Geological controls on the petro-elastic behaviour of carbonate pore systems

An application to Late Paleozoic carbonates

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Carbonate reservoirs seismic characterization

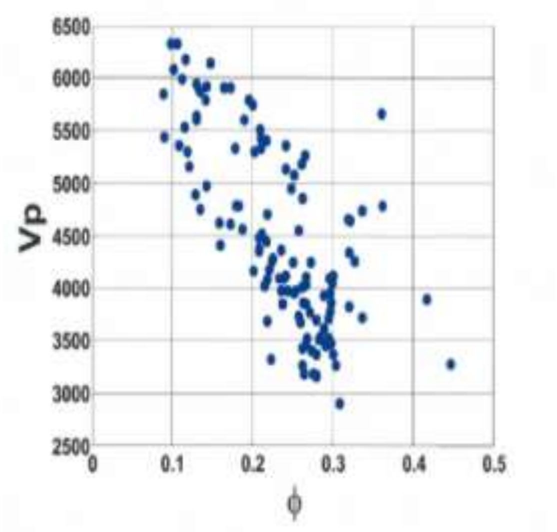
Carbonates pore systems complexity

Variable pore types (blue=pore)

Variable pore size (black=pore)

Variable connectivity

Velocity vs porosity
Dataset: variable carbonates

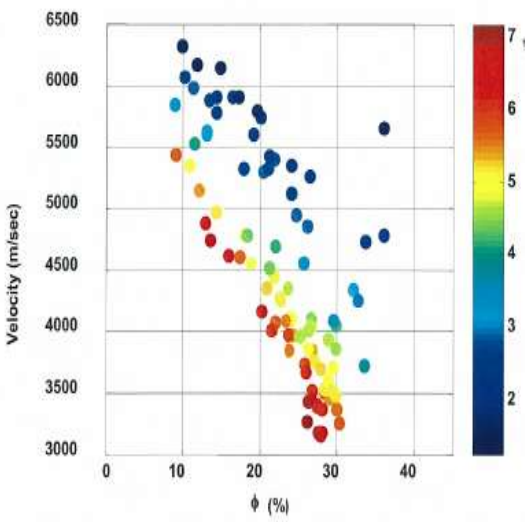


Anselmetti and Eberli, 1993

Different Vp/Porosity relationships obtained considering the factor GK= flexibility of the rock frame

GK is related to geological variables (pore type and size)

Velocity vs porosity
Same dataset, color code is G_K



Anselmetti and Eberli, 1993

High GK =
Weak rock frame
Slow trend

Low GK =
Stiff rock frame
Fast trend

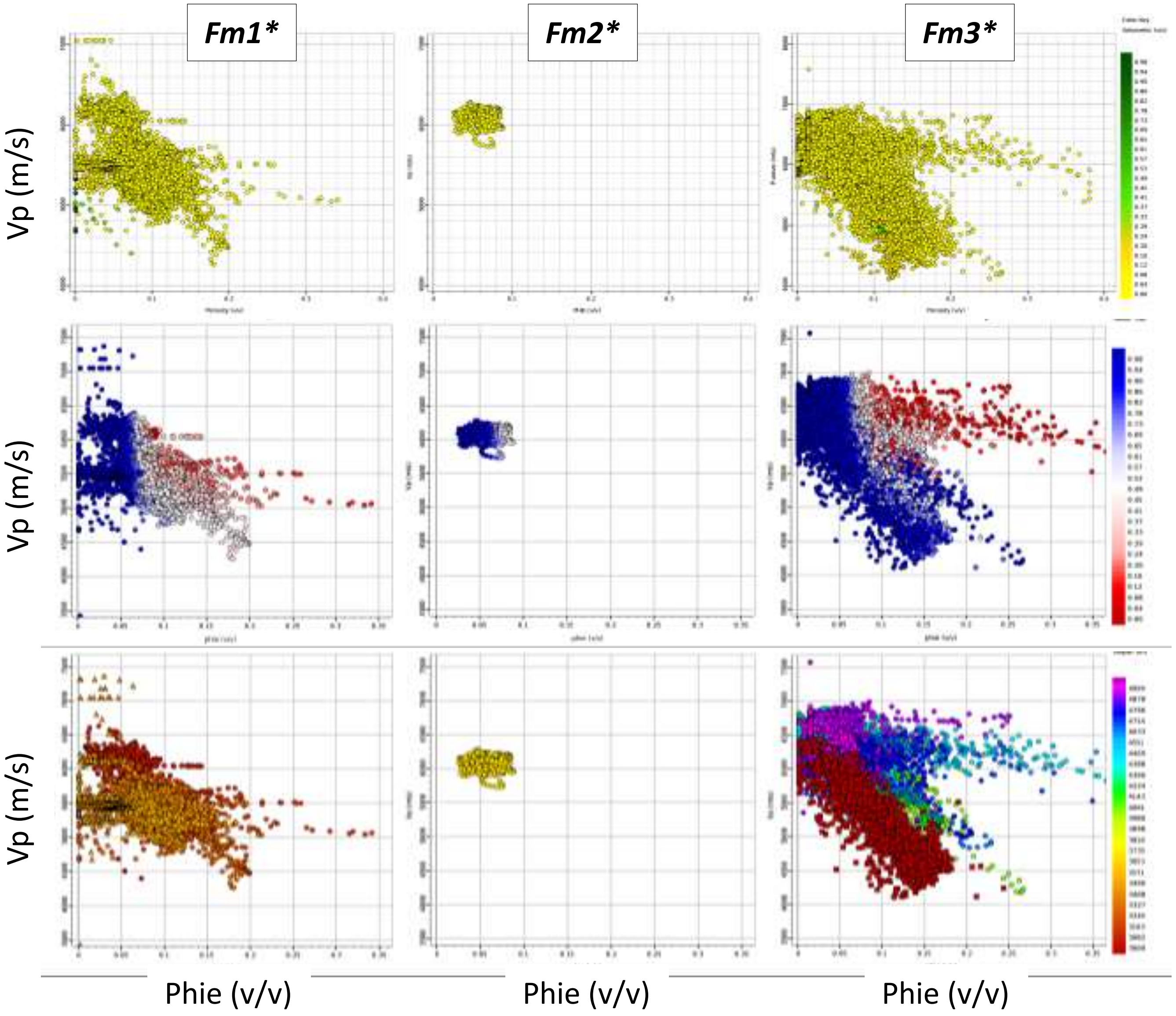
Data scattering in porosity vs velocity domain

(data collected at a regional scale)

Colour is **<u>clay content</u>** (green is shale and yellow is no-shale)

Colour is **<u>water saturation</u>** (blue is water and red is hydrocarbon)

Colour is **<u>depth</u>** (red is shallower and magenta is deeper)



Vp is P-wave velocity; Phie is effective porosity

Seismic characterization of carbonate reservoirs is made difficult by their **heterogeneity**:

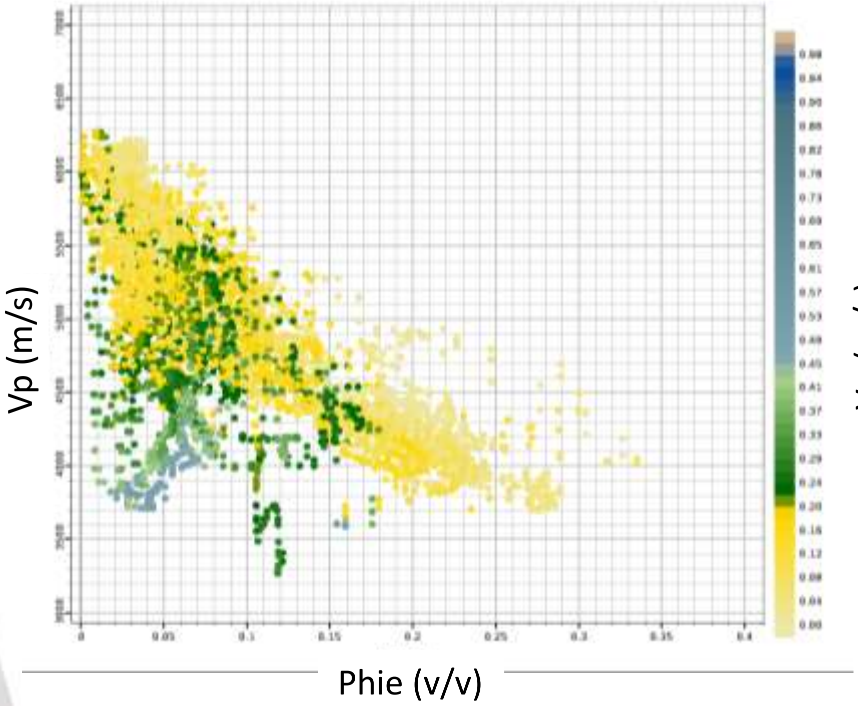
large uncertainty in linking elastic properties to geological variables (multiple depositional, diagenetic and structural controls).

****Formations 1, 2 and 3 are Late Permian deposits; Fm1 is younger than Fm3.***

Data scattering in porosity vs velocity domain

(data collected at a local scale)

Colour is **clay content** (green is shale and yellow is no-shale)



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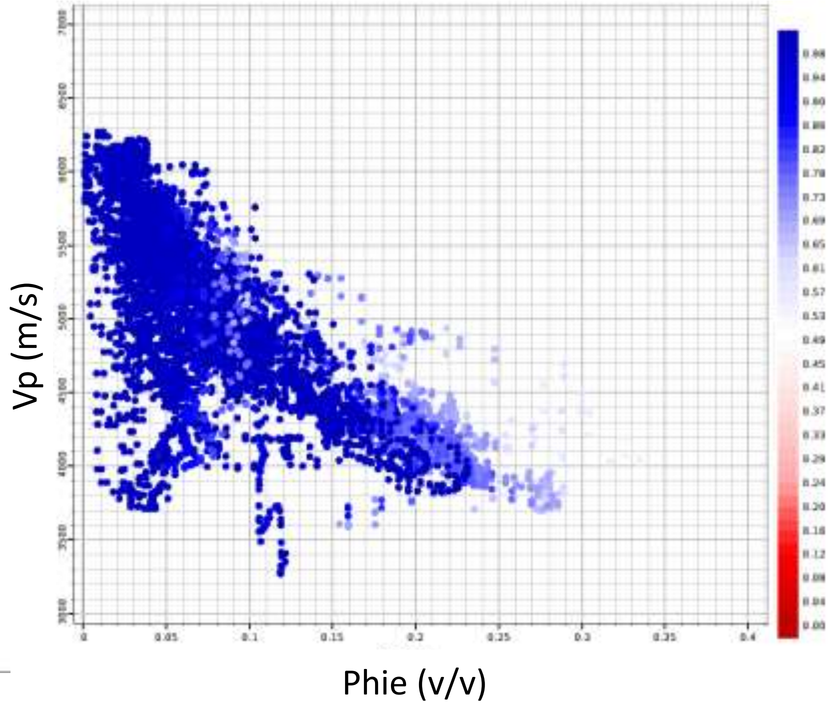

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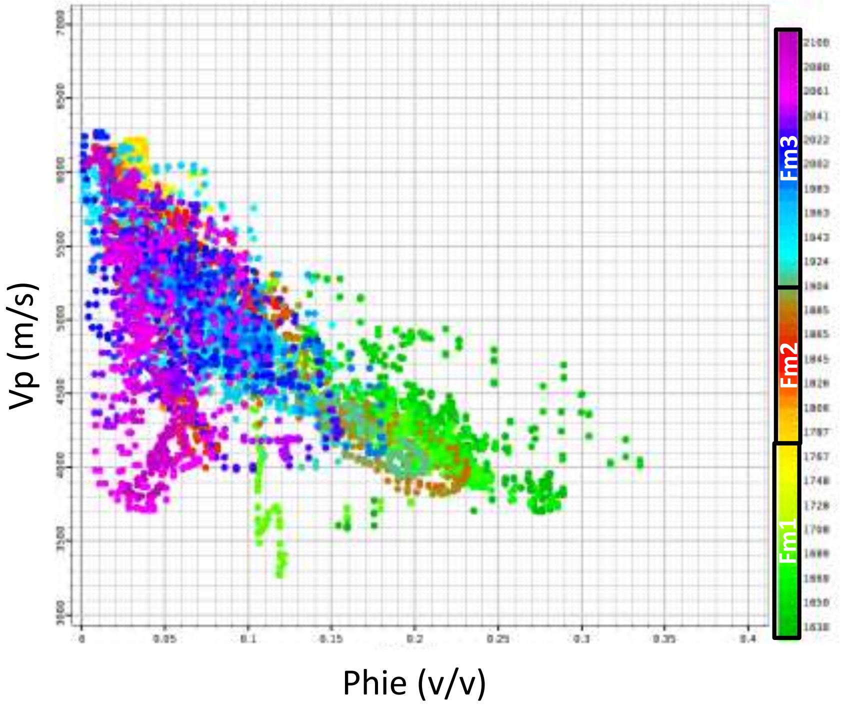
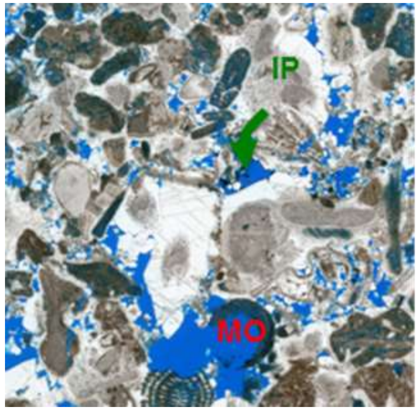
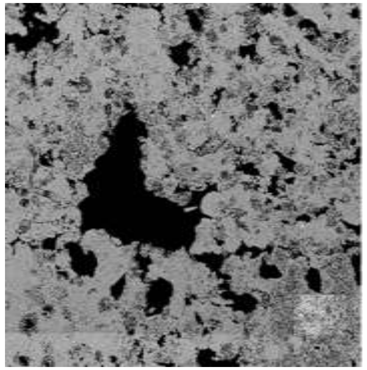


Integrated workflow

PORE SYSTEM CHARACTERIZATION

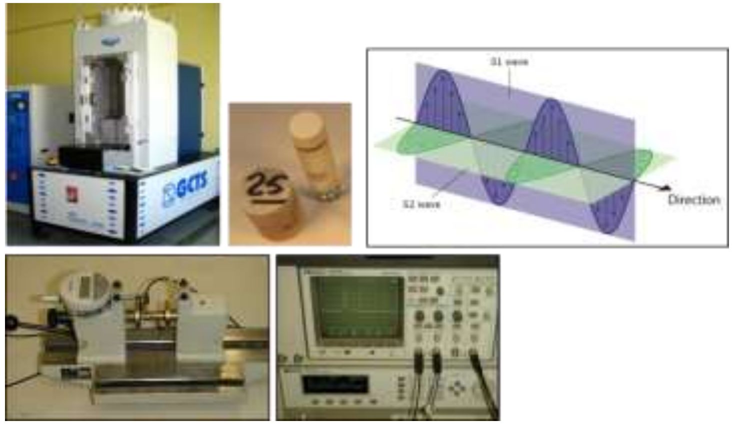
- *Petrographic description: lithology, texture and components, diagenetic features, pore types.*
- *Pore Network Characterisation: pores quantitative measurements and statistics of geometrical variables.*
- *Routine Core Analysis on core plugs and Computed Tomography: samples heterogeneity evaluation.*

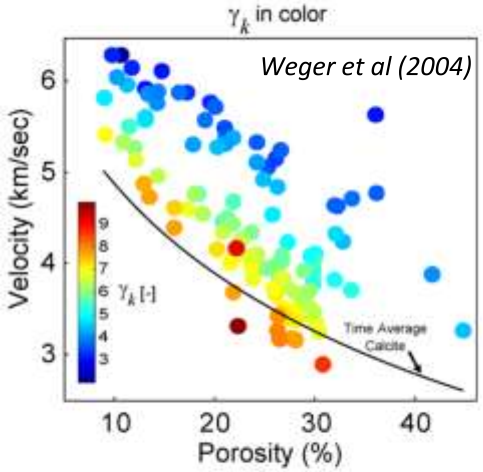




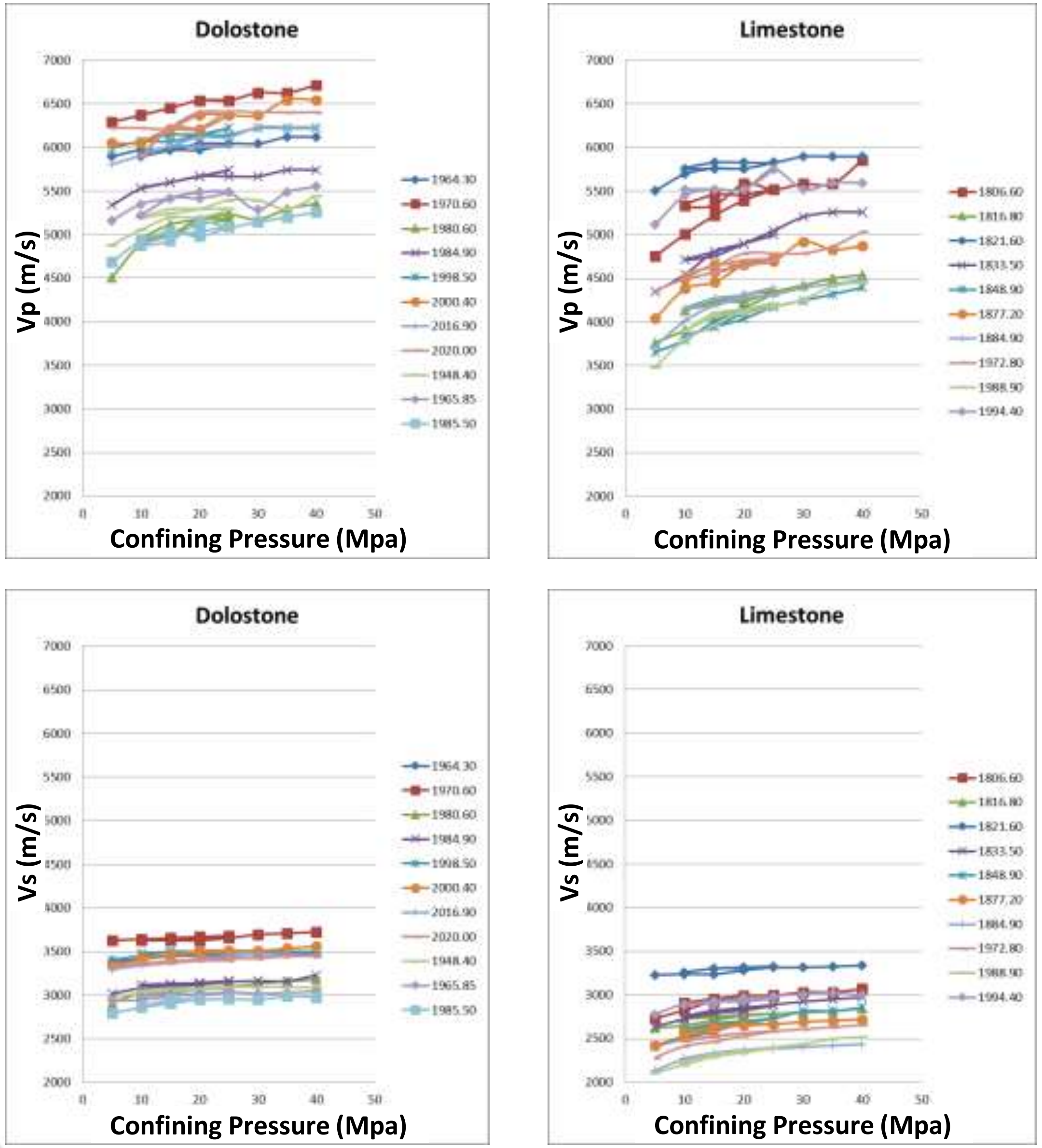
PETRO-ELASTIC ANALYSIS

- *Ultrasonic tests on core samples: P and S waves at different confining stress values*
- *Rock physics analysis: core + well log data*





Ultrasonic measurements and well log data

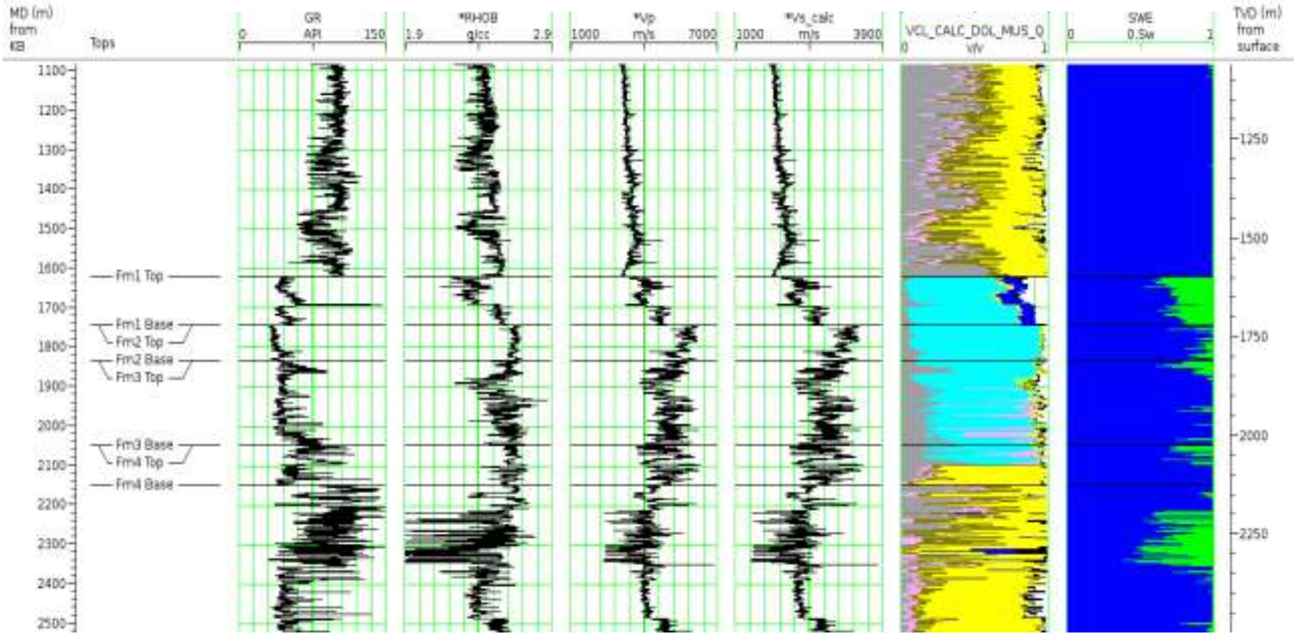


Ultrasonic tests on core samples

Ultrasonic measurements on 32 rock samples with addition of literature data of Late Paleozoic Carbonates (Colpaert et al., 2007): elastic parameters have been evaluated at a confining pressure of 25 Mpa at dry conditions.

Laboratory vs log data comparison has been also performed to correlate core to seismic scale.

Well 1



wireline well log data

eni

Frame flexibility factor - Extended Biot Theory (Sun, 2000 & 2004)

- The pore structure can be described by two parameters: the **frame flexibility factor** γ_k and the **frame stiffness factor** f_k
- This two parameters allow a topological characterization of the pore structure comparable with parameters like pore type, size and geometry, derived from petrographic image analysis, without the need to simplify the pore geometry with idealized aspect ratios.
- P-wave and S-wave velocities can be expressed in terms of porosity, elastic moduli and density of the rock solid and fluid components, and by the rock frame factors.

$$V_p = \sqrt{\frac{\frac{4}{3\mu_S(1-\varphi)^{c\gamma_k}} + K_S + \varphi_K(K_f - K_s)}{\varphi\rho_f + (1-\varphi)\rho_s}}$$

$$V_s = \sqrt{\frac{\mu_S(1-\varphi)^{c\gamma_k}}{\varphi\rho_f + (1-\varphi)\rho_s}}$$

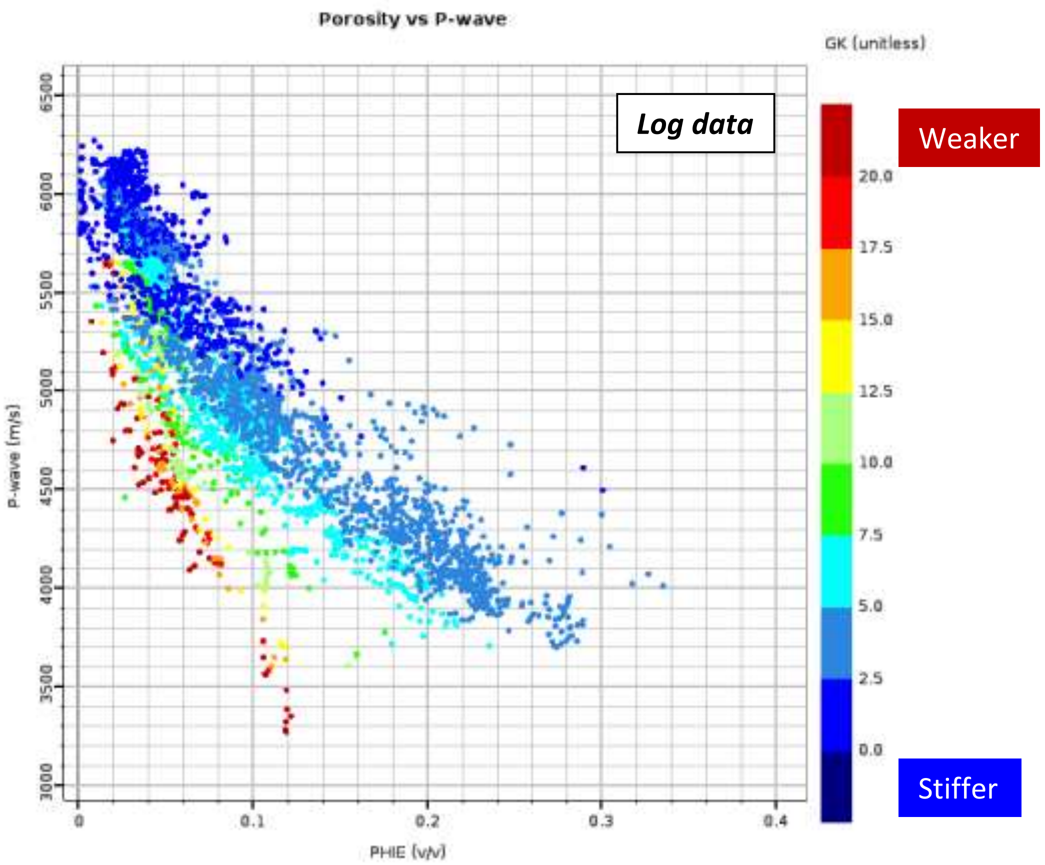
- Where φ is the porosity, K_s is the rock frame bulk modulus, K_f is the fluid component bulk modulus, μ_s is the rock frame shear modulus, ρ_s is the solid component density, ρ_f is the fluid component density, γ_k is the frame flexibility factor, c is the gamma ratio, assumed 8/11 (Sun, 2004).
- The frame flexibility factor γ_k characterizes the ***flexibility*** of the rock frame due to the pore structure and it can be expressed as:

$$\gamma_k = \frac{\ln \frac{\varphi K(K_f - K_s) - K_f(K - K_s)}{\varphi^2(K_s^2 - K_f K_s) - \varphi(K_s^2 - K_f K) - K_f(K - K_s)}}{\ln(1-\varphi)} + 1$$

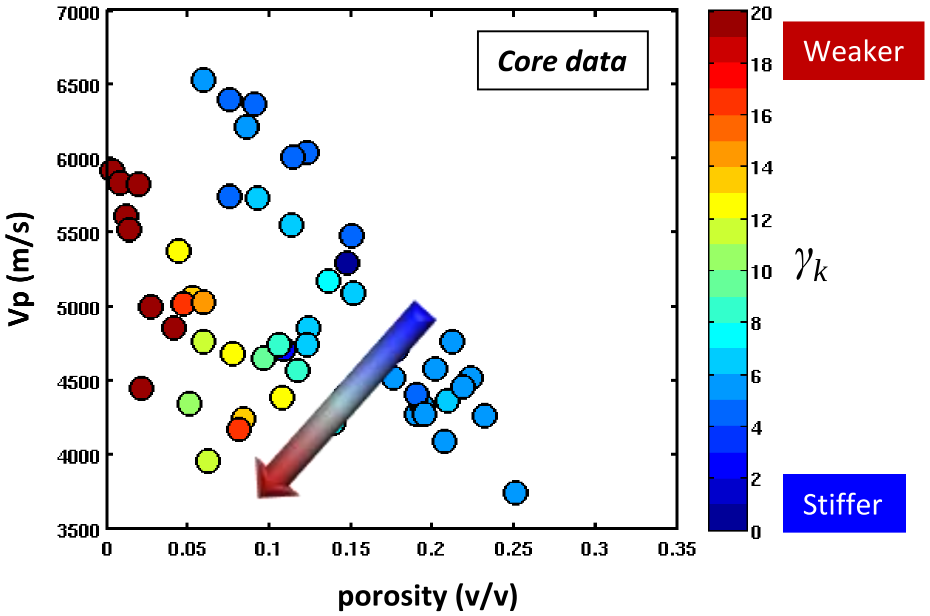
- The frame stiffness factor f_k describes the ***stiffness*** and ***rigidity*** of the rock frame due to both pore structure and porosity and it can be expressed as:

$$f_k = (1-\varphi)^{\gamma_k - 1}$$

Frame flexibility factor from log & core data



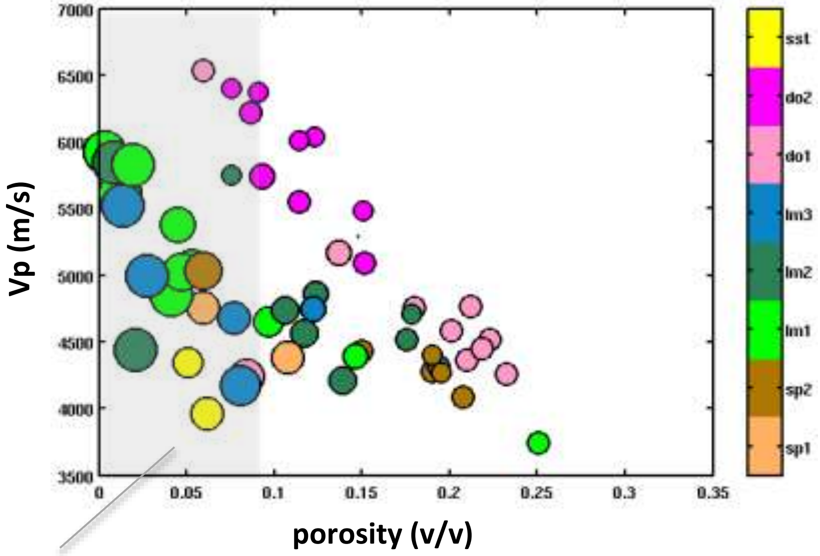
γ_k factor mostly varies in relation to geologic controls, such as lithology or pore type (Colpaert et al., 2007)



The γ_k variations can be related to changes of the rock texture and pore type by a general rule (Weger et al., 2004):

- a **lower γ_k** corresponds with a ***"stiff and fast"*** internal rock structure, marked by large particles and overall simple pore geometry (large pores with a smooth outline);
- a **higher γ_k** corresponds with a ***"weak and slow"*** internal rock structure, marked by fine-grained particles and pores (rough and complex small pores and micro-porosity).

Results (1/2)



The color-key reflects the lithotype and the bubble size reflects the γ_k value.

The fast and slow trends show a relationship with the lithotype.

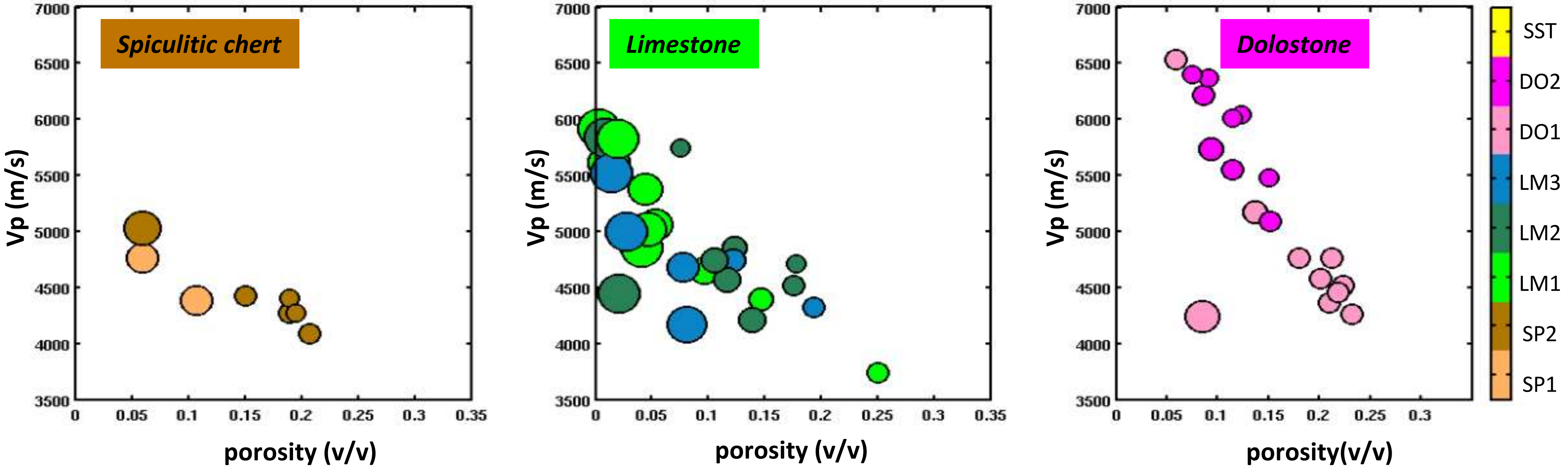
For a given porosity value

- dolostones (pink) are faster than limestones;
- cherts (brown) align on the dolostone trend;
- sandstones (yellow)are slower than carbonates.

The γ_k is generally lower in dolostones than in limestones.

Porosity threshold 10%: γ_k values is generally high for all types of samples

a better clustering is detectable considering a combined classification including both lithology and dominant pore type



PORE TYPE

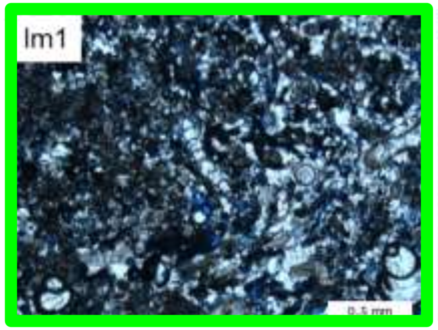
1 - interparticle + intercrystalline + microinterparticle porosity

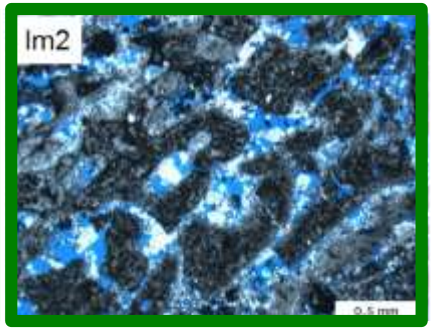
2 - vugs and connected molds

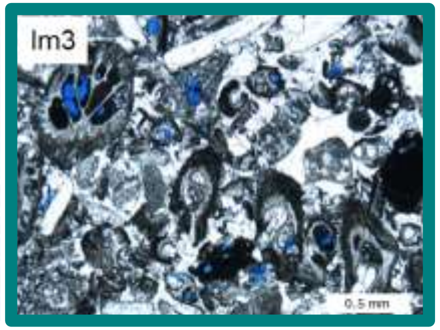
3 - intraparticle and isolated molds

Results (2/2)

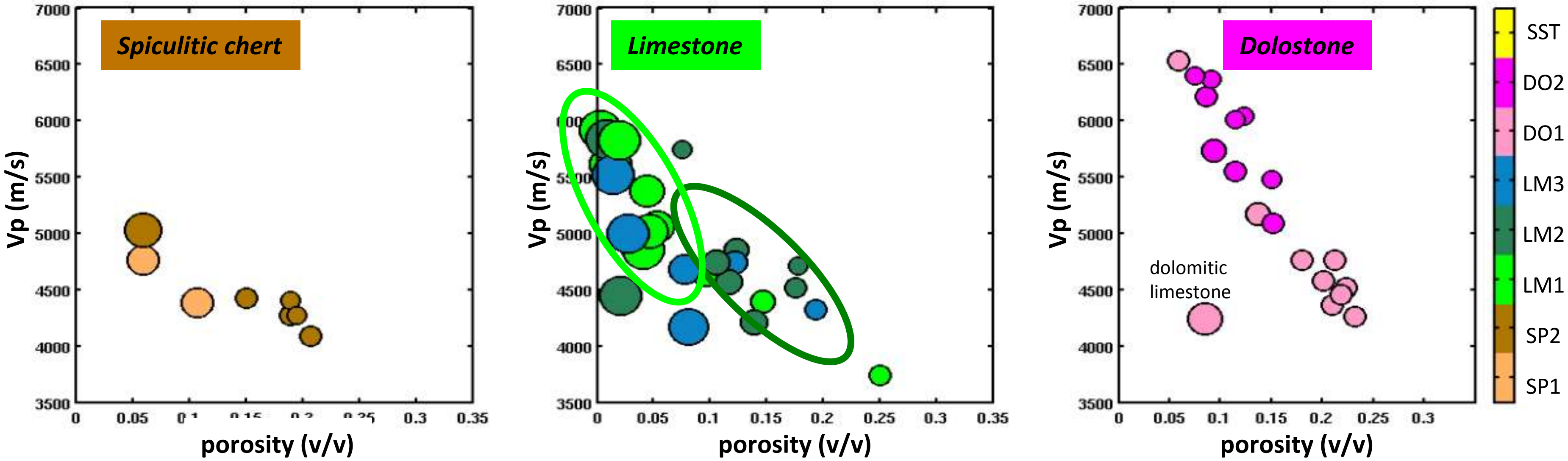
Our work suggests that lithology/mineralogy is the most significant geological control on the acoustic properties of the examined samples.





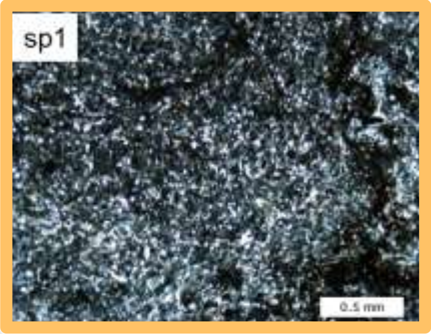


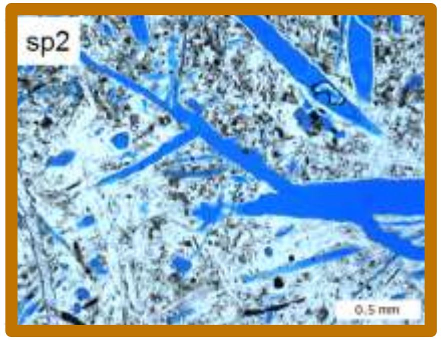
The influence of **pore type and geometry** only becomes detectable in **high porosity limestones**.

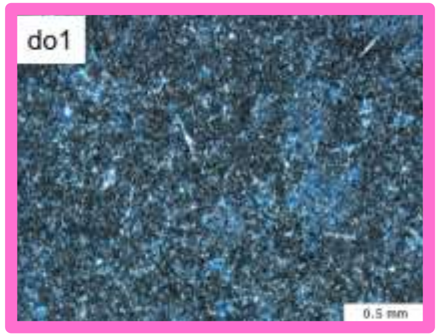


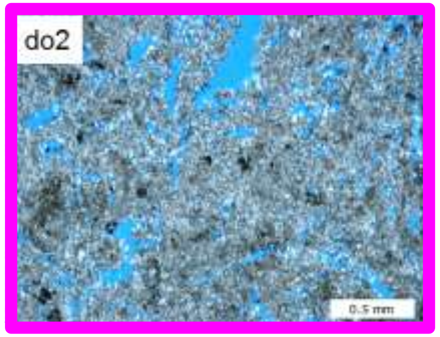
PORE TYPE

1. interparticle + intercrystalline + microinterparticle porosity
2. vugs and connected molds
3. intraparticle and isolated molds









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