PS An Evaluation of Existing Carbonate Pore System Classifications and Rock-Typing Approaches*

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Abstract

Restrictions on the most commonly used porosity classification schemes for carbonate reservoirs stem from poorly-defined relationships between porosity and permeability. The rock fabric method of Lucia (1995, 1999) and the more elaborate pore classification scheme of Lonoy (2006) represent attempts to overcome this problem. Although these approaches provide a considerable improvement on more traditional classifications, there have been few independent attempts to evaluate the relative merits of each. The aim of this study is to evaluate the two carbonate porosity classification schemes using a well constrained dataset from the Upper Cretaceous of offshore Tunisia.

The methodology employed for this study involved the examination of thin sections and the integration of routine core analysis data. Following pore classification using each scheme, permeability was calculated and compared to measured values. Neither classification scheme worked particularly well for the dataset in this study. Only one pore-type class yielded the porosity-permeability trends anticipated according to Lonoy (2006), and none of Lucia's (1995, 1999) rock-fabric classes adhered to the trends expected. Furthermore, permeability calculated using Lonoy's (2006) scheme resulted in better correlation with measured values than when using Lucia's (1995, 1999) scheme, although neither scheme resulted in well-matched values. The inability of both schemes to adequately characterise porosity-permeability relationships is due to pore-type diversity. With Lucia's (1995, 1999) classification scheme, the presence of large amounts of separate-vug porosity poses problems when calculating interparticle porosity. Lonoy's (2006) classification scheme is based on dominant pore type and size; therefore the presence of several pore types and sizes in a sample reduced the correlation between matrix-related porosity and permeability. Recommendations for improving the applicability of both approaches are presented in this study.

References

Archie, G.E., 1952, Classification of carbonate reservoir rocks and petropyhysical considerations: AAPG Bulletin, v. 36/2, p. 278-298.

Choquette, P.W., and L.C. Pray, 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: AAPG Bulletin, v. 54/2, p. 207-250.

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional textures, in Classification of Carbonates Rocks: AAPG Memoir 1, p. 108-121.

Lonoy, A., 2006, Making sense of carbonate pore systems: AAPG Bulletin, v. 90/9, p. 1381-1405.

Lucia, F.J., 1999, Carbonate reservoir characterization: Berlin, Springer-Verlag, 226 p.

Lucia, F.J., 1995, Rock-fabric/petrophysical classification of carbonate pore space for reservoir characterization: AAPG Bulletin, v. 79/9, p. 1275−1300.

Moore, C.H., 2001, Carbonate reservoirs: Porosity evolution and diagenesis in a sequence-stratigraphic framework: Developments in Sedimentology, v. 55, 444 p.

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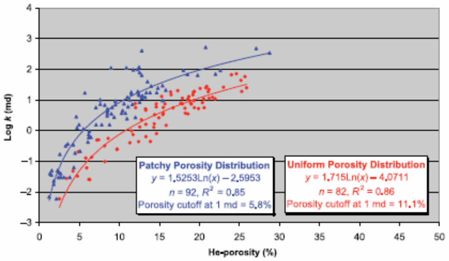
1 Introduction

- The most extensively used pore classification systems for carbonate rocks are limited
- This is due to poorly defined relationships between porosity and permeability
- The rock fabric method of Lucia (1995, 1999) and the more elaborate pore classification scheme of Lonoy (2006) represent attempts to overcome this problem
- Rock fabric elements are combined with petrophysical data
- These represent an improvement on existing classification systems (Archie, 1952; Dunham, 1962; Choquette & Pray, 1970)
- There have been few independent attempts to evaluate the relative merits of each scheme
- The aim of this study is to evaluate and compare the carbonate porosity classification schemes of Lucia (1995, 1999) and Lonoy (2006)

2 Lonoy (2006) Scheme

- 20 pore-type classes, based on pore type, size and distribution
- Scheme texturally derived from Choquette and Pray (1970) and incorporates pore-size differentiation from Lucia (1995, 1999)



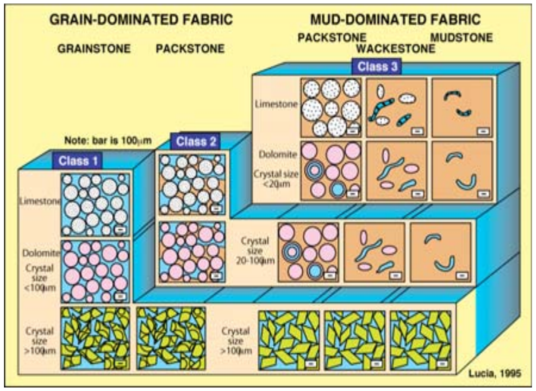
Example of porosity-permeability cross-plot for Interparticle Mesopores (Lonoy, 2006)

Pore Type	Pore Size	Pore Distribution	Pore Fabric	R^2
Interparticle	Micropores (10–50 μm)	Uniform	Interparticle, uniform micropores	0.88
		Patchy	Interparticle, patchy micropores	0.79
	Mesopores (50–100 μm)	Uniform	Interparticle, uniform mesopores	0.86
		Patchy	Interparticle, patchy mesopores	0.85
	Macropores (>100 μm)	Uniform	Interparticle, uniform macropores	0.88
		Patchy	Interparticle, patchy macropores	0.87
Intercrystalline	Micropores (10–20 μm)	Uniform	Intercrystalline, uniform micropores	0.92
		Patchy	Intercrystalline, patchy micropores	0.79
	Mesopores (20–60 μm)	Uniform	Intercrystalline, uniform mesopores	0.94
		Patchy	Intercrystalline, patchy mesopores	0.92
	Macropores (>60 μm)	Uniform	Intercrystalline, uniform macropores	0.80
		Patchy	Intercrystalline, patchy macropores	
Intraparticle			Intraparticle	0.86
Moldic	Micropores (<10–20 μm)		Moldic micropores	0.86
	Macropores (>20–30 μm)		Moldic macropores	0.90
Vuggy			Vuggy	0.50
Mudstone microporosity	Micropores (<10 μm)		Tertiary chalk	0.80
			Cretaceous chalk	0.81
		Uniform	Chalky micropores, uniform	0.96
		Patchy	Chalky micropores, patchy	

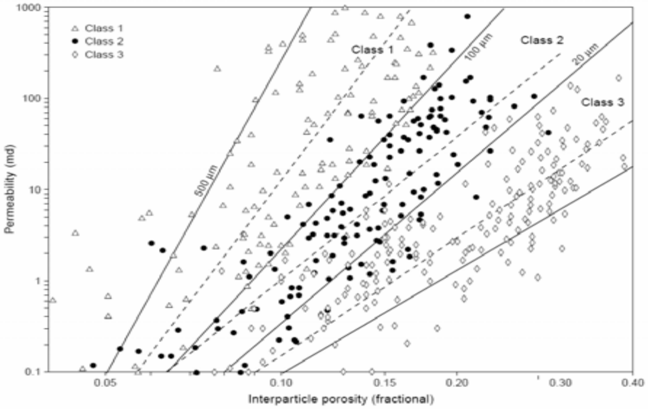
Porosity classification system, Lonoy (2006)

3 Lucia (1995, 1999) Scheme

- 3 rock-fabric classes, based on grain size and sorting, combined with petrophysical data (interparticle porosity)
- Grain size and sorting define the 3 permeability fields that these rock fabrics plot into, whilst interparticle porosity defines the pore-size distribution and thus permeability within the field
- Lucia (1995, 1999) notes that the most useful division of pore types for petrophysical purposes is of pore space between grains or crystals (interparticle) and all other pore space (vuggy)
- Lucia (1995, 1999) recognises two types of vuggy porosity; separate-vug (fabric-selective, pores connected via matrix); and touching-vug (non fabric-selective, forms an interconnected pore network of significant extent)



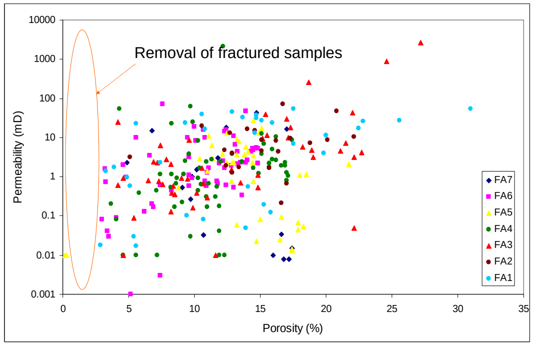
Petrophysical and rock fabric classes based on similar capillary properties and interparticle porosity/permeability transforms, modified from Lucia (1995, 1999) (from Moore, 2001)



Porosity-permeability cross plot illustrating trends exhibited by each of the 3 rock fabric classes (Lucia, 1995, 1999)

4 Methodology

1. Routine core analysis data from c.430 core plugs from reservoir interval was input into a porosity-permeability cross plot to allow QC of the dataset to remove fractured samples
2. Rock samples (c. 50) were studied petrographically and classified using both Lucia's and Lonoy's schemes
3. Porosity was point-counted, with reference to pore type
4. Porosity-permeability cross-plots were constructed for each scheme
5. Permeability was calculated using each scheme and compared to measured permeability



Porosity-permeability cross plot of data from all core plugs in reservoir interval. Orange oval indicates fractured samples that were removed

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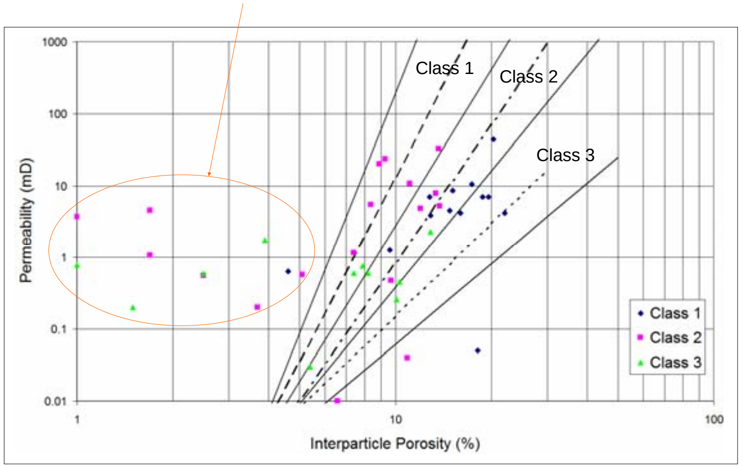
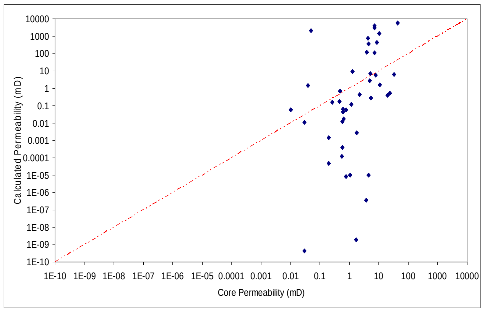
5 Results - Lucia (1995, 1999) Scheme

- Samples from each class generally do not plot within the associated permeability field; there is no clear distinction between class 1, 2 and 3
- Class 1 samples are concentrated in the class 2 permeability field, with several samples in the class 3 field and no samples in the class 1 field
- Class 2 samples mainly fall outside of and within the class 1 permeability field, with some samples in the class 2 field
- Class 3 samples show little trend, occurring in all three fields and outside of the class 1 field
- Many samples fall outside of the class 1 field, suggesting that interparticle porosity is underestimated

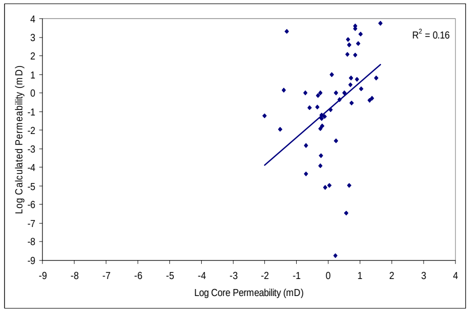


Porosity-permeability cross-plot of data divided by Lucia (1995, 1999) class

- Permeability calculated using Lucia's (1995, 1999) transform is overestimated for high permeabilities or grossly underestimated for low permeabilities
- Comparison shows very low R² value (0.16), indicating poor estimation of permeability



Cross-plot to show comparison between measured and calculated permeability using Lucia's (1995, 1999) calculation

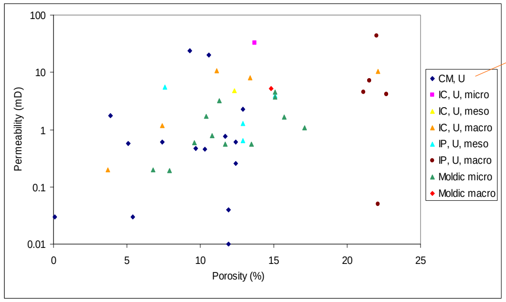


Cross-plot of logarithm permeability to show comparison between measured and calculated permeability using Lucia's (1995, 1999) calculation

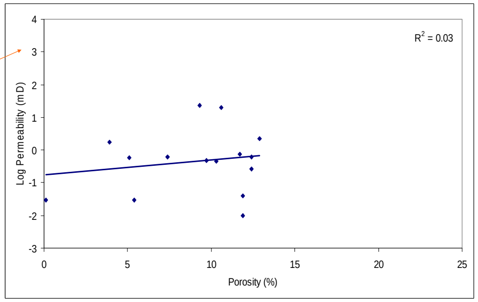
6 Results – Lonoy (2006) Scheme

- It was not possible to evaluate all 20 pore-type classes, since not all were encountered in the dataset
- It was difficult to obtain the high R² values predicted, except for Intercrystalline Uniform Macropores
- Calculated permeability was underestimated overall
- Comparison of calculated and measured permeability shows a low R² value (0.22), indicating poor estimation of permeability

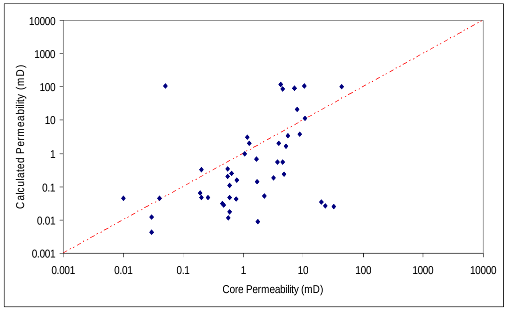
Pore-type class	R²: this study	R²: Lonoy (2006)
Chalky microporosity, uniform	0.03	0.96
Intercrystalline uniform macropores	0.86	0.80
Moldic micropores	0.45	0.86
Interparticle uniform mesopores	0.75	0.86
Interparticle, uniform macropores	0.02	0.86



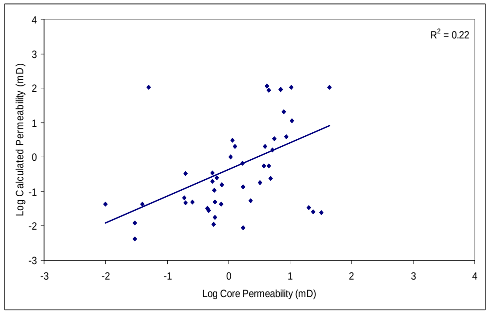
Porosity-permeability cross-plot of data divided by Lonoy (2006) class (CM, U = Chalky Micropores, IC, U = Intercrystalline, Uniform Macropores, IP, U = Interparticle, Uniform Mesopores)



Porosity-permeability cross-plot for Uniform Chalky Micropores



Cross-plot to show comparison between measured and calculated permeability using Lonoy's (2006) scheme



Cross-plot of logarithm permeability to show comparison between measured and calculated permeability using Lonoy's (2006) scheme

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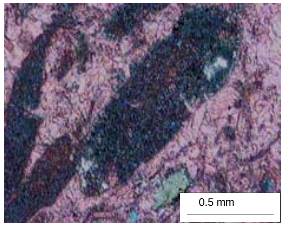
7 Discussion – Lucia (1995, 1999) Scheme

- Many samples fall outside of the class 1 permeability field, suggesting interparticle porosity is underestimated
- According to Lucia (1995, 1999), interparticle porosity is calculated by subtracting separate-vug porosity from total porosity:

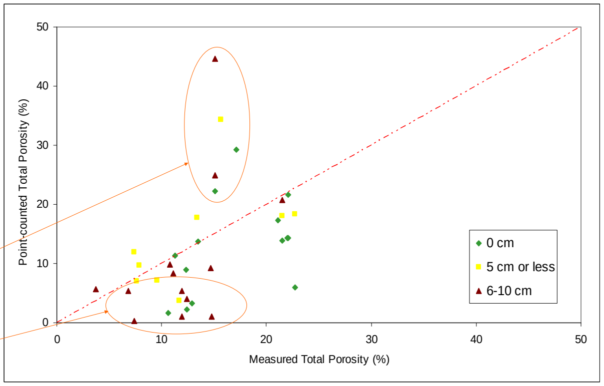
Interparticle porosity = Total porosity – Separate-vug porosity

- In order to accurately point-count interparticle porosity, assume total point-counted porosity is the same as measured porosity
- A cross-plot of these two values shows that point-counted total porosity is 1-10% lower than measured porosity
- This is due to samples that contain microporosity, which cannot be point-counted
- Samples that have higher point-counted porosity than measured porosity contain dominantly intraparticle microporosity
- This pore type cannot be accurately point-counted (represents a fraction of the grain area that was counted)
- Inaccuracy associated with point-counting intraparticle microporosity may lead to overestimation of this pore type and therefore incorrect calculation of interparticle porosity

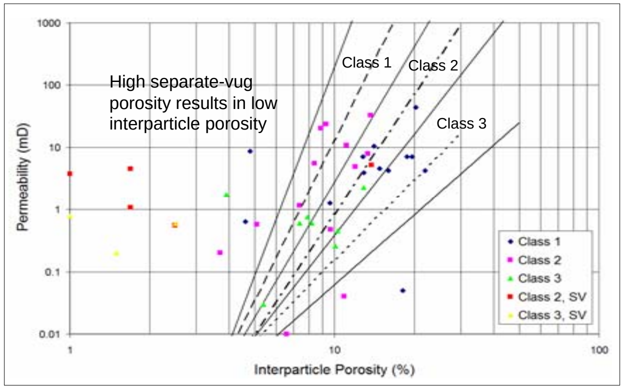


Intraparticle microporosity (separate-vug porosity)

Non-visible microporosity



Cross-plot of measured and point-counted total porosity



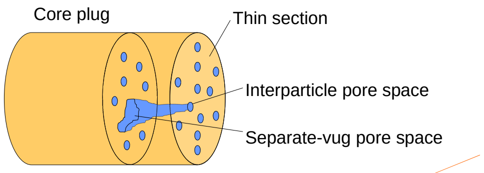
- To assess the impact of pore type in this study, samples with dominantly separate-vug porosity were highlighted
- These samples have low interparticle porosity
- Suggests Lucia's (1995, 1999) classification is best applied to dataset with low separate-vug porosity

Porosity-permeability cross-plot of data divided by Lucia (1995, 1999), with samples that have dominantly separate-vug (SV) porosity highlighted

8 Discussion – Lonoy (2006) Scheme

- Lonoy's classification is based on dominant pore type
- However, the majority of samples contain several pore types
- Scatter of data points around porosity-permeability trend lines is due to the presence of several pore types in each sample
- Re-plotting pore types using pore-type specific porosity generally increased R^2 value, but not in every case
- Therefore this is not the sole explanation for the low R^2 values, although it goes some way to explain why the R^2 values in this study are lower than those expected by Lonoy (2006)

Pore-type class	R^2 (total porosity)	R^2 (pore-type specific porosity)
Chalky microporosity, uniform	0.03	0.13
Intercrystalline uniform macropores	0.86	0.95
Moldic micropores	0.45	0.48
Interparticle uniform mesopores	0.75	0.32
Interparticle, uniform macropores	0.02	0.08



Sketch showing affect of scaling difference on pore types viewed in thin section

- Wide range of pore sizes in each sample may also account for low R^2 values
- Intercrystalline uniform macropores is the only class that follows the trends expected, probably due to the more predictable effect of dolomite on porosity
- Scaling difference between thin section and core plug may result in data being poorly constrained around expected trend lines

9 Conclusions

- Neither scheme yields the results expected by their authors for the dataset in this study
- Of the two schemes, Lonoy's (2006) classification resulted in better prediction of permeability
- The inability of both the Lucia (1995, 1999) and Lonoy (2006) schemes to accurately characterise porosity-permeability relationships is due to pore-type diversity
- With Lucia's (1995, 1999) scheme, there were problems with calculating interparticle porosity with large amounts of intraparticle porosity (separate-vug) present
- With Lonoy's (2006) scheme, there were problems with pore type and size diversity
- The scaling difference between thin sections and core plugs due to core-plug heterogeneity caused problems when point-counting pore types
- The main limitation of this study was the sample size
- A recommendation is to repeat the study with a much larger dataset to allow better assessment of porosity-permeability relationships and to allow evaluation of more of Lonoy's pore-type classes

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