon Classified Pore Systems

Rosetta Stone Pd Code Frequency Distributions
Baseline Adjusted at 5.2% and renormalized

Code Key Order - 1st,2nd,3rd

Pore System Pd range: M: Log Pd<1.66, 1: LogPd<2.79, 2: Log Pd<3.4, else 3



Porositons from Multiple Arab Reservoirs show similar behaviors except when Echinoderm – Syntaxial overgrowth cements are present – see Clerke Geo 2010

Porositon – Porobodon Conjecture

Maximum Pore Throat Diameter modes may be related to common pore body diameters



Modes in the Pore Body Spectrum?

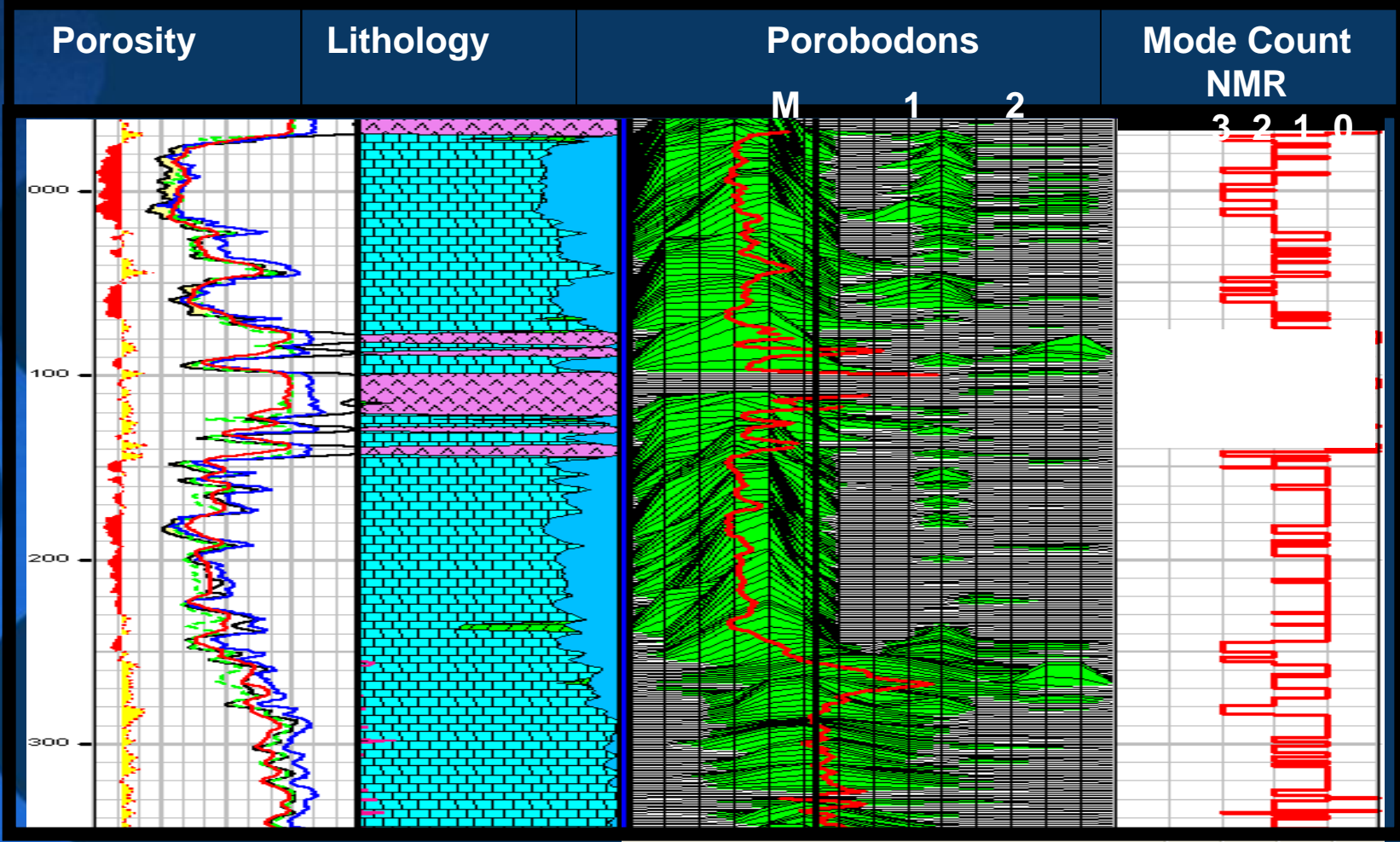
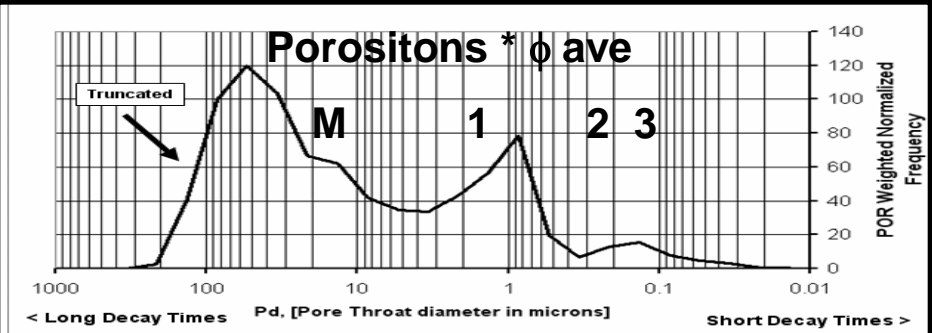
- If there are modes in the pore body spectrum then we have been playing the NMR inversion game poorly
- NMR inversion currently assumes smoothness (regularization)
- Like playing Hangman assuming 'q' is as common as 'p' or 'r, s'
- NMR Inversion can be improved by including mode probabilities in the pore body spectrum, if they exist !

CIPHER Technology

Joint Development of Saudi Aramco and Schlumberger

In fact even with regularization we don't get rid of the
recurring modes!

Arab D NMR Signals





Modes Modes Everywhere

Cantrell and Hagerty, GeoArabia Vol 4, No 2, 1999

Skeletal- Oolitic

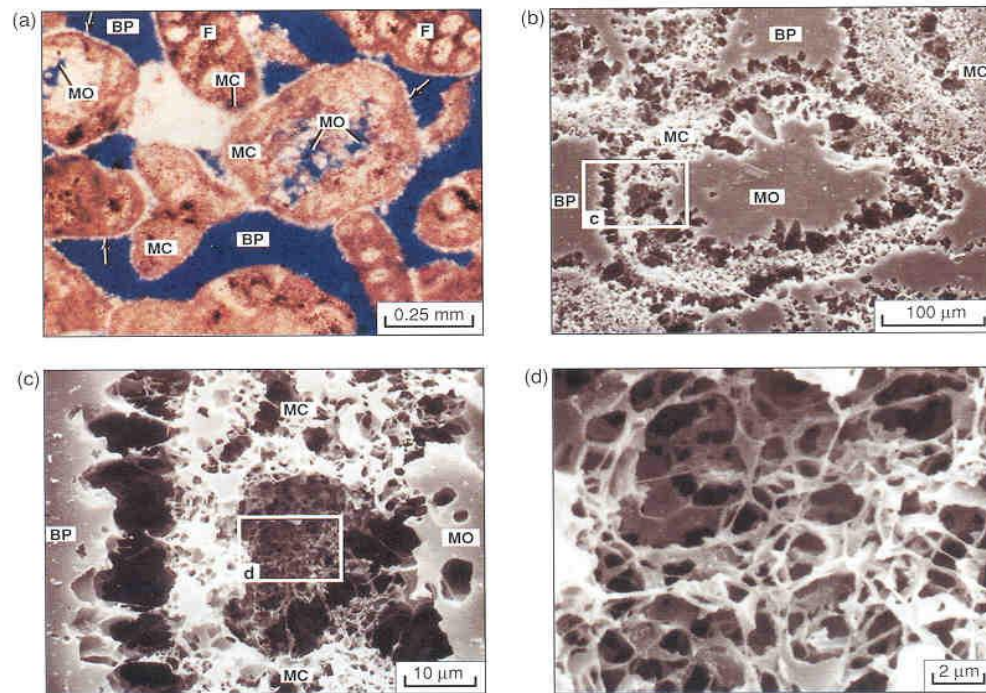


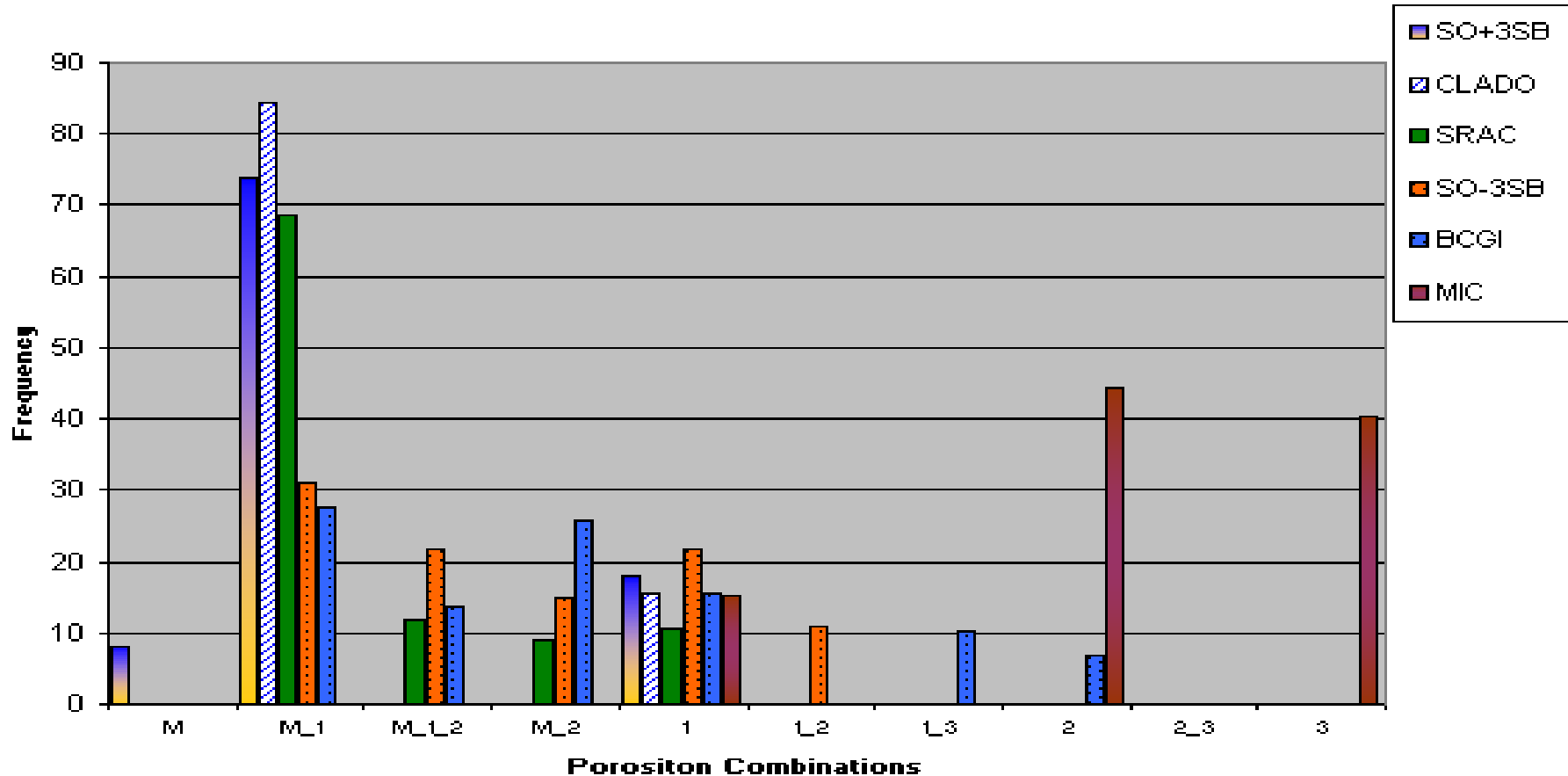
Figure 3: Microporosity in Arab Formation carbonates. In thin section, porosity is filled by blue-dyed epoxy, calcite is stained pink to red, other minerals are unstained. (a) Thin section photomicrograph of skeletal-oolitic grainstone. Interparticle (BP) and moldic (MO) macropores are abundant. Microporosity (MC) occurs within micritized grains and foraminifera (F). Isopachous fringing calcite cement (arrows) coats most grains in this sample (plane-polarized light, Saudi Arabia, Abqaiq field, Arab-D). (b) SEM photograph of epoxy pore cast of sample shown above. Carbonate has been etched away by dilute hydrochloric acid, leaving epoxy replica of pore space. Interparticle (BP) and moldic (MO) macropores are present as solid epoxy, while microporous grains (MC) display fine network of hair-like micropores. (c) Detail of area outlined in sample shown in (b). Microporosity (MC) occurs as tortuously interconnected fine pores, while large moldic (MO) and interparticle (BP) pores are completely filled by epoxy. Note the thin, straight micropores between cement crystals that surrounded the grain before being etched away during sample preparation. (d) Higher magnification view of area outlined in previous example. Prior to leaching, this micritized grain consisted of well-sorted calcite crystals 1 to 4 microns in size; microporosity occurs as highly interconnected pores generally 1 micron or less in diameter.

HWM-C Facies in terms of Porositon Classified Pore Systems

Rosetta Stone Pd Code Frequency Distributions
Baseline Adjusted at 5.2% and renormalized

Code Key Order - 1st,2nd,3rd

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UMiami, Carbonate Sedimentology Laboratory

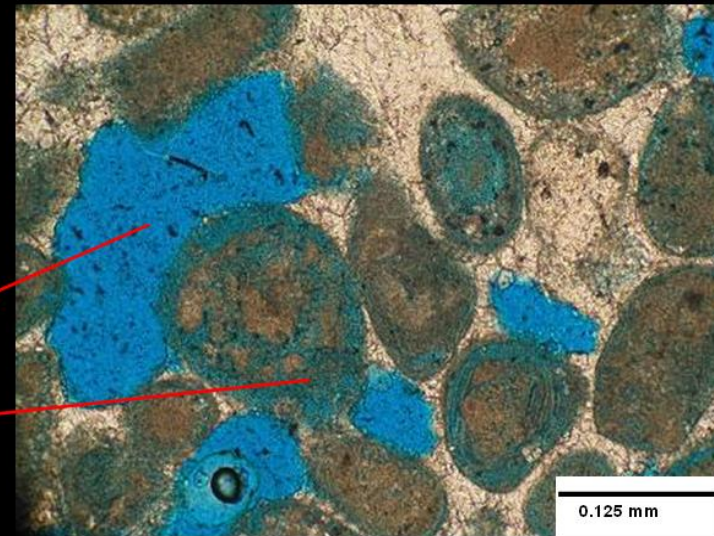
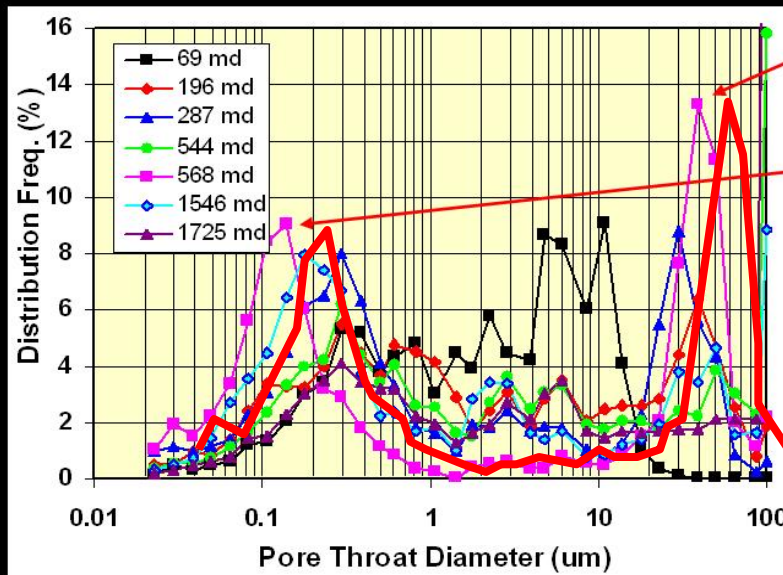
Dual porosity systems in recent carbonates



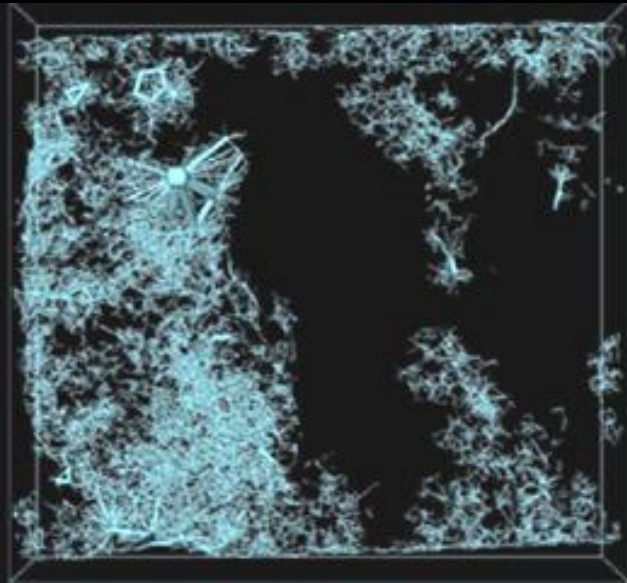
Diagenesis x Petrophysics

Microporosity and large intergranular pores

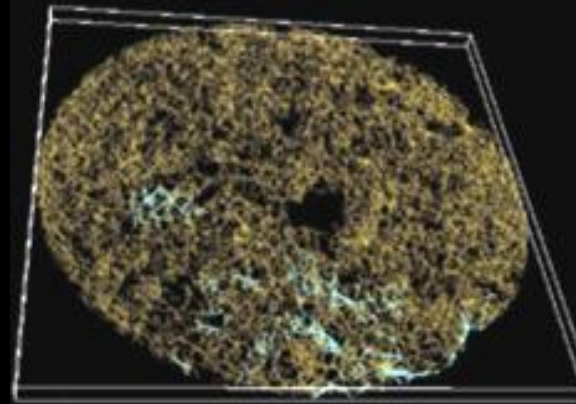
Bimodal pore throat size distribution



Macropores



Micropores



Macropores & Micropores

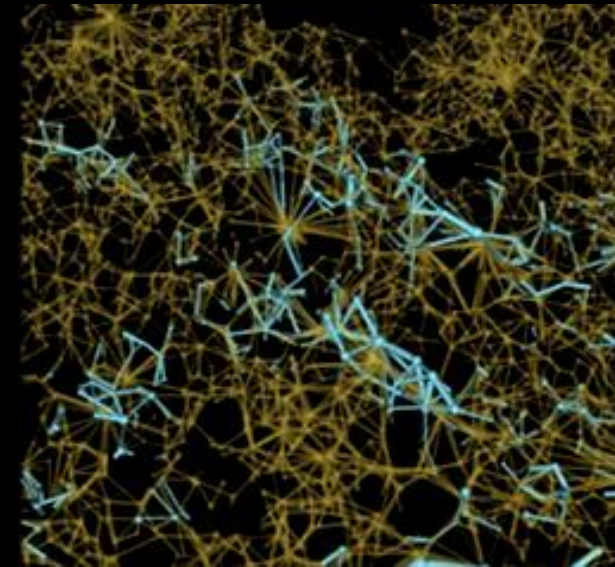
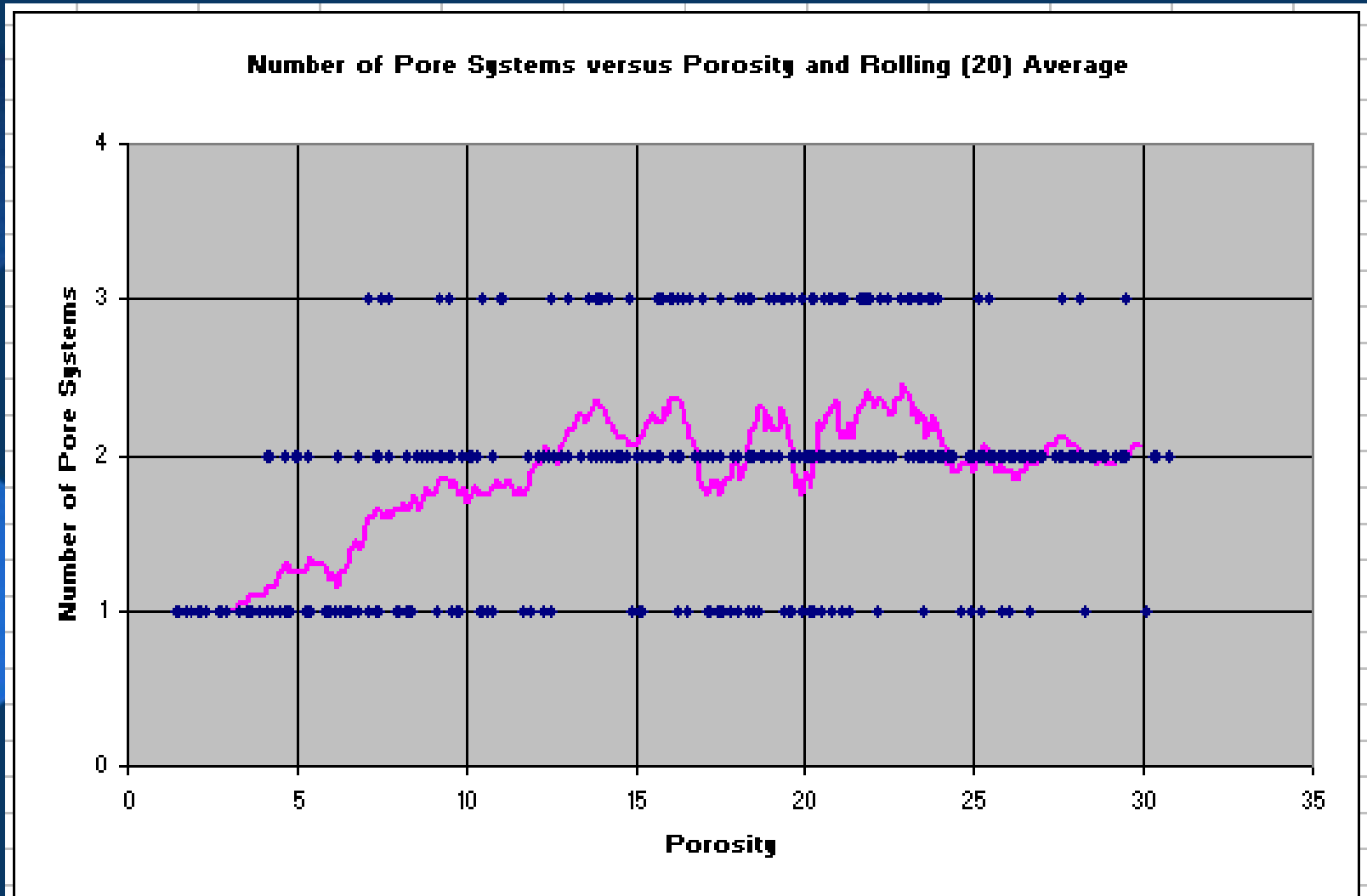


Figure 6: Connectivity of the families of pore network associated with varying length scales from a middle eastern carbonate (Sok et al., 2007). On the left is the resolvable macroporous network. Large regions which exhibit no spanning macroporosity are evident. Decoration of the pore network with pore elements associated with smaller pore sizes leads to a highly interconnected pore network. The enhanced connectivity of the pore space evident in this data illustrates the importance of inclusion of (Type I) microporosity in studies of spontaneous imbibition and recovery as noted by Clerke.

Rosetta Stone Selected Results

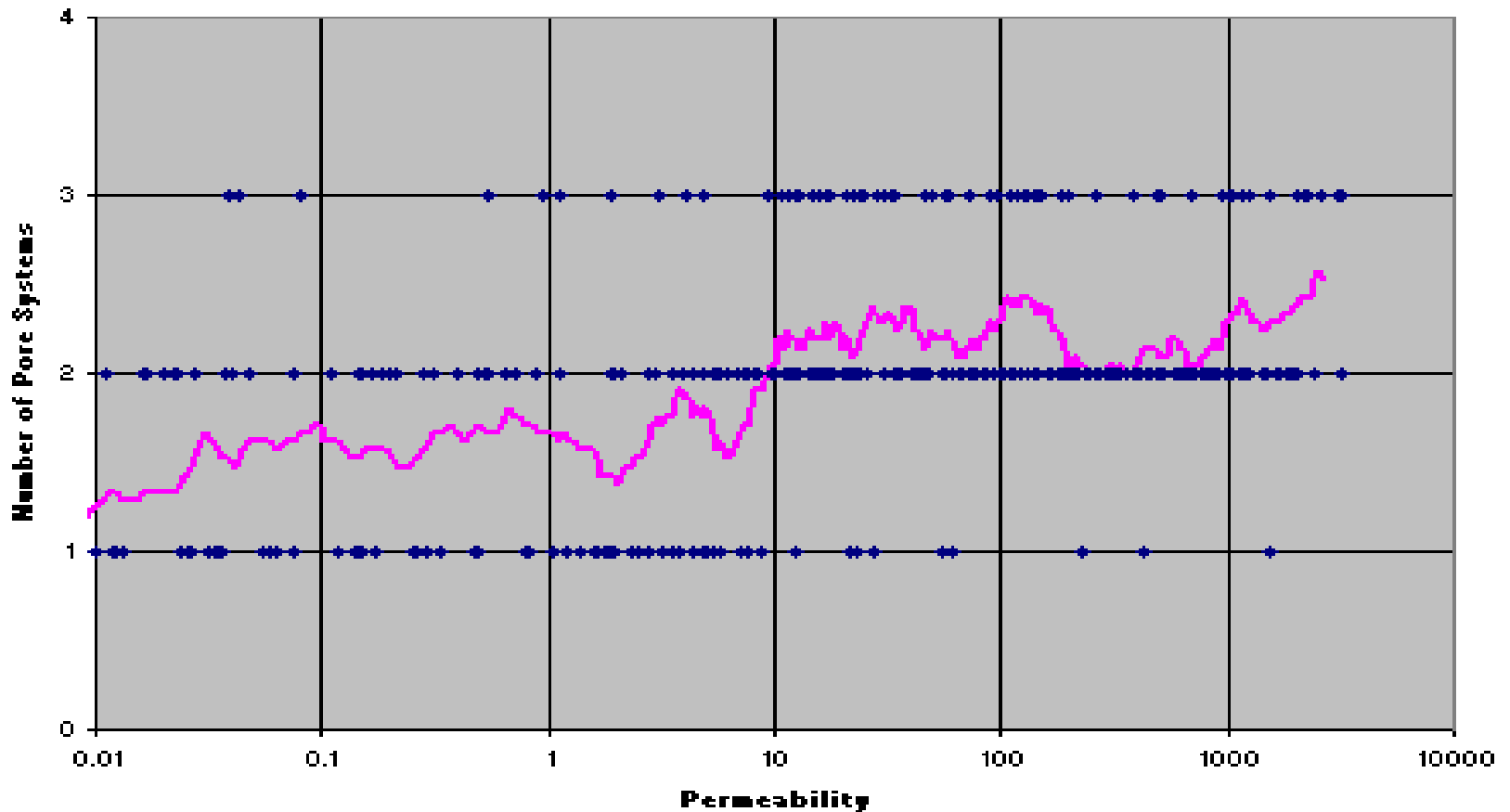
Bimodality common in porous reservoir rock



Rosetta Stone Selected Results

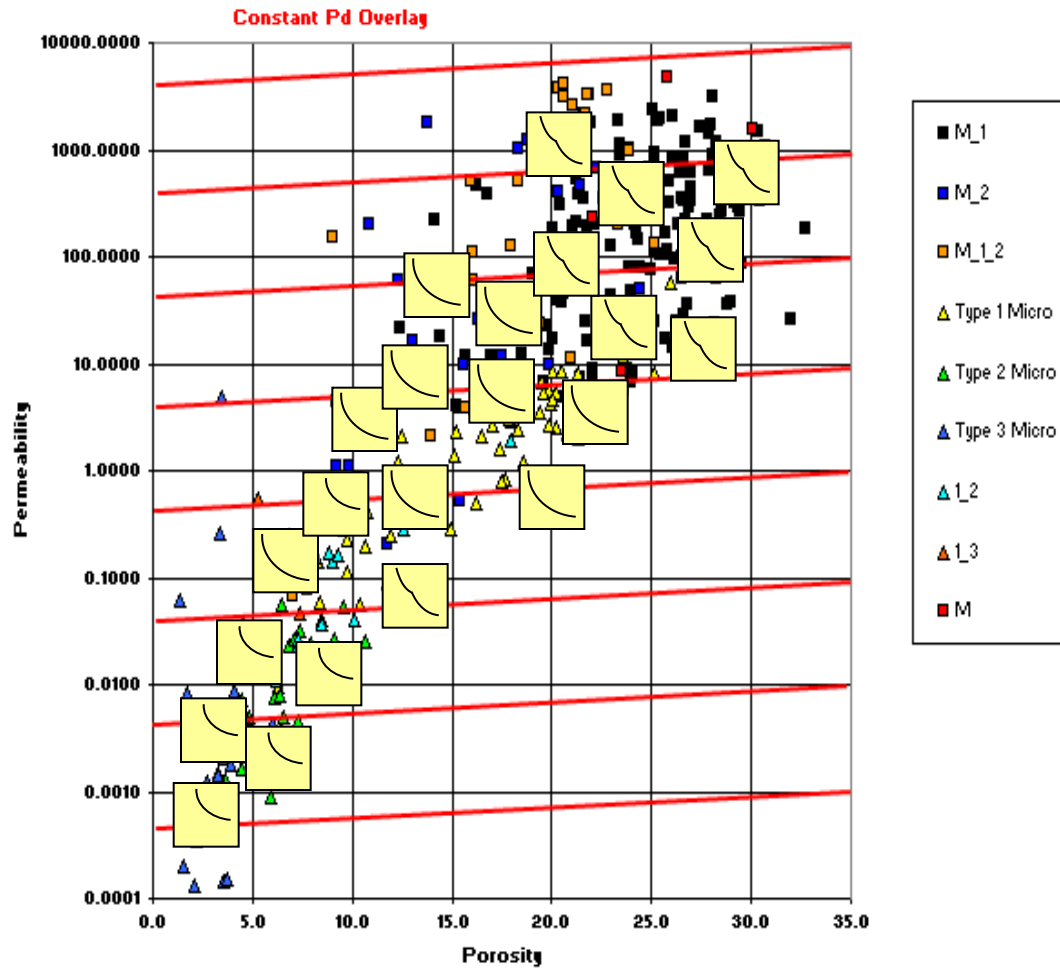
Bimodality common in permeable reservoir rock

Number of Pore Systems versus Permeability

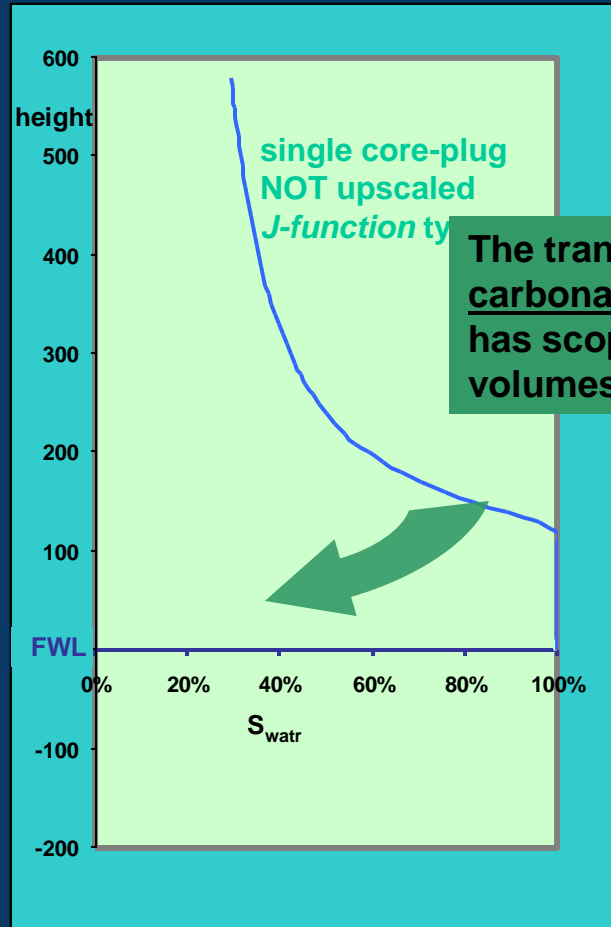


Map Inversion Rock Typing (MIRT)

Porosity versus Permeability for Major Porositons or Combinations

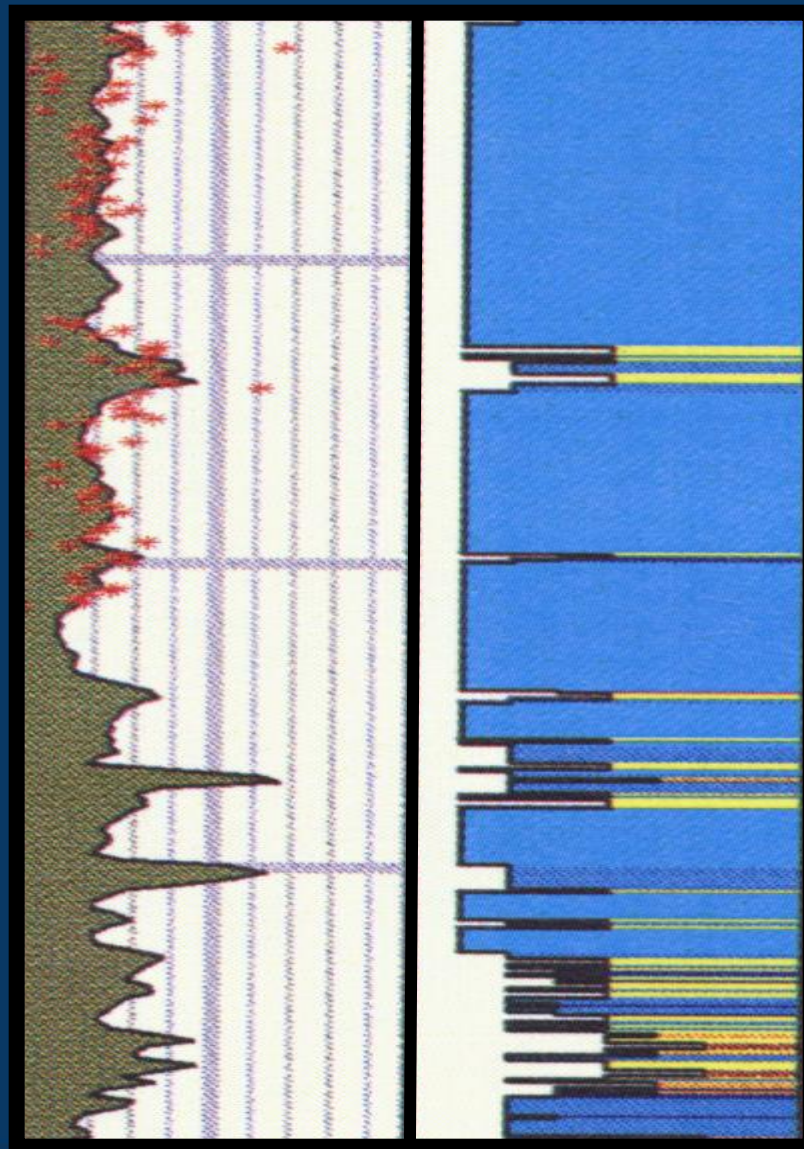


New upscaled multimodal saturation height models



The transition zone of carbonate oil reservoirs has scope for additional volumes

ROS by Rosetta Stone Ultimate Recovery Rock Types



Transport Property Models for Multimodal Carbonate Pore Systems

- active investigations
- improved understanding of Rock – Fluid interactions