PSDM for Unconventional Reservoirs? A Niobrara Shale Case Study*

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Abstract

As of this writing, unconventional resource plays absorb a significant proportion of onshore U.S. E&P budgets. The perceived simplicity and homogeneity of unconventional reservoirs explained their initial appeal to firms seeking to reduce “dry hole risk”. However, as inconsistent drilling results from many resource plays highlight, shale reservoirs are neither simple nor homogeneous. Used infrequently 5-10 years ago, drillers today commonly employ 3D seismic to improve horizontal well “geosteering”. Explorers also increasingly rely on 3D seismic to delineate productive “sweet spots”. In particular, differential horizontal stress (from azimuthal anisotropy analysis) and elastic inversion for “brittleness” are paired to find optimal drill locations and wellbore orientation. While prestack depth migration (PSDM) is commonly applied in “complex” plays such as the sub-salt Gulf of Mexico, it has been adopted in resource plays at a slow (but accelerating) pace. PSDM promises two major “structural” benefits over conventional time imaging: More accurate geologic dips between well control Crisper and better positioned view of faulting. Additionally, in areas that exhibit velocity complexity, seismic anisotropy, and dipping beds, PSDM can provide more accurate input for most attribute technologies. We present a case study from a wide-azimuth 50 mi^2 survey acquired in the Niobrara Shale. While the study area exhibits mildly dipping beds, a significant shallow lateral velocity variation motivates the use of PSDM to correct event dips and improve the focusing of faults. Vertical mistie correction predicted the top Niobrara to within 4 feet on a new well, but we show enough variation in Thomsen delta to justify anisotropic PSDM. Azimuthal velocity analysis using Wave Equation PSDM (WEM) azimuth angle gathers indicates a very weak level of overburden azimuthal anisotropy. However, we show that amplitude versus azimuth (AVAZ) may better measure differential horizontal stress in the target interval. We show that the contrast in Young's Modulus across the Niobrara has significant azimuthal variations, implying a distinct preferred direction in terms of stiffness.

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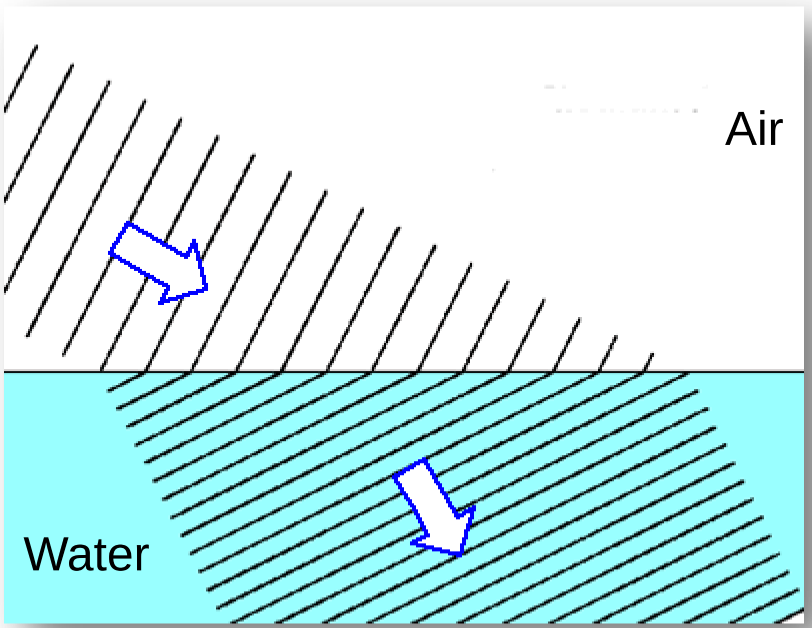
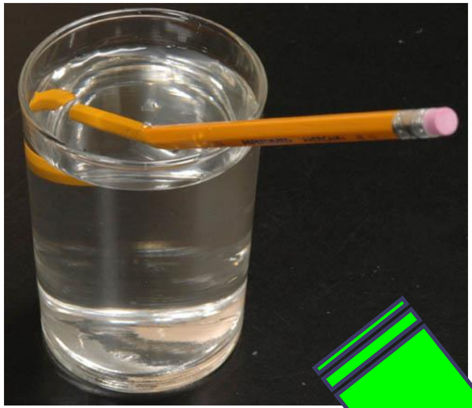
April 7, 2014

WAVE IMAGING TECHNOLOGY a division of GeoCenter LP

Why Prestack Depth Migration (PSDM)?





Simple refraction

Kirchhoff

WEM

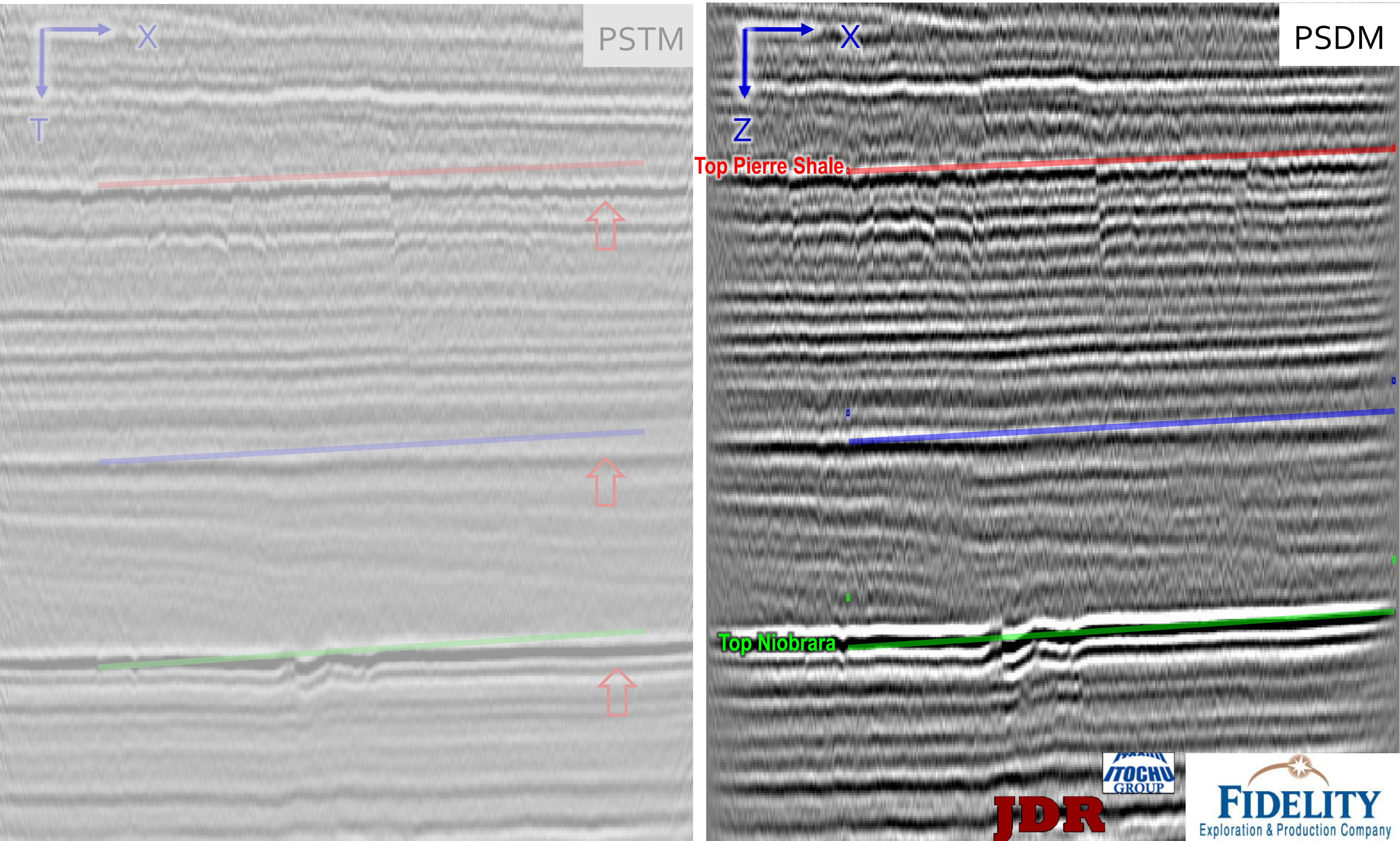
RTM

Complex focusing

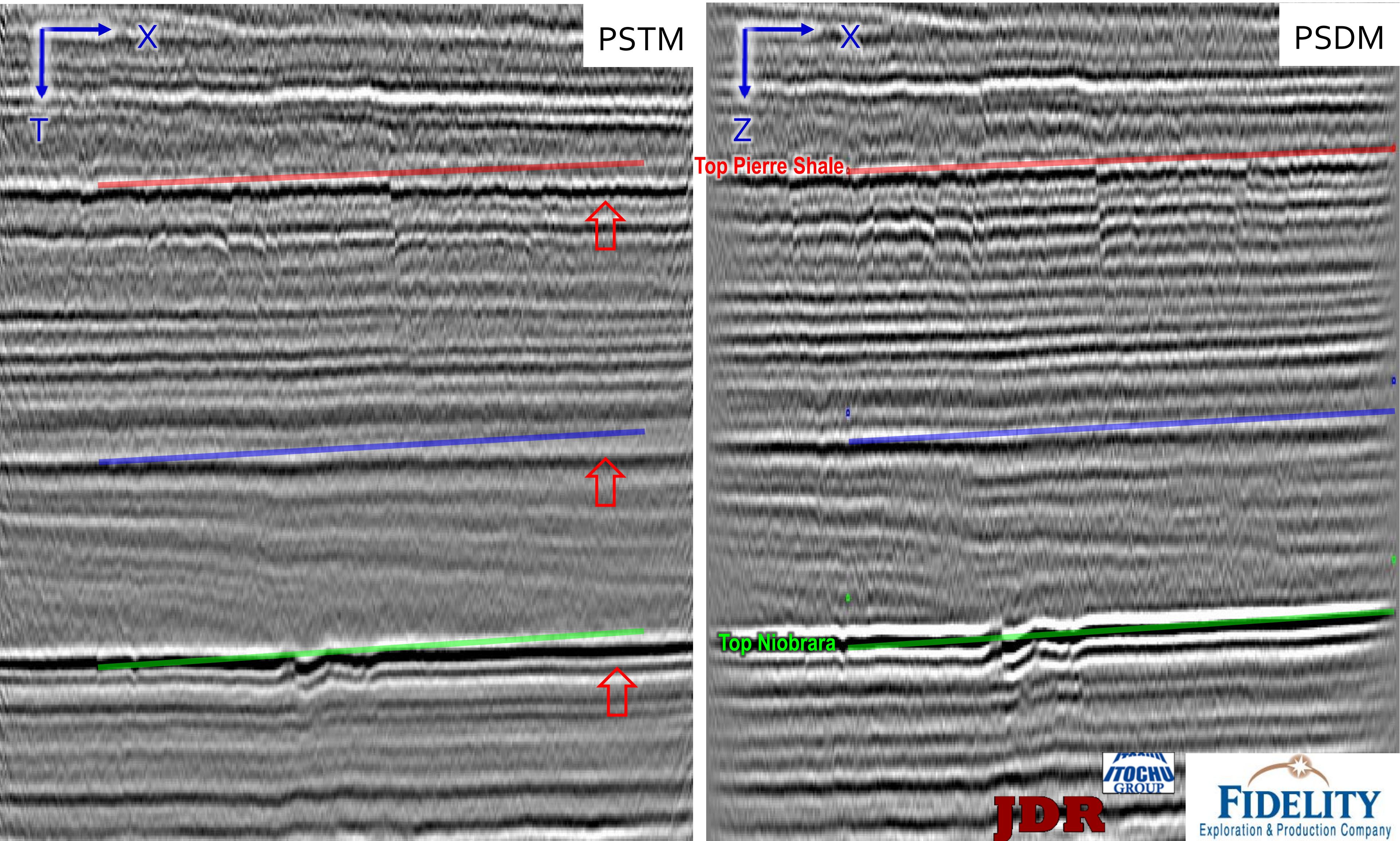
Niobrara Shale Case Study

- High fold 50 mi^2 3D; Laramie County, WY
- Part 1: Structural Imaging
  - Recover true geologic dip
  - Improve fault imaging
- Part 2: "Sweet Spot" Delineation
  - Natural fractures
  - HTI vs. AVAZ

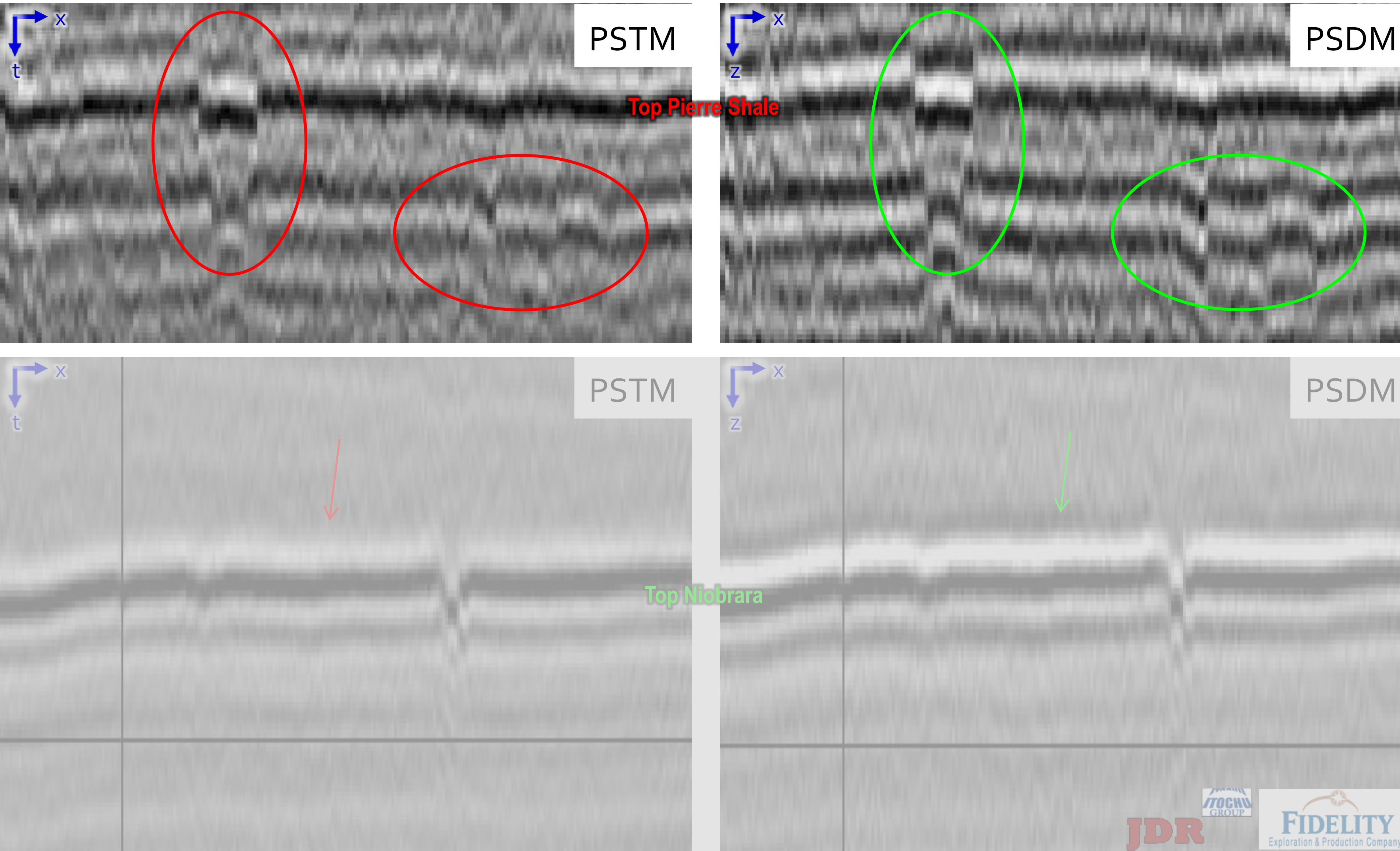
PSDM: Better Geosteering



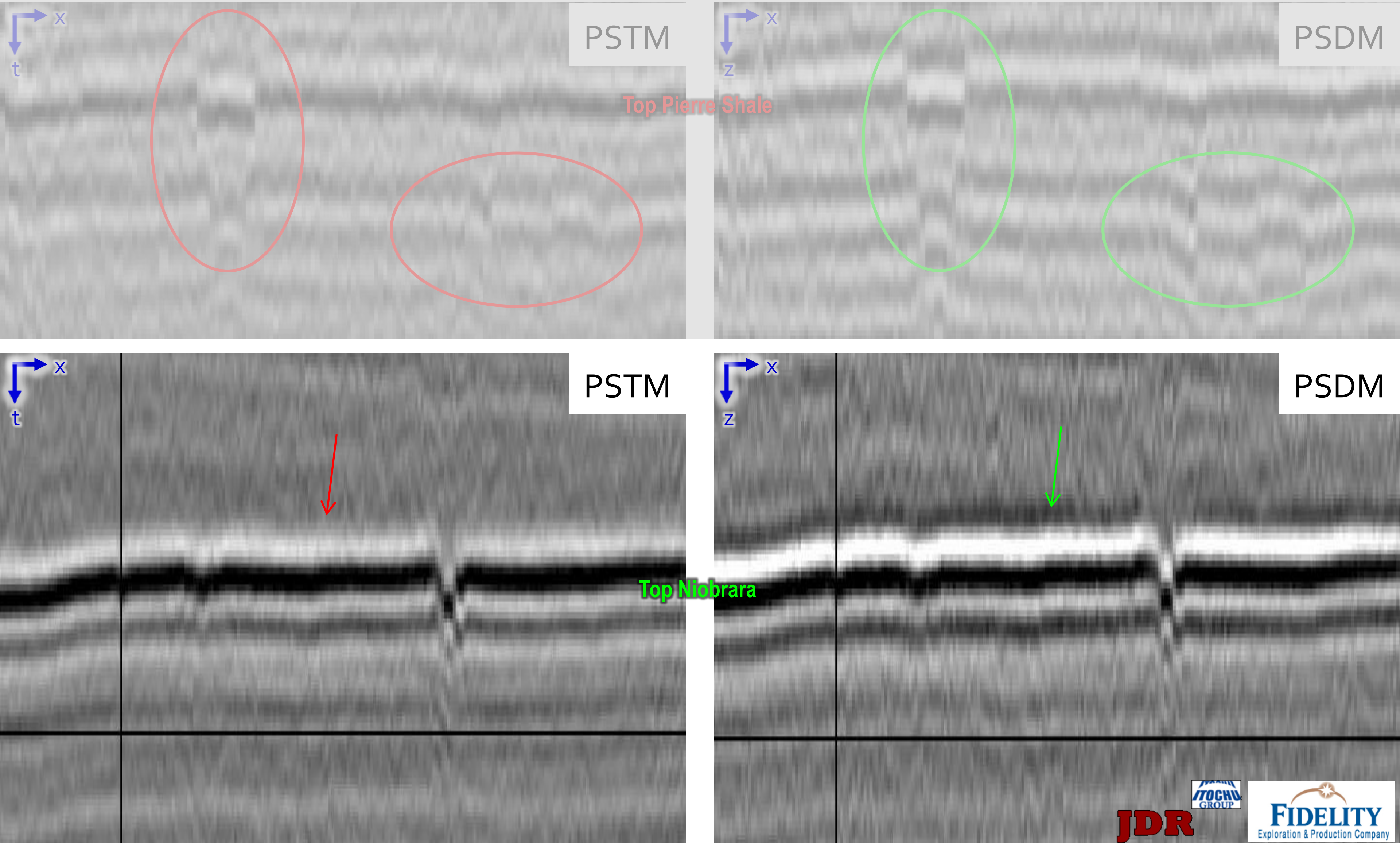
PSDM: Better Geosteering



PSDM: Better Fault Imaging

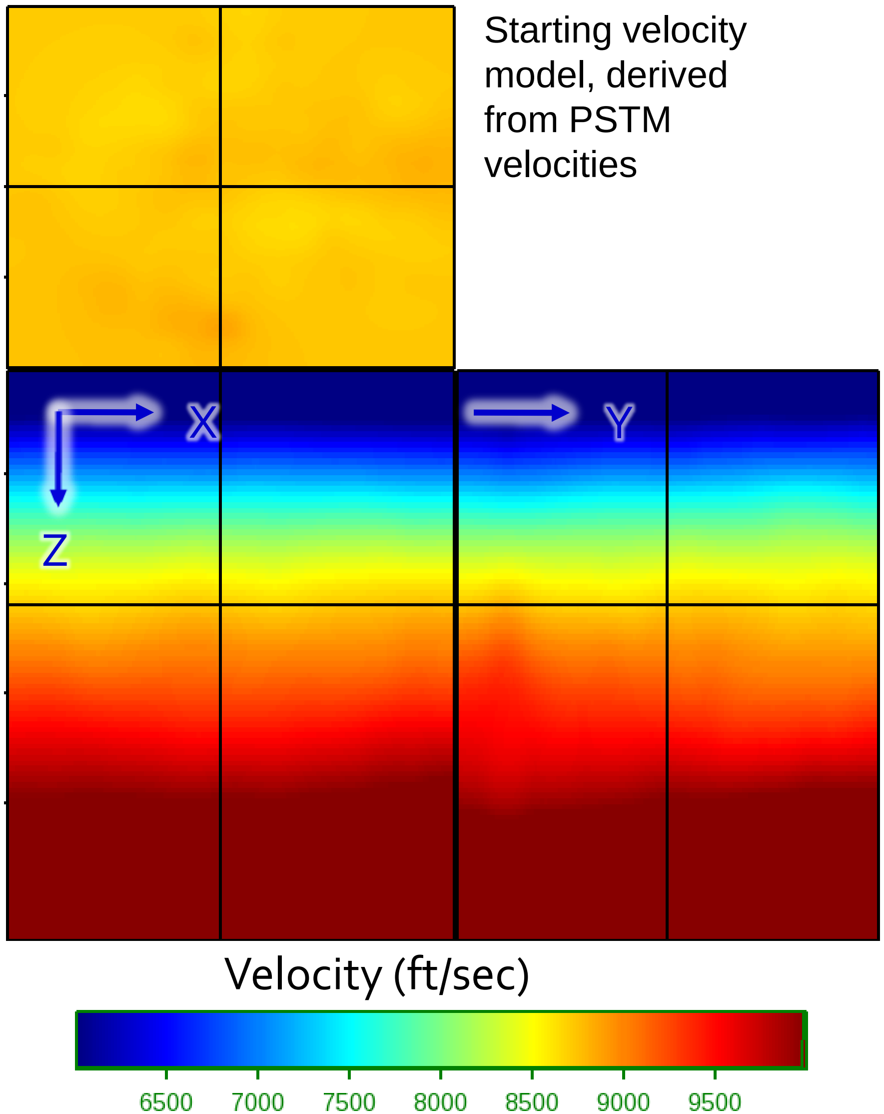


PSDM: Better Fault Imaging

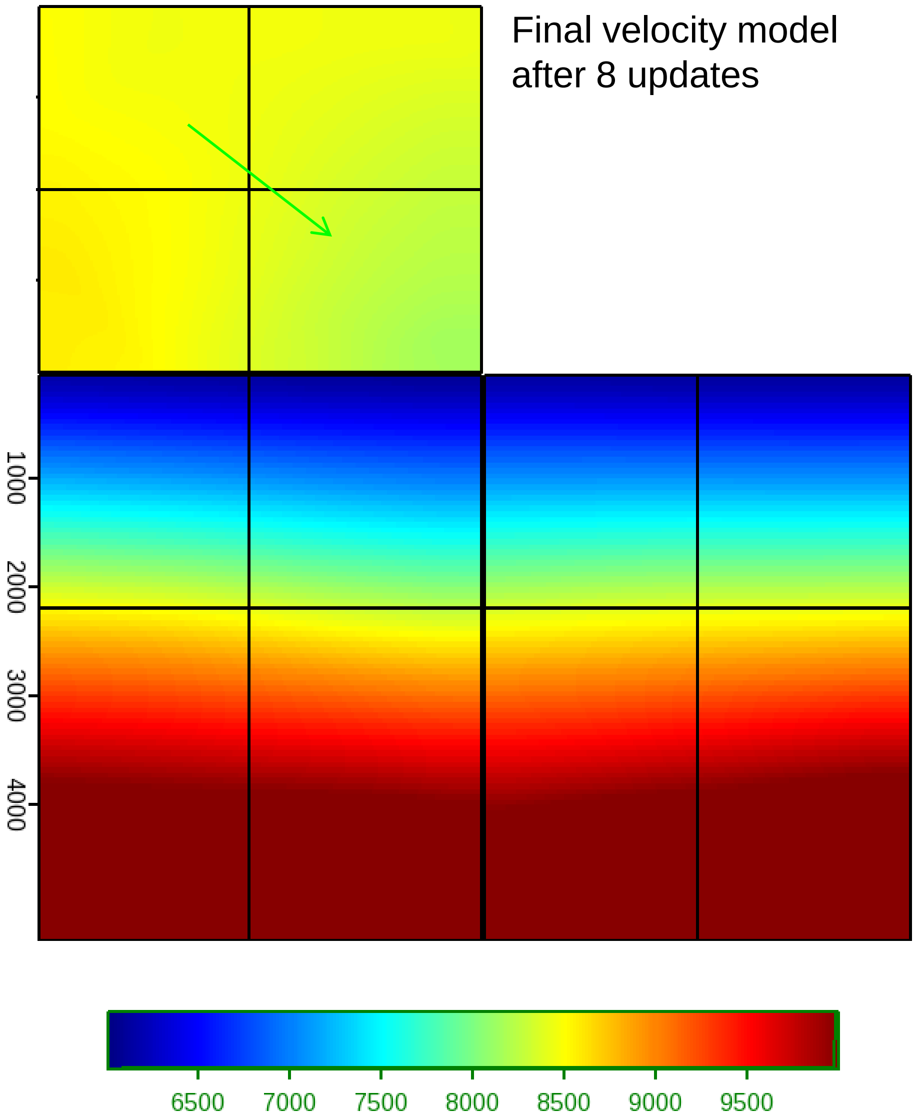


In PSDM: Velocity is Everything!

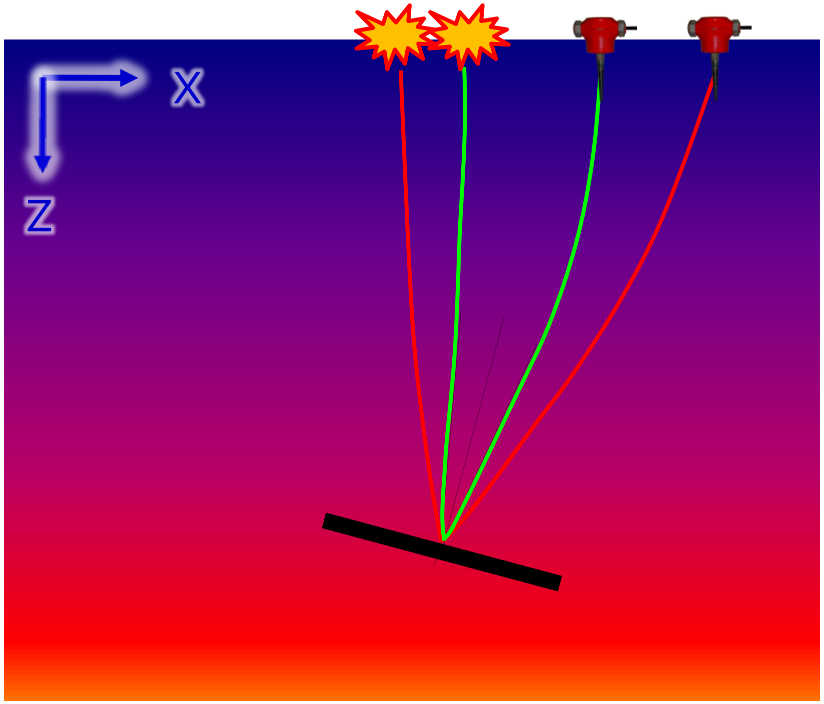
Starting velocity model, derived from PSTM velocities

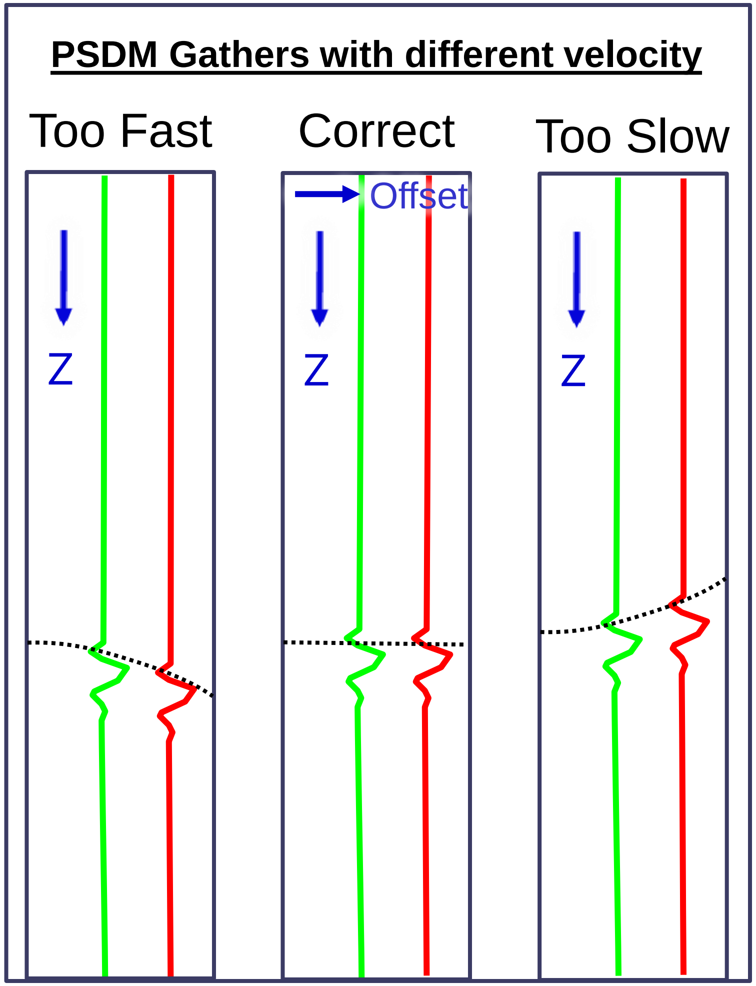


Final velocity model after 8 updates

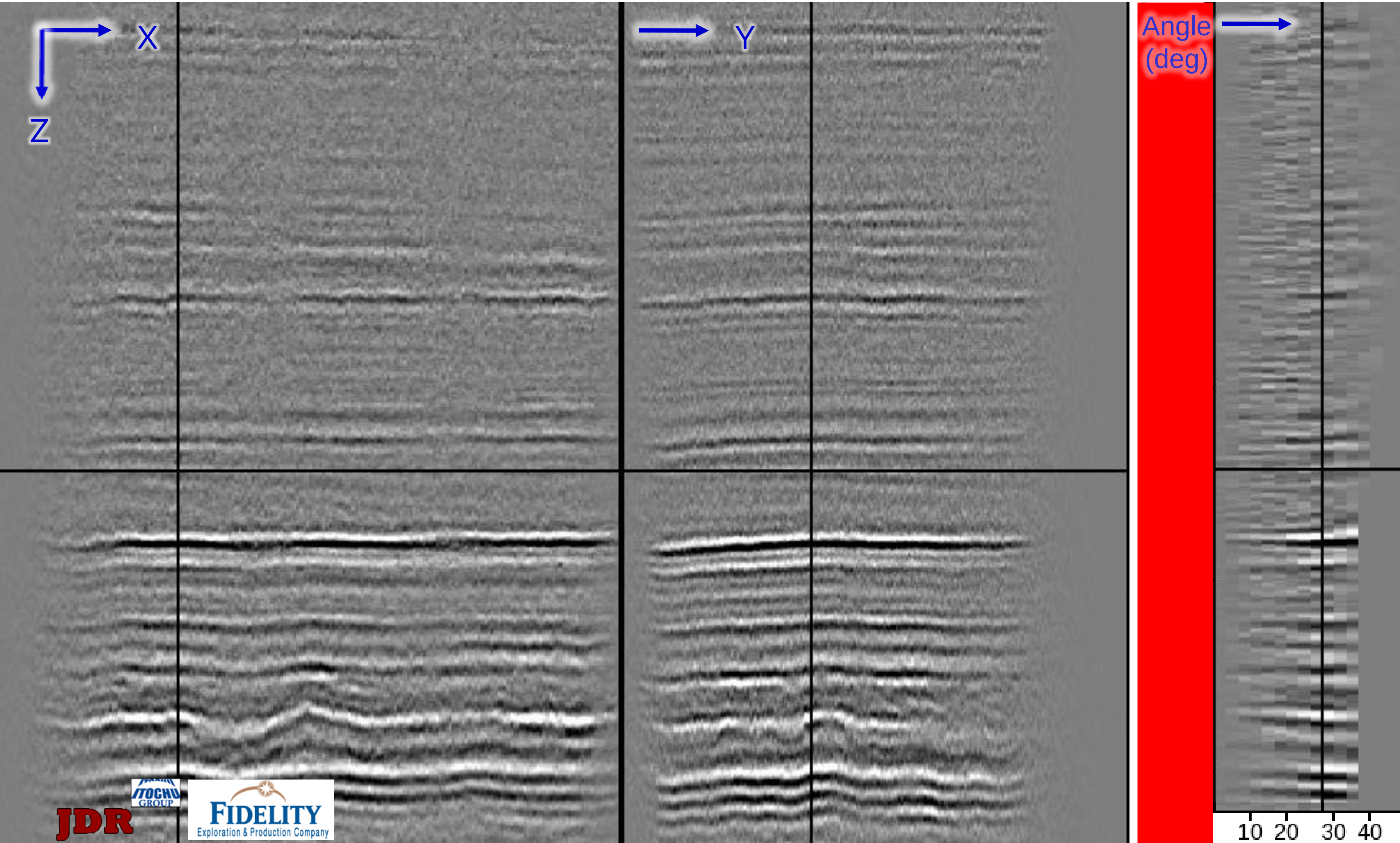


PSDM Velocity Update

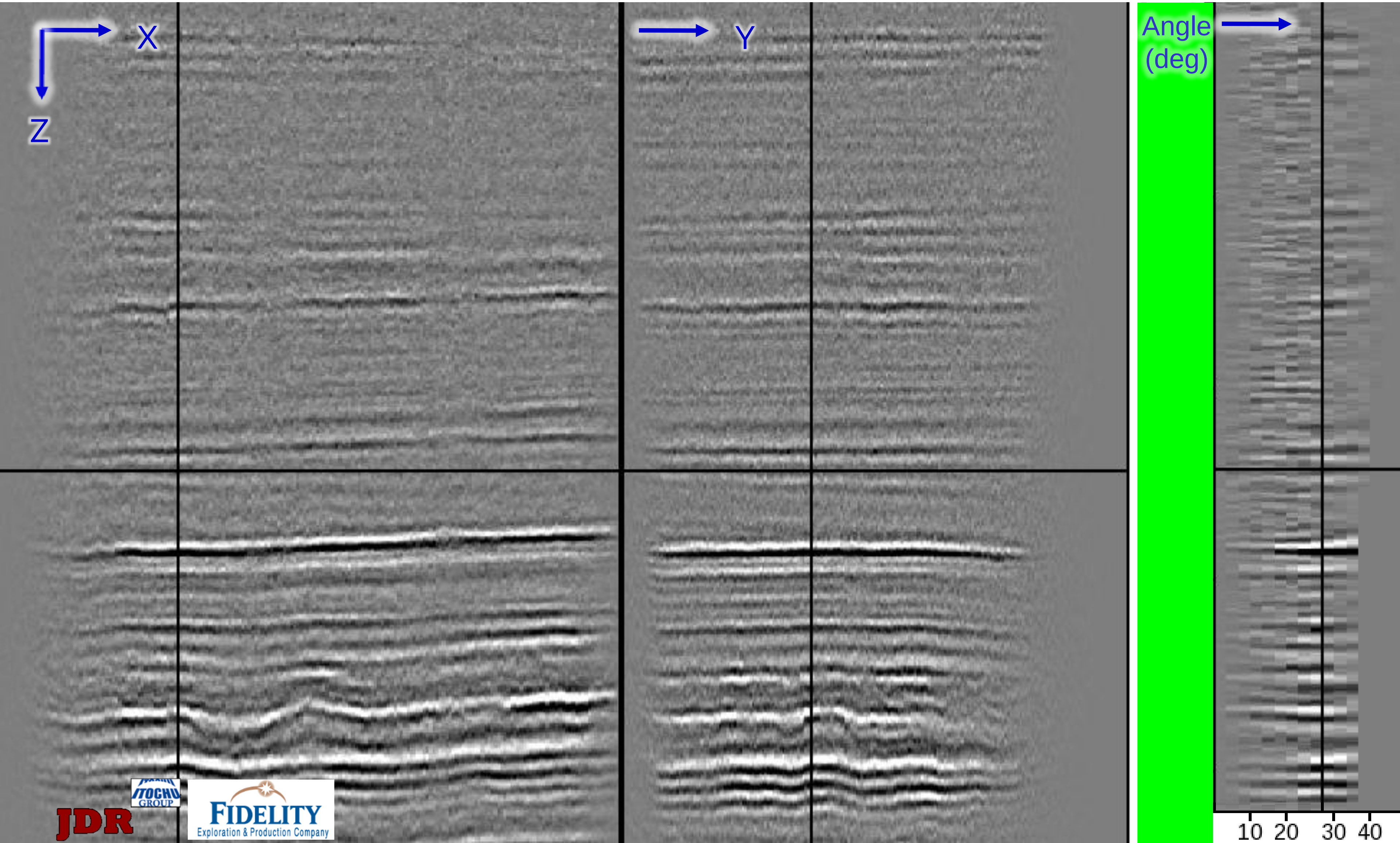




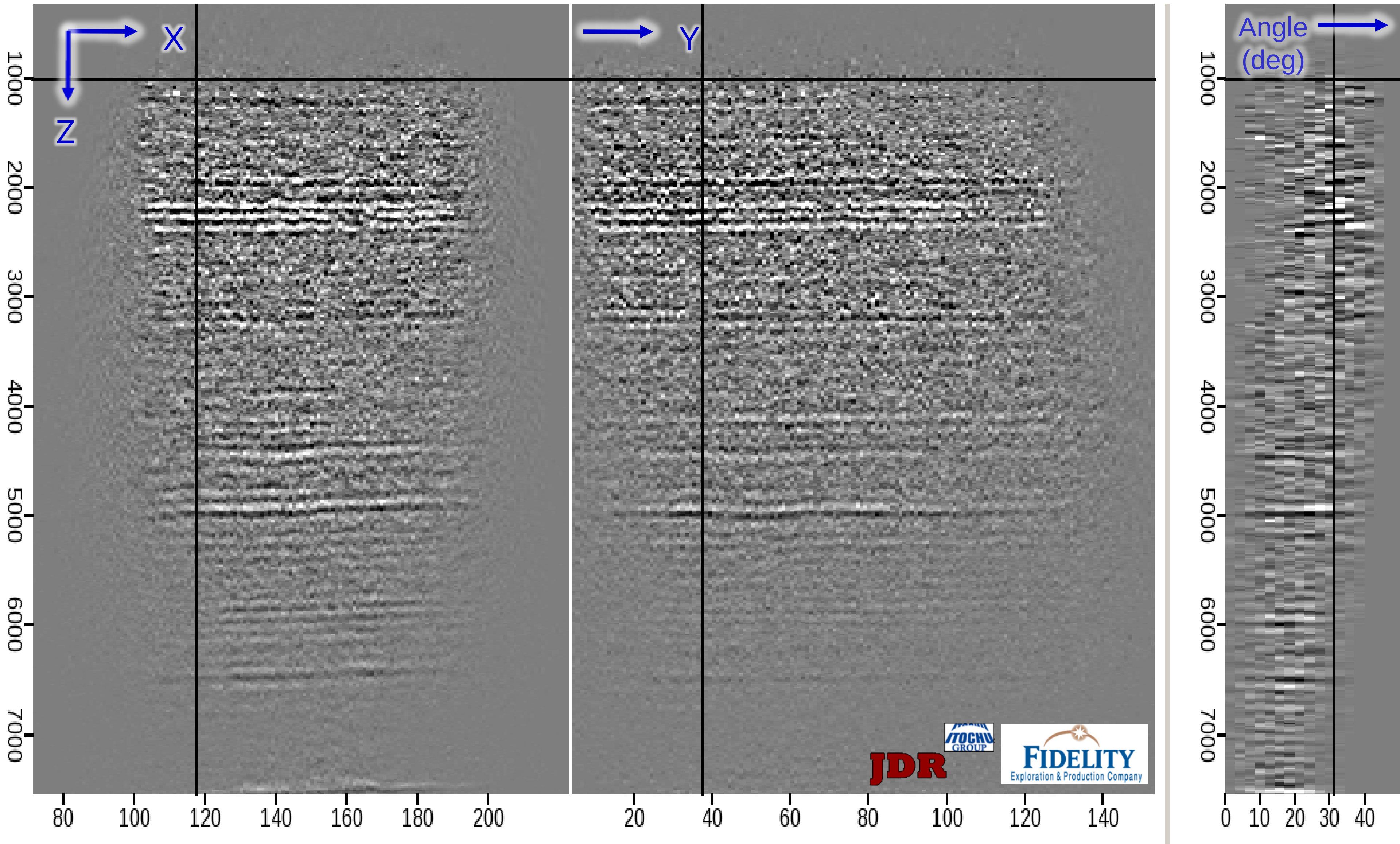
Angle Gathers: PSTM Velocity



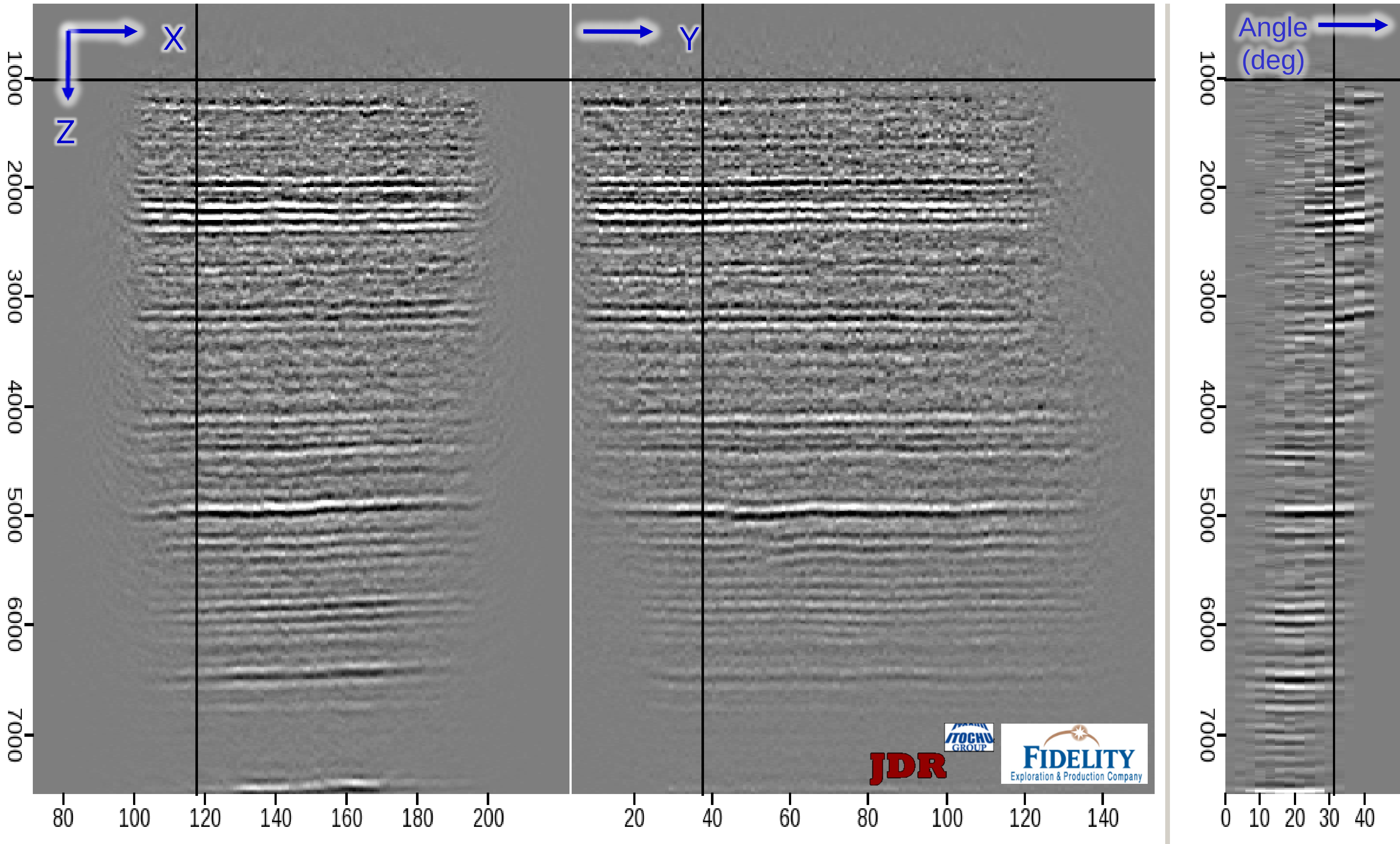
Angle Gathers: Optimized Velocity



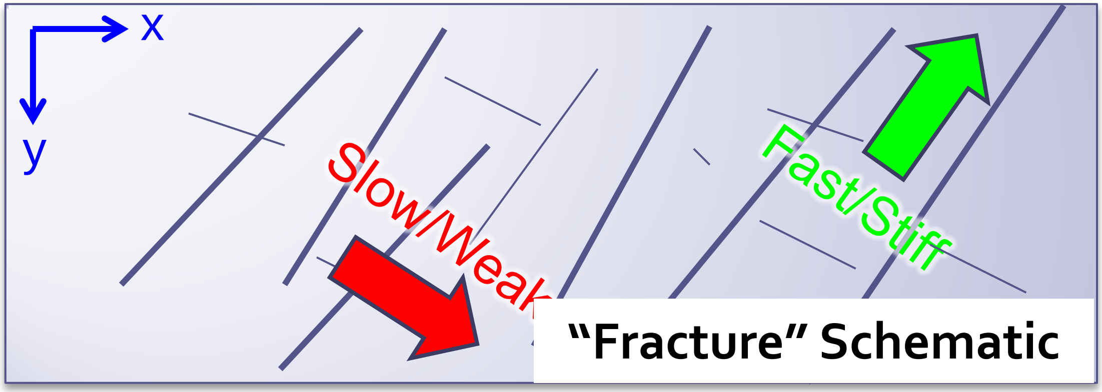
Raw WEM Angle Gathers



5D Interpolated WEM Angle Gathers



“Fractures” from PSDM Angle Gathers

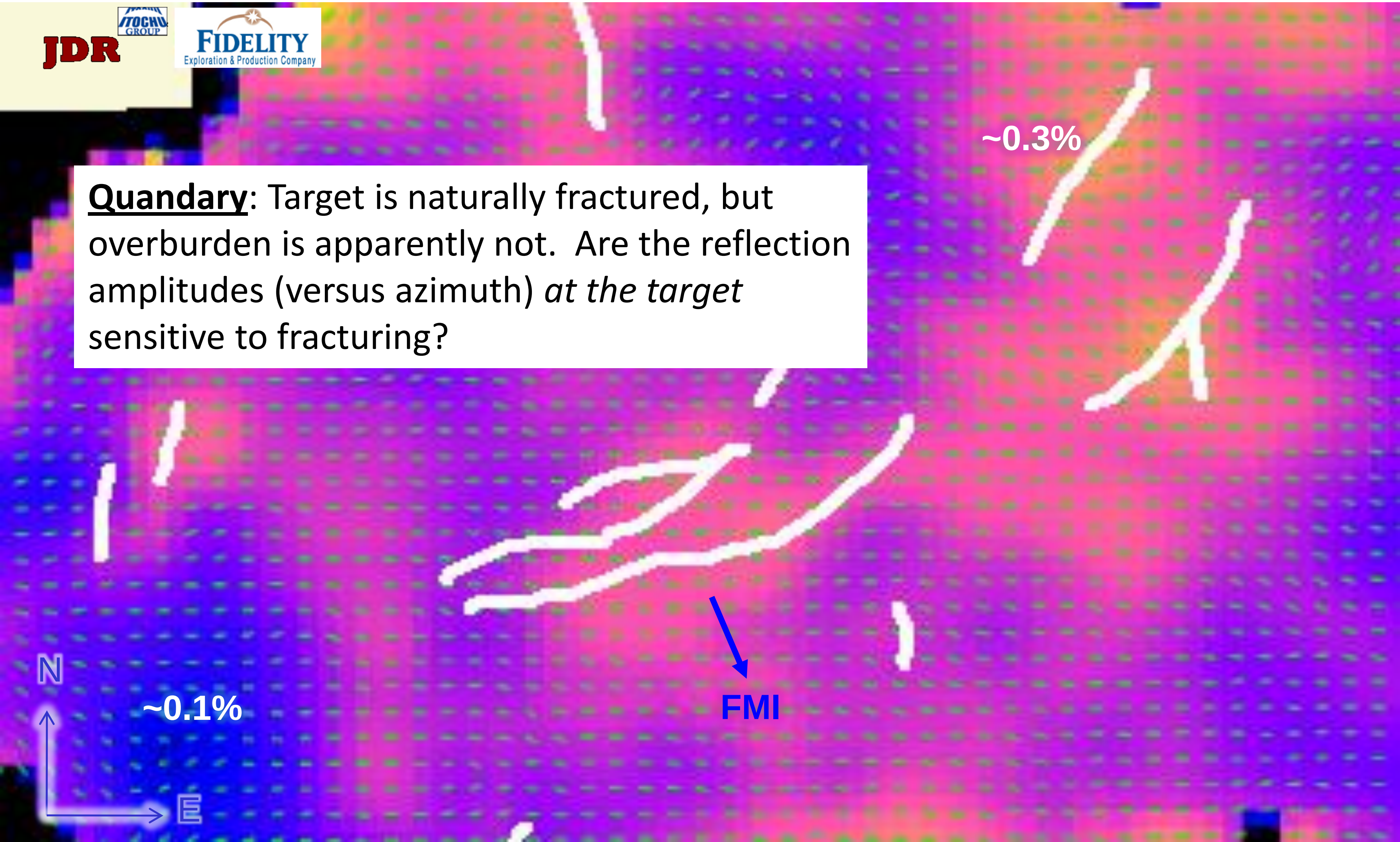


“Fracture” Schematic

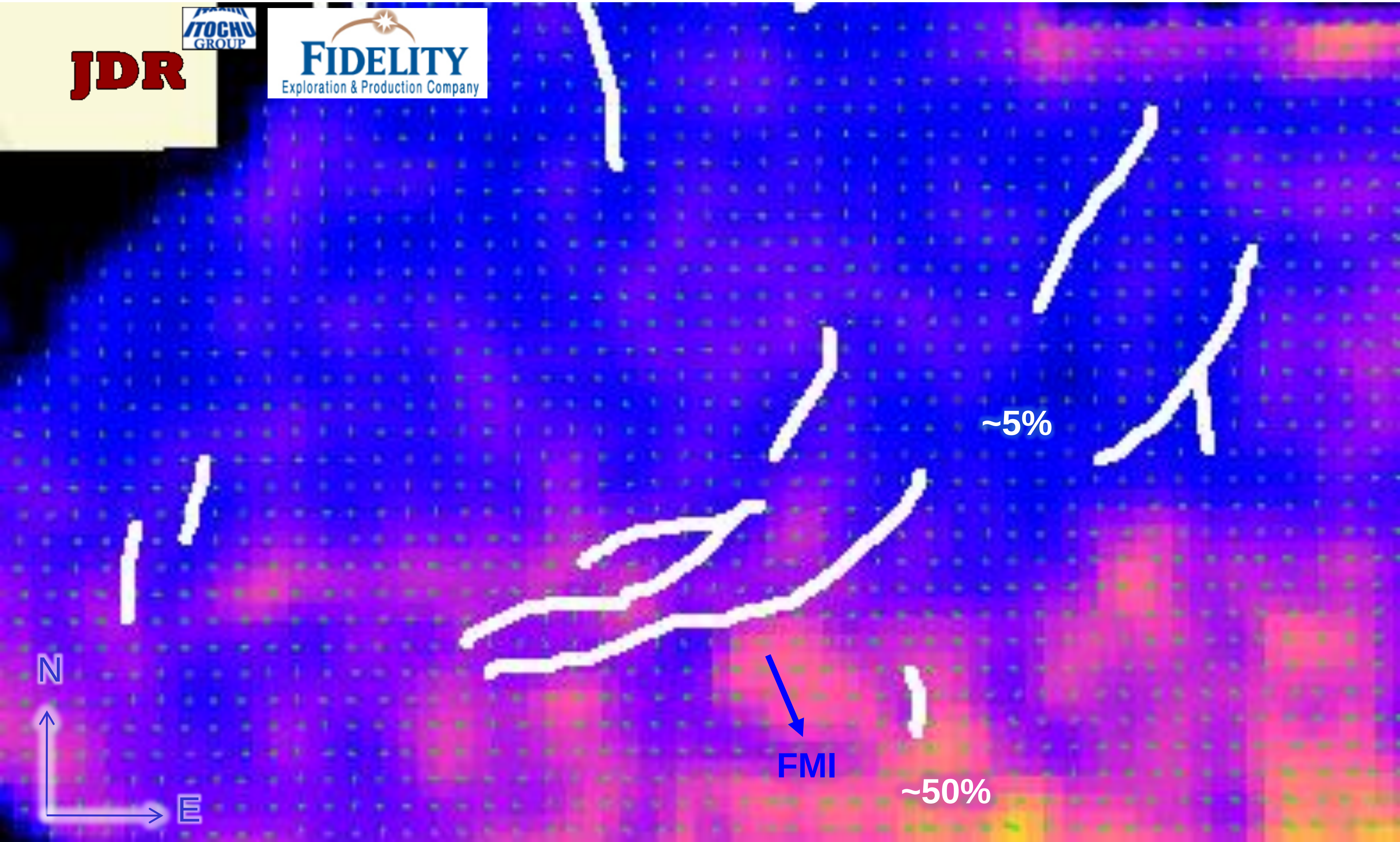
- HTI Analysis – Azimuthal Velocity Variation
  - Good: regional stress variations
  - Bad: localized fracture trends
- AVAZ – Azimuthal AVO Analysis
  - Good: Localized fracture intensity
  - Bad: Fracture orientation

HTI "Fracture" Map

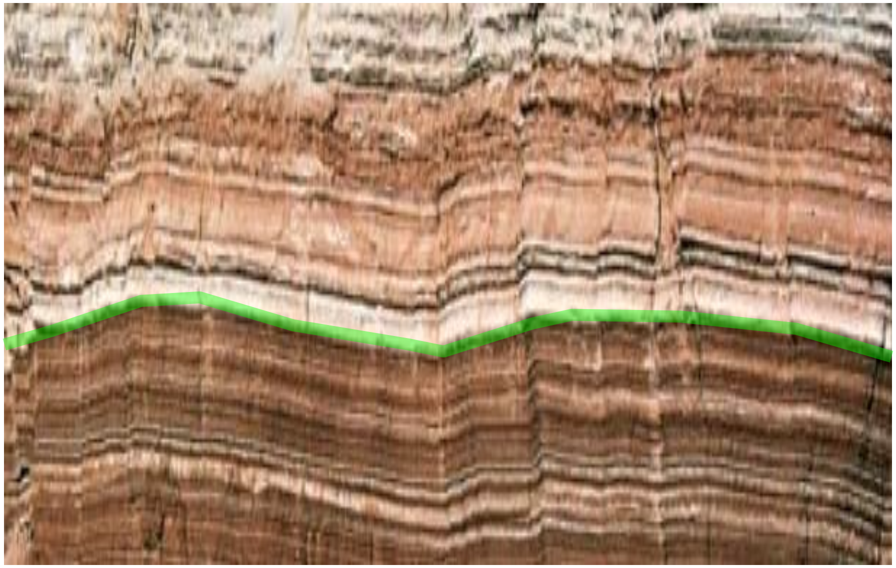
<u>Quandary</u>: Target is naturally fractured, but overburden is apparently not. Are the reflection amplitudes (versus azimuth) *at the target* sensitive to fracturing?



From AVAZ Slope

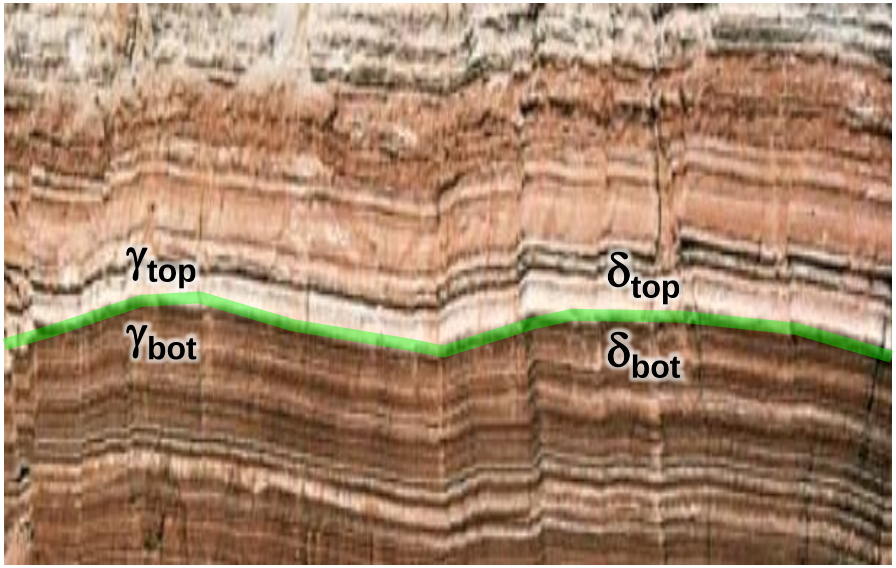


What causes AVAZ?

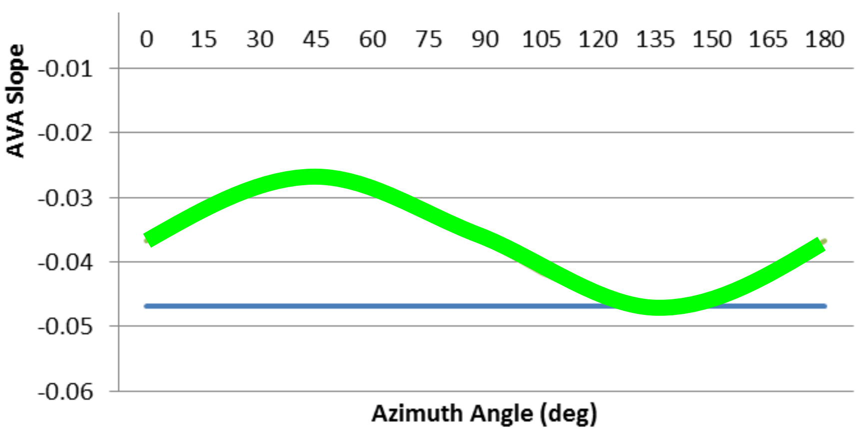


- Change in azimuthal anisotropy (Thomsen) parameters across an interface
- P-waves: δ, ε
- S-waves: γ
  - From sonic scanner

50 Percent AVAZ?



- Change in azimuthal anisotropy (Thomsen) parameters across an interface
- P-waves: δ, ε
- S-waves: γ
  - 0.03 in one well



Realistic assumptions → 50% AVAZ

Elliptical: $\delta=\varepsilon$

$\gamma_{bot} - \gamma_{top} = 0.05$

$\delta_{bot} - \delta_{top} = 0.01$

Takeaways

- Part 1
  - PSDM:
    - Removes false time structures
    - Better positions/focuses steep dips and faults
  - 5D Interpolation is here to stay
  - High-intensity velocity analysis = PSDM success
- Part 2
  - WEM angle gathers: attributes in complex geology
    - Top-to-bottom Azimuthal anisotropy was weak here
    - AVAZ analysis appears more promising

Acknowledgements

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