Relationship Between Acoustic and Petrophysical Properties of Permian Dolograinstones*

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Abstract

This research investigates the relationship between acoustic properties and petrophysical properties within one outcropping grainstone cycle in the Permian San Andres Formation at Lawyer Canyon, Wets Texas.

The commonly accepted assumption for moldic carbonate rock is that rocks with rounded pores have a stiffer matrix and a higher Vp than rock with a high aspect ratio for a given porosity. One recent study has shown that the nature of the crystalline matrix between spherical pores is actually the main control on acoustic properties.

Acoustic properties were measured directly on the outcrop and on mini-core plug collected along a 900 meter transect within a single grainstone body that shows lateral changes from interparticle porosity dominated to oomoldic porosity dominated. The studied grainstones are dominated by small (150-µm) peloids, ooids, fusulinids, and mollusk fragments. Porosity varies from 11 to 29%, and permeability ranges from 0 to 60 md. Vp and Vs show variation up to 1,500 m/s for a given porosity. The distinction in the velocity-porosity cross-plot between grainstone with interparticle porosity and moldic grainstone is not clear. If we plot acoustic properties against distance along the outcrop face, a separation in acoustic properties between the zone with moldic pores and the interparticle-porosity-dominated zone cannot be seen. Petrographic analysis under plain light microscope shows no apparent difference between fast and slow samples for a given porosity. However, under UV light, samples with a lower-than-average velocity for a given porosity have a matrix between pores with significant amounts of intercrystalline microporosity. Conversely, rocks with a higher-than-average velocity for a given porosity all show a lack of microporosity in the matrix connecting the pores. The amount of intercrystalline microporosity in the matrix seems to be the primary control on stiffness of the rock framework and not the pore type, as previously assumed.

This study has direct implications for interpreting sonic log and calibrating seismic inversion techniques in reservoirs that have oomoldic pores.

Selected References

Baechle, G.T., A. Colpaert, G.P. Eberli, and R.J. Weger, 2008, Effects of microporosity on sonic velocity in carbonate rocks: The Leading Edge, v. 27/8, p. 1012-1018.

Eberli, G.P., L.B. Smith, E. Morettini, and L. Al-Kharusi, 2003, Porosity partitioning in sedimentary cycles; implications for reservoir modeling: AAPG Annual Meeting Expanded Abstracts, v. 12, p. 48.

Janson, X., G.P. Eberli, F. Bonnaffe, F. Gaumet, and V. De Casanove, 2007, Seismic expressions of a Miocene prograding carbonate margin, Mut Basin, Turkey: AAPG Bulletin, v. 91/5, p. 685-713.

Kerans, C.F., J. Lucia, and R.K. Senger, 1994, Integrated characterization of carbonate ramp reservoirs using Permian San Andres Formation outcrop analogs: AAPG Bulletin, v. 78/2, p. 181-216.

Marion, D., and D. Jizba, 1997, Acoustic properties of carbonate rocks: use in quantitative interpretation of sonic and seismic measurements: Carbonate Seismology, p. 75-93.

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May 2013

Objective

Our overall research project proposes to investigate vertical and lateral seismic velocity heterogeneity in carbonate reservoir rocks *to optimize the use of seismic inversion techniques for carbonate reservoir characterization*

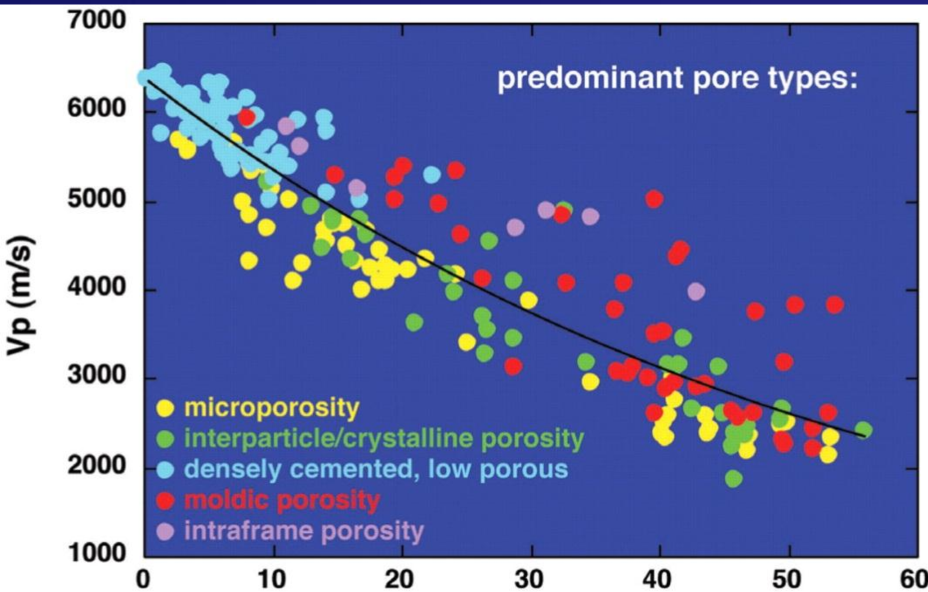
To better constrain the potential relationship between seismic velocity and other petrophysical characteristics, we investigate sonic velocity within well-constrained geological framework, in this case a single grainstone body.

Problem : Untested Assumption

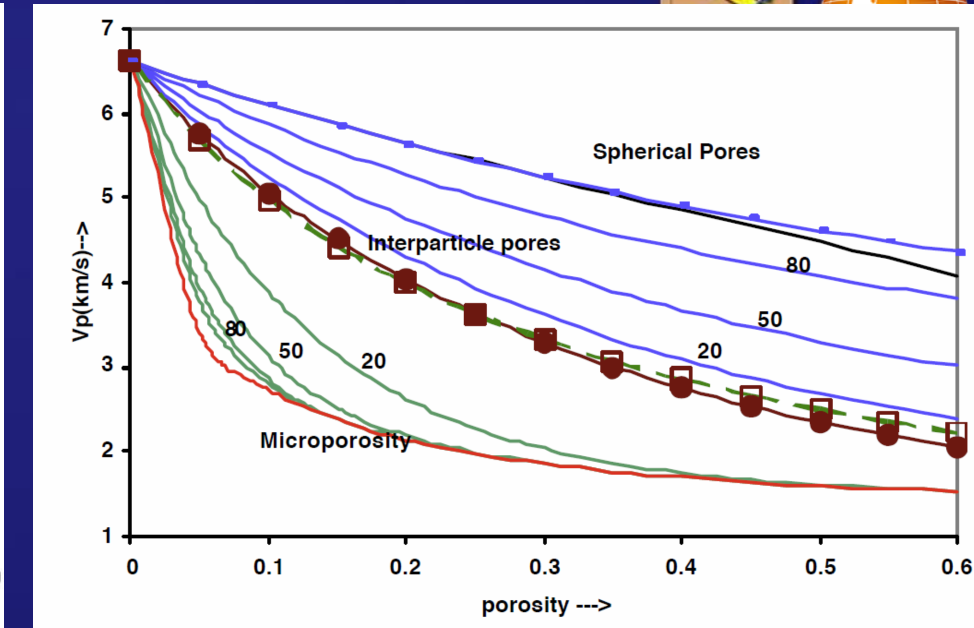
In our past seismic modeling experiments to investigate the potential of AVO technique (Janson et al, AAPG 2007) to detect moldic pore, we used the assumption that Vp/Vs ratio in moldic pore is high.

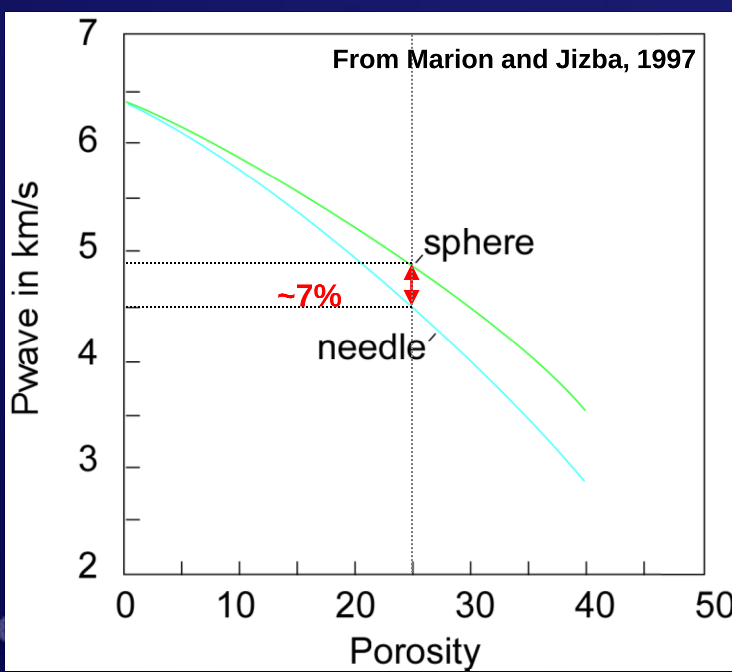
This assumption was supported by :

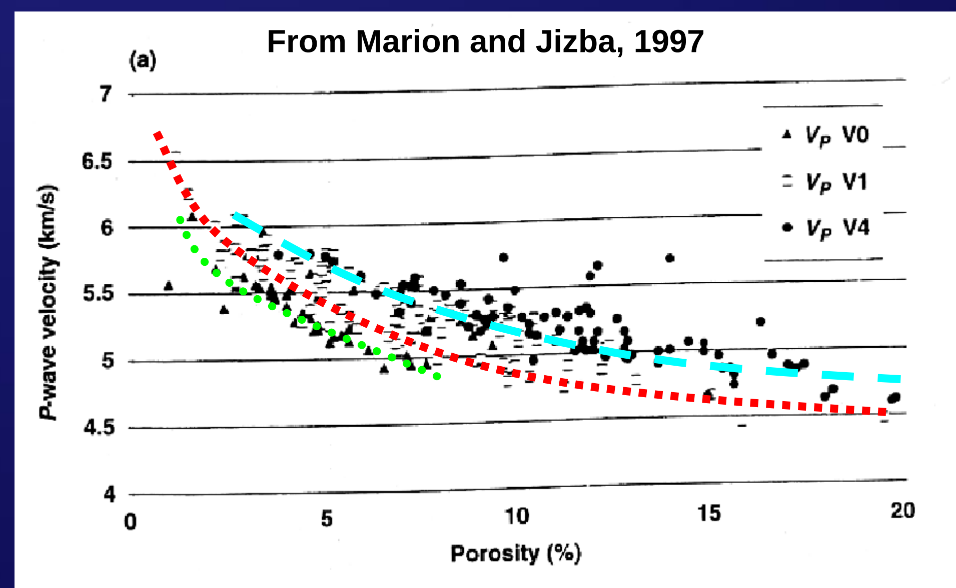
- many studies that have shown that Vp is high in moldic pore because of the stiff frame.
- This effect is not believed to affect Vs.



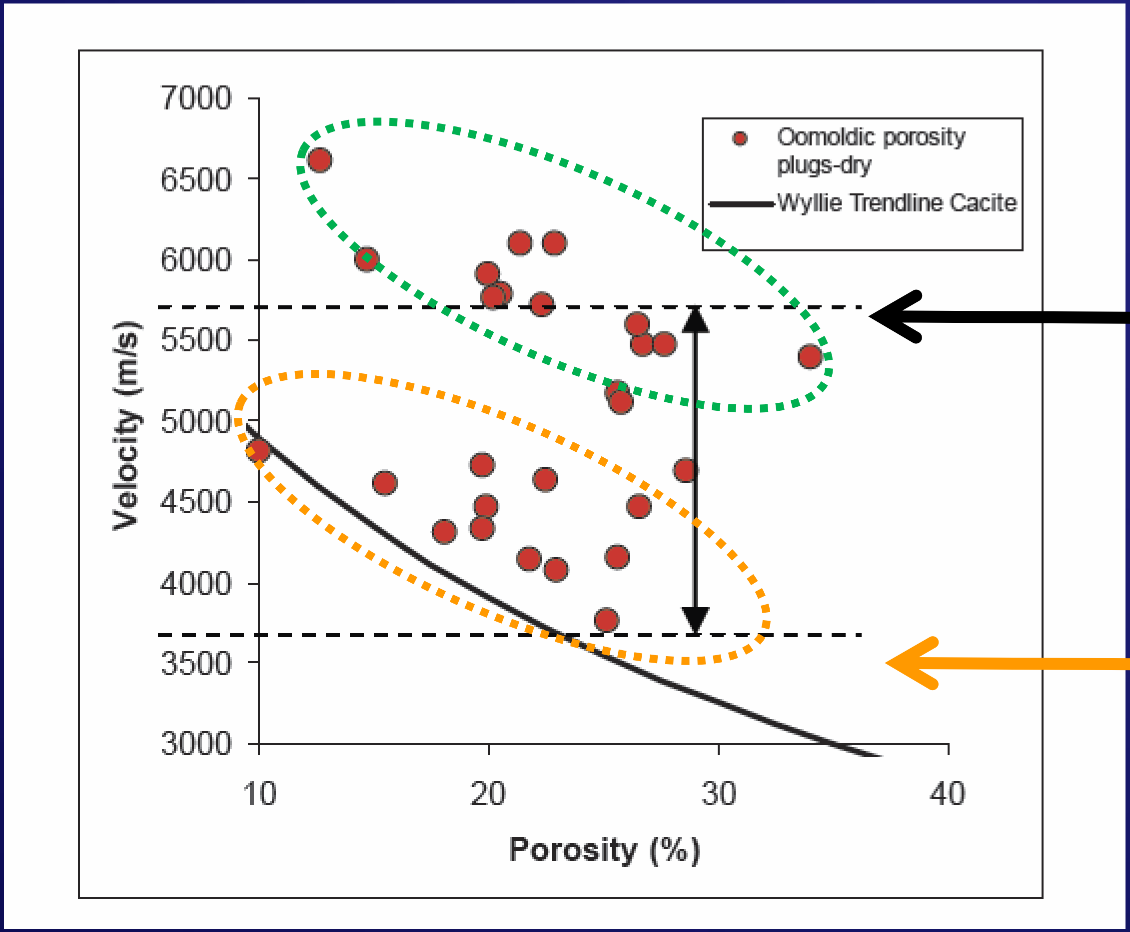
From Eberli et al, 2003

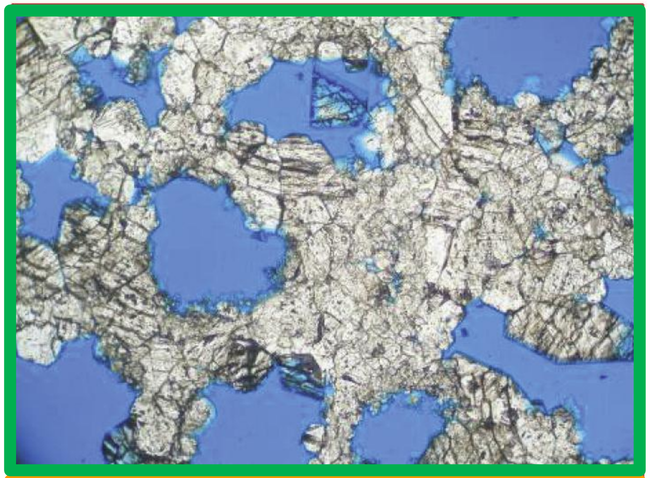


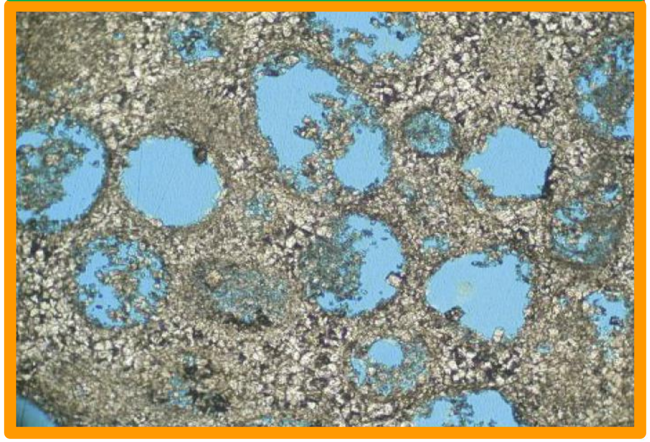




Recent results from Baechle et al. 2008







Thin section photograph show the oomoldic pore types of samples with 23% porosity. (field of view: 1.5 mm).

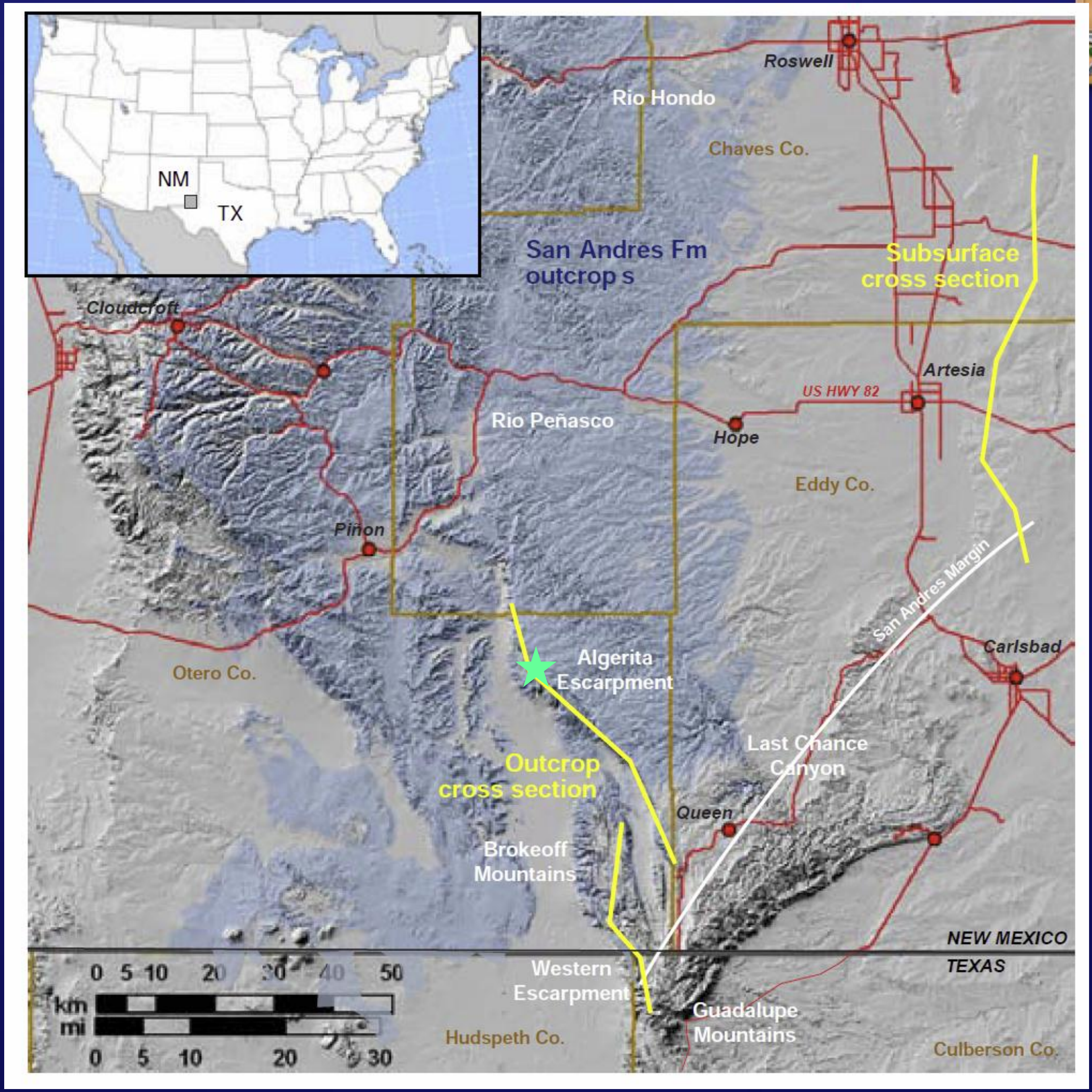
Matrix crystalline structure control velocity more than pore size or shape

Problem : Untested Assumption

The question is:

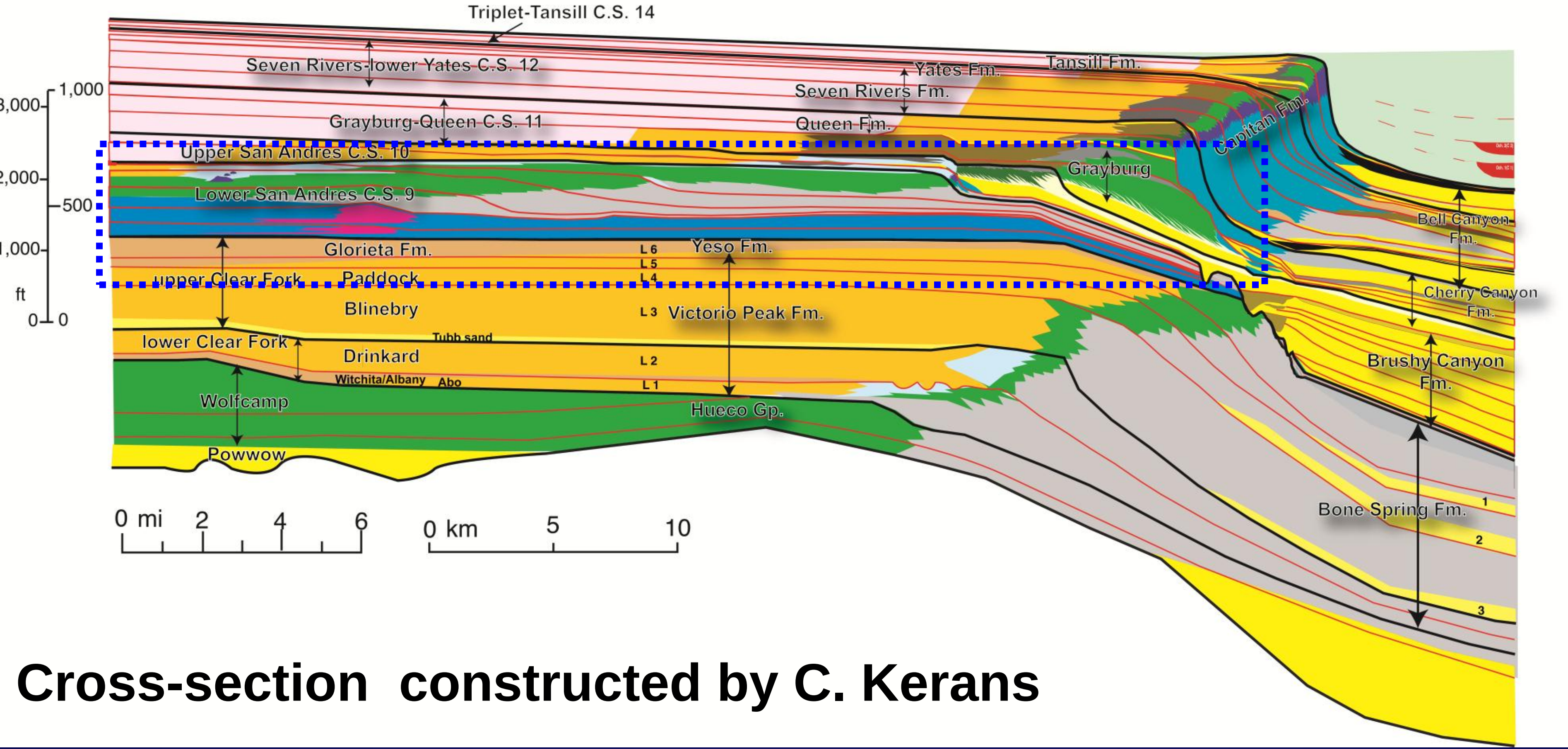
does our dataset, which consist mostly of moldic dolograinstone with fairly homogeneous crystal size behave similarly than the oomoldic limestone rock of Baechle et al. 2008?

An if so, can we explain and predict the scattering of velocity ?


NM
TX
Roswell
Rio Hondo
Chaves Co.
San Andres Fm
outcrop s
Subsurface
cross section
Cloudcroft
Artesia
US HWY 82
Rio Peñasco
Hope
Eddy Co.
Piñon
San Andres Margin
Carlsbad
Algerita
Escarpment
Otero Co.
Last Chance
Canyon
Outcrop
cross section
Queen
Brokeoff
Mountains
NEW MEXICO
TEXAS
0 5 10 20 30 40 50
km
mi
0 5 10 20 30
Western
Escarpment
Guadalupe
Mountains
Hudspeth Co.
Culberson Co.

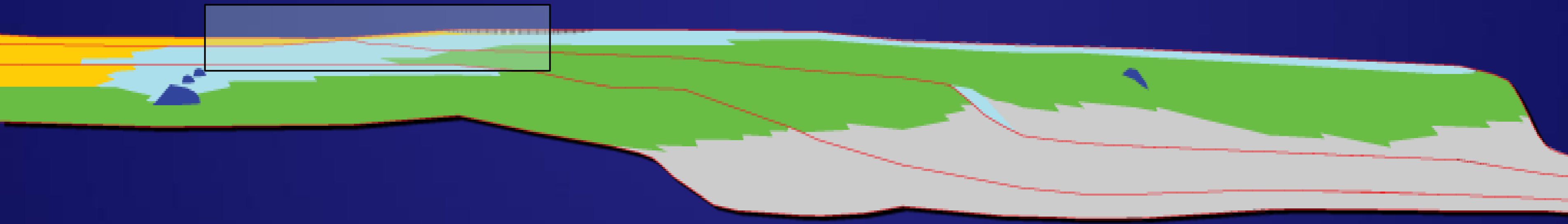
N

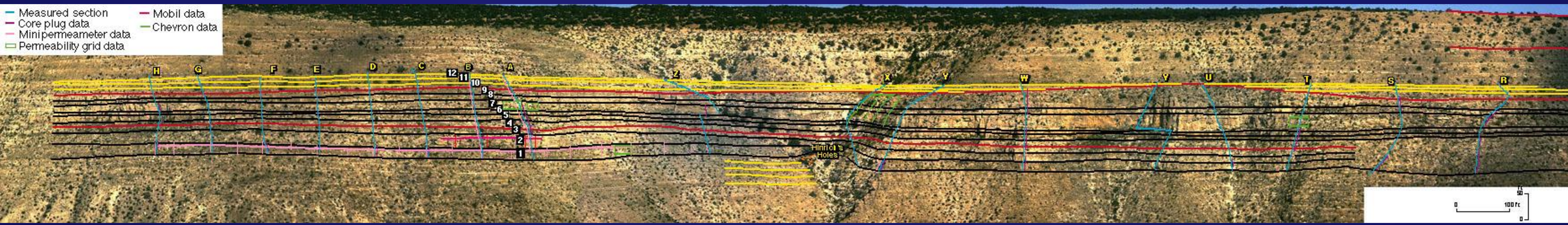
S

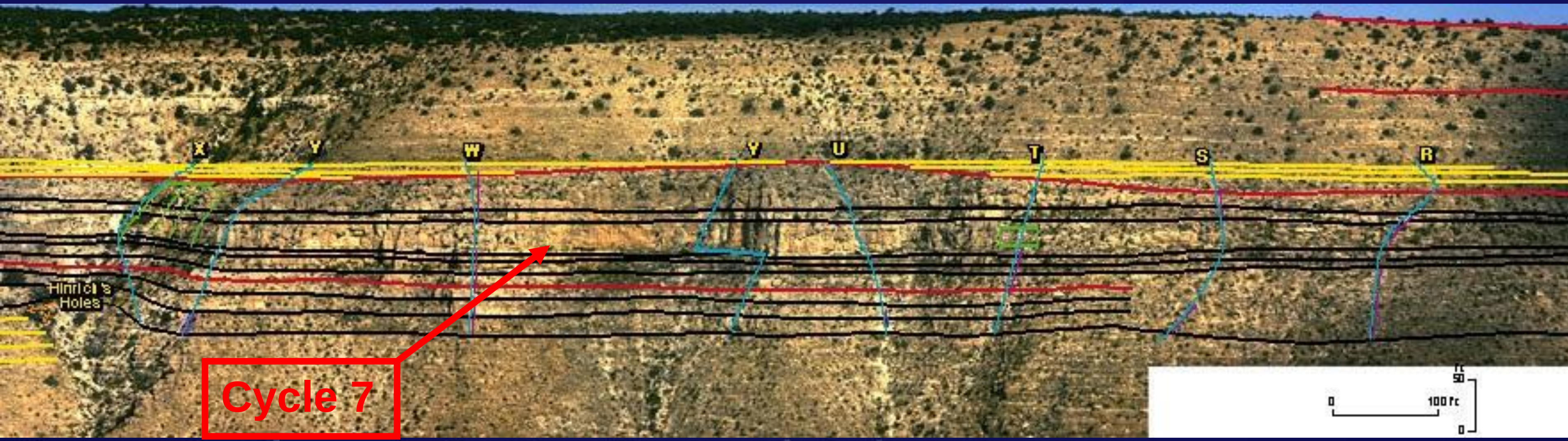


Cross-section constructed by C. Kerans

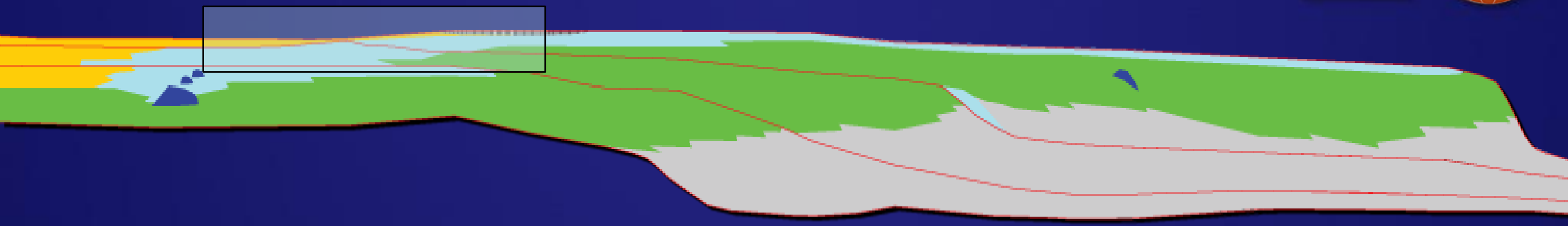
Guadalupian 2-3

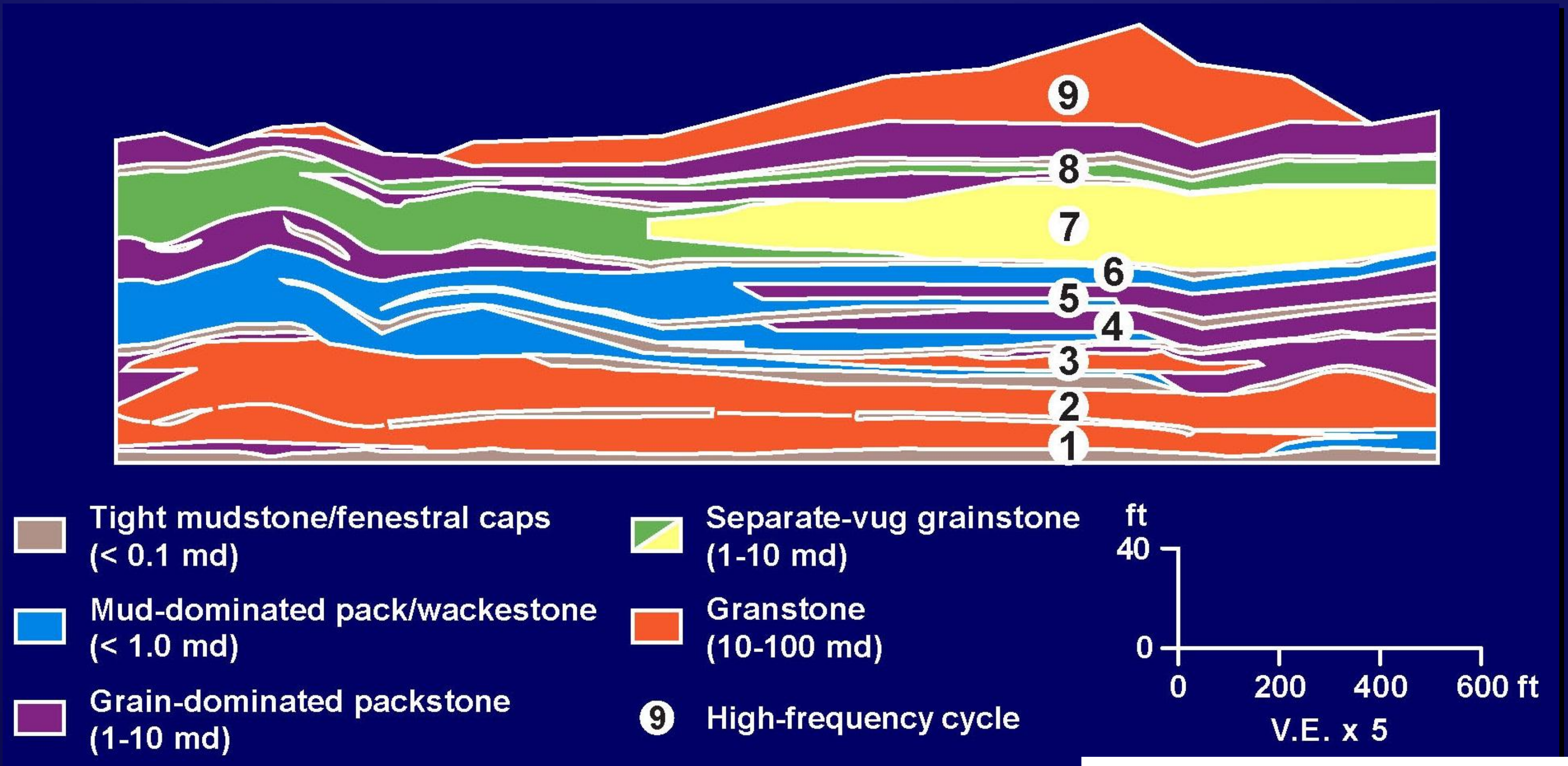






Guadalupian 2-3



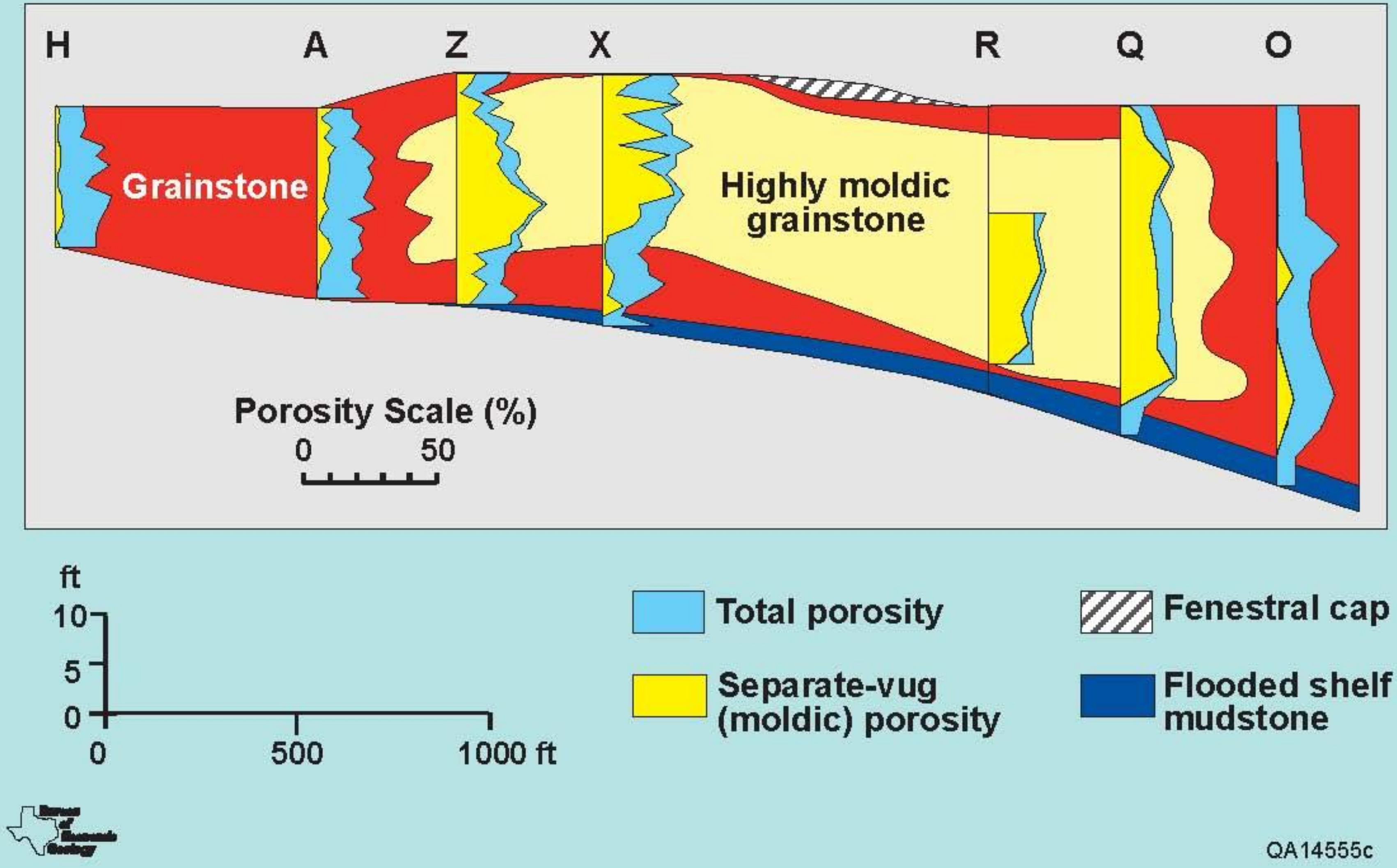


Kerans et al., 1994

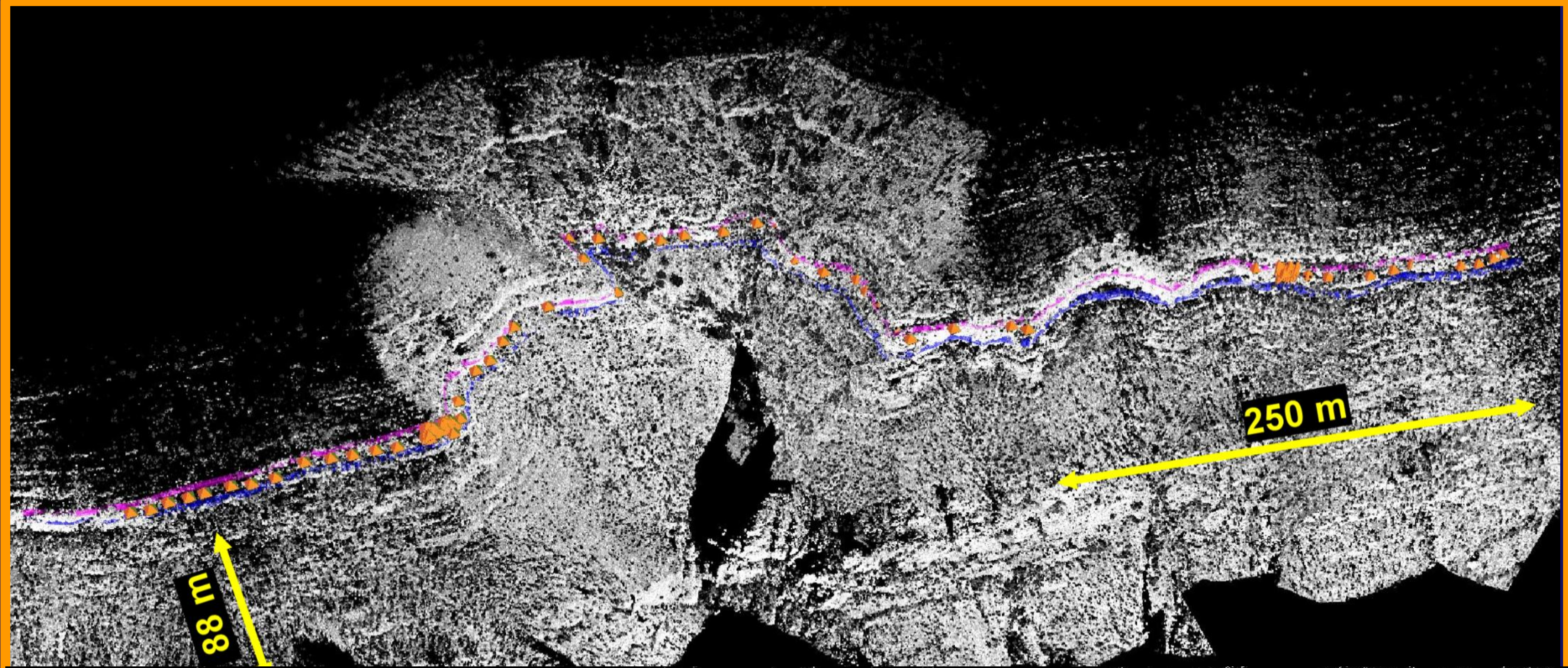
DISTRIBUTION OF MOLDIC POROSITY

High-Frequence Cycle 7

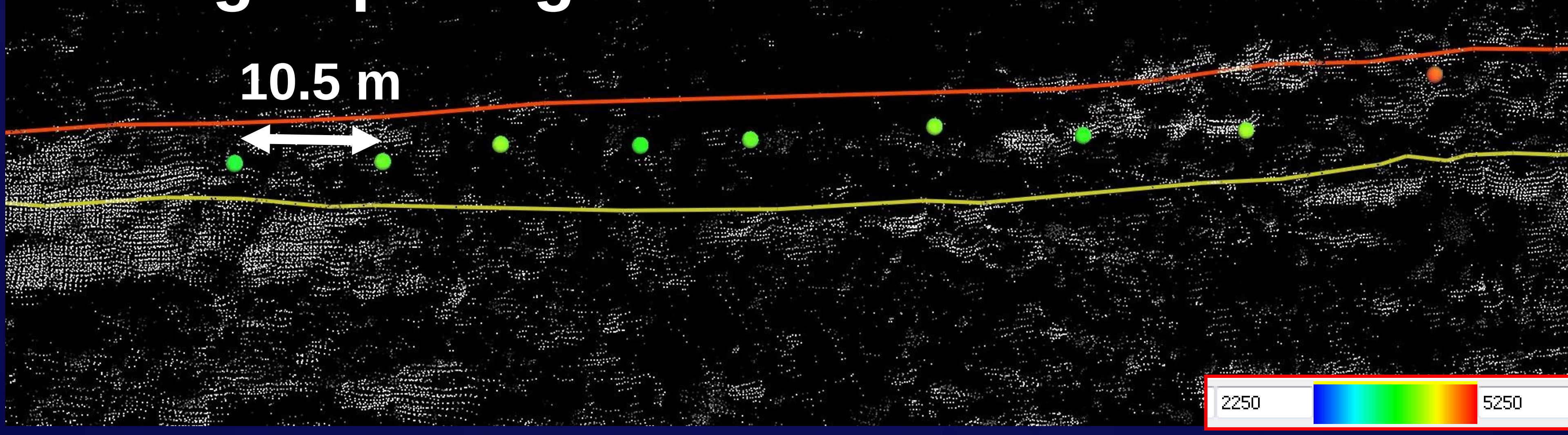
Upper San Andres, Lawyer Canyon



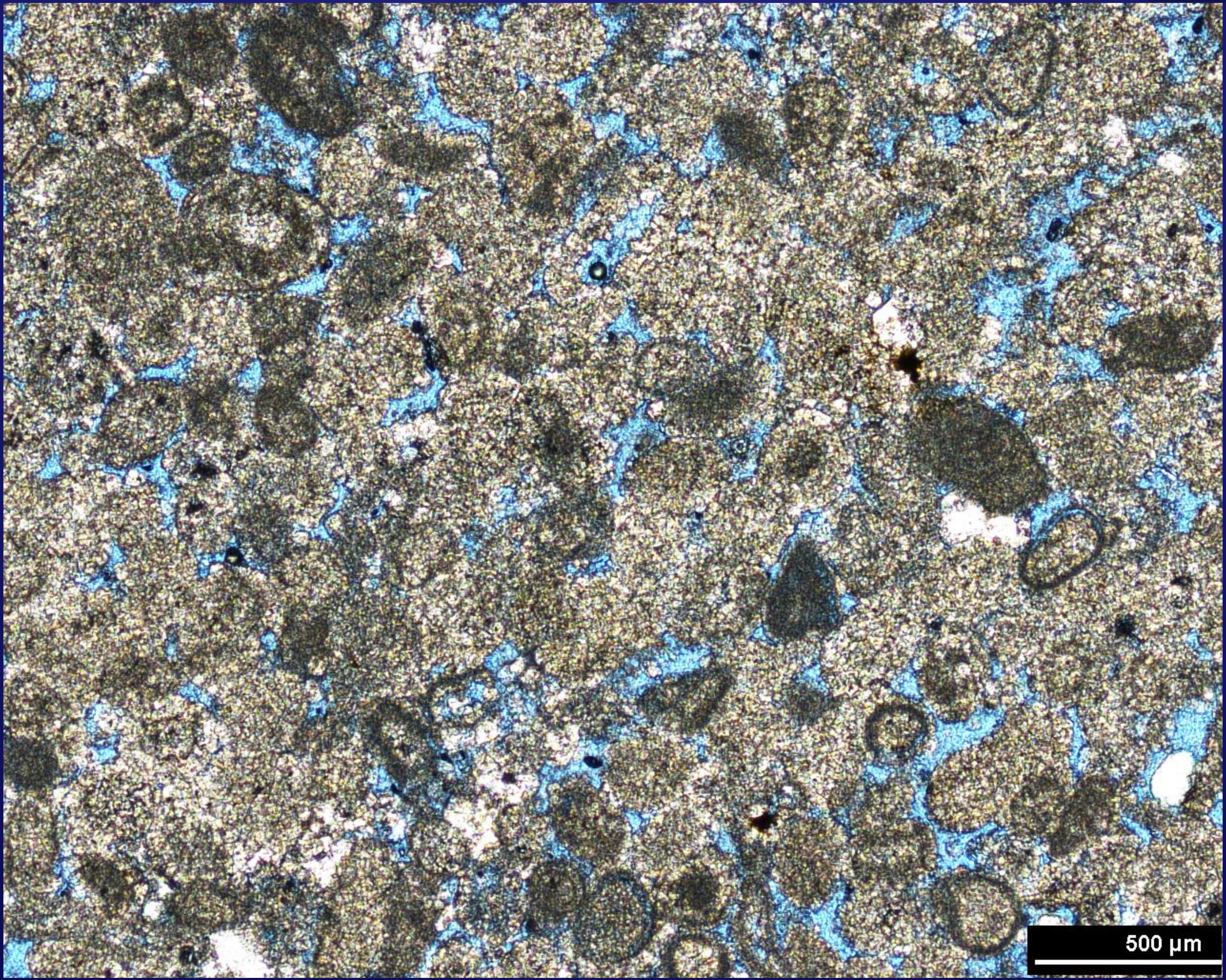
QA14555c



Average spacing ~ 10 m

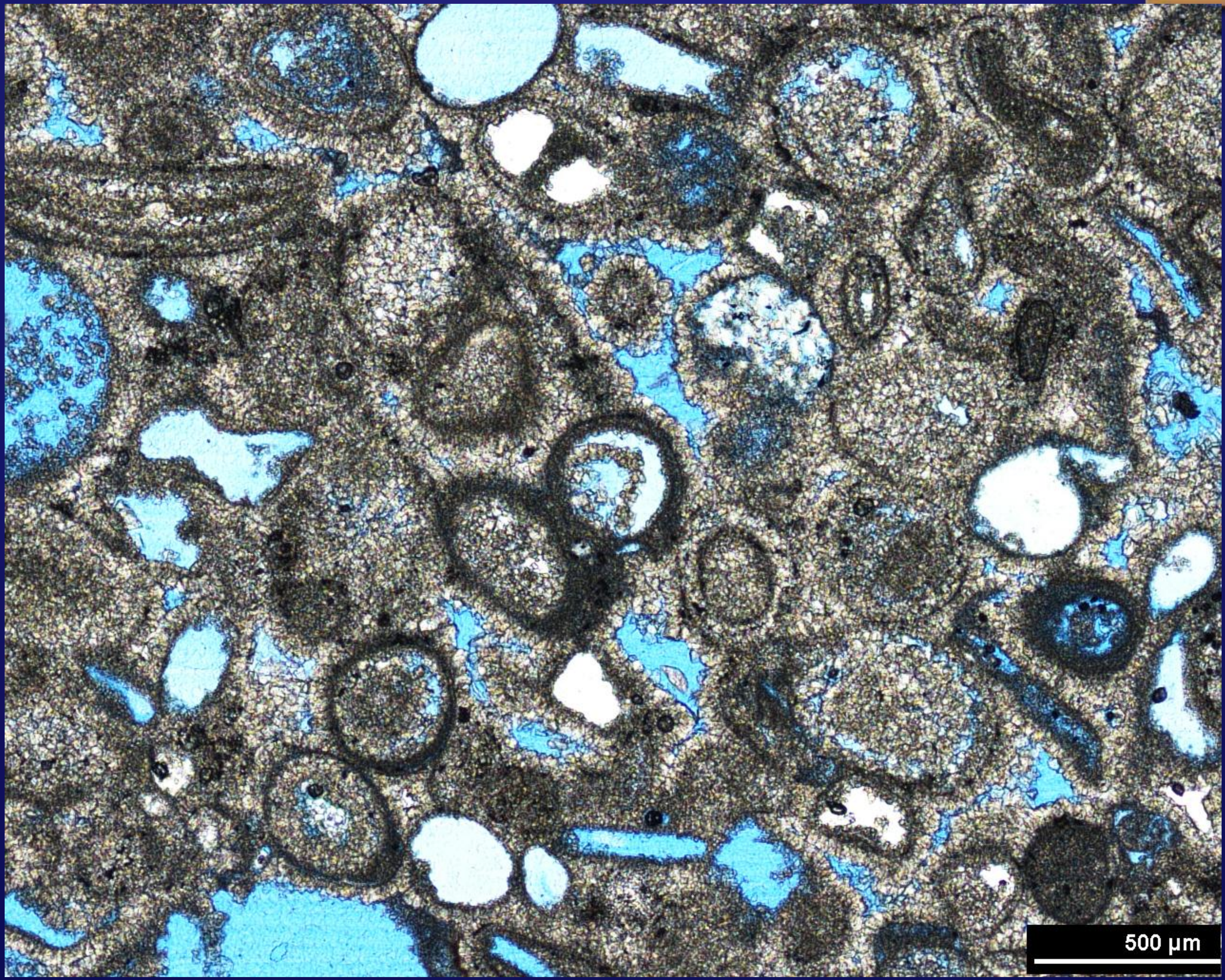


Interparticle Porosity



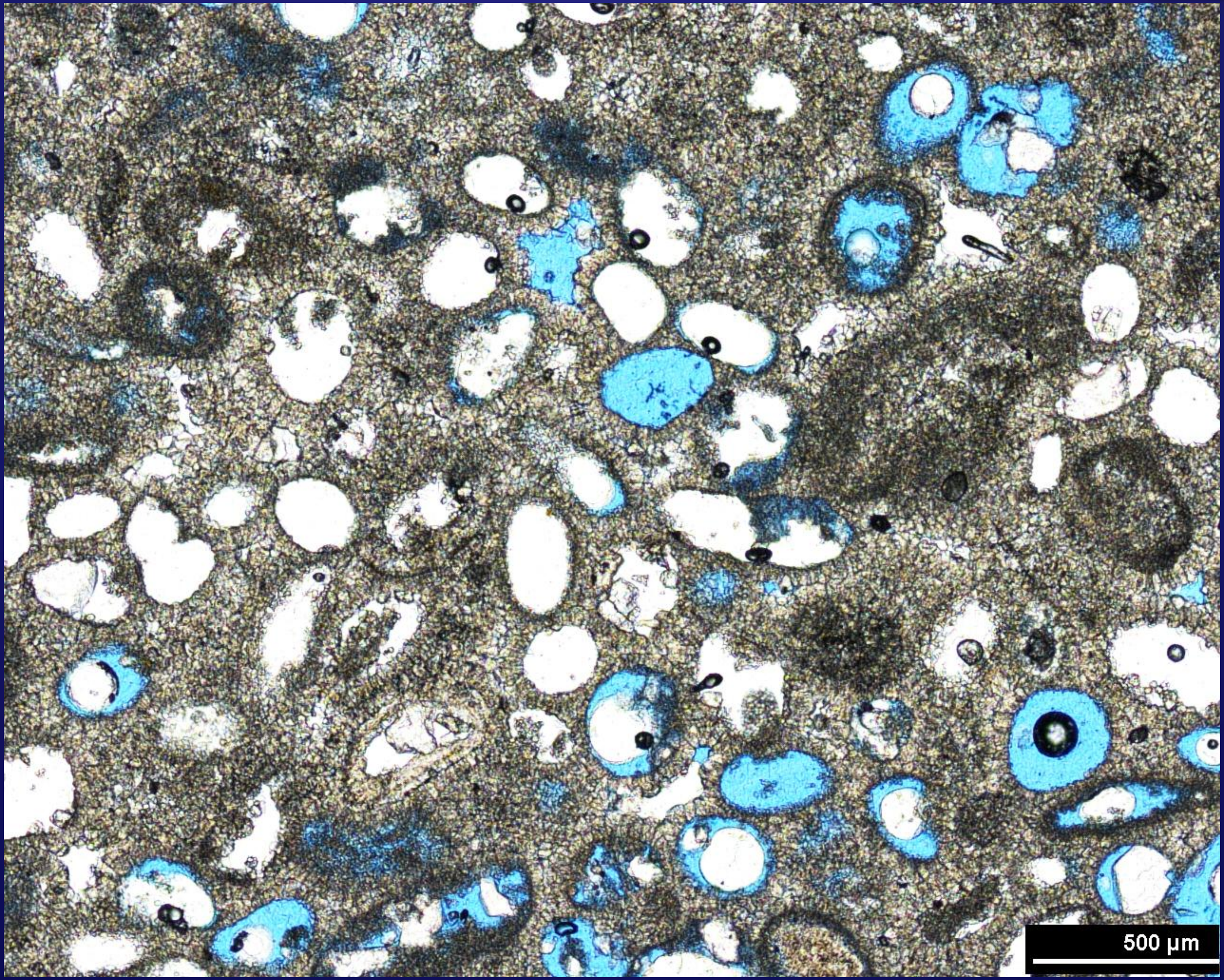
Φ= 15.4% K= 3.29 mD Vp= 4483 m/s Vs= 2731 m/s

Moldic



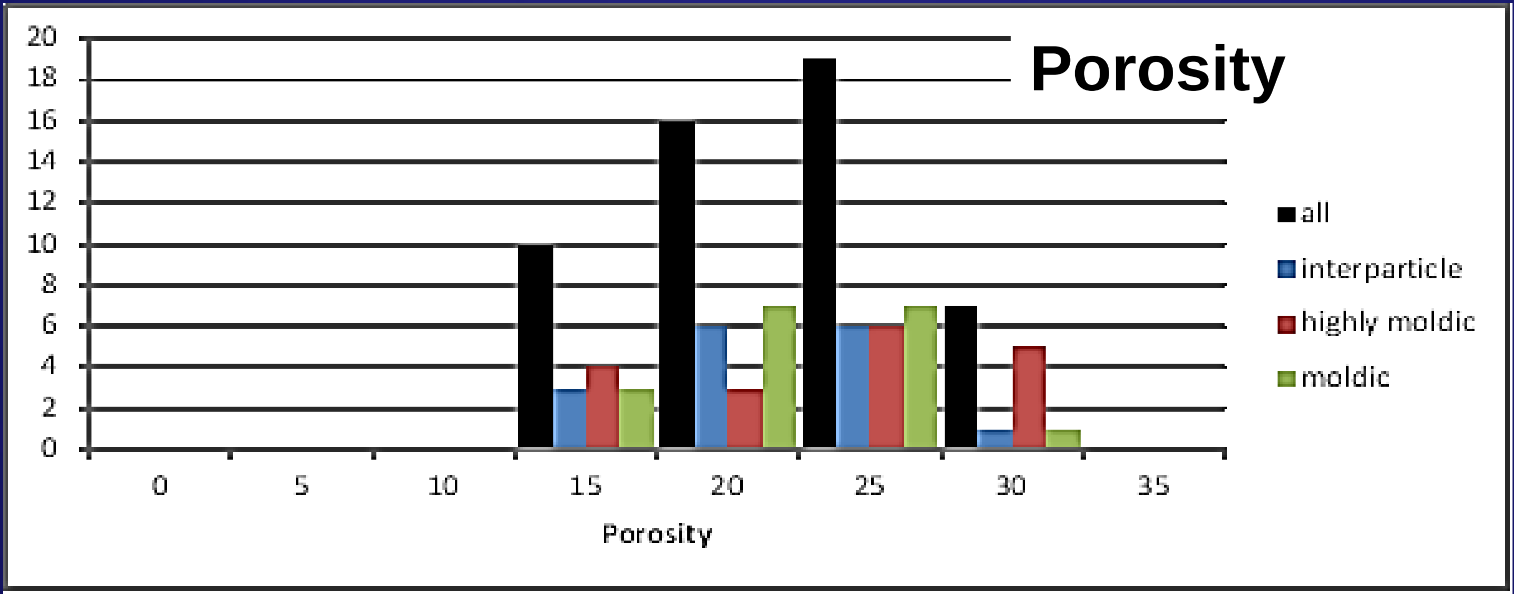
Φ= 25.1%   K= 4.4 mD   Vp= 4494 m/s   Vs= 2307 m/s

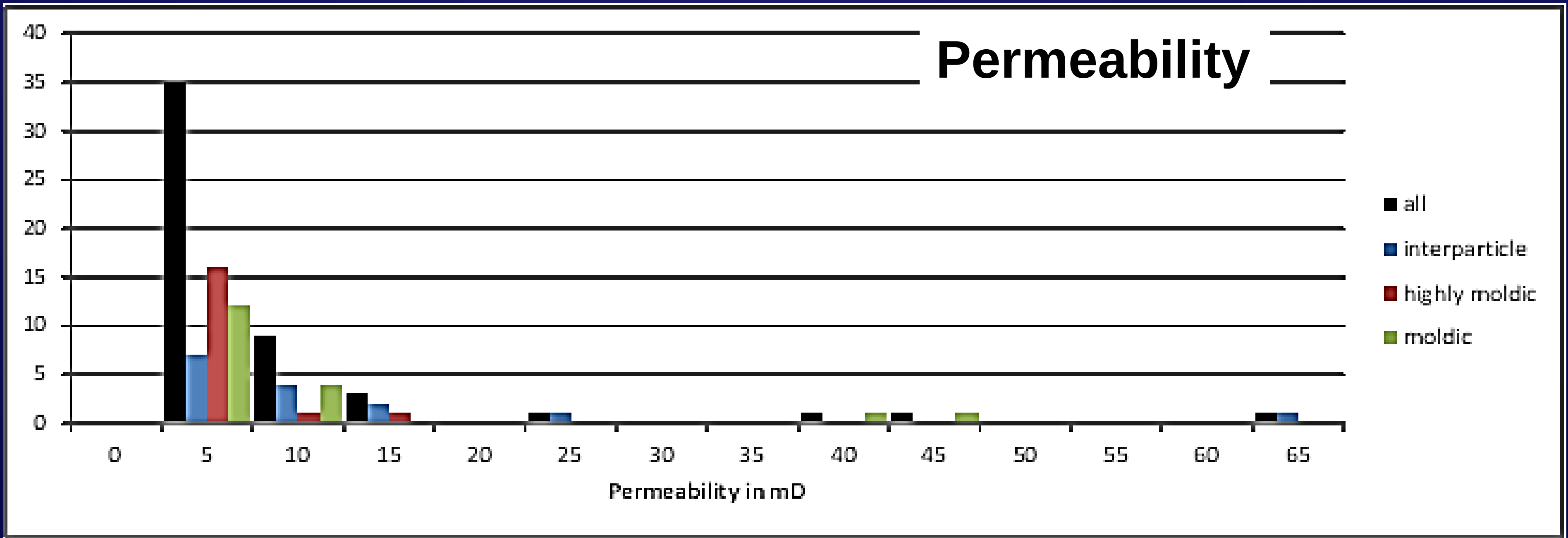
Highly Moldic



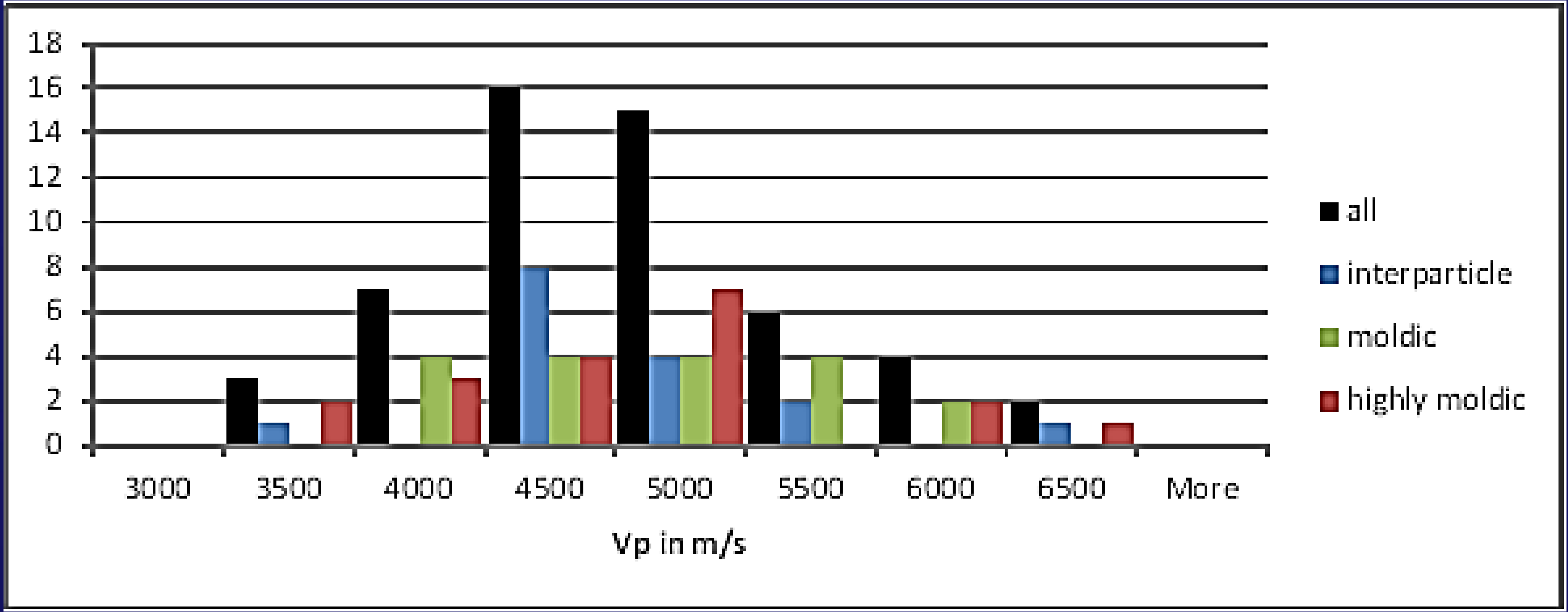
Φ= 26.4%   K= 0.36 mD   Vp= 4607m/s   Vs= 2794 m/s

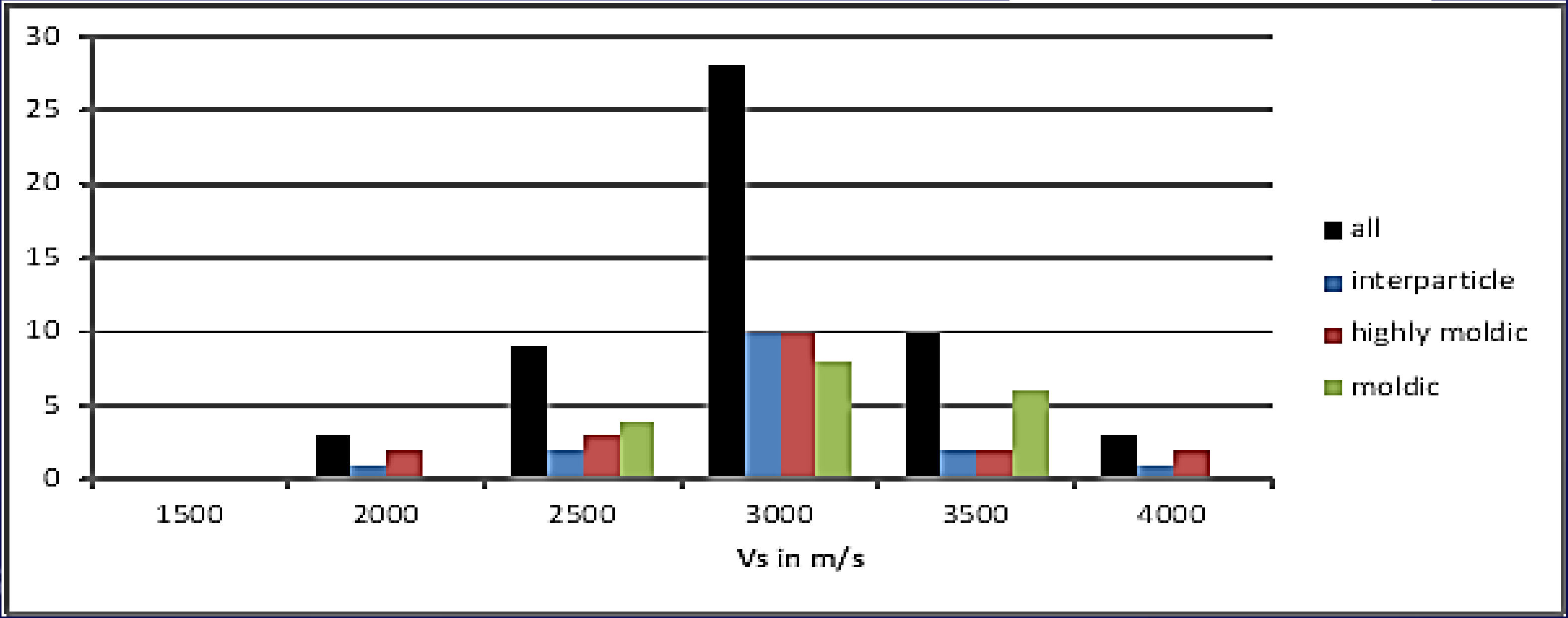
Φ and K Histograms



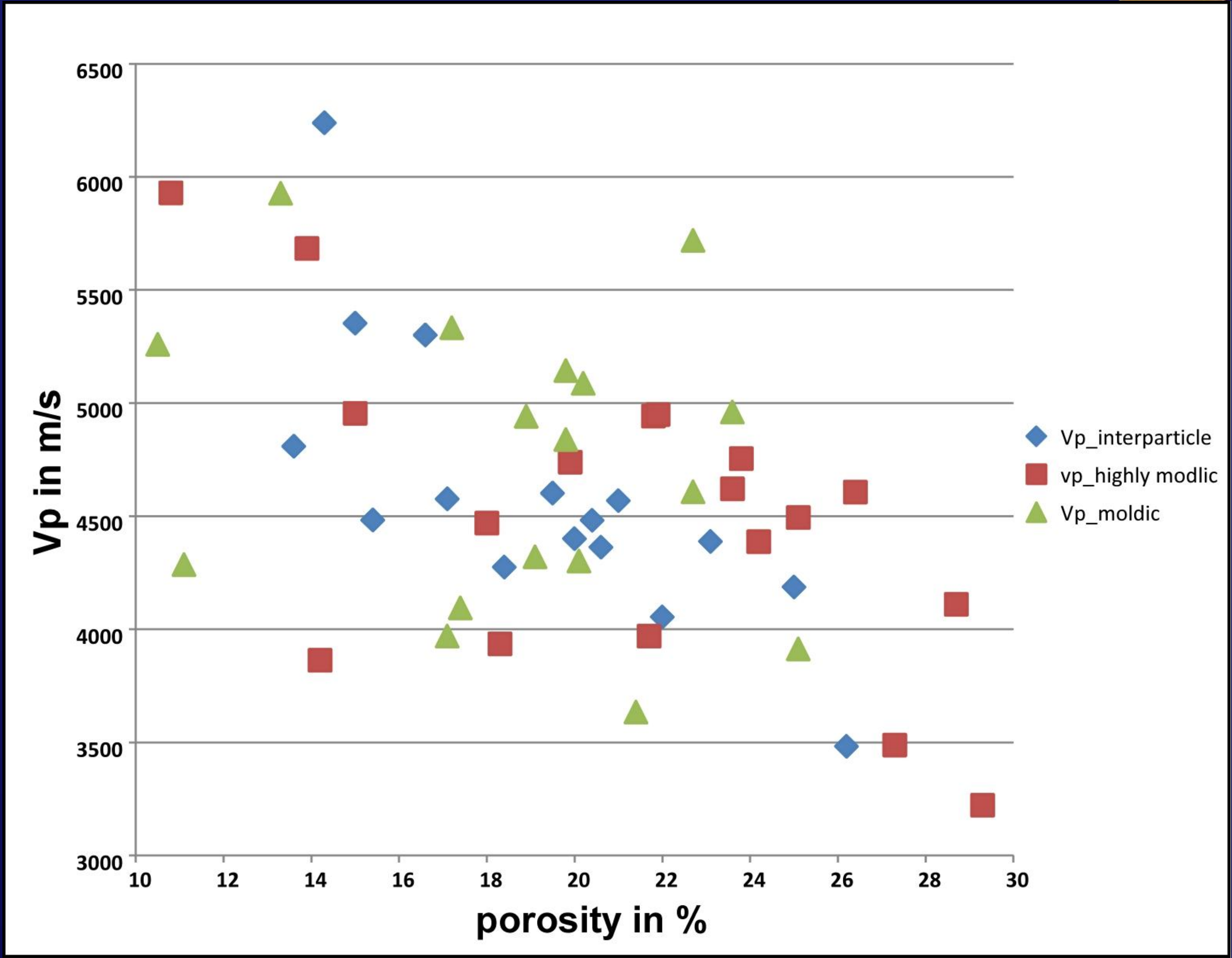


Velocity Histograms

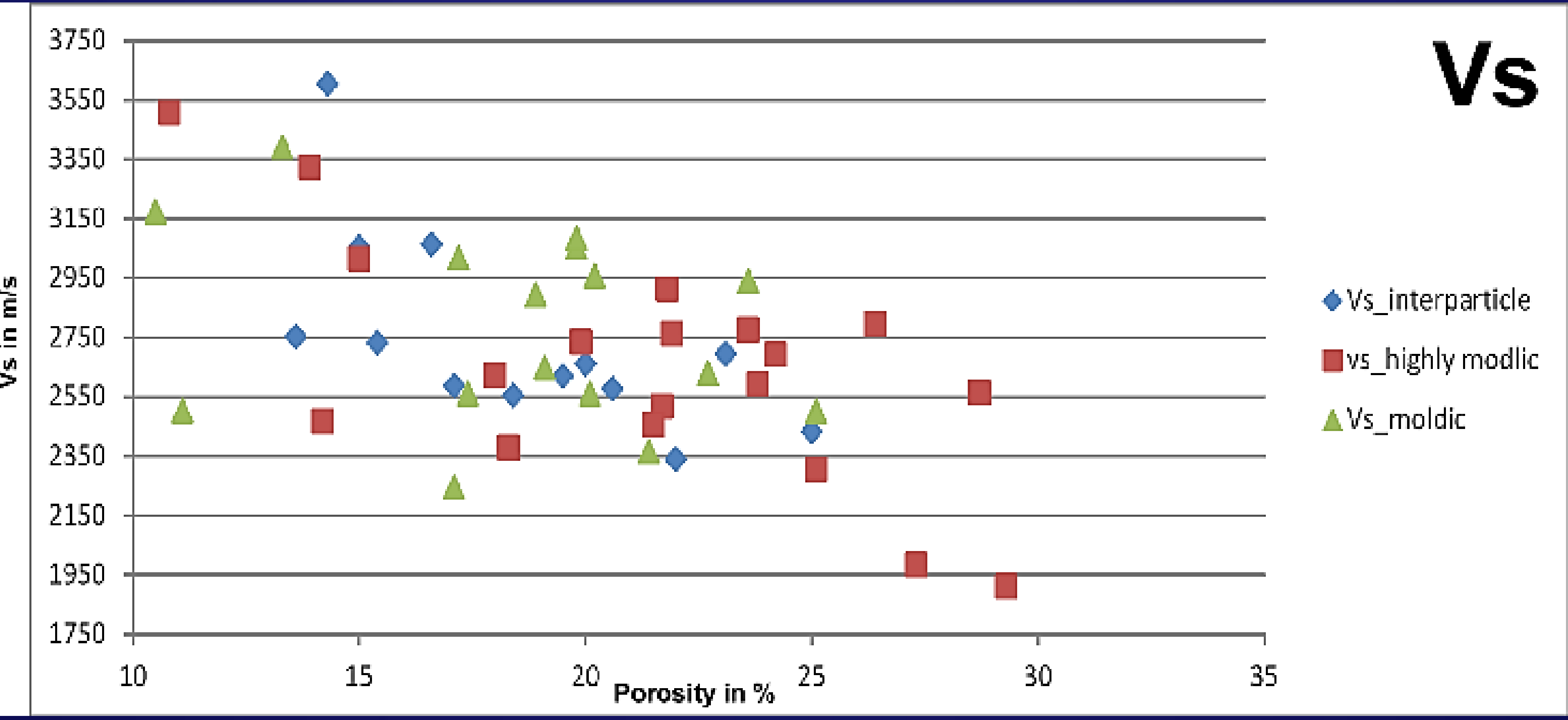




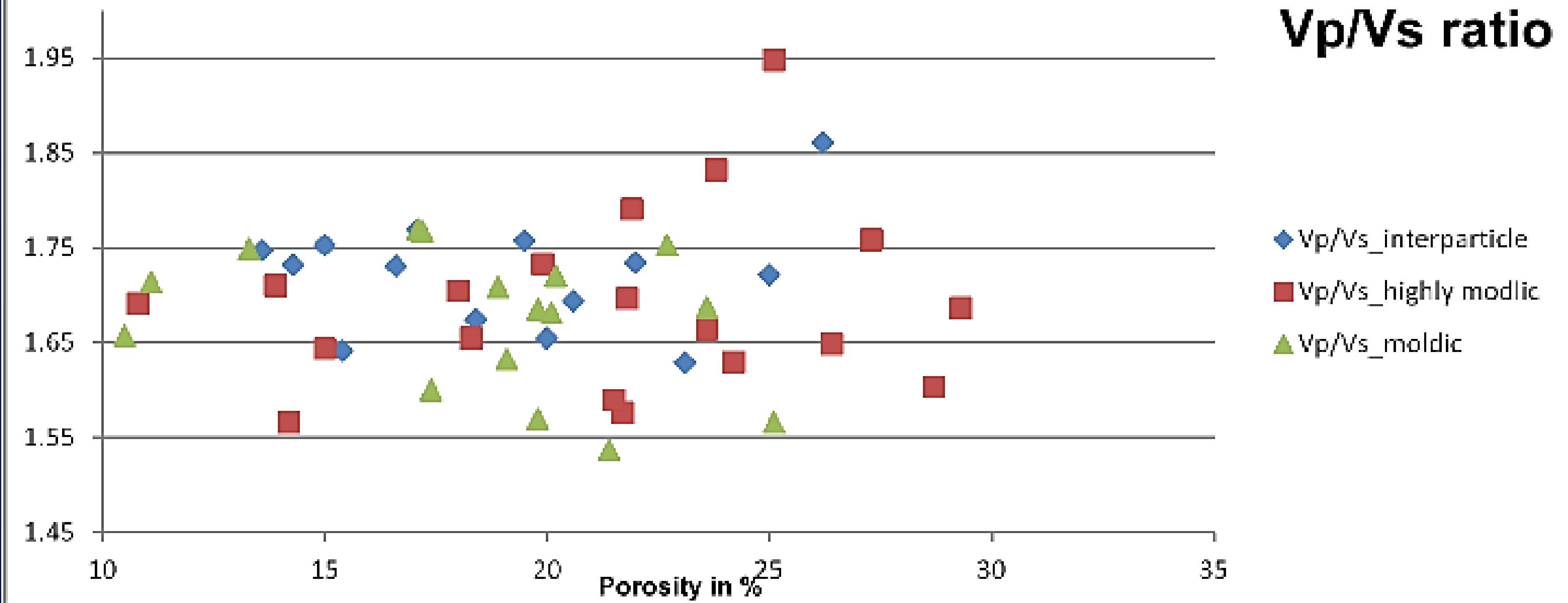
Velocity Porosity Cross-plot

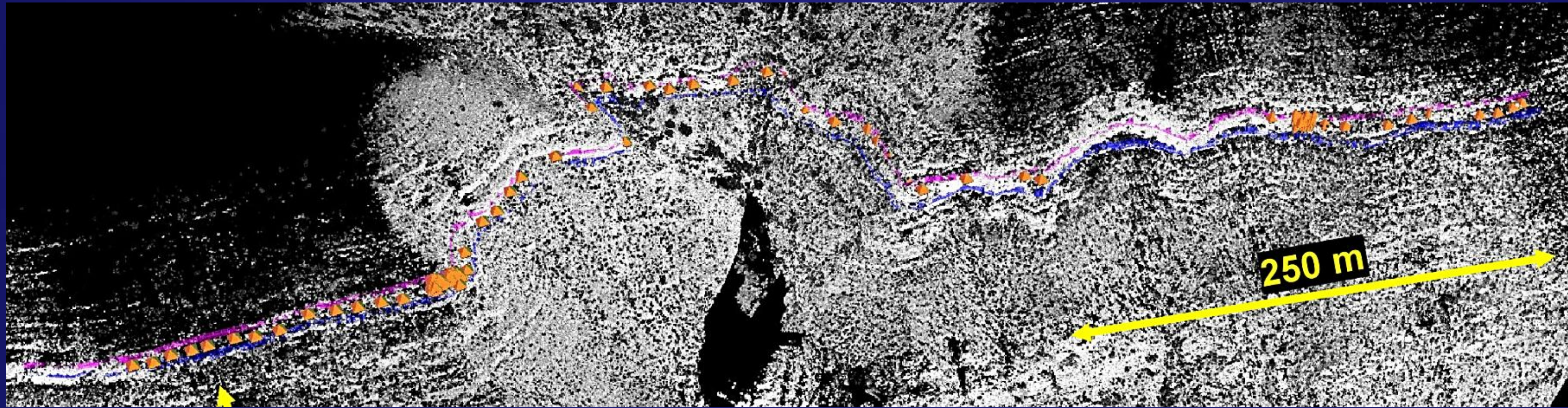


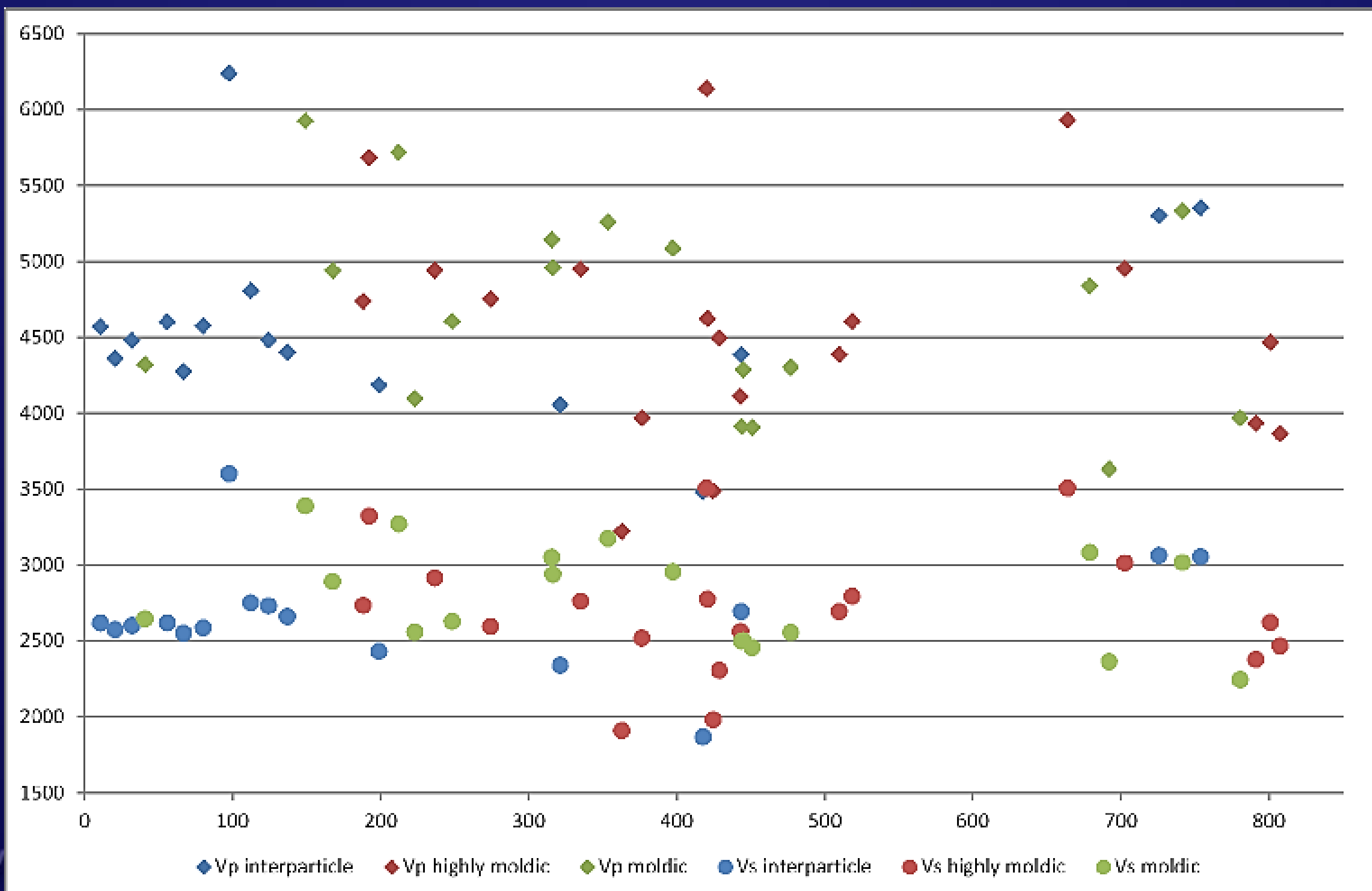
Velocity Porosity Cross-plot



Vp/Vs ratio

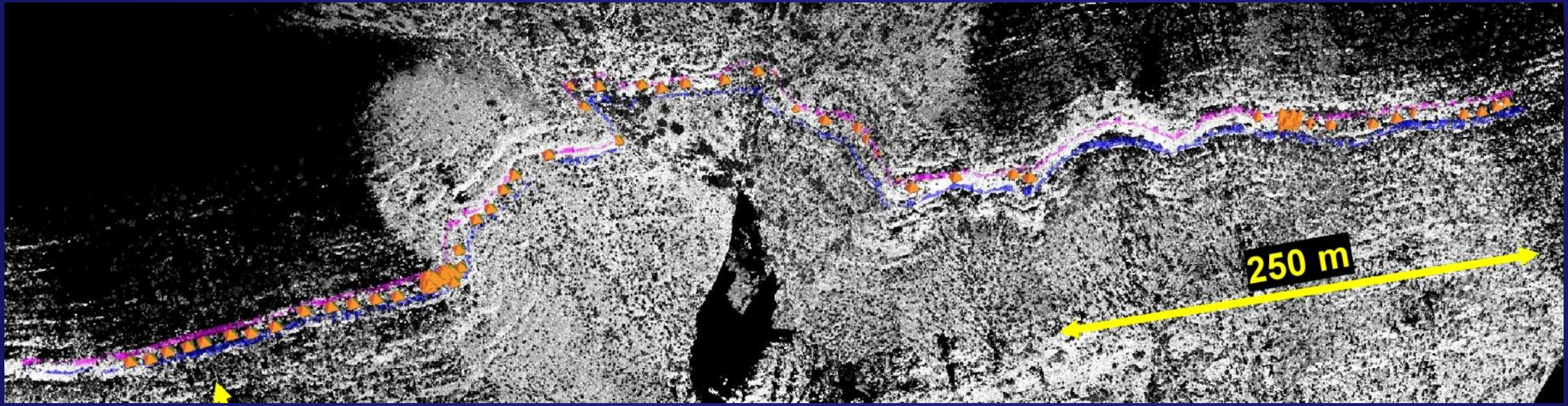

1.95
1.85
1.75
1.65
1.55
1.45
10
15
20
25
30
35
Porosity in %
Vp/Vs_interparticle
Vp/Vs_highly modlic
Vp/Vs_moldic

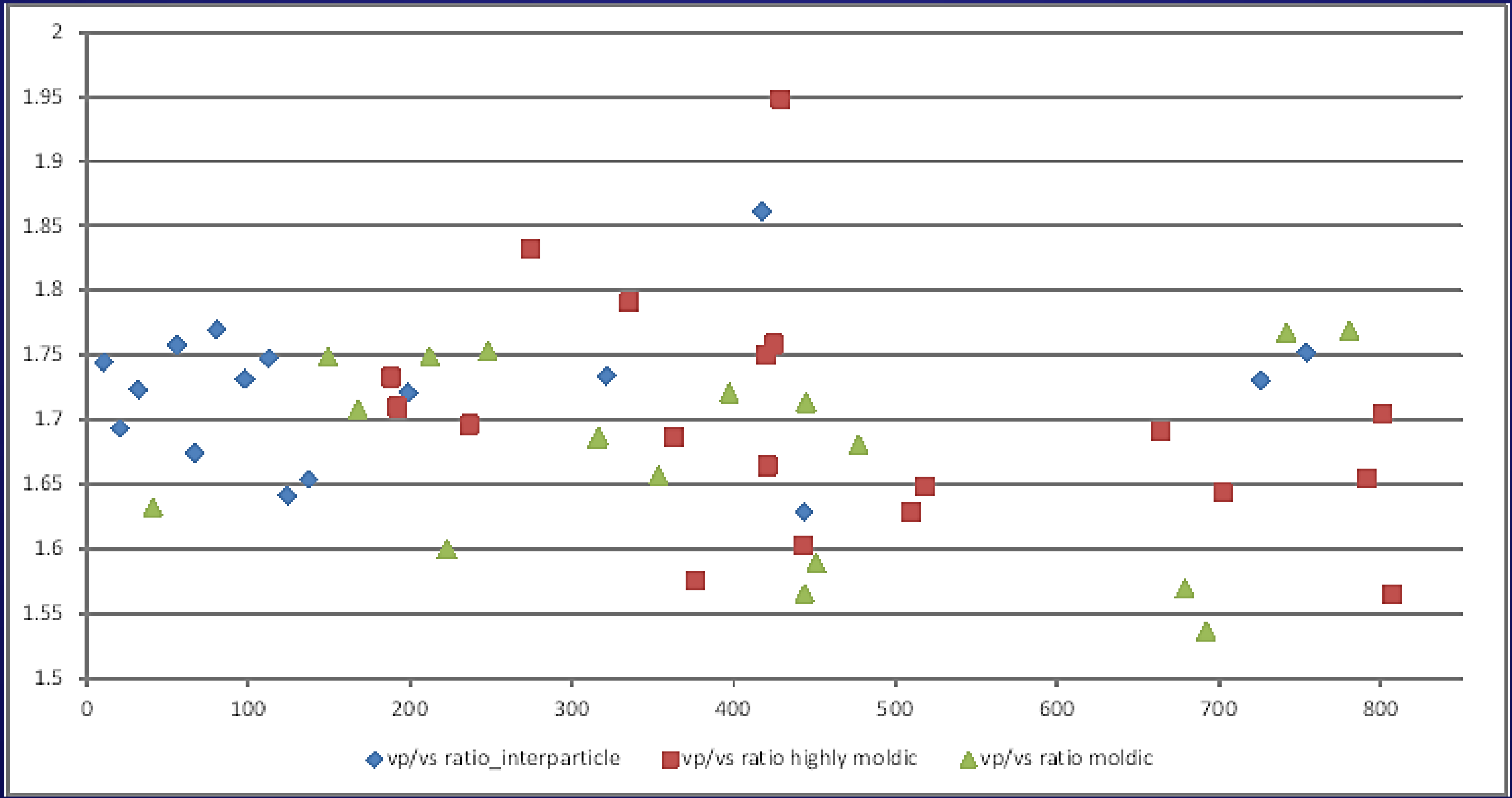

250 m


6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
0
100
200
300
400
500
600
700
800
Vp interparticle
Vp highly moldic
Vp moldic
Vs interparticle
Vs highly moldic
Vs moldic

Vp

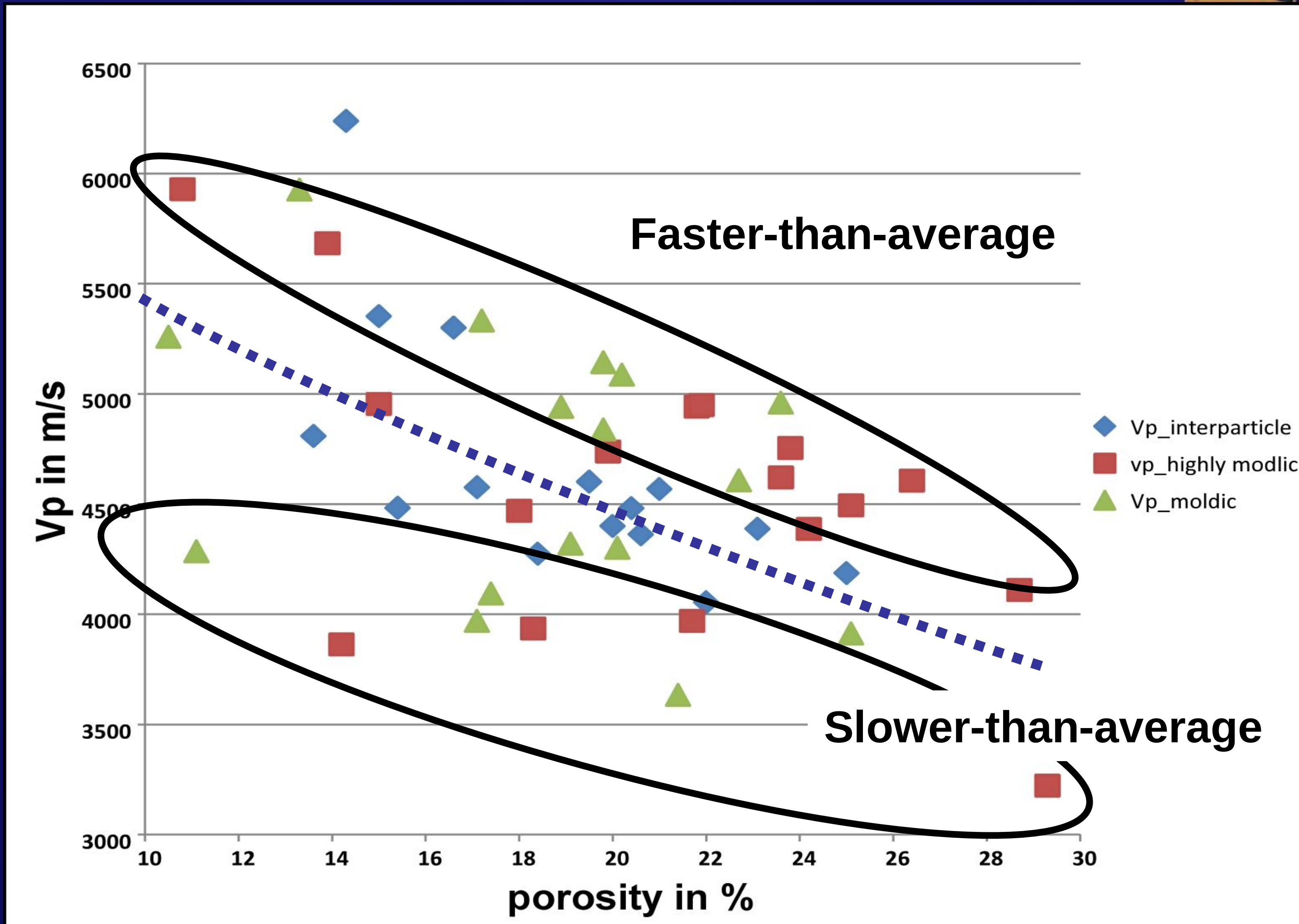
Vs





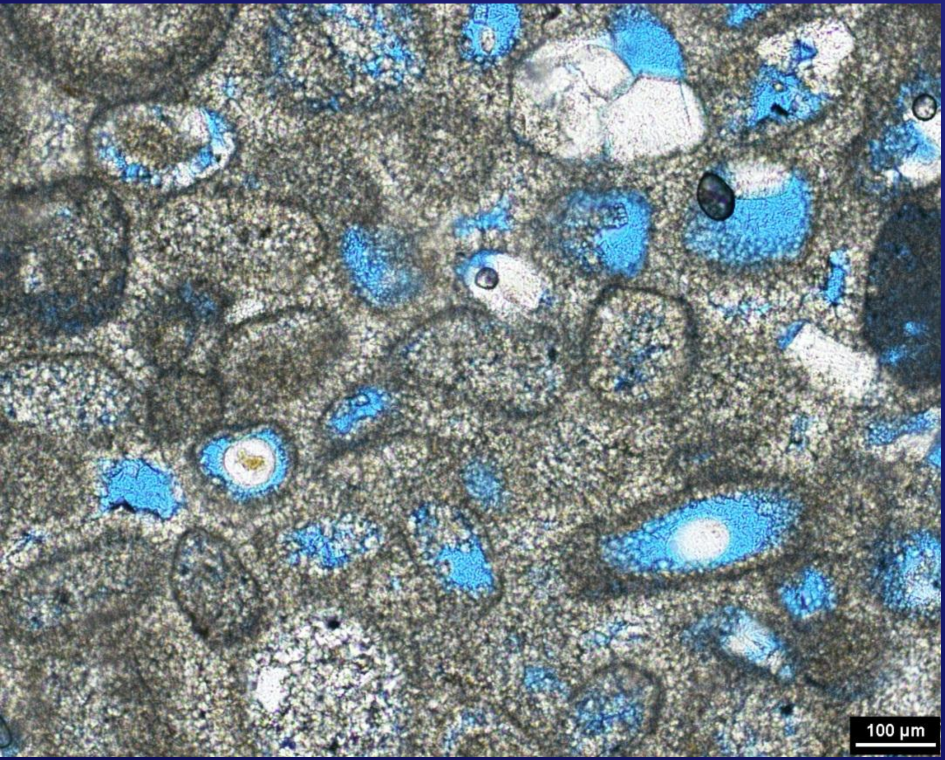
There is no clear Vp/Vs ratio increase in the moldic grainstones. Just more scatter!

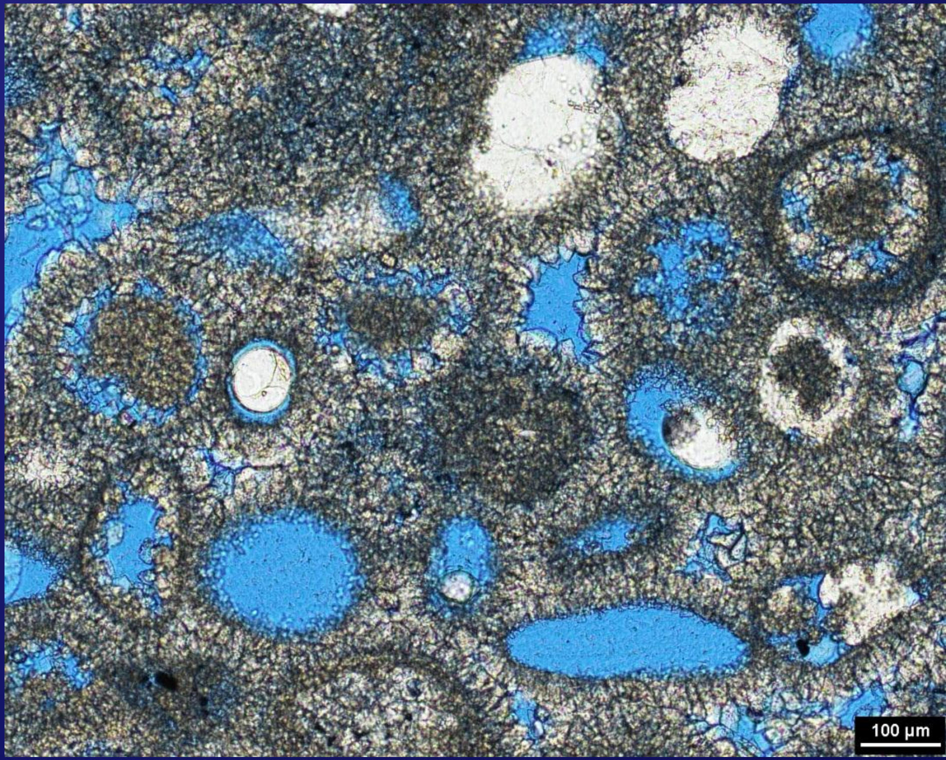
Velocity Porosity Cross-plot



Behave the same as Baechle (2008) data

22 % Porosity Moldic Grainstone





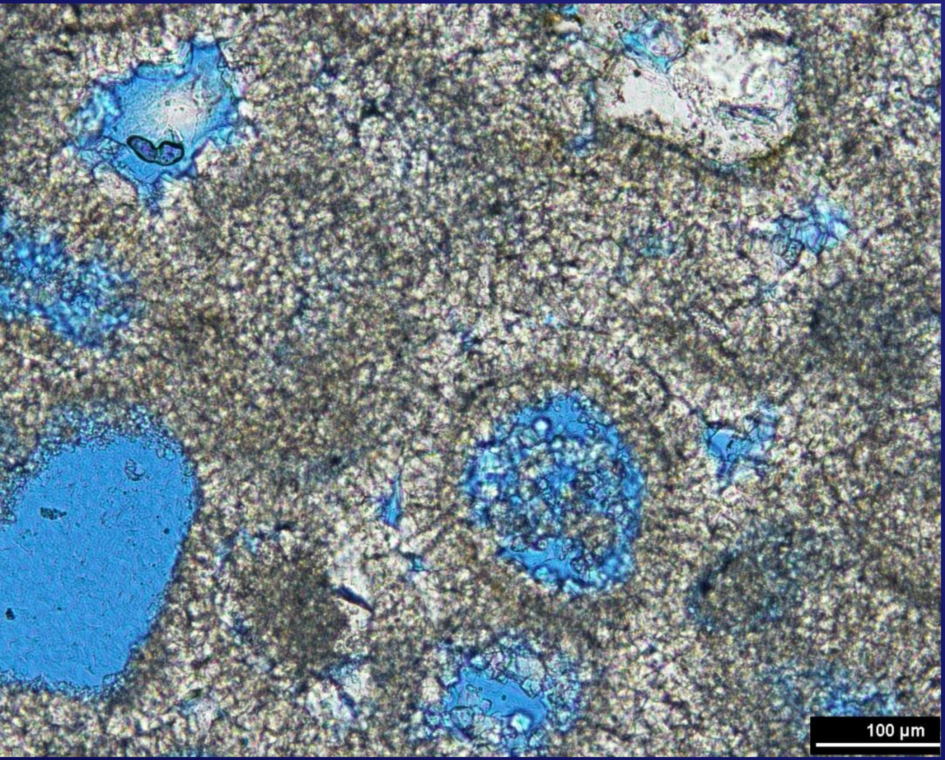
las60

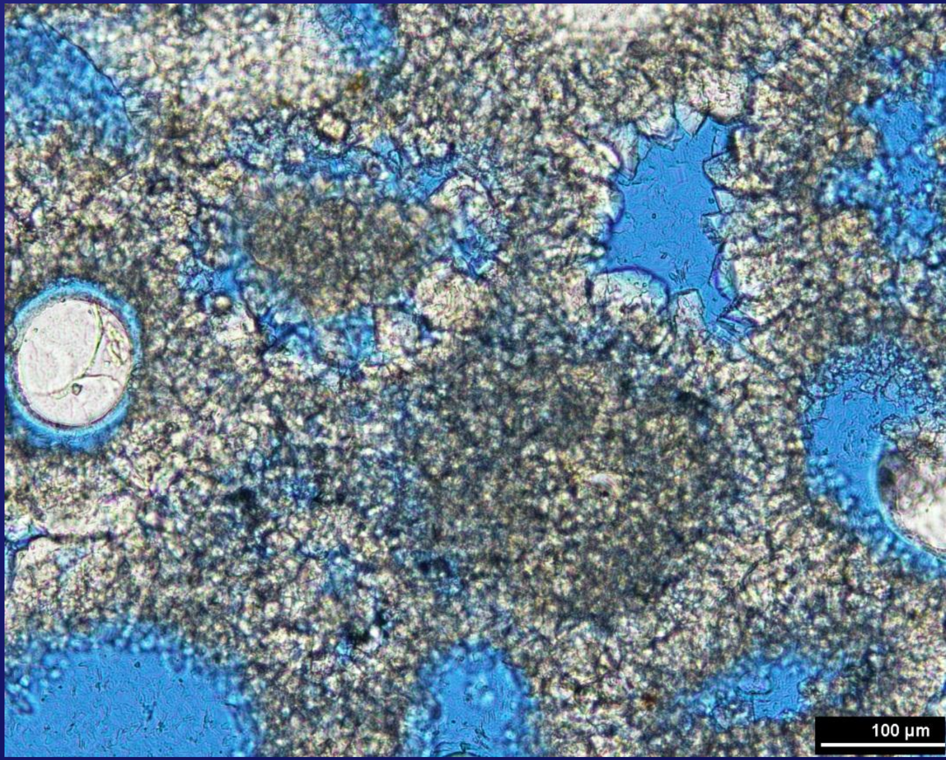
Φ= 21.8 K=3.173 md

lys120

Φ= 21.4 K=6.11 md

22 % Porosity Moldic Grainstone





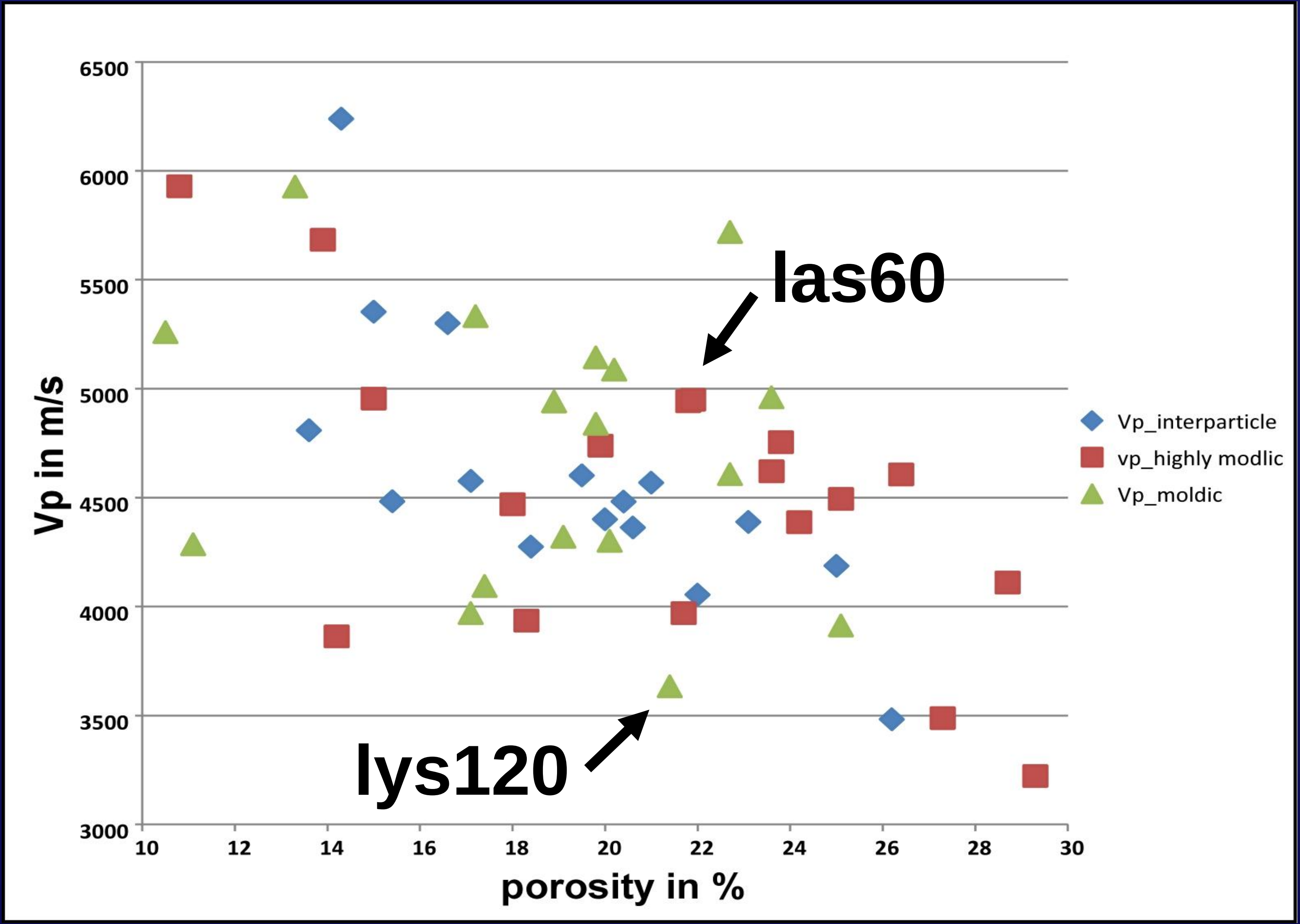
las60

Φ= 21.8 K=3.173 md

lys120

Φ= 21.4 K=6.11 md

Velocity Porosity Cross-plot

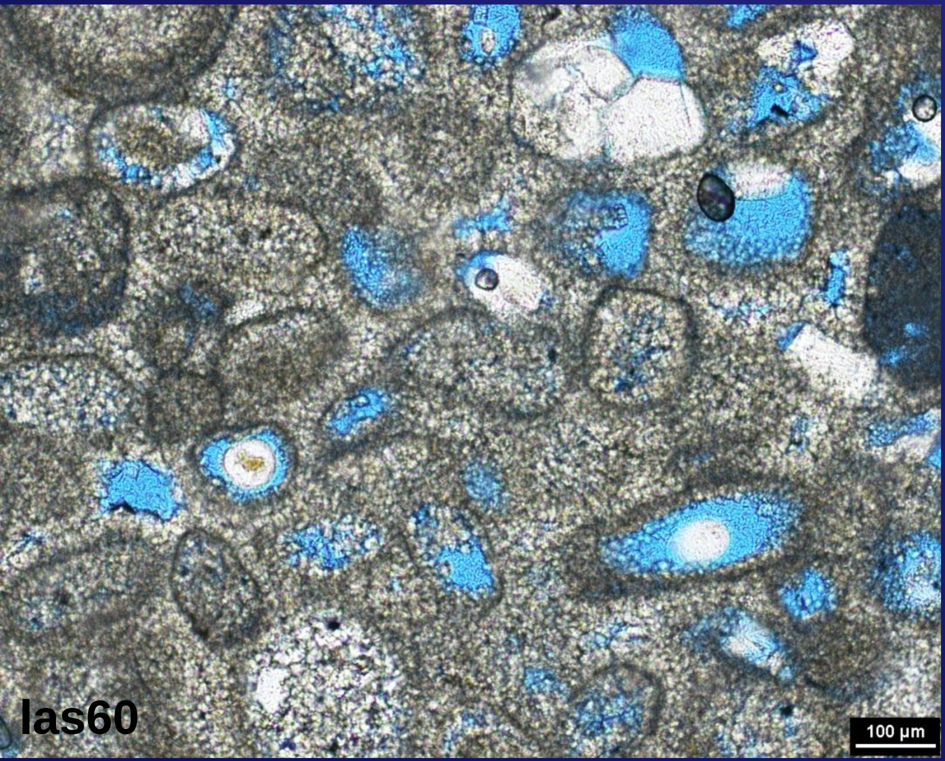


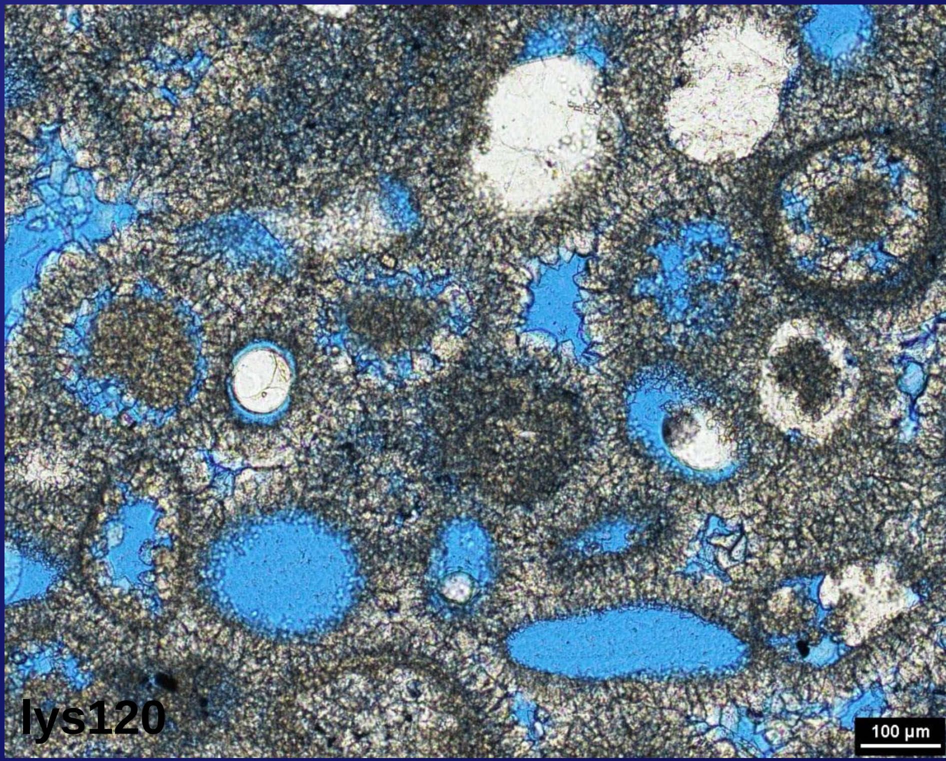
There is a 1200 m/s difference between these 2 grainstones!

Plain light image

Vp=4942 m/s

Vp=3362 m/s



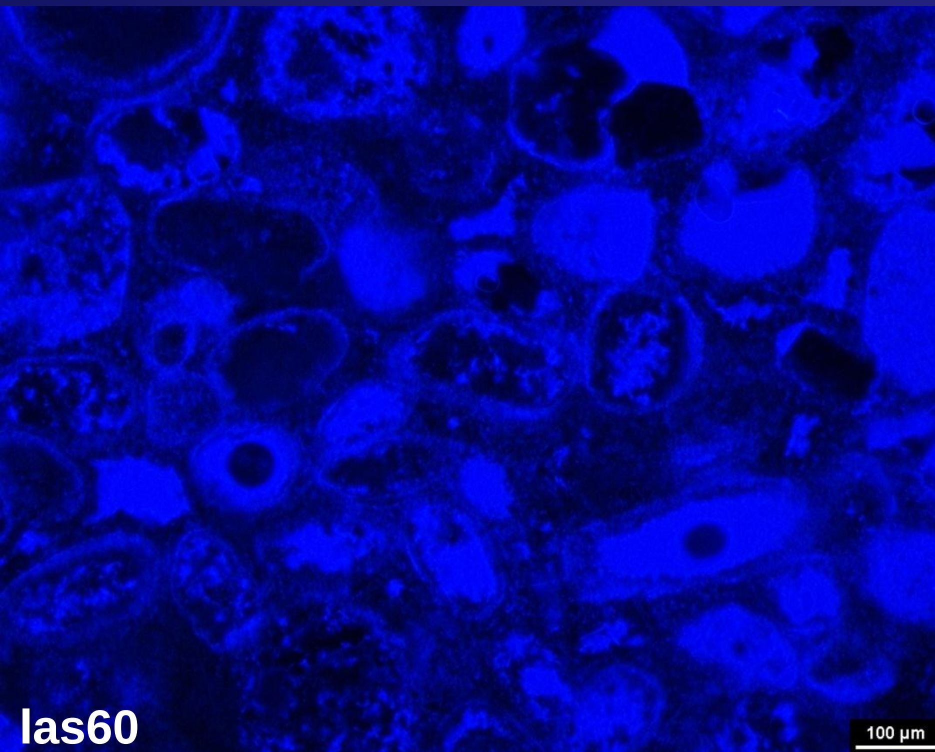


Fast

Slow

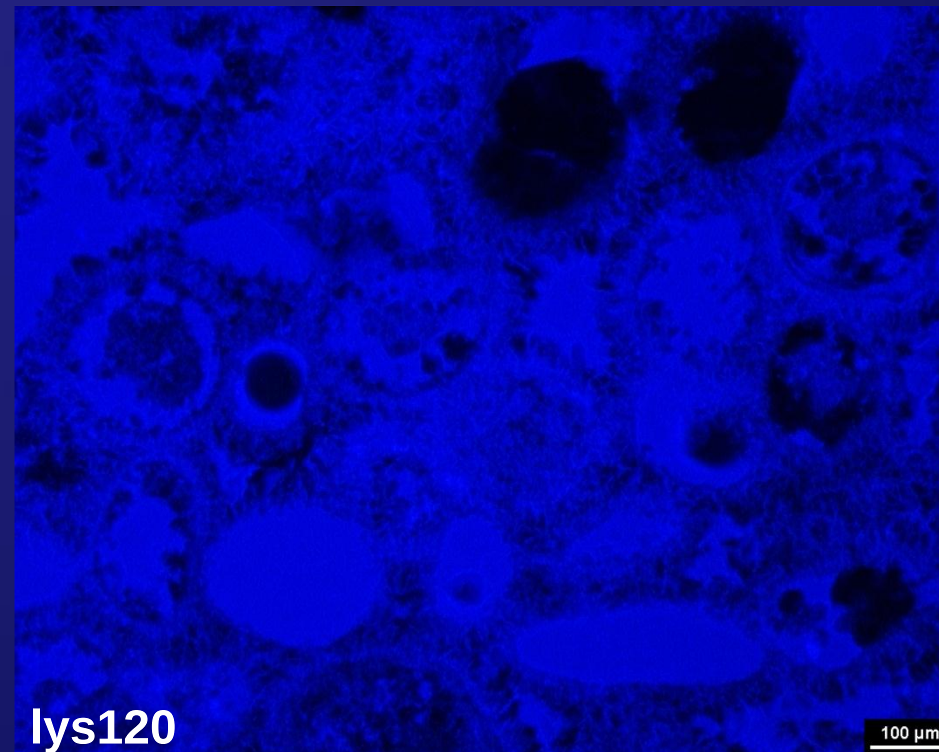
UV light image

Fast



Little microporosity in between the crystal forming the matrix in between large pores
=> Stiff Framework

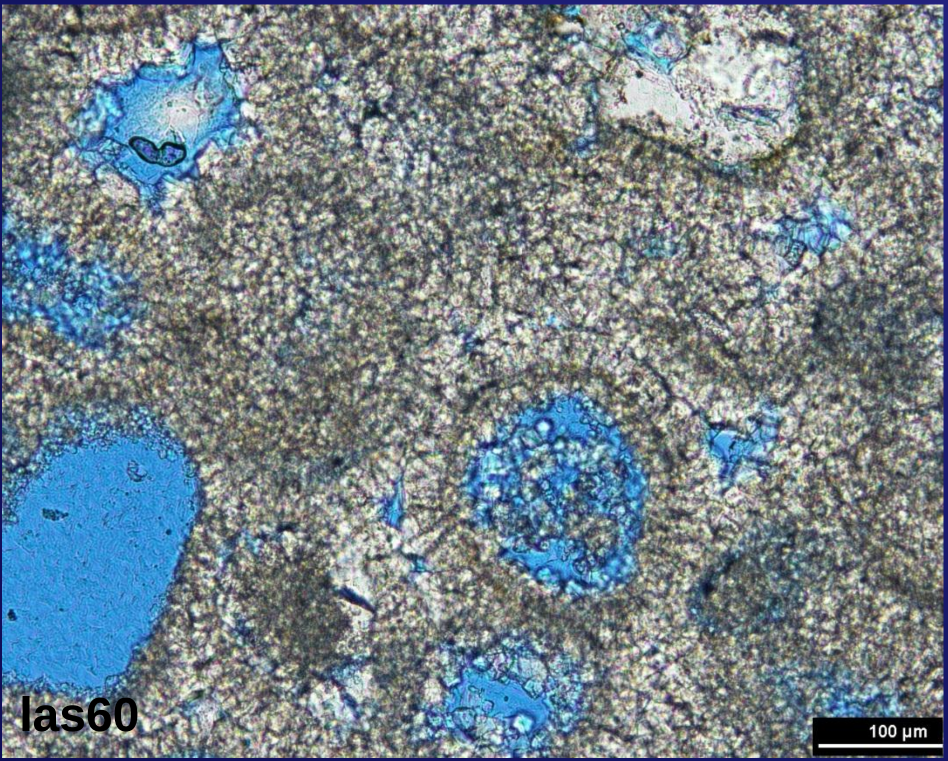
Slow



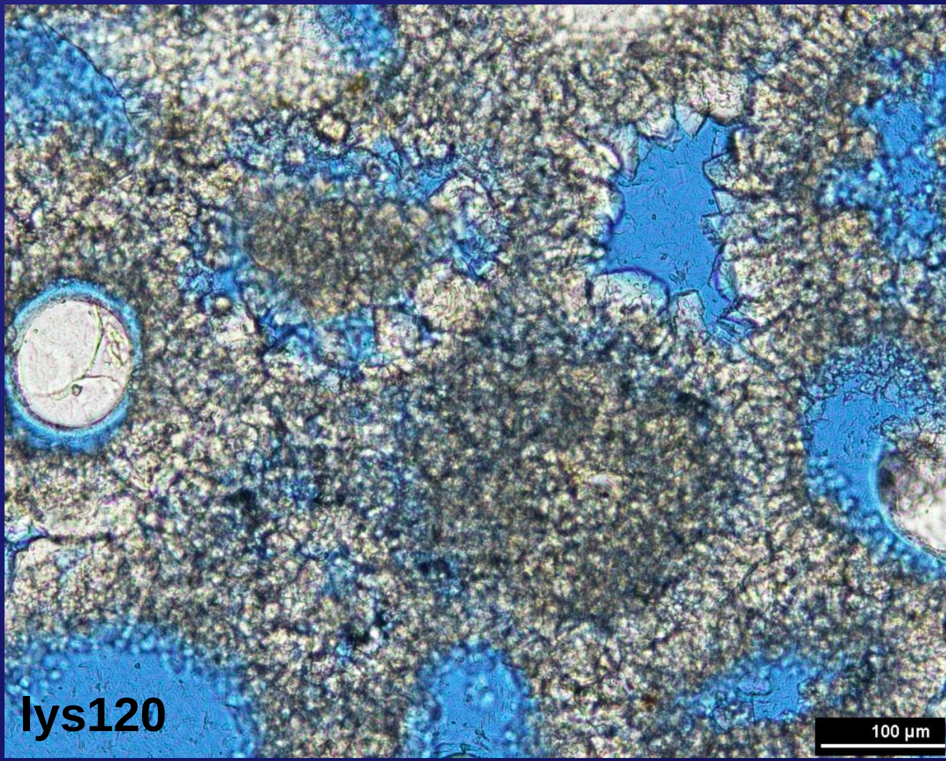
High amount of microporosity in between the crystal forming the matrix in between large pores => Weak framework

Plain light image

Fast



Slow

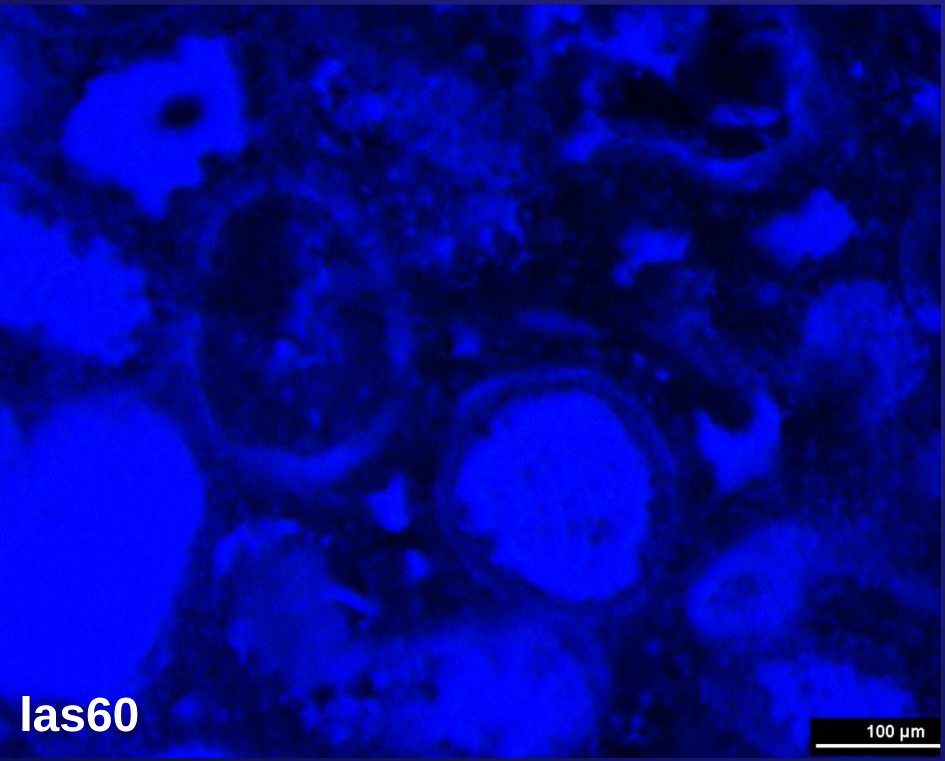


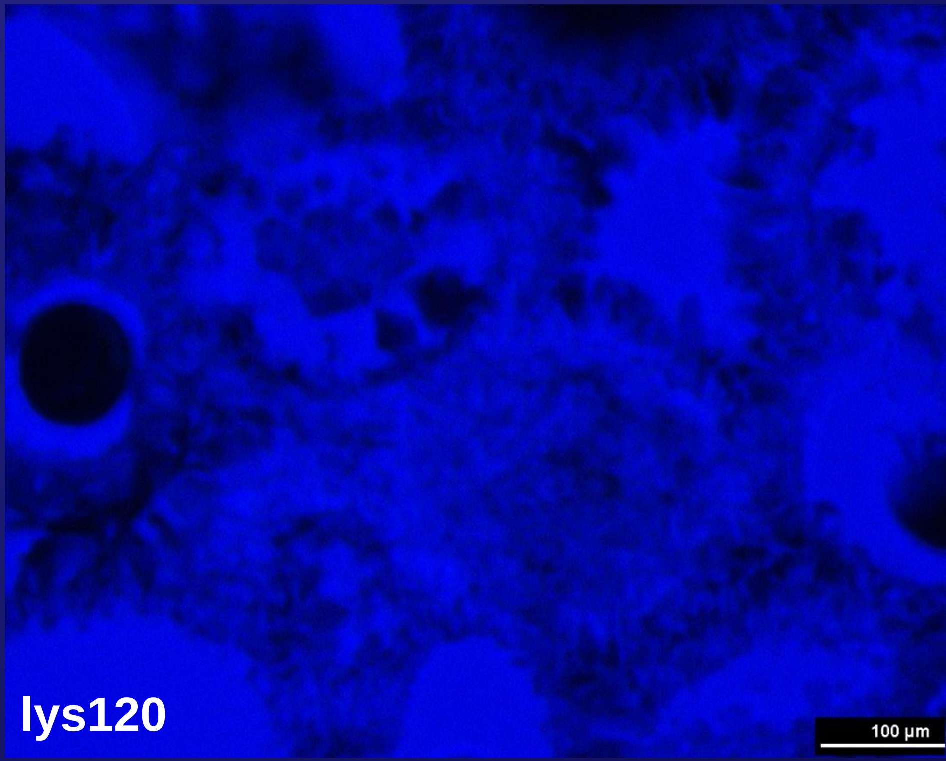
Stiff Framework

Weak Framework

UV light image

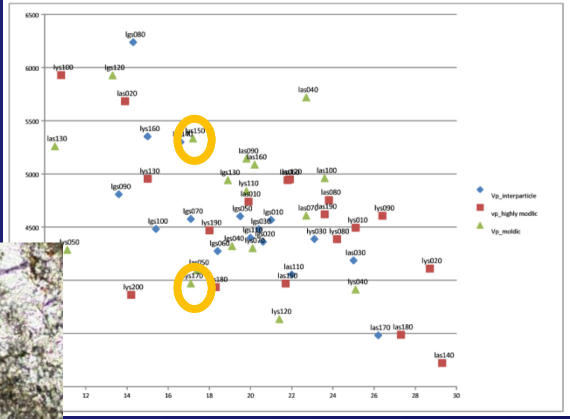
Fast	Slow





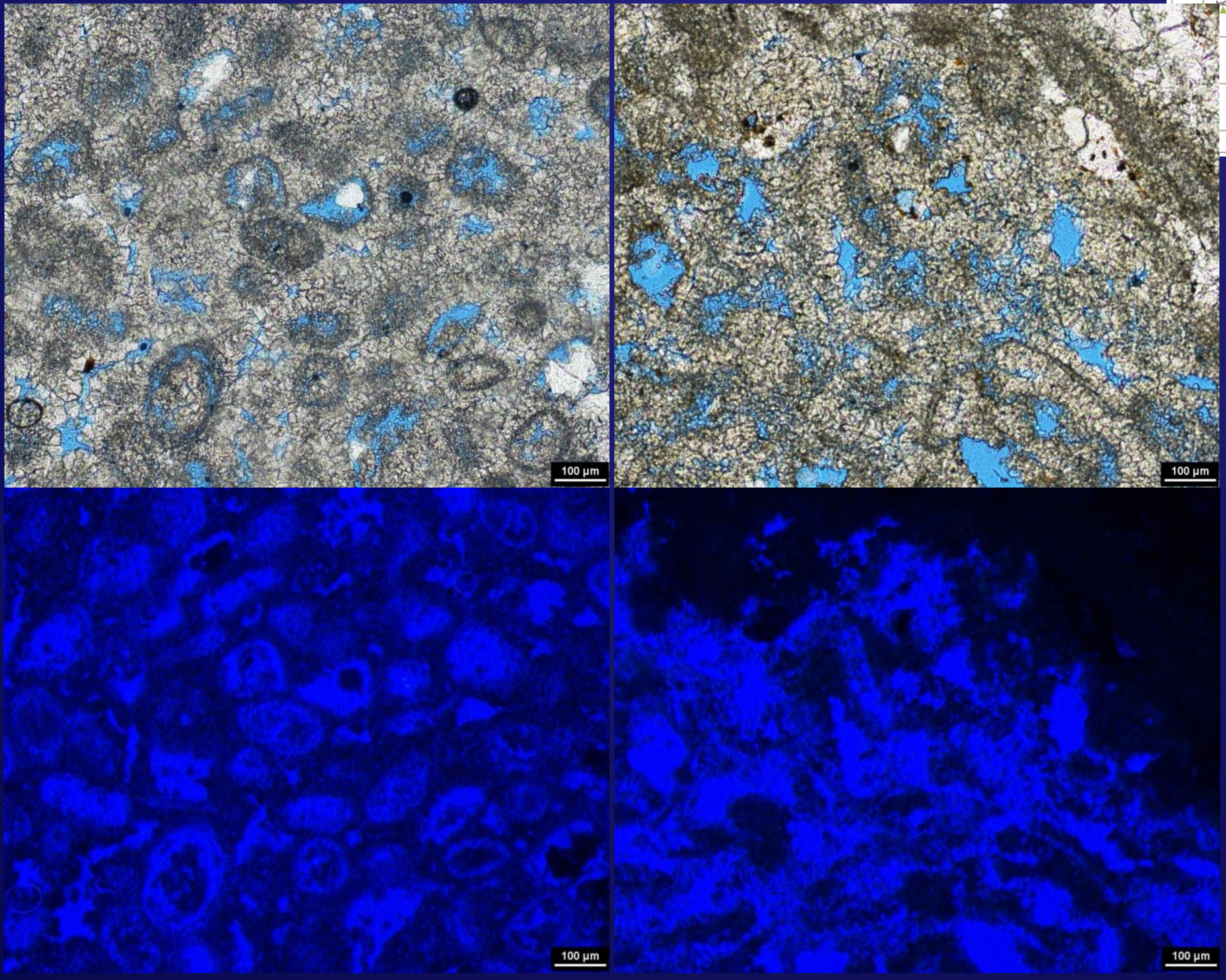
Stiff Framework	Weak Framework

17% Porosity Grainstone

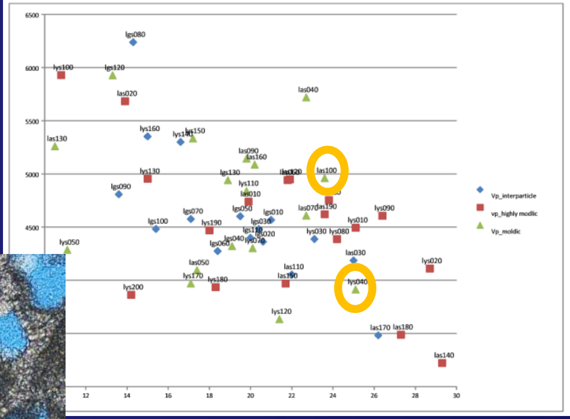


Fast

Slow

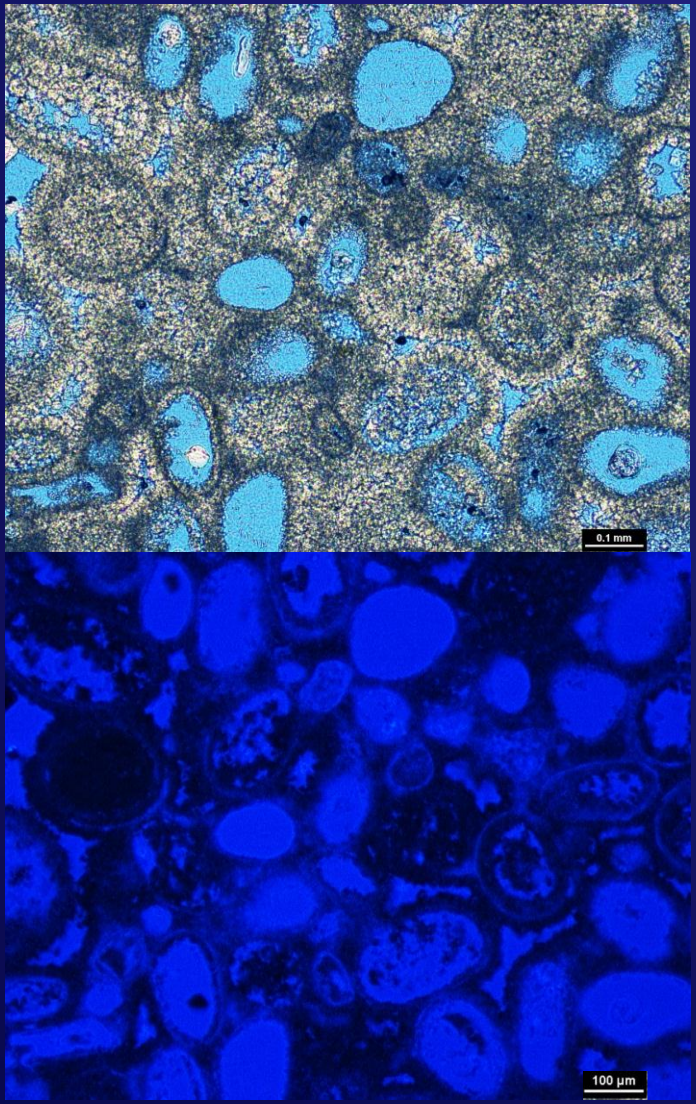


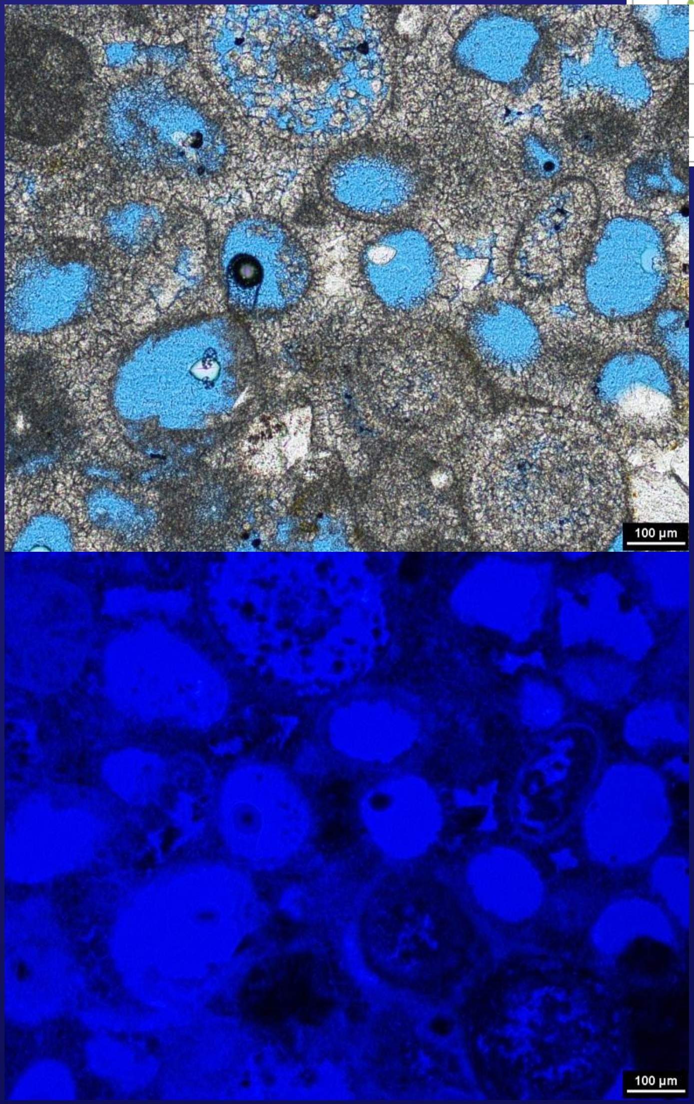
24-25% Porosity Grainstone



Fast

Slow





Reservoir Characterization Research Laboratory

Porosity Distribution (point-counting)

Fast Velocity Group

Sample Name	Plug Phi	Visible Phi	nonvisible phi	UV Micropores		
				Cement	Grains	
Las 60	21.8	12	10	no	x	DGstn
Las 80	23.8	17	7	no	x	DGstn
Lys 10	25.1	19	6	no	x	DGstn
Lys 80	24.2	17	7	no	x	DGstn

Slow Velocity Group

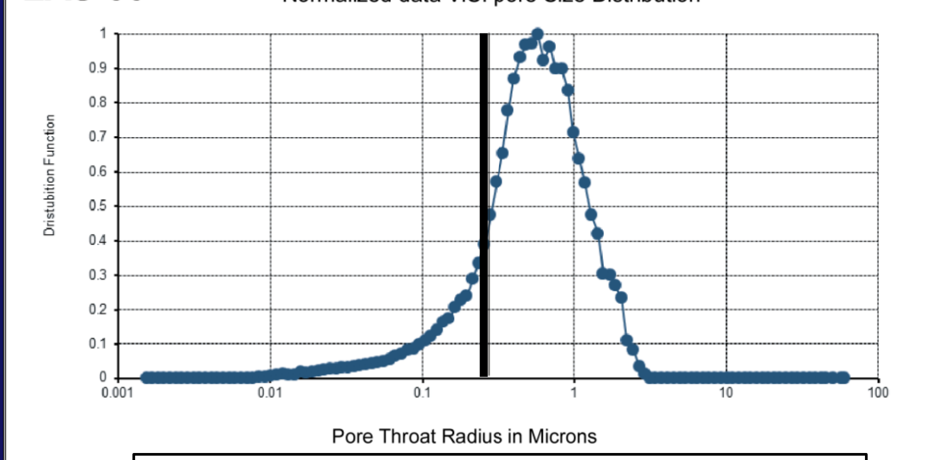
Sample Name	Plug Phi	Visible Phi	nonvisible phi	UV Micropores		
				Cement	Grains	
Lys 120	21.4	5	16	x	x	DGstn
Lys 180	18.3	5	13	x	x	GDDP
Lys 200	14.2	4	10	x	x	DGstn
Lys 170	17.1	4	13	x	x	GDDP

Low Phi Group (Fast?)

Sample Name	Plug Phi	Visible Phi	nonvisible phi	UV Micropores		
				Cement	Grains	
Lys 160	15.0	8	7	no	x	DGstn
Lys 150	17.2	7	10	x	x	DGstn

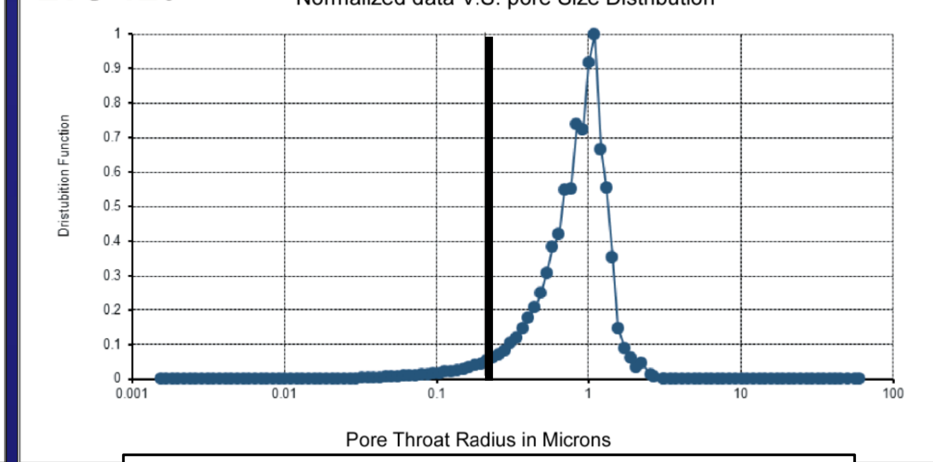
MICP data

LAS 60



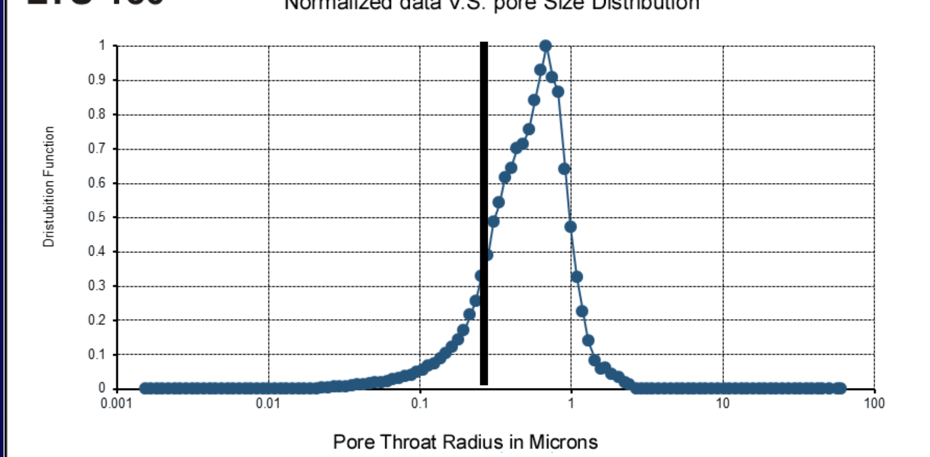
Porosity (%)			
Micro	Meso	Macro	Total
8.96	11.08	0	20.04

LYS 120



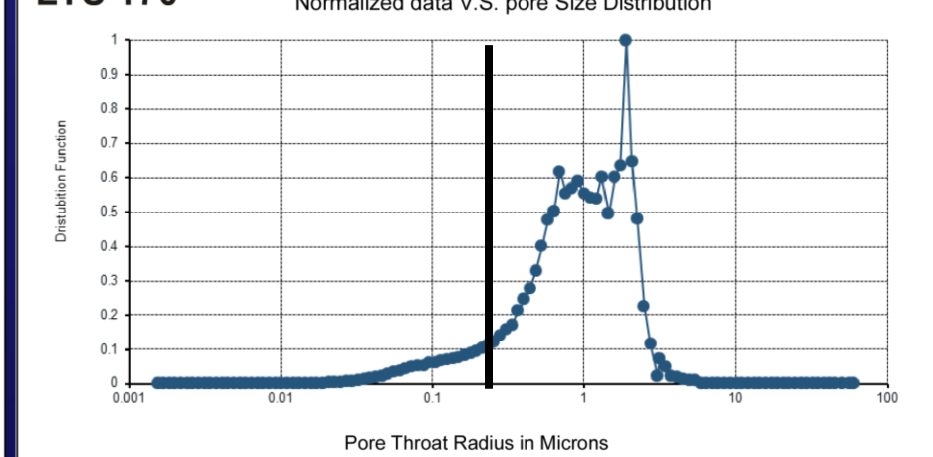
Porosity (%)			
Micro	Meso	Macro	Total
3.92	18.22	0	22.14

LYS 150



Porosity (%)			
Micro	Meso	Macro	Total
2.86	10.00	0	12.85

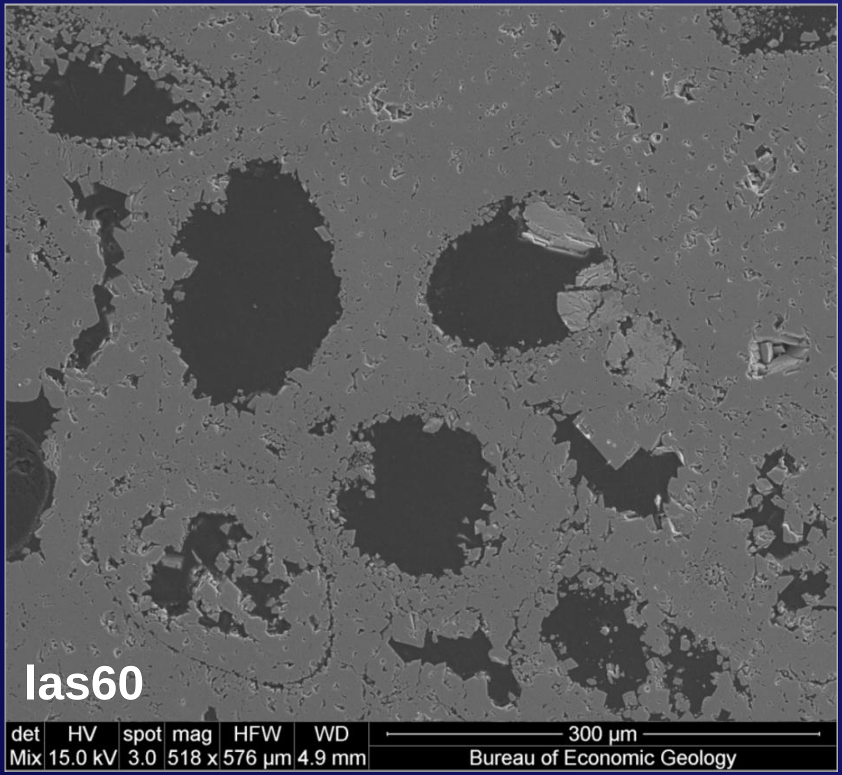
LYS 170



Porosity (%)			
Micro	Meso	Macro	Total
7.39	9.04	0	16.43

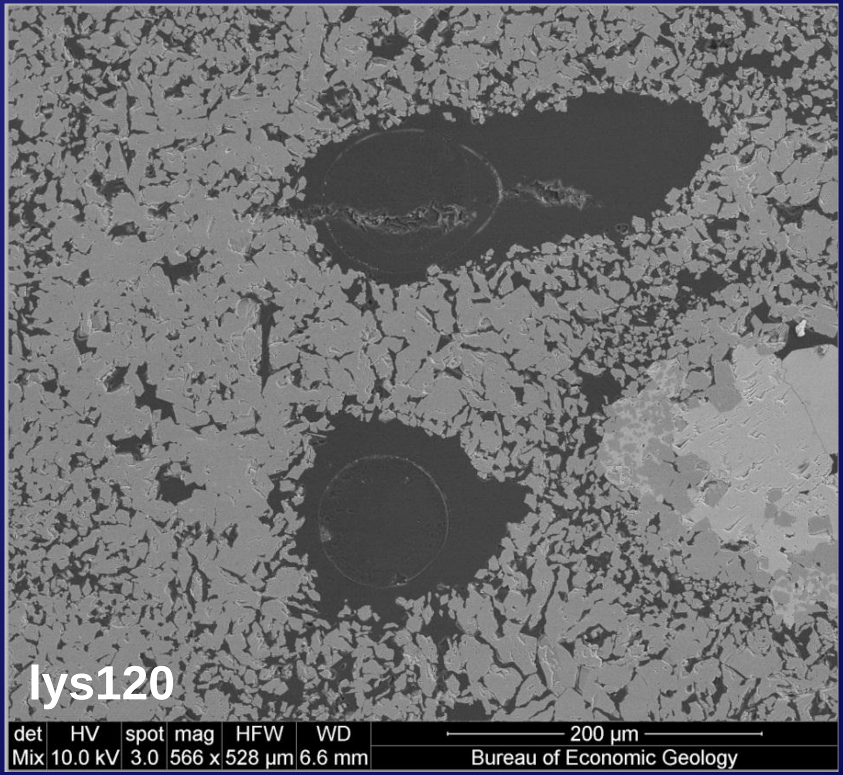
SEM

Fast



Stiff Framework

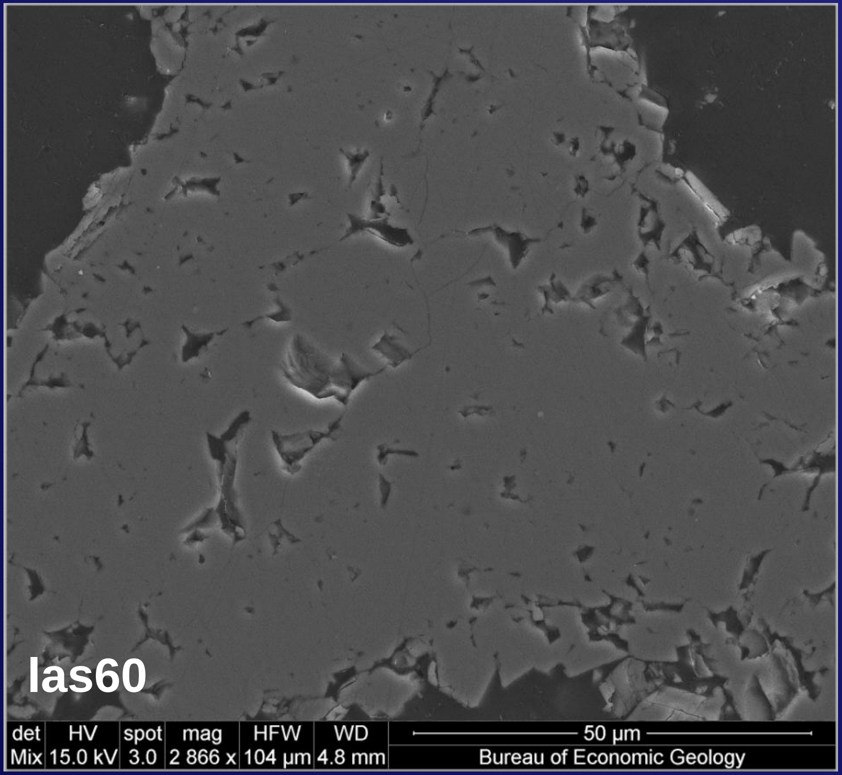
Slow



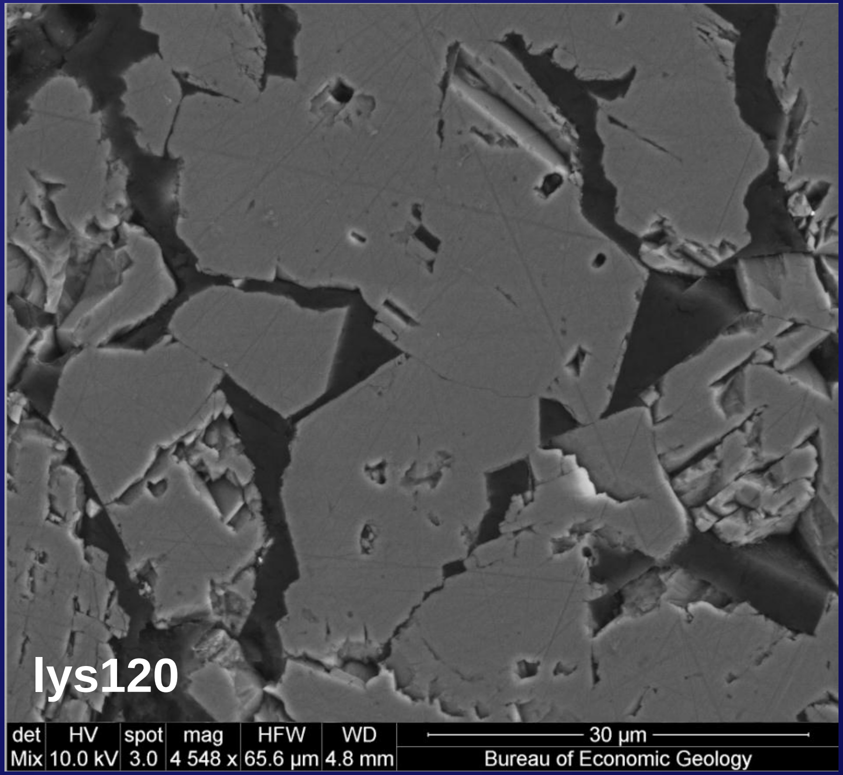
Weak Framework

SEM

Fast | **Slow**



Stiff Framework



Weak Framework

Results

- Velocity in the cycle 7 grainstone varies up to 1500 m/s for a given porosity.
- Velocity scatter is more important in the moldic and highly moldic grainstones than in the interparticle porosity-dominated grainstones.
- Velocity versus porosity plot don’t show any trend. Moldic and highly moldic grainstones can be slower or faster than average.
- There is no Vp/Vs ratio increase between interparticle-porosity-dominated grainstone and moldic grainstone.

Results

- Photomicrograph of fast or slow grainstone for a given porosity don’t show striking petrographic difference under plain light.
- Under UV light and SEM, the amount of microporosity in between the dolomite crystals in the matrix between macropores correlate well with the acoustic behavior of these grainstones.
- Highly microporous matrix leads to weak framework and slow velocity. Conversely low amount of microporosity in the matrix yield a stiff framework and fast velocity.
- These results completely invalidate the assumptions used in previous years for AVO modeling.