A New Genetic Classification of Carbonate Porosity and Its Application to Reservoir Characterization*

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Abstract

Carbonate pore types are formed by depositional, diagenetic, or fracture processes such that the spatial distribution of porosity may or may not conform to depositional facies boundaries. Pores may be formed or altered by diagenesis and brittle fracture. Understanding carbonate porosity requires identifying pore characteristics that reflect the processes that created them. It requires determining how genetic pore types are related to petrophysical characteristics and how pore-forming processes have influenced bulk-rock properties.

Genetic pore types are part of a larger collection of rock properties formed by the three end-member processes; consequently, genetic pore types must have characteristics that correspond to petrological or stratigraphic attributes that serve as "tags" for the genetic pore types. Examples of "tags" may include unconformities, paleosols, evaporite horizons, predictable occurrences in stratigraphic cycles, or distinctive geochemical, fluid inclusion, and cathode luminescence signatures. Such tags may be recognizable in cores and thin sections, on outcrops, in sequence stratigraphic "stacking patterns", on wireline logs, and in seismic signatures.

If the mode and time of origin of the "tags" can be identified, it is then possible to predict the spatial distribution of the corresponding genetic pore types. Rock properties that correspond to genetic pore types can be put in larger stratigraphic context for use in reservoir characterization, flow unit mapping, and reservoir modeling.

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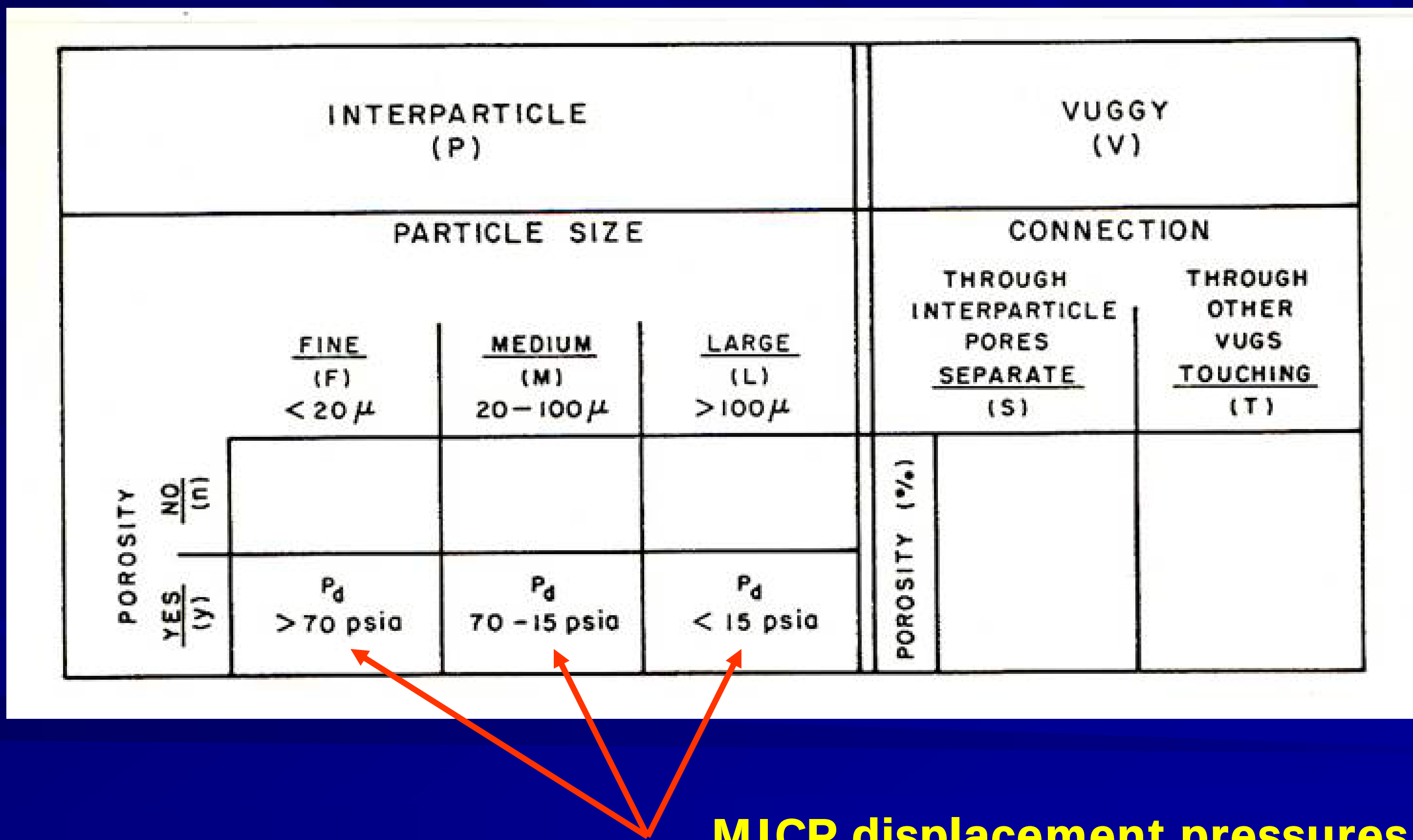
Outline

- Current porosity classification systems
- Why add another one?
- The new classification
- The new classification in exploration & development
- The new classification in petrophysics & reservoir characterization

The First of Current Classifications
Archie (1952)

- 3 Textural categories
  - Type I: “Hard, crystalline, dense” (today’s lithographic limestone)
  - Type II: “Earthy, chalky, grains < 50 μm” (today’s chalk)
  - Type III: “Granular; saccharoidal” (today’s grainstones)
- 4 Classes of “visible porosity”
  - Class A: No visible φ @ 10x
  - Class B: Visible φ between 1 & 10 μm
  - Class C: Pores > 10 μm but < size of rotary cuttings (~2 mm)
  - Class D: Vugs; pores larger than rotary cuttings

Lucia’s work at Shell in the 1960’s led to this scheme. Note inclusion of petrophysical characteristics and differences between interparticle and vuggy porosity. (Lucia, 1983)



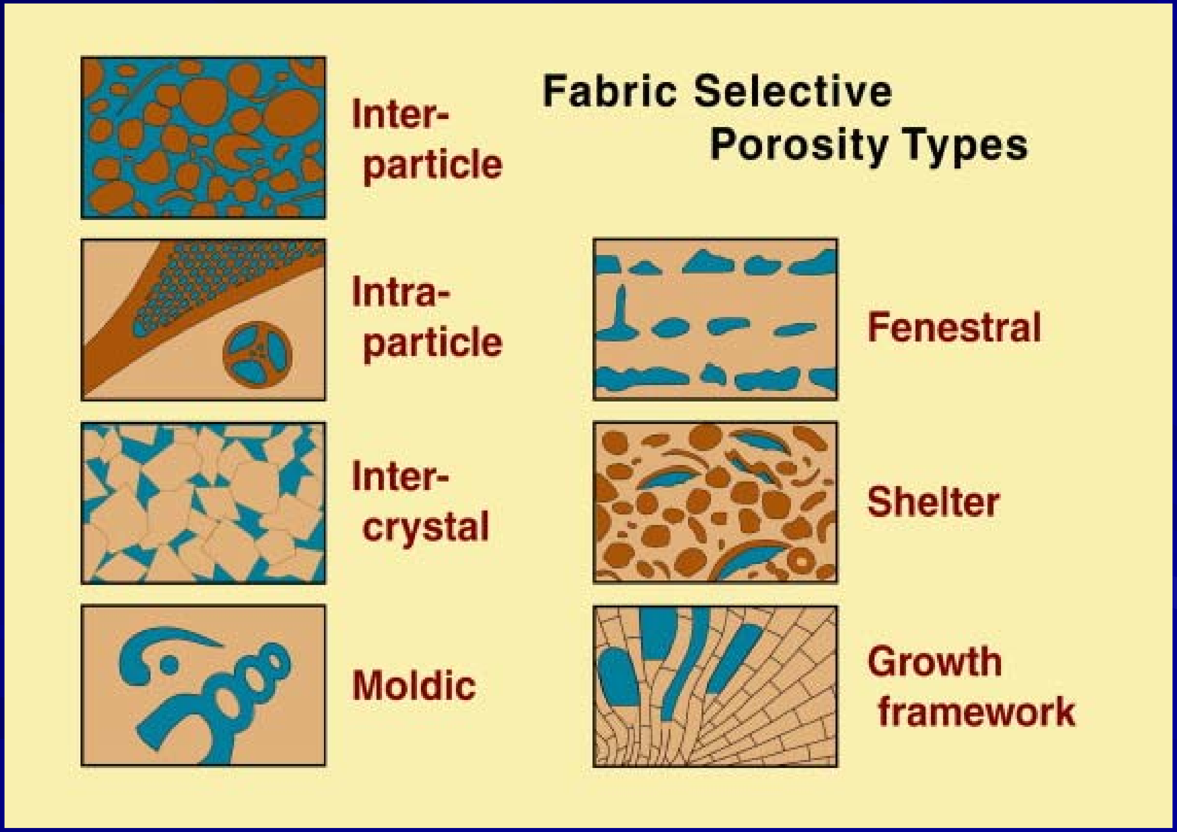
MICP displacement pressures

Choquette & Pray (1970) introduced "fabric selective or not" to classifications

Depositional origin

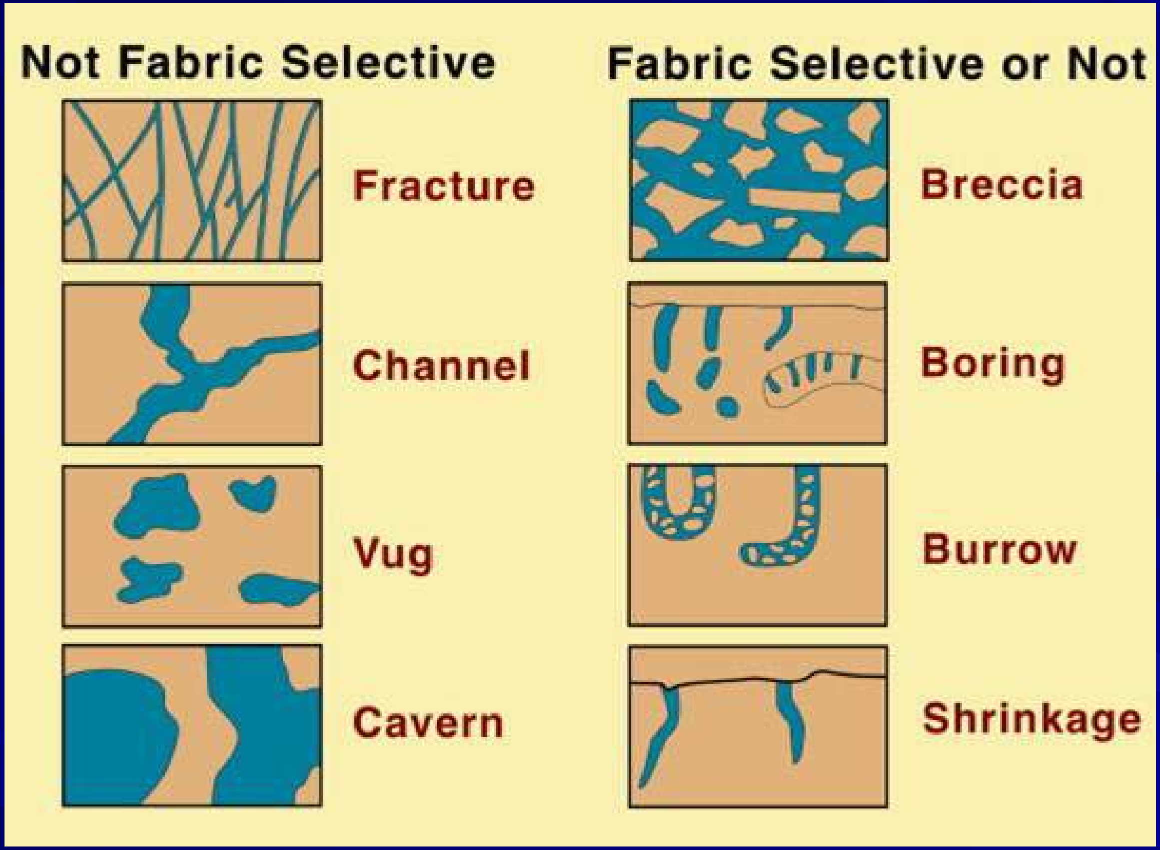
Diagenetic Origin

Diagenetic Overprint



Depositional origin

Choquette – Pray, continued



Mechanical origin

Diagenetic origin

Tectonic or solution collapse origin

Biogenic

Diagenetic origin (desiccation-syneresis)

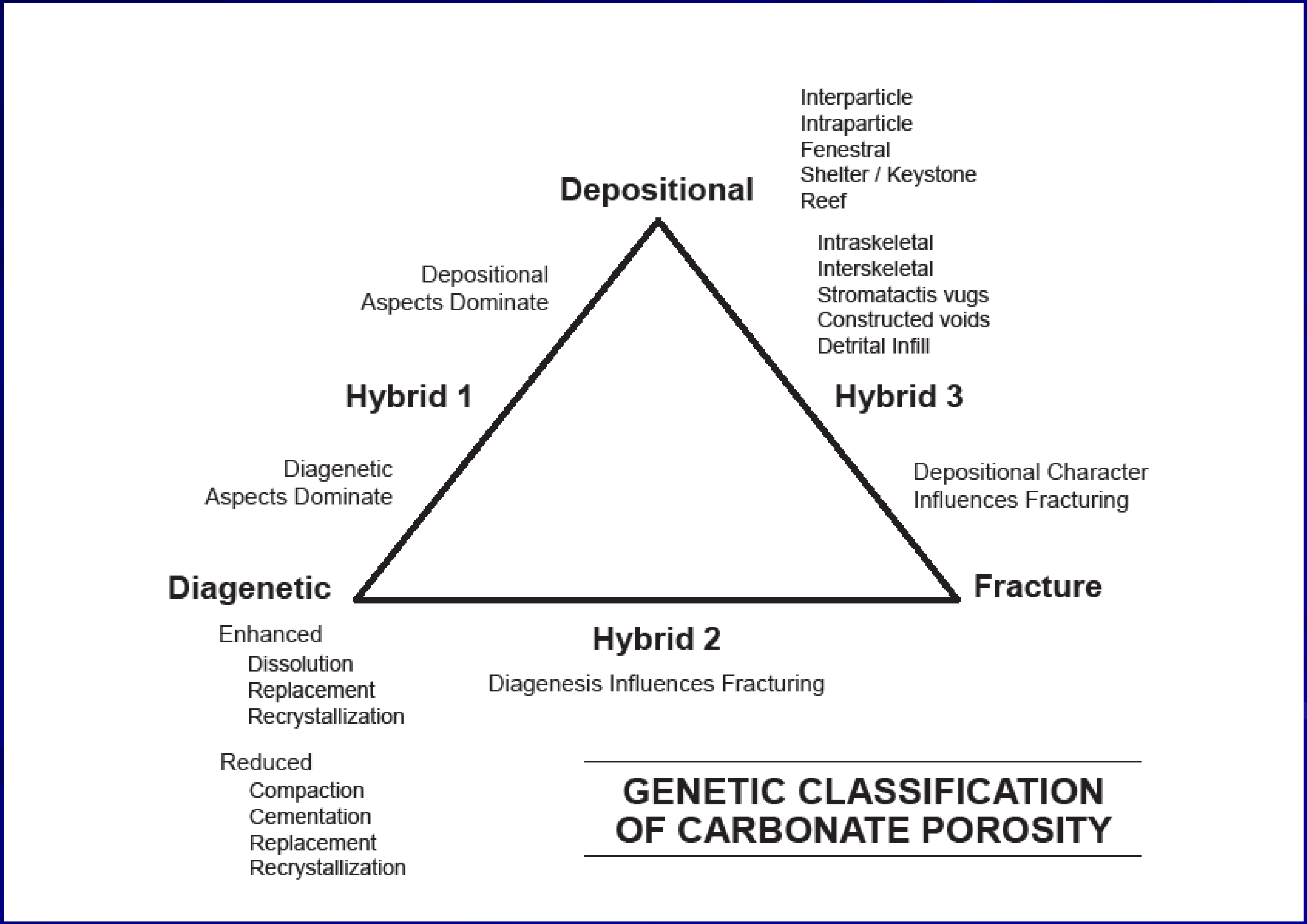
Lonoy (2006) Added New Twists to Existing Classifications

- Uses Lucia system but with pore size; not particle size
- Emphasizes φ distribution
- 12 New categories added for interparticle - intercrystalline φ - based on Lucia/Choquette Pray schemes
- Distinguishes macro vs micromolds
- 4 New categories for micro-φ in mudrocks

Why Add Another Classification?

- Two main reasons
  - 1. Methods for correlating & mapping pore types and related 'flow units' at reservoir scale is not addressed in previous schemes. "How do I predict spatial distribution of these pore types?"
  - 2. Ways to assess contribution of genetic pore types to reservoir performance (petrophysical rock typing) has not been adequately developed and tested

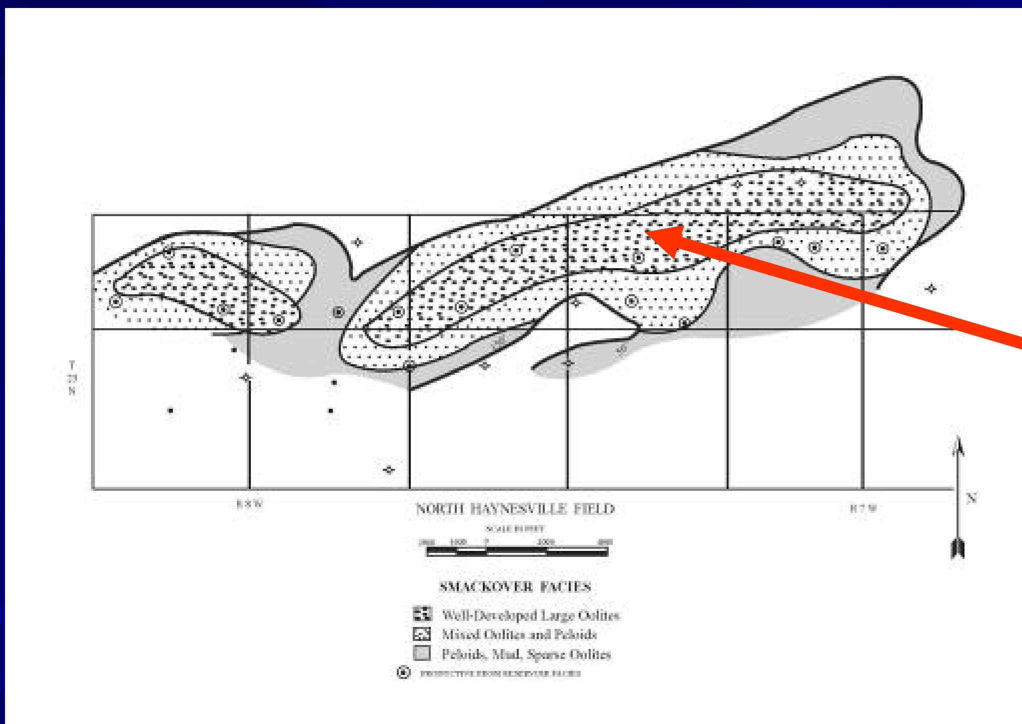
A New Classification



The New Classification in Exploration-Development

- Links genetic φ-types to co-varying “bundled” attributes such as facies type; cross-cutting diagenetic features; position in sequence or stacking patterns; associated evaporites/soils/karst, etc.
- Helps identify, correlate, & map readily traceable rock/stratigraphic attributes that covary with genetic φ
  - Depositional pores: facies map = porosity map
  - Diagenetic pores: strat signal left by diagenesis = key to porosity mapping
  - Fracture pores: tectonic geometry & mechanical stratigraphy = keys to porosity mapping

Example 1: Depositional Porosity
Facies Maps = Proxies for Porosity Maps

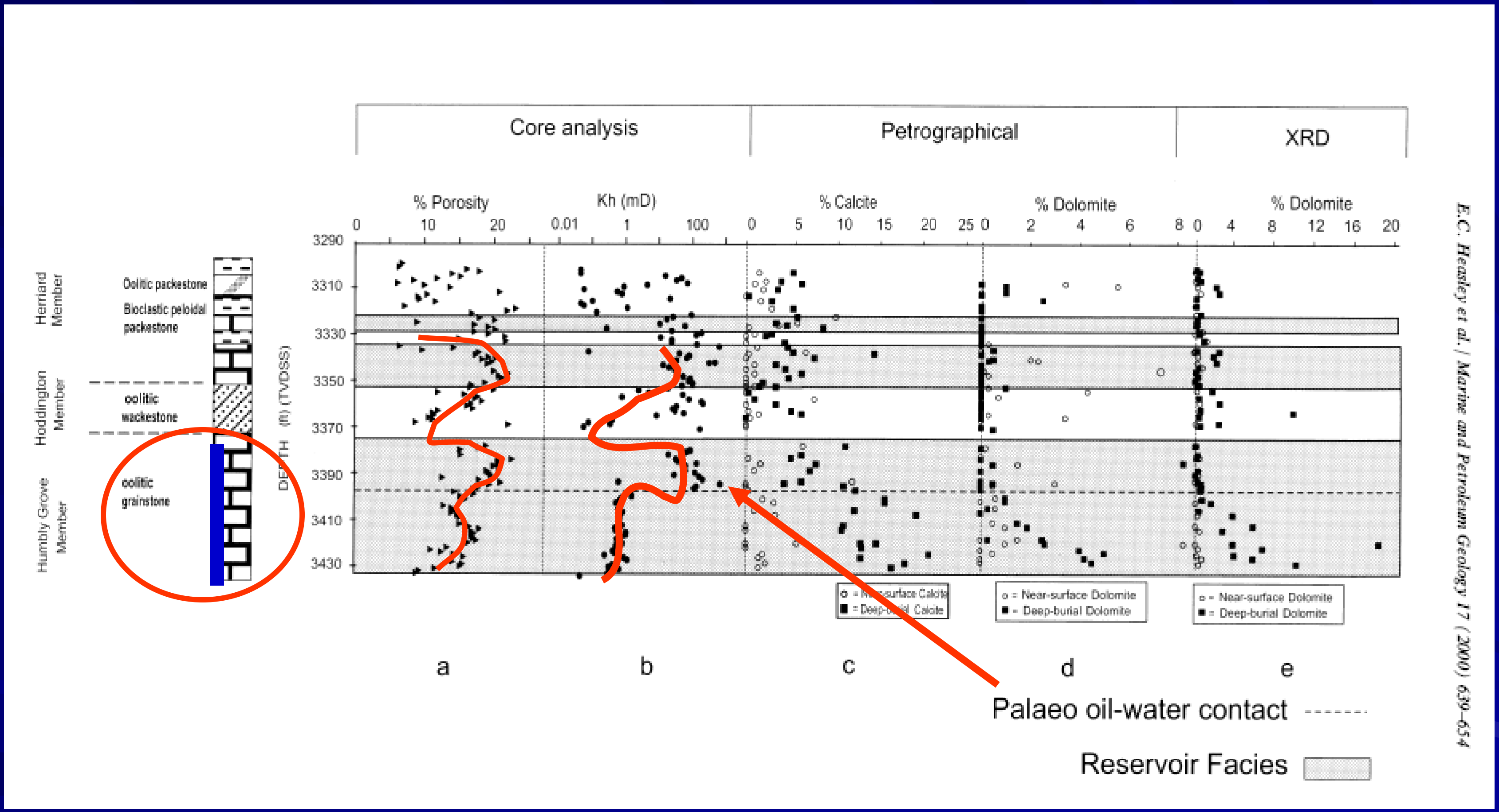


N Haynesville Smackover field, LA.

Oolite gnst; depositional inter-granular porosity

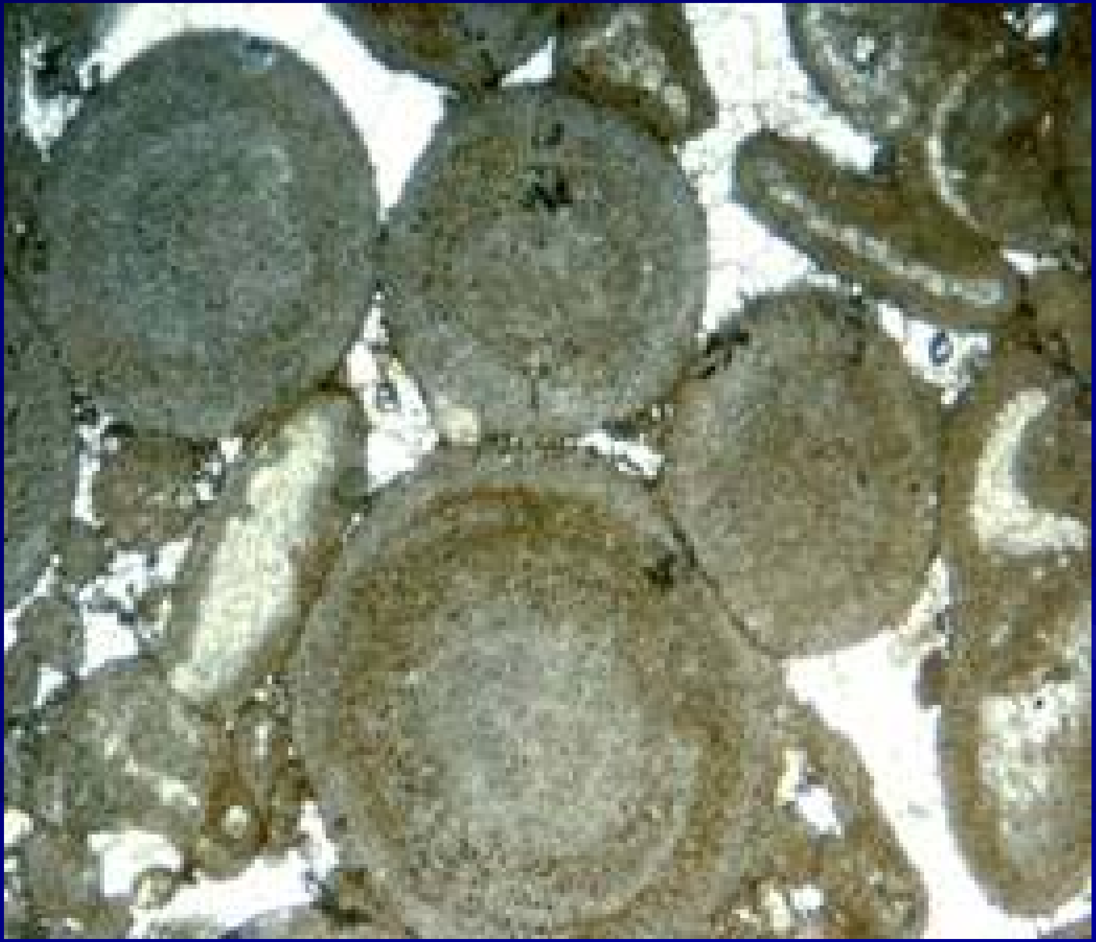
Example 2: Hybrid Porosity

Cement-reduced depositional φ + diagenetic micro-φ below paleo-o/w contact in oolite grainstone

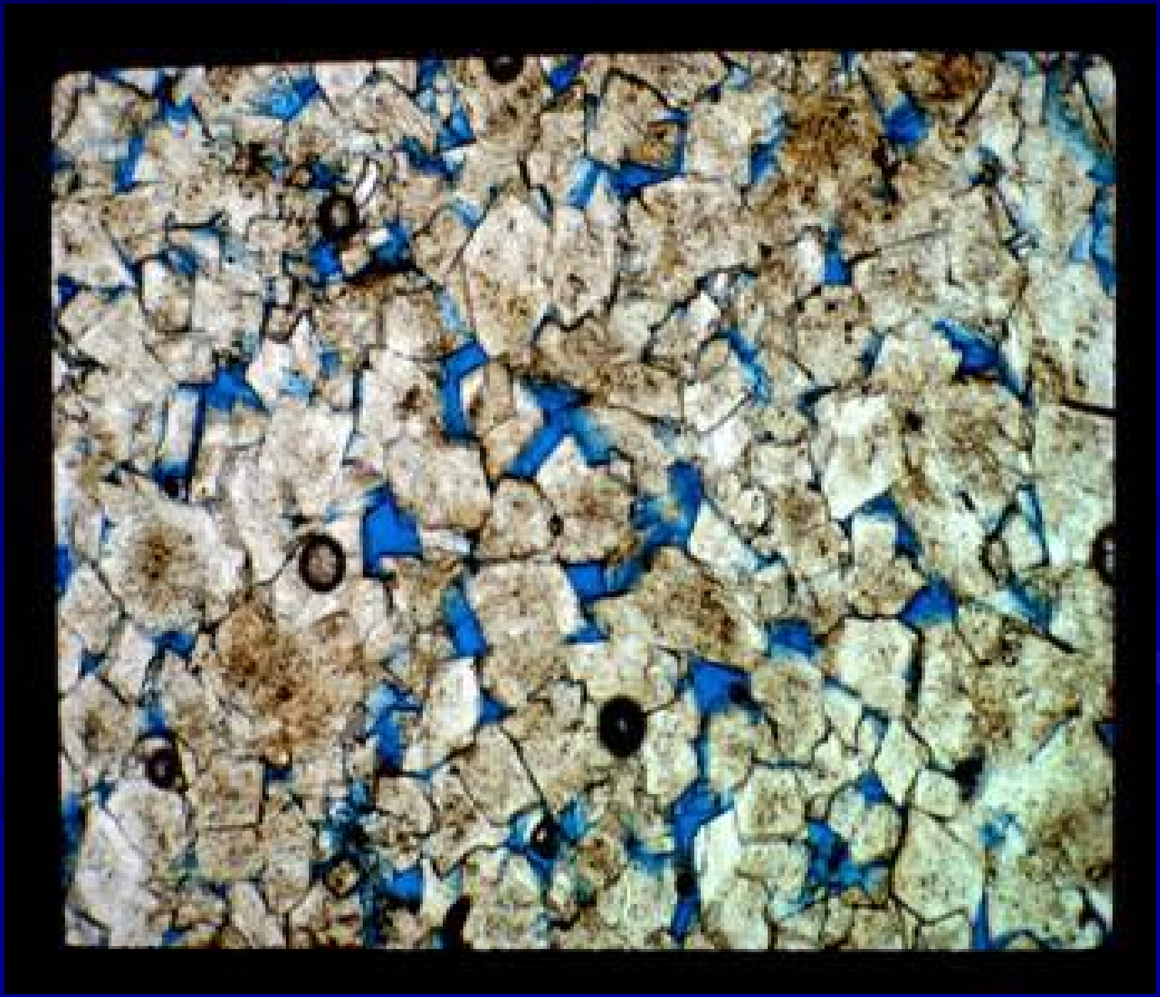


Humbly Grove Oolite, Jurassic, Weald Basin, UK
Heasley et al. (2000)

Hybrid Pores: cement-reduced intergranular φ + diagenetic micro-φ

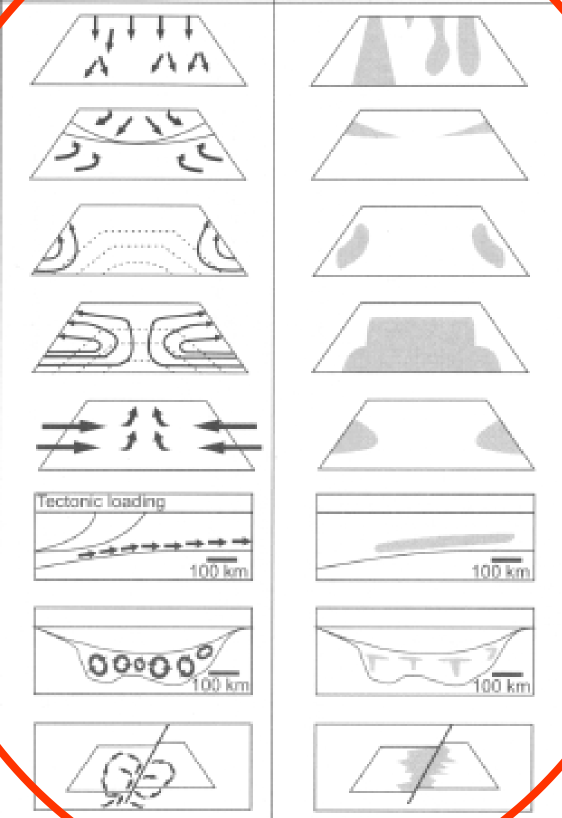


Example 3: Purely Diagenetic Porosity - Intercrystalline Pores in Dolostone



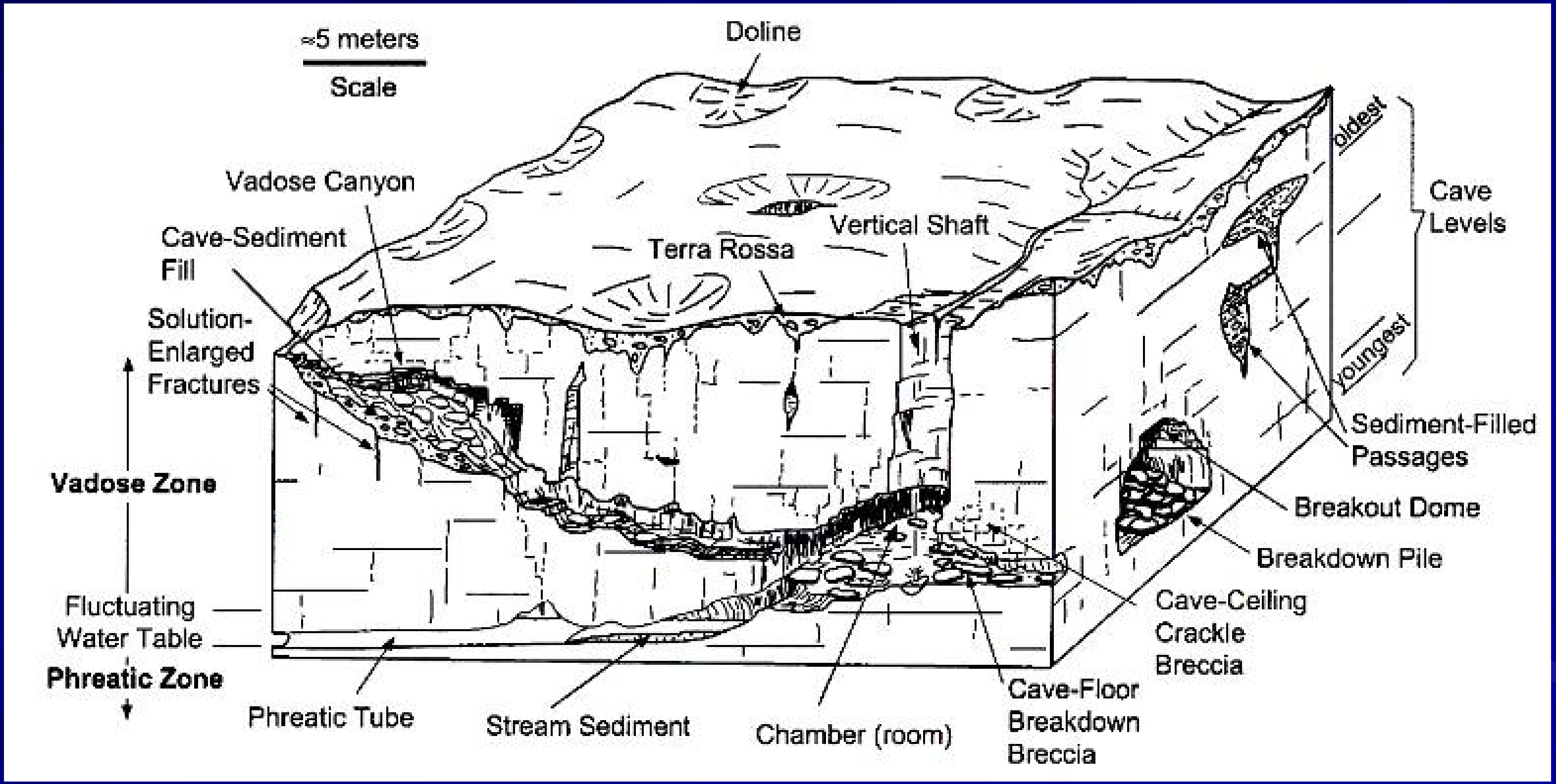
Distribution of dolomite depends more on mechanism of dolomitization & hydrologic model than on depositional processes and facies boundaries

Dolomitization Model	Source of Mg^{2+}	Delivery Mechanism	Hydrological Model	Predicted Dolomite Patterns
A. Reflux Dolomitization	seawater	storm recharge, evaporative pumping, density-driven flow		
B. Mixing Zone (Dorag) Dolomitization	seawater	tidal pumping		
C1. Seawater Dolomitization	normal seawater	slope convection ($K_v > K_h$)		
C2. Seawater Dolomitization	normal seawater	slope convection ($K_h > K_v$)		
D1. Burial Dolomitization (local scale)	basinal shales	compaction-driven flow		
D2. Burial Dolomitization (regional scale)	various subsurface fluids	tectonic expulsion topography-driven flow		
D3. Burial Dolomitization (regional scale)	various subsurface fluids	thermo-density convection		
D4. Burial Dolomitization (local and regional scales)	various subsurface fluids	tectonic reactivation of faults (seismic pumping)		



Machel, 2004

Example 4: Purely diagenetic φ in vadose-phreatic caves: φ follows dissolution path & collapse zones



Loucks, 1999

Ex. 4 Continued: what determines poroperm boundaries in paleocave reservoirs?

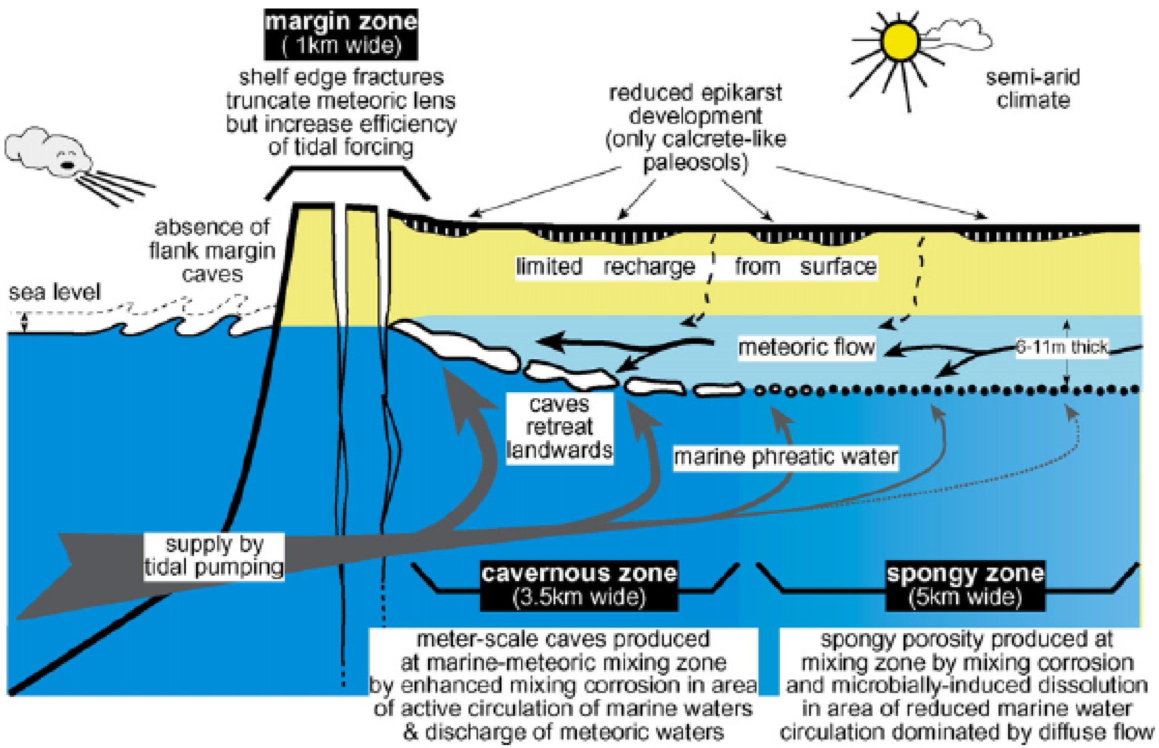
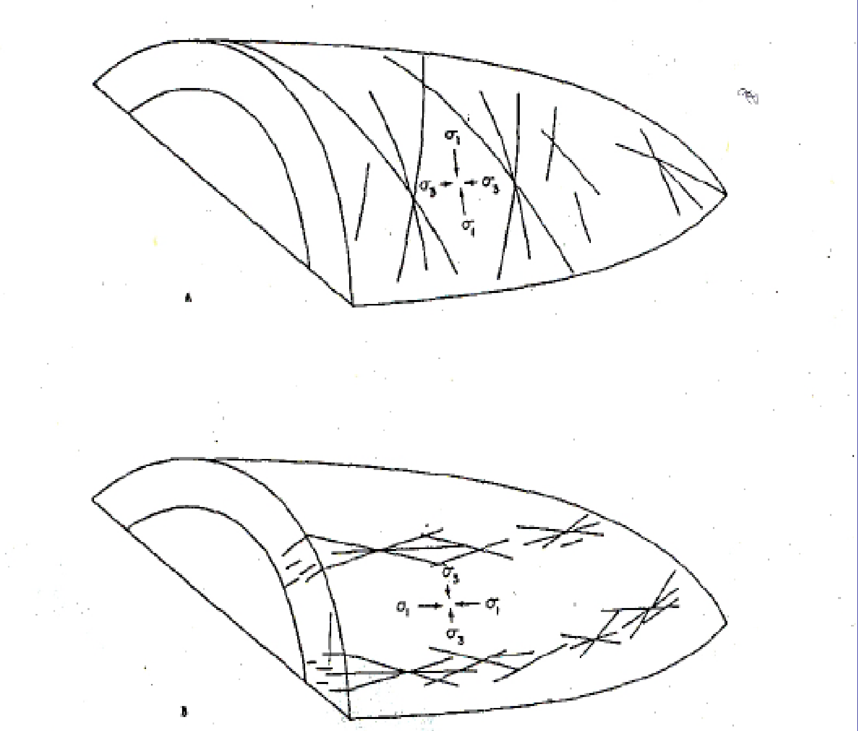


Fig. 14. Palaeohydrological model of macro-porosity evolution in Danian limestones, identifying the fracture belt and the two distinct settings of dissolution (cave and spongy zones), reflecting contrasting levels of circulation in the palaeo-aquifers.

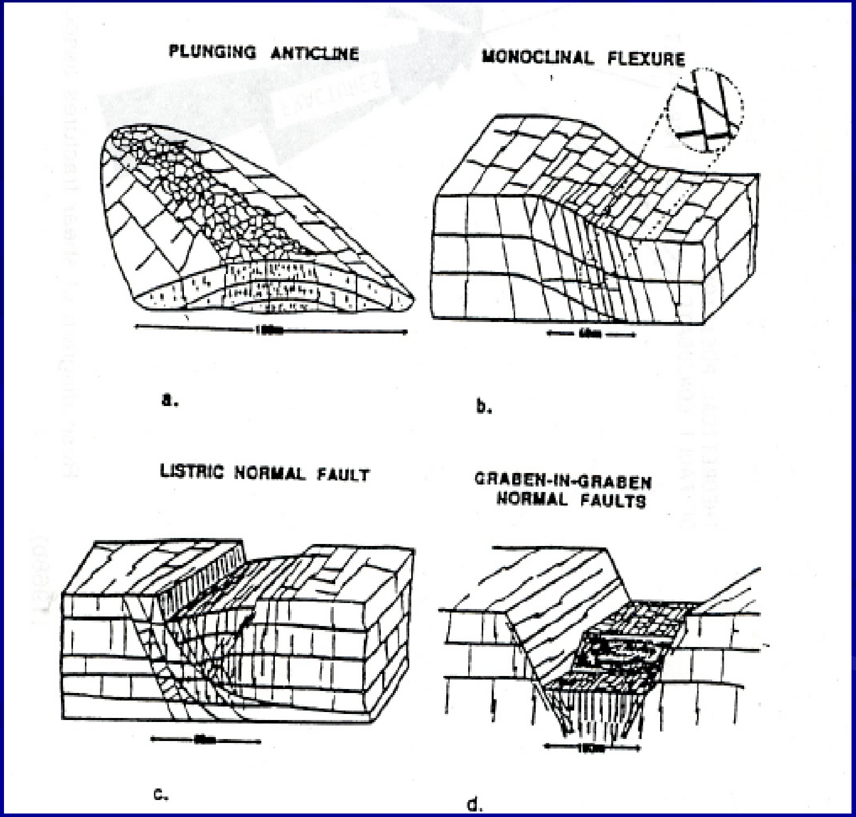
Baceta et al., 2007

Example 5: Fracture Systems
Poroperm follows tectonic geometry & mechanical stratigraphy – not depositional or diagenetic boundaries



—Schematic illustration of most common fractures associated with a fold. A. Pattern 1. B. Pattern 2. Both patterns maintain consistent relation to bedding, but not to fold trend.

Stearns & Friedman (1972)



Corbett et al., (1991)

Fracture Hybrids: diagenetically altered fractures: fractures dominate capacity to flow; vugs = capacity to store

Dissol'n-enlarged vugs with late saddle dolomite

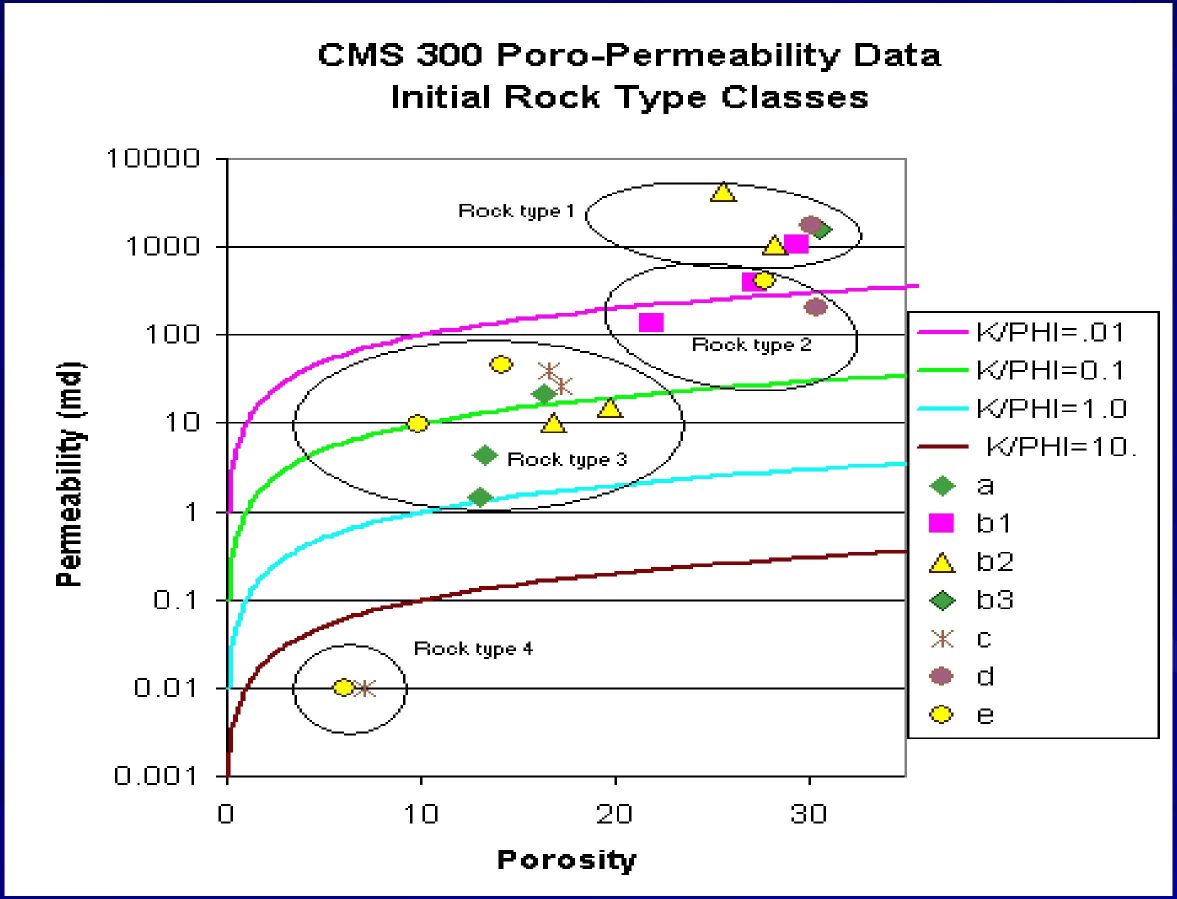
Stylolites

Fractures – some with dissol'n vugs

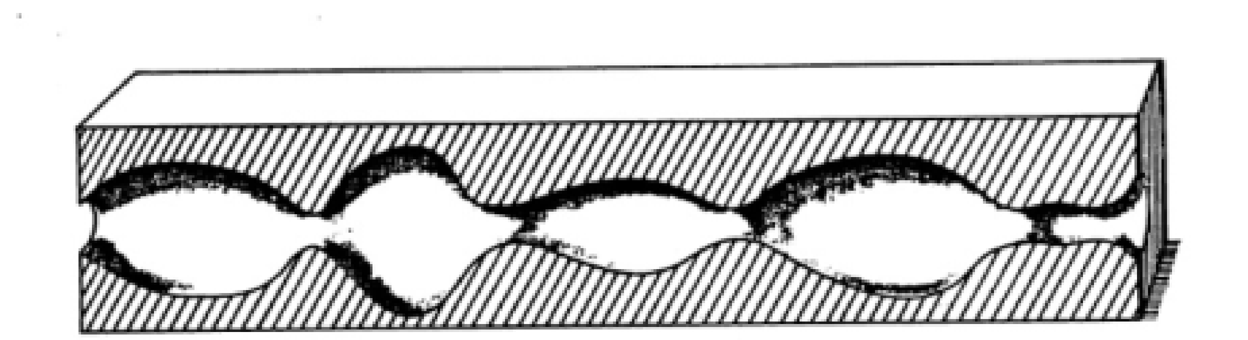
The new classification in petrophysics & reservoir characterization

- Petrophysical rock types are currently based on facies
- Multiple rock types may exist in 1 facies
- As rock typing is based on pore throat size or k/φ ratios…
- Petrophysical rock types based on genetic pores & their geometry should more accurately discriminate between quality ranked flow units

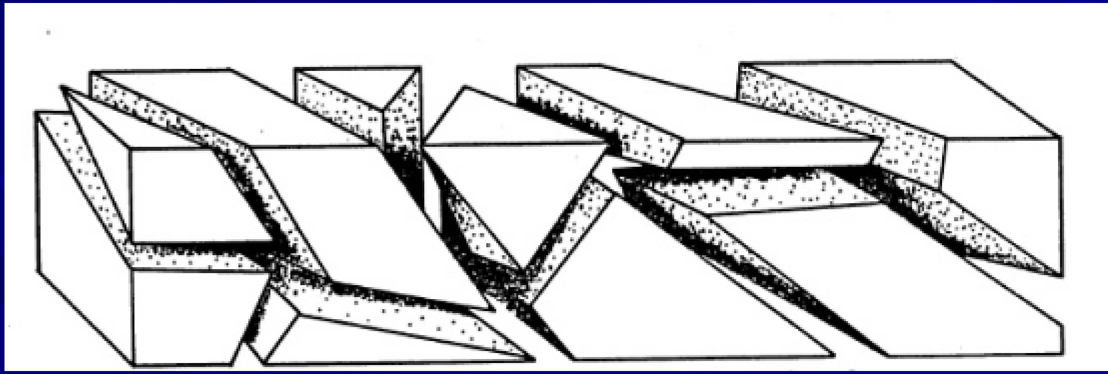
Example 6: Winland-type plot to discriminate between petrophysical rock types based on facies



Petrophysical Rock Types Depend on Pore/Pore Throat Geometry



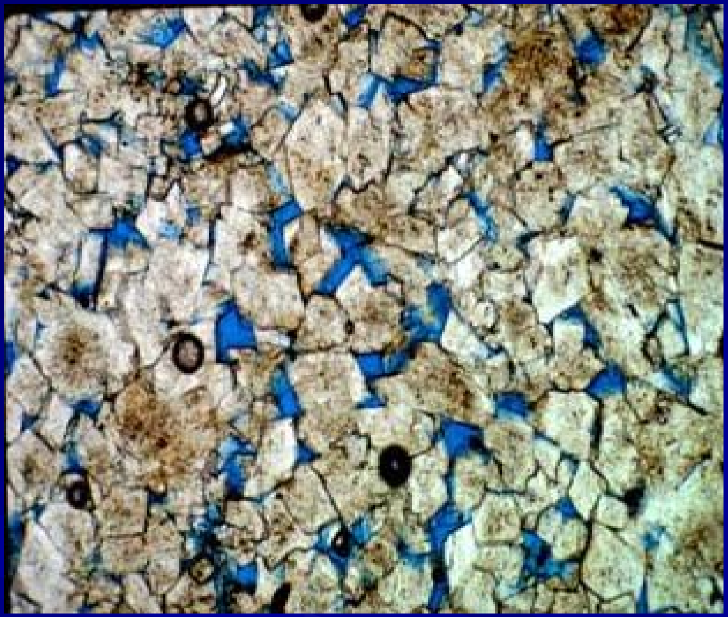
Pinch / swell 'tubes' typical of intergranular pore / pore throat geometry



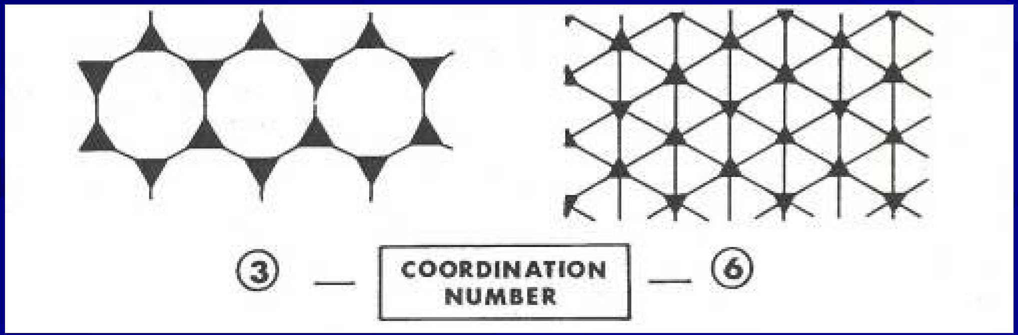
'Sheet' pore / throat geometry typical of open intercrystalline pores in dolostones

Winland (1976) courtesy K. Steffensen, BP

Pore/Throat Geometry Dictates Reservoir Performance & Recovery Efficiency (RE)



Lower RE



Higher RE

Conclusions

- Genetic classification identifies rock properties and covariant genetic pore types "bundled" by common origin
- Knowing cause-effect origin of pores, pore/rock-type bundles are mappable at field scale e.g., diagenesis associated with unconformities, fractures associated with structural geometry, depositional pore systems associated with facies boundaries
- The classification facilitates improved reservoir definition, flow unit mapping, & petrophysical rock typing based on pore type & pore/pore throat geometry instead of 'facies type'