Applied Geoscience Conference

Integrating Geology and Geophysics into Engineering workflows to Enhance Unconventional Production

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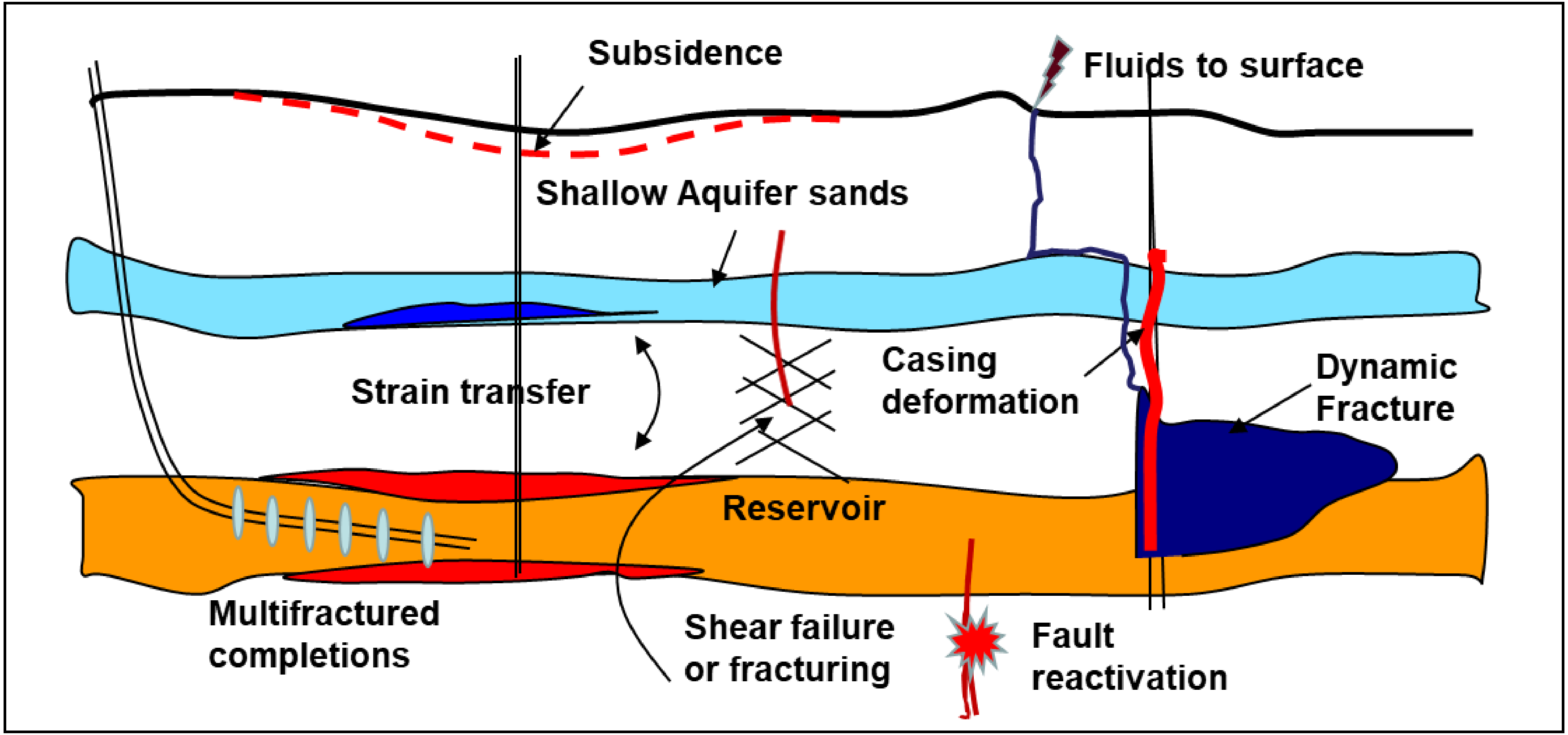
Outline

- General:
  - What is reservoir geomechanics?
  - A bit about integration – what, when and why..
    - Integration with geophysics – the big picture
    - Integrating geophysics into geomechanics and reservoir modeling workflows
- Specific examples of workflows (case studies):
  - PP and stress characterization
  - Use of 1-D MEM to generate 3-D MEM using geostat simulation
  - Geomechanical heterogeneity completion optimization (Montney)
  - Geological features – Induced seismicity
- Summary
  - General integrated workflow

What is geomechanics? Why do we need it?
Where does geomechanics integrate into reservoir management?

Tony Settari

What is geomechanics as a discipline?

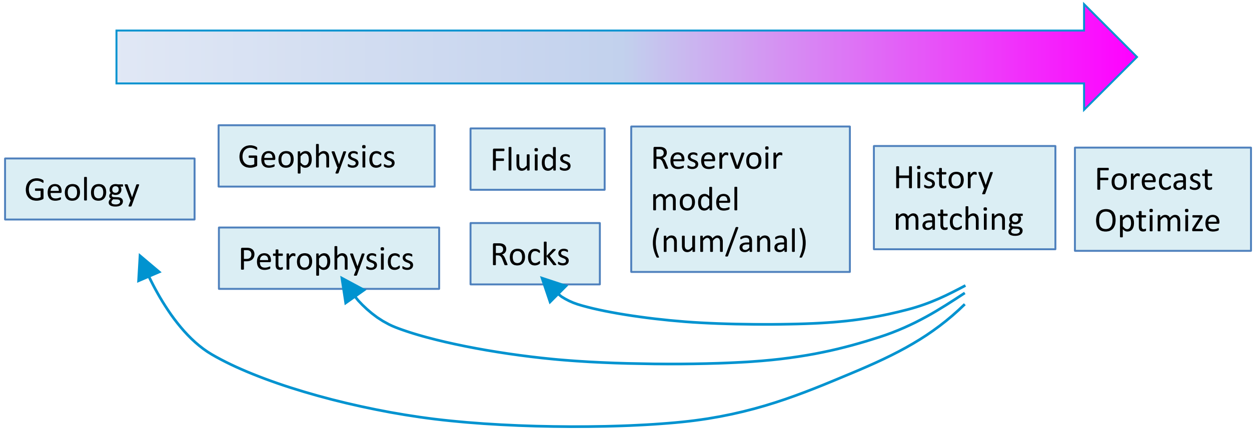


Some meanings of integration

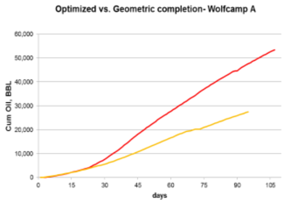
- **Integration of physics (capturing more complexity)**
  - Historical example: development of reservoir modeling – from dry gas to gas-water to black oil to compositional to thermal to including reactions (chemical, combustion, ...), etc.
  - More recently: **Coupling of geomechanical modeling with reservoir simulators**
- **Integration of tools**
  - A large array of analysis techniques and corresponding software exist, from very simple to complex simulation models
  - They may share data required to use them
  - They may overlap or diverge in the assumptions of the underlying physics and simplifying assumptions
- **Integration of data**
  - Gathering data into a database is not sufficient – needs critical evaluation
  - Past efforts to build integrated databases including many disciplines have by and large failed
  - Discovering new physics or new coupling phenomena may require new data.
  - **Ultimately one should pursue all three ....**

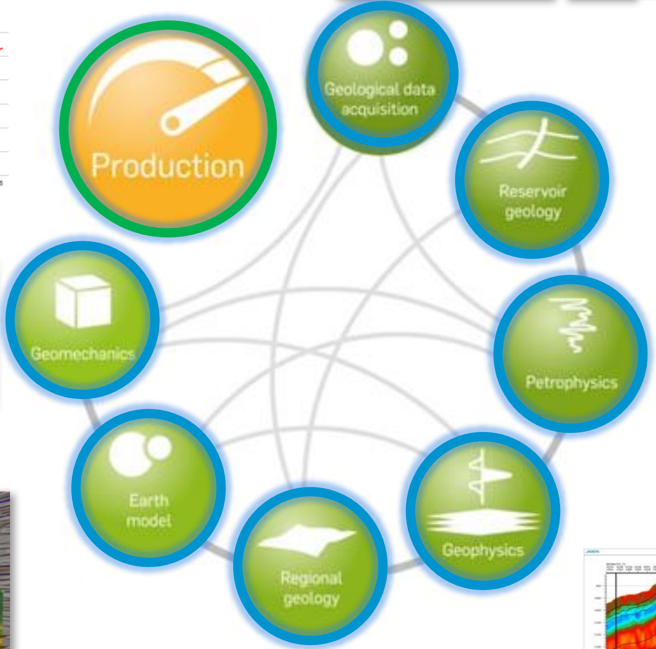
A historical example – traditional approach from geology to reservoir forecasting

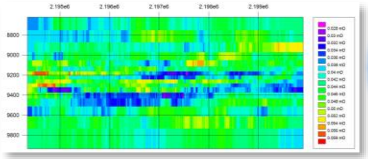
- The path follows the sequence of work traditionally done to develop a field
- Each step typically relies only on the results of previous steps
- In commercial arena, this is now being referred to as a "workflow" which strings together the available software packages of the technology provider, but too often the feedback loops are missing!

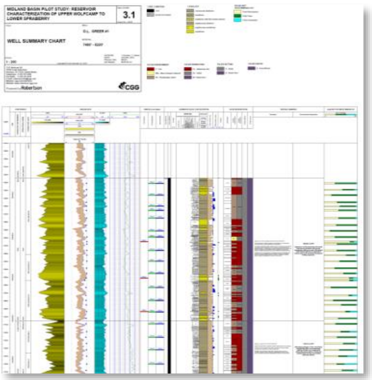


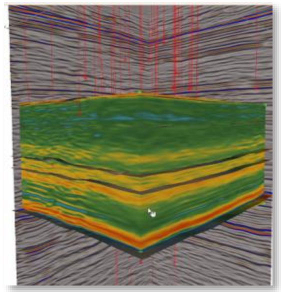
Real Integration

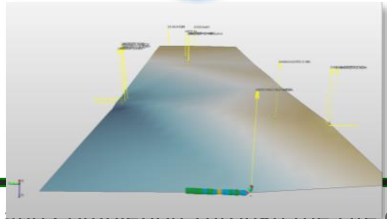


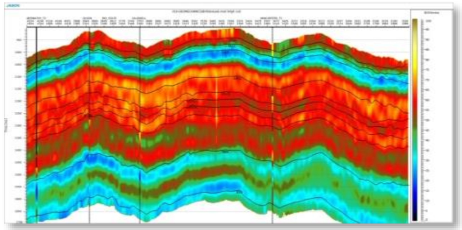






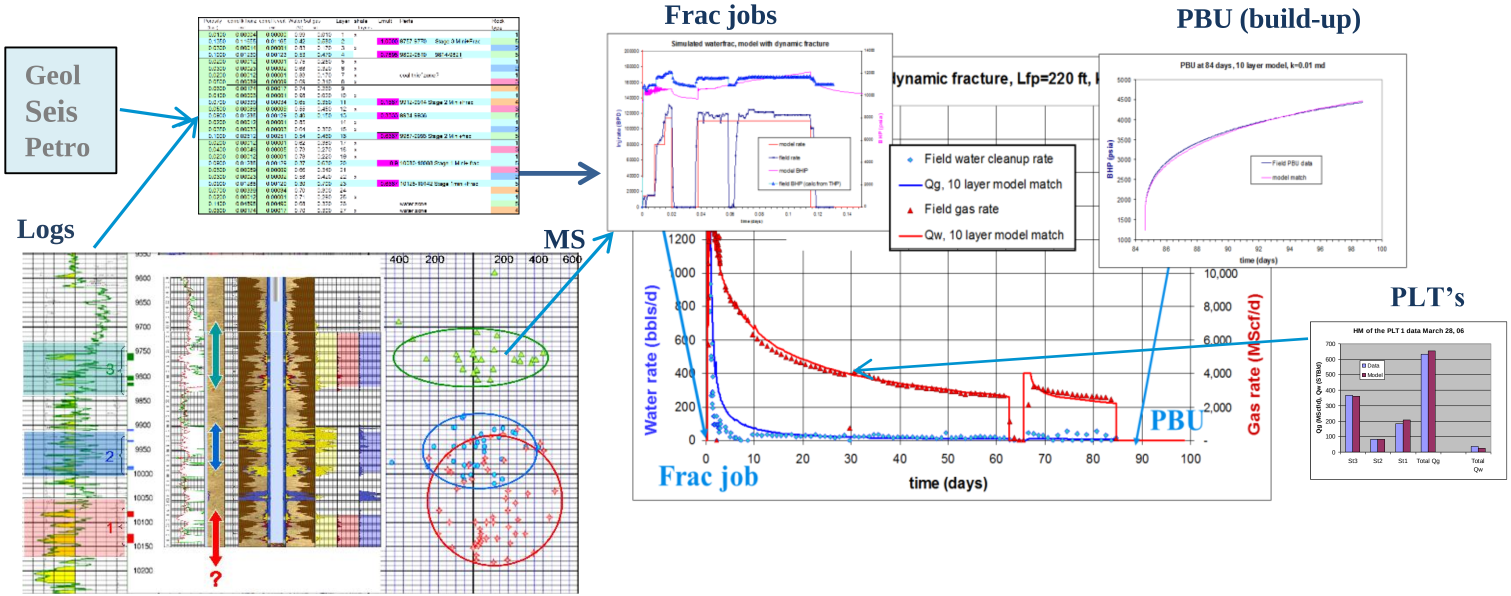






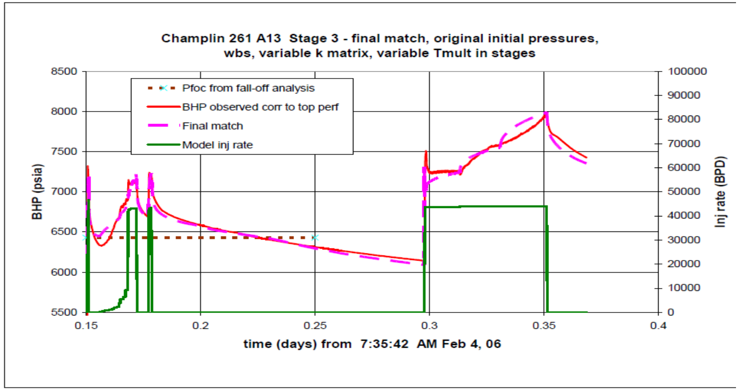
An early example – tight gas, conventional well (SPE HFTC 2009 HFJ 2015)

- A successful attempt to include the data from geology to production to build a single well model:
  - Geology, Petrophysics + geophysics - Log data and stress characterization
  - Frac job data, MS data - PLT's and shut-ins due to workovers
  - Well testing (PTA data) - Production history (Gas, water, P)
- The case proved the value of multi-disciplinary, integrated workflow

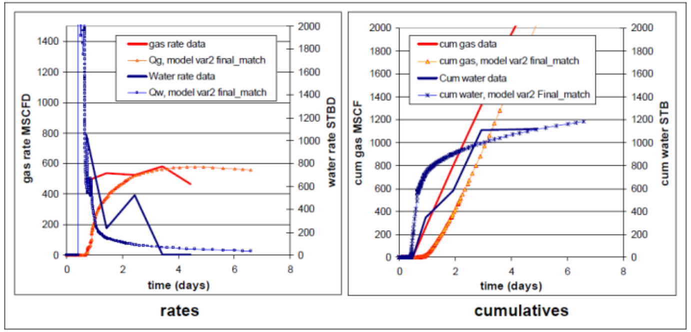


Dashboard plots from SPE 119394/HFJ 2015 (Generic Workflow)

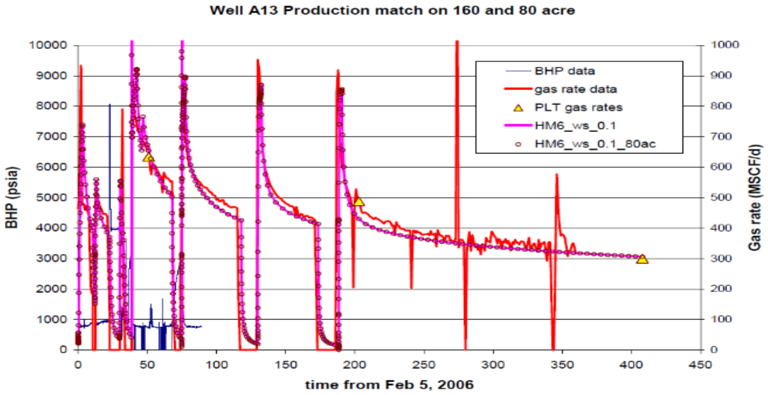
1. Fracture Stimulation



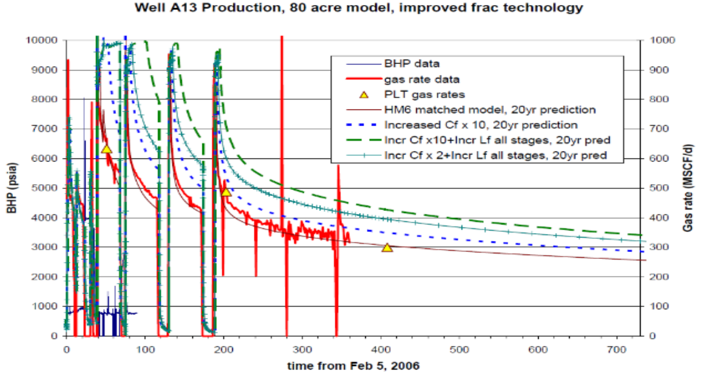
2. Flowback/Clean-up match



3. Production History match



4. Sensitivity/Optimization



Current state: unconventional wells - maximum, interactive use of the geology and geophysics for completion and production optimization

- We have been extending these concepts to integrate geology and geophysics with geomechanical/reservoir modeling, allowing us:
  - to utilize new advances in seismic reservoir characterization (SRC) for both flow and geomechanical properties, and stress state
  - to better drill and complete wells and capture variations in rock properties, and
  - To evaluate how these variations impact the potential injection and production well performance
  - To finally build highly-constrained, accurate models using interactive (not linear) workflows
- **This approach has now been extended throughout production history matching to optimization of future drilling and completion designs**

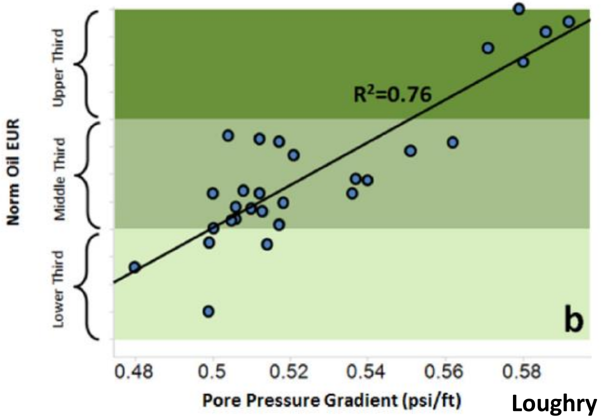
Specific examples of workflows (case studies)

Dale Walters

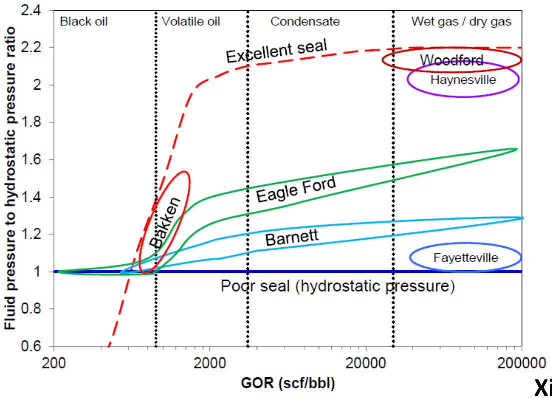
1D Mechanical Earth Model (1DMEM) – Pore Pressure and Stress Characterization

Why are PPP & 1D-MEM important in unconventionals?

- PPP (Pore Pressure Prediction)
  - Wellbore stability, induced seismic
  - Well/field Productivity
  - Basin modeling
    - Sealing mechanism
    - Thermal maturity of TOC (Total Organic Carbon)
- 1D-MEM (Mechanical Earth Model):
  - In-situ stress, *E*, Poiss Ratio: HF modeling
  - Anisotropy: Wellbore orientation, complex fracs,
  - Natural Fractures identification (ID)
  - Stress barriers ID

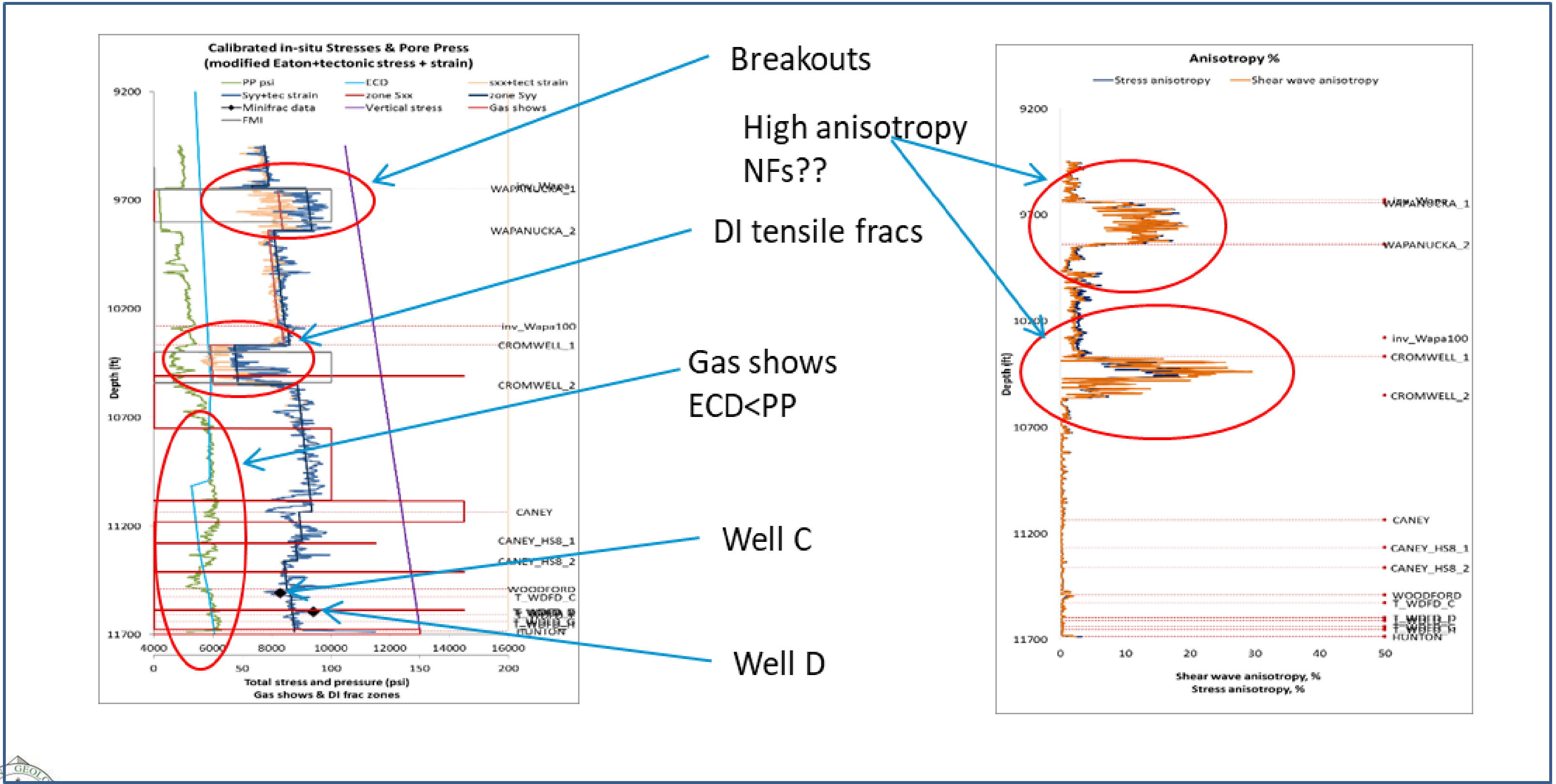


Loughry et al, 2015



Xia et al, 2013

1D-MEM calibration: tectonic stress + strain



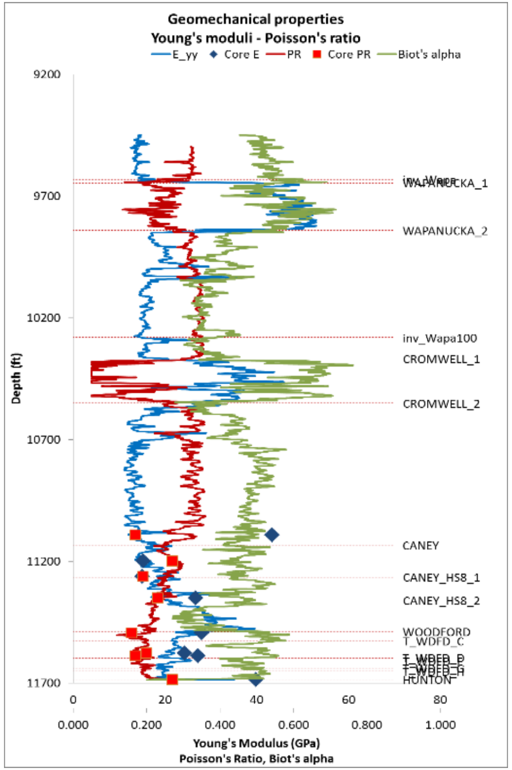
NF = natural fracs

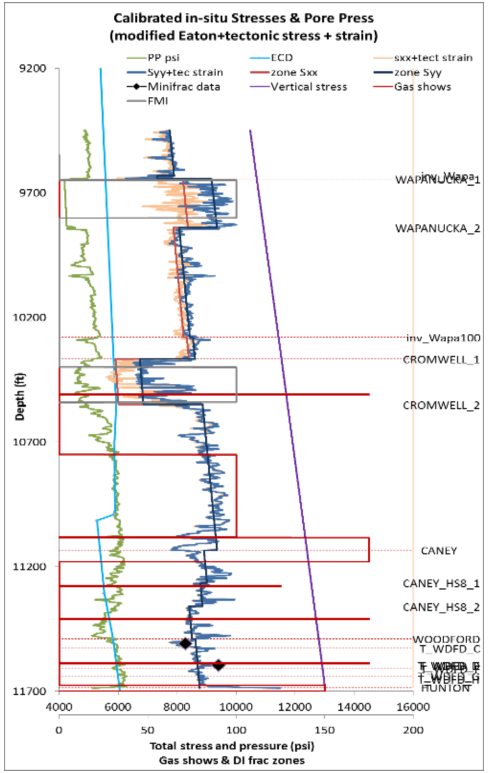
DI = drilling induced

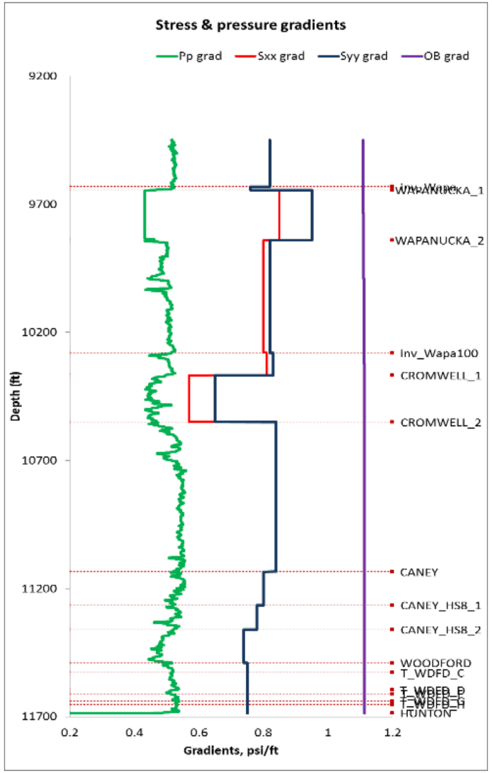
ECD = equiv. circulating density

PP = pore pressure

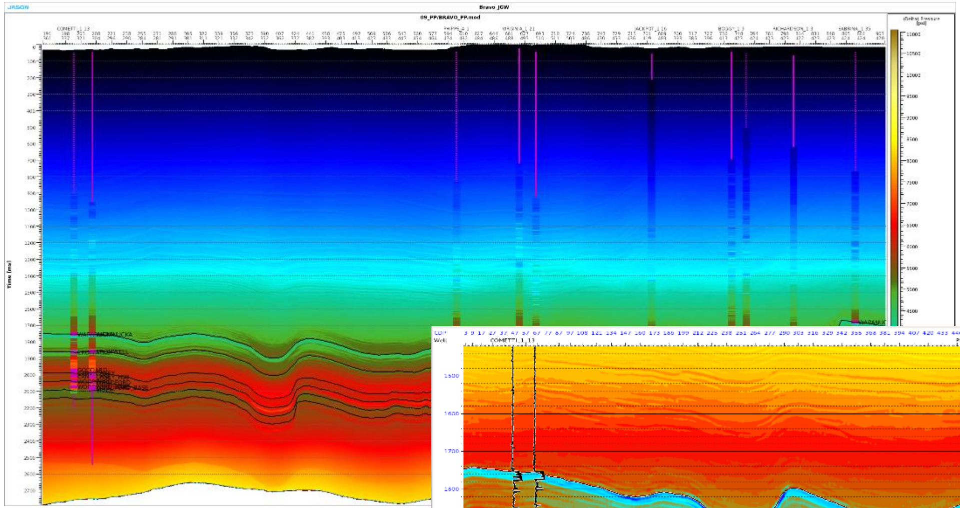
Well B: 1D-MEM Results



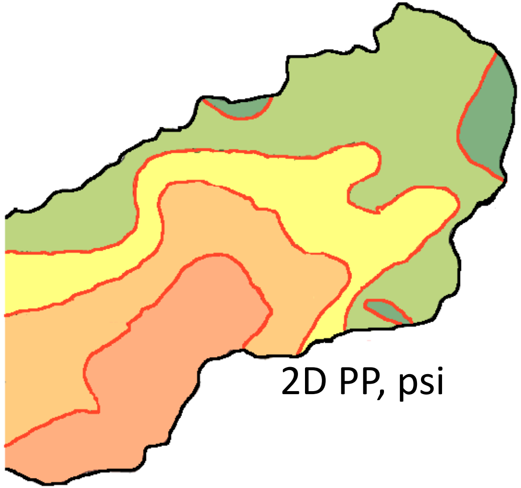




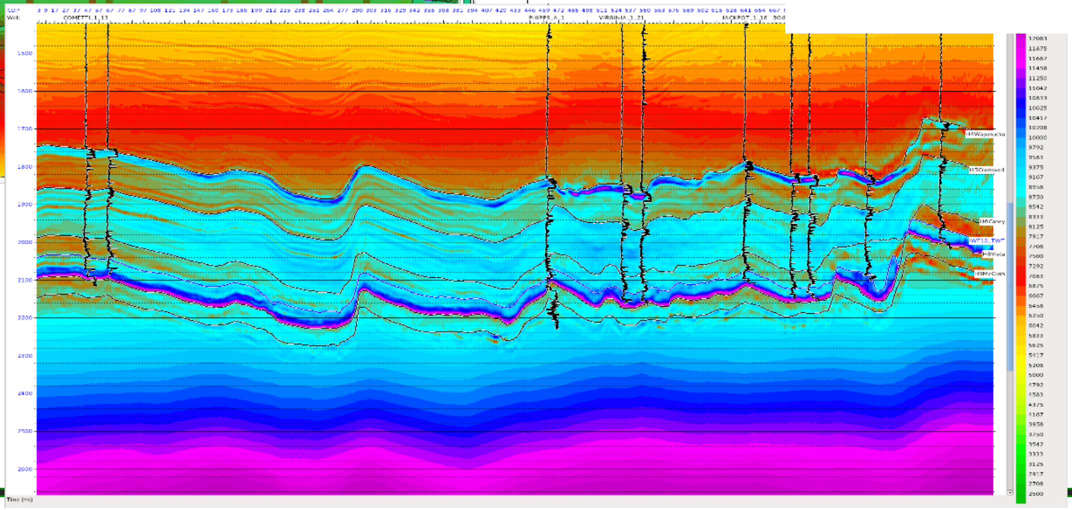
End Goal: 3D cube of PP and Stresses



Stresses, psi



2D PP, psi



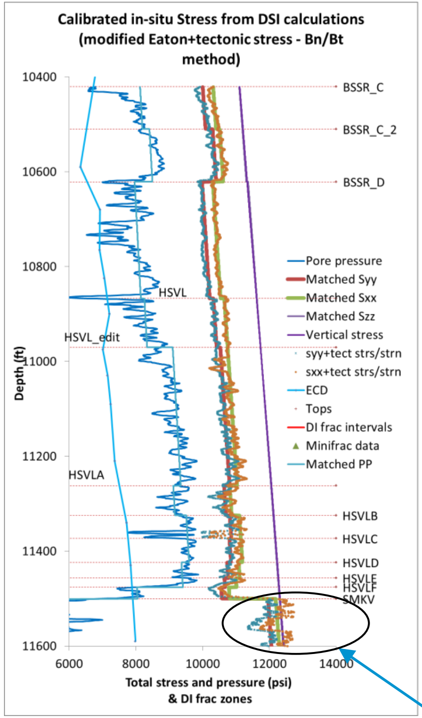
3D PP, psi

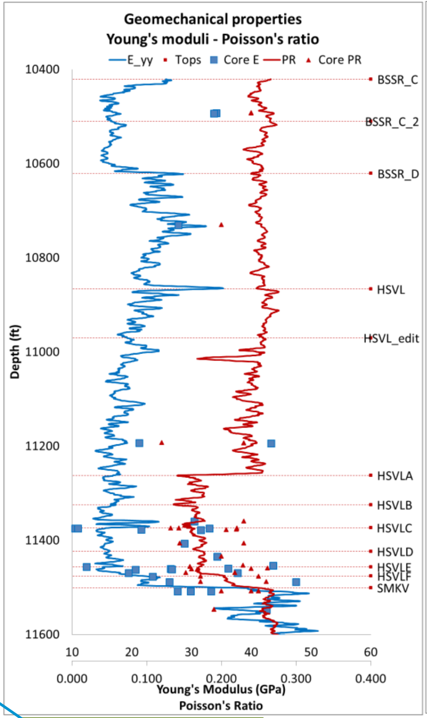
1DMEM Workflow

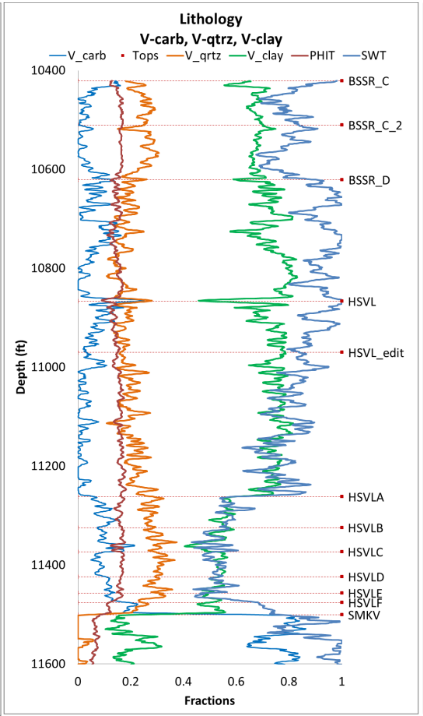
	Geo Inputs				Eng Inputs			
Input data	Dens	Vp, Vs	Mineralogy	S_w, Porosity	DFITS	Drilling data	FMI/BO	Lab Meased
Process Data	Poro correct, Litho Correct				Dynamic elastic props Biot Coeff Stress/strain loads calibrate			
Results	3D PPP (1DMEM feedback to SRC inversion giving 3DMEM)				**Stress state (magnitude and orientation); Dry Static elastic props; strength props**			

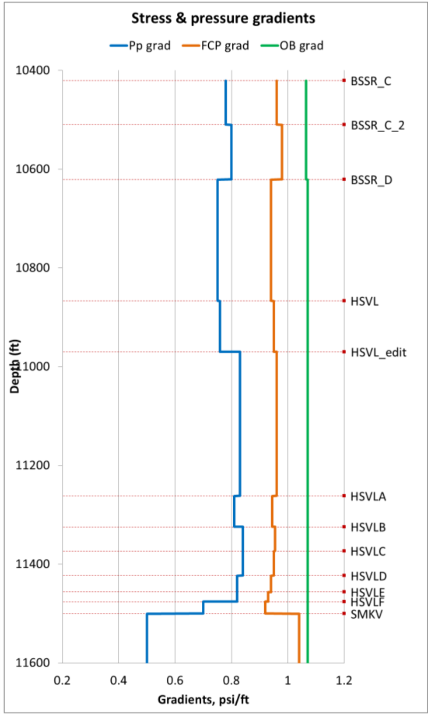
Haynesville Example:
Stress Characterization by Zone
Height Containment

1D MEM based on tectonic stress & strain





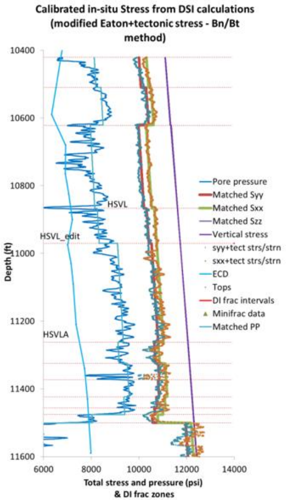


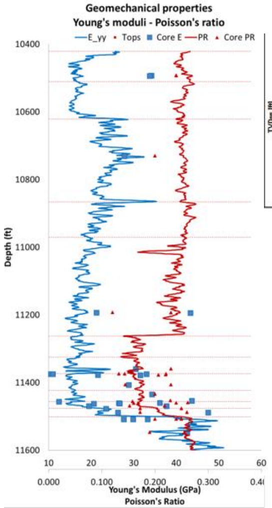


Stress values are within an acceptable range

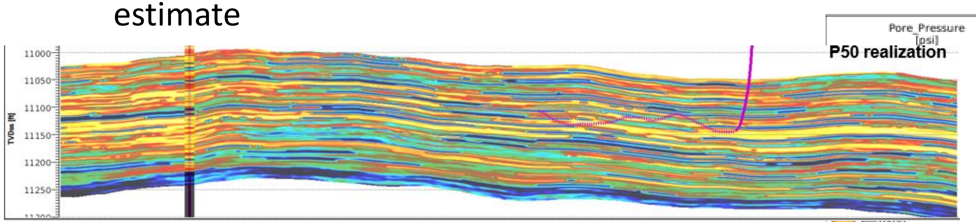
1D-MEM to 3D-MEM to frac modeling

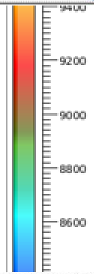
1. 1DMEM → PP estimate



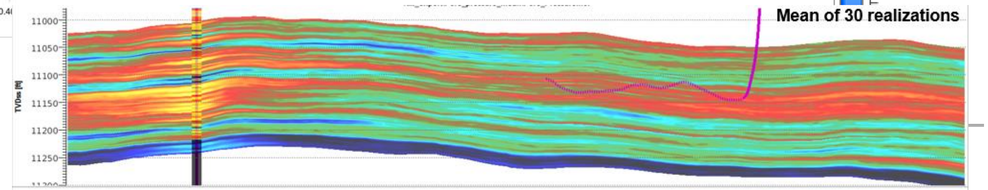


2. Calibrate rock physics → generate 3D PP estimate

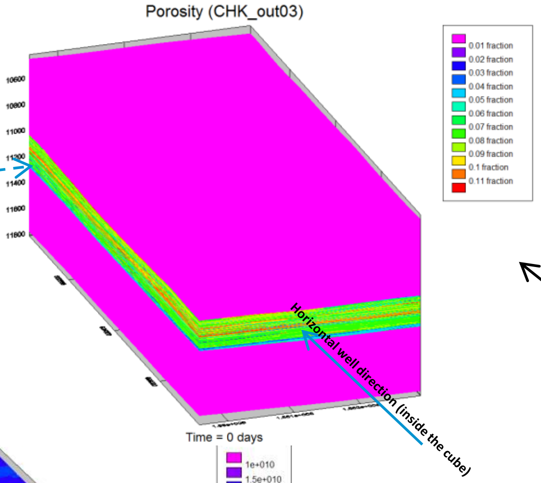


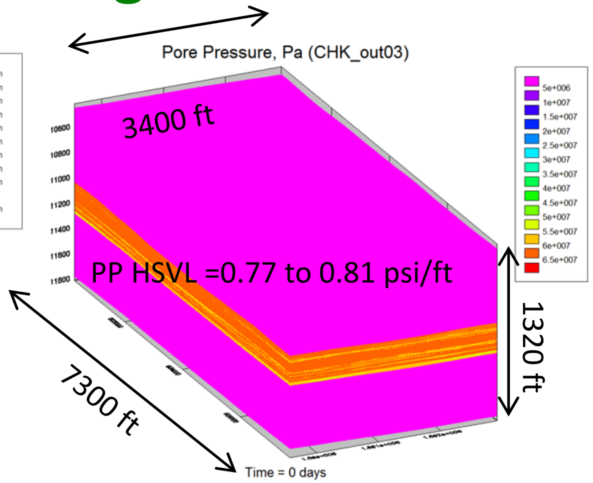


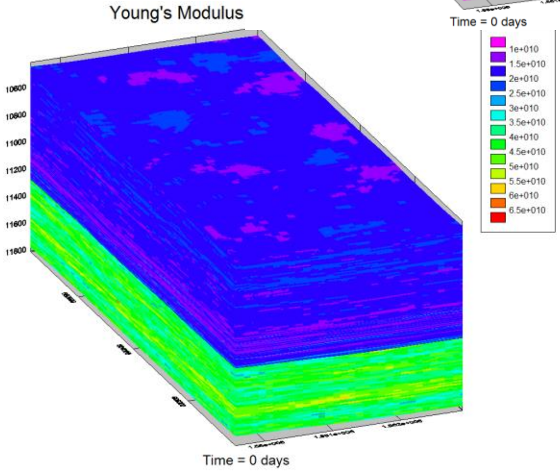
3. Incorporate engineering feel for 3D PP → generate 3D PP estimate

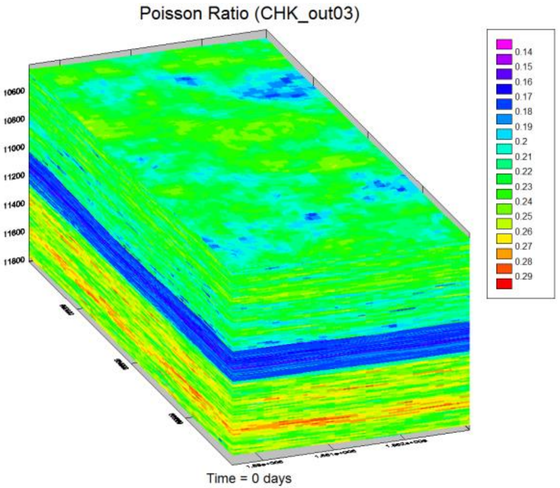


Use 1D-MEM to generate 3D-MEM using GeoStat simulation

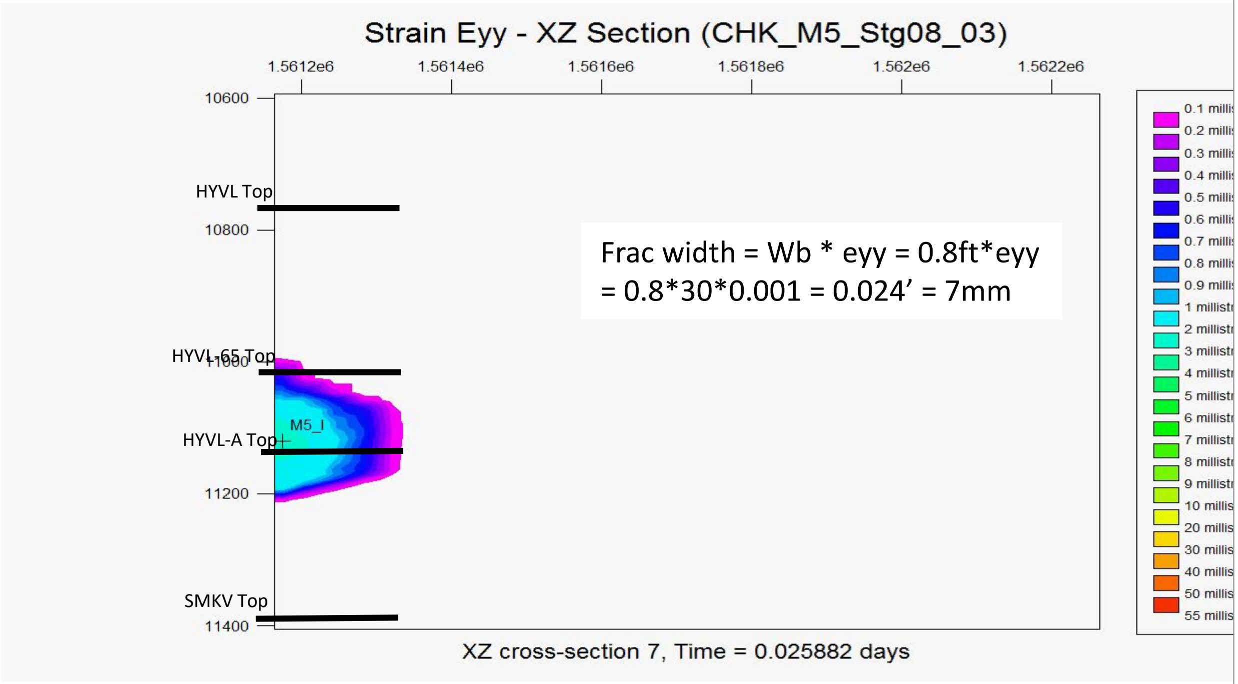




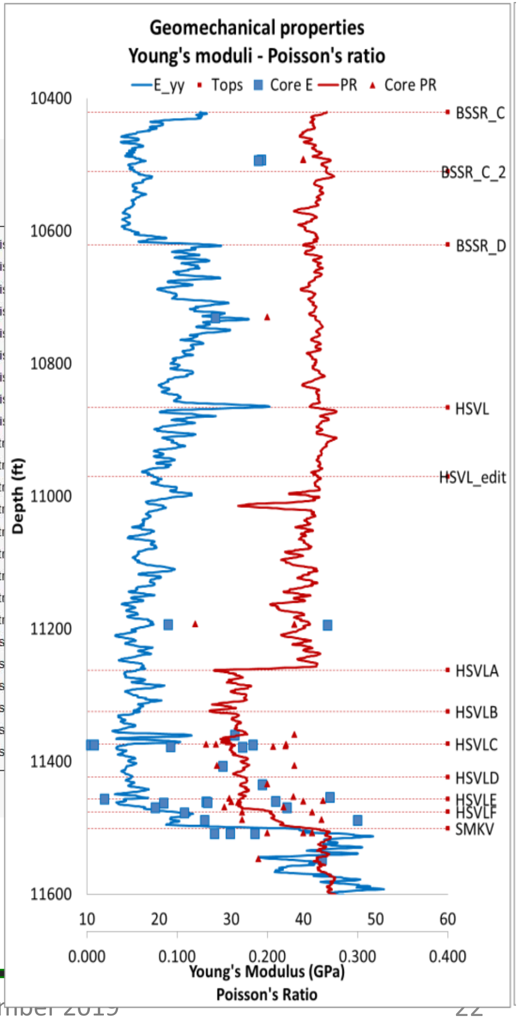




Simulation results – Fracture Width



Frac width = Wb * eyy = 0.8ft*eyy
= 0.8*30*0.001 = 0.024’ = 7mm



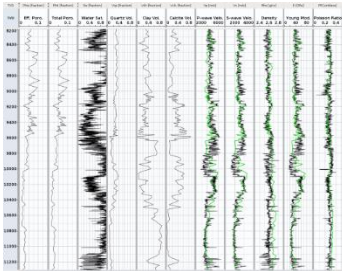
Workflow Summary

- Geoscience Characterization
  - Petrophysics, Structure tops, Seismic Inversion
  - V_p, V_s, Mineralogy, S_w , Porosity, Elastic props (dynamic and wet)
- Engineering Characterization
  - PPP, Elastic props (static and dry), Stress state (magnitude and orientation)
  - 3D-MEM feedback from 1D-MEM calibrated/correlated back to 3D-inversion
- Engineering Analysis
  - Optimize Multi-Fracture stimulation
  - Optimize Well placement and spacing

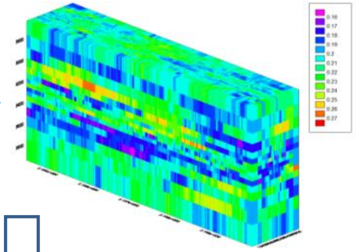
Geomechanical Heterogeneity Completion Optimization

Cuttings to S(t)imulation Workflow

RoqScan + Cuttings

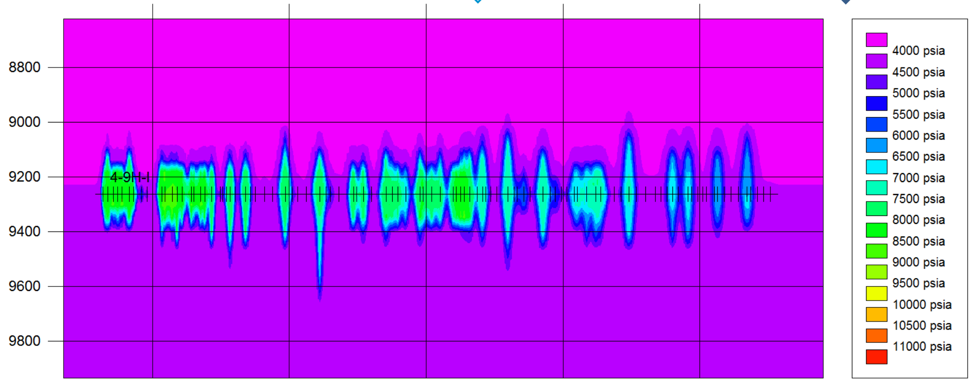


Elastic Pseudo Logs (VP, VS, YM, PR)



3D MEM

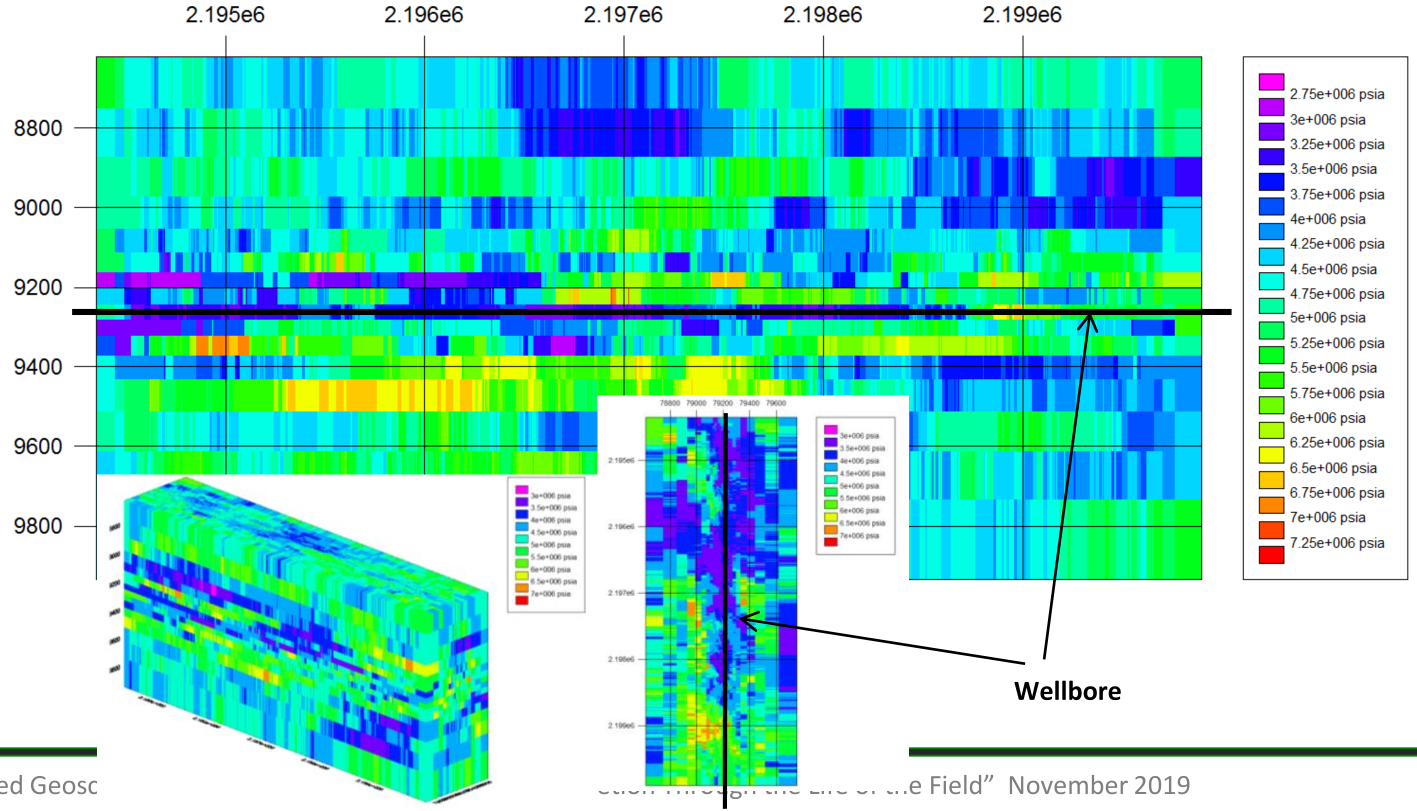
3-D coupled reservoir and geomechanics model using the 3DMEM data



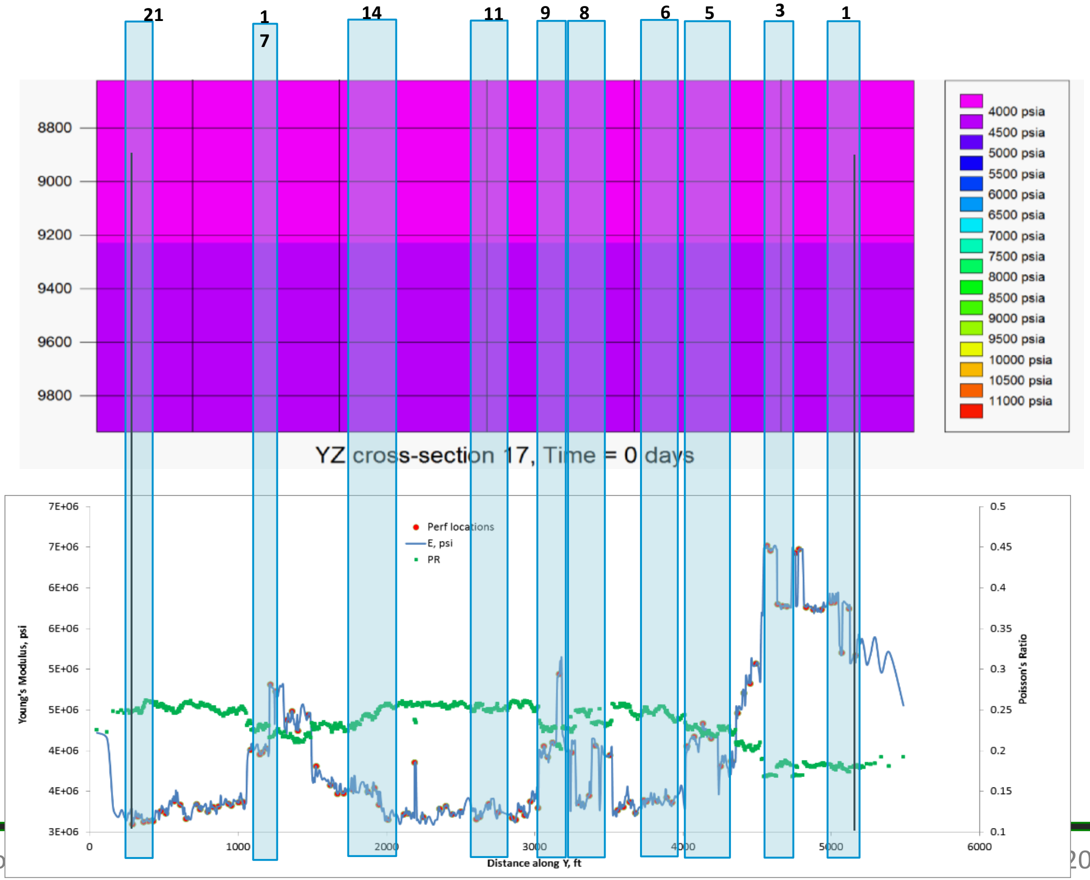
GeoSIM™- Coupled Reservoir & Geomechanical Simulator

Premise:
Stages with more uniform E and ν are likely to generate more uniform fractures

Convert 3D-MEM to 3D Geomechanical Model
Young's Modulus profile along well bore (YZ cross section)



Completion Optimization accounting for Brittleness



Stages 6, 11, 21 fairly homogenous

Stages 1, 3, 5, 8, 9 and 14 heterogeneous

Workflow Summary

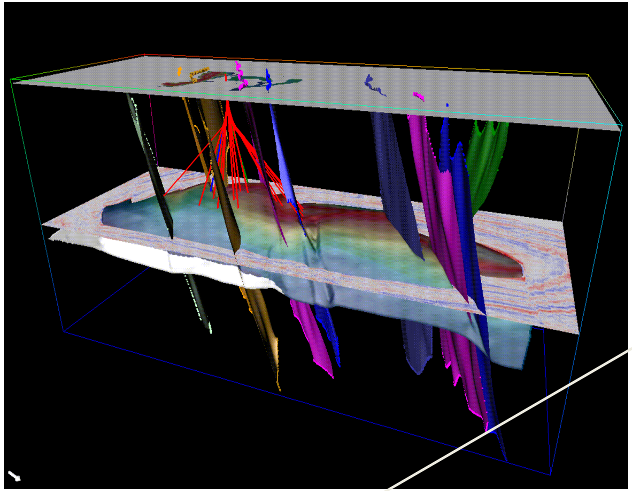
- Geoscience Characterization
  - Petrophysics, Cuttings analysis, Structure tops, Geomodeling
  - V_p, V_s, Mineralogy, S_w, Porosity, Elastic props (dynamic and wet)
- Engineering Characterization
  - PPP, Elastic props (static and dry), Stress state (magnitude and orientation)
- Engineering Analysis – history matching provides feedback look
  - Fracture simulation, fall-offs between stages
  - Completion Optimization
  - Well spacing

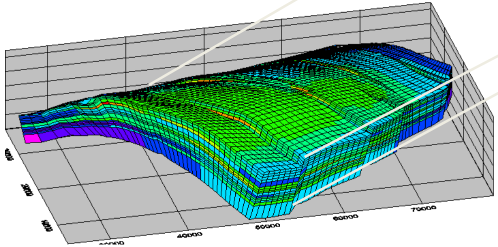
Induced seismicity

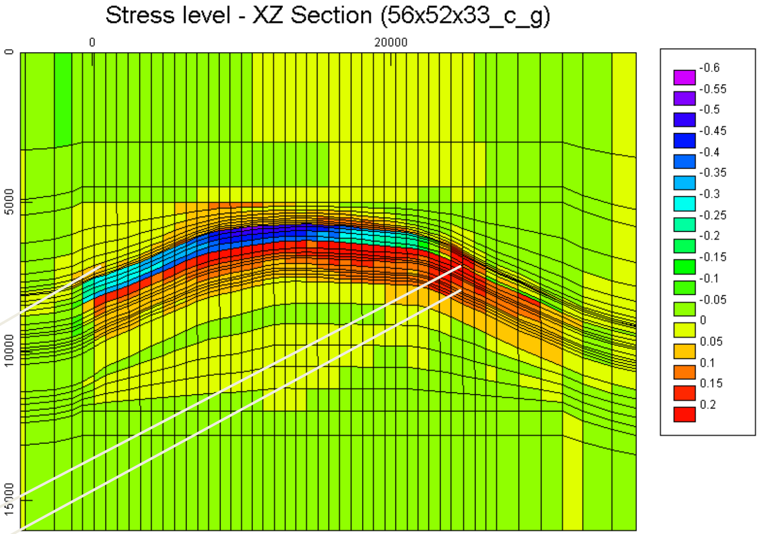
Earthquakes -current concern in the industry

- In the past concern primarily for complex offshore fields
- Disposal of drilling cuttings / PW disposal, geothermal projects, …
- Unconventionals:
  - Stimulation usually not considered capable of large magnitude earthquakes – conventional wisdom
  - However – depletion during production has risk potential!
- Large role played by geology+geophysics
- Integration with geomechanics is essential

Example – Lunskoye field, offshore Sakhalin Island (ARMA/USRMS Paper 05-732, 2005)







Large Model: Fault between 3 & 4 –Incremental Stress Level between 2006 to 2051

-Depletion strengthens the faults in the reservoir

- Direction of max shear rotates

Seismicity Induced by operations poses many risks!

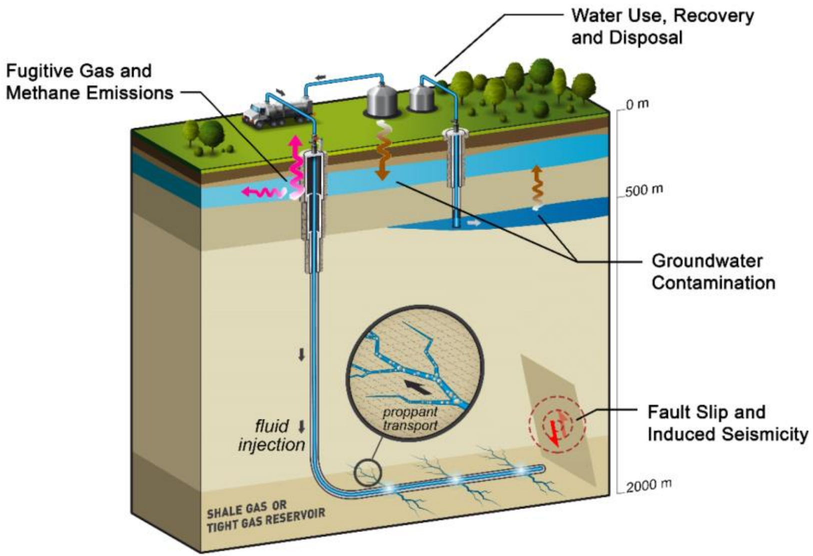


Figure 2. Environmental concerns associated with multistage hydraulic fracturing operations for unconventional gas development. Source: Eberhardt and Amini (2018).

Risks:

- Human environment + lives
- Surface/sea floor contamination
- Surface structures + equipment (Roads, dams, factories)
- Integrity of completions
- Damage to sea floor installations
- Etc.

Seismicity induced by geological Features in the Montney:

NRCan reported Earthquakes to Dec. 1, 2018

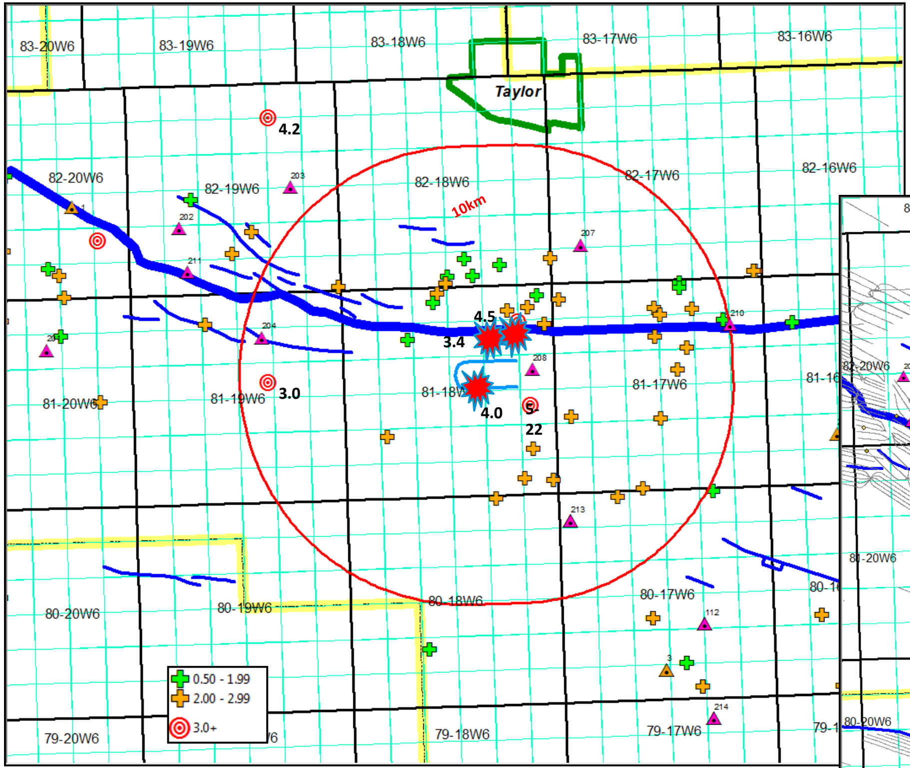
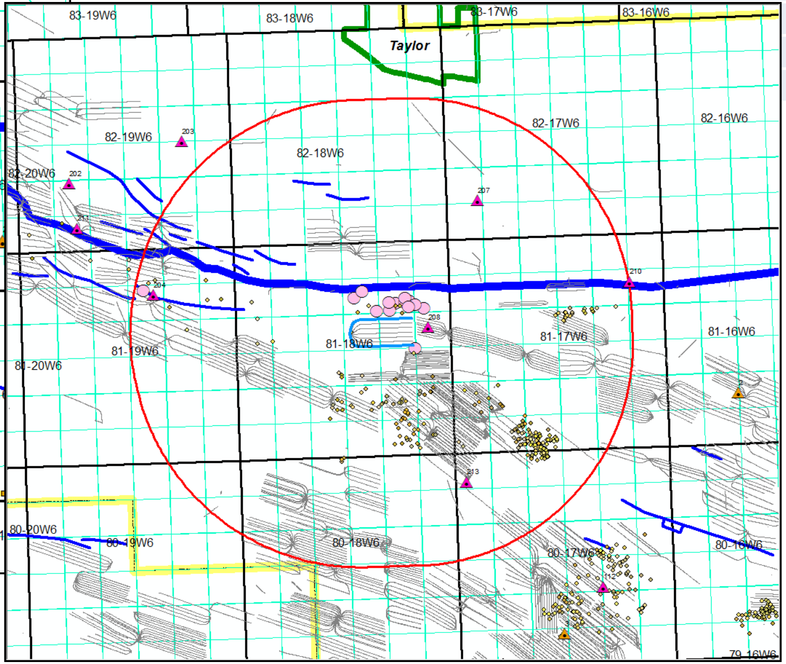
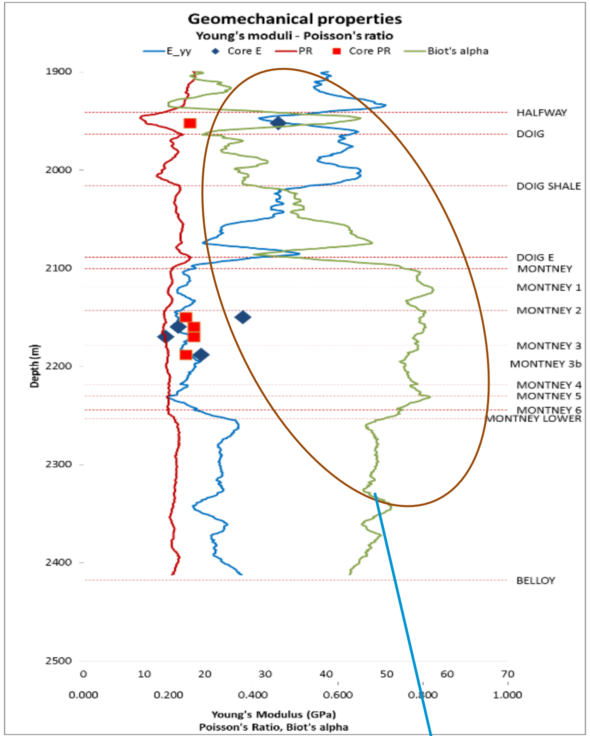
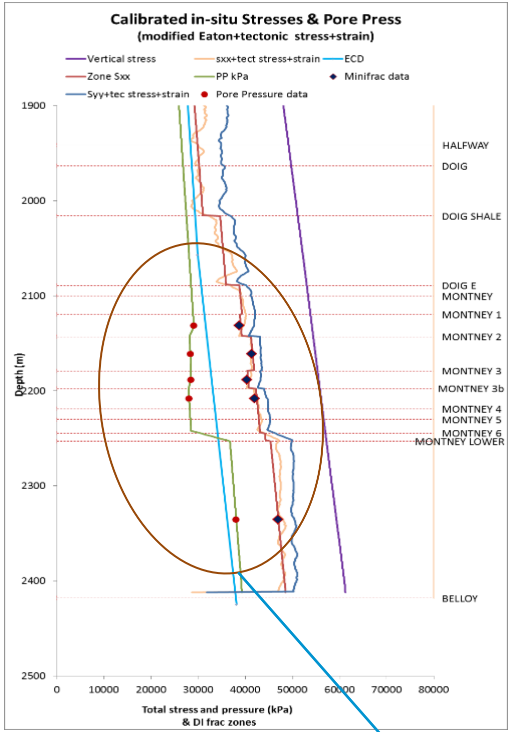


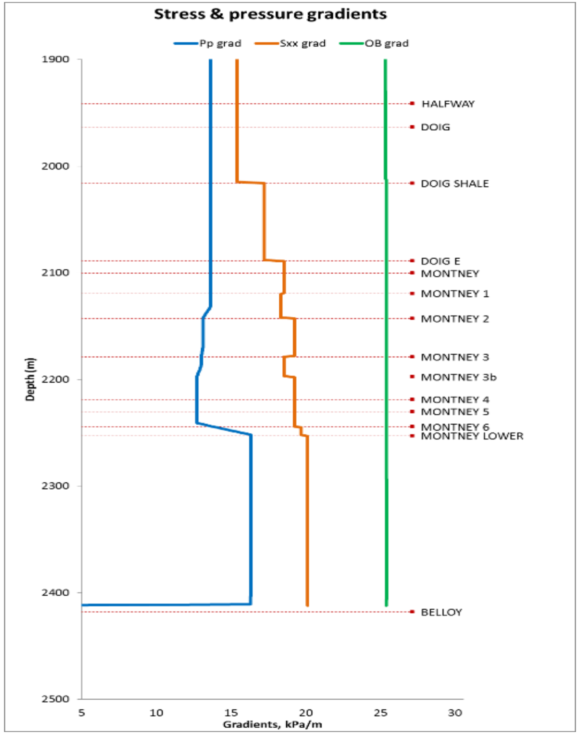
Table of NRCan EQ >3.0		
Date	Time (UTC)	Mag
2018-11-30	02:15:01	4.0ML
2018-11-30	02:06:02	3.4ML
2018-11-30	01:27:06	4.5Mw
		3.0ML
		3.9Mw
		4.2Mw



1D-MEM – PPP and Stress Initialization



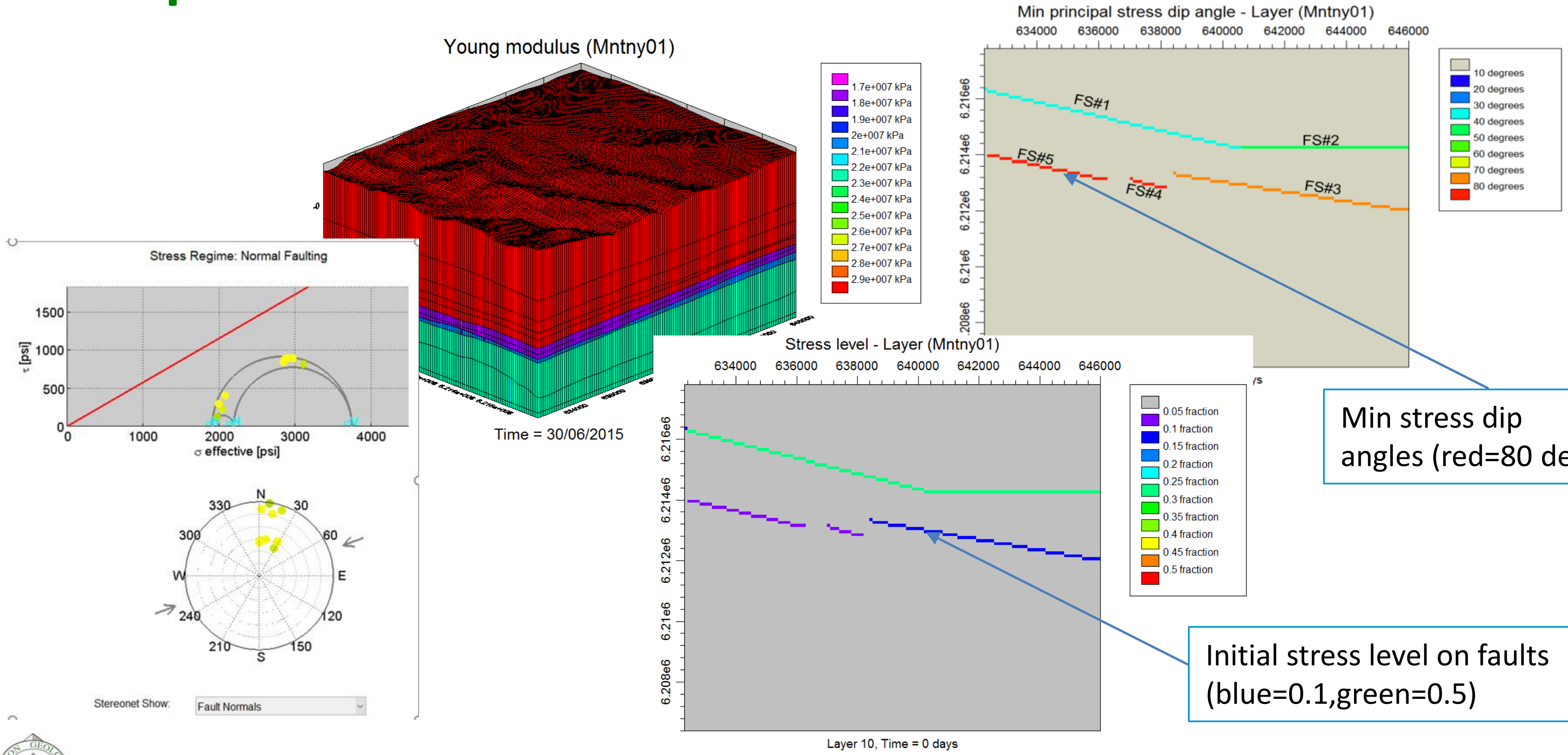




E and PR checked against lab data

PP and Sh calibrated to field data

Maps → 3D Geomechanical Model → ΔP to failure



Min stress dip angles (red=80 deg)

Initial stress level on faults (blue=0.1,green=0.5)

Can we engineer for safe operation?

- Analysis of the historical events and criteria for continuing operation
  - 3D Geomechanical model:
    - Critical state fault analysis
    - Uncertainty Analysis
  - Identify critical fault geometries
  - Maximum operating constraints
  - Define safe offsets

Conclusions from the work to date

- Integrated approach of G+G+G enhances our understanding and fidelity of the end result: reservoir performance forecasting and optimization
- Workflows developed provide seamless integration of the steps and feedback loops
- The same benefits obtain in development of offshore fields, reservoir management with 4-D seismic, sub-salt seismic interpretation, etc.

Thank you

Credits:

- Bob Bachman, Vivek Swami, Mohammad Nassir and others …. CGG Calgary + Houston

- **Richard Sullivan, Vik Sen, Lou Ji … Anadarko**

- Many others from different companies that were willing to try new things over the last 20+ years of development and applications of geomechanical modeling technology