Prestack Depth Migration for "Easy" Unconventional Plays?*

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Abstract

Traditionally, prestack depth migration (PSDM) was considered an exotic technology, applicable only for imaging 'complex' geology. Offshore subsalt imaging drives application of the most advanced wave equation PSDM technologies, like Reverse-Time depth Migration (RTM). However, given the recent resurgence of onshore exploration, we ask: can PSDM make an impact on 'easy' onshore plays? We list three key reasons for (re)considering PSDM: 1) Remove false time structures caused by lateral variations in velocity. The 'fault shadow' effect is a radical example of a false time structure. However, with horizontal shale play drillers trying to stay in thin zones, even mild variations in velocity can play havoc on wells drilled on time migrated data. While time images can be 'tied' to well control, consider that horizontal drilling generally drains a given reservoir with fewer boreholes, meaning fewer well tops per square mile. A lot (of structure) can happen in between two horizontal wells! 2) Improve focusing of dipping beds and faults. Time migration laterally mispositions dipping reflectors and blurs fault truncations. Drillers hate surprises in the form of 'hidden' faults, which can present a geohazard, or require geosteering (think a 20-foot fault cutting a 20-foot zone). The combination of modern wide-azimuth, high-fold seismic with PSDM presents a powerful tool for fault delineation. 3) Improve the accuracy of seismic attributes. Most prestack attributes, whether AVA elastic inversion or azimuthal anisotropy analysis, are computed with time migrated data. However, reflector dip and/or velocity variation render the conversion of surface offset or surface source/receiver azimuth to true reflection angle ambiguous or impossible. In theory, PSDM, with true reflection angle gathers, is the ideal vehicle for attribute computation, and in the coming years, will become increasingly adopted. The talk, illustrated with a number of onshore US examples, seeks to highlight the following key points: 1) PSDM is a powerful tool for unconventional exploration. 2) PSDM matches or beats time migration in terms of vertical and spatial resolution. SDM is not for every project, and expectations must be calibrated. 4) Dense, iterative velocity analysis is key to PSDM success. 5) Anisotropic PSDM is the only rigorous way to handle

depth/seismic misties. 6) RTM is the ‘gold standard’ PSDM algorithm. 7) PSDM angle gathers are the optimal input for attribute analysis.

Reference

Ruger, A., 1998, Variation of P-wave reflectivity with offset and azimuth in anisotropic media: Geophysics, v. 63, p. 935. doi:10.1190/1.1444405

PSDM for "Easy" Unconventional Reservoirs?

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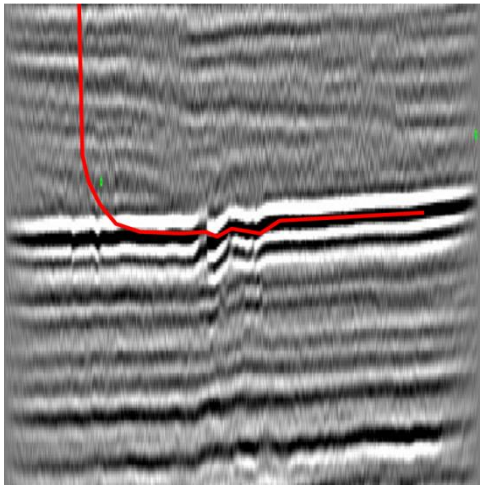
Rocky Mountain Section, AAPG
September 10, 2012

Wave Imaging Technology Inc.

Seismic: Financial Impacts

Fine Scale

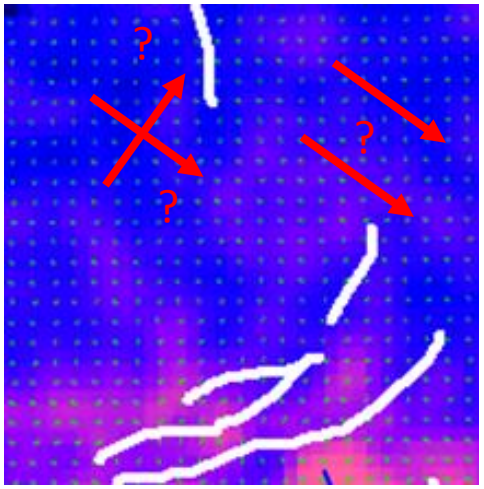


Where to drill?

Avoid sidetracks
Stay in zone

Part 1

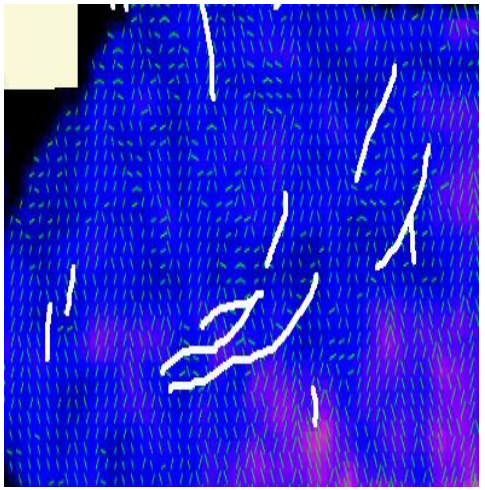
Medium Scale



How/Where to drill?

Borehole orientation
Best wells first

Wide Scale



If to drill?
Where to lease?

Best parts of basin
Extend sweet spots

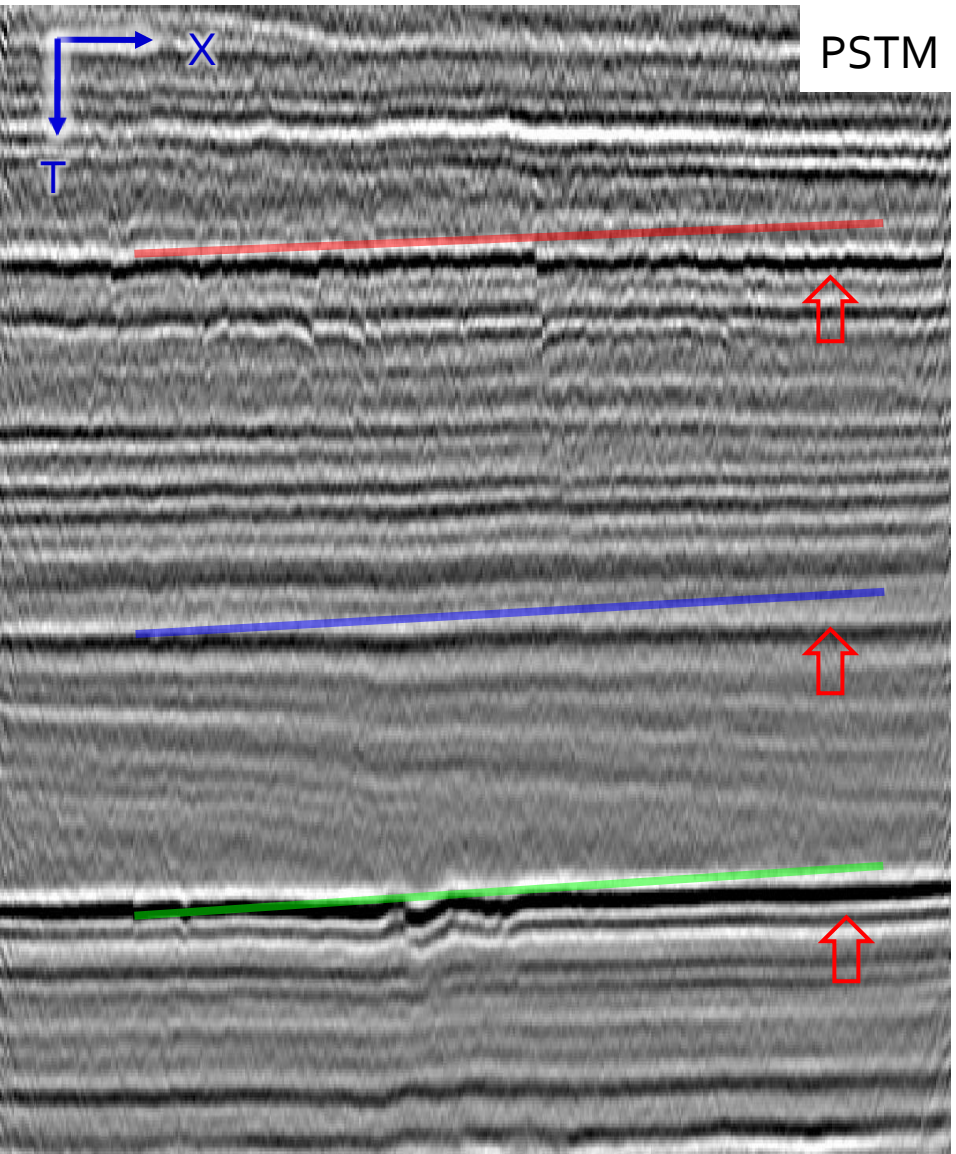
Part 2

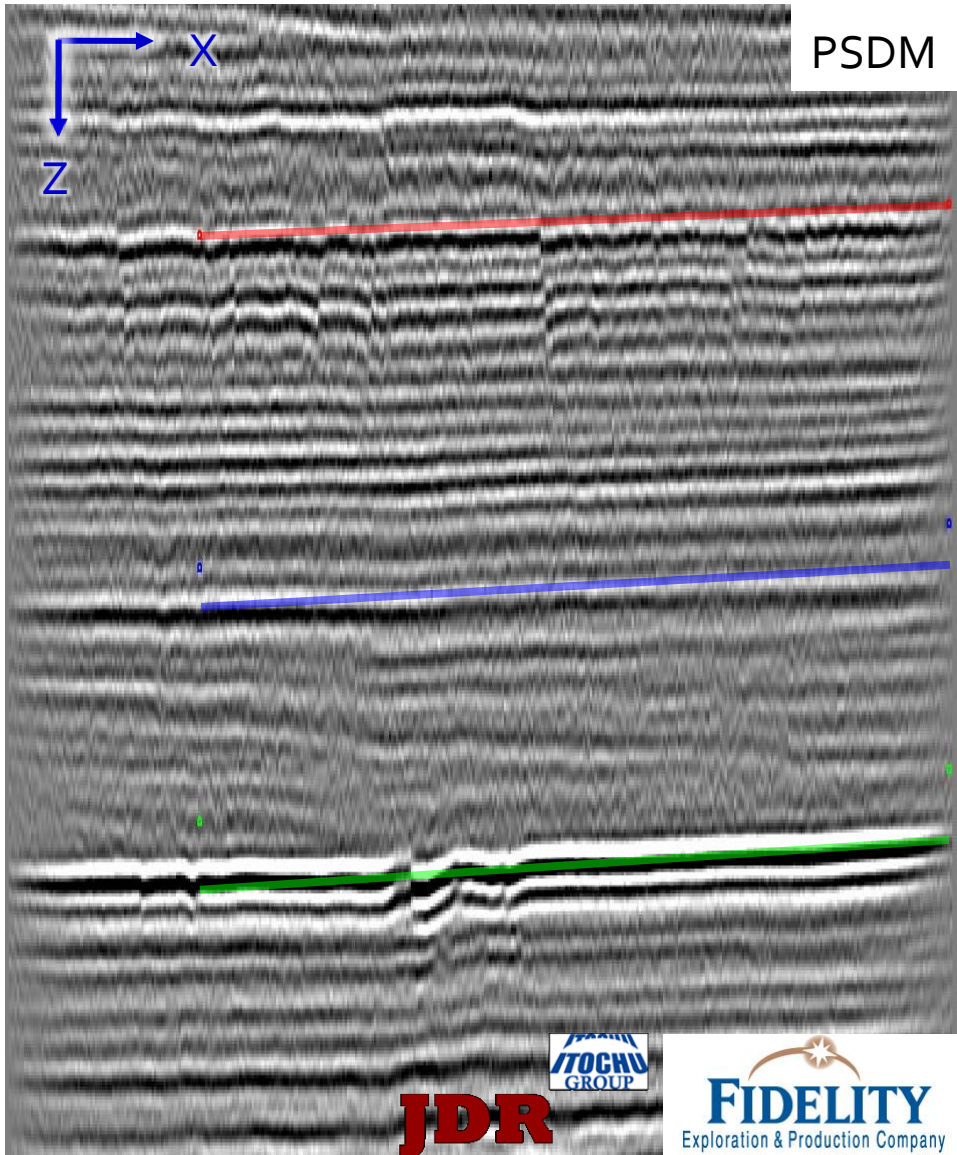
Today → **Tomorrow** → **Future**

Niobrara Shale Case Study

- Hi-res 50 sq mi 3D, Laramie Co., WY
  - 200 fold, Wide azimuth
- Part 1: Structural Imaging
  - Success = Velocity
  - Improved event geometry, fault imaging
- Part 2: "Sweet Spot" Delineation
  - Azimuthal anisotropy
  - AVAZ

Part 1: Improved Structural Imaging





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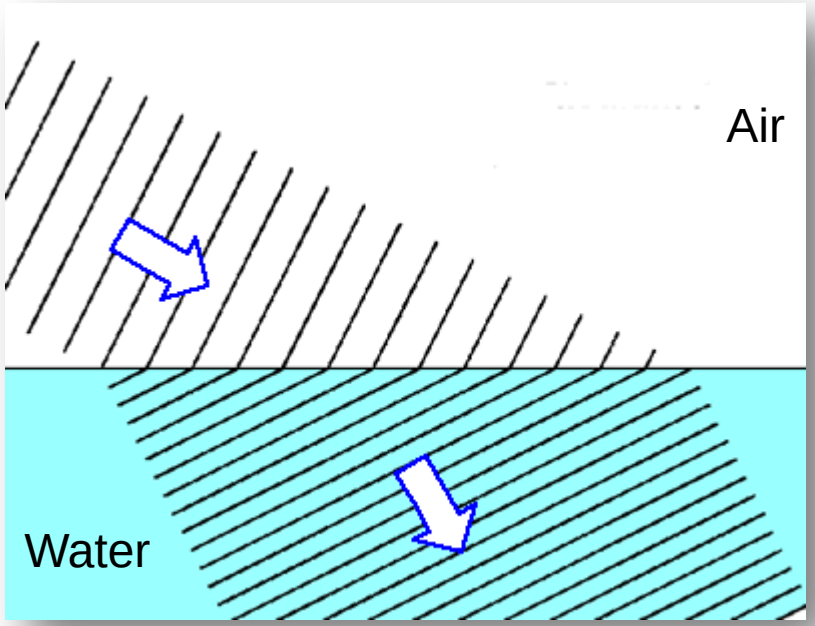
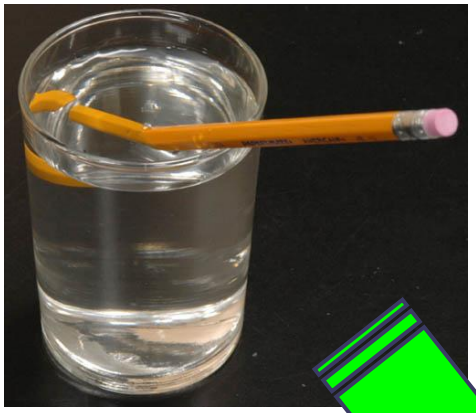
Why Wave Equation PSDM?





Simple refraction

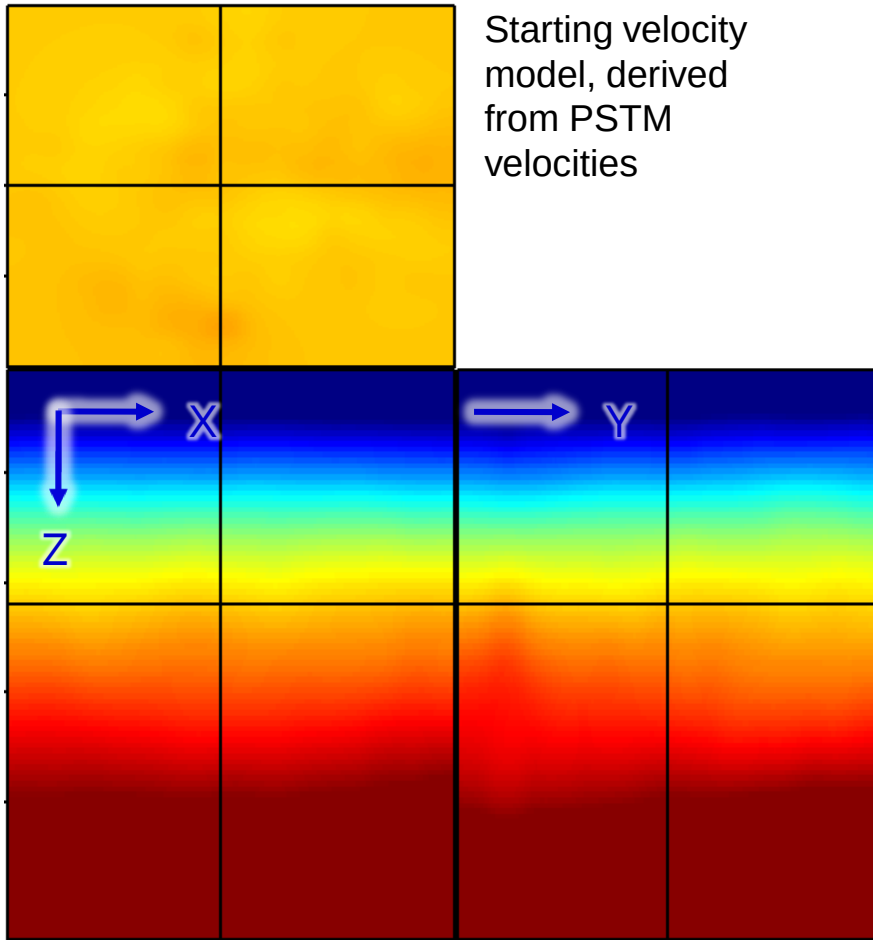
Kirchhoff

WEM

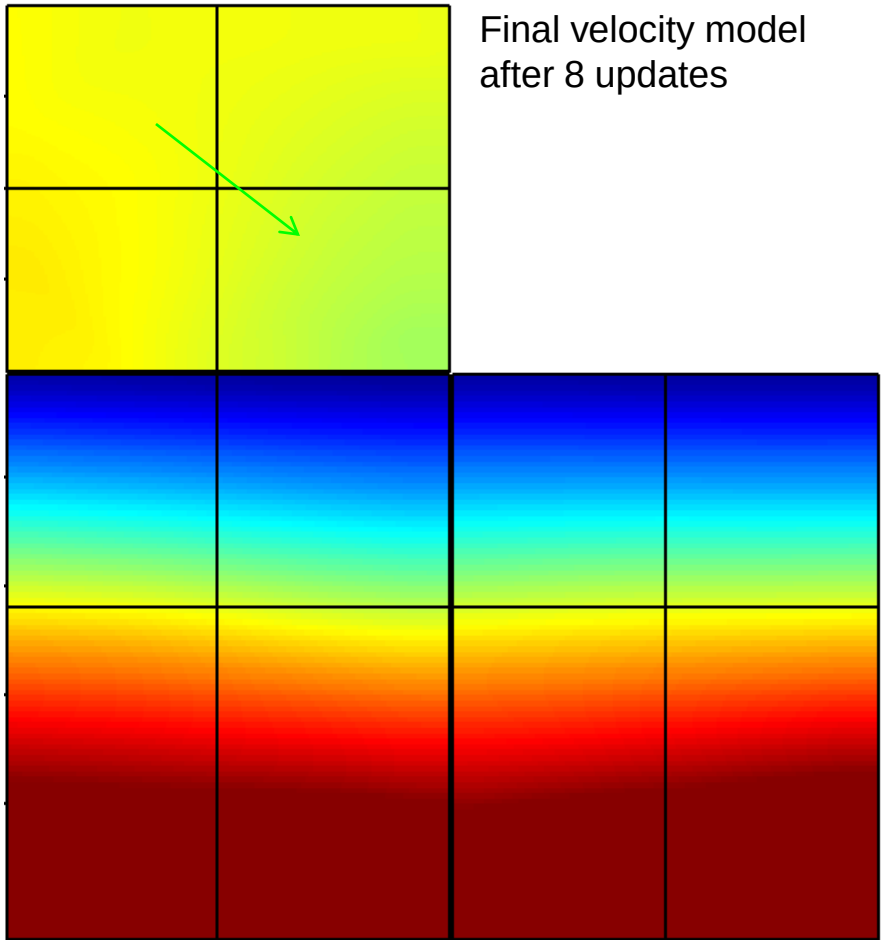
RTM

Complex focusing

Shallow Low-Velocity Wedge

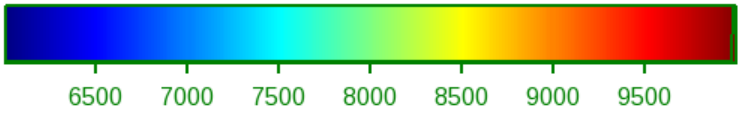


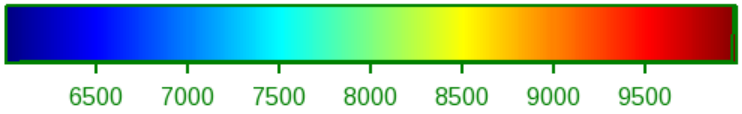
Starting velocity model, derived from PSTM velocities



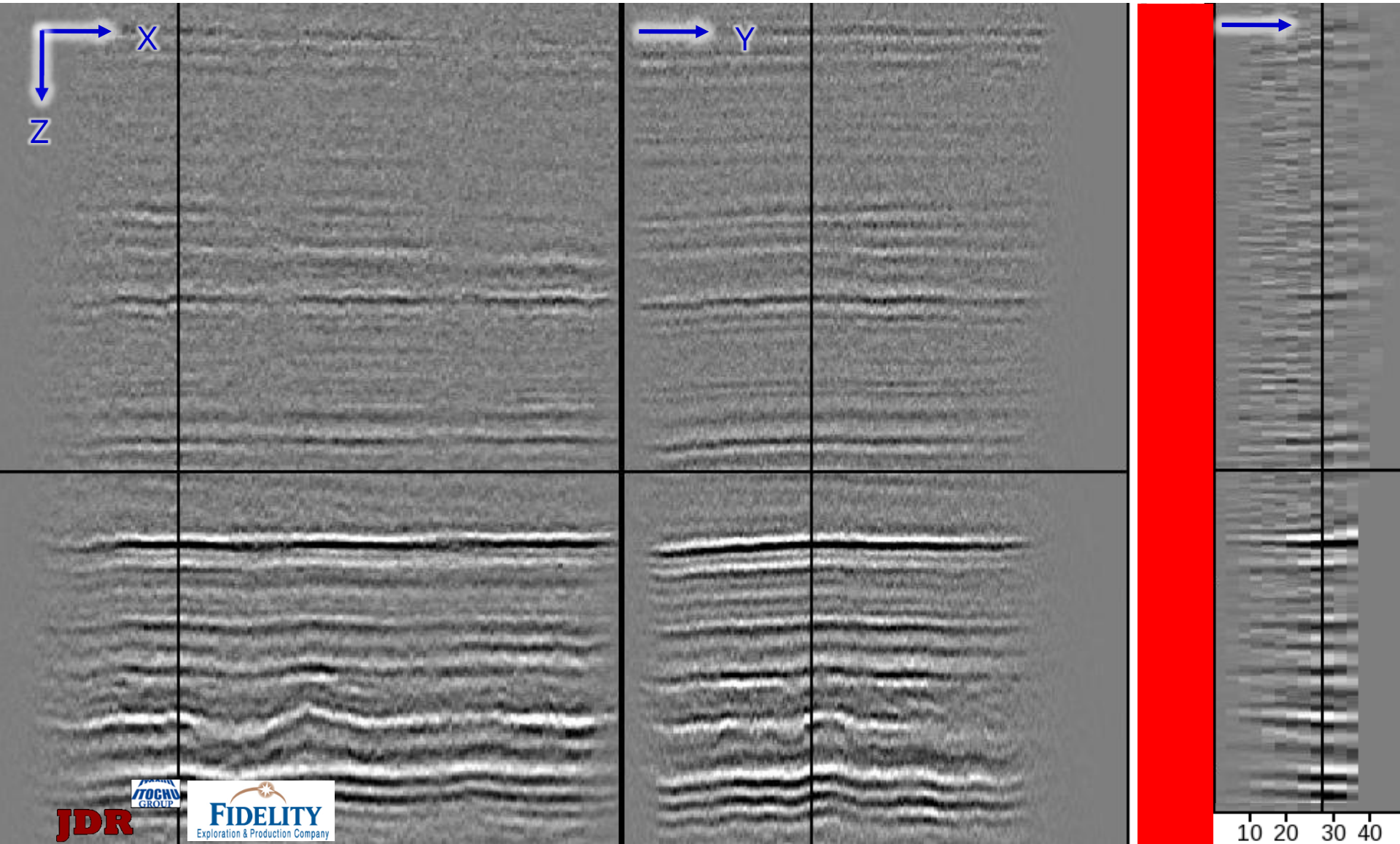
Final velocity model after 8 updates

Velocity (ft/sec)

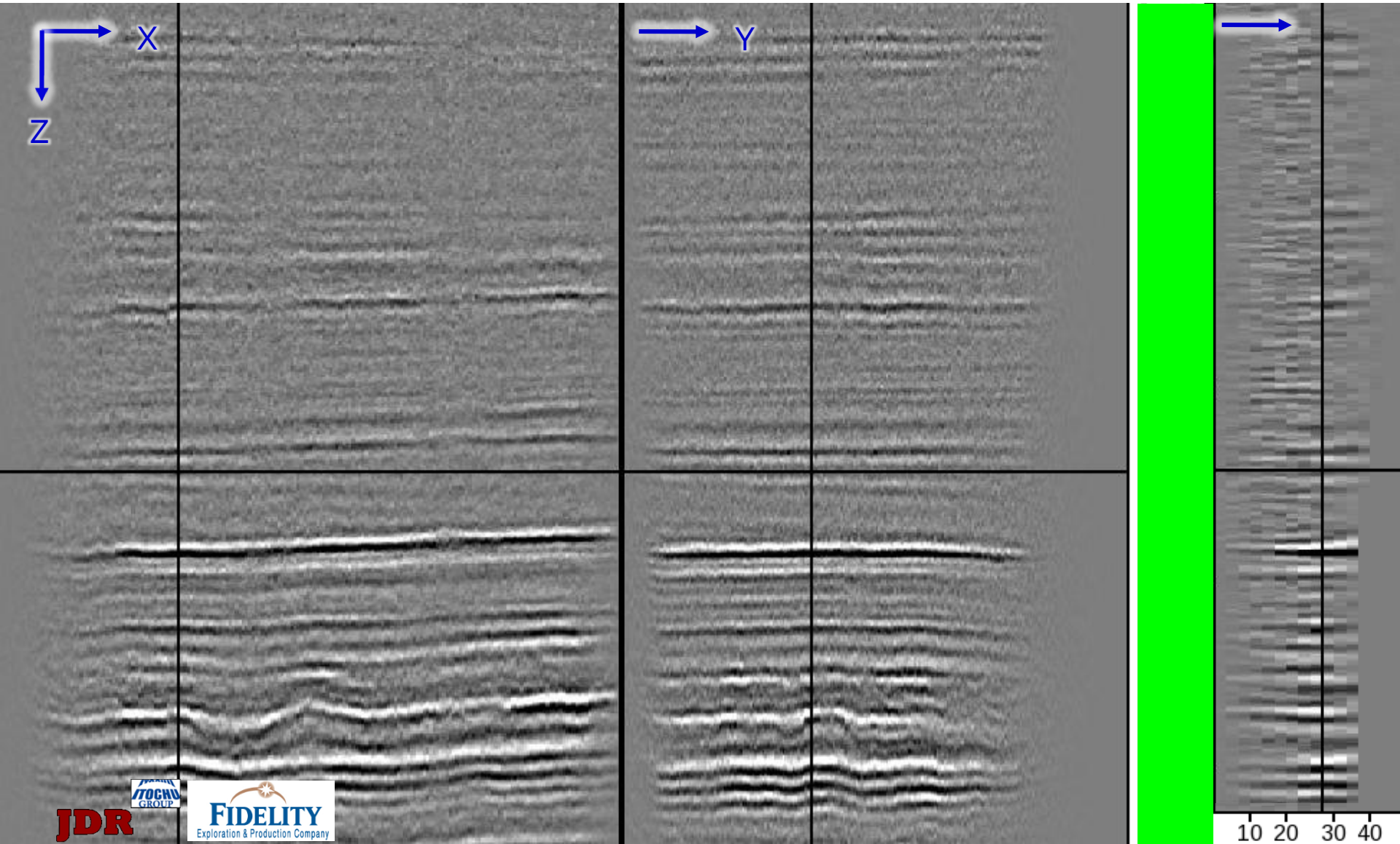




Angle Gathers: PSTM Velocity



Angle Gathers: Optimized Velocity



PSTM: Location 1

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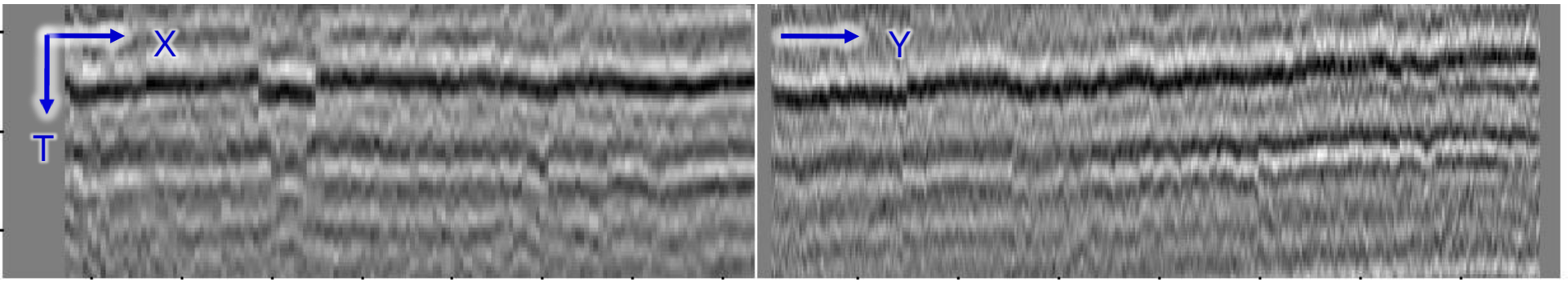

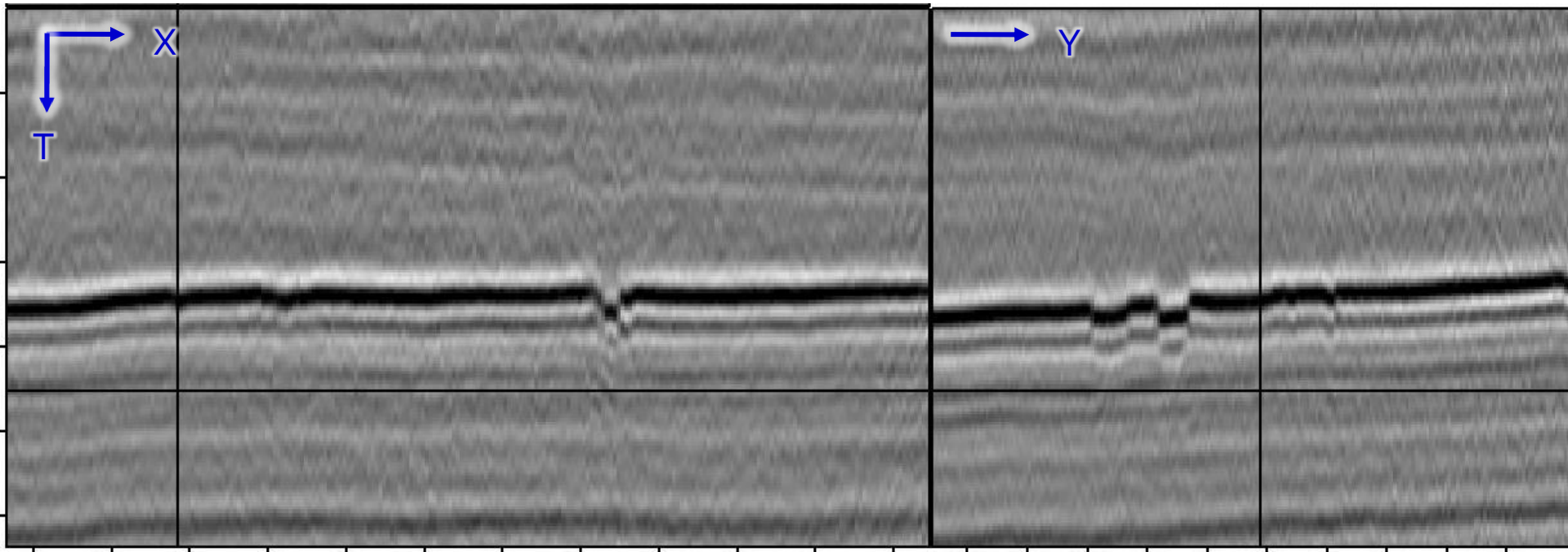

PSDM: Location 1

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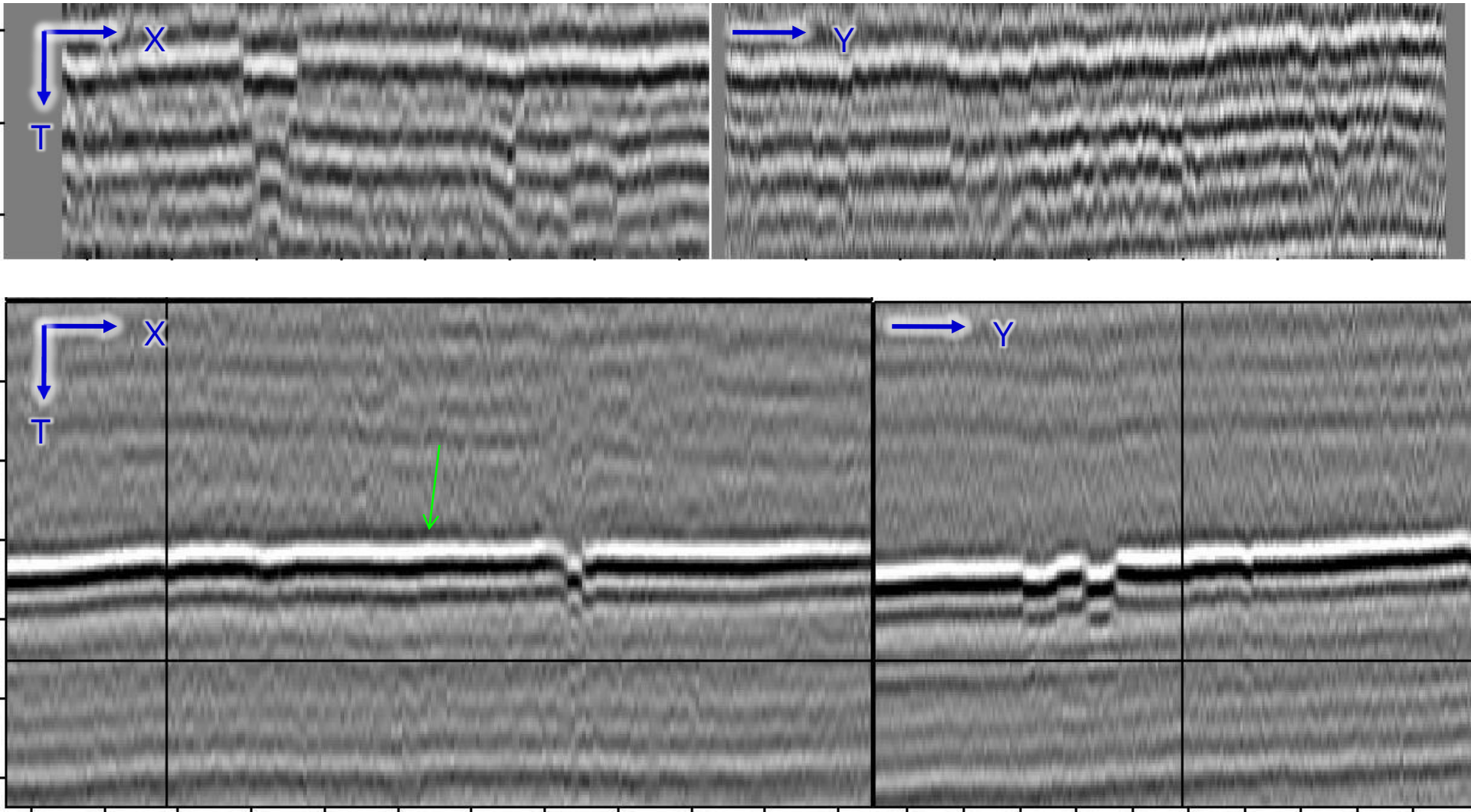
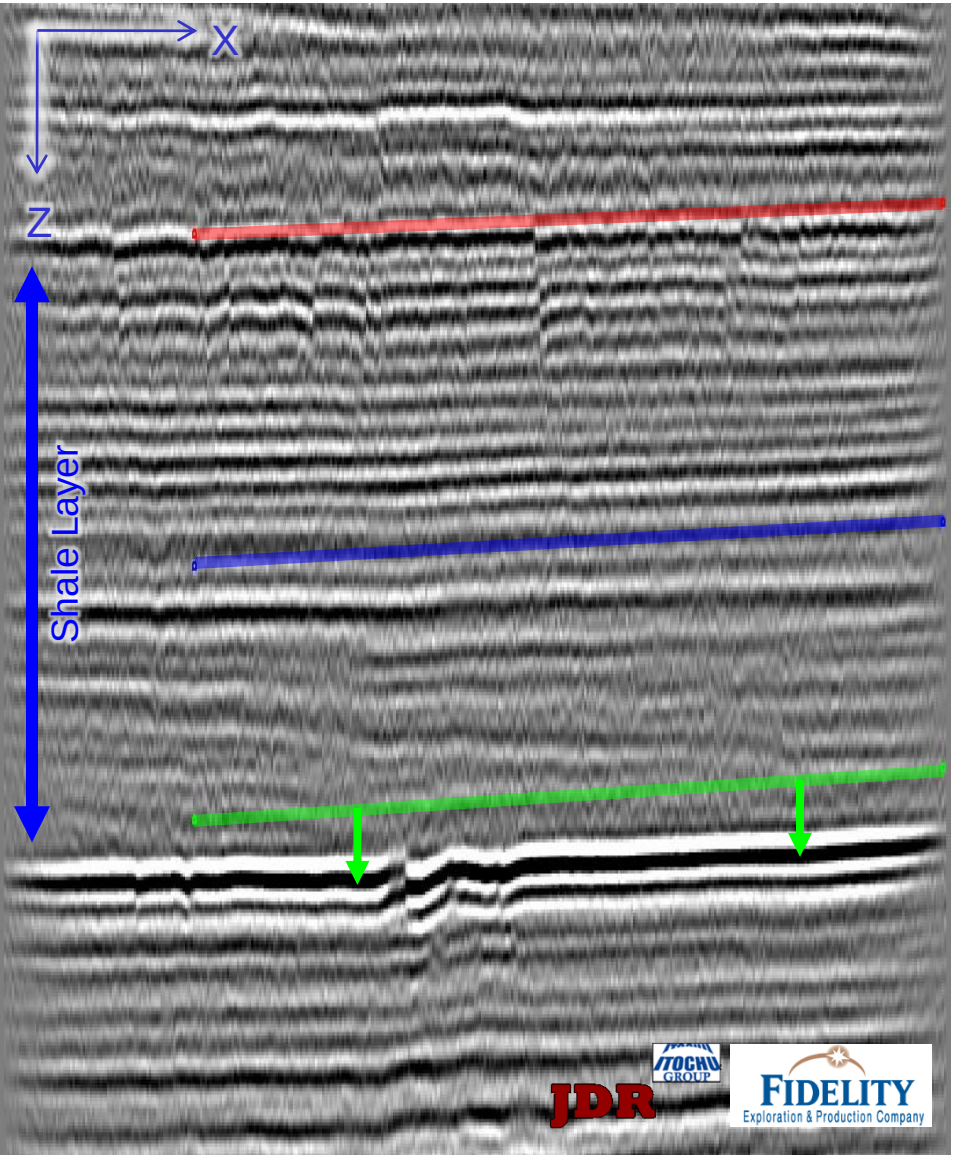
Converted to Time

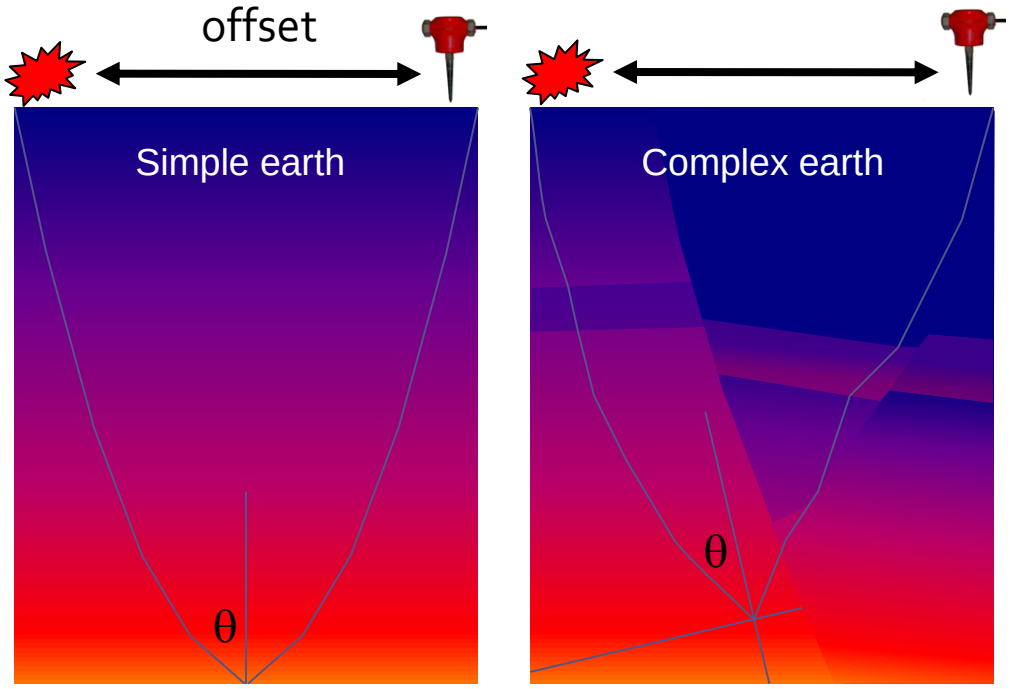


Vertical Anisotropy



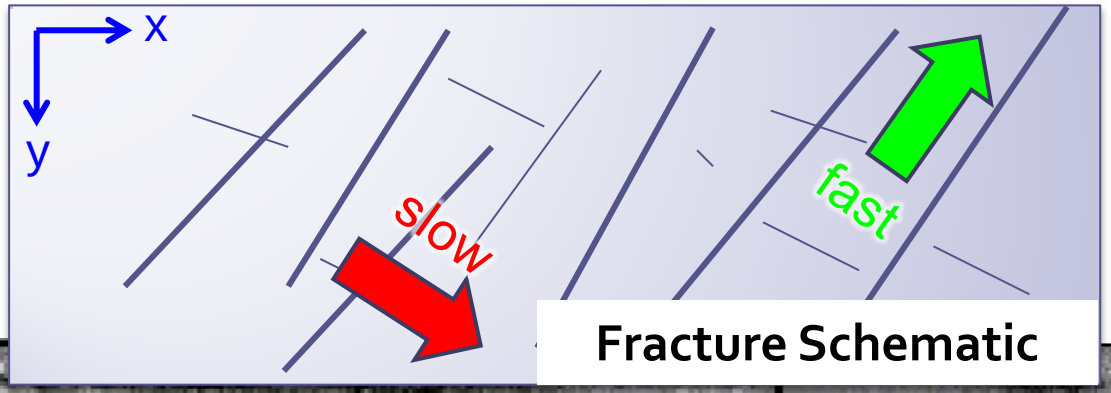
- Anisotropic shale layer induces significant misties
- Measure misties at well tops
  - Build Thomsen δ for anisotropic PSDM…
  - …or warp image to fit tops
- Note: Dip is preserved
- 4 ft, 12 ft accuracy on two new wells

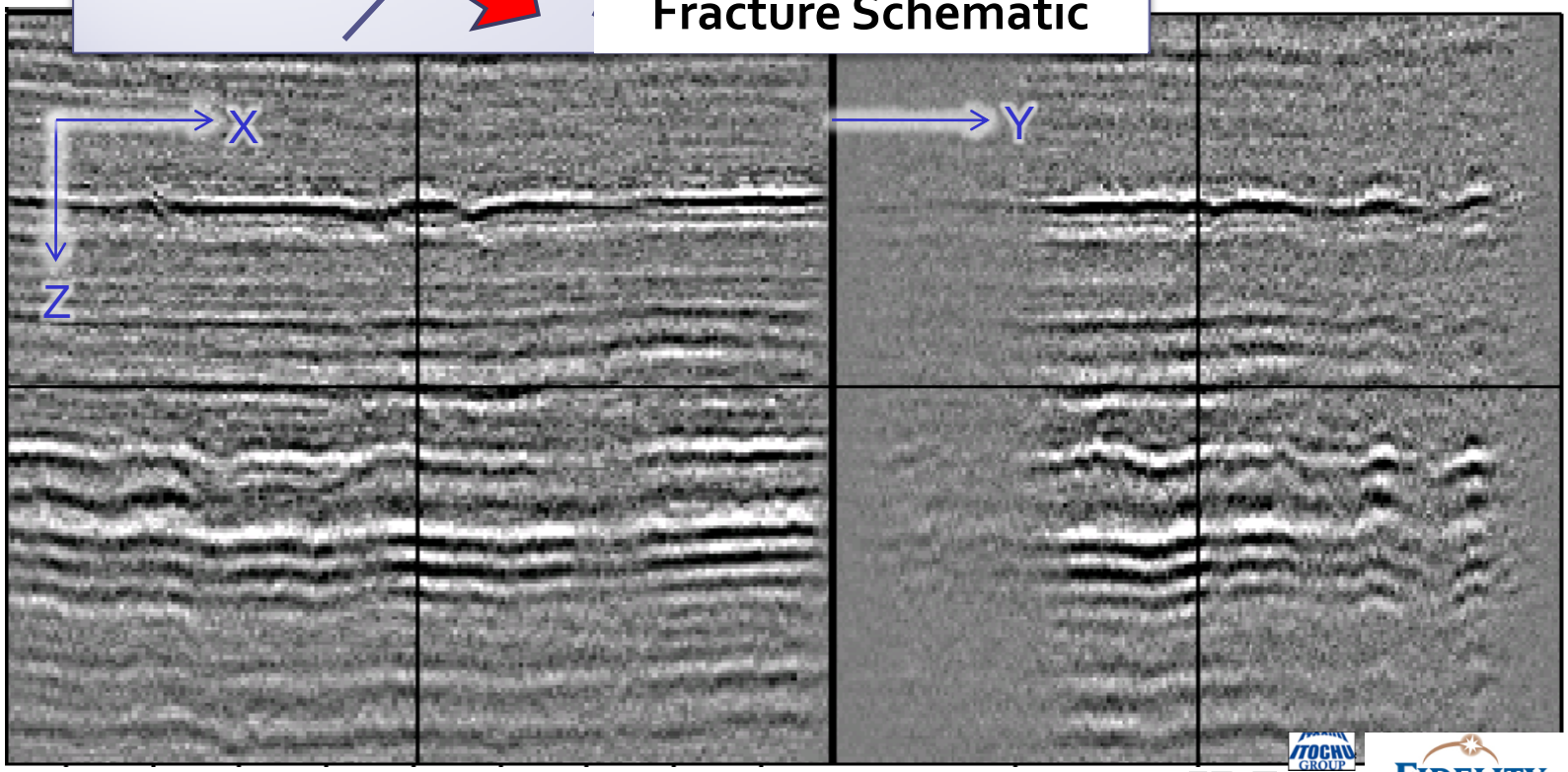
Part 2: Sweet Spot Delineation



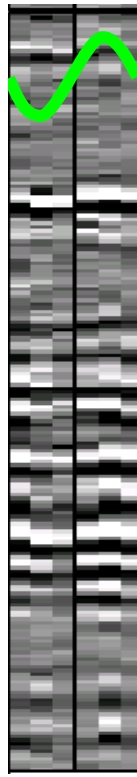
- Complex Earth → difficult to relate offset to angle…
- …Or surface azimuth to azimuth angle
- Ideal attributes →
  - With real angle gathers
  - In depth

Azimuth Angle Gathers





Azimuth (deg)



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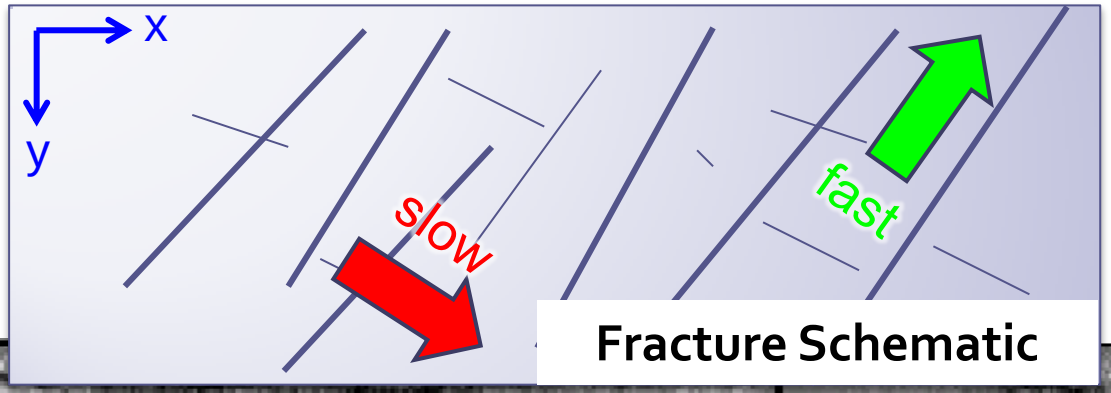
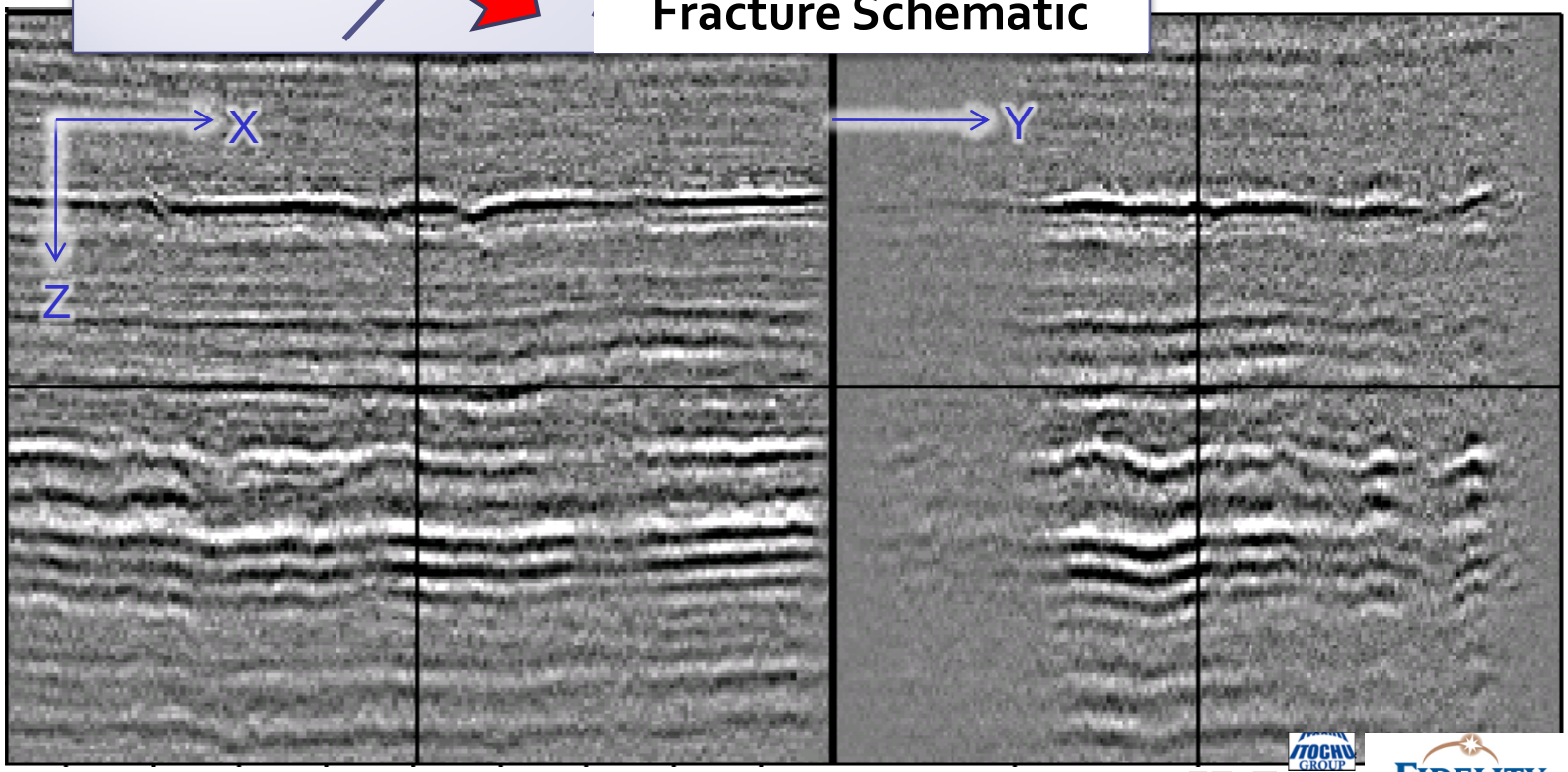
Azimuth Angle Gathers (flattened)





Azimuth (deg)

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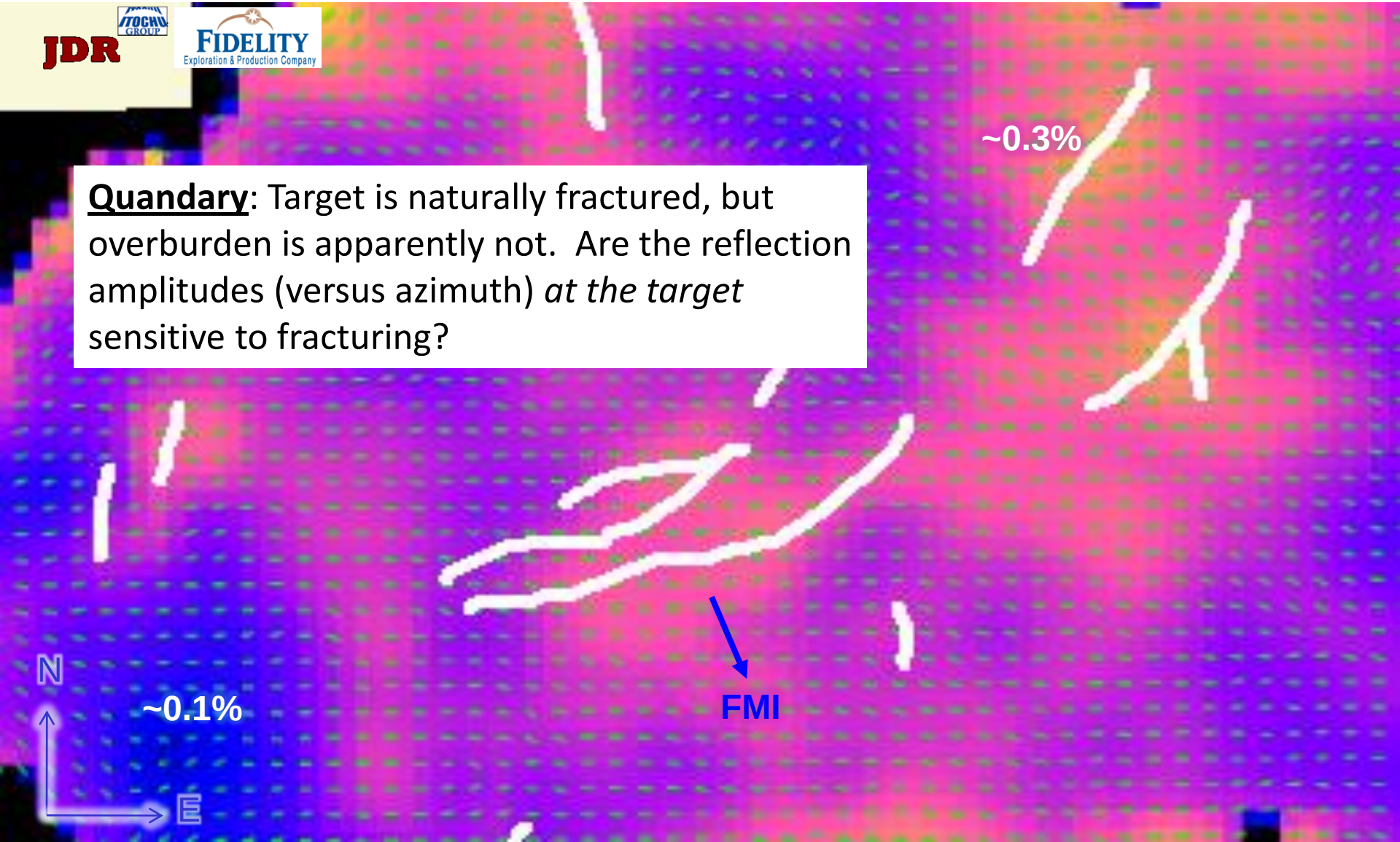
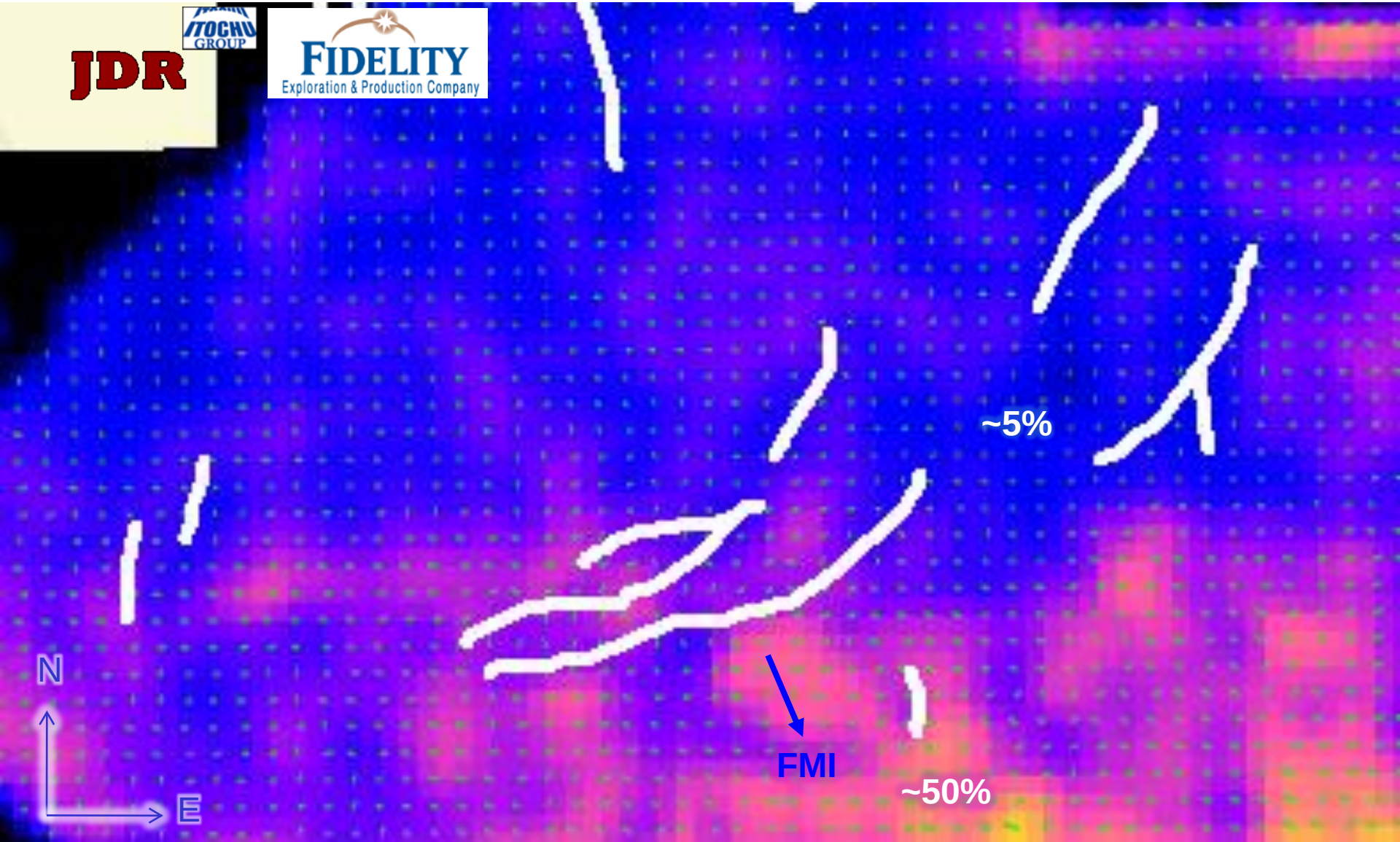
Fracture (Horizontal Stress) Map



AVA + Azimuth = AVAZ

- WEM Incidence vs. Azimuth angle gathers
- For each azimuth, compute 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 Sensitivity (Rüger, 1998)

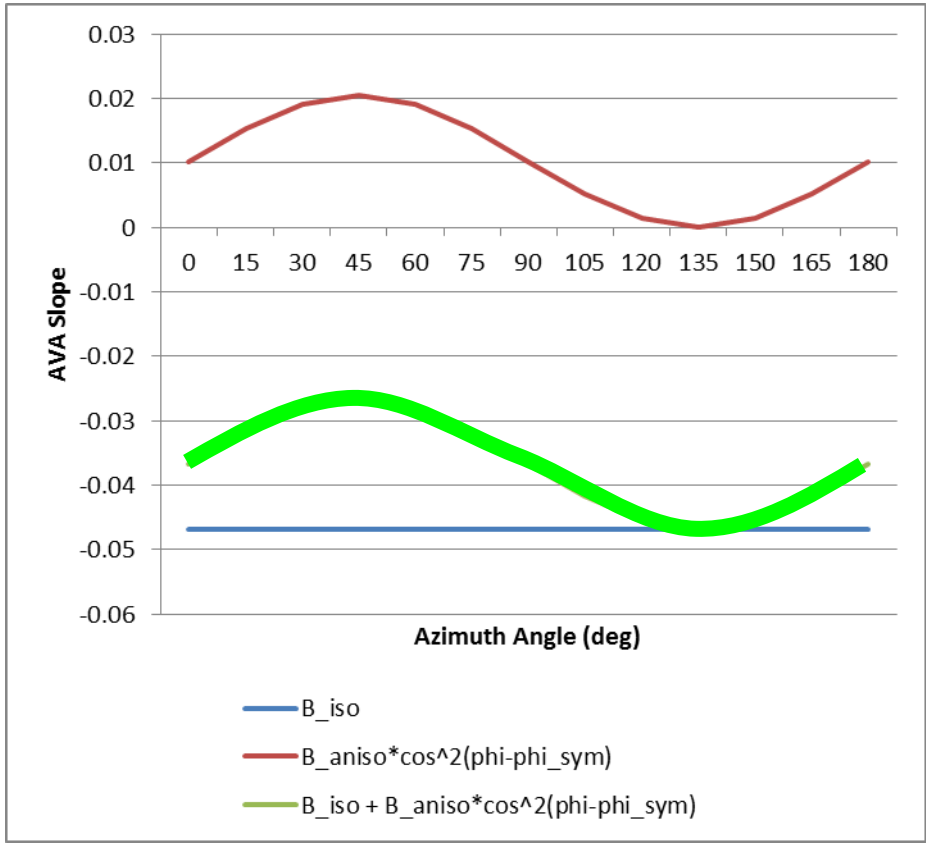
$$B(\phi) = B^{iso} + B^{aniso}\cos^2\left(\phi - \phi_{sym}\right)$$

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

Takeaway: realistic parameter assumptions produce 50% AVAZ variation

Assumptions for most sensitive parameters:

- $\gamma_{bot} = 0.05$
- $\gamma_{top} = 0.0$
- $\delta_{bot} = 0.01$
- $\delta_{top} = 0.0$
- 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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