PSDM for "Easy" Unconventional Reservoirs?

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Pacific Coast Section SEG Luncheon

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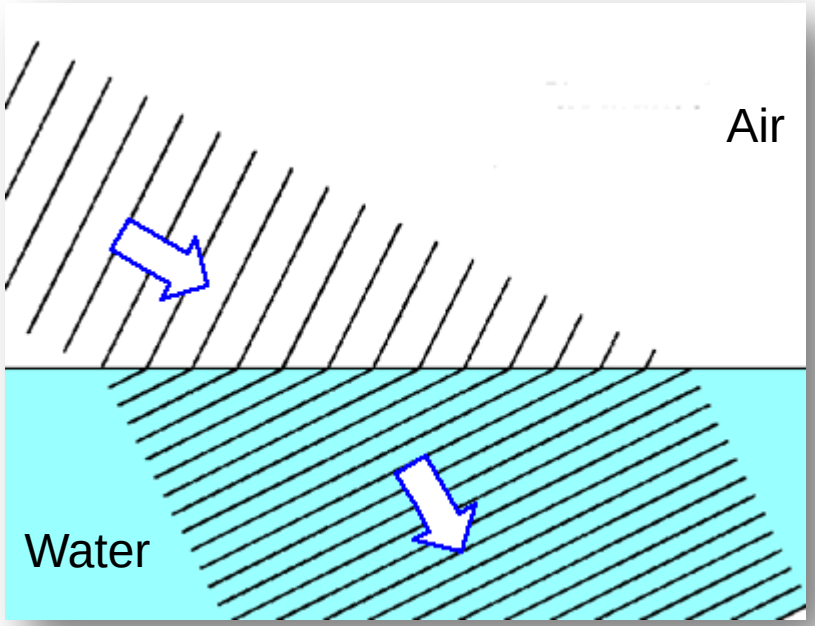
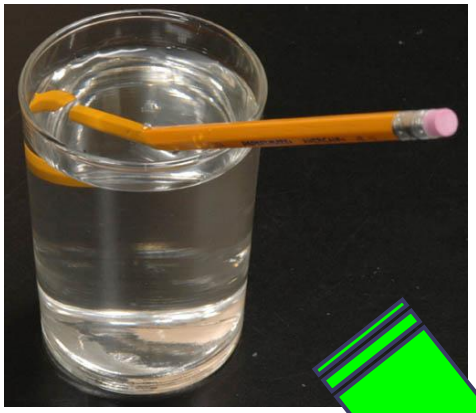
Wave Imaging Technology Inc.

About This Talk (~40 min)

- **Who** – "Seismically-conversant" geoscientists
- **What** – Prestack Depth Migration (PSDM)
- **Where** – US Shale Oil play
- **Why**? PSDM becoming the onshore norm…
  - What is it? Why do it?
  - Special unconventionals impact?

Why Wave Equation PSDM?





Simple refraction

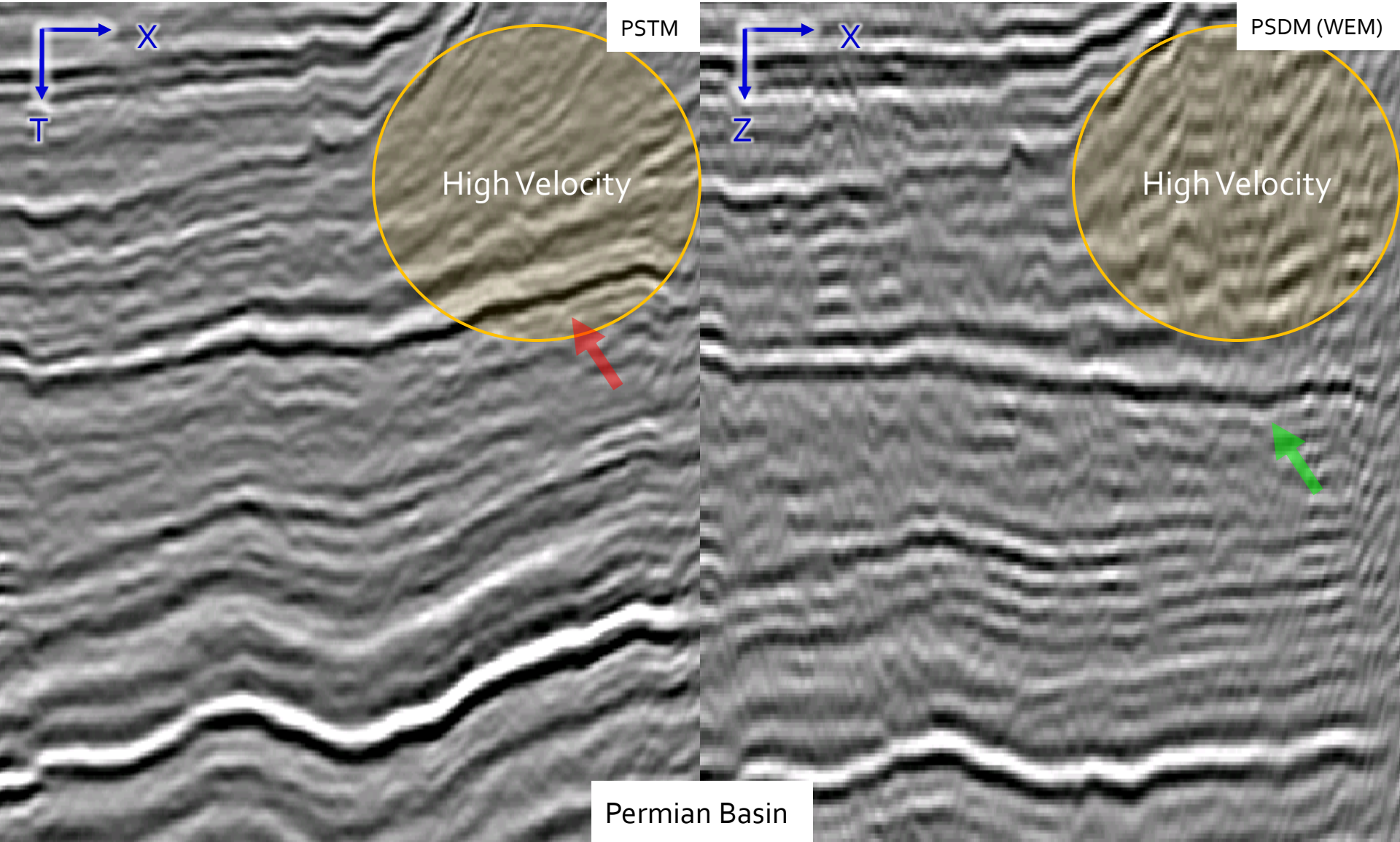
Kirchhoff

WEM

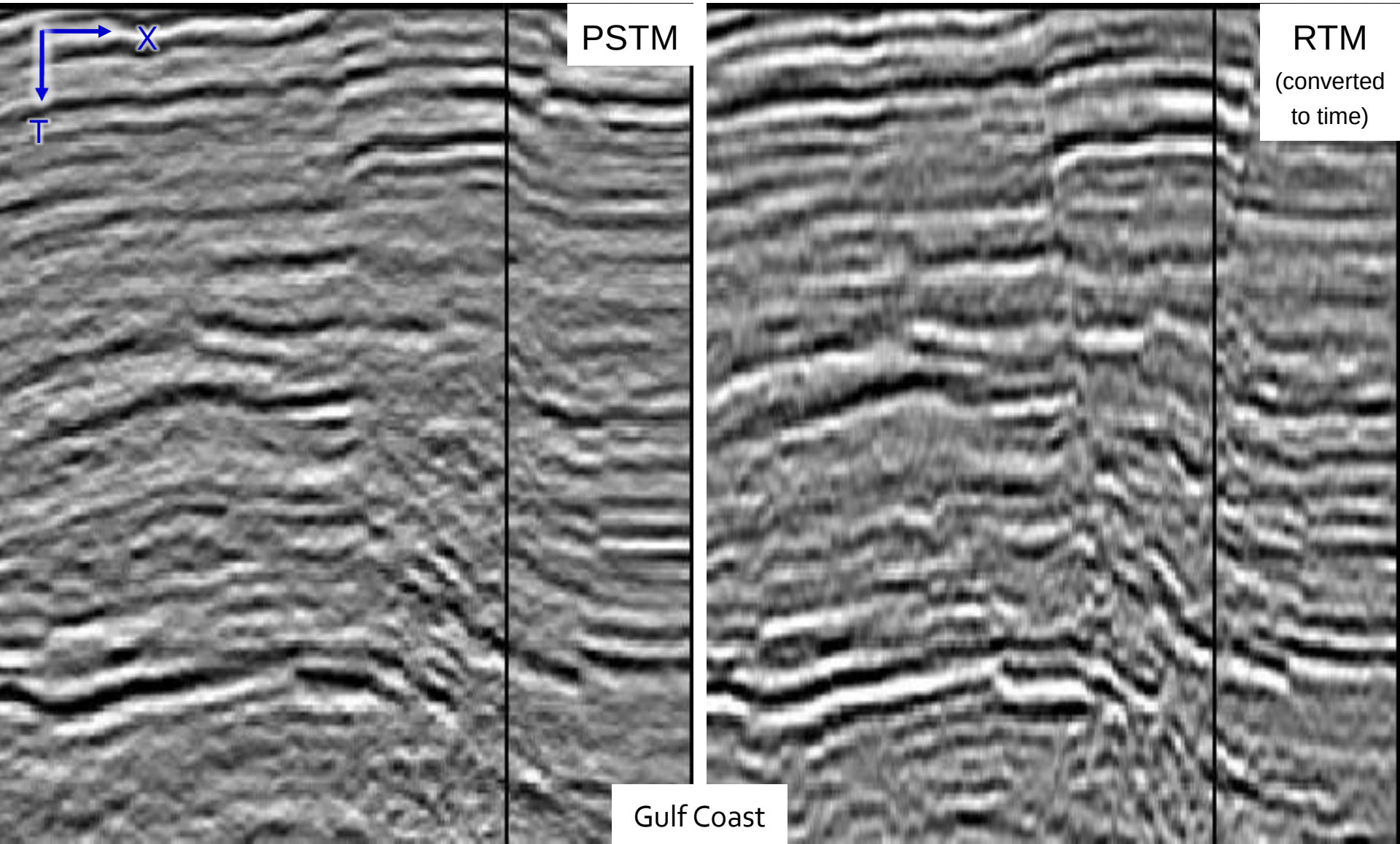
RTM

Complex focusing

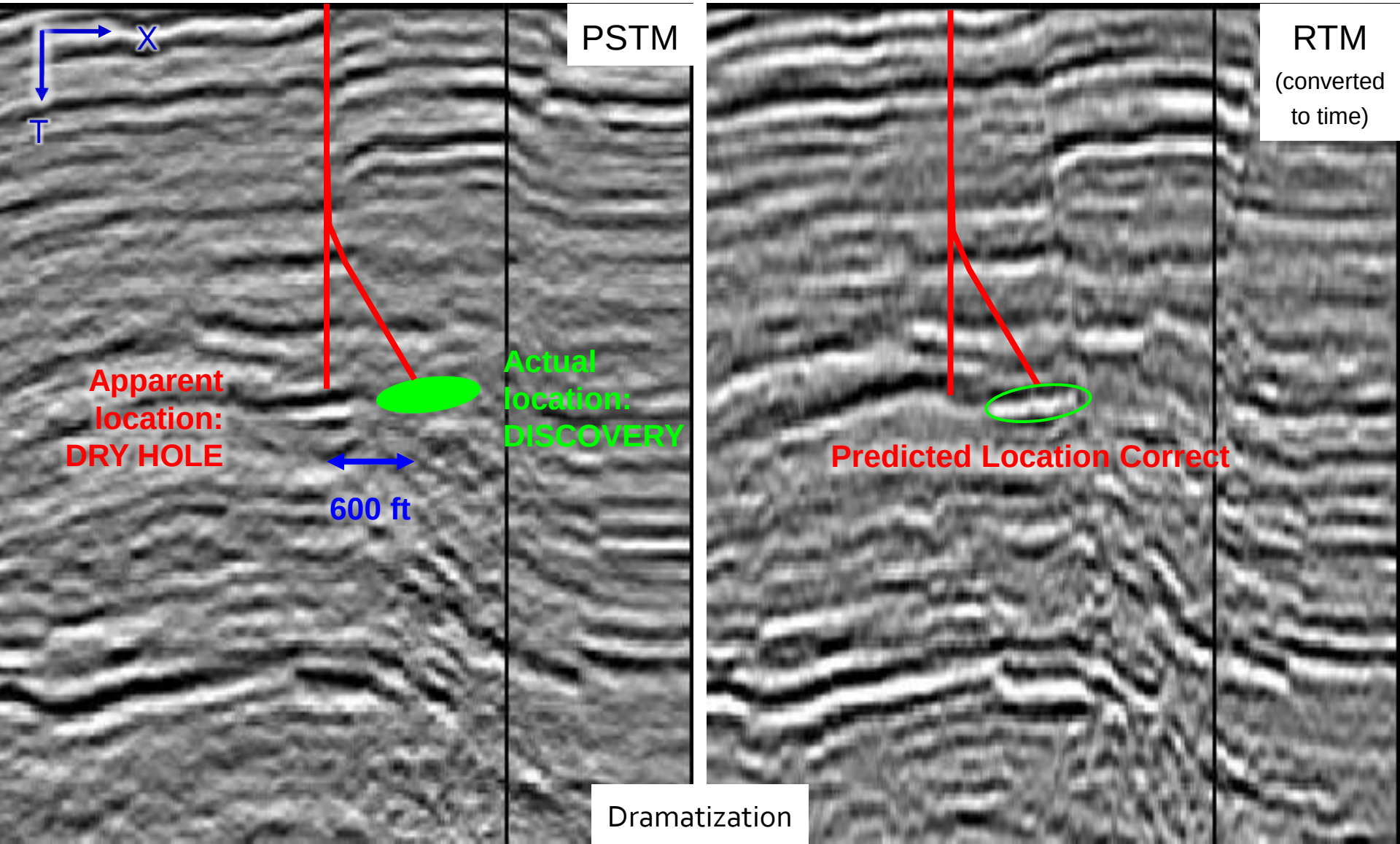
PSDM: Removes False Time Structure



PSDM: Better Steep Dips & Faults

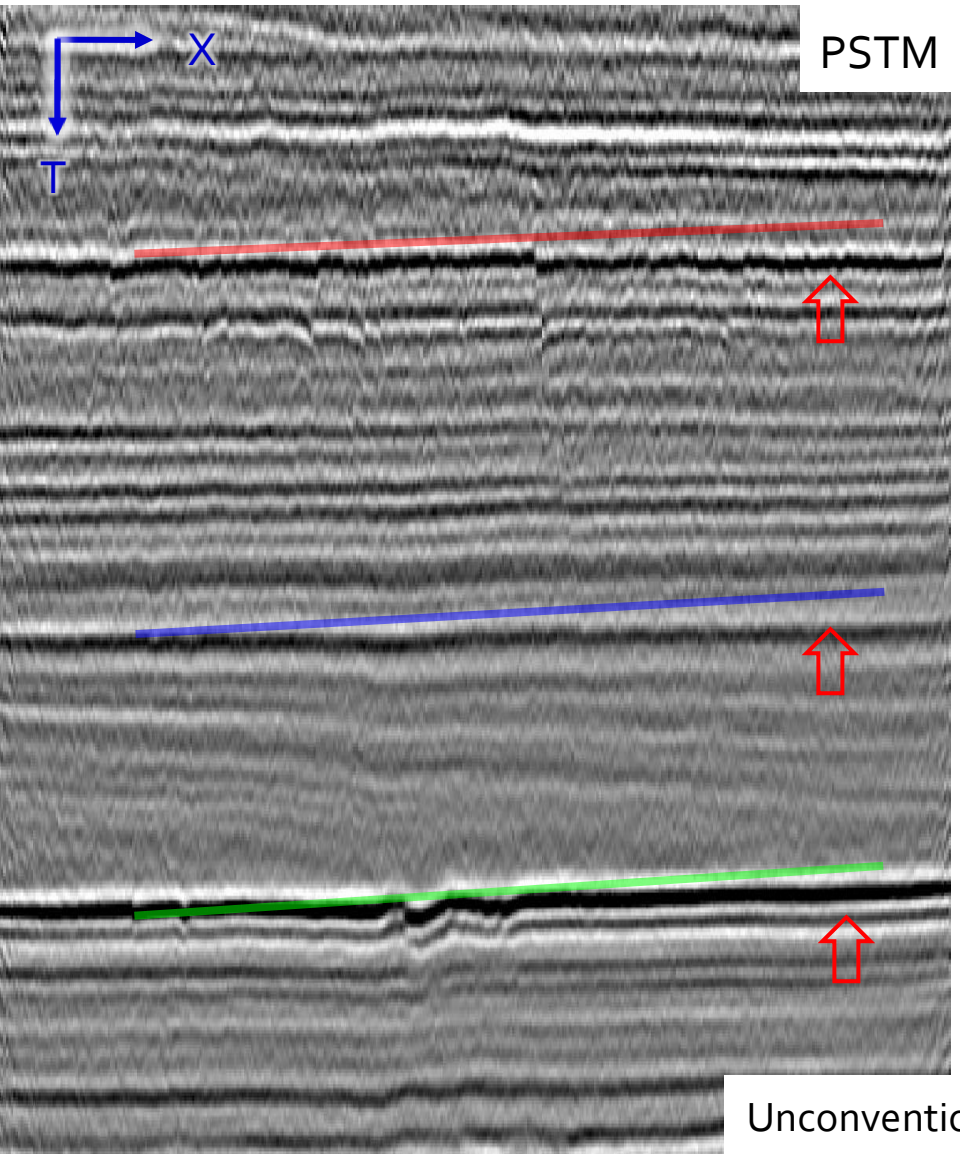


PSDM: Better Lateral Positioning

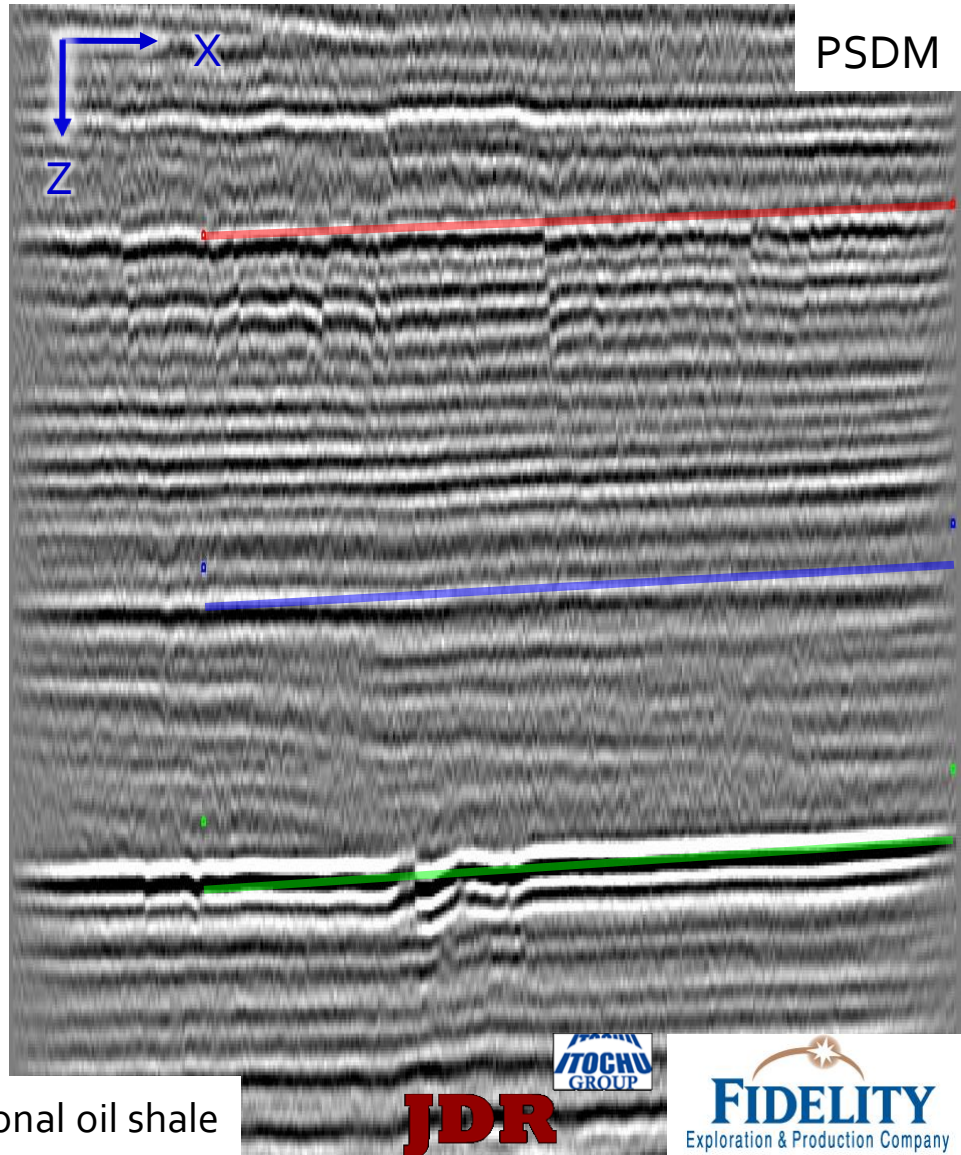


Dramatization

Myth 1: Not for Resource Plays?



PSTM



PSDM

Unconventional oil shale

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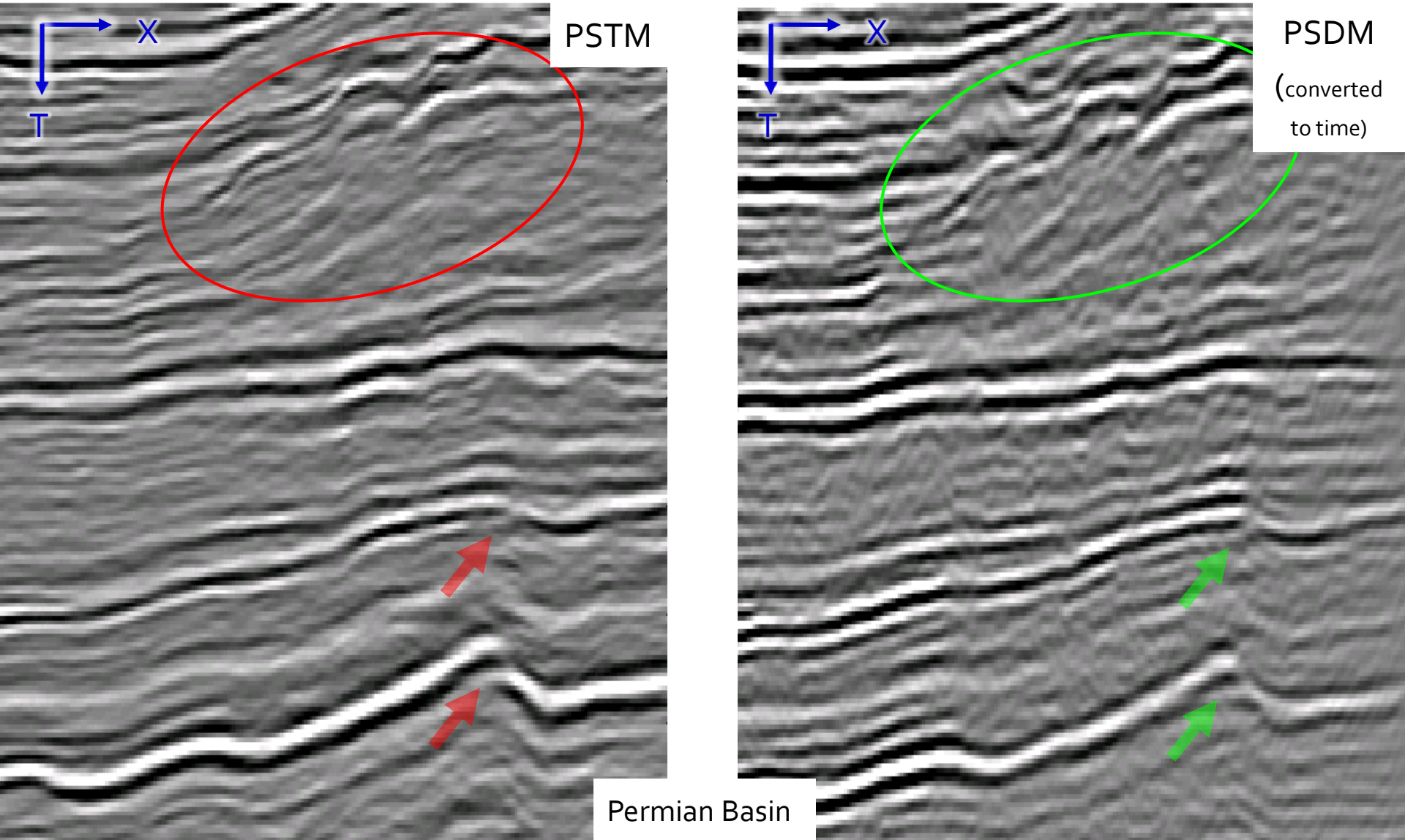
FIDELITY
Exploration & Production Company

Myth 2: Lower Frequency Content?

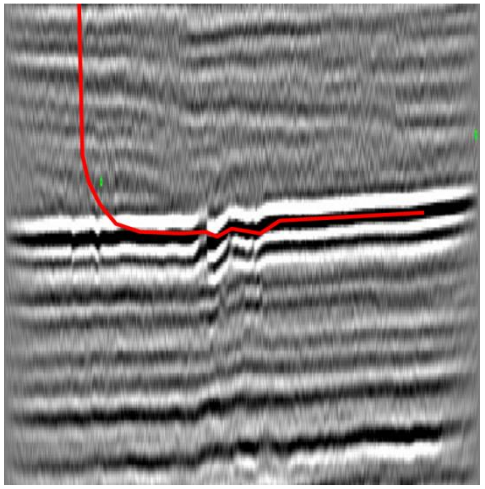


Unconventional Case Study

- Hi-res 50 sq mi 3D, US Oil Shale play
- Part 1: Structural Imaging
  - Success = Velocity
  - Improved event geometry, fault imaging
- Part 2: "Sweet Spot" Delineation
  - Azimuthal anisotropy
  - AVAZ

Seismic: Financial Impacts

Fine Scale

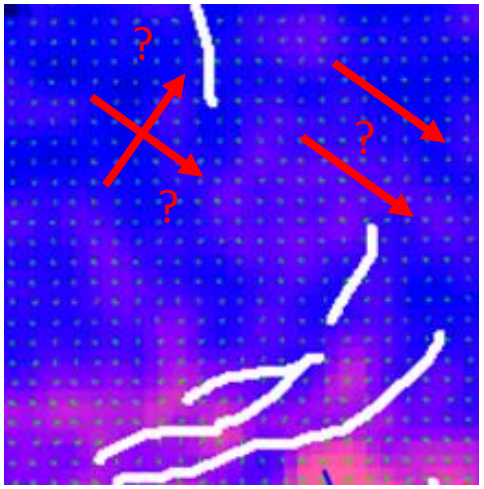


Where to drill?

Avoid sidetracks
Stay in zone

Part 1

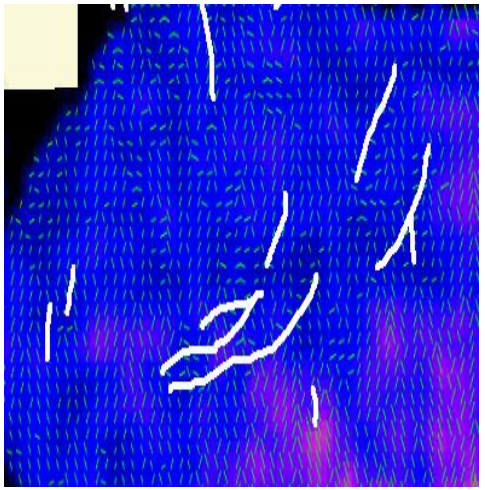
Medium Scale



How/Where to drill?

Borehole orientation
Best wells first

Wide Scale



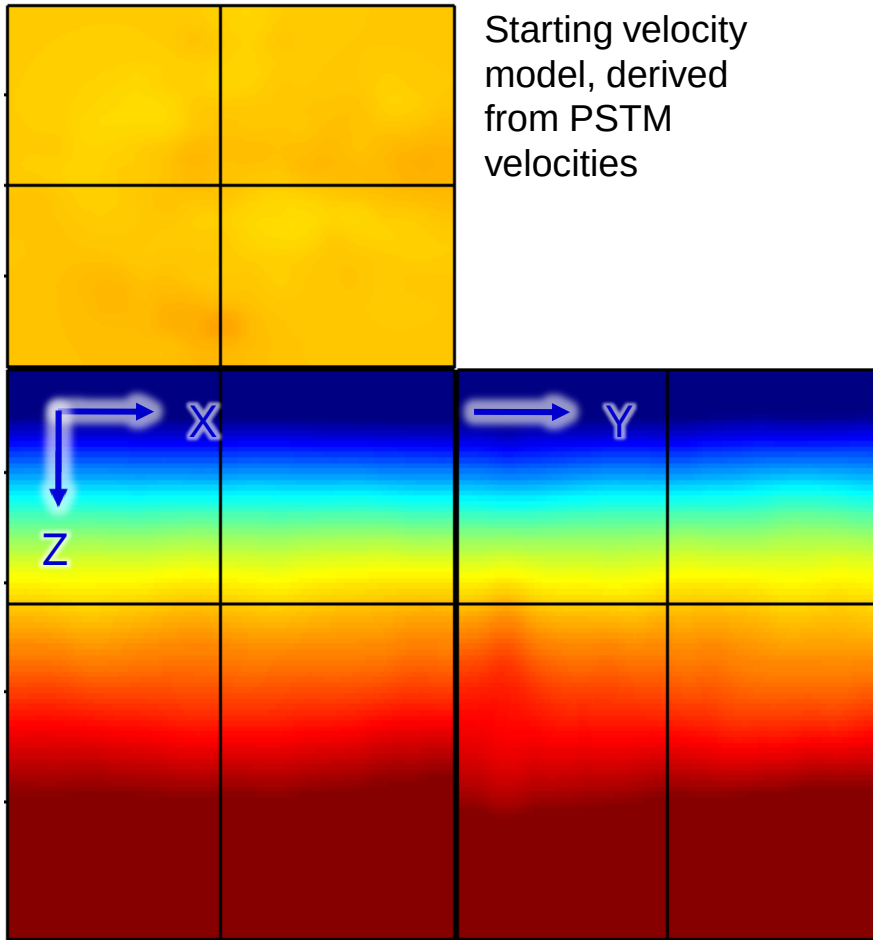
If to drill?
Where to lease?

Best parts of basin
Extend sweet spots

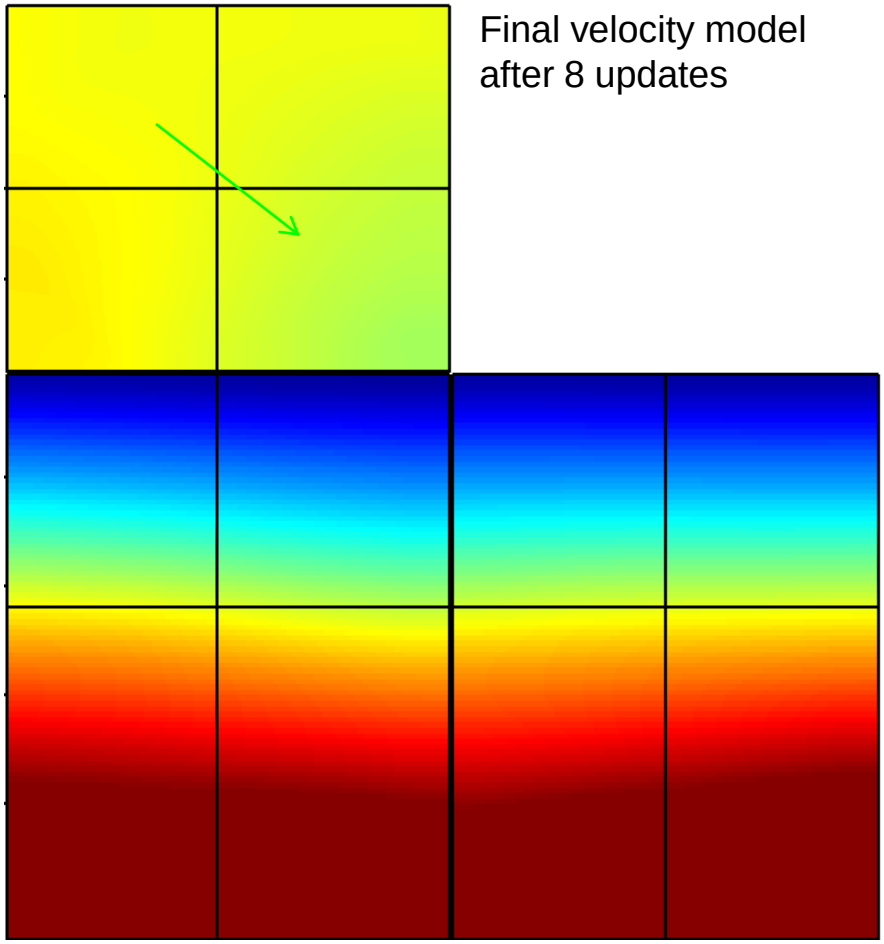
Part 2

Today → **Tomorrow** → **Future**

Initial vs. Final PSDM Velocity

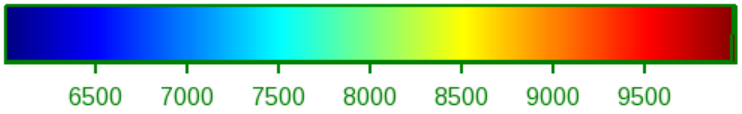


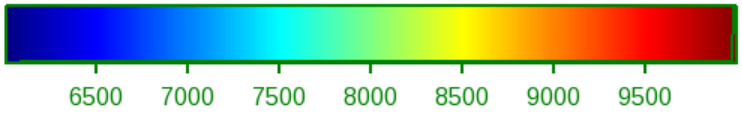
Starting velocity model, derived from PSTM velocities



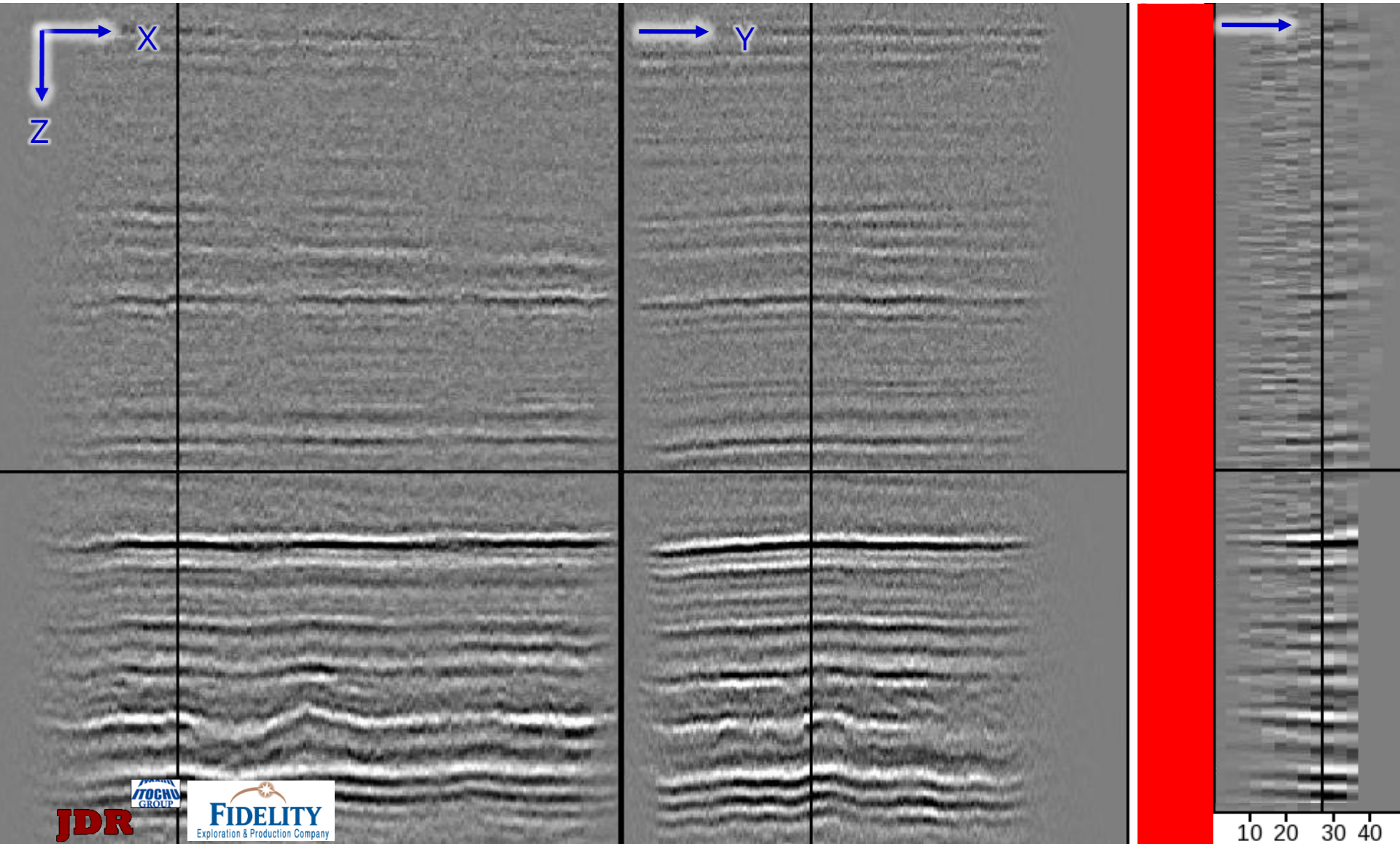
Final velocity model after 8 updates

Velocity (ft/sec)





Angle Gathers: PSTM Velocity



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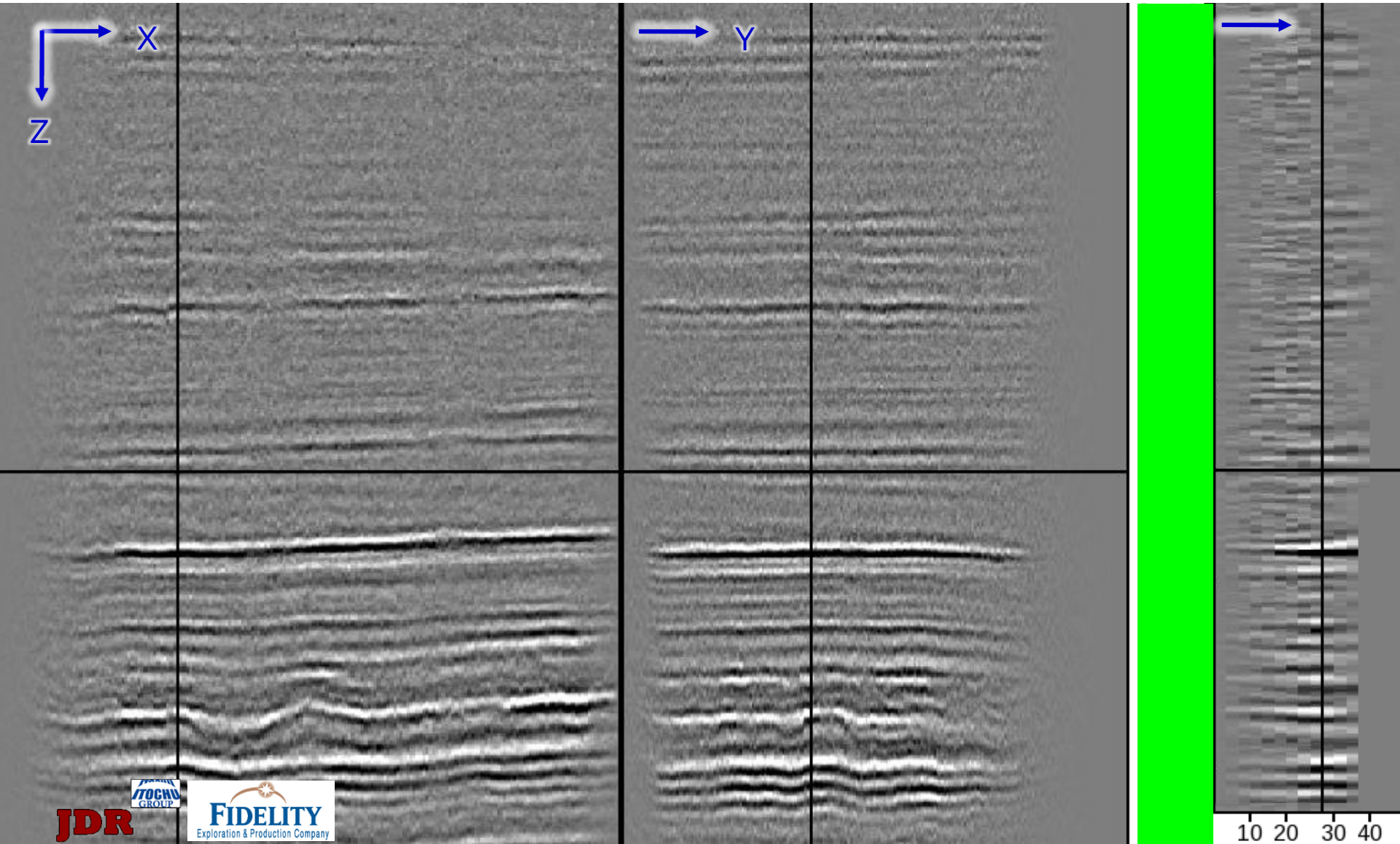
Angle Gathers: Optimized Velocity



PSTM: Location 1

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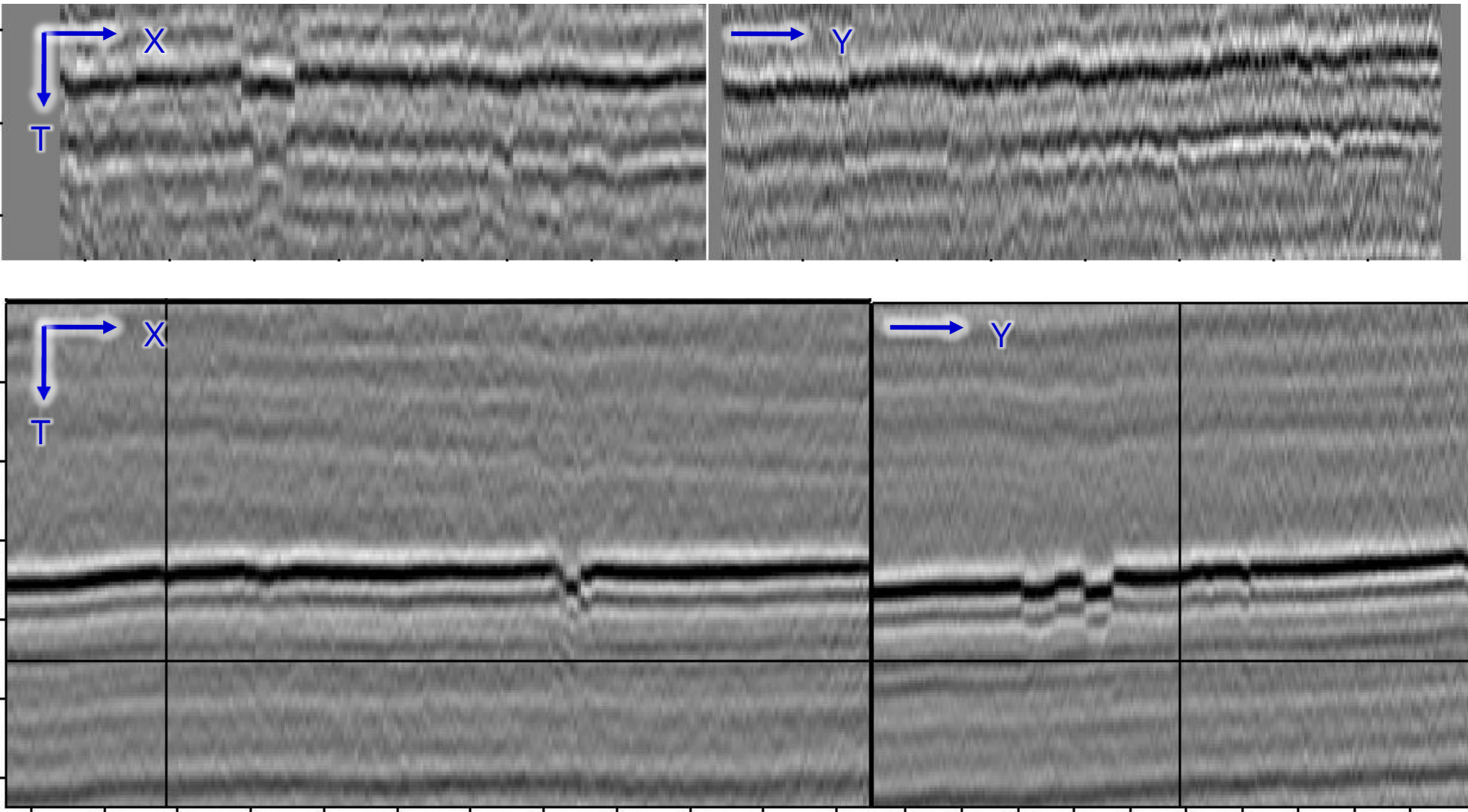

PSDM: Location 1

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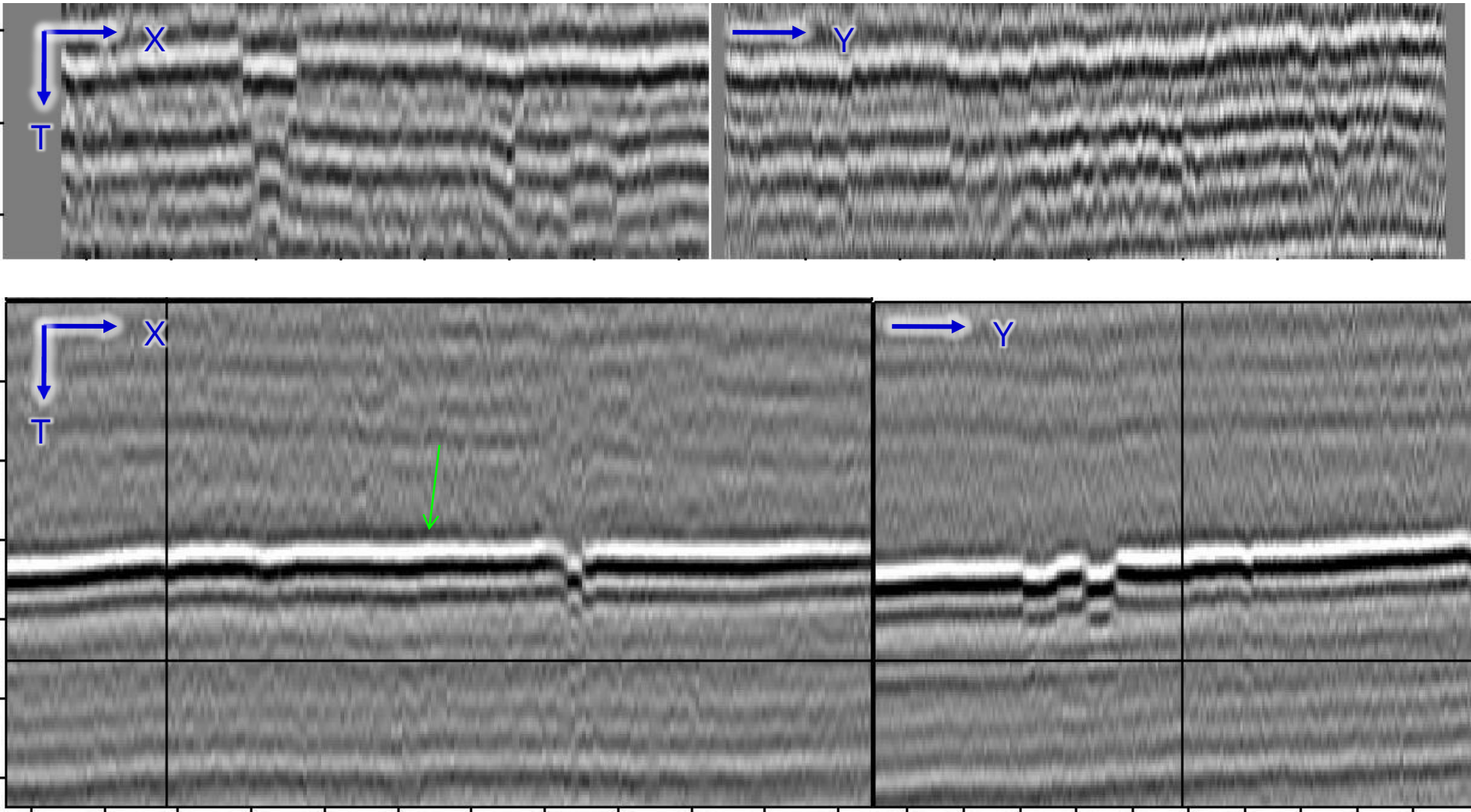
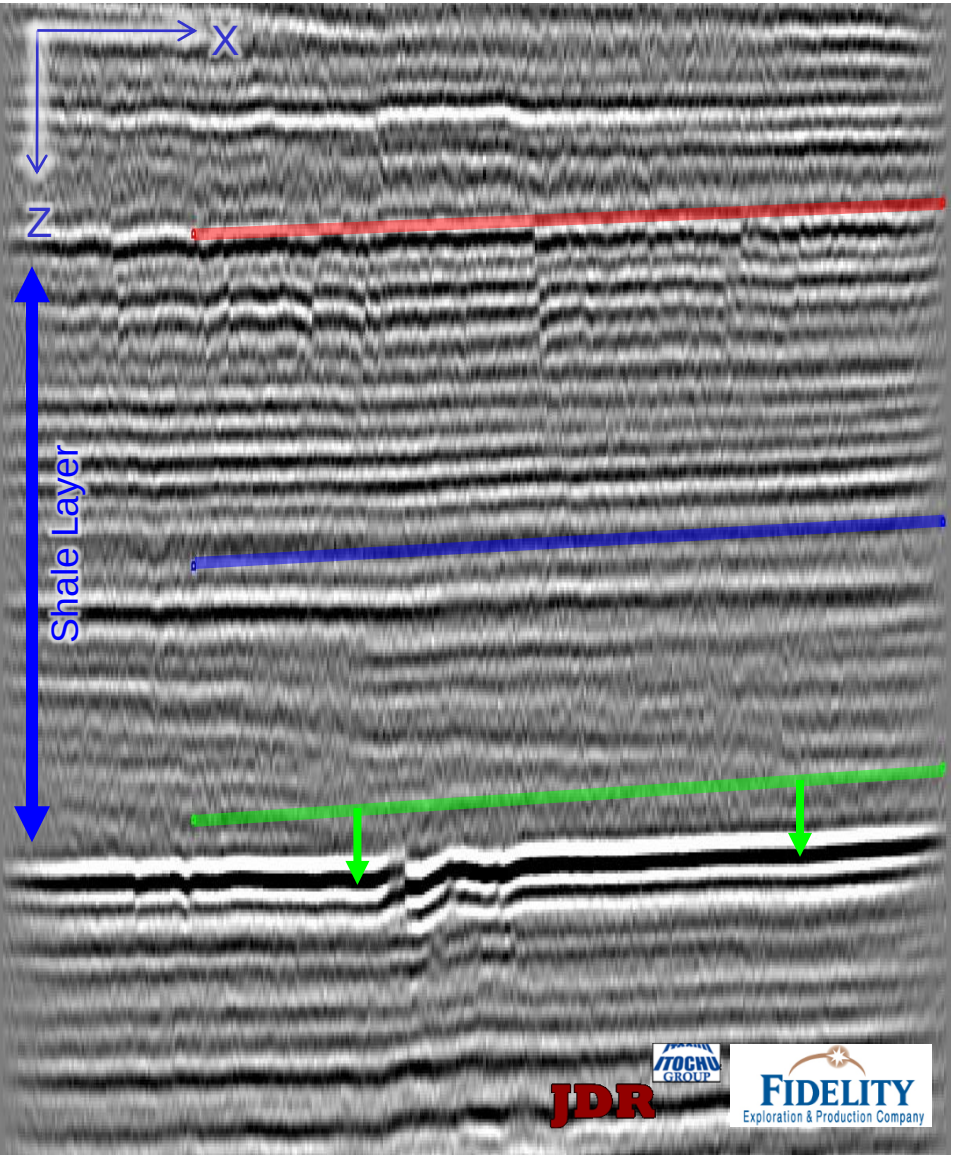
Converted to Time



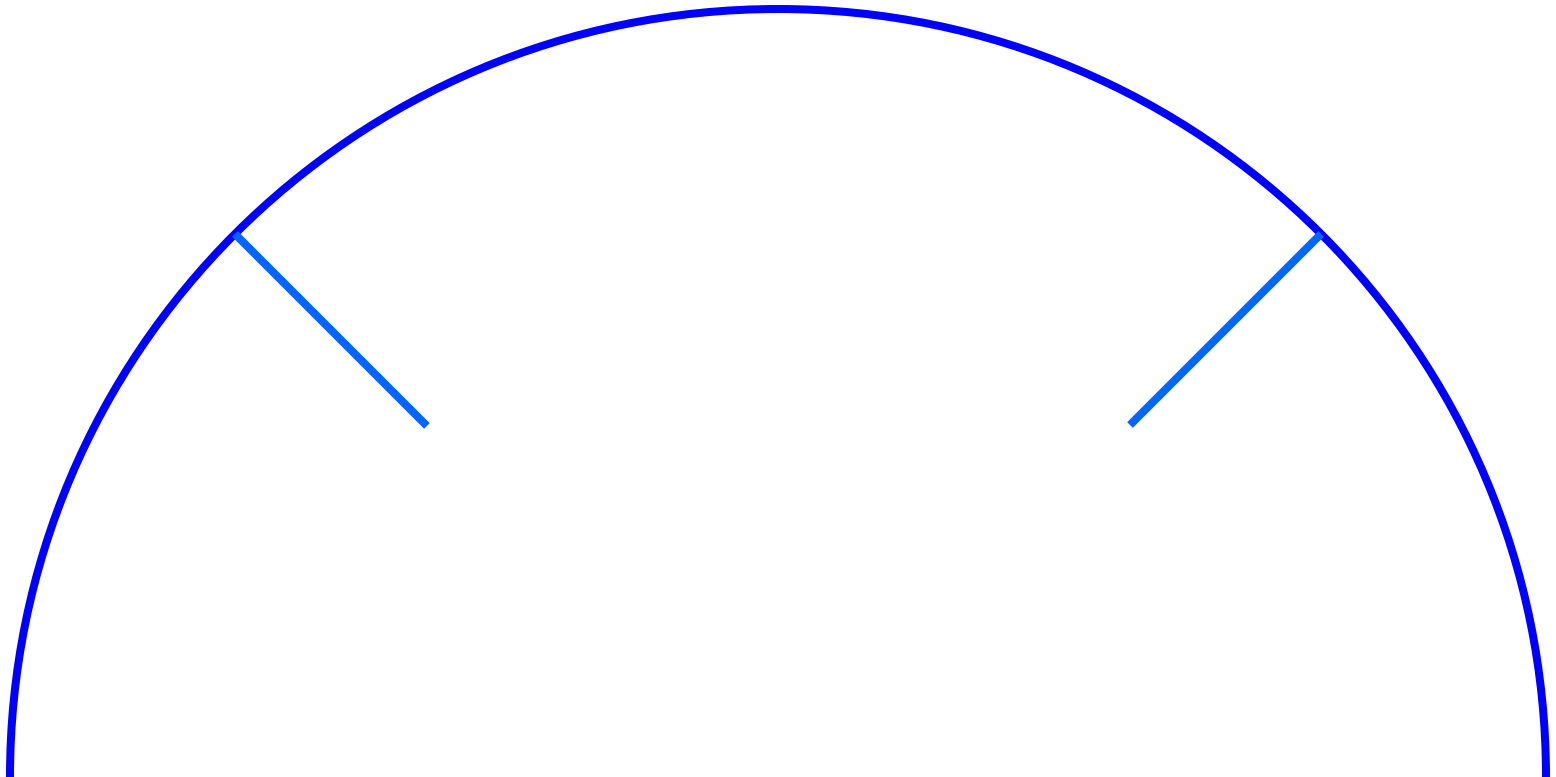
Vertical Anisotropy



- Anisotropic shale layer induces significant misties
- Measure misties at well tops
  - Build Thomsen δ for anisotropic PSDM…
  - …or warp image to fit tops
- Note: Dip is preserved
- 4 ft accuracy on new well

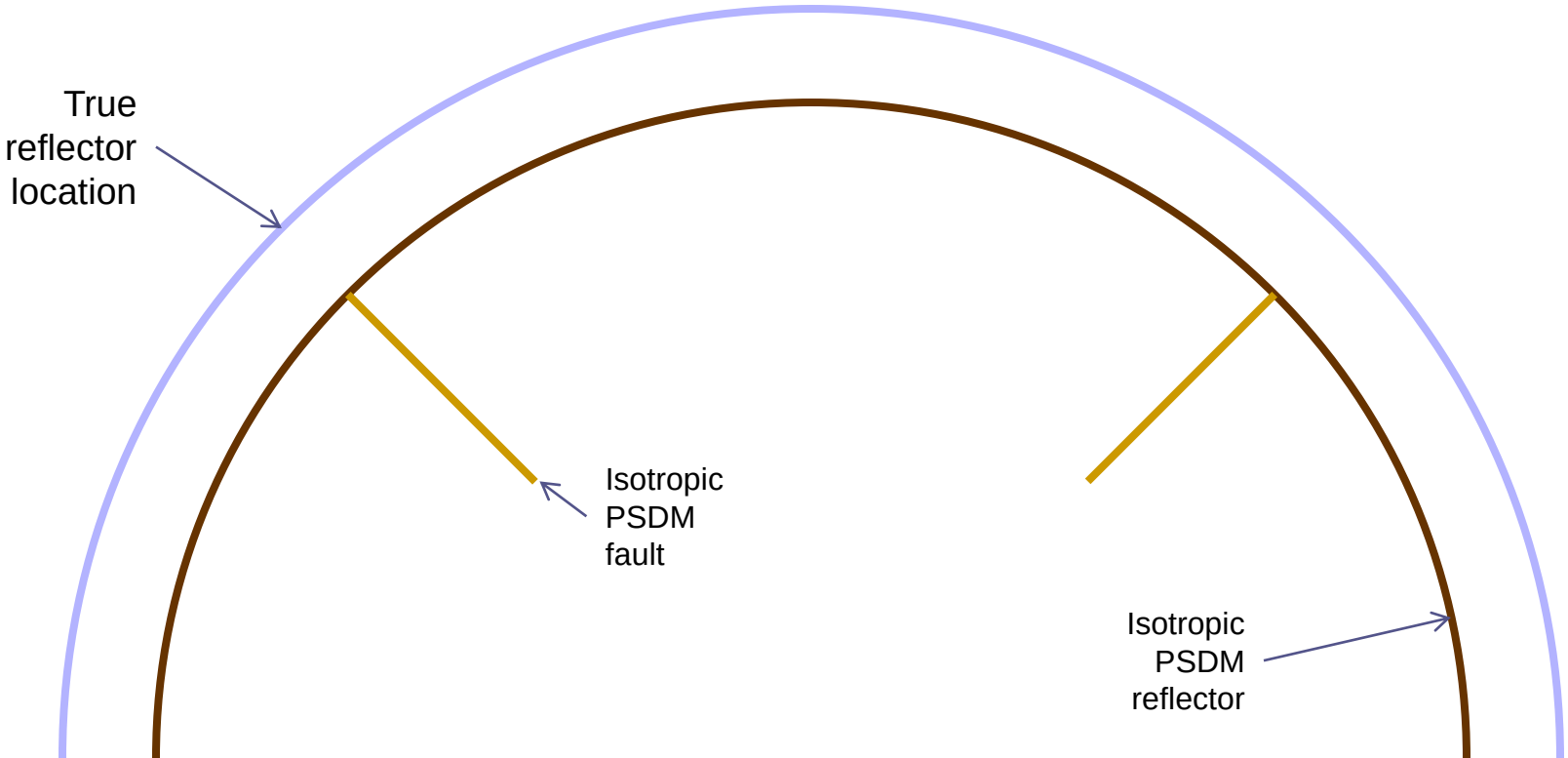
Why Anisotropic PSDM? (1 of 5)

Here, we have a simple “anticline” and two “faults”.



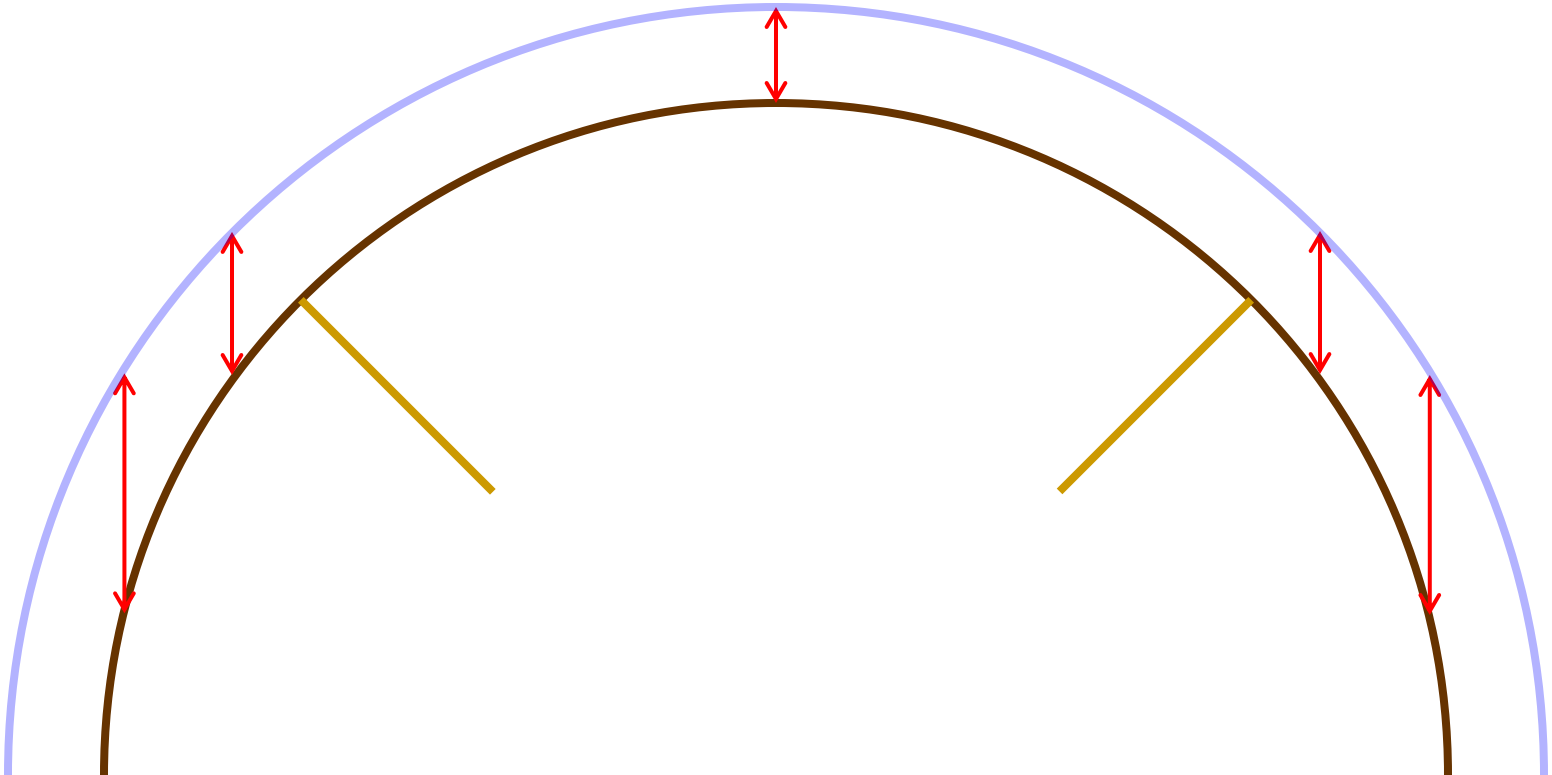
Why Anisotropic PSDM? (2 of 5)

Isotropic PSDM in an anisotropic earth positions events too deeply.



Why Anisotropic PSDM? (3 of 5)

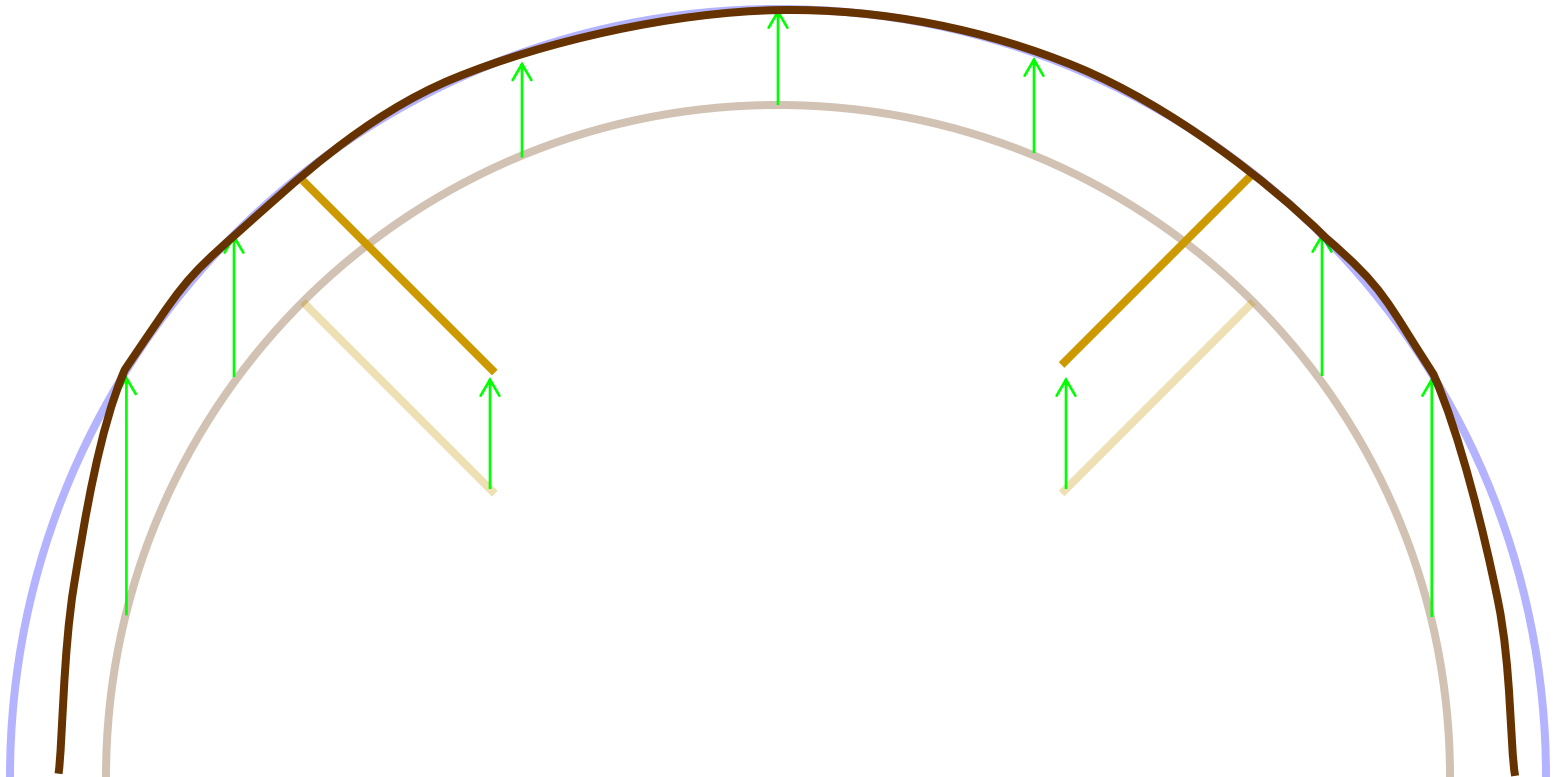
We measure depth misties at several well locations…



Why Anisotropic PSDM? (4 of 5)

…and vertically shift the image to match the well control.

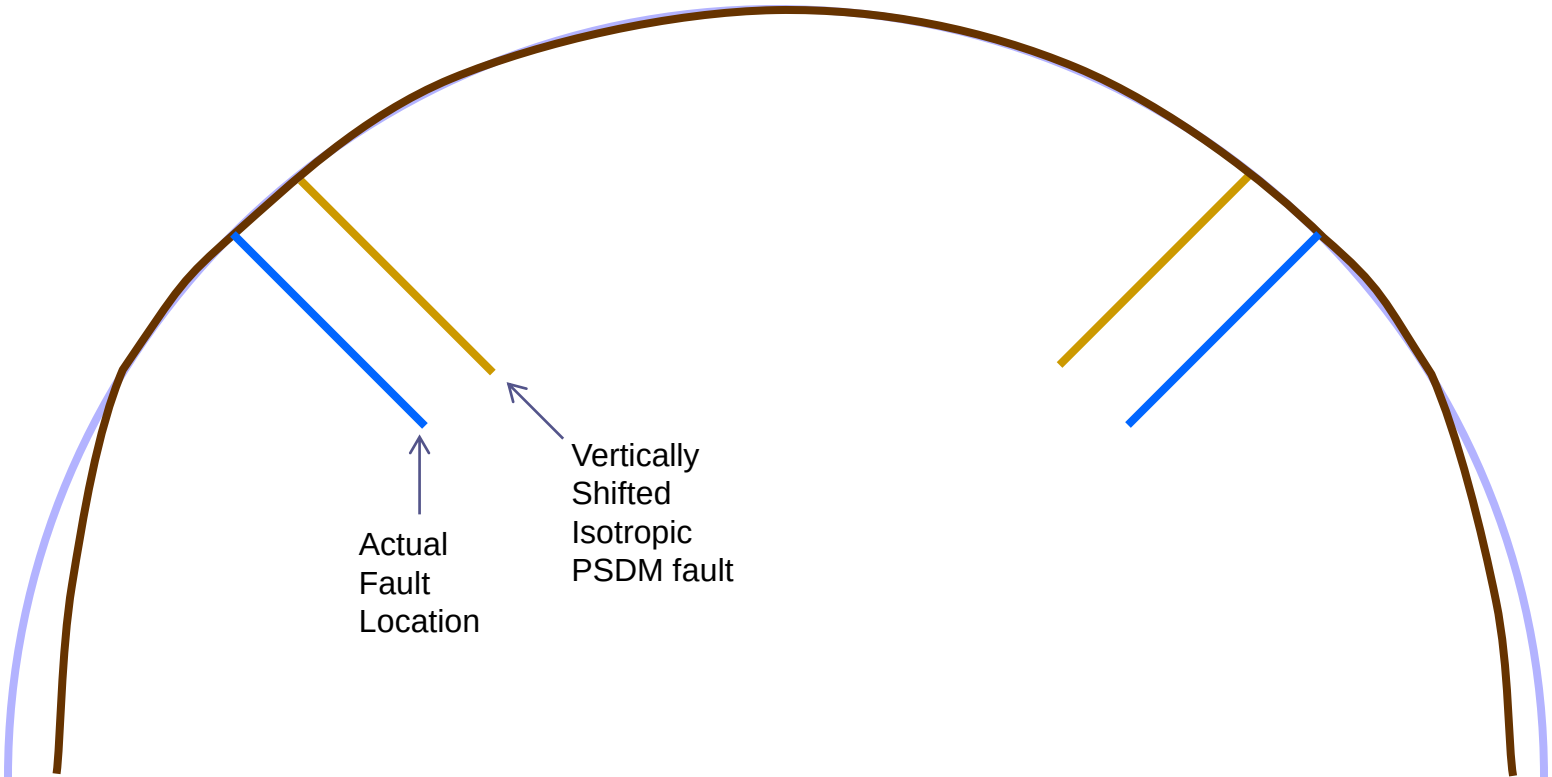
We match the anticline's structure accurately, but there's a problem…



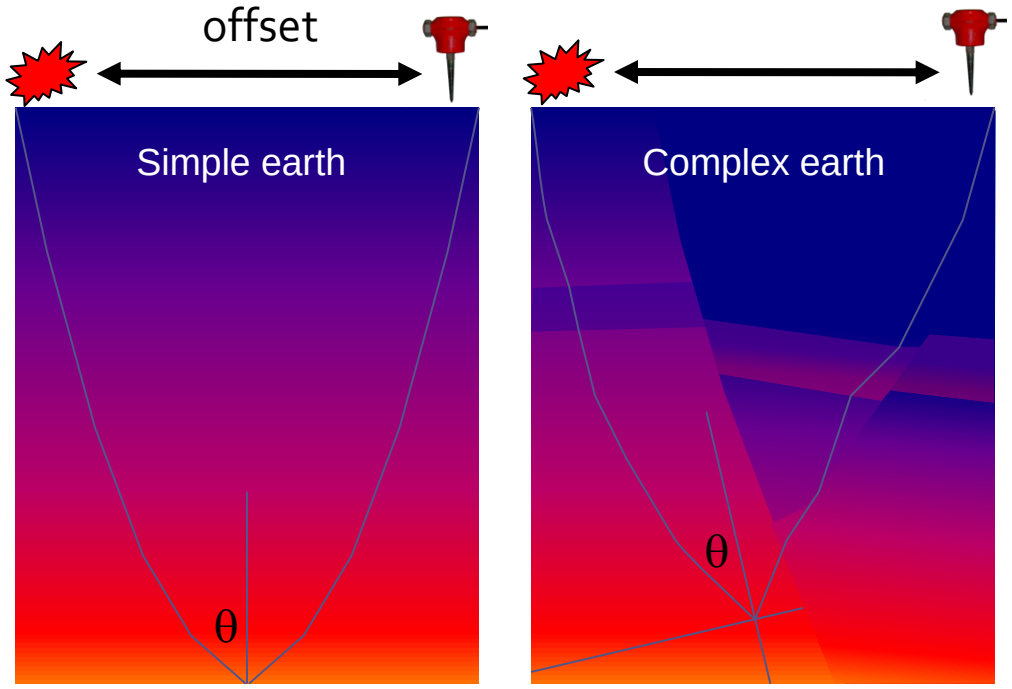
Why Anisotropic PSDM? (5 of 5)

…The “faults” are laterally mispositioned!

Anisotropic PSDM is the *only* systematic way to correctly position steep dips

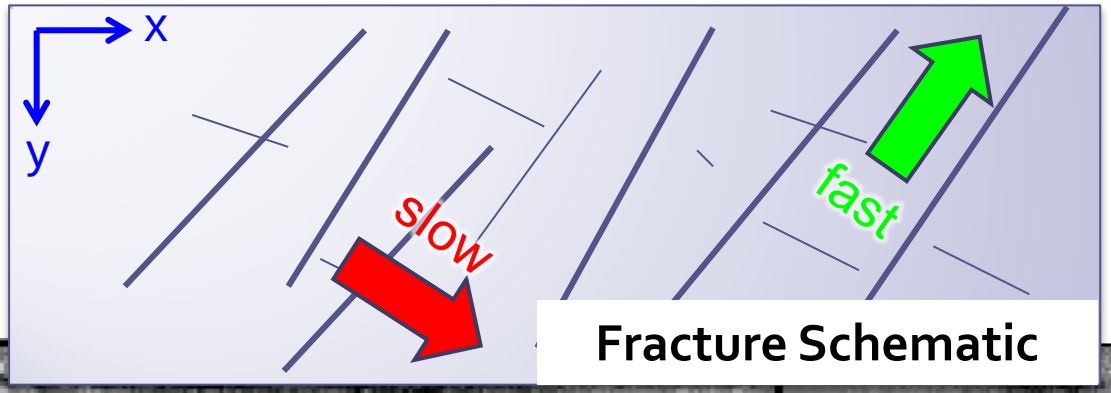


PSDM Angle Gathers for Attributes

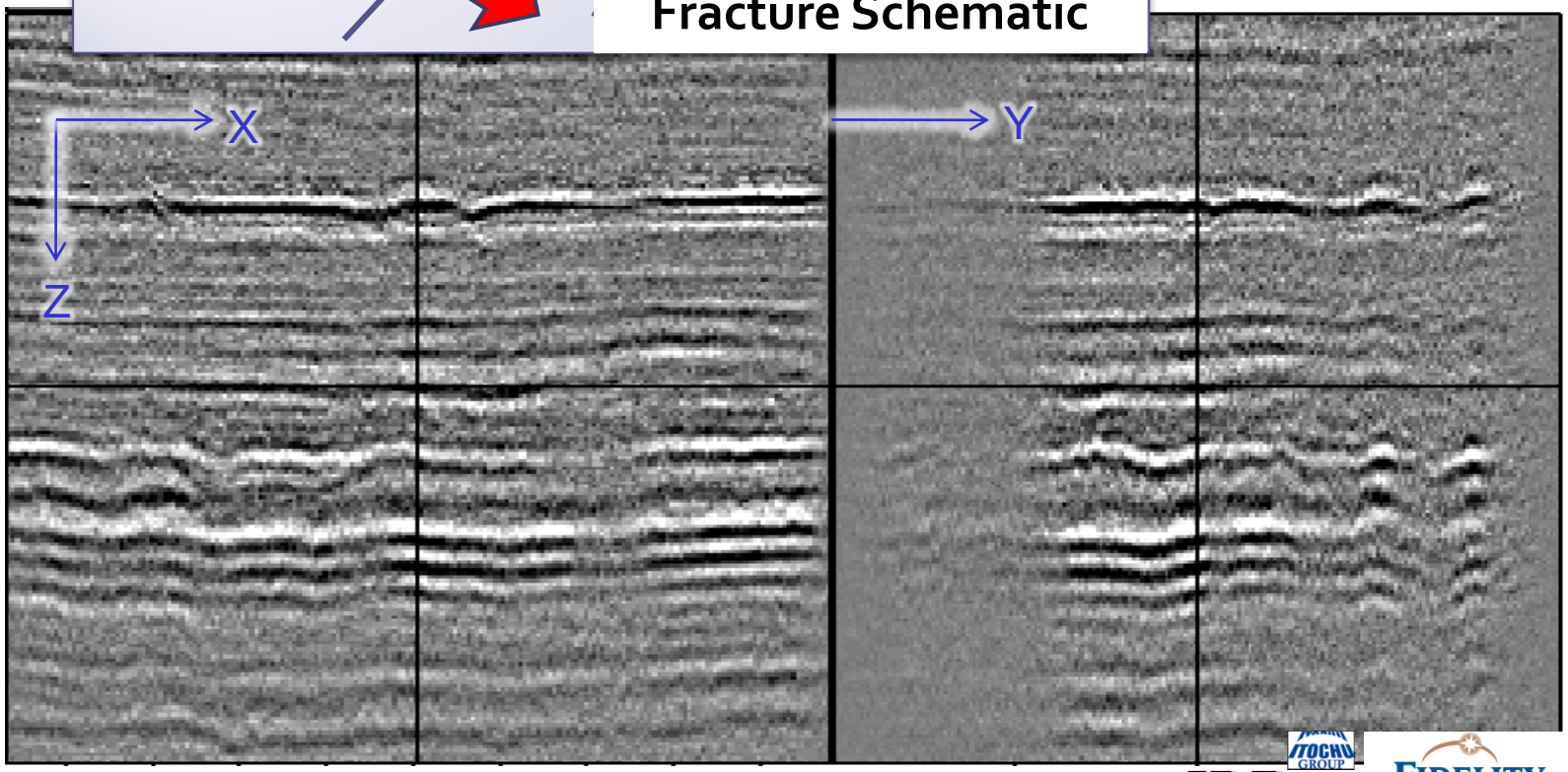


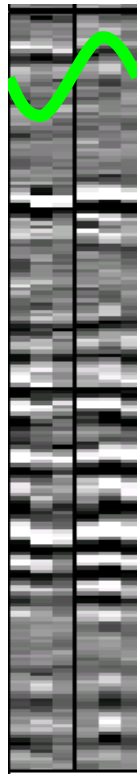
- Complex Earth → difficult to relate offset to angle…
- …Or surface azimuth to azimuth angle
- Ideal attributes →
  - With real angle gathers
  - In depth

Azimuth Angle Gathers



Azimuth (deg)





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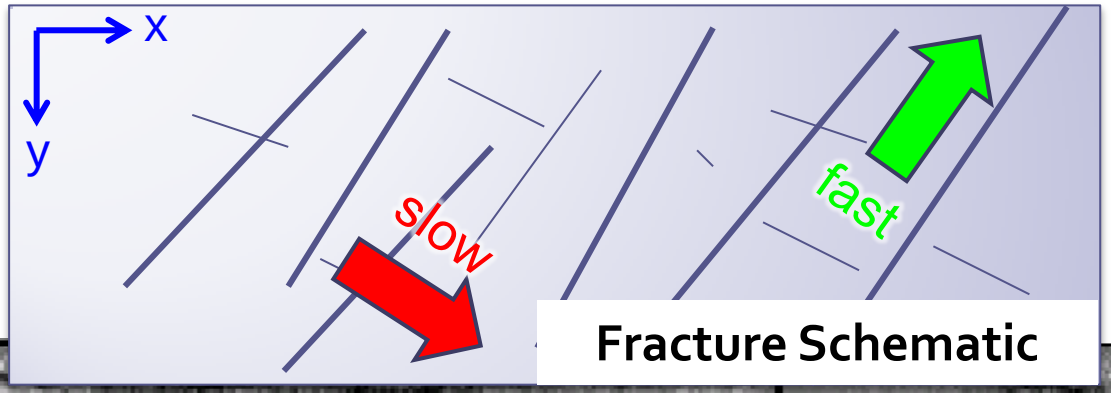
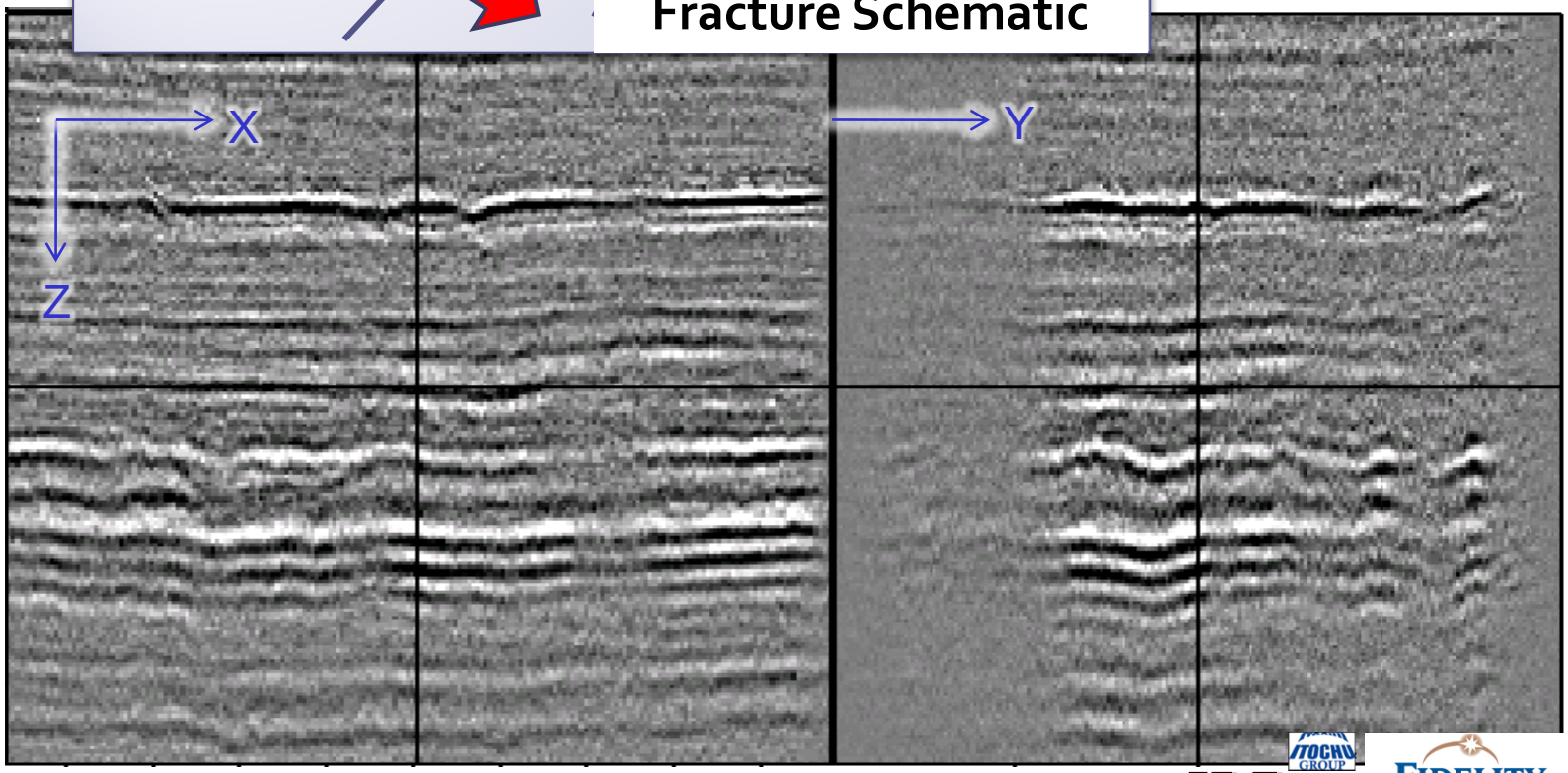
Azimuth Angle Gathers (flattened)





Azimuth (deg)

0 90

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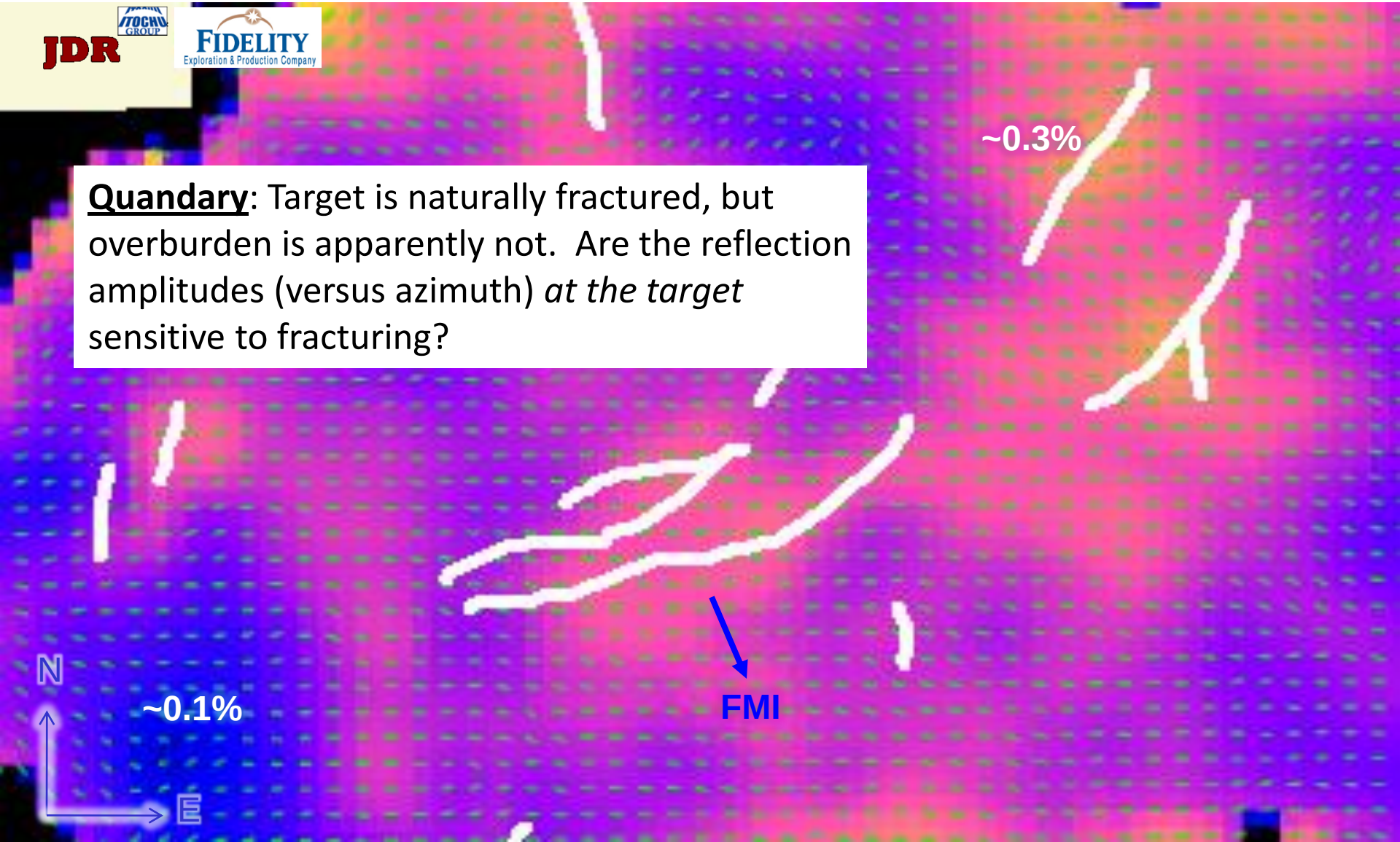
Fracture (Horizontal Stress) Map



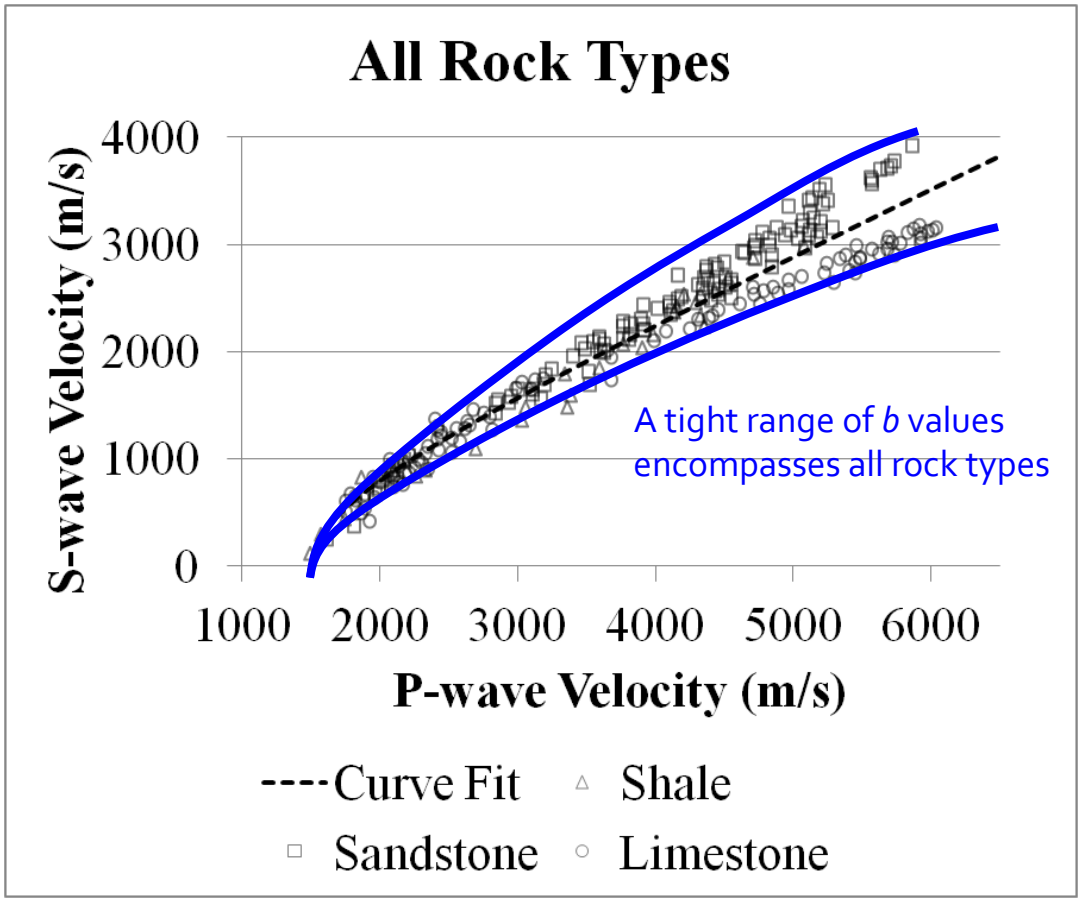
AVA Angle Gather Calibration

Relate VP/VS to seismic amplitudes

V_P/V_S relation (Mavko & Mukerji, 1998):

$$V_P = V_f \sqrt{\frac{V_S^2}{b^2} - 1}$$

$$b^2 = \frac{V_f^2\left[1 - \frac{3}{4}\frac{B}{A}\right]}{7 + V_f^2 / V_P^2}$$



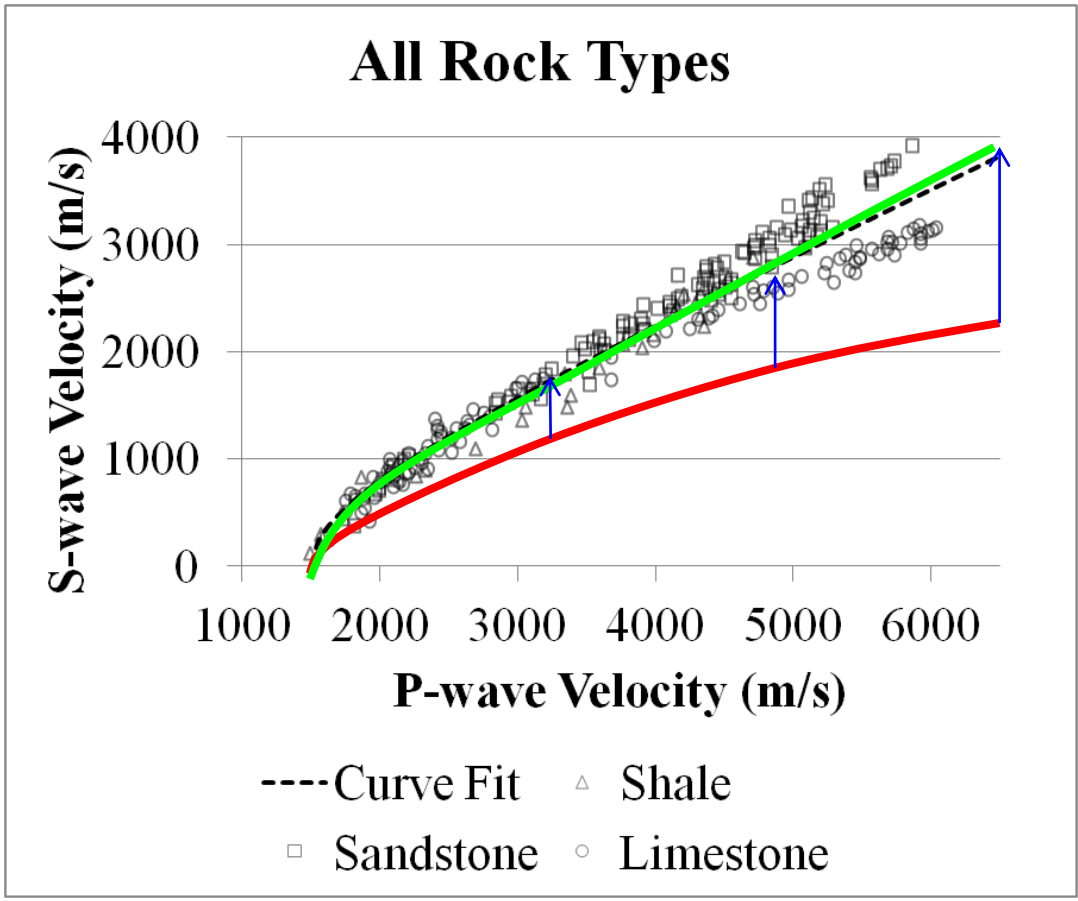
AVA Angle Gather Calibration

Step 1: Measure slope, intercept from PSTM or PSDM gathers

Step 2: Compute hyperbolic parameter b (red curve →)

Step 3: Compare to b obtained from lab data (green curve →)

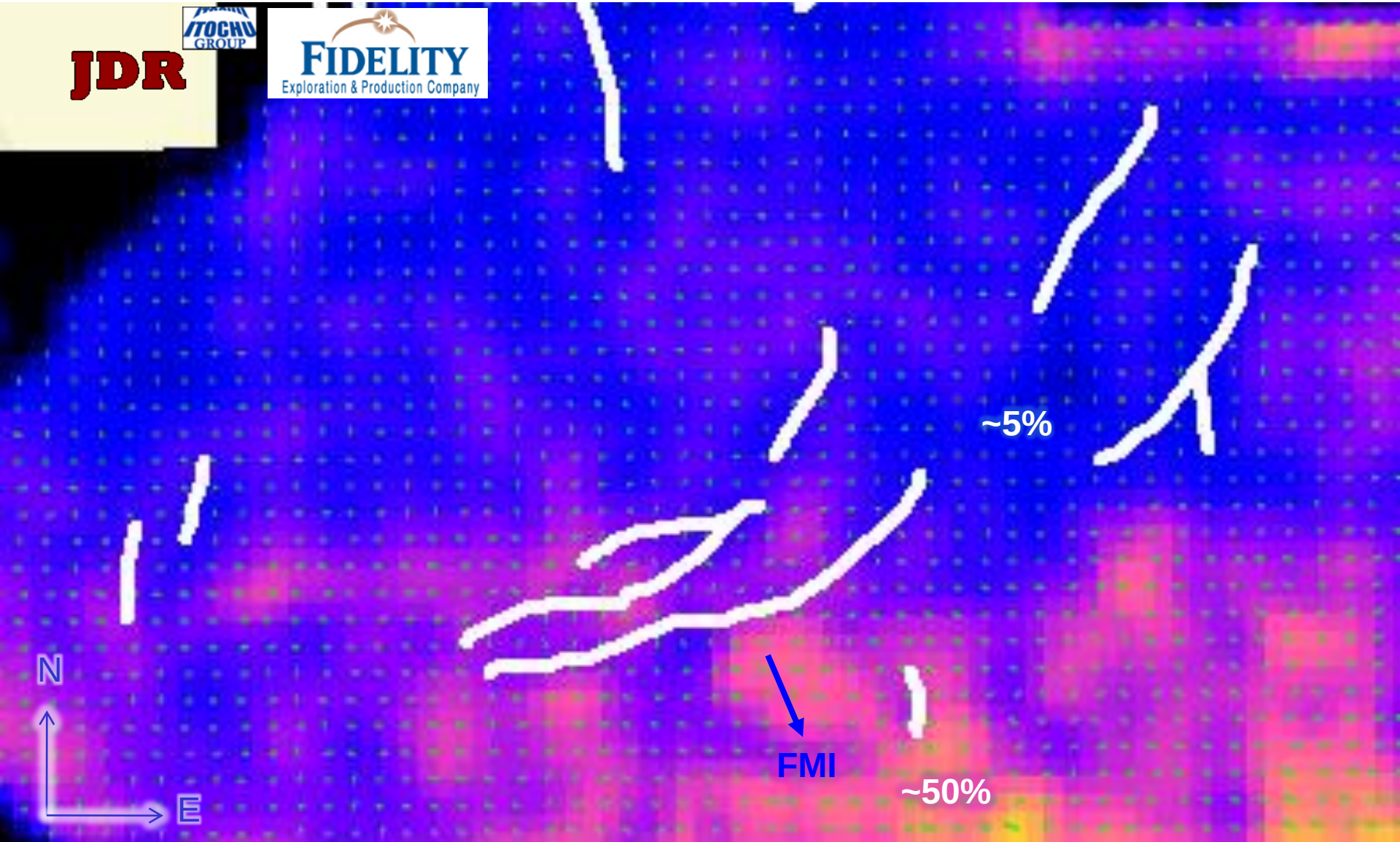
Calibration: *Find single scale factor that produces a measured b consistent with b from lab data*



AVA + Azimuth = AVAZ

- WEM Incidence vs. Azimuth angle gathers
- For each azimuth, calibrate AVA slope
- Make “fracture” map from AVA slope vs. azimuth using Rüger analysis
- More apparent sensitivity to fractures in target zone

From AVAZ Slope



AVAZ Math (Rüger, 1998)

P-wave AVA "slope" vs. azimuth

The quantities are written in terms of elastic properties above ("top") and below ("bot") the interface. Note: we assume elliptical HTI anisotropy.

$$B(\phi) = B^{iso} + B^{aniso}\cos^2(\phi - \phi_{sym})$$

$$B^{aniso} \approx \frac{1}{2}\left[\delta_{bot} - \delta_{top} + 2\left(\frac{\overline{V}_S}{\overline{V}_P}\right)^2(\gamma_{bot} - \gamma_{top})\right]$$

P-wave azimuthal anisotropy

S-wave azimuthal anisotropy

AVAZ Math (Rüger, 1998)

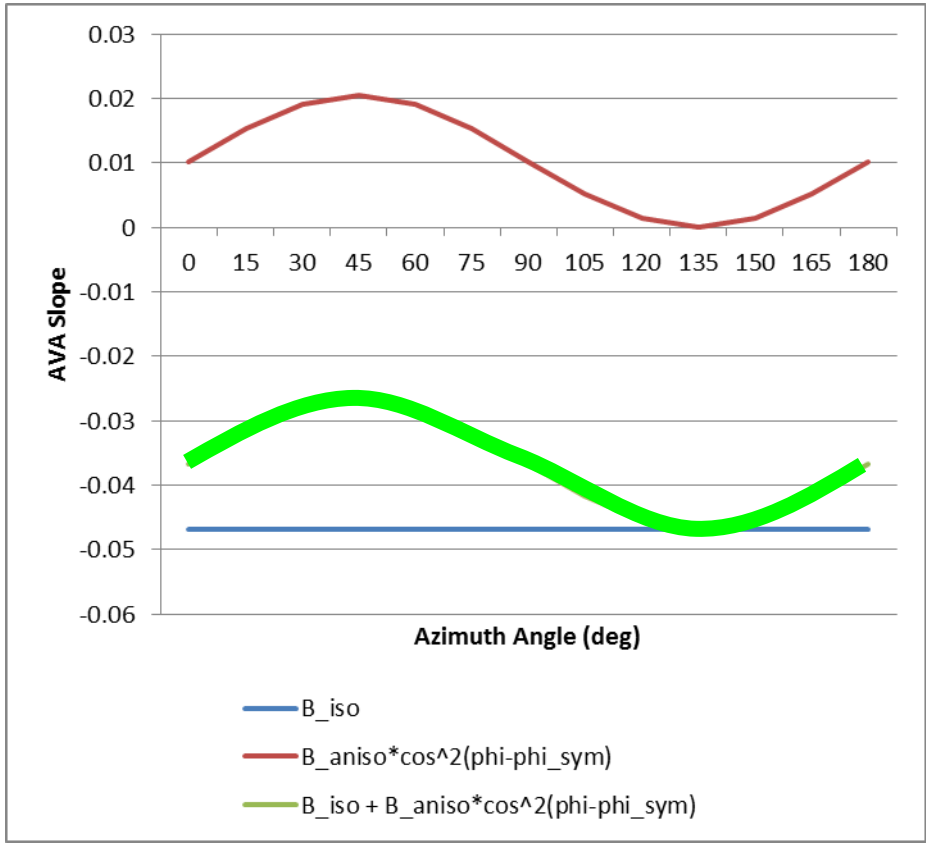
$$B(\phi) = B^{iso} + B^{aniso}\cos^2\left(\phi - \phi_{sym}\right)$$

$$B^{aniso} \approx \frac{1}{2}\left[\delta_{bot} - \delta_{top} + 2\left(\frac{\overline{V_S}}{\overline{V_P}}\right)^2\left(\gamma_{bot} - \gamma_{top}\right)\right]$$

Note how a very realistic set of assumptions produces a 50% azimuthal variation in AVA slope!

Assumptions for most sensitive parameters:

- γ_{bot} = 0.05
- γ_{top} = 0.0
- δ_{bot} = 0.01
- δ_{top} = 0.0
- VP-VS ratio = 2 above and below



Takeaways

- Part 1
  - PSDM:
    - Removes false time structures
    - Better positions/focuses steep dips and faults
  - High-intensity velocity analysis = PSDM success
  - Anisotropic PSDM: How to move events correctly

- 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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