SPE Young Professionals Webinar

A conversation on the interdisciplinary nature of geomechanics in the Oil & Gas industry

Notes on the constant pursuit for integrated domain efforts and its challenges

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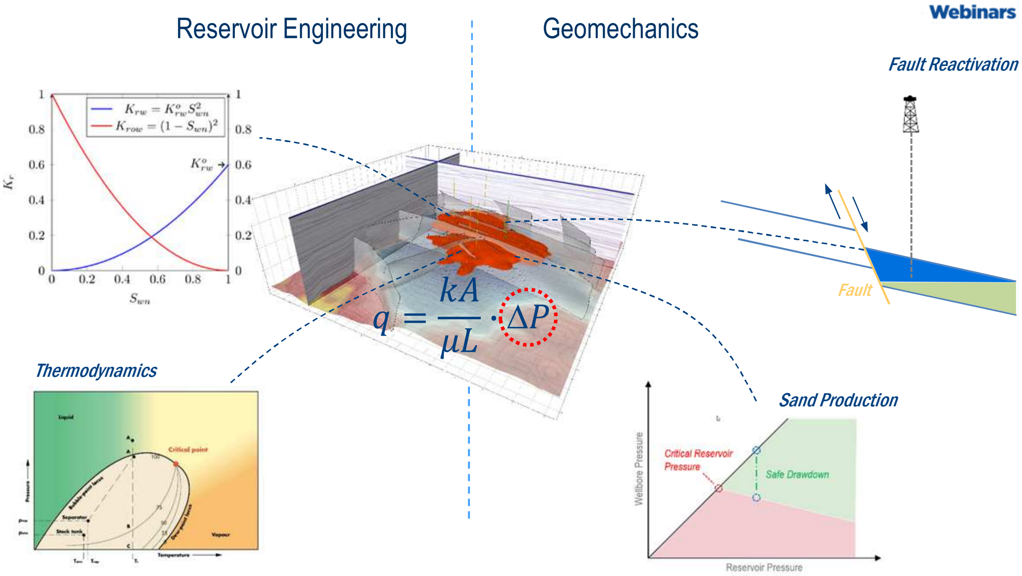
September 6th, 2018

Presentation objectives

- To share examples of how geomechanics can serve as a discipline that brings together many domains in the pursuit of integrated subsurface modelling
- To highlight some of the challenges of integrated modelling efforts and to discuss the strategies that geomechanical applications follow to address such challenges
- To showcase geomechanical modelling as a template for integration and to discuss examples of how it may apply to young professionals working in other domains

Traditional view of Geomechanics



Geomechanics as a interdisciplinary endeavor

Geomechanics as an integrated discipline in O&G is a consequence of:

1) The underlying state variable touches many applications

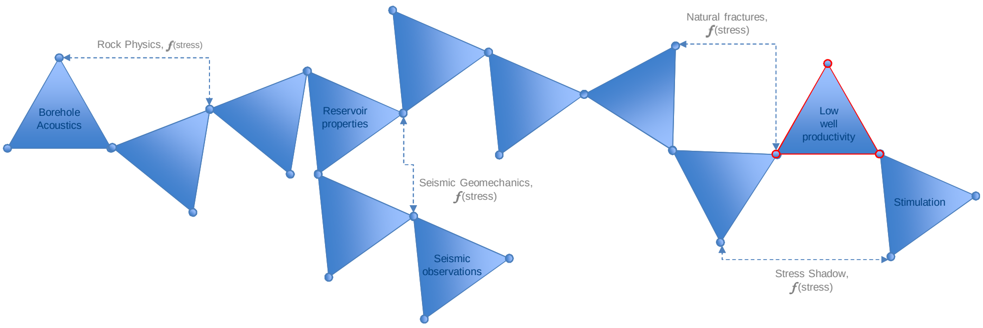
- Stress and strain as a unified language between physical processes
- Besides the study of operational hazards, integration is the compelling event for geomechanics

2) Most of the data sources are borrowed

- The build-up of the value proposition of geomechanics will commonly start with borrowed data
- Physical processes that operate at many spatial scales: data scarcity will always be –relatively- more severe

Geomechanics as a interdisciplinary endeavor

A connected vs an integrated process:

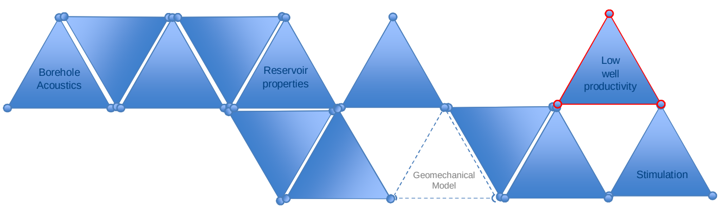


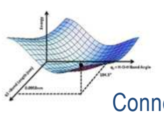
- "Unified language"
- Integration as value proposition
- Borrowed, scarce data sources

"Geomechanicists are *stress detectives*"

Geomechanics as a interdisciplinary endeavor

A connected vs an integrated process:





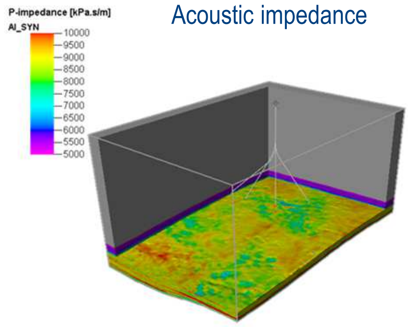
Connection between degrees of freedom → Minimum energy principle, Occam's razor →

- Uniqueness
- Stability
- Accessibility

A Geomechanical Model

1) Well & Seismic Data

Acoustic impedance

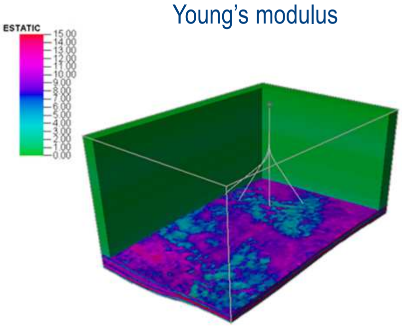


A Geomechanical Model

1) Well & Seismic Data

2) Stiffness and Strength

Young's modulus



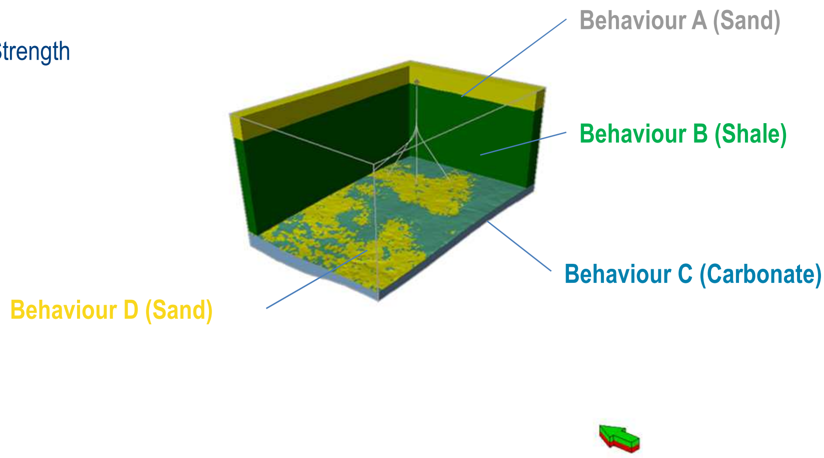
The heterogeneity of the seismic data represents the variability of geomechanical properties

A Geomechanical Model

1) Well & Seismic Data

2) Stiffness and Strength

3) Physics Model



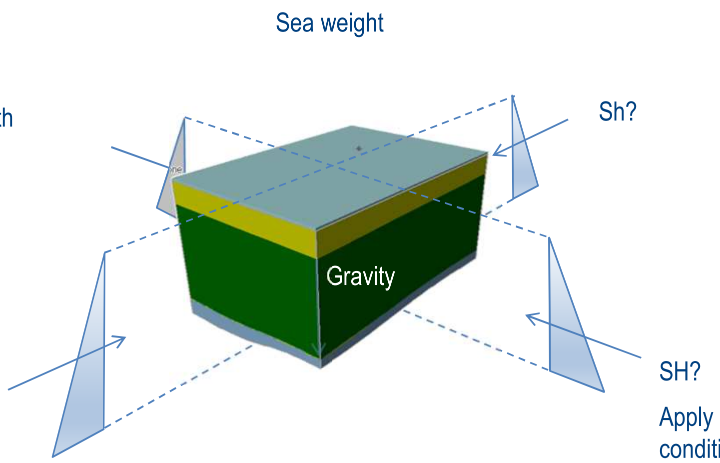
A Geomechanical Model -> Predict Stresses

1) Well & Seismic Data

2) Stiffness and Strength

3) Physics Model

4) Stress State



Apply stress boundary conditions at a distance from the area of interest

A Geomechanical Model -> Solve for Stresses!

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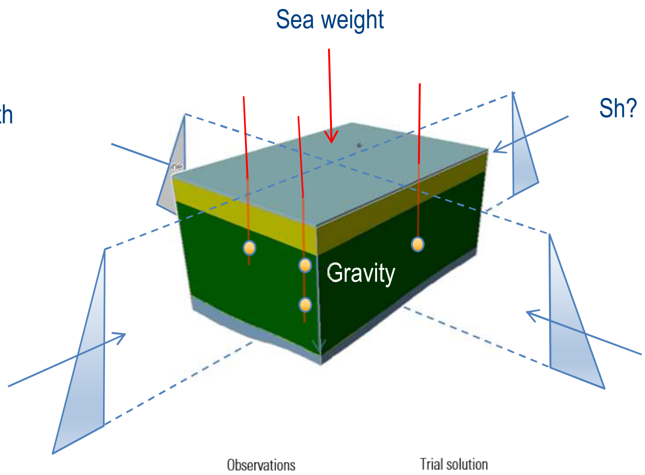
1) Well & Seismic Data
2) Stiffness and Strength
3) Physics Model
4) Stress State
4) History Matching



Solve for stress boundary conditions that explain 1DMEM observations

$$f(BC_i) = \sum\Big(\overbrace{s'_{observatios}(x,y,z)}^{\text{Observations}} - \overbrace{s'(BC;x,y,z)}^{\text{Trial solution}}\Big)$$

Example Applications

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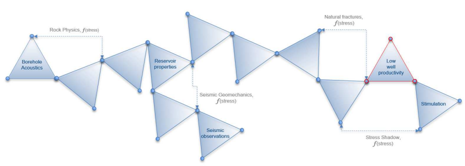

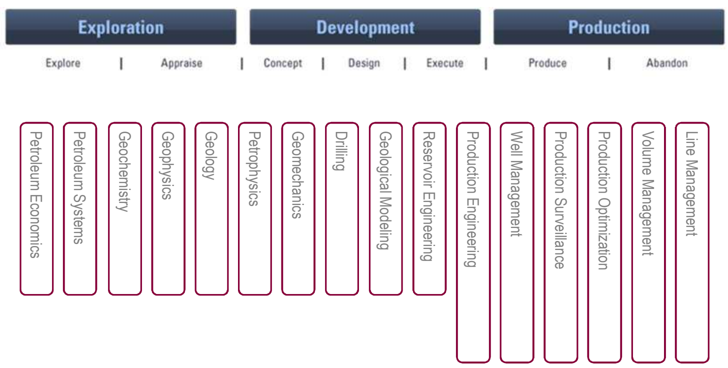

Example Applications

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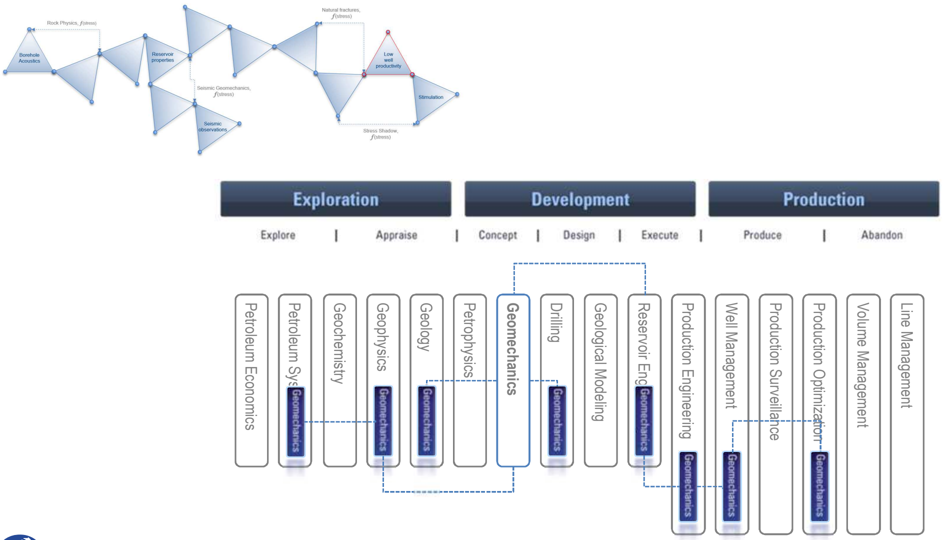

Example Applications

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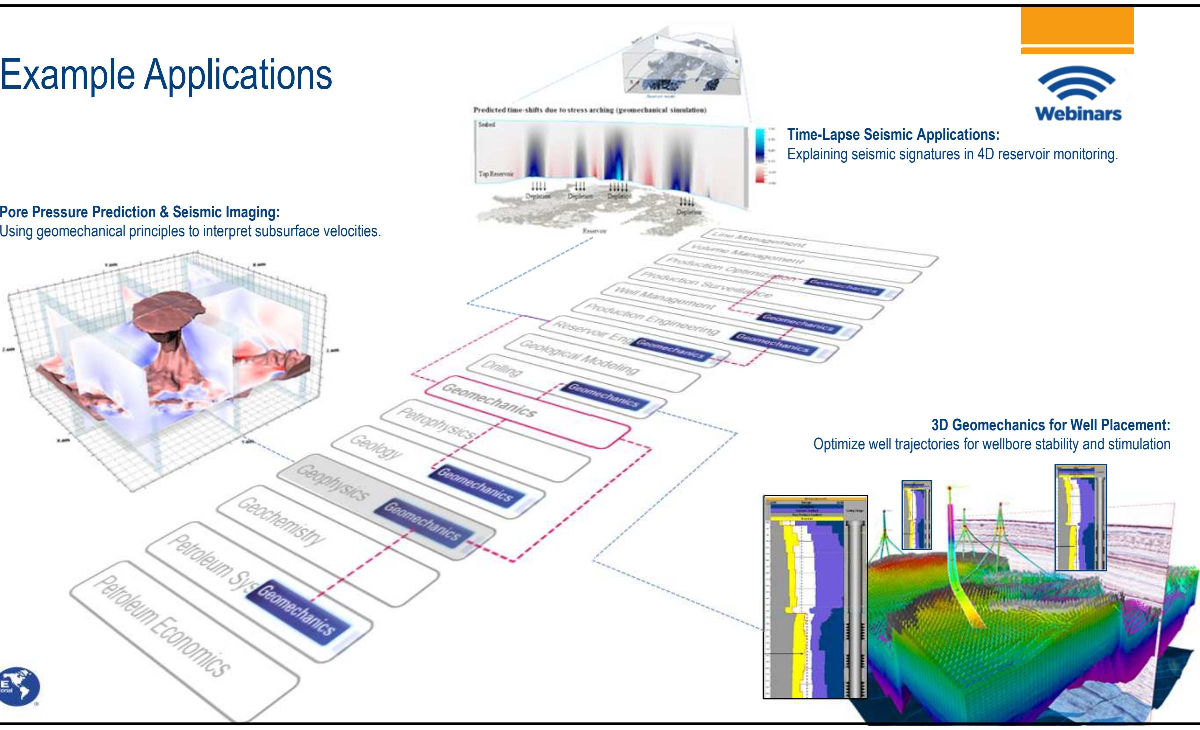
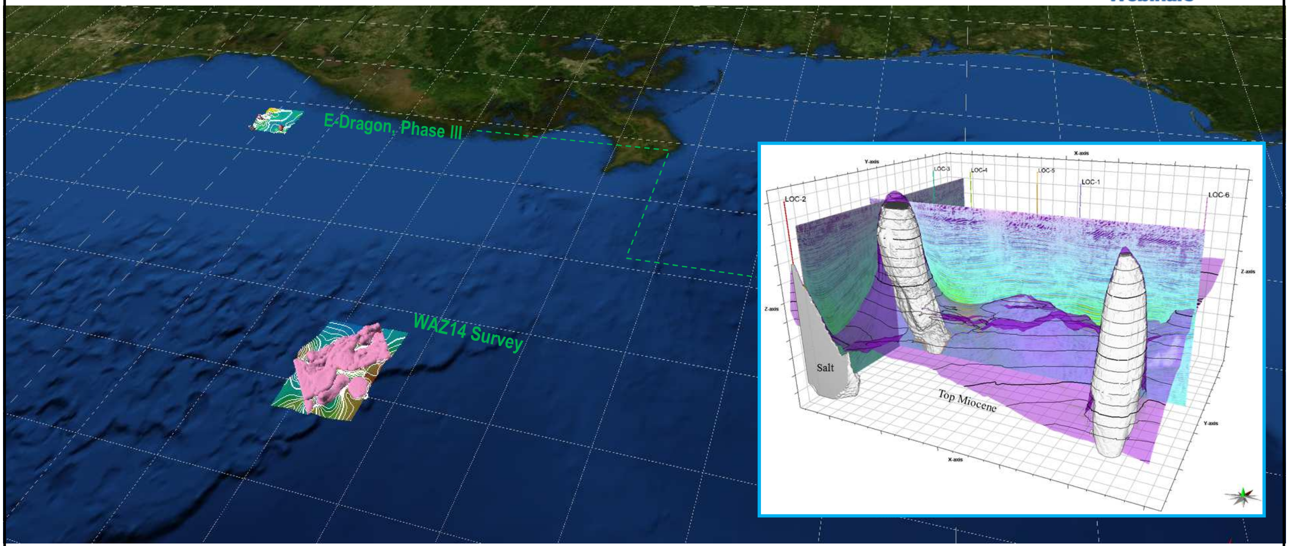
Time-Lapse Seismic Applications:
Explaining seismic signatures in 4D reservoir monitoring.

Pore Pressure Prediction & Seismic Imaging:
Using geomechanical principles to interpret subsurface velocities.

3D Geomechanics for Well Placement:
Optimize well trajectories for wellbore stability and stimulation

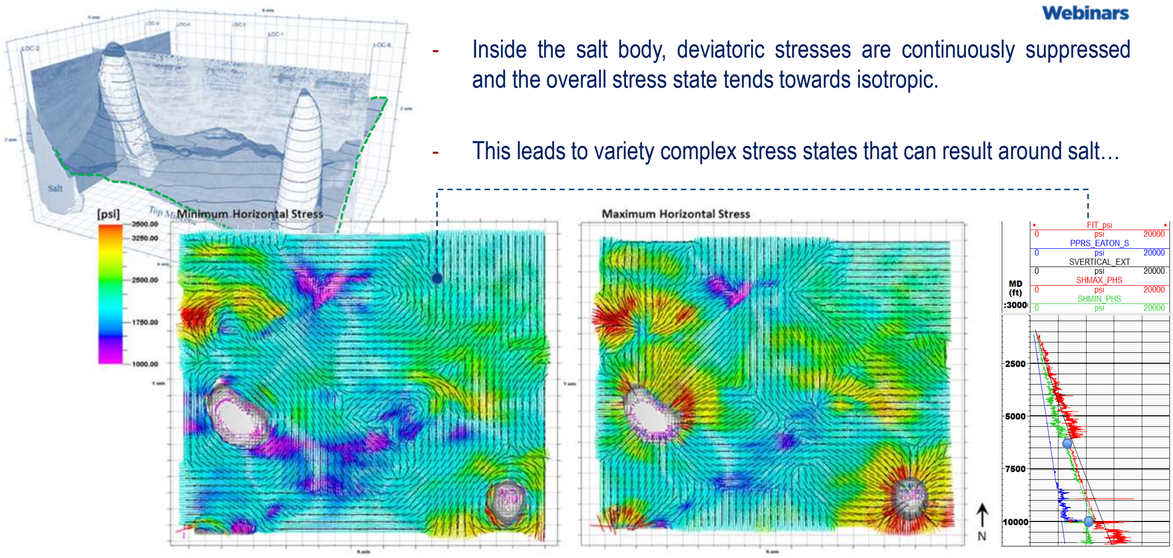


Example #1: Seismic Inversion, Drilling and Geomechanics



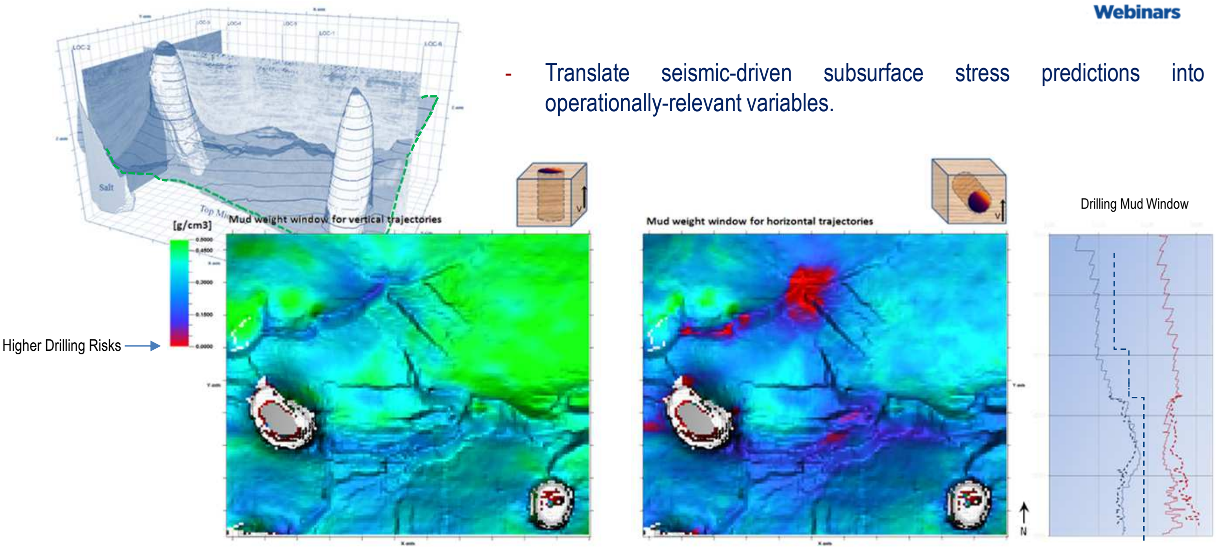
Subsurface Stress Models

- Inside the salt body, deviatoric stresses are continuously suppressed and the overall stress state tends towards isotropic.
- This leads to variety complex stress states that can result around salt…

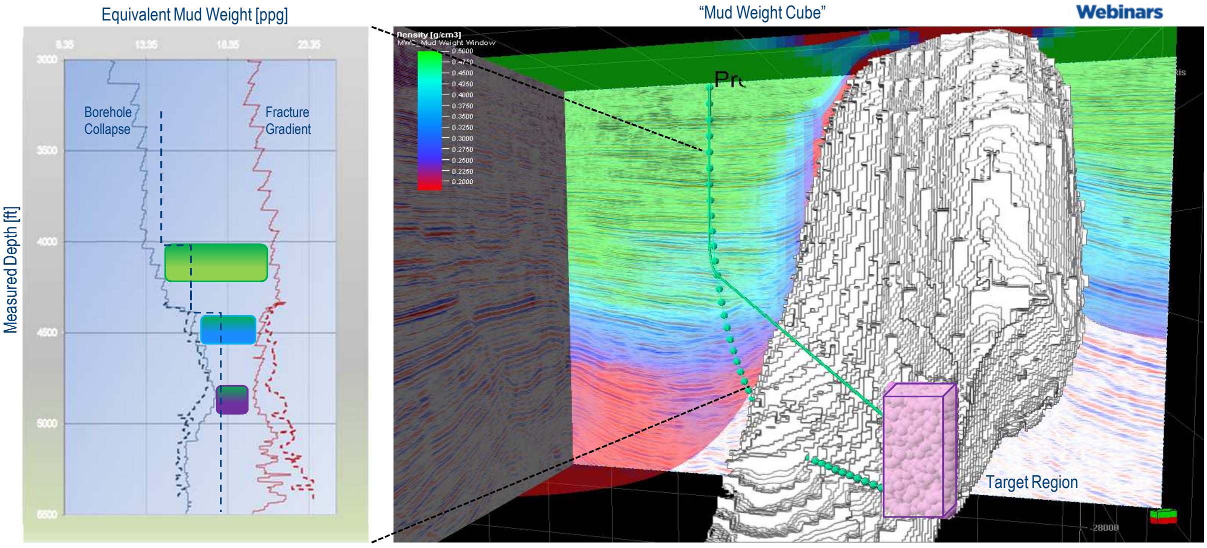


Subsurface Stress Models -> Safe Drilling Windows

- Translate seismic-driven subsurface stress predictions into operationally-relevant variables.



Subsurface Stress Models to Drilling Windows



Example #2: Reservoir Monitoring and Geomechanics

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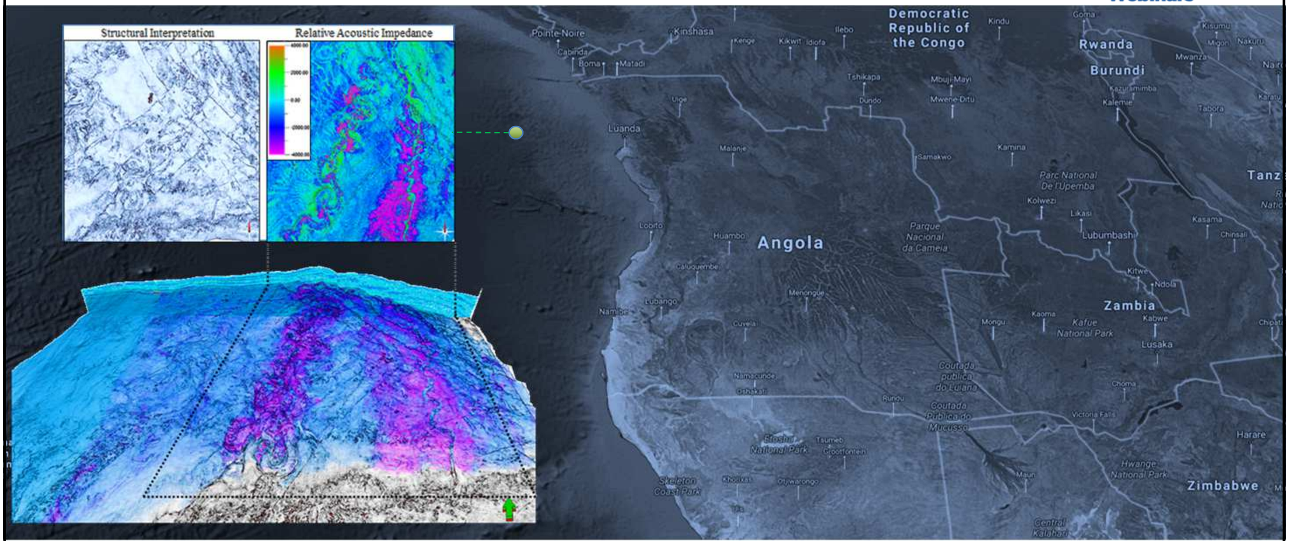

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Using Seismic Data in Reservoir Simulation

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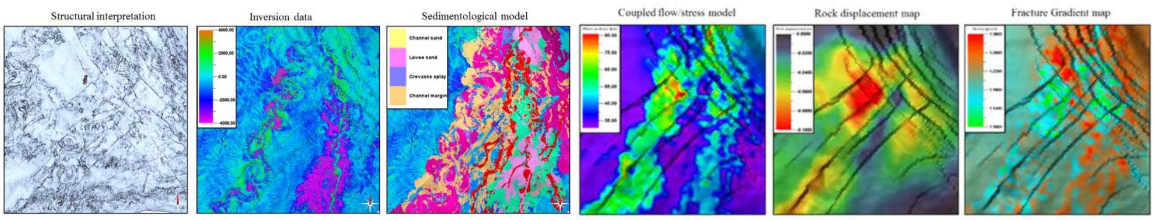

Geophysics Geology Reservoir Engineering Geomechanics Drilling

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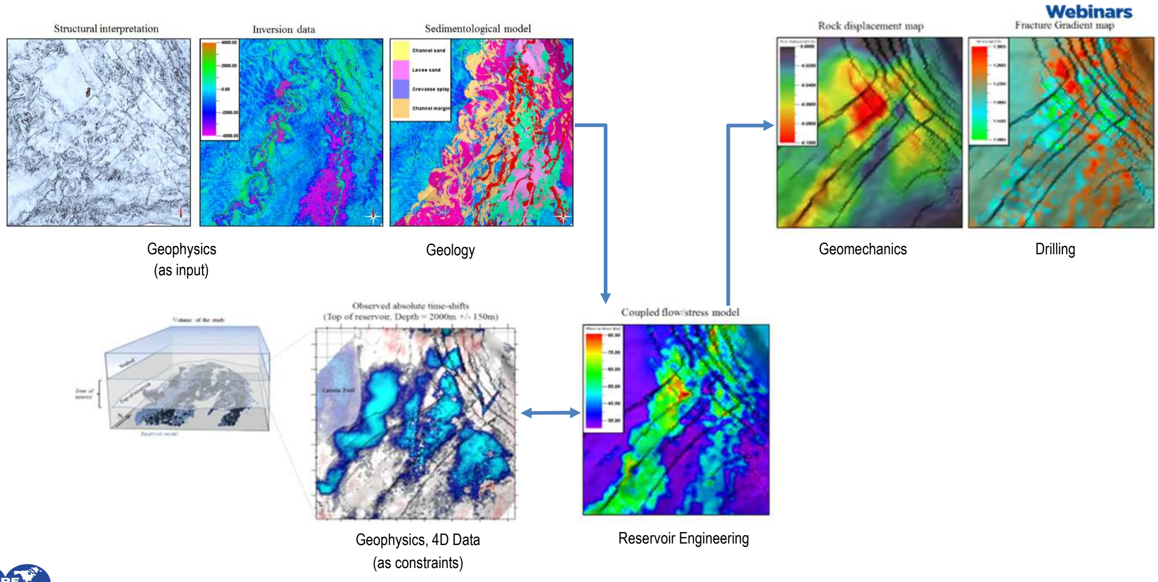
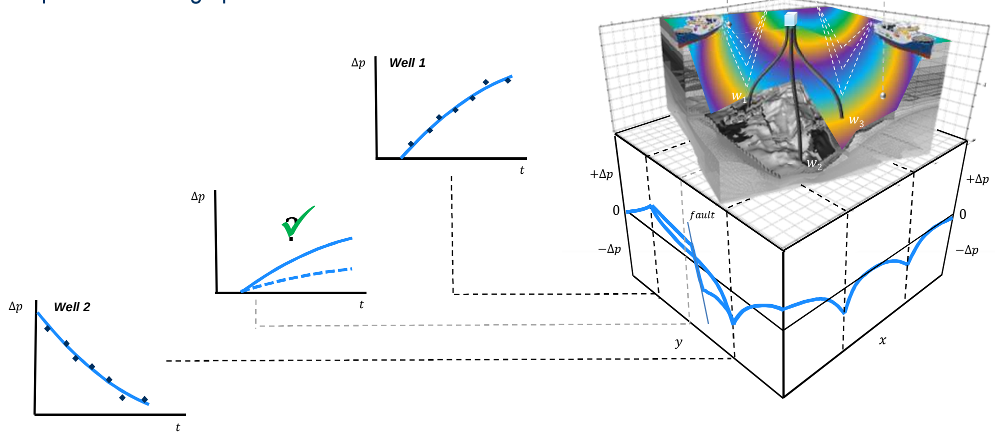
Using (Time-Lapse) Seismic Data in Reservoir Simulation



Seismic Reservoir Monitoring via Geomechanics

By comparing with actual time-shift observations, it is possible to assist history matching workflows to solve for reservoir pressure change patterns.

$$f(\Delta p) = \int_V \Big(\overbrace{\Delta \boldsymbol{t}_{seismic}(x,y,z)}^{\text{Observations}} - \underbrace{\Delta \boldsymbol{t}_0(x,y,z)}_{\text{Baseline model, "Geological prior"}} - \overbrace{\Delta \boldsymbol{t}_i(\Delta p; x,y,z)}^{\text{Inversion update}}\Big)\, dV$$



Field Evidence of Such Geomechanical Predictions?

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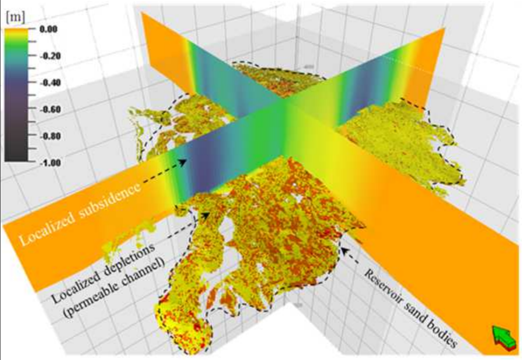
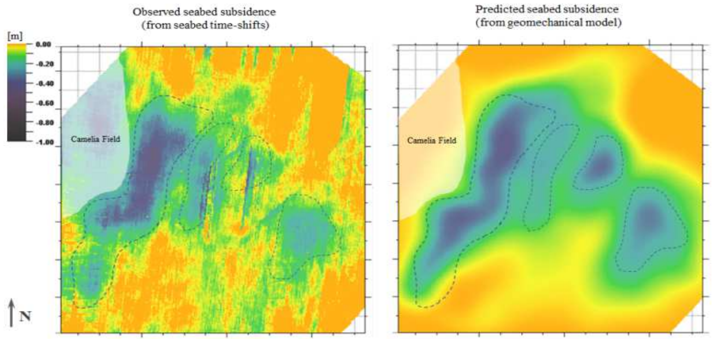


Variable displacements result from localized depletion along permeable channel sands and increased slip potential in heavily faulted regions, for example, to the northeast of the field.

Map view: Seabed vertical rock displacement (**subsidence**) for the year 2012.



Linking the Reservoir with its Surroundings

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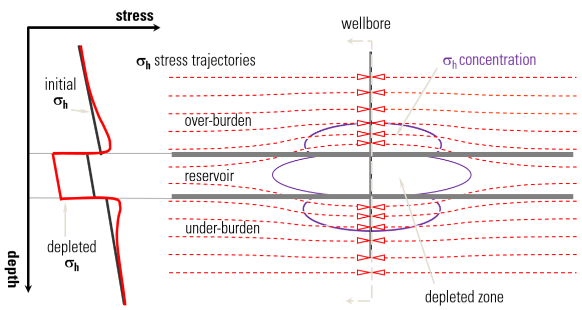
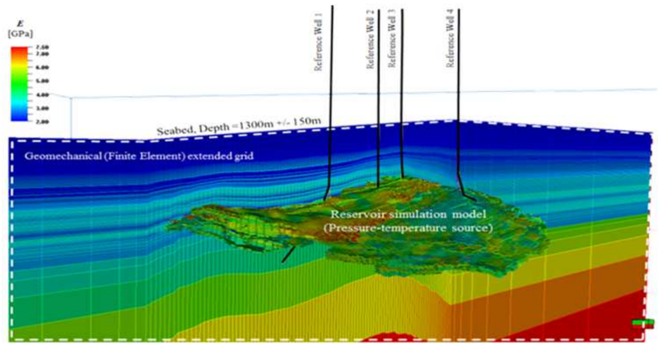
Underlying Physical Mechanism



Numerical Representation:
Fluid-Flow/Geomechanical Model



Linking the Reservoir with its Surroundings: 4D Seismic

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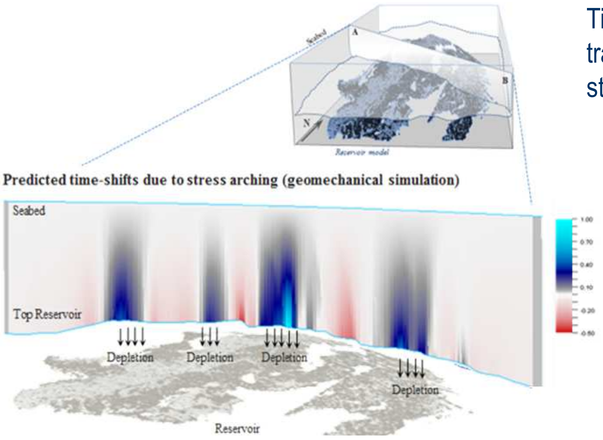
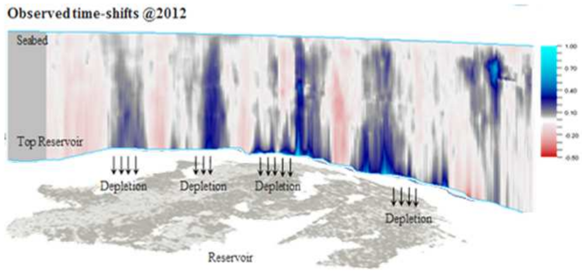
Time lapse time-shifts are a measure of the differences in travel times between two seismic surveys, possibly due to stress dependent velocity changes over time.





$$\Delta t|_{(z_1,z_2)} \approx \int_{z_1}^{z_2} \frac{\varepsilon_{33}}{v_o}\,\partial z + \int_{z_1}^{z_2} \frac{1}{v_o}\Big(\underbrace{R_1\varepsilon_{33}}_{\text{Axial}} + \underbrace{R_2\,(\varepsilon_{vol} - \varepsilon_{33})}_{\text{Orthogonal}}\Big)\partial z$$

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Geomechanics-Driven Reservoir Model Updates

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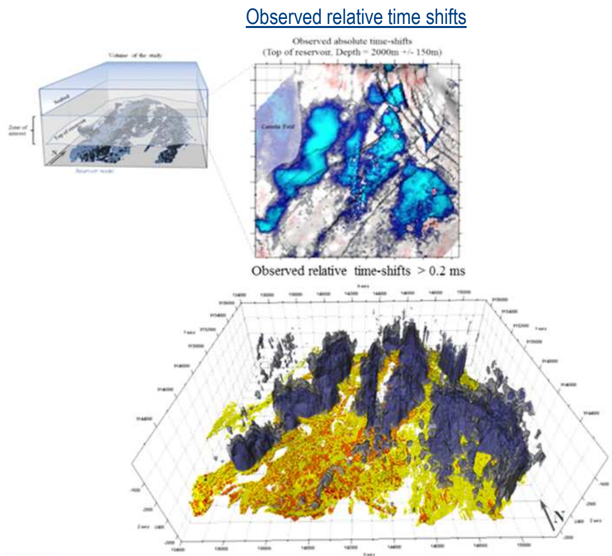

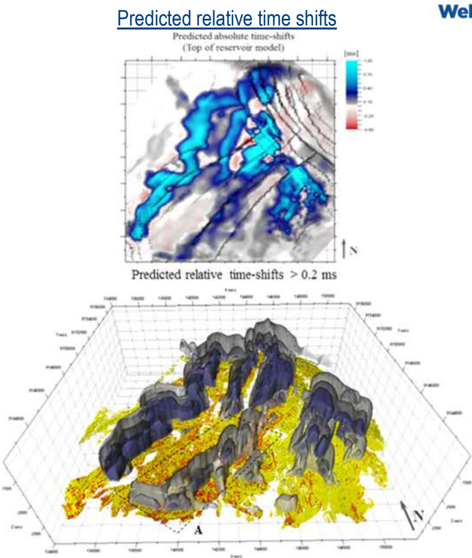

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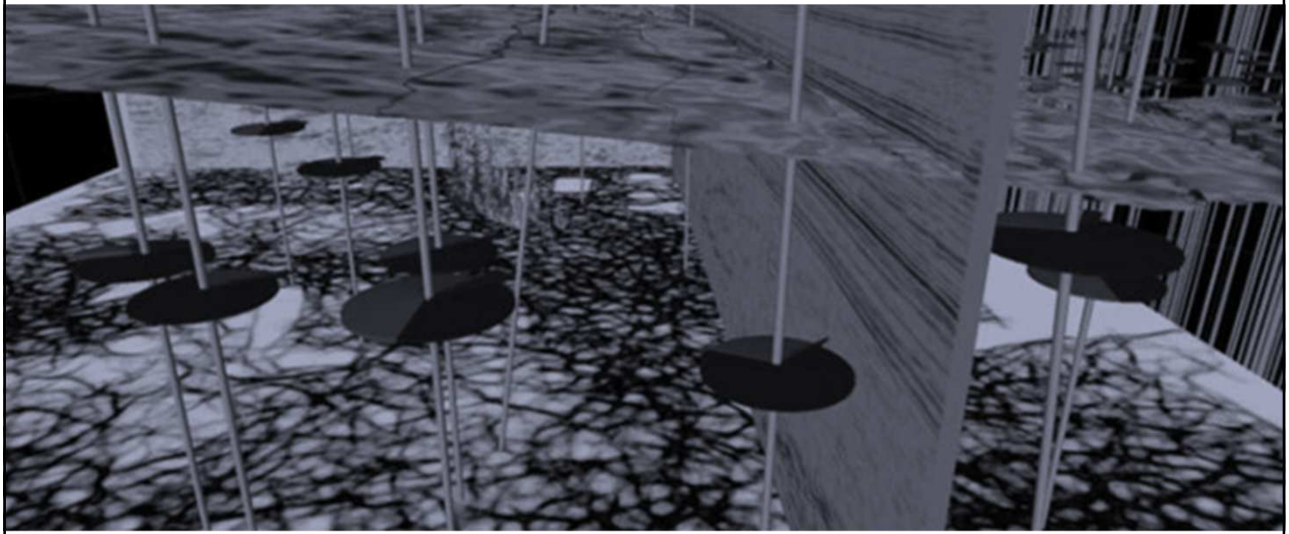
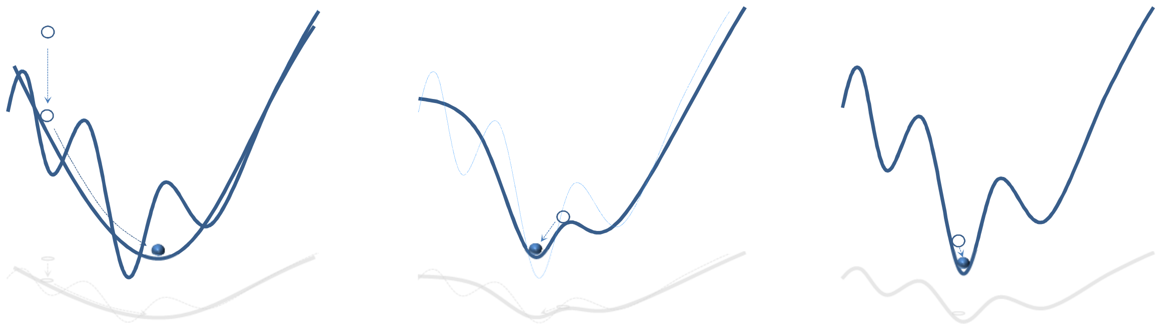
Example #3: Unconventionals



How do we tackle complex numerical problems?

For example, find the global minimum of:



Different levels of analysis at different scales

The Scales Involved in Stress Modelling for Unconventionals

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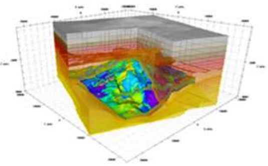
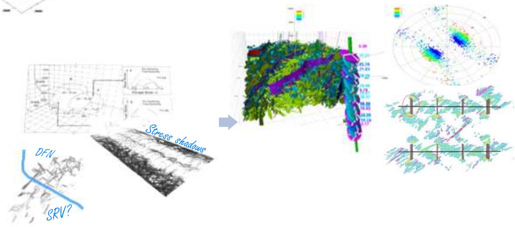
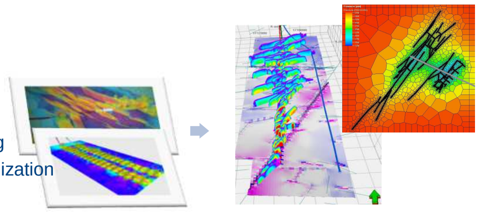


Field Scale
-Subsurface data integration
-Stress regime, structural effects



Pad Scale
-Effects of natural fractures
-ISIP and HF performance patterns

Well Scale
-Hydraulic fracture modeling
-Completion design & optimization
-Production forecasting



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Interpretation frameworks: 3D Geomechanical Models

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Applications to US Land Unconventionals: The Haynesville Shale

Minimum Horizontal Stress Map

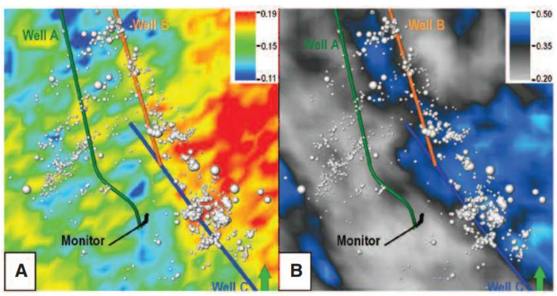
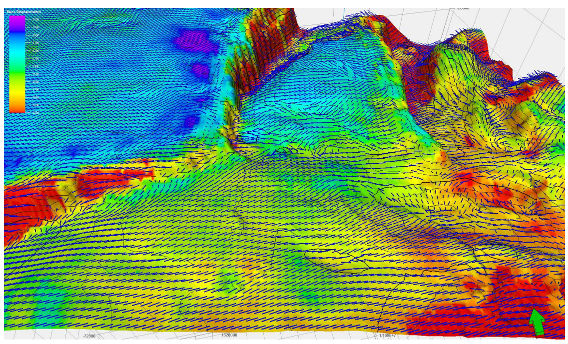


Figure 5 shows microseismic events sized by magnitude and overlaid on maps of minimum Poisson's Ratio (left), and mean rock fabric (right).

(Haege et al. 2014)

Minimum Horizontal Stress Map



(Rodriguez-Herrera et al. 2013, ARMA)

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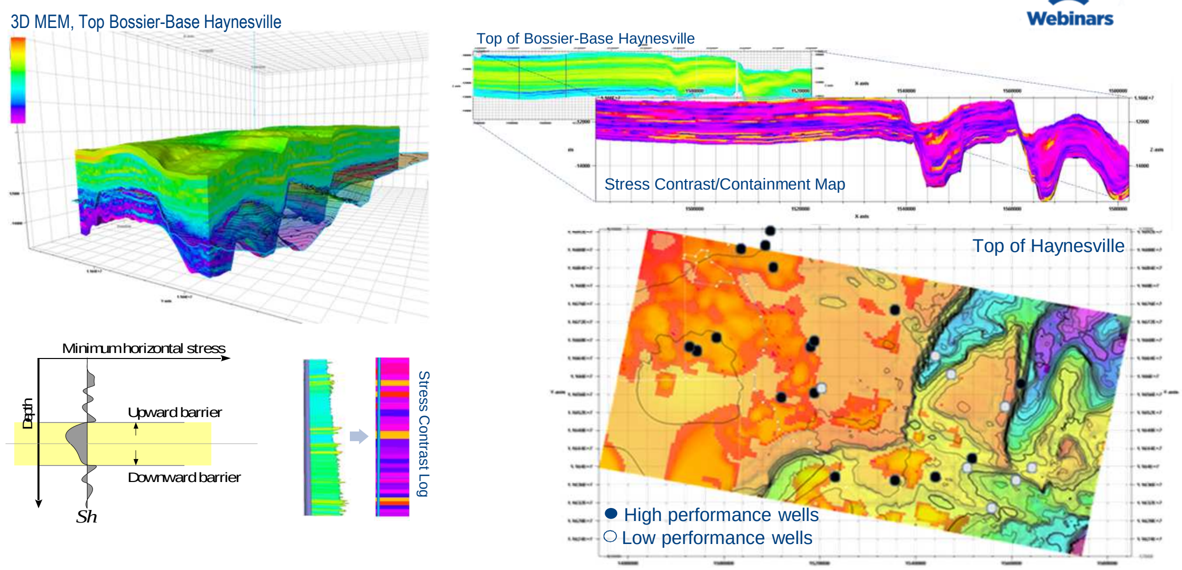
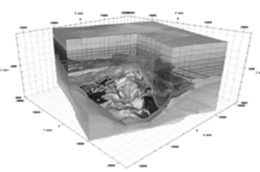
Field-Scale Screening of Stimulation Performance: Containment

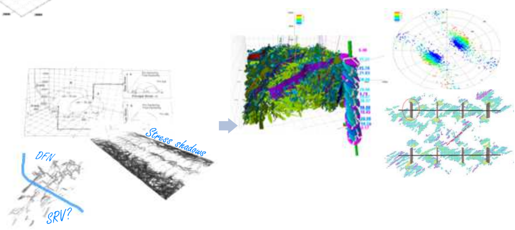


(Rodriguez-Herrera et al. 2013, ARMA)

The Scales Involved in Stress Modelling for Unconventionals

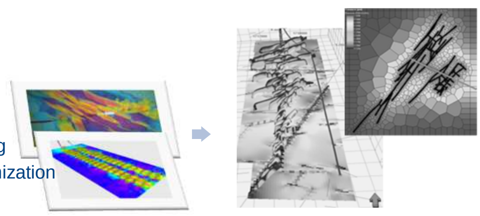


Field Scale
-Subsurface data integration
-Geomechanical model creation



Pad Scale
-DFN Calibration
-ISIP and HF performance patterns

Well Scale
-Hydraulic fracture modeling
-Completion design & optimization
-Production forecasting



Pad Scale Geomechanics: Horn River Basin, British Columbia

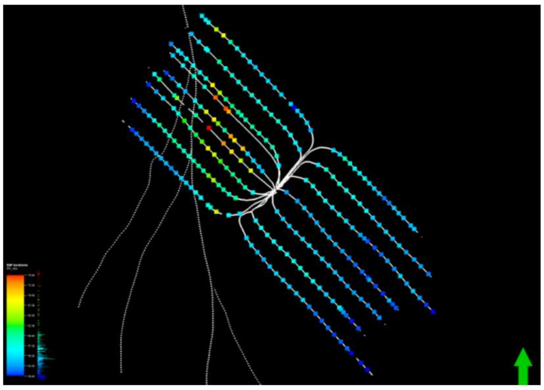


Figure 1: Instantaneous shut-in pressures (ISIPs) for the production pad considered in this paper, with points color coded by ISIP from low (blue) to high (red). The dashed lines show the location of 4 faults interpreted on the depth-migrated data. The arrow points north.

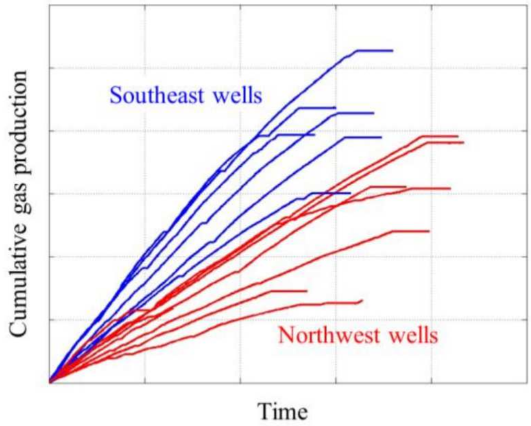


Figure 2: Cumulative gas production for the southeast wells (blue) compared to northwest wells (red).

(Sayers, Lascano, Gofer, den Boer et al. 2016, SEG)

Driving Mechanical Properties with AVA Seismic Inversion

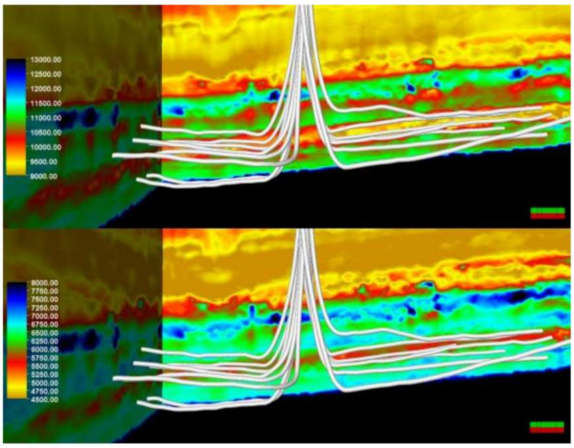
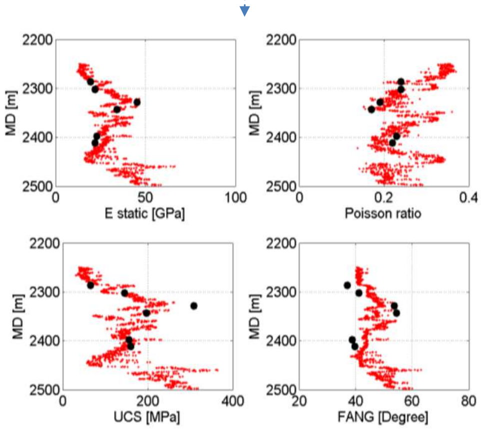


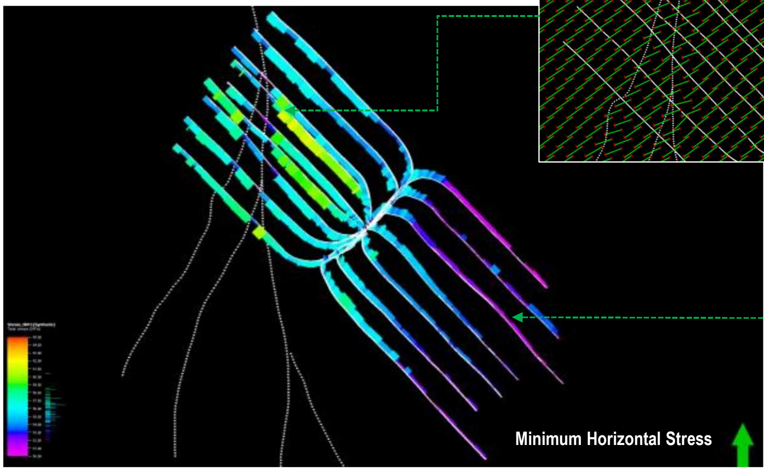
Figure 3: Cross-sections of inverted P-impedance (top) and S-impedance (bottom) with production wells (white) superimposed.

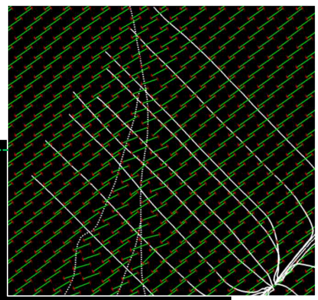
Rock Physics Transforms

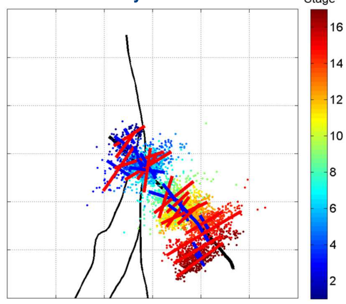


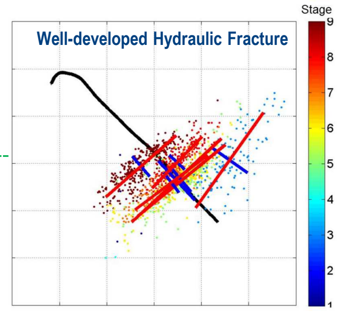
(Sayers, Lascano, Gofer, den Boer et al. 2016, SEG)

Effects of Faulting on Hydraulic Fracture Behaviour



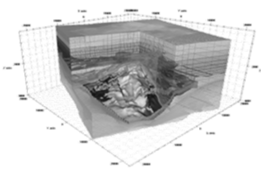




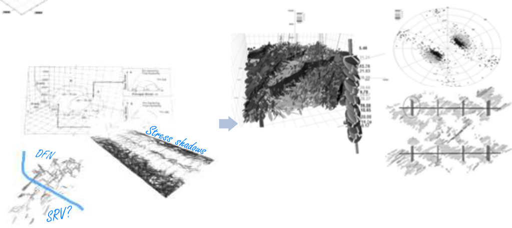


(Sayers, Lascano, Gofer, den Boer et al. 2016, SEG)

The Scales Involved in Stress Modelling for Unconventionals

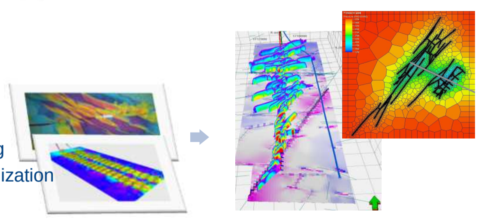


Field Scale
-Subsurface data integration
-Geomechanical model creation

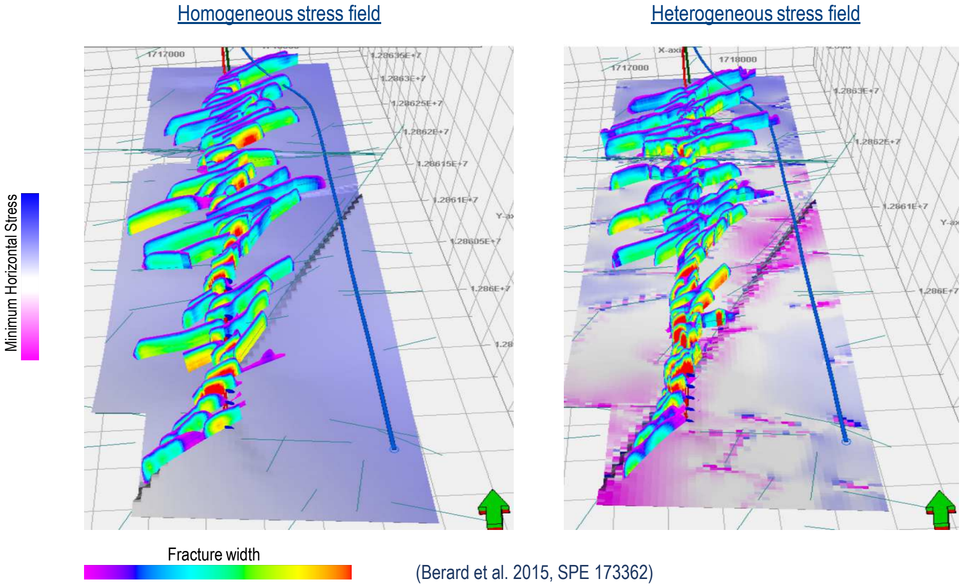


Pad Scale
-Natural fractures
-ISIP and HF performance patterns

Well Scale
-Hydraulic fracture modeling
-Completion design & optimization
-Production forecasting



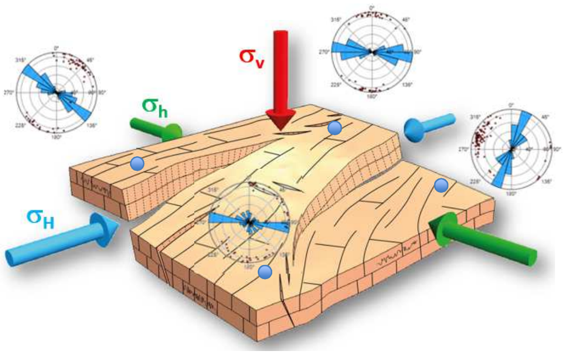
Hydraulic Fracture Design: Connection with Geomechanics

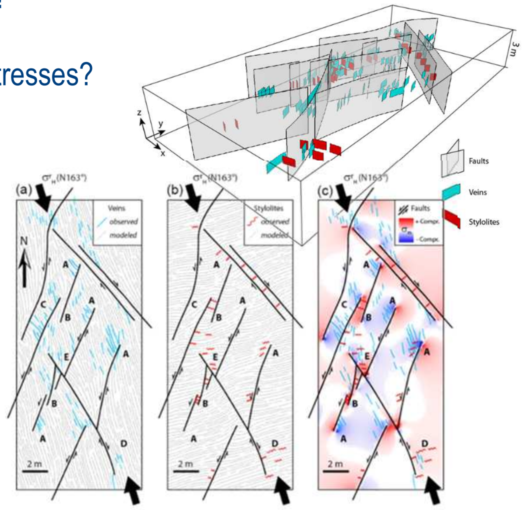


(Berard et al. 2015, SPE 173362)

Insights from Geology: Effects of Stress Orientation

- Relationship between hydraulic and natural fractures?
- Relationship between natural fractures and far field stresses?



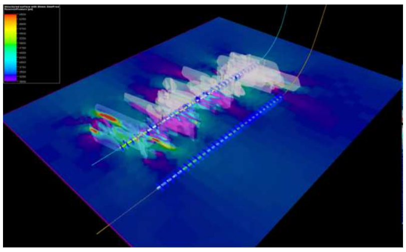


(Maerten and Maerten, 2010)

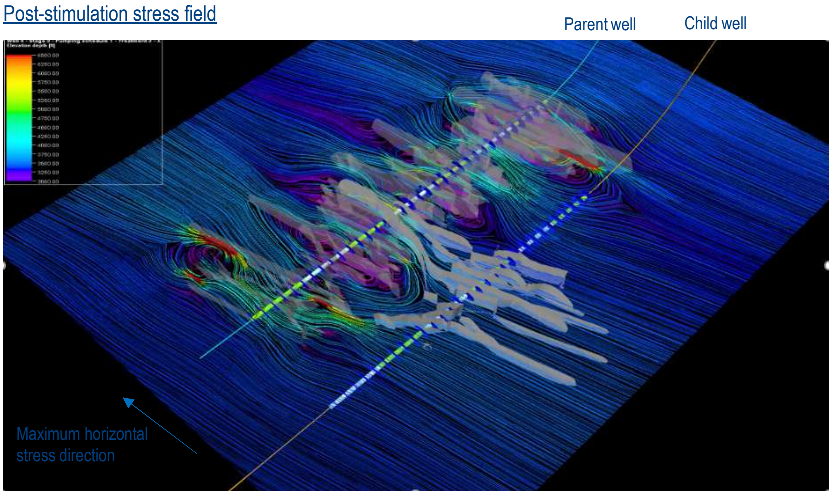
Hydraulic Fracture Design: Effects of Stress Orientation

- Similar processes drive hydraulic fracture orientation w.r.t the perturbed far field stresses

Pre-stimulation stress field

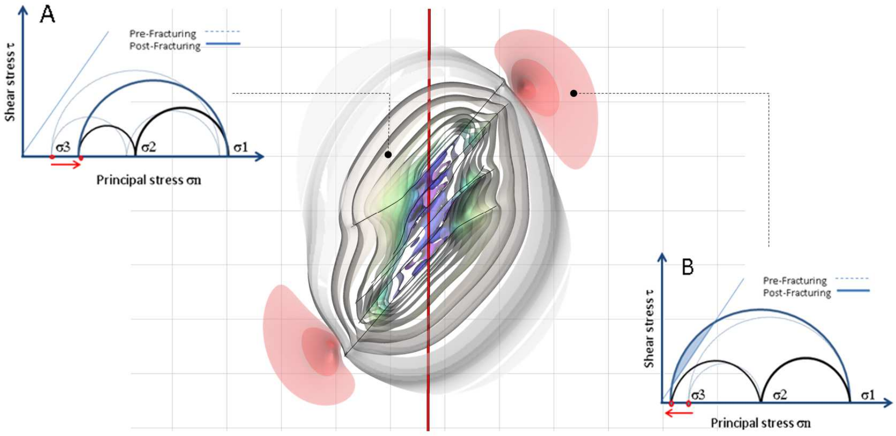


Post-stimulation stress field



Microseismicity, Stresses and Hydraulic Fractures

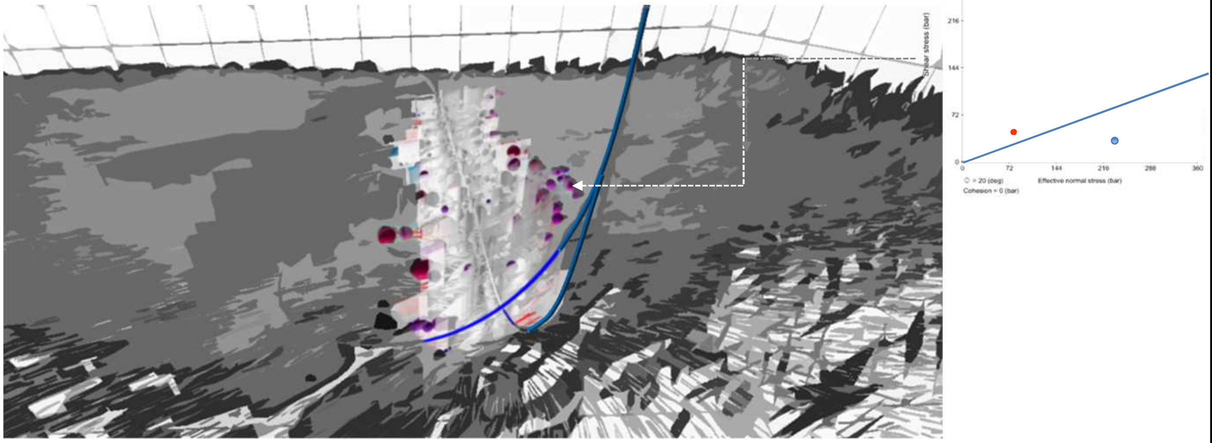
Slippage of natural discontinuities constitute an important portion of recorded MS events



Ueda, K., et al., SPE-189845, image courtesy of K. Fischer

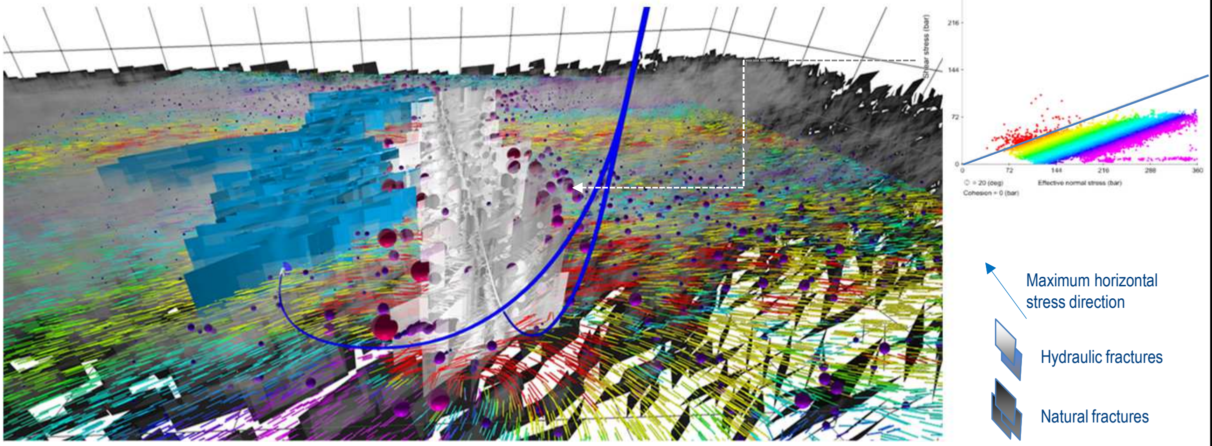
Microseismicity, Stresses and Hydraulic Fractures

Microseismic event clouds can be interpreted as a collection of indirect observations of subsurface stress conditions.



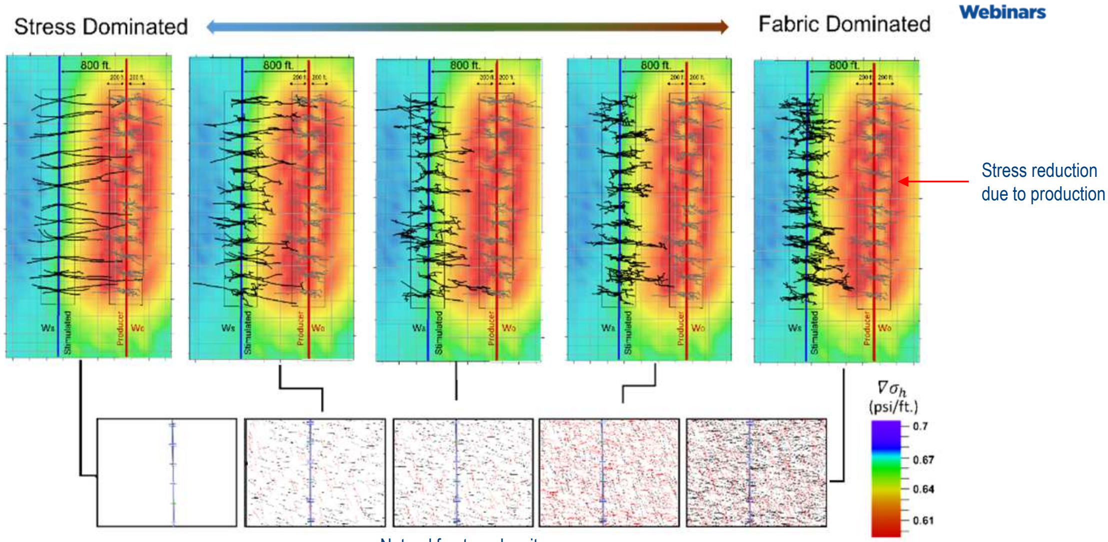
Microseismicity, Stresses and Hydraulic Fractures

Modelling can then be used to decompose these observations into the relative contributions from natural fractures, hydraulic fractures and in-situ conditions.



Well spacing optimizations: Bringing it all together

Webinars



Natural fracture density

(Garcia-Teijeiro, Rodriguez-Herrera & Fischer, 2016)

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Concluding Remarks

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- Geomechanics provides a set of methodologies to integrate different stages of the E&P cycle by means of a systematic use of equivalent physical quantities.

- A connected process is not a sufficient condition for integration. Given the intrinsic uncertainty in subsurface modelling, integration through geomechanics can reduce the space of possible solutions to the “subsurface story” problem.

- Developing a geomechanics study is a two-way street. In many situations, geomechanics experts mediate between the involved parts rather than being “the part”. Being involved in geomechanics simply means connecting to other disciplines based on stress-dependent phenomena.

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Notes on the constant pursuit for integrated domain efforts and its challenges

Adrian Rodriguez-Herrera, Schlumberger

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September 6th, 2018