A study of the petrophysical, microstructural and geomechanical properties of oolithic limestones from the Paris basin

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OUTLINE

- Objectives
- Geological background
- Petrophysical study
- Geomechanical study
- Conclusion

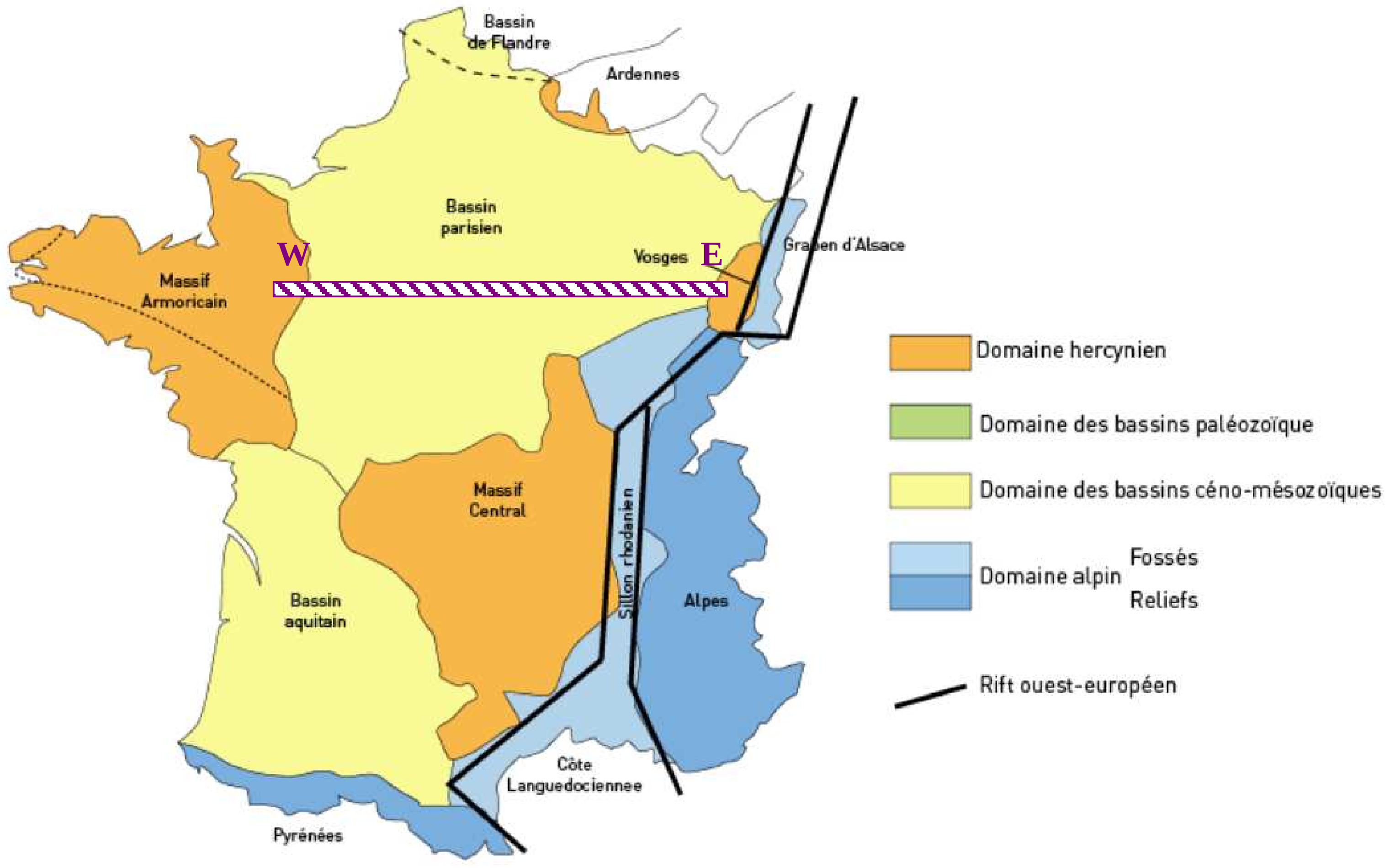
OBJECTIVES

- investigate the petrophysical, microstructural and geomechanical properties of the “Oolithe Blanche” formation, a deep saline aquifer in the center of the Paris basin and a possible target for CO2 sequestration, and also for geothermal production,

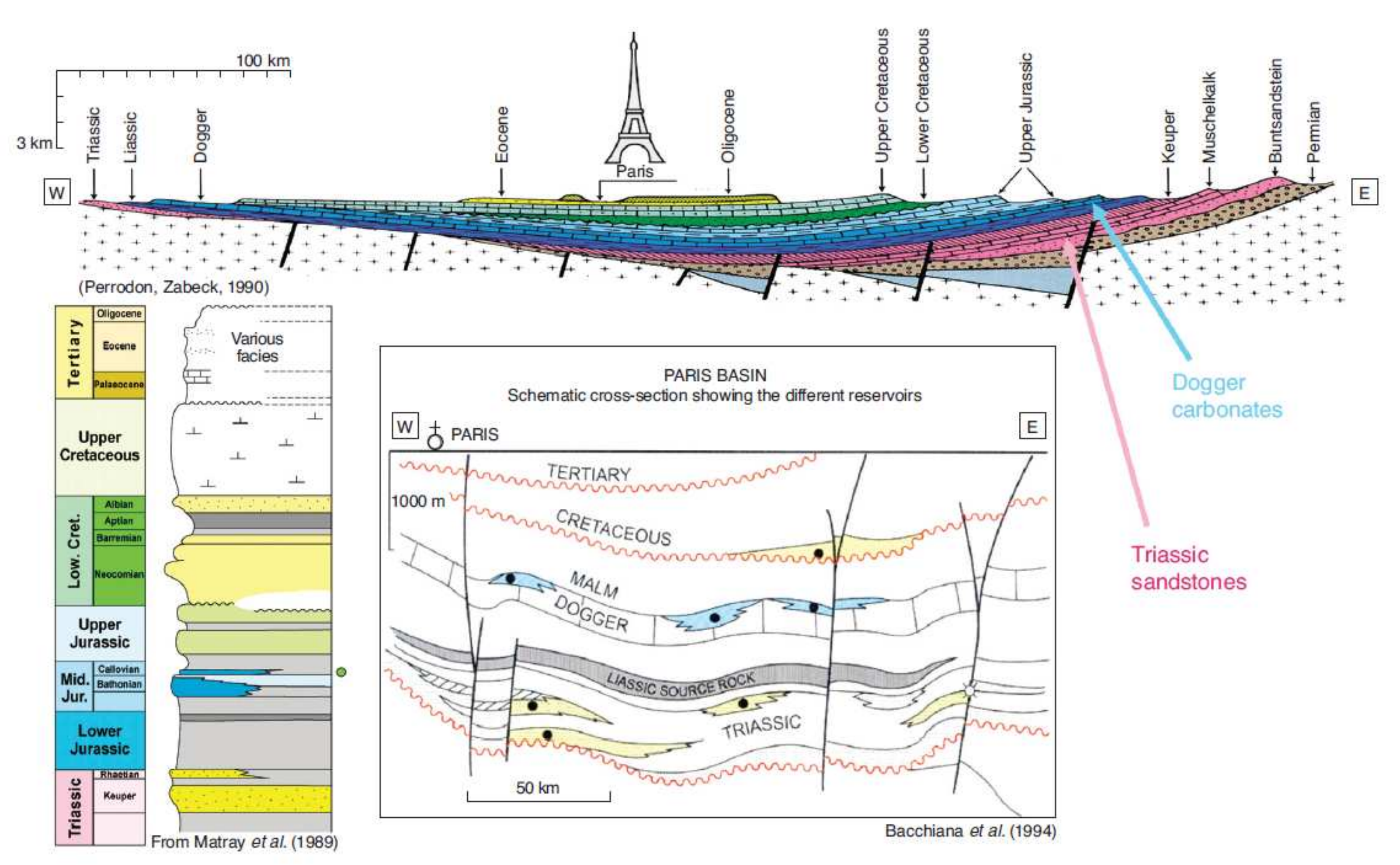
- make the link with the sedimento-diagenetic environment, by conducting an integrated study involving researchers in different fields – rock physics, geomechanics and sedimentology,

NB: regarding the scarcity of core data available, the study is focused on **field analogs** retrieved in quarries located in the south-eastern part of the Paris basin, in Burgundy.

GEOLOGICAL BACKGROUND

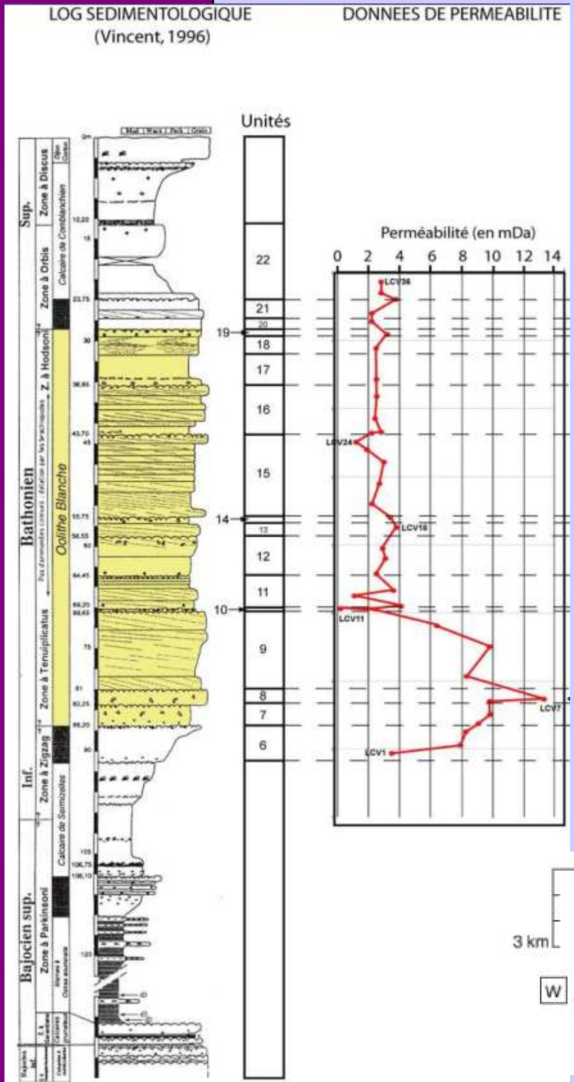


GEOLOGICAL BACKGROUND



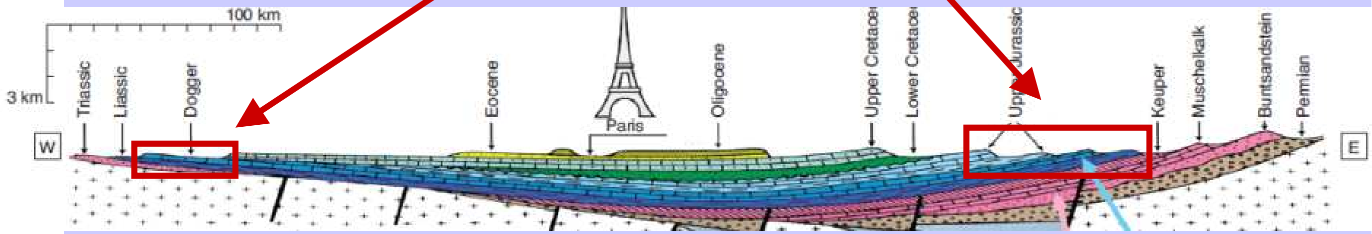
(Brosse et al., 2010)

GEOLOGICAL BACKGROUND

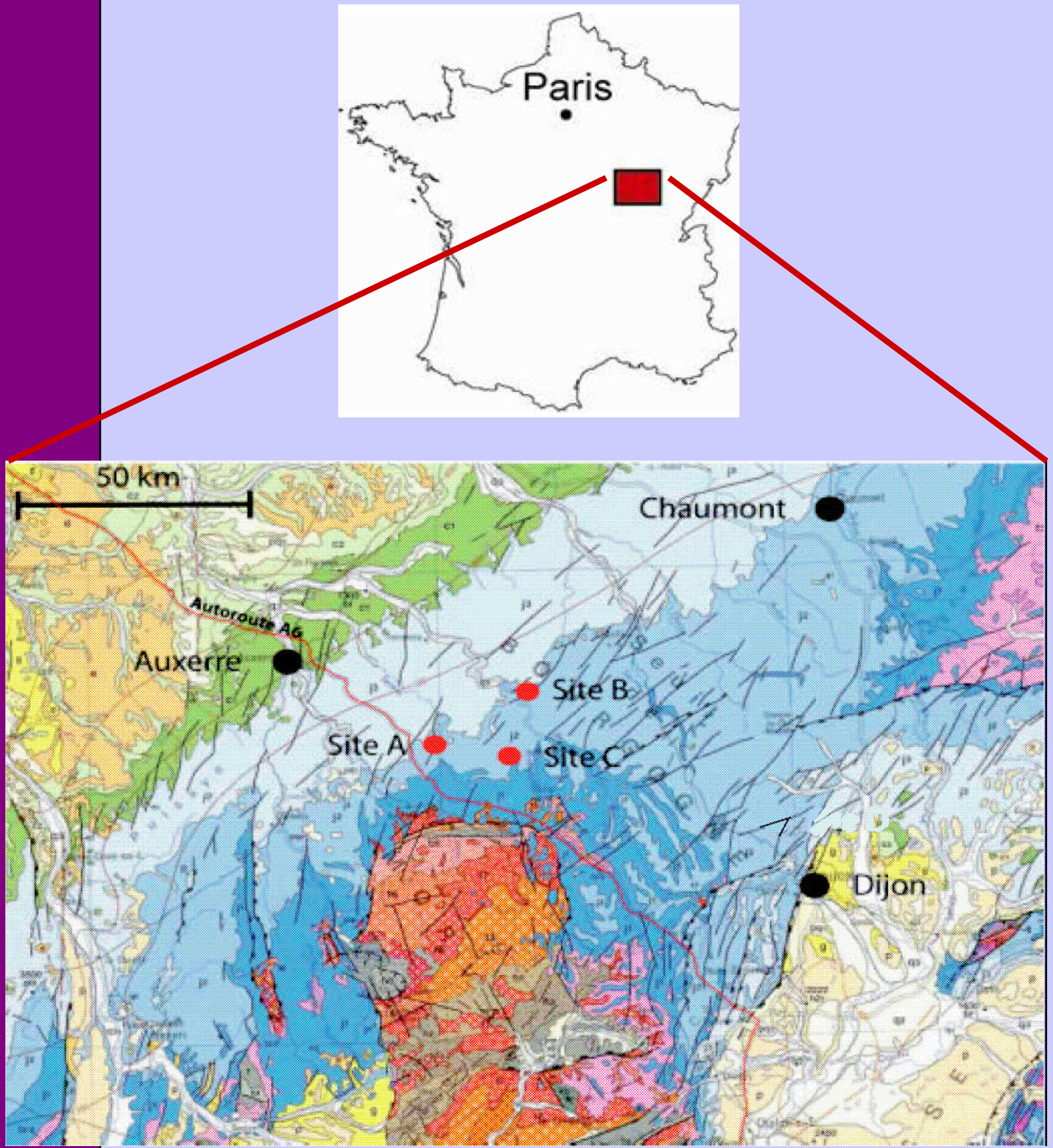


The Oolithe Blanche formation

- **age:** **middle jurassic (Bathonian, ~-166 M.y.)**
- **depth:** **0 m to 1900 m**
- **thickness:** **70 to 80 m**
- **outcrops in the Western and Eastern part of the basin**



GEOLOGICAL BACKGROUND



3 quarries in Burgundy were investigated:

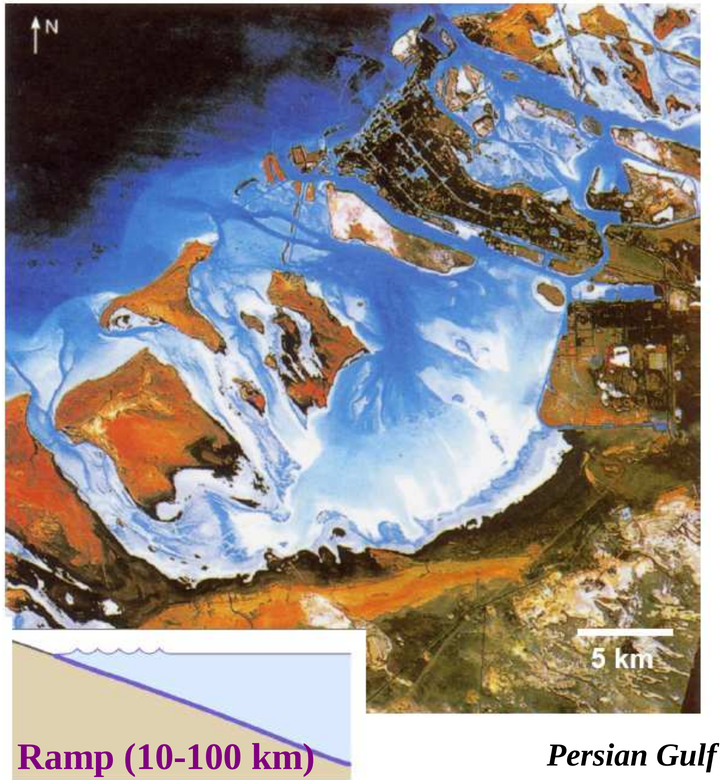
Site A : Massangis

Site B : Ravières

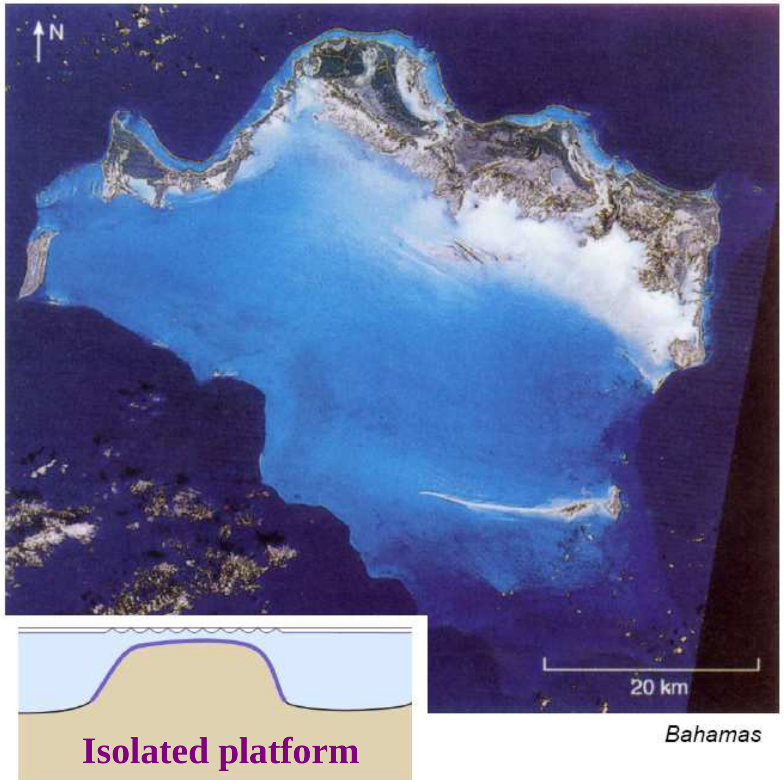
Site C : Bierry-lès-Belles-Fontaines

GEOLOGICAL BACKGROUND

165 millions years ago, Paris was looking like that



Persian Gulf



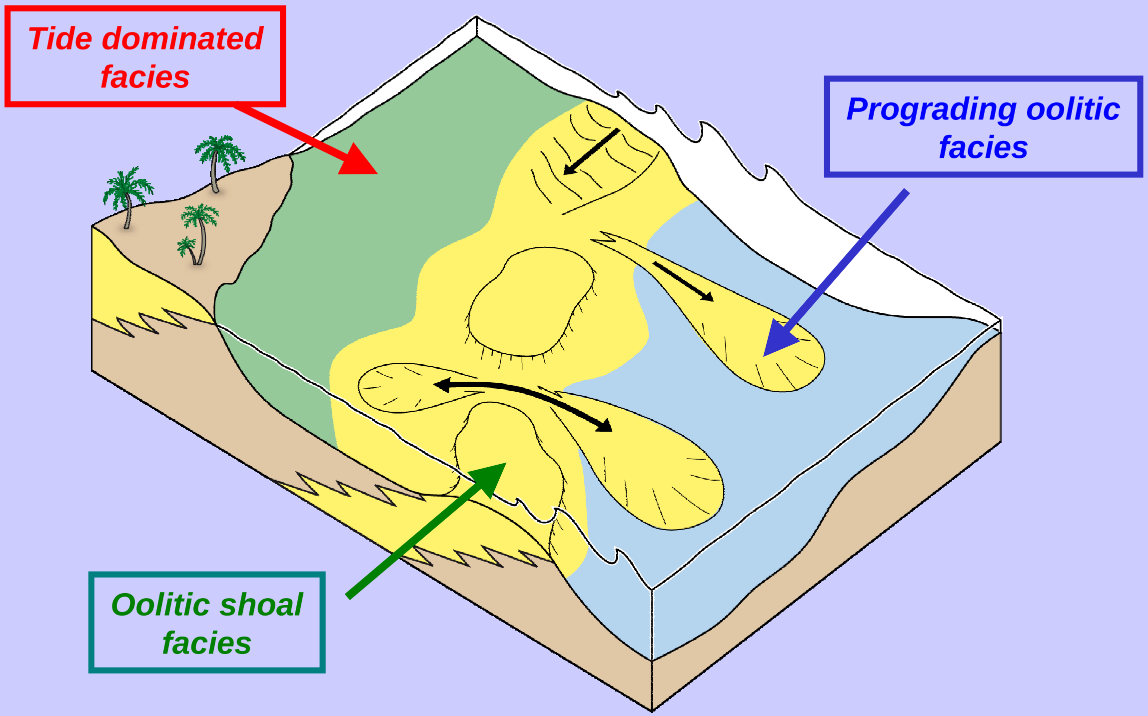
Bahamas

GEOLOGICAL BACKGROUND

Sedimentologists tell us that…

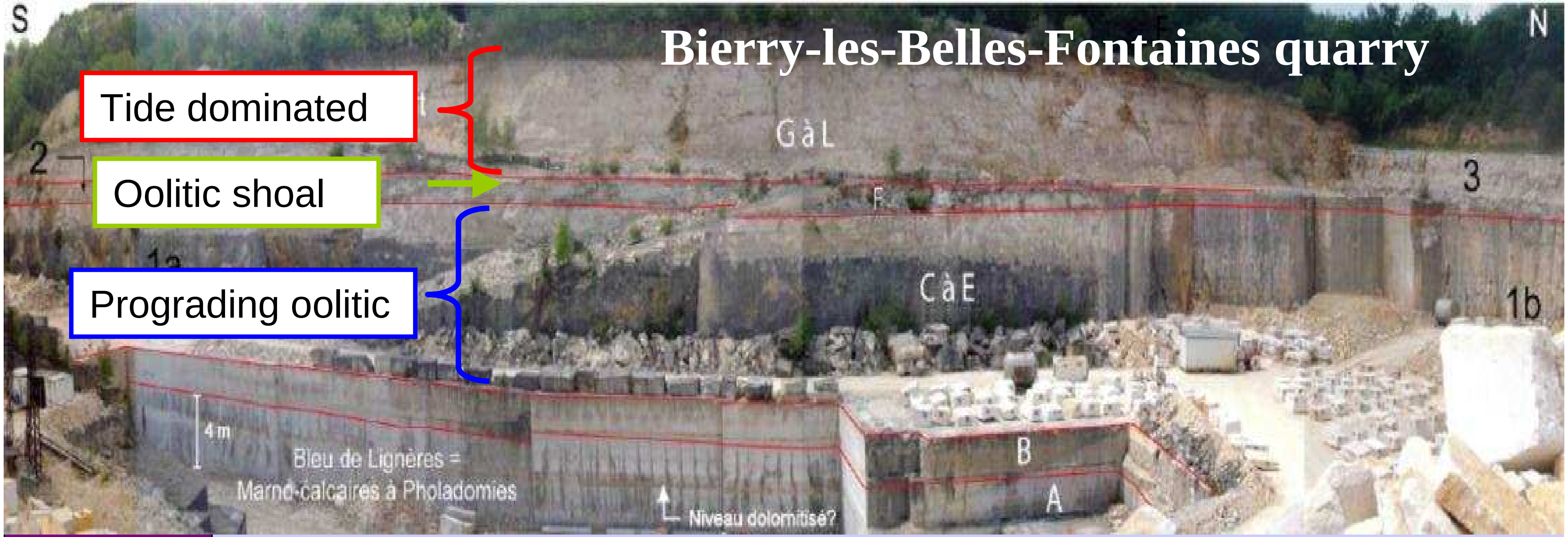
During the deposition of carbonate formations, several facies can be identified, depending on:

- **the depth of the sea floor**
- **the topography of the sea floor**

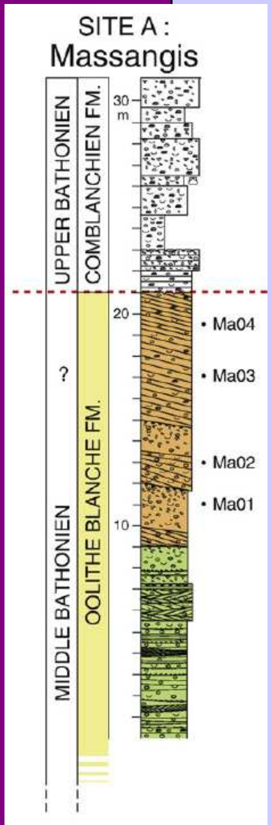


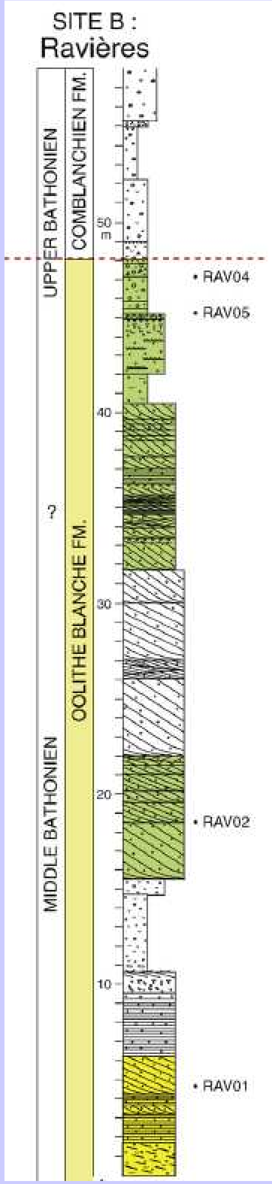
GEOLOGICAL BACKGROUND

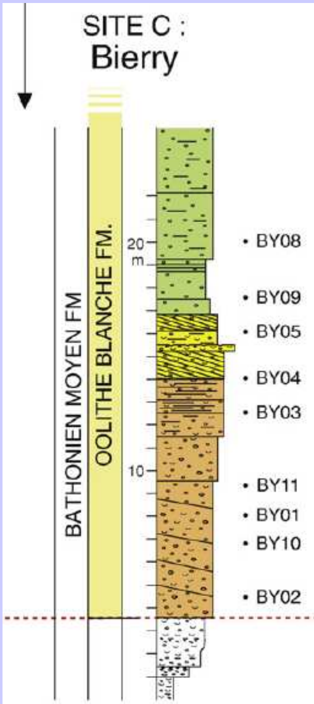
The three sedimentological facies can be observed on outcrops



PETROPHYSICAL STUDY







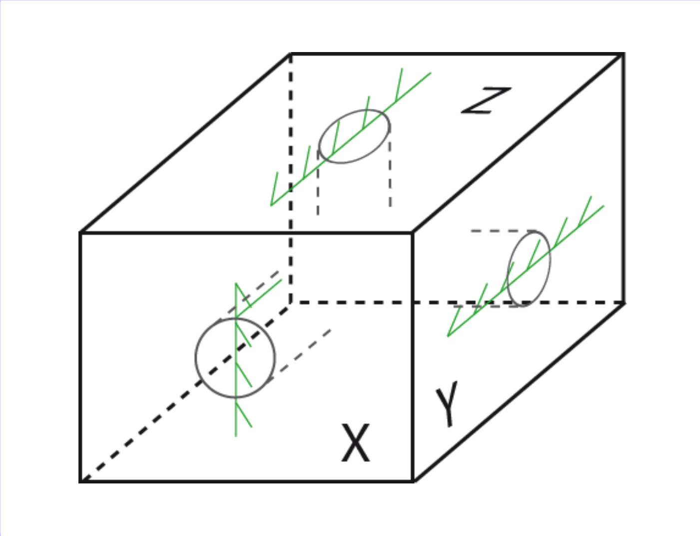
10 blocks → prograding oolitic

3 blocks → oolitic shoal

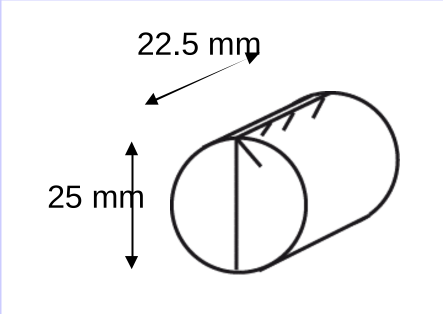
5 blocks → tide dominated

PETROPHYSICAL STUDY

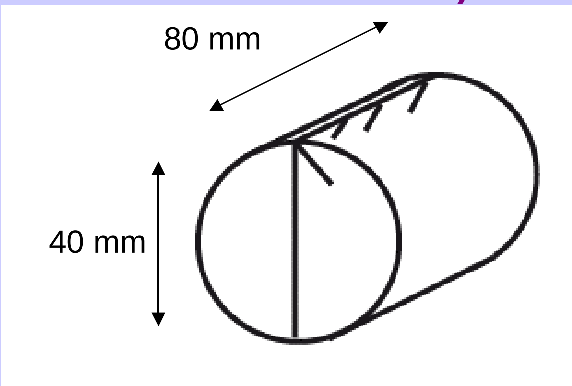
Core sampling method



« small » samples
(ultrasonic and electrical measurements)



« big » samples
(permeability, mechanical tests)



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PETROPHYSICAL STUDY

List of measurements

Porosity (triple weight method)

Hg porosimetry (max pressure 210 MPa)

Water permeability

Capillary imbibition tests

Electrical conductivity (brine saturated samples)

Ultrasonic velocities (mostly P wave)

Microstructure observations (optical and SEM)

Image analysis (quantification of elements)

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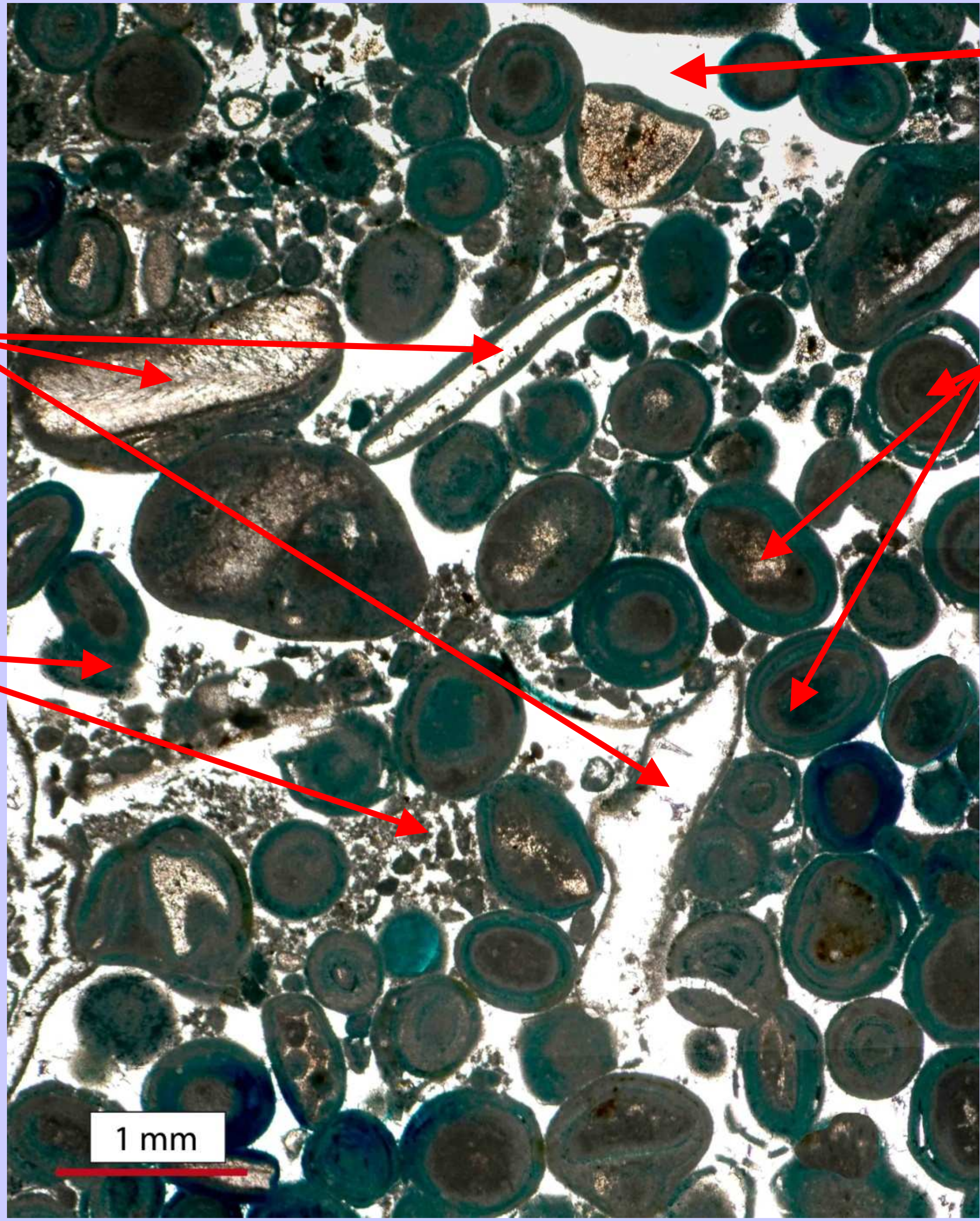
OPTICAL MICROSCOPY



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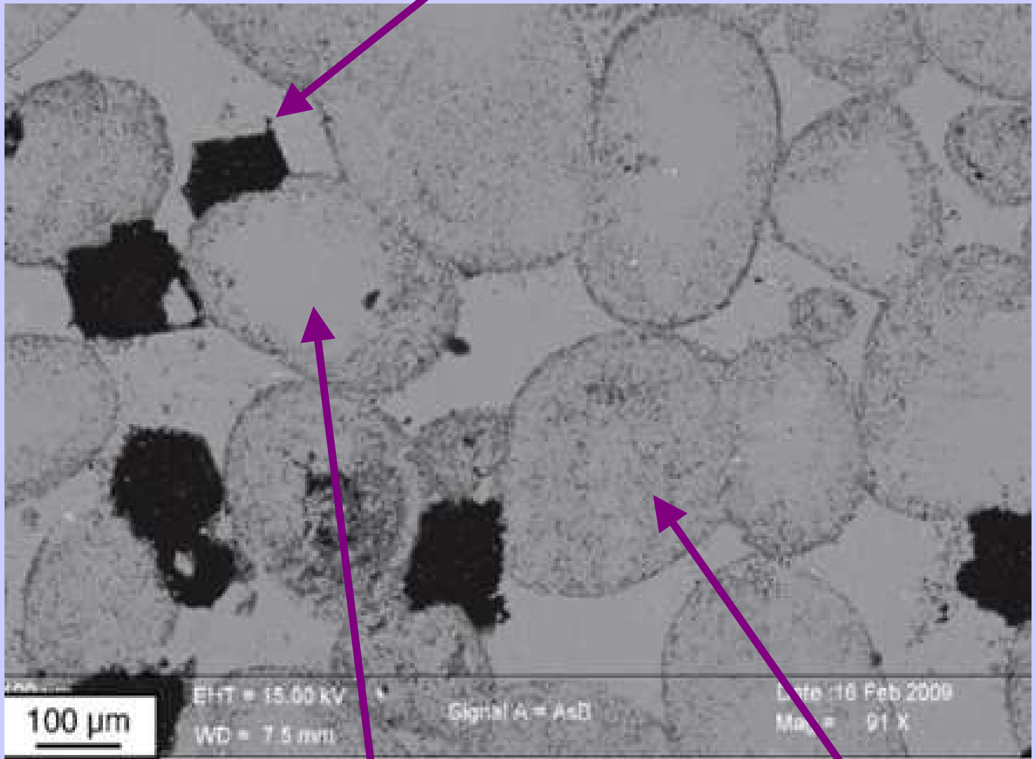
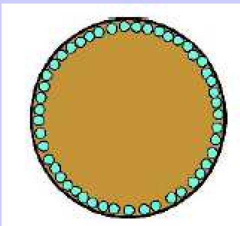
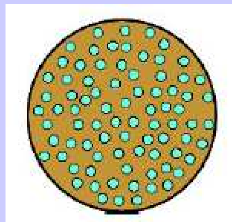
PETROPHYSICAL STUDY

macroporosity





« Rim » microporosity



uniform microporosity

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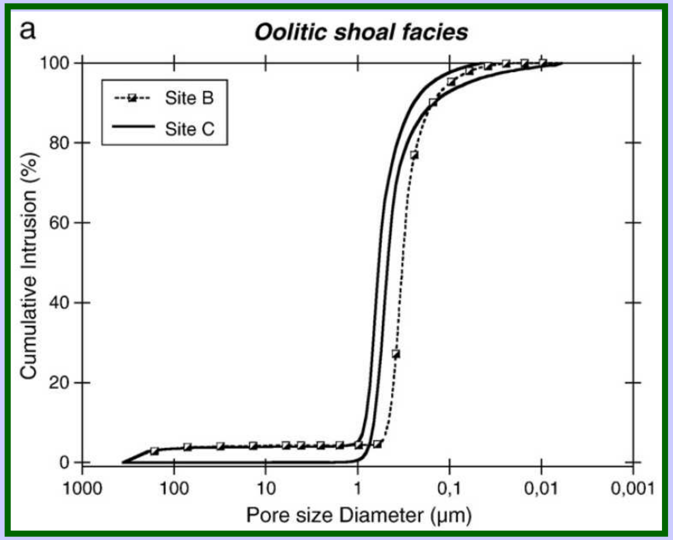
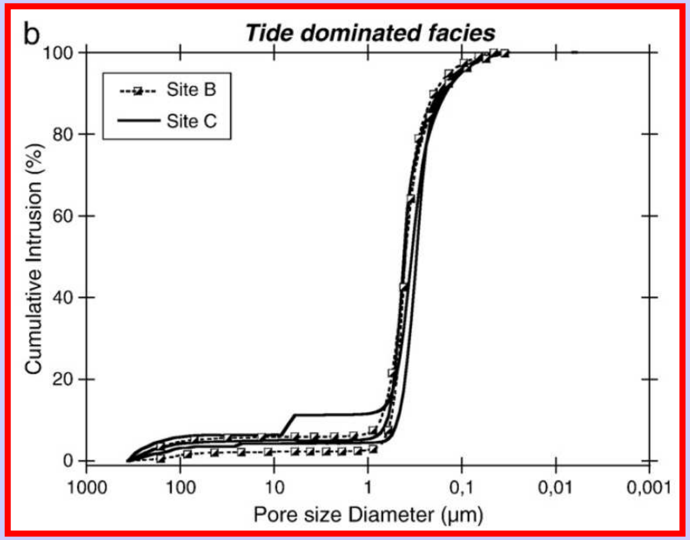
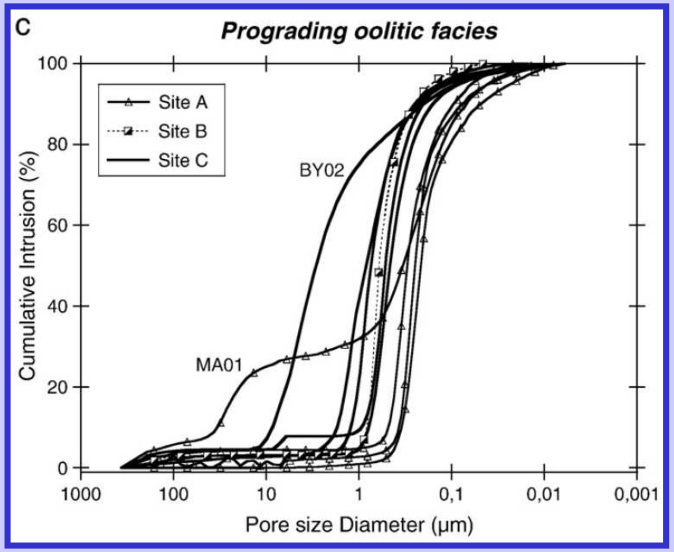
MERCURY POROSIMETRY







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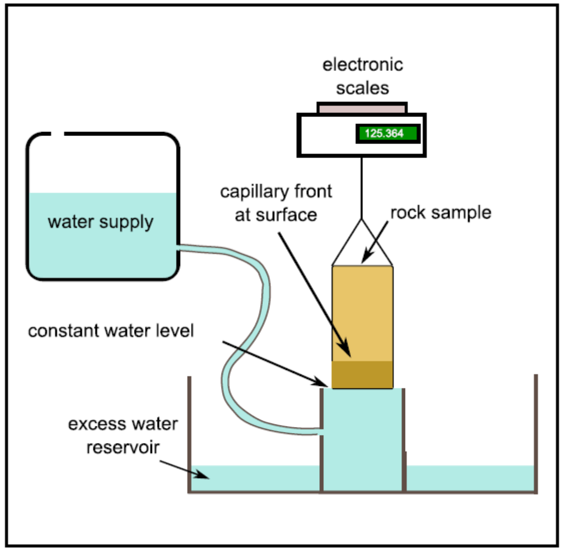
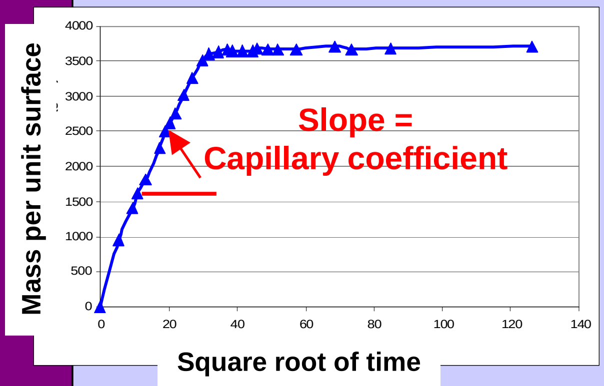
CAPILLARY IMBIBITION





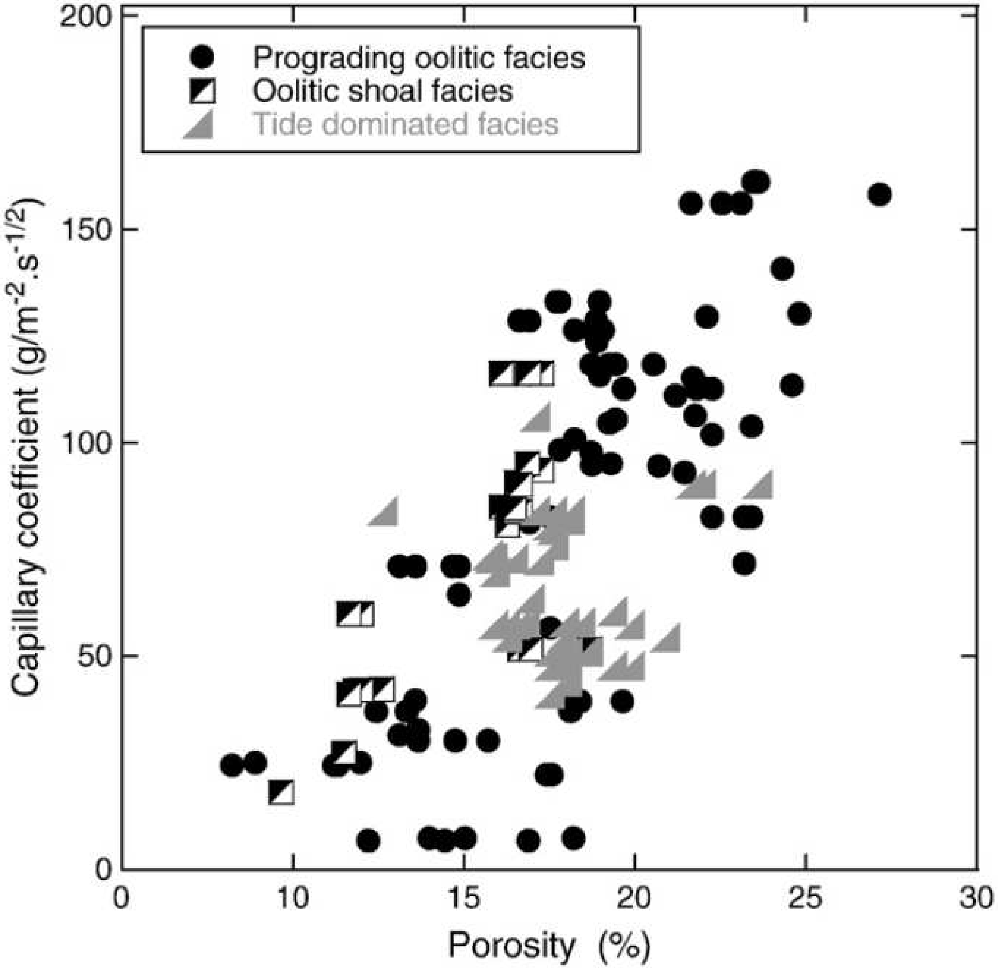


Fig. 9. Imbibition coefficients as a function of porosity.

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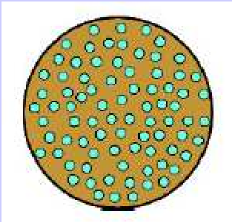
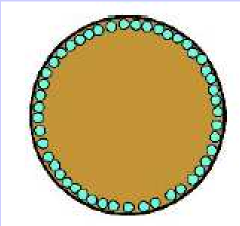
PETROPHYSICAL STUDY

no clear control

by the facies, but …





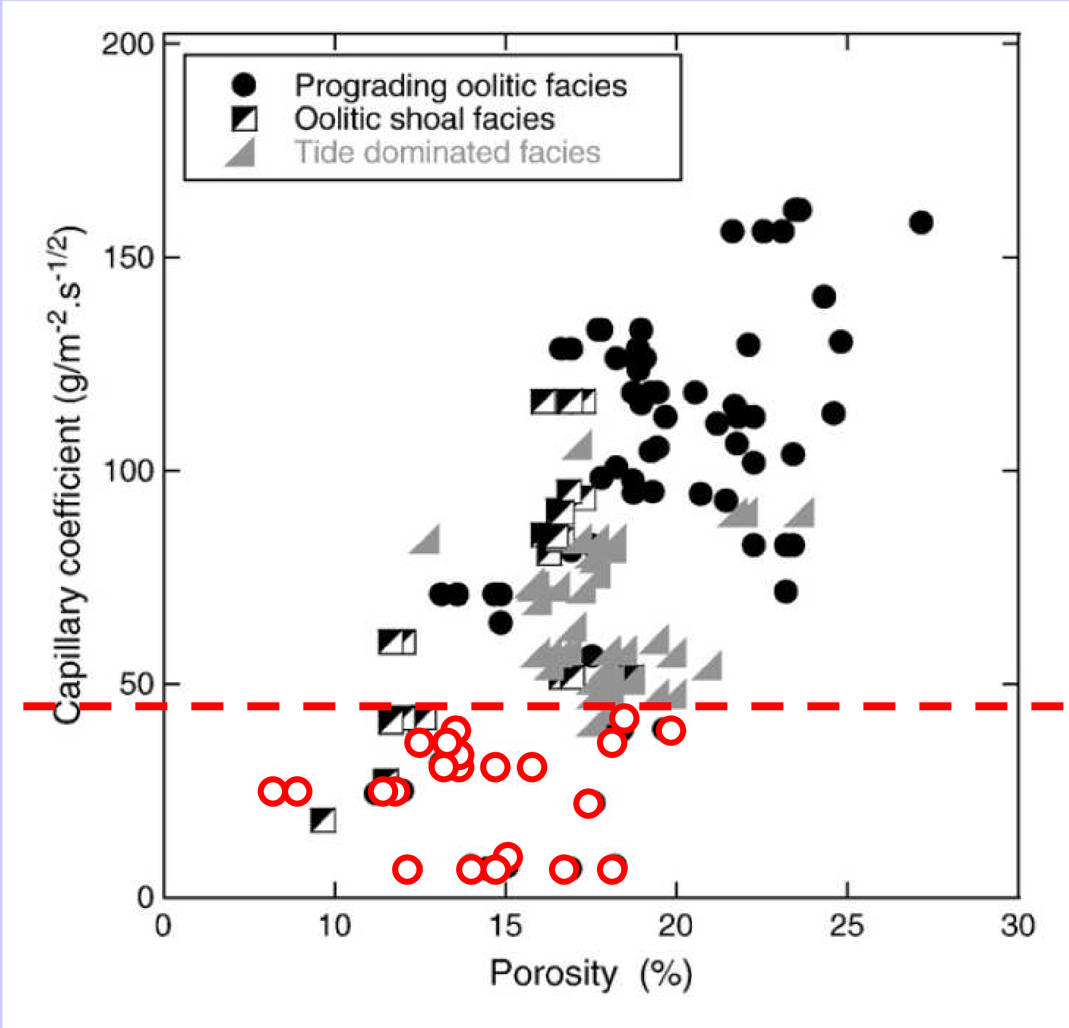


Fig. 9. Imbibition coefficients as a function of porosity.

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PETROPHYSICAL STUDY

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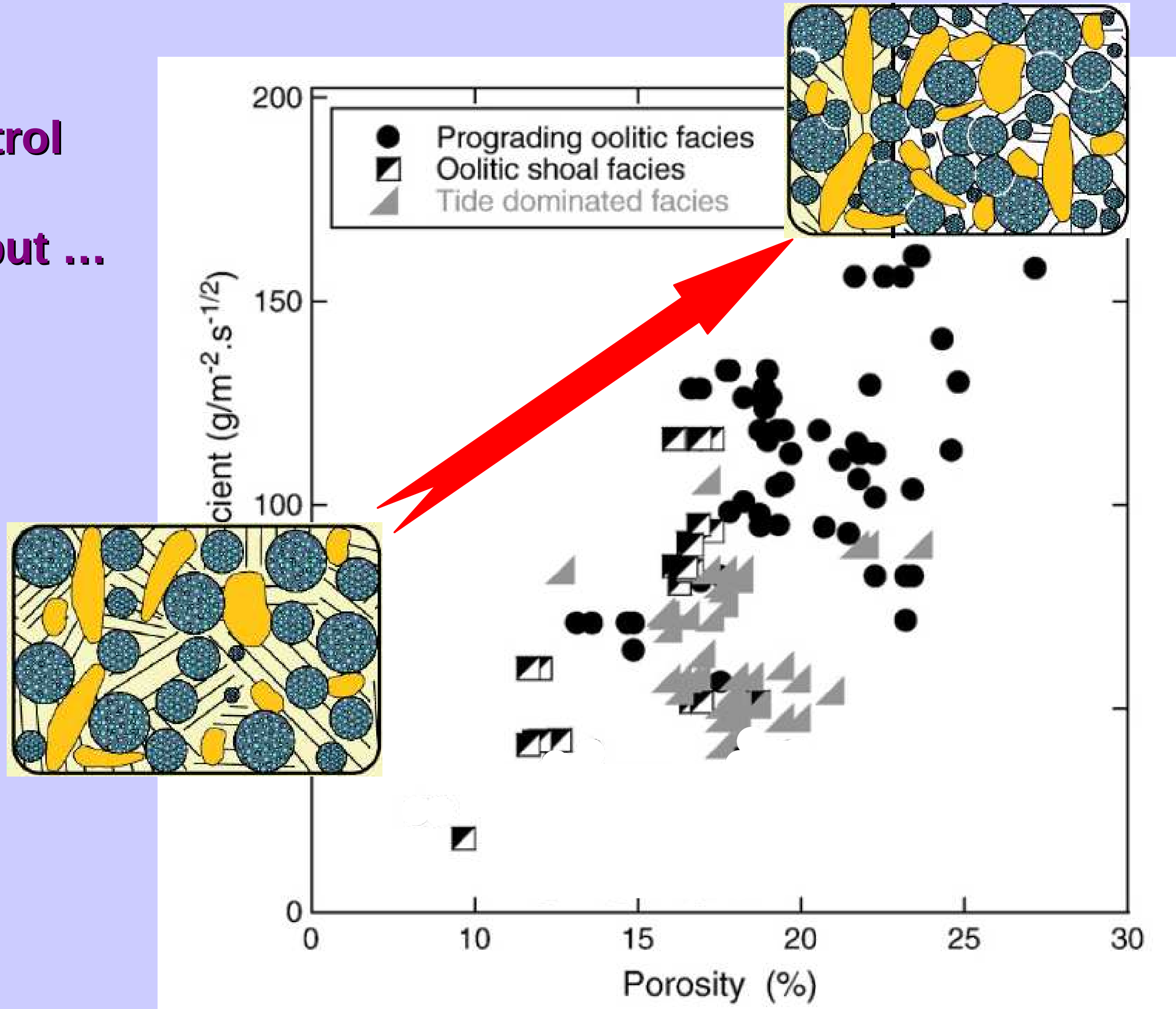

Fig. 9. Imbibition coefficients as a function of porosity.

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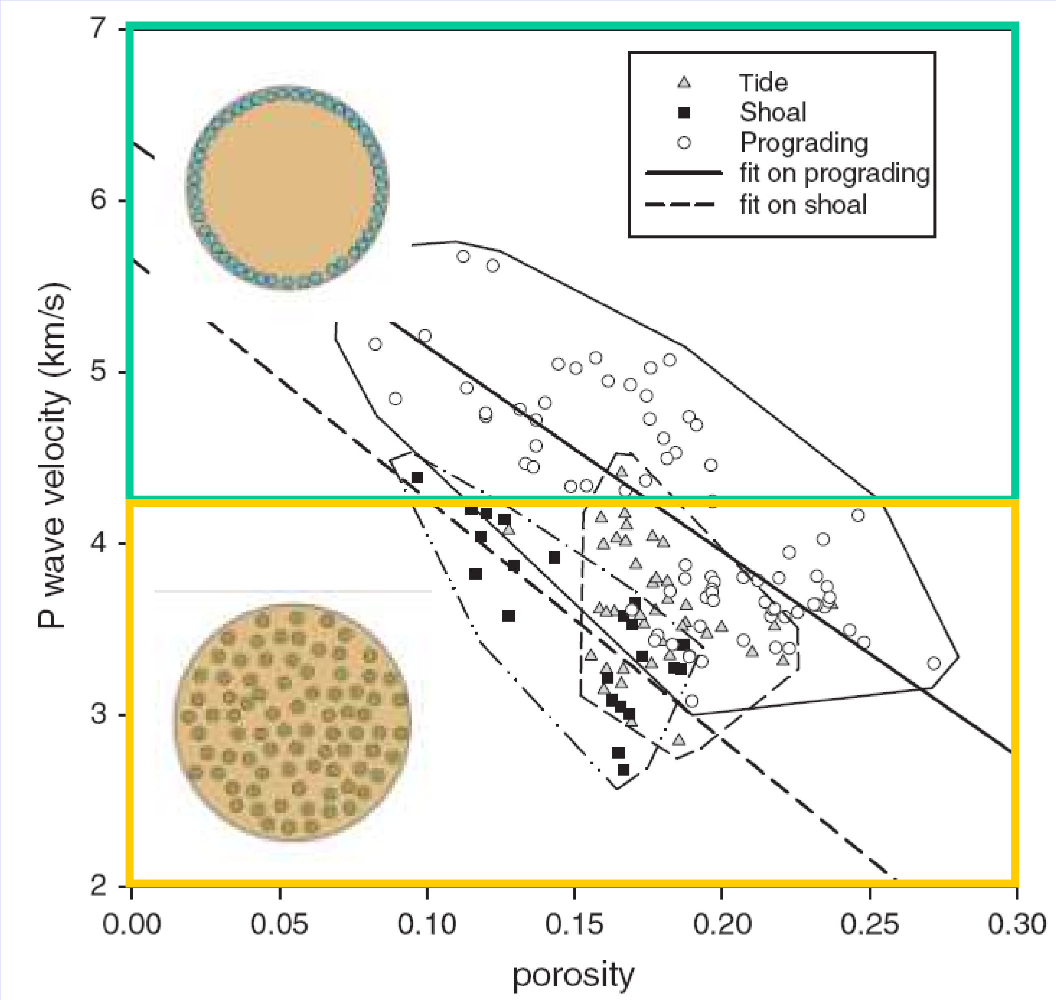
ULTRASONIC VELOCITY



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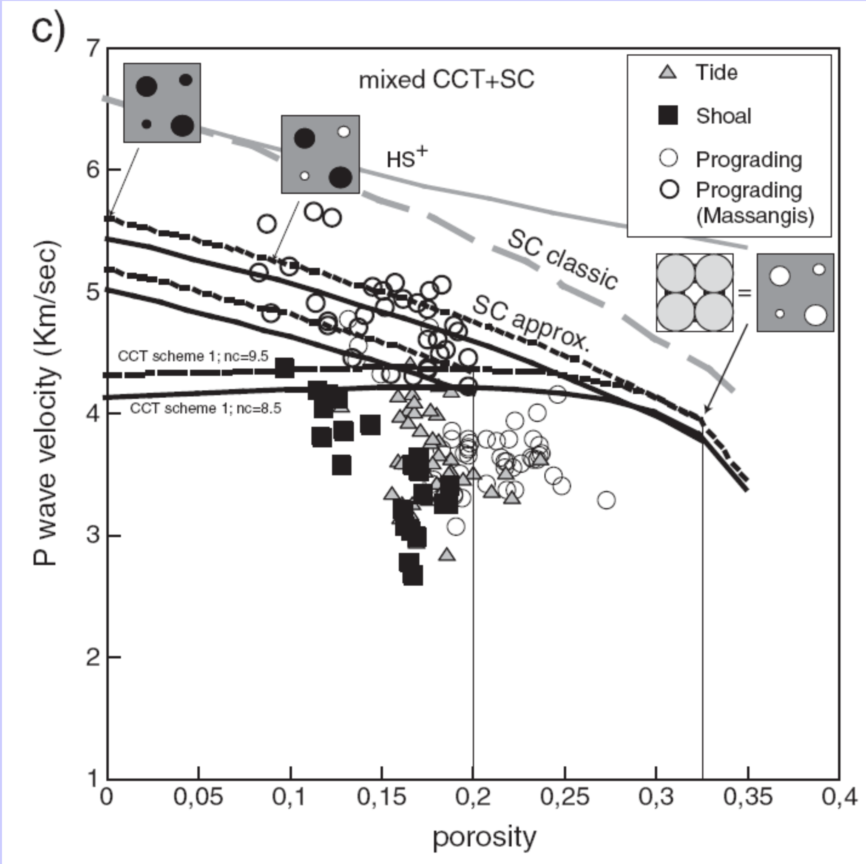
PETROPHYSICAL STUDY

various attempts to model the velocity-porosity evolution…



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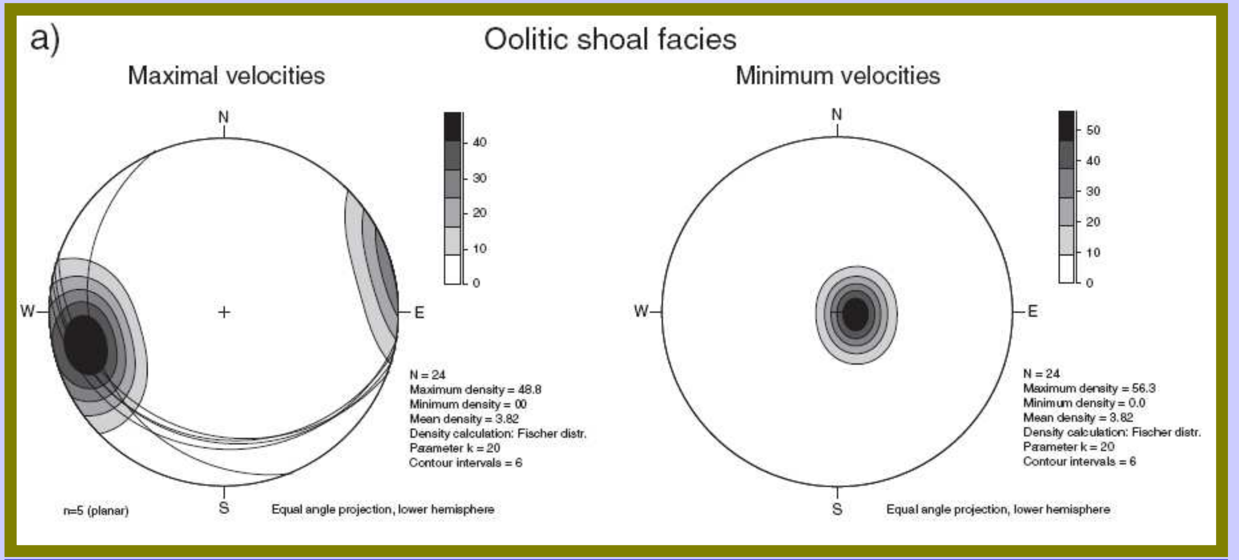
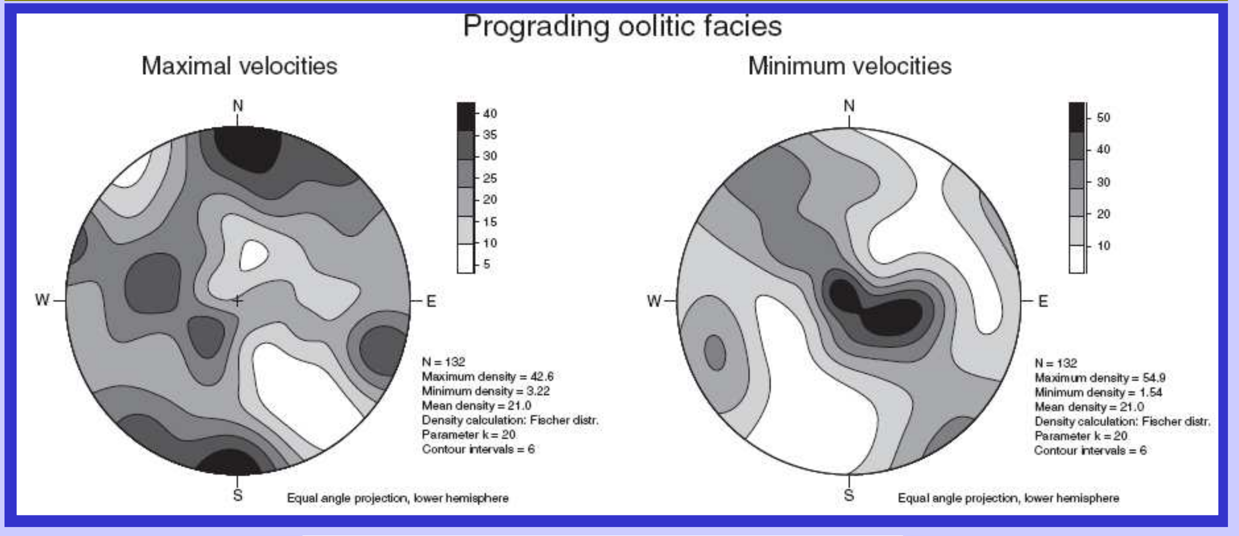
analysis of P wave velocity anisotropy…





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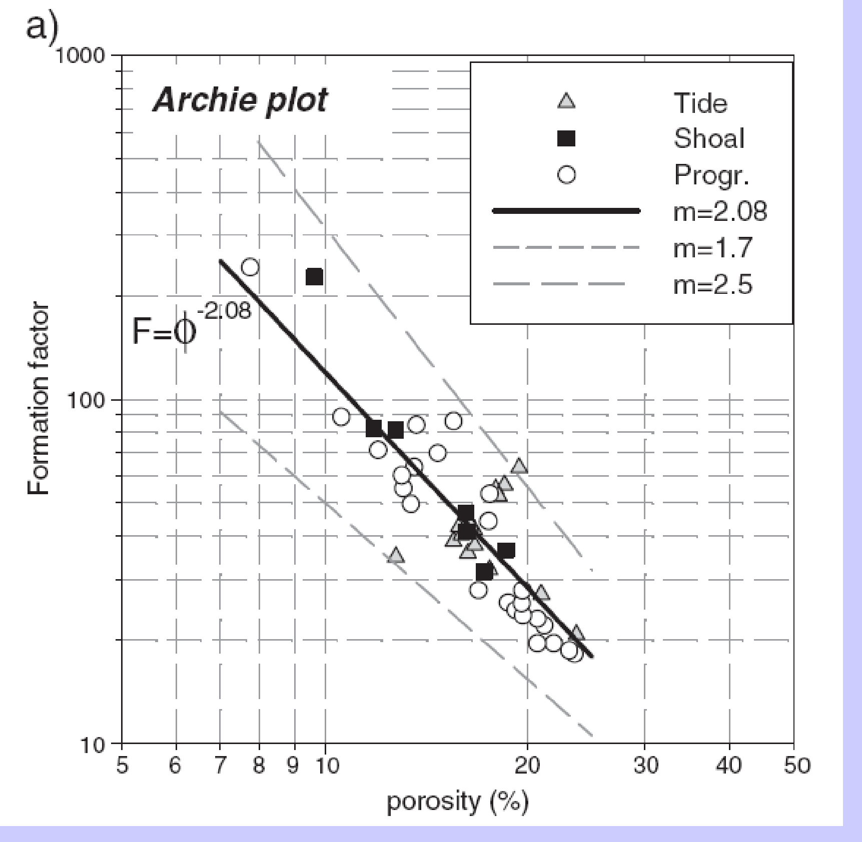
ELECTRICAL CONDUCTIVITY

$$\sigma_r = (1/F)\sigma_f + \sigma_s$$

F : formation factor

σ_s : surface conductivity



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PETROPHYSICAL STUDY

PERMEABILITY

Permeability range:
0.06 mD < k < 9 mD

Table 3
Permeability measurements and prediction from three different models: the percolation model by Katz and Thompson (1987), the statistical model by Guéguen and Dienes (1989), and the 3D network model. The input data for the models are the rock porosity and microstructural attributes derived from the mercury injection spectra.

Facies	Sample name	Porosity (%) (3 weights method)	Peak diameter on Hg porosimetry (µm)	[Diameter range] and *standard error* for simulation (µm)	F	Measured permeability (mD) (steady-state)	Percolation model K and T (mD)	Statistical model G and D (mD)	3D network model (mD)	Ratio (k_net.)/(k_exp.)	Occupancy ratio (%)
Tide	RAV02Za	18.54	0.35	[0.1–1] 0.3	56.27	0.11	0.0096	0.177	0.264	2.40	40–50
Tide	RAV04Zc	21.02	0.40	[0.1–1] 0.2	27.09	0.16	0.0261	0.263	0.393	2.46	40–50
Tide	RAV05Zb	16.5	0.40	[0.06–1] 0.2	40.40	0.11	0.0175	0.206	0.312	2.84	40–50
Tide	BY08Yb	17.61	0.30	[0.03–1] 0.4	31.97	0.109	0.0125	0.124	0.182	1.67	60–70
Tide	BY09Yb	18.17	0.25	[0.05–0.8] 0.3	52.43	0.098	0.0053	0.089	0.133	1.36	70–80
Oolitic shoal	RAV01Xd	16.25	0.30	[0.06–0.6] 0.25	46.93	0.068	0.0085	0.114	0.173	2.54	40–50
Oolitic shoal	BY04AZb	16.26	0.60	[0.06–1] 0.2	41.15	2.8	0.0387	0.457	0.691	0.25	X
Prograding	BY01Zb	19.25	0.50	[0.06–1.1] 0.5	24.43	8.94	0.0453	0.376	0.554	0.06	X
Prograding	BY02AZa	17.54	X	X	44.17	7.61	X	X	X	X	X
Prograding	BY03AZb	16.94	0.45	[0.04–1.1] 0.4	27.87	0.23	0.0322	0.268	0.403	1.75	60–70
Prograding	BY10Zc	20.72	0.50	[0.1–3] 0.6	23.03	2	0.0480	0.405	0.556	0.28	X
Prograding	BY11Za	19.70	0.80	[0.1–2] 0.4	27.82	0.68	0.1018	0.985	1.46	2.15	50–60
Prograding	MA01AXc	14.72	0.15	[0.03–1] 0.6	69.78	0.065	0.0014	0.026	0.0353	0.54	X
Prograding	MA03AZa	13.44	0.30	[0.1–0.8] 0.2	49.58	0.07	0.0080	0.095	0.143	2.04	40–50
Prograding	RAV03Zb	23.11	0.60	[0.15–1] 0.3	18.64	1	0.0855	0.650	0.959	0.96	100

measurements **prediction of models**

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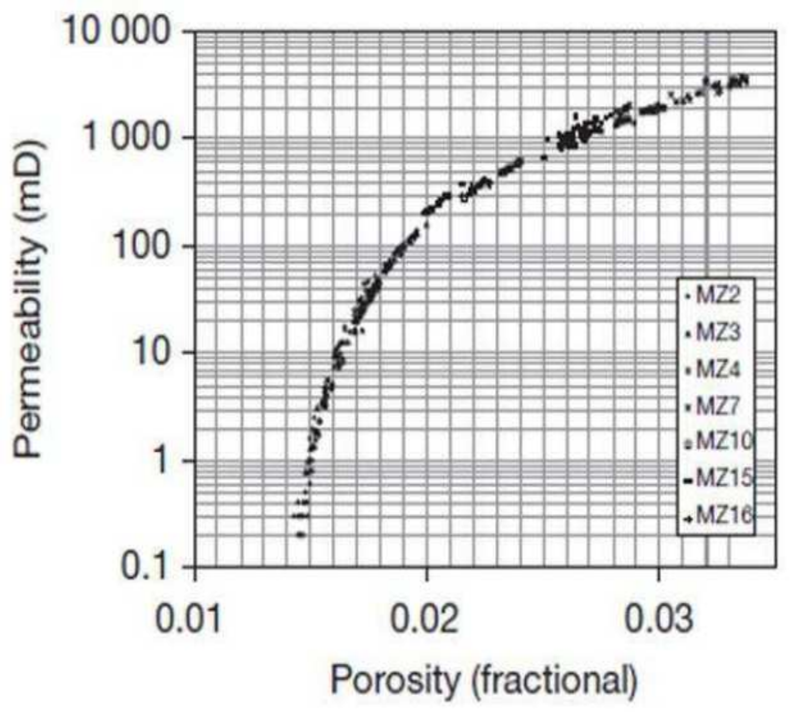
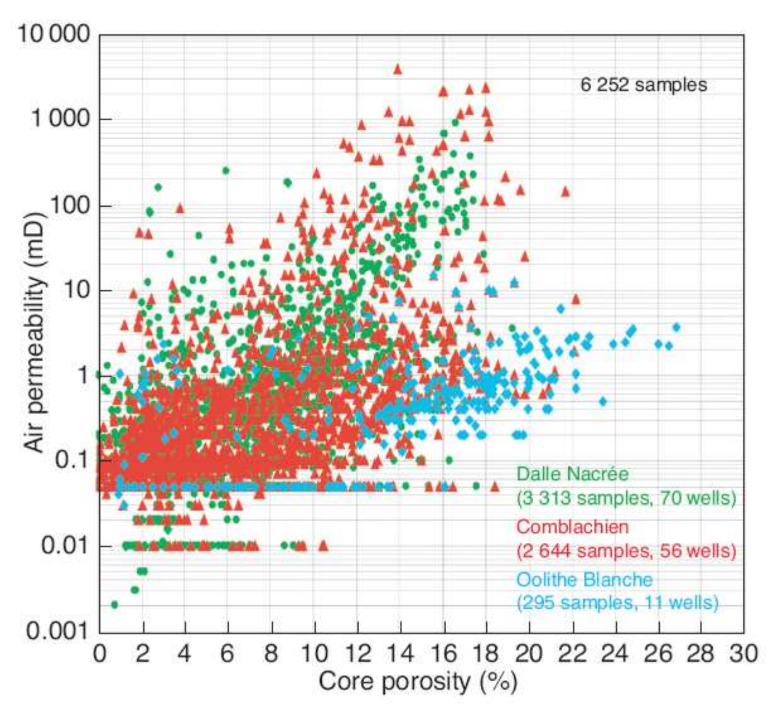
looking for correlations…





the ideal case of Fontainebleau sandstone

… and this is how it looks like in carbonate rocks of the Paris basin

(Delmas et al., 2010)

PETROPHYSICAL STUDY

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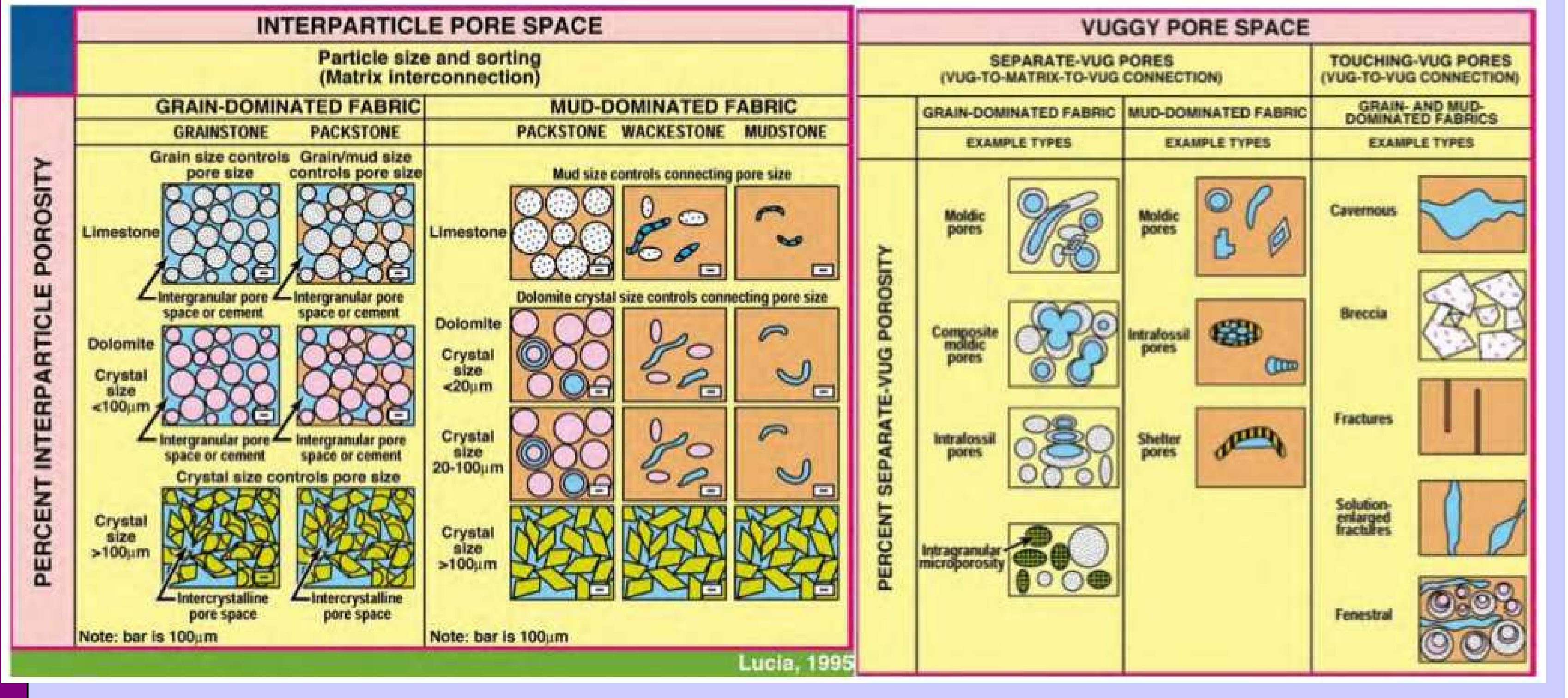
Why is it so ?

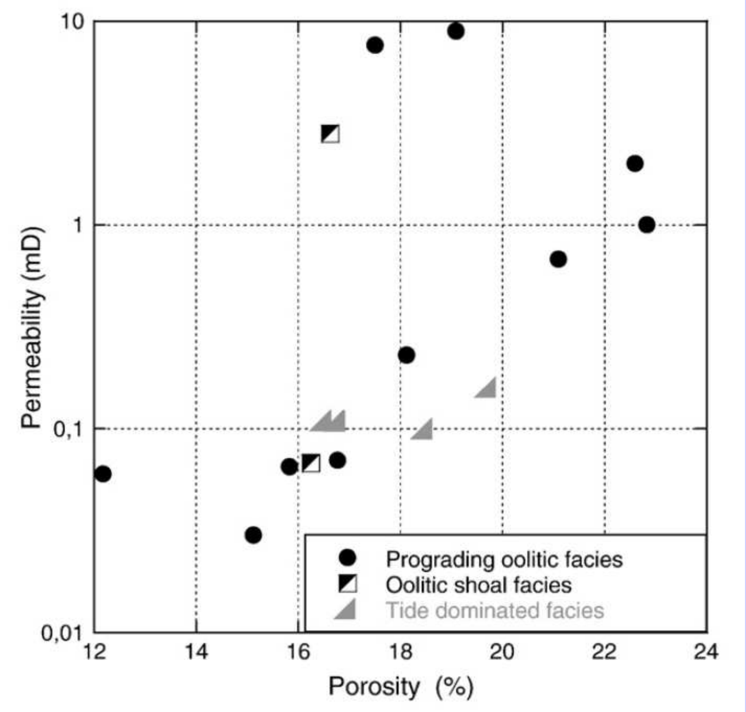


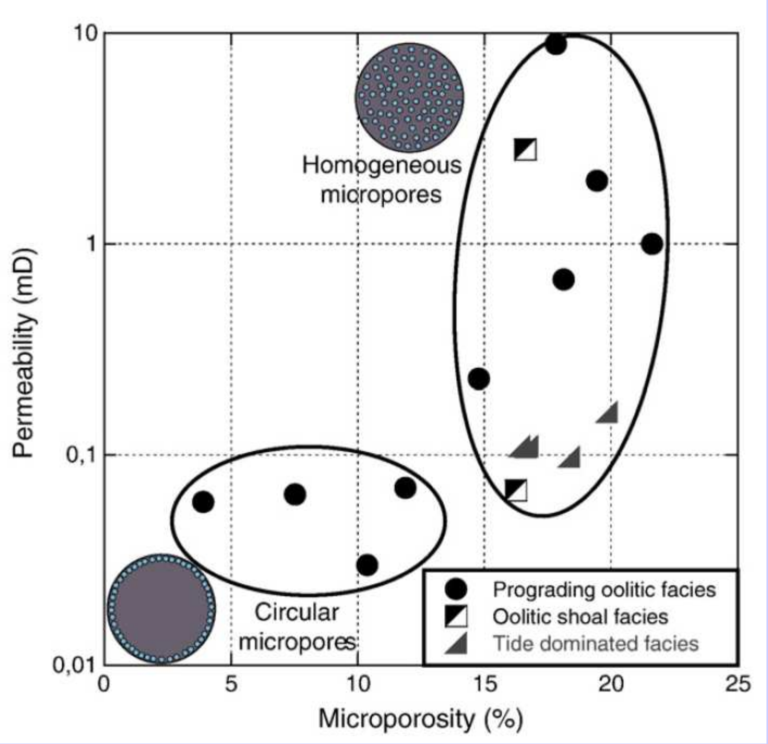
... because of the tremendous heterogeneity and variety of microstructures in carbonate rocks

PETROPHYSICAL STUDY

P E R M E A B I L I T Y

For our oolithe blanche samples:





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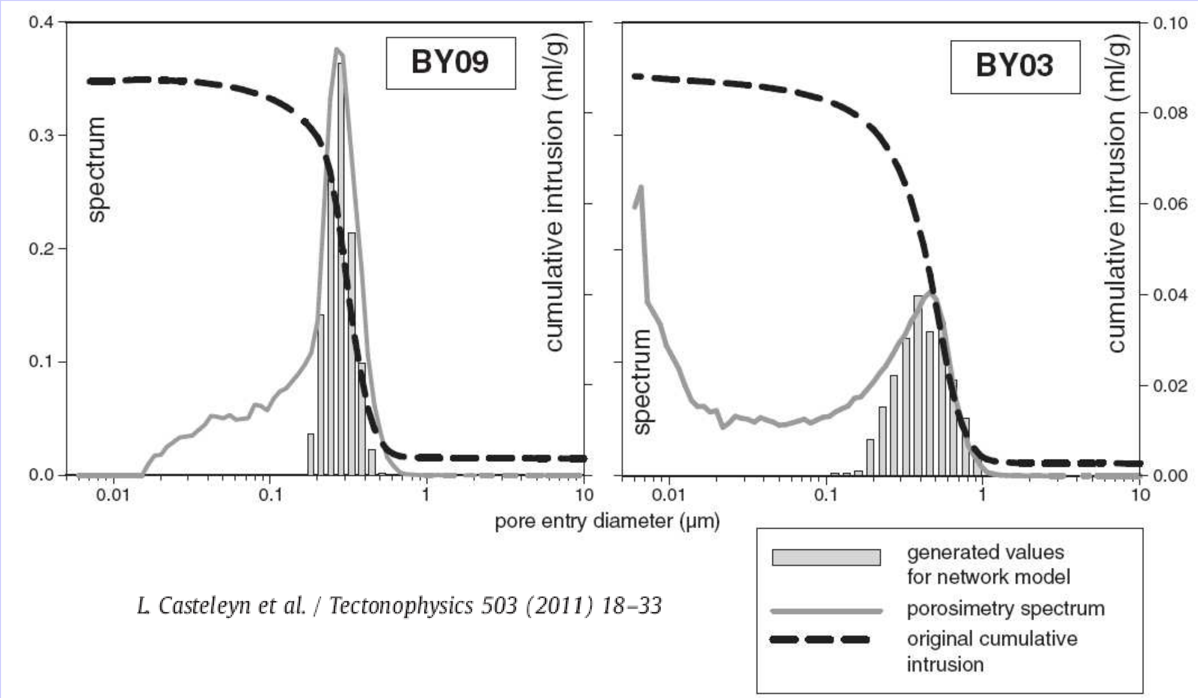
PETROPHYSICAL STUDY

P E R M E A B I L I T Y

Predictive models of permeability

1) Katz & Thompson (1986) → percolation model
2) Guéguen & Dienes (1989) → statistical model
3) 3D network of pipes → numerical model

In each case, the input data corresponds to microstructure information provided by mercury porosimetry



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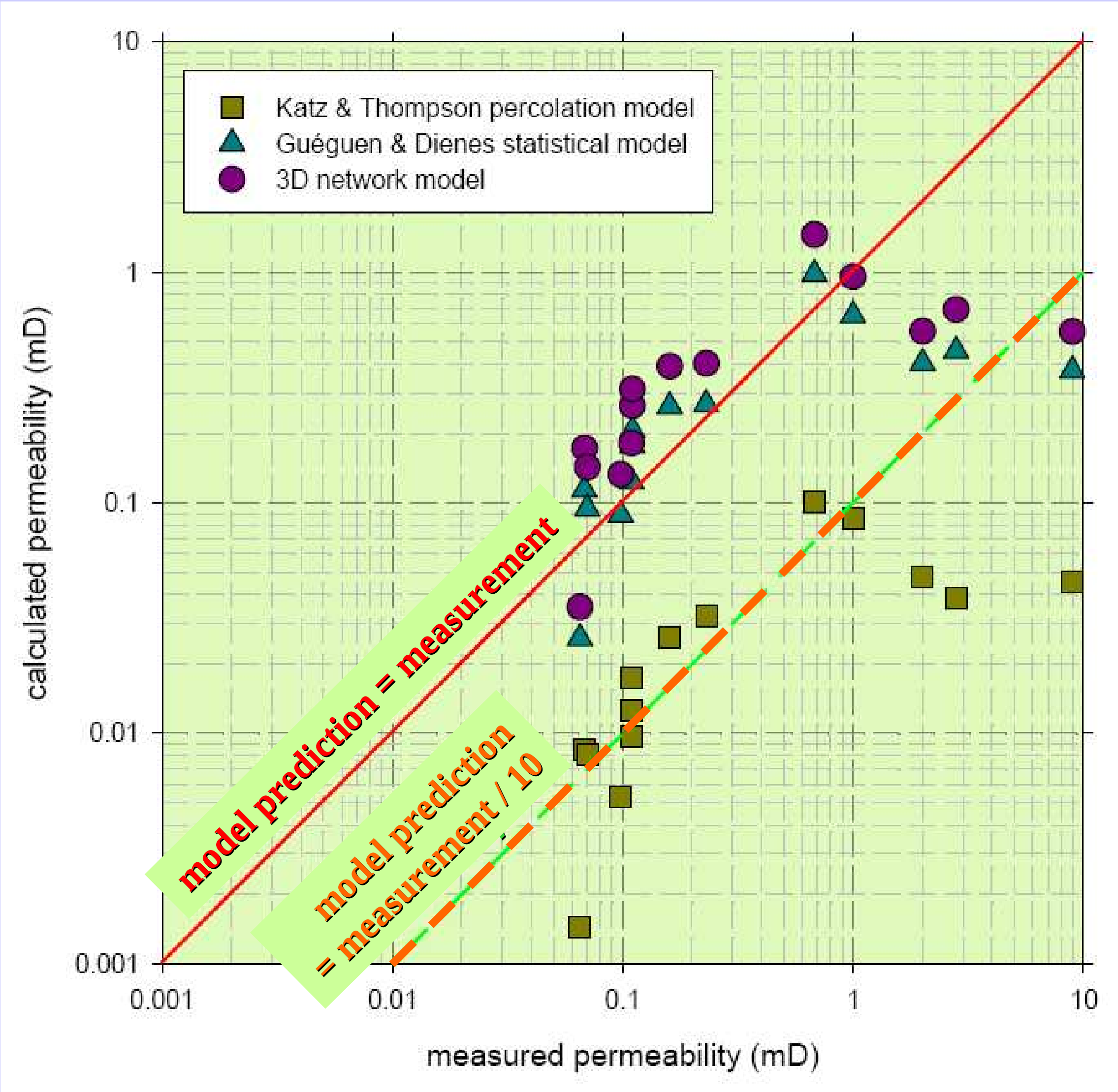
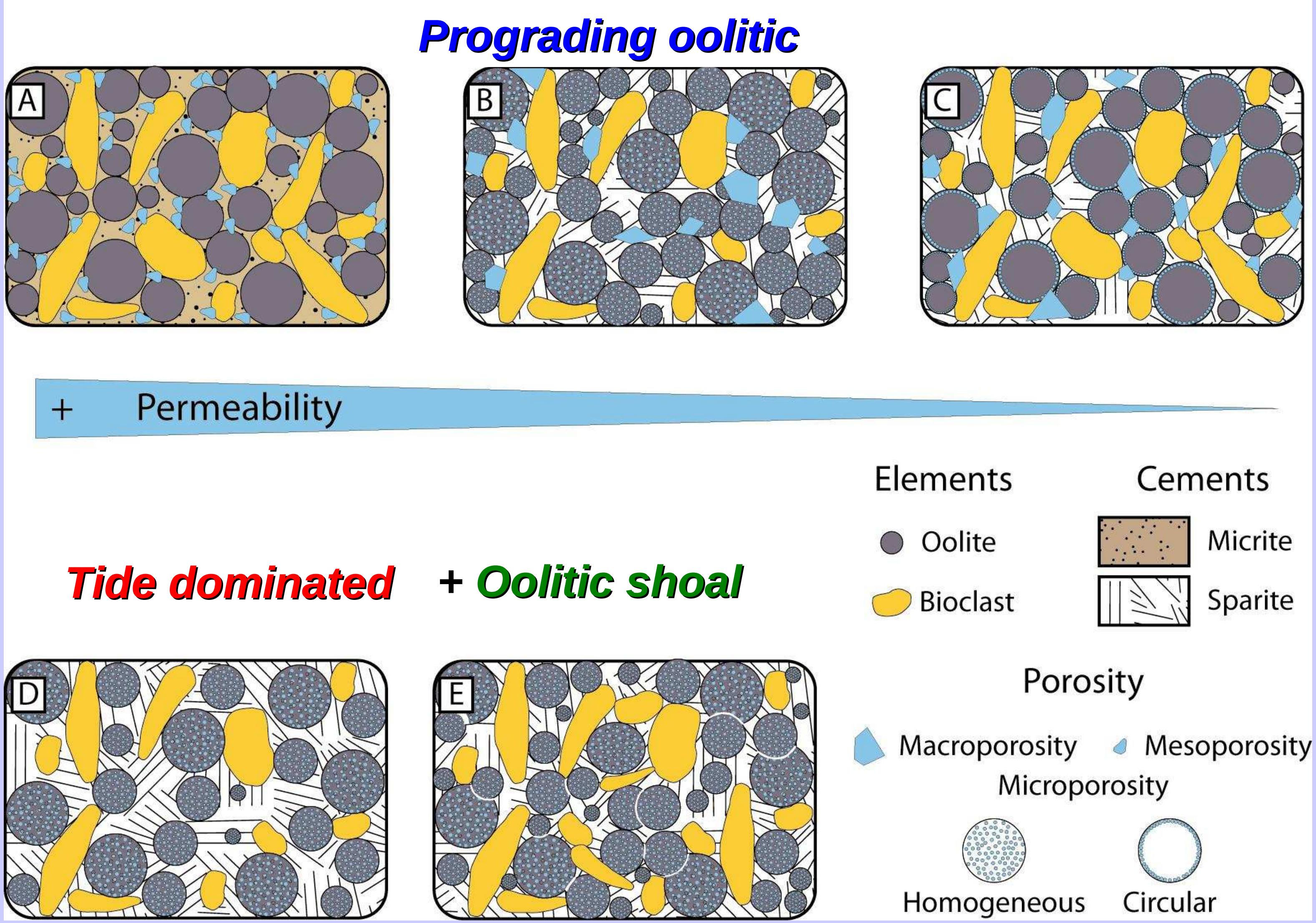


P E R M E A B I L I T Y

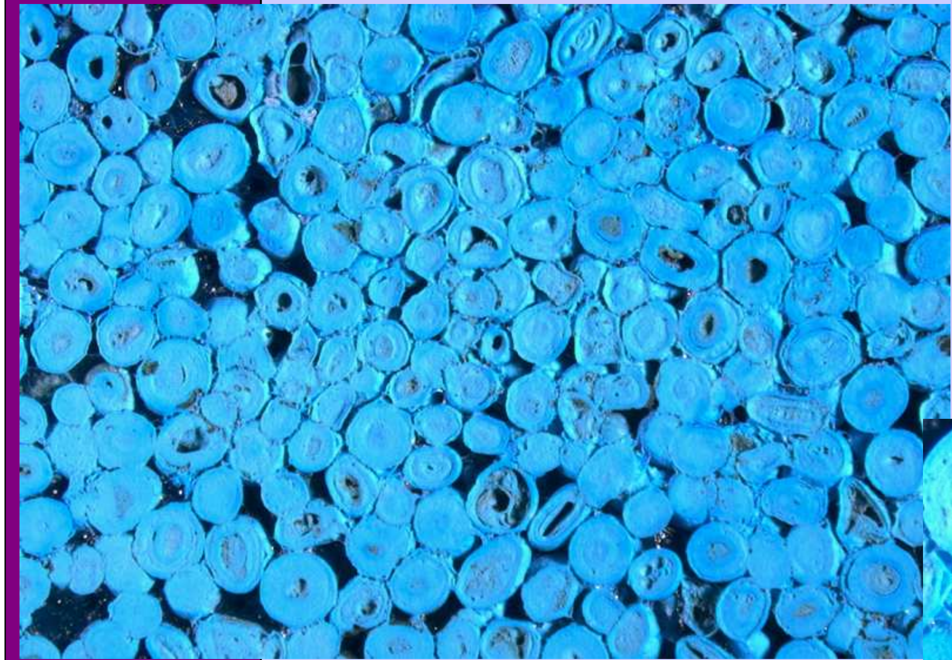
PETROPHYSICAL STUDY



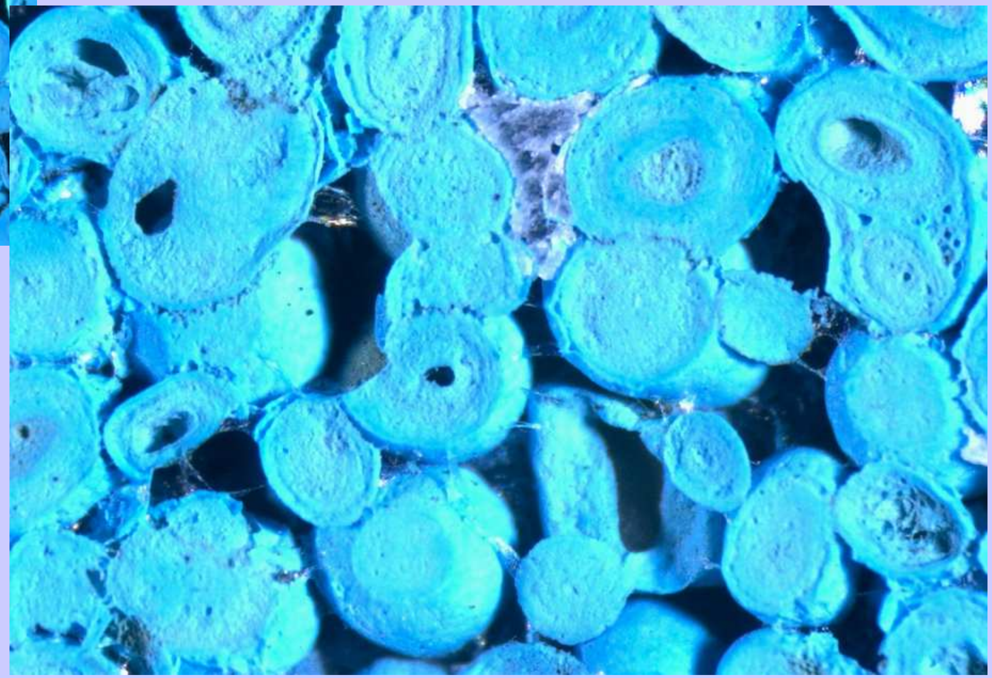
microstructures have a strong control on fluid transport !

PETROPHYSICAL STUDY

Key parameter: the 3D connectivity of microporous oolites
→ pore casts



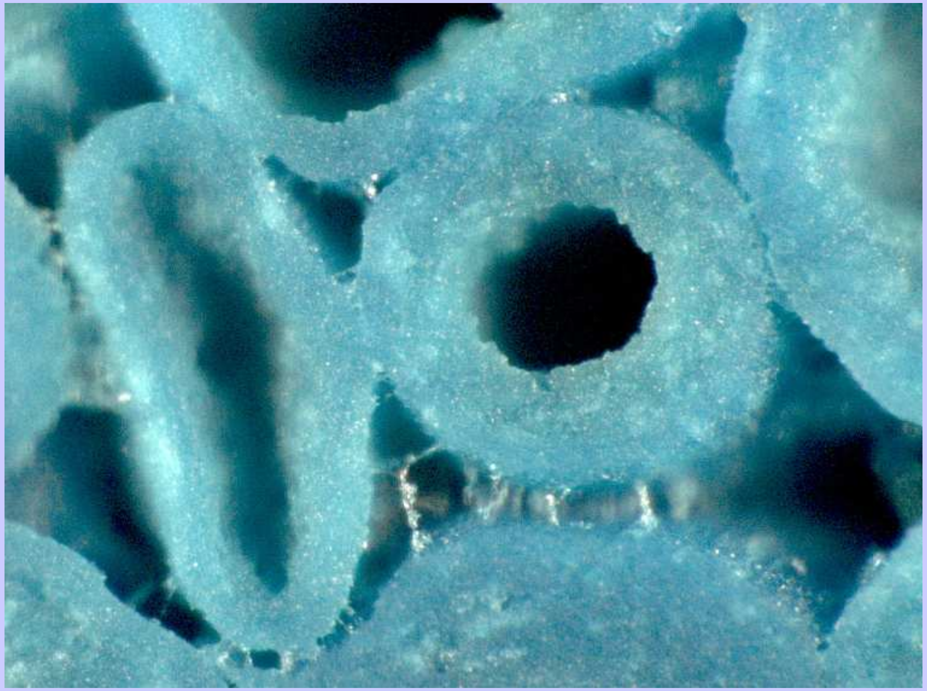
Pores impregnated with blue dyed epoxy



Calcite removed by acid (HCl)

PETROPHYSICAL STUDY

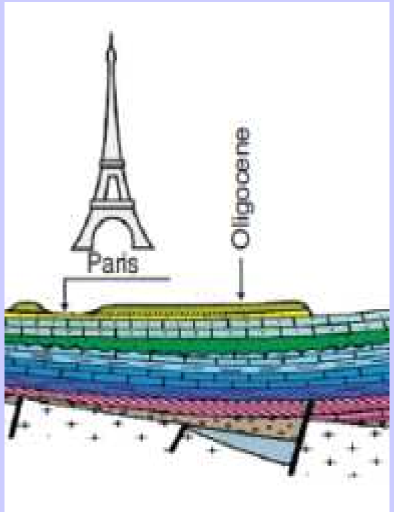
Key parameter: the 3D connectivity of microporous oolites
→ <u>pore casts</u>



GEOMECHANICAL STUDY

Triaxial apparatus at ENS, Paris

Triaxial experiments at in situ conditions



z = 1800 m

σ_3* = 23 MPa

Temp. = 55°C

on two samples with contrasting microstructures

Work still in progress …

GEOMECHANICAL STUDY

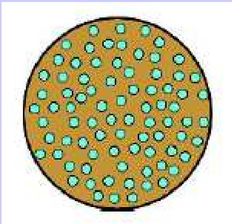
Description of the two samples

BY11: quarry = Bierry, facies = prograding oolitic

MA04: quarry = Massangis, facies = prograding oolitic

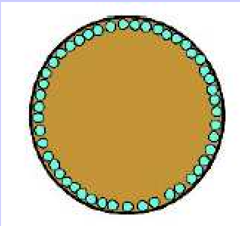
Sample name	Oolites (%)	Pellets (%)	Bioclasts (%)	cement (%)	porosity (%)	Hg poro peak (µm)	permeability (mD)
BY11	31.5	47.7	18.8	6.3	19.7	0.70	0.68
MA04	15.0	57.7	27.4	2.2	15.4	0.30	0.06

BY11:



« uniform » intra-oolite micro-porosity

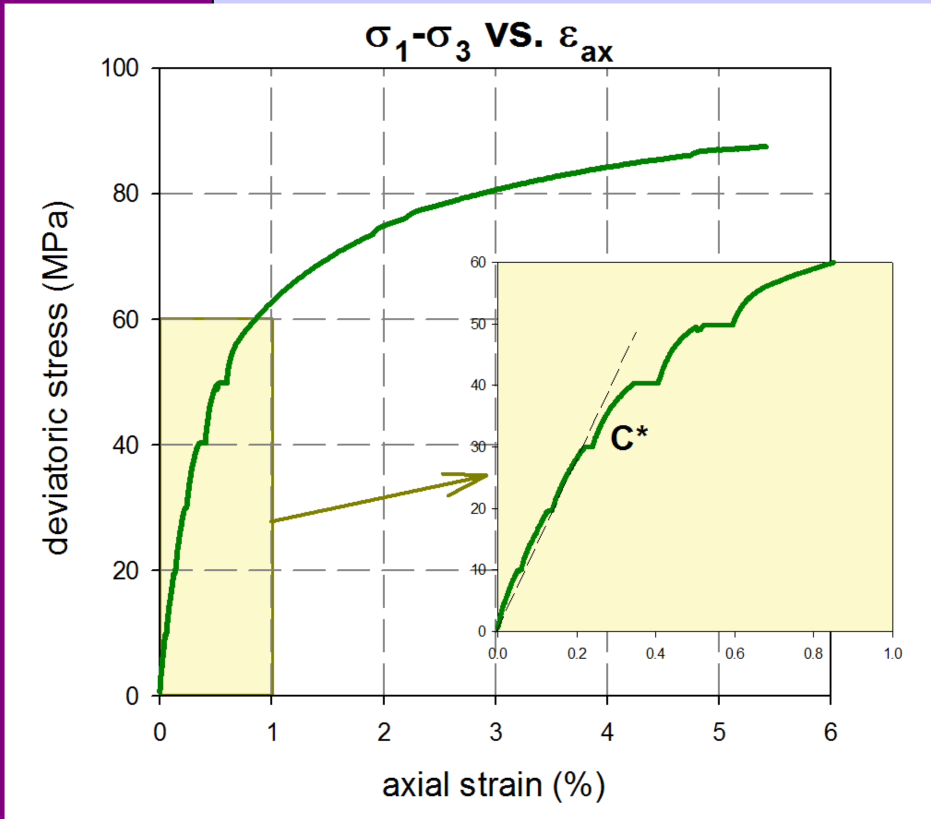
MA04:

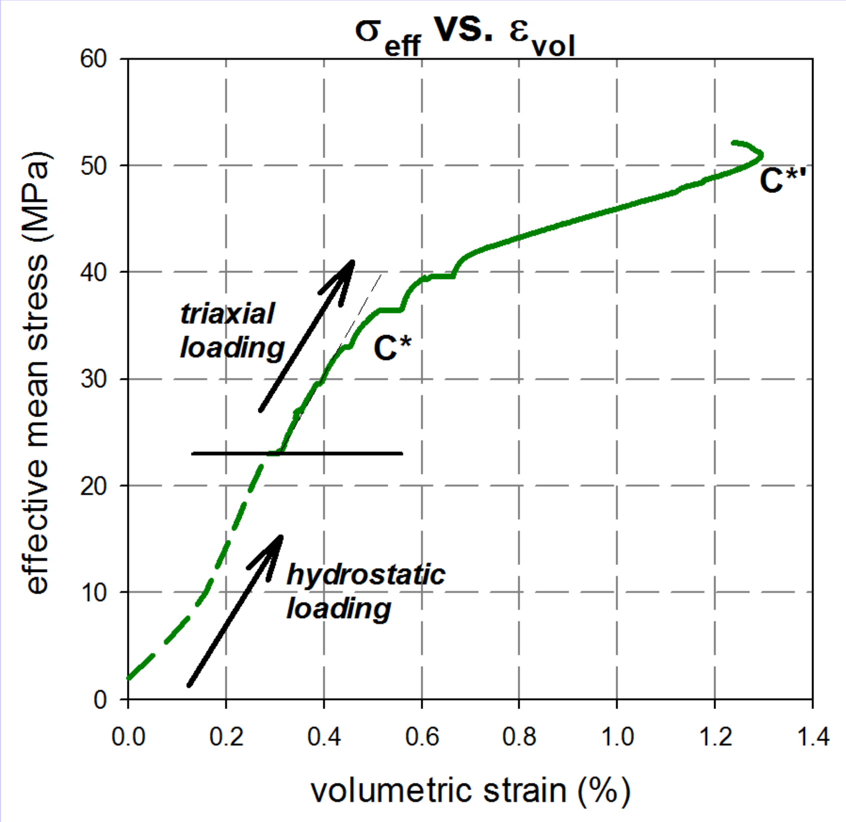


« rim » micro-porosity

GEOMECHANICAL STUDY

Sample BY11: Loading curves

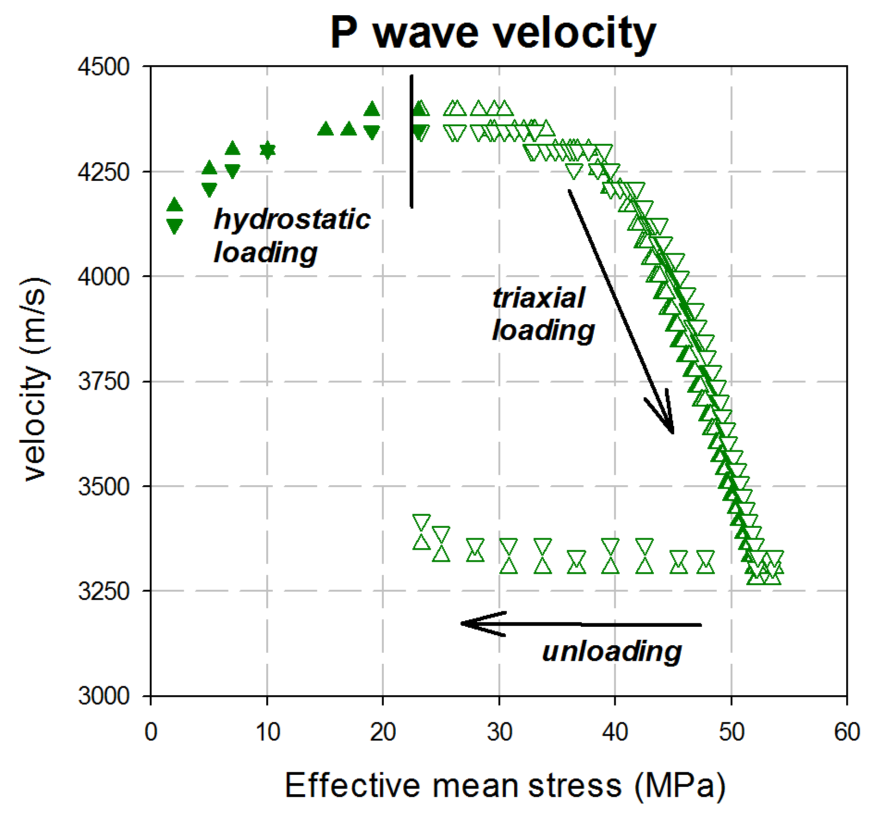


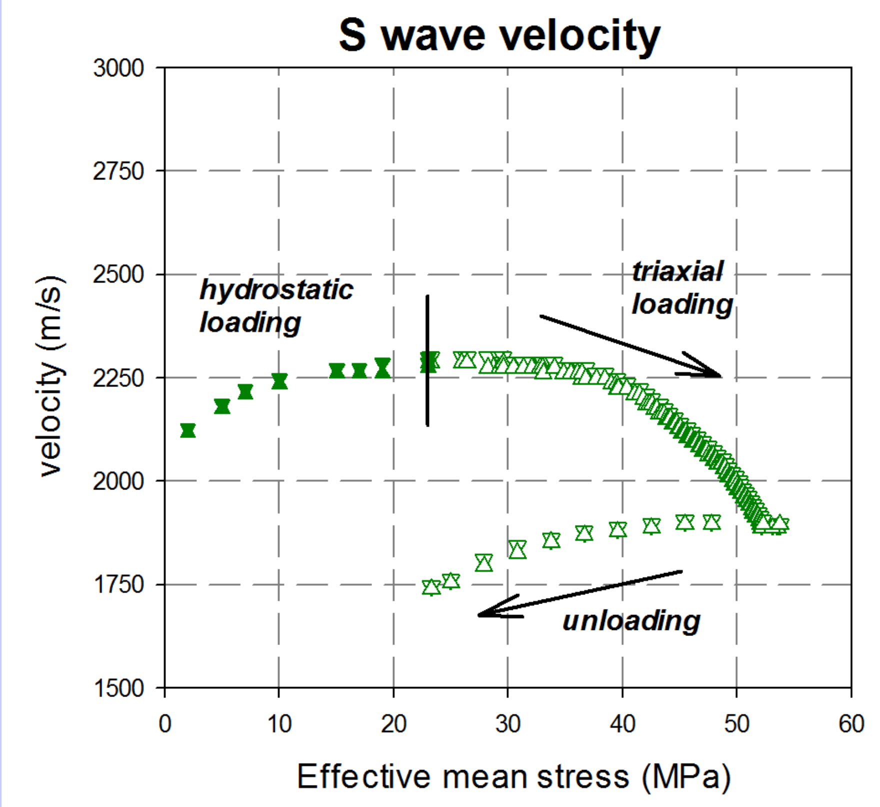


« ductile » type of behaviour

GEOMECHANICAL STUDY

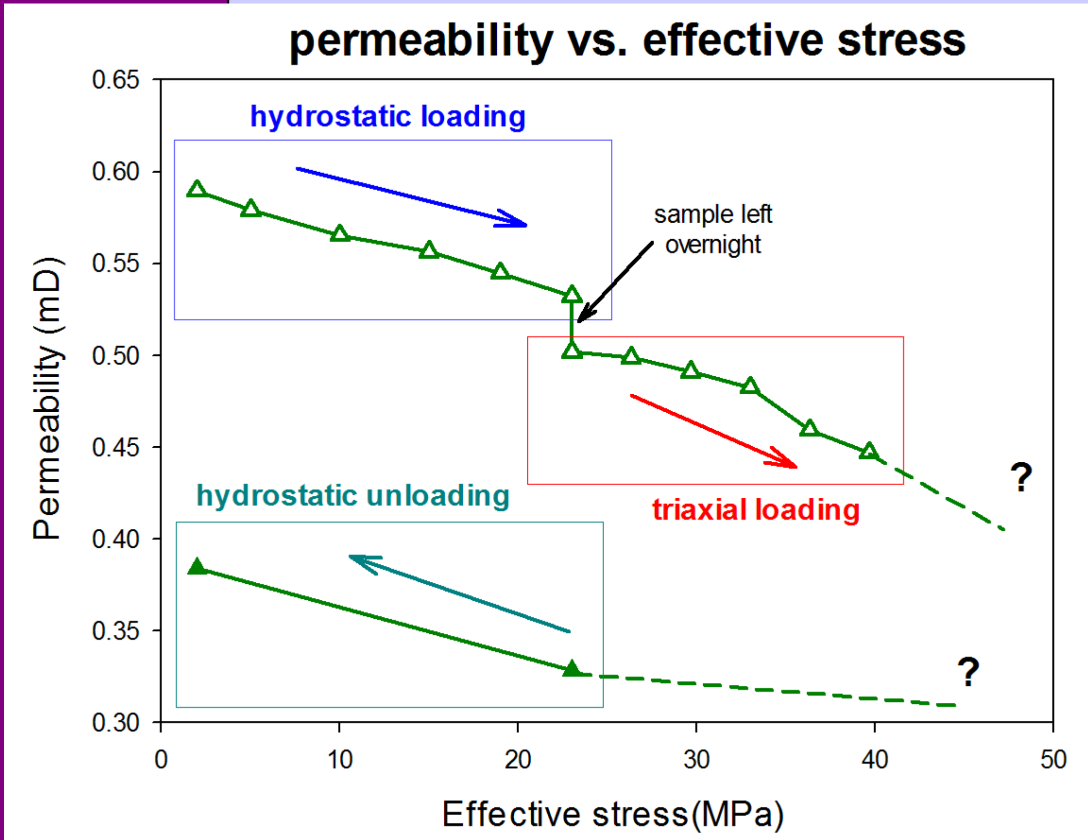
Sample BY11: ultrasonic velocities

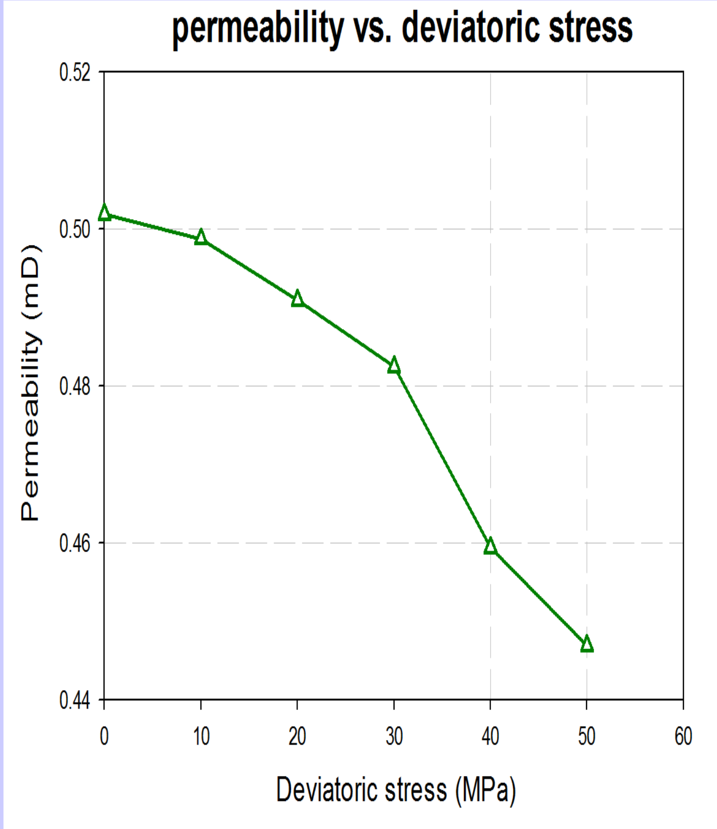




GEOMECHANICAL STUDY

Sample BY11: permeability





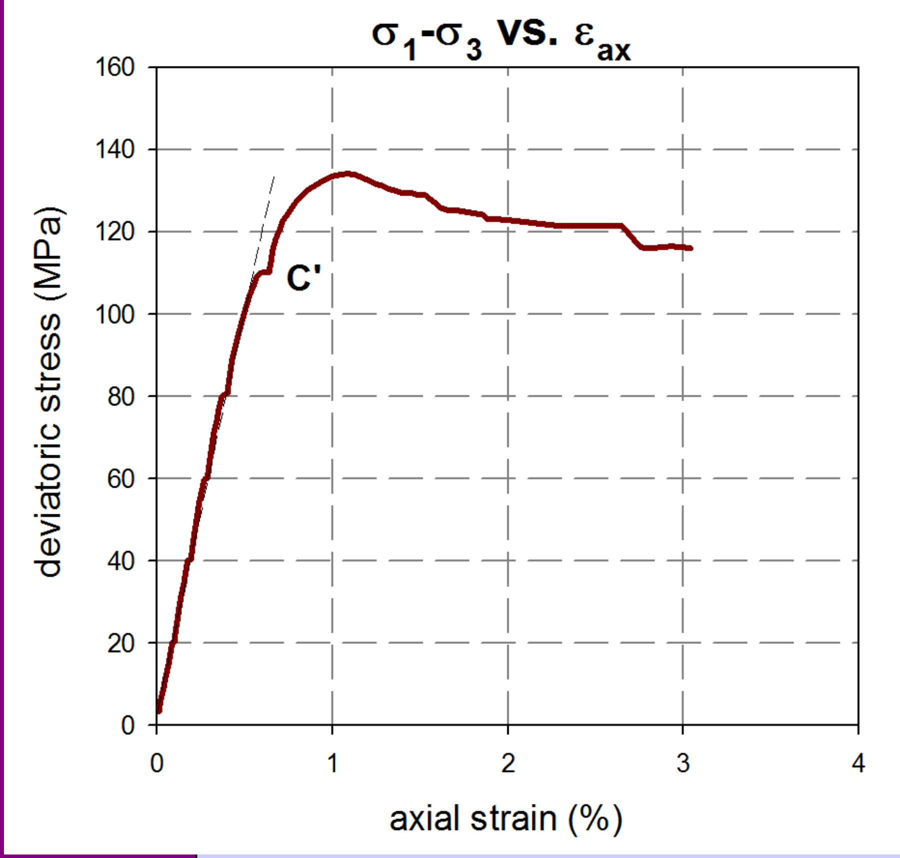
GEOMECHANICAL STUDY

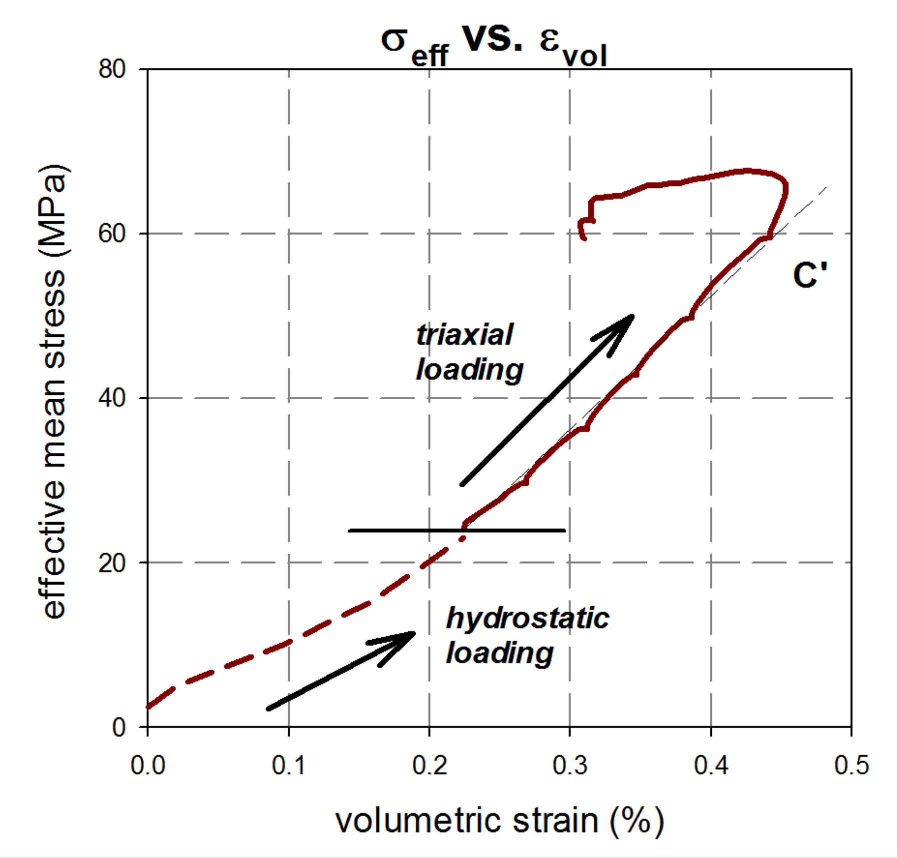
Sample BY11: after unloading

- **no localization observed**
- **a slight barrel shape**

GEOMECHANICAL STUDY

Sample MA04: loading curves

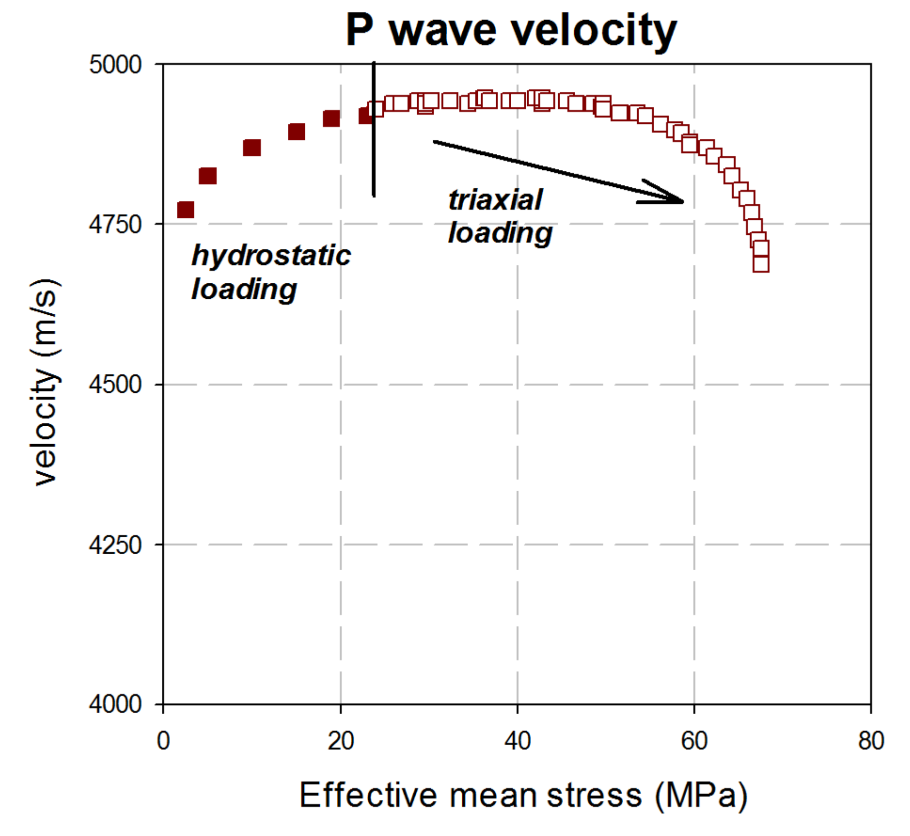


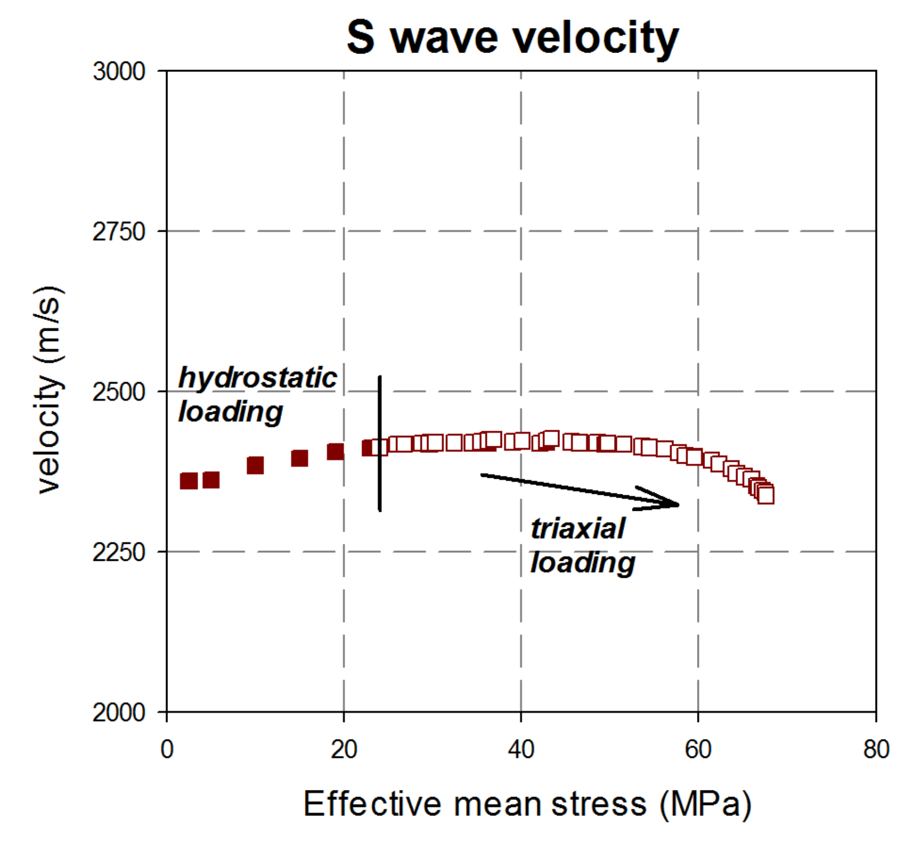


« brittle » type of behaviour

GEOMECHANICAL STUDY

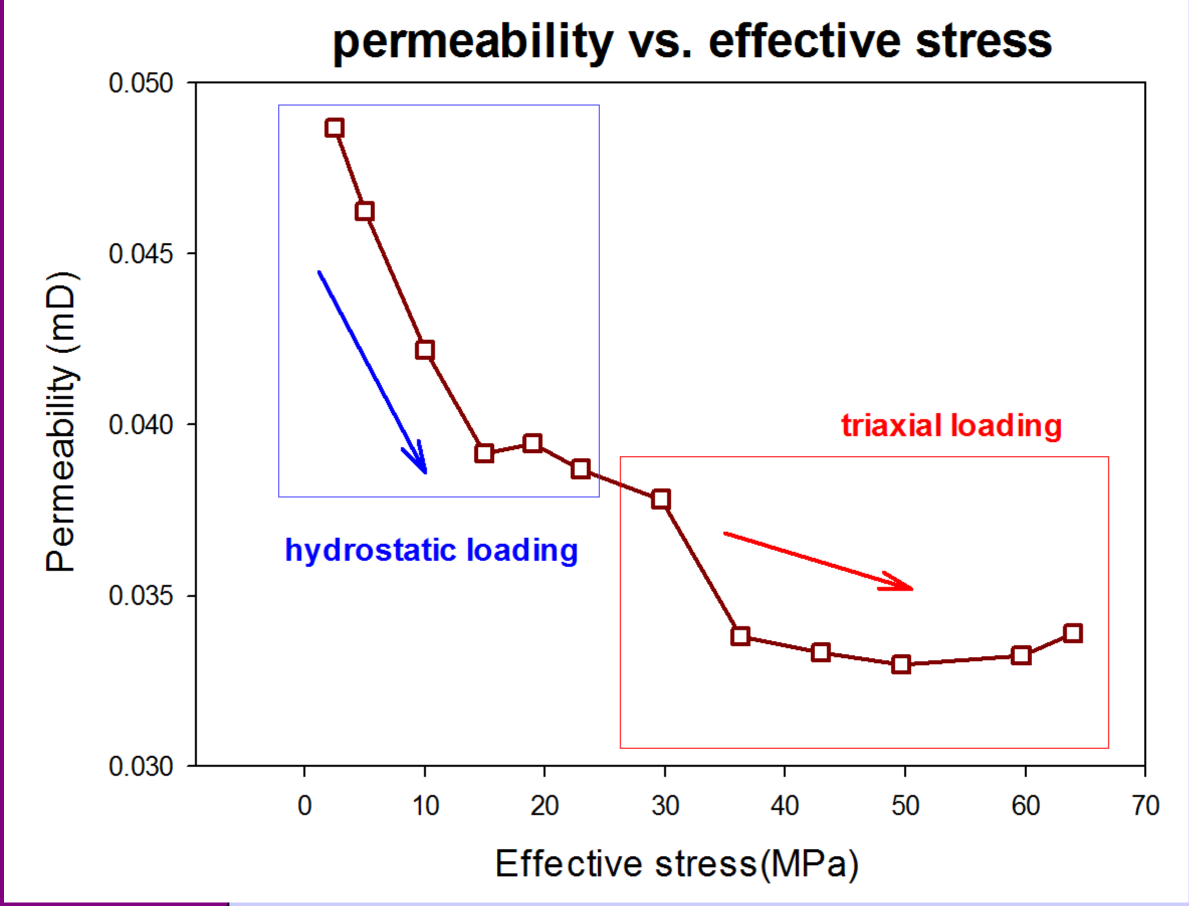
Sample MA04: ultrasonic velocities

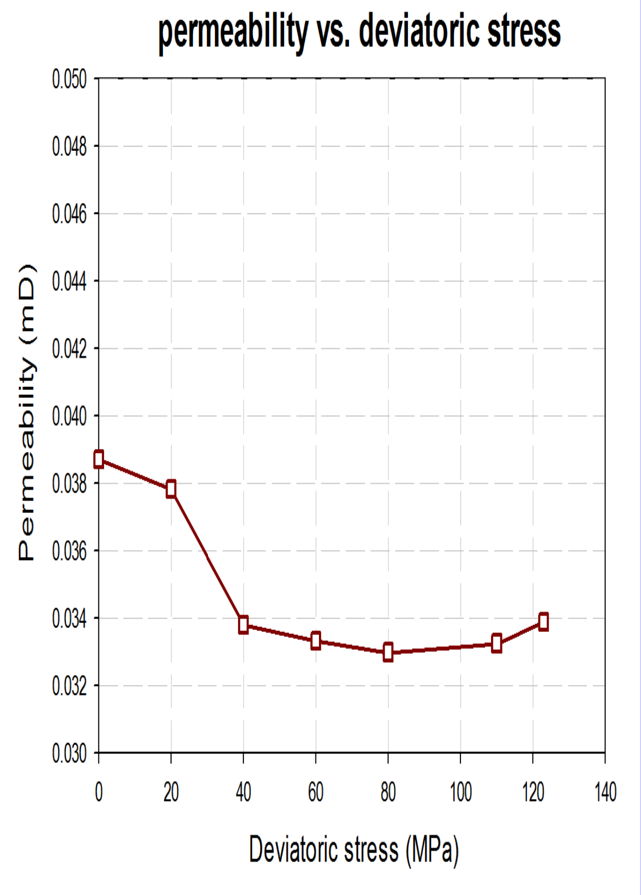




GEOMECHANICAL STUDY

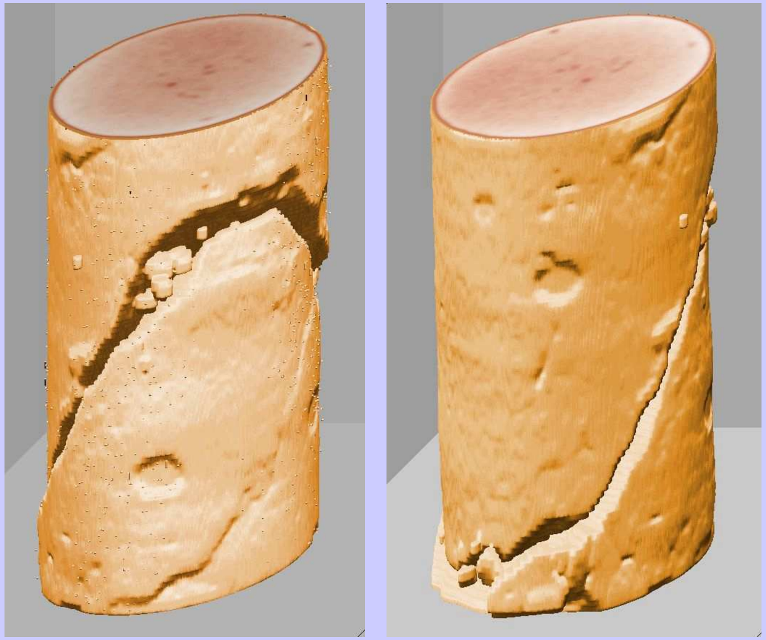
Sample MA04: permeability

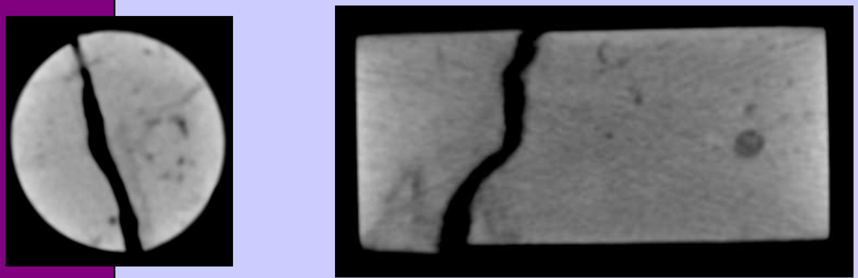




GEOMECHANICAL STUDY

Sample MA04: after unloading

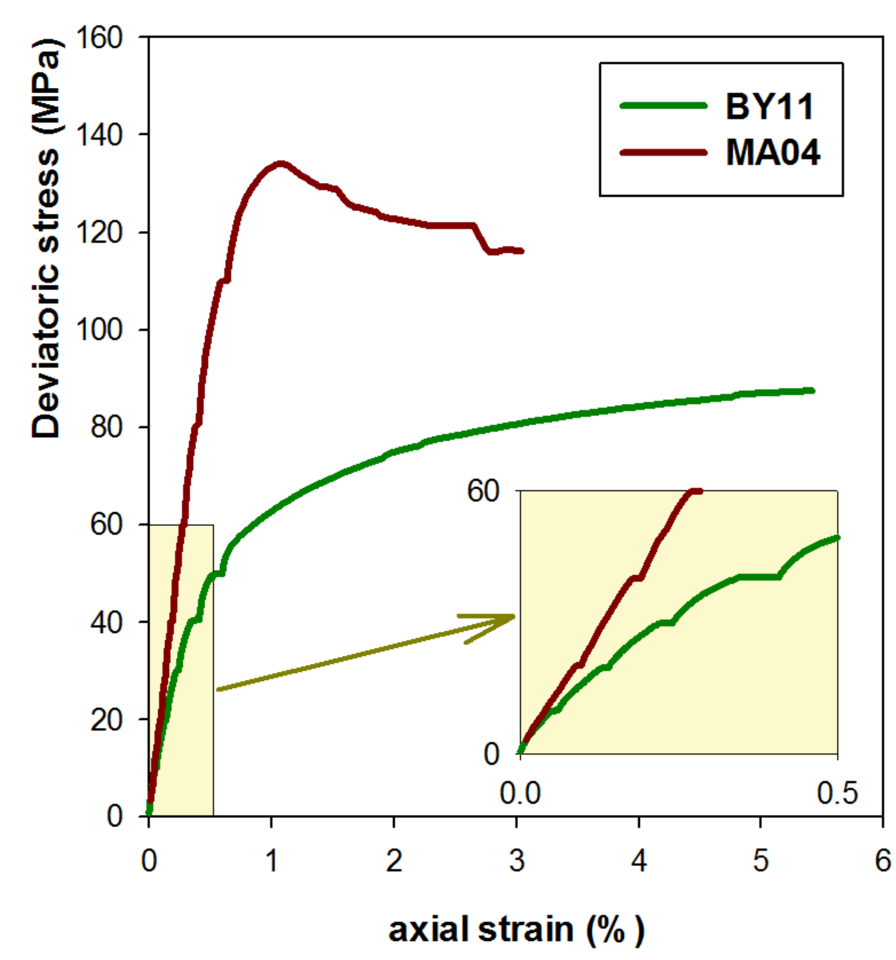


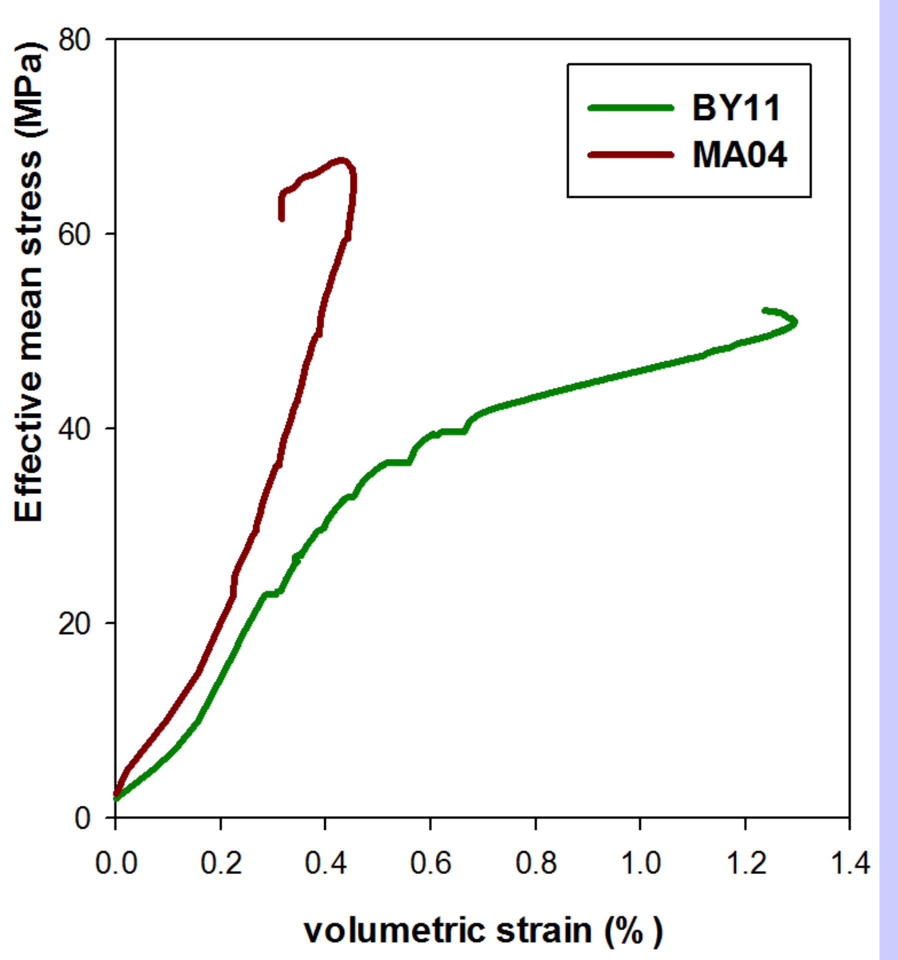


X-ray scanning shows that the sample failed with a clear fracture

GEOMECHANICAL STUDY

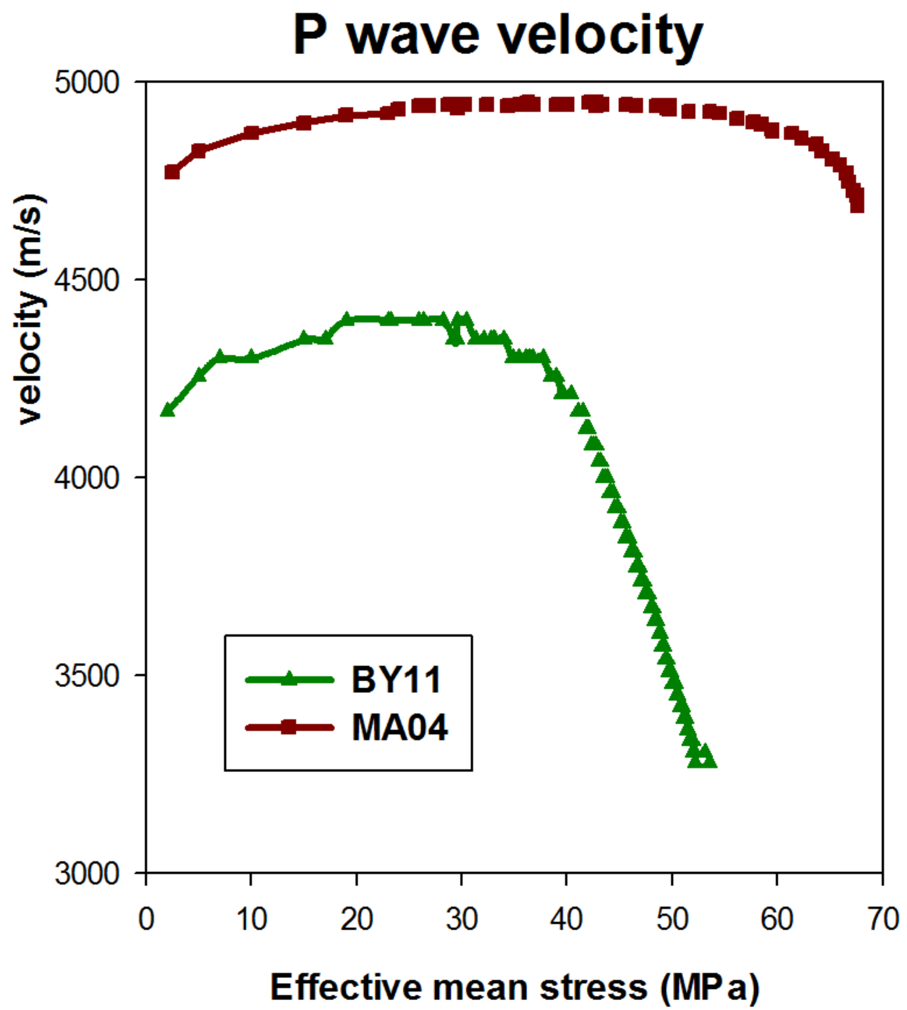
Comparison of loading curves

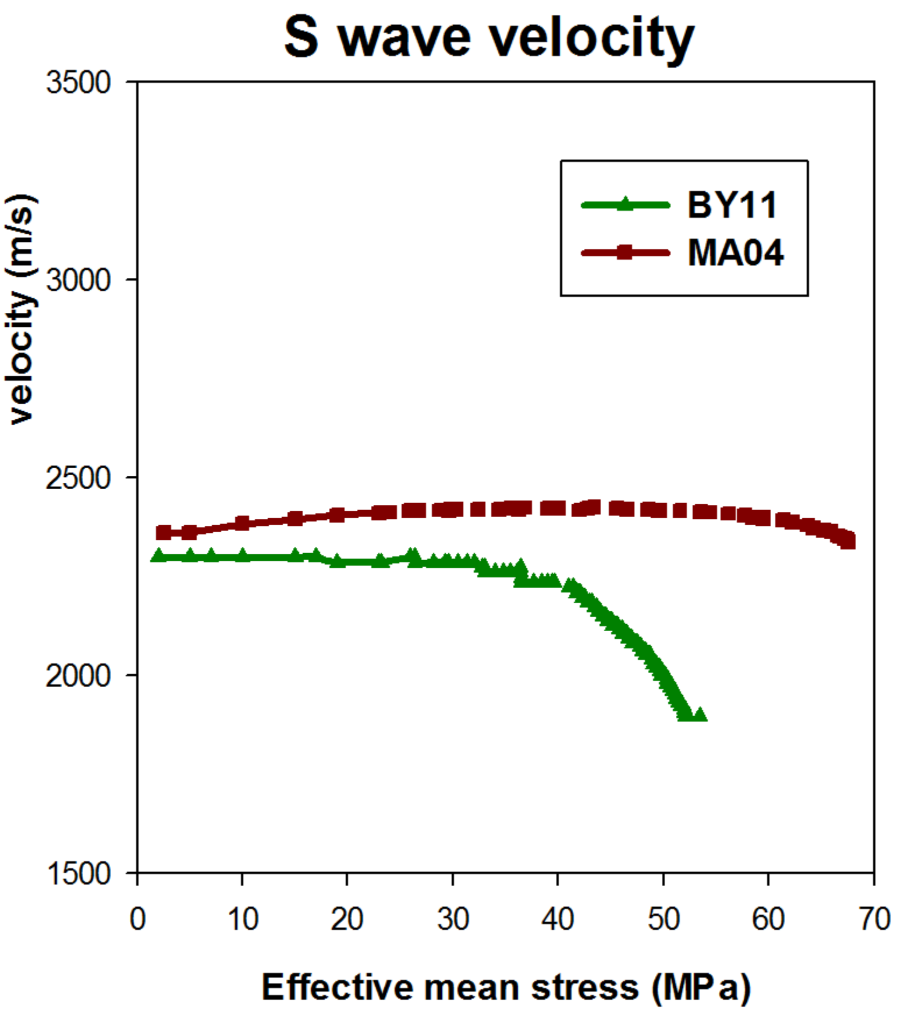




GEOMECHANICAL STUDY

Comparison of velocity evolution





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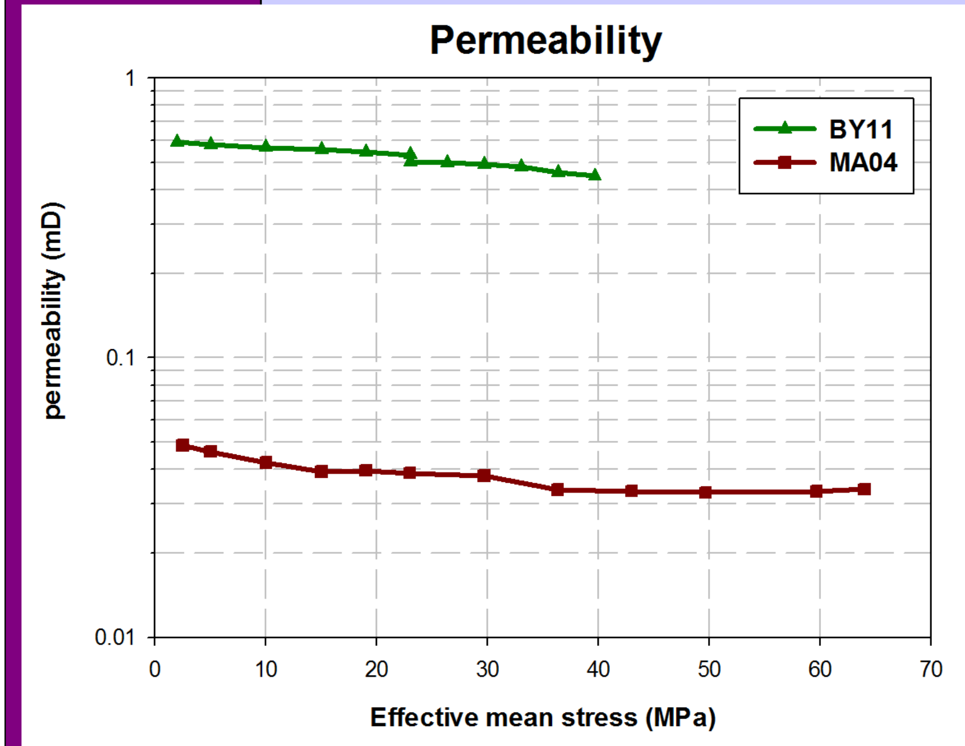
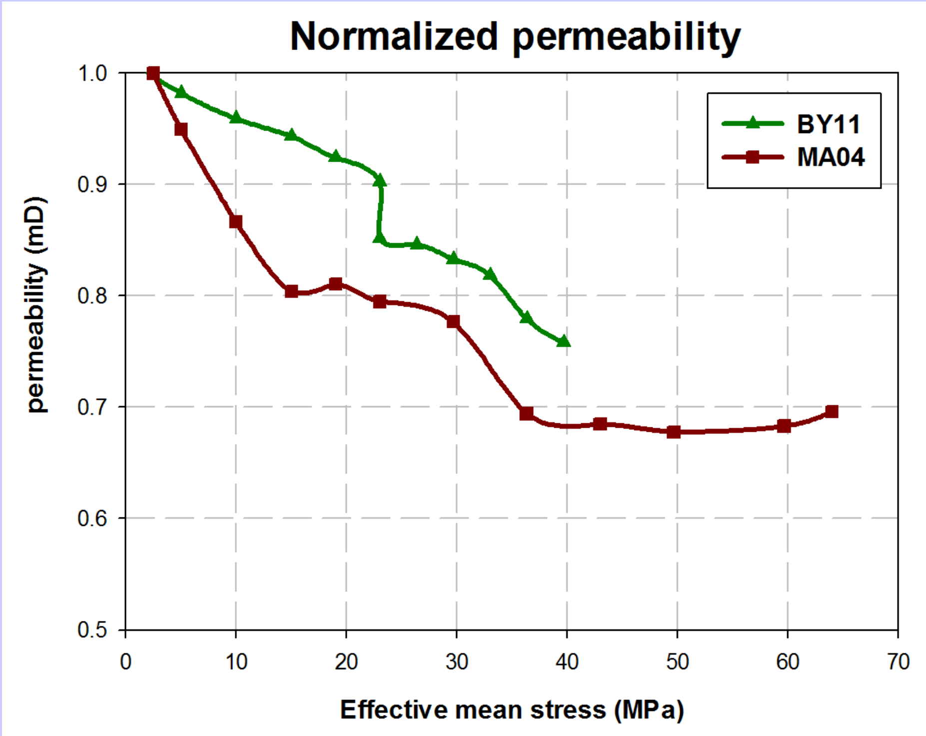
GEOMECHANICAL STUDY

Comparison of permeability evolution





Conclusions

The Oolithe Blanche is a microporous reservoir with a low permeability
8 % < porosity < 24 %
0.06 mD < permeability < 9 mD

Despite of the complexity of microstructures, some clear trends were found for the petrophysical properties

Contrasting results were obtained for two samples deformed under the same conditions in triaxial tests, showing a strong control of the microstructures on the mechanical properties