ROCK PHYSICS OF LOW POROSITY/LOW PERMEABILITY SANDSTONES

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TAD M. SMITH

TIGHT GAS SANDS: OVERVIEW

- Formal definition of “tight” is a reservoir with permeability less than 0.1 mD (Federal Energy Regulatory Commission)
- Typically also low porosity (∅ < ~10%)
- Tight gas sand reservoirs currently account for approximately 19% of total U.S. gas production (Oil and Gas Investor, 2005)
  - Estimated reserves in all unconventional reservoirs is approximately 200 Tcf
  - “tight” gas sand reservoirs may contain up to 35% of the U.S. recoverable gas resources
  - some facts on tight gas sands in the Rockies:
    - → Upwards of 41.7 Tcf
    - → Montana and the Dakotas could contribute another 100 Tcf
    - → Within the Green River and Wind River basins, more than 1,000 Tcf of gas is thought to occur in tight gas sands at depths greater than 15,000 feet
- Geophysical understanding is growing
- Rock physics lags behind other aspects of tight gas sand reservoirs

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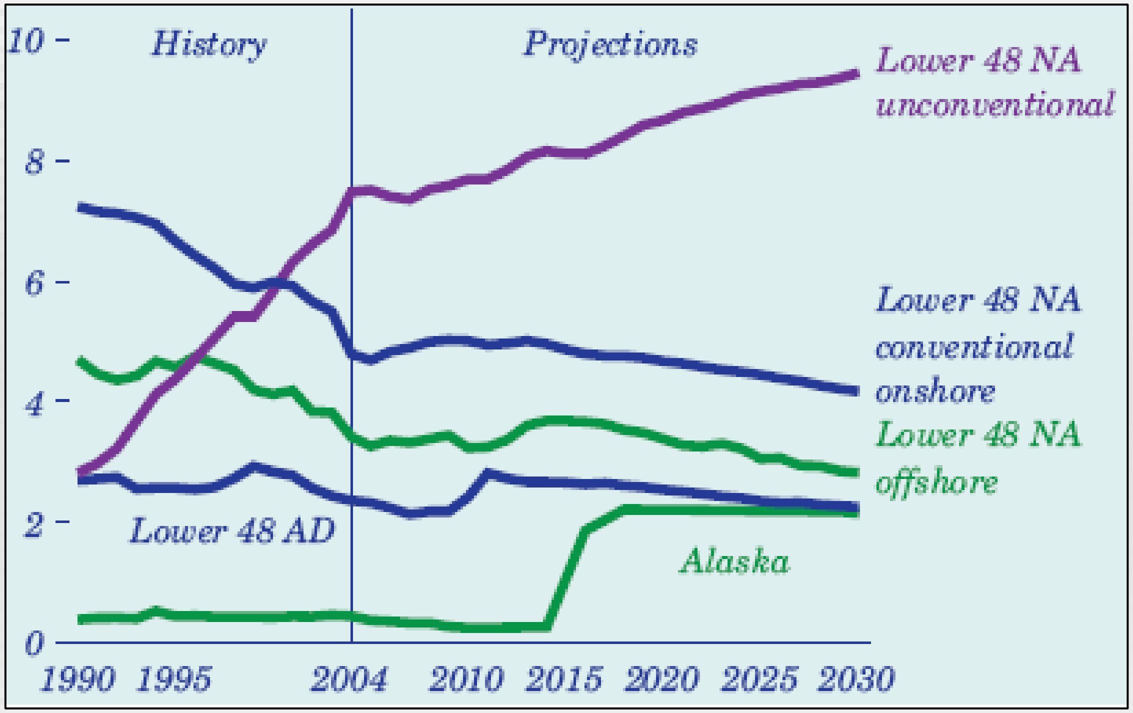
TIGHT GAS SANDS: OVERVIEW



Projected growth in unconventional gas production during the next 23 years. Y-axis scale is annual production, in TCF (http://www.eia.doe.gov/oiaf/archive/aeo06/pdf/trend_4.pdf)

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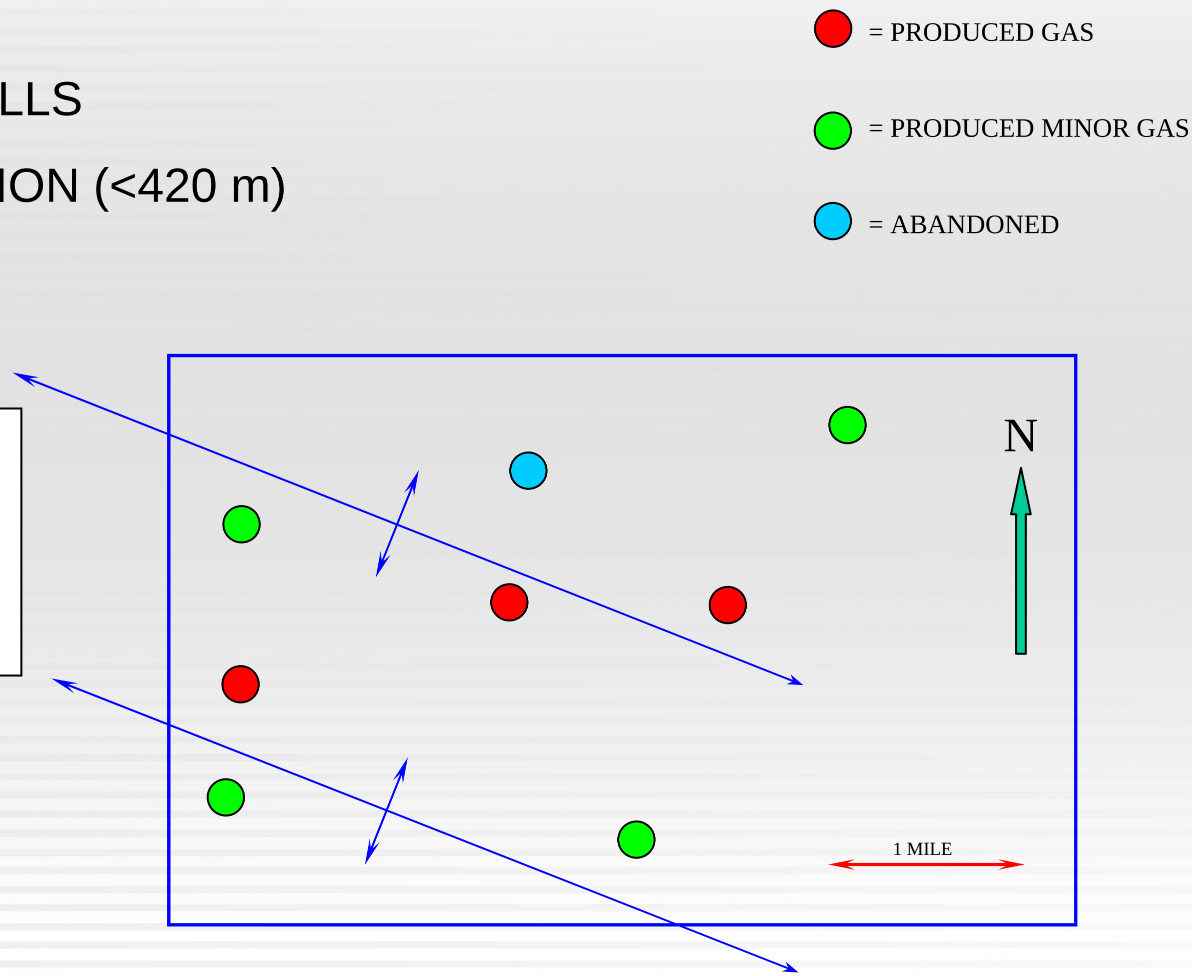
THIS PROJECT…

- CLOSELY SPACED WELLS
- SMALL DEPTH VARIATION (<420 m)



KEY ELEMENTS OF RESERVOIR:

✓ Quartz sand (>80% quartz)
✓ Relatively thin (10-20 m)
✓ Low porosity (avg. ≈ 4.5%)
✓ Fractured

PROJECT DATASET:

✓ One well with dipole
✓ 5 wells with image logs
✓ Two wells with core
✓ Consistent logging suite
✓ Oil-based mud

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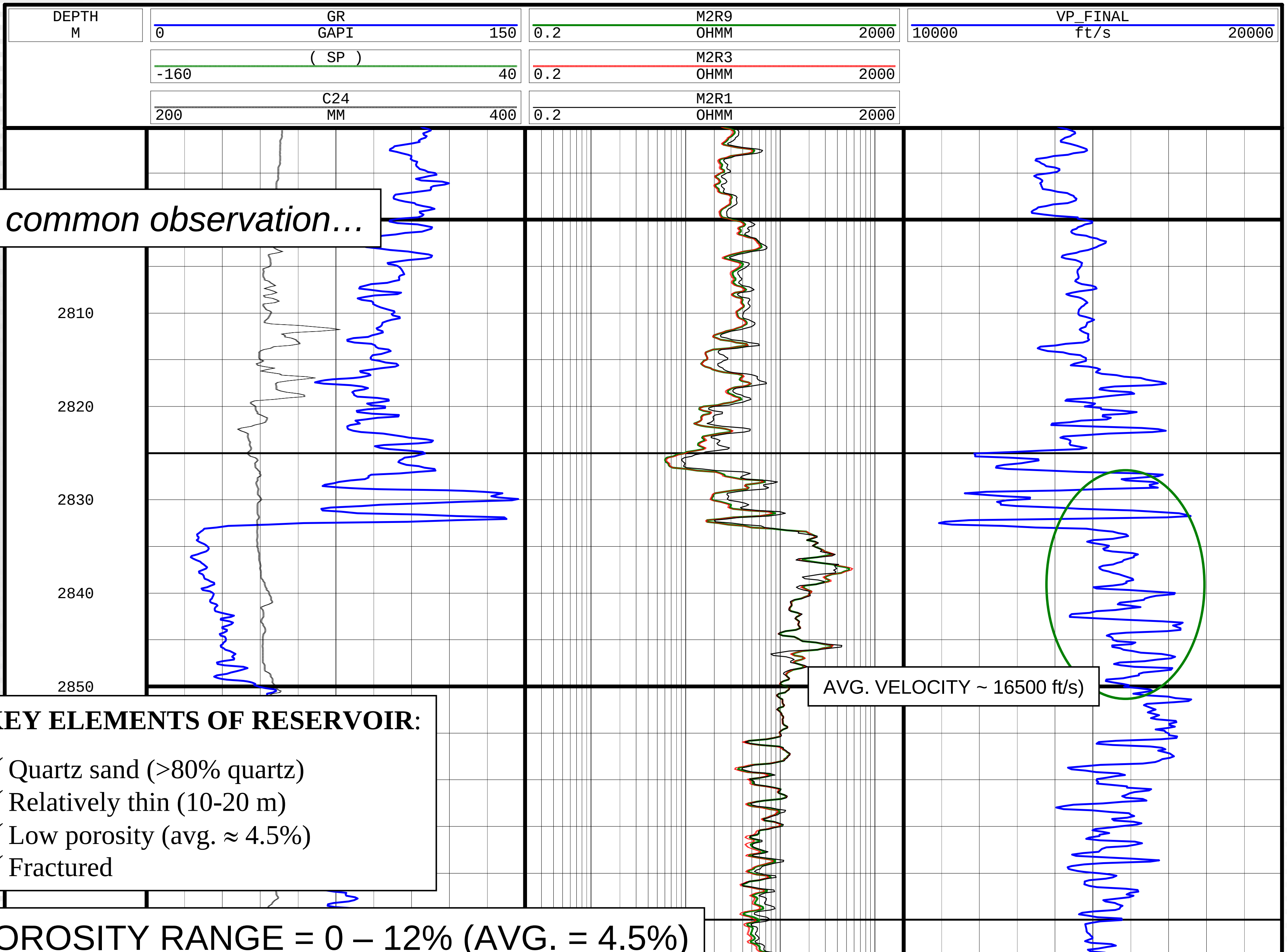
A common observation…



KEY ELEMENTS OF RESERVOIR:

- ✓ Quartz sand (>80% quartz)
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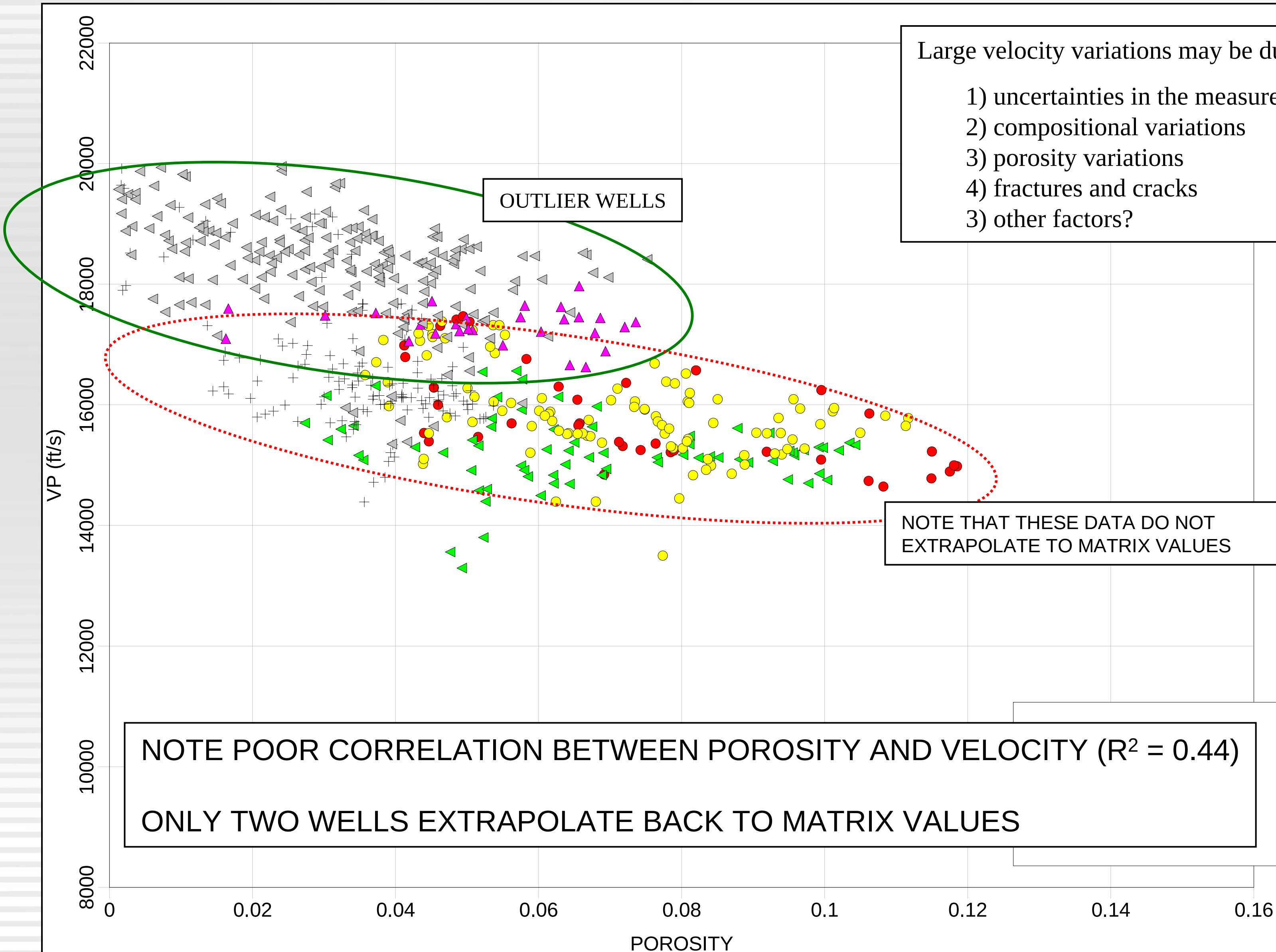
POROSITY RANGE = 0 – 12% (AVG. = 4.5%)

VELOCITY VARIATIONS; POROSITY



Large velocity variations may be due to

1) uncertainties in the measurements
2) compositional variations
3) porosity variations
4) fractures and cracks
3) other factors?

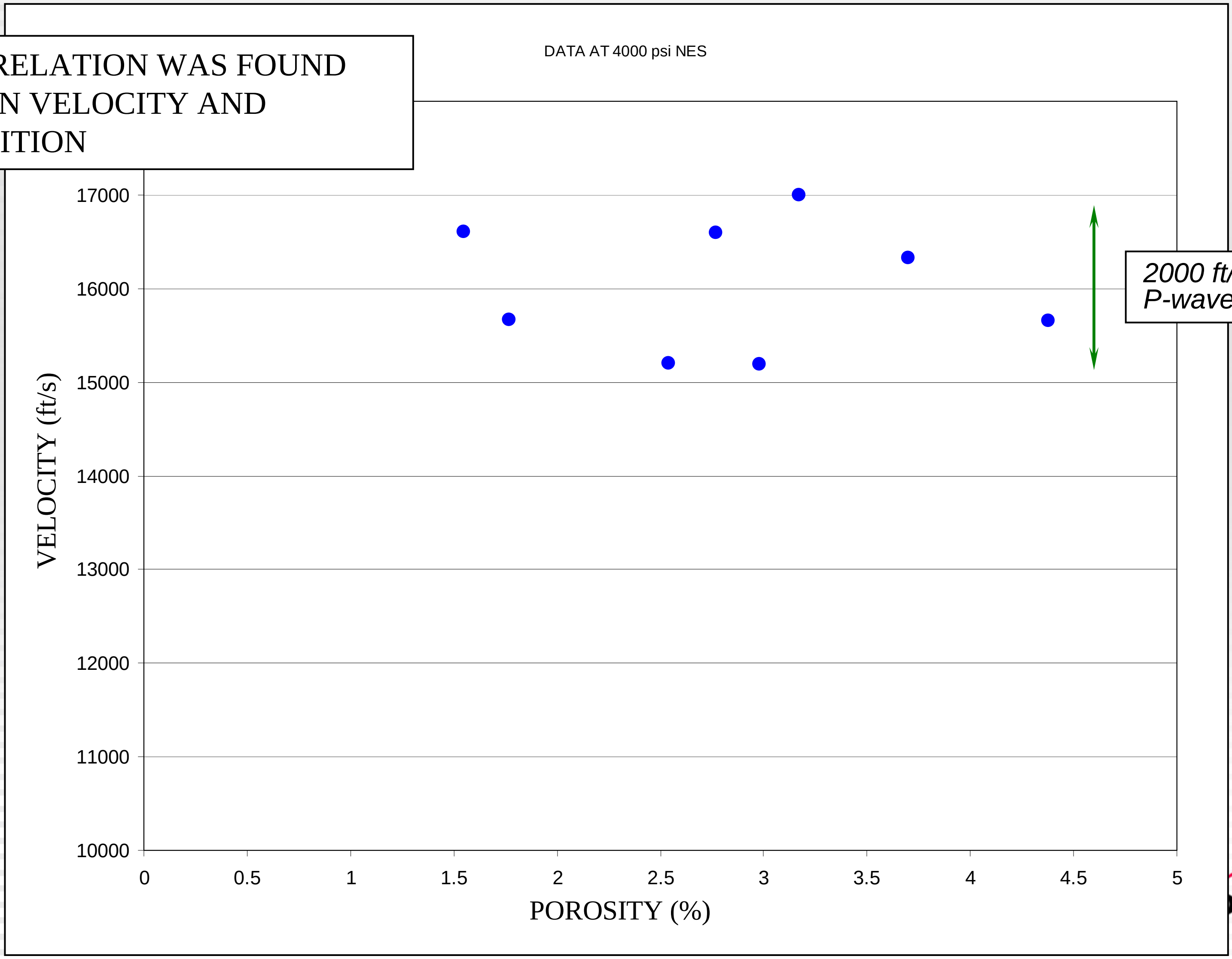
NOTE THAT THESE DATA DO NOT EXTRAPOLATE TO MATRIX VALUES

NOTE POOR CORRELATION BETWEEN POROSITY AND VELOCITY (R^2 = 0.44)

ONLY TWO WELLS EXTRAPOLATE BACK TO MATRIX VALUES

POROSITY; LAB MEASUREMENTS

NO CORRELATION WAS FOUND BETWEEN VELOCITY AND COMPOSITION



2000 ft/s spread in P-wave velocity

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KEY POINTS:

- NO CLEAR RELATIONSHIP BETWEEN VELOCITY AND POROSITY
- NO APPARENT RELATIONSHIP BETWEEN COMPOSITION AND VELOCITY
- WHAT ELSE?

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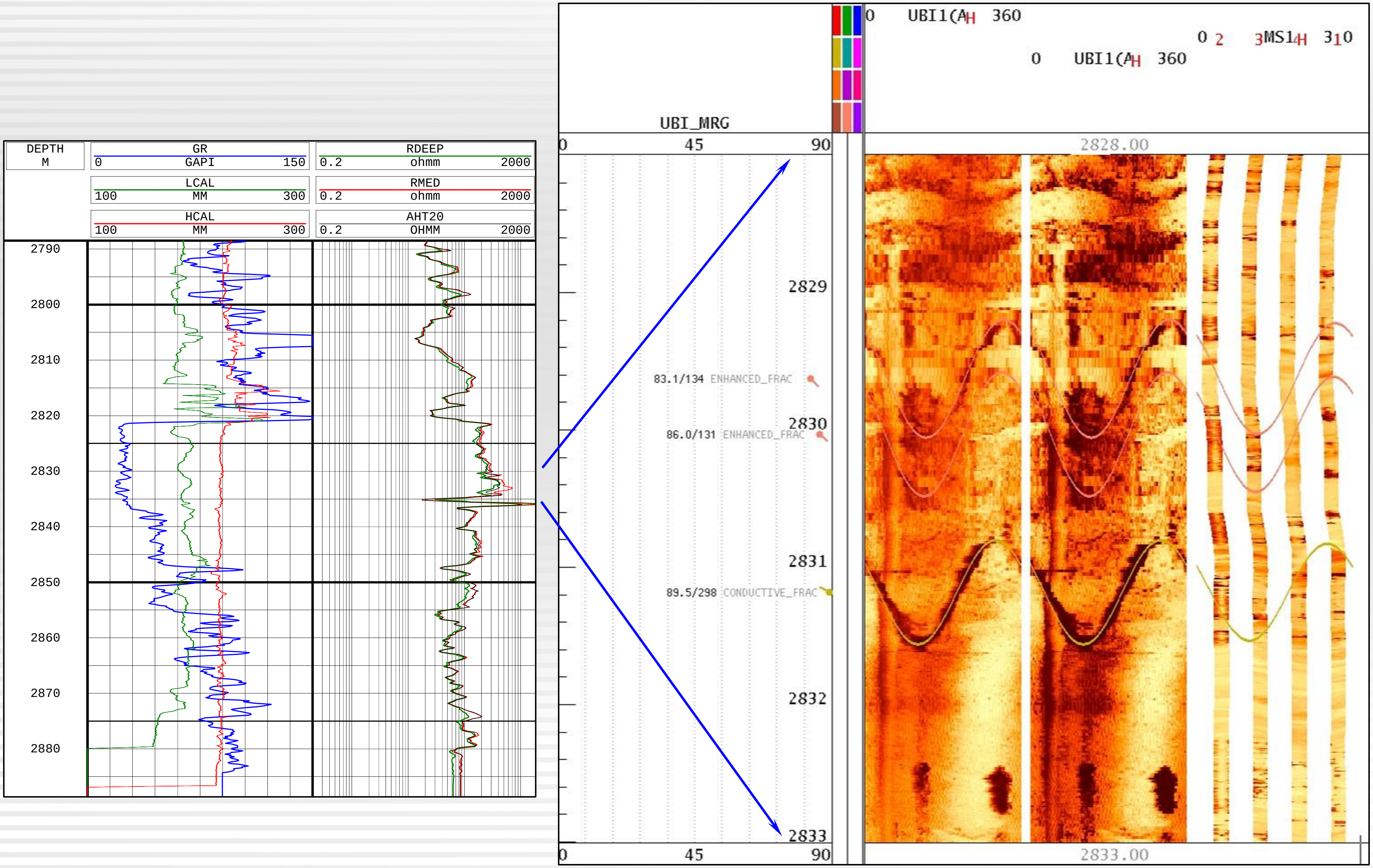
FRACTURES


DEPTH M
GR 0 GAPI 150
RDEEP 0.2 ohmm 2000
LCAL 100 MM 300
RMED 0.2 ohmm 2000
HCAL 100 MM 300
AHT20 0.2 OHMM 2000
2790
2800
2810
2820
2830
2840
2850
2860
2870
2880
UBI_MRG
0 45 90
2829
83.1/134 ENHANCED_FRAC
2830
86.0/131 ENHANCED_FRAC
2831
89.5/298 CONDUCTIVE_FRAC
2832
2833
0 UBI1(AH 360
0 UBI1(AH 360
2828.00
2833.00

FRACTURES AND CRACKS

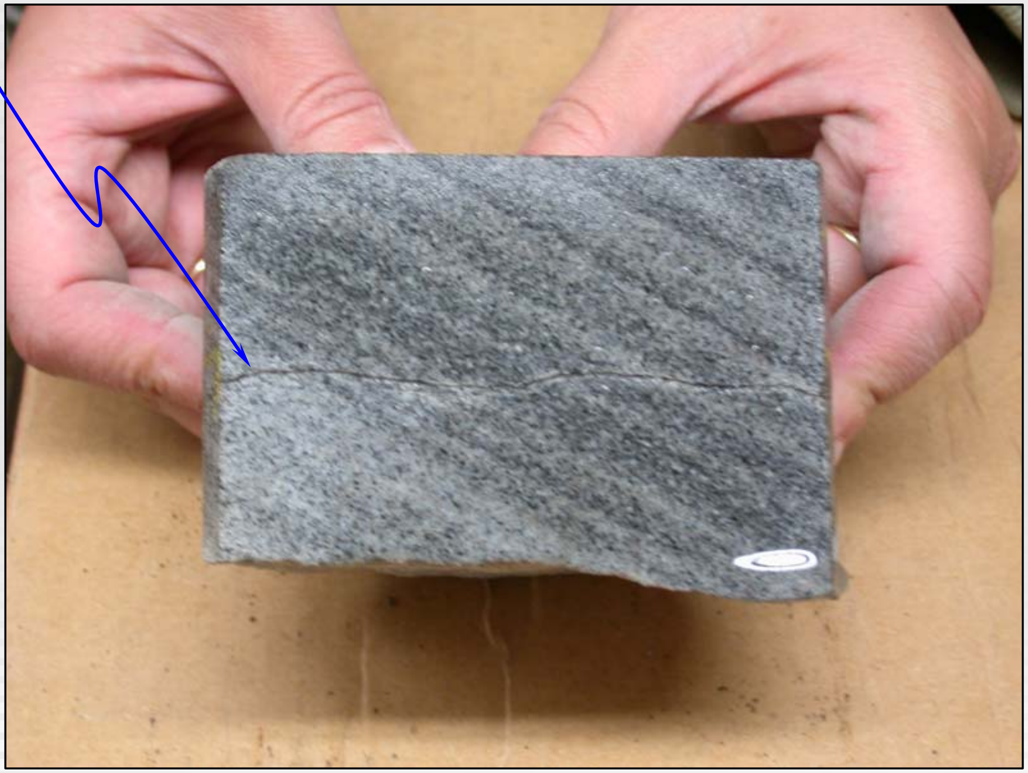
Parting surfaces and stylolites

Difficult to determine which are natural vs. induced

Locally cemented

SMALL SCALE FRACTURES

PARTIALLY CEMENTED CRACK



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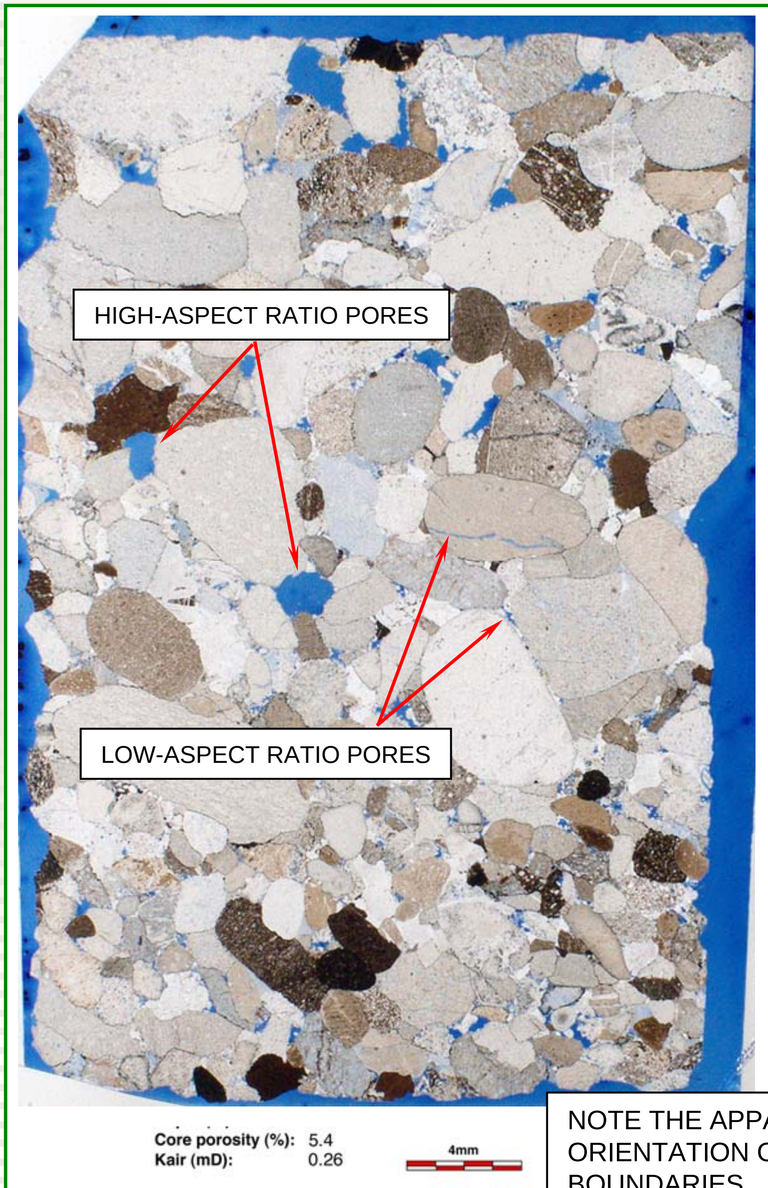
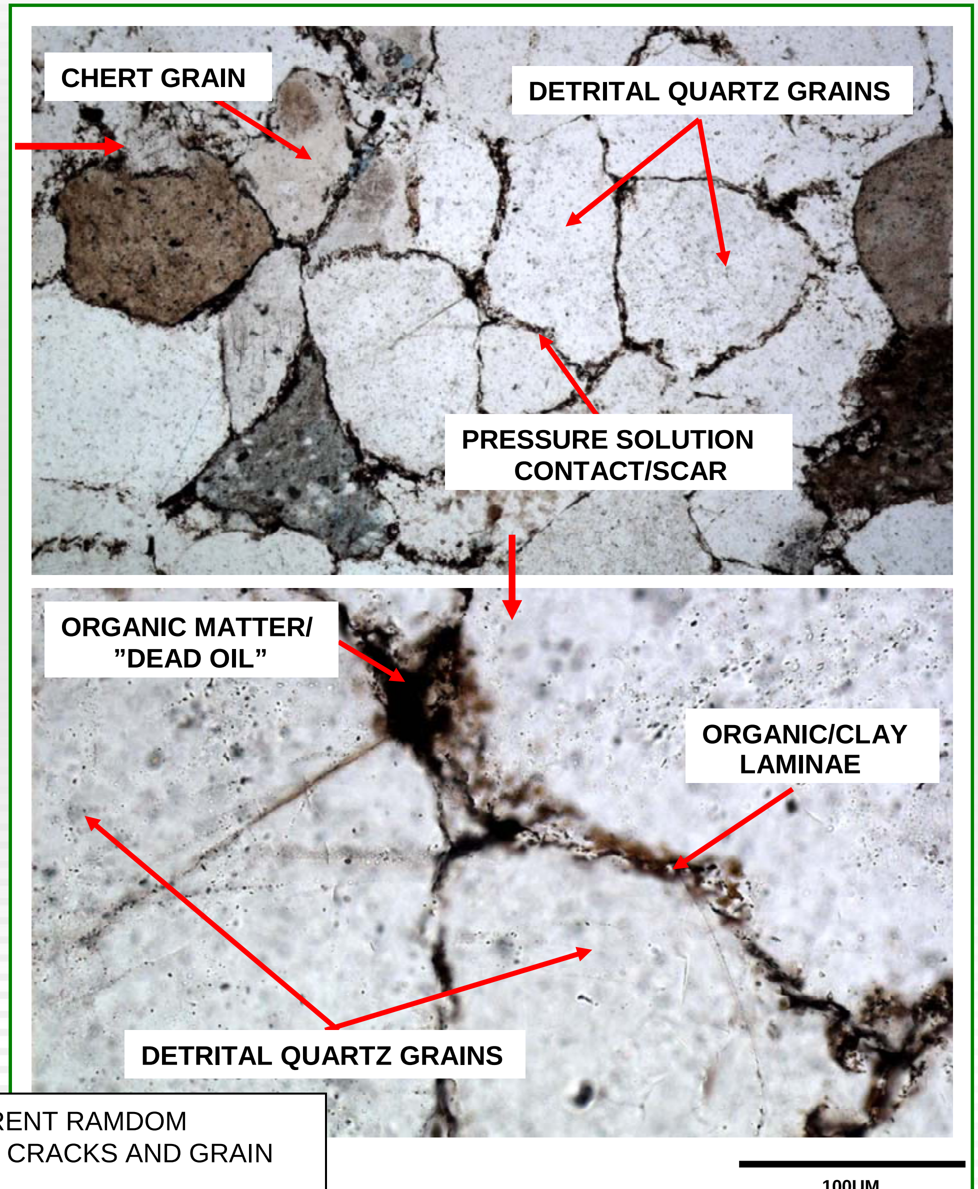
VELOCITY VARIATIONS; CRACKS



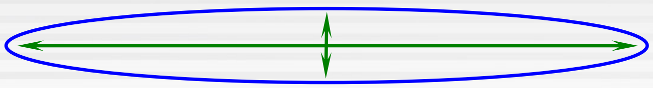


NOTE THE APPARENT RAMDOM ORIENTATION OF CRACKS AND GRAIN BOUNDARIES

KUSTER AND TOKSÖZ, 1974

- ✓ BEST FOR LOW POROSITY ROCKS
- ✓ MULTIPLE PORE GEOMETRIES CAN BE MODELED
- ✓ RANDOM ORIENTATION (ISOTROPIC DISTRIBUTION)

α = aspect ratio = short axis/long axis



$\alpha \approx 0.1$

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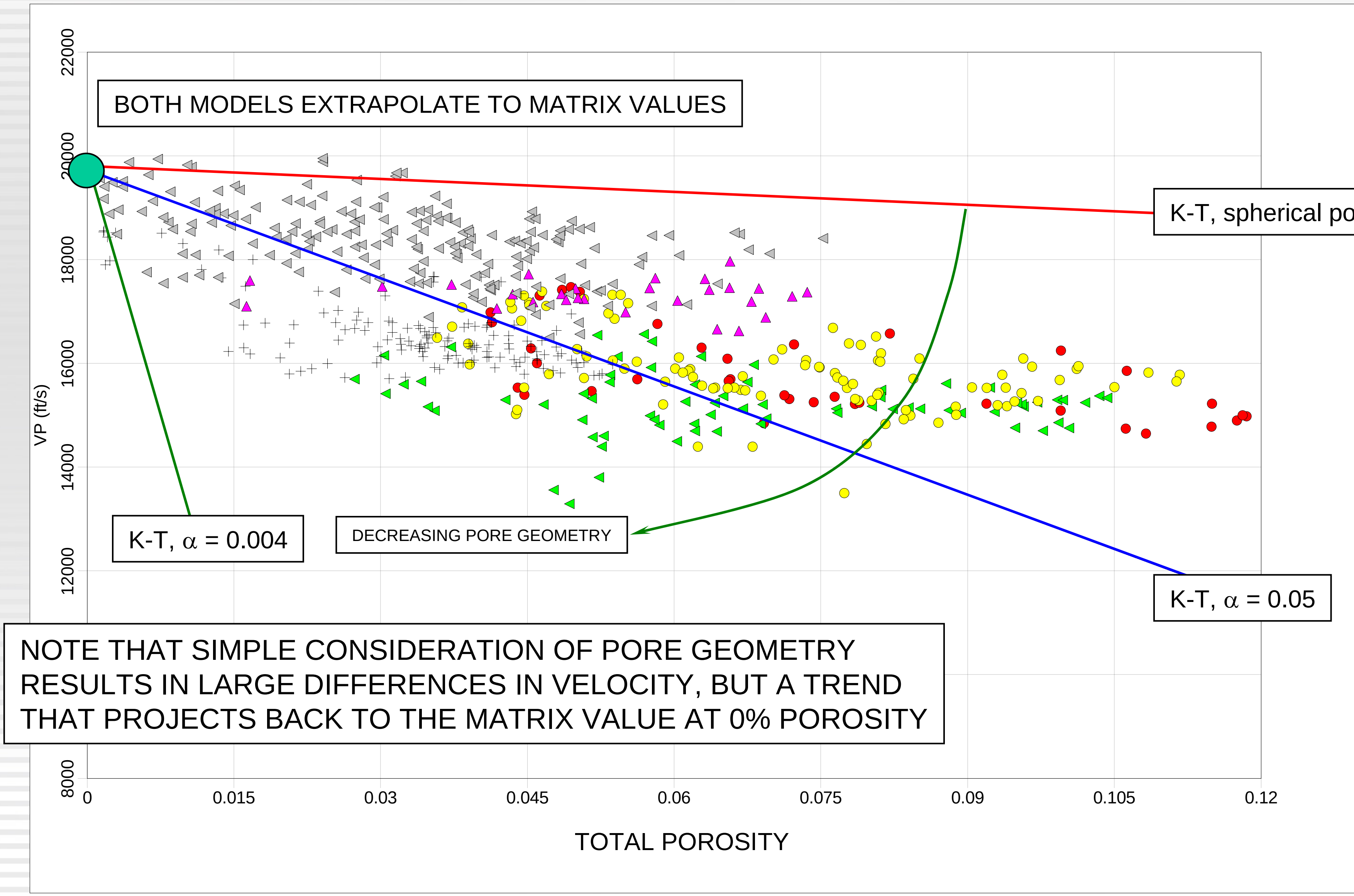
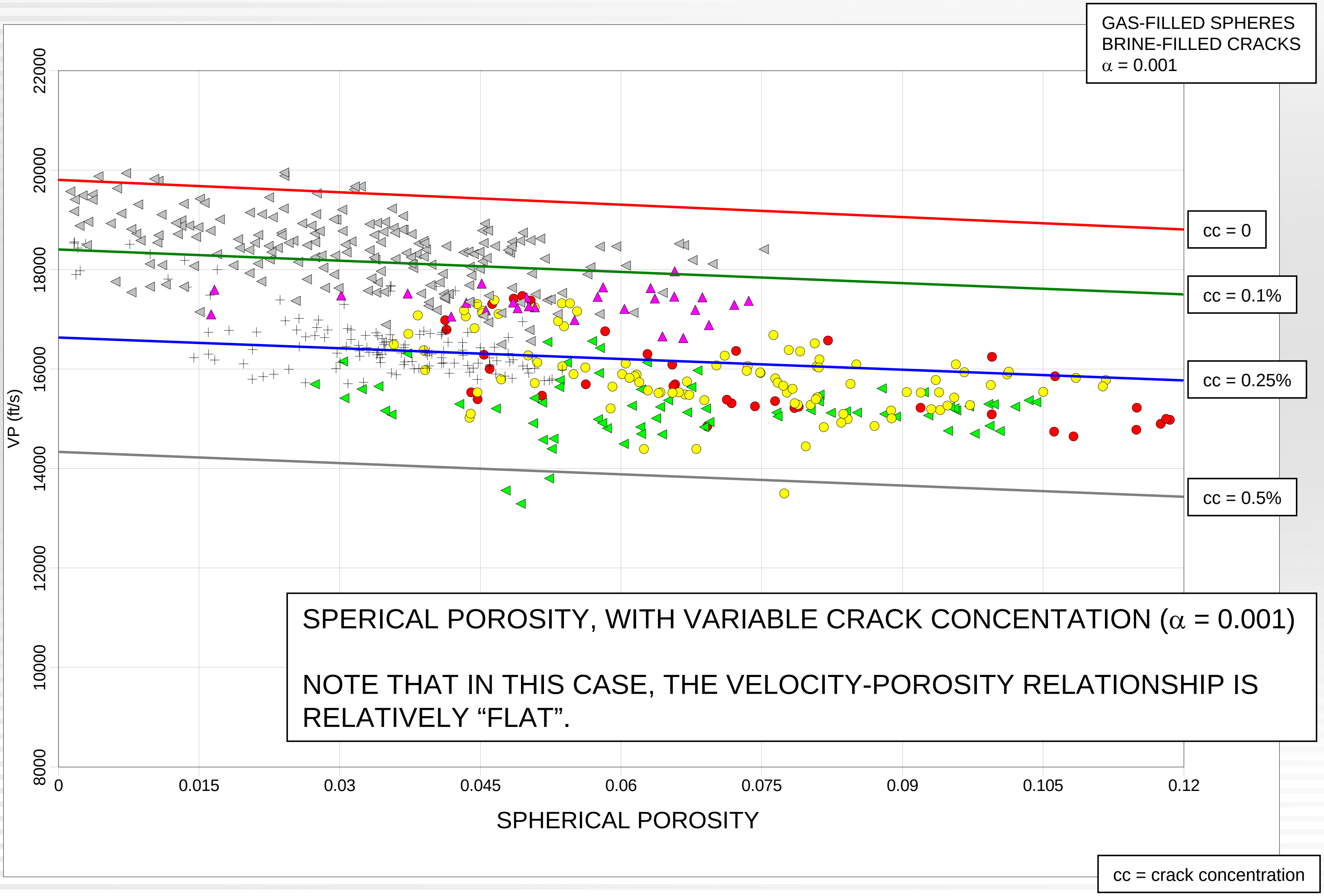
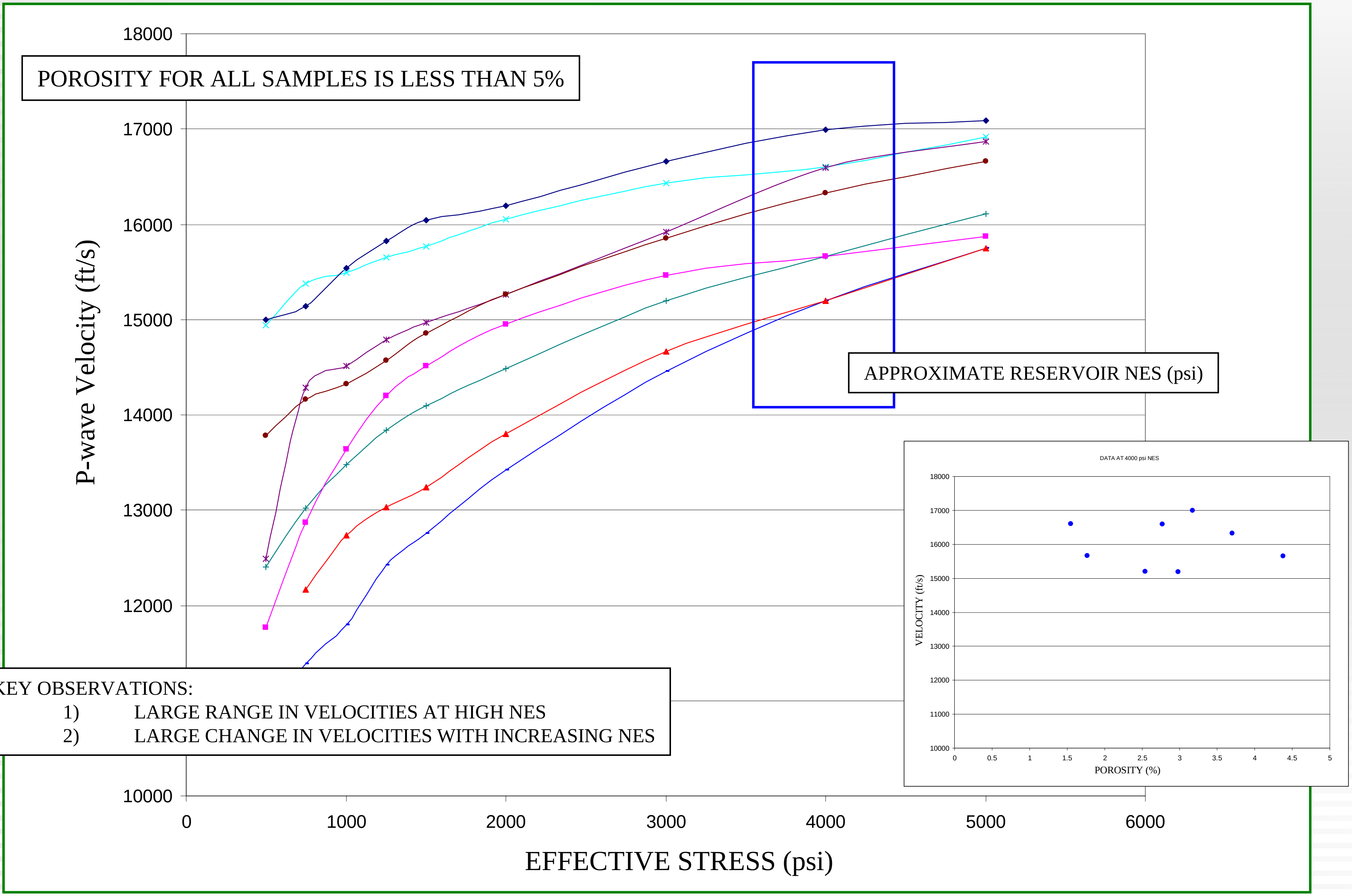
MULTIPLE PORE GEOMETRIES



VARIABLE CRACK CONCENTRATION



CORE VELOCITIES



KEY OBSERVATIONS:

1) LARGE RANGE IN VELOCITIES AT HIGH NES
2) LARGE CHANGE IN VELOCITIES WITH INCREASING NES

"SLOT" PORES IN TIGHT GAS SANDS

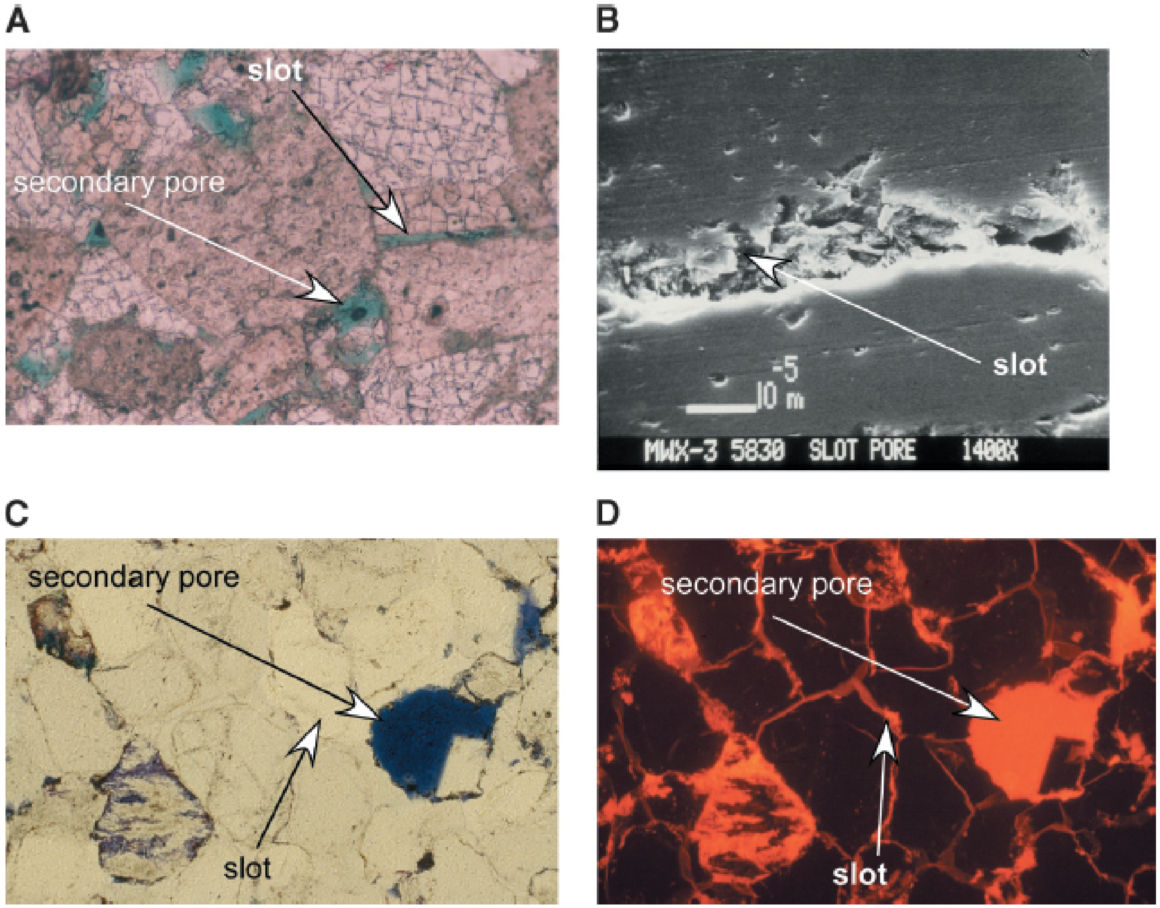


Figure 3. Photomicrograph and scanning electron microscope images illustrating slot-type pores and pore throats commonly found in low-permeability reservoirs. The slot-type pore network commonly consists of secondary, solution-derived pores that are connected by narrow, sheetlike slots. At overburden stress, these narrow slots compress significantly, reducing permeability. (A) Frontier Formation, Amoco Shute Creek 1, 10,779.8 ft (3285.6 m), 100×, plane polarized light; (B) Williams Fork Formation, MWX 3, 5830 ft (1777 m), 1400×; (C) Travis Peak Formation, SFE 2, 8275.3 ft (2522 m), 100×, plane polarized light; (D) Travis Peak Formation, SFE 2, 8275.3 ft (2522 m), 100×, fluorescent light. Photographs for (B), (C), and (D) are provided courtesy of D. J. Soeder, U.S. Geological Survey.

Shanley et al., 2004

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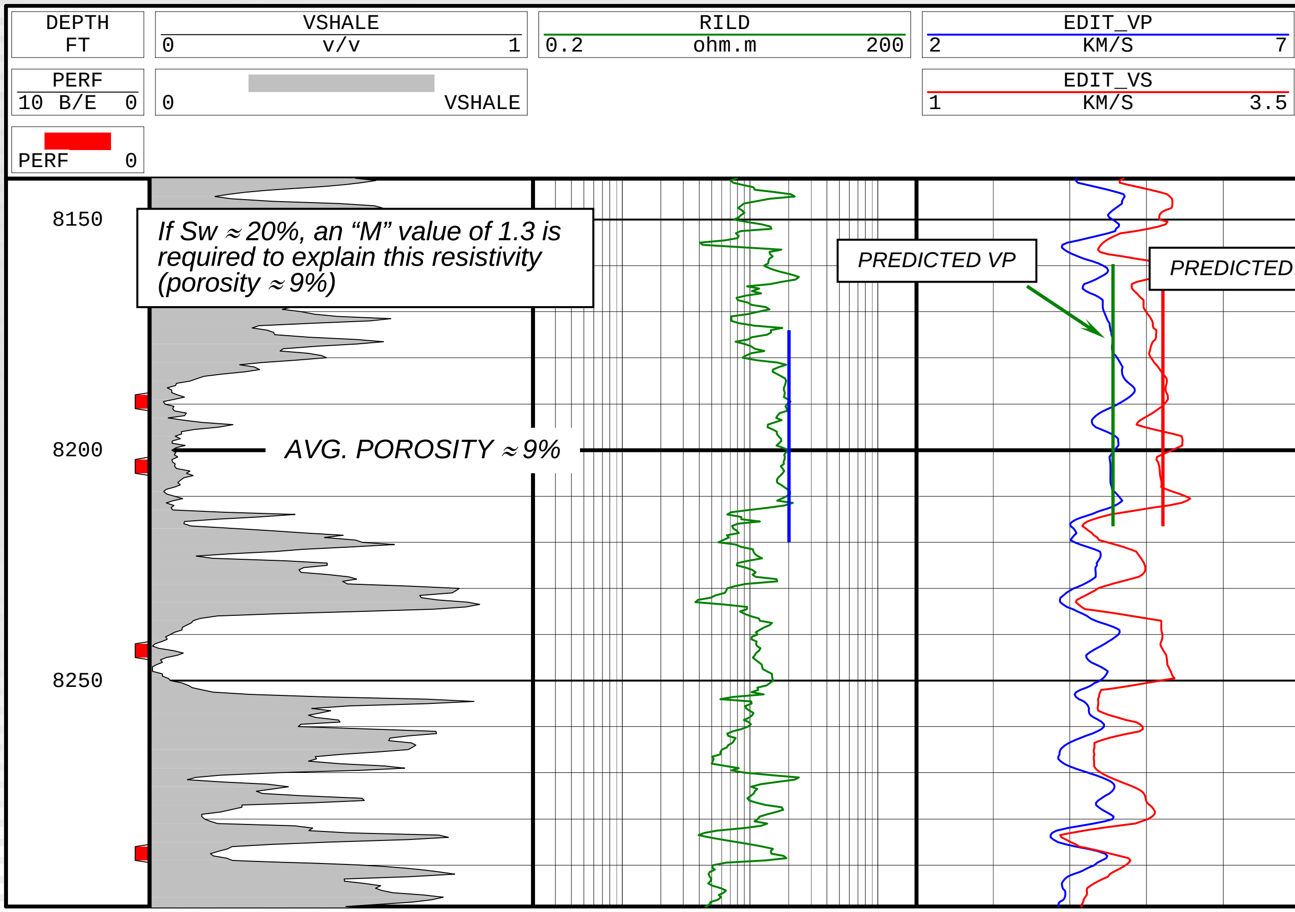
"SLOT" PORES

"PAY" SAND



***ASSUMPTIONS**:*

Quartz matrix
Gas saturated spheres (log-porosity)
Brine-filled cracks (slot pores)
Crack aspect ratio = 0.01

Sphere concentration = 6%
Crack concentration = 2.5%

VP = 4.583 km/s
VS = 2.744 km/s

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OBSERVATIONS/CONCLUSIONS

- POROSITY DOES NOT APPEAR TO BE CORRELATED WITH VELOCITY IN MANY LOW POROSITY SANDS
- VELOCITY-POROSITY RELATIONSHIPS IN LOW POROSITY ROCKS CANNOT BE EXPLAINED WITHOUT THE ADDITION OF CRACKS TO THE ROCK MATRIX
- THIS IS PROBABLY ALSO RELATED TO PETROPHYSICAL OBSERVATIONS OF "SLOT PORES"
  - Used to explain very low "M" values in some low porosity sandstones.
  - Implications
- VP and VS TYPICALLY CANNOT BE EXPLAINED SIMULTANEOUSLY BY USING ONLY ONE PORE GEOMETRY (i.e., need multiple pore aspect ratios)
- THIS SHOULD BE CONSIDERED WHEN MODELING POROSITY IN LOW POROSITY ROCKS
  - *Velocities and moduli may not be correlated with porosity!*

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OBSERVATIONS/CONCLUSIONS

- CARE MUST BE TAKEN WHEN USING ANY SEISMIC DATA TO MAP POROSITY
  - In low porosity rocks, the effects of pore geometry are probably more important than the total porosity
  - Amplitude anomalies in low porosity reservoirs may be may be indicators of lithology, and *not* reservoir quality
- IMPLICATIONS FOR PERMEABILITY AND/OR ATTENUATION?

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ACKNOWLEDGEMENTS

- ConocoPhillips
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- Carl Sondergeld
- Chandra Rai

QUESTIONS?

$$K_{sat} = K_{fr} + \frac{\left(1 - \frac{K_{fr}}{K_0}\right)^2}{\frac{\phi}{K_{fl}} + \frac{(1-\phi)}{K_0} - \frac{K_{fr}}{K_0^{\,2}}}$$

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