Quantifying Anisotropy for Geomechanics*

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Abstract

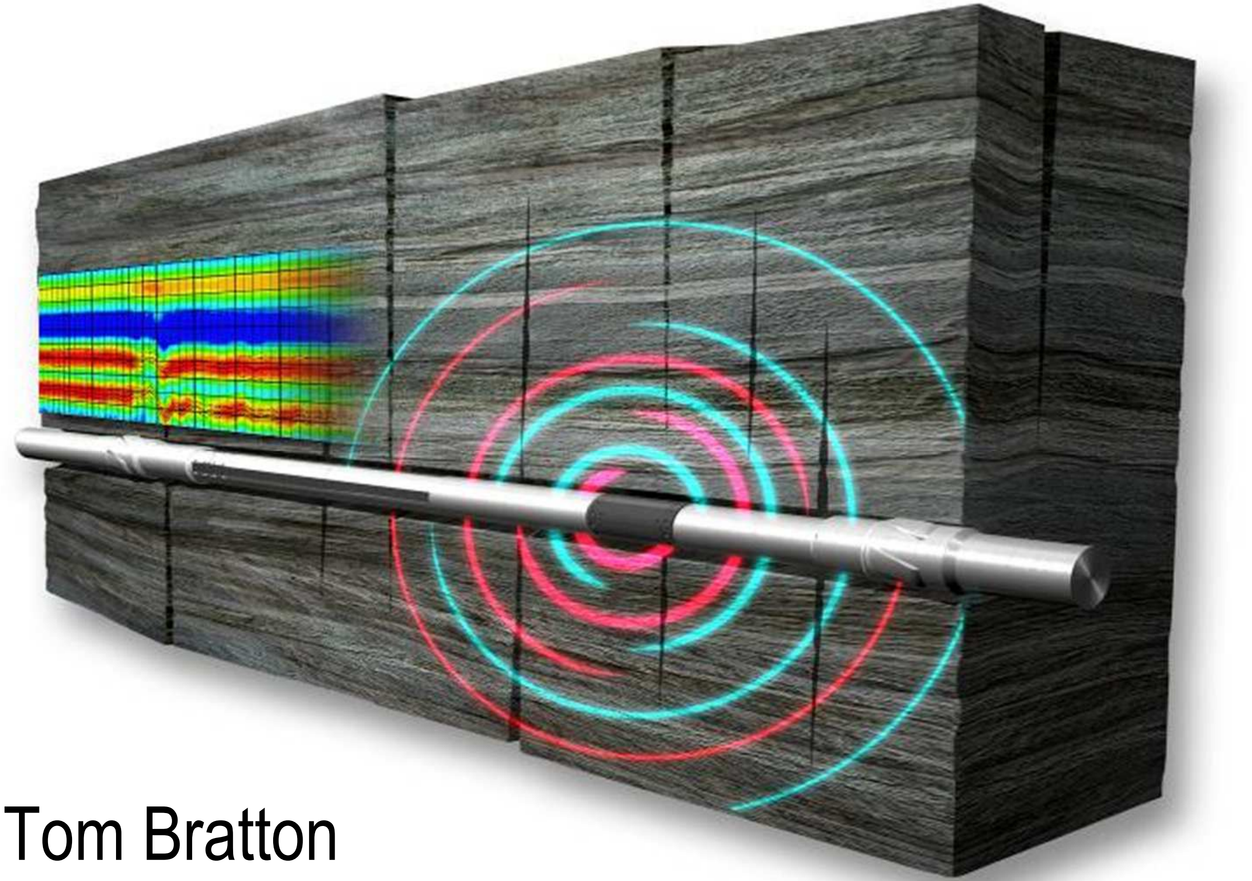
Geomechanics can make a significant economic impact in tight gas reservoirs both in drilling and stimulation operations. The current generation of geomechanical solutions models the formation assuming it is homogeneous and isotropic (HI). Most formations, especially at the scale of the geomechanical problem, are heterogeneous and anisotropic. While HI models can be calibrated, changes in pore pressure or fracture gradient are interpreted when, in reality, it is only the anisotropy that is changing. Because of the number of unknowns, no single source of data is sufficient to solve the problem. Data must be integrated from multiple wells and across multiple scales (e.g., core, log, and seismic scales). Acoustical logging data provide a natural starting point to solve these multidisciplinary and multivariate geomechanical problems. A workflow is presented that first diagnoses the type of acoustical anisotropy at the log scale. Core data, representative of the unfractured background matrix, is then integrated with the log data to quantify static elastic properties. Fracture compliances can then be determined in the fractured intervals. Upscaling is then applied for integration with the seismic data. An anisotropic mechanical earth model is constructed after the acoustical velocities have been integrated with core and seismic data. The anisotropic earth model is then used to address a number of drilling and completion problems. A variety of technologies were applied in different case studies, and these case studies illustrate how an understanding of anisotropic geomechanics translates into both drilling and completion optimization.

References

Schoenberg, M., and C.M. Sayers, 1995, Seismic Anisotropy of Fractured Rock: Geophysics, v. 60, p. 204-211.

Okafor, Z.M., S.M. Higgins-Borchardt, G. Akinniranye, T.R. Bratton, R.J. Avila, and D. Boone, 2010, Managed-Pressure Drilling Using a Parasite Aerating String: SPE Drilling & Completion, v. 25/A, p. 564-576.

Quantifying Anisotropy for Geomechanics



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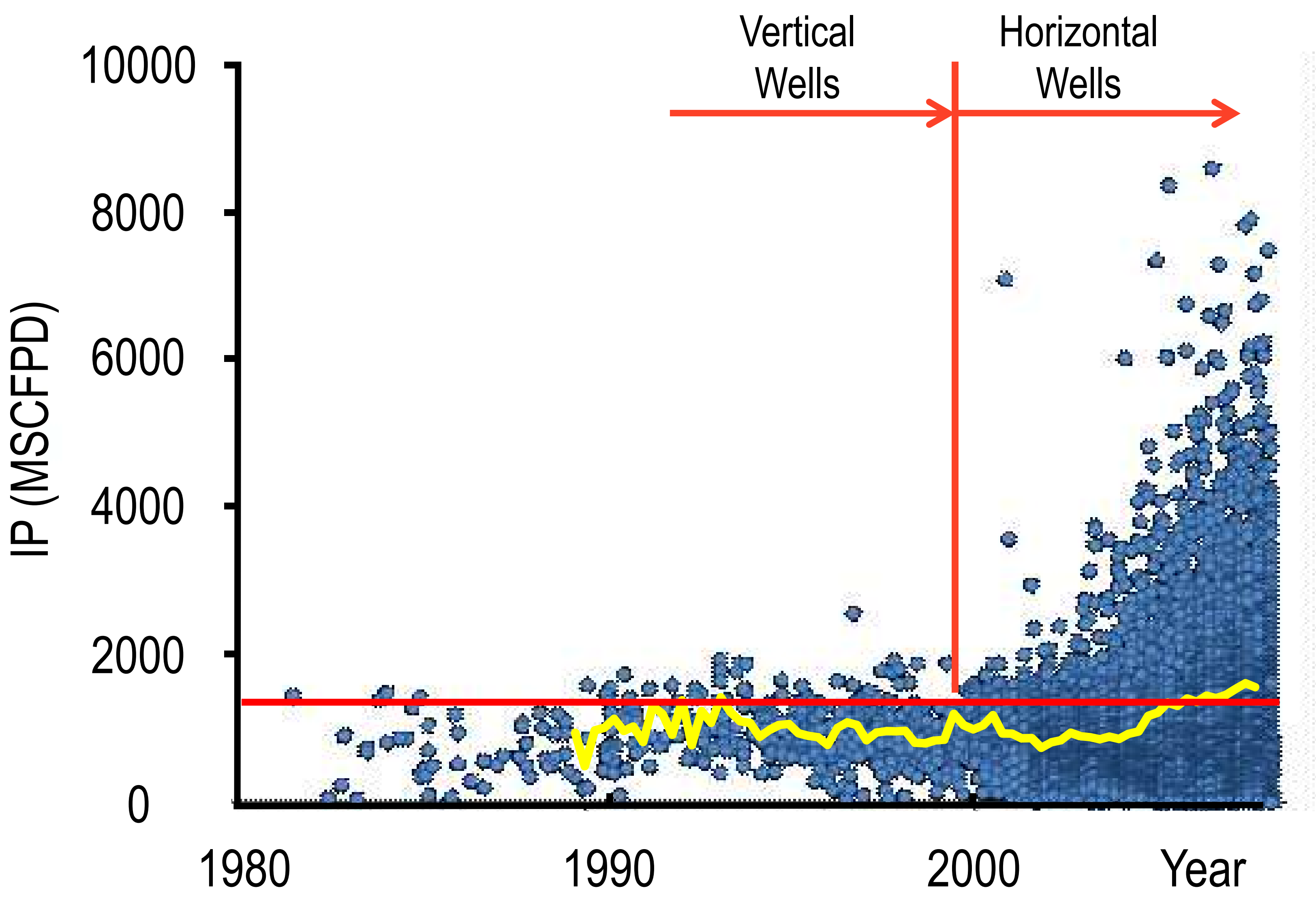
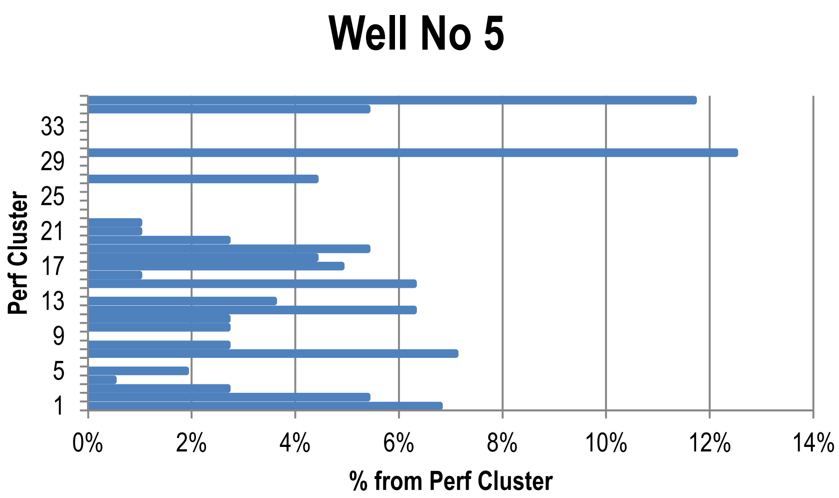
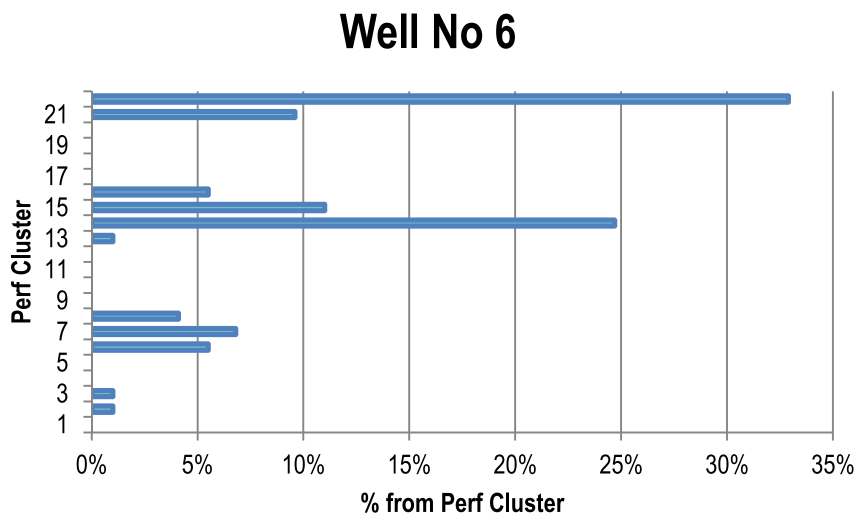
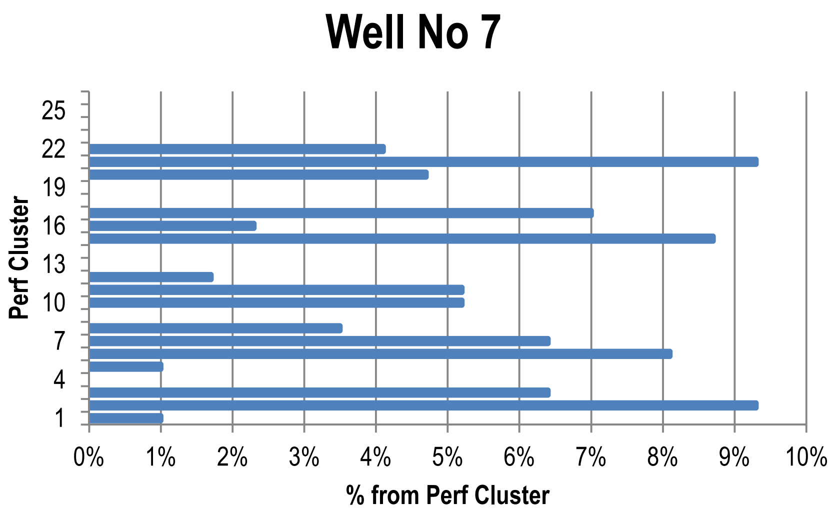
Production Variability is Enormous

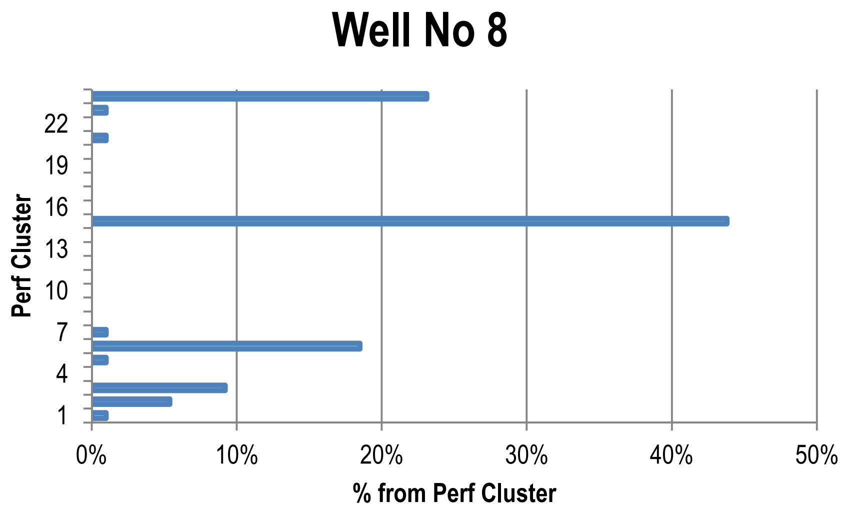


Performance of Perforation Clusters Highly Variable; Many Clusters Non-Productive







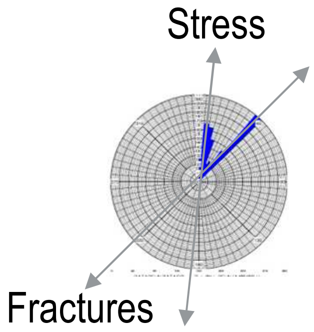


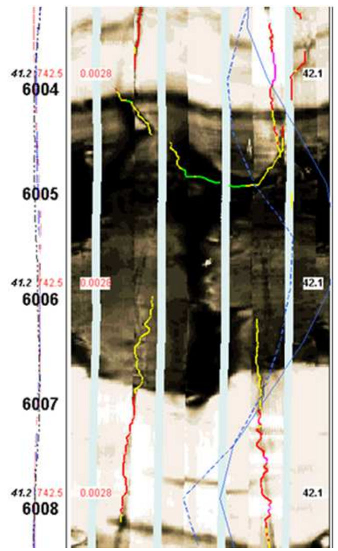
Sweet Spot Characterization

- Sweet Spot Definition
- Reservoir Quality
  - Porosity, lithology, saturation, permeability
  - Fluid quality
- Completion Quality
  - Data requirements - vertical well, horizontal well
  - Vertical well - Containment
  - Horizontal well – Fracture complexity, completion design

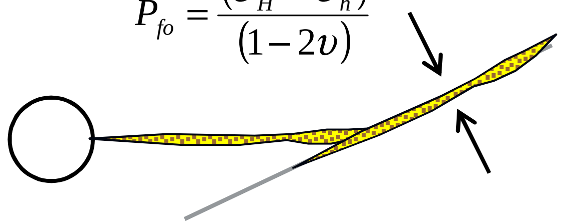
Completion Quality – Vertical Wells

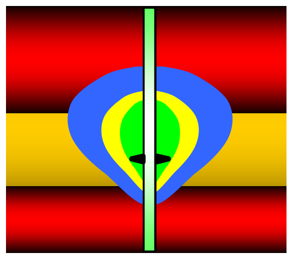
- Data requirements
  - Images, acoustics, core
- Directions
  - Maximum horizontal stress
  - Fracture strike
- Containment via stress
  - Magnitude of SigV, SigH and Sigh
- Containment via heterogeneity
  - Fractures
  - Bedding

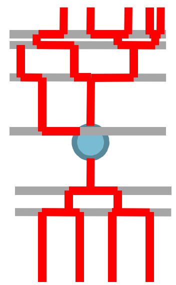




$$P_{fo} = \frac{(\sigma_H - \sigma_h)}{(1 - 2\upsilon)}$$

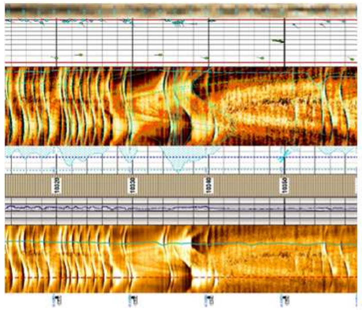


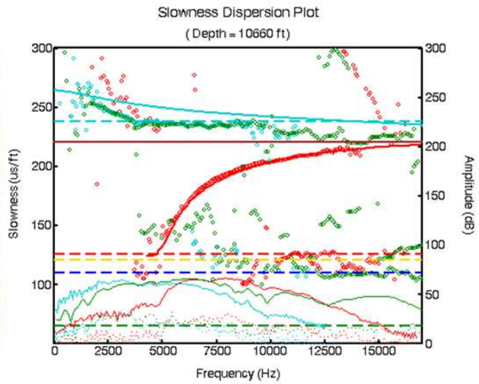


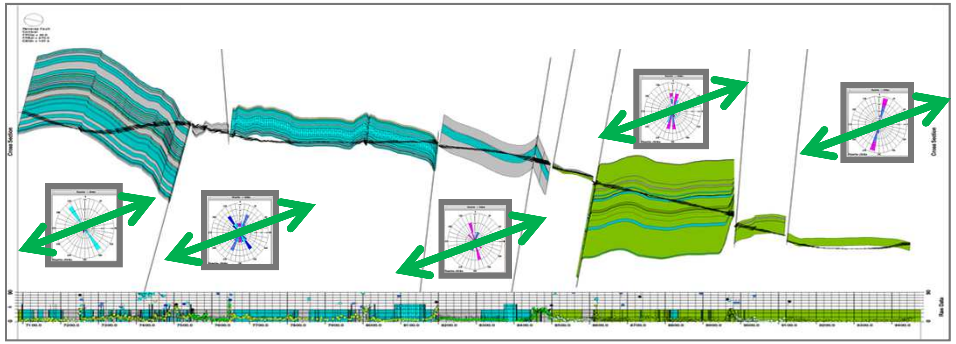


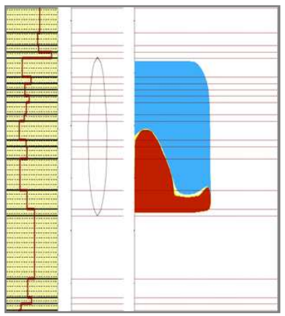
Completion Quality – Horizontal Wells

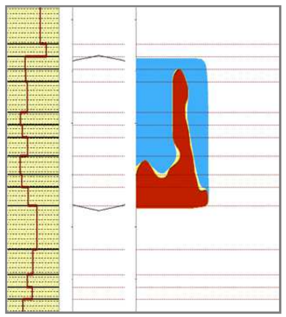
- Wellbore images and acoustics
- Structural complexity
- Natural fracture attributes
- Elastic Moduli
  - Breakdown pressure
  - Fracture compliance
- Completion decisions
  - Staging
  - Completion materials, embedment





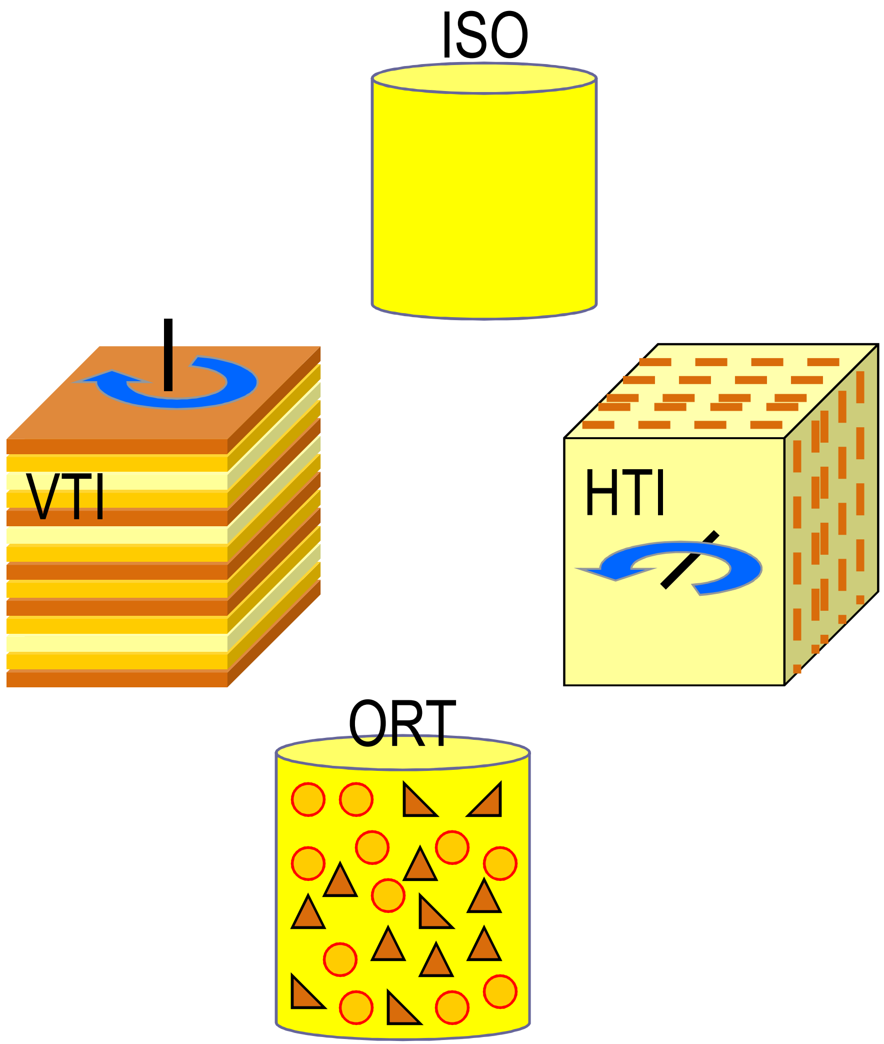




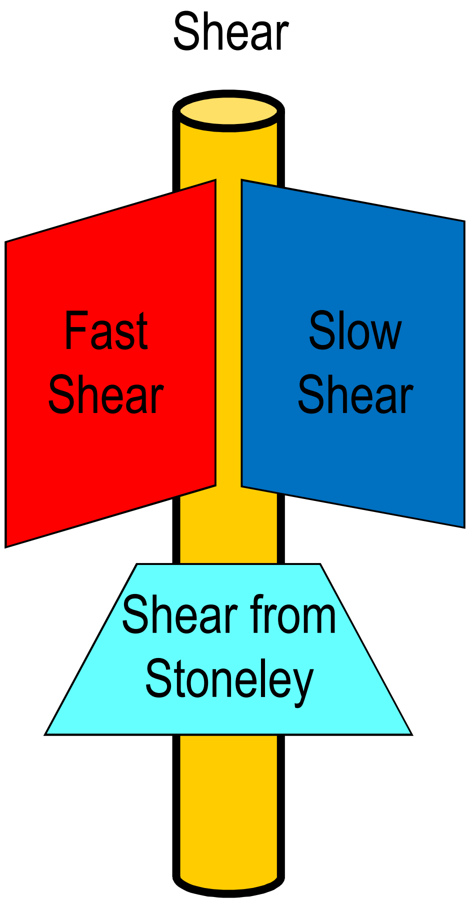


Anisotropy – 3 Types

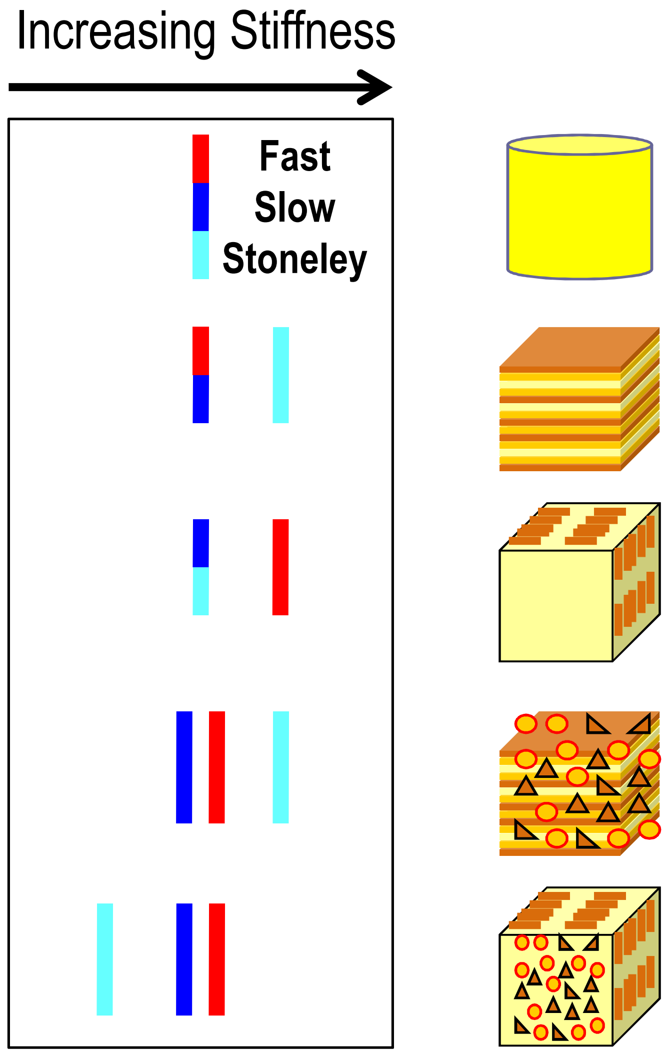
- Isotropic
  – Property is the same in 3 directions
- Transverse isotropic
  – Property is the same in 2 directions
- Orthotropic
  – Property is different in 3 directions



Acoustical Classification
3 Shear Moduli – 5 Major Cases

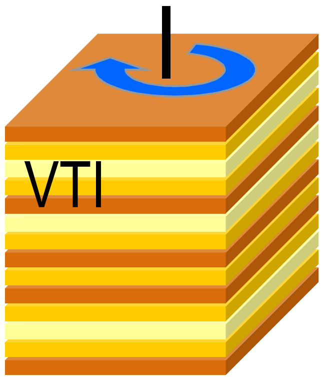


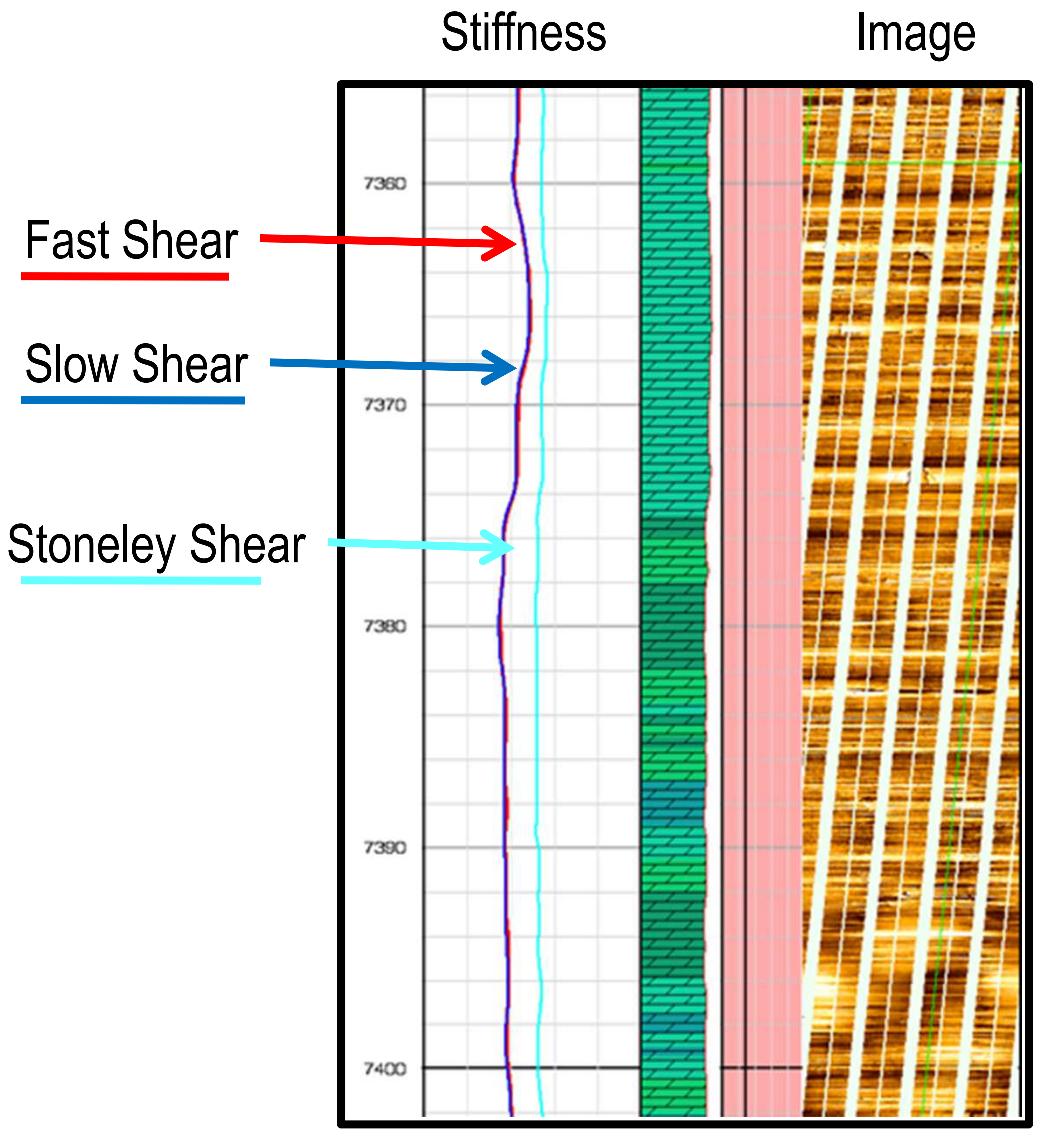
1. Isotropic
2. Layering VTI
3. Fracturing HTI
4. ORT / VTI-like
5. ORT / HTI-like



Structural Anisotropy – Background Matrix is VTI

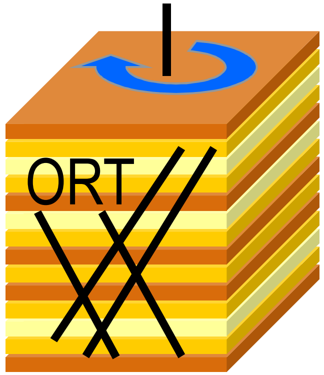
- Upper Barnett
- Multiple layers
- No fracturing
- Significant VTI anisotropy

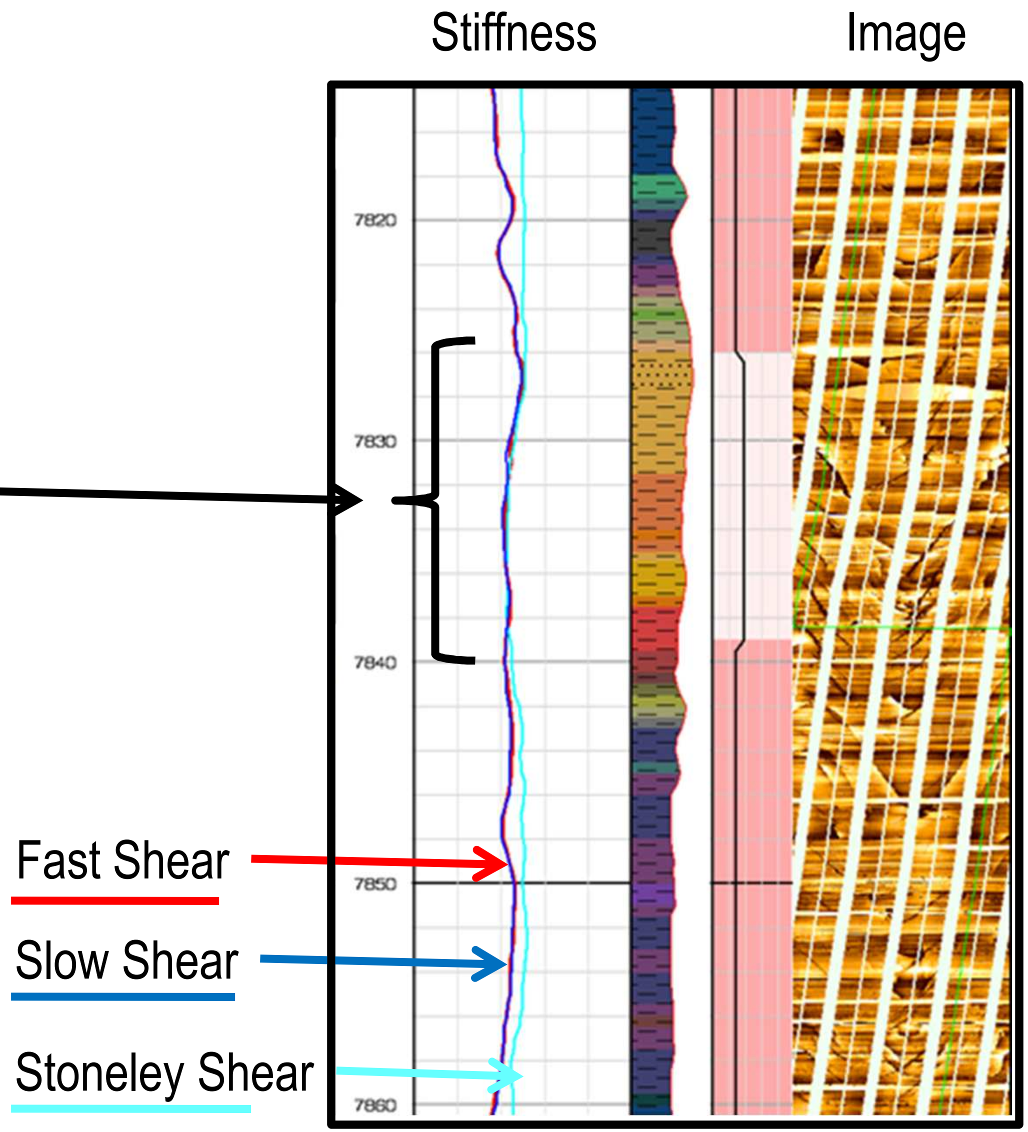




Matrix + Vertical Fractures

- Lower Barnett
- Multiple layers
- Multiple fractures
- Isotropic ???





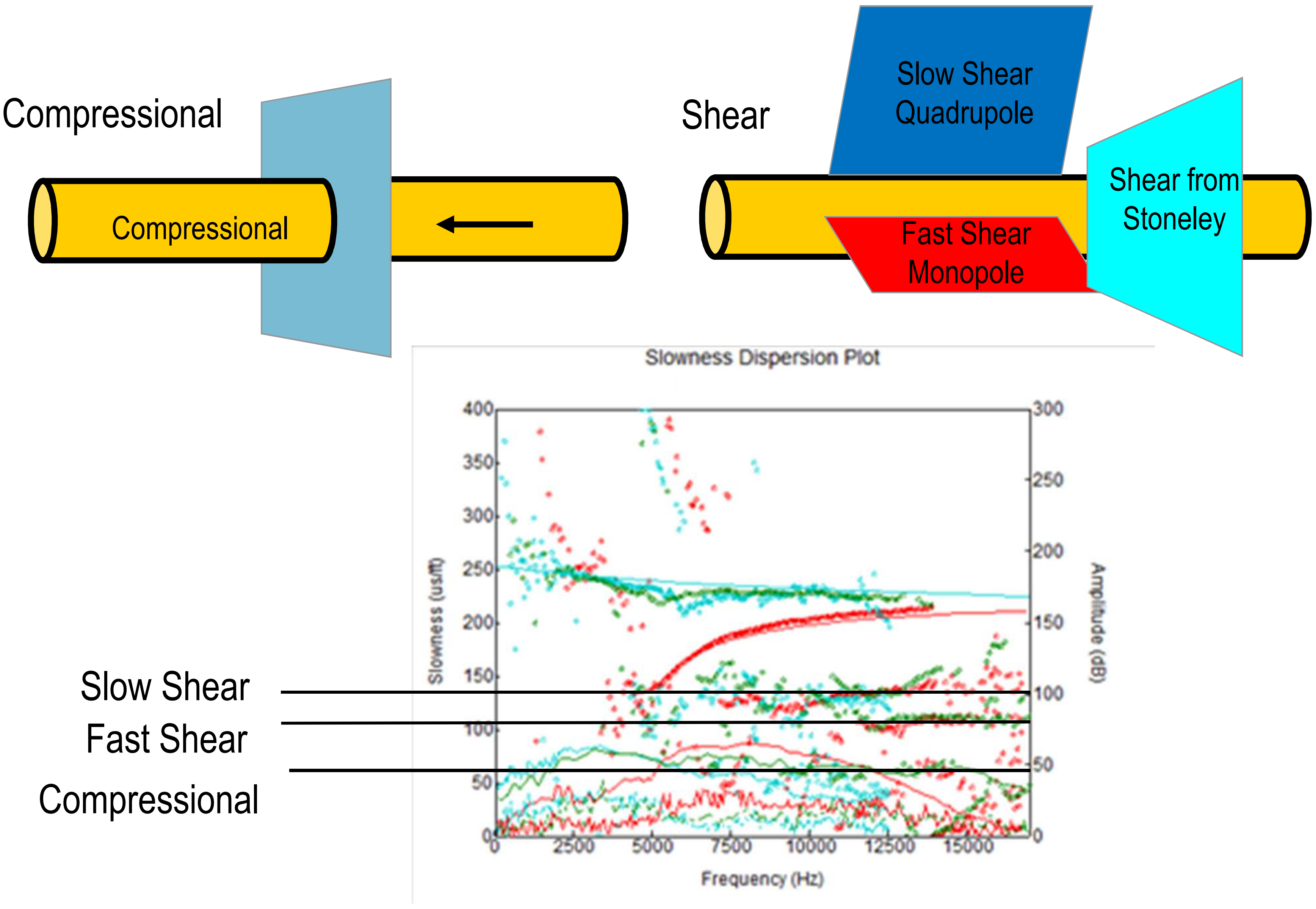
Anisotropy Model

$$\sigma_i = C_{ij}\varepsilon_j \qquad \varepsilon_i = S_{ij}\sigma_j \qquad S_{Total} = S_{Core} + S_{Fracture}$$

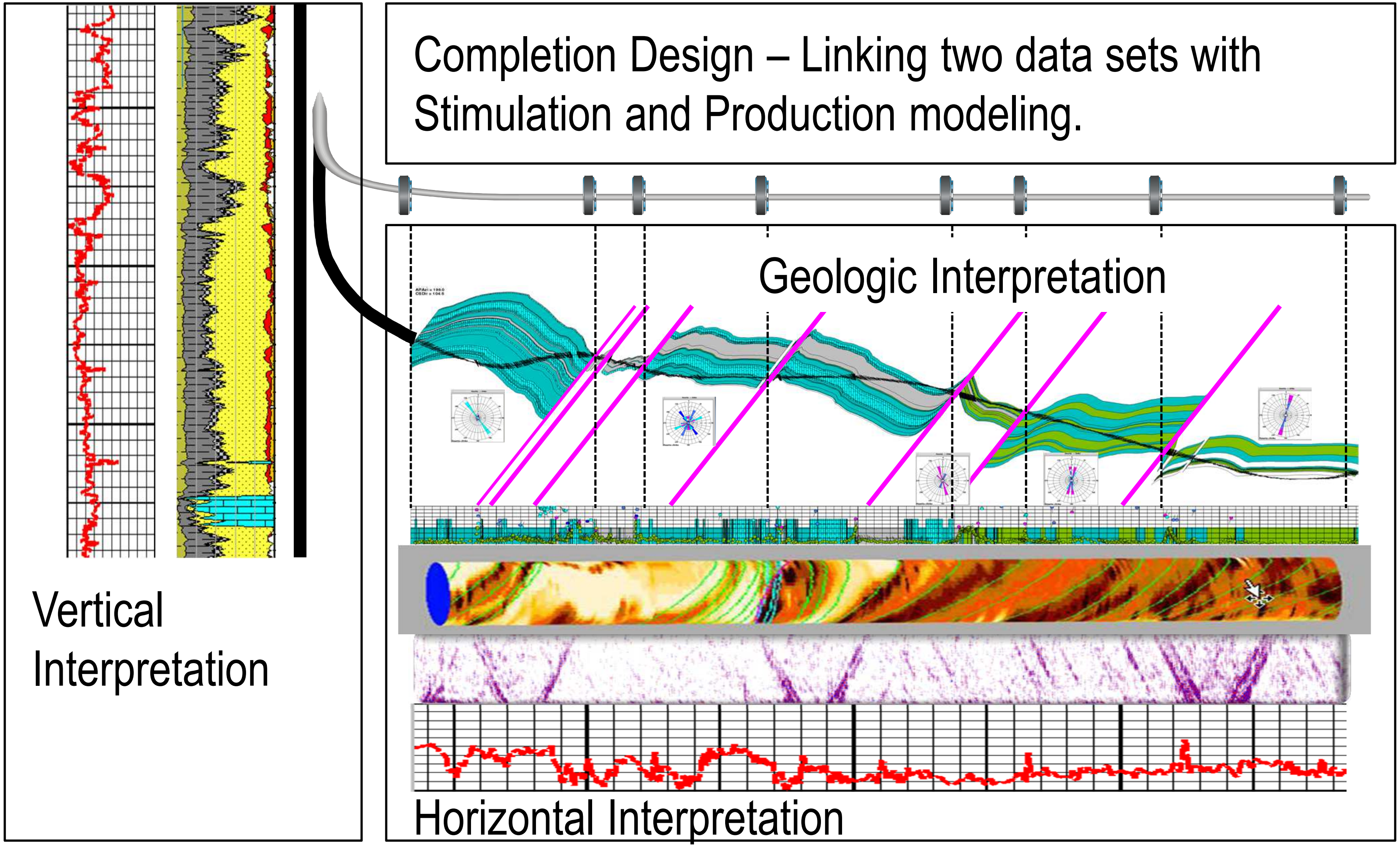
$$S_{ij} = \begin{bmatrix} \frac{1}{E_H}+\alpha_{HH} & \frac{-\nu_{hH}}{E_h} & \frac{-\nu_{VH}}{E_V} & 0 & 0 & 0 \\ \frac{-\nu_{Hh}}{E_H} & \frac{1}{E_h}+\alpha_{hh} & \frac{-\nu_{Vh}}{E_V} & 0 & 0 & 0 \\ \frac{-\nu_{HV}}{E_H} & \frac{-\nu_{hV}}{E_h} & \boxed{\frac{1}{E_V}+\alpha_{VV}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \boxed{\frac{1}{G_{VH}}+\alpha_{hh}+\alpha_{VV}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \boxed{\frac{1}{G_{Vh}}+\alpha_{HH}+\alpha_{VV}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \boxed{\frac{1}{G_{hH}}+\alpha_{HH}+\alpha_{hh}} \end{bmatrix}$$

Schoenberg & Sayers, Seismic Anisotropy of Fractured Rock, Geophysics 1995

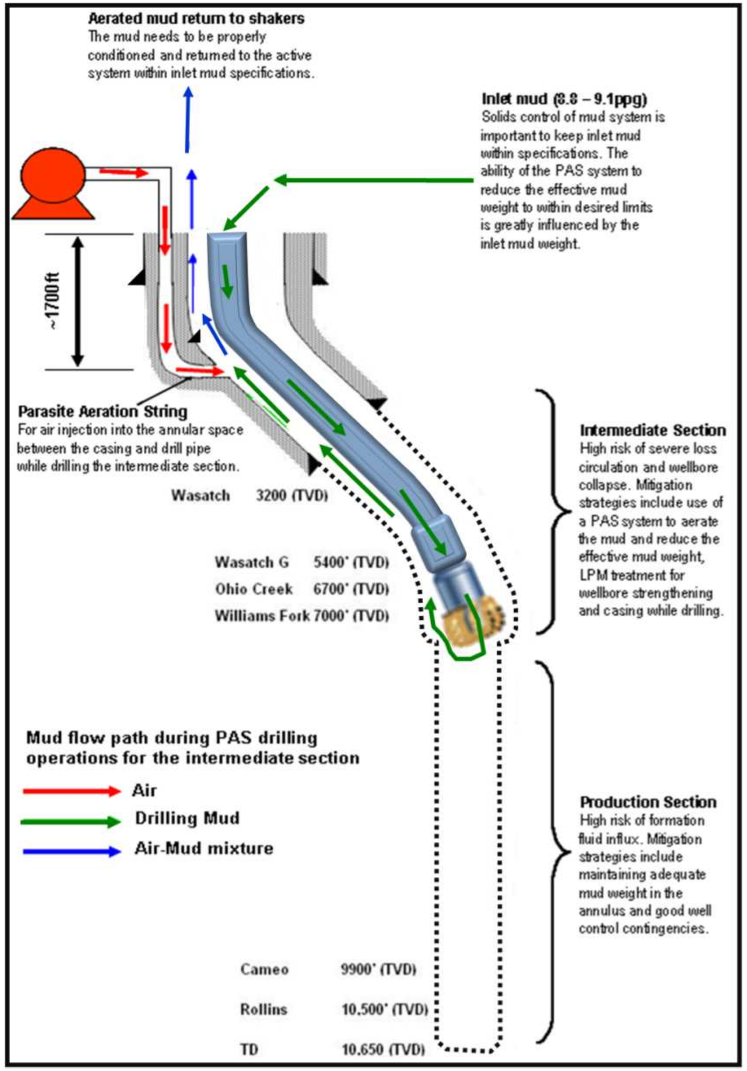
Horizontal Well Acoustics

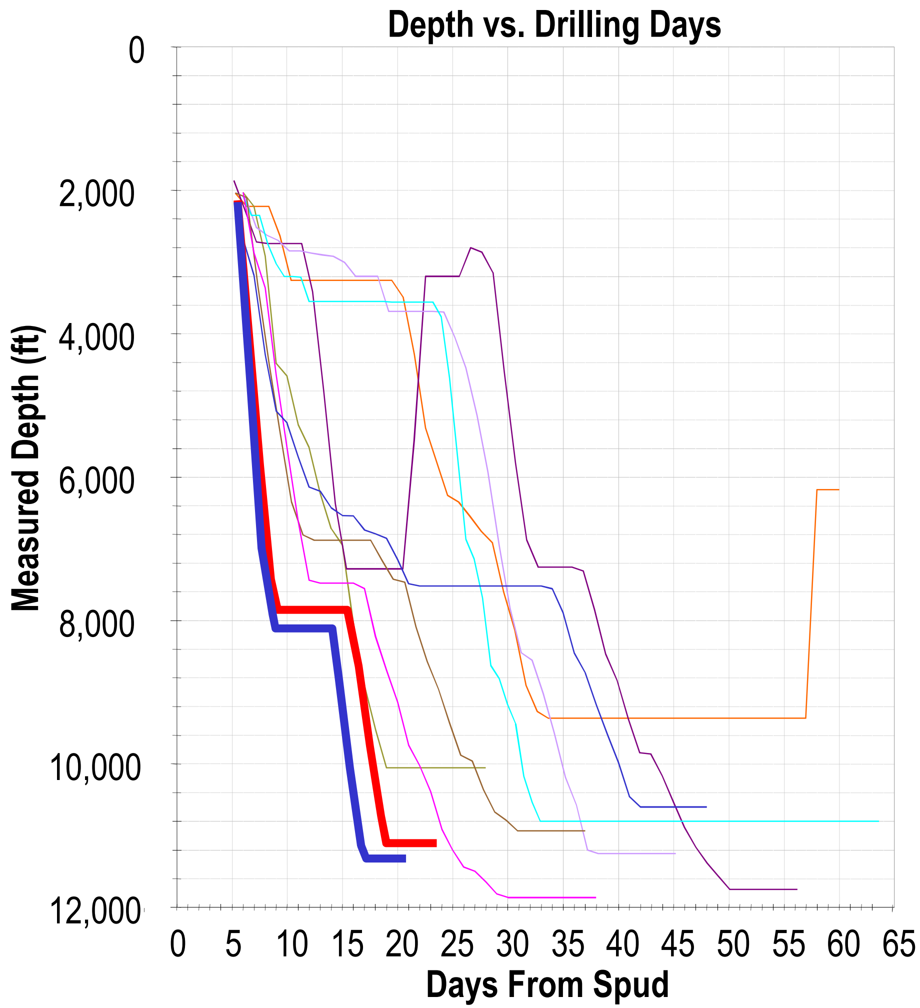


Horizontal Well Completion Design



Integration of Geomechanics with Drilling Engineering





Managed Pressure Drilling using an Aerating String – SPE 2010

Conclusions

- Formations are very complex
  - Heterogeneous and generally anisotropic
- Geomechanics can have a huge impact on both drilling and completion efficiency
- The key to geomechanics:
  - Integration
  - Wellbore images, acoustics, core
  - Vertical and horizontal well data