Applied Geoscience Conference

Advanced seismic inversion for geomechanics applications in unconventional reservoirs

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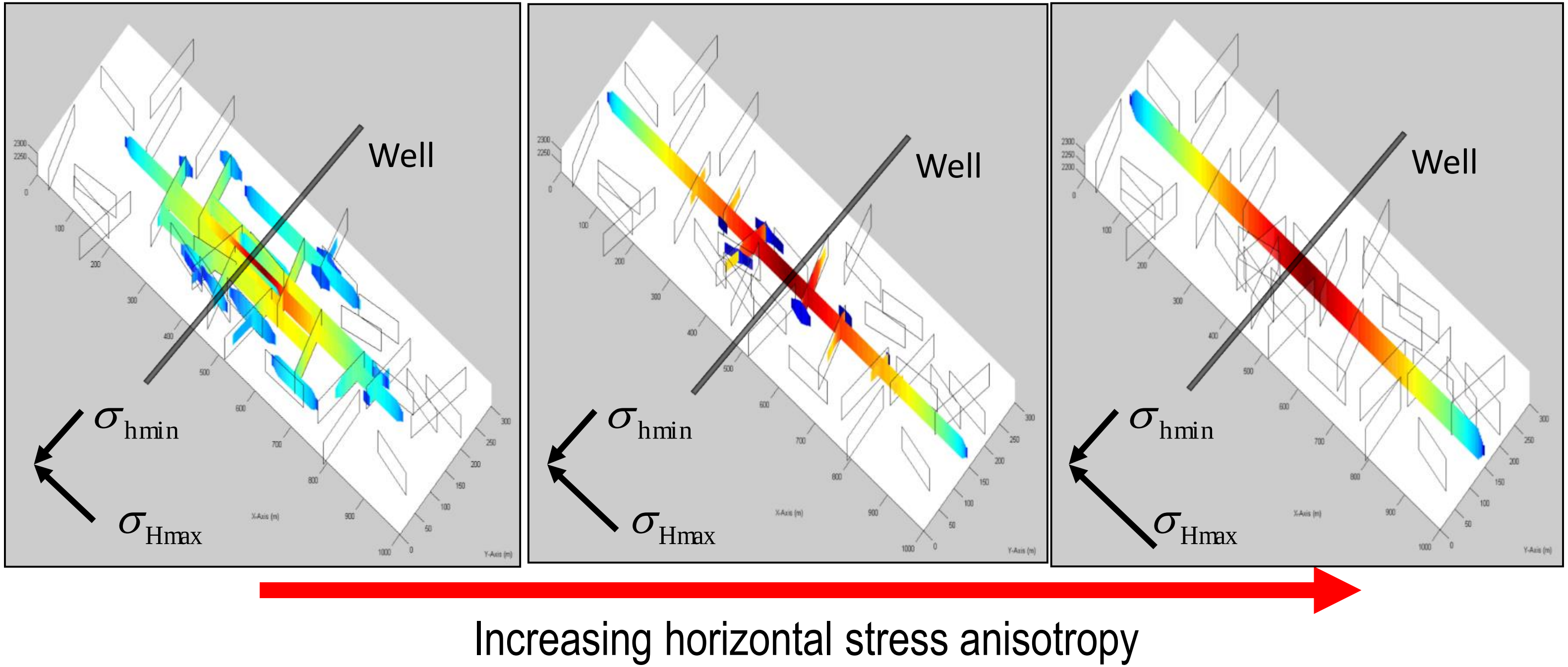
Introduction

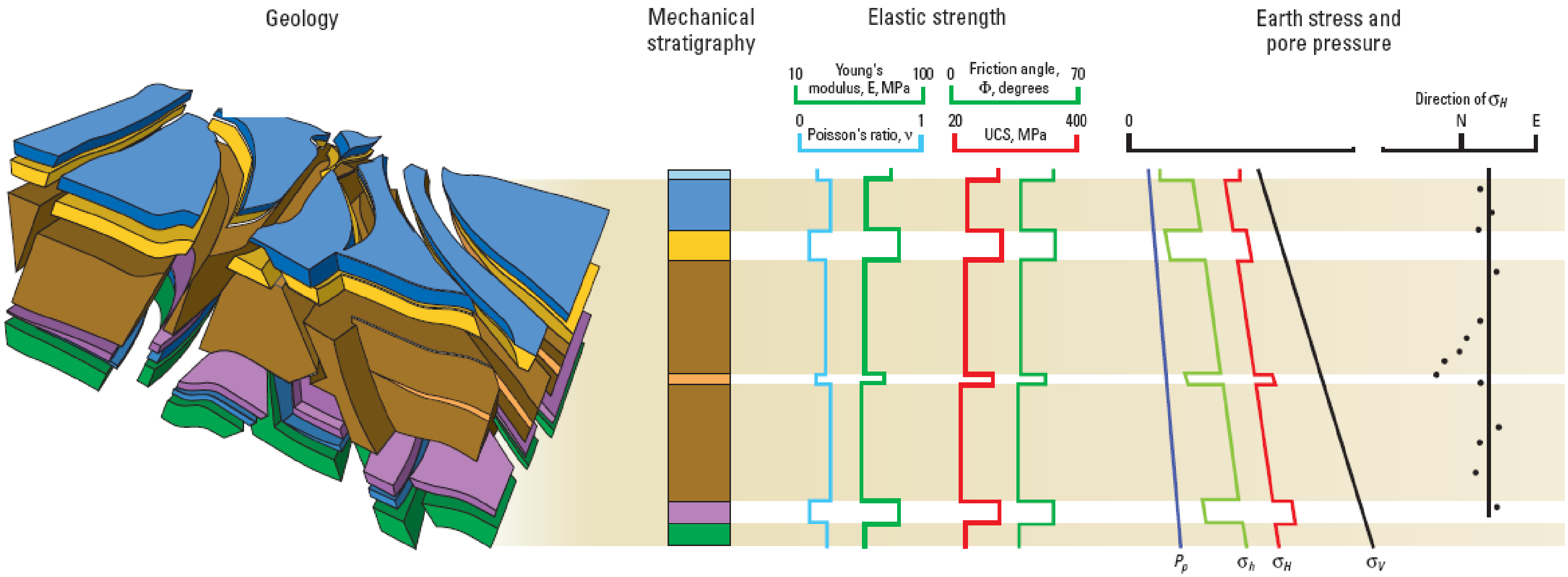
- Sensitivity of hydraulic fracturing to stress and natural fractures
- 3D Mechanical Earth Model
- Prestack seismic inversion
- Mechanical stratigraphy
- Geomechanical properties
- Pore pressure
- In-situ stress
- Conclusion

Sensitivity of hydraulic fractures to stress and fractures



Ref: Kresse et al., 2011, ARMA 11-363

The 3D Mechanical Earth Model



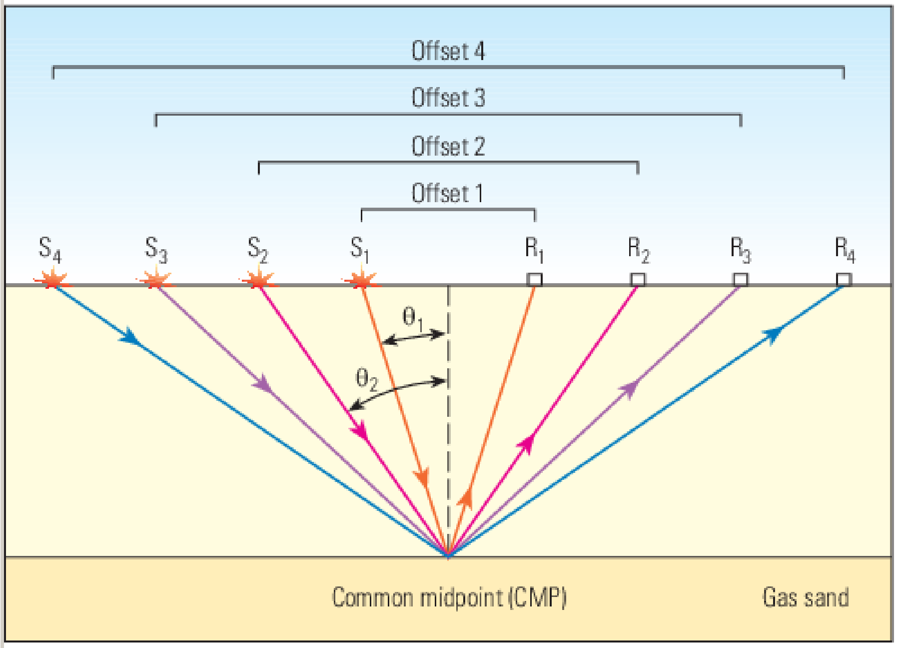
Framework model

Mechanical Stratigraphy

Elastic properties and strength parameters

Earth Stress and Pore Pressure

Amplitude Variation with Offset (AVO)



AVO is the variation in the amplitude of a seismic reflection with offset (distance) between source and receiver.

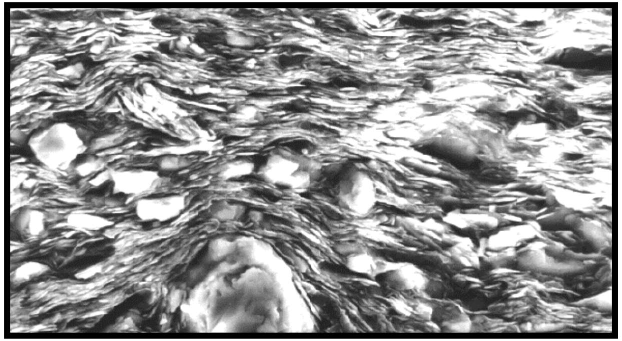
The variation with q allows the P-impedance, $I_P = \rho V_P$, S-impedance, $I_S = \rho V_S$, and $V_P / V_S = I_P / I_S$ to be determined.

Ref: F. Barclay et al. (2008) Seismic inversion: Reading between the lines: Oilfield Review, 20, no. 1, 42-63.

Seismic inversion for unconventional reservoirs

Seismic inversion for unconventional reservoirs needs to take into account anisotropy:

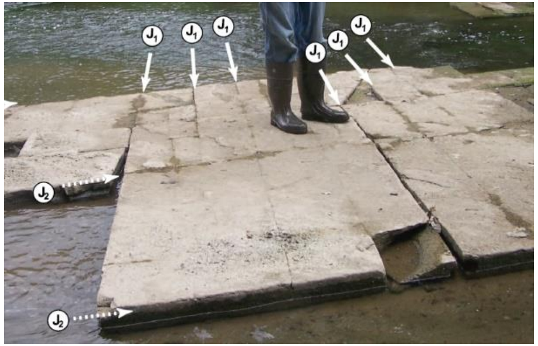
Transverse isotropy



37 µm

Kimmeridge shale
Photo by John Cook
Schlumberger Cambridge Research

Orthotropic

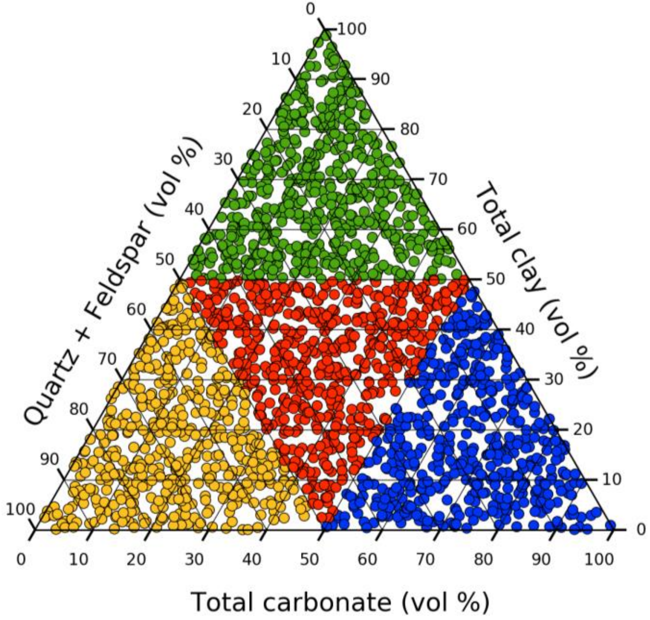


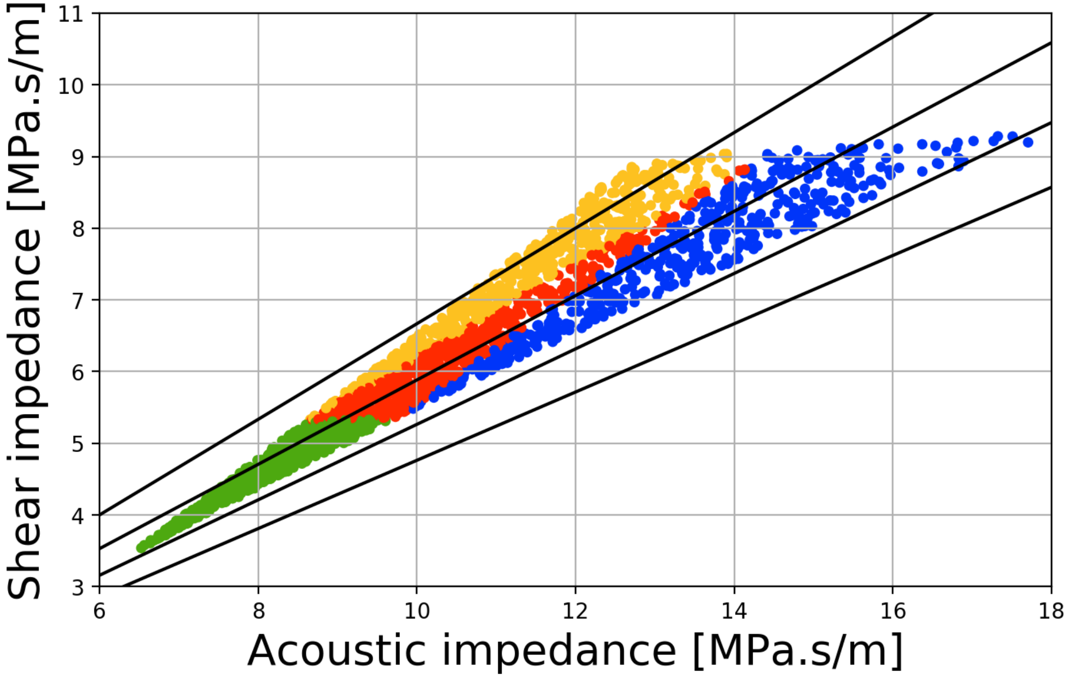
Marcellus shale
Engelder et al. (2009)
AAPG Bulletin, 93, 857–889

Monoclinic

Utica shale
Photo by Bob Jacobi
http://blog.aapg.org/learn/?p=472

Mechanical stratigraphy





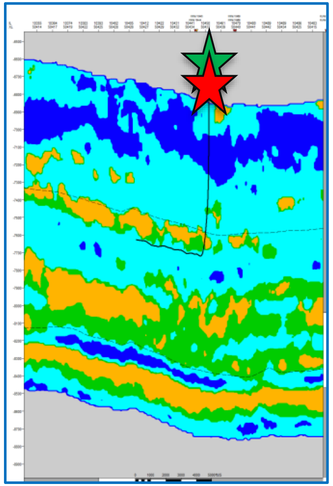
Ref: Sayers and Dasgupta, The Leading Edge, 38, pp.358-365.

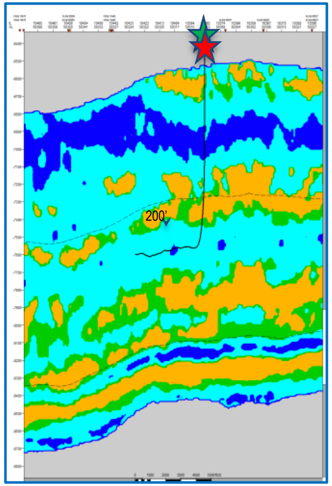
Mechanical stratigraphy

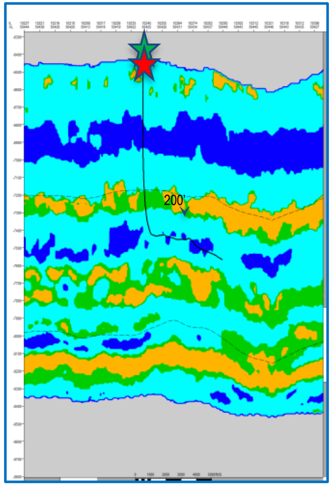
High Oil Prod.
High Gas Prod.
Mod. Oil Prod.
Mod. Gas Prod.

Siliceous Shale
Argillaceous Shale
Calcareous Shale
Carbonate

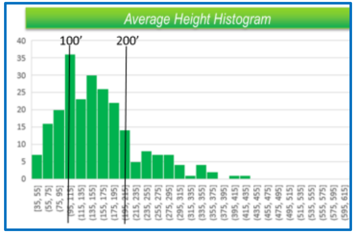
Rock Classes







Typical Fracking Height

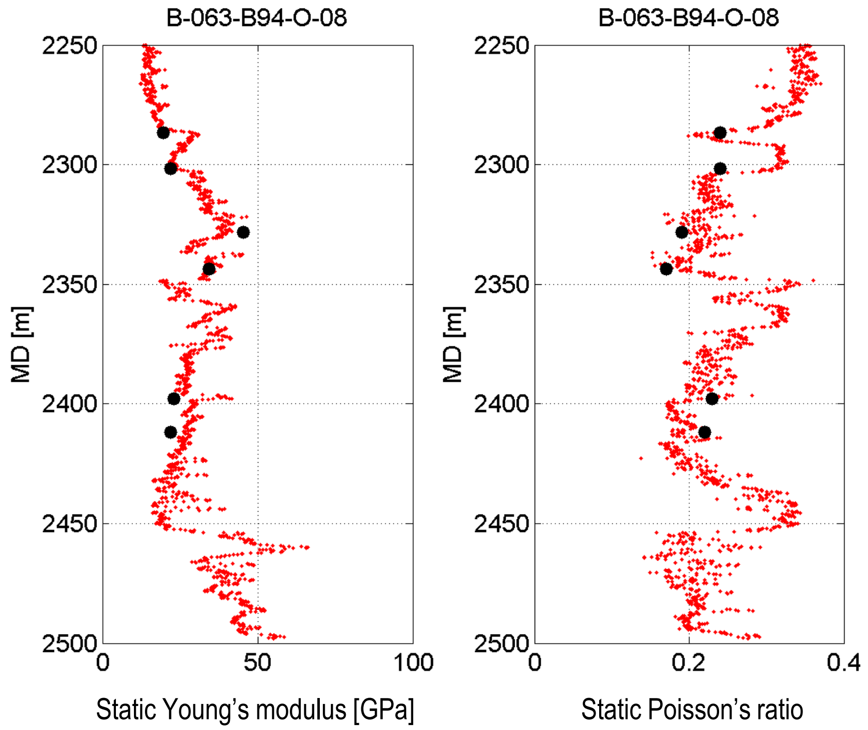


Most fracs < 200ft for this formation

Well placement impacts production!

Ref: S. Dasgupta, C. Sayers and D. Paddock (2019) AAPG ACE, 19-22 May, San Antonio.

Geomechanical properties



Static Young's modulus and Poisson's ratio predicted using the dynamic to static correlations (red) compared with core measurements (black dots).

Ref: Sayers, Lascano, Gofer, den Boer, Walz, Hannan, Dasgupta, Goodway, Perez and Purdue (2016) SEG abstract.

Pore pressure

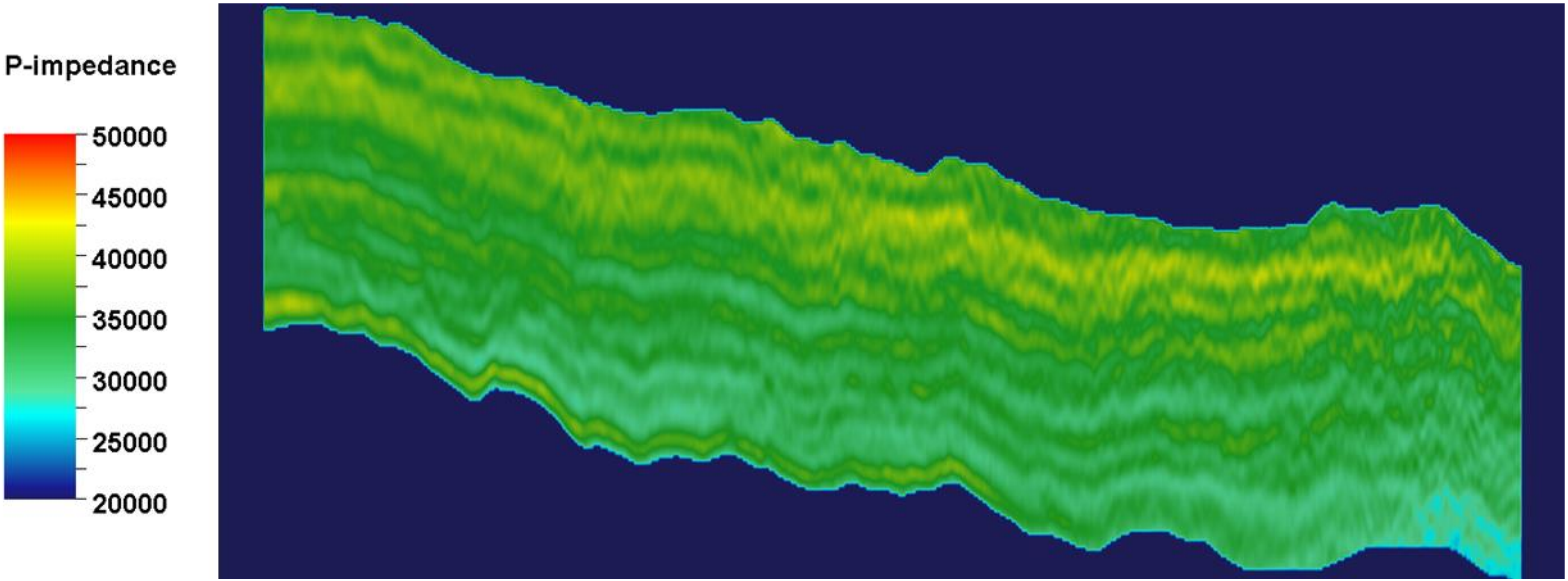
Pore pressure is difficult to measure in low permeability rocks, but has an important impact on drilling, hydrocarbon production and geomechanics applications such as hydraulic fracturing, etc.

For highest vertical resolution, use results of AVO inversion for pore pressure estimation.

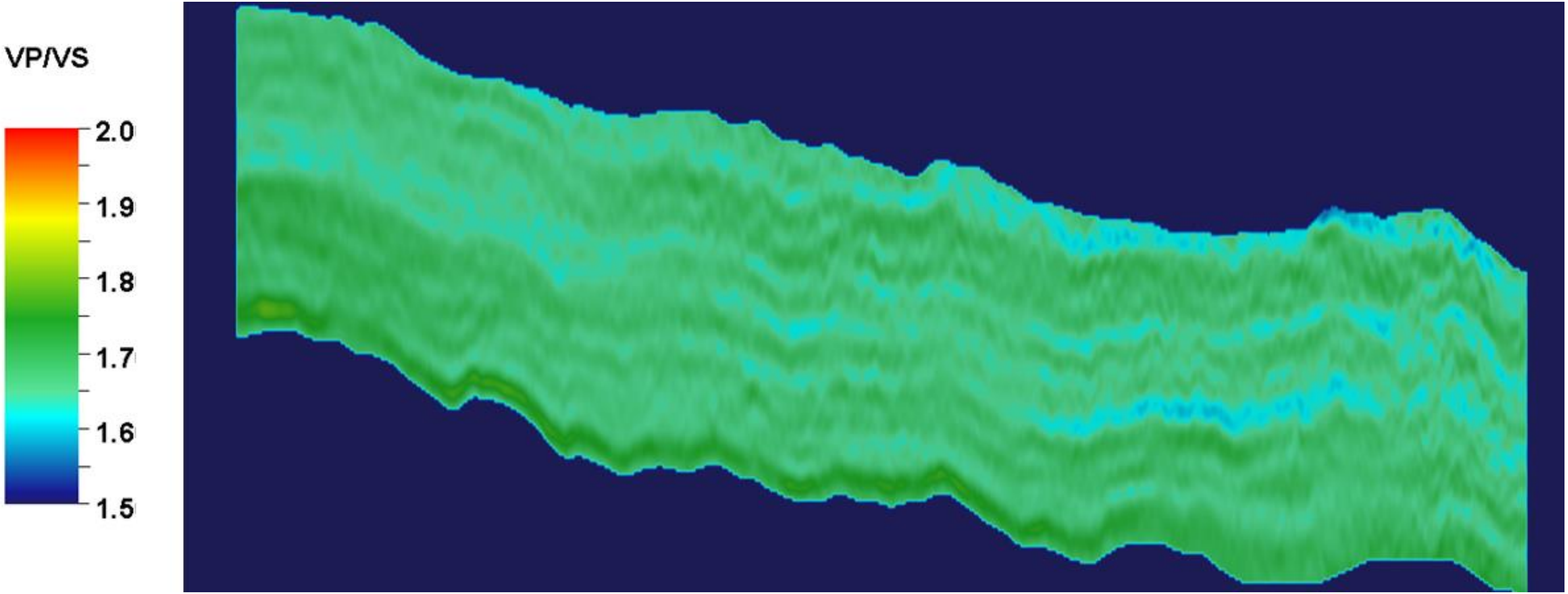
In general, the relation between the AVO inversion results and pore pressure is lithology-dependent:

$$P_p = P_p(\text{lithology},\ I_P,\ V_P/V_s,\ \sigma_{ij})$$

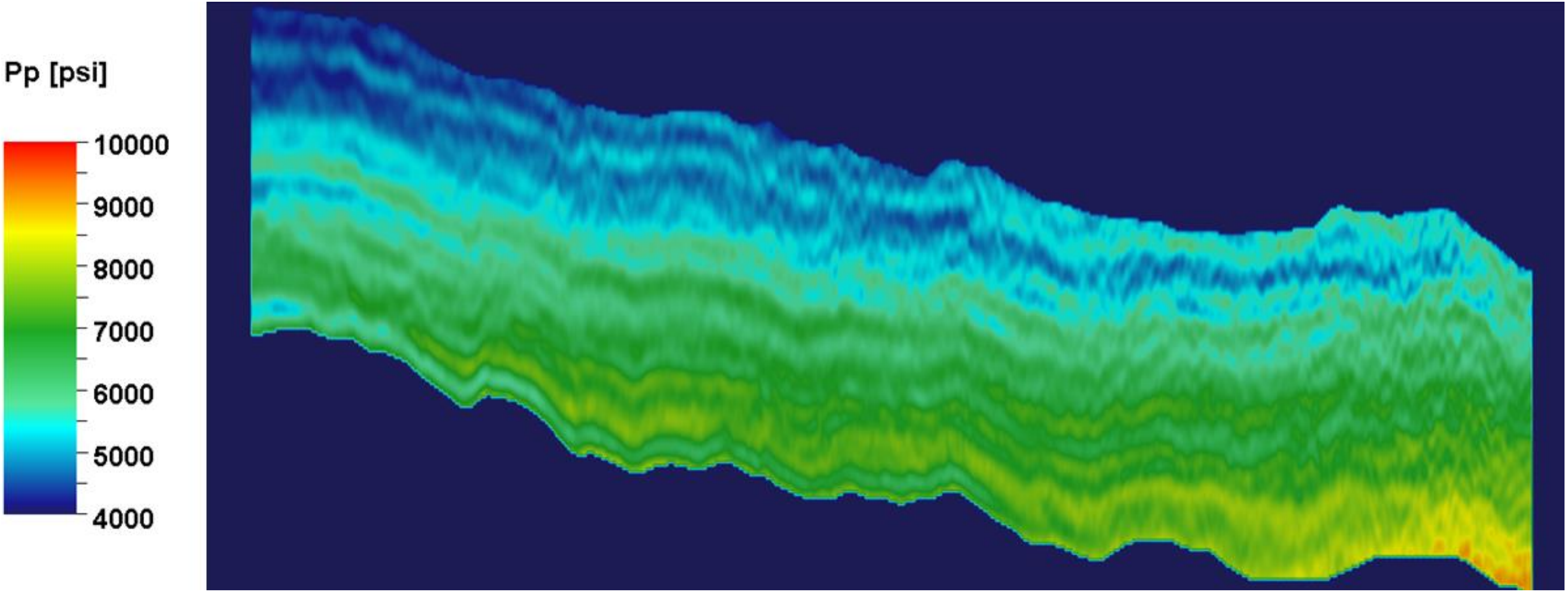
P-impedance between 3rd Bone Spring and Base Wolfcamp



V_P/V_S between 3rd Bone Spring and Base Wolfcamp

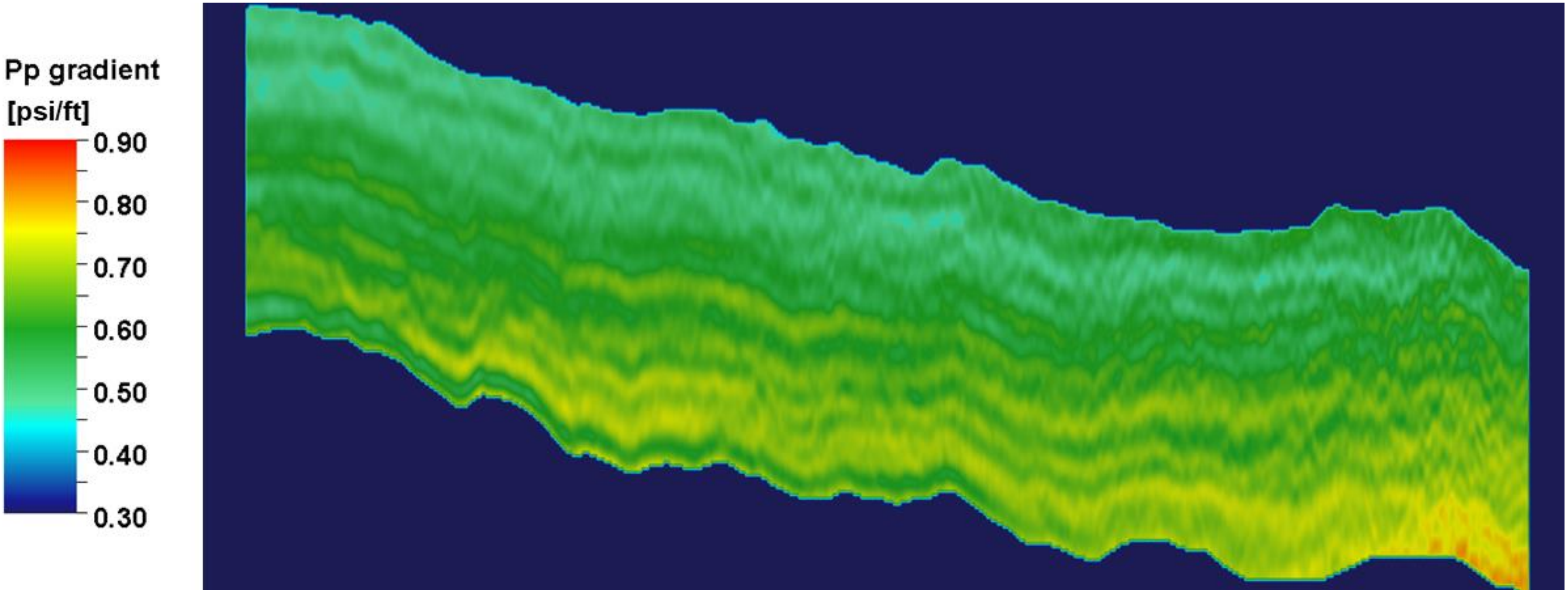


Pore pressure from acoustic and shear impedance



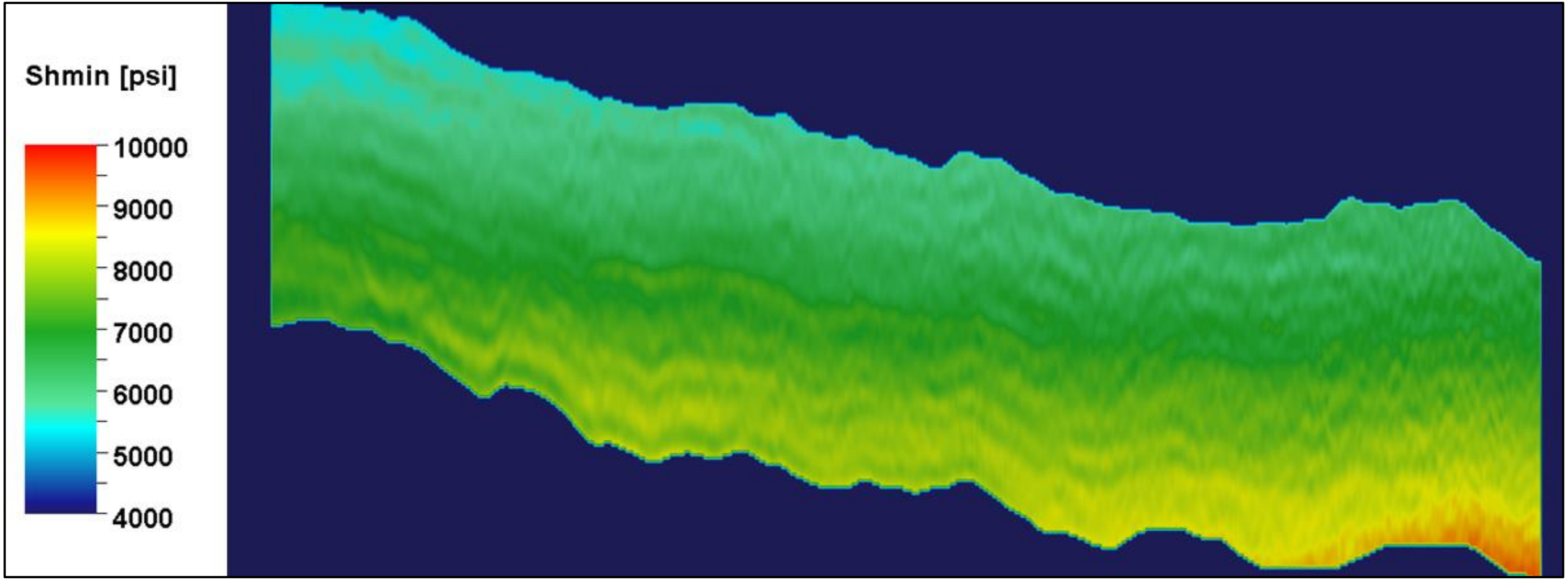
$$P_p = P_p(\text{lithology},\ I_P,\ V_P/V_s,\ \sigma_{ij})$$

Pp gradient from acoustic and shear impedance



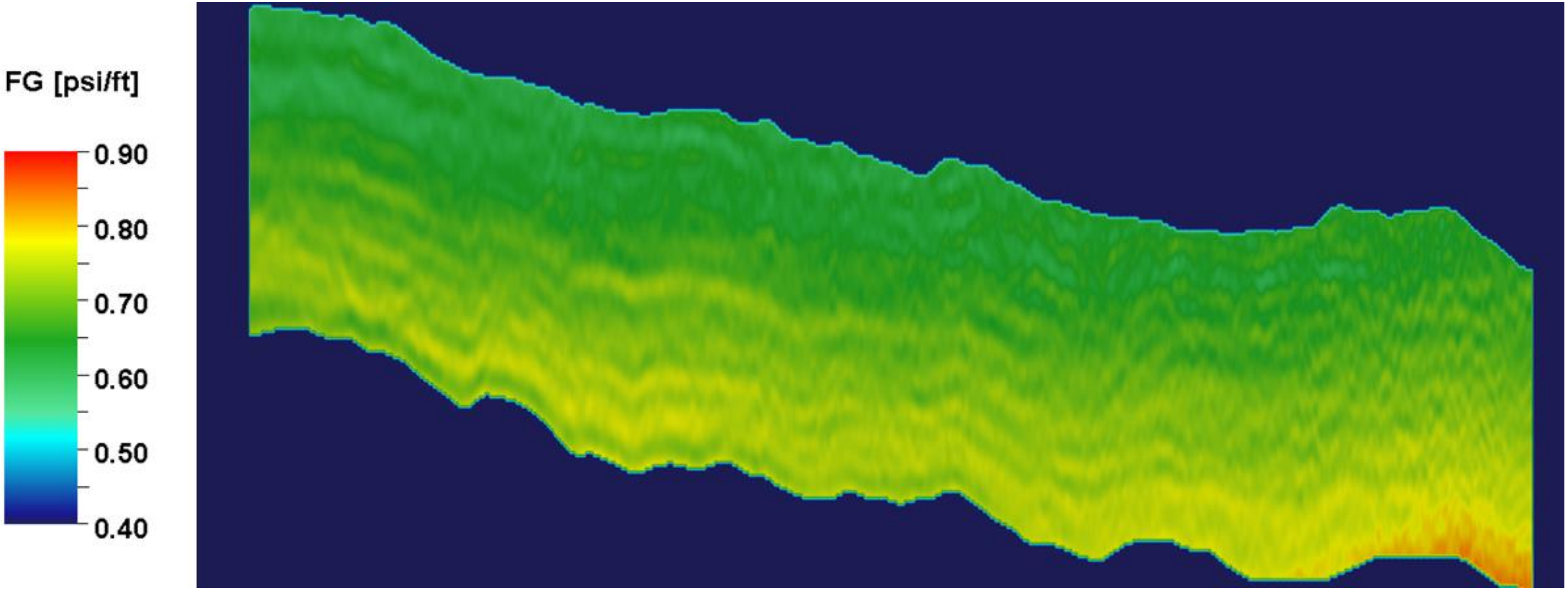
$$P_p = P_p(\text{lithology},\ I_P,\ V_P/V_s,\ \sigma_{ij})$$

Minimum Horizontal Stress



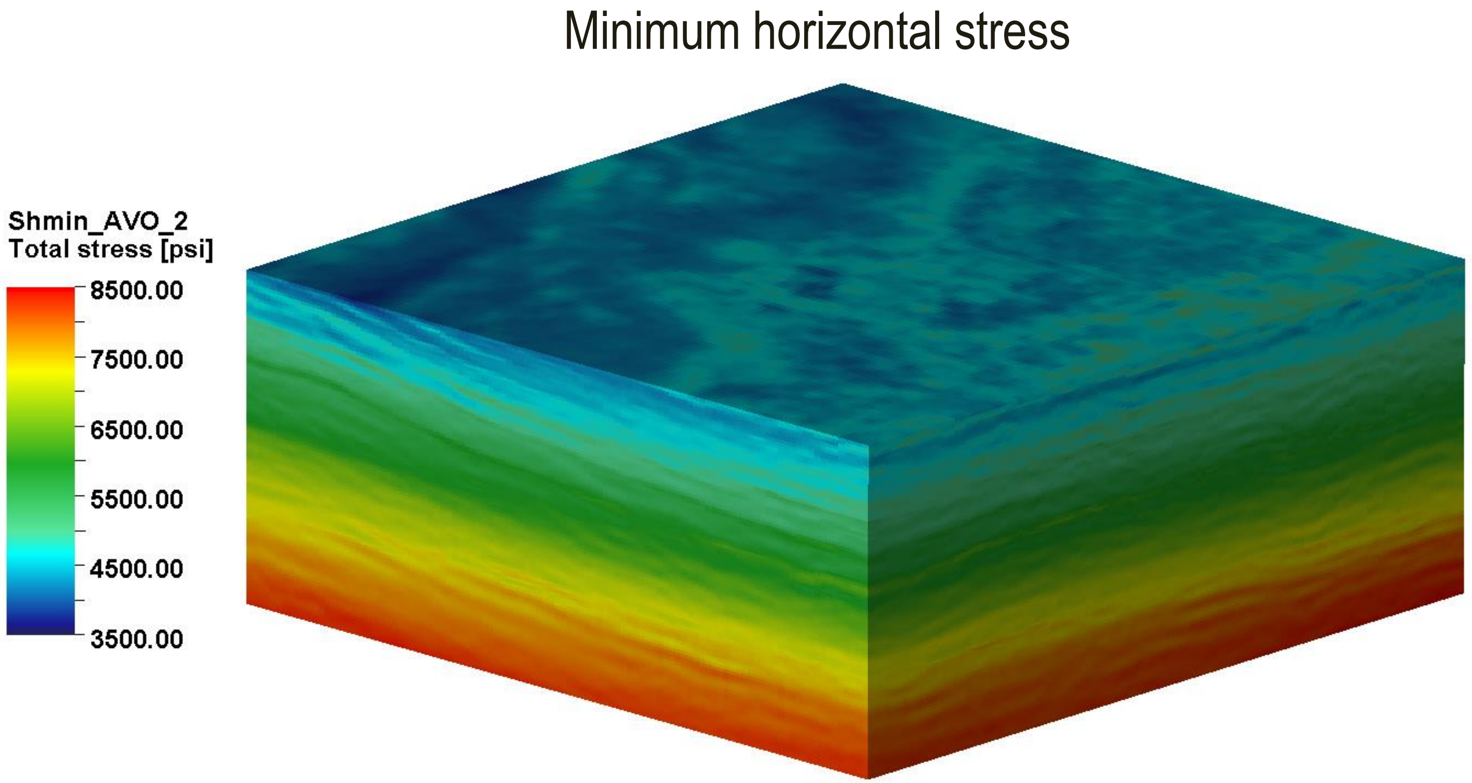
$$\sigma_{\mathrm{h}} = \alpha_{\mathrm{h}} p + K_0 \left(\sigma_{\mathrm{V}} - \alpha_{\mathrm{V}} p \right) + \frac{E}{\left(1 - \nu^2\right)} \left(\varepsilon_h + \nu \varepsilon_H \right)$$

Fracture Gradient

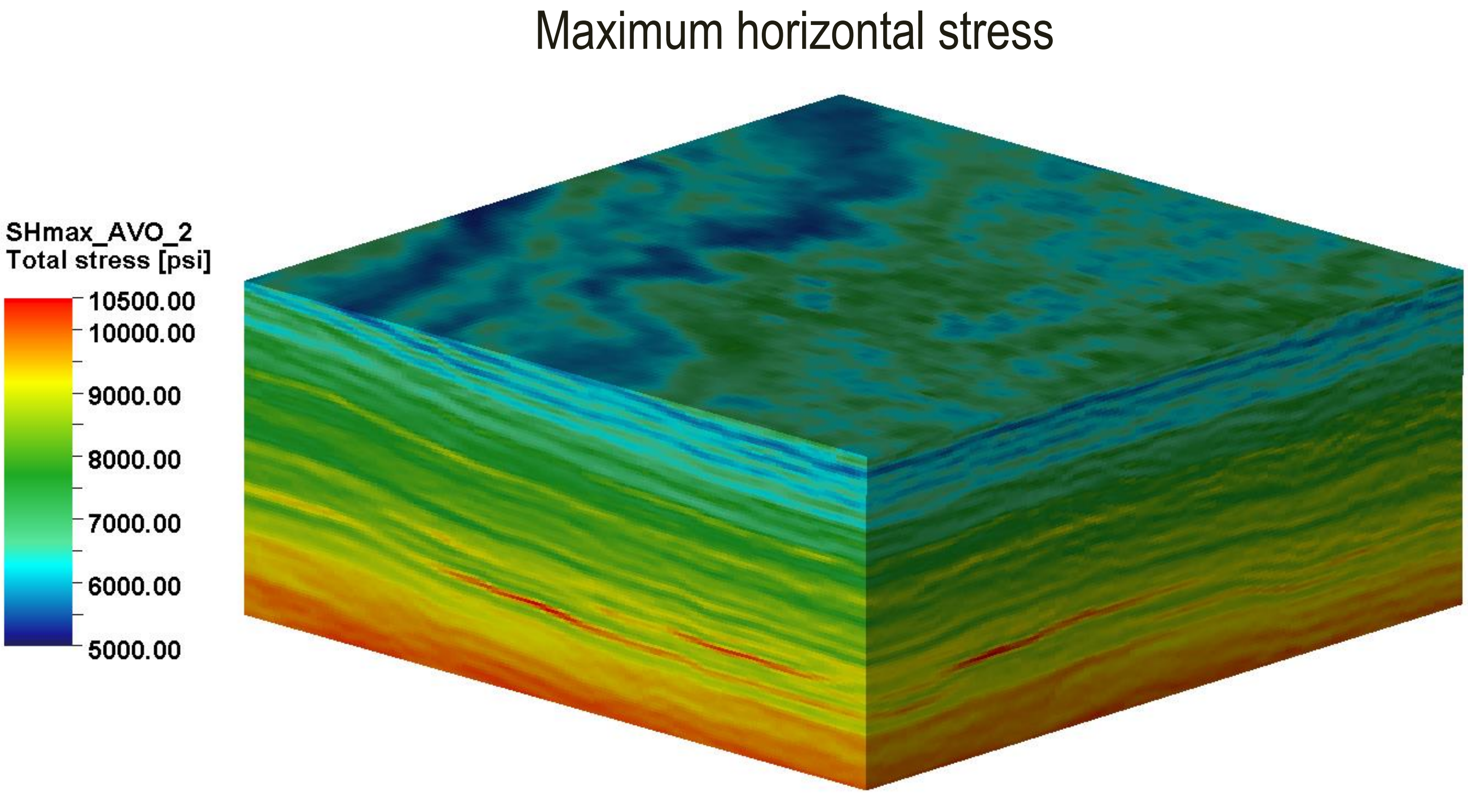


$$\sigma_{\mathrm{h}} = \alpha_{\mathrm{h}} p + K_0 \left(\sigma_{\mathrm{V}} - \alpha_{\mathrm{V}} p \right) + \frac{E}{\left(1-\nu^2\right)} \left(\varepsilon_h + \nu \varepsilon_H \right)$$

Seismic-based 3D Finite Element Model

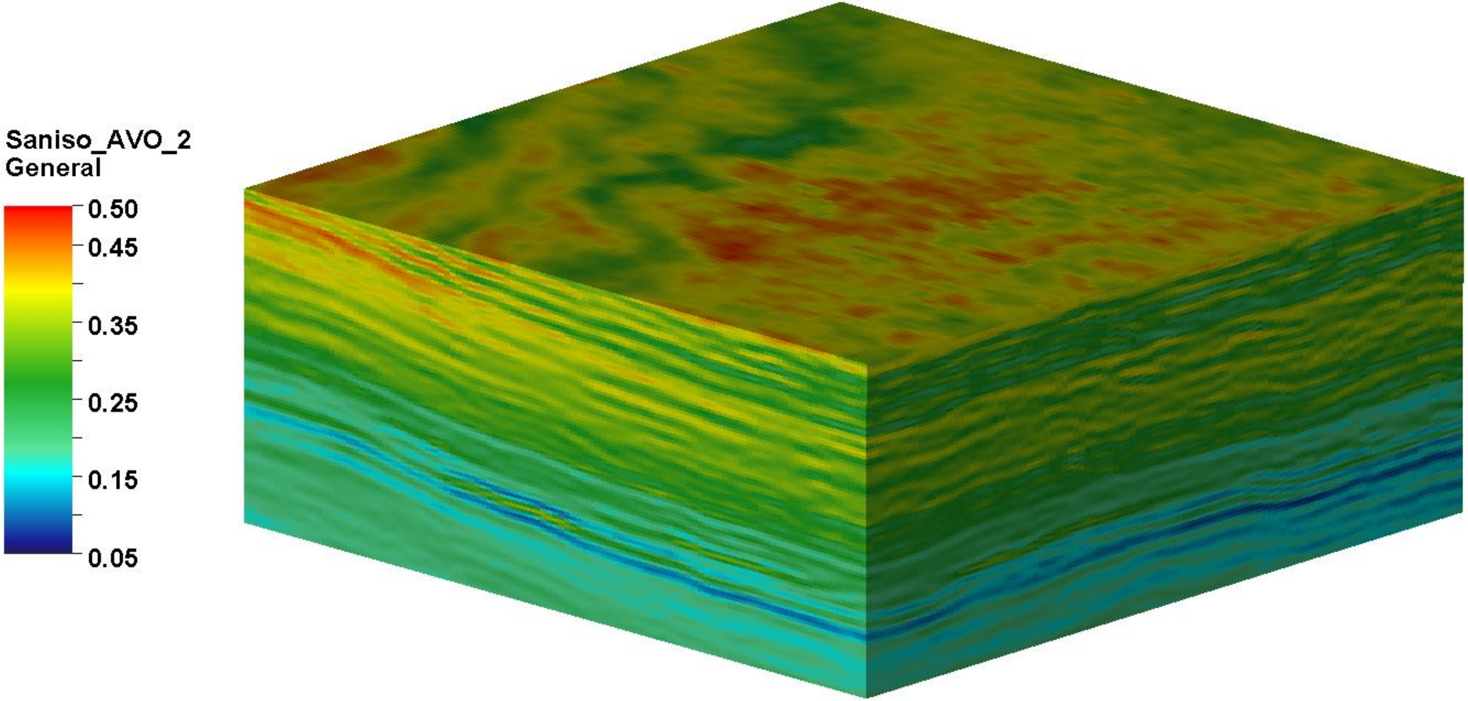


Seismic-based 3D Finite Element Model

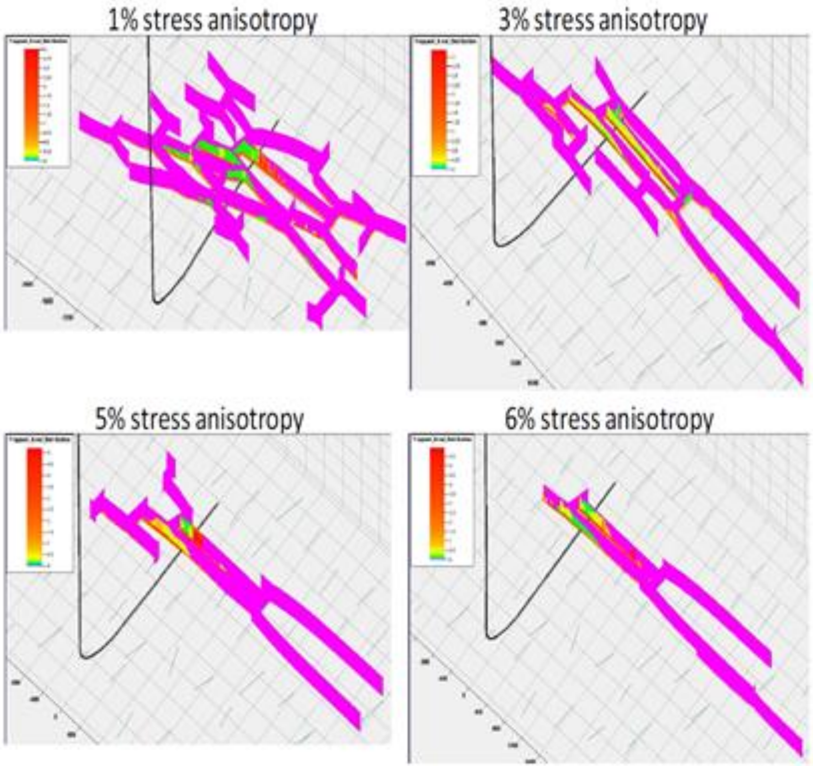


Seismic-based 3D Finite Element Model

Horizontal stress anisotropy



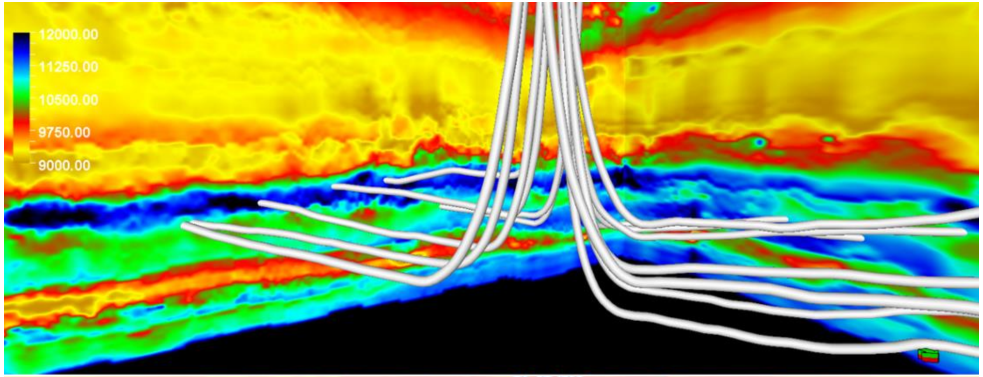
Effect of horizontal stress anisotropy on hydraulic fractures



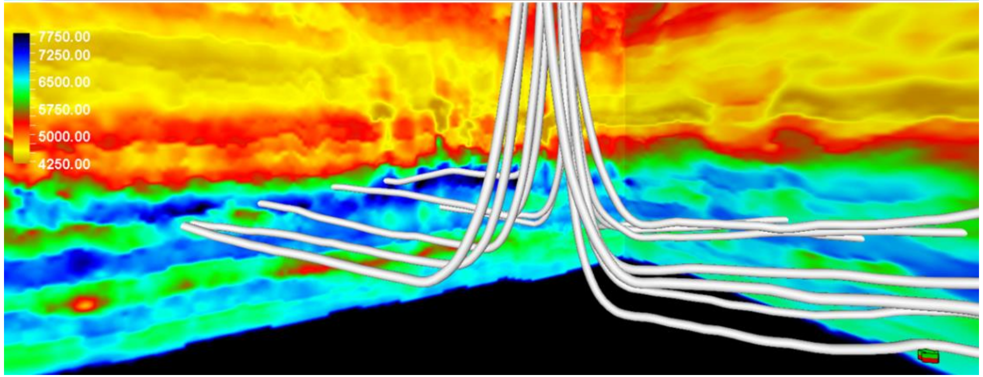
Simulations of the same hydraulic fracture treatment with different horizontal stress anisotropy (minimum horizontal stress is constant).

Ref: Cohen et al. (2012) SPE 152541

Horn River example



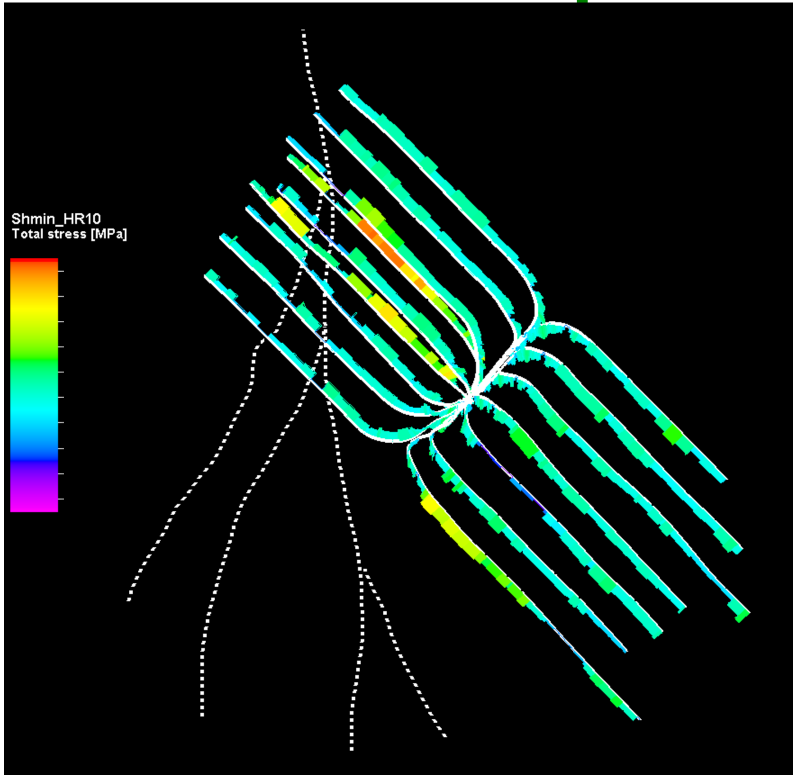
Acoustic impedance



Shear impedance

Ref: Sayers, Lascano, Gofer, den Boer, Walz, Hannan, Dasgupta, Goodway, Perez and Purdue (2016) SEG abstract.

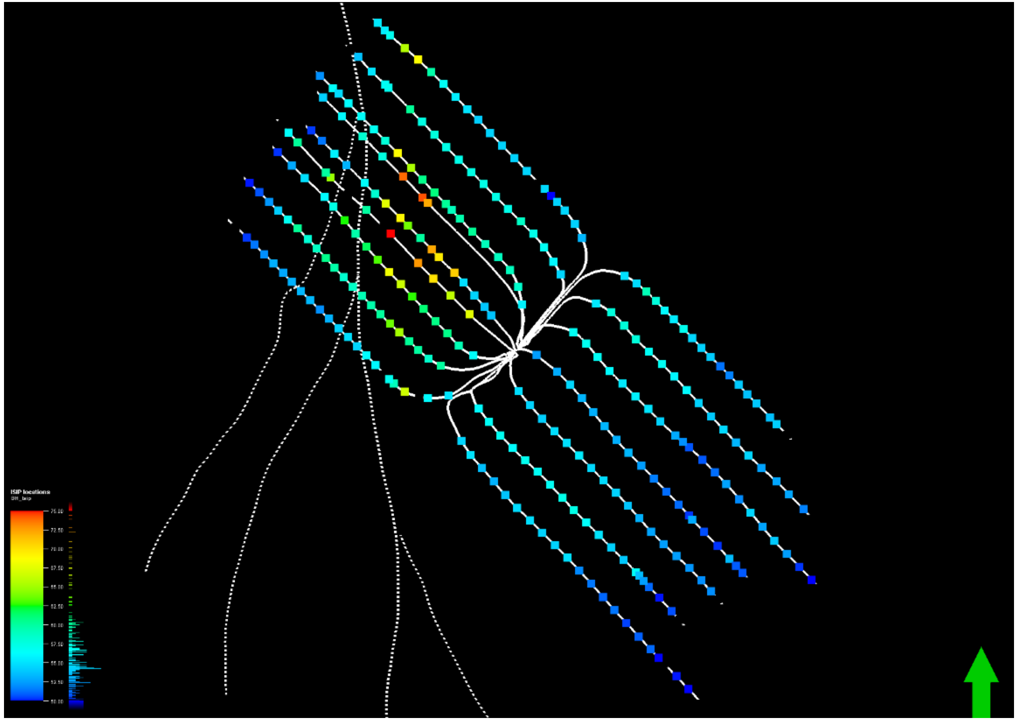
Horn River example



Minimum horizontal stress from Finite Element Model

Ref: Sayers, Lascano, Gofer, den Boer, Walz, Hannan, Dasgupta, Goodway, Perez and Purdue (2016) SEG abstract.

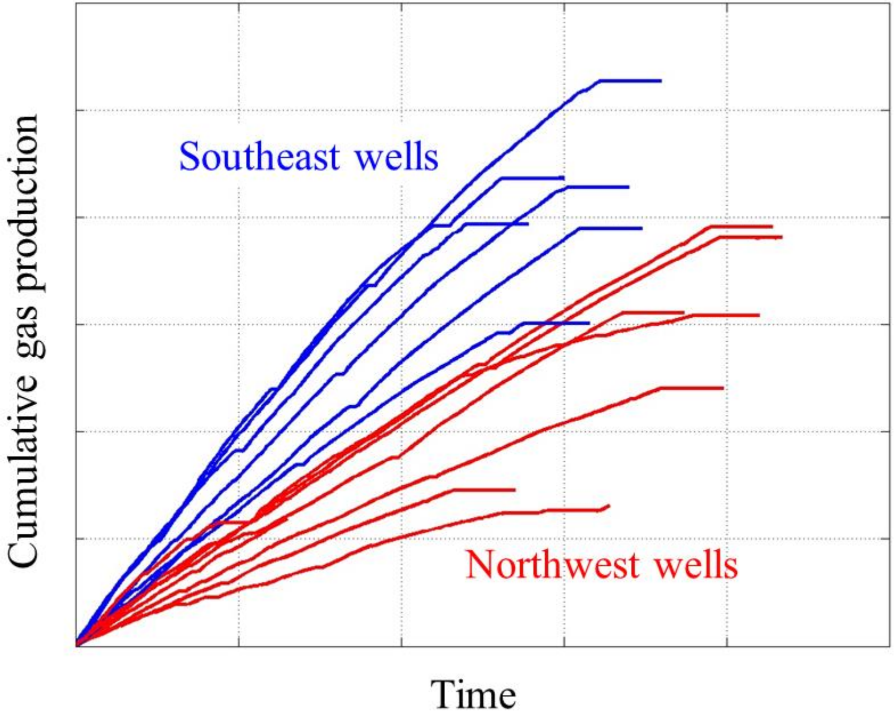
Horn River example



Instantaneous shut-in pressures (ISIPs) for a production pad in the Horn River Basin, with points color coded by ISIP from low (blue) to high (red).

Ref: Sayers, Lascano, Gofer, den Boer, Walz, Hannan, Dasgupta, Goodway, Perez and Purdue (2016) SEG abstract.

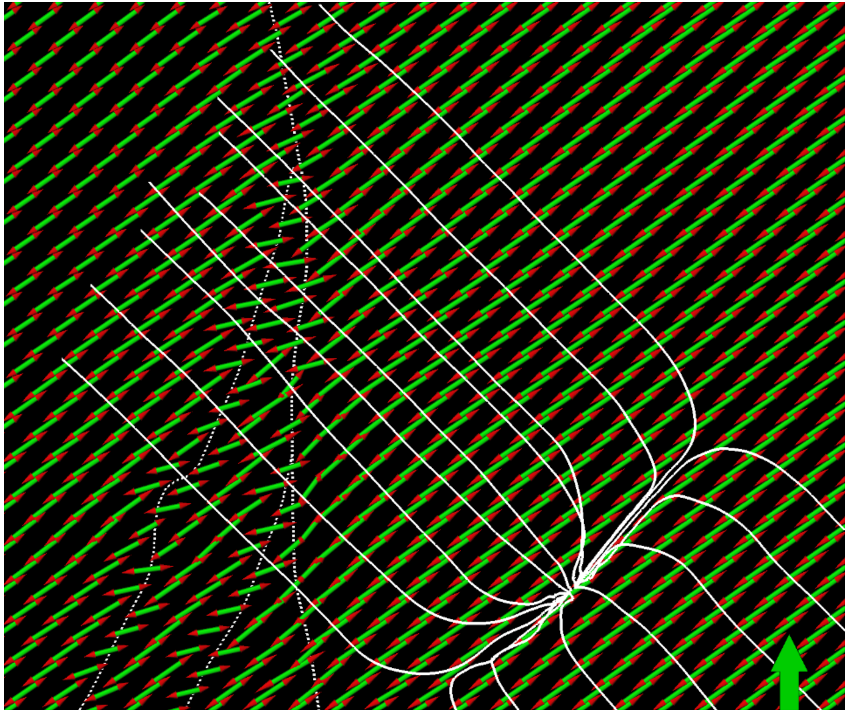
Horn River example



Cumulative gas production for the southeast wells (blue) compared to northwest wells (red).

Ref: Sayers, Lascano, Gofer, den Boer, Walz, Hannan, Dasgupta, Goodway, Perez and Purdue (2016) SEG abstract.

Horn River example



Direction of maximum horizontal stress from Finite Element Model

Ref: Sayers, Lascano, Gofer, den Boer, Walz, Hannan, Dasgupta, Goodway, Perez and Purdue (2016) SEG abstract.

Conclusions

- In-situ stress and horizontal stress anisotropy are needed to model the propagation of hydraulic fractures
- Pore pressure has an important impact on drilling, hydrocarbon production and geomechanics applications
- Pore pressure, in-situ stress and horizontal stress anisotropy can be characterized using AVO inversion to build a predictive 3D mechanical Earth Model
- This enables optimization of well location, borehole trajectory, well spacing, and the design of hydraulic fractures, before the well is drilled