AV Fracture Interpretation in the Barnett Shale Using Macro and Microseismic Data*

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Abstract

The Barnett Shale was deposited in the Fort Worth Basin during the Mississippian in a marine setting and unconformably overlies Ordovician carbonates. In the area of this study, the underlying Viola limestone has been eroded, juxtaposing the Barnett Shale against the porous and water-bearing Ellenberger Limestone. We explore the challenge of Barnett Shale development: to maximize stimulated reservoir volume within the shale, without tapping the adjacent Ellenberger water reservoir.

The Barnett Shale ranges in thickness from about 50 feet in the south to nearly 1000 feet to the northwest. From the southwest boundary of the Llano arch, the Barnett Shale dives from a depth of 2500 feet down to 8000 feet near the Muenster Arch, the northern field boundary. The top of the Barnett in the study area is located at 6400 feet and has a thickness of 500 feet. Barnett shale porosity ranges from 0.5 to 6% with permeabilities as low as 70 nanodarcies. Low clay content (20-30%) makes the Barnett more "fracture friendly" than typical shales, a feature verified by analyzing microseismic magnitudes and density.

Investigation of stress information and our measurement of published microseismic data all indicate a current stress orientation along a 50-60/230-240 degree azimuth. Common geologic models of the Muenster Arch indicate that the primary modern-day stress is to the southwest, supporting the 230-240 degree estimate. Time-lapse analysis of microseismic from this project also indicates preferred induced fracturing along this same orientation. Of particular interest is the high variability of microseismic activity on adjacent fracturing stages, which correlates with "macroseismic" indicators of natural fracturing.

Circular "collapse chimneys" of fractured rock pockmark much of the study area and range from beneath the Ellenberger and can extend up thousands of feet to the Pennsylvanian Caddo (Atoka) Limestone. While opinions vary on the relative influence of karsting

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and basement faulting upon the creation of these fractured columns, it is essential to avoid these features both during well planning and completions. This study indicates how "macroseismic" attributes are used to interpret fracture volumes for well planning purposes. Further, calibration of microseismic measurements with extracted macroseismic attributes provides predictive capabilities for estimating fracturing intensity and orientation, for optimal completions design.

References

Beck, B.F., and W.C. Sinclair, 1986, Sinkholes in Florida, an introduction: Florida Sinkhole Research Institute, University of Central Florida Report 85-86-4, 16p.

Givens, N., and H. Zhao, 2004, The Barnett Shale: Not so simple after all (abstract): Search and Discovery Article #90026 (2004), also AAPG Annual Meeting Program, v. 13, p. A52. (http://www.searchanddiscovery.net/documents/abstracts/annual2004/Dallas/Givens.htm)

Pollastro, R. M., 2003, Geologic and production characteristics utilized in assessing the Barnett Shale continuous (unconventional) gas accumulation, Barnett-Paleozoic total petroleum system, Fort Worth Basin, Texas: Barnett Shale Symposium, November 12–13, 2003, Ellison Miles Geotechnology Institute at Brookhaven College, Dallas, Texas, 6 p.

Pollastro, R.M., 2007, Total petroleum system assessment of undiscovered resources in the giant Barnett Shale continuous (unconventional) gas accumulation, Fort Worth Basin, Texas: AAPG Bulletin, v. 91, p. 551-578.

Zhao, Hank, Natalie B. Givens, and Brad Curtis, 2004, Thermal maturity of the Barnett Shale determined from well-log analysis: AAPG Bulletin; v. 91; p. 535-549.



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Murray Roth - Transform Amanda Thompson - Devon



Fort Worth Basin **OKLAHOMA** Hardeman Basin **Broken Bone** Graben Red River Arch Muchster Arch TEXAS Eastern Shelf 30 Bend Permian Fort Arch Worth Basin Dallas Province 20 20 Fort Worth Basin Llano 35 Uplift 10 Austin Houston 50 Miles 10 MEXICO

Fort Worth Basin **OKLAHOMA** Hardeman Basin **Broken Bone** Graben C Red River Arch Milenster Arch TEXAS Eastern Shelf 30 Bend Permian Fort Arch Worth Basin Dallas Province 20 20 Fort Worth Basin **Historic Stress Direction** Llano Uplift 10 Austin Houston 50 Miles 10 MEXICO

Fort Worth Basin **Current Maximum** Stress Direction OKLAHOMA Hardeman Basin **Broken Bone** Graben C Red River Arch TEXAS Eastern Shelf 30 Bend Permian Fort Arch Worth Basin Dallas Province 20 20 Fort Worth Basin **Historic Stress Direction** Llano Uplift 10 Austin Houston 50 Miles 10 MEXICO



Reservoir Details

Reservoir

Drilling depth

Gas Producing Interval

Average Porosity

Matrix permeability

Well Spacing

Reserves

Av. EUR/ vertical well

Av. EUR/ horizontal well

Drilling/Completions

Mississippian shales

6500-8500ft

50 - 1000 ft

6 %

~70+ nanodarcies

200 acres

75-140 BCF/section

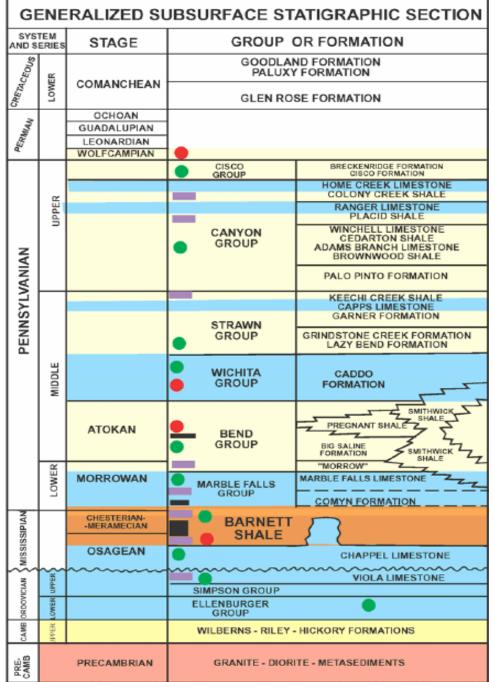
0.7 BCF

1.4-2.4 BCF

\$1.5-\$2.0M/well

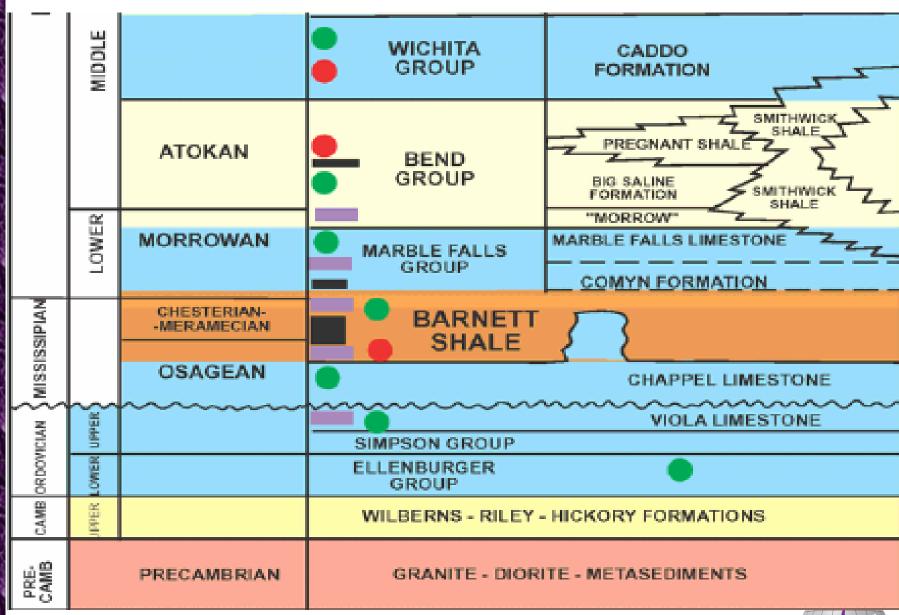


Fort Worth Stratigraphic Section





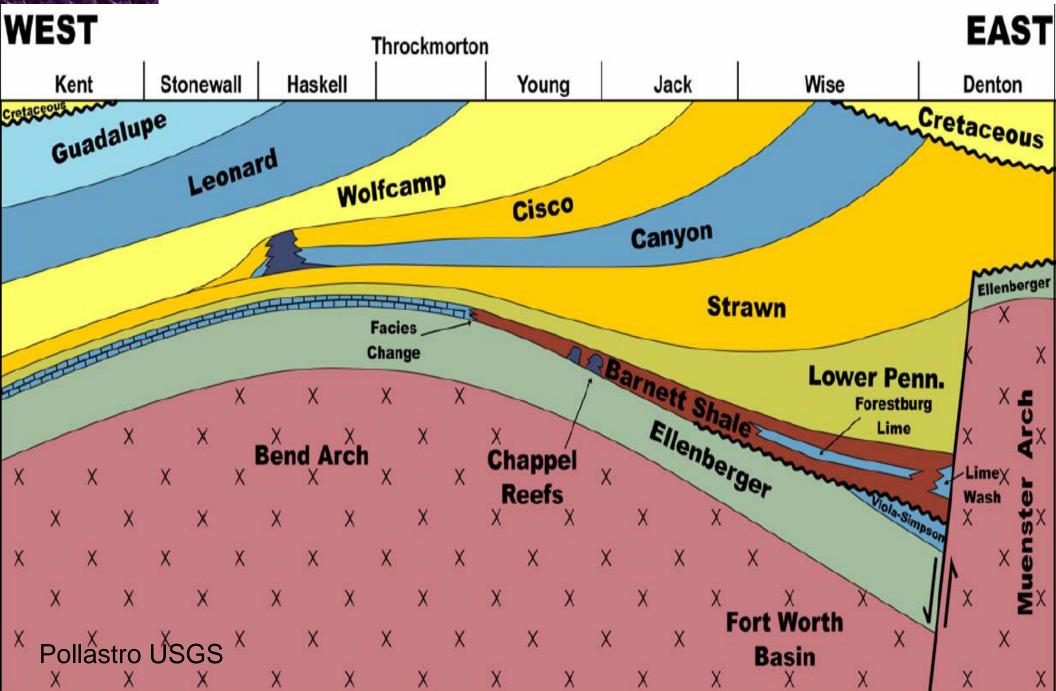
Fort Worth Stratigraphic Section



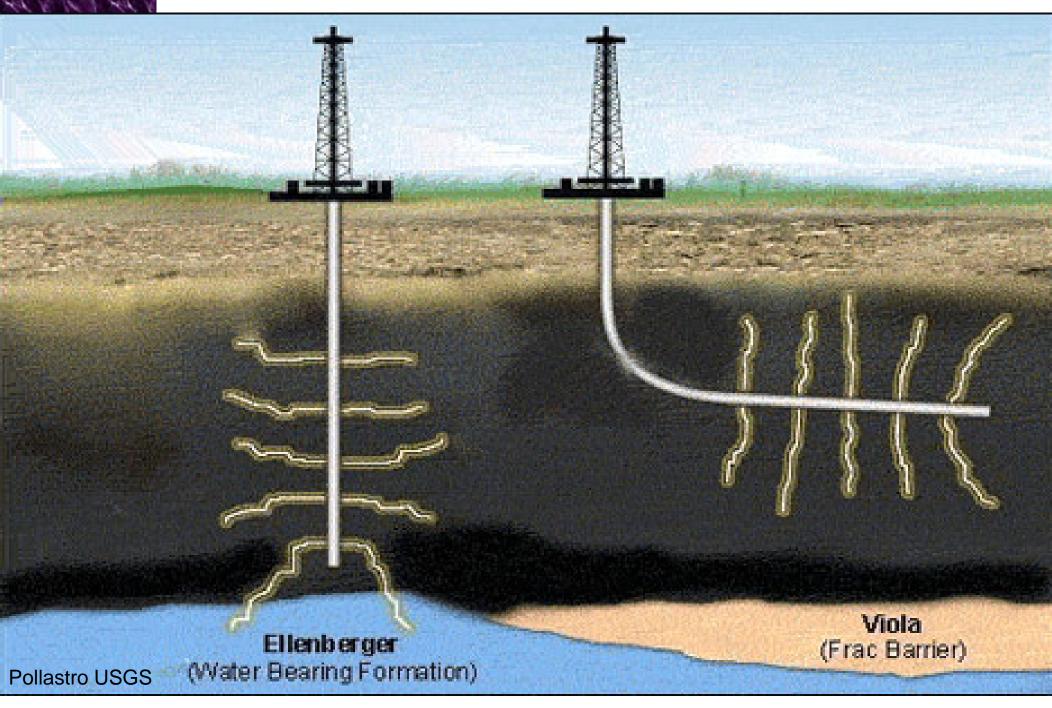




West-East Cross-section



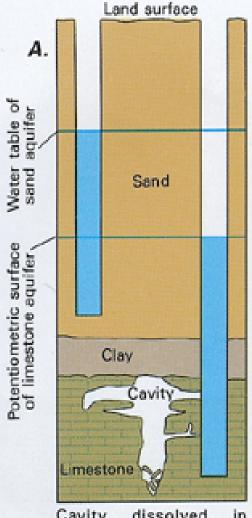
Avoiding the Ellenberger



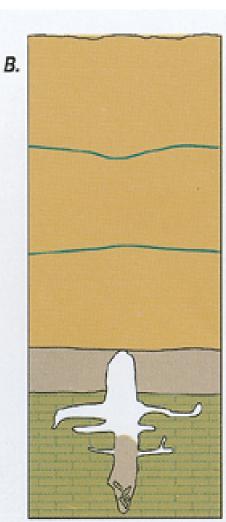


Karsting-Enhanced Collapse

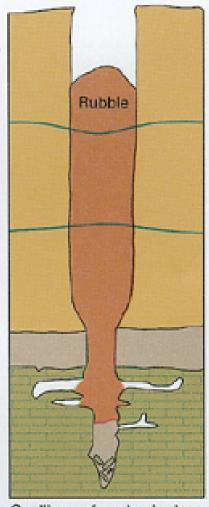
C.



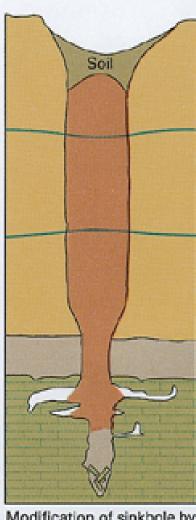
Cavity dissolved in limestone by percolating ground water. Time: Centuries.



Collapse of overlying clay into cavity by spalling. Time: Months to years.



Spalling of cohesionless sand into cavity. Time: Hours to days.

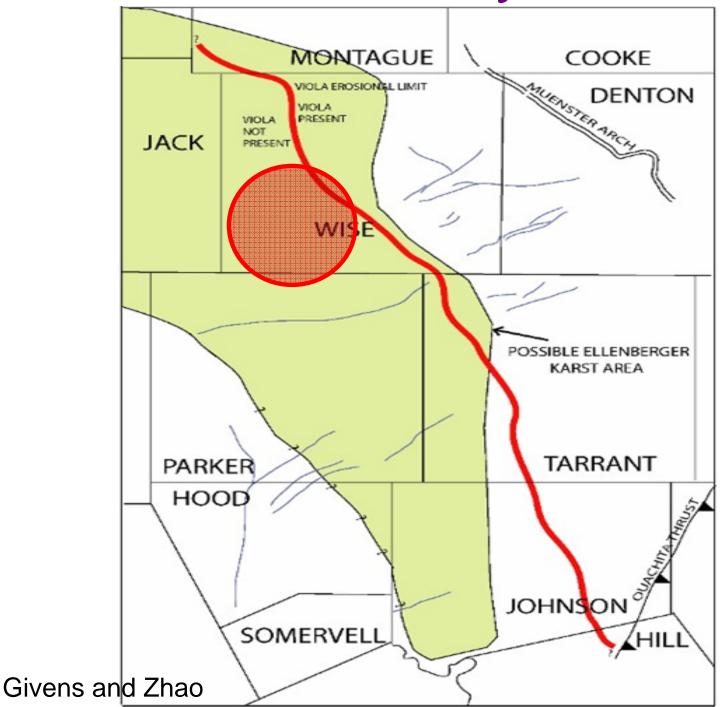


Modification of sinkhole by surface erosion. Time: 10 years after C.

Modified from Beck and Sinclair, 1986

Figure 64. Collapse sinkholes form suddenly as a cavity roof collapses after dissolution of the limestone beneath the roof. The roof may consist either of clay, as shown here, or of limestone.

Case Study Area







Some Important Guidelines

- Real Estate
 - Location, Location





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- Real Estate
 - Location, Location

- Barnett Shale
 - Location, Location, Orientation

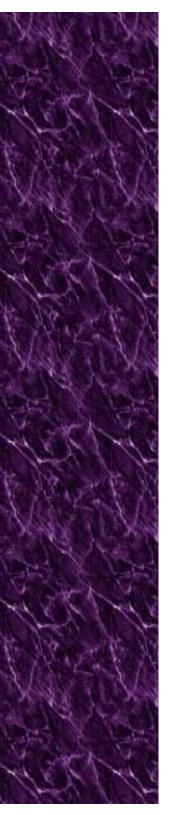




Some Important Guidelines

- Real Estate
 - Location, Location

- Barnett Shale
 - Location, Location, Orientation
 - "The Barnett isn't a naturally-fractured shale play; it's a shale-that-can-befractured play." Daniel Miller, 2004

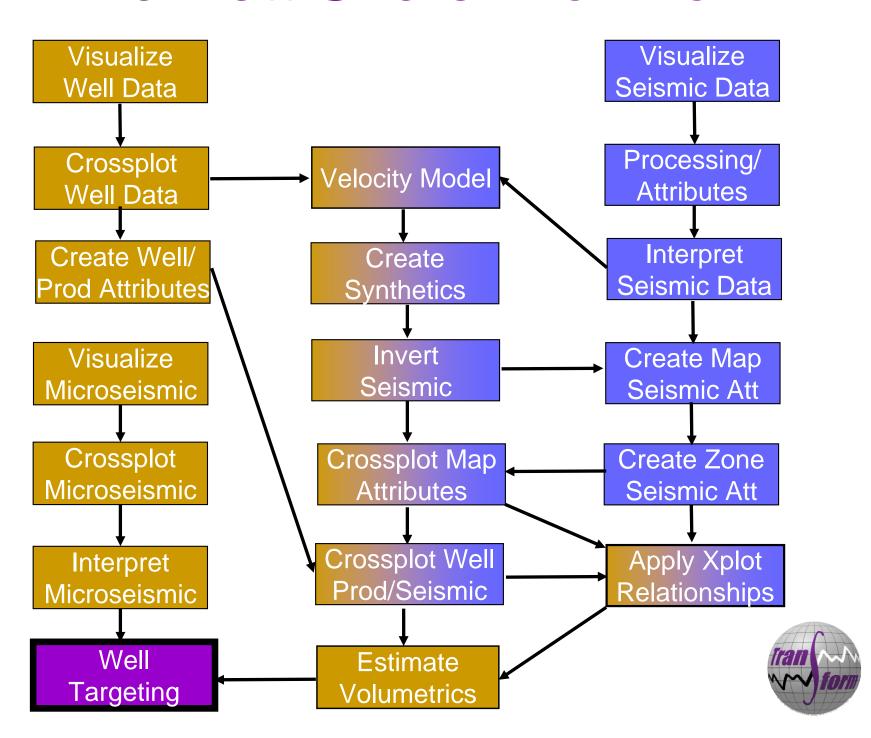


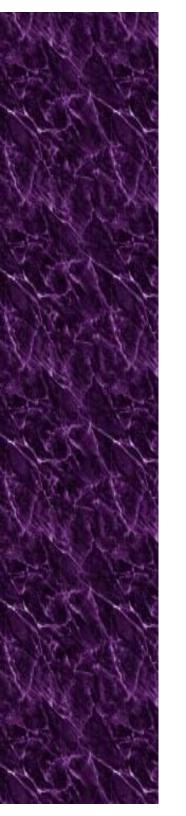
Keys to Optimized Barnett Drilling/Completions

- Location Accurate well path positioning in Lower Barnett
- 2) Orientation Optimal lateral well orientation with maximum stress
- 3) Location Avoid fractured "collapse chimneys"



Barnett Shale Workflow



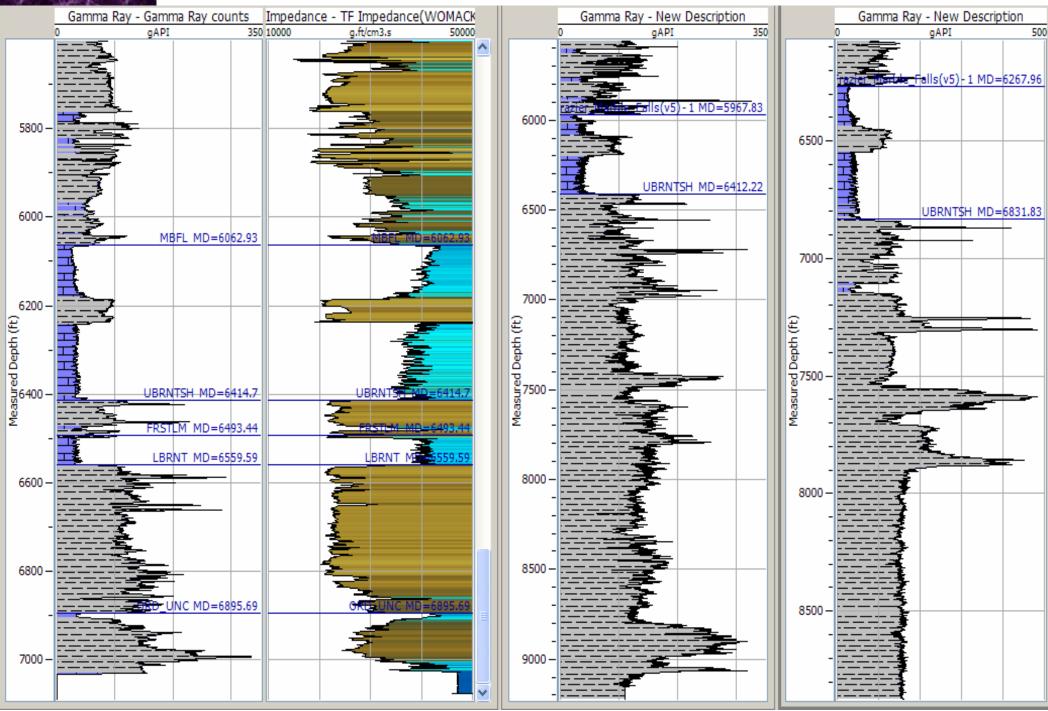


Keys to Optimized Barnett Drilling/Completions

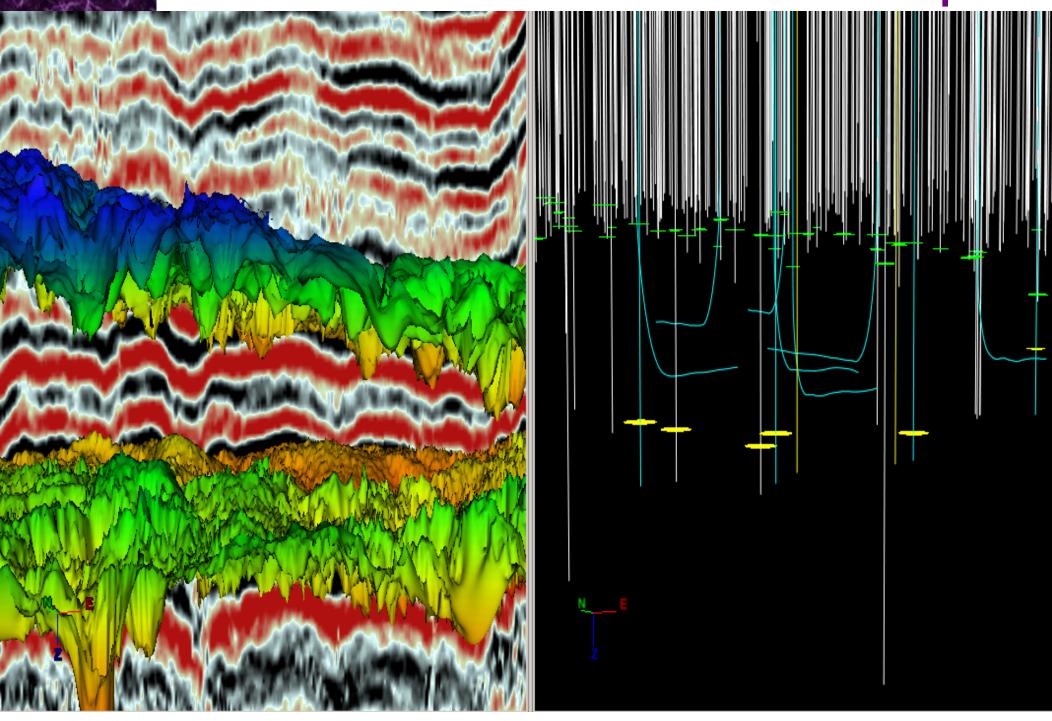
- 1) Accurate well path positioning
 - Intersect most productive Lower Barnett
 - Avoid drilling/fracing into Ellenberger
 - Support "toe-up" well steering
- 2) Optimal lateral well orientation
- 3) Avoidance of fractured "collapse chimneys"



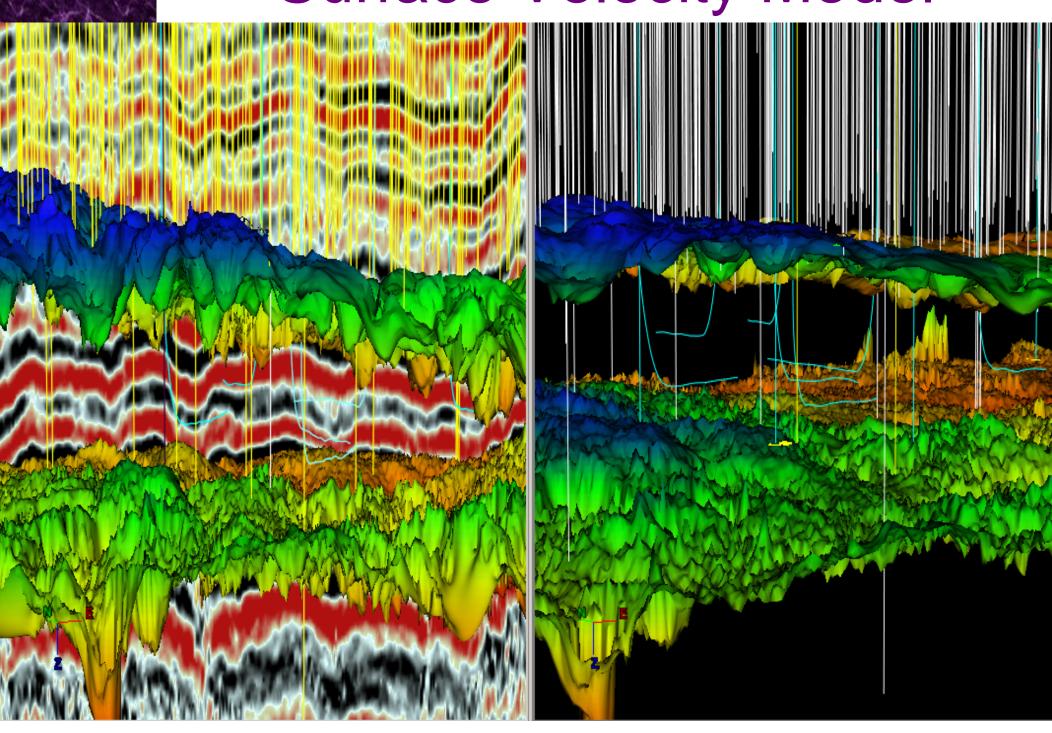
Barnett Shale Zone

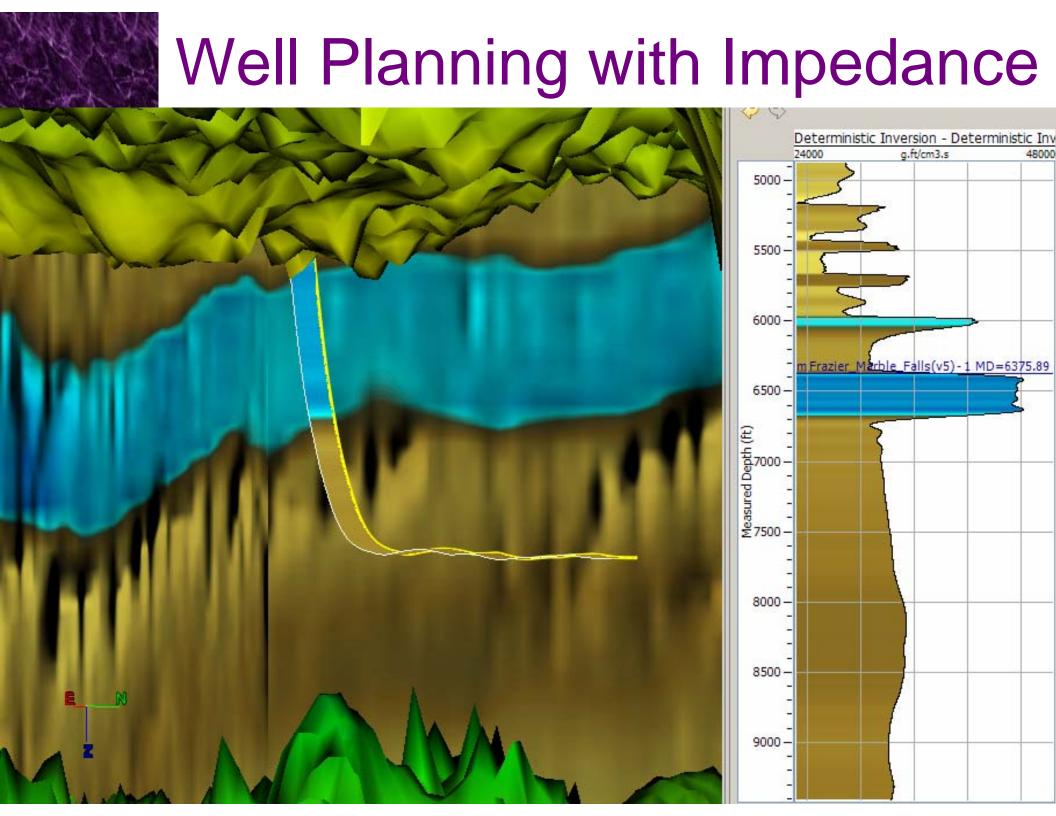


Seismic Horizons/Well Tops

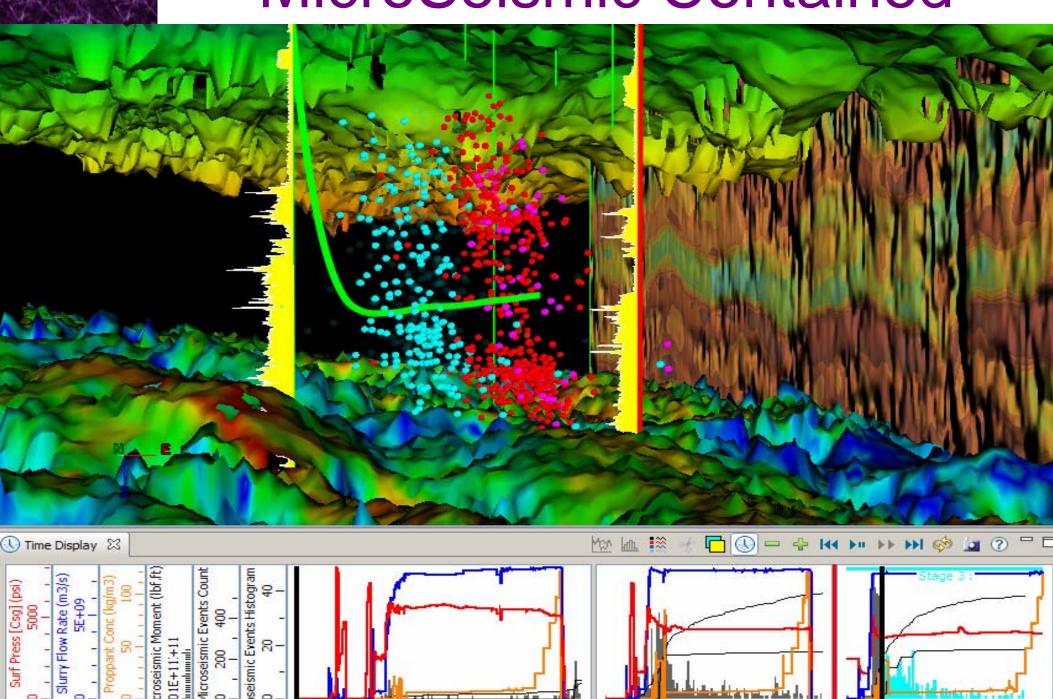


Surface Velocity Model





MicroSeismic Contained



10:00

12:00



Accurate Well Path Planning

- Interpret time horizons/well tops
- Grid and QC well tops
- Create surface velocity model to Barnett (grid tops using horizons)
- Extend surface velocity model with isochron/isochore interval velocity map
- Create Ellenberger depth surface
- Depth convert seismic/impedance/curvature
- Update model with new well tops
- Opportunity for real-time well monitoring



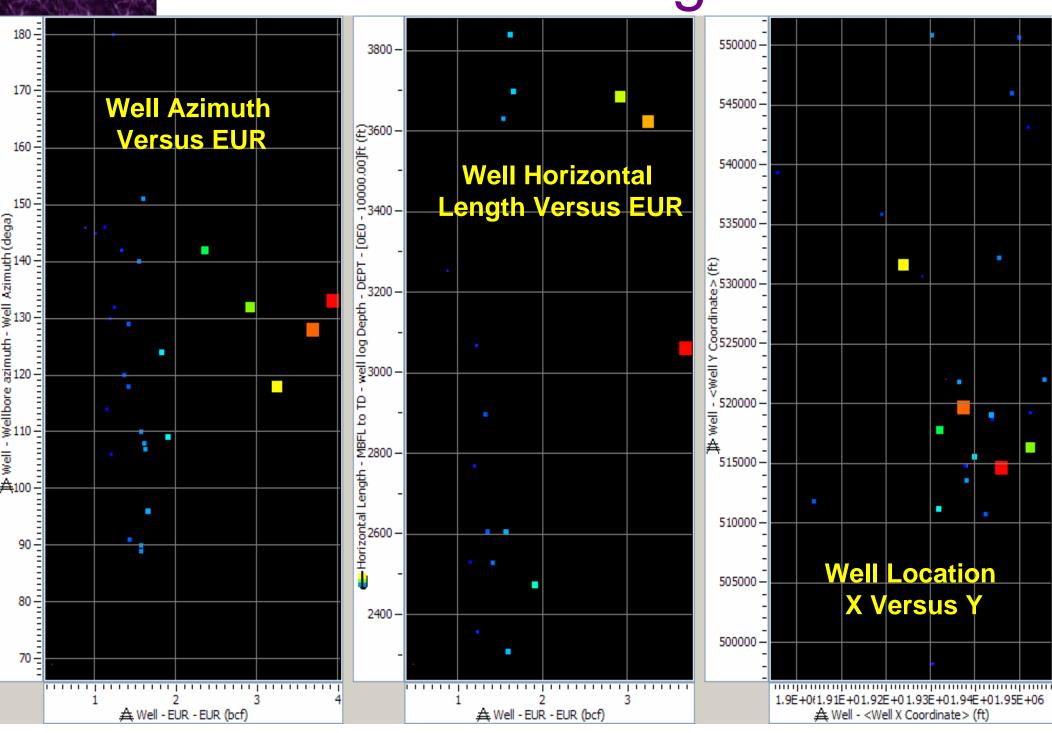


Keys to Optimized Barnett Drilling/Completions

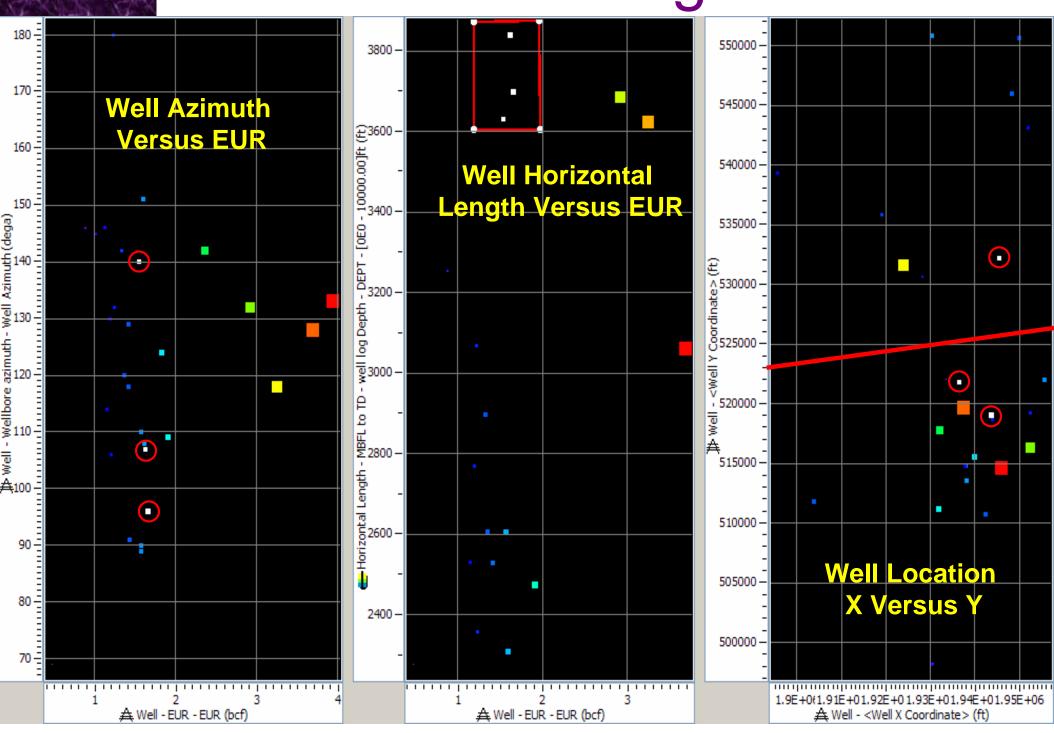
- 1) Accurate well path positioning
- 2) Optimal lateral well orientation
 - Create diffuse hydraulic fracture patterns
 - Align perpendicular to current horizontal maximum stress (NE/SW)
 - Align parallel to natural fractures
- 3) Avoidance of fractured "collapse chimneys"



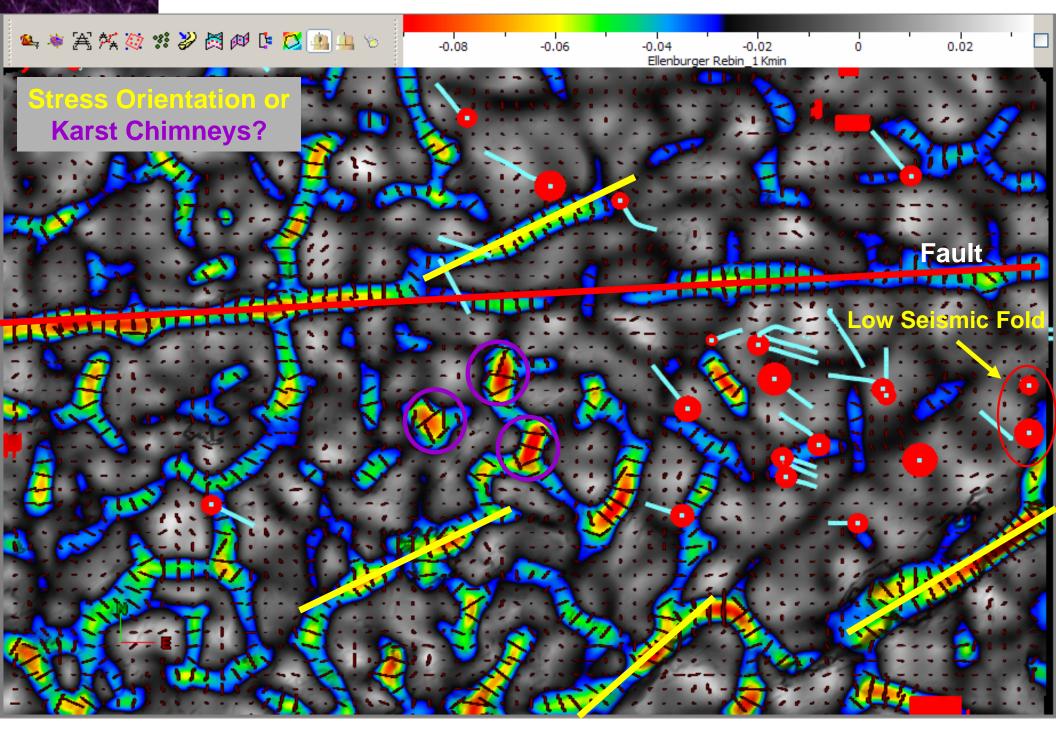
Well Azimuth/Length and EUR



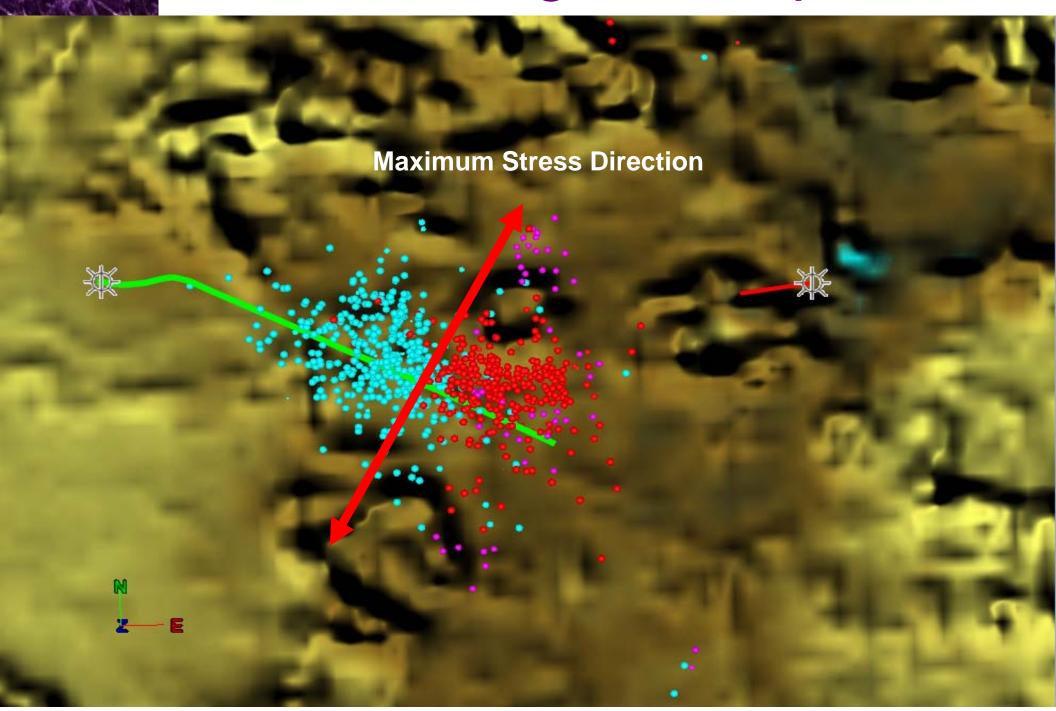
Well Azimuth/Length and EUR



Volume curvature – Kmin/Azimuth



Well Planning with Impedance





Optimize Lateral Well Orientation

- Calculate volume curvature, incoherence, etc.
- Estimate azimuthal velocity anisotropy
- Integrate display of seismic attribute data
- Visualize microseismic and macroseismic
- Estimate maximum stress/fracture directions
- Estimate stress anisotropy
- Determine fracturing patterns





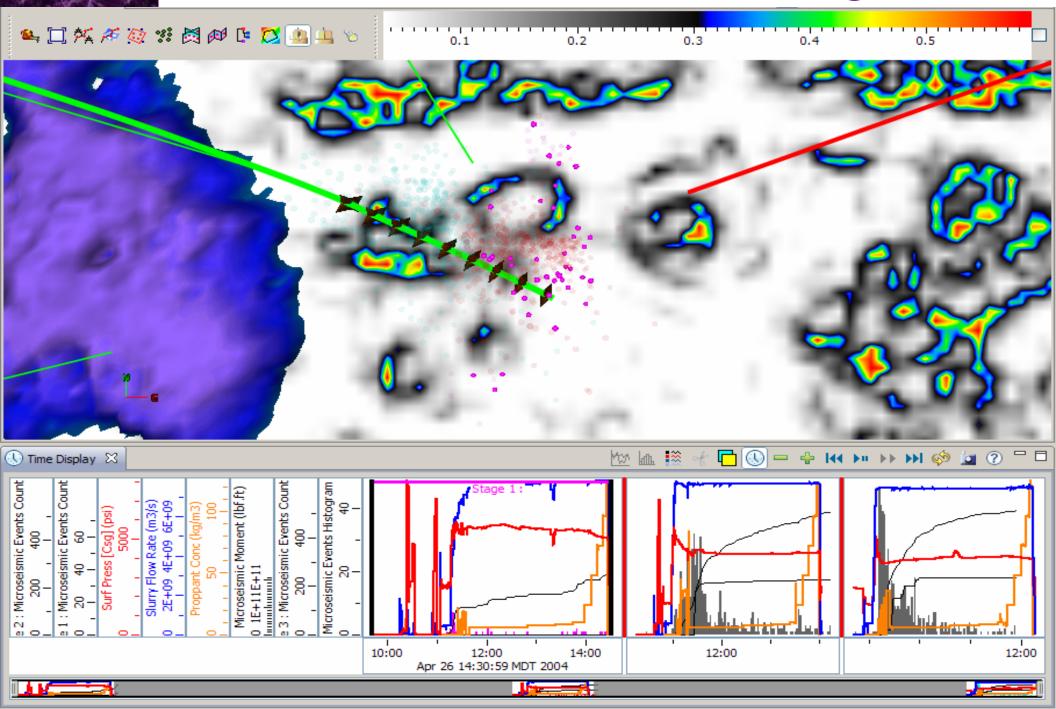
Keys to Optimized Barnett Drilling/Completions

- 1) Accurate well path positioning
- 2) Optimal lateral well orientation
- 3) Avoidance of fractured "collapse chimneys"
 - Prevent tapping into Ellenberger aquifer
 - Avoid wasting frac energy
 - Minimize drilling hazards

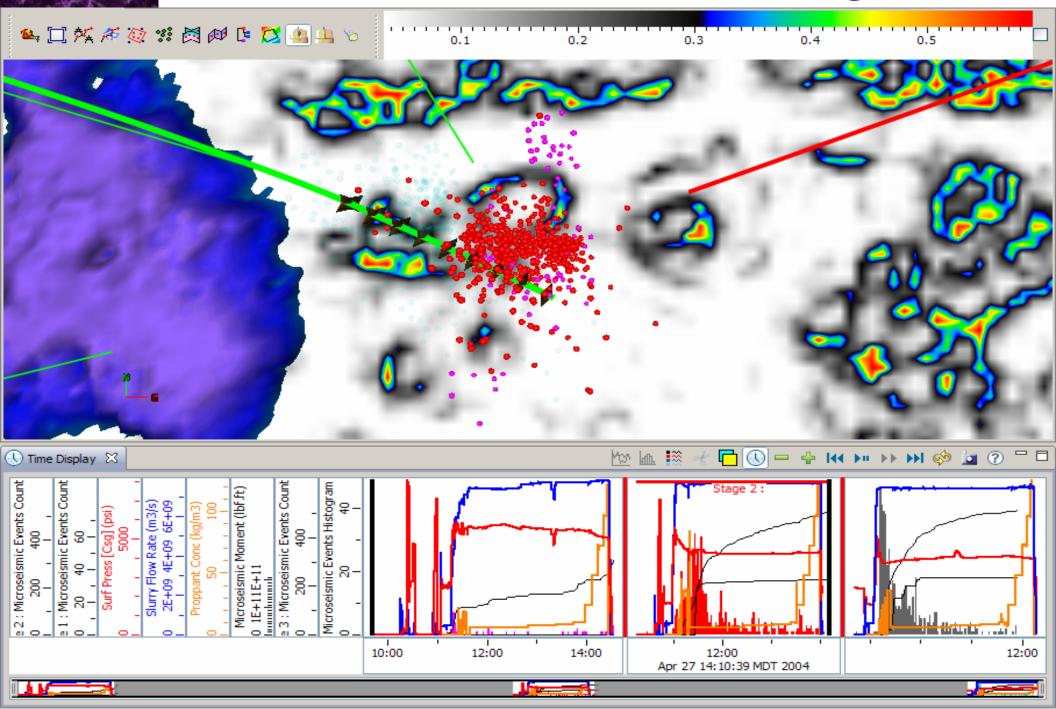


Microseismic from 3-Stage Frac e 2 : Microseismic Events Count 0 200 400 1 : Microseismic Events Count Microseismic Events Histogram 12:00 10:00 14:00 Apr 26 09:40:54 MDT 2004

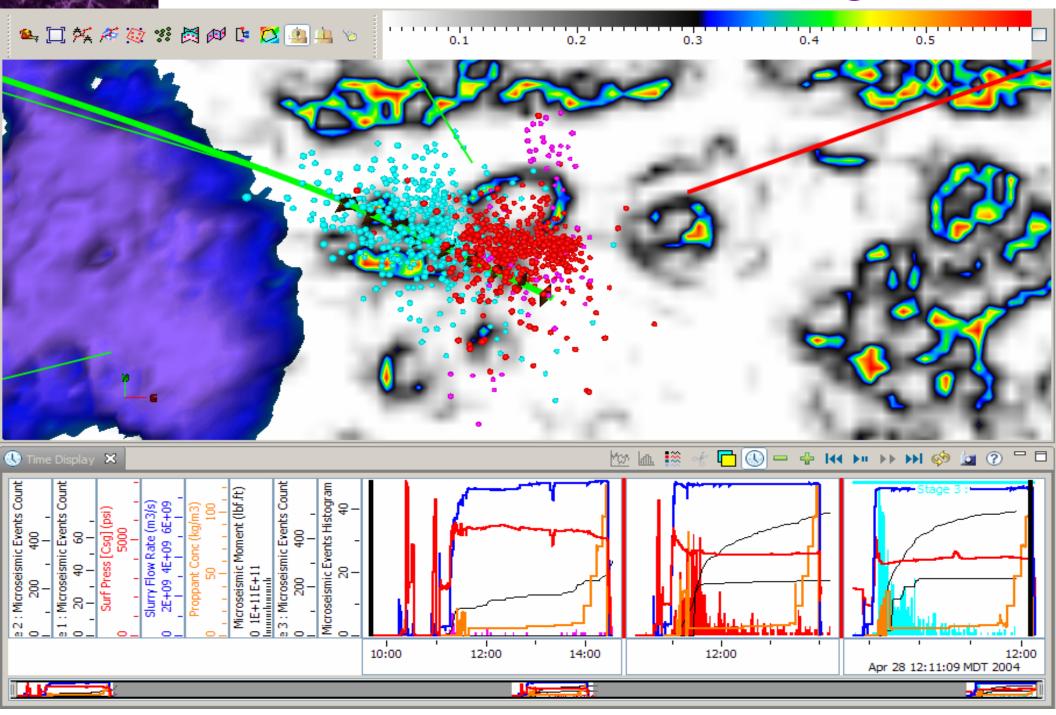
Microseismic from Stage 1



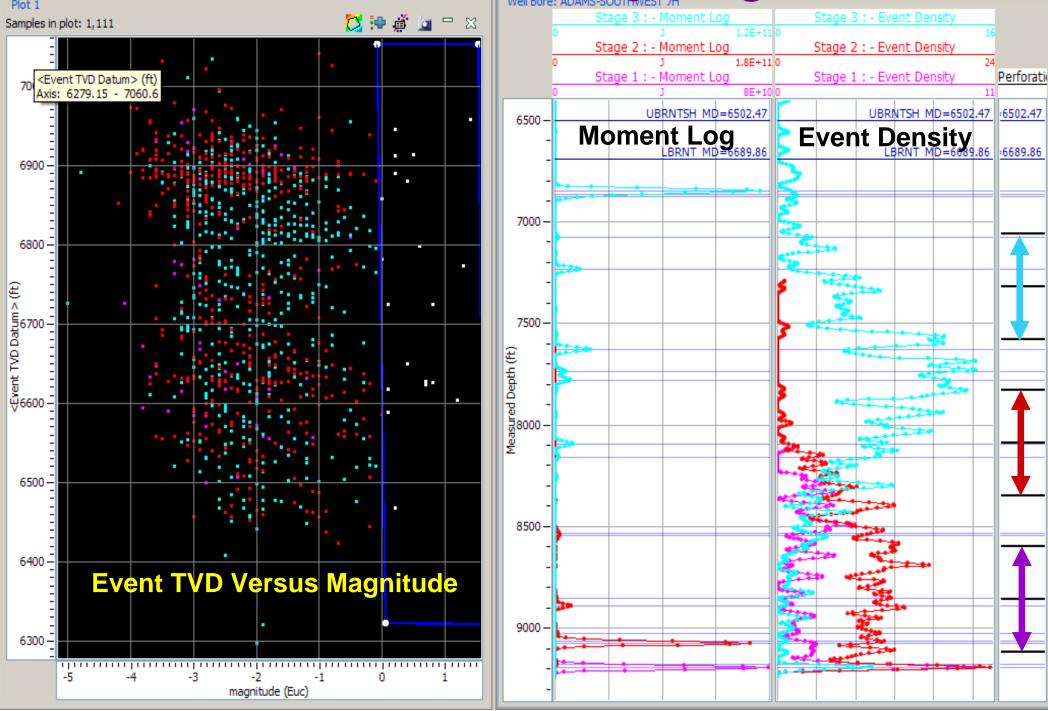
Microseismic from Stage 2



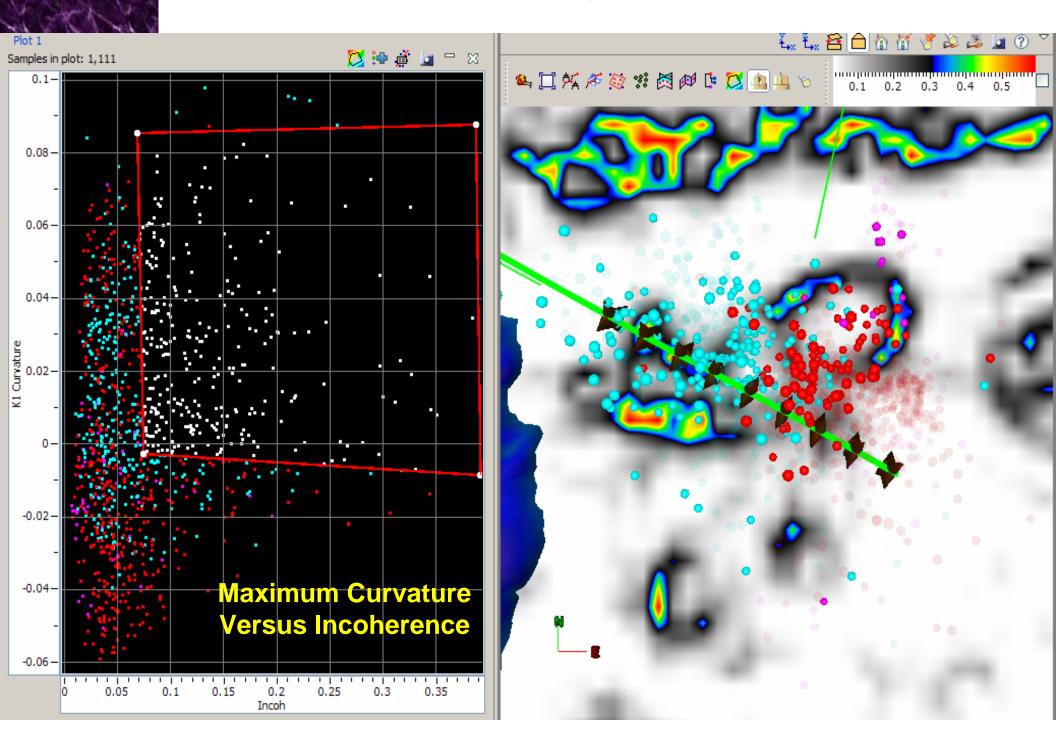
Microseismic from Stage 3



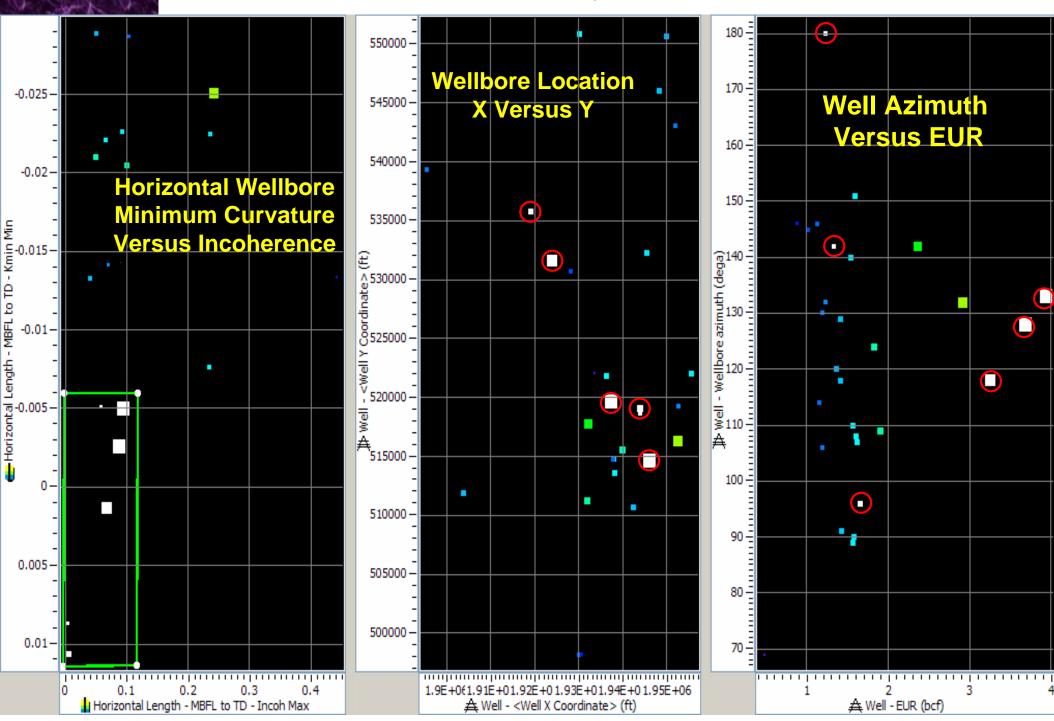
Event Density Migration



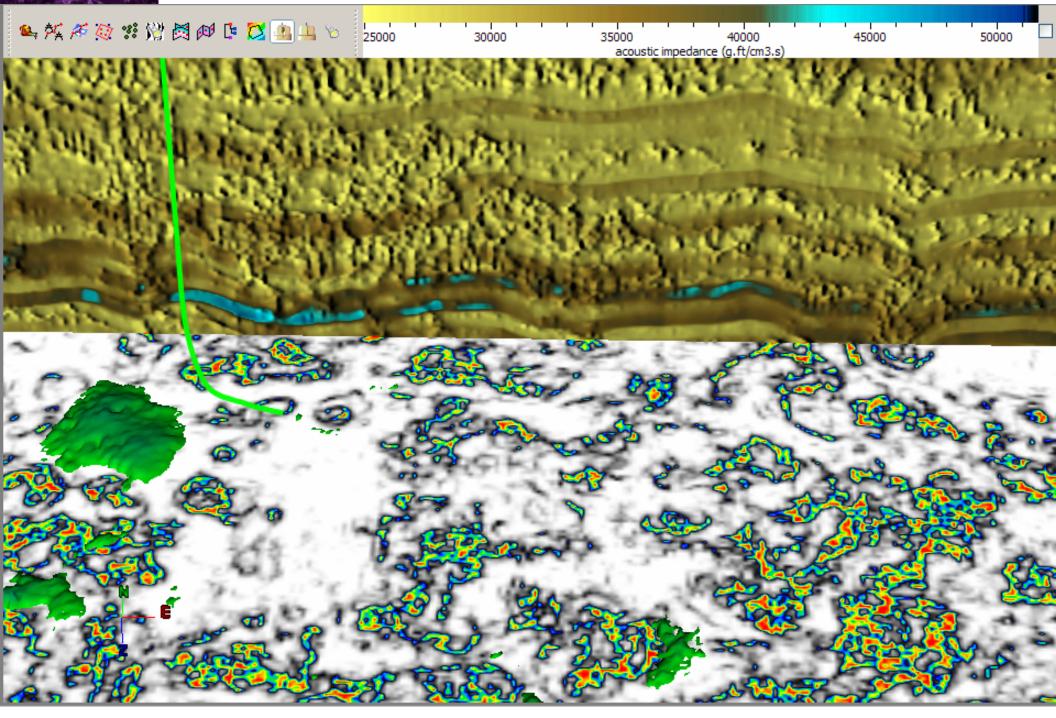
Microseismic/Macroseismic



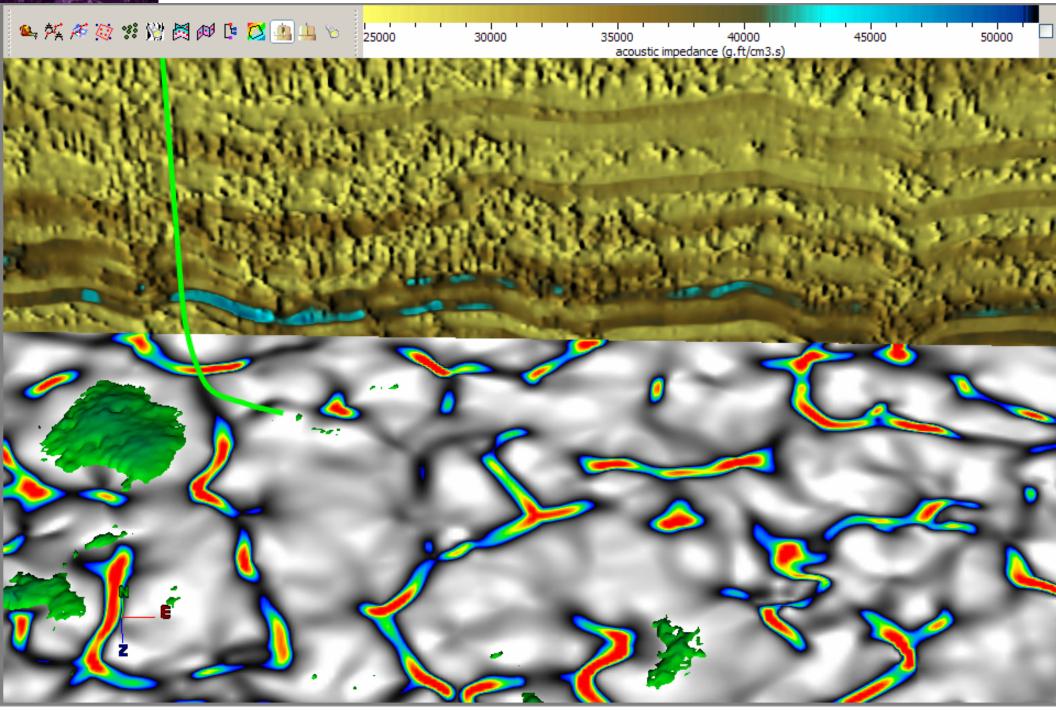
Correlate Kmin, Incoh and EUR



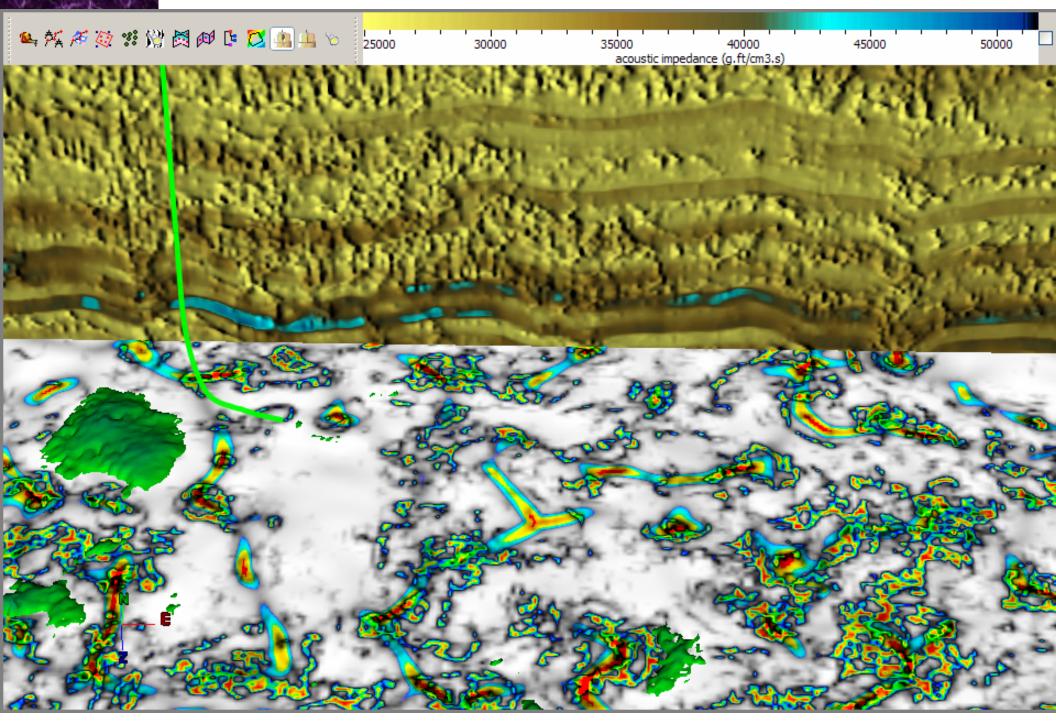
Incoherence – Collapses Extent



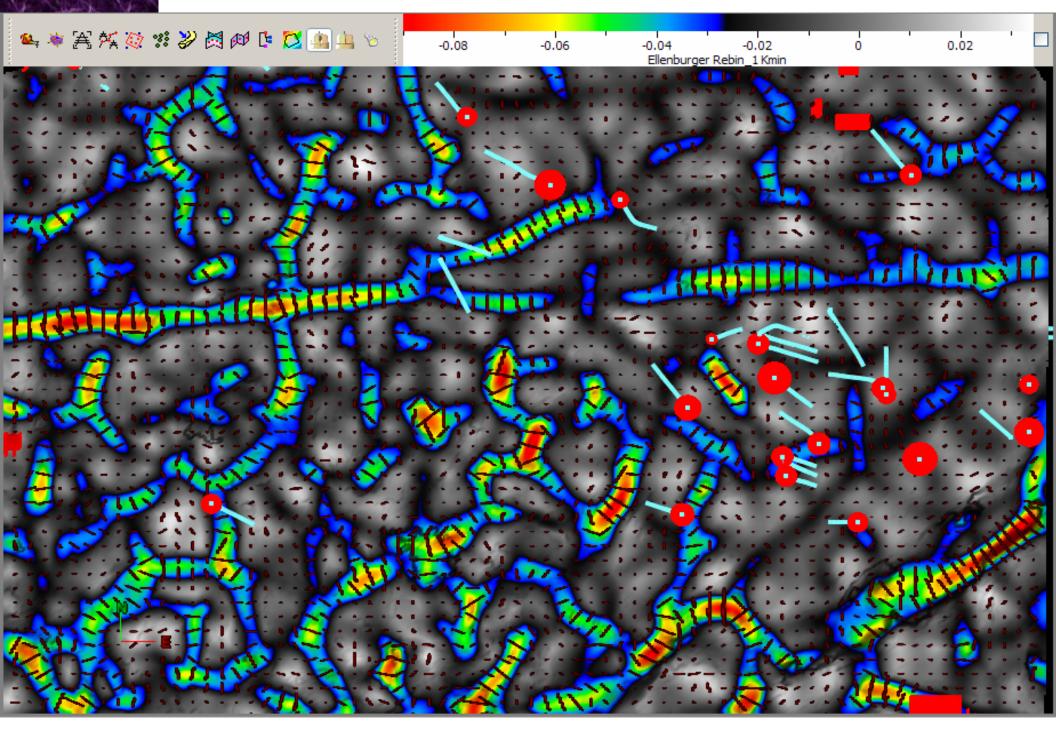
Min Curvature – Collapses Core



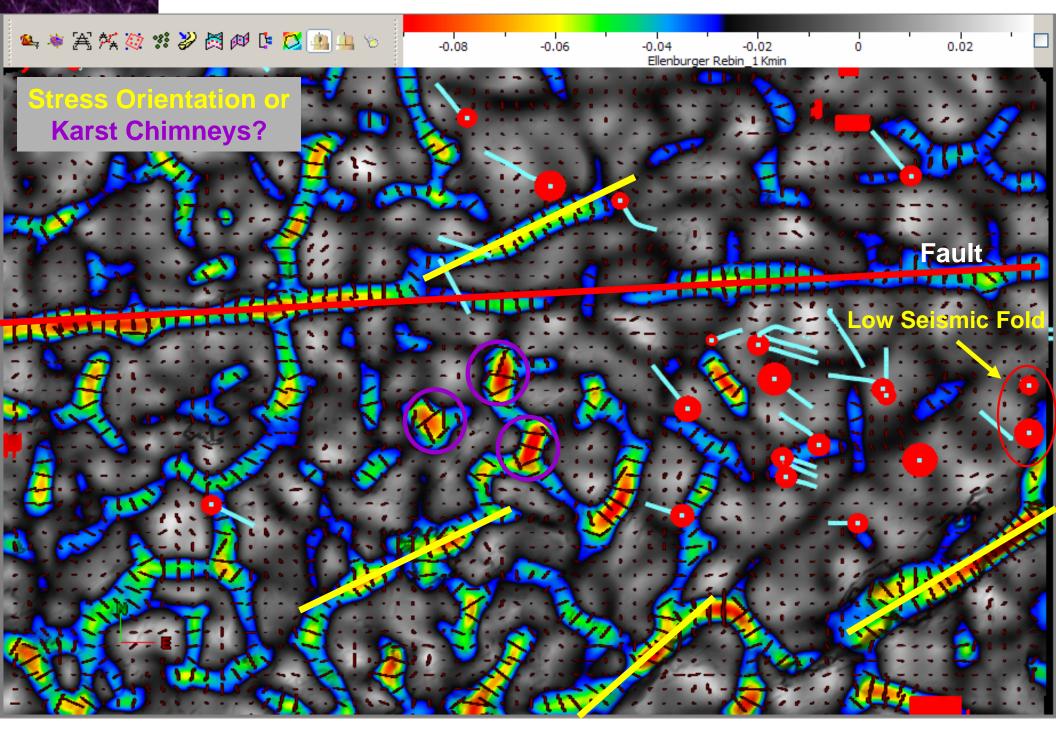
Incoherence and Min Curvature



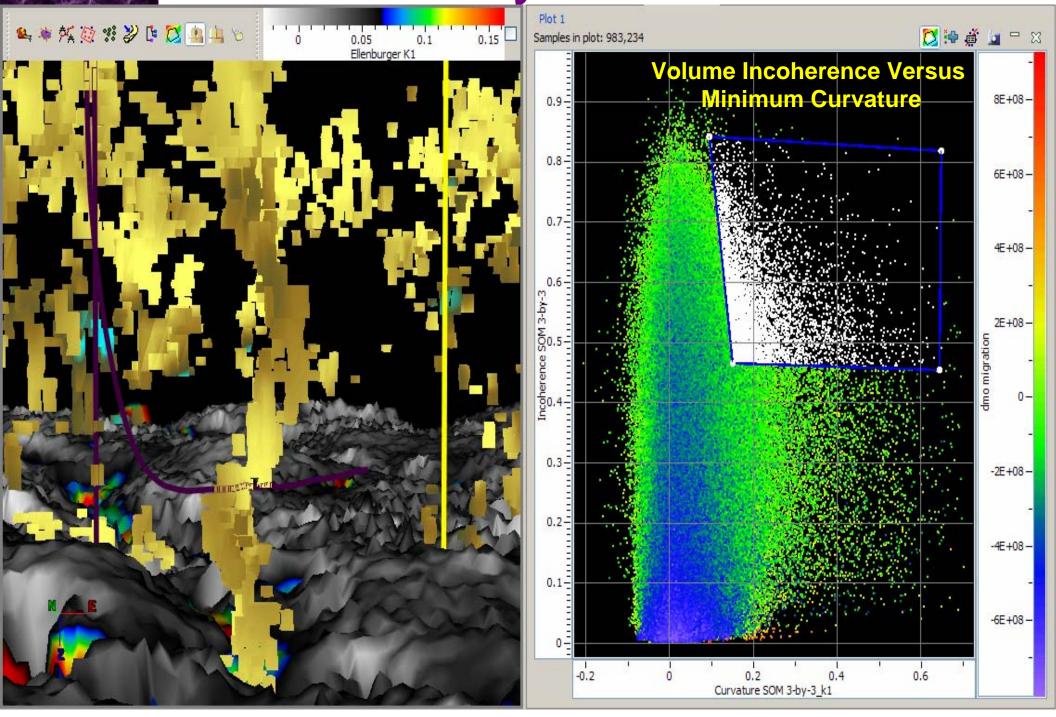
Volume curvature – Kmin/Azimuth



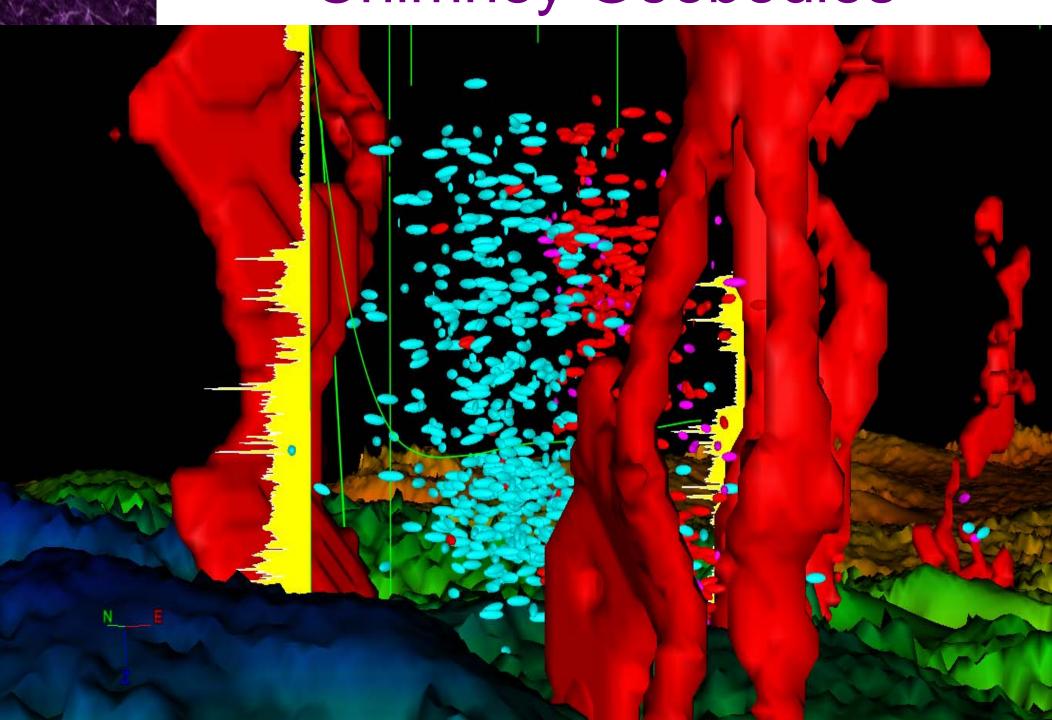
Volume curvature – Kmin/Azimuth



Chimney Identification



Chimney Geobodies





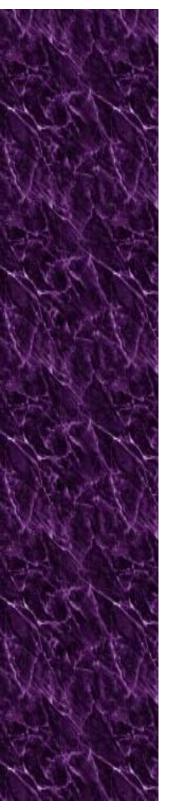
Avoidance of fracture "collapse chimneys"

- Visualize time-lapse treatment data and microseismic
- Calculate volume seismic curvature, incoherence
- Crossplot production, microseismic and seismic attribute data
- Interpret fracture "geobodies"
- Plan well paths and completions to avoid collapse chimneys



Conclusions

- Macro/Micro Seismic interpretation is essential for optimized tight-gas drilling and completions in the Barnett Shale
 - Location accurate well placement in the Lower Barnett is essential = accurate velocity modeling and depth conversion
 - Orientation well alignment (~130° E/N)
 normal to major stress orientation drives
 better production = identifying stress/fracture
 direction from velocity anistropy and/or
 seismic curvature and microseismic
 - Location avoiding fractured collapse chimneys is important for preventing water production and wasting fracture energy = integrated microseismic and macroseismic (curvature and incoherence) interpretation



Acknowledgements

- Huge thanks to Mike Ammerman for many helpful discussions about the Barnett Shale
- Another huge thanks to Devon
 Energy for permission to publish this work
- Big thanks to Transform Software and Services for supporting this work with time and software



Location, Location, Orientation

