Mechanical Properties of the Niobrara Formation*

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Abstract

Due to burial, subsidence, diagenesis and compaction, the Niobrara Formation requires horizontal drilling and multi-stage fracture stimulation. The unconventional characteristics of this major resource play in the Rocky Mountain Region are the reason why laboratory measurements of the mechanical and lithological properties of the Niobrara Formation will be presented in this work. This information is essential for designing hydraulic fractures in tight formations.

The samples used in this study were obtained from the CEMEX's Lyons Cement plant in Boulder County, Colorado, from where three lithofacies were sampled: the Fort Hays Member, the D chalk and the Lower Marl. For each of these facies, tensional and unconfined compressive strength were acquired in order to obtain general failure criteria. Triaxial tests, using varying axial, confining and pore pressures, were conducted to obtain Young's modulus and Poisson's ratio values under different conditions, as well as changes in porosity and permeability. Also, ultrasonic velocity measurements will be done for establishing a correlation between static and dynamic properties, which can be used to extract mechanical properties from well logs.

These strength properties will be related to clay content, carbonate content, porosity and permeability, to determine which parameters have major or no influence in the fracture growth, length and extent. These properties will also serve to find numerical relationships that can be applied to other facies of the Niobrara Formation. It might be expected that the marl intervals in the Niobrara Formation contain the height of the simulated hydraulic fracture, due to their higher clay content in comparison to the chalk intervals, which would give them a plastic behavior.

AAPG-RMS 2011 Annual Meeting

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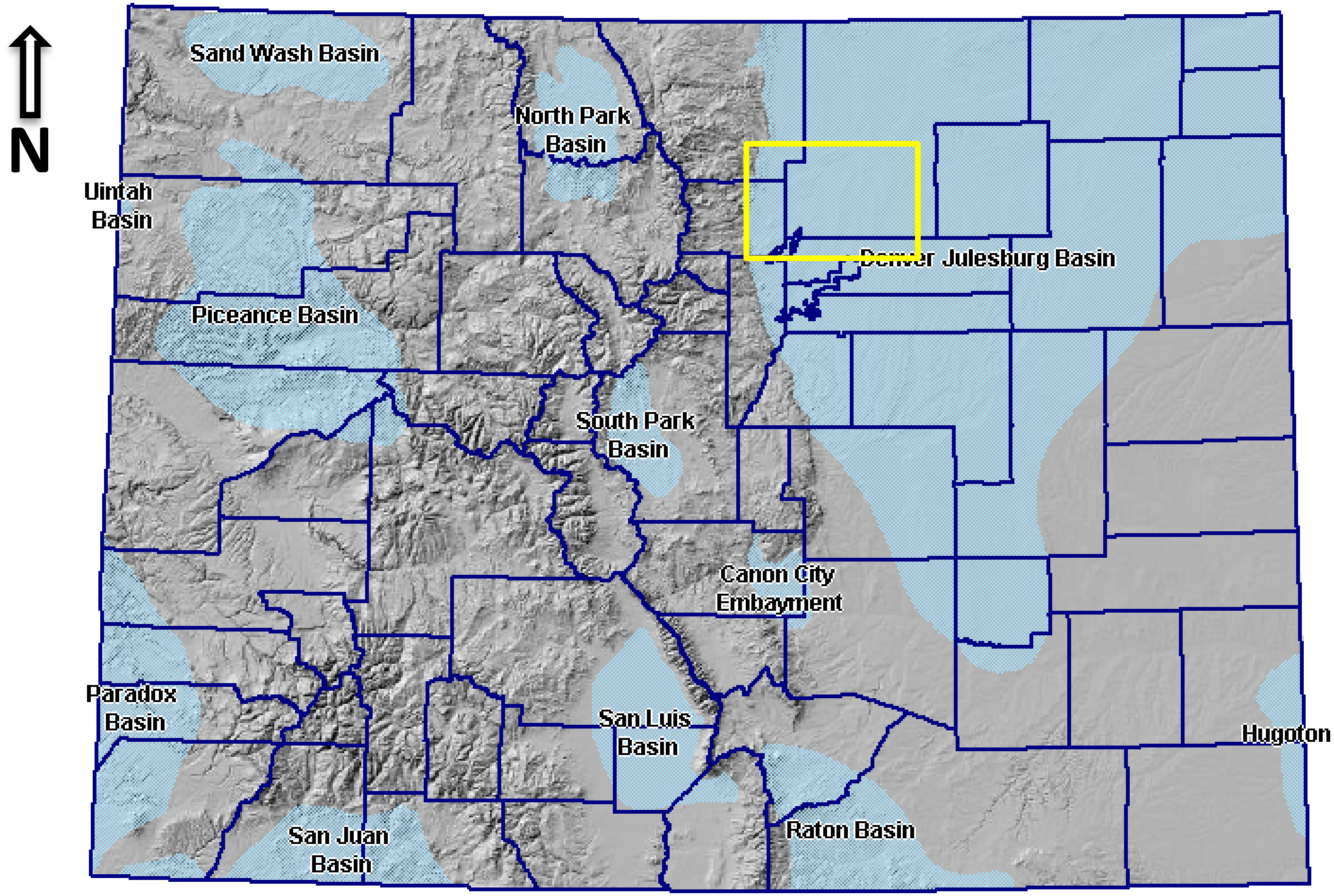
Outline

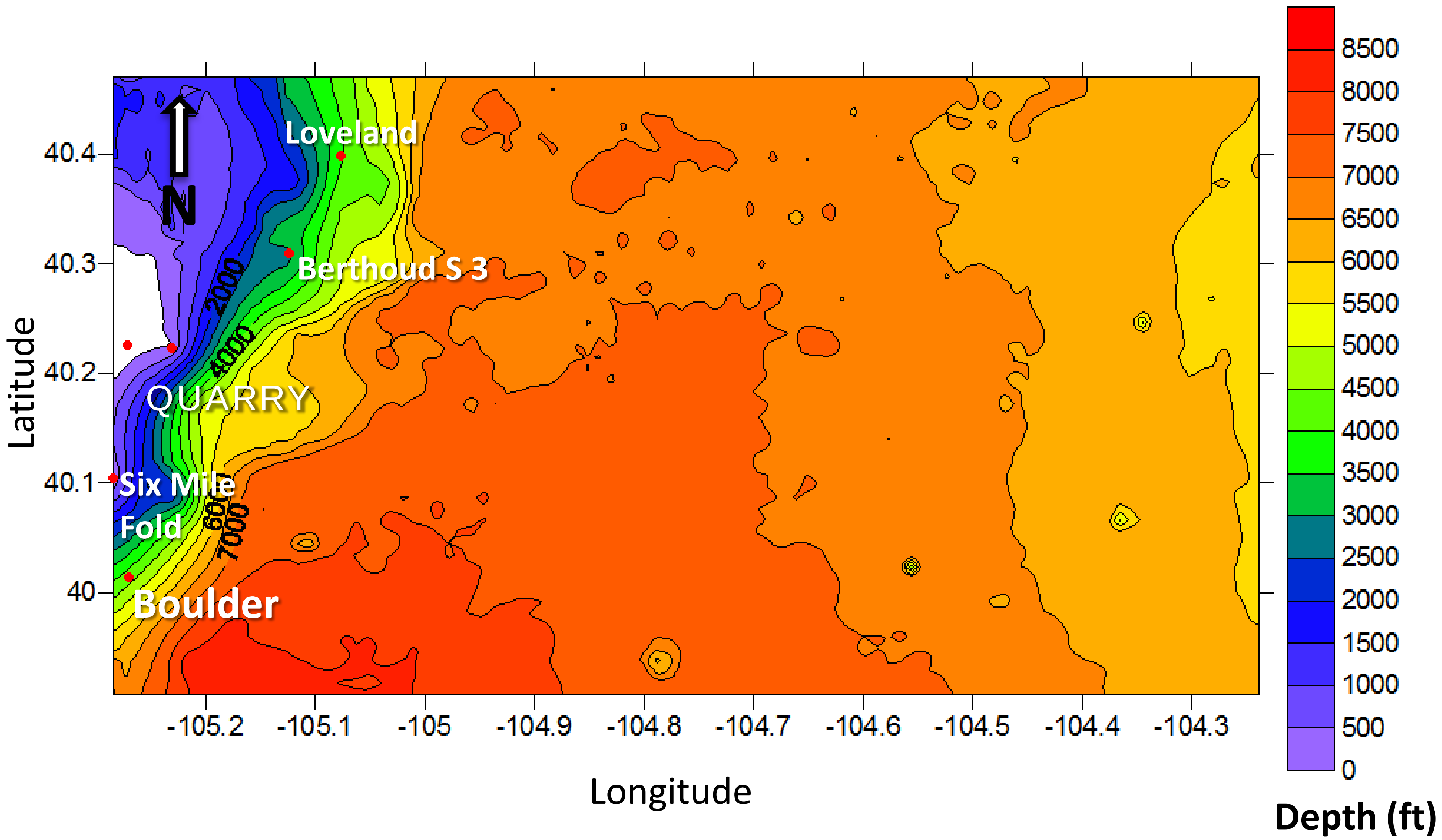
- Study area
- What we learn from logs
  - Why are mechanical properties important?
  - Young's Modulus and Poisson's ratio definition
  - Mechanical properties as a function of Gamma Ray
- What we learn from rocks
  - Triaxial tests
  - Dynamic mechanical properties
  - Effective stress coefficient
- Summary and conclusions

Study area



Colorado State

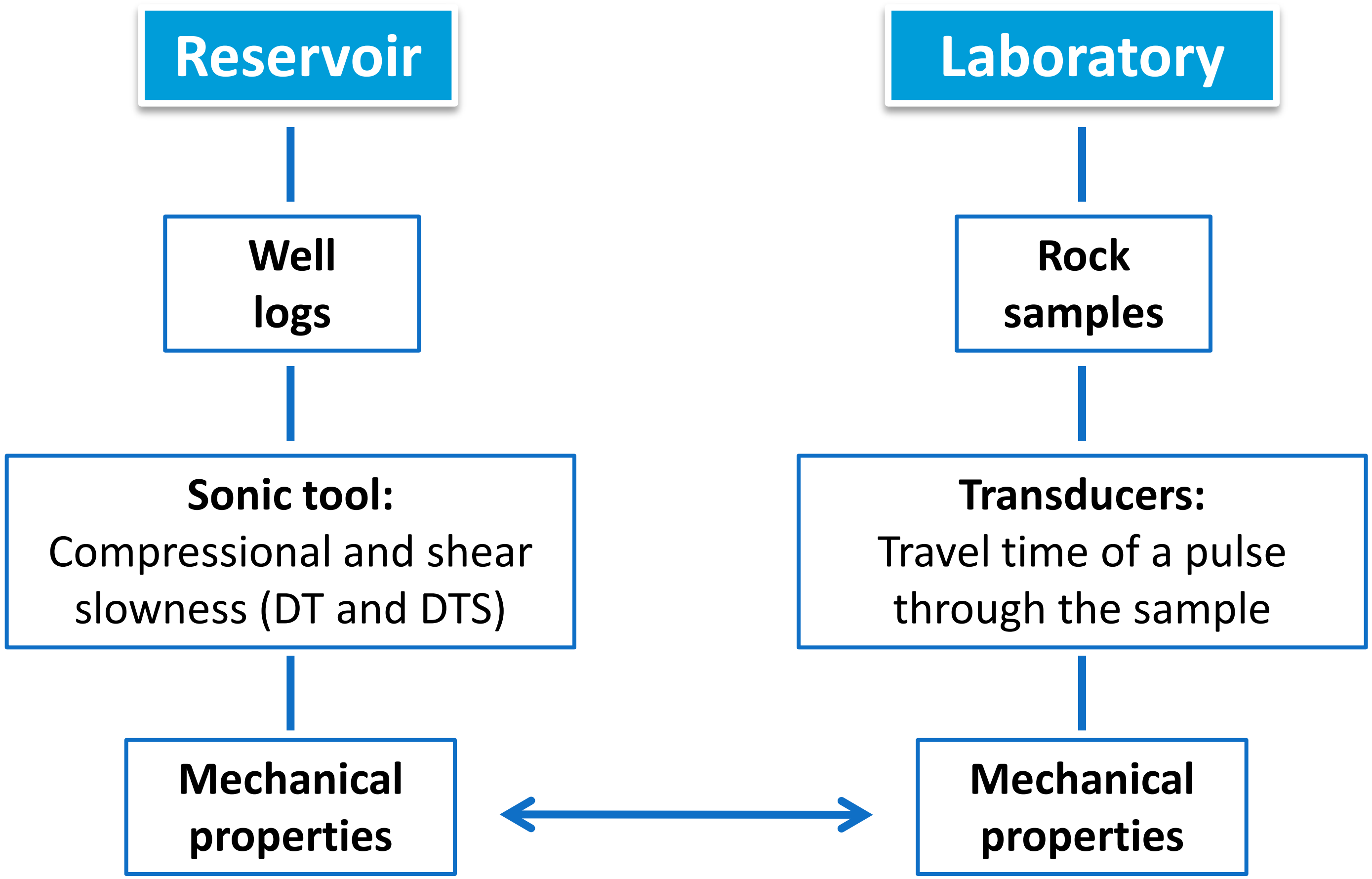
Top Niobrara Contour Map



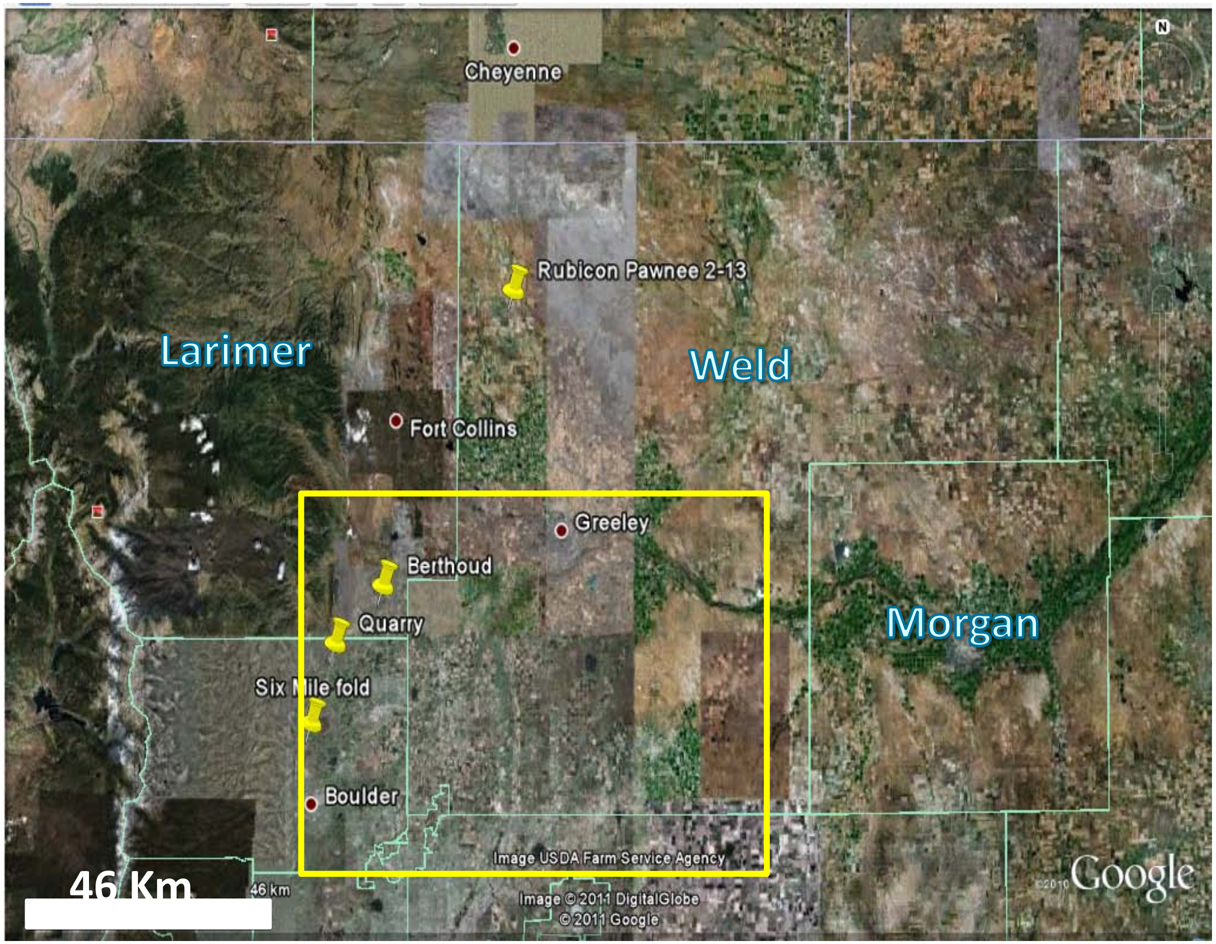
Distance Quarry-Berthoud: 13 Km (8.1 miles)

Projection: UTM 13
Datum: NAD 27

What we learn from logs



What we learn from logs



Distance Quarry-Rubicon Pawnee 2-13-1: 67 Km (42 miles)
API #: 05-123-30997

What we learn from logs

Formulas

$$Vp = \sqrt{\frac{K + 4/3\mu}{\rho}} \qquad Vs = \sqrt{\frac{\mu}{\rho}}$$

K:	Bulk Modulus
μ:	Shear Moulus
ρ:	Density

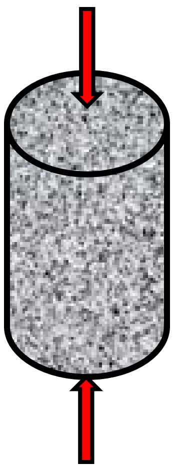
Young's Modulus

$$E = \frac{9K\mu}{3K + \mu}$$

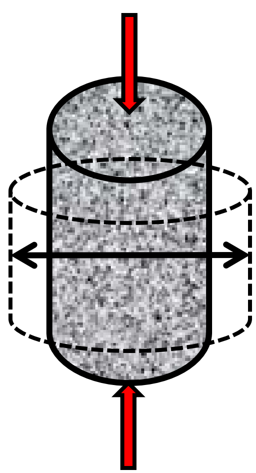
Poisson's Ratio

$$\nu = \frac{1}{2}\,\frac{Vp^2 - 2Vs^2}{Vp^2 - Vs^2}$$

What we learn from logs

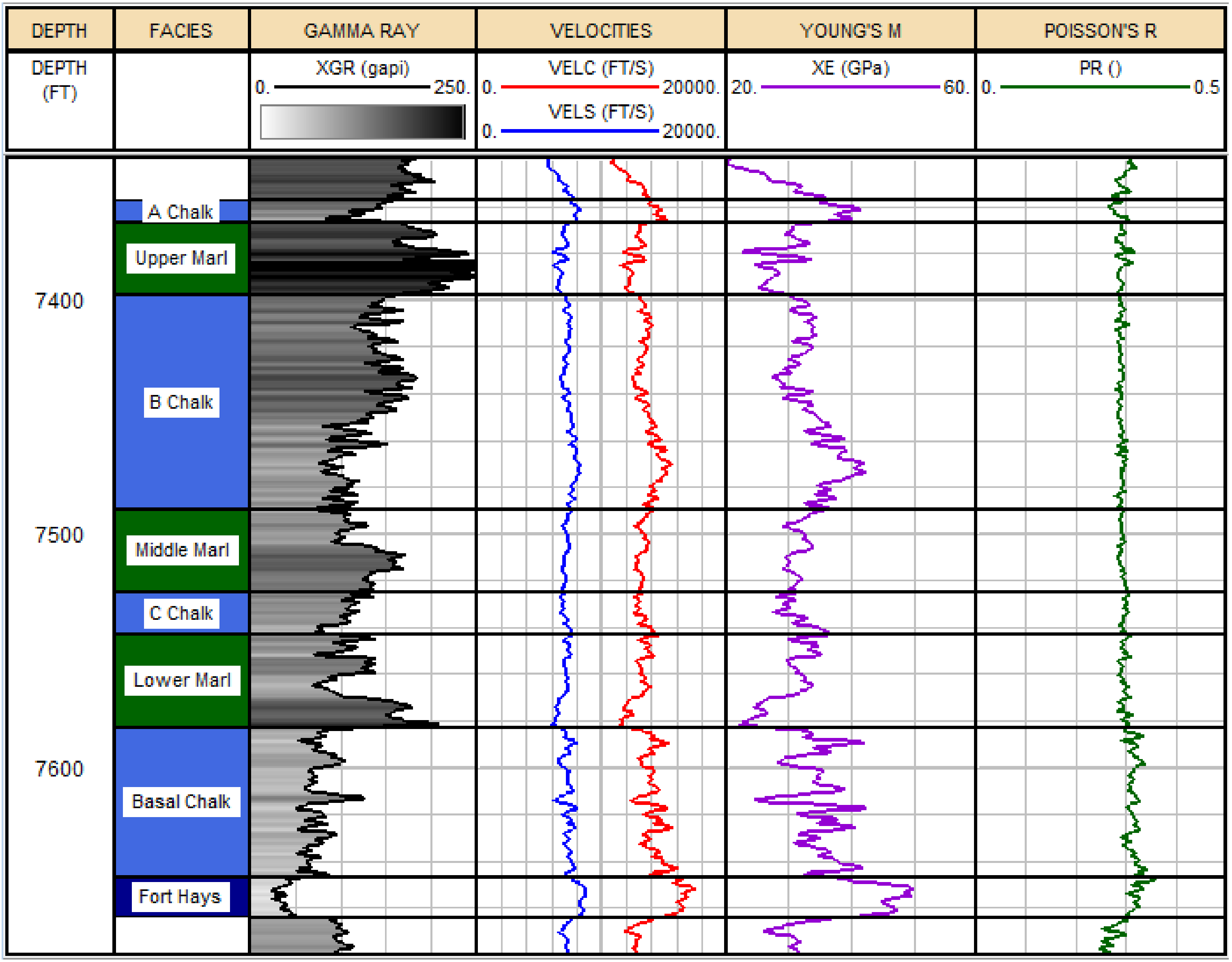


Young's Modulus $E = \frac{\text{Stress}}{\text{Strain}}$

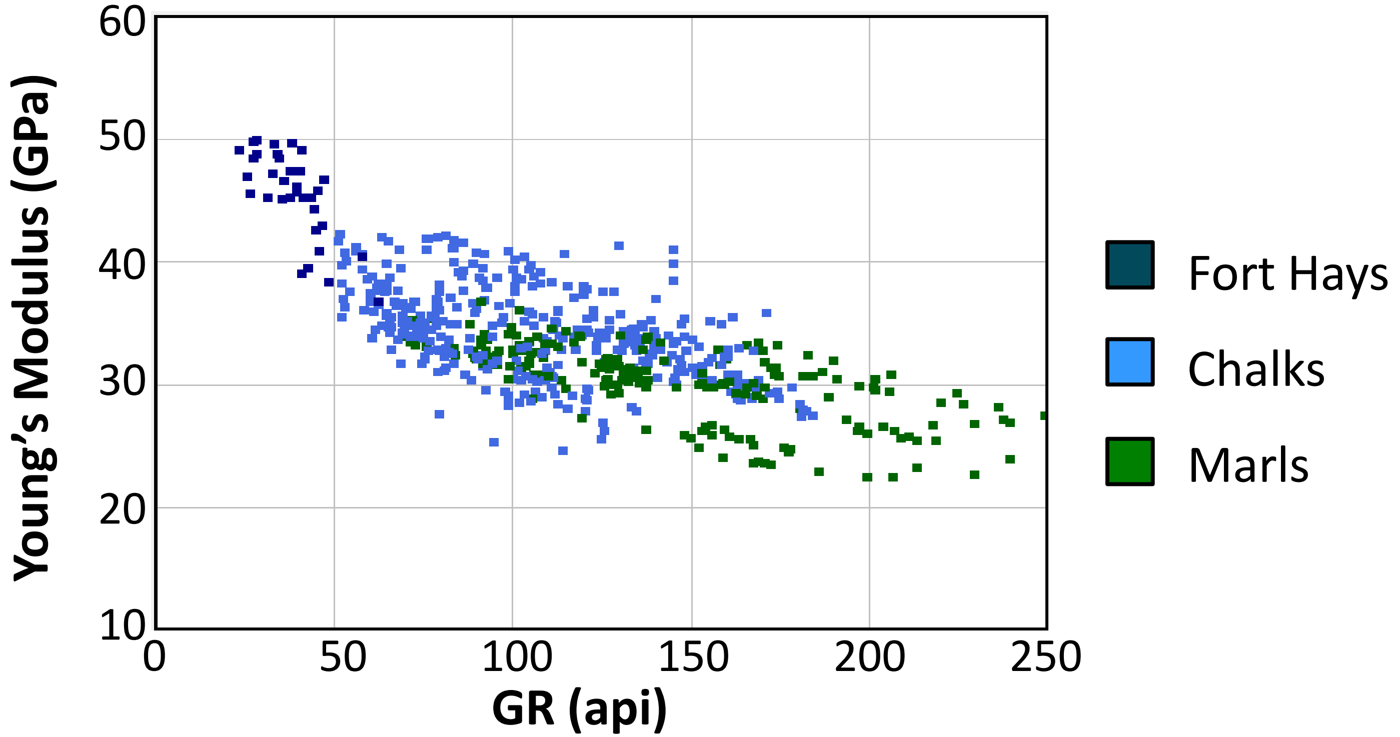


Poisson's Ratio $\nu = \frac{\text{Radial strain}}{\text{Axial strain}}$

Rubicon Pawnee 2-13-1

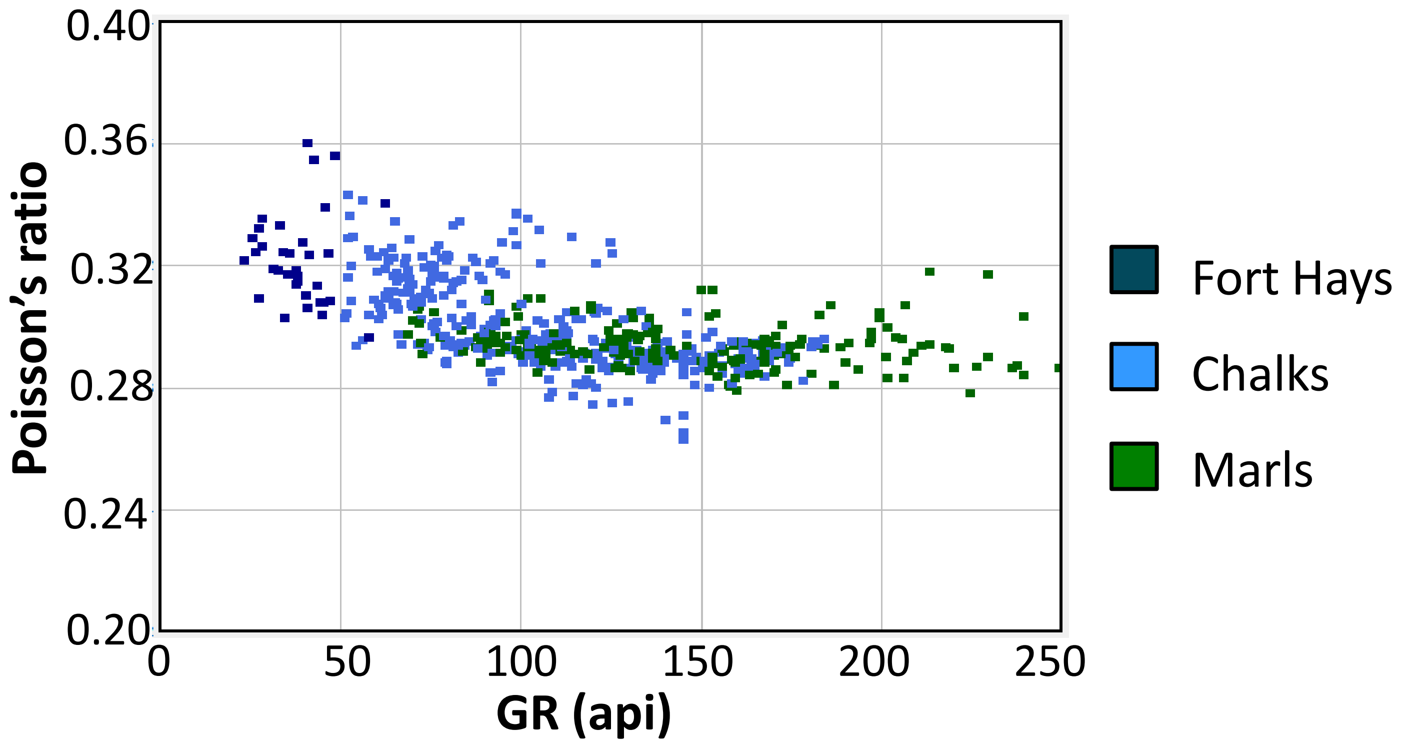


Young's Modulus as a function of Gamma Ray



Facies	Min (GPa)	Max (GPa)	Mode (GPa)
Fort Hays	36.8	50.0	**45.0-48.0**
Chalks	24.5	42.4	**34.1**
Marls	22.2	36.8	**30.6**

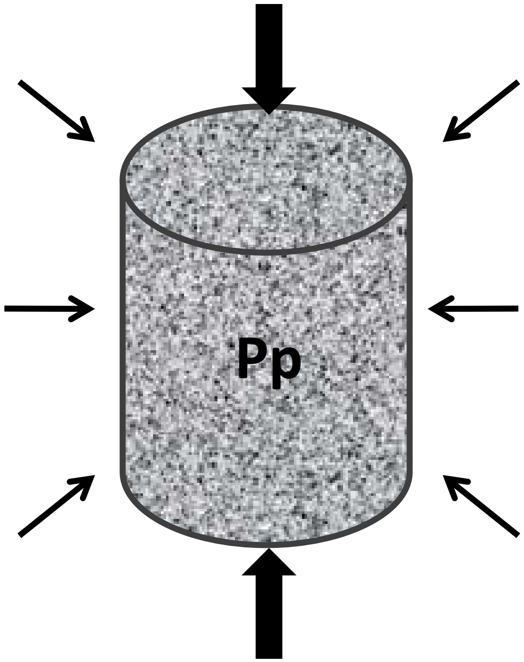
Poisson's ratio as a function of Gamma Ray



Facies	Min	Max	Mode
Fort Hays	0.30	0.36	**0.32**
Chalks	0.26	0.34	**0.29**
Marls	0.28	0.32	**0.29**

What we learn from rocks

Triaxial tests

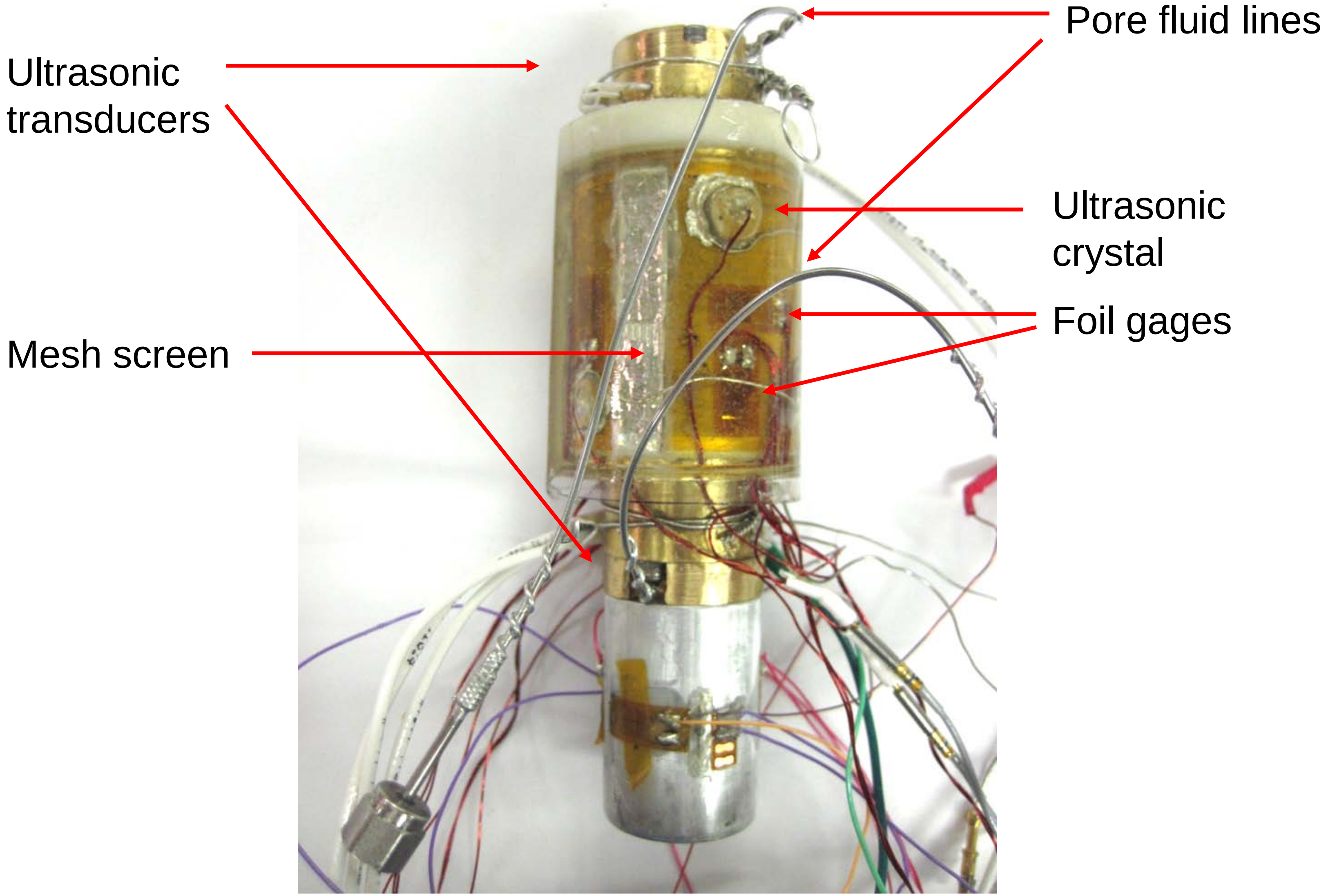


Simulation of reservoir conditions

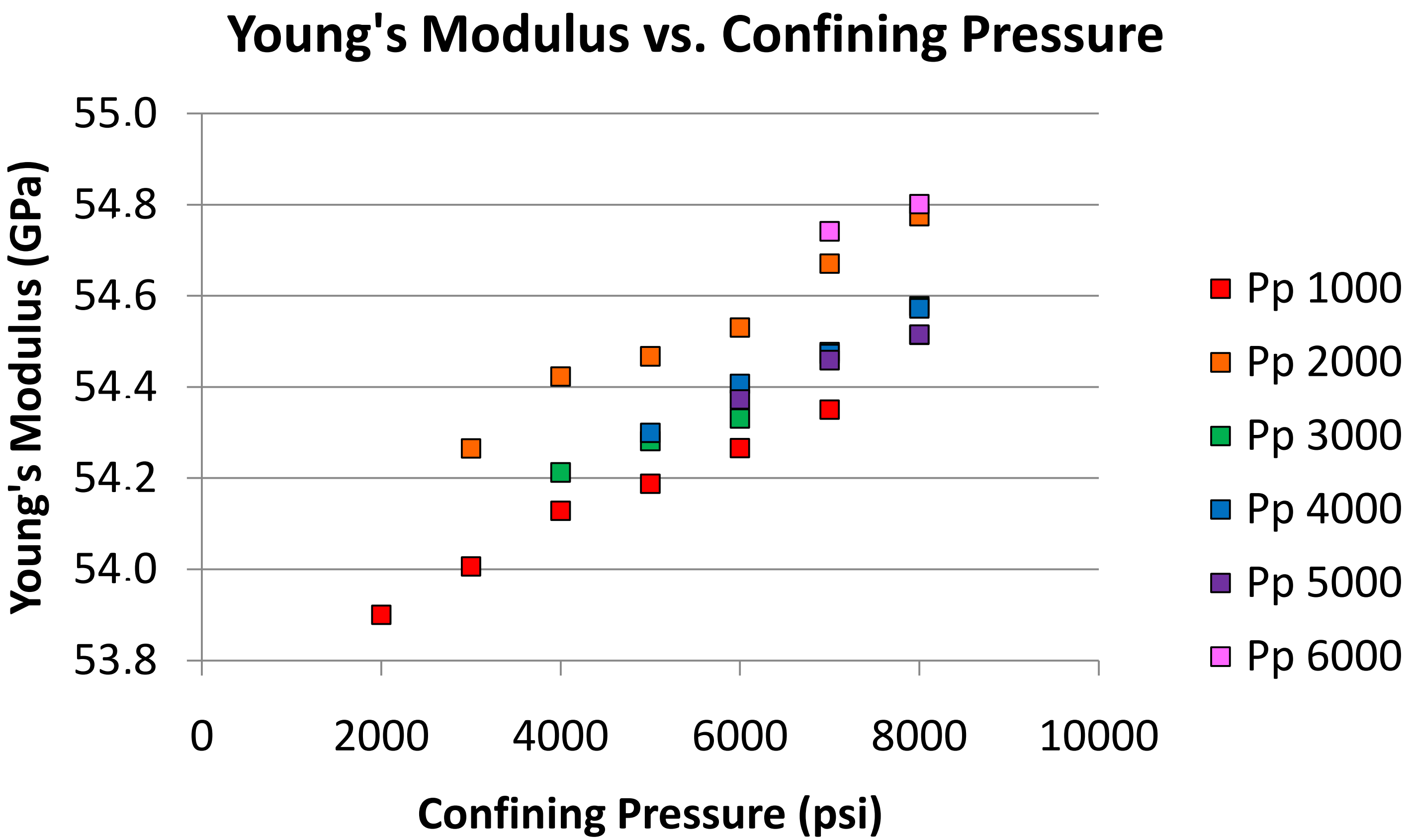
- Axial pressure 1 psi/ft
- Confining pressure
- Pore pressure 0.62 psi/ft

At a depth of 8000 ft:
Axial pressure : 8000 psi
Pore pressure: 6000 psi

What we learn from rocks

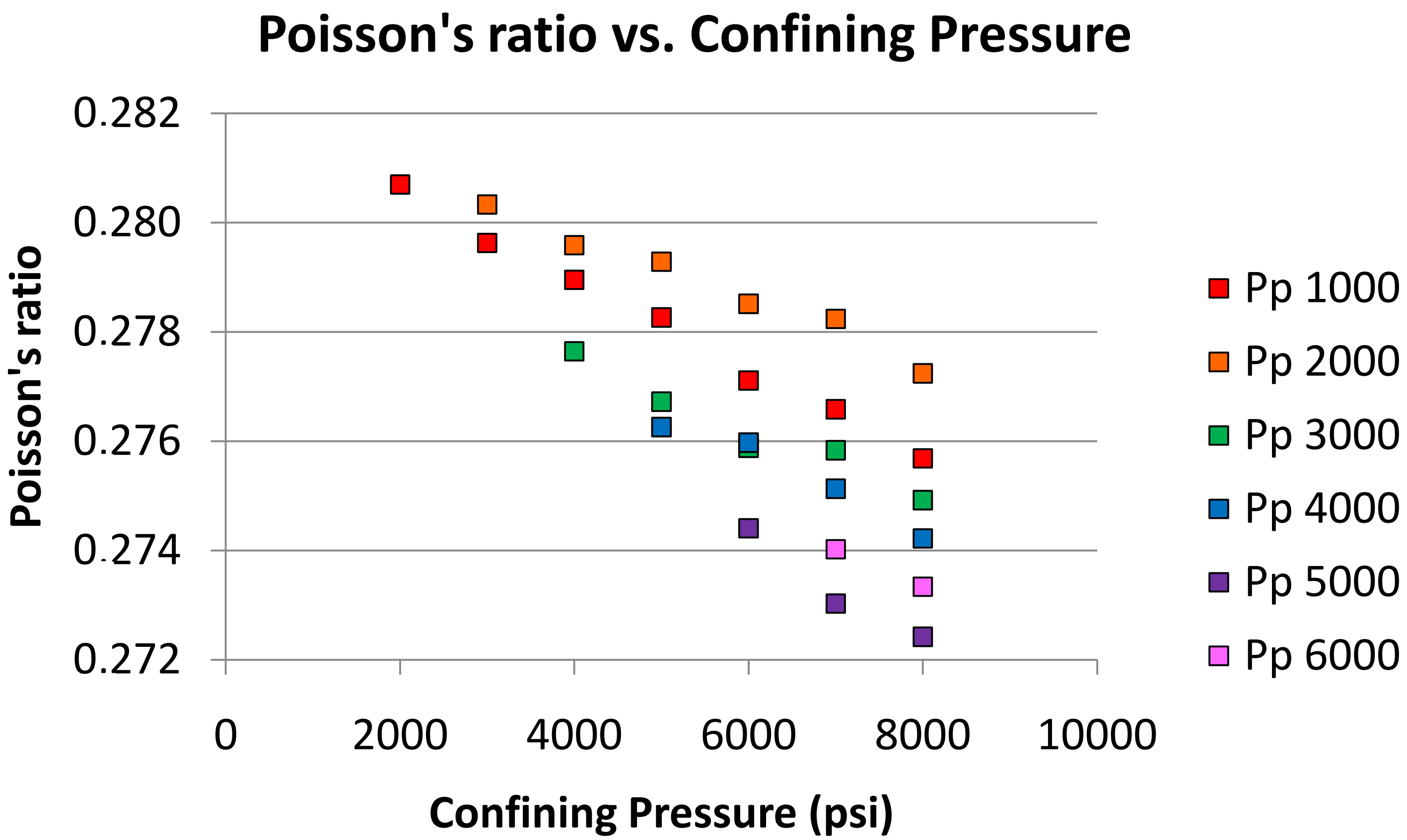


Fort Hays sample



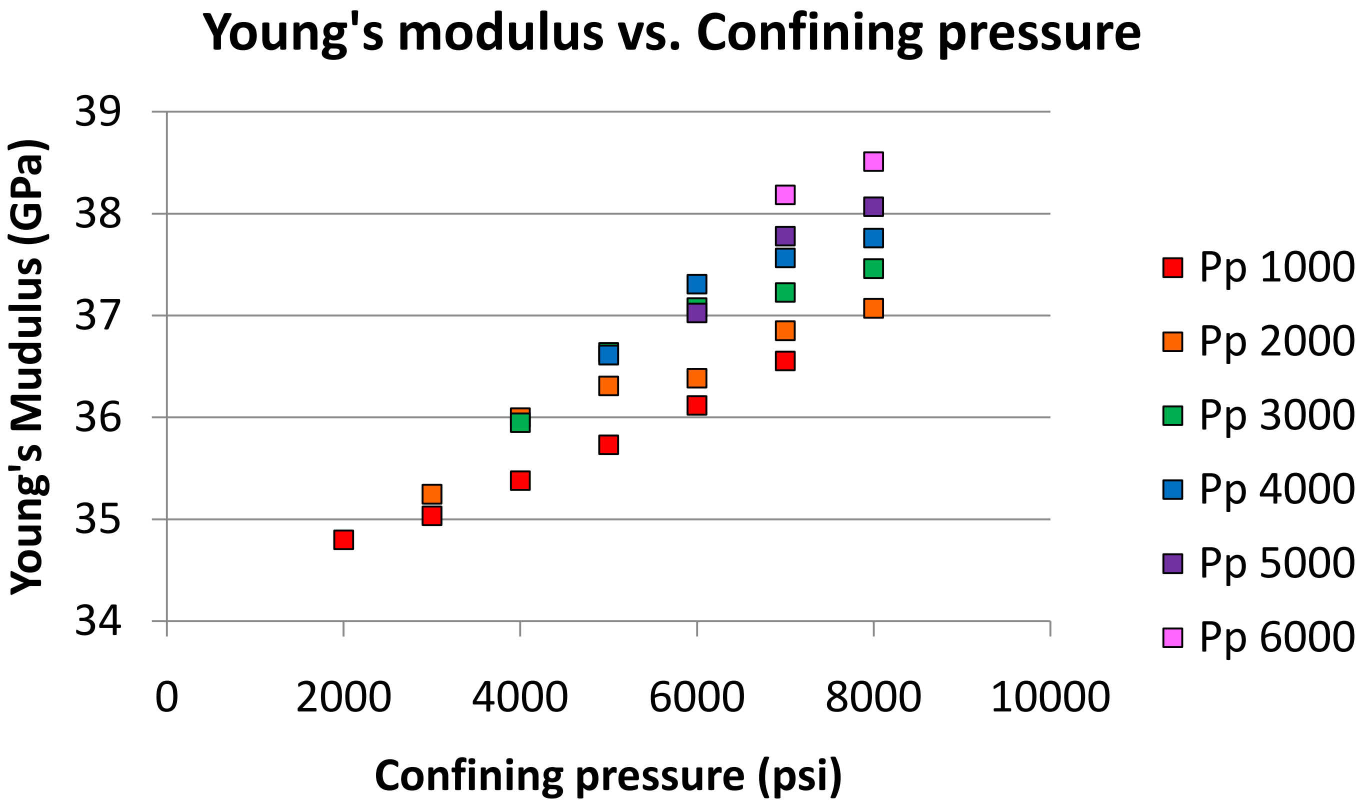
Error: ±1 Gpa
Mean: 45-48 GPa

Fort Hays sample



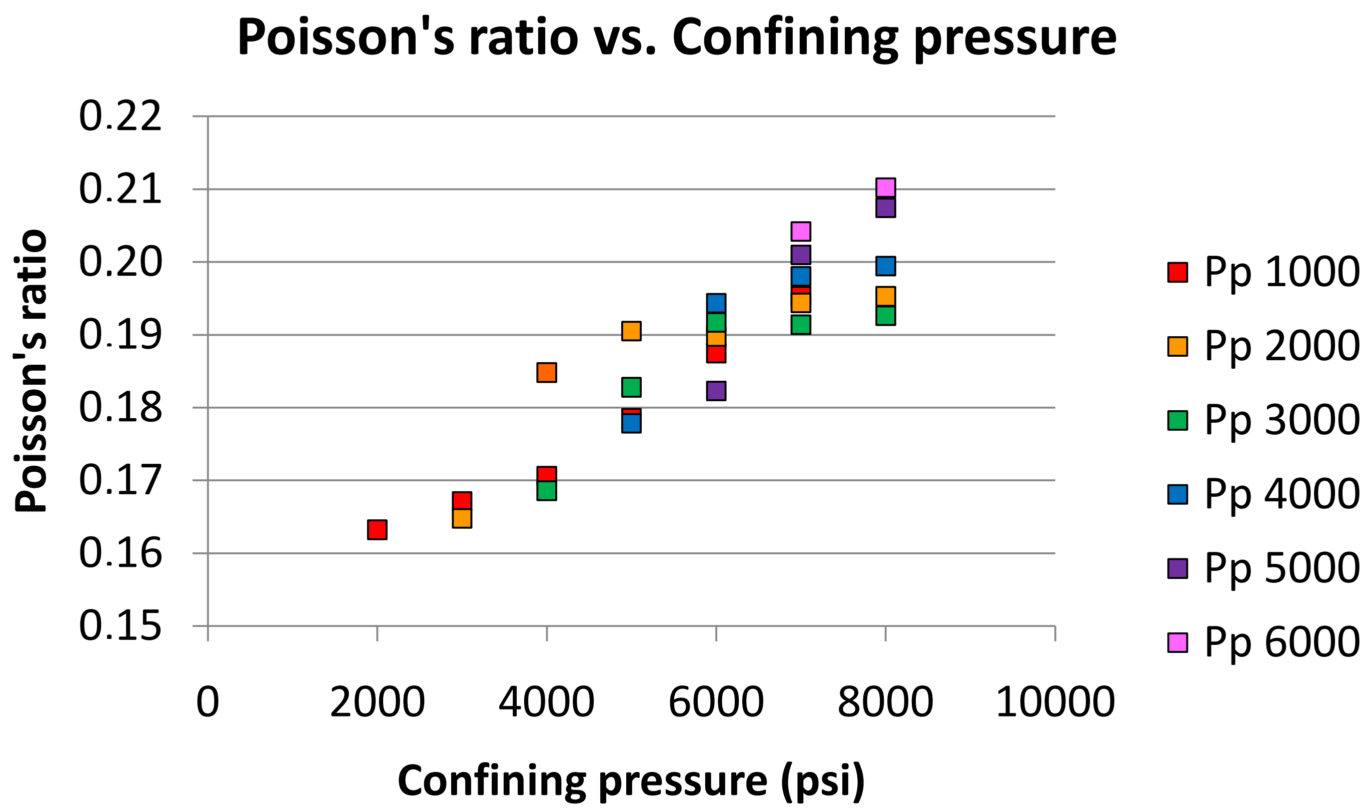
Error: ± 2%
Mode: 0.32

Lower Marl sample



Error: ±1 Gpa
Mean: 30.6 GPa

Lower Marl sample



Error: ± 2%
Mode: 0.29

Effective stress coefficient

Differential pressure $Pd=Pc-Pp$

Effective pressure $Peff= Pc - nPp$

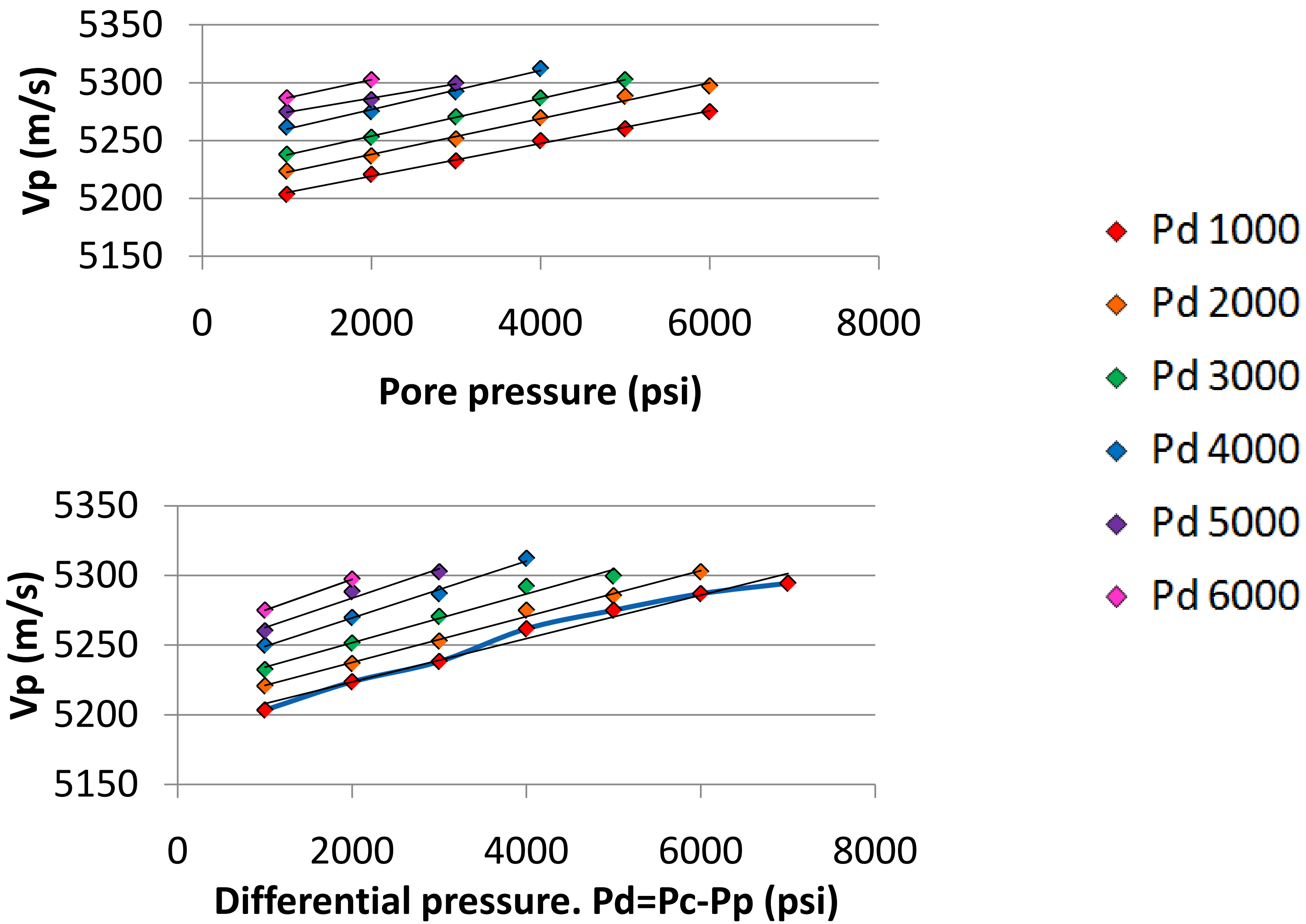
$$n = 1 - \frac{(\partial Vp/\partial P_p)_{Pd}}{(\partial Vp/\partial P_d)_{Pp}}$$

Minimum horizontal in-situ stress calculation

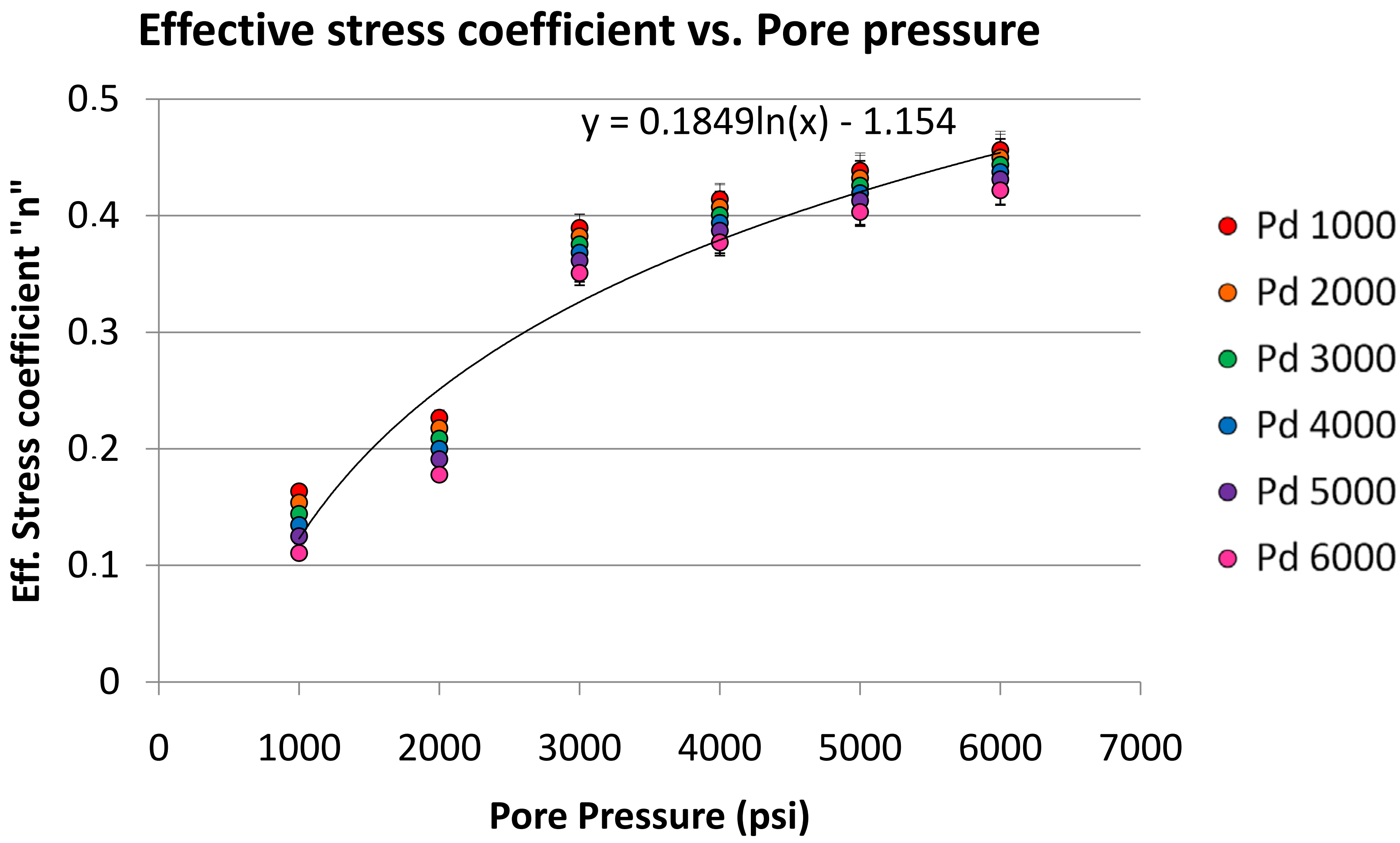
$$\sigma_h = \frac{\nu}{1-\nu}(\sigma_v - nP_p) + nP_p + Tectonic\ stresses$$

$$\sigma_h = \frac{E_h}{E_v}\frac{\nu_v}{1-\nu_h}(\sigma_v - nP_p) + nP_p + Tectonic\ stresses$$

Fort Hays sample

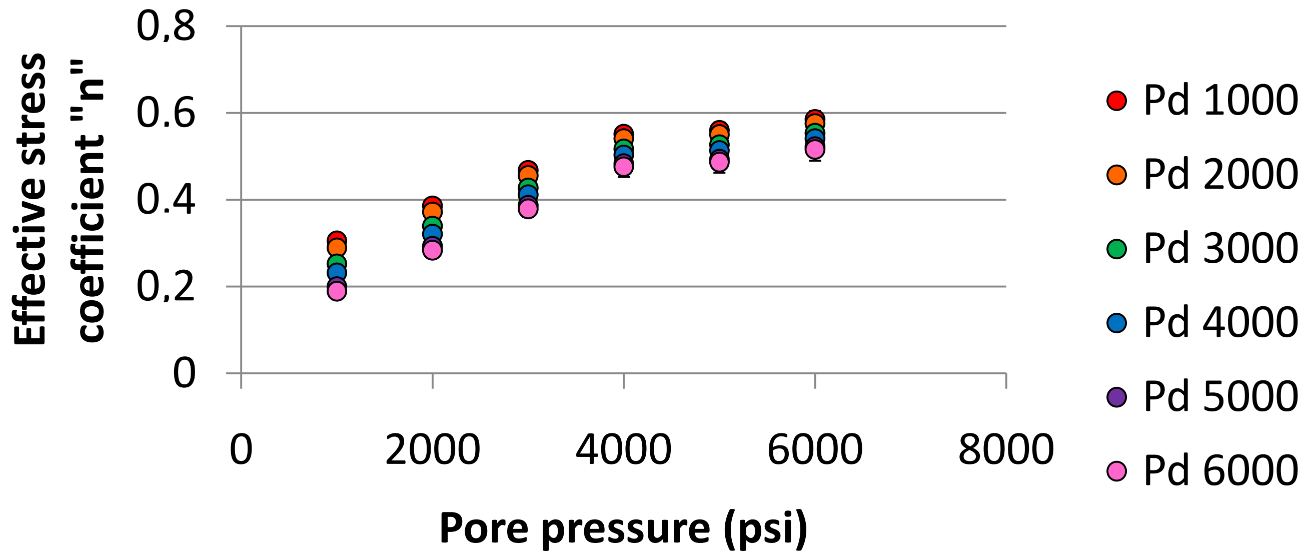


Fort Hays sample

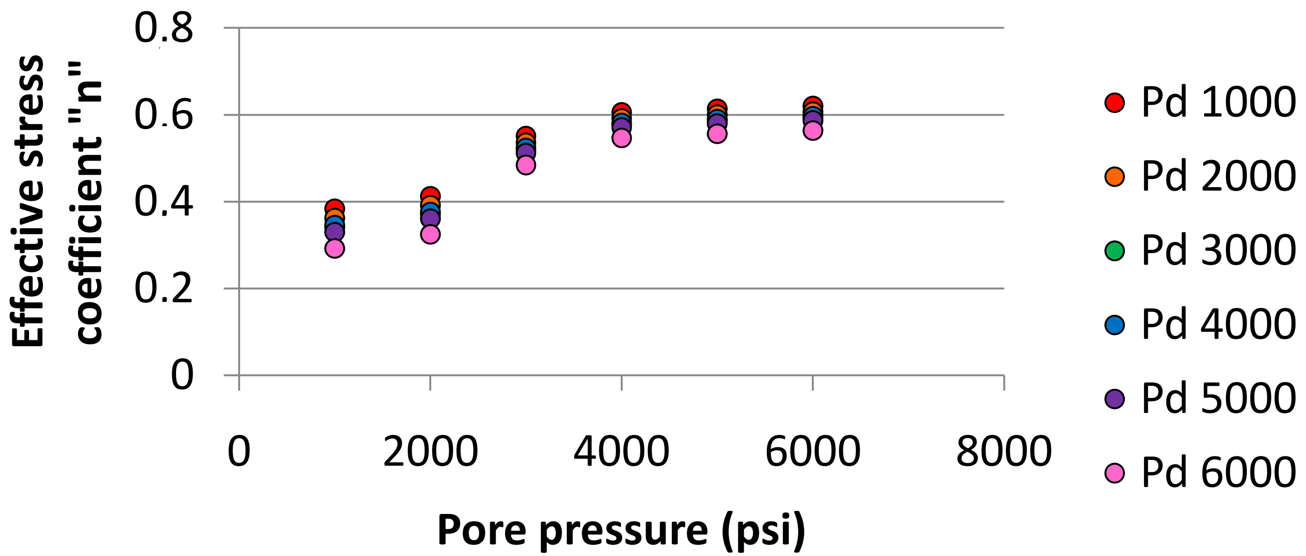


Lower Marl sample

Vp 0



Vp 90



Summary and conclusions

- What we learn from logs
  - Fastest way to obtain mechanical properties of a complete, continuous interval of interest.
  - Good to have DT, even better to have DTS.
  - Horizontal wells will allow the measurement of horizontal properties.

- What we learn from rocks
  - Mechanical properties can be measured in different directions, obtaining anisotropic measurements of the mechanical properties.
  - The effective stress coeficient “n” is a valuable measurement, that controls the in-situ stress conditions of the reservoir. This is highly important as it will define the behavior of the reservoir, including fracture initiation and growth. Assuming a value of n=1 would give an error of the effective pressure of 55% (in comparison to n=0.5)

Thanks for your attention

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