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Use of wire line logs for estimation of strength variability in cap--rock lithologies

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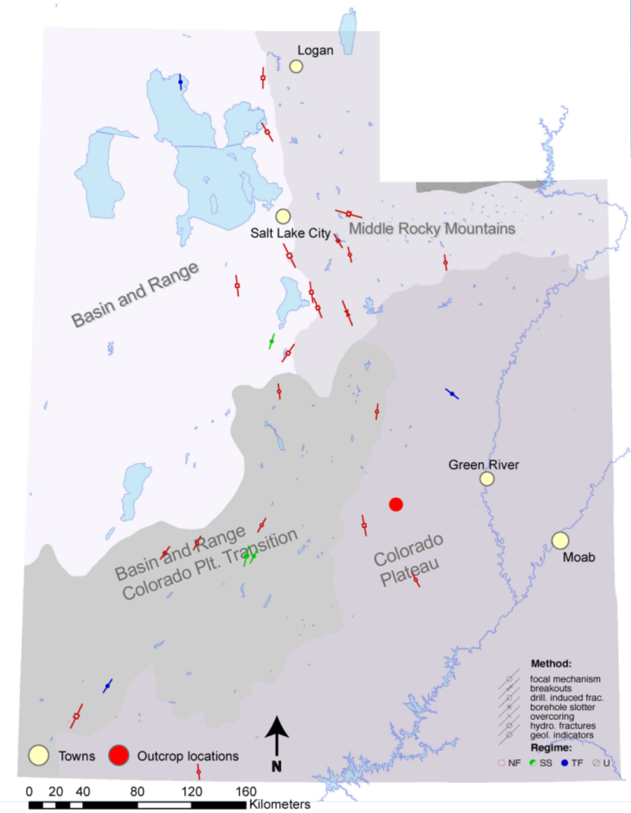
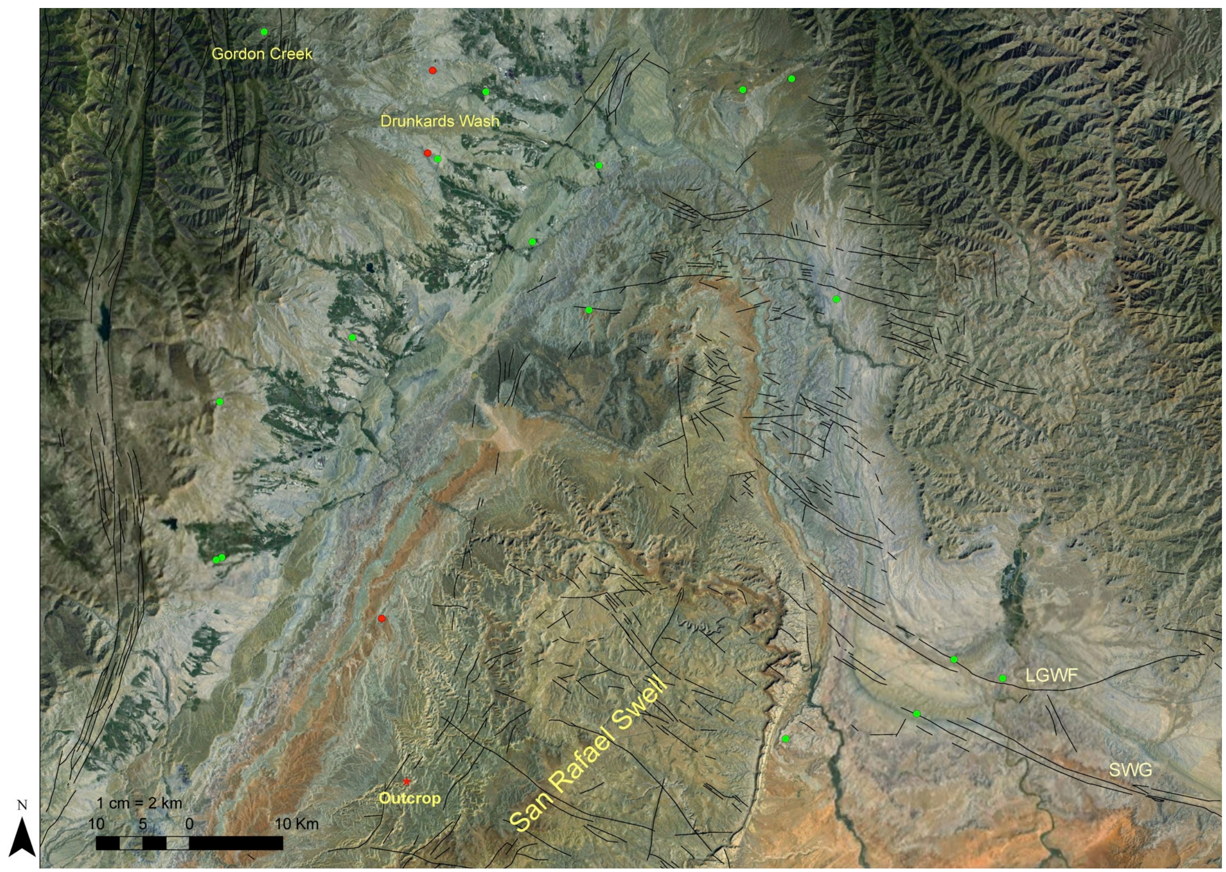
Introduction

- Characterization of cap-rock lithologies at reservoir-seal and intra-seal interface
- Examine lateral and vertical variability of Poisson's Ratio and Young's Modulus
- Field and sub-surface methods and results

Study Area

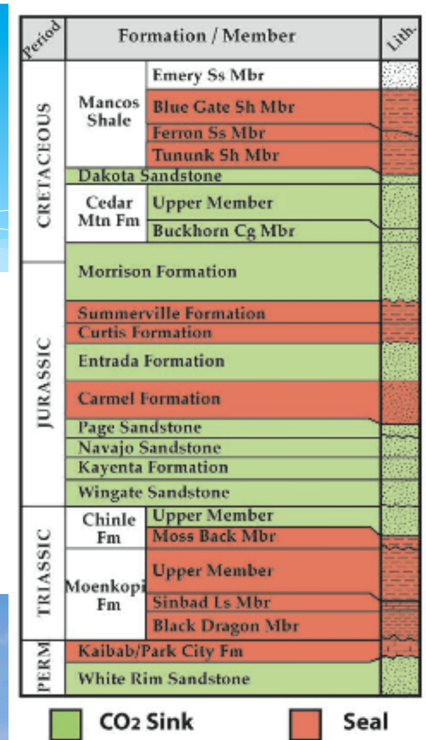


- Pilot study – Jurassic Carmel Formation
- Located on western edge of San Rafael Swell along I-70
- 20 wells analyzed covering approximately 440 km^2

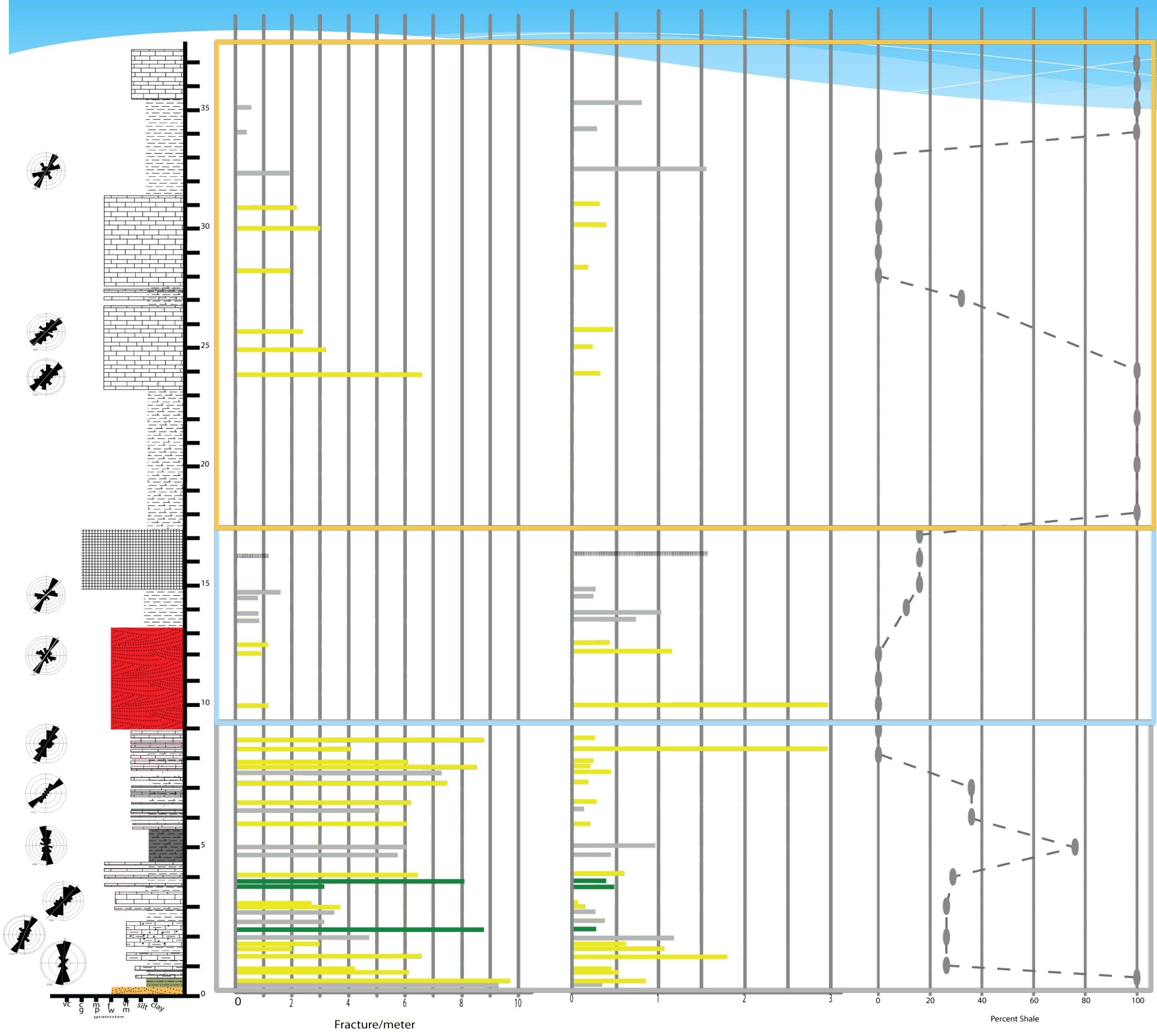


Jurassic Carmel Formation

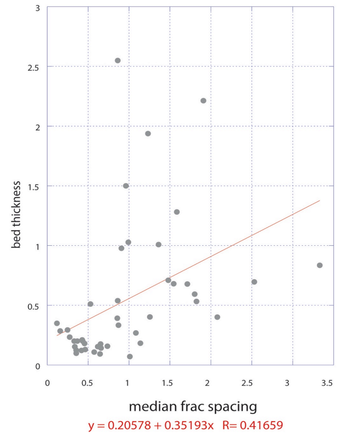
- Seal to the underlying Navajo Sandstone
- I-70 outcrop at western edge of San Rafael Swell
- Mineralized fractures (veins) and open fractures
- Mixed siliciclastic carbonate sedimentary sequence of shallow marine to peritidal origin



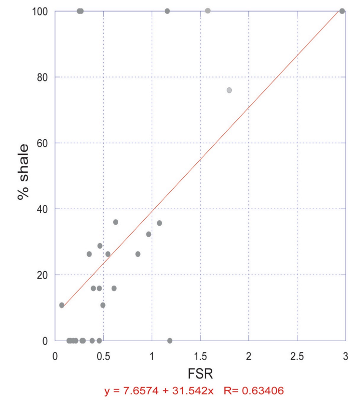
From: NETL: SWP



Fracture Intensity
Fracture Spacing Ratio
Percent Shale
Fracture/meter
Percent Shale
grainsize



bed thickness
median frac spacing
y = 0.20578 + 0.35193x R= 0.41659



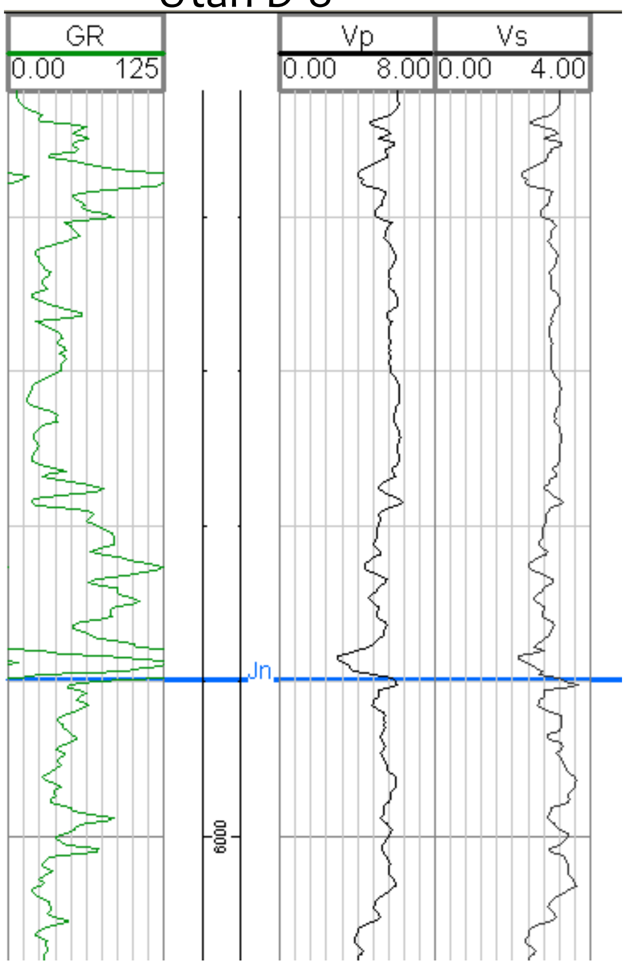
% shale
FSR
y = 7.6574 + 31.542x R= 0.63406

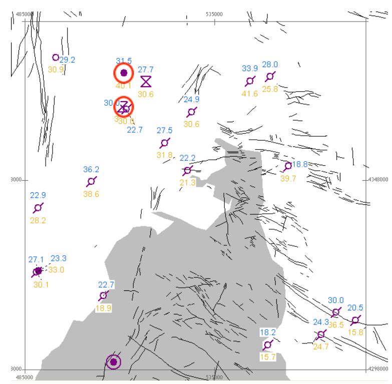
Shear Velocity Calculations

- Covert digitized sonic log travel times to velocity
- Vertical resolution limited by frequency and distance between transmitter and receiver ~ 2 ft or 61 cm

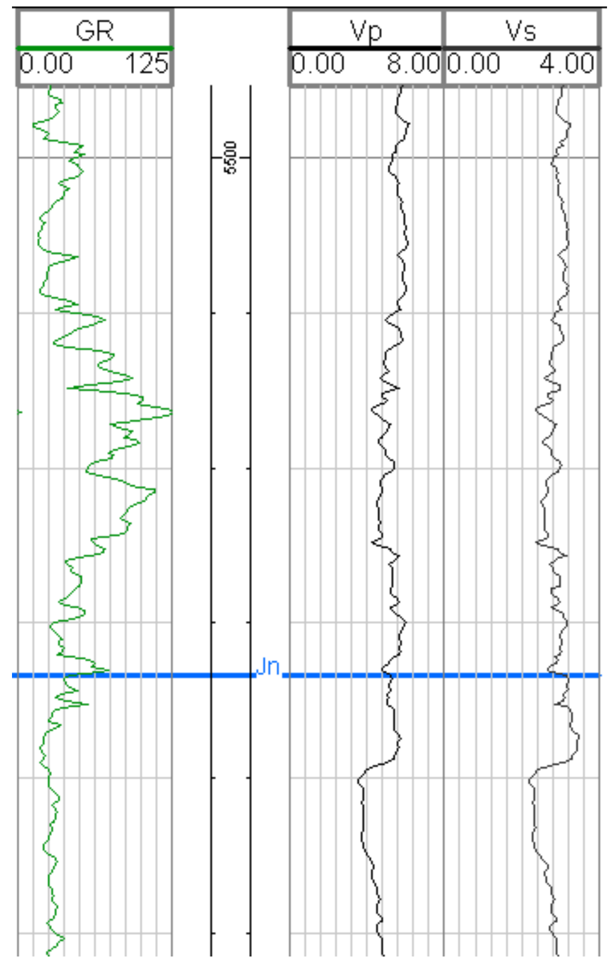
2.71 km

Utah D-8



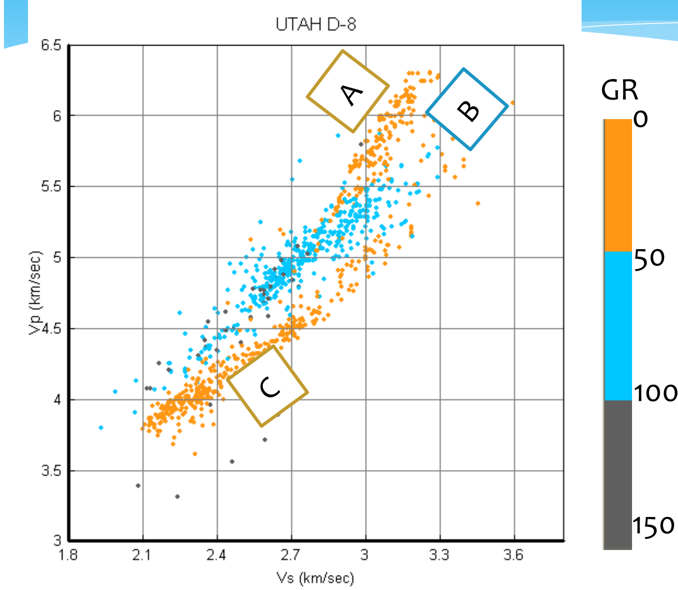


Utah D-7

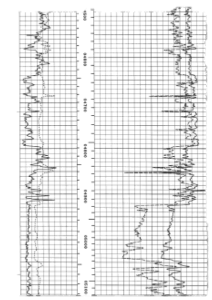


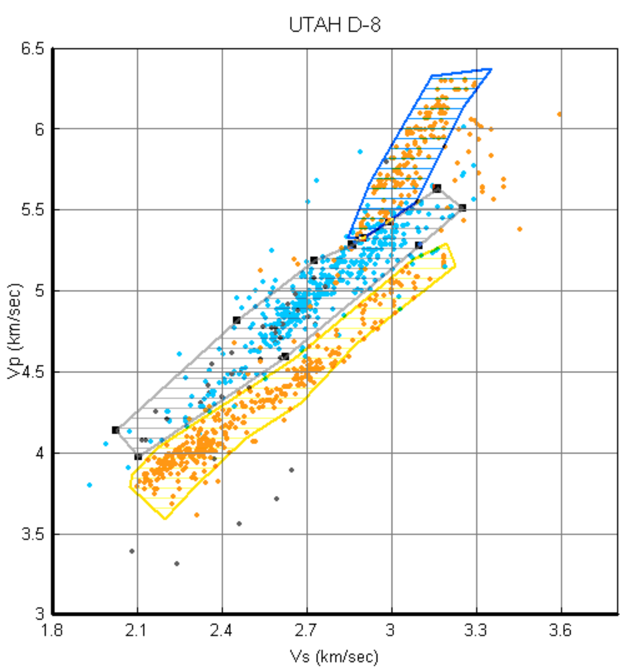
Well log analysis

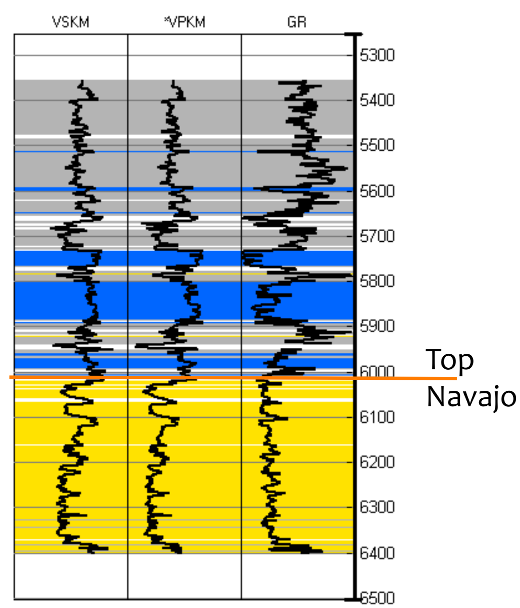
Raster well log data from 20 wells used to derive Poisson's Ratio and Young's Modulus



- Dipole sonic logs not available for all wells – must derive shear velocity from compressional velocity
- Empirical – based on relationships established by previous workers and verified using dipole sonic logs from two wells
- Need bulk density to calculate Young' s Modulus
    - Density is often presented as density porosity must convert to bulk density







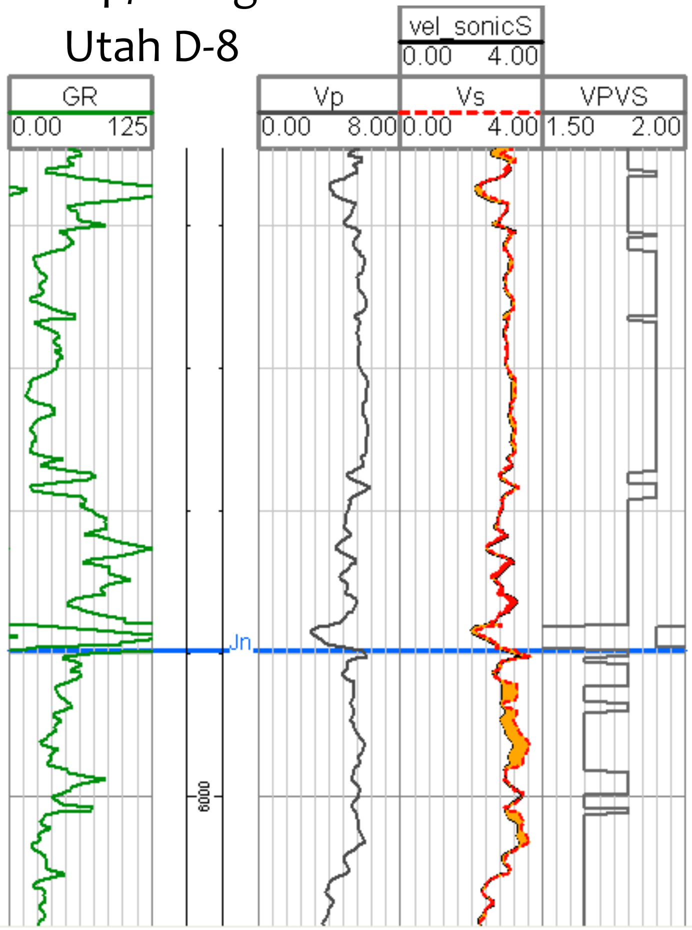
Gamma Ray	V_p/V_s	Cross plot
GR<50, Carmel	1.9	A
150>GR>50	1.8	B
GR<50, Navajo	1.6	C
GR>150	1.5	

Shear Velocity Calculations

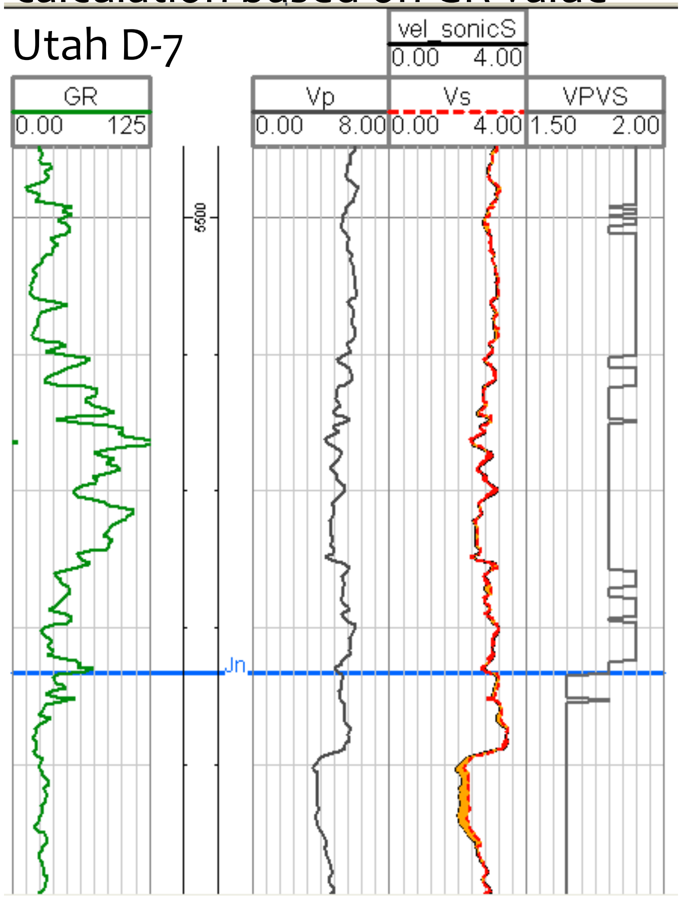
Vs from Vp and observed lithology relationship

- Control wells show a 3.1-3.8% difference between measured and calculated shear velocity
- Vp/Vs log shows the relationship used for Vp to Vs calculation based on GR value

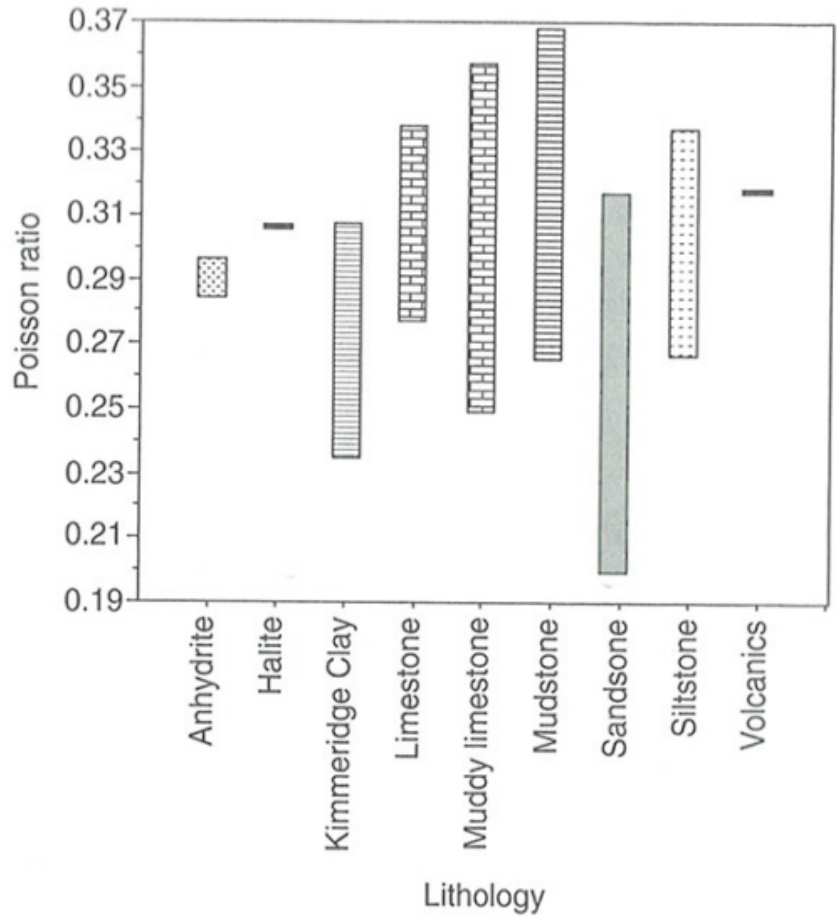
Utah D-8



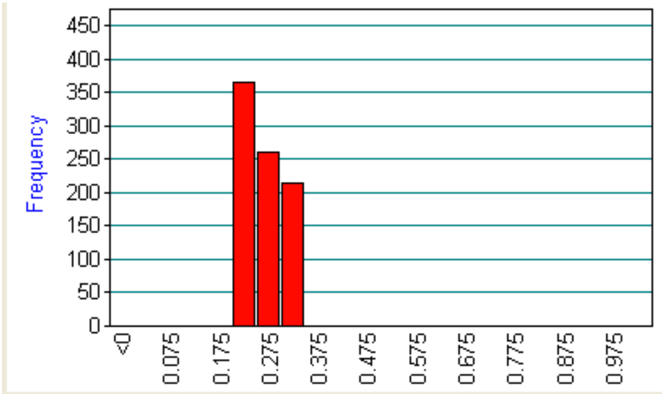
Utah D-7



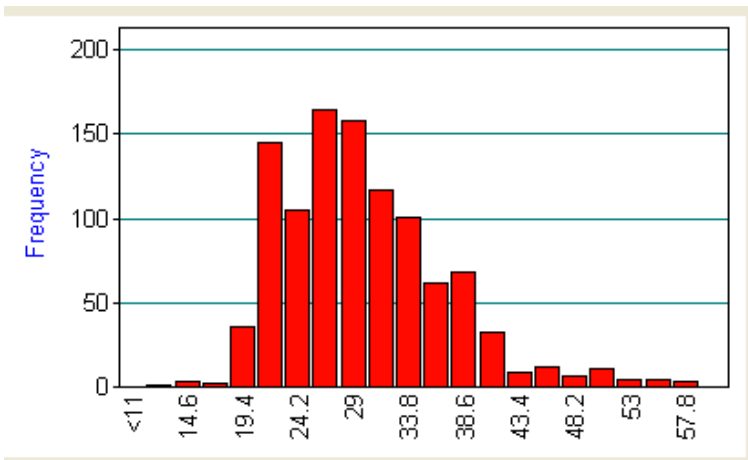
Poisson's Ratio



Published Poisson's ratio for various lithologies (from BP)

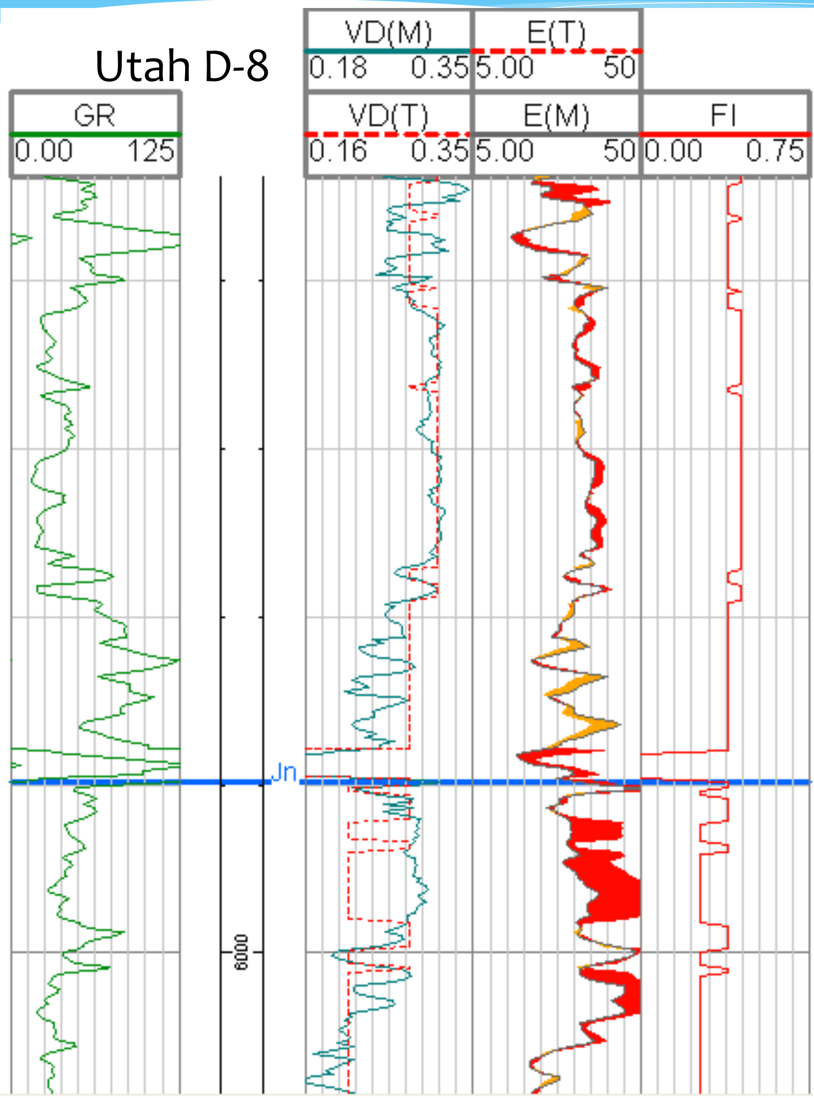


Poisson's Ratio – calculated values fit with published values for sandstone, muddy limestone and mudstone

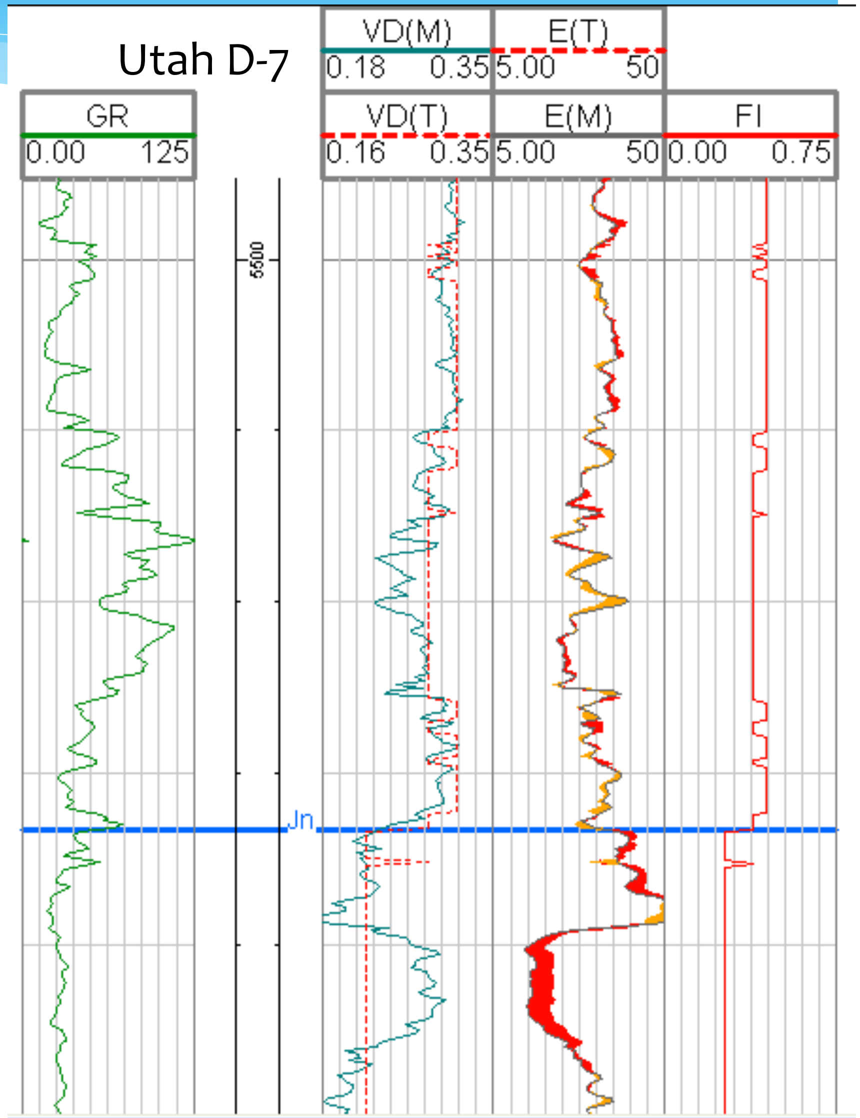


Young's Modulus GPa

Young’s Modulus Calculations



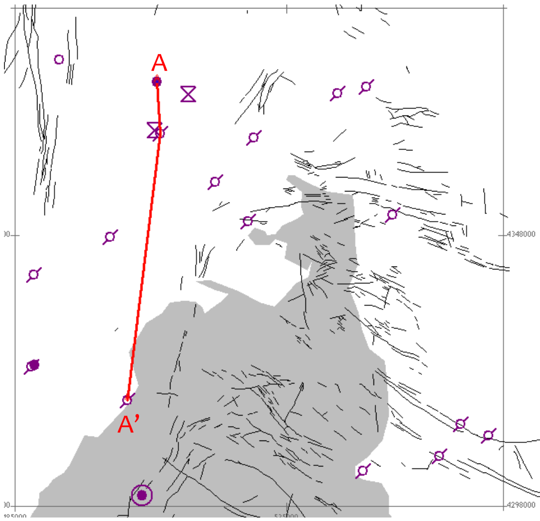
Percent difference
Carmel 1.3% Navajo 13%



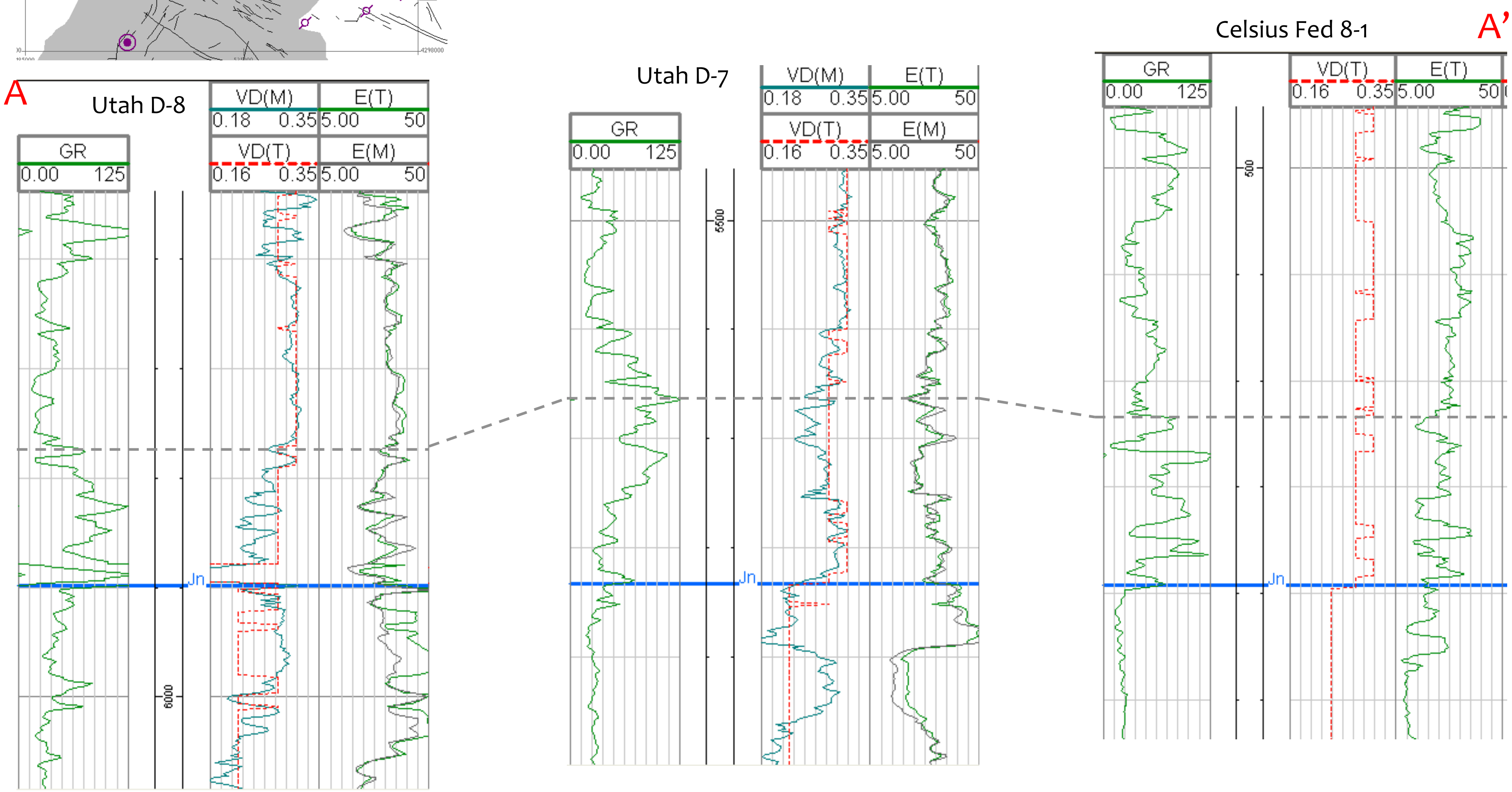
Percent difference
Carmel 1.5% Navajo 2.3%

Results

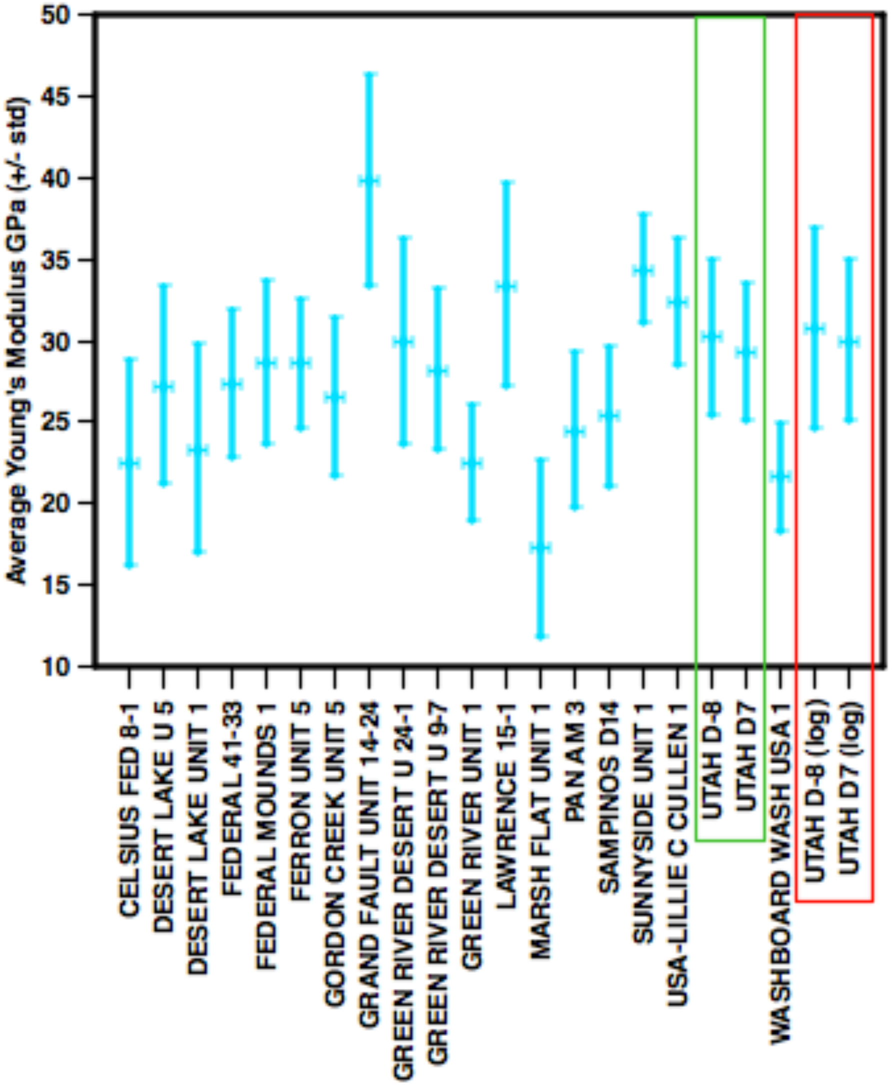
Poisson's ratio and Young's modulus calculated 20 wells



- Poisson's ratio reflects an average of expected values over a defined by GR lithologic zones

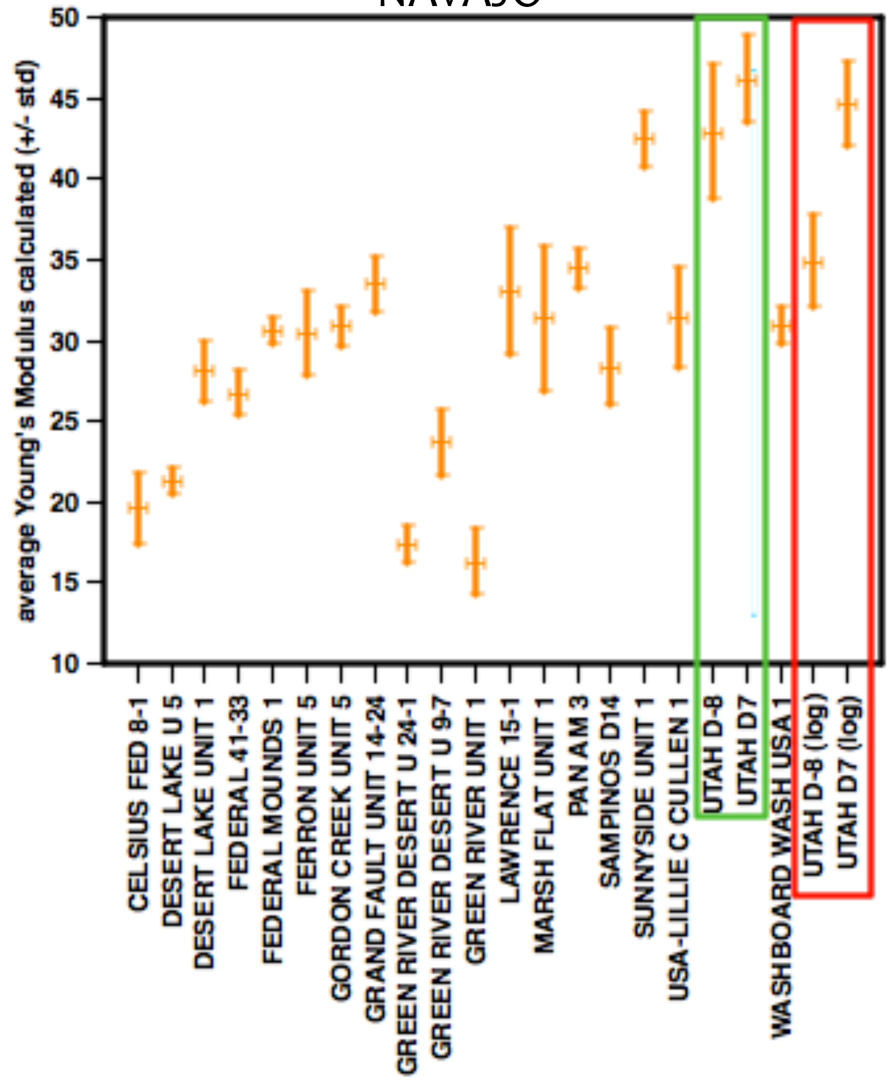


Variability in calculated E_d

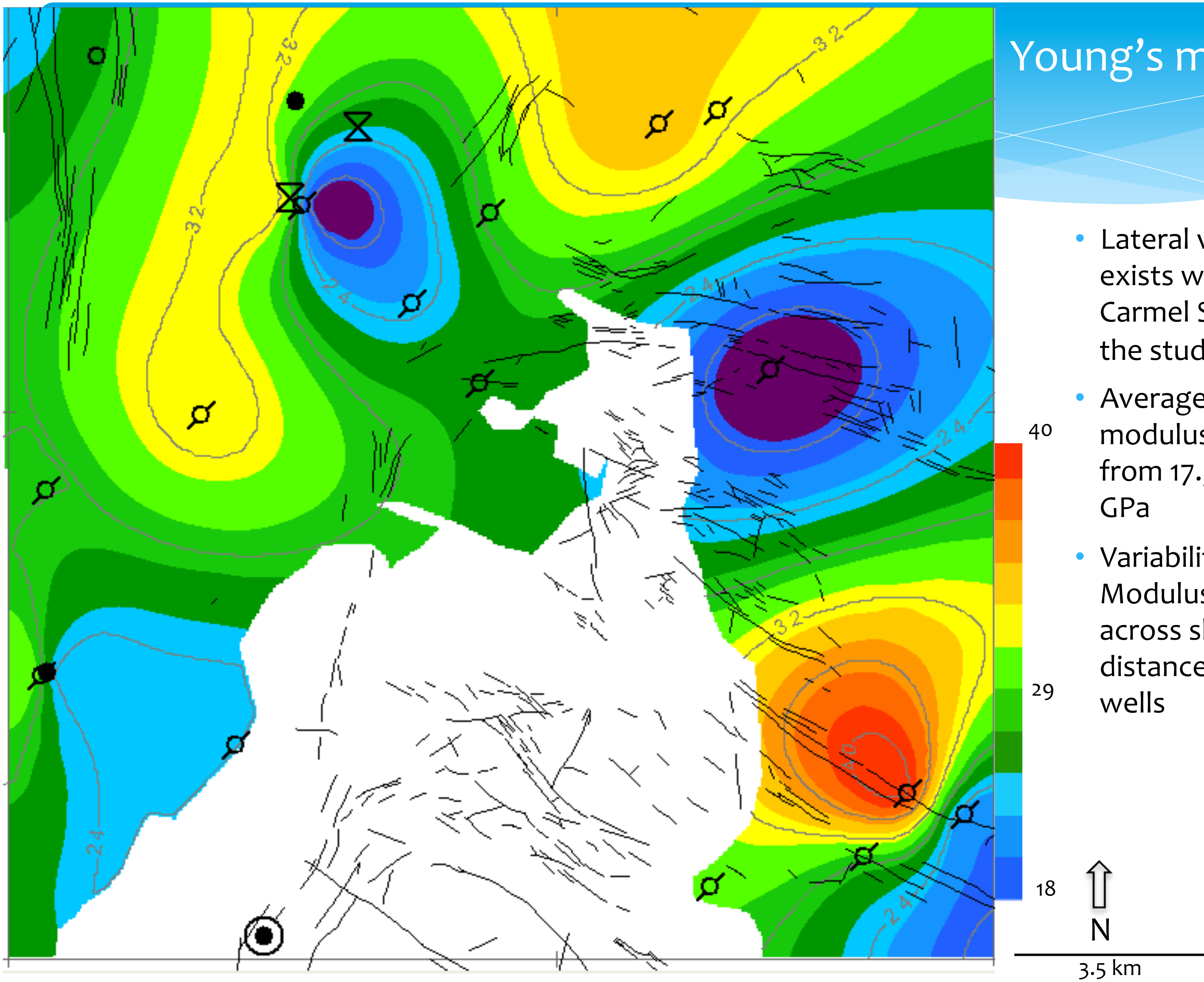


CARMEL SEAL

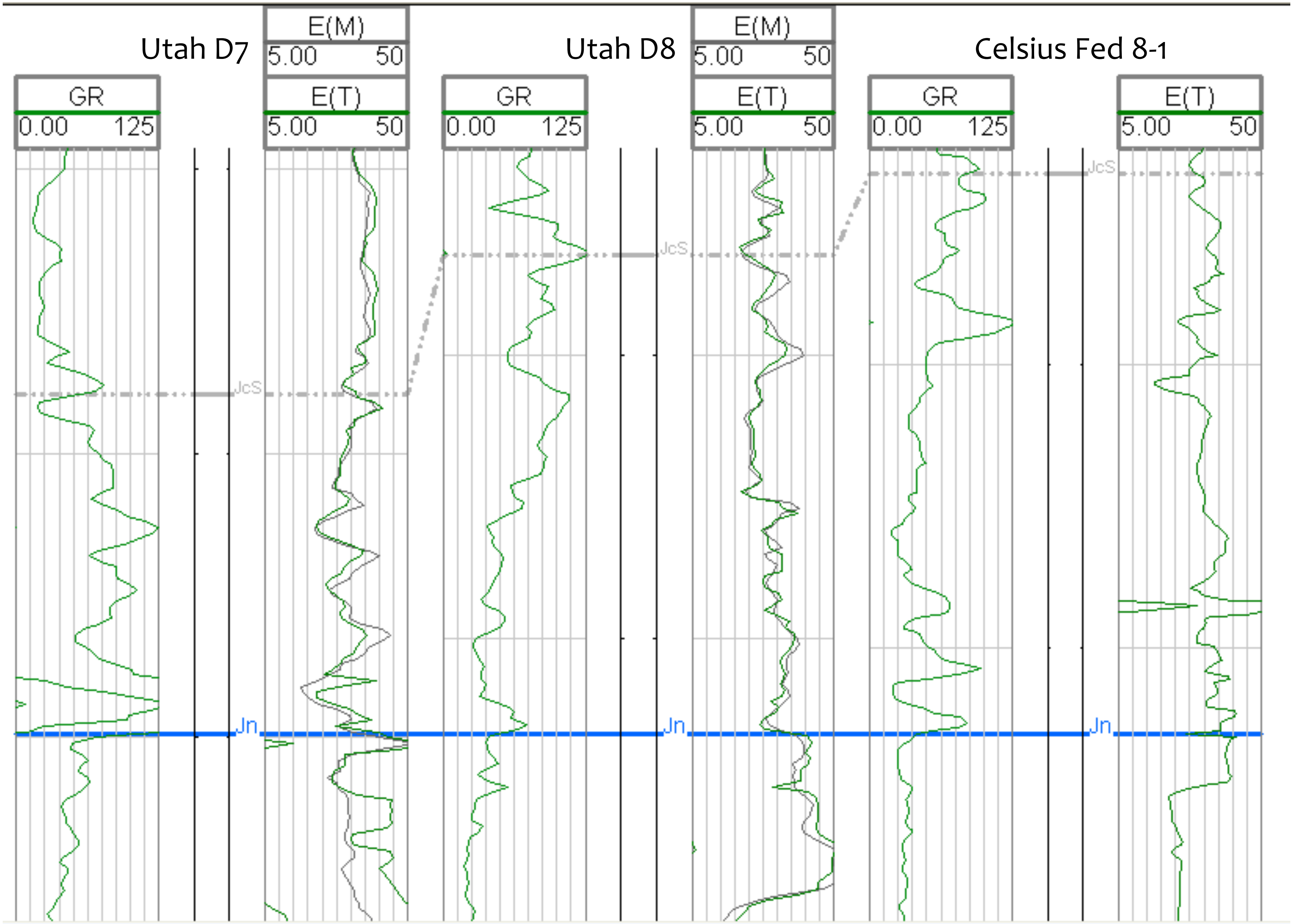
NAVAJO



Young's modulus

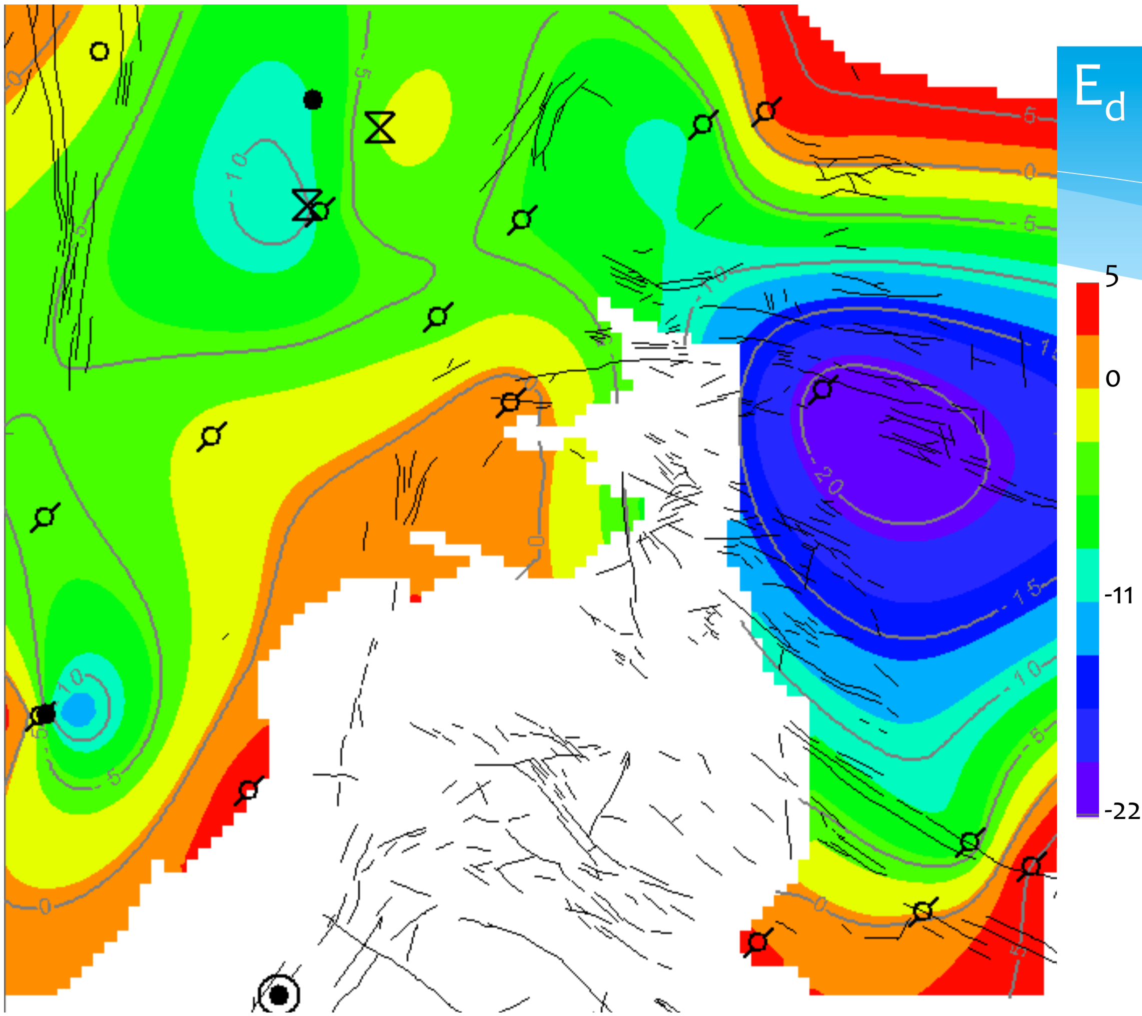


- Lateral variability exists within the Carmel Seal across the study area
- Average Young's modulus ranges from 17.3 to 39.7 GPa
- Variability in Young's Modulus observed across short distances in offset wells

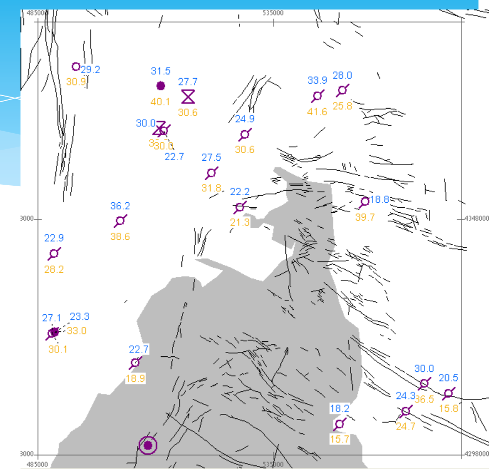


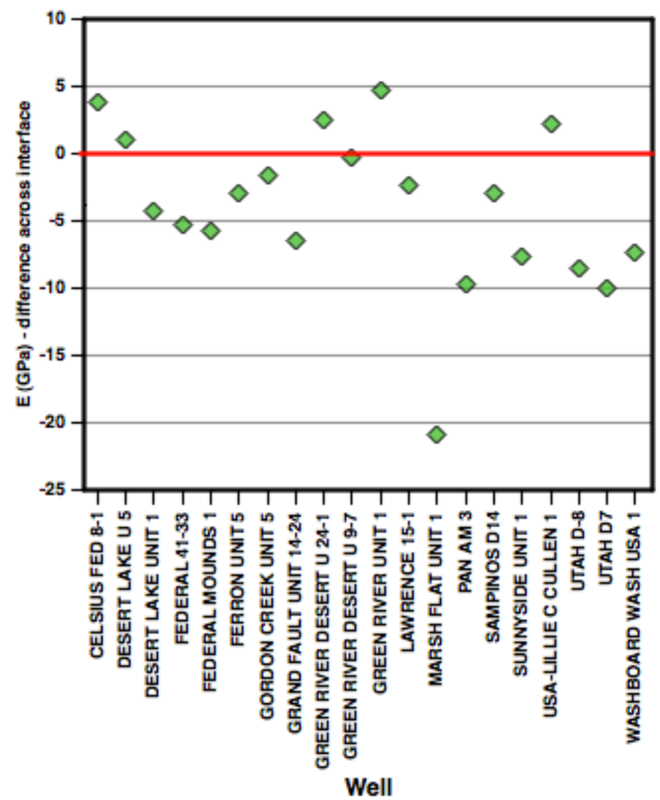
Utah D7
Utah D8
Celsius Fed 8-1
GR
0.00 125
E(M)
5.00 50
E(T)
5.00 50
JcS
Jn

E_d – reservoir seal interface



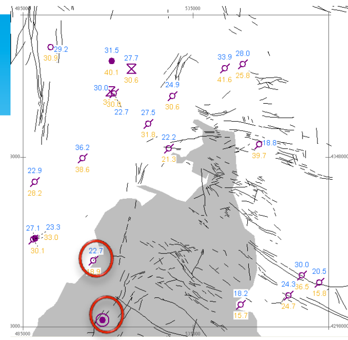
Outcrop location





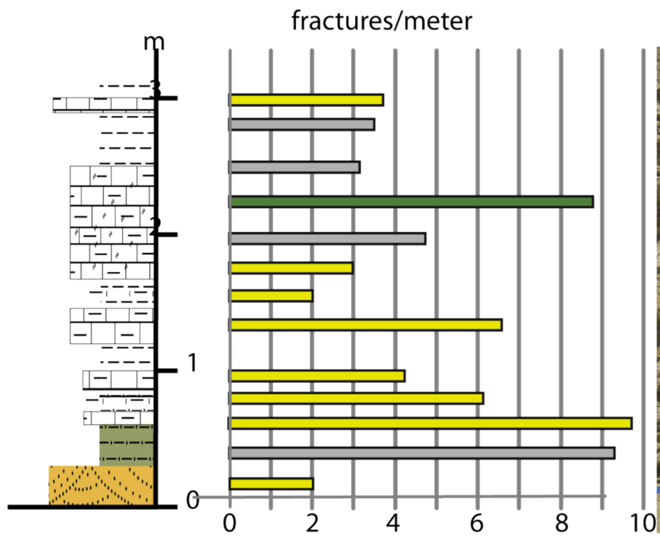
- Difference map average E_d– Carmel/Navajo Interface
- Most wells show a decrease across the interface
- Average change is 5 GPa

Reservoir Seal interface



GR log
Calculated
Young's
Modulus

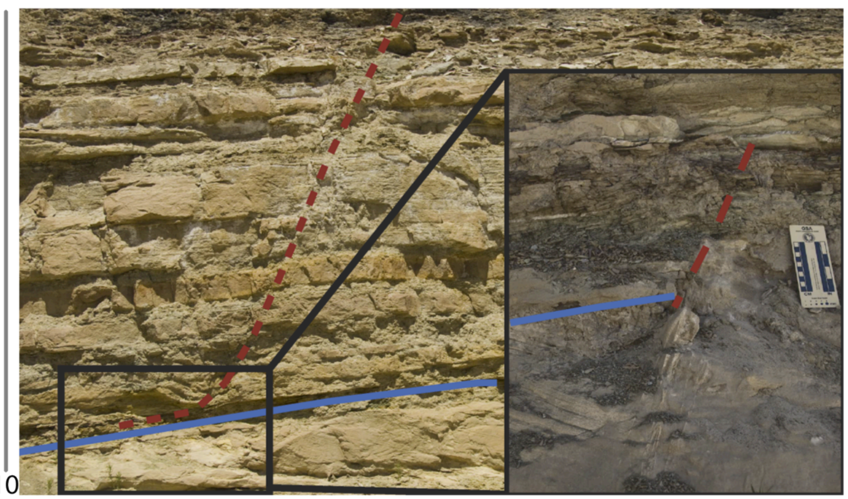
Reduction of
4 GPa



Measured
strat
column

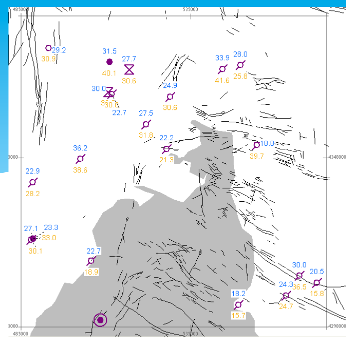
Fracture density histogram
Compiled from scanlines
and ortho-image analysis

Scanline lithology
mixed
sandstone/limestone
shale/siltstone



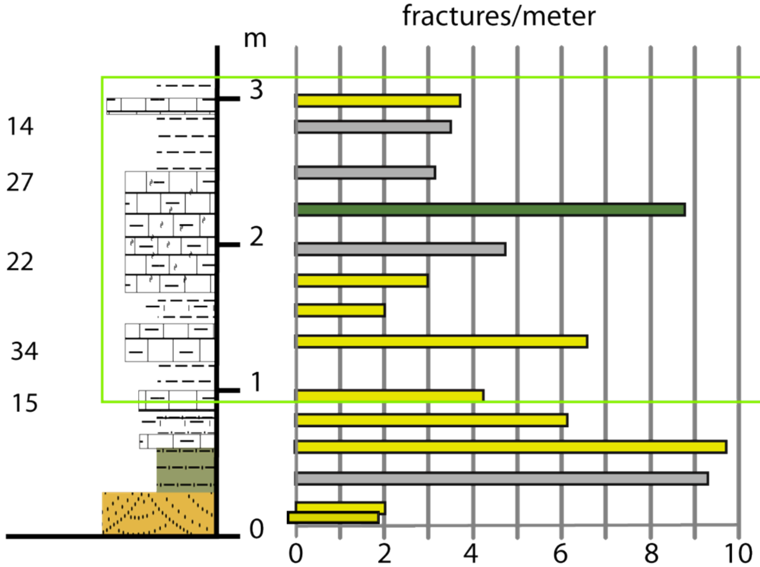
Navajo Carmel contact
Inset shows deformation band in
Navajo & associated small normal fault
in overlying Carmel

Intra-seal bedding interface



GR log
Calculated Young's Modulus

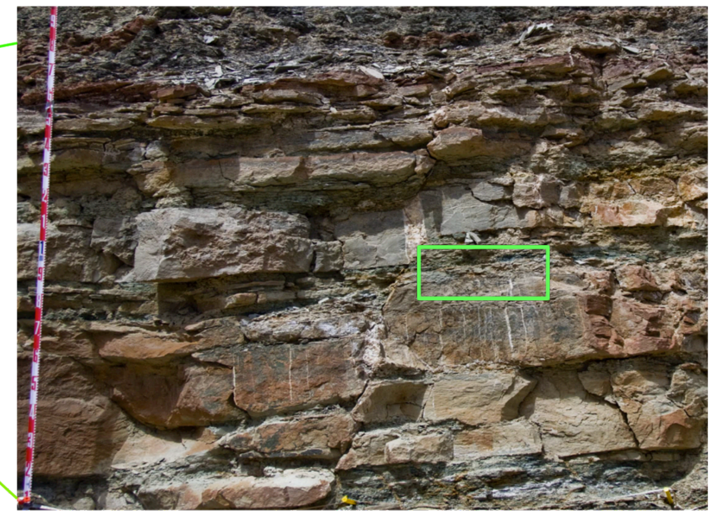
Fracture density histogram
Compiled from scanlines
and ortho-image analysis



Measured strat column

Scanline lithology
- mixed
- sandstone/limestone
- shale/siltstone

Discontinuities within the Carmel seal
inset shows fracture pattern changes
across bed interface



Intra-Carmel variations in E_d of 5-19 GPa

Conclusions

- Shear velocity values can be estimated from compressional velocity – providing estimates of elastic moduli
- Variations in elastic moduli are observed laterally and across interfaces
- Fracture density in outcrop shows a relationship to lithology and bed thickness – this relationship is also observed in the calculated rock strength in the well bore
- E_d shifts average 5 GPa across Navajo Carmel interface, larger shifts of up to 19 GPa observed within the Carmel
- Establishing a link between outcrop discontinuity distributions and well log data will be useful in constraining risk during design and implementation of CO_2 sequestration projects and provides data for modeling scenarios

Acknowledgements and Questions

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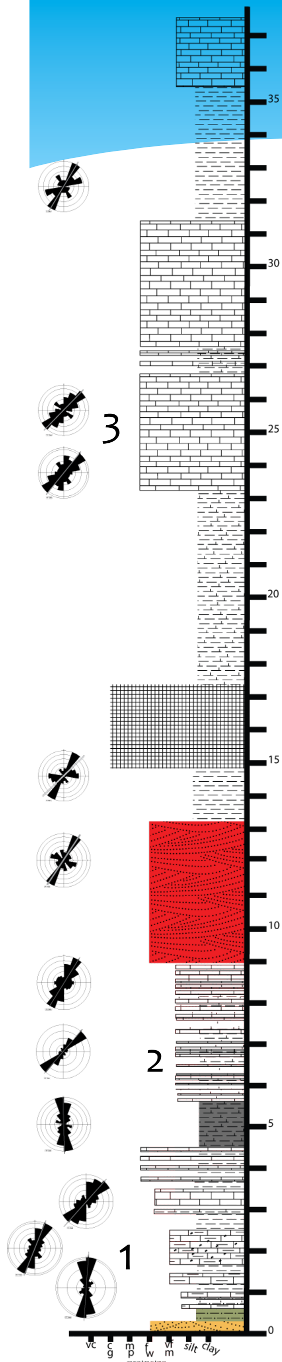
Sirovision Software – University Grant

Going forward

- Outcrop correlation across lateral sedimentologic changes and offset wells
- Burial history – are the subsurface rock strength values observed associated with burial history – deepest burial of paradox sediments around Green River
- Interface (reservoir/seal and within seal) modeling of fracture propagation

Outcrop analysis – Outcomes

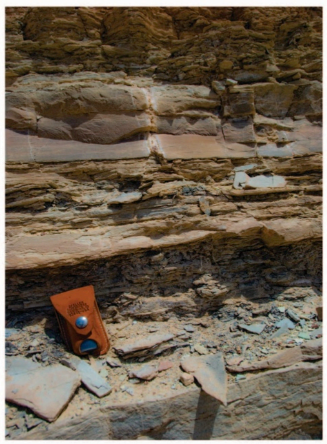
Lithologic heterogeneity results in assorted fracture patterns

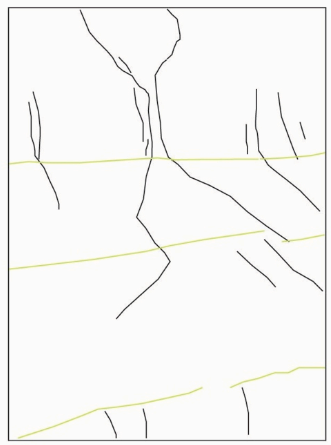


3

Fracture swarms observed at changes in lithology these units lack shale inter-beds and occur in limestone dominated facies.

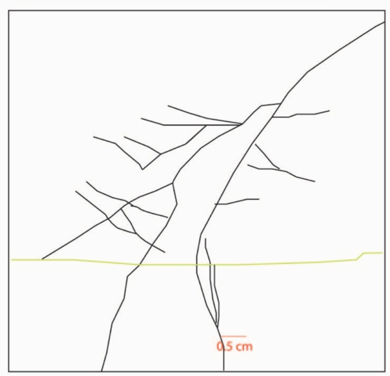
2





Bifurcation of fractures across lithologic boundaries

1



Mineralized fractures in resistant medium bedded sandy limestone experience deflection and arrest in the inter-bedded shale.