Multi-Scale Seismic Measurements for Quantifying Fracture Properties in Gas Reservoirs

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Industry: ConocoPhillips Inc.,

Lynn Inc.,

Schlumberger-Doll Research,
Schlumberger Reservoir Technologies

University: Stanford University, Virginia Tech.

British Geological Survey: EAP

[✦]**Lawrence Berkeley National Laboratory**

Statement of Problem

- **Optimize production in fractured reservoirs**
  - **Small fractures often control the permeability over a large area**
  - **Fractured reservoirs often occur in heterogeneous geologic environments**
  - **Past advances in seismic imaging using surface methods identify anisotropy**
  - **Anisotropy can be caused by geologic fabric as well as fractures**
  - **Needed are methods/approaches to sort out the different effects in order to identify the fractures controlling flow and transport**

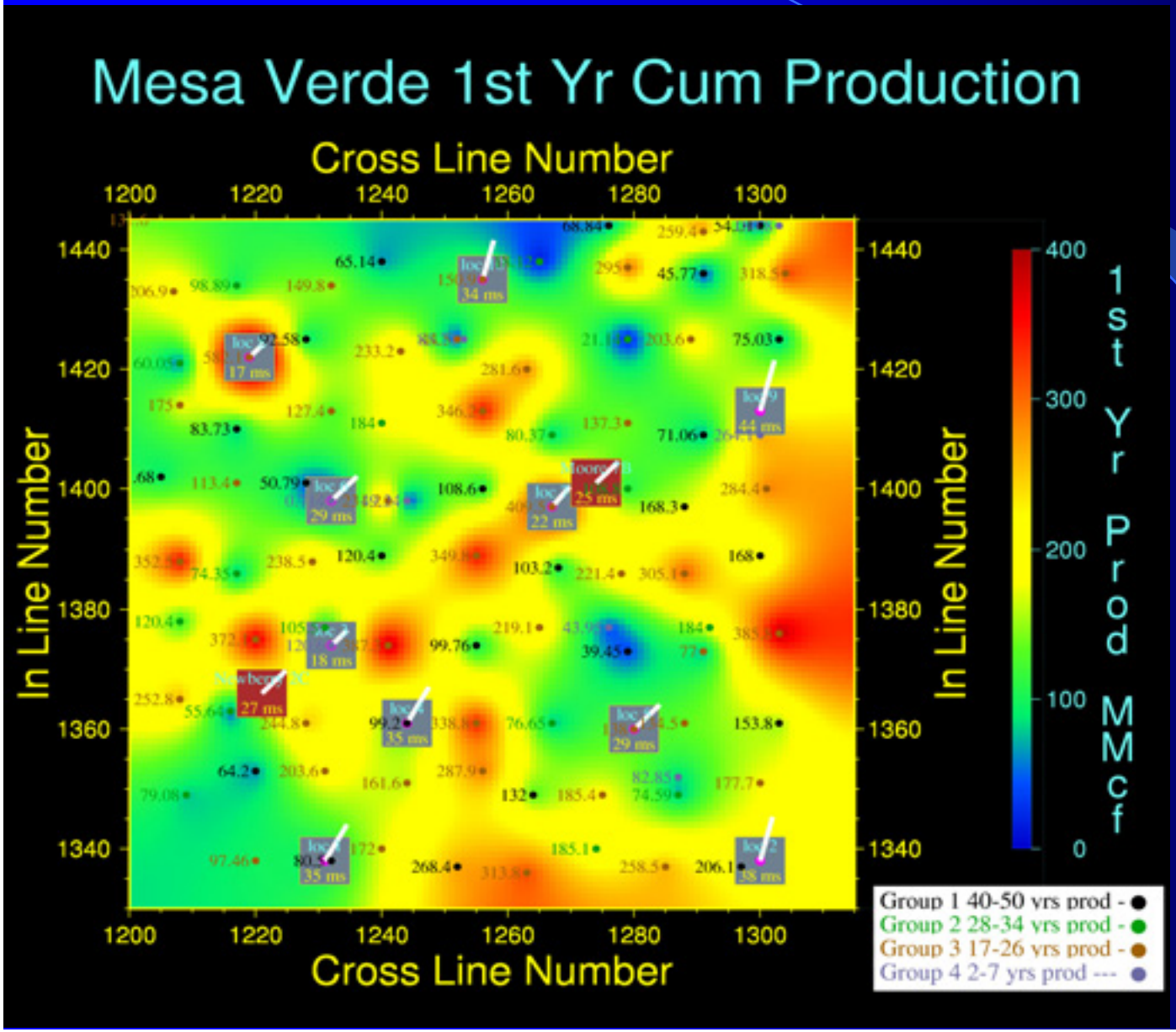
Needs Addressed

- **Today's technology can locate fracture patterns and general geometry, but there are no reliable methods to quantify fracture characteristics**
  - **Fracture density**
  - **Fracture spacing**
  - **Fracture interactions**
  - **Fracture fillings**
  - **Fracture permeability**

Overall Objectives

- **Extend current state-of-the-art 3-D imaging to extract the optimal information for fracture quantification**
  - **Beyond anisotropy to characterize and locate fractures controlling production**
- **Develop next generation capability in fracture imaging for true 3-D imaging of the static and dynamic fracture properties**
  - **extract more information from current surface seismic**
  - **develop capability to observe reservoir changes as it is produced**
  - **<u>Define appropriate scale of measurements</u>**

Anisotropy (from surface seismic) vs Production



Little Correlation between Anisotropy and Production

Possible Anti-Correlation

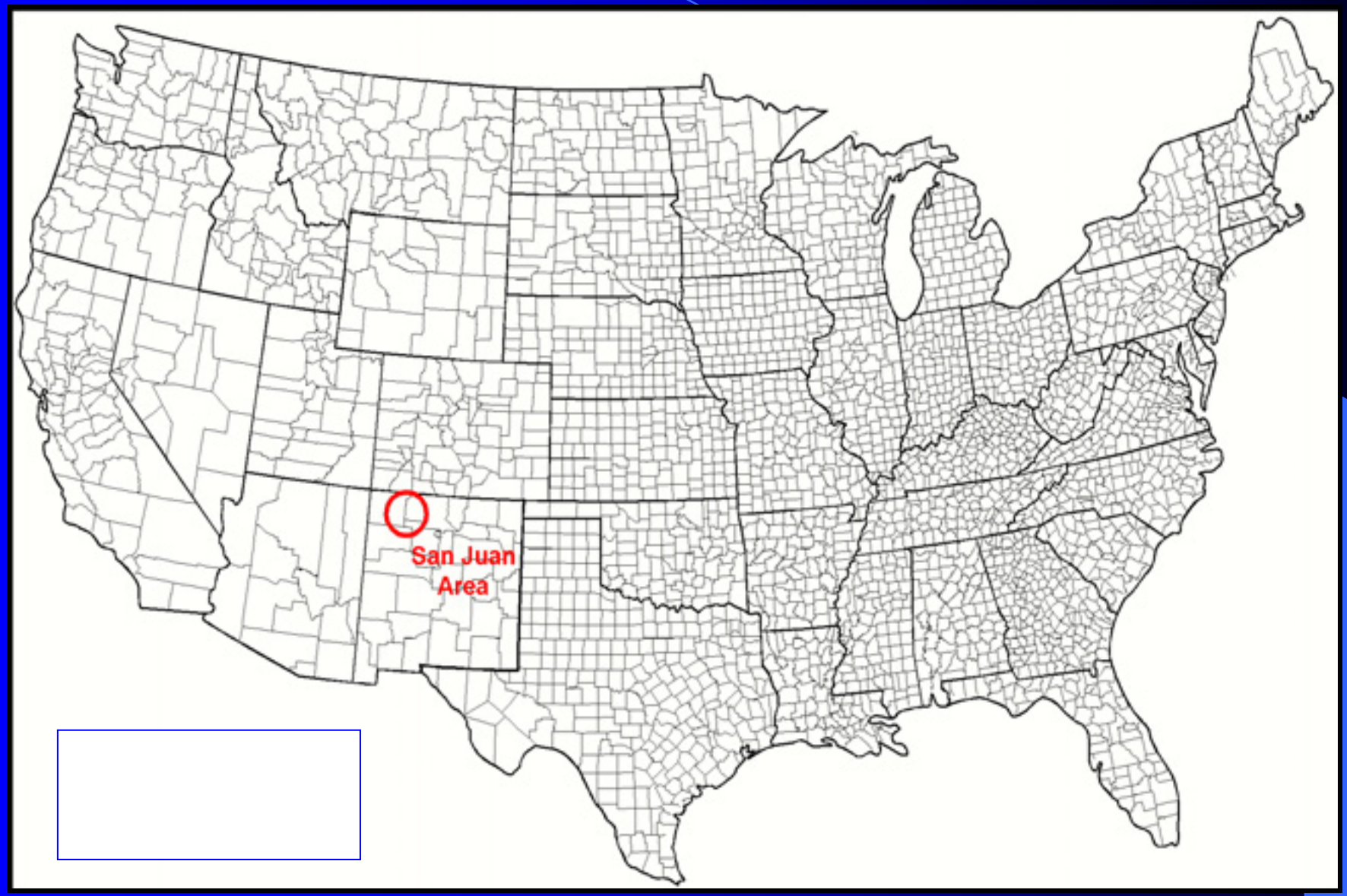
Approach

- Past work has been in smaller scale experiments, theory and laboratory work has supported high frequency and detectability hypothesis
- Now we are scaling up to field scale in production environment
- Use both surface and borehole methods (multi scale experiments)
- Consider effect of matrix as well fractures
- Develop methods in conjunction with users of technology for optimal technology transfer

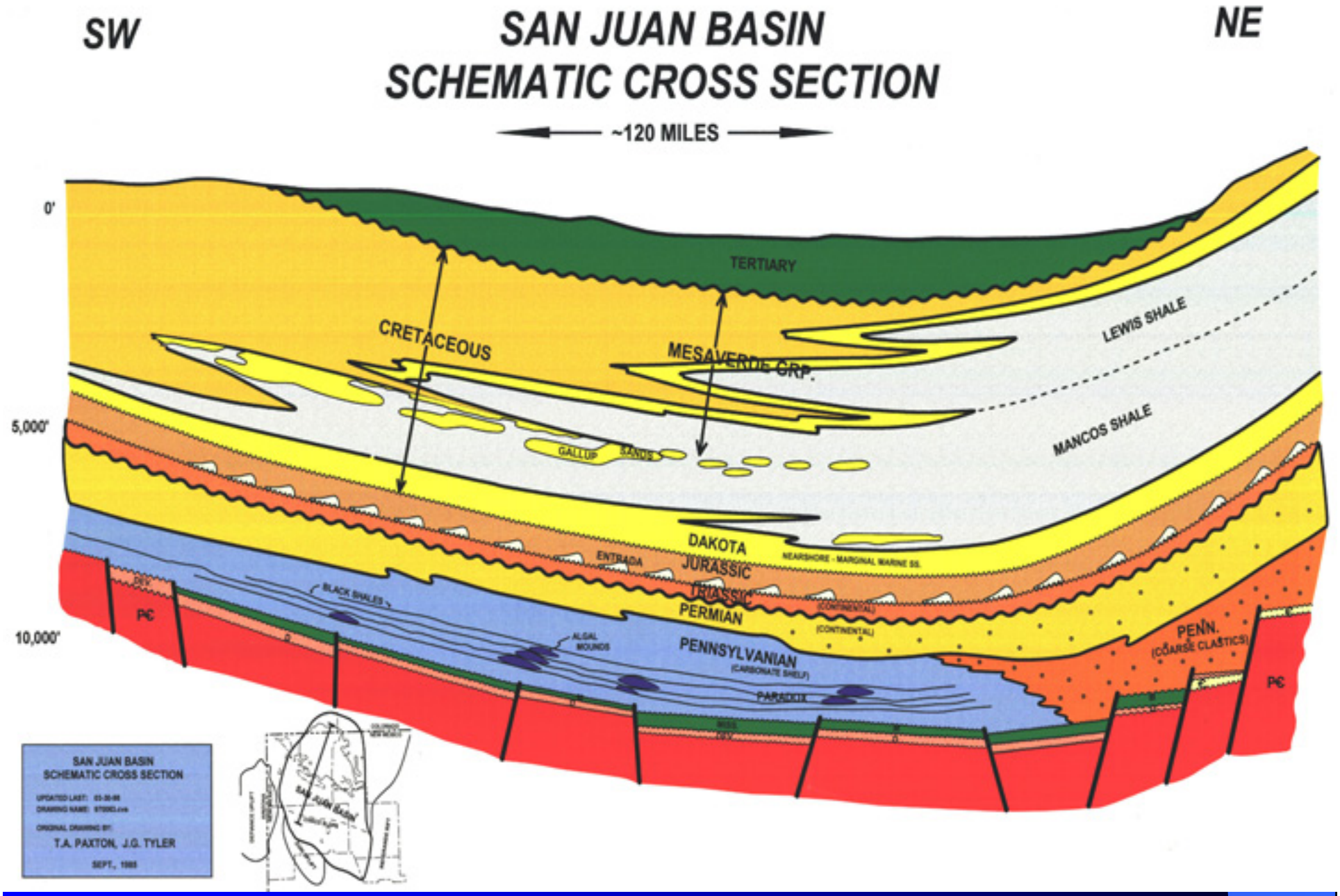
Tasks

- **Modeling (LBNL, Conoco, VT, Stanford)**
  - **Examine effects of fractures on 3-d wave field**
  - **Borehole effects**
  - **Matrix Heterogeneity**
- **Processing and Interpretation (Conoco, LBNL Stanford, VT, BGS)**
  - **Validate different theories and modeling**
- **Field Measurements(LBNL, Schlumberger)**
  - **Design and acquire data based on above results**
- **Reservoir Simulation(Schlumberger)**
  - **Integrate results for improved predictive capability**
- **Integration (All)**

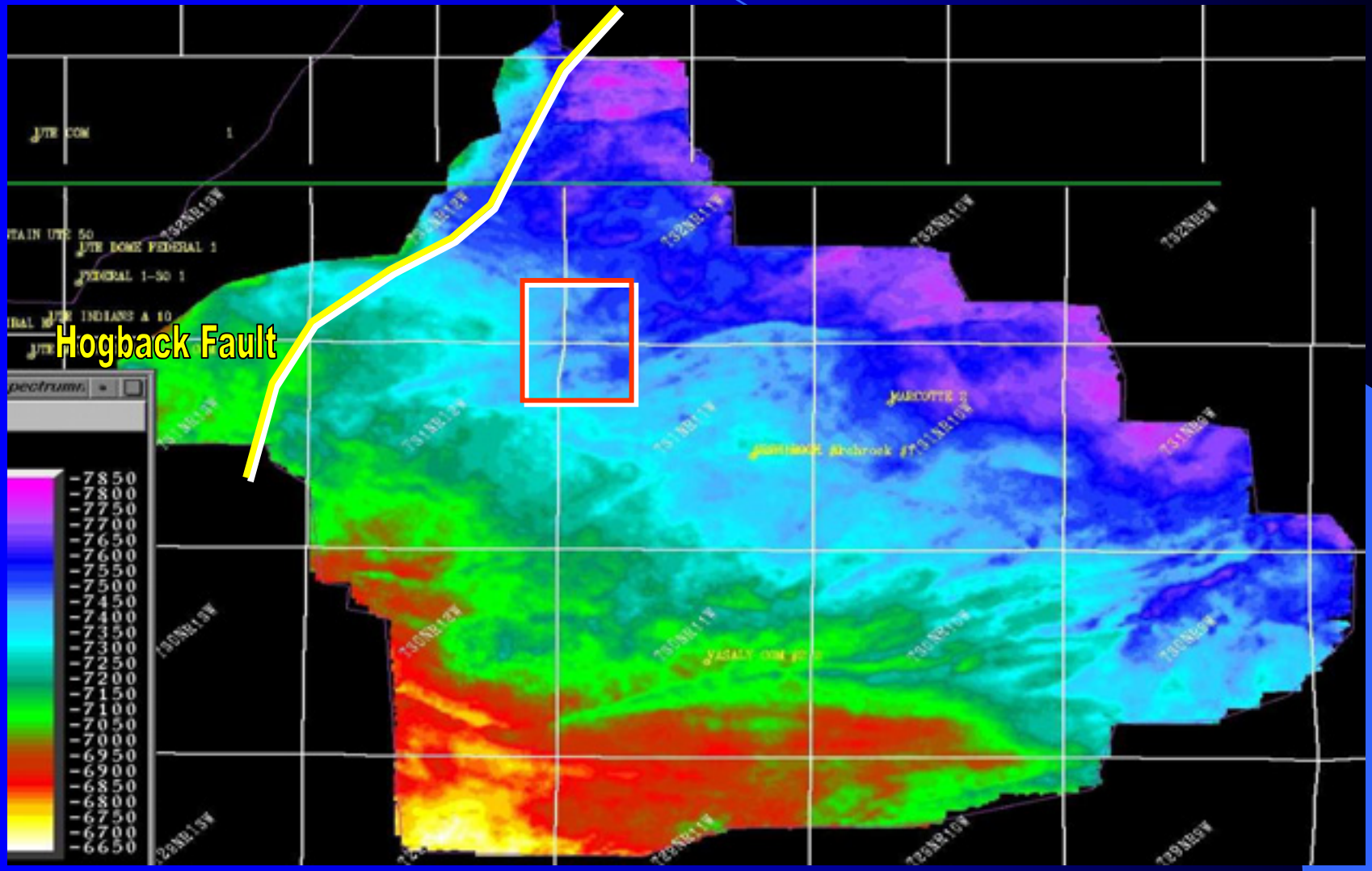
Study Location Map



SAN JUAN BASIN
SCHEMATIC CROSS SECTION



3-D Surface Seismic, 20 Sq. mile San Juan study area

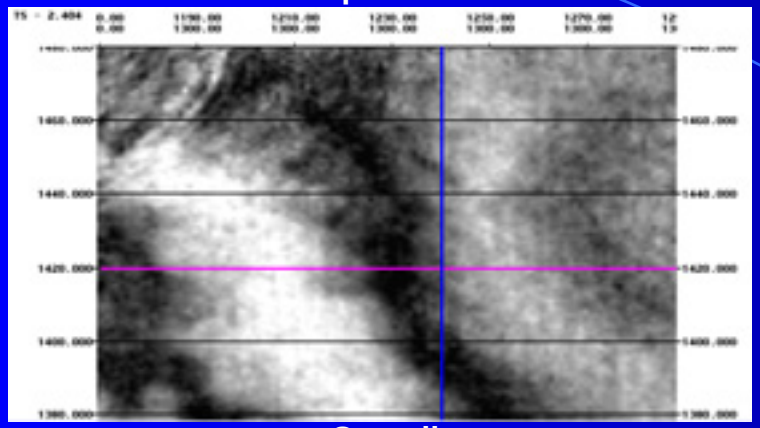


Field Measurements

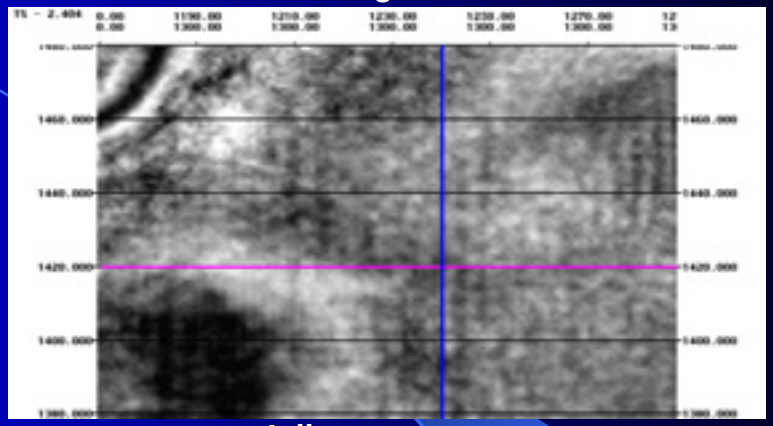
- 3-D seismic data (20 sq Mi, reprocessed) (8 to 30HZ data)
  - P-waves
  - Multi-component (3-C versus 9-C)
- 9-C 3-D VSP (10 to 120Hz)
  - > 53 source locations (10 -120, Hz for P, 10- 70 S, Hz), 160 levels-25 foot spacing
  - IVI & IO Shear Source Comparison
- Single Well Seismic (orbital, PZT) (50 - 400 Hz, 4 Khz)
- Supplemental Well Logs (8KHz)
  - ñ Acoustic monopole compressional and shear.
  - Acoustic cross-dipole
  - Acoustic Stoneley mode logs
  - Four-arm borehole caliper
  - Gamma ray
  - Formation micro-imager (FMI),

Reprocessed versus Orginal 3D

Reprocessed

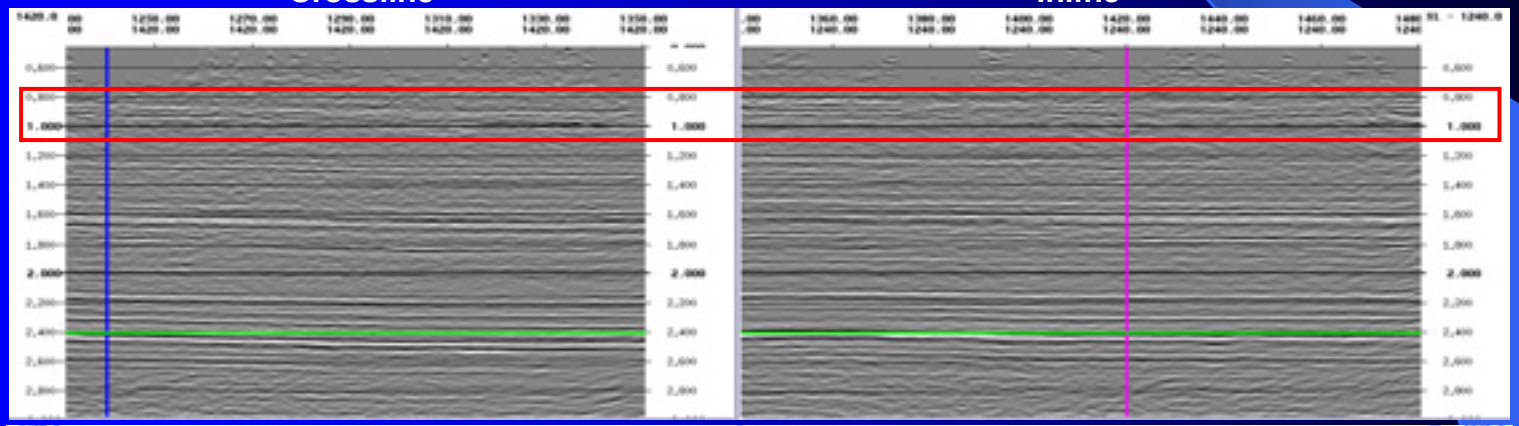


Original

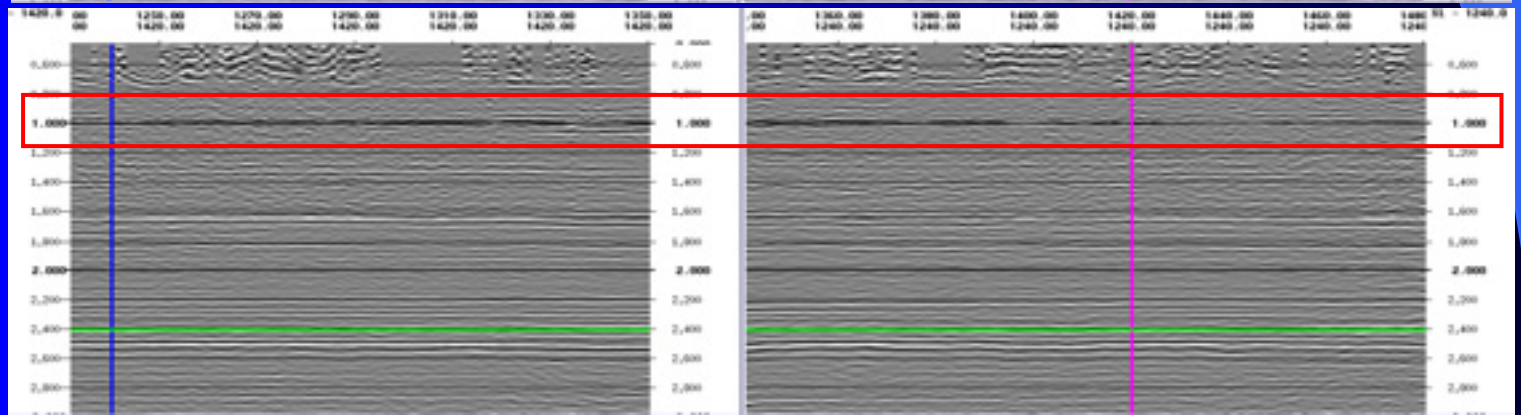


Crossline **Inline**

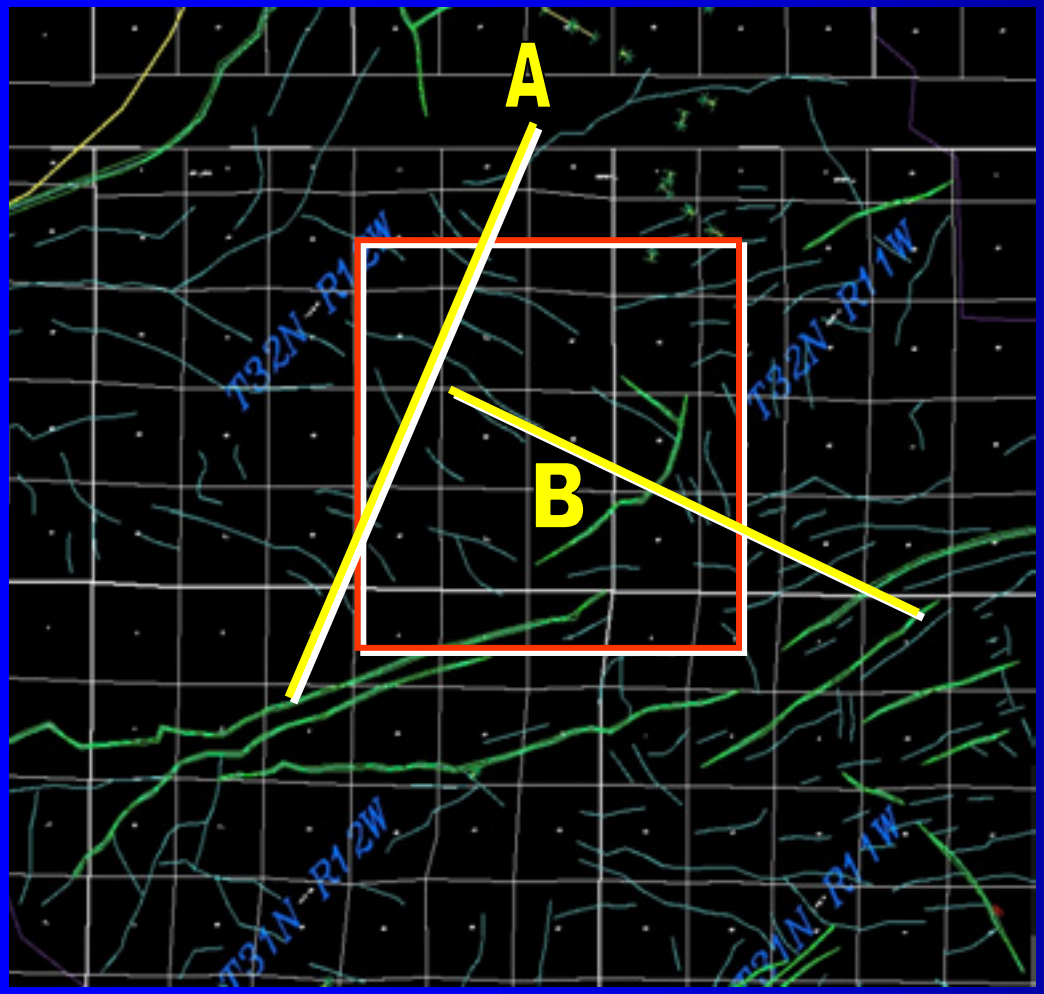
Reprocessed

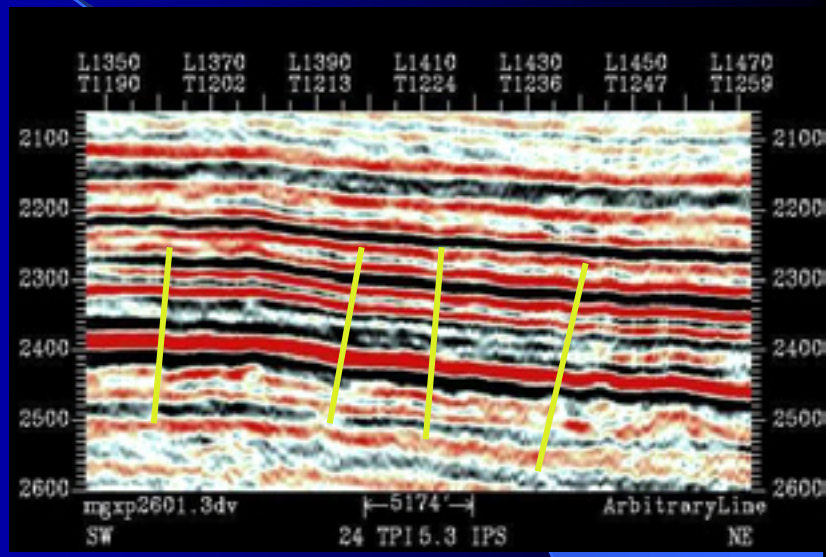


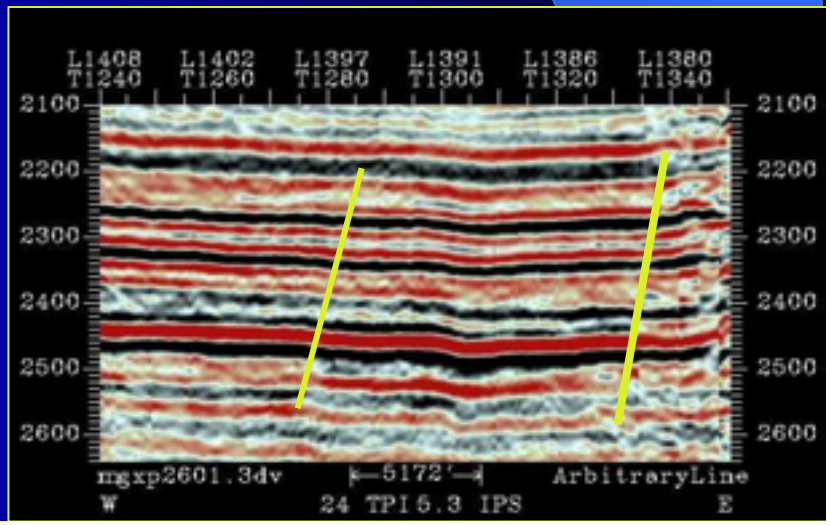
Original

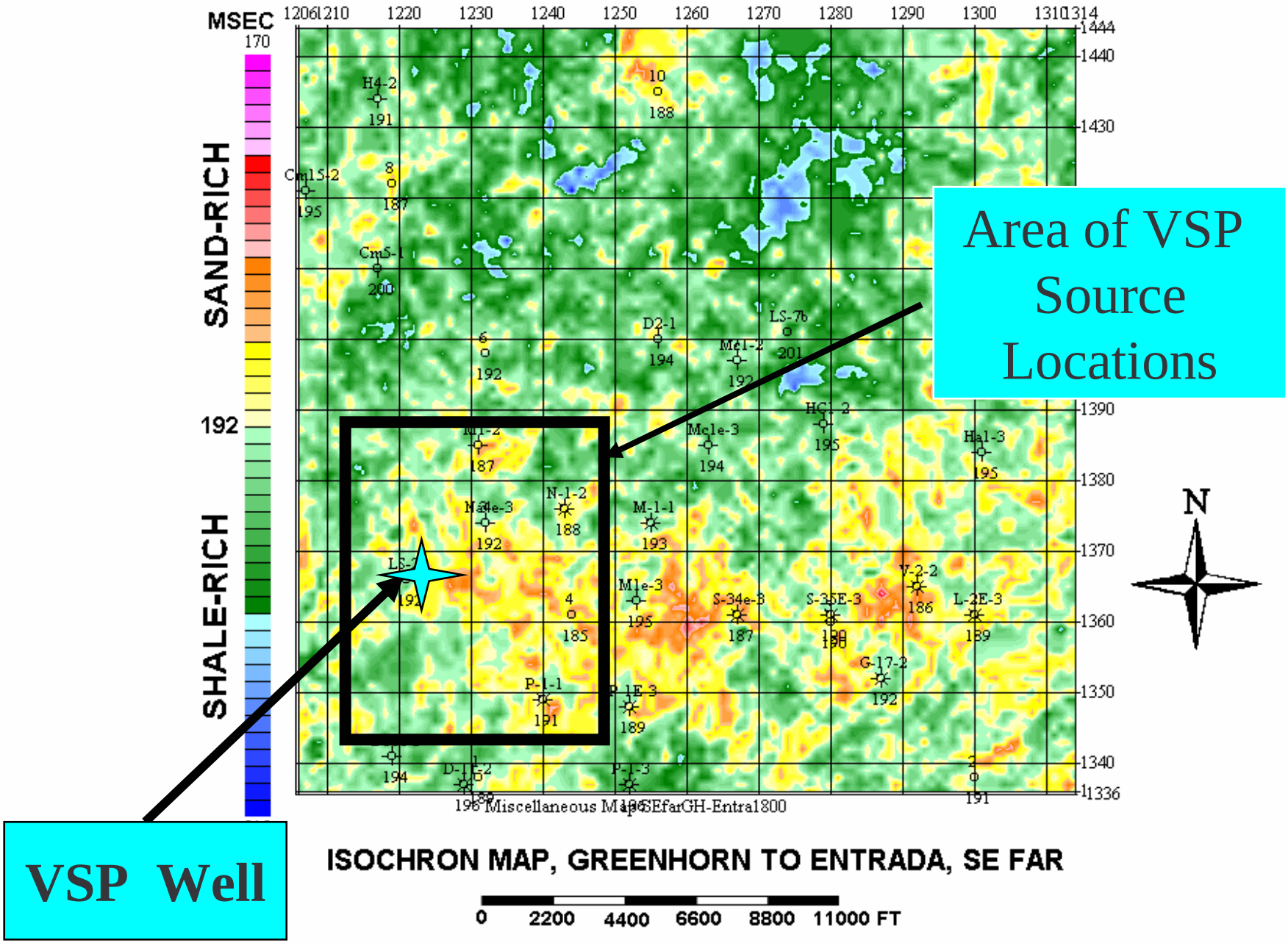


3D Fault/Fracture Map with Seismic (reprocessed)

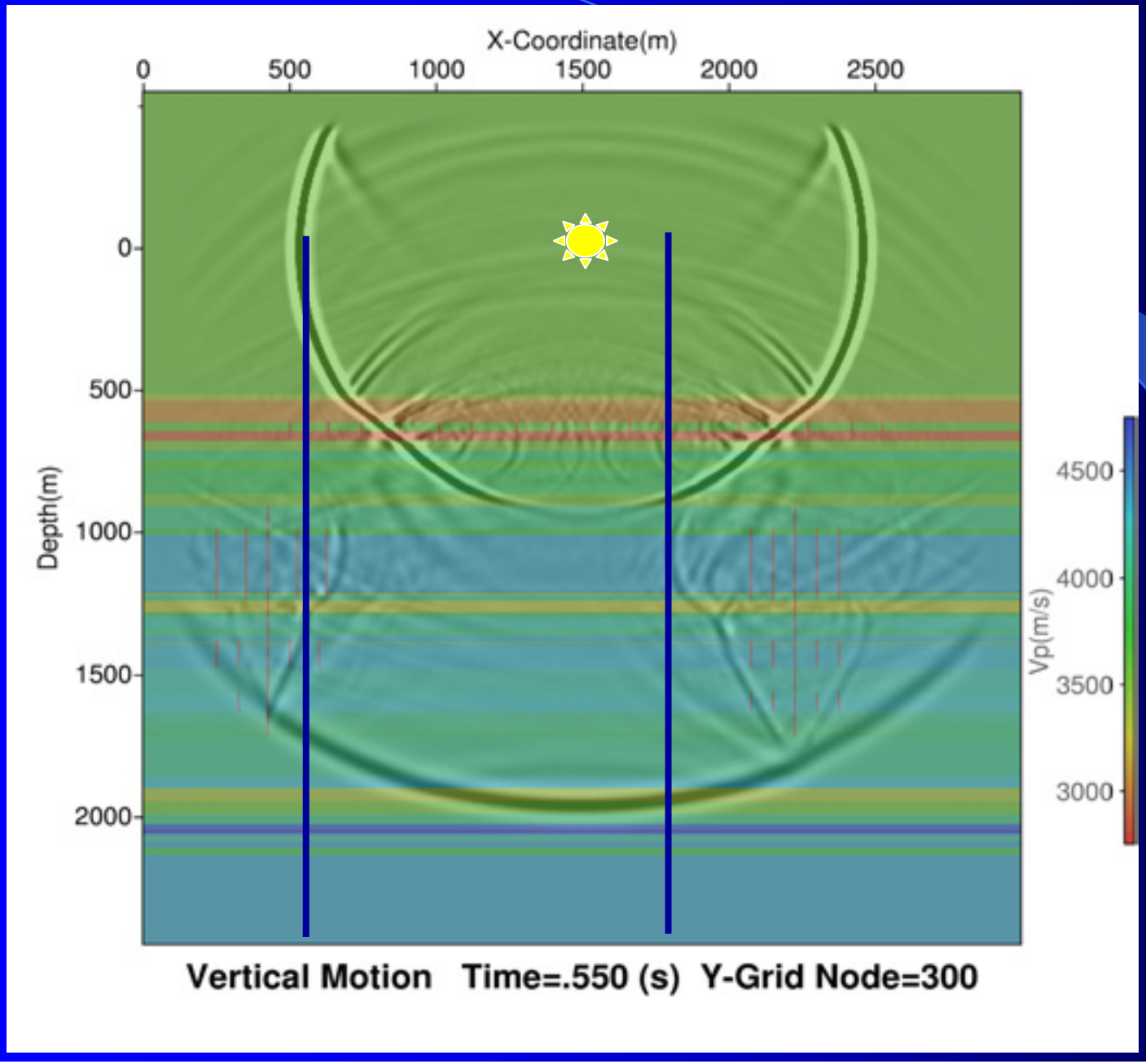







MSEC
170
192
SAND-RICH
SHALE-RICH
Area of VSP Source Locations
VSP Well
N
ISOCHRON MAP, GREENHORN TO ENTRADA, SE FAR
0 2200 4400 6600 8800 11000 FT

3-D Finite Difference Modeling

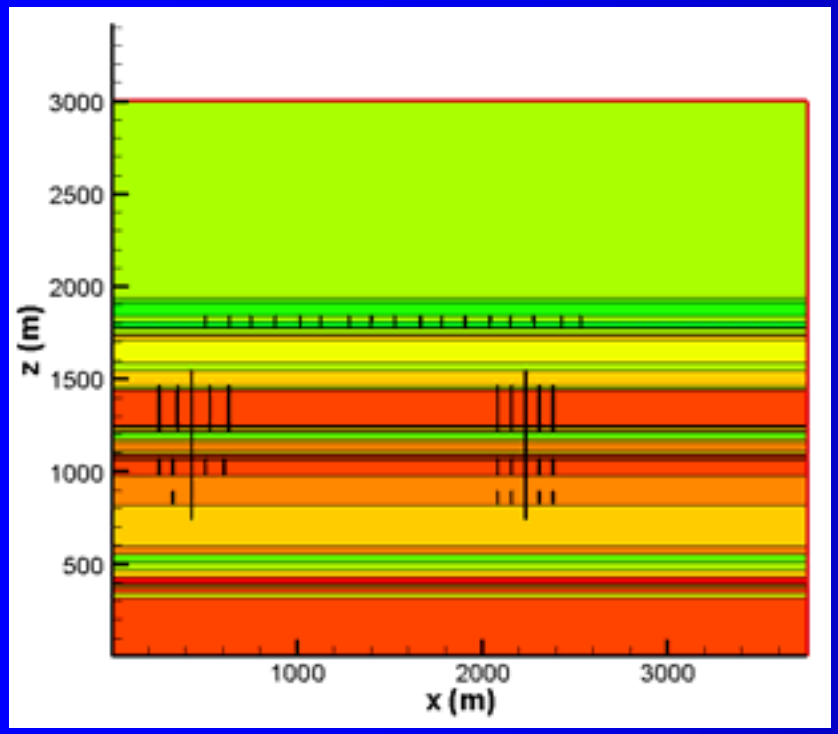


Source Location

Intermediate and far Offset VSP locations

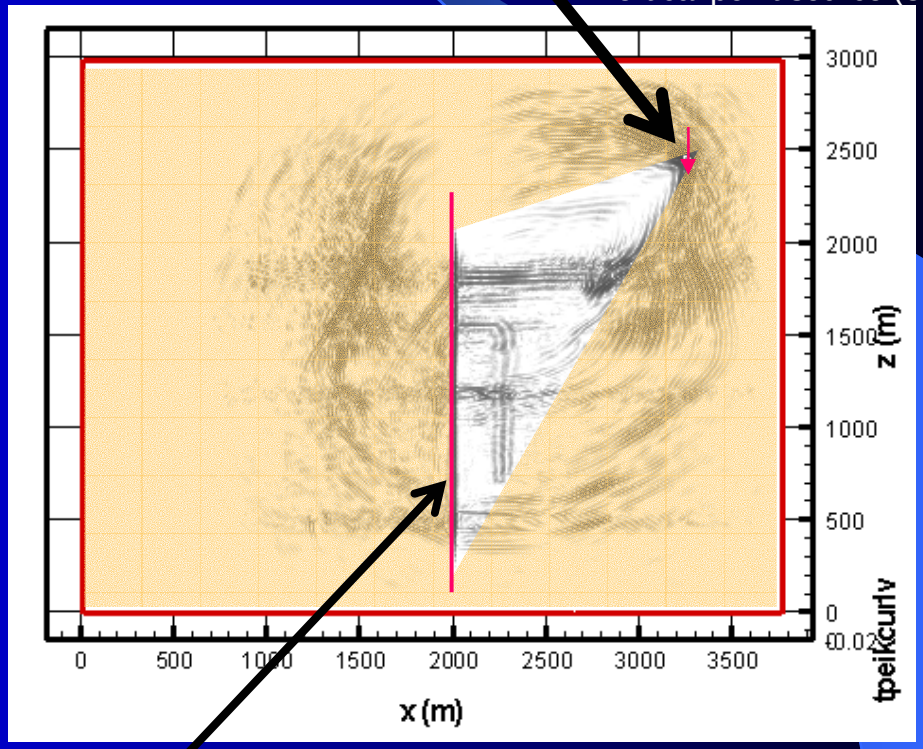
Model 103 San Juan Synthetic VSP

45 Layer Model



Converted Wave Reverse Time Migration (curl(v)@t_P)

vertical point source (30 Hz)



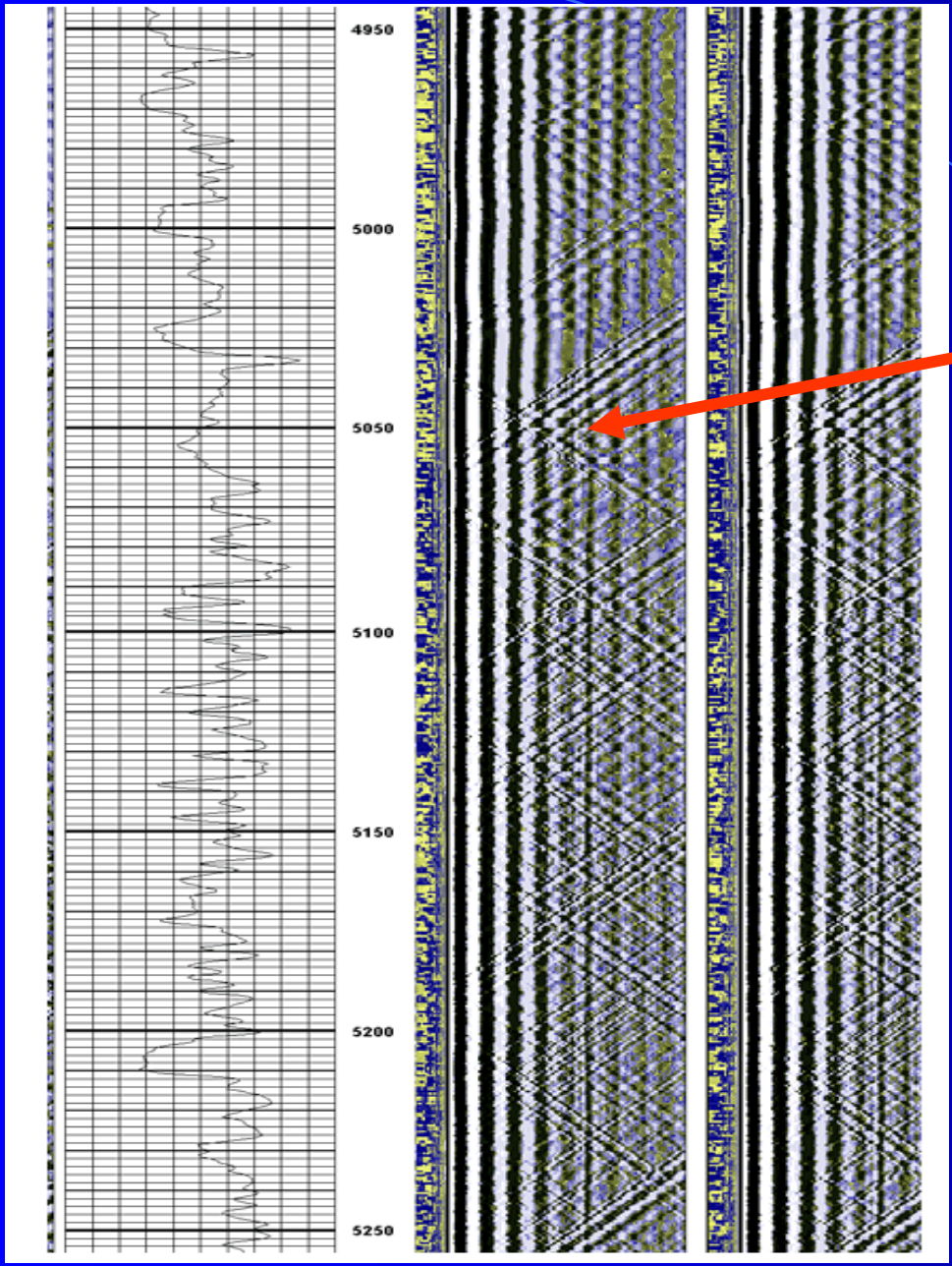
145 2-component particle velocity receivers

Note: used smoothed velocity model for RTM.

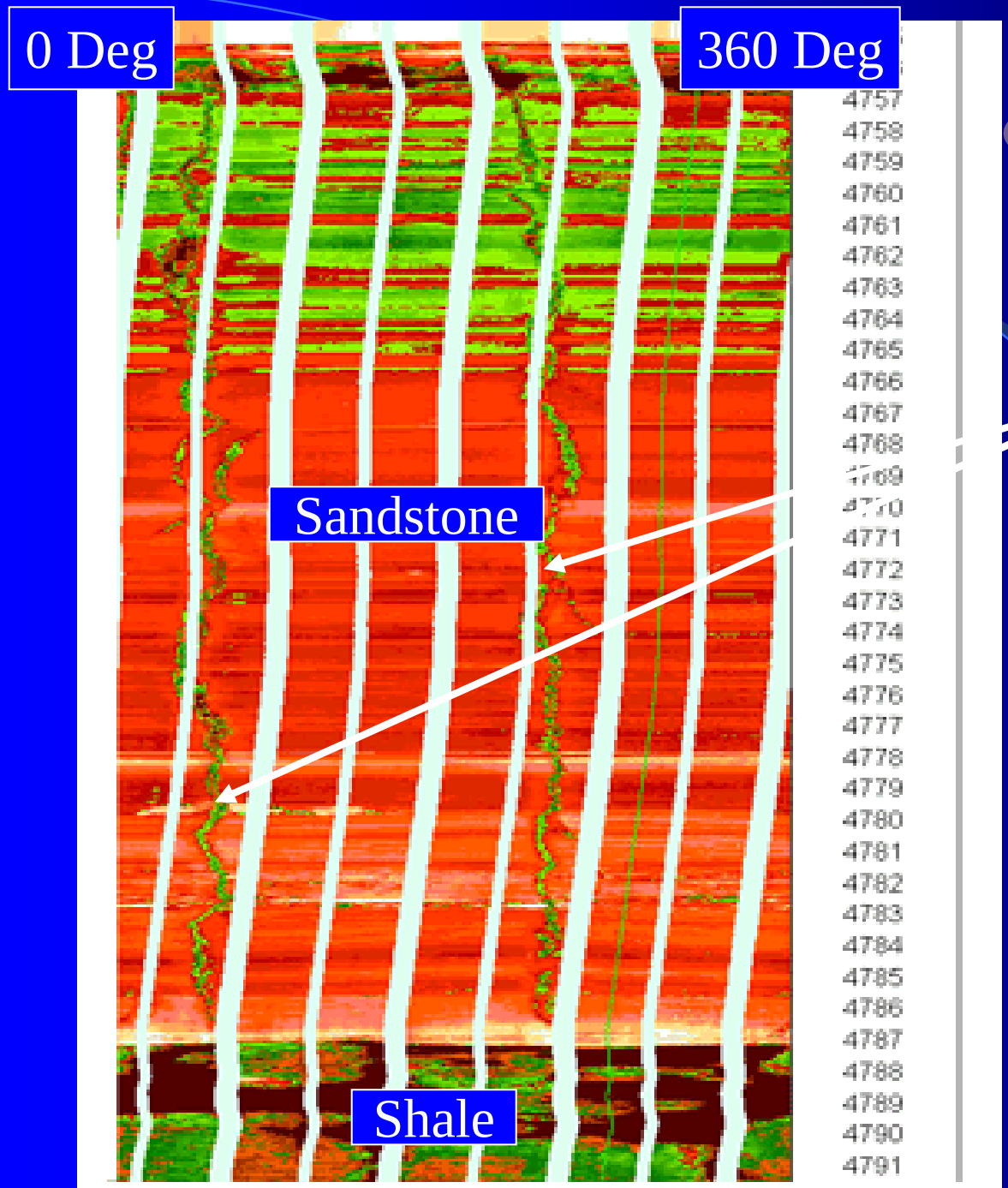
Well Log Results

- **DSI shows significant splitting in the following depth ranges**
  - **4250-4450 ft, fast direction N45E**
  - **4900-5200 ft, fast direction N30E**
  - **5250-5800 ft, fast direction N50E**
  - **5900-6300 ft, fast direction N60E**
  - **6500-6650 ft, fast direction N70E**

- **The Stoneley log shows big chevrons in many places – mainly they are wash-outs, breakouts and induced fractures, or bedding the most significant depths are**
  - **4125-4325, 4475-4600, 4675-4900, 5050-5600, 6550-6650, 7000-bottom of log at 7075 ft.**
  - Few fractures detected in zone of VSP and Single Well with well logs

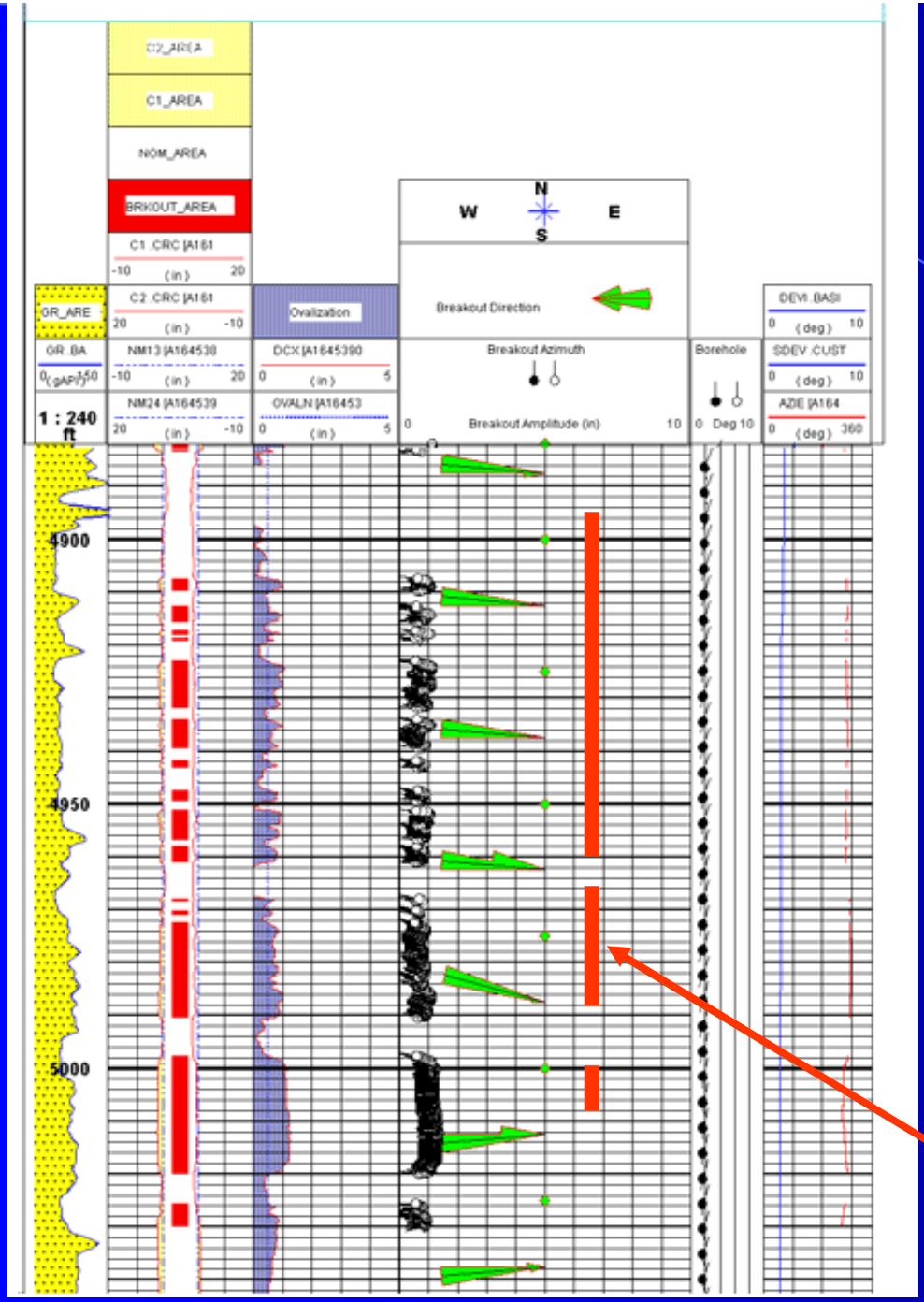


- Stonely Logs
  - Chevrons are reflections off of discontinuities



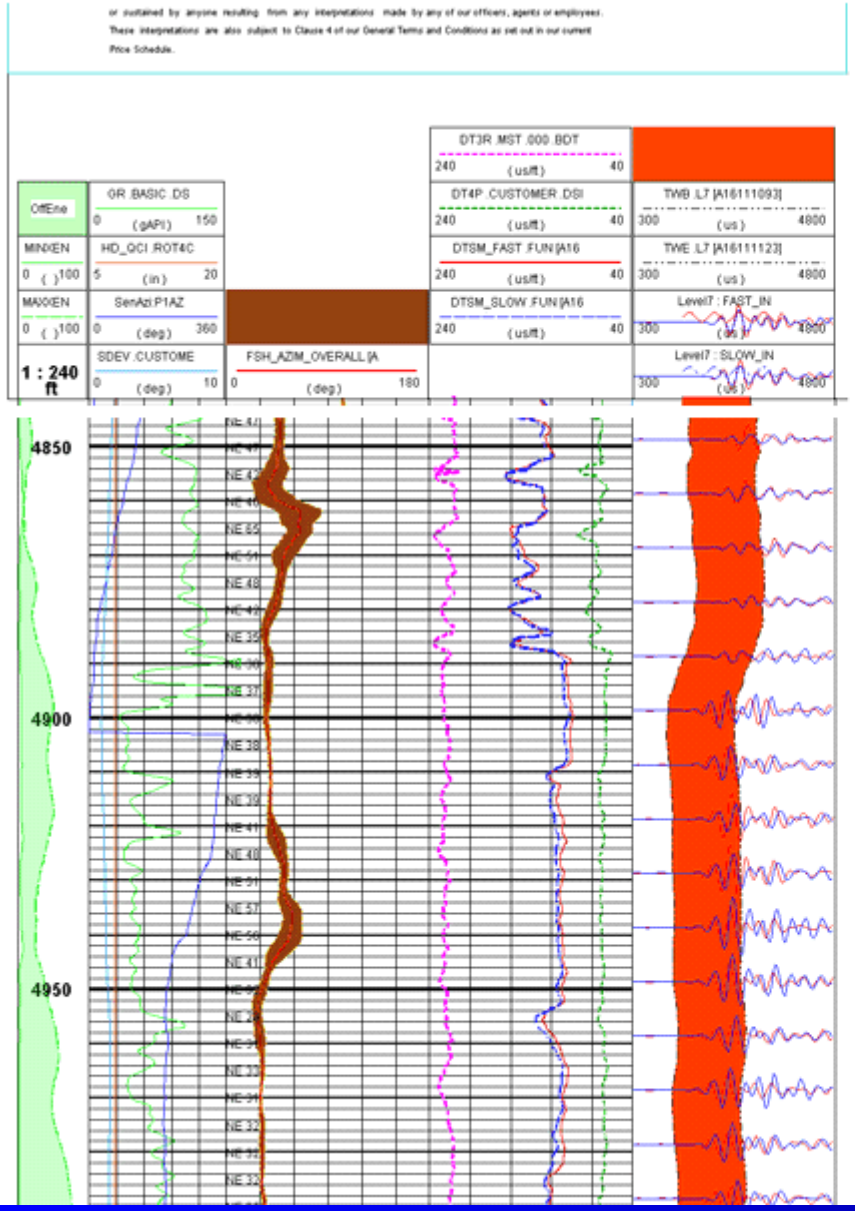
- FMI Logs

Drilling induced Fractures (N 30 deg E)



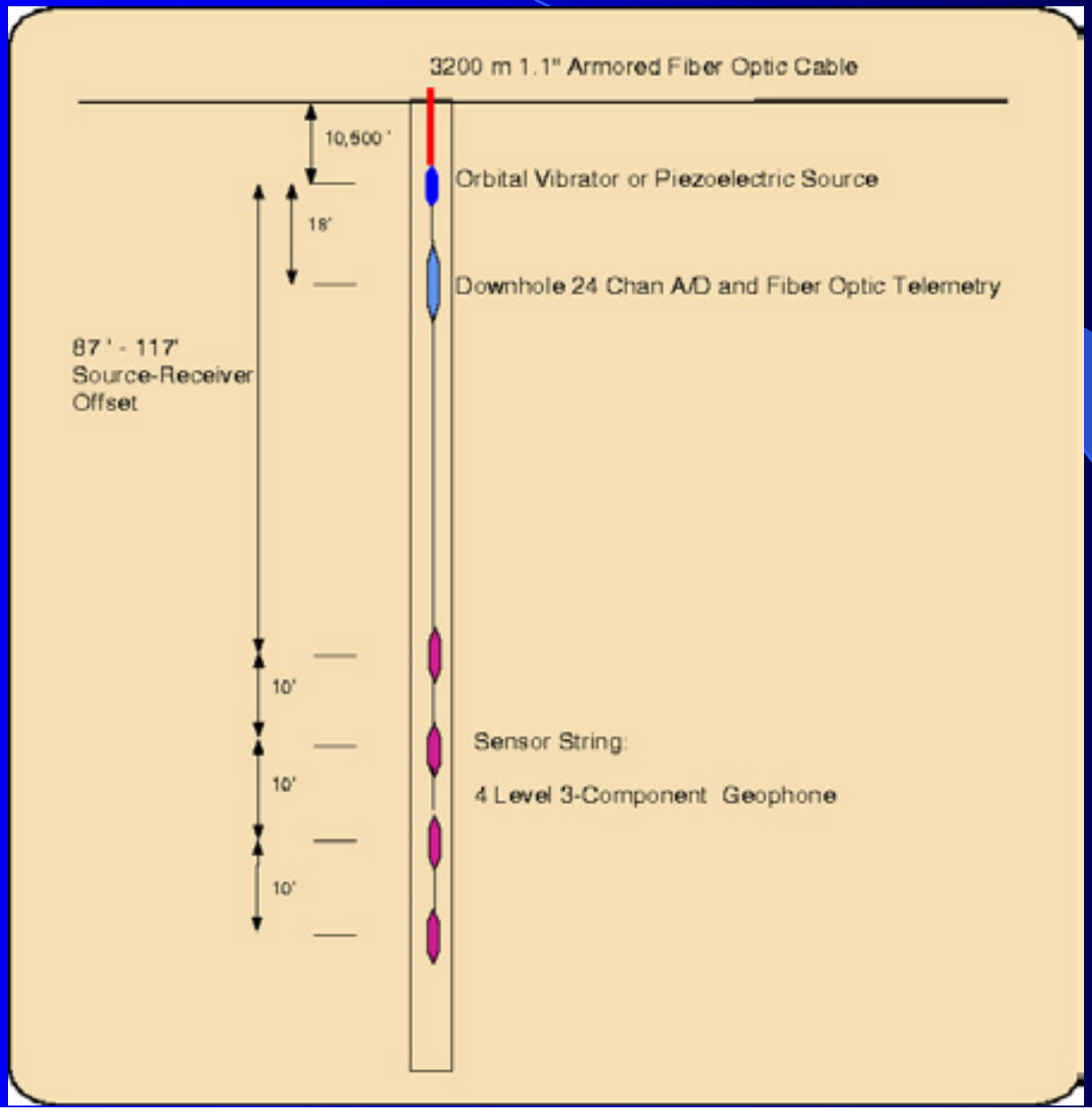
- Gamma Ray
- Breakout direction (E-W)
- Ovality
- Breakout direction (north up)

Perforation Zones



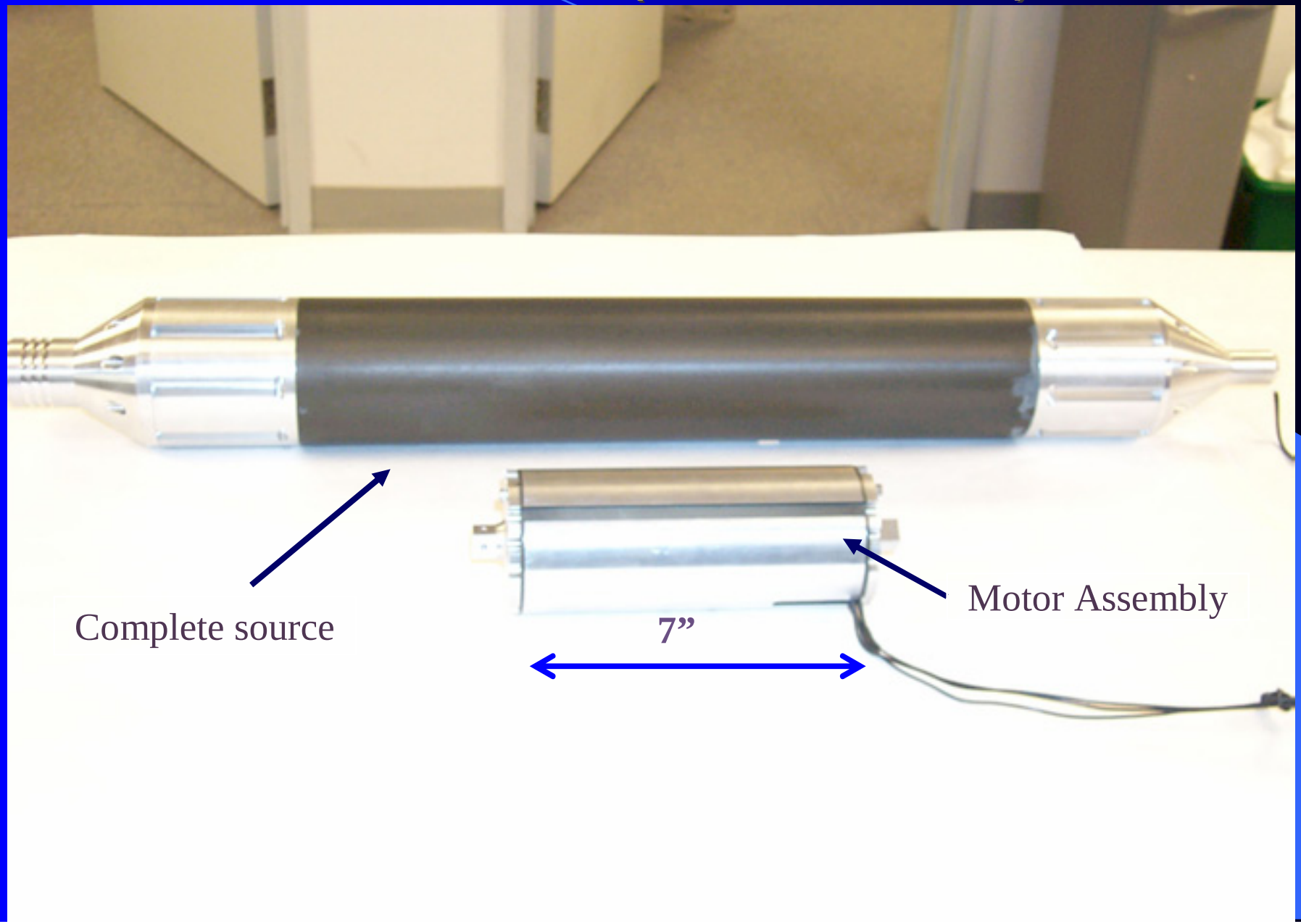
DSI Log Anisotropy NE 30 (fast)

Single Well Equipment Geometry



Tube wave Suppressor with Single well tools

New source (3.5“, 1000 Hz)



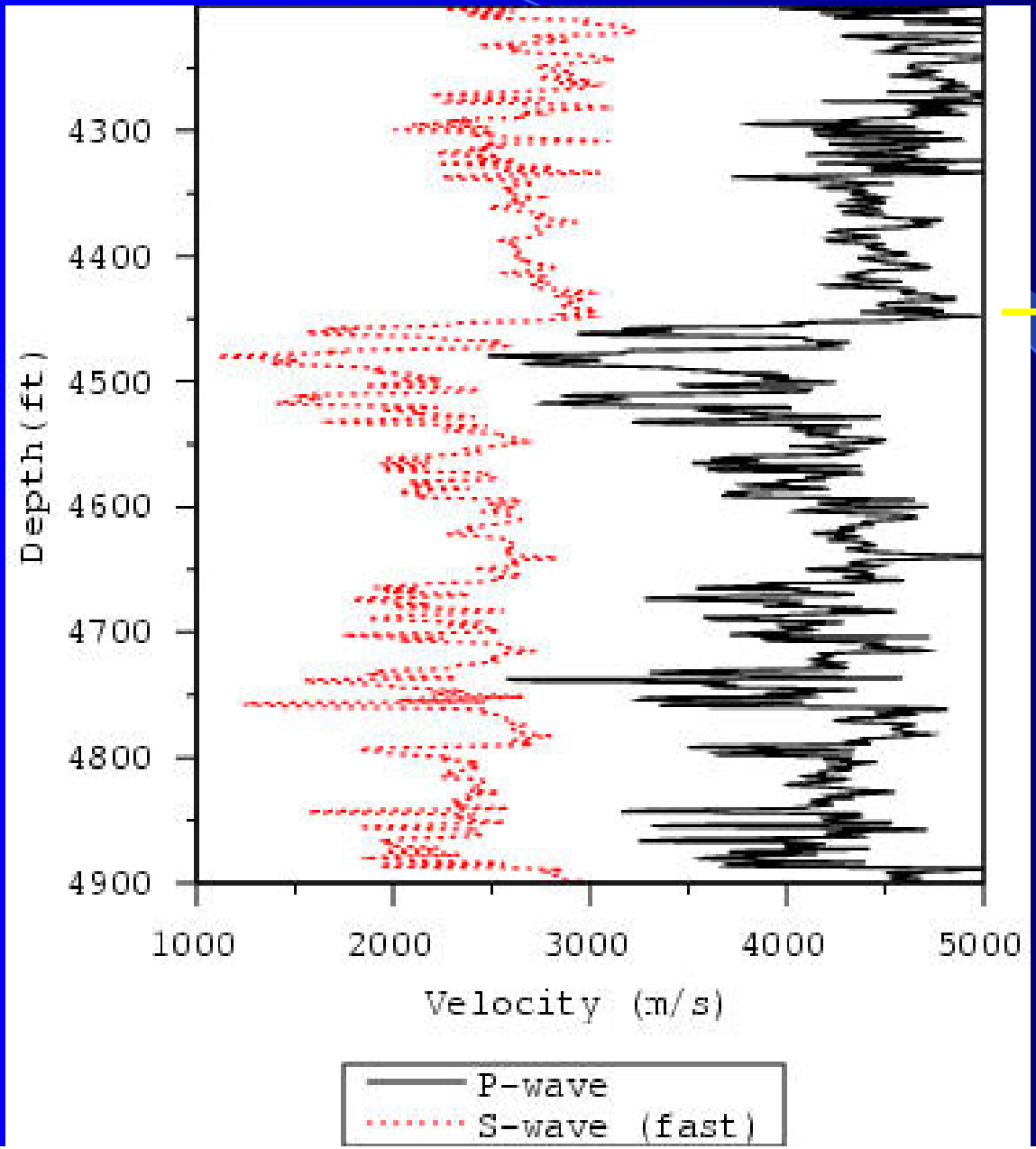
Single Well Survey

Limited high frequency piezoelectric/hydrophone data

Orbital Vibrator – 3-Component Geophone data:
Source Depths 4900’ – 4245’ at 5’ intervals
4 Geophones per shot at offsets 87, 97, 107, 117 feet

Source receiver coverage to 5017 depth

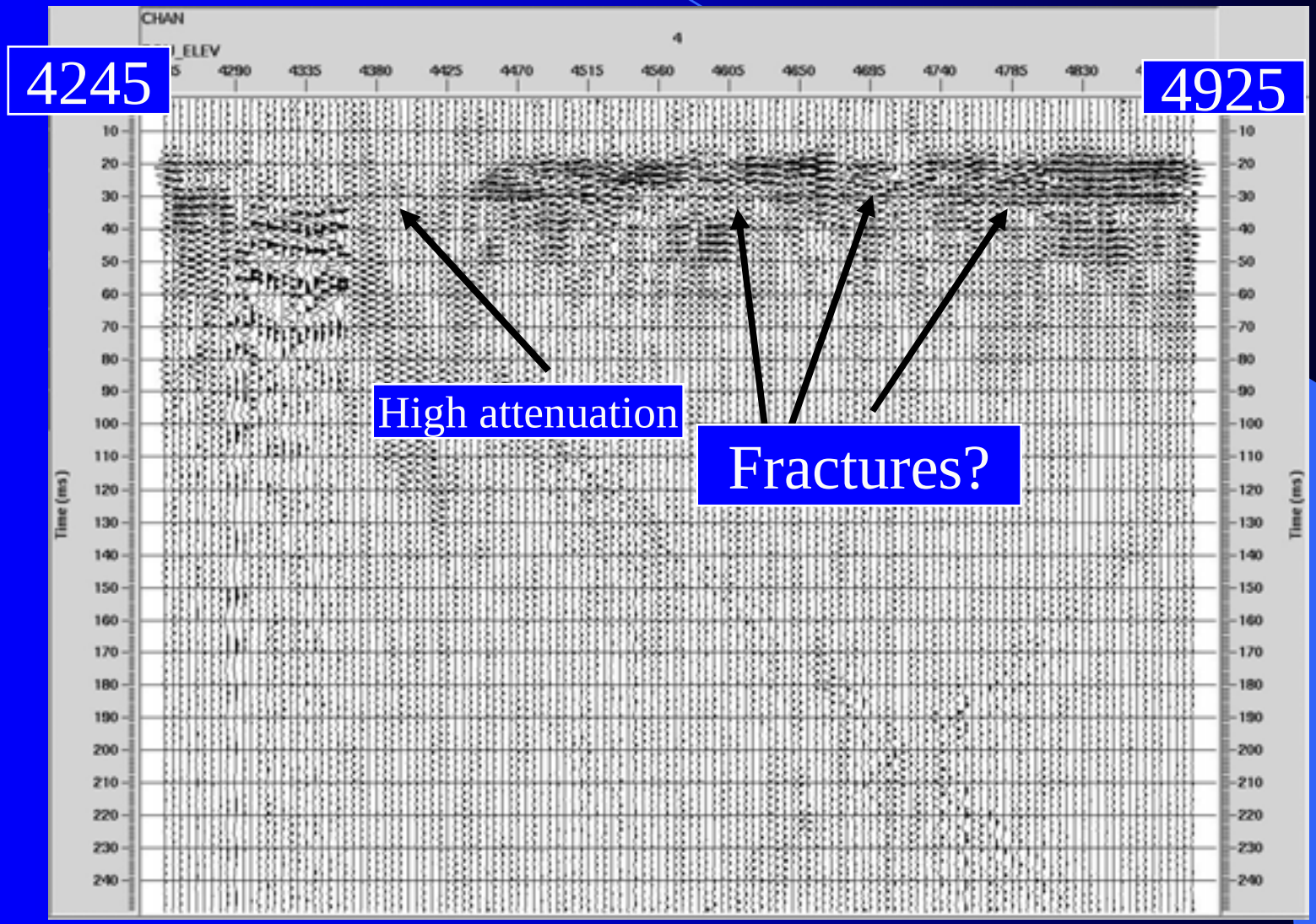
Sonic Log (P and S) in Single Well Depths



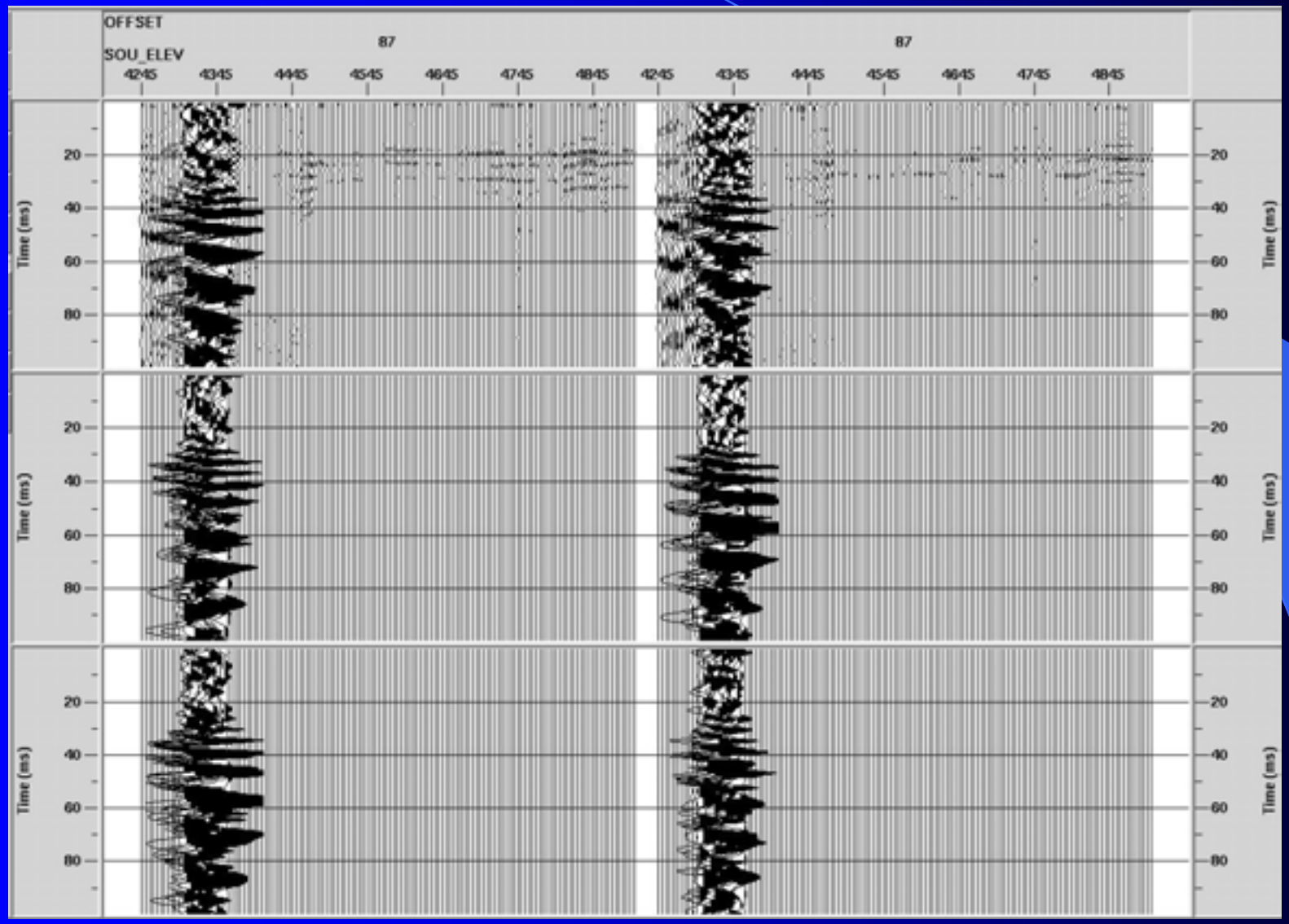
Cliffhouse

Menefee

OV-Geo Chan 4 (H1), CDP Stack



True amplitude 6-C Offset Gather



Sensor: Vertical

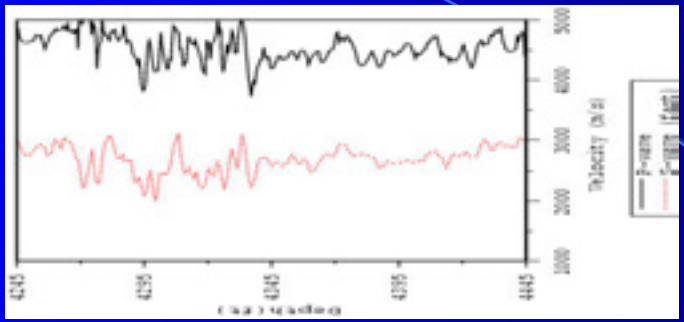
Horiz 1

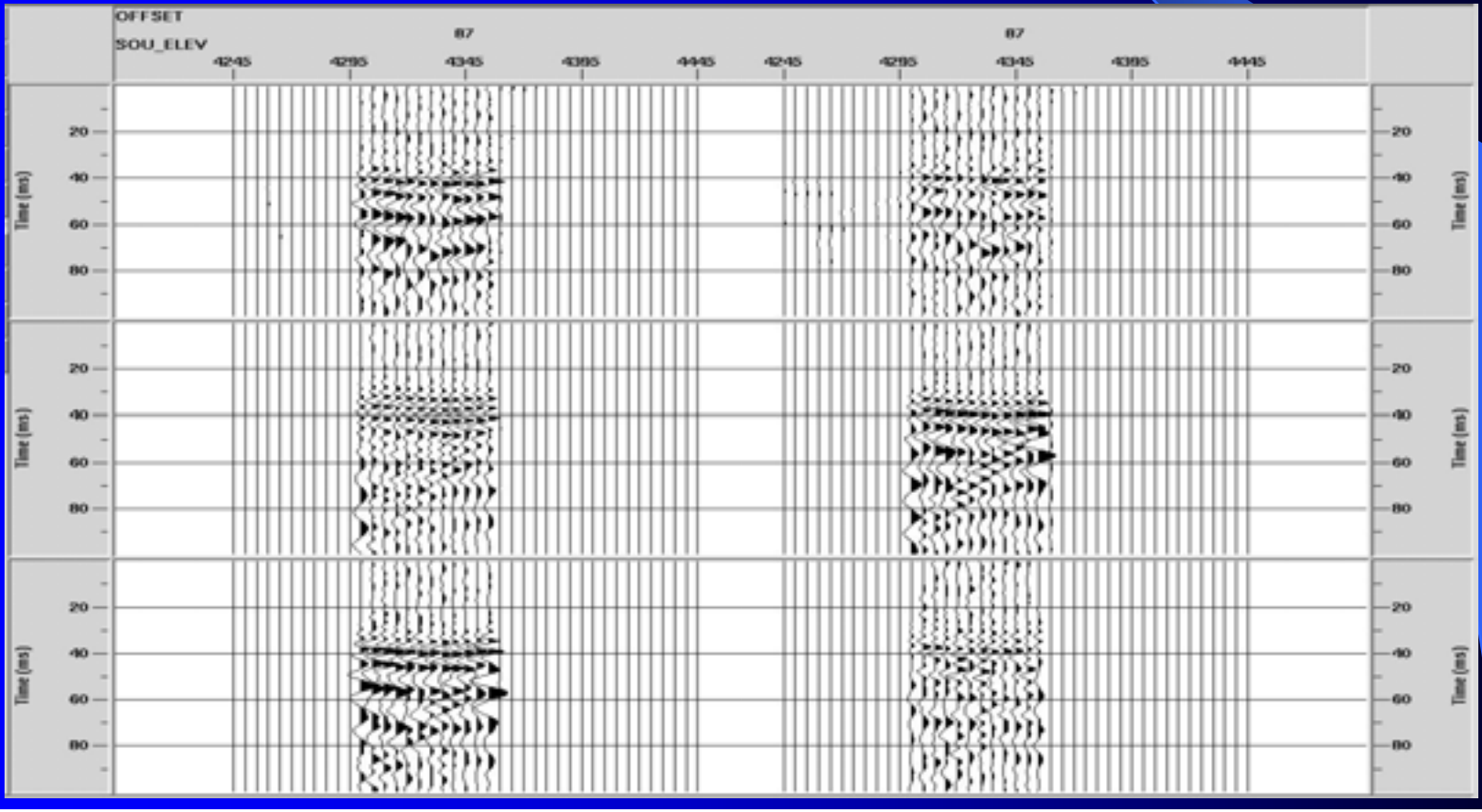
Horiz 2

Anomalous zone with sonic log: Formation velocity does not explain anomaly

P-vel

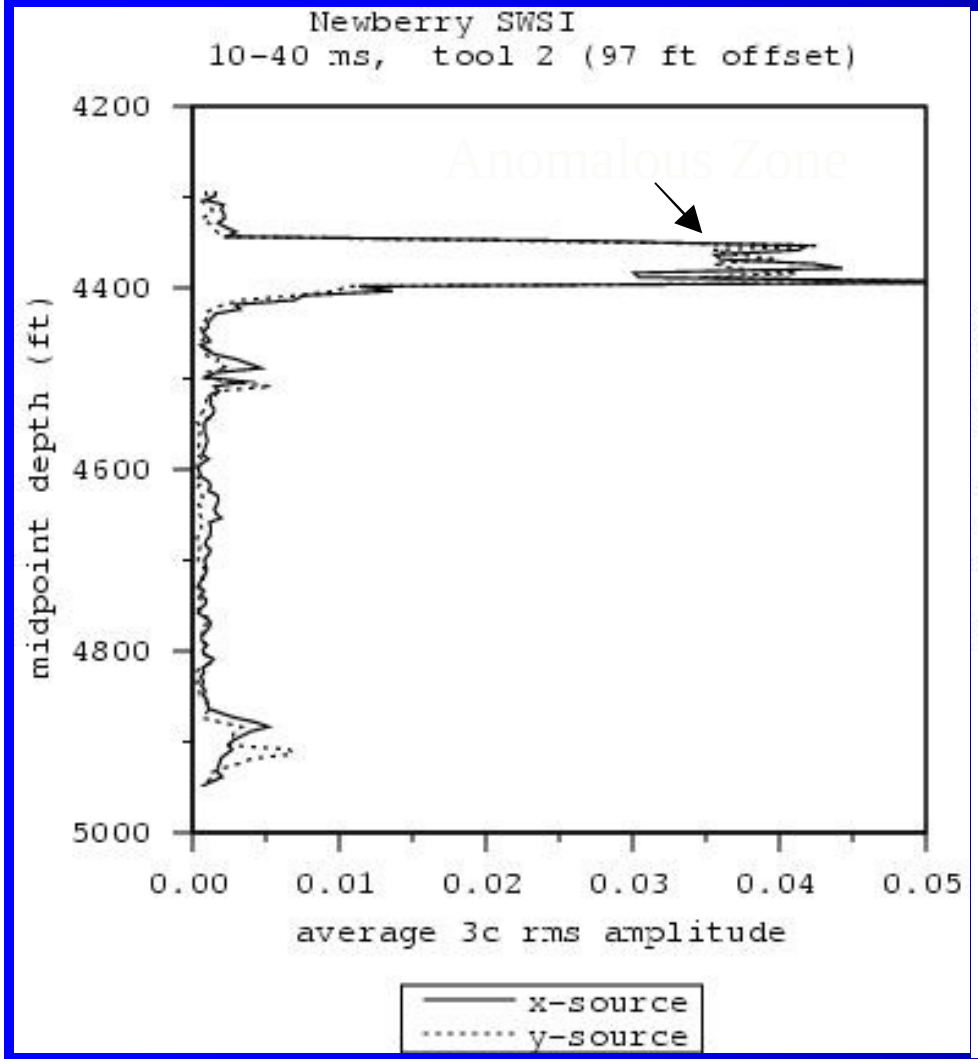
S-vel

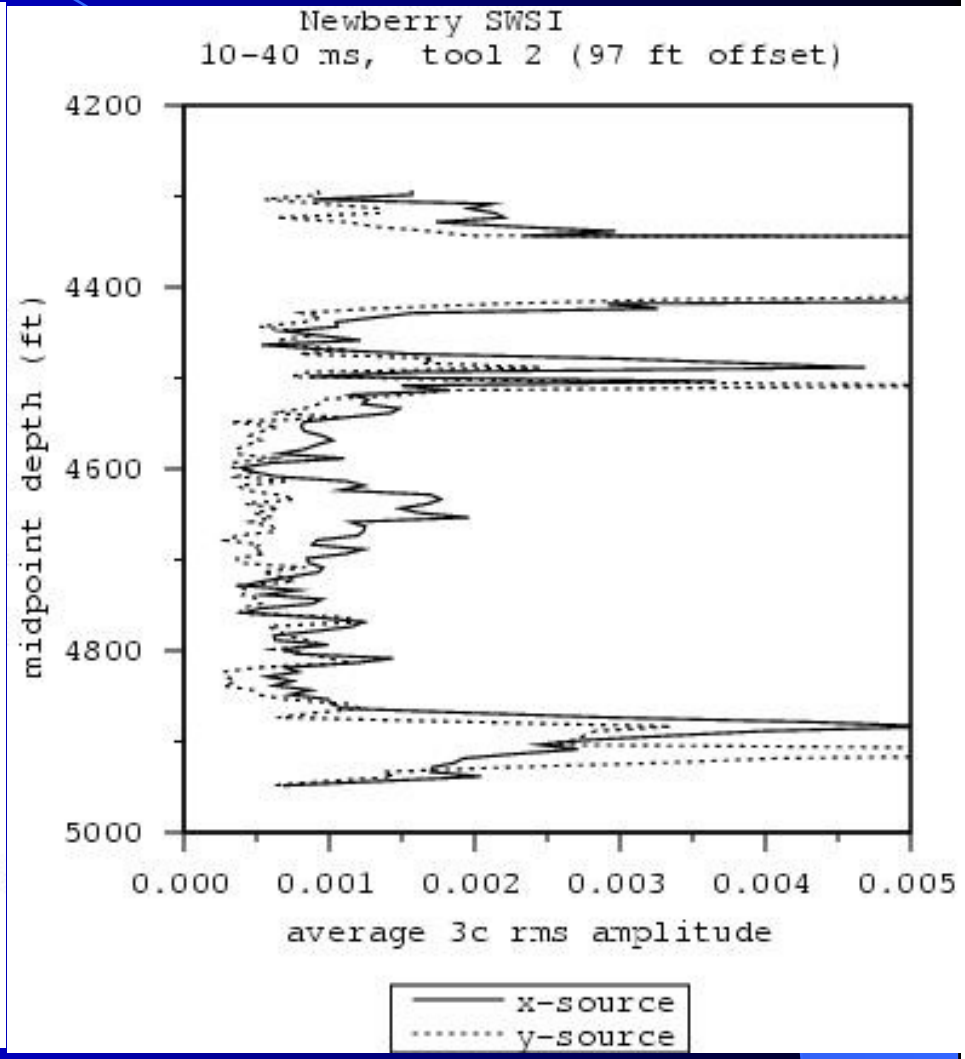


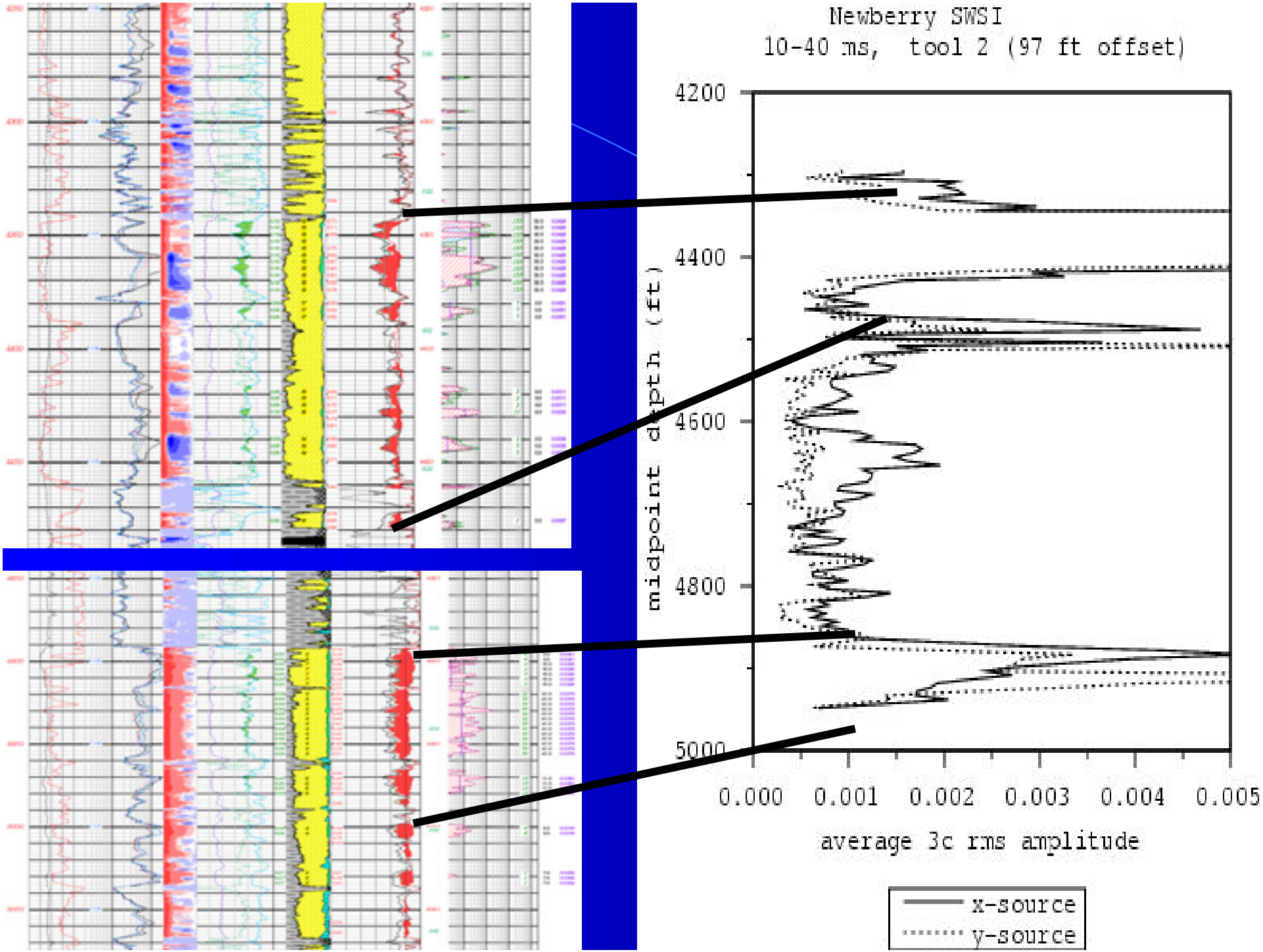


SWSI RMS Amplitude

Full Scale **Zoom x10**



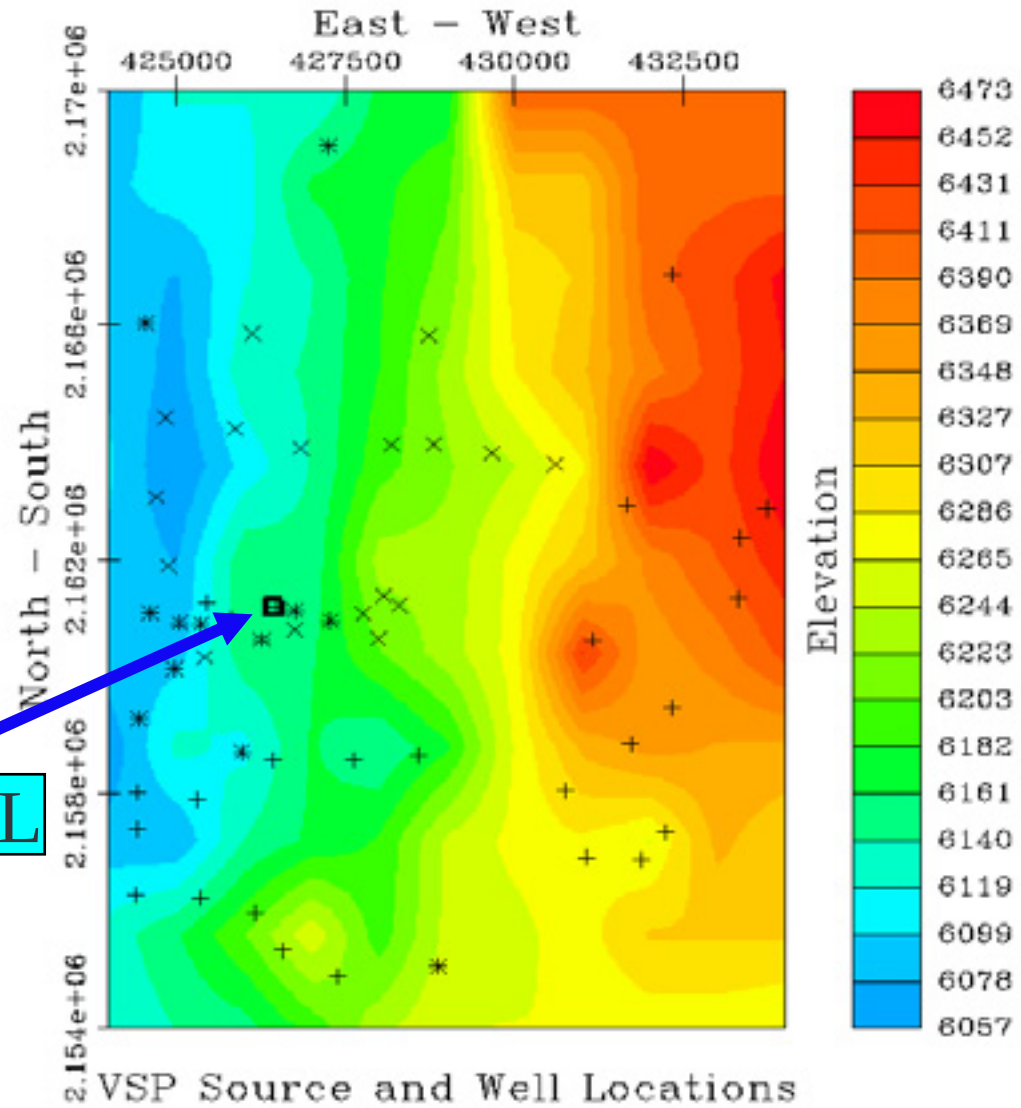



Newberry SWSI
10-40 ms, tool 2 (97 ft offset)
4200
4400
4600
4800
5000
midpoint depth (ft)
0.000
0.001
0.002
0.003
0.004
0.005
average 3c rms amplitude
x-source
y-source

3-D VSP Shot Points

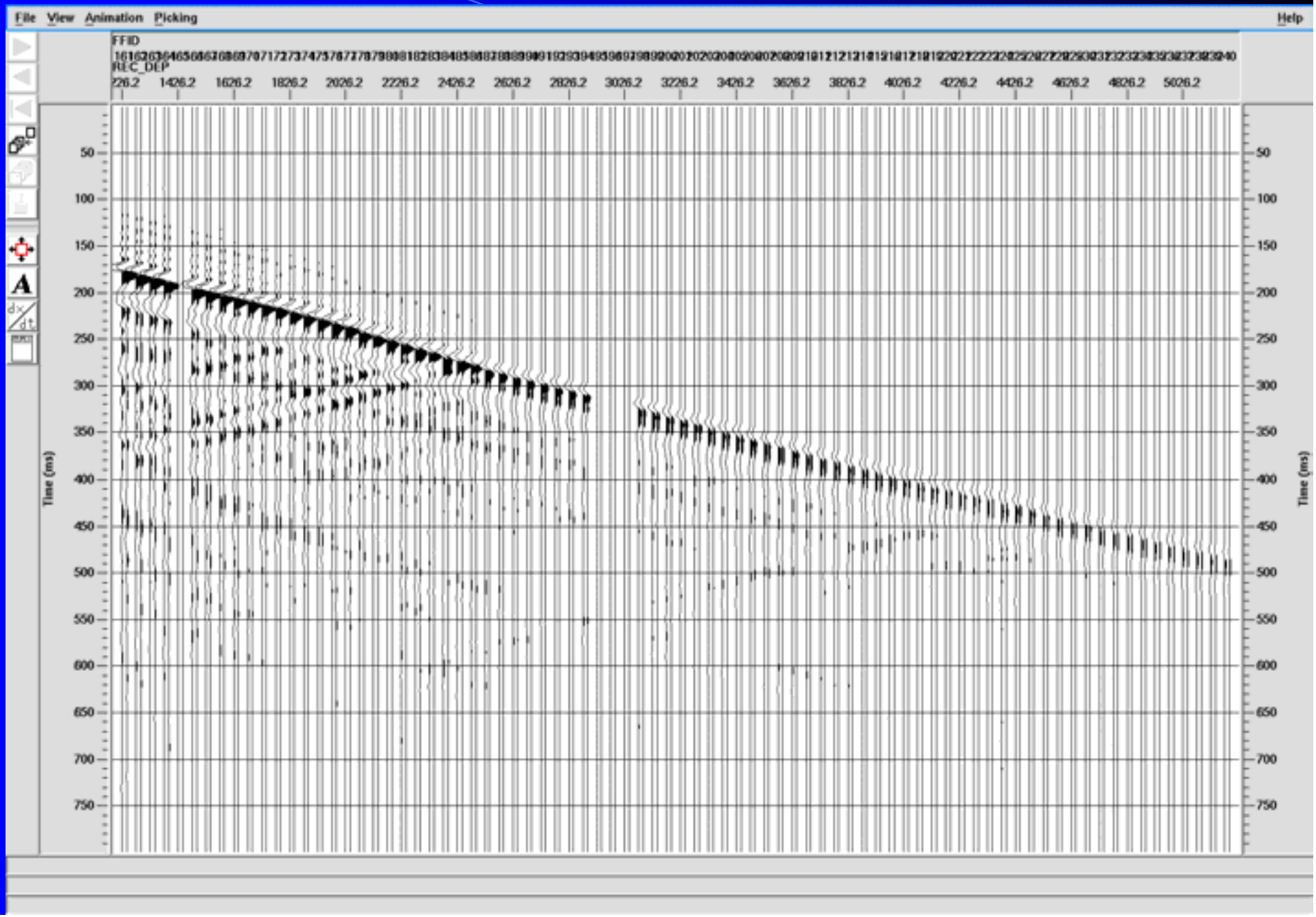
+ - I O Vib
x - IVI Vib
■ - receiver

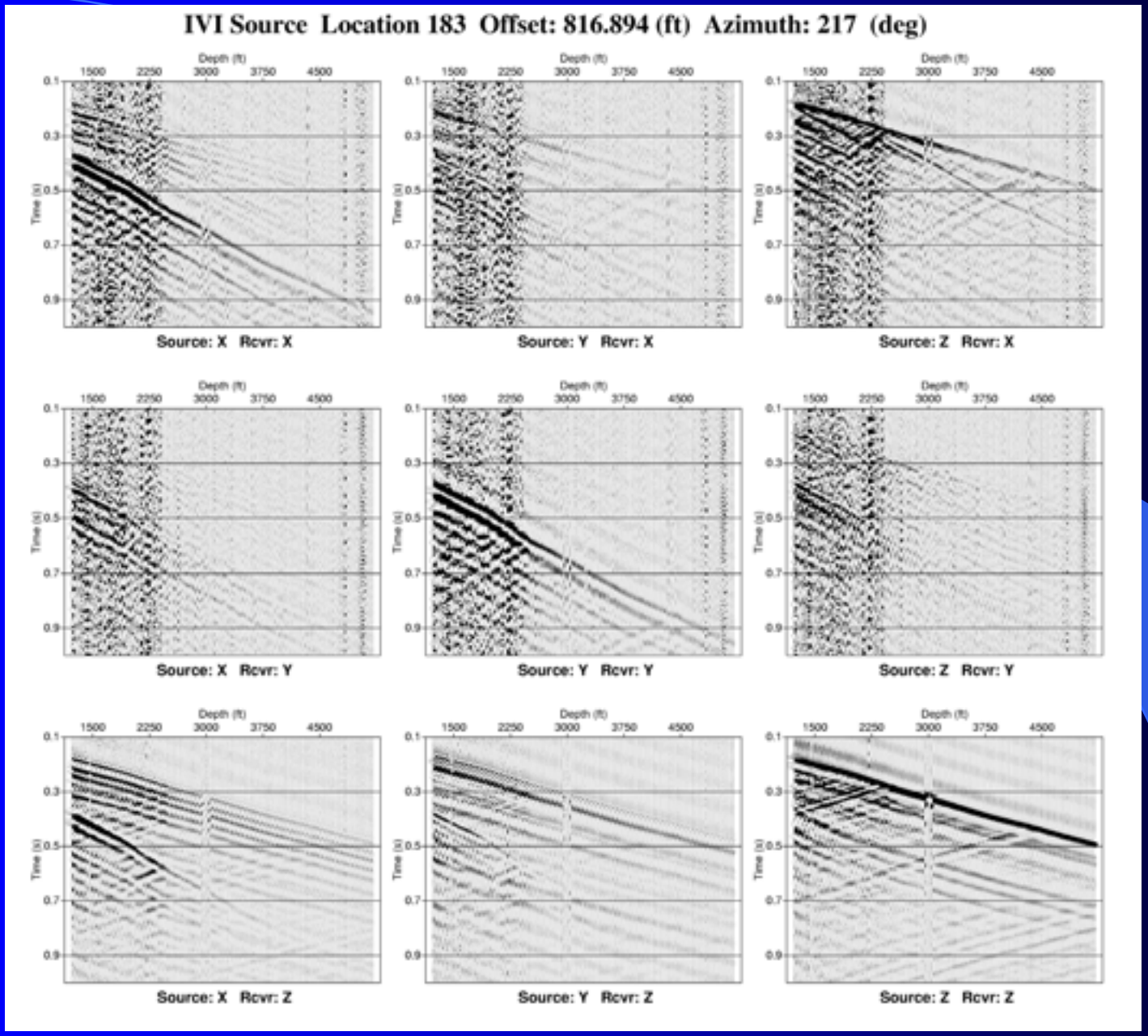
VSP WELL



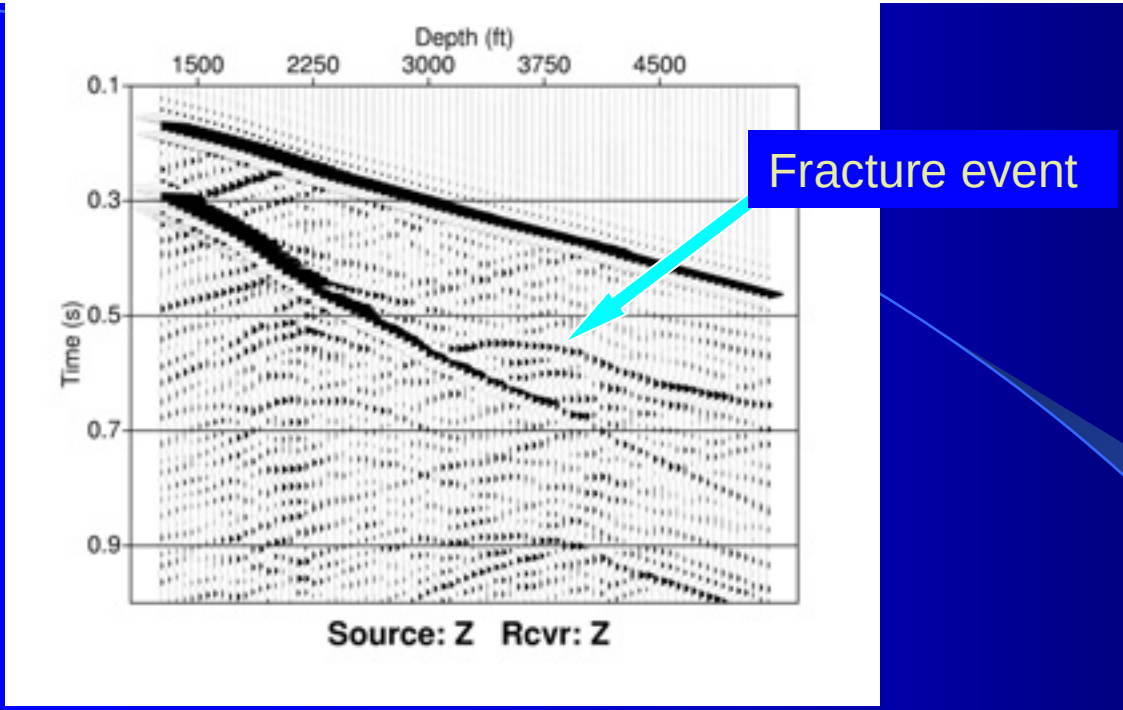
coxvd, Fri Sep 13 15:08

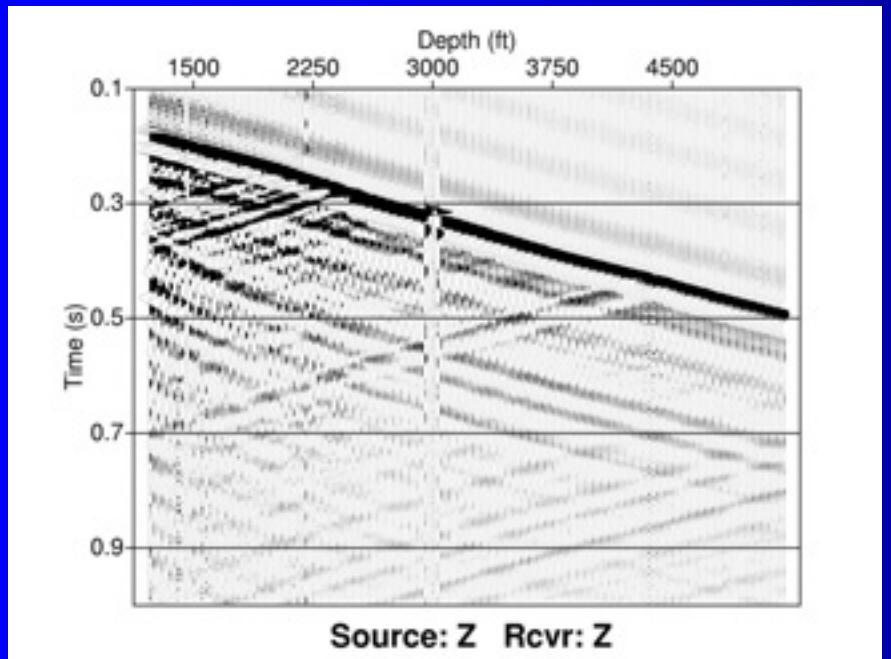
IO-IVI Trace Comparison filtered to 10-90 Hz





Intermediate Offset Data Example



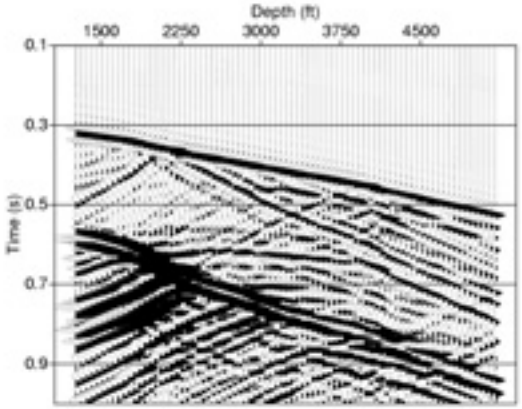


Synthetic and Field Data Comparison for Intermediate Offset

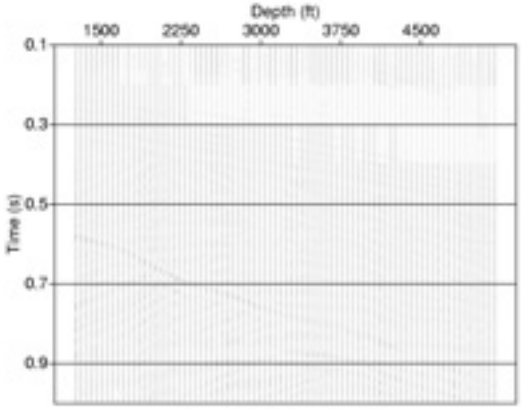
Z-Z Components

Synthetic and Field Data Comparison for Far Offset

Synthetic Z Source grid: 110 300 Offset: 3116.8 (ft) Azimuth: 89 (deg)



Source: Z Rcvr: X



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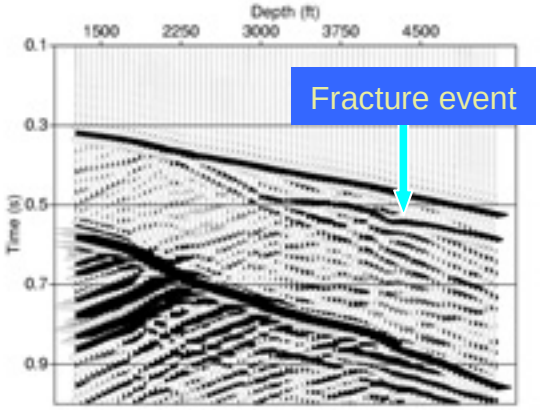
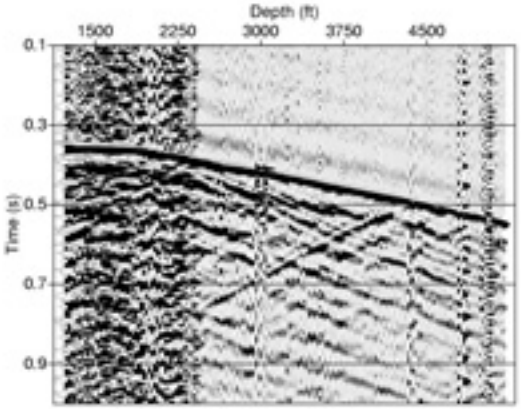
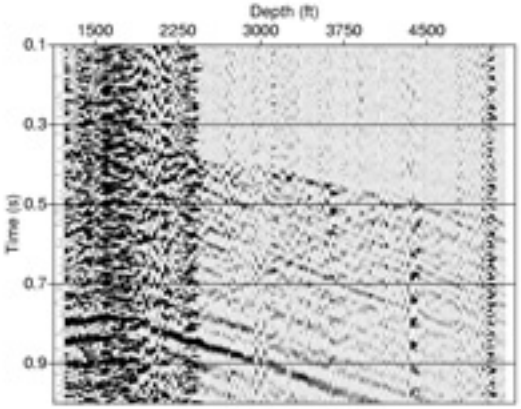


Source: Z Rcvr: Z

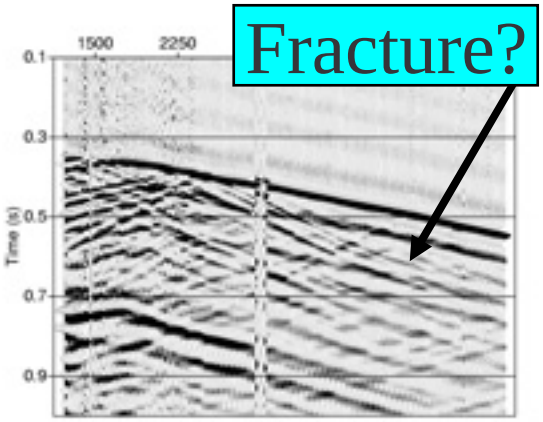
IVI Source Location 187 Offset: 3110.6 (ft) Azimuth: 348 (deg)



Source: Z Rcvr: X

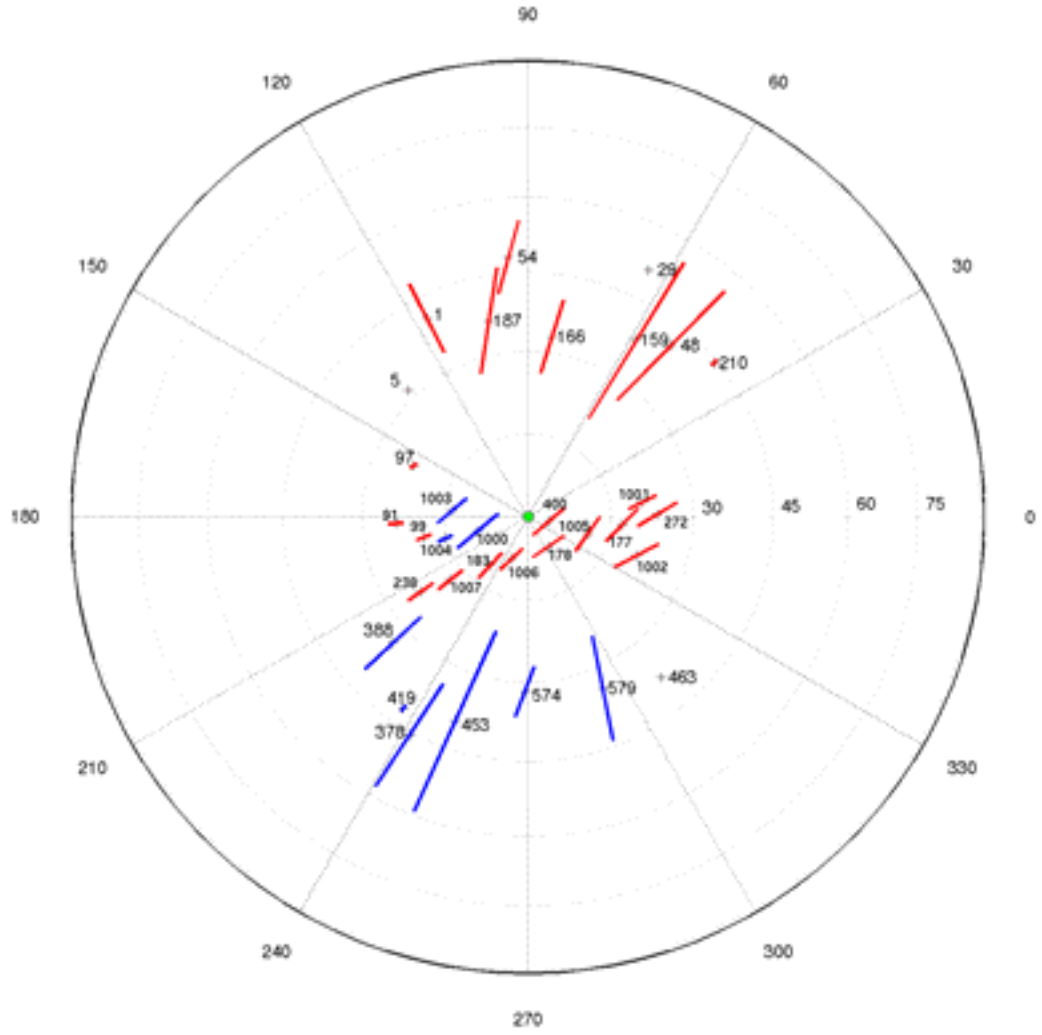


Source: Z Rcvr: Y

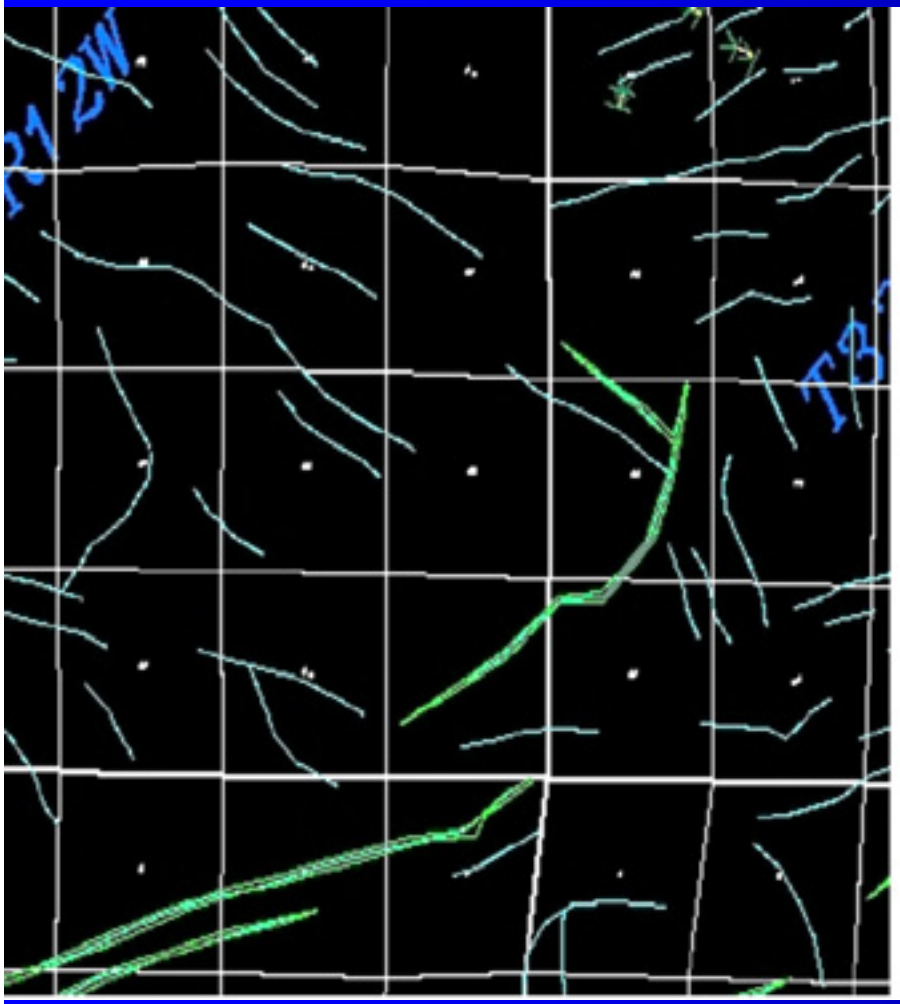


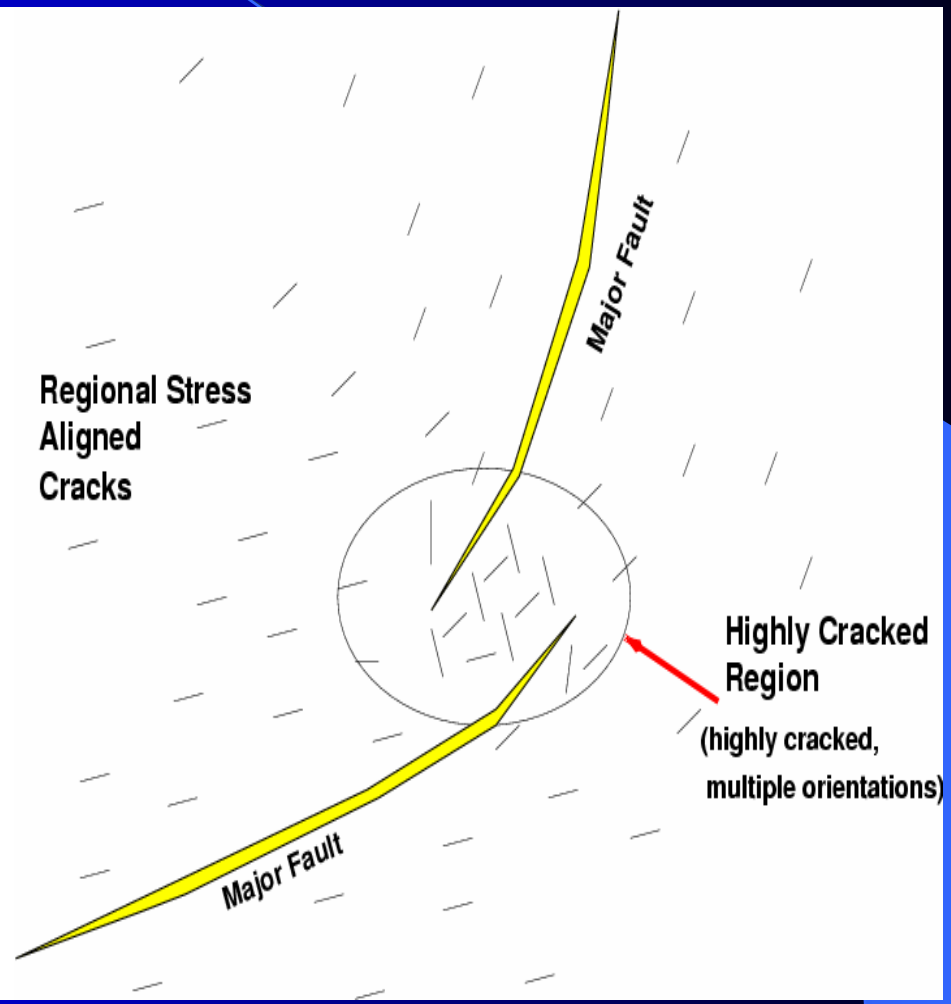
Source: Z Rcvr: Z

VSP Shear Wave Splitting Analysis



Possible Fracture model that matches observation





Summary/ Future Work

- **VSP/Single Well Data Analysis indicates complexity**
  - **Anisotropy analysis (LBL/ConocoPhillips)**
  - **Time-frequency analysis (LBL/EAP)**
  - **Discrete fracture analysis (LBL)**
  - **P-wave imaging (Stanford)**
- **Modeling(LBNL/ConocoPhillips)**
  - **Incorporate well log fracture results**
  - **More source offsets**
- **Reservoir simulation (Schlumberger)**
  - **incorporate fractures from field data into model**
  - **simulate data**
  - **compare to actual production**
- **<u>This is "one data point", need to test at other sites combining surface and borehole surveys</u>**

Anticipated Products and Benefits

- Greatly advanced commercially available technology to quantify fracture properties in gas reservoirs
- Advancement and optimization of current 3-D seismic technology
- Leap to true 3-D subsurface imaging using seismic methods
- Improved links with reservoir modeling technology for fracture characterization

Acknowledgements

- **ConocoPhillips Inc.: John Queen, Jim Murphy, Mark Fortuna, Peter Eike, John Sinton, Peter D'onfro Alan Huffman**
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- **Stanford University: Jerry Harris**
- **Virginia Tech: Mathias Imhoff**
- **British Geological Survey, Enru Liu**
- **Lawrence Berkeley National Laboratory: Tom Daley, Dale Cox, Kurt Nihei, Larry Myer, Sagi Nakagowa**
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