


INTEGRATED MICROSEISMIC AND 3D SEISMIC PERSPECTIVES

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Audience and Date
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Presentation sequence

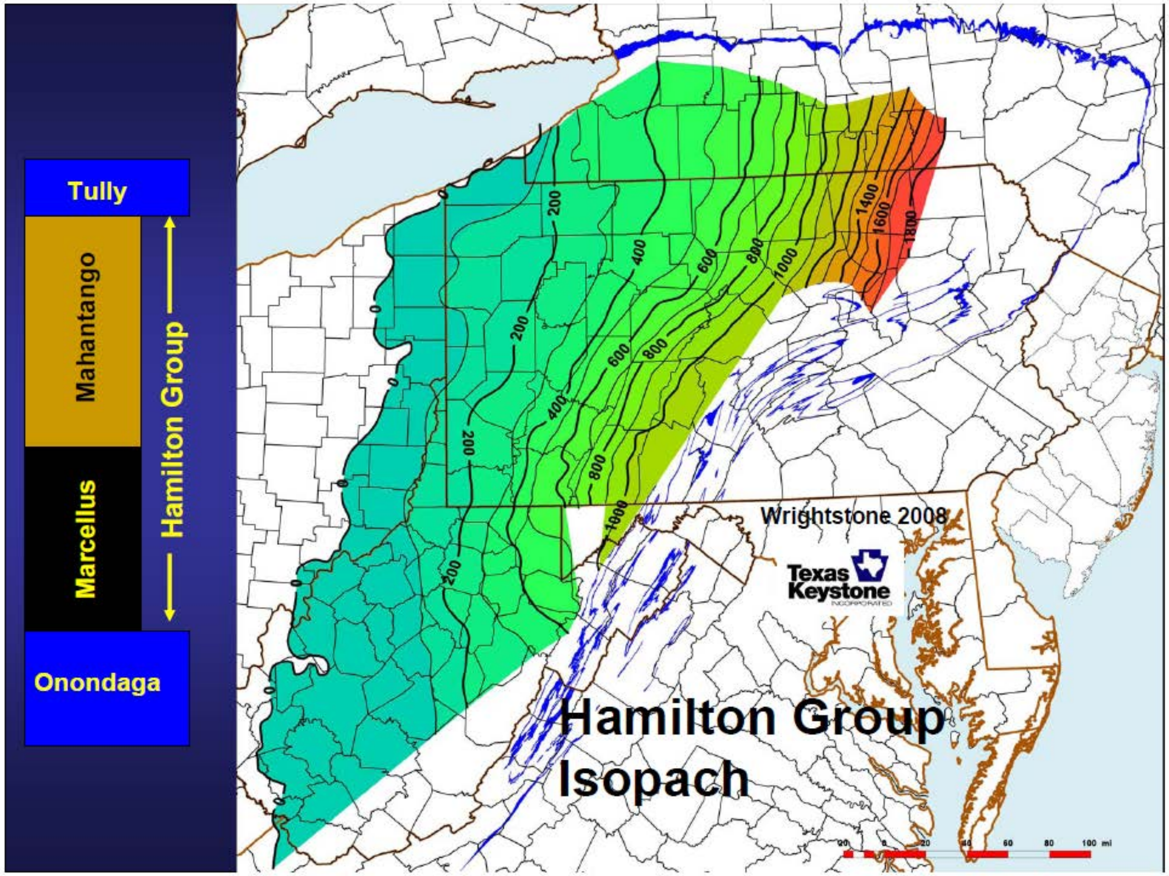
This presentation is divided into 5 parts. Some portions of the presentation can be skipped in the interest of time

1. Learning about your prospect
2. Hydraulic fracture stimulation, microseismic events and the local fracture network
3. 3D seismic and microseismic interpretation
4. Estimating the stimulated reservoir volume
5. Reservoir fracture model development

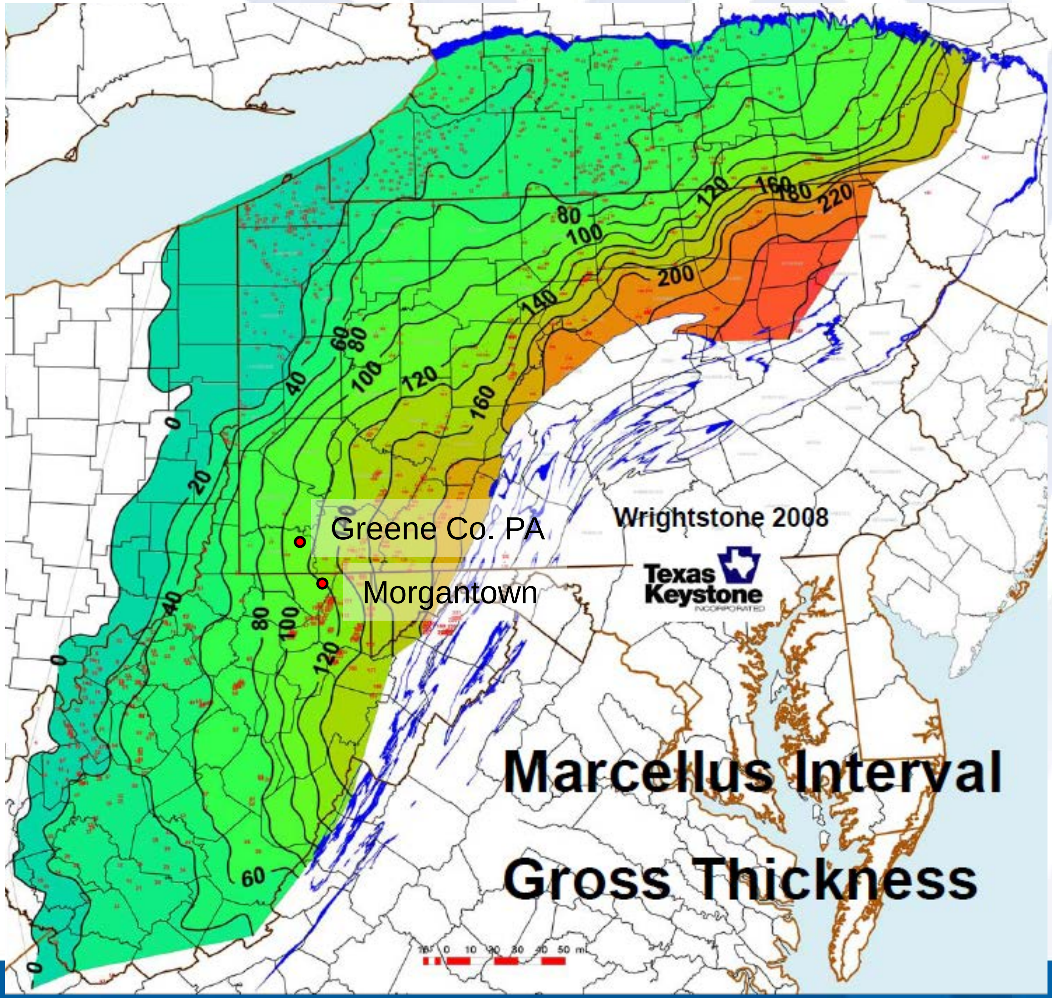
Subtopics are referenced in the following slides

1.
   - I. Locations of examples illustrated in the presentation
   - II. Some pitfalls in developing a deeper unconventional play
   - III. Subsurface characterization
2.
   - IV. Hydraulic fracture stimulation (HFS)
   - V. Fracture rupture types produced by HFS
   - VI. Microseismic events produced during HFS
3.
   - VII. Estimating the subsurface fracture network from 3D seismic
   - VIII. Interpreted microseismic event trends
   - IX. Microseismic event trend relationships to discontinuities extracted from 3D seismic
4.
   - X. The stimulated reservoir volume from dots in the box to energy weighted estimates
5.
   - XI. Generating a discrete fracture network resulting from HFS
   - XII. Modeling stimulation of the ambient natural fracture network

I. Hamilton Group distribution Appalachian Basin

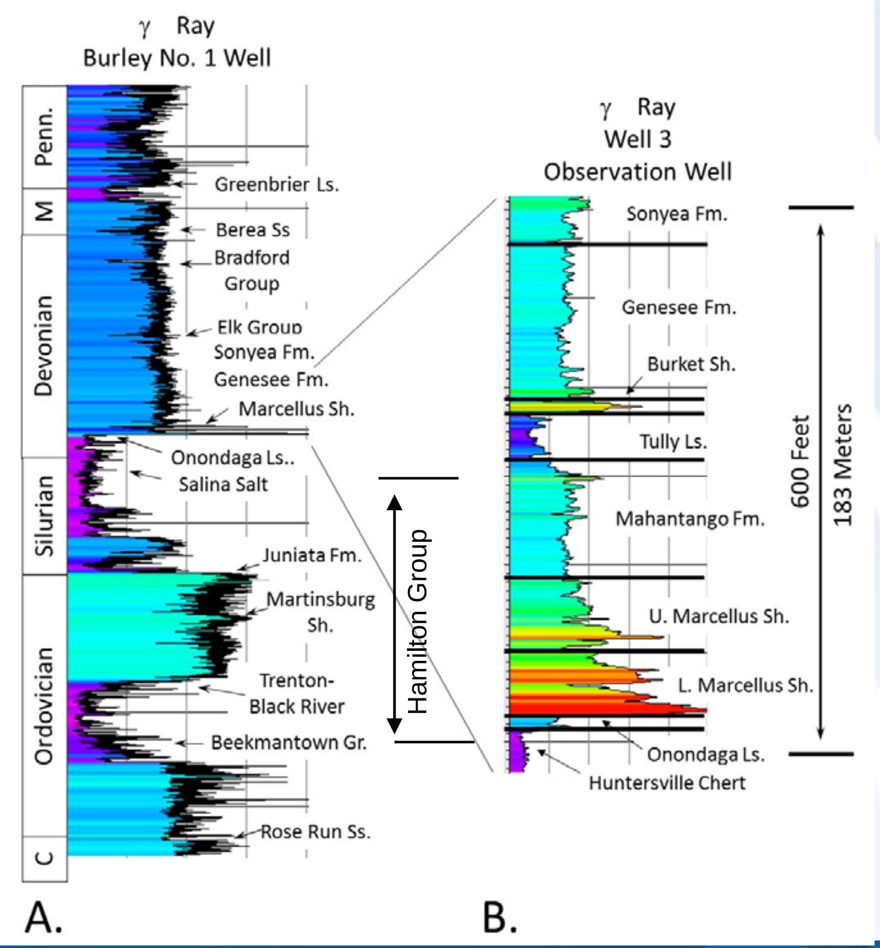


Marcellus thickness map- we'll look at some data from a couple areas

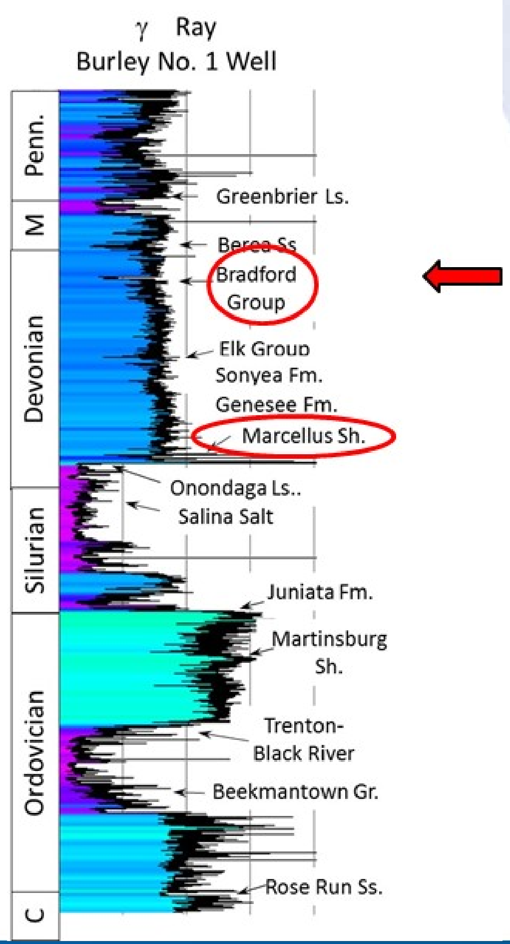


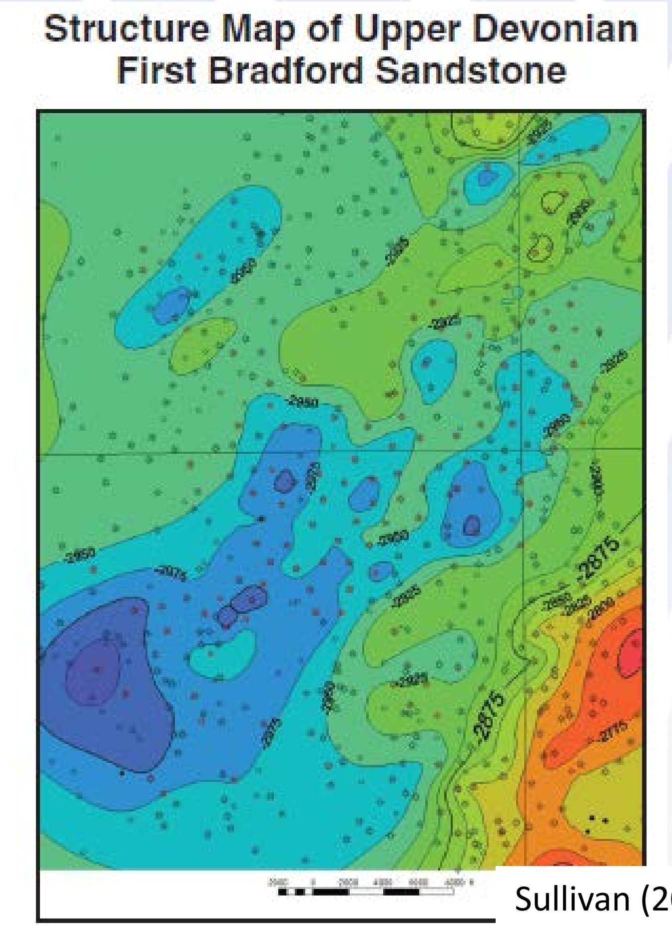
An example Marcellus play Greene Co. PA – Stratigraphic context

Example central Appalachian stratigraphic column



II. Some potential pitfalls
How well do you know your play?

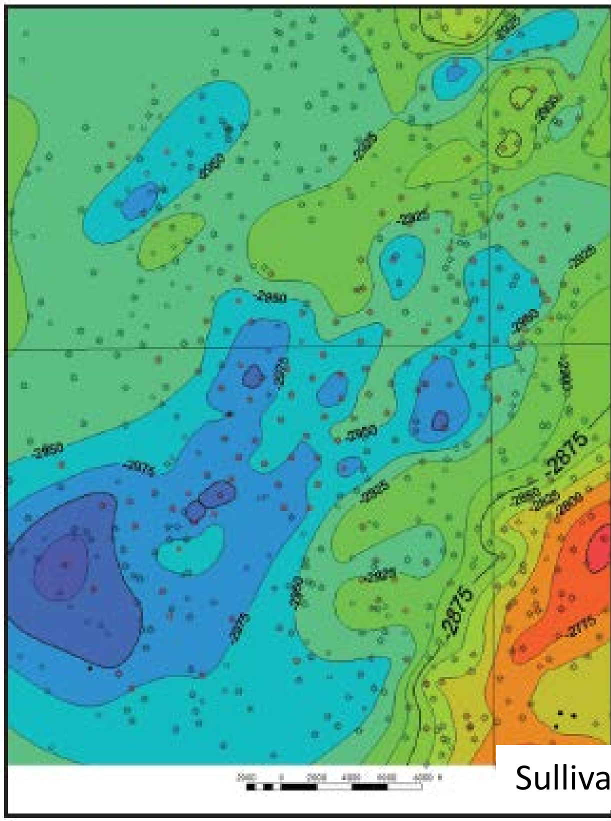




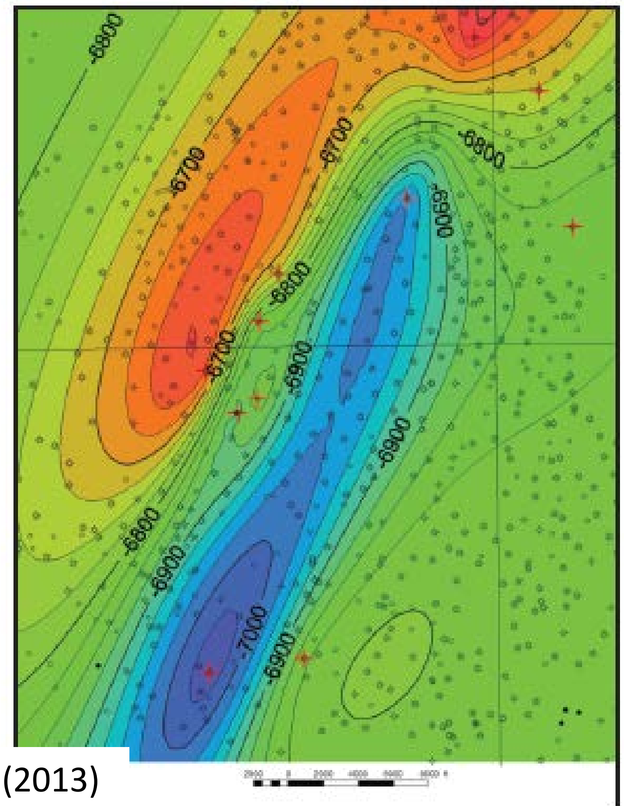
Sullivan (2013)

Initial wells drilled into the Marcellus reveal deeper structure is more complex

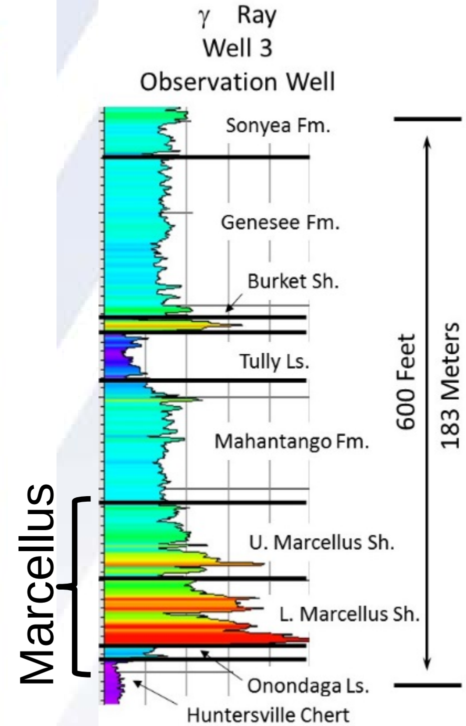
Structure Map of Upper Devonian First Bradford Sandstone



Structure Map after Nine Initial Marcellus Vertical Wells

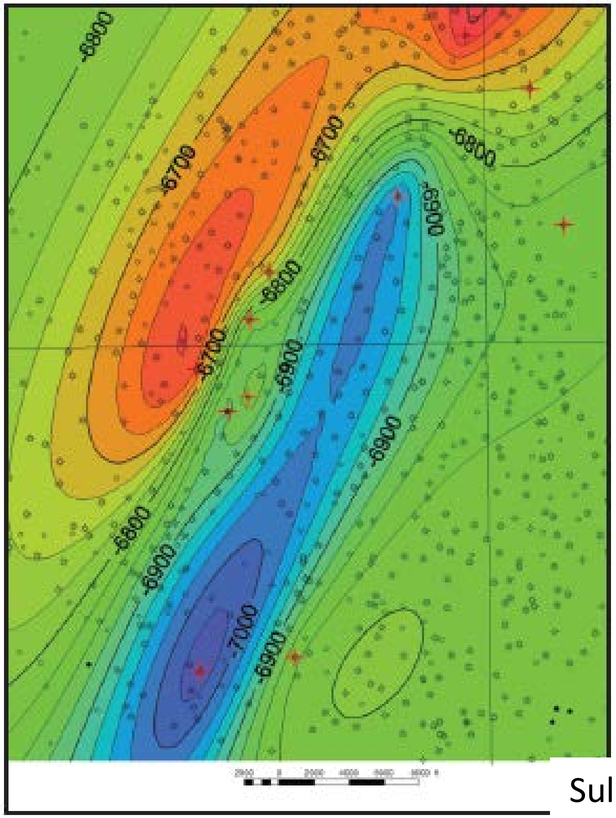


Sullivan (2013)

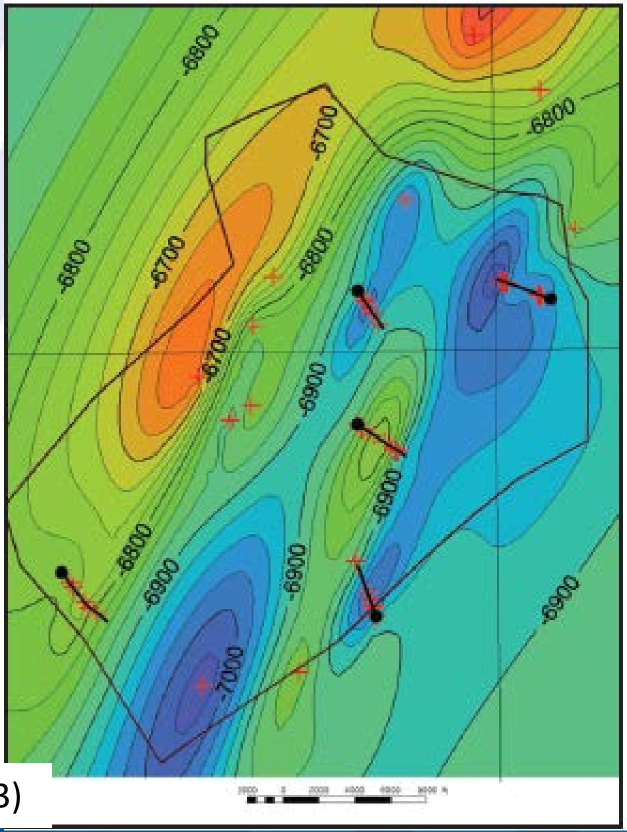


The slow evolution of a structural view of the reservoir unfolds
It's time for 3D seismic

Structure Map after Nine Initial Marcellus Vertical Wells

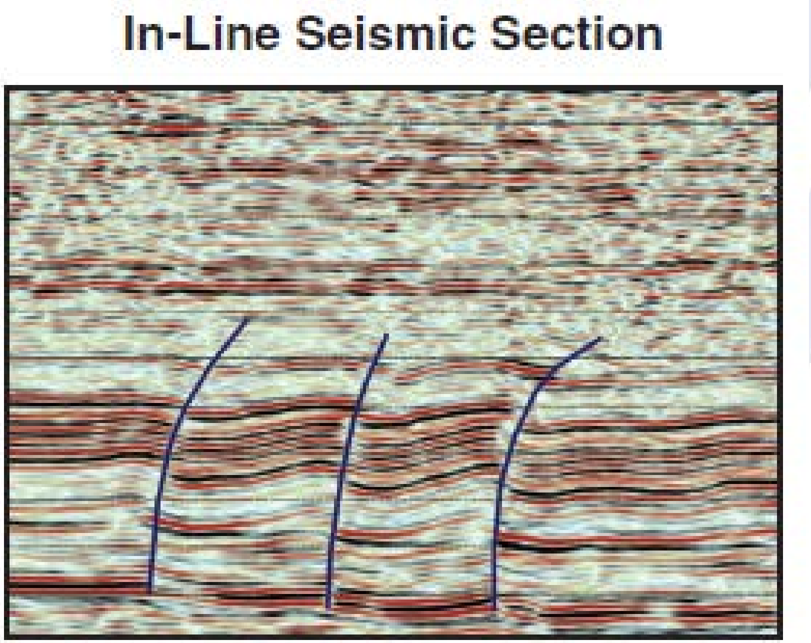


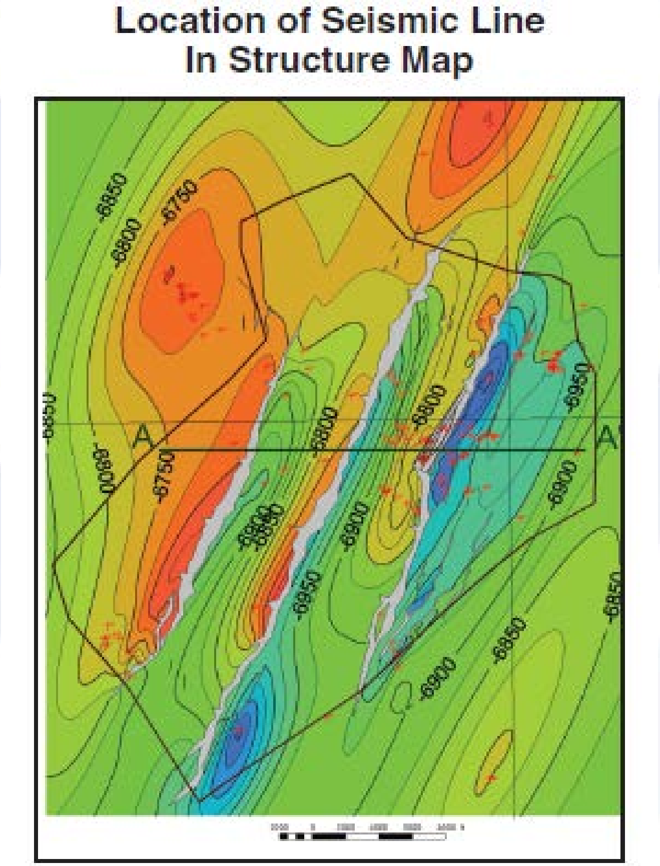
Structure Map after First Five Marcellus Horizontal Wells



Sullivan (2013)

3D seismic reveals complex detached structures

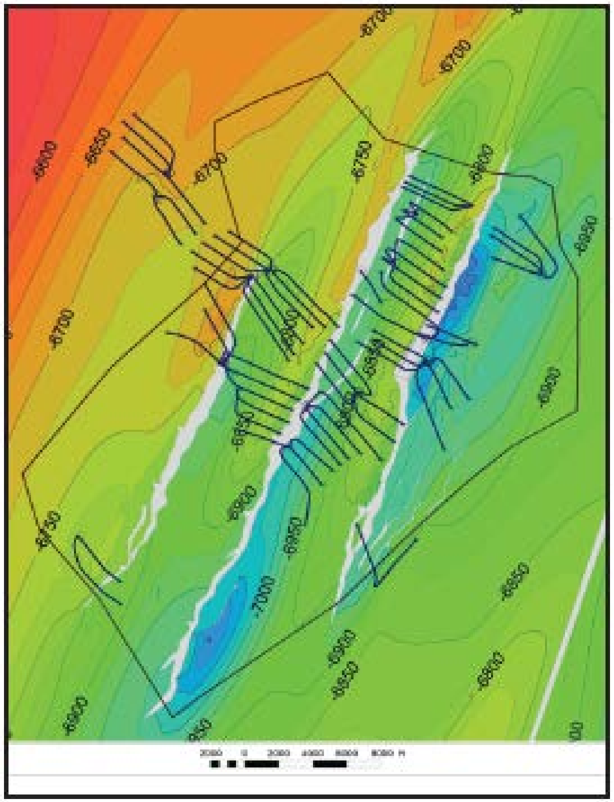


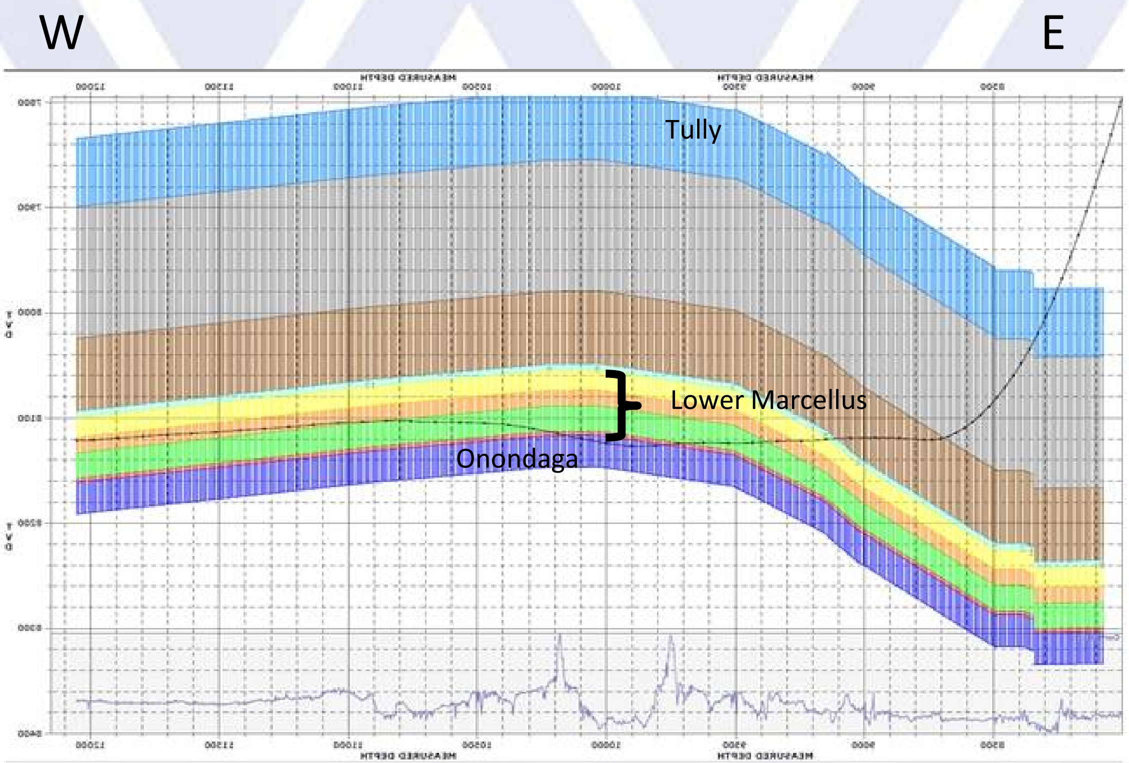


Sullivan (2013)

3D seismic reveals subtle structure and helps optimize well placement

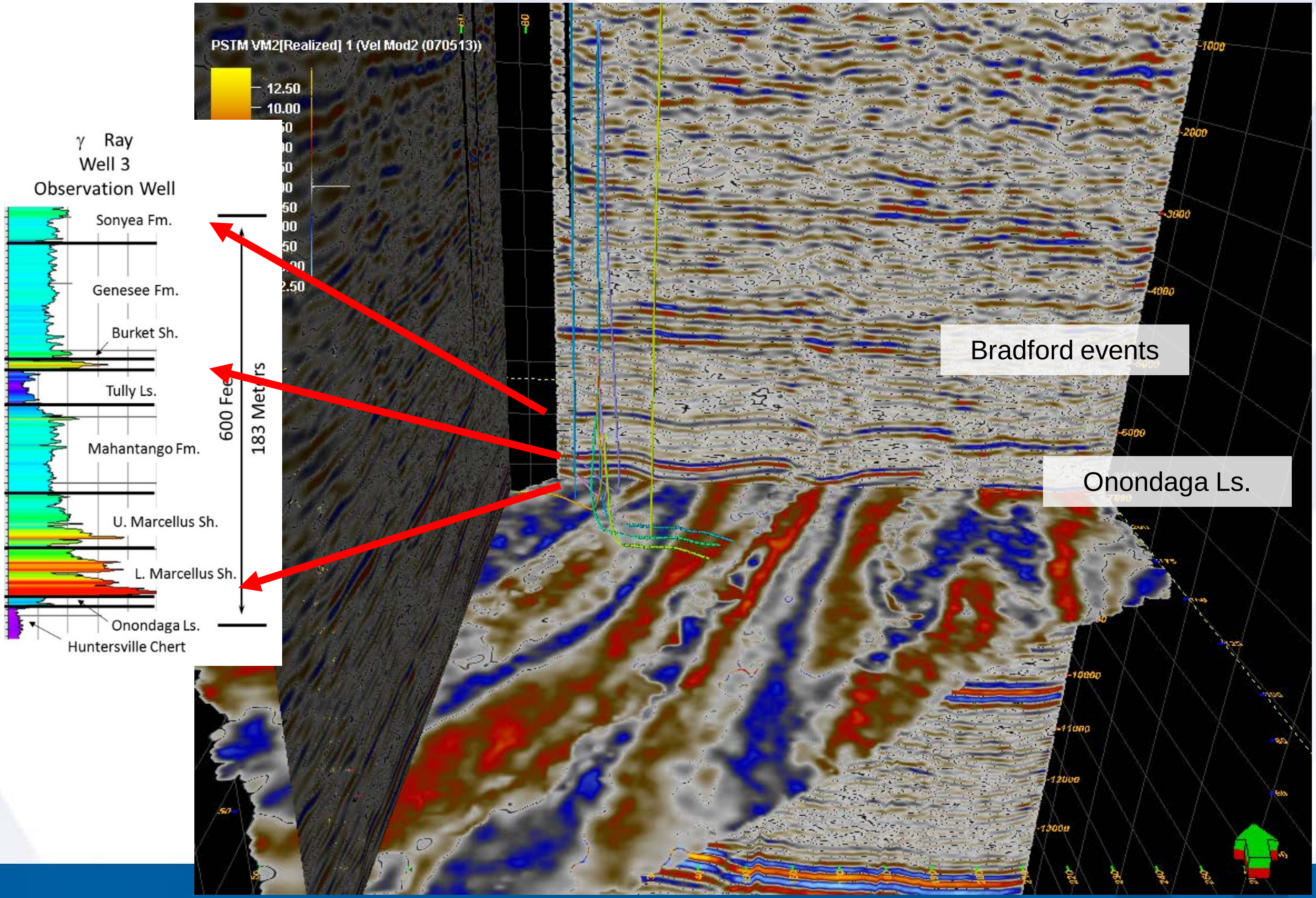
Post-Seismic Structure Map and Horizontal Wells



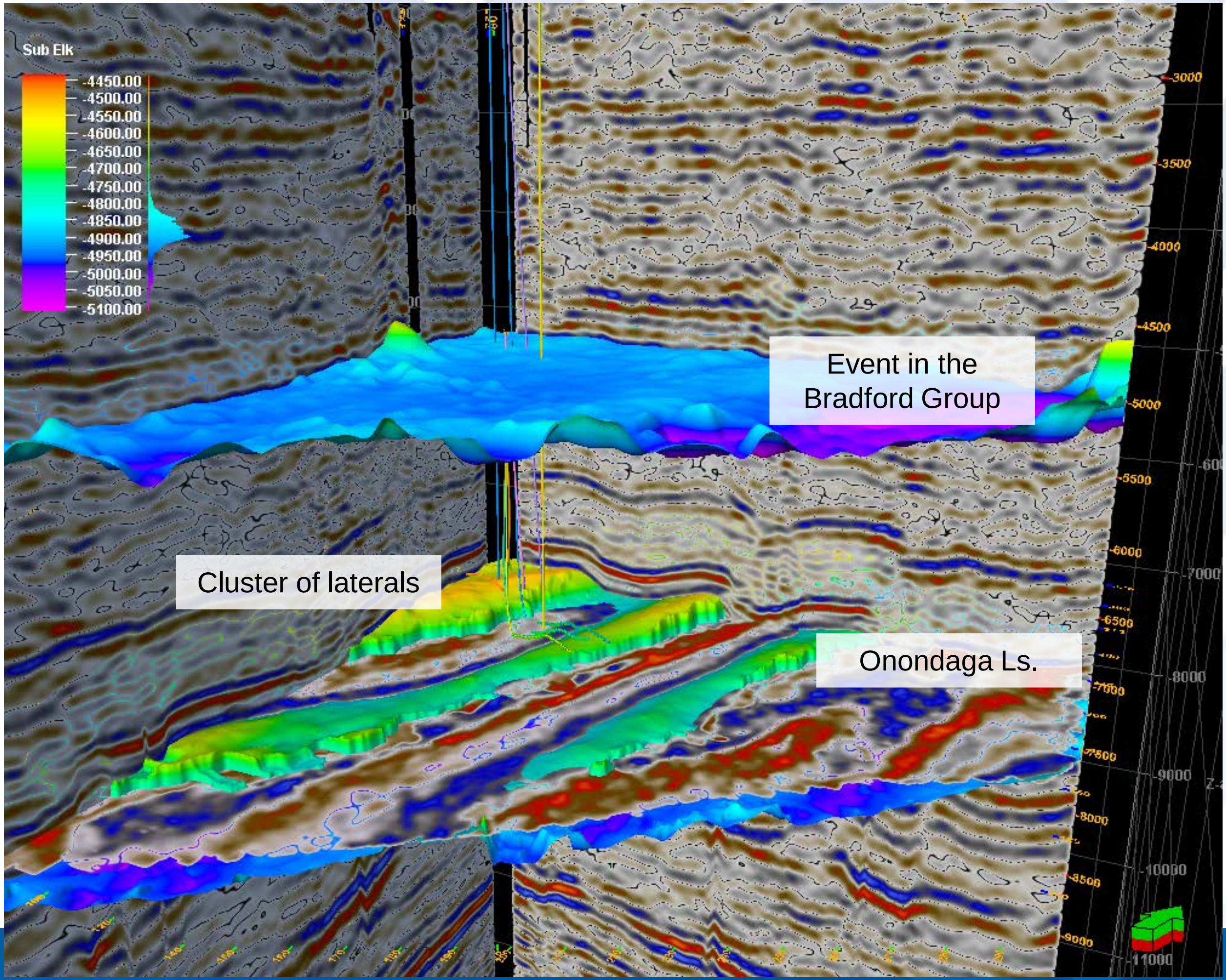


Sullivan (2013)

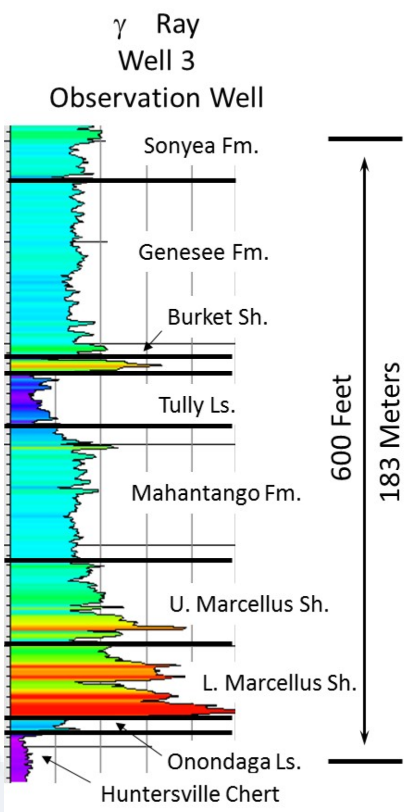
III. Subsurface characterization
3D seismic view

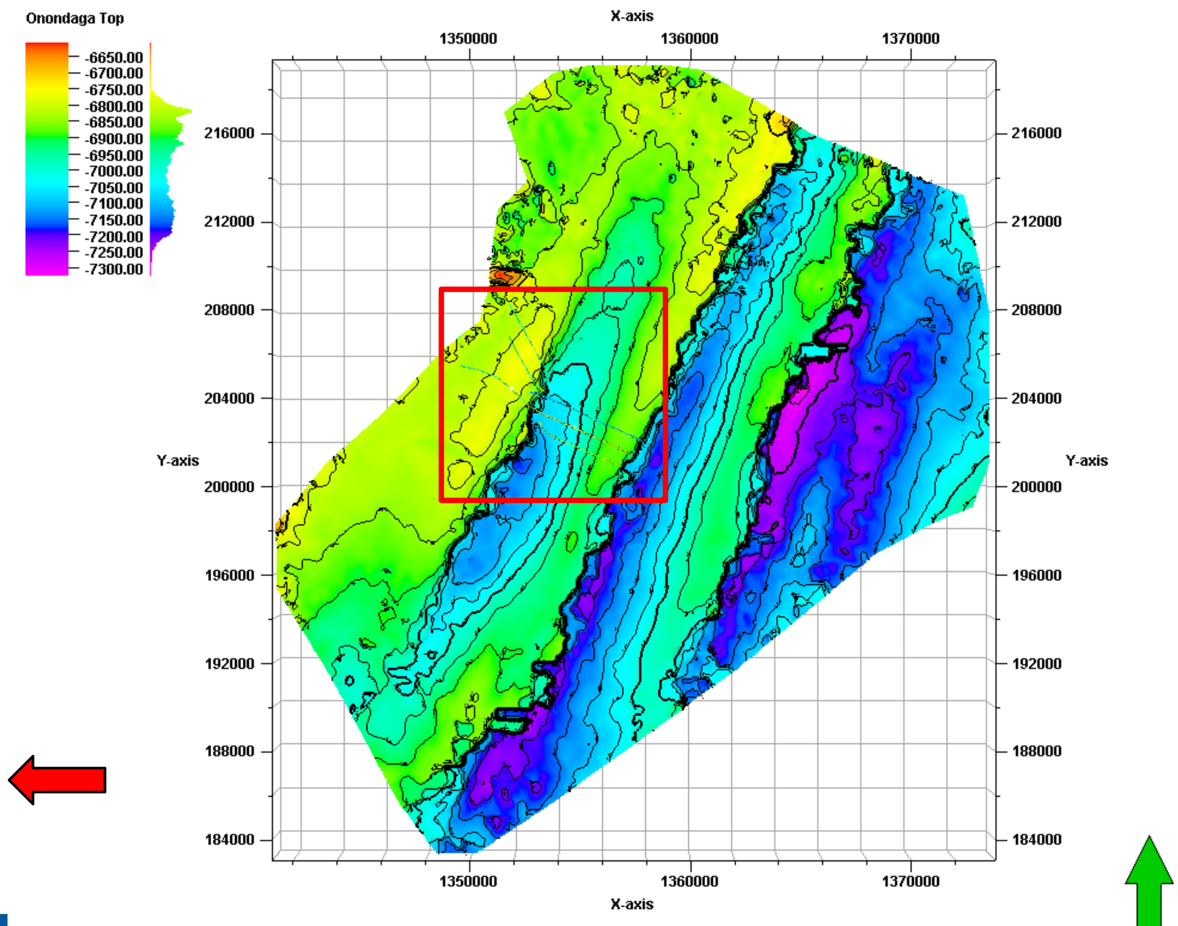


Disharmony between deep and shallow structure revealed in 3D seismic

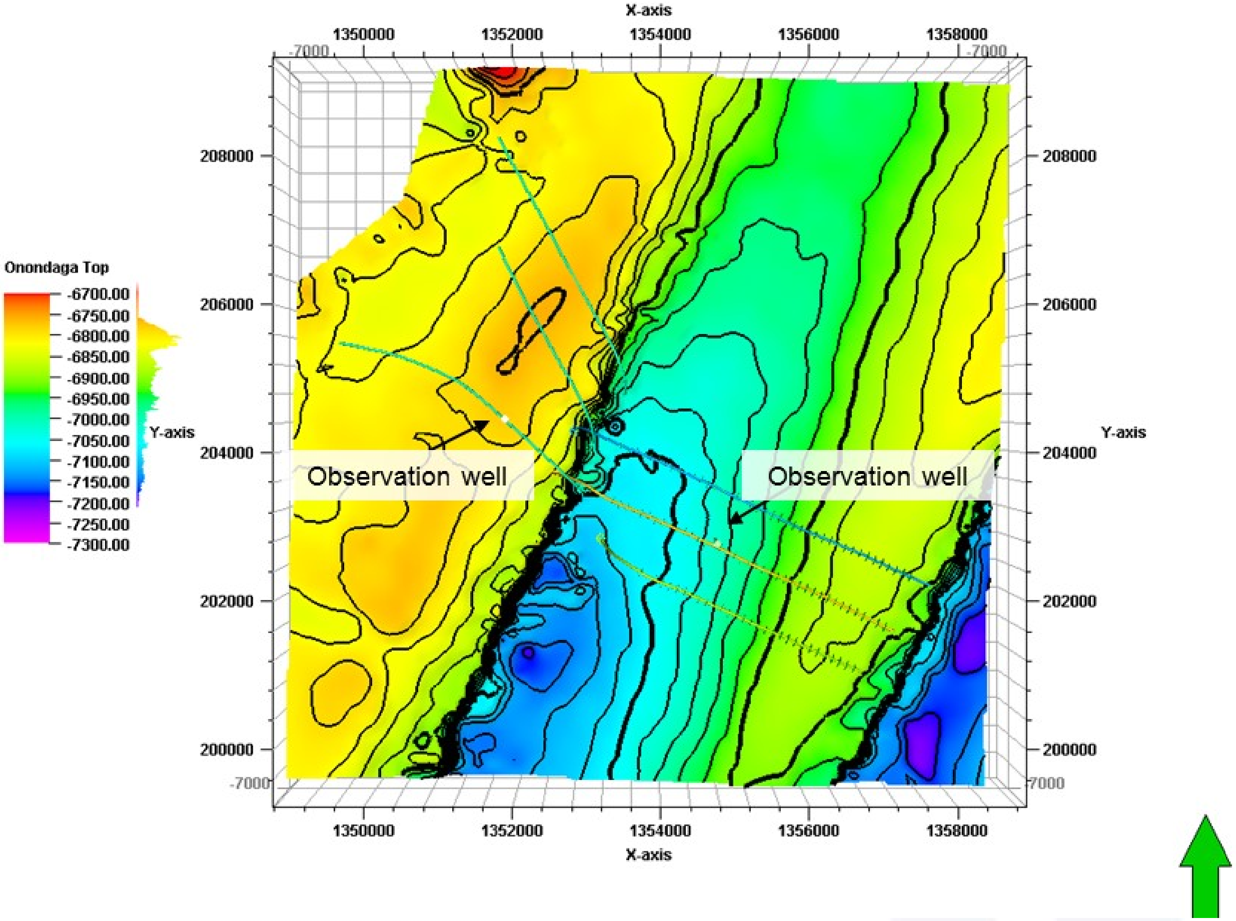


Interpreted 3D seismic structure on the Onondaga Ls./base of Marcellus

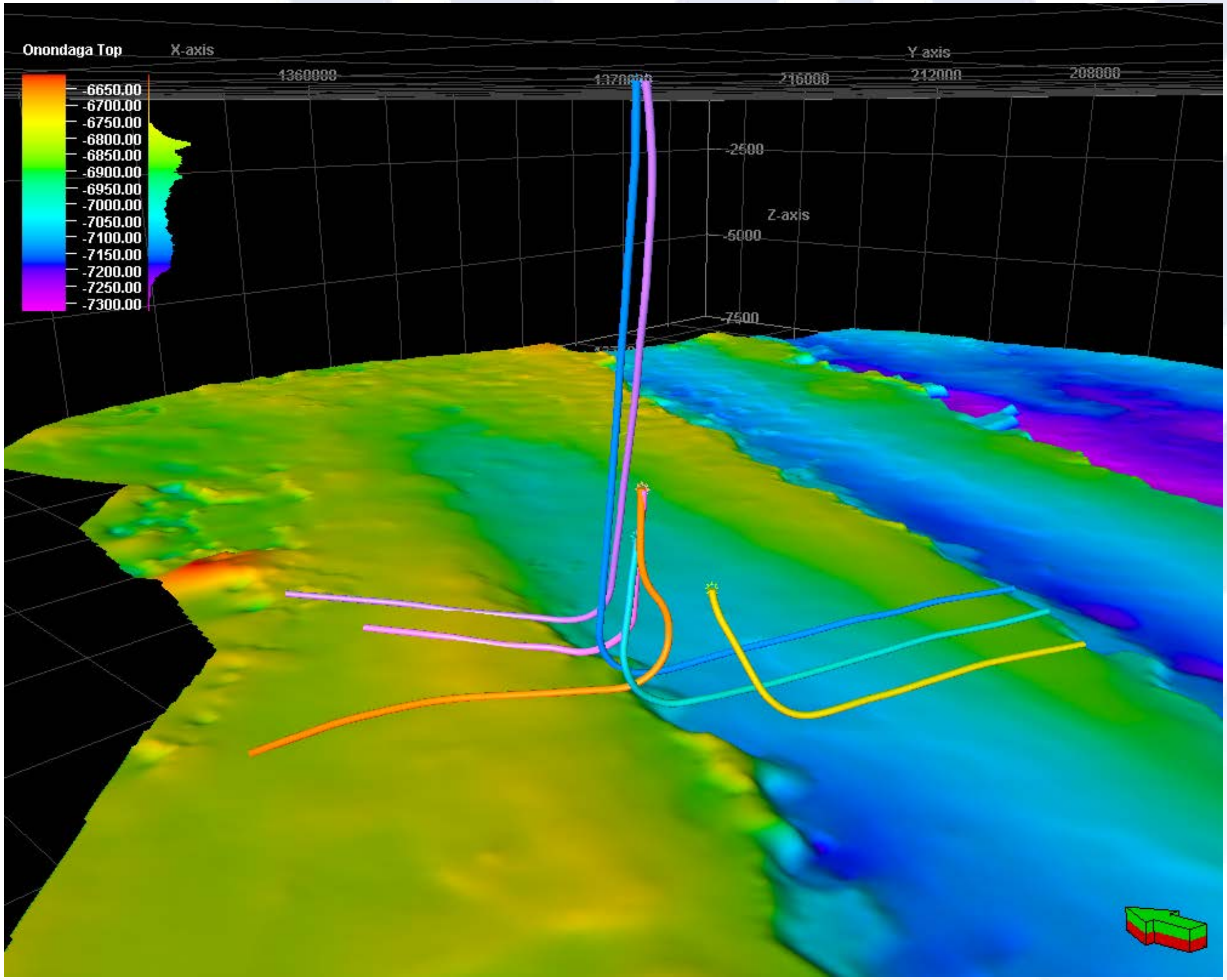




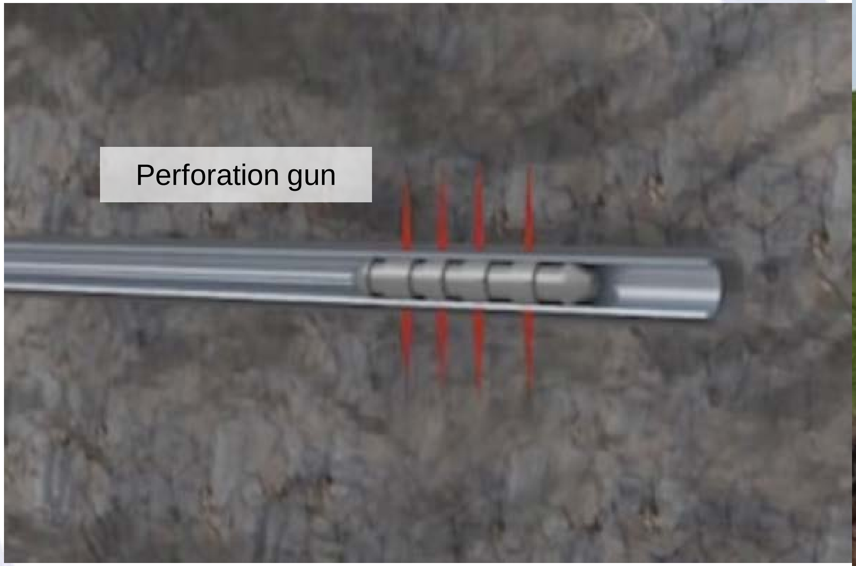
We will look at microseismic data from this group of wells



Multiple wells from a single pad to minimize environmental impact while maximizing reservoir contact

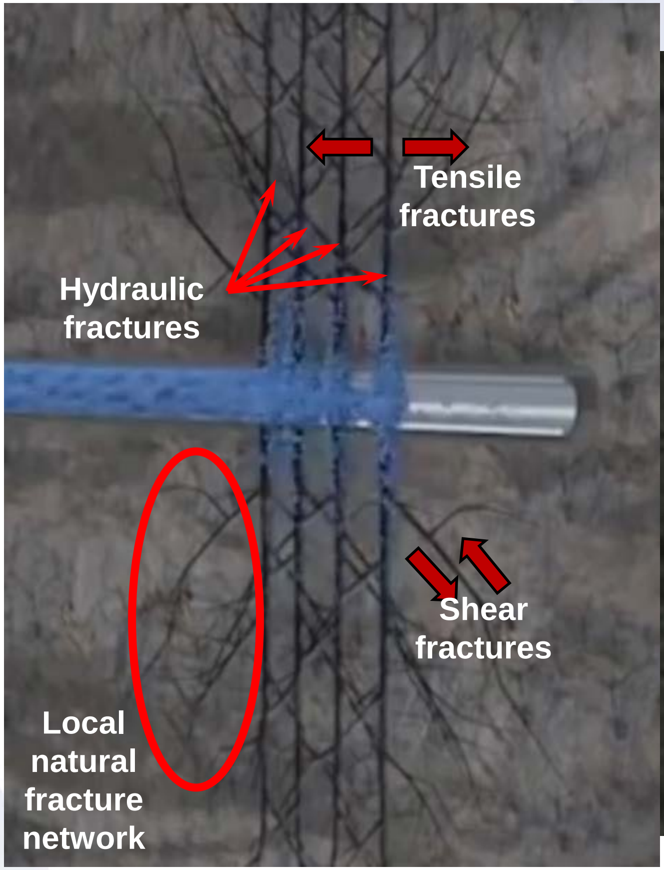


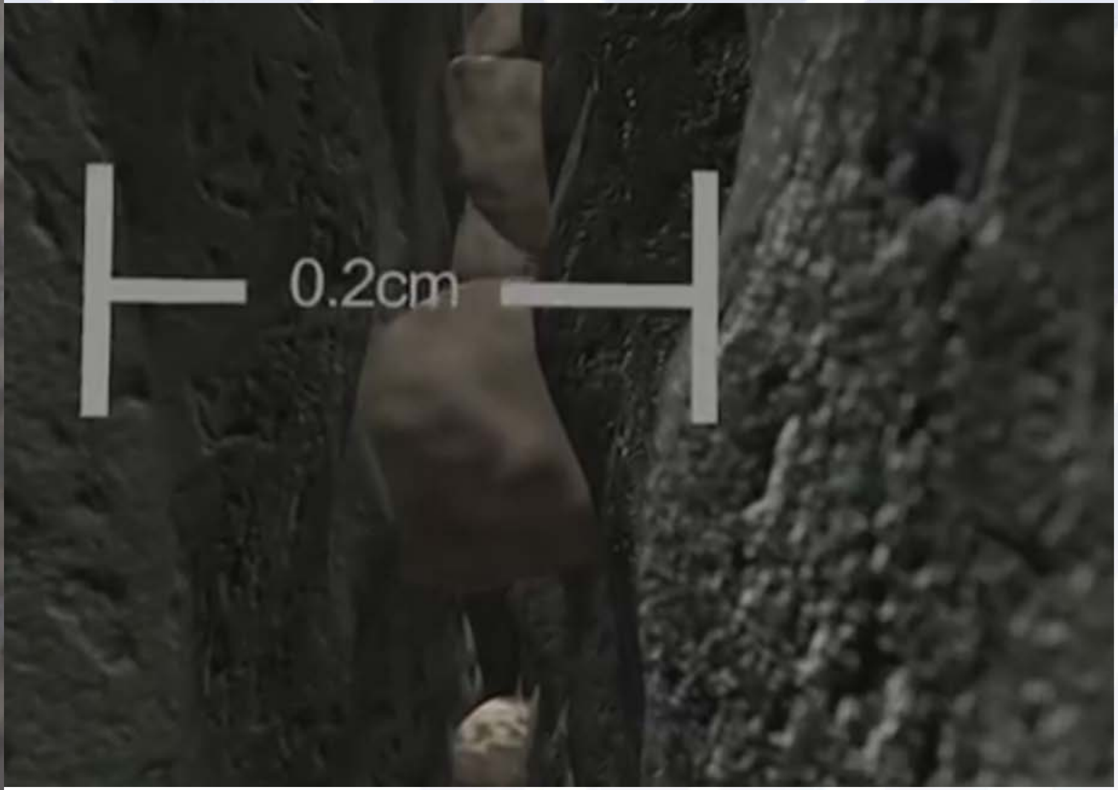
IV. Hydraulic fracture stimulation (HFS)



See https://www.youtube.com/watch?v=VY34PQUiwOQ Marathon Oil

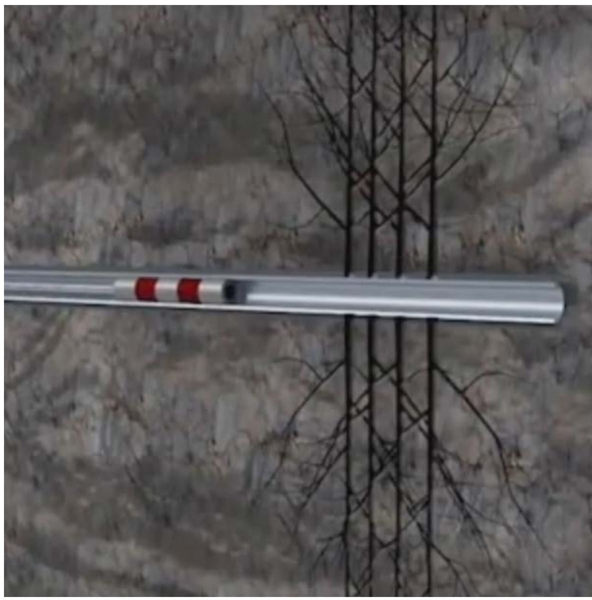
Fluid and proppant injection under high pressure creates a network of fractures in your reservoir

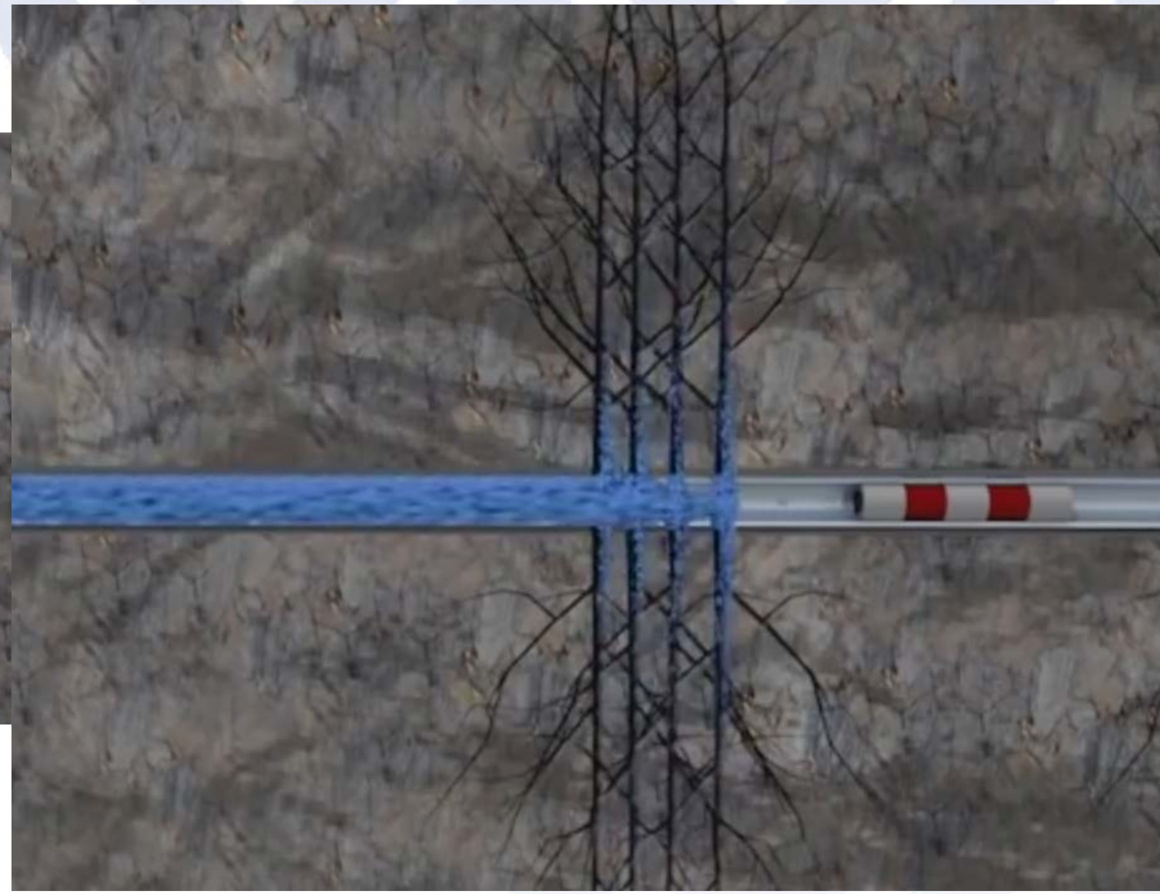




See https://www.youtube.com/watch?v=VY34PQUiwOQ Marathon Oil

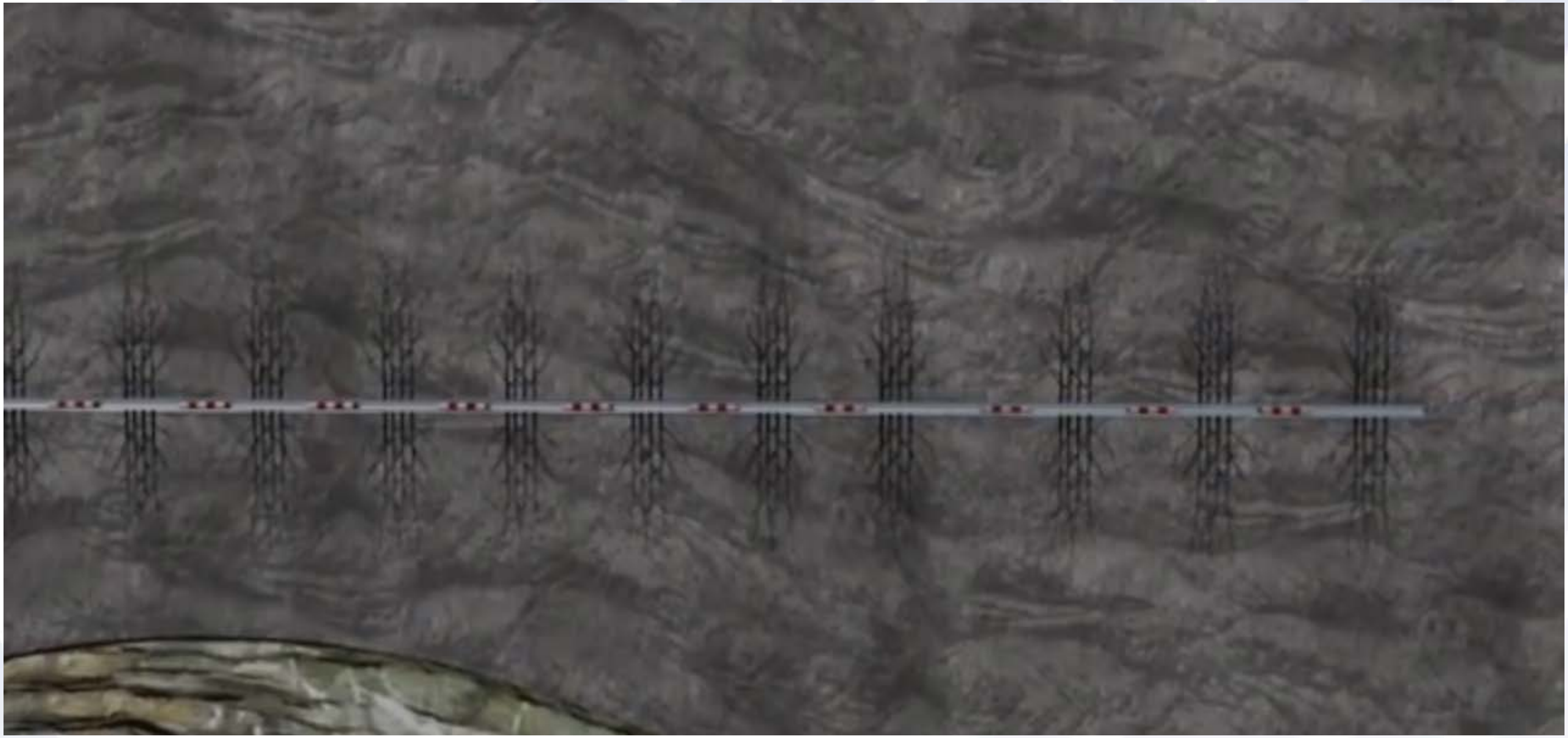
The initial segment or stage is isolated using a plug and the next stage is fracked





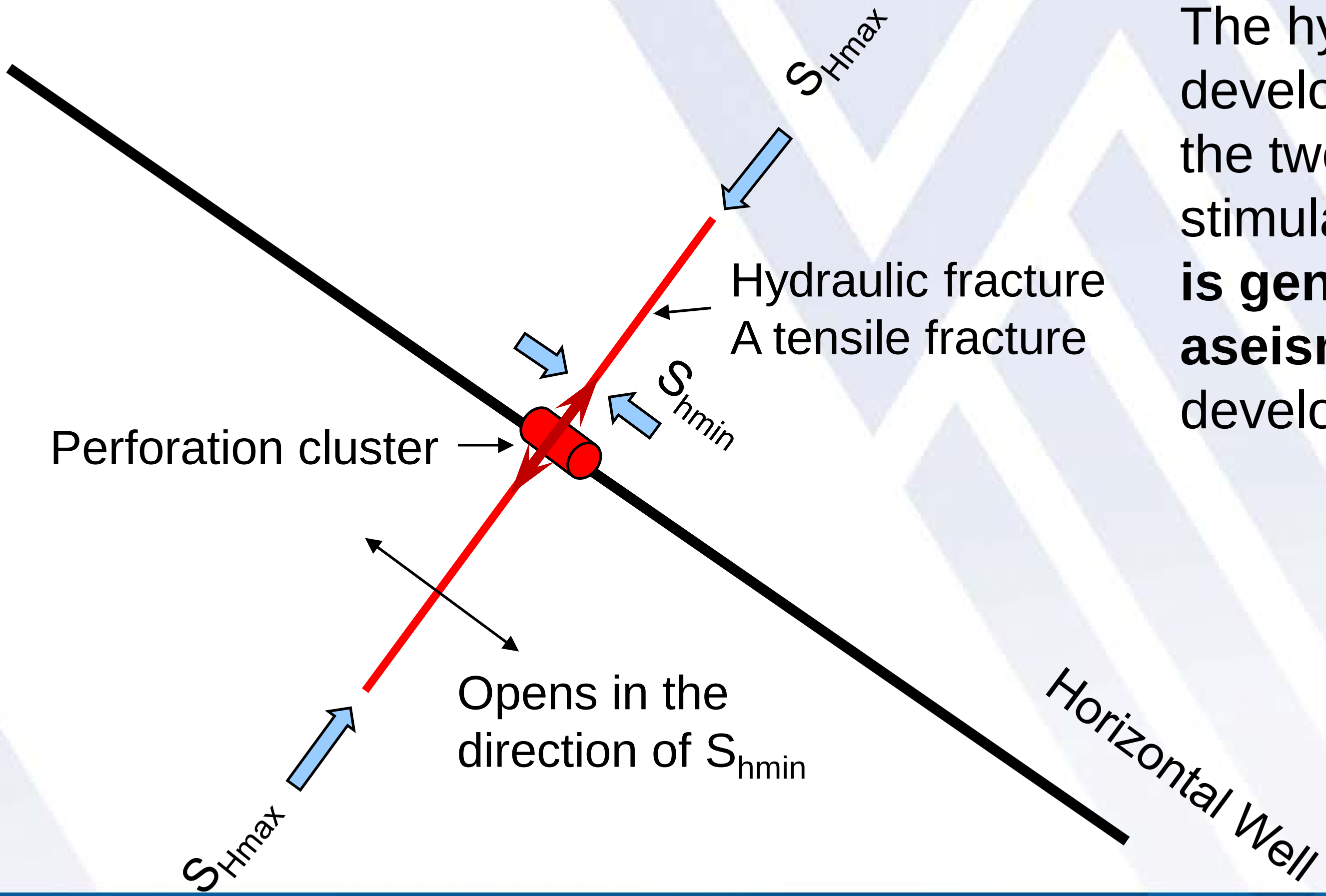
See https://www.youtube.com/watch?v=VY34PQUiwOQ Marathon Oil

The process is repeated for numerous stages along the length of the lateral



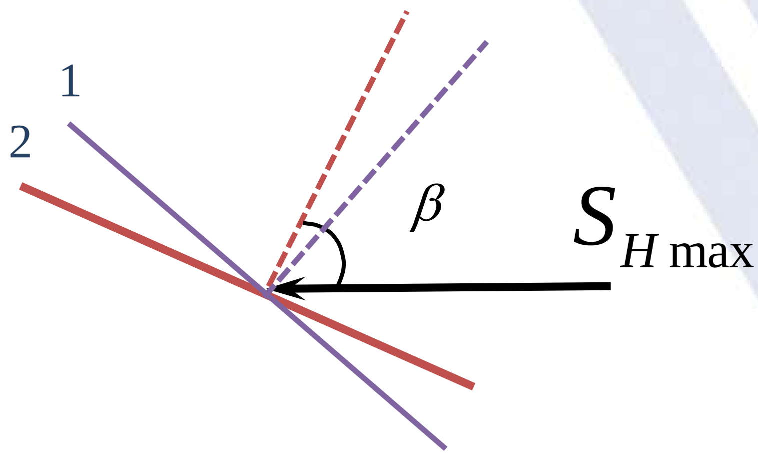
See https://www.youtube.com/watch?v=VY34PQUiwOQ Marathon Oil

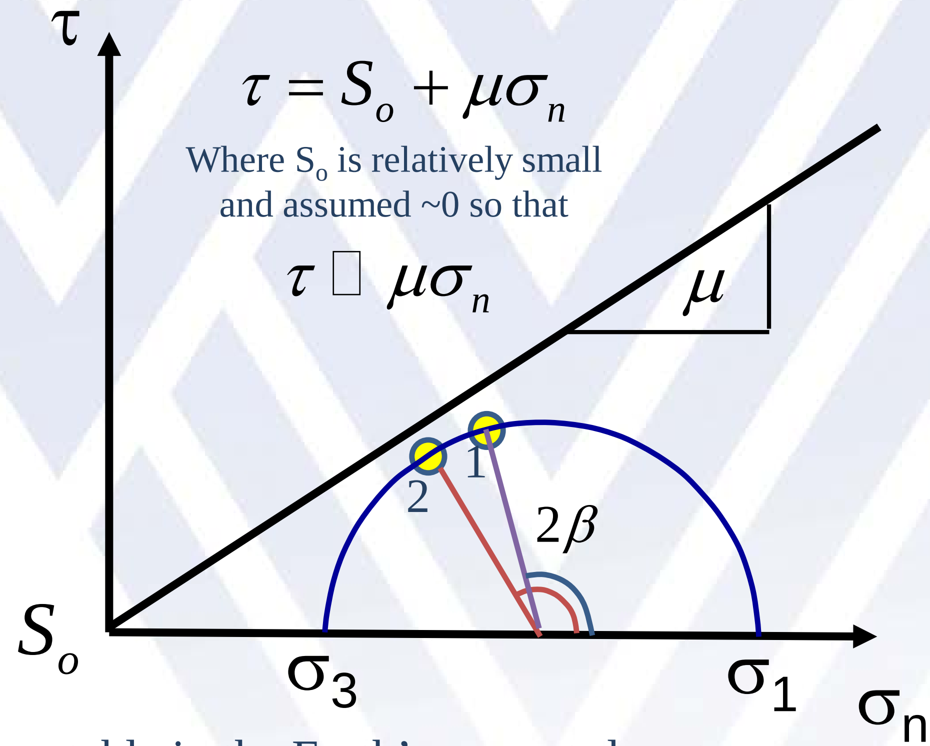
V. Microseismic events produced during HFS
The main hydraulic fracture is a tensile fracture.



The hydraulic fracture develops slowly over the two to three hour stimulation period **and is generally quiet or aseismic during** its development.

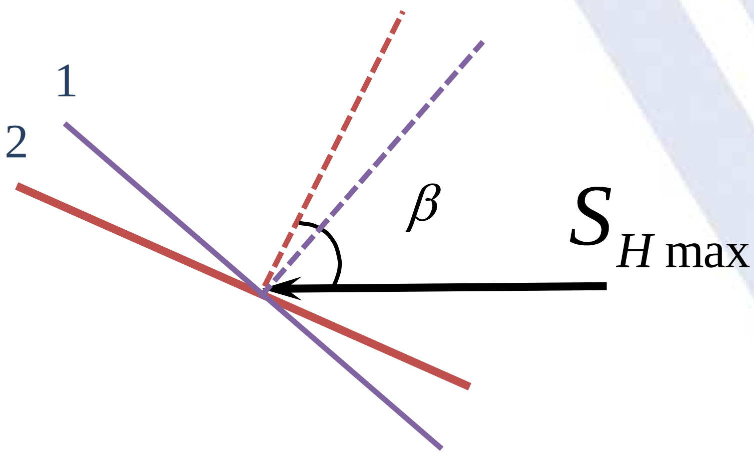
Old faults and fractures in the Earth's stress field and the influence of increased pore pressure through hydraulic fracture stimulation



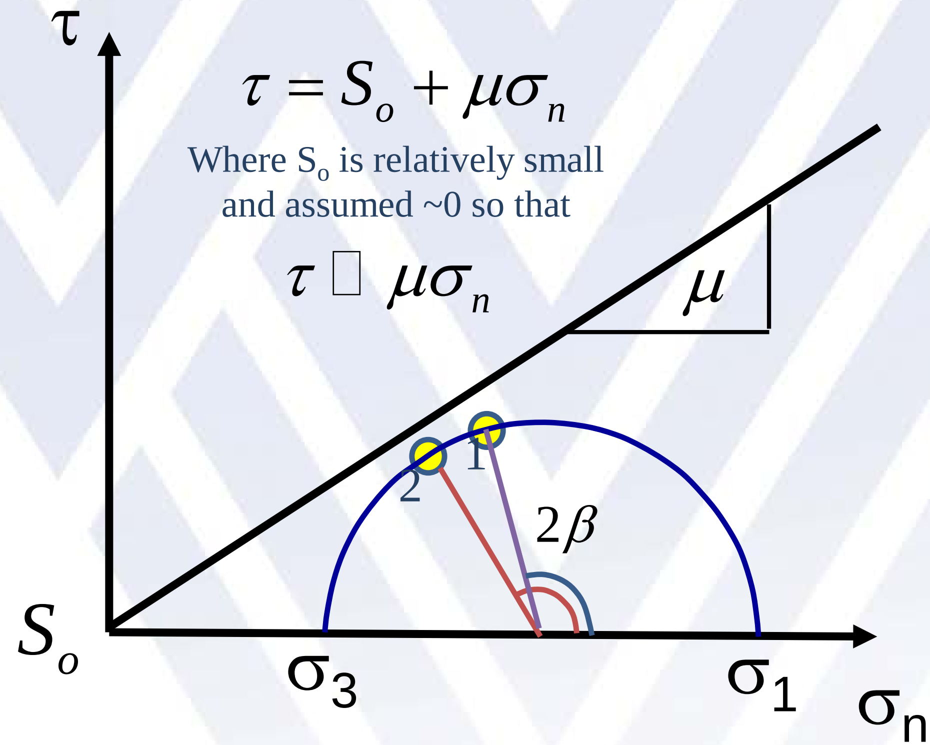


While these old faults and fractures are stable in the Earth's present-day stress field, they often fail during HFS in response to pore pressure increase. Recall that $\sigma = S - P_p$ so if the pore pressure is increased through hydraulic fracture stimulation σ will shift to the right.

Old faults and fractures in the Earth's stress field and the influence of increased pore pressure through hydraulic fracture stimulation

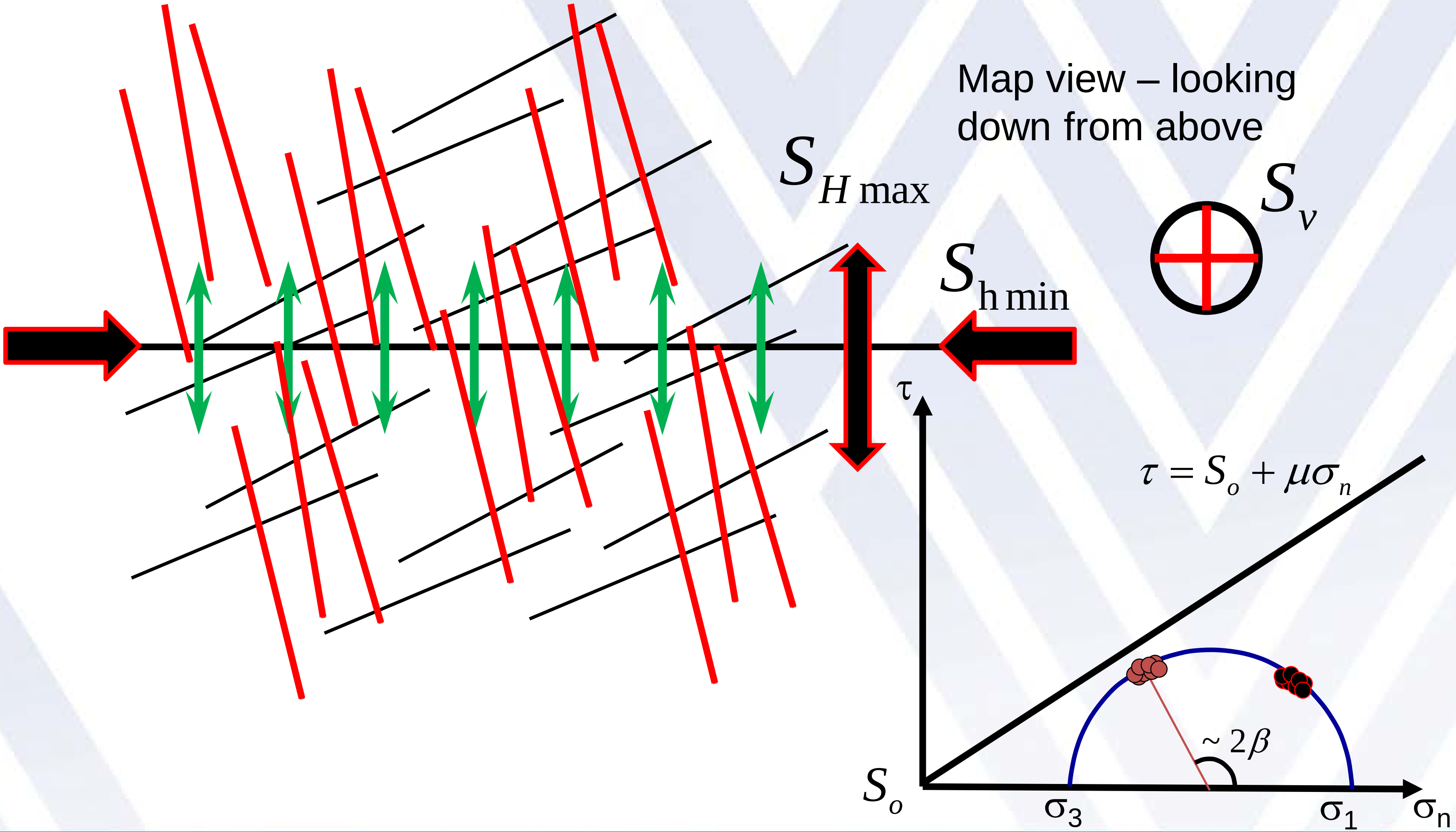


The near zero S_o assumes the fractures are critically stressed or near failure to begin with

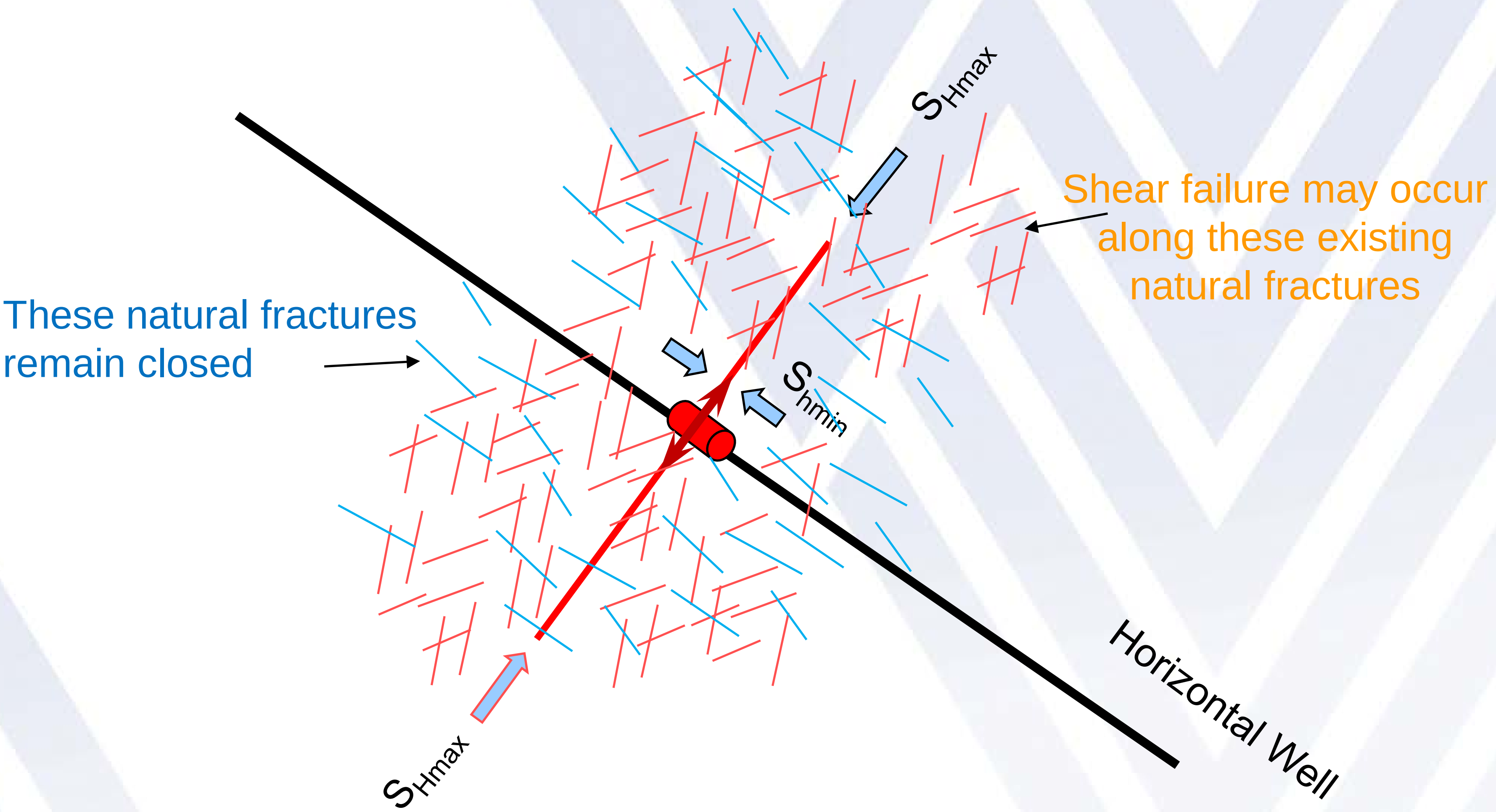


The increase in pore pressure associated with hydraulic fracture stimulation can lead to rupture on previously existing faults and fractures optimally oriented with respect to S_{Hmax} for failure to occur.

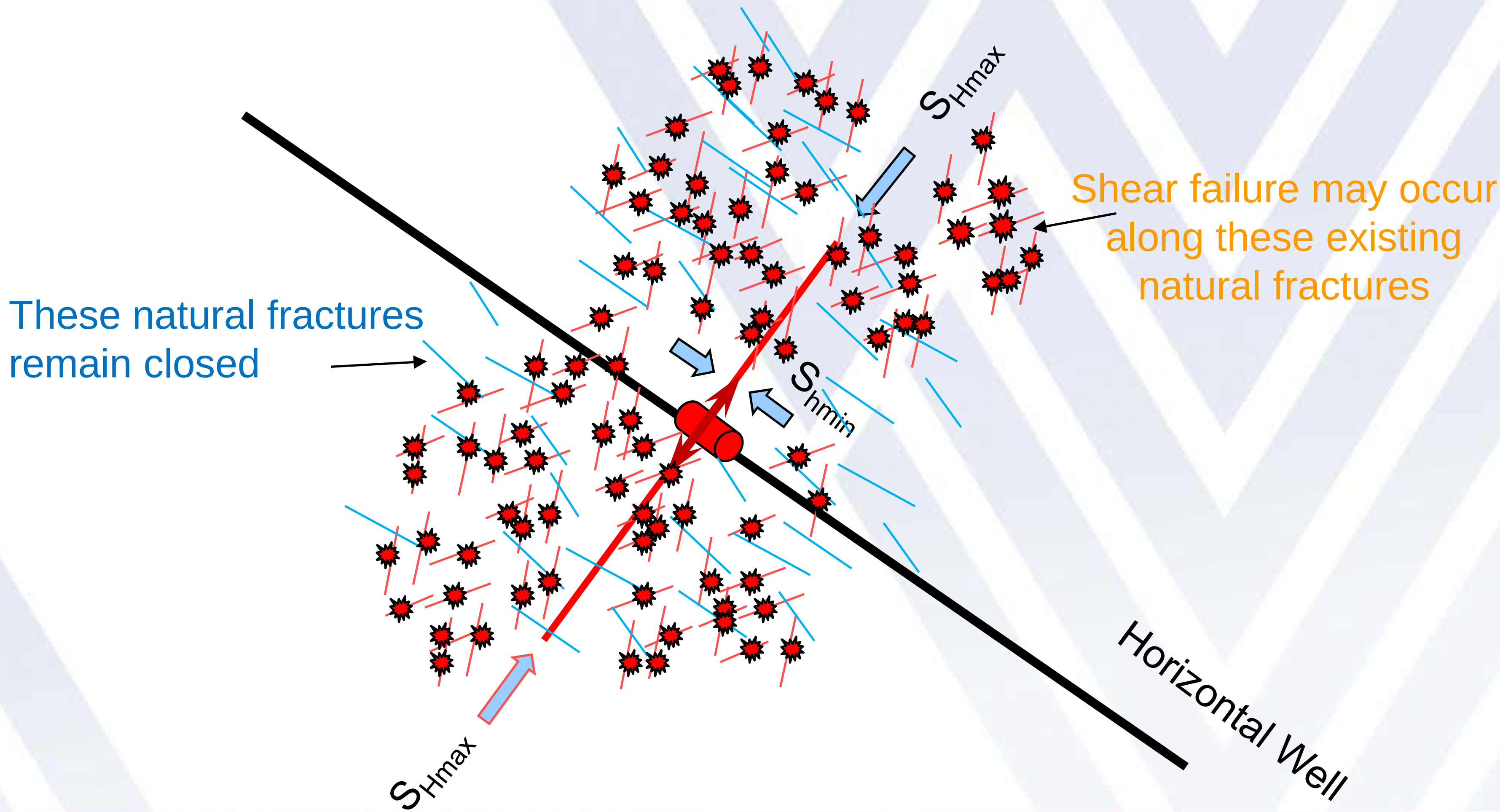
Essential data: natural fracture orientations, orientations and magnitudes of principal stresses and pore pressure



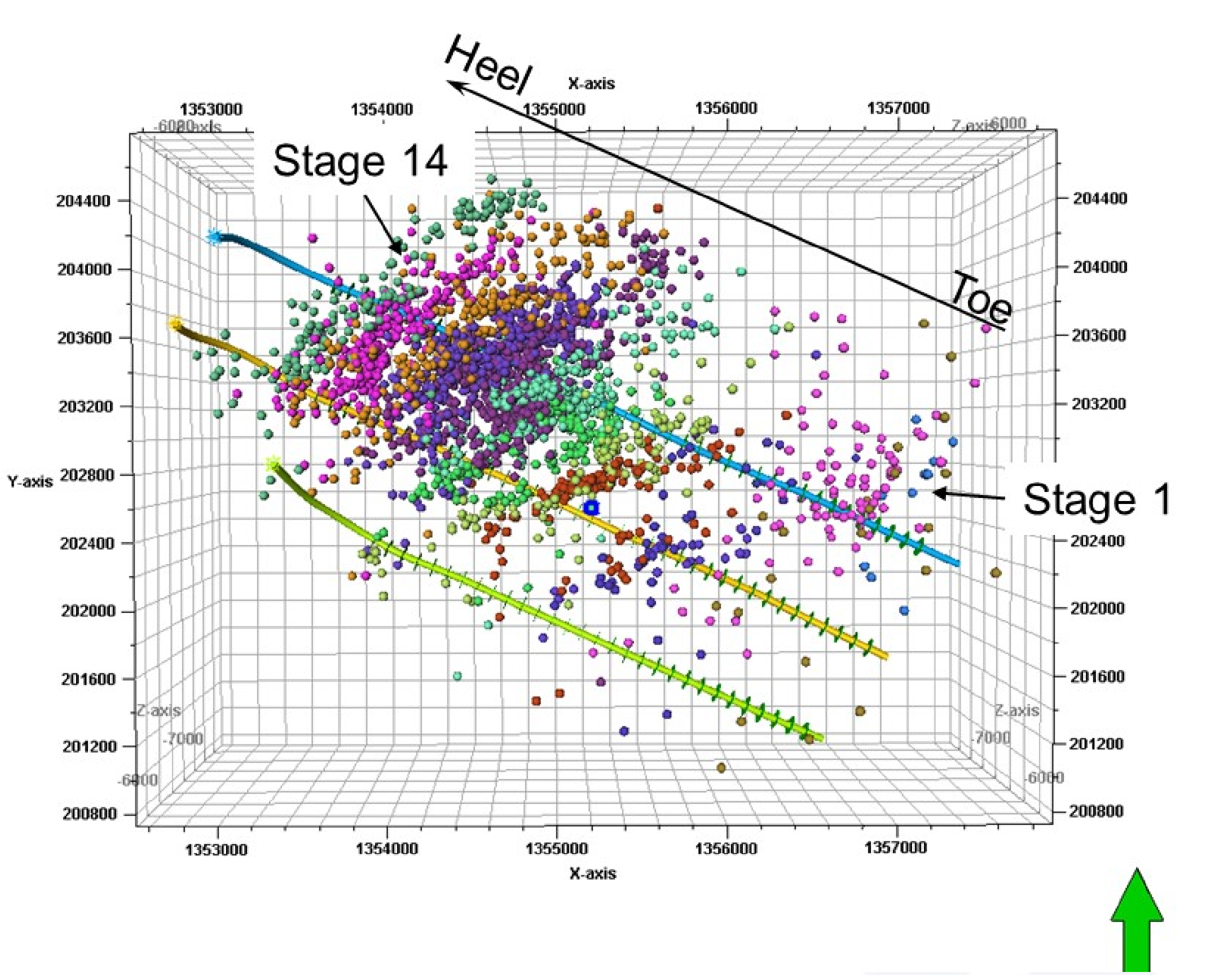
The hydraulic fracture



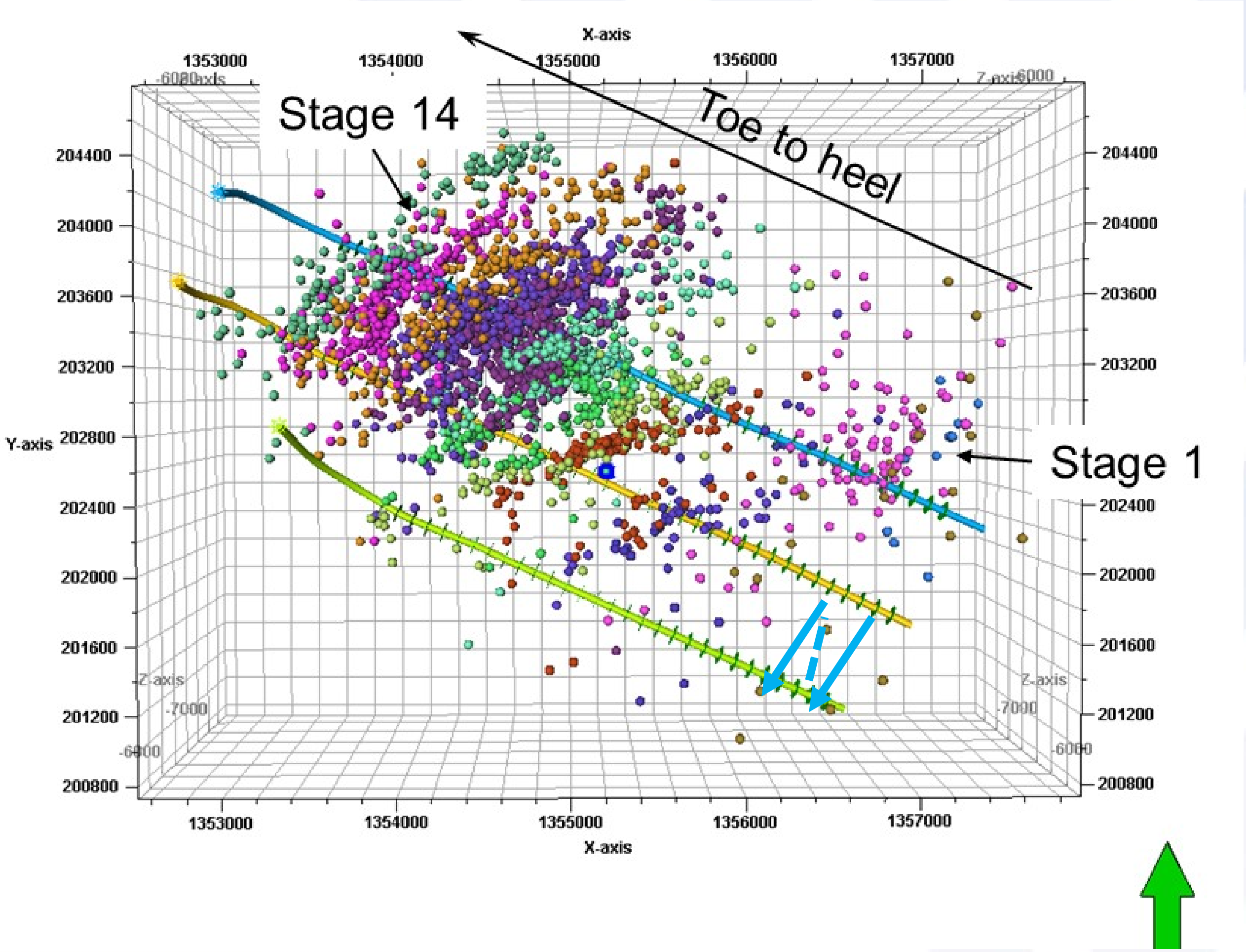
VI. Detected microseismic events associated predominantly with shear failure



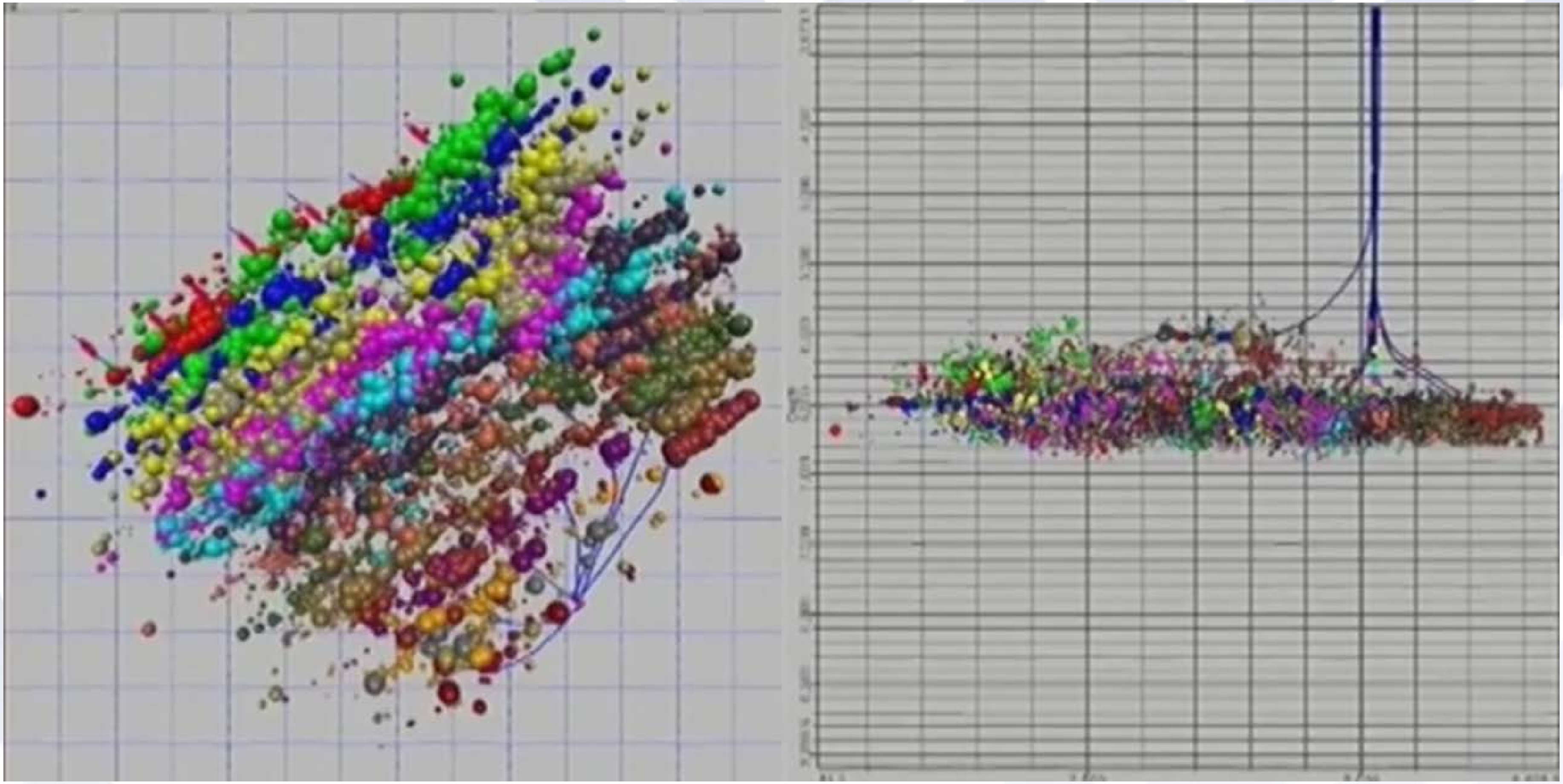
Microseismic events well 1 colored by stage
Treatment proceeds from toe to heel



Treatments can be conducted well-by-well or back and forth between wells in what is called a zipper frac

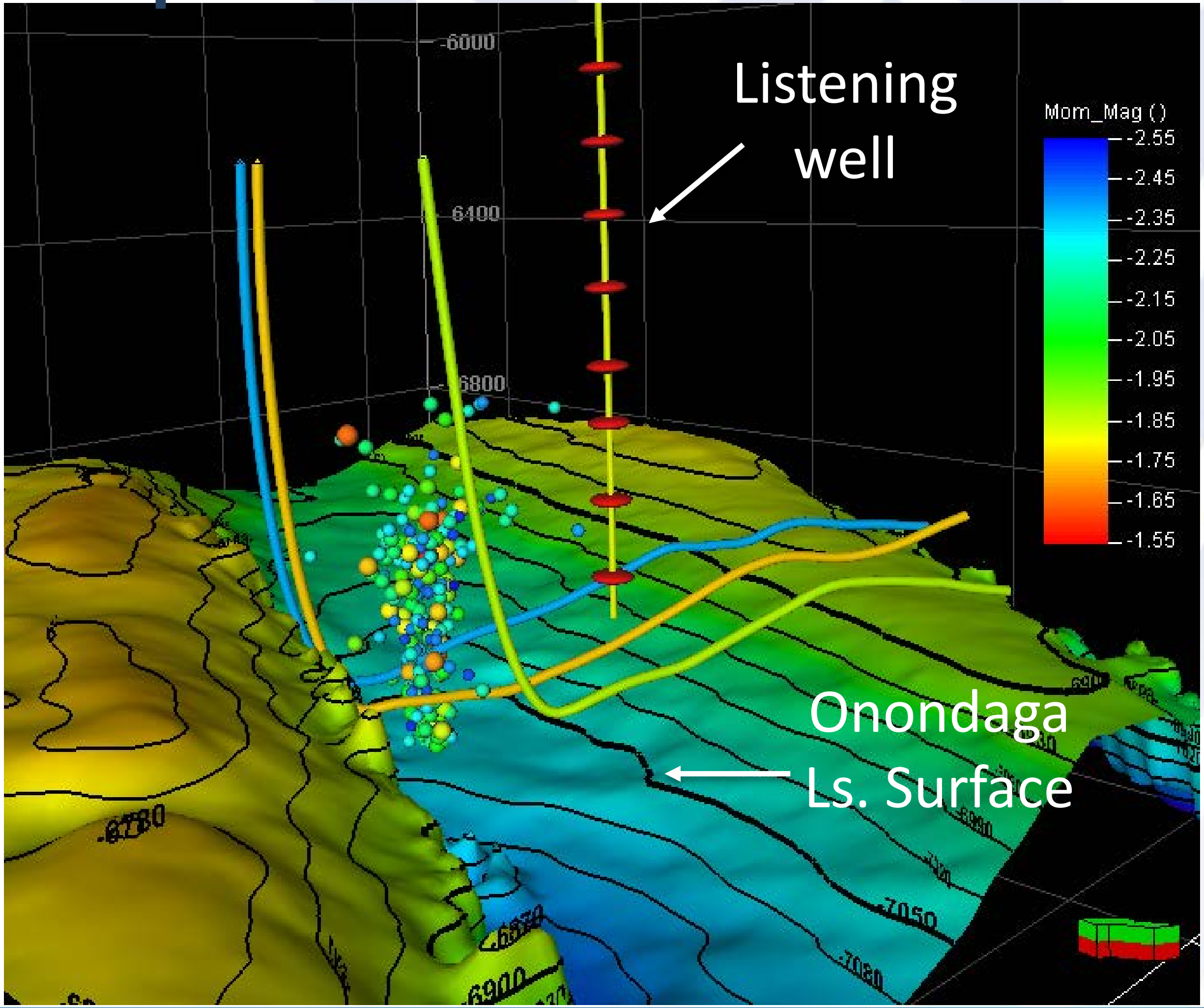


The zipper frac can help pre-stress the rock and make it easier for stages in adjacent wells to open fractures

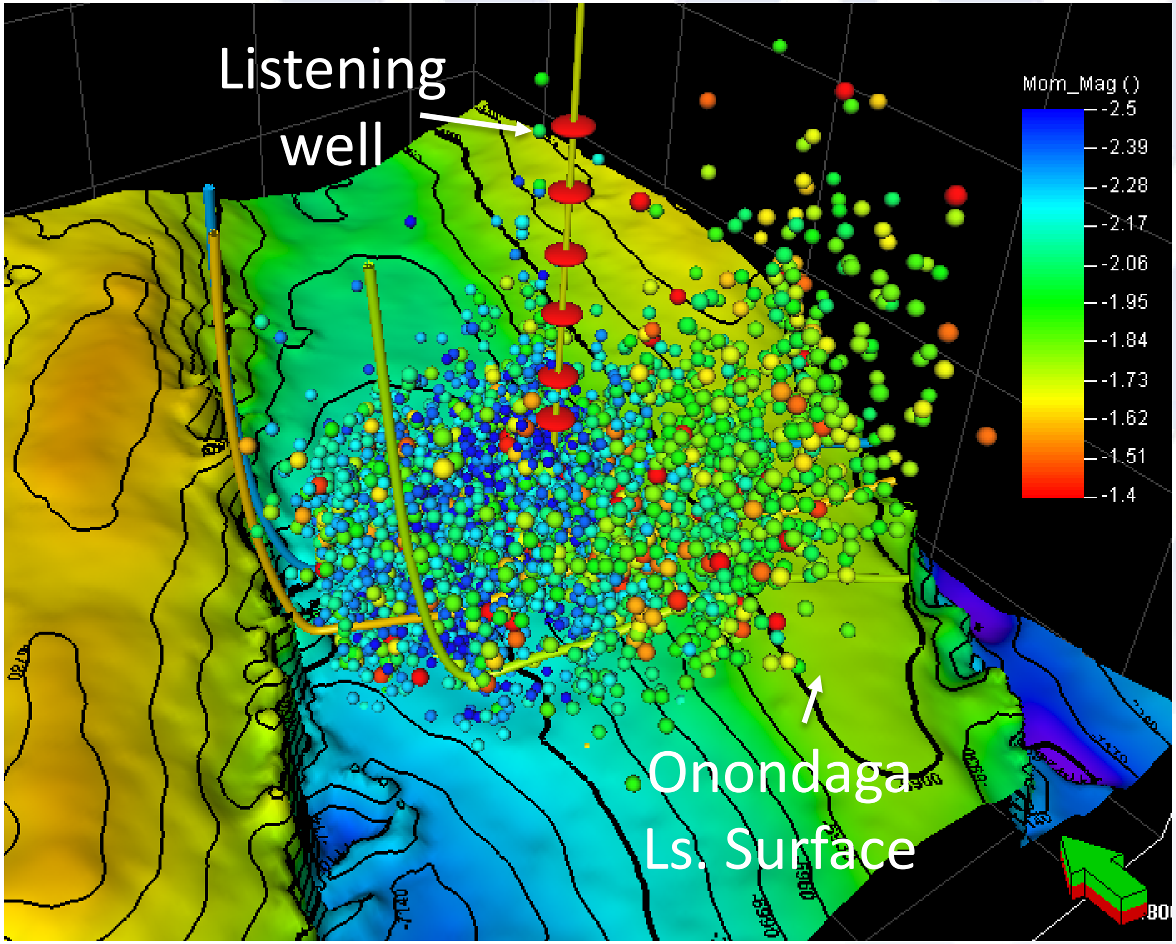


https://www.youtube.com/watch?v=2LgmleH86_s Microseismic Inc

Geophone sensor locations



Events from three wells



Magnitude varies from about -2.5 to -1.4

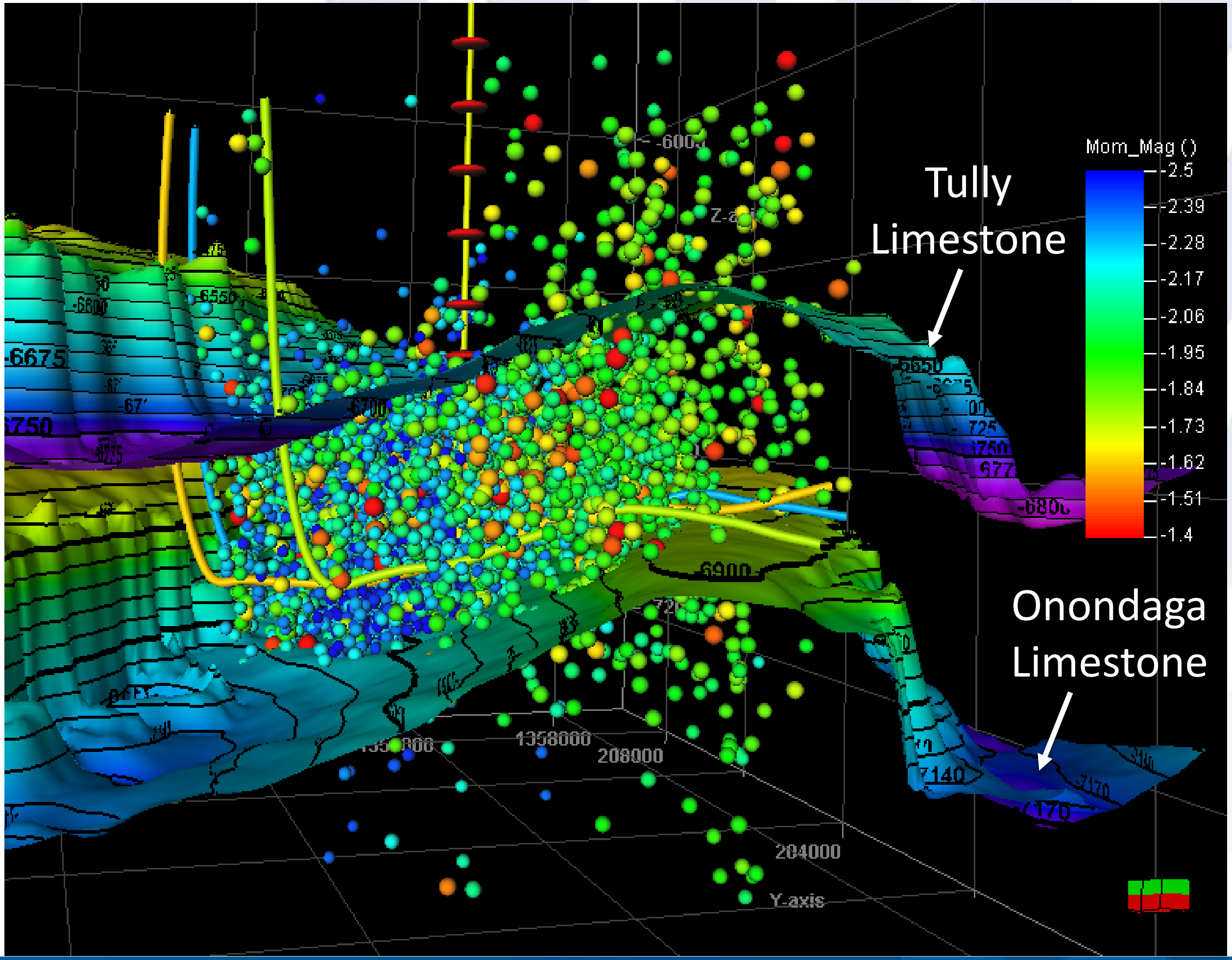
Magnitude and energy in practical terms (taken from IHS webinar)

Magnitude -2.25 corresponds to energy released in dropping a gallon jug of milk from waist height

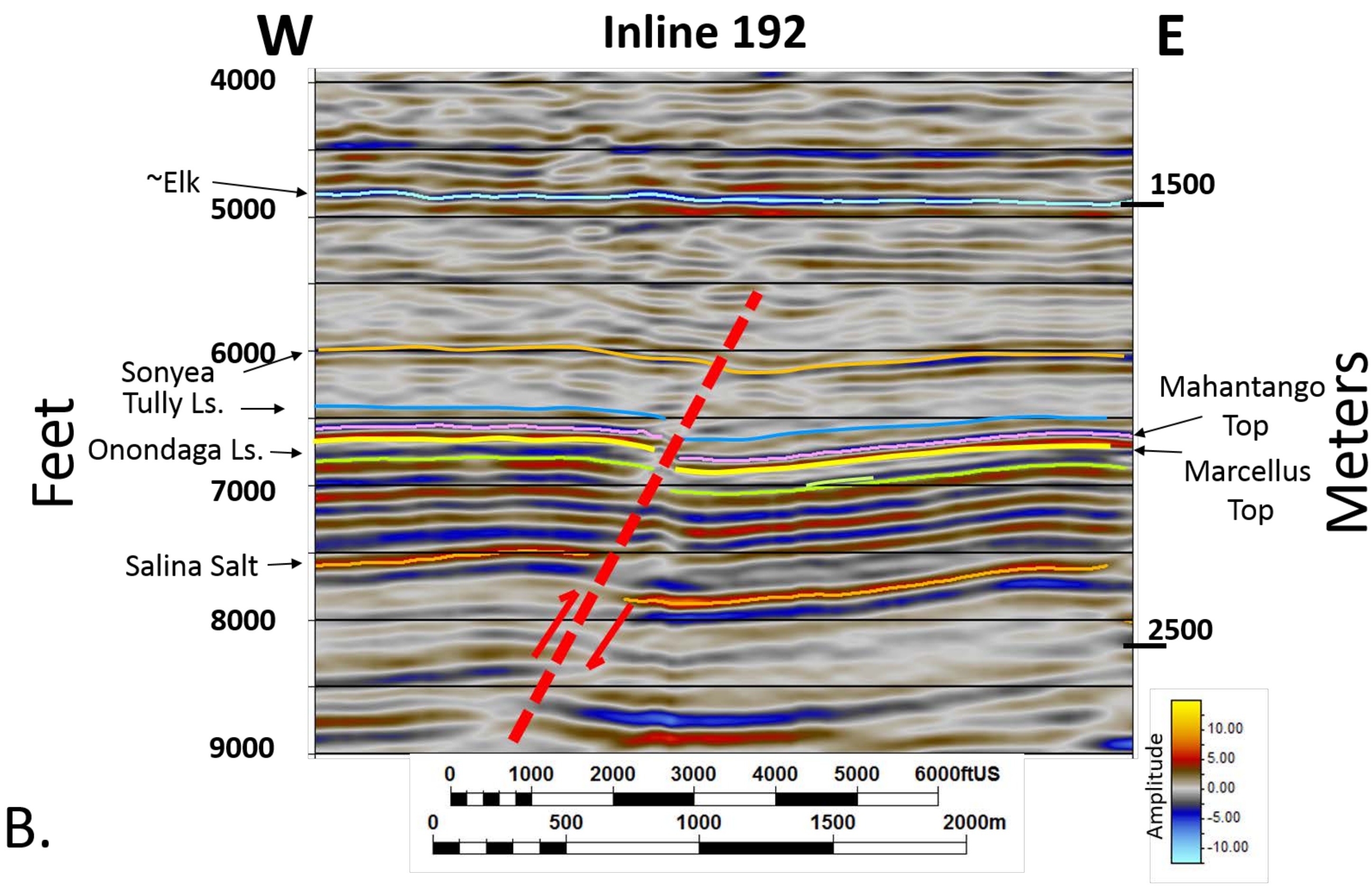
Moment Magnitude	Energy Release (kJ)	Energy Equivalent
-4	0.00006241	key press on keyboard
-3.5	0.00035138	heartbeat
-3	0.00197829	dropping an apple 6 ft
-2.5	0.01113778	air gun/bb gun
-2	0.06270569	powerful sling shot
-1.5	0.35303305	Firecracker
-1	1.98757607	home-run hit
-0.5	11.19005329	.50 caliber rifle
0	63.00000000	15 grams of TNT
0.5	355.00000000	35 mph car crash
1	1998.65000000	stick of dynamite
1.5	11252.39950000	WWII conventional bomb
2	63351.00918500	Quarry Blast
2.5	356666.18171155	lightning bolt
3	2008030.60303603	15 gallons of gasoline

Microseismic Range:
.5 to -4

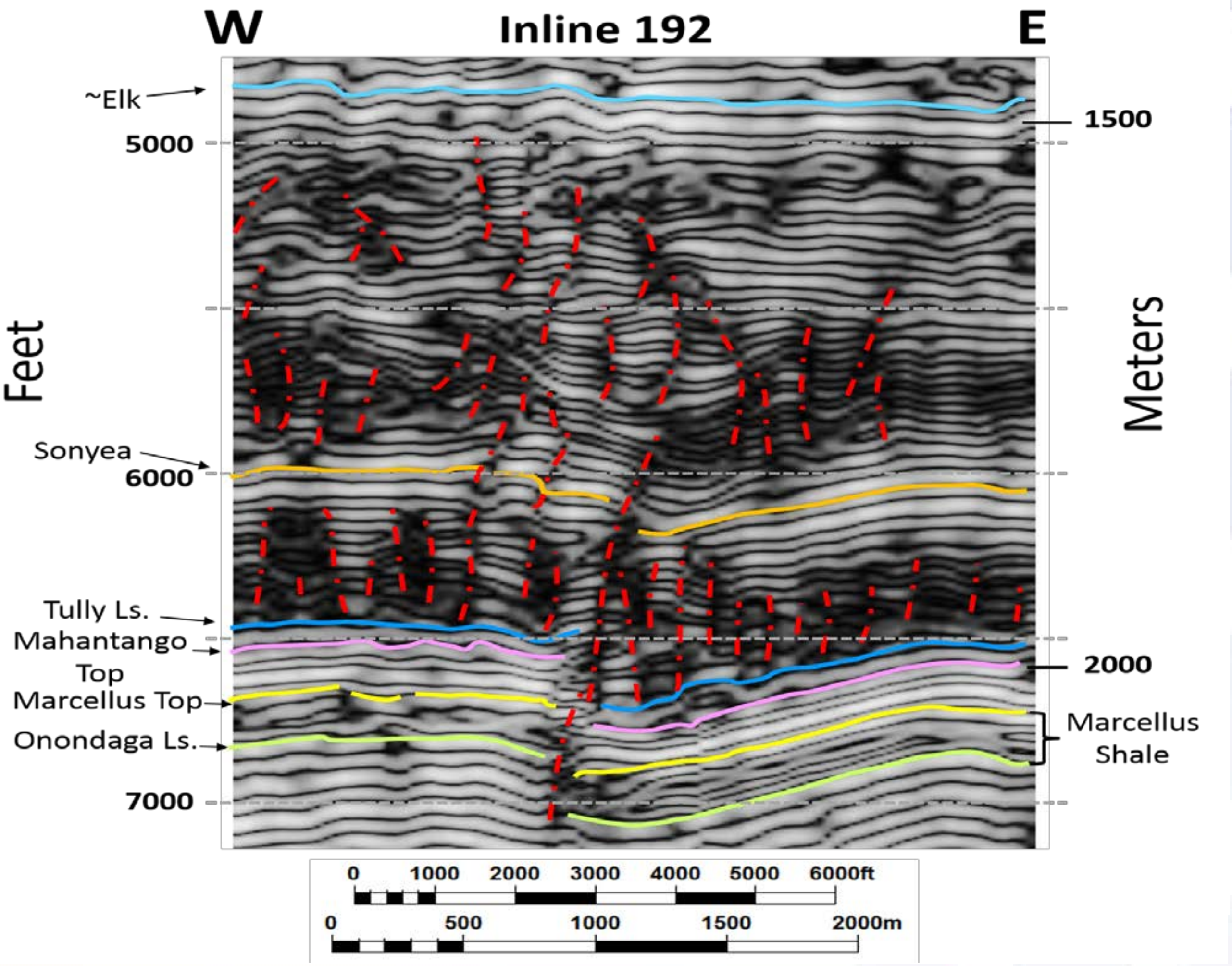
Events are largely confined between frac barriers



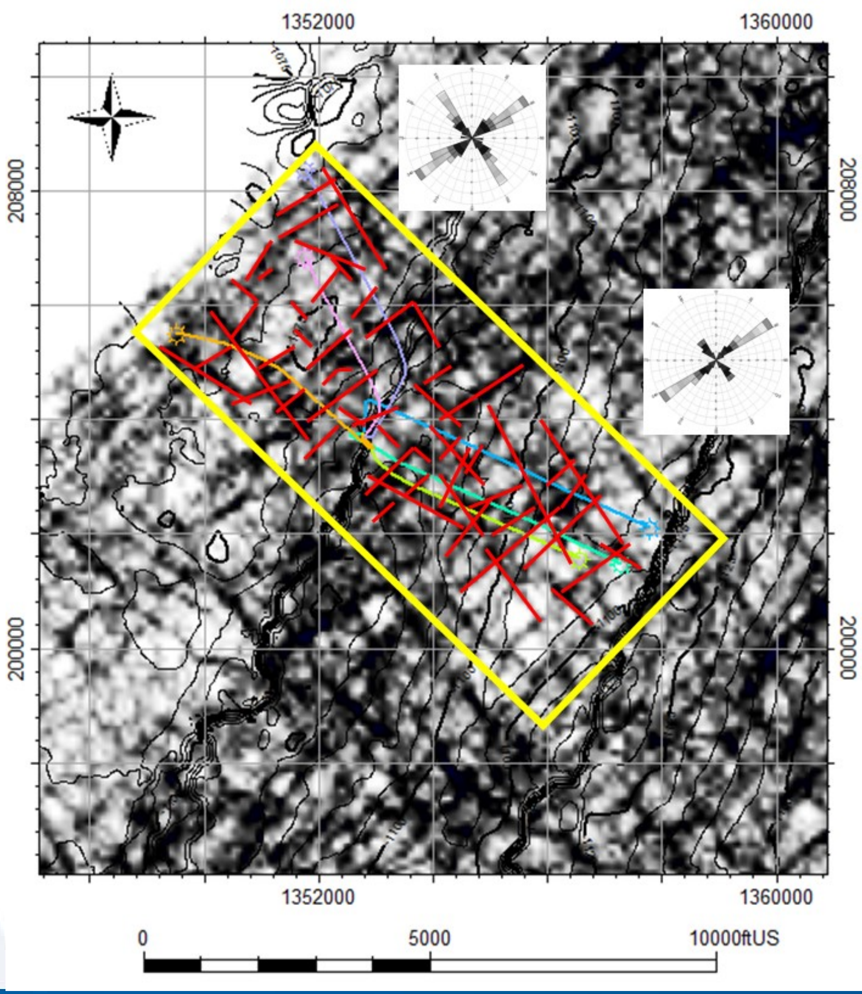
VII. Unveiling subsurface faults and fracture zones in 3D seismic using post-stack processing



Time variant trace amplitude slice view



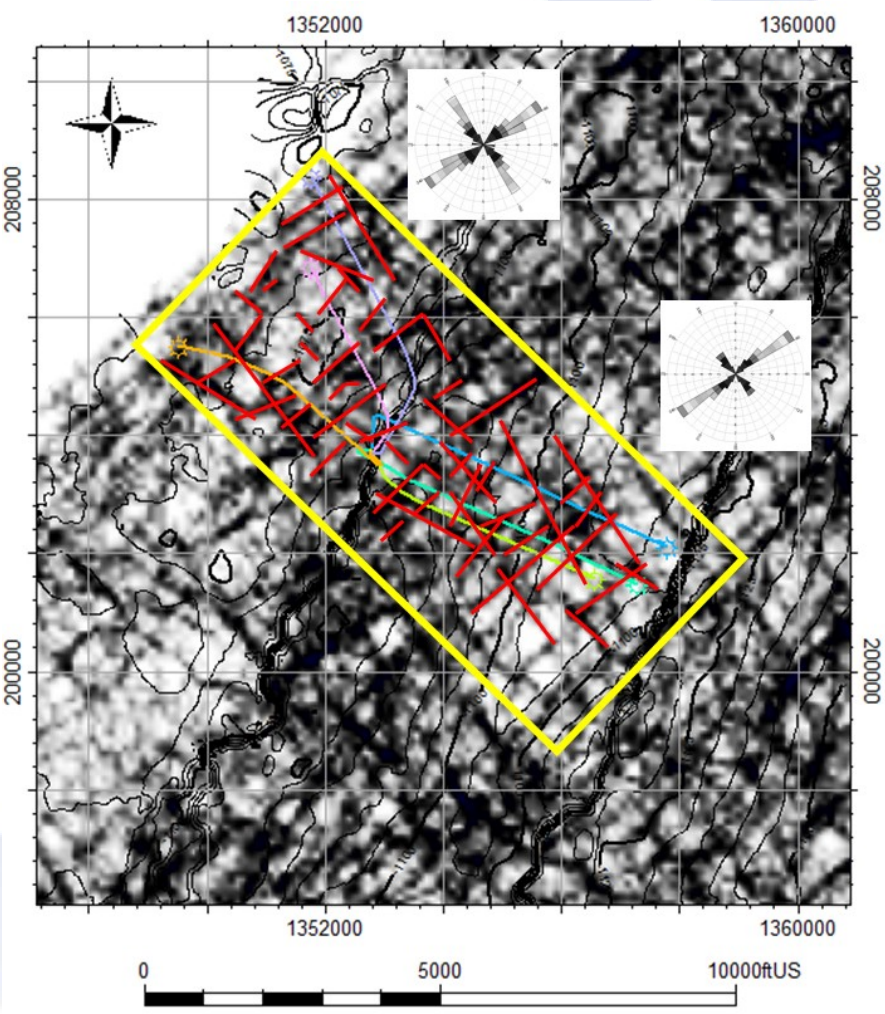
Map view of extracted seismic discontinuity trends. What do they tell us about the reservoir?



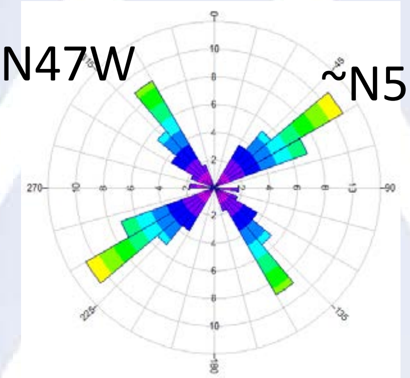
Base of the Marcellus

These discontinuities are interpreted to be associated with old faults and fracture zones. These interpreted old faults and fracture zones may rupture in response to hydraulic fracture stimulation and enhance the stimulated reservoir volume (SRV).

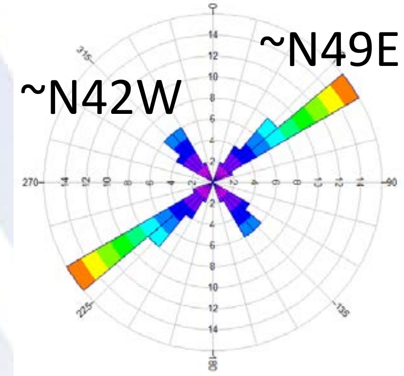
In this area we see two prominent discontinuity trends

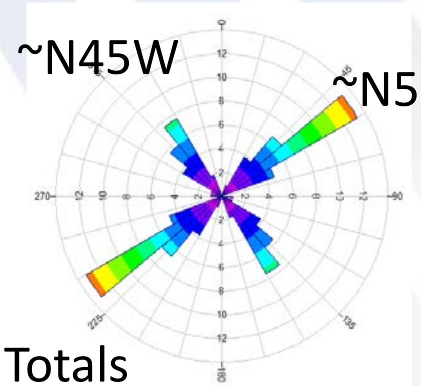


Discontinuities trends interpreted northwest laterals



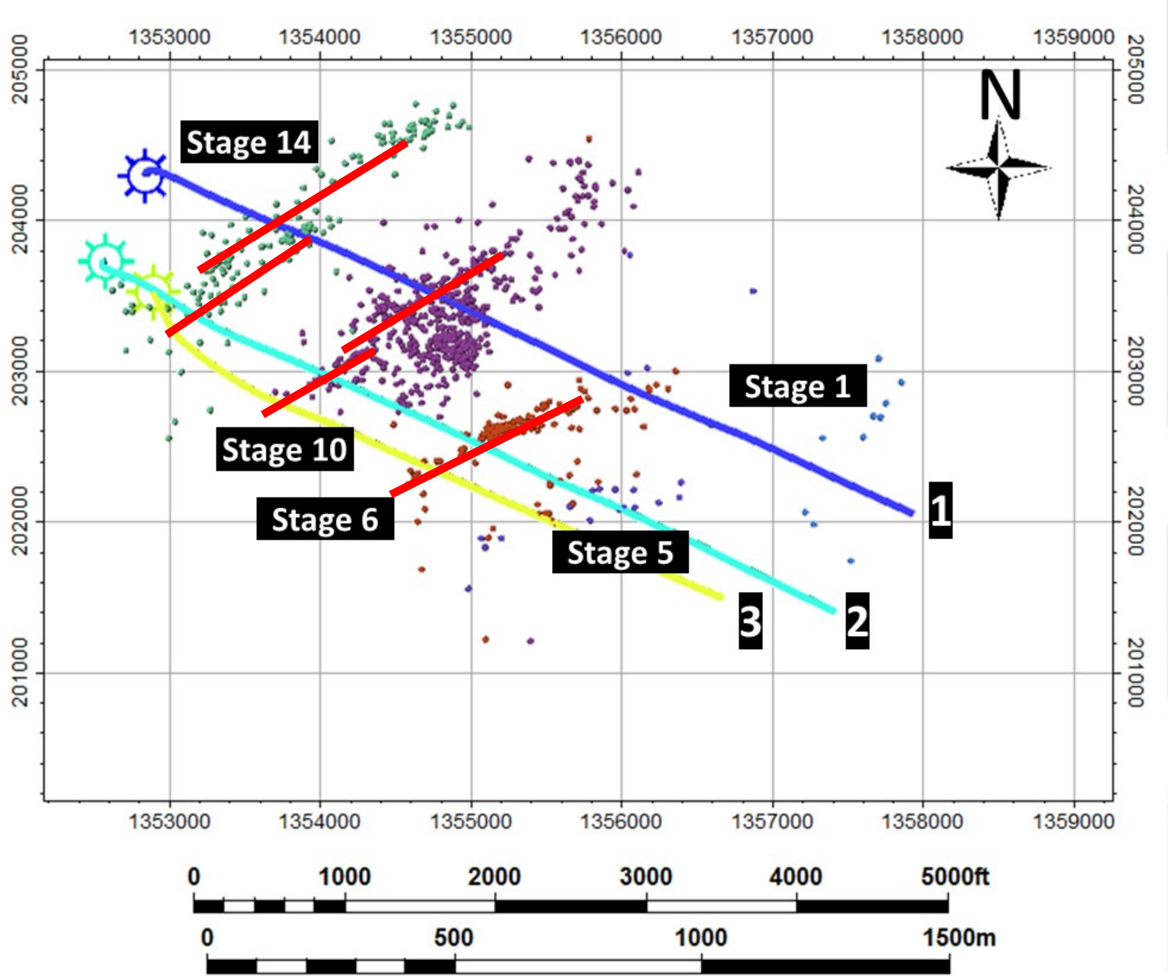
Discontinuities trends southeast laterals



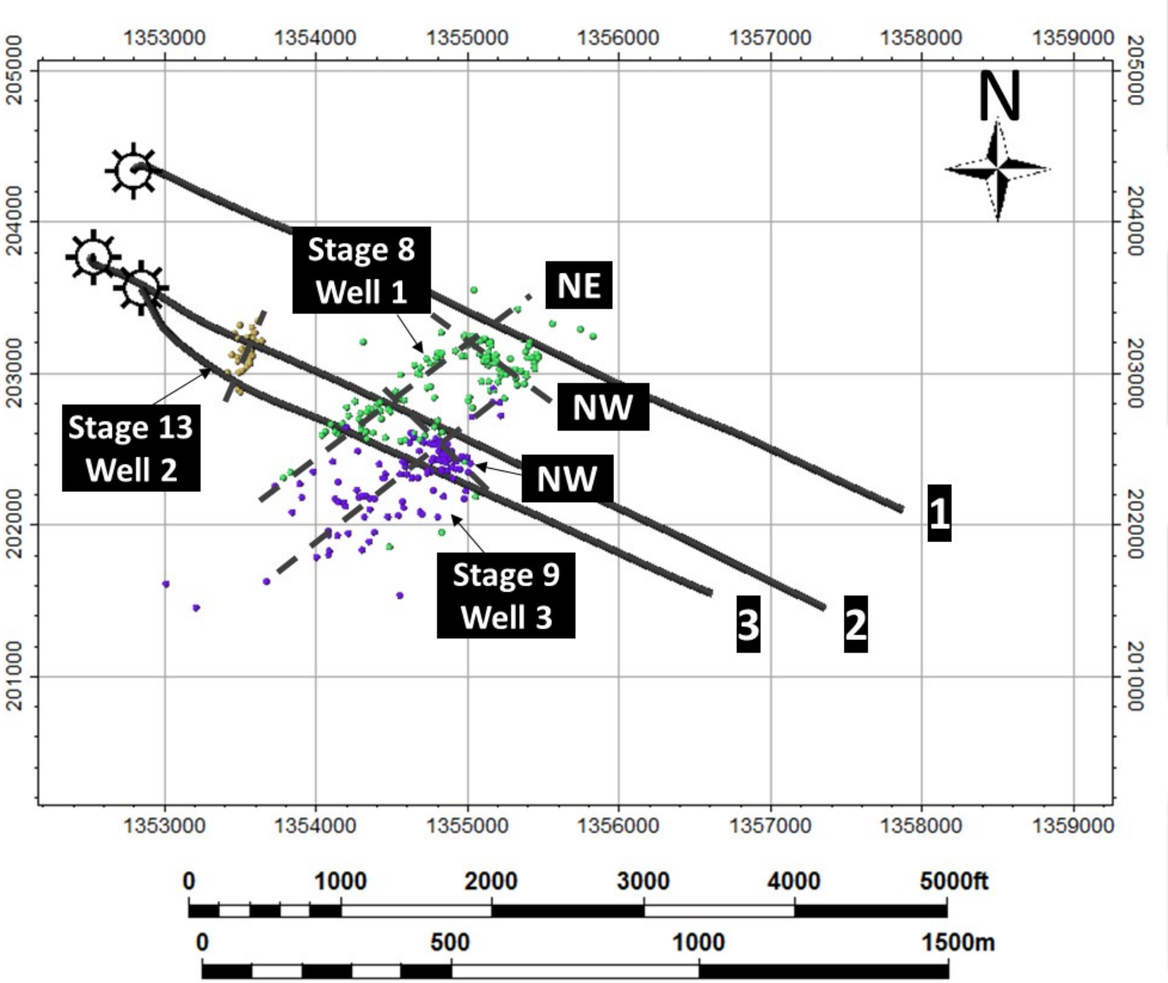


Totals

VIII. Interpreted microseismic event trends

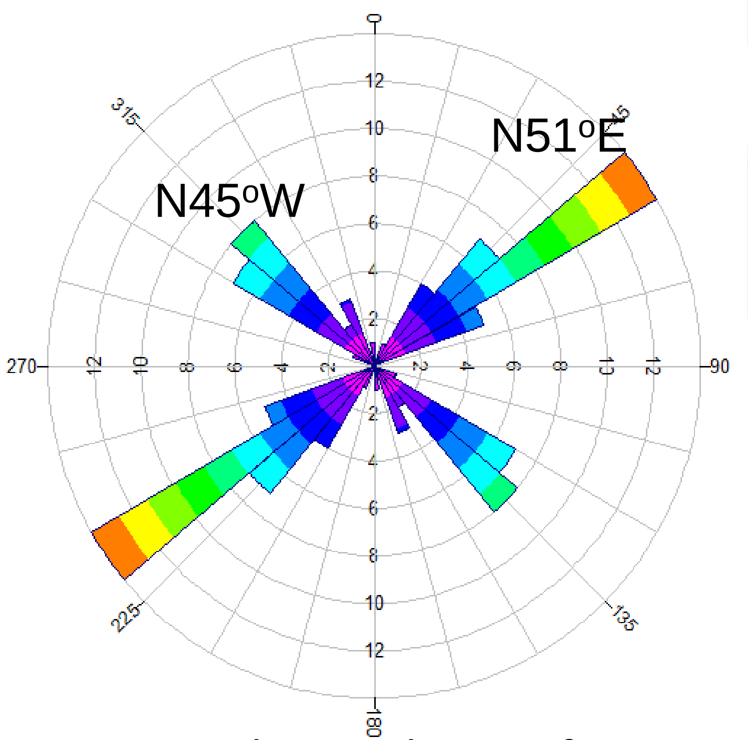


Interpreted event trends

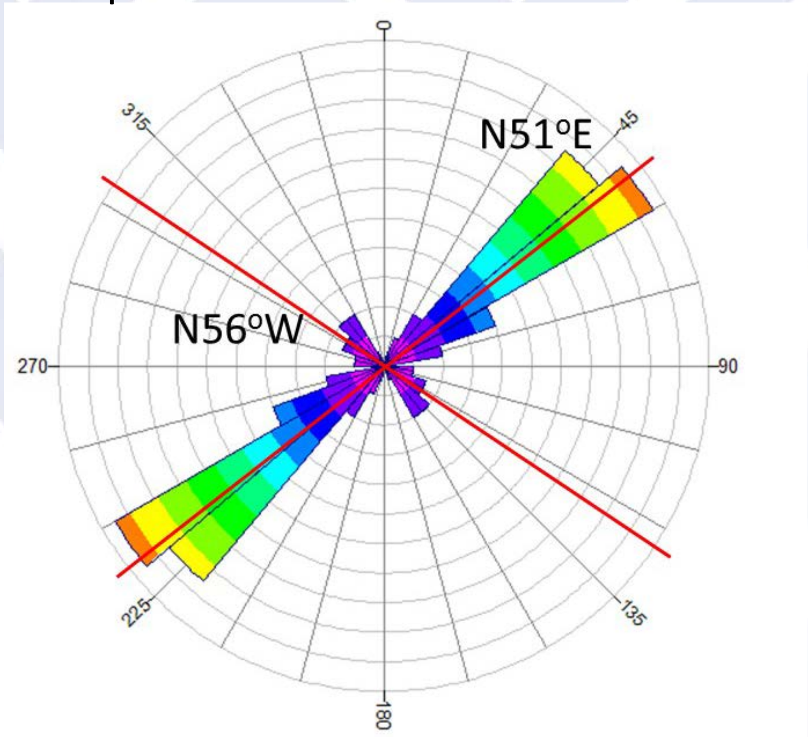


IX. Comparing discontinuity and microseismic event trends

Interpreted discontinuity trends

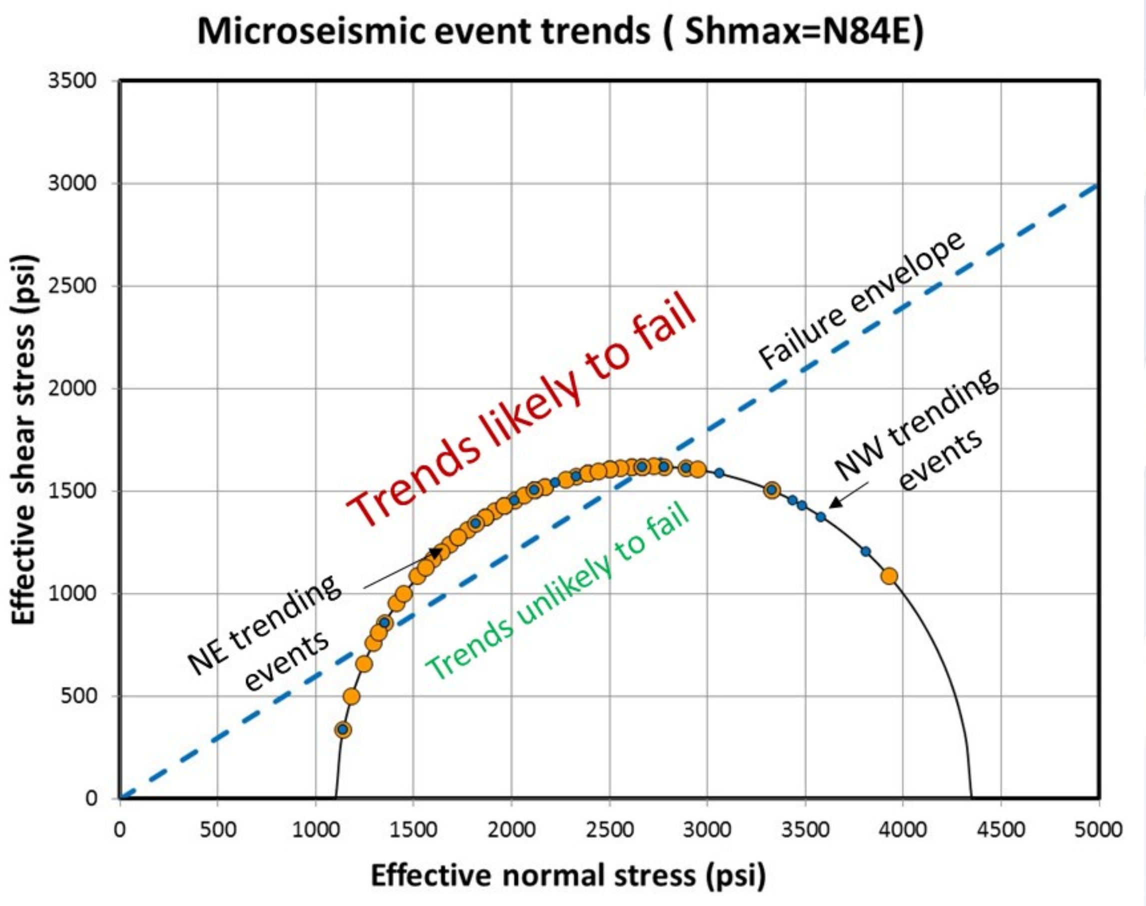


Interpreted microseismic event trends

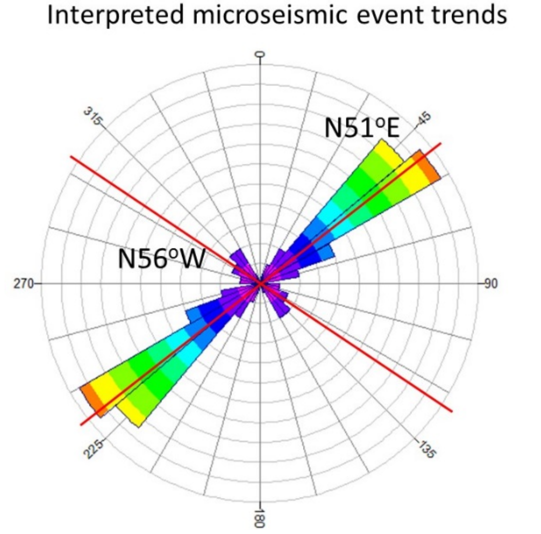


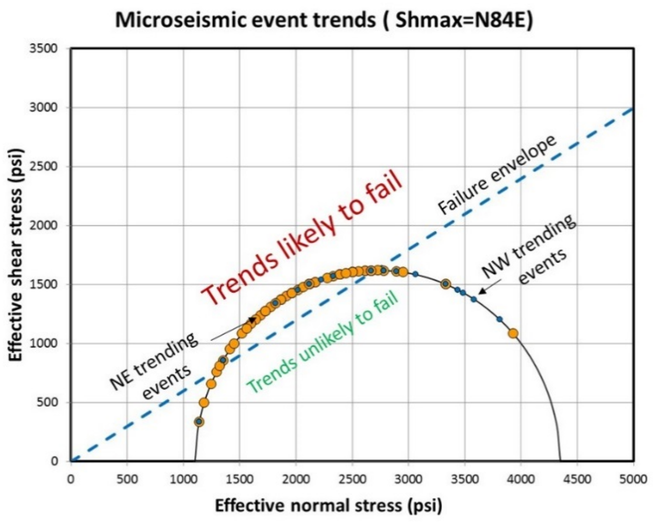
The similarity of microseismic event trends to seismic discontinuity trends suggests seismic discontinuities are reactivated small faults and fracture zones in response to HFS.

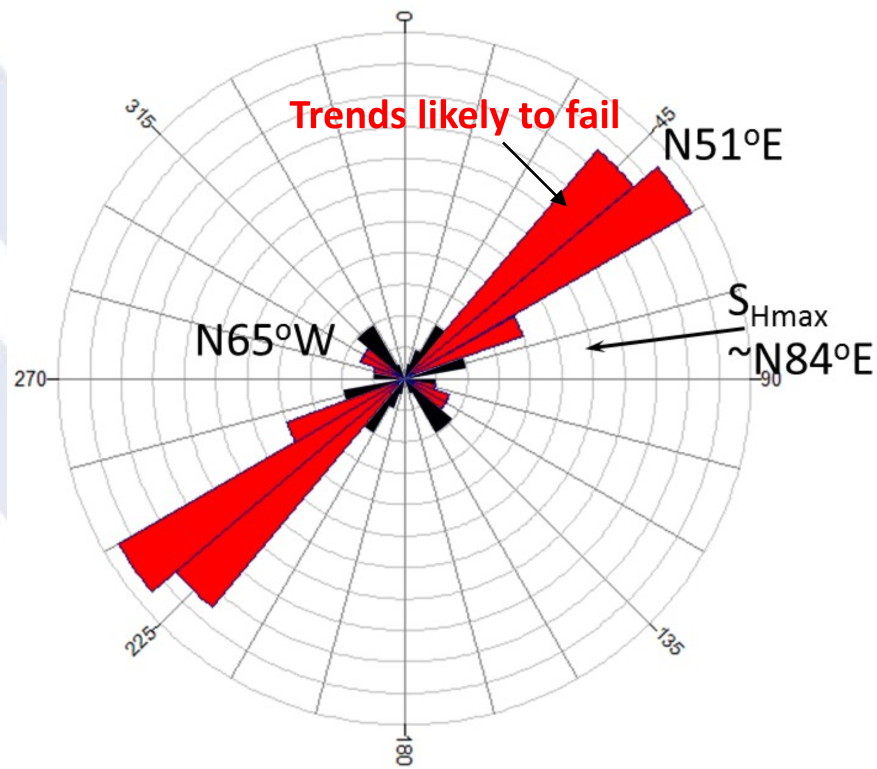
Using failure criterion we estimate interpreted trends most likely to fail.



Evaluating the interpreted microseismic event trends

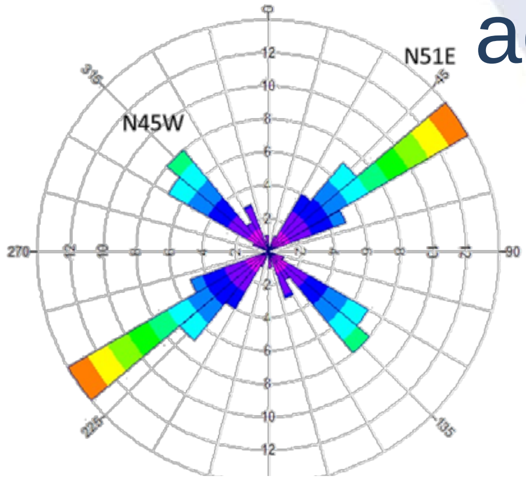


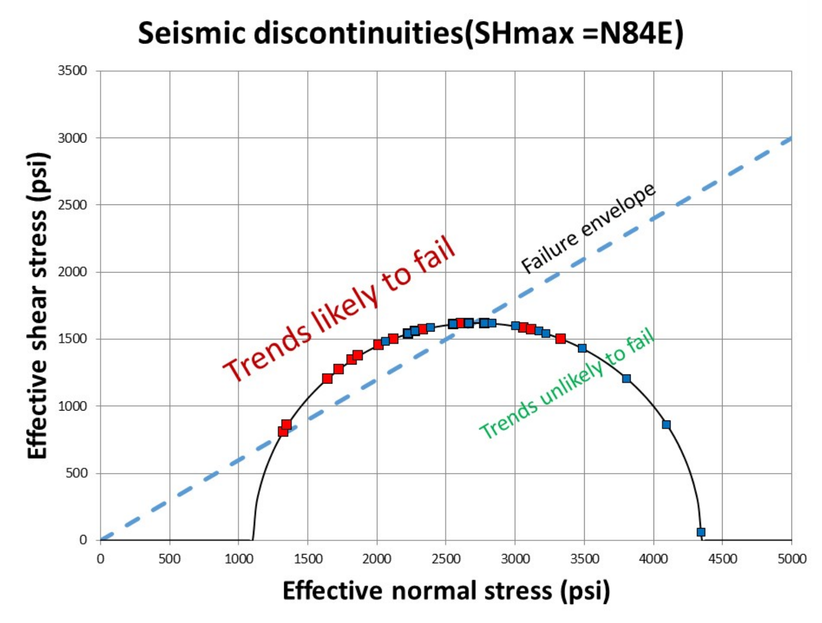


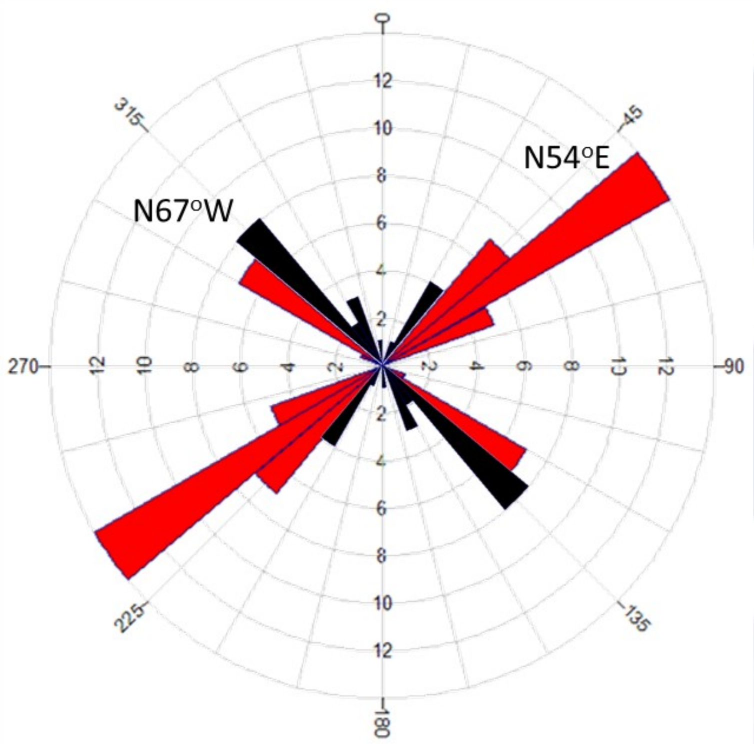


We use the "most likely to fail" trends to define the natural fractures and faults in our discrete fracture network

Seismic discontinuity trends most likely to accommodate failure

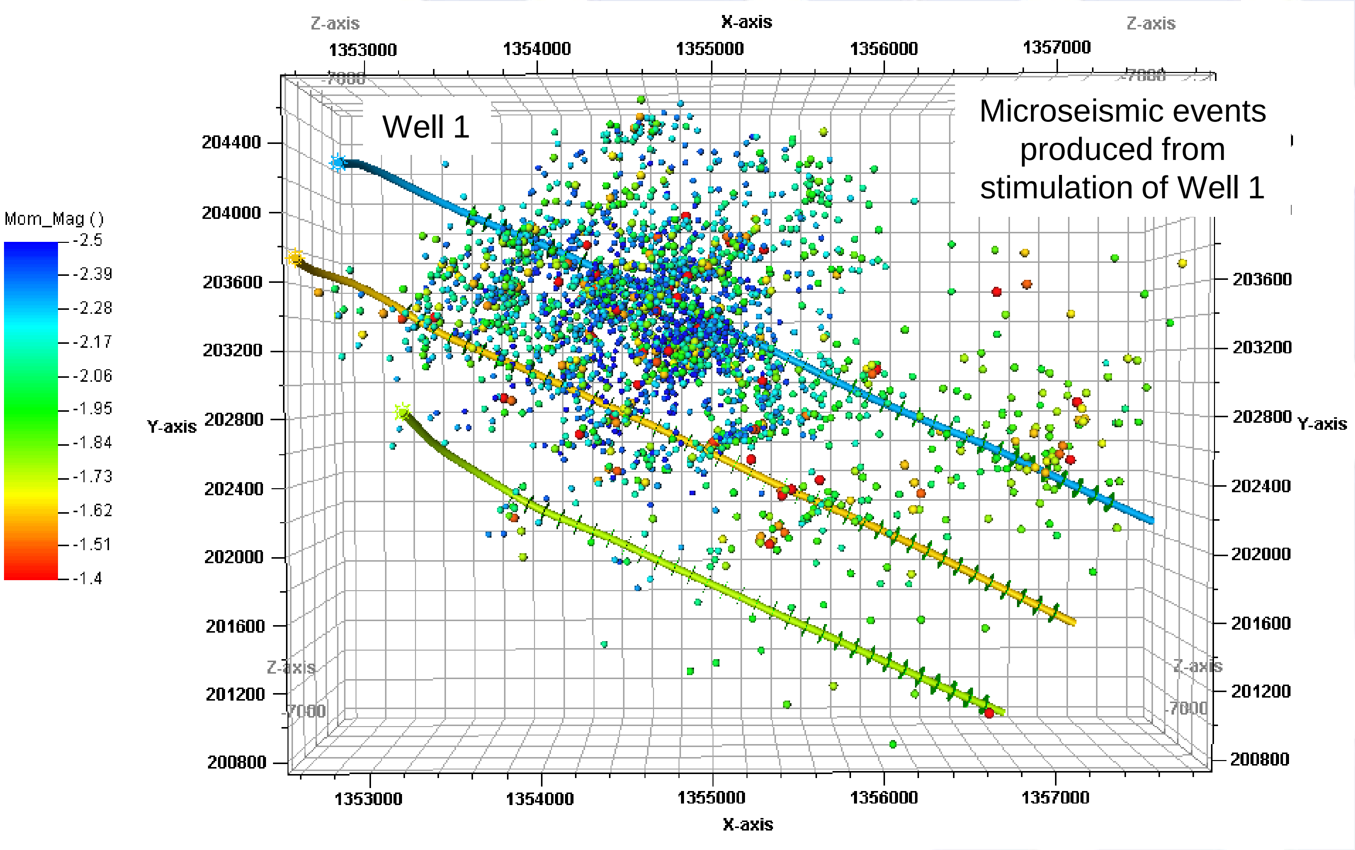




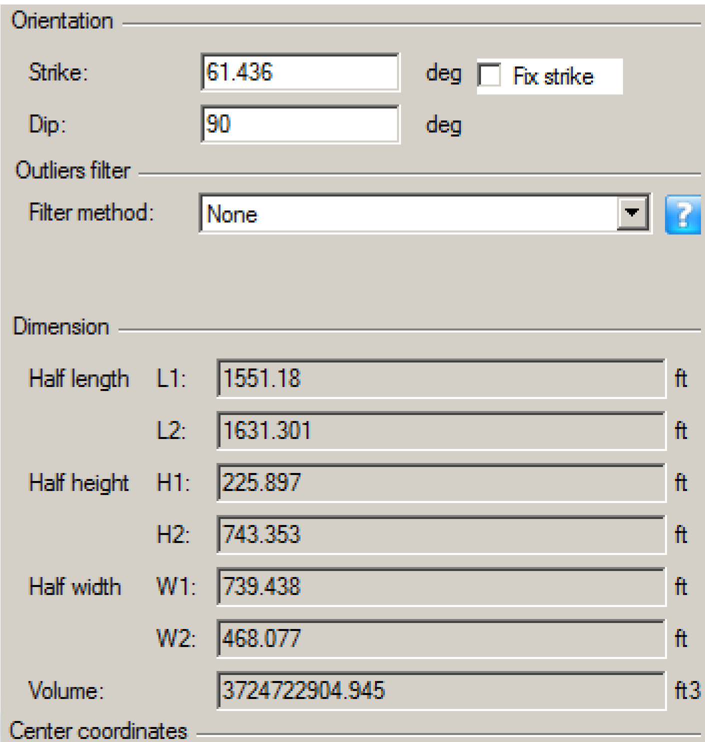


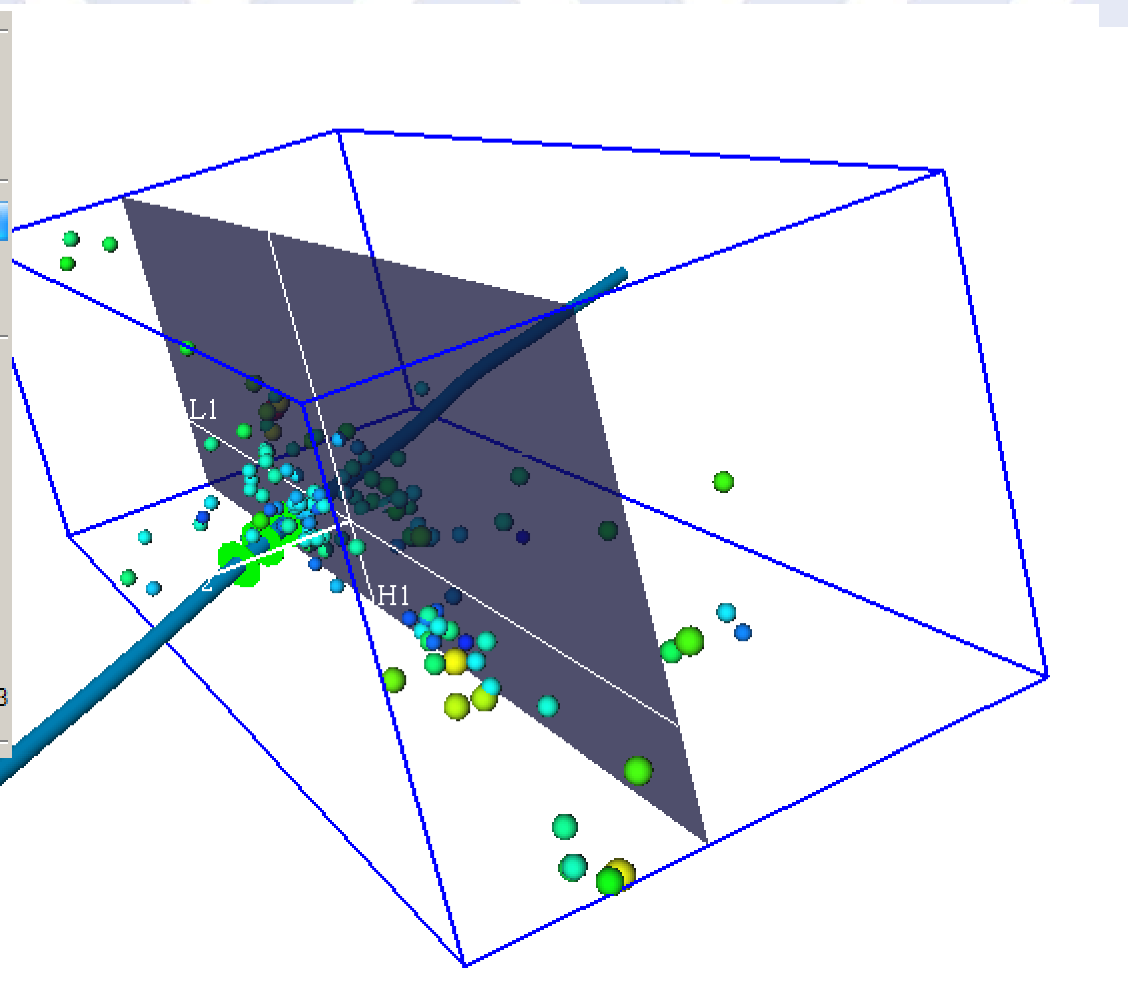
X. The stimulated reservoir volume (SRV)

Information about the SRV comes in the form of the microseismicity produced through HFS



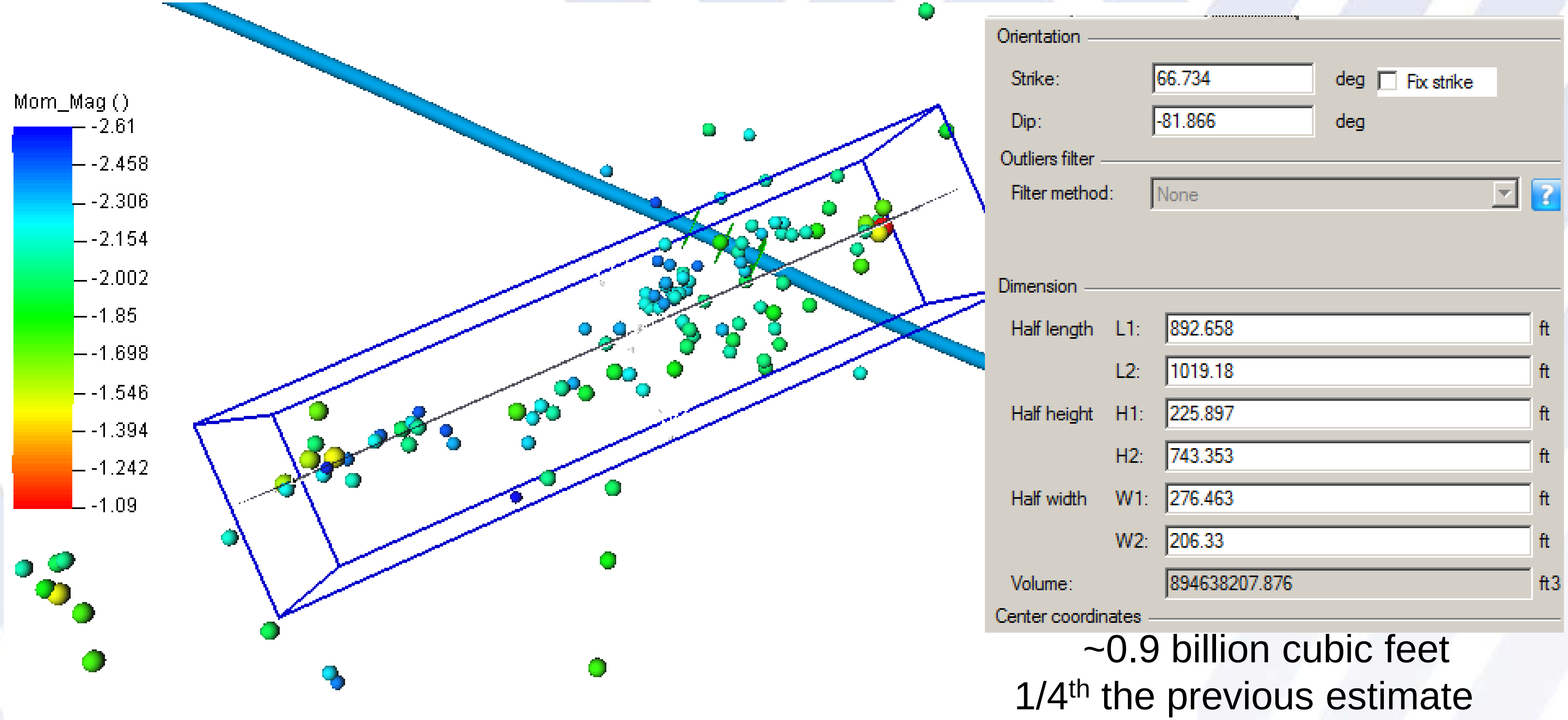
Dots in the box estimation





3.7 billion cubic feet

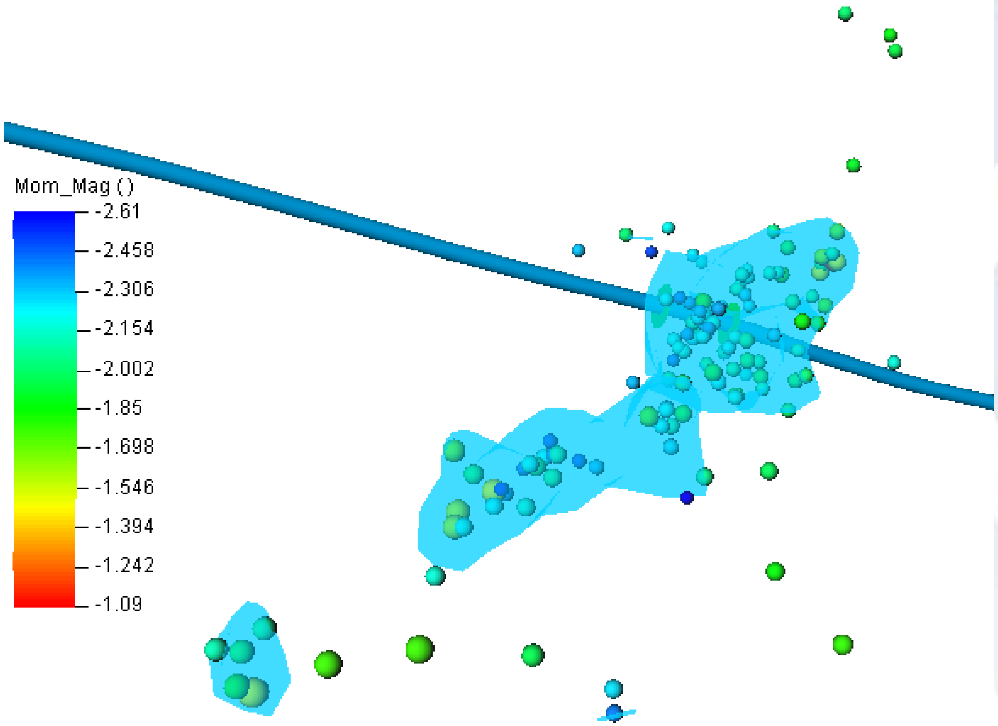
We can refine the “SRV” box to “hug” the concentration of events

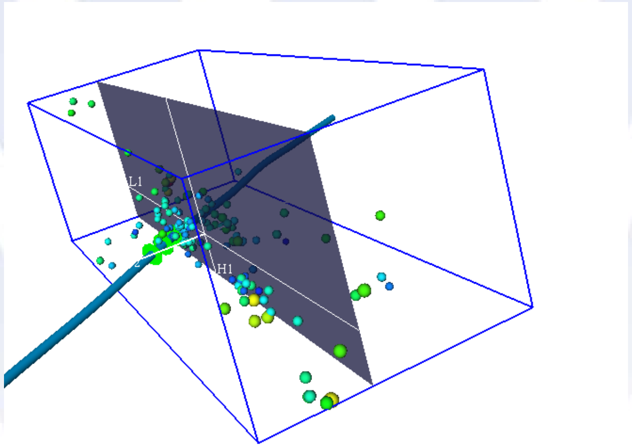


~0.9 billion cubic feet

1/4th the previous estimate

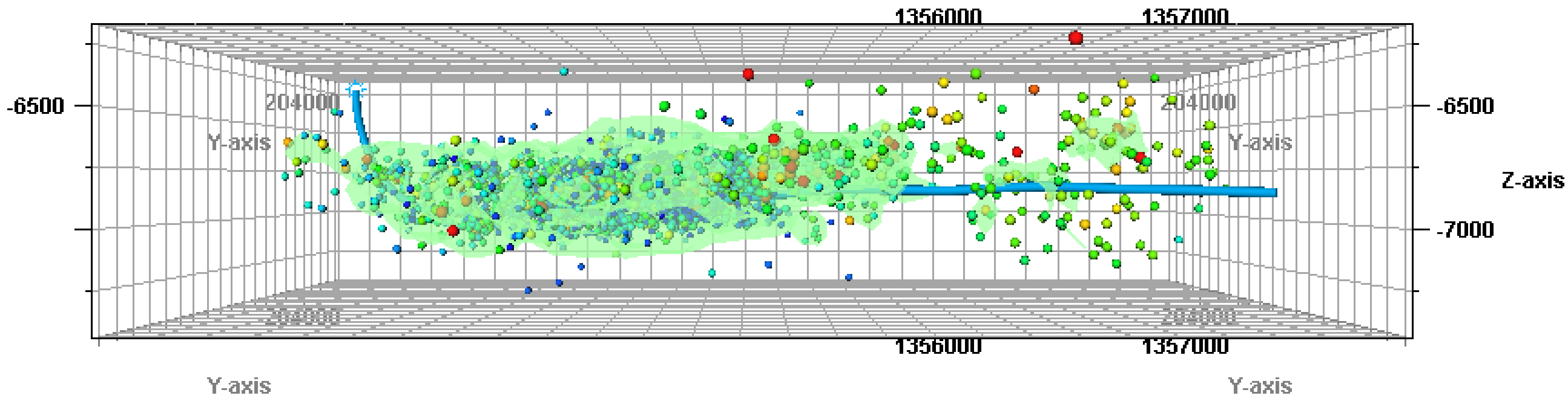
“Shrink wrapped” SRV estimate





0.192 billion cubic feet or about 1/19th of the initial dots-in-the-box estimate.

Using the shrink-wrap approach for the entire well we get an SRV of ~1.9Bcf



The whole-well SRV estimated in this manner is about ½ the SRV estimated for the ***single*** stage shown earlier using the dots in the box approach

The Energy Weighted SRV.
Energy is related directly to surface rupture area

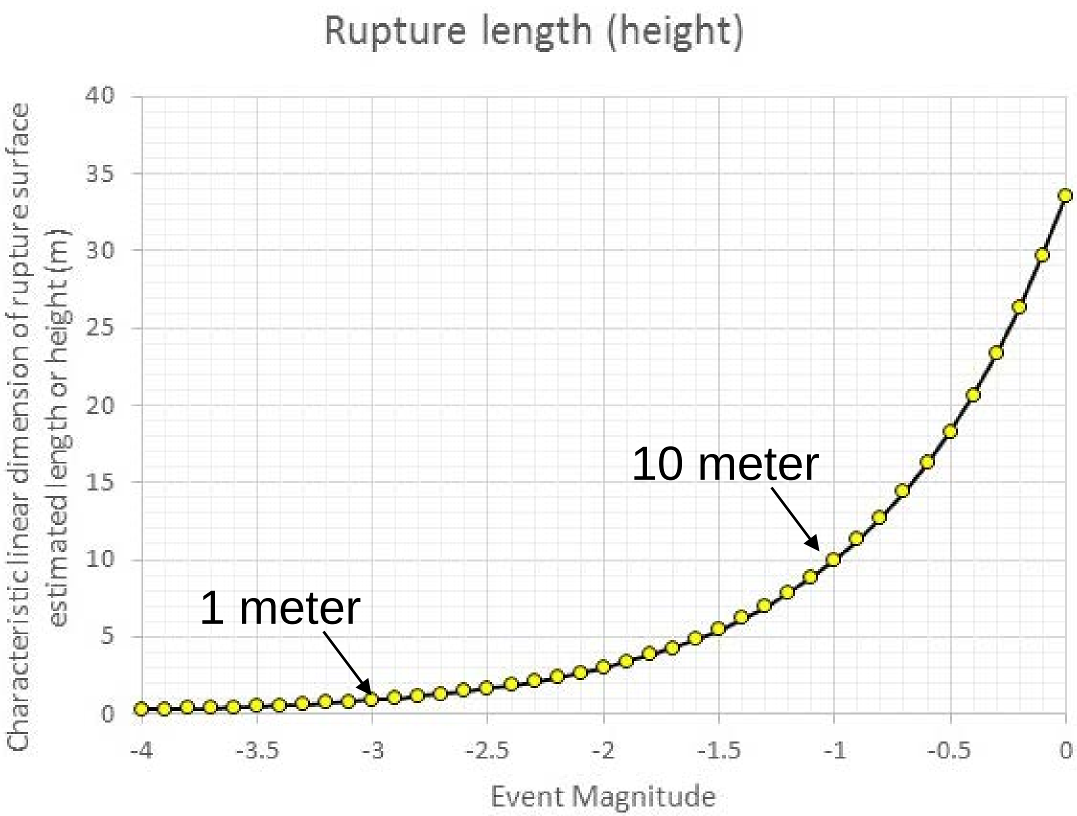
$$\log E_{oneevent} = 1.5M_{thatevent} + 4.8$$

$$E = 63096 * 10^{1.5M}$$

$$\log A = 1.05M - 2.95$$

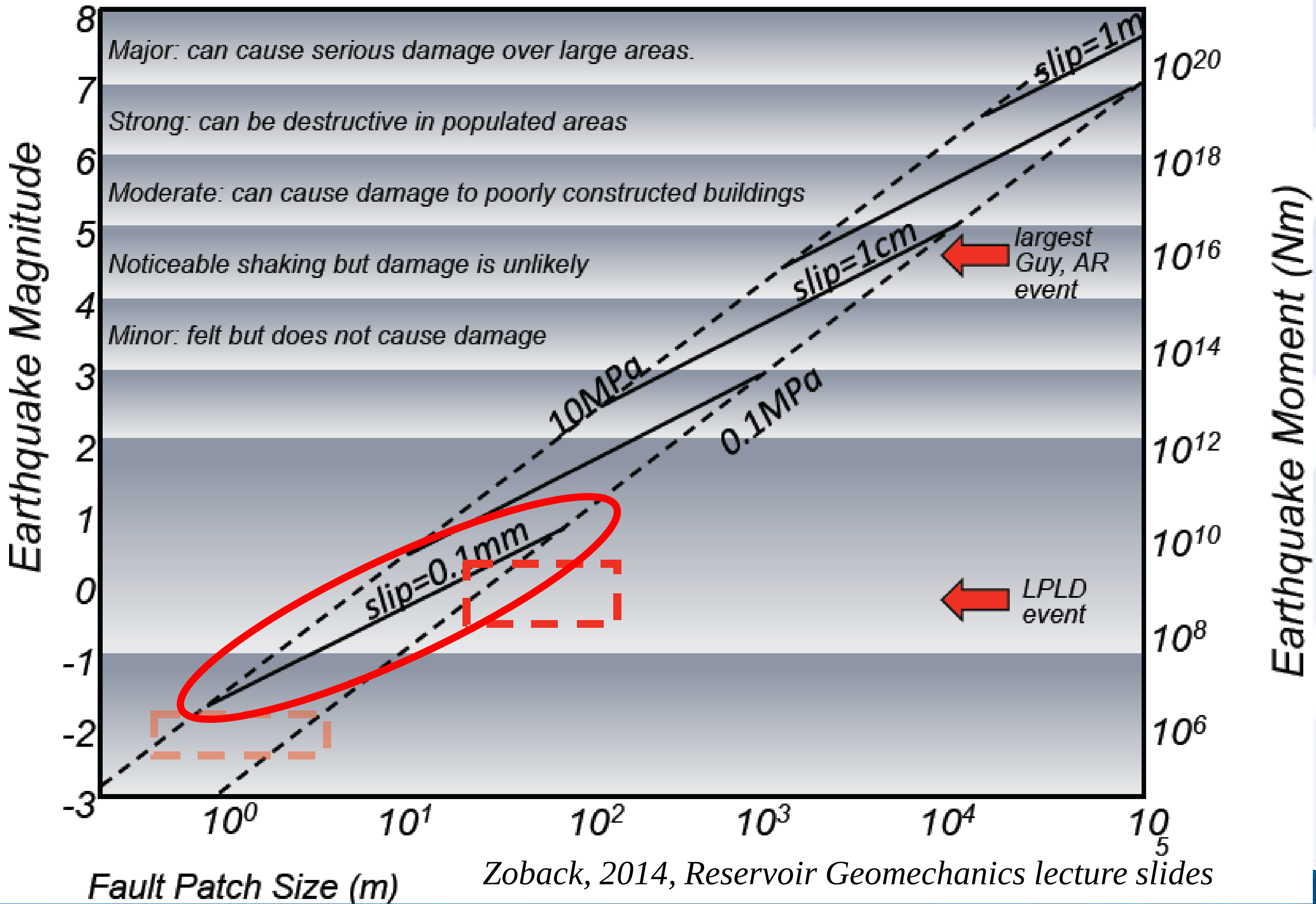
$$A = 1122.02\left(10^{1.05M}\right)$$

Energy in Joules and area in m^2



Characteristic linear dimension ~$\sqrt{fracture\ area}$

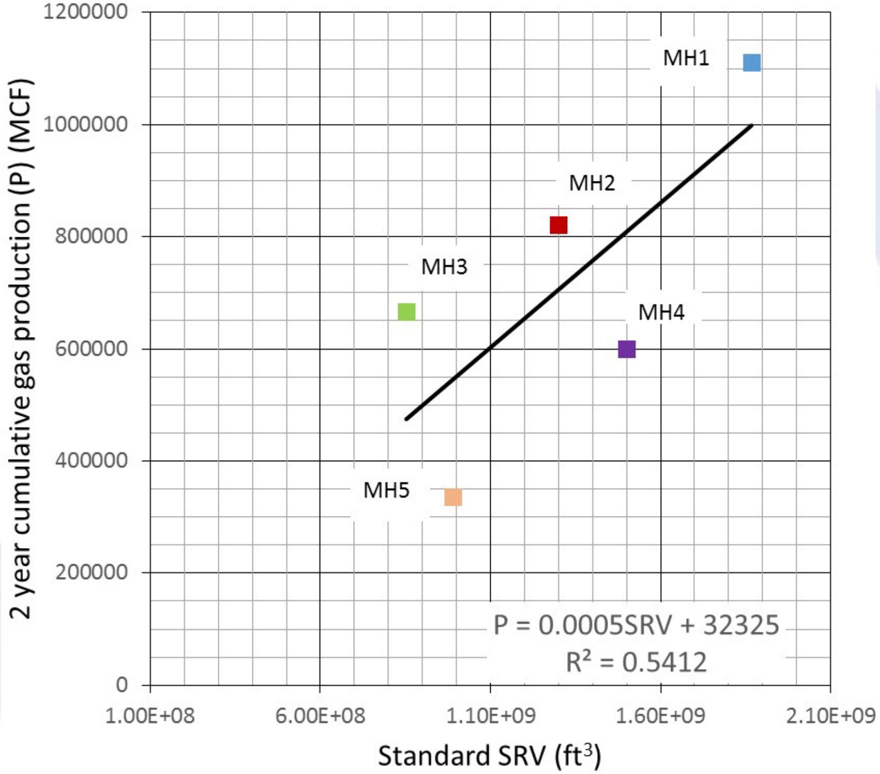
Magnitude - fault plane area and slip relationships

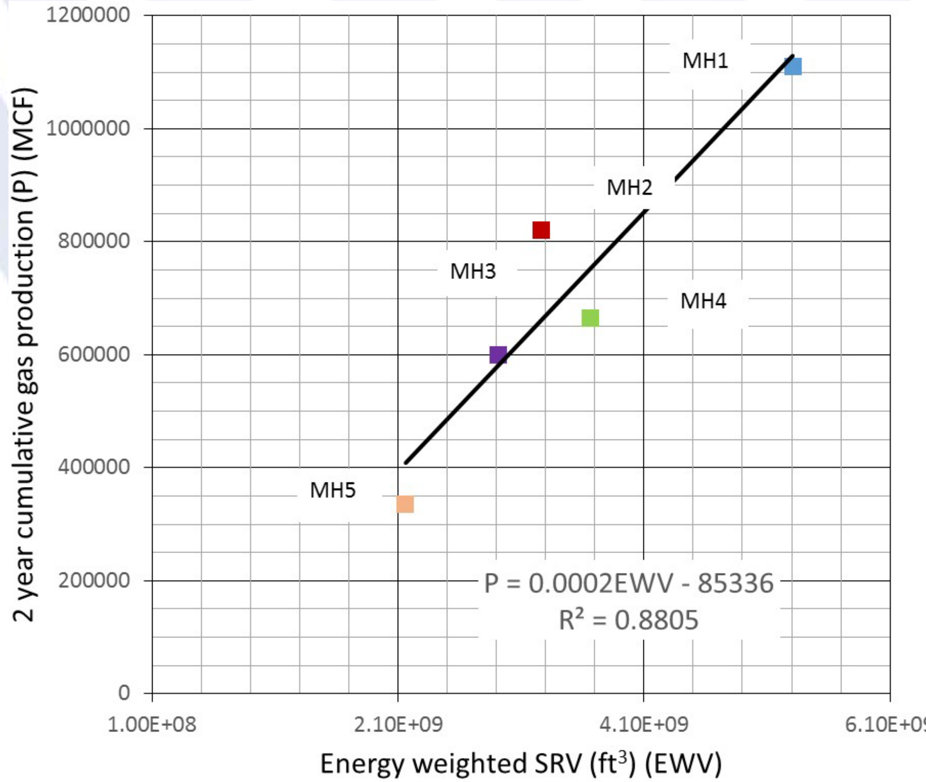


Zoback, 2014, Reservoir Geomechanics lecture slides

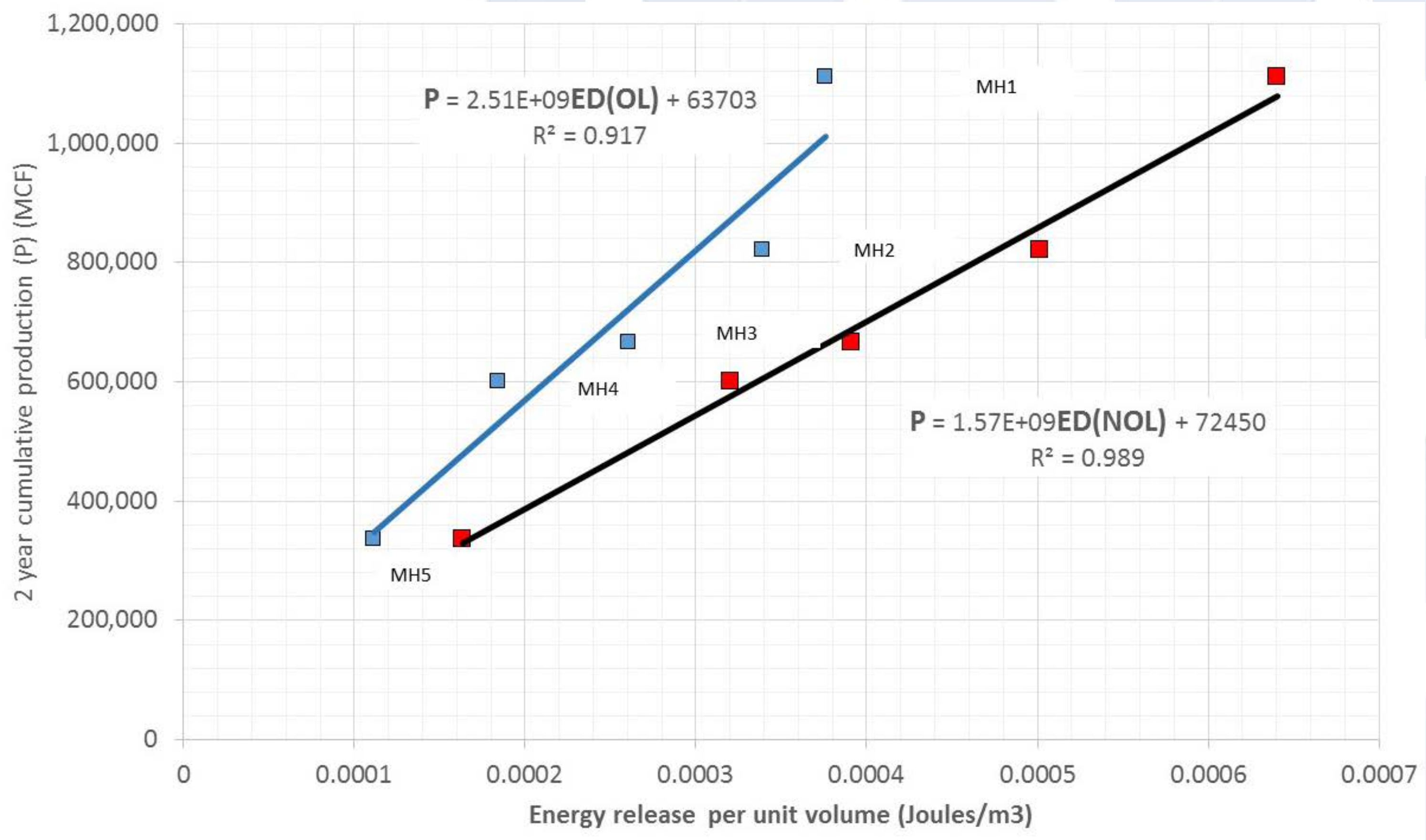
These cross plots are based on the total cloud of microseismicity – not just the reservoir bound events

An energy weighted estimate of the SRV is related directly to ruptured surface area and has a higher correlation to production than the standard density weighted estimate

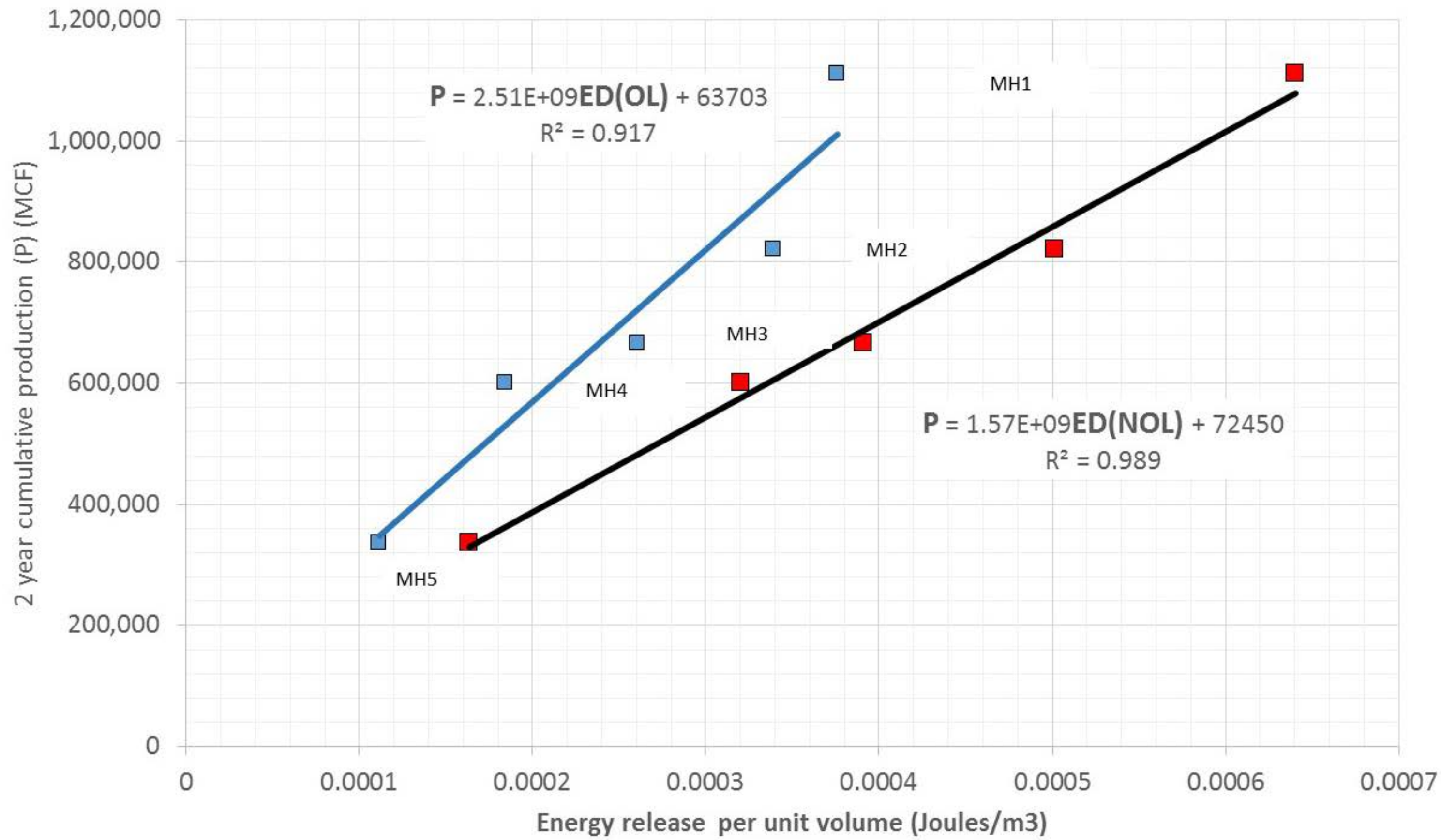




Energy release per unit volume directly related to total rupture surface area



If we have a few wells in the area we should be able to estimate long term production for additional wells



XI. Modeling the stimulated reservoir fracture network

- We use radiated energy release as a direct measure of rupture area created in response to HFS.

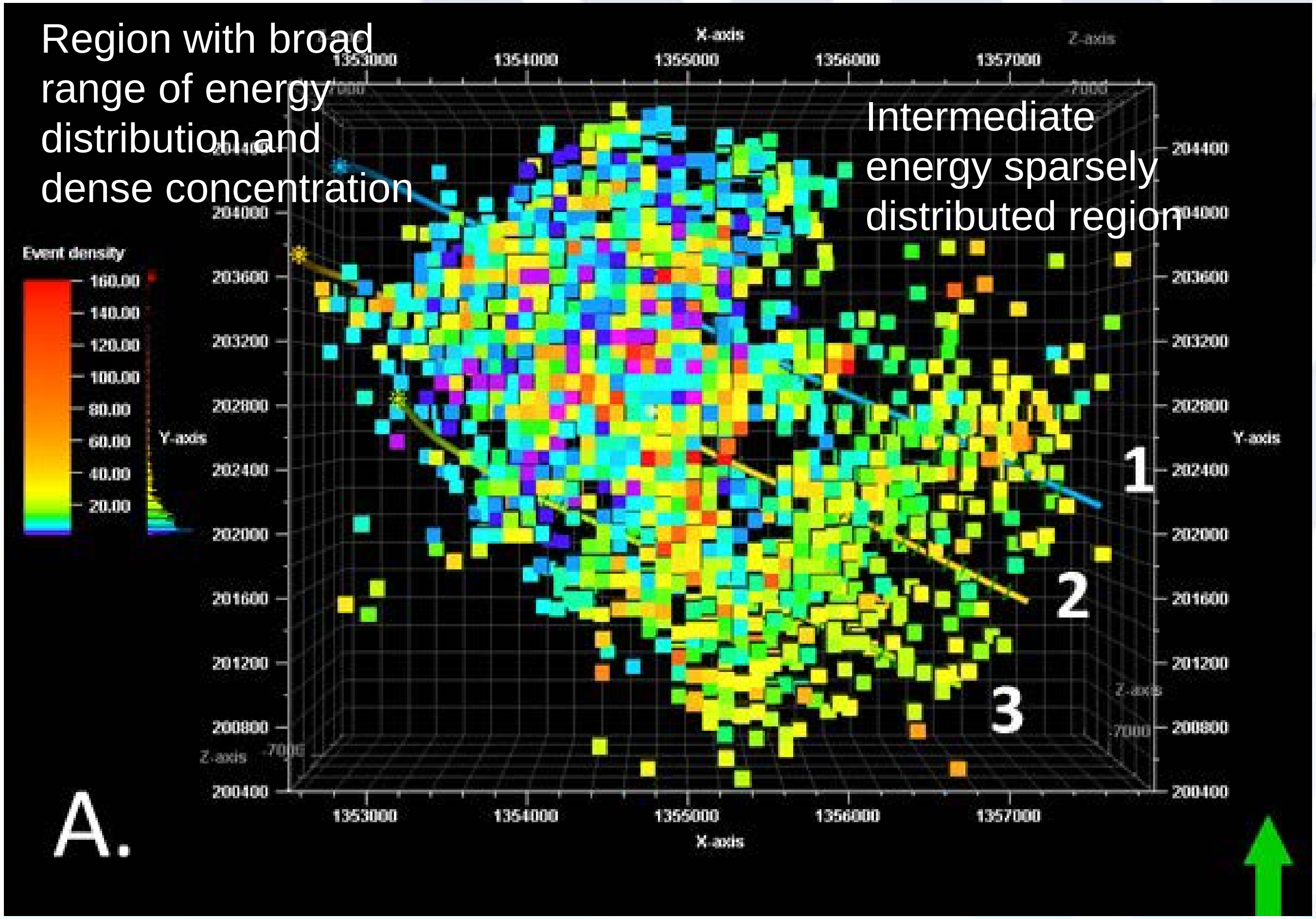
- We create an energy weighted grid to control the distribution of fractures in a model DFN used to represent the stimulated reservoir volume.

- In the absence of image log data we define fracture sets using microseismic event orientations most likely to accommodate failure.

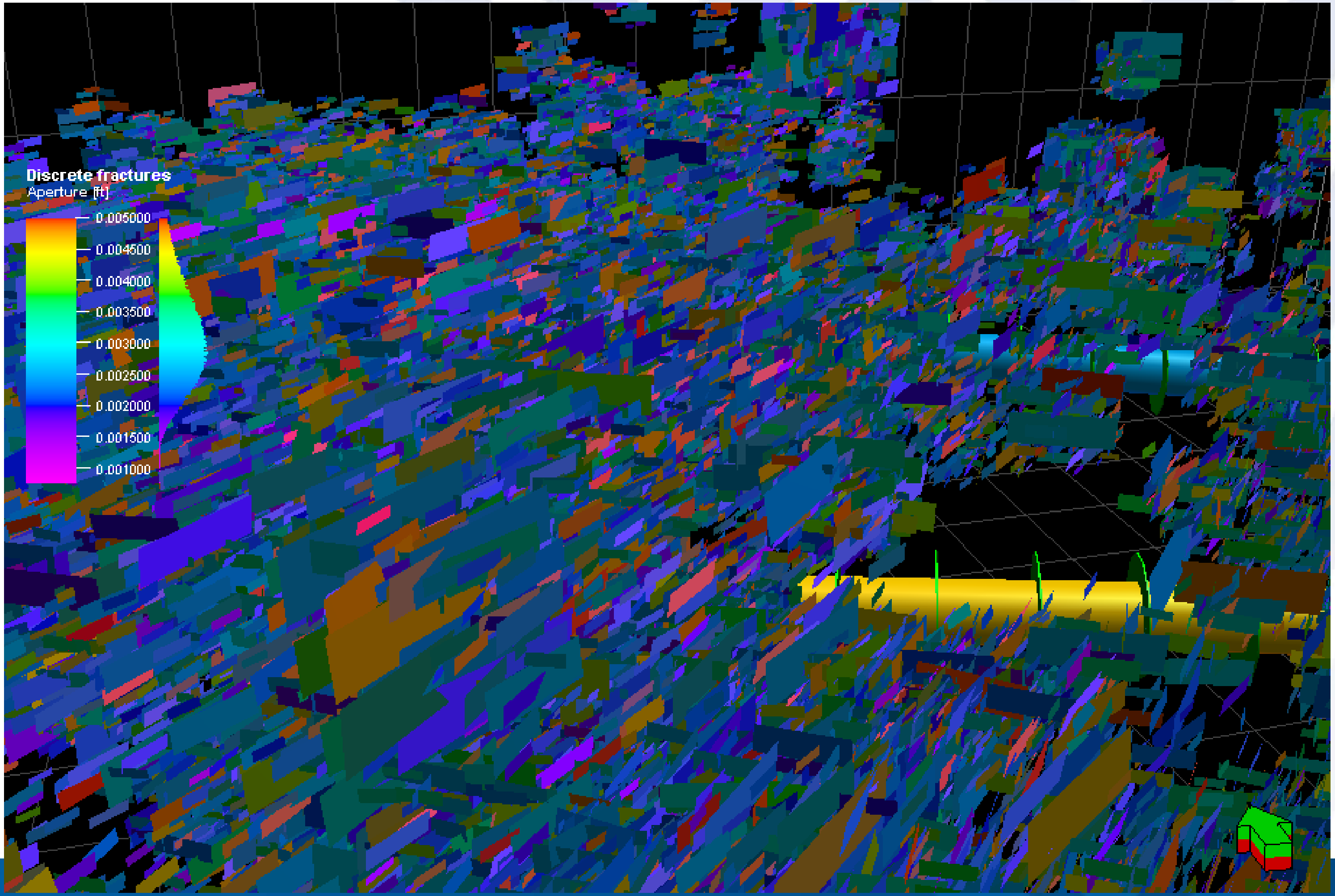
- The energy weighted grid is scaled to represent fracture intensity

- Two grids are developed: one for each fracture set scaled in proportion to their relative occurrence

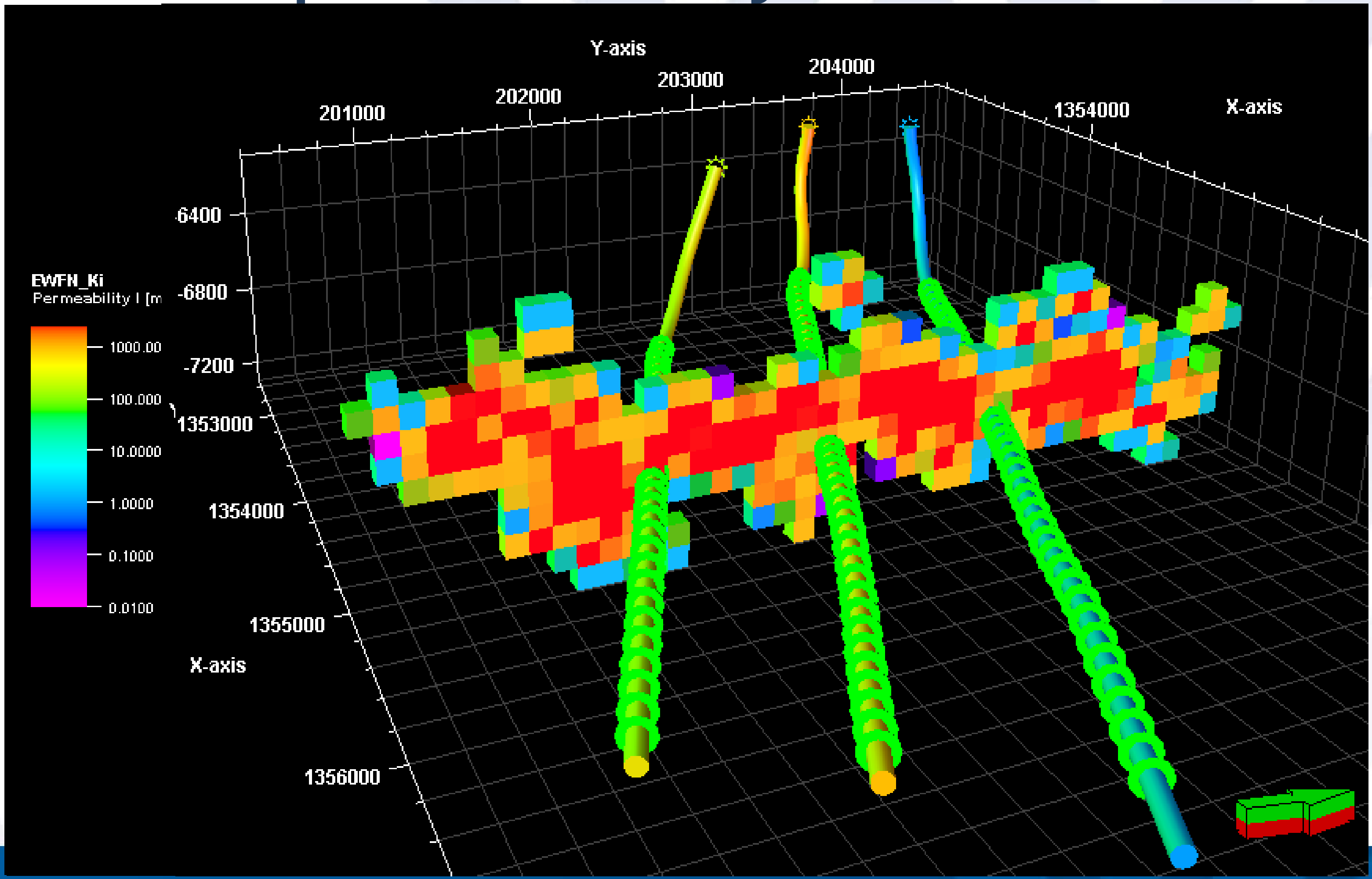
Energy weighted event density grid is used to control fracture intensity distribution



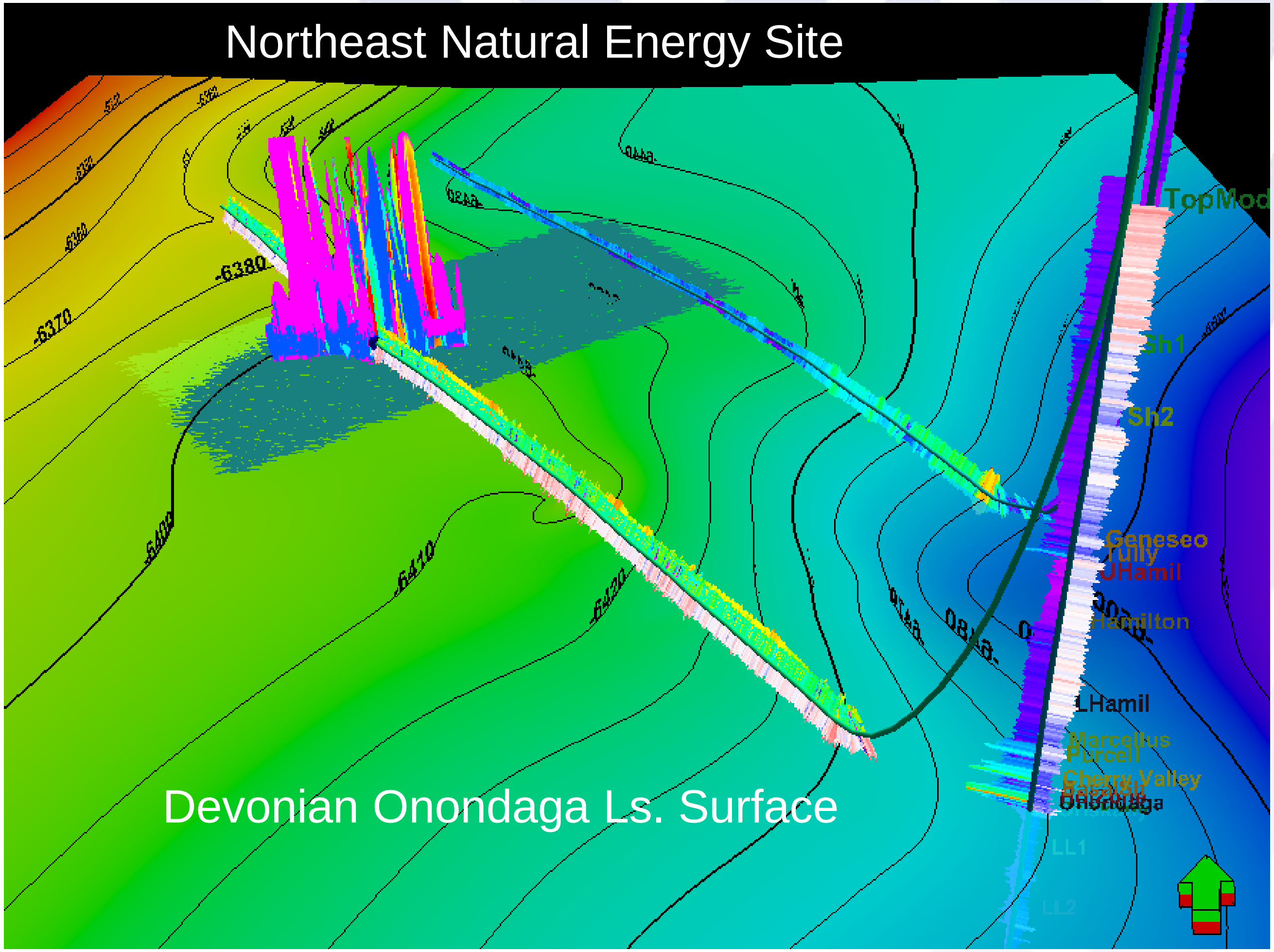
Model of the stimulated natural fracture network



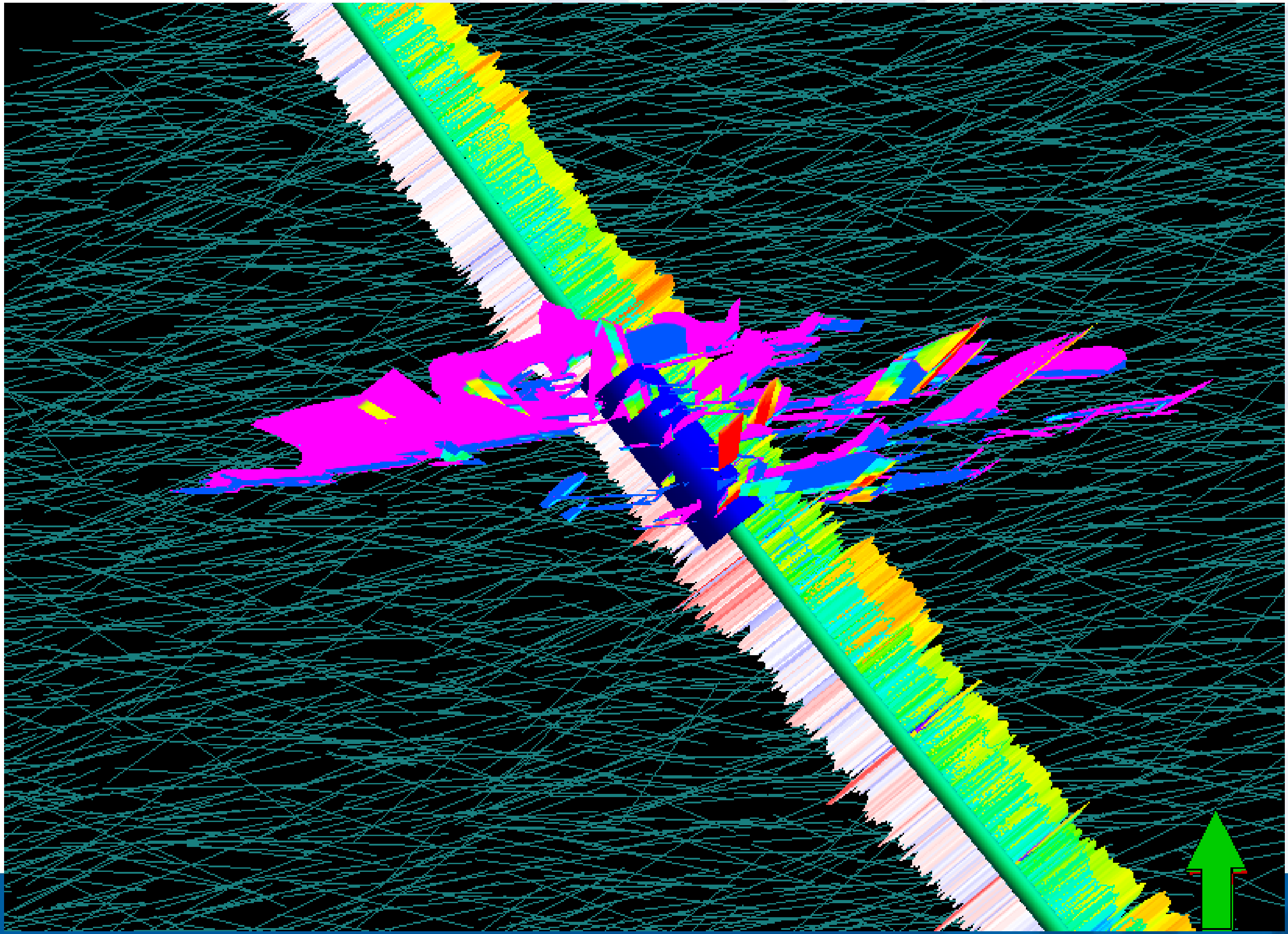
Upscale into porosity and permeability cubes



XII. Recent reservoir modeling software developments allow us to model stimulation of the natural fracture network



Fracture orientations from the Quanta Geo log used to create model DFN for stimulation



Conclusions

- *3D seismic can help optimize development of your unconventional play*
- *Understanding the local fracture network and orientation of the maximum horizontal stress can help maximize stimulated reservoir volume and cumulative production*
- *Energy density can be used as a predictor of longer term well productivity*
- *Information about the local fracture network can help you develop accurate models of the stimulated reservoir fracture system that may help design infill well placement*