[AV]Converted Shear-Wave Seismic Fracture Characterization Analysis at Pinedale Field, Wyoming

By
James E. Gaiser[1] and Richard R. Van Dok[1]

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[1]WesternGeco, Denver, CO

Abstract

Multicomponent 3D surveys where downgoing compressional (P) waves convert to upgoing shear (S) waves at interfaces provide a practical means for analyzing fracture properties. This is particularly important for delineating naturally fractured reservoirs by exploiting the unique characteristics of S-wave azimuthal anisotropy induced by vertical fracturing. In the presence of fractured media, S-waves split into a fast wave that is polarized parallel to fractures and a slow wave that is polarized normal to fractures. The amount of splitting (time difference between the two S-waves) is proportional to fracture intensities. To investigate this phenomenon, we utilize a wide range of source-receiver azimuths in the processing and analyze the fast and slow S-waves to extract fracture information.

A 3D 3-component (one vertical and two horizontal geophones) survey from Wyoming is presented, acquired over the southern tip of the Pinedale field. The targets are naturally fractured gas sand reservoirs in the Lance formation. From the analysis of fast and slow S-waves a regional direction of anisotropy was observed. Layer-based analyses confirmed the presence of azimuthal anisotropy in the overburden, which required compensation during the processing to isolate S-wave splitting properties at reservoir depths. Results from the layer-stripping analysis suggested areas of increased fracturing in the overburden as well as at target levels that are associated with faults over the crest and along the limbs of the Pinedale anticline. Although FMI logs show mostly bedding planes near horizontal dip, at many levels where dip is larger, the dip direction is qualitatively in agreement with the principal S-wave directions.

Converted Shear-Wave Seismic Fracture Characterization Analysis at Pinedale Field, Wyoming

James E. Gaiser and Richard R. Van Dok*

WesternGeco, Denver, Colorado

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WesternGeco

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- John Markert and Jeff Thompson with WesternGeco

Azimuthal Anisotropy: Fractures

SANDSTONE

http://pyrite.igs.indiana.edu/indgeol/reference/

SANDSTONE

(J.Olson)

SANDSTONE

LIMESTONE

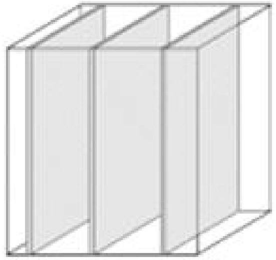
(Roberts 1989)

Fractures tend to be aligned and vertical – stress regime

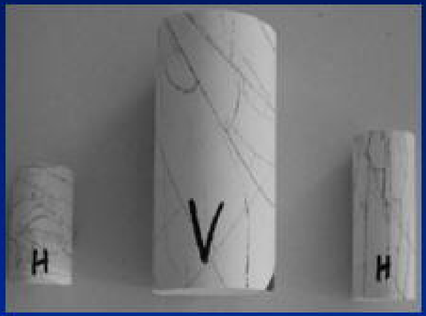
They are smaller than the seismic wavelength

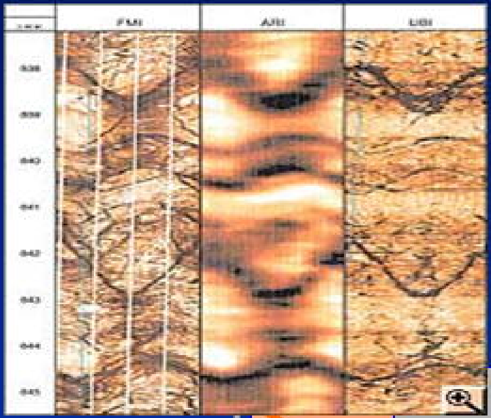
Measure seismic attributes to infer fracture systems

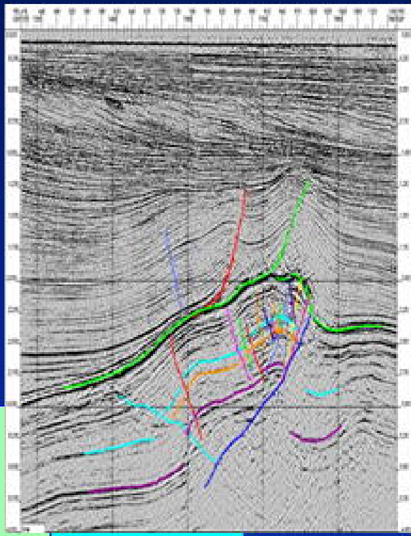
Transversely isotropic with horizontal axis of symmetry (HTI)



Quantitative Measurements of Fracturing



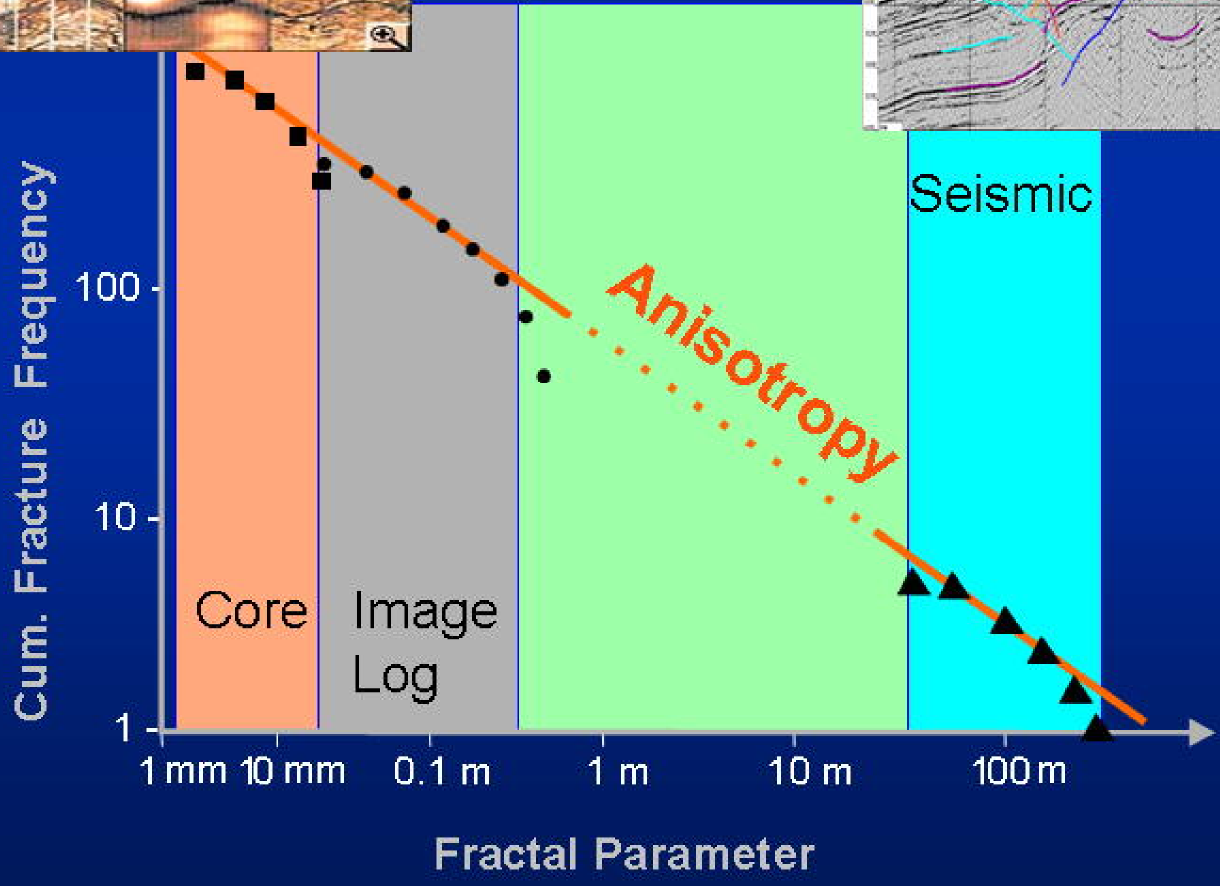




Fractal Diagram

Fractal Properties

- Size / Length
- Clustering
- Displacement
- PD Relationship

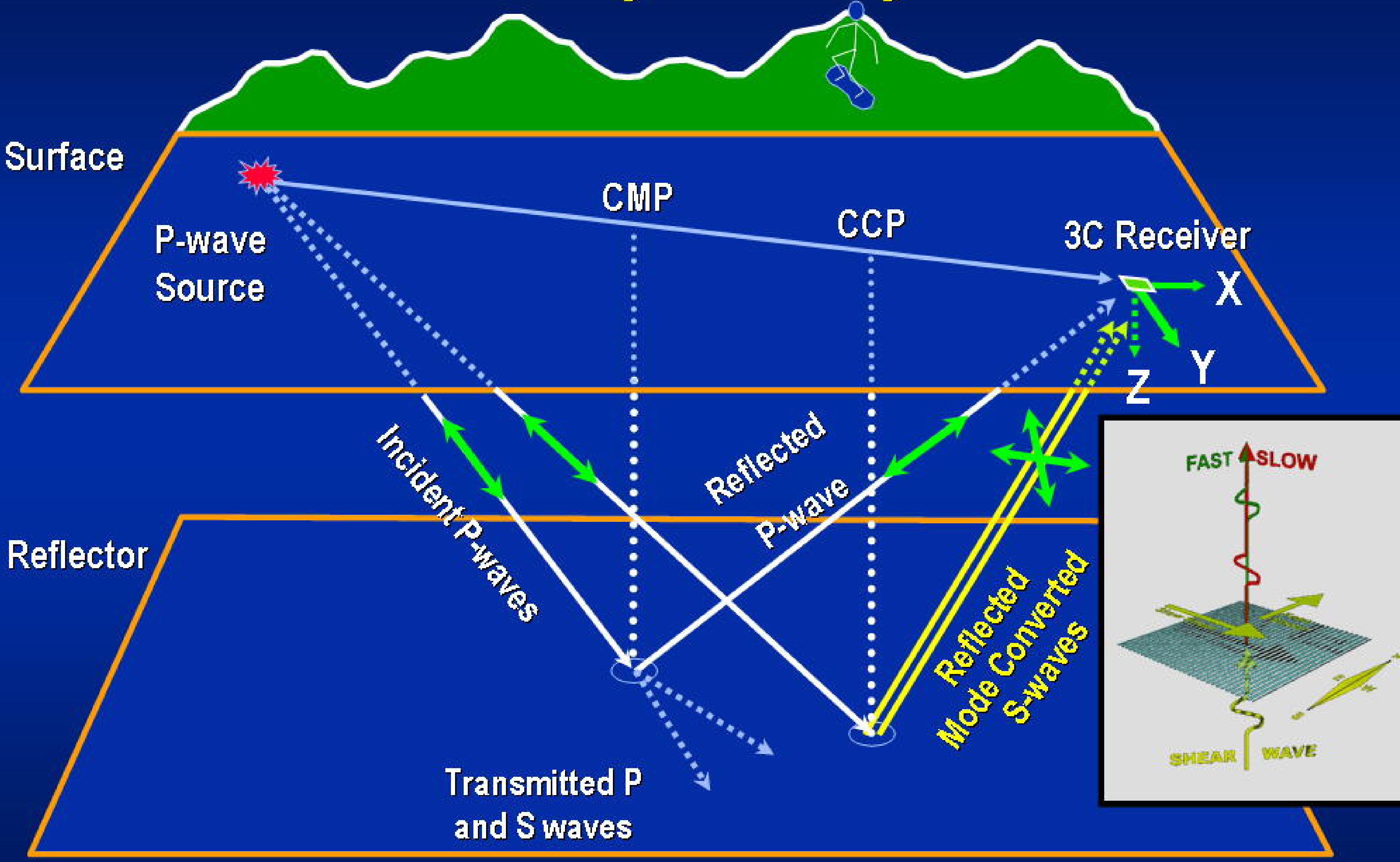


from Mattner (2002)

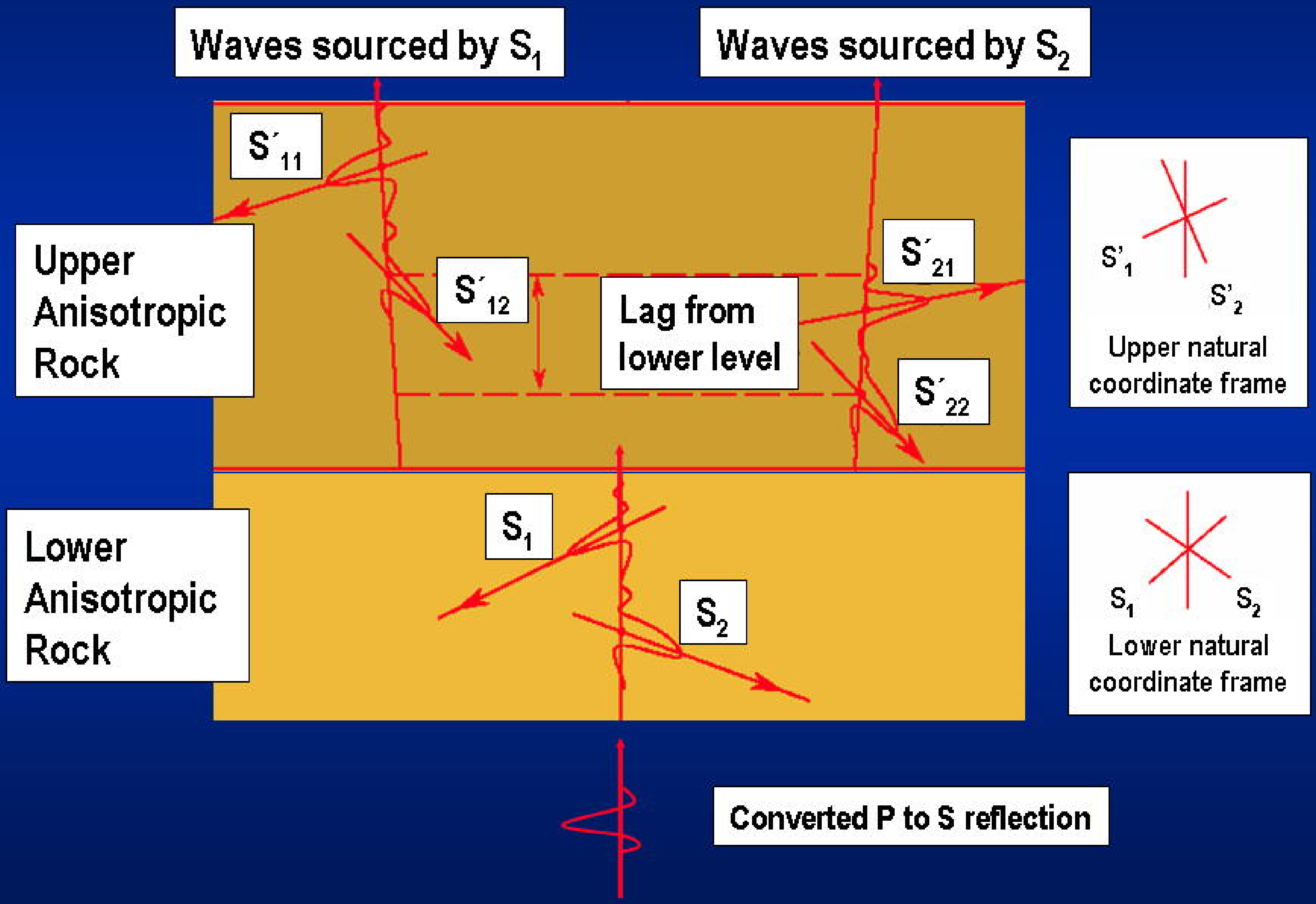
Outline

- Processing and analysis highlights
- Pinedale Field case study
- Discussion and conclusions

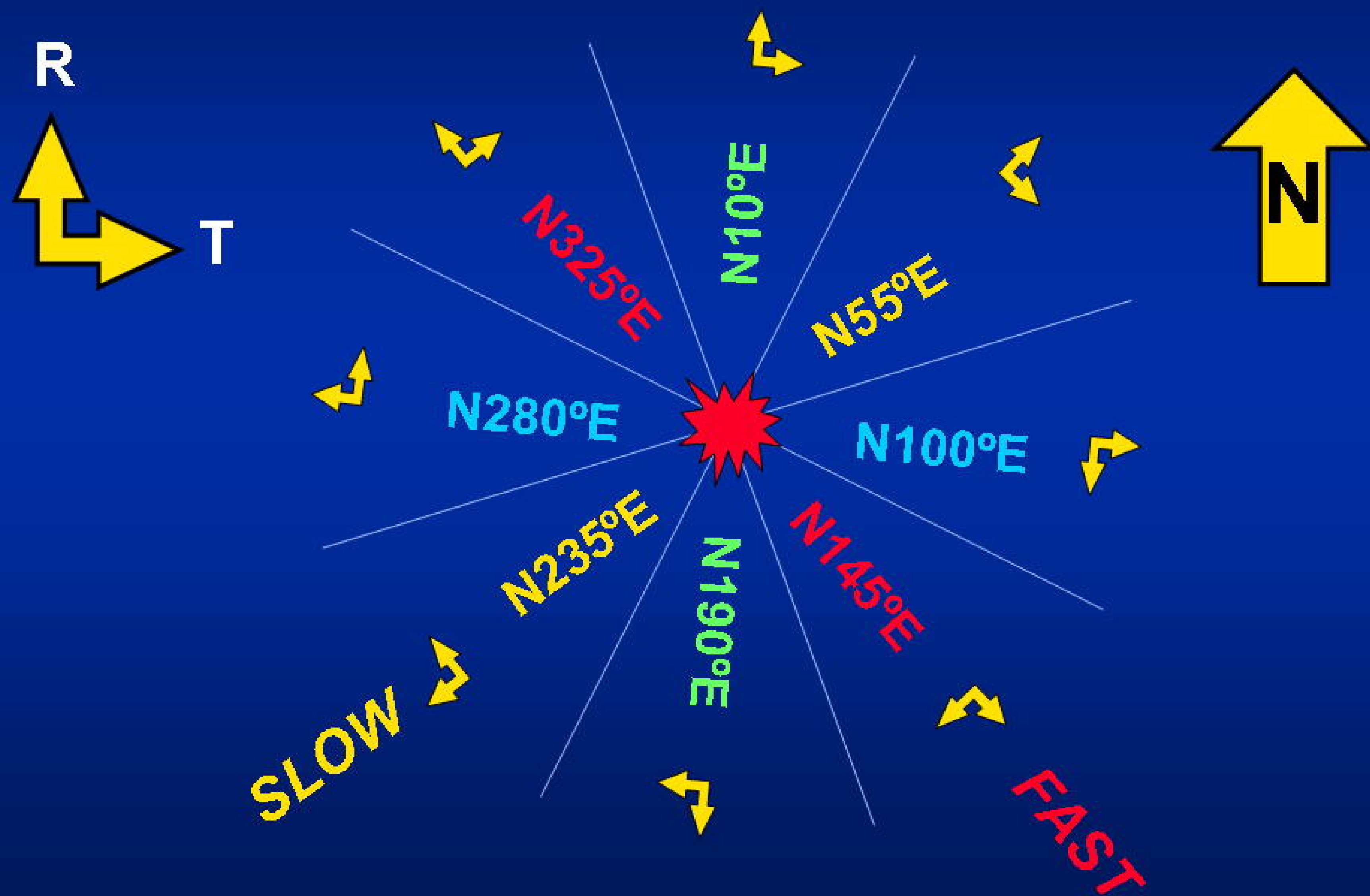
Converted-Wave Survey Geometry



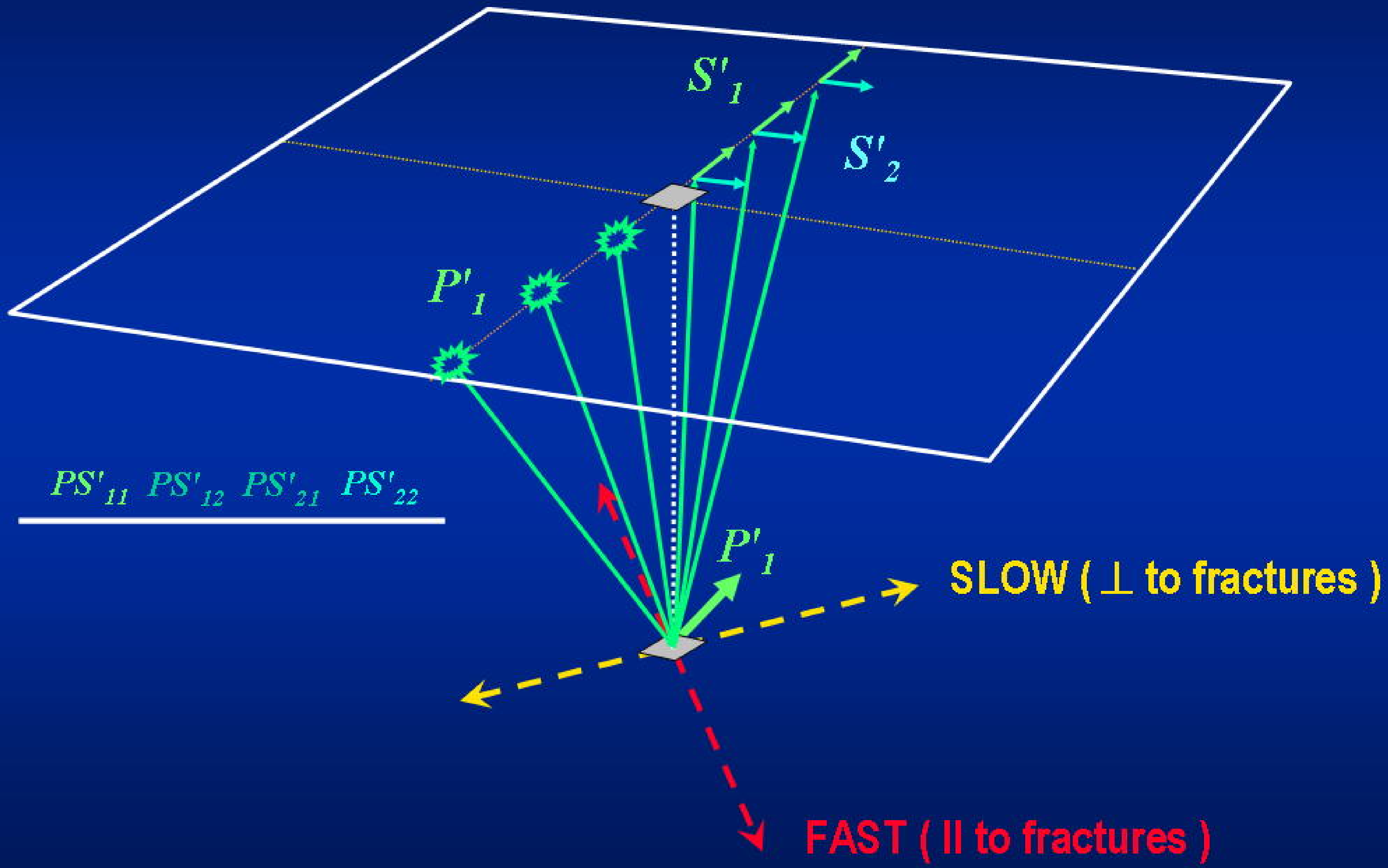
Complexity of S-wave Splitting



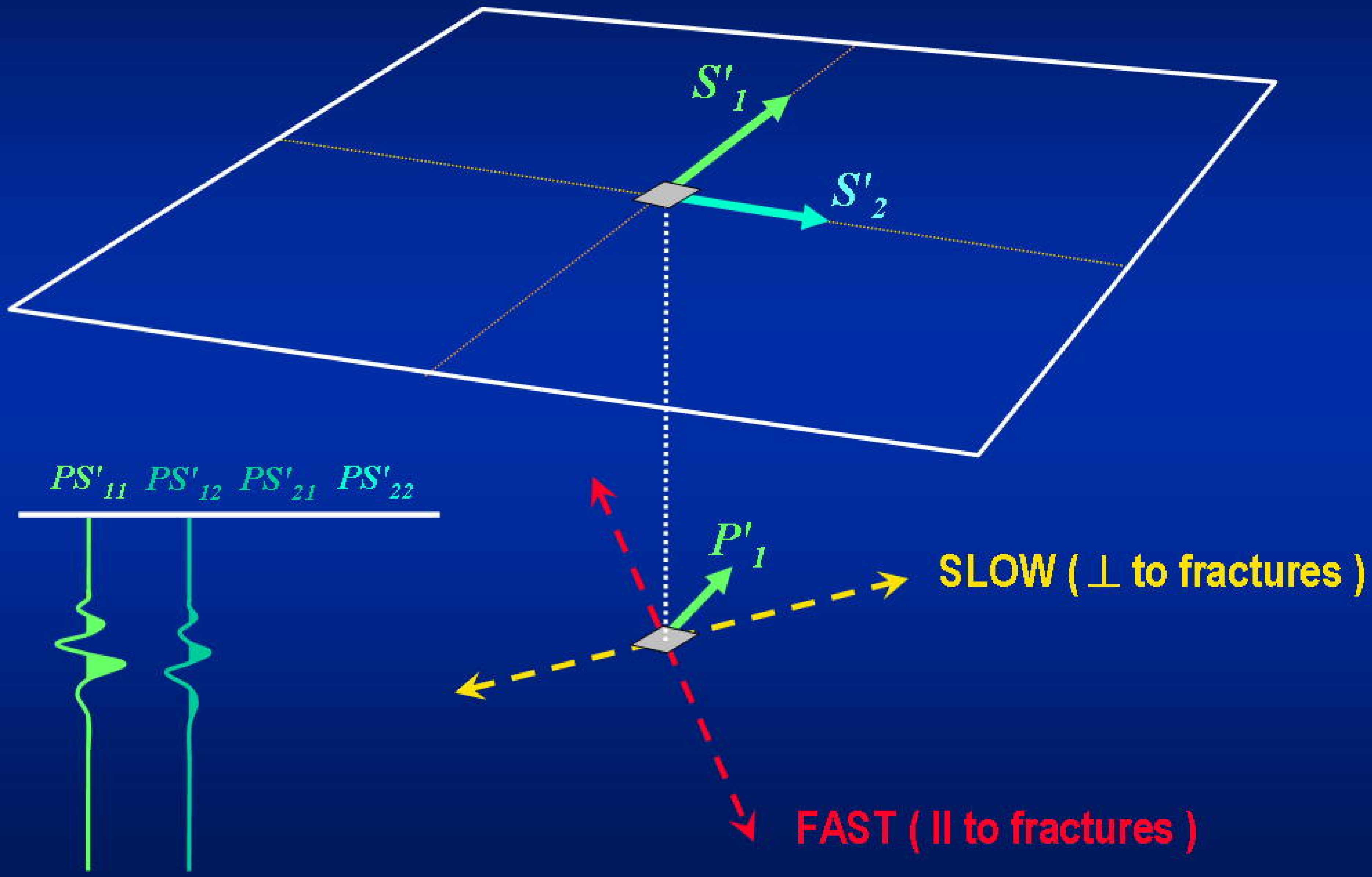
Source to Receiver Azimuth Limitation



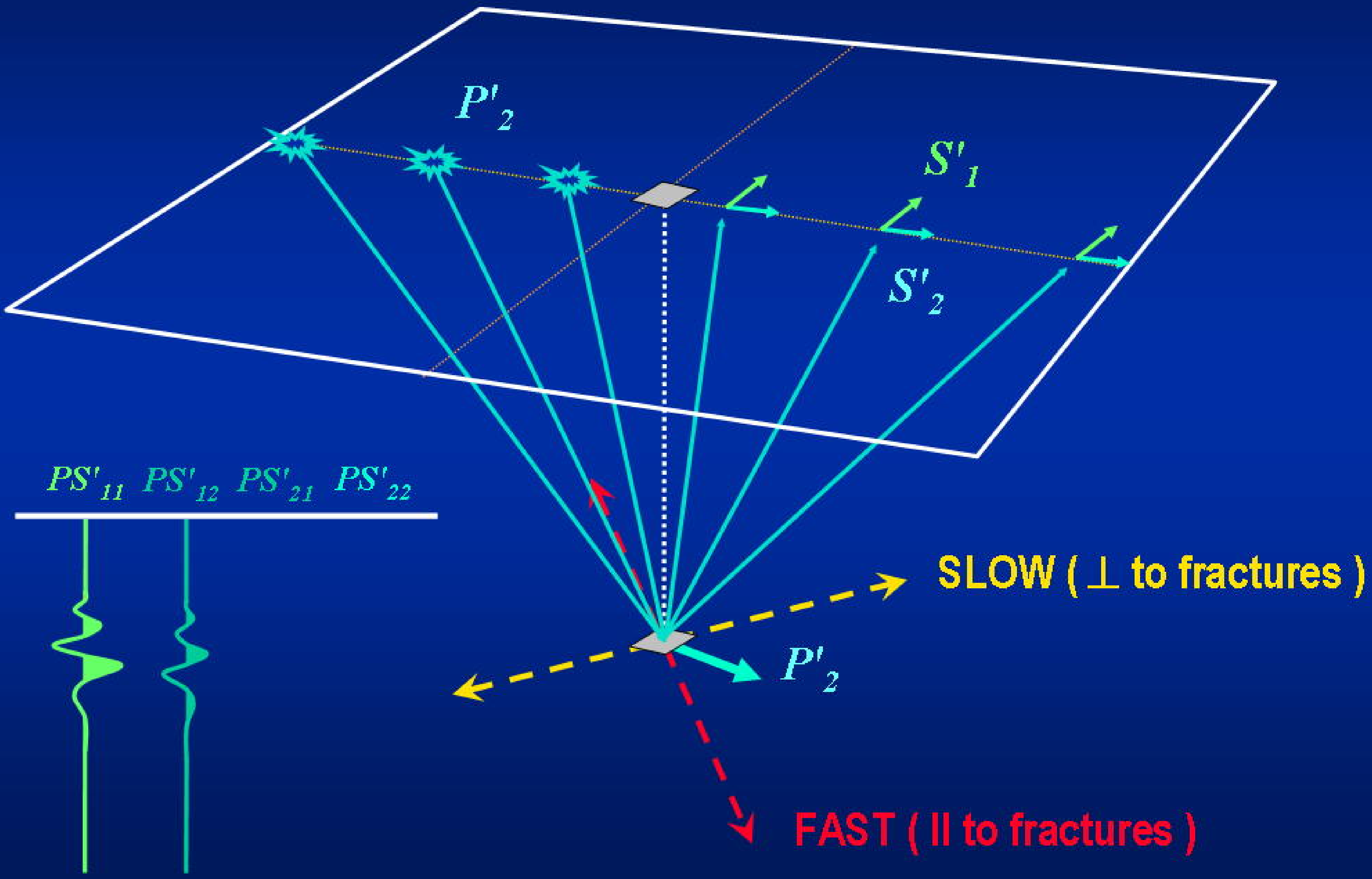
P_1-wave Direction: Prestack



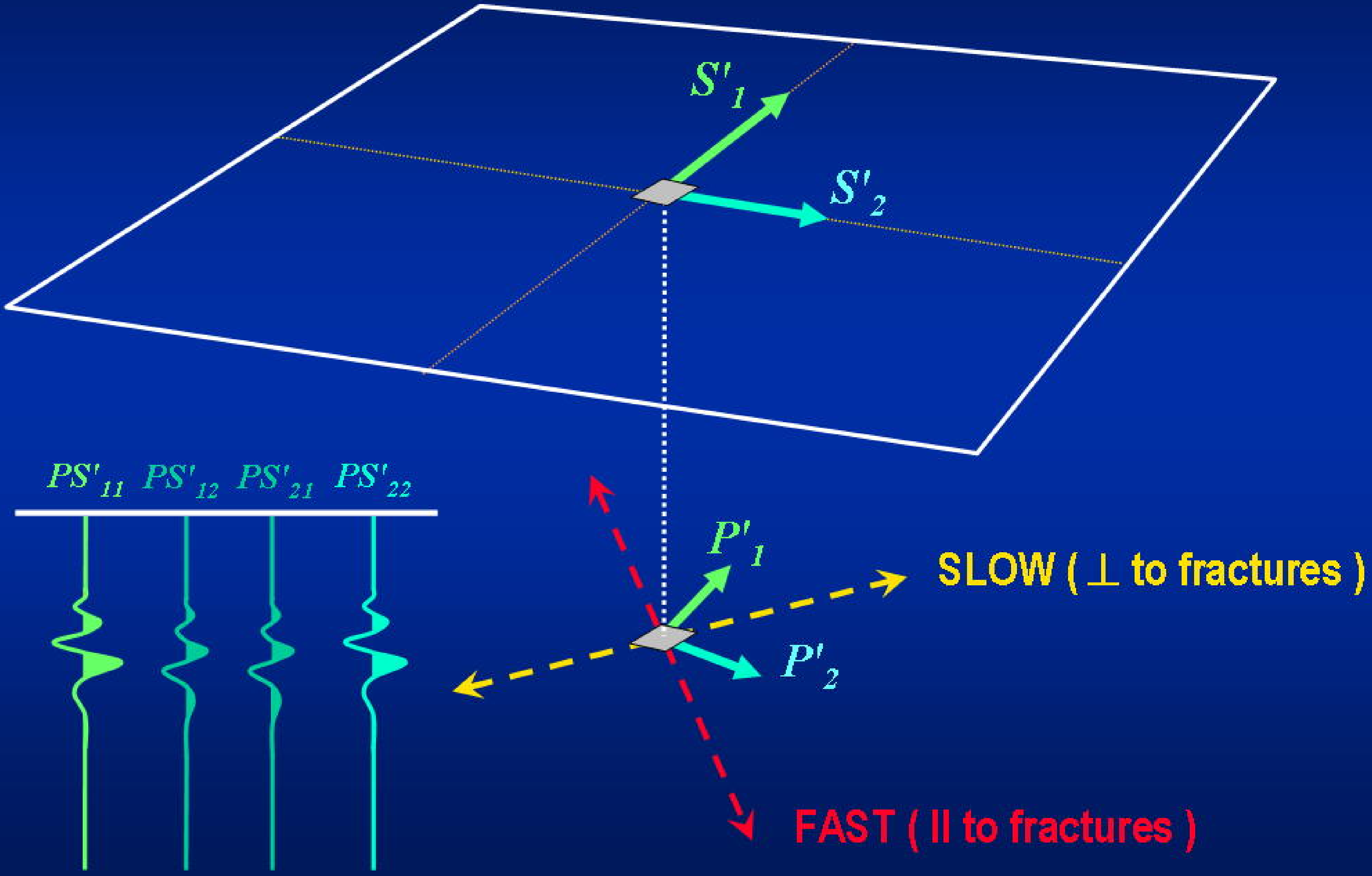
P_1-wave Direction: Stacked



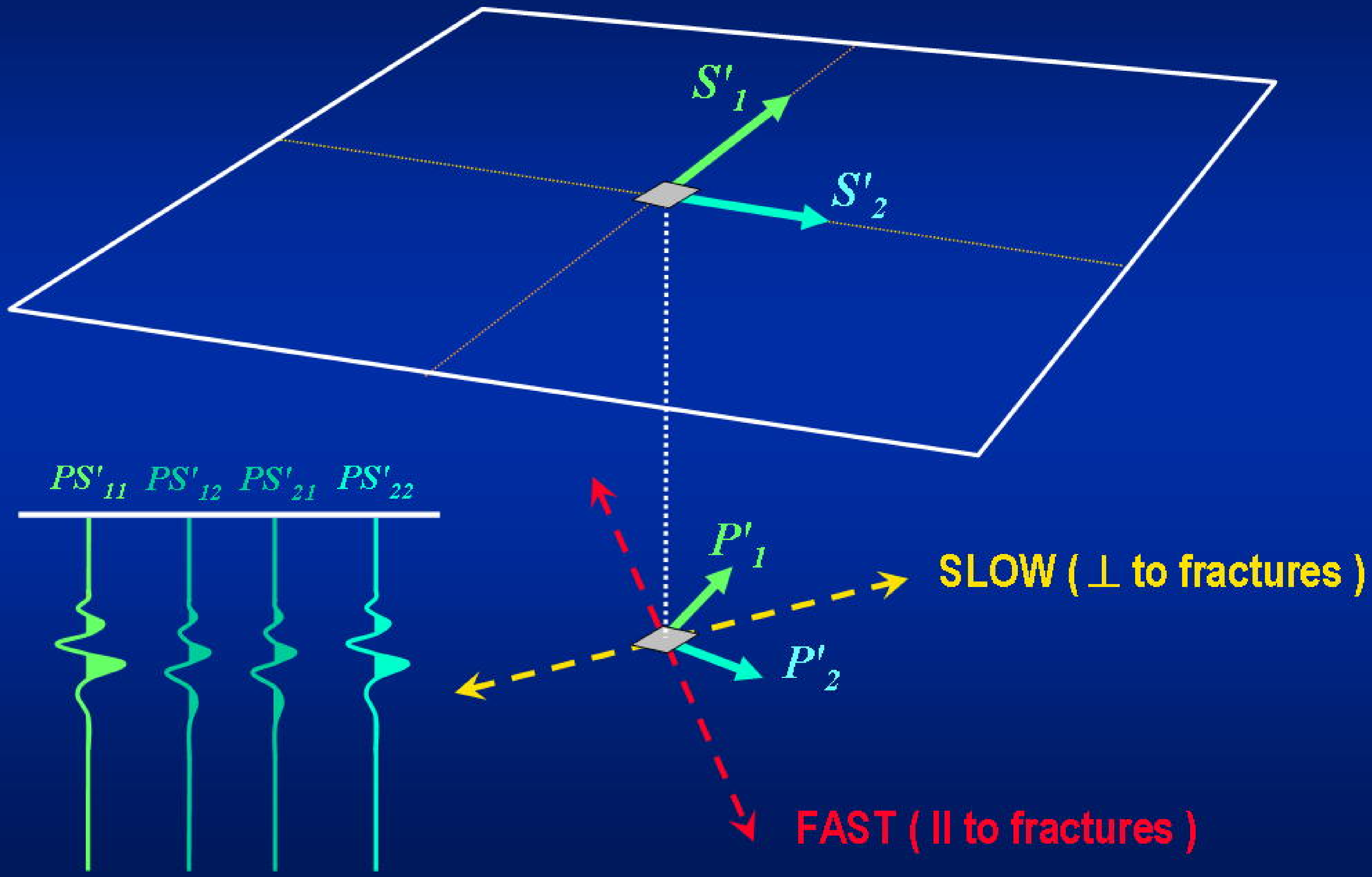
P_2-wave Direction: Prestack



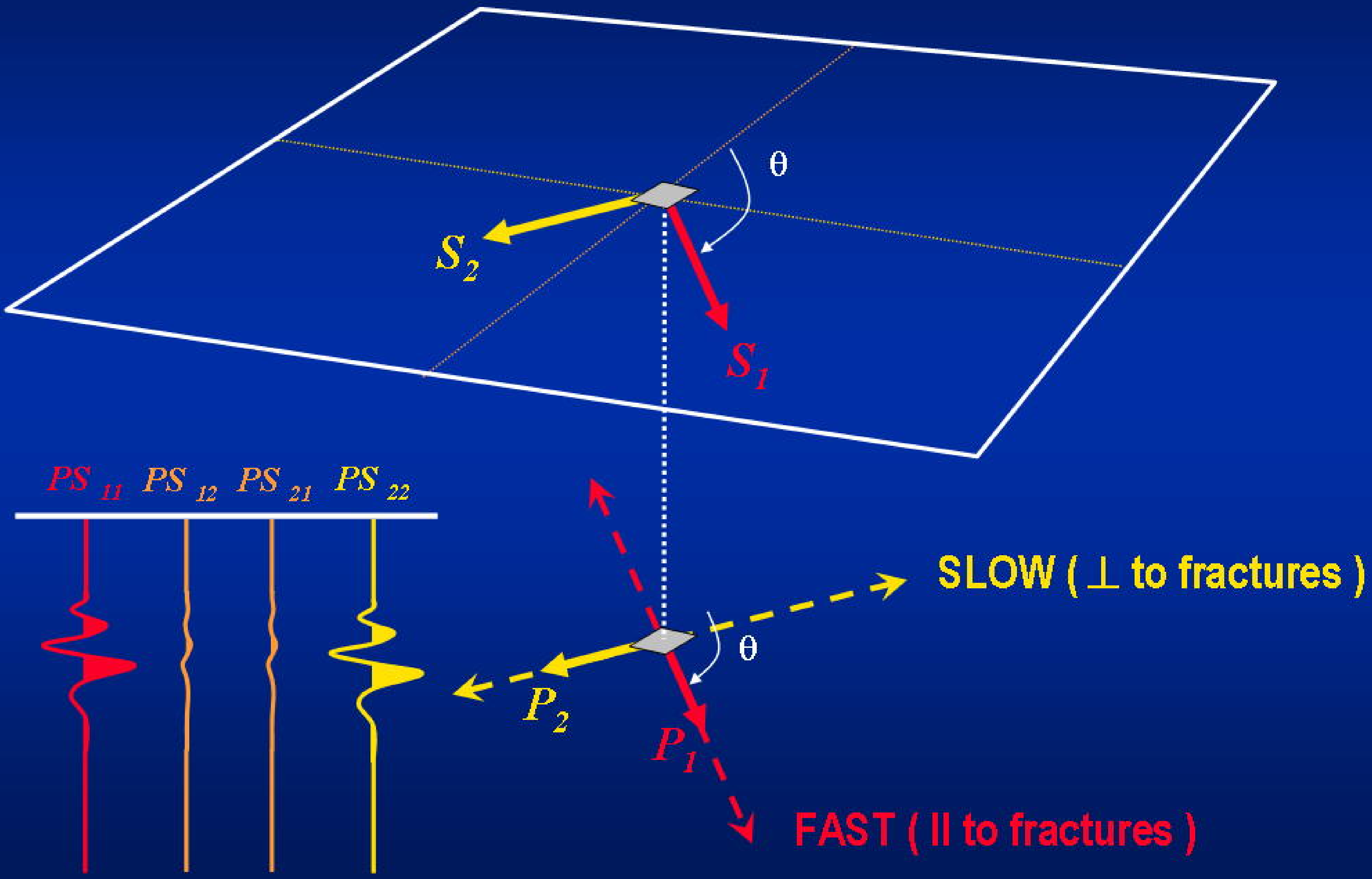
P_2-wave Direction: Stacked



2Cx2C Data Before Rotation to Principal Directions



2Cx2C Data After Rotation to Principal Directions



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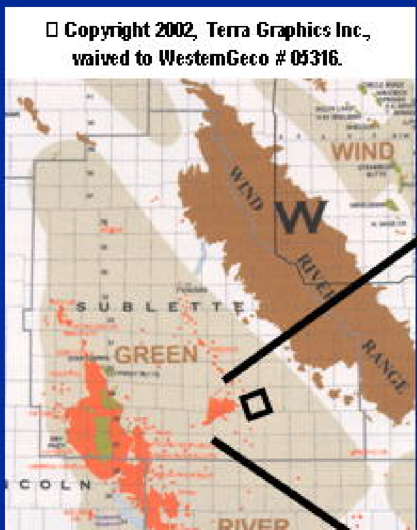
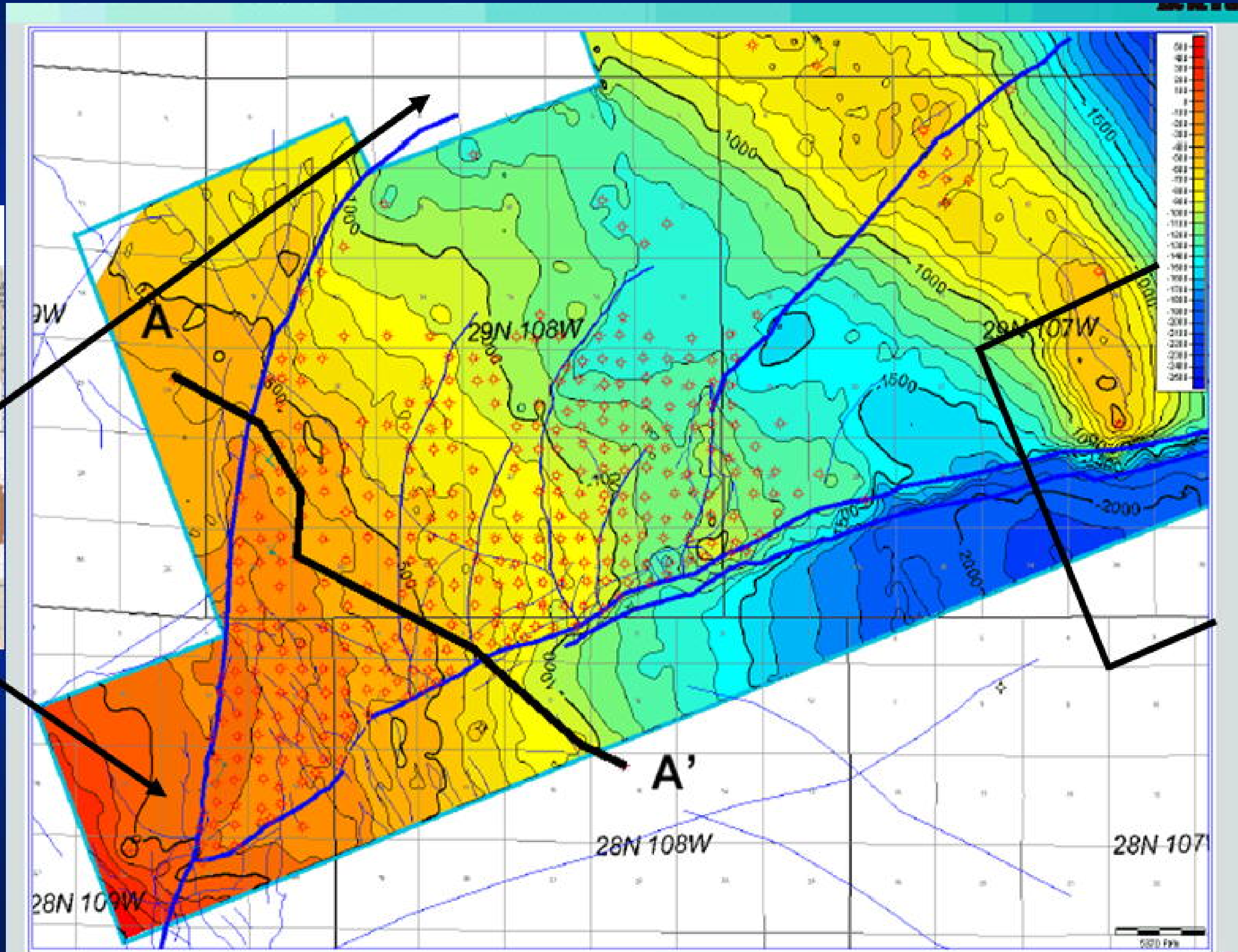
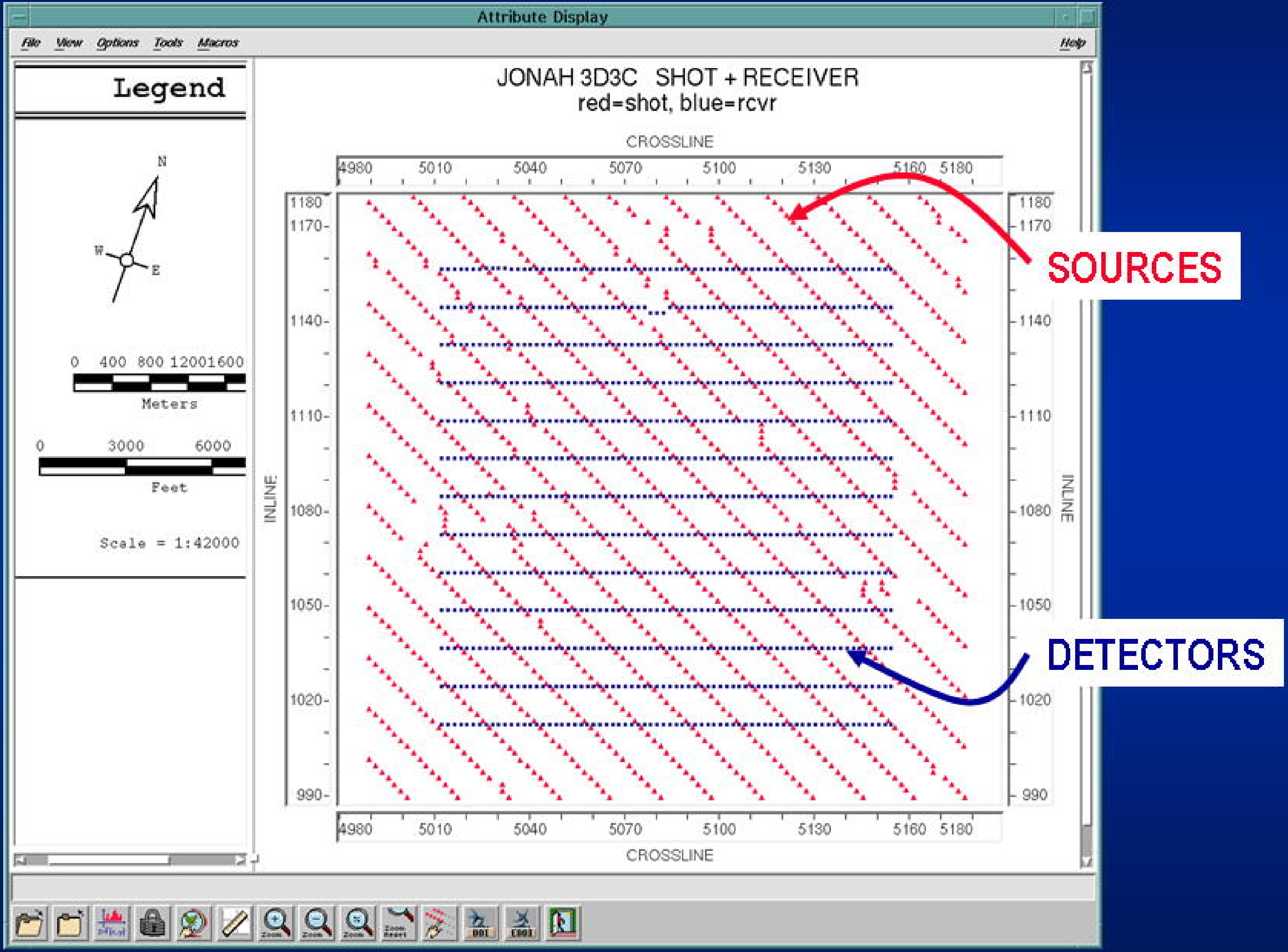
Structure Contour – Base Fort Union

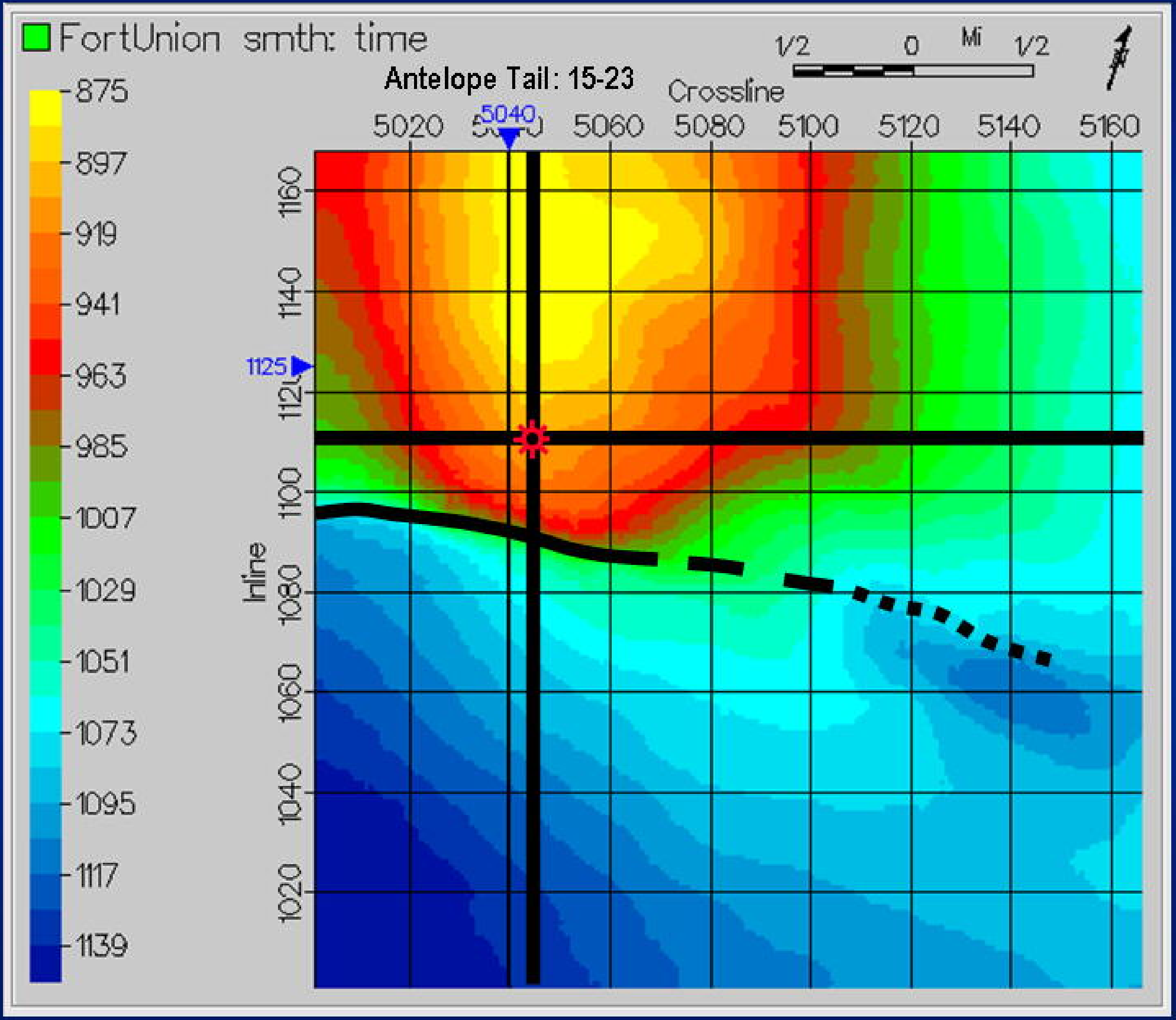




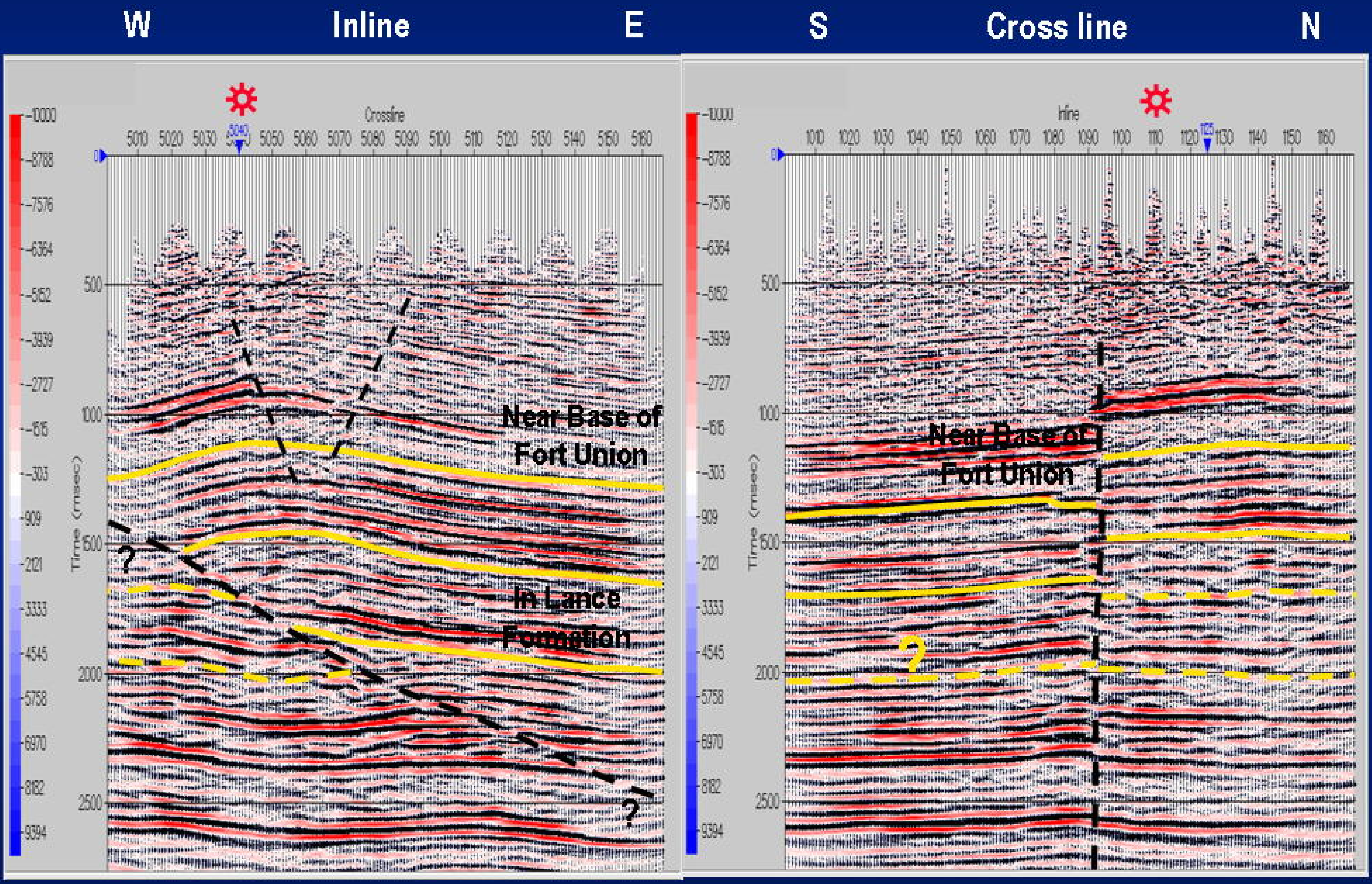
Pinedale Shot-Receiver Geometry



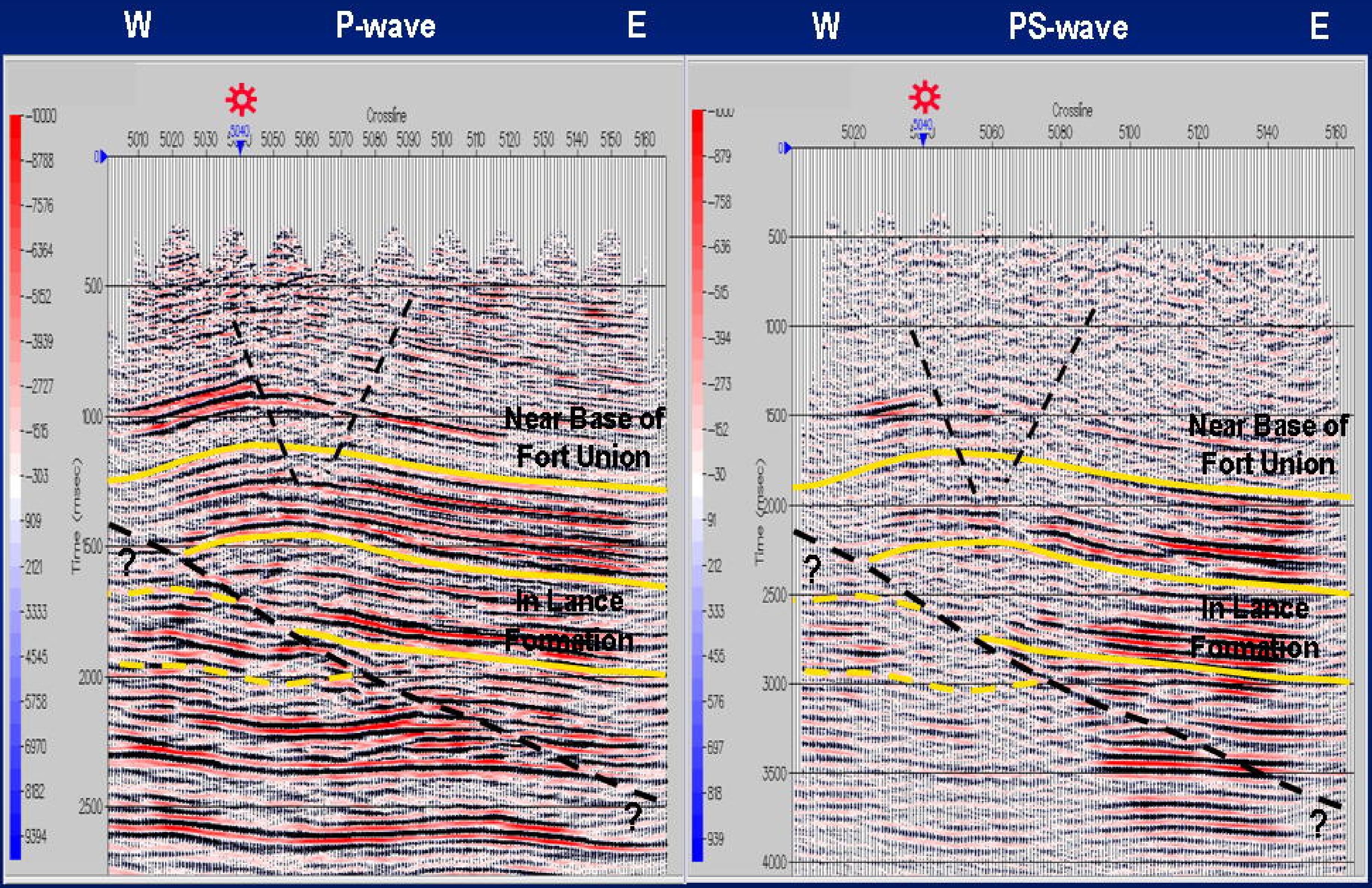
P-wave Isochron: In Lower Fort Union Formation



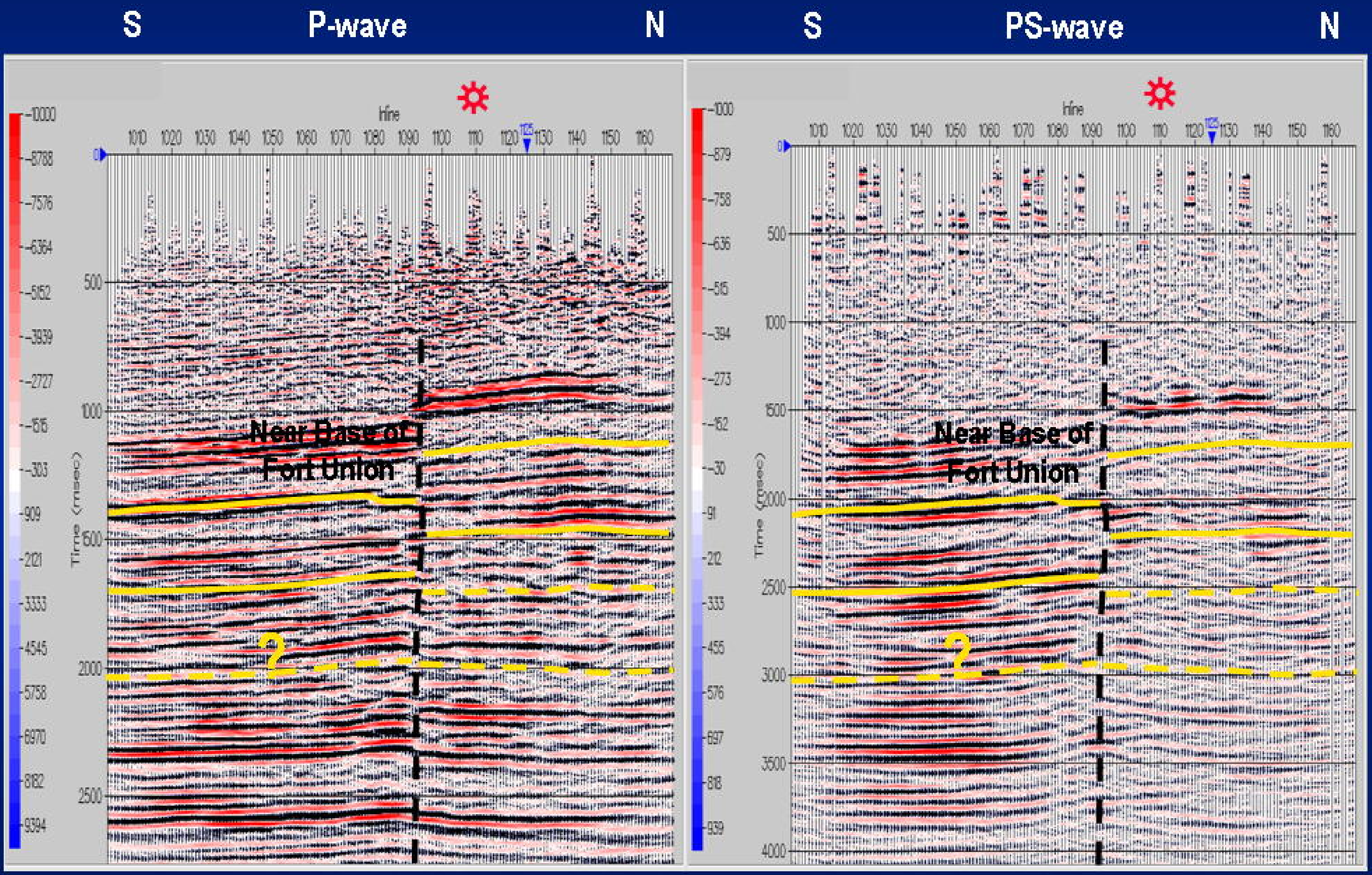
P-wave


W
Inline
E
S
Cross line
N
Crossline
Inline
Time (msec)
Near Base of Fort Union
In Lance Formation
Near Base of Fort Union
?
?
?

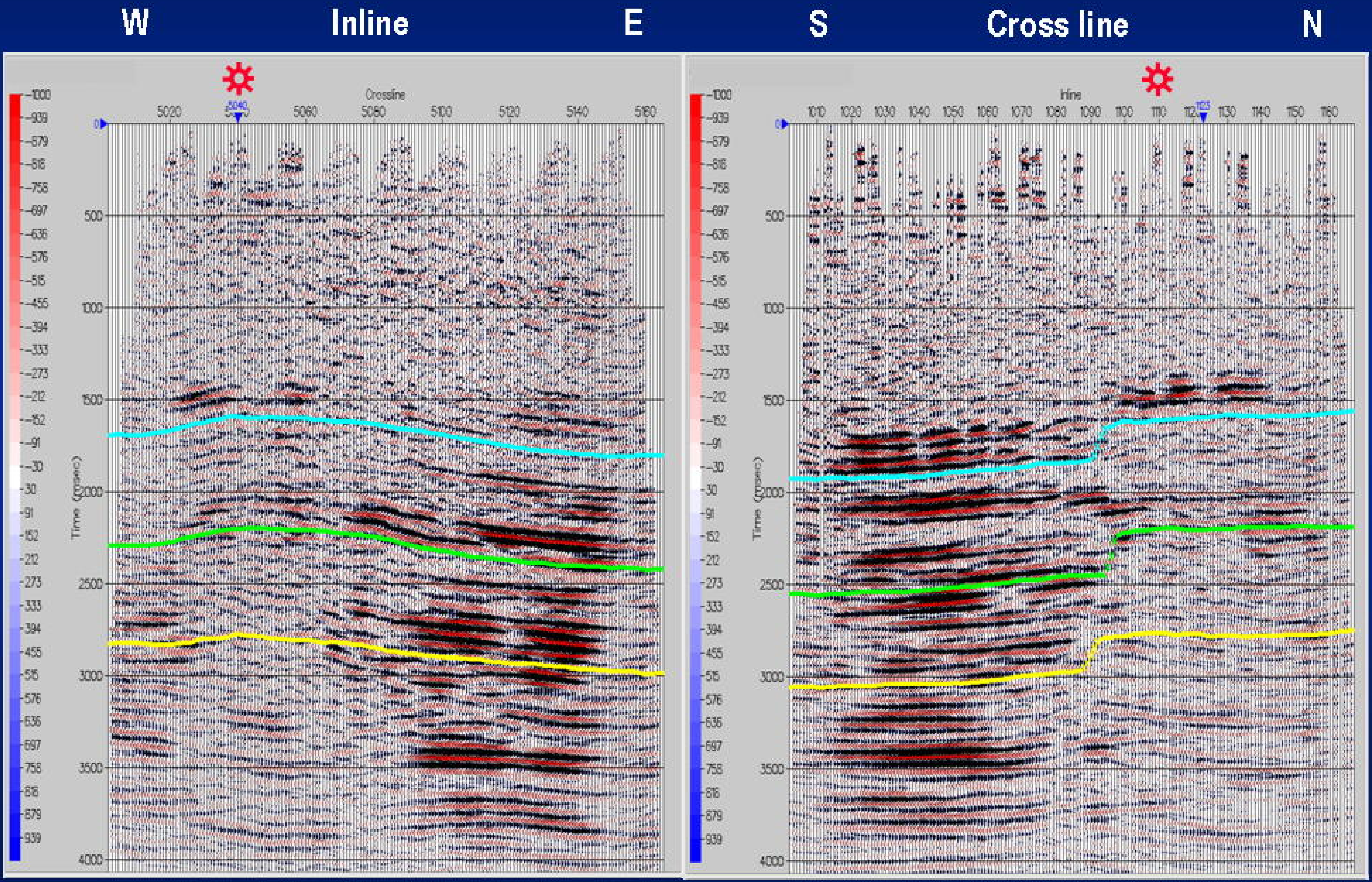
P-wave and PS-wave Inline



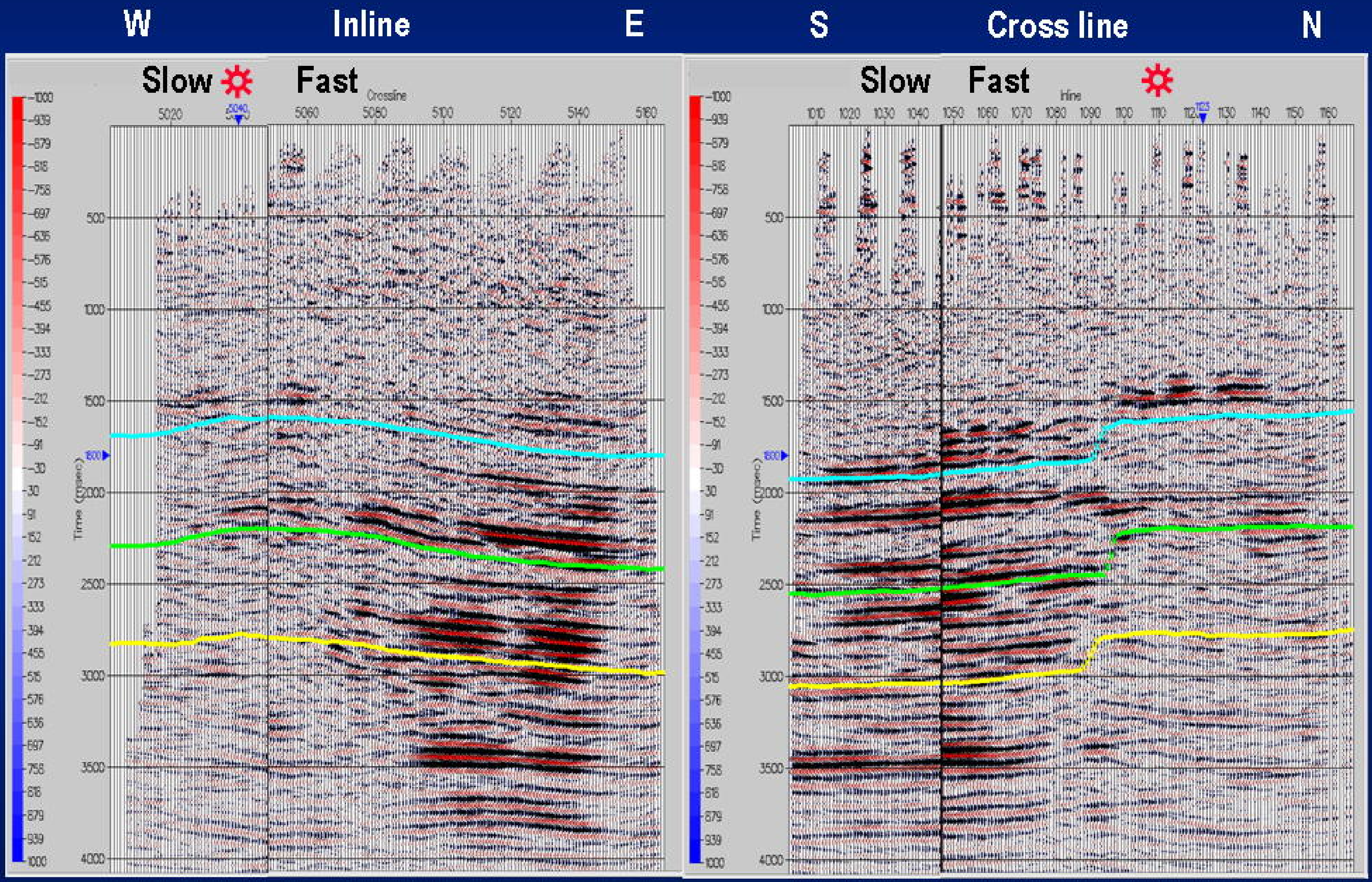
P-wave and PS-wave Cross line



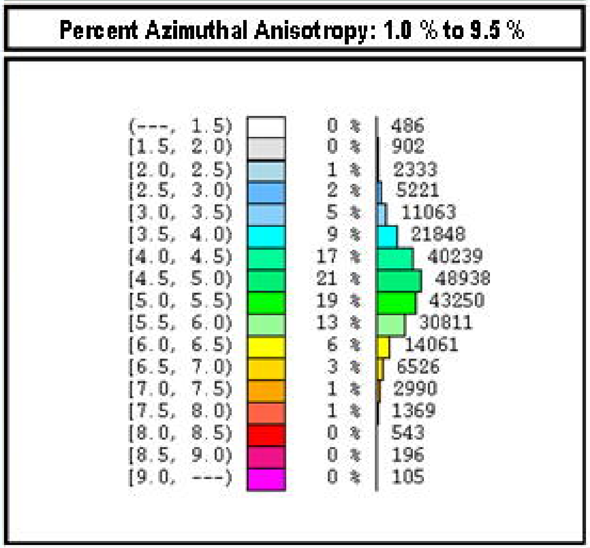
Fast PS-wave Direction: N145E

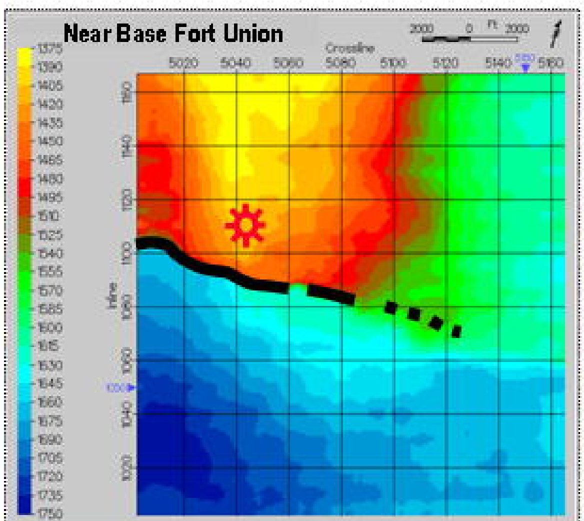


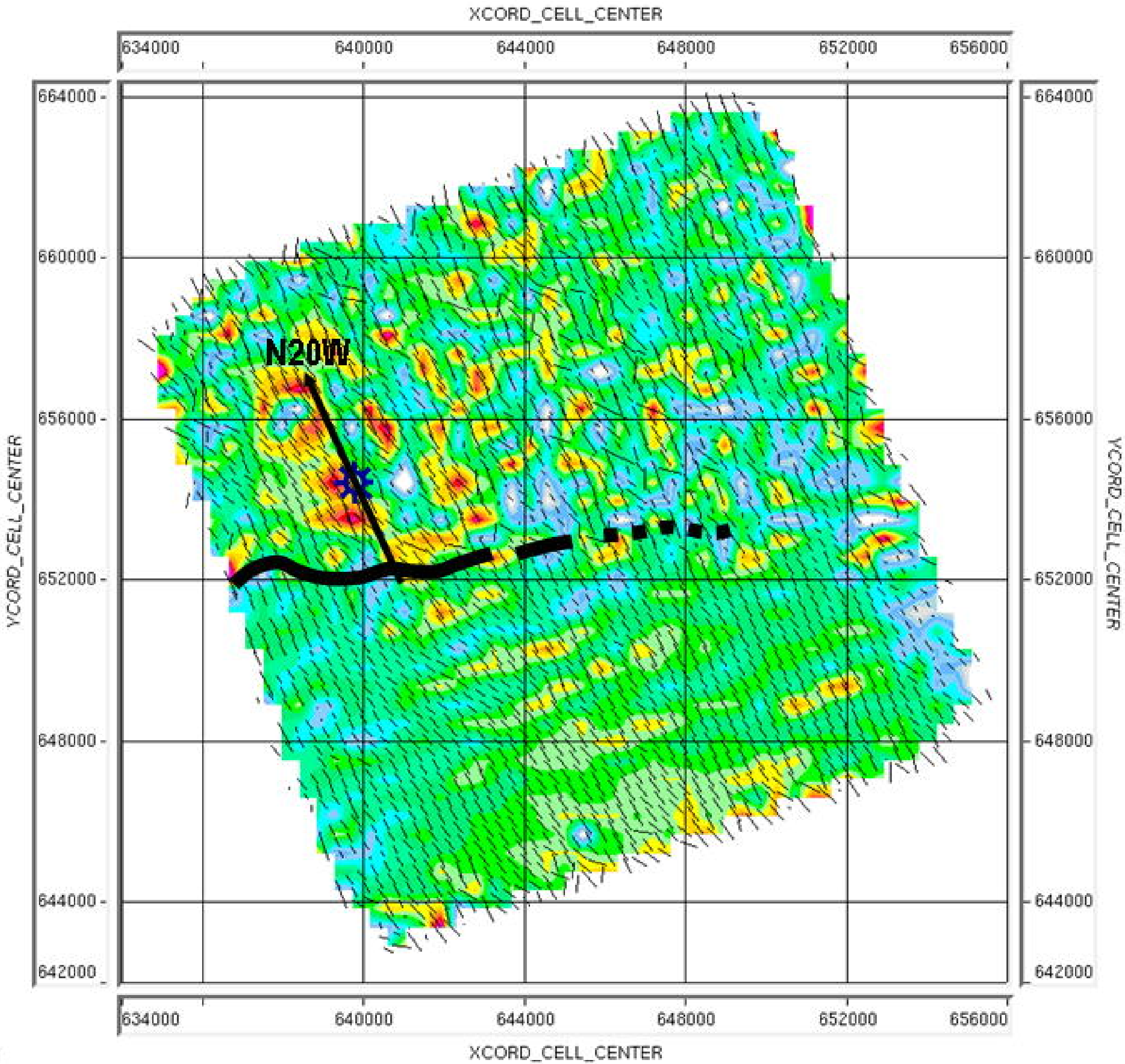
Slow vs. Fast PS-wave



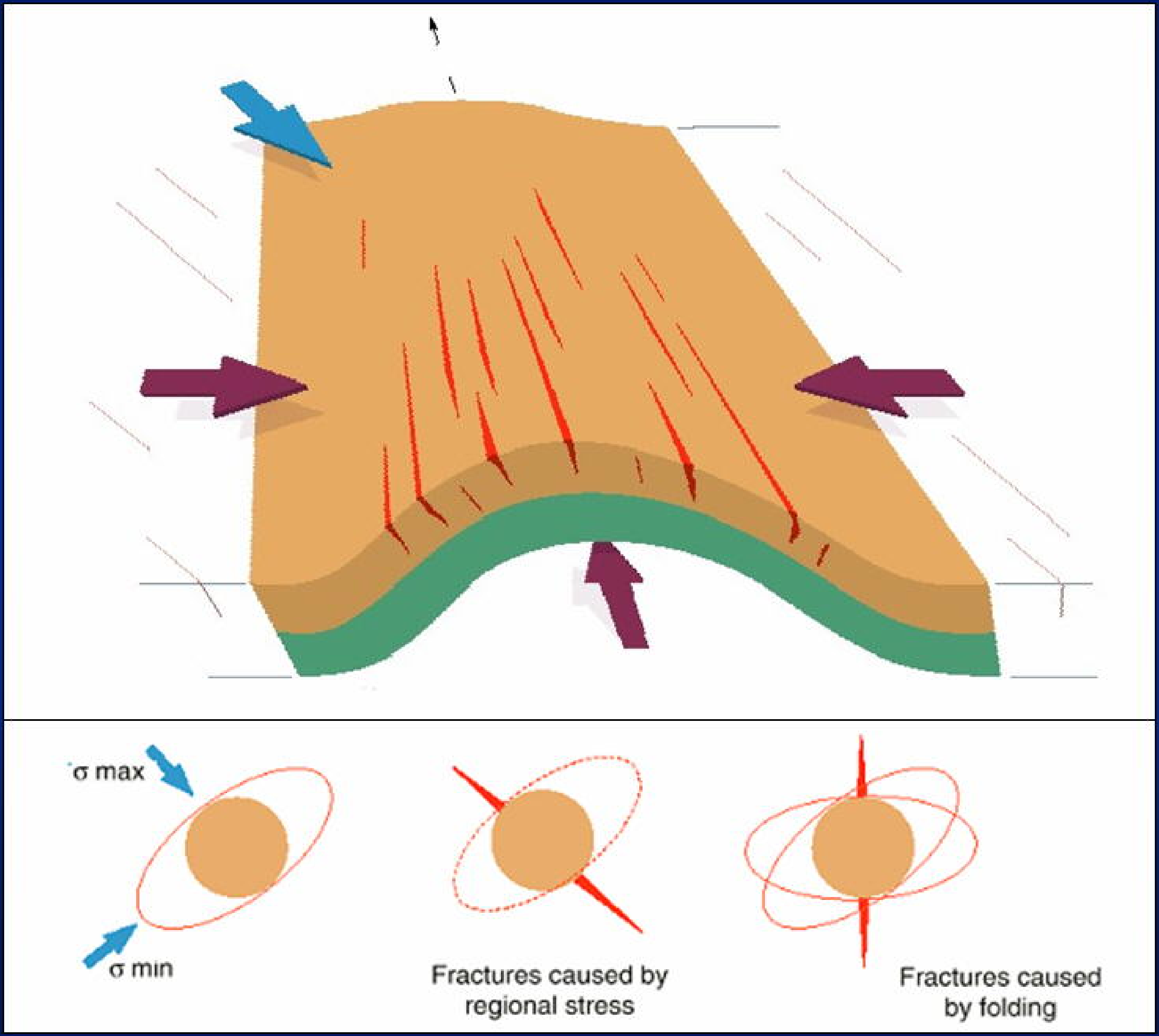
Azimuthal Anisotropy: Lower Fort Union



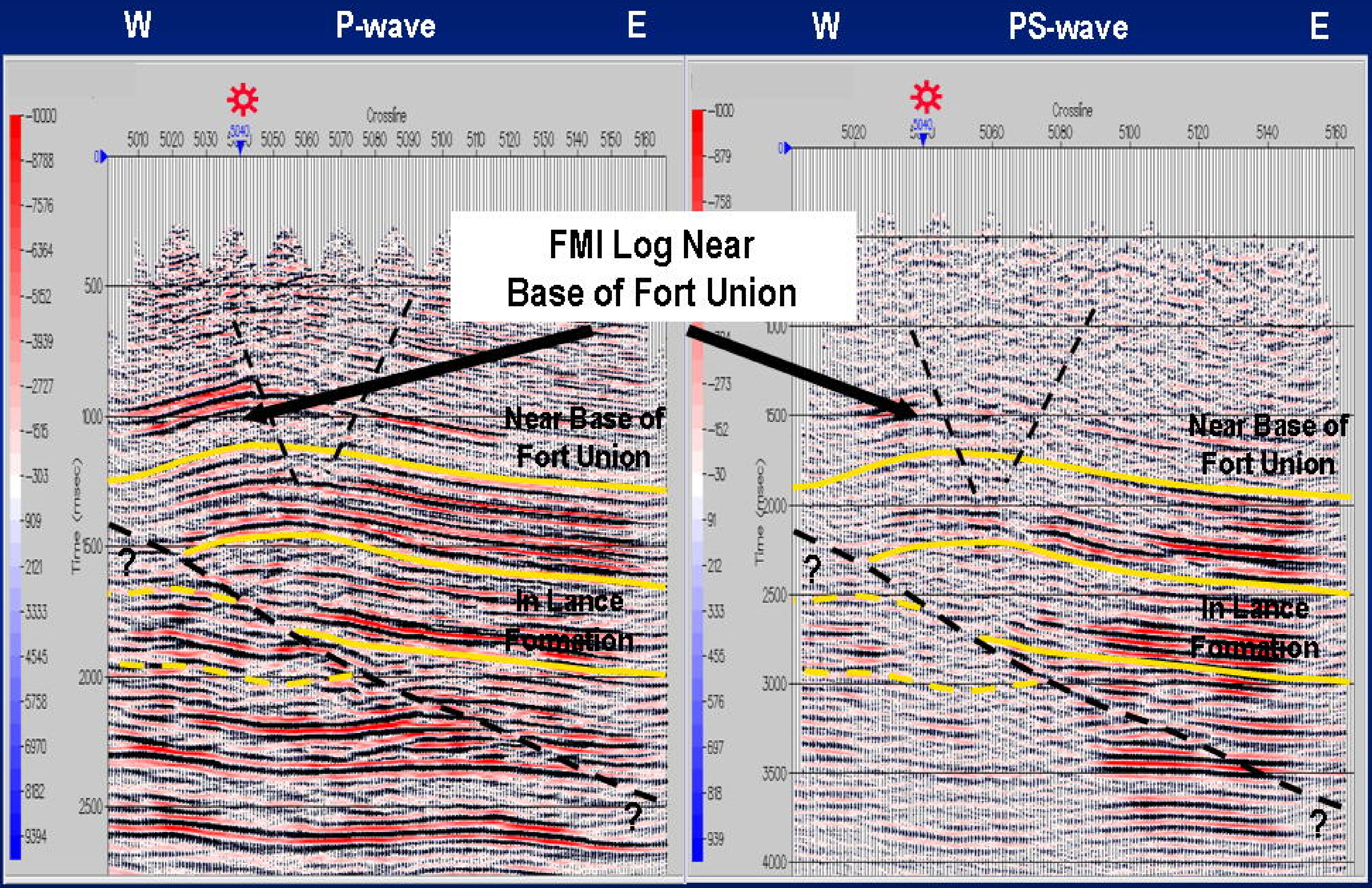




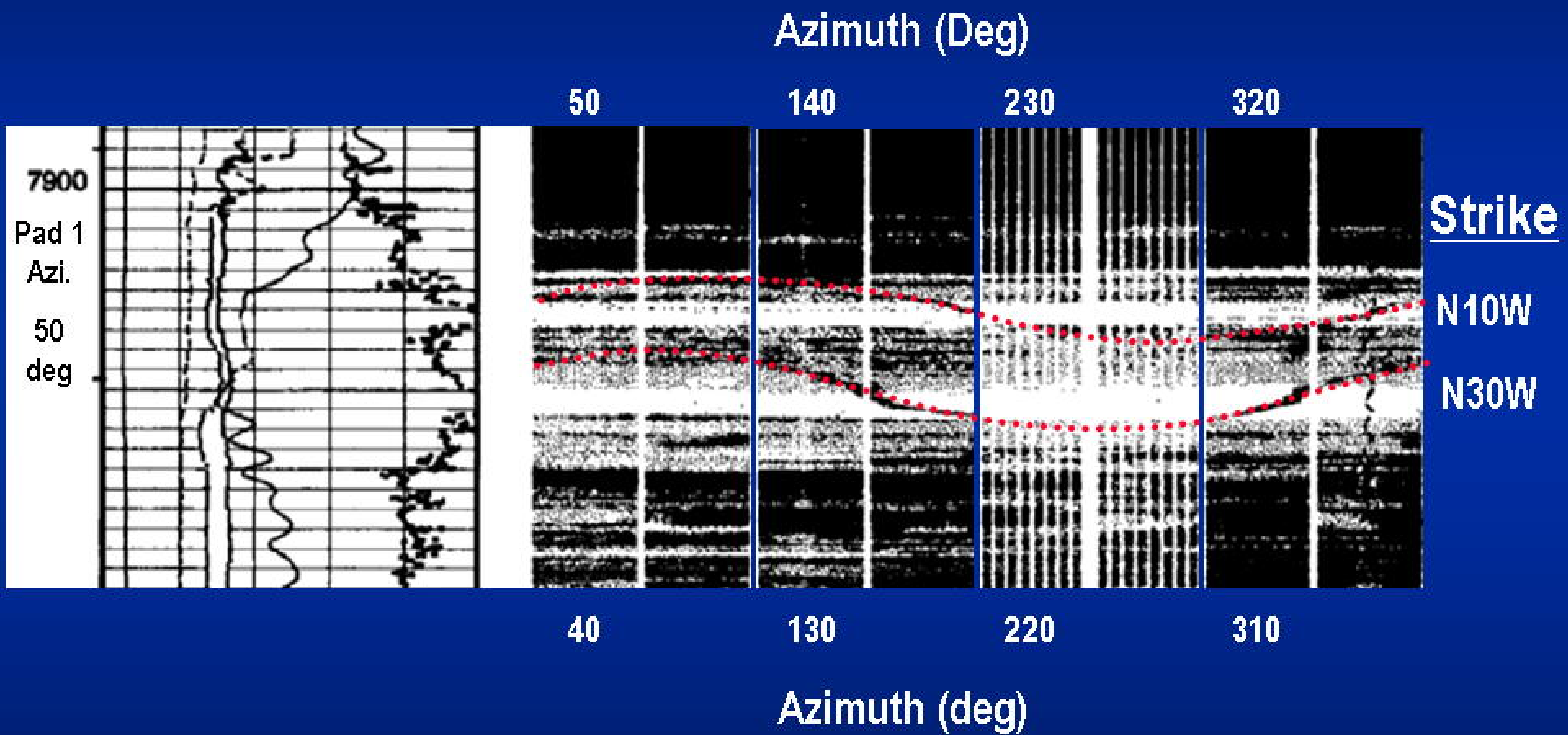
Fault and Fracture Trends



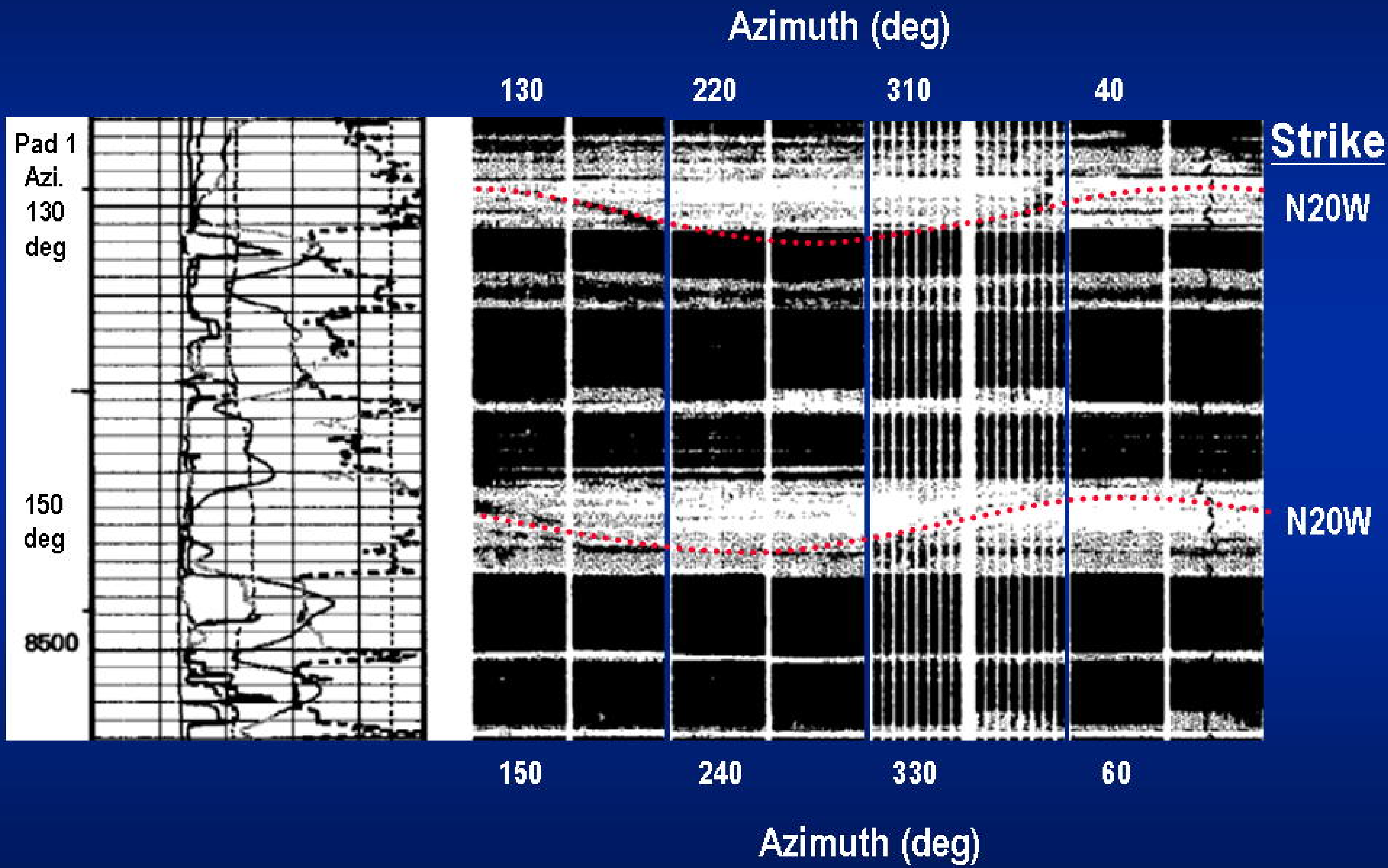
P-wave and PS-wave Inline



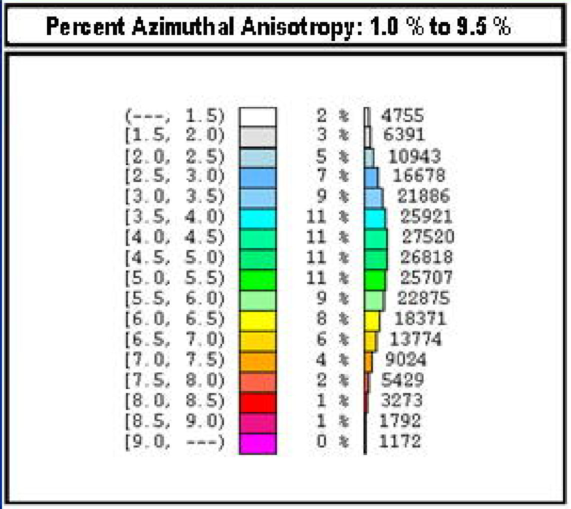
FMI Log at 7900: Near Vertical Fractures

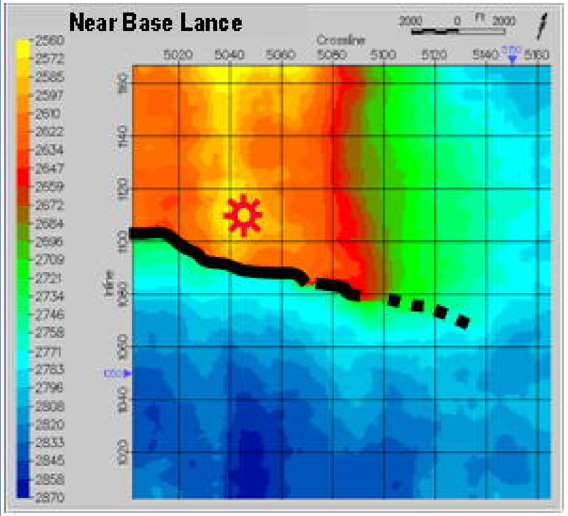


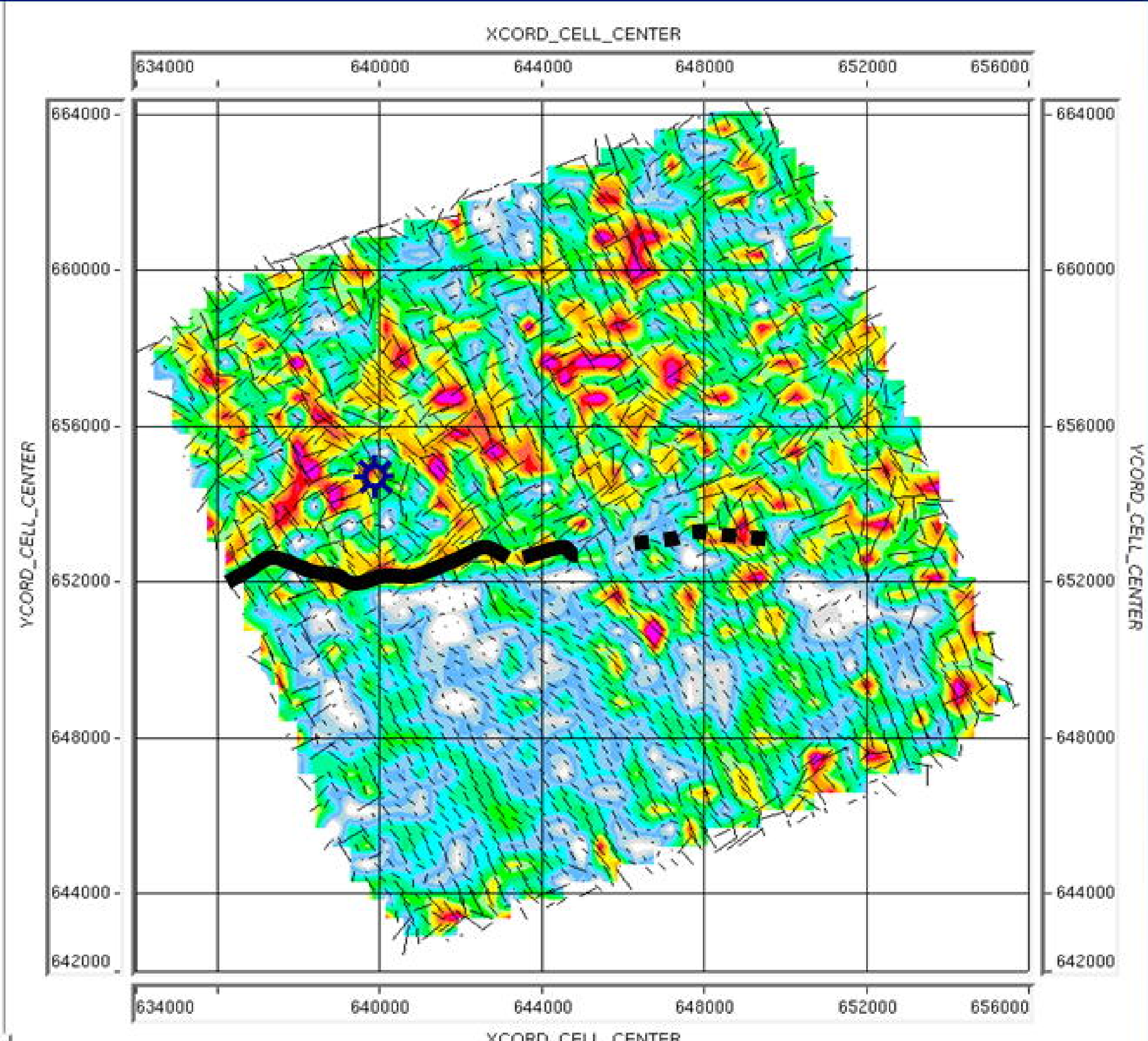
FMI Log at 8500: Near Vertical Fractures



Azimuthal Anisotropy: Lance formation







Discussion: Borehole information for calibration

- Antelope # 15-23 on the apex of the anticline
- FMI and dipole sonic logs
  - FMI shows mostly bedding planes near horizontal
  - But at many levels dip exceeds 30° and 40° - near vertical
  - Strike direction agrees with the fast S-wave direction
- For optimal calibration with PS-wave data
  - Cross-dipole should be acquired (not available)
  - Quantitative estimates of azimuthal anisotropy
  - Orientation and magnitude of anisotropy
- Near-offset S-wave source VSPs
  - S-wave splitting at same seismic wavelengths

Conclusions

- Early estimation of principal S-wave orientation is critical for processing.
- Alford rotation analysis is a valuable tool to quantify the time variant S-wave birefringence.
- More intense azimuthal anisotropy on the crest and flanks of the Pinedale anticline suggest potential fracture sweet spots.
- Fast S-wave direction agrees with the strike of near vertical fractures on the FMI log, and appears to be sensitive to local horizontal stresses.