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Active seismic imaging using microseismic events

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Outline

1. “Passive” seismic imaging approach
2. Location procedure
3. Imaging procedure
4. Application to the microseismic events recorded at SAFOD
5. Comparison with existing surface seismic images
6. Correlation with lithology

“Passive” seismic imaging approach

Idea: to treat a microseismic event as a standard active seismic source and the corresponding recorded wavefield as a reflection seismic shot gather

Motivation: reflections within the seismograms occur due to faults or layer discontinuities in the vicinity of the hypocenter and the receiver array and can be imaged using migration techniques adapted from reflection seismics

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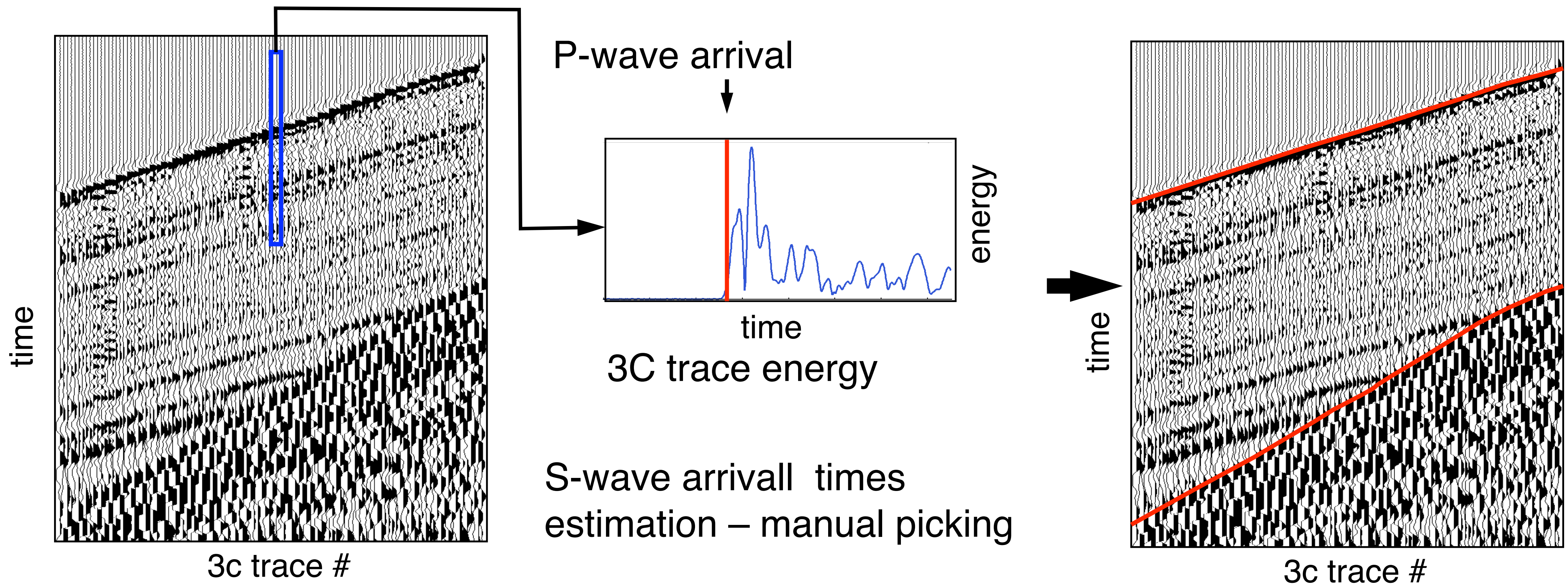
Location method

1. P- and S-wave arrival time estimation
2. Direct P-wave polarization estimation
3. Event location in space
4. Event location in time

(Rentsch et al., 2007)

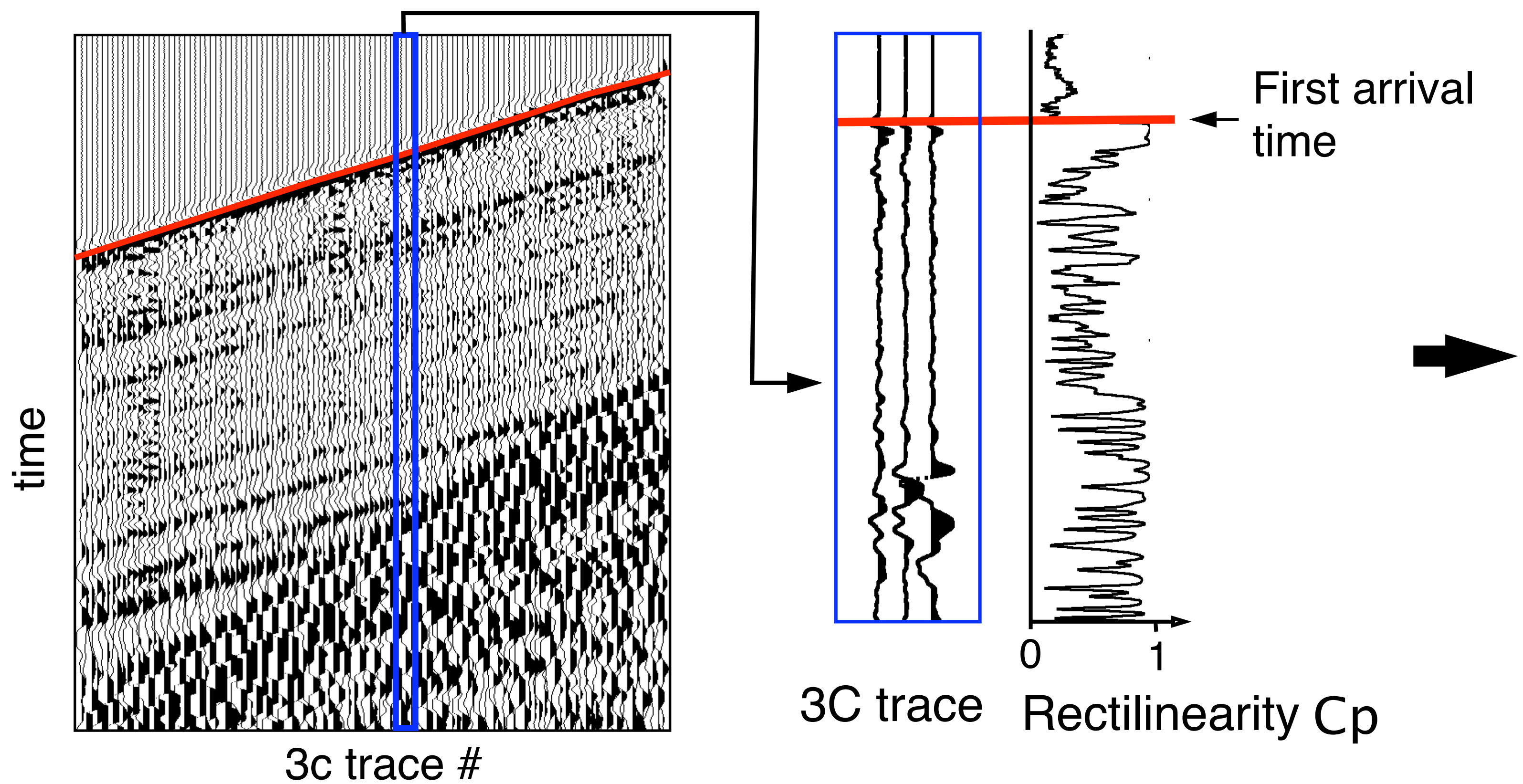
Location method: step 1

1. P- and S-wave arrival times estimation



Location method: step 2

2. Direct P-wave polarization estimation



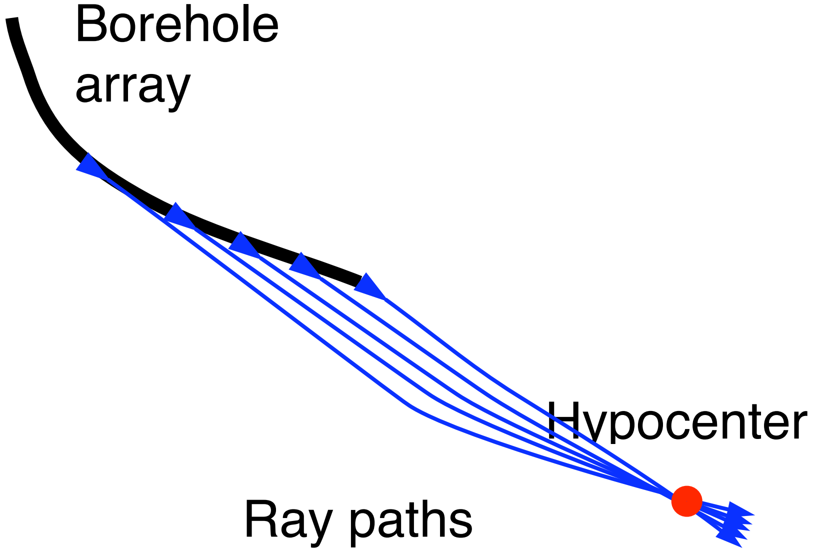
a. Calculate covariance matrix
b. Calculate eigenvalues and eigenvectors λ and ν
c. Eigenvector corresponding to highest eigenvalues specifies the polarization

$$Cp(t) = \frac{(\lambda_1 - \lambda_2)^2 + (\lambda_2 - \lambda_3)^2 + (\lambda_3 - \lambda_1)^2}{2(\lambda_1 + \lambda_2 + \lambda_3)^2}$$

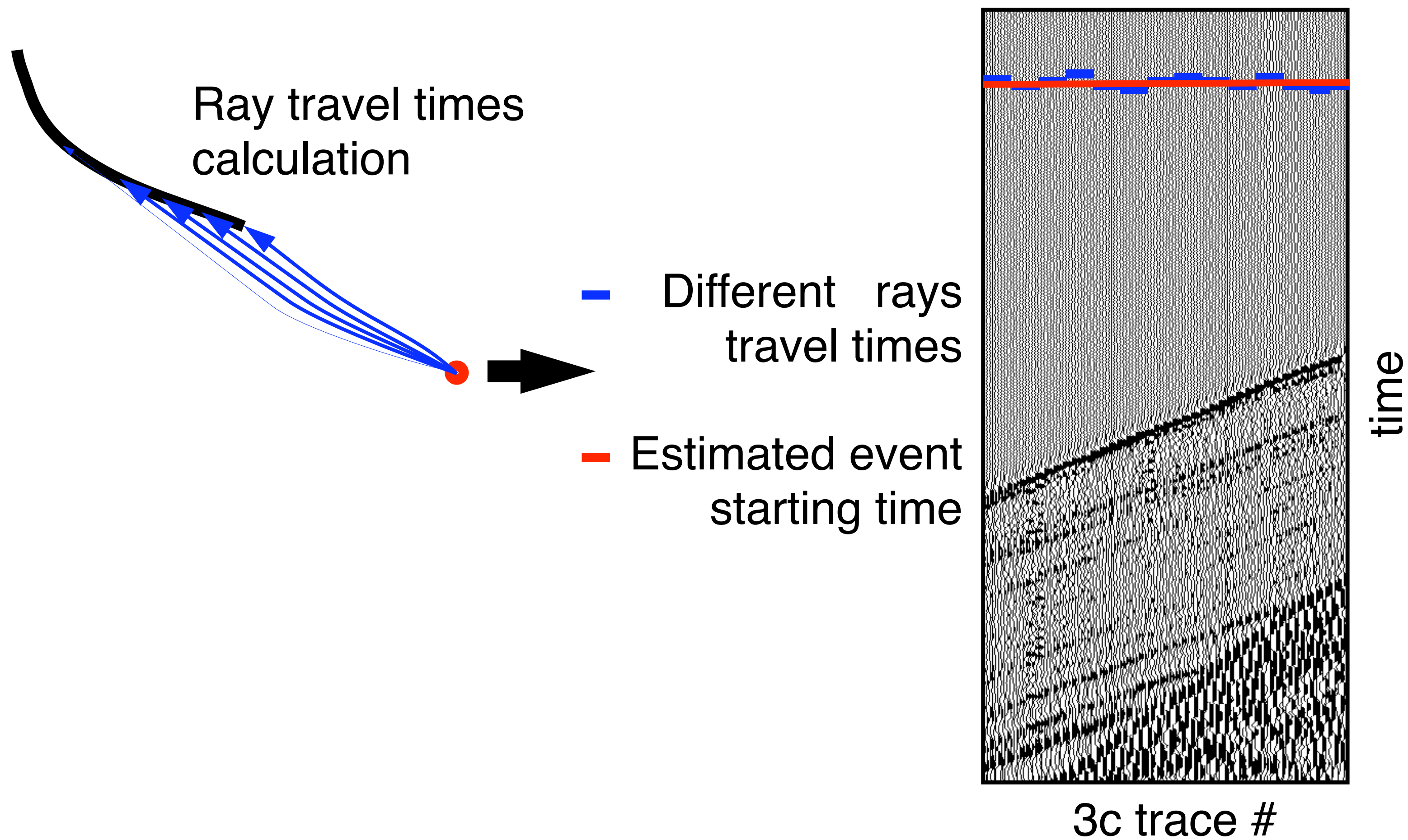
(Soma et al., 2007)

Location method: step 3&4

3. Estimation of the event location



4. Estimation of the event starting time



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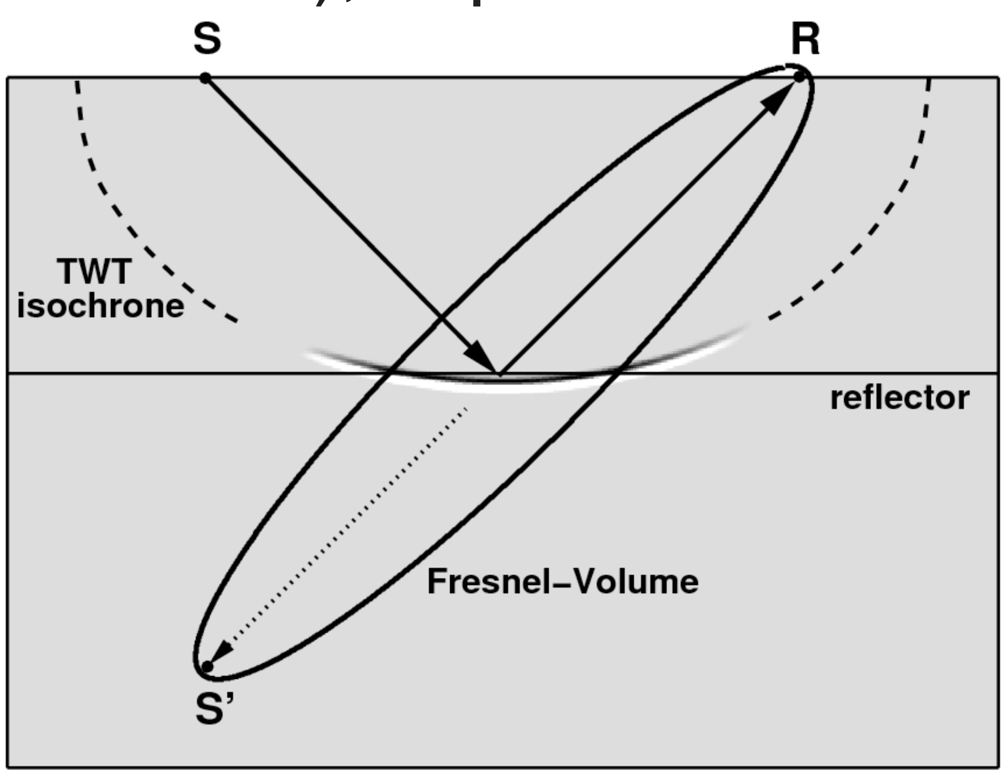
Imaging procedure: principle of 3D Fresnel-Volume-Migration

Basis: 3D Kirchhoff prestack depth migration

Principle: restriction of migration operator to the region around the actual reflection point

Benefits: improved image quality and better resolution (less artefacts), in particular for low fold and steeply dipping reflectors

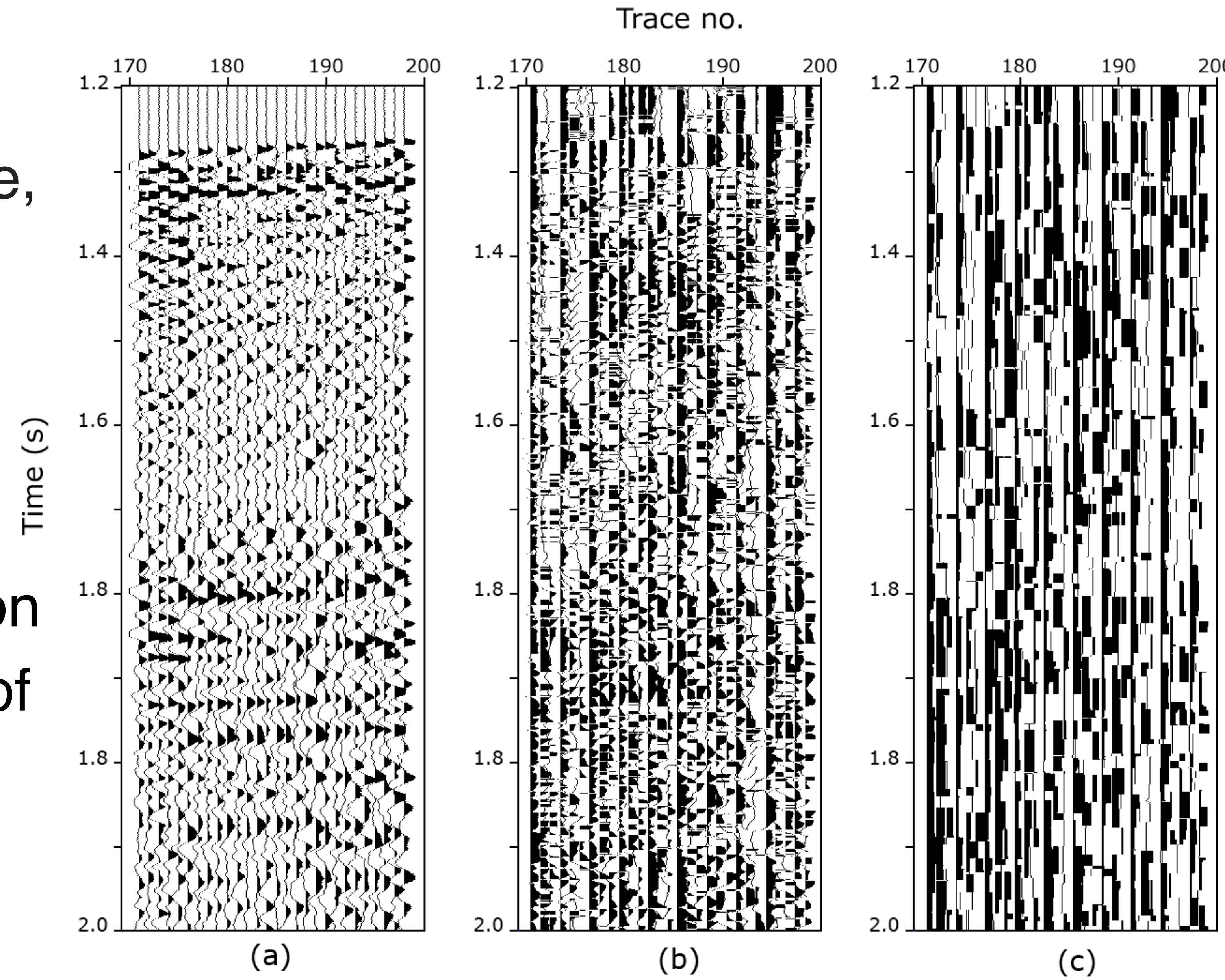


(Buske et al., 2006)

Imaging procedure: estimation of reflected waves polarization

Principle: for each time sample, assign the polarization value corresponding to the highest rectilinearity from some time window around it

Benefits: extract the information about emergence polarization of the strongest reflection at the current time; it helps to avoid defocusing of resulting images

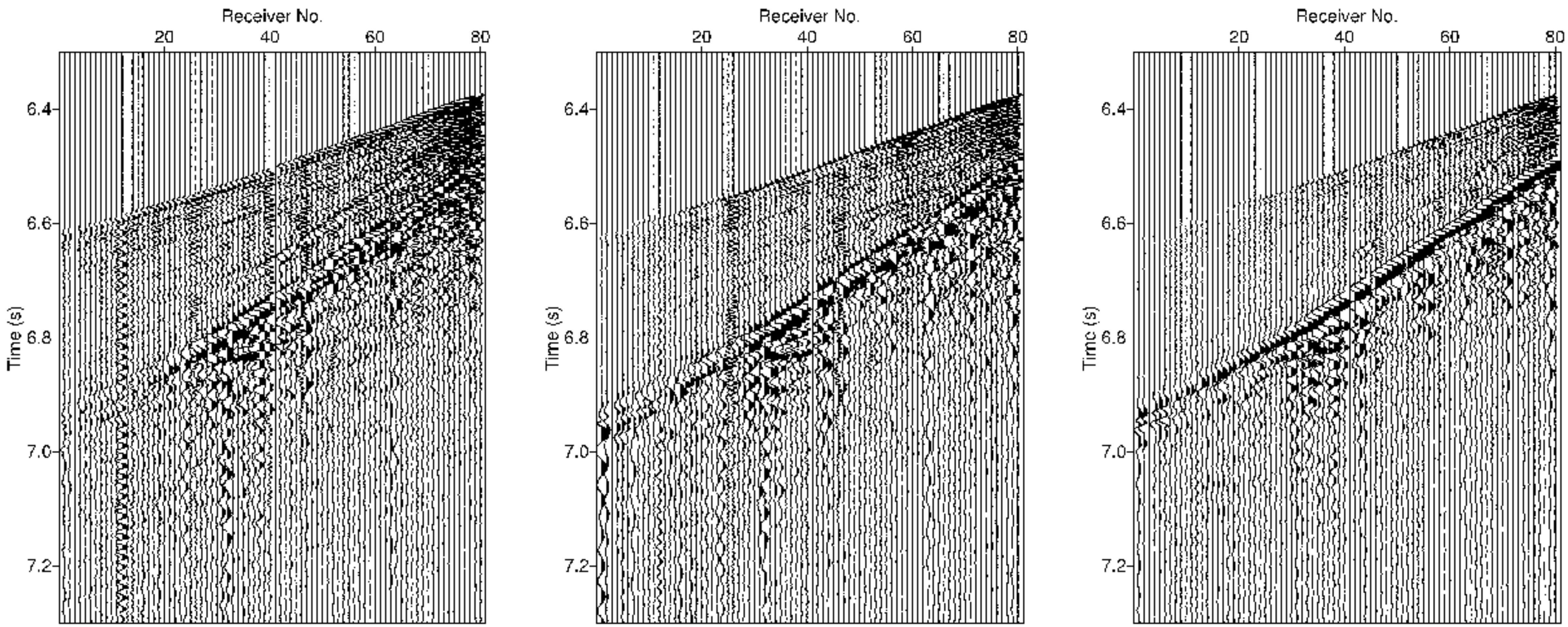


(a) Part of three-component data of May 5, 2005 event.
(b) Polarization calculated for each sample separately.
(c) Polarization calculated by means of the sliding window algorithm.

Application to the SAFOD dataset

- P/GSI seismometer array in main hole (80 three-component receivers between 880-1702 m b.s.l.)

- Time period: April 29 – May 11, 2005



Vertical-component

North-component

East-component

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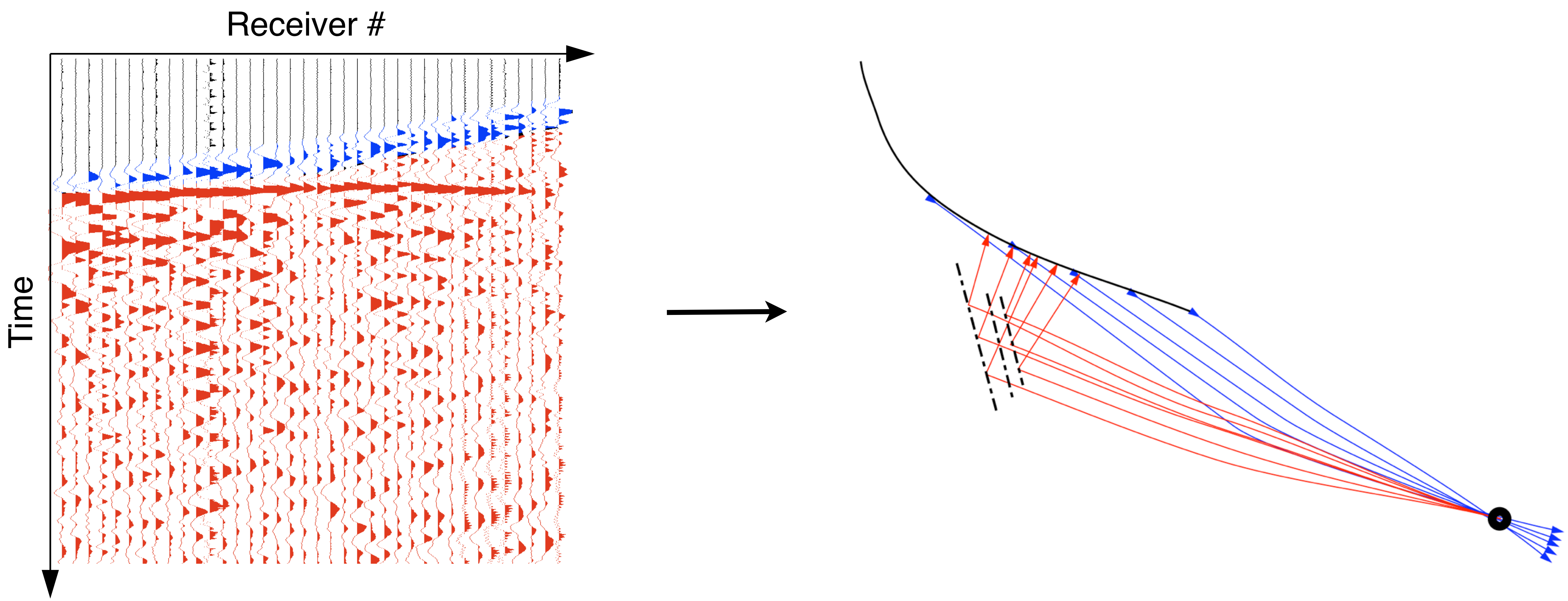
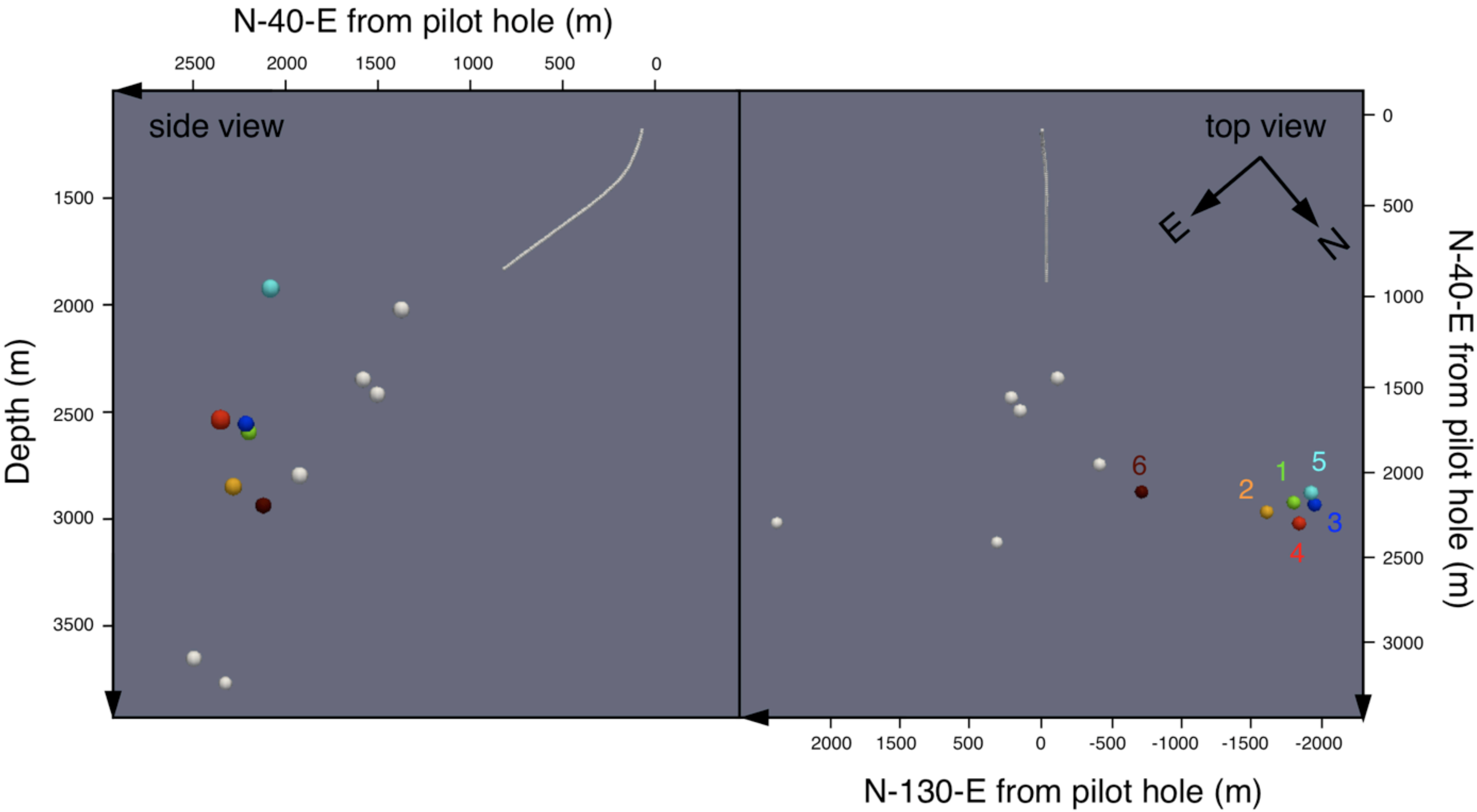
Application to the SAFOD dataset: scheme



- Blue part - direct wave, used for location
- Red part - PP reflections wavefield, used for imaging

Application to the SAFOD dataset: located events



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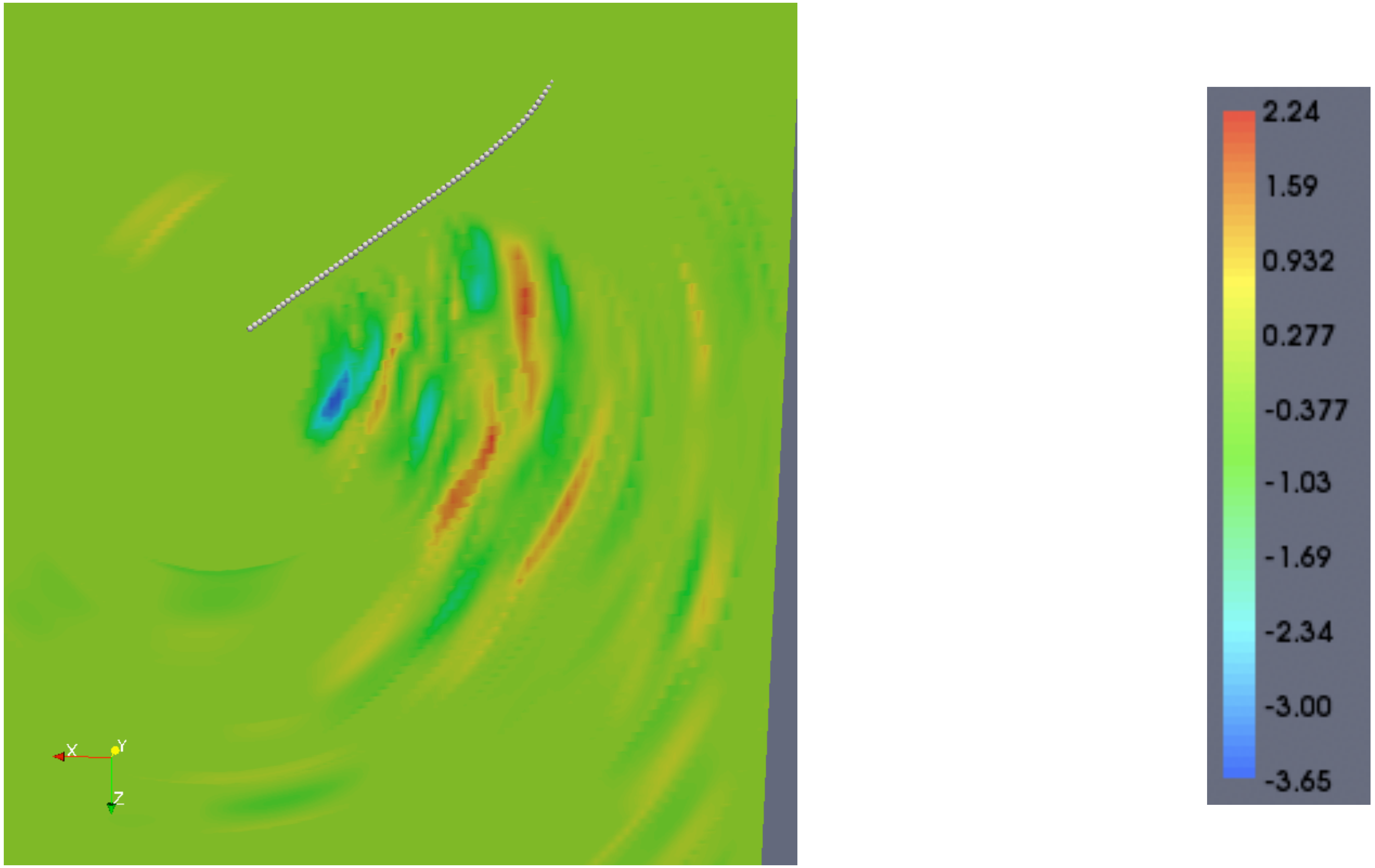
Application to the SAFOD dataset: image for single event



Next slide: images for six different events

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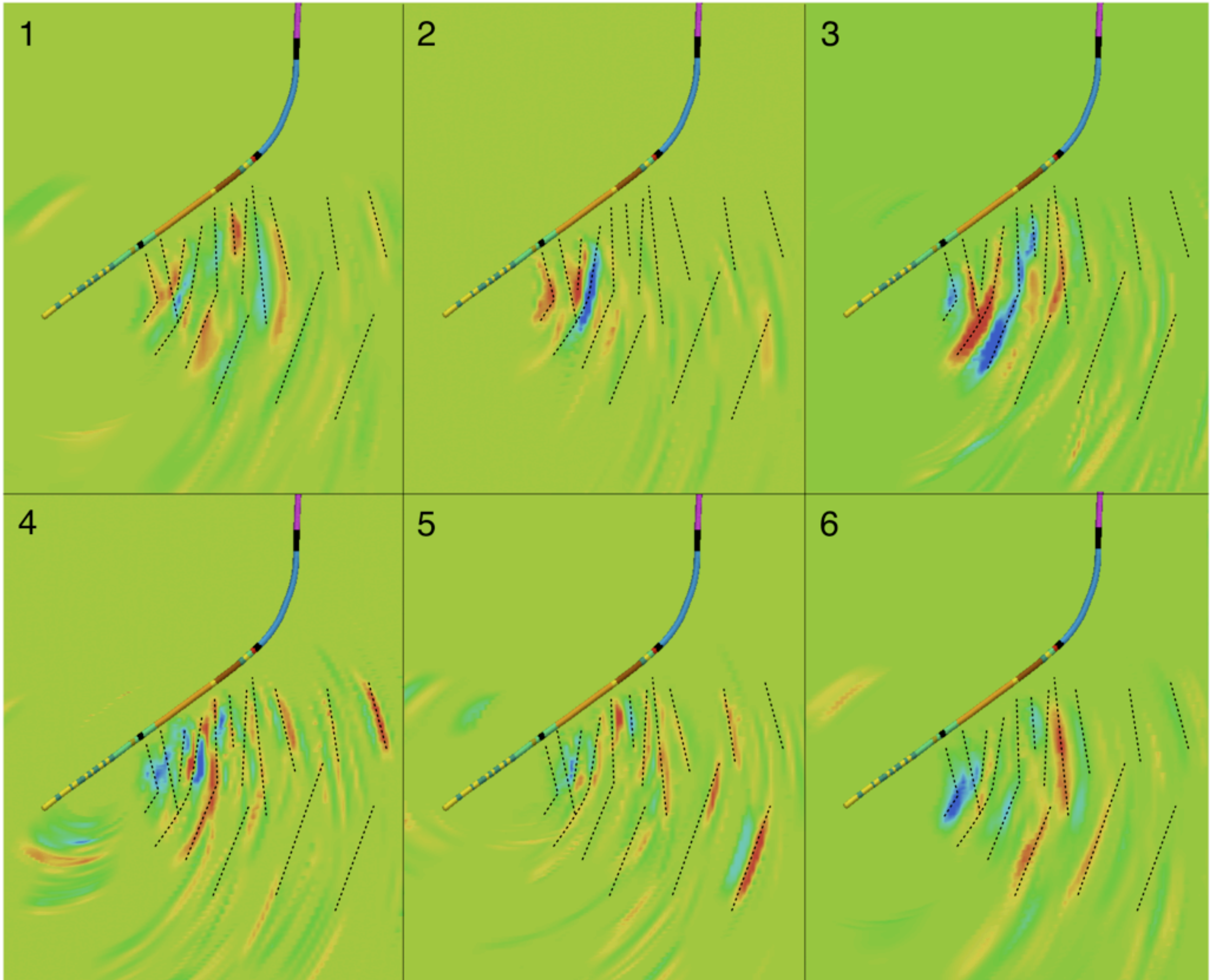

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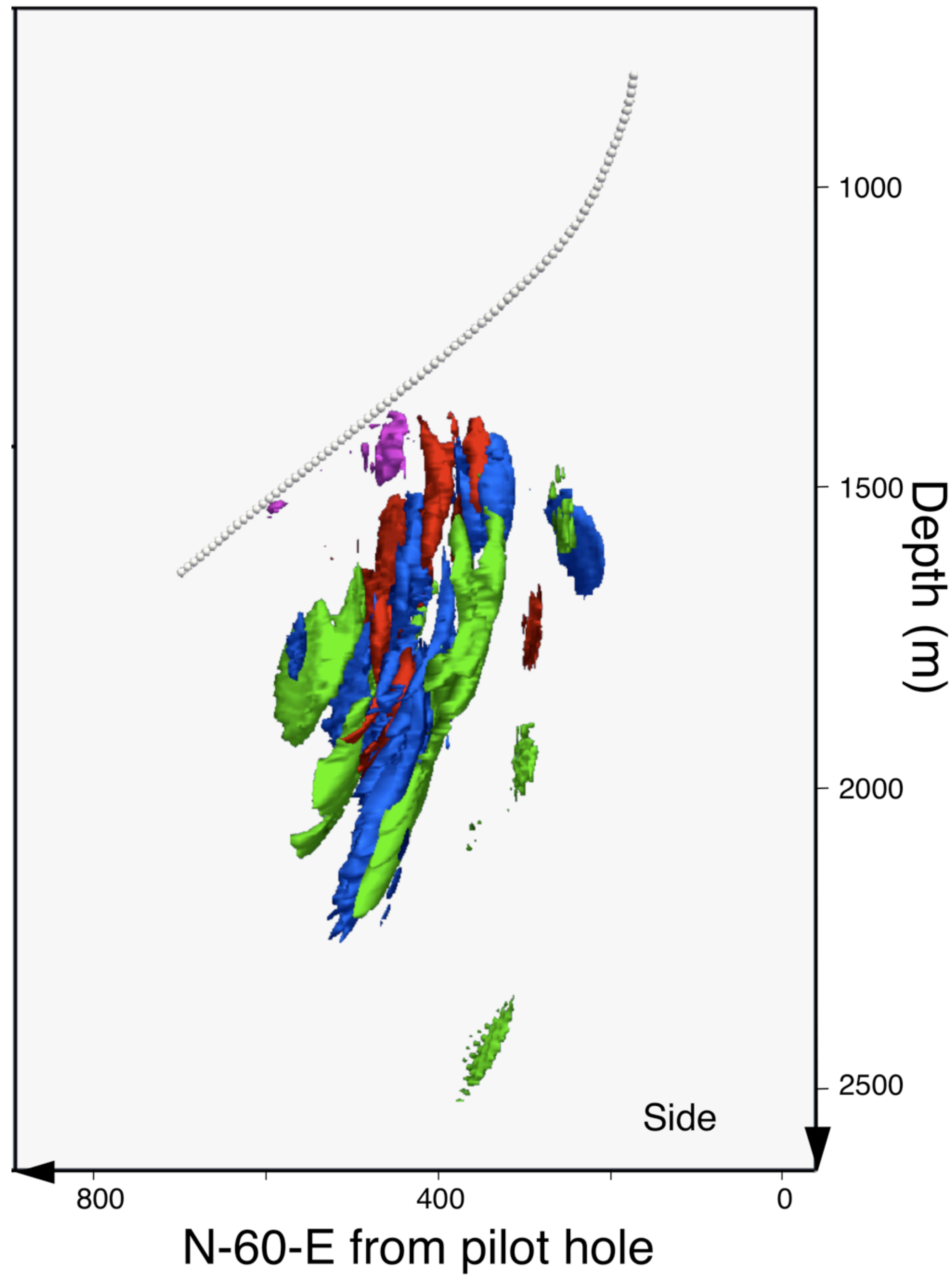

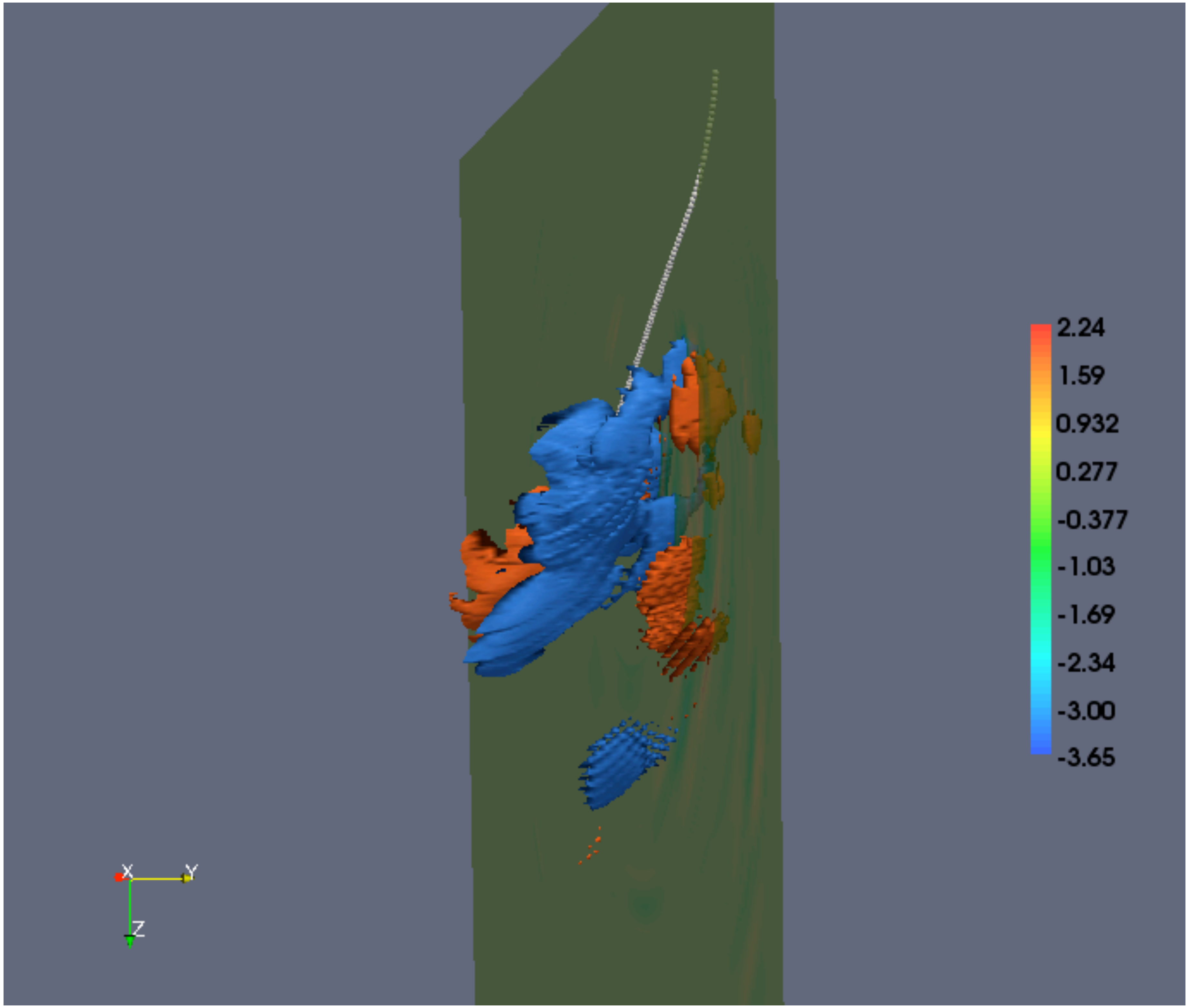
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-0.377
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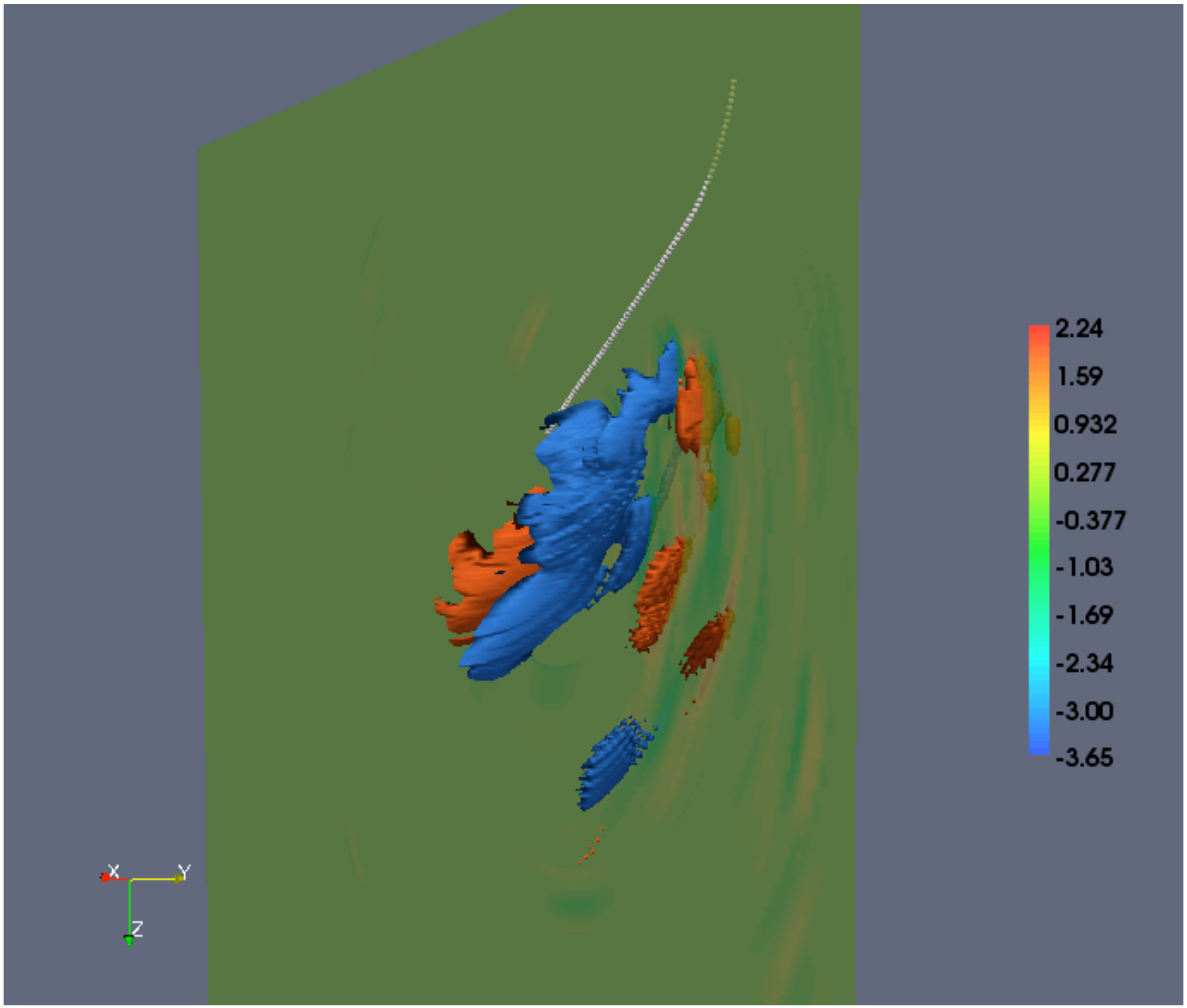
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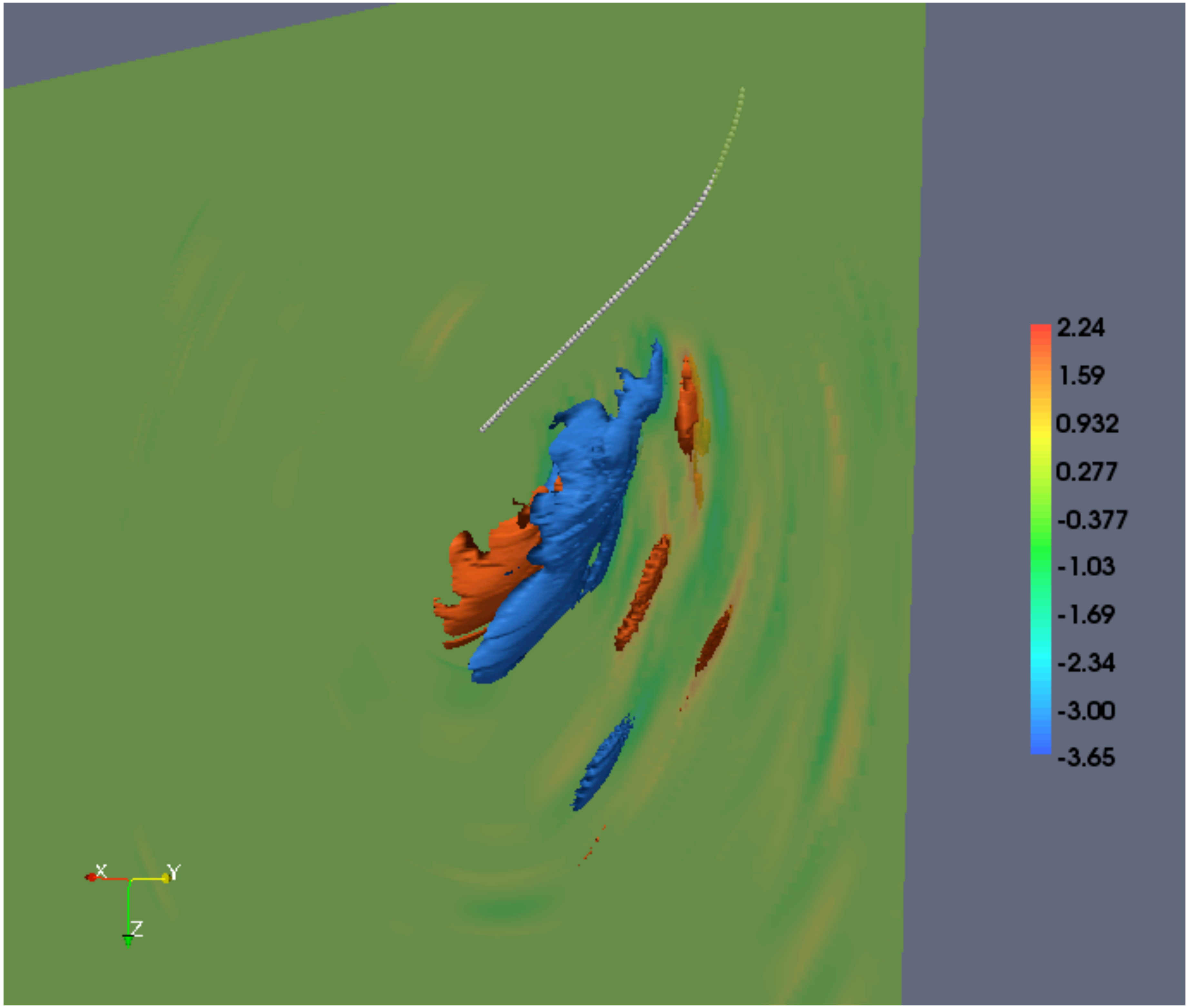

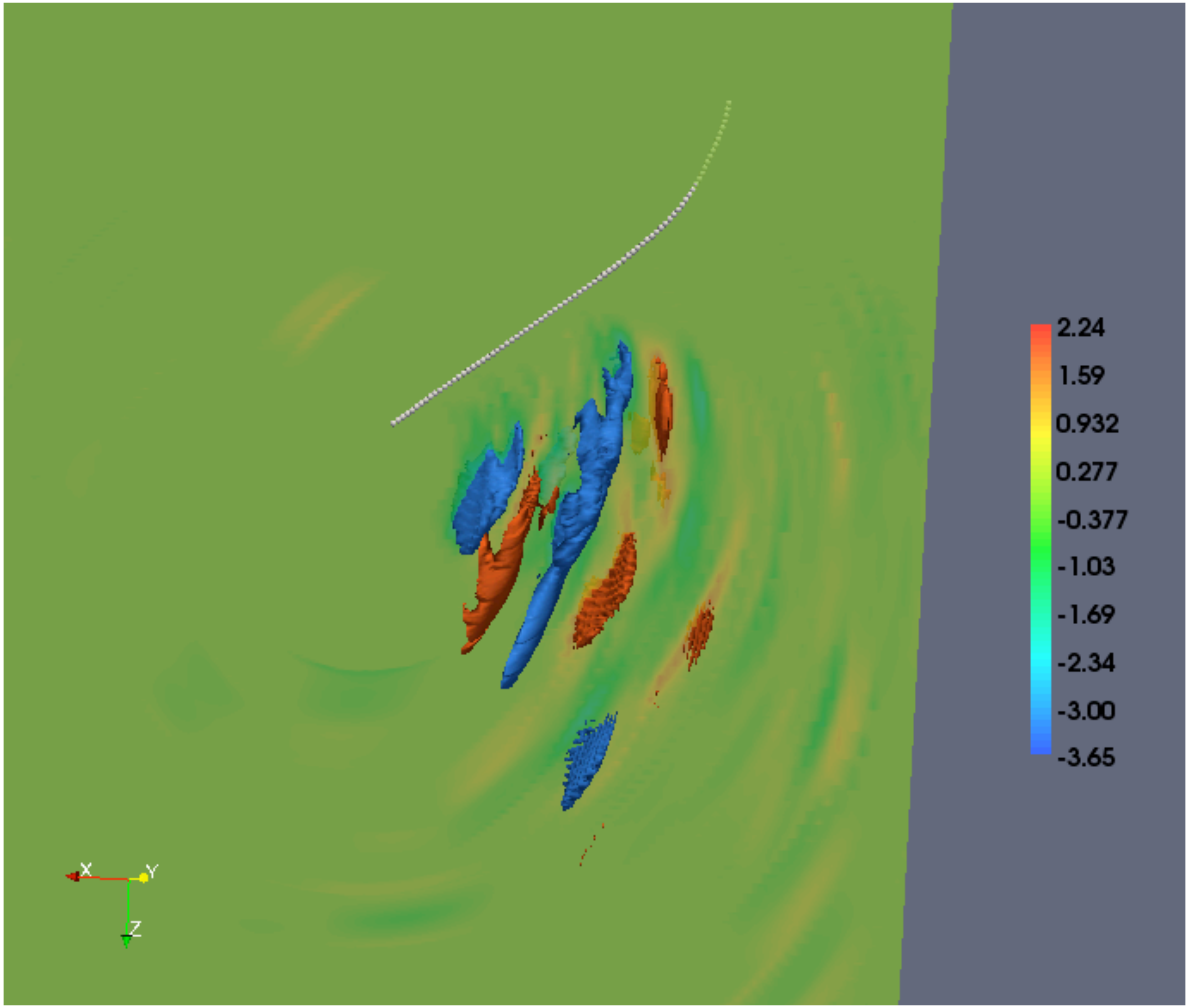
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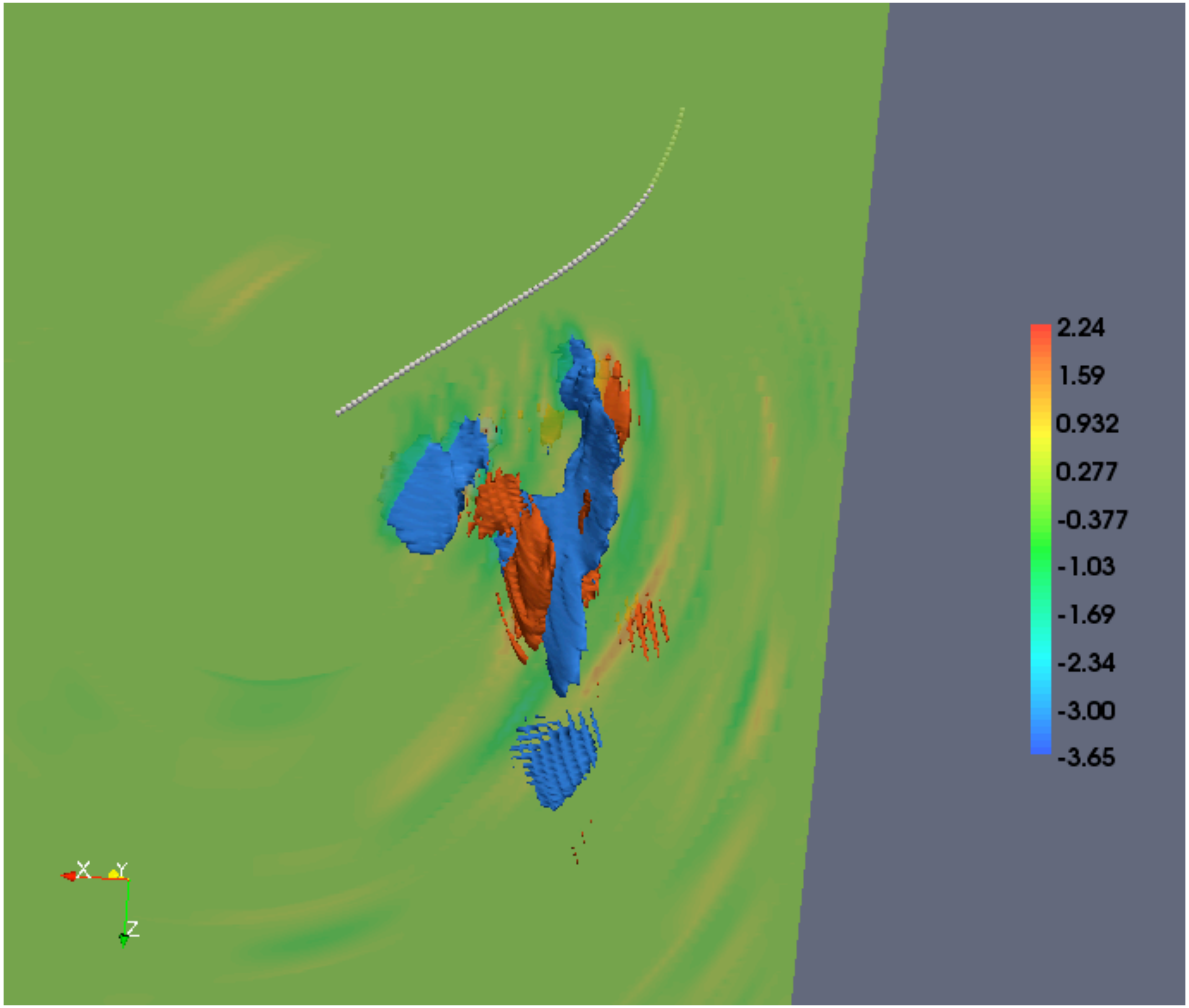
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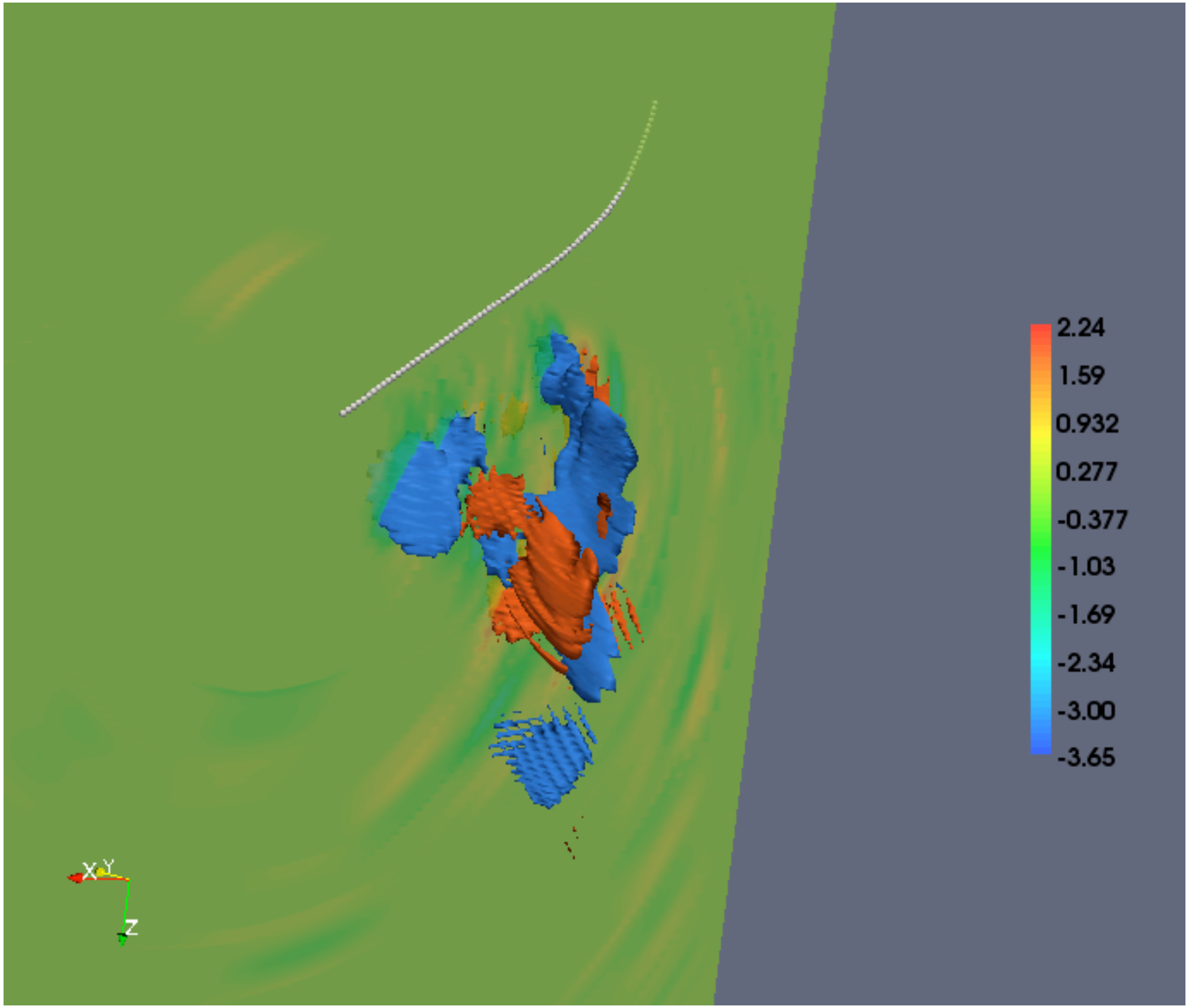

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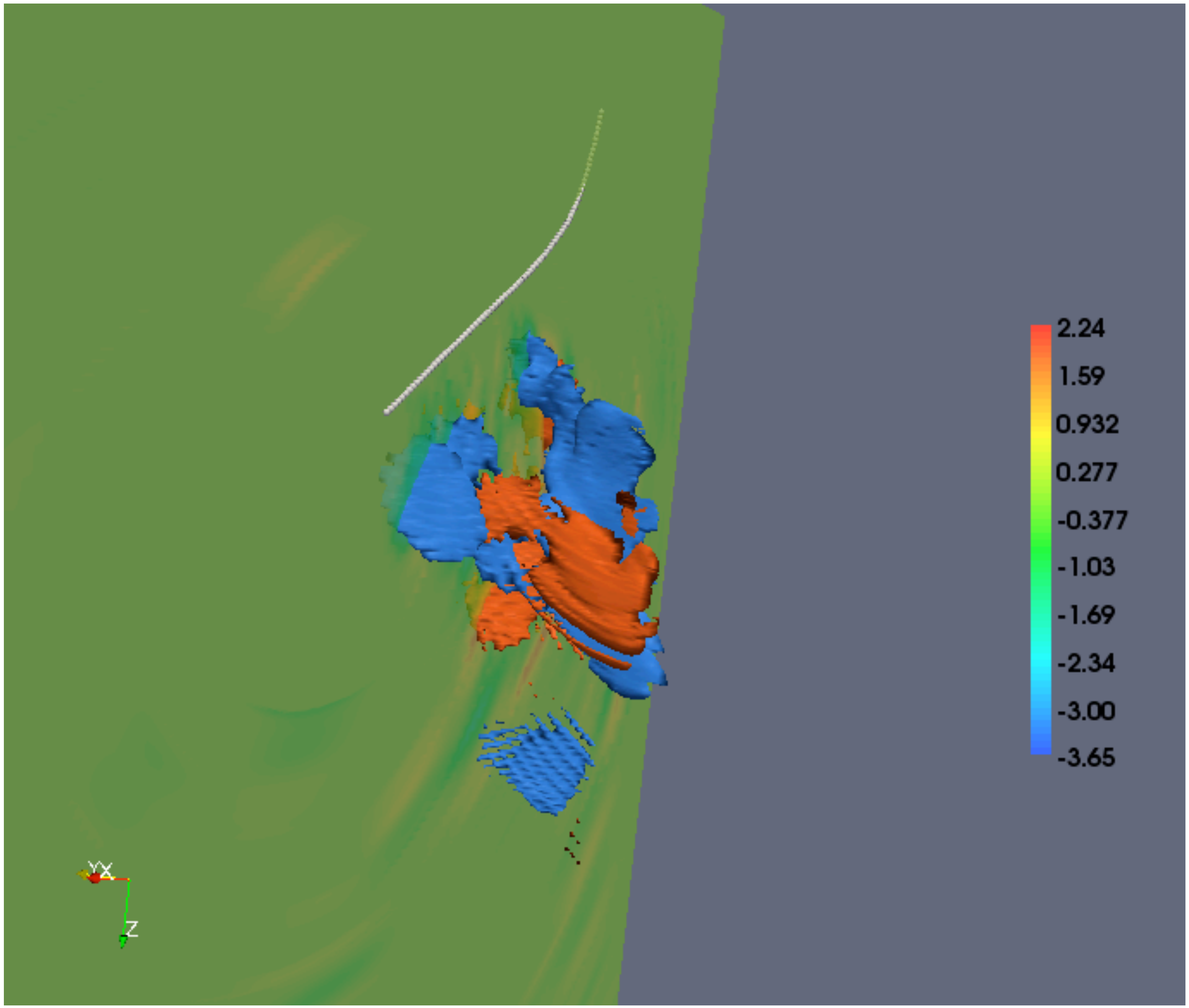

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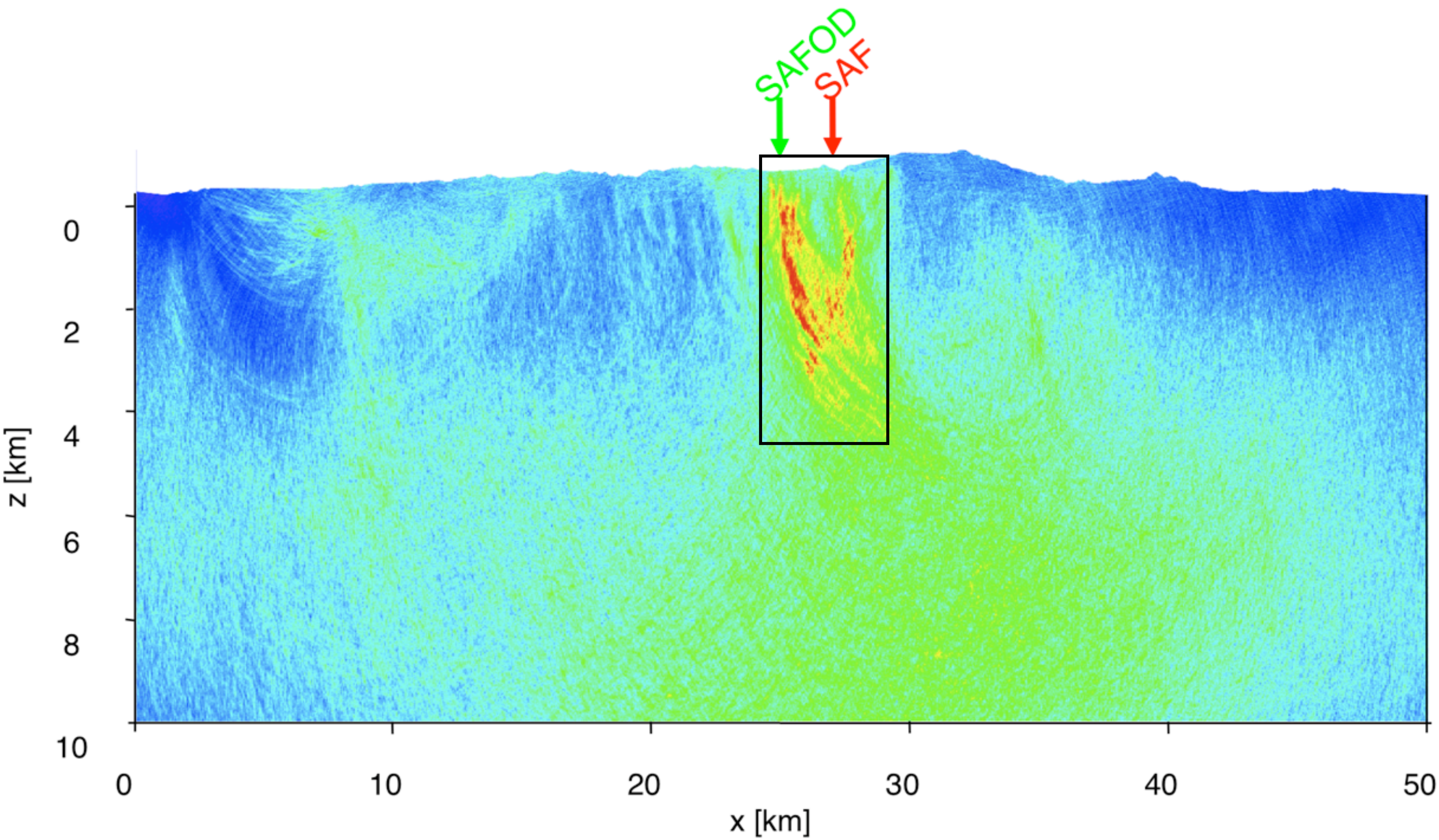
Large scale surface seismic image



(Buske et al., 2007)

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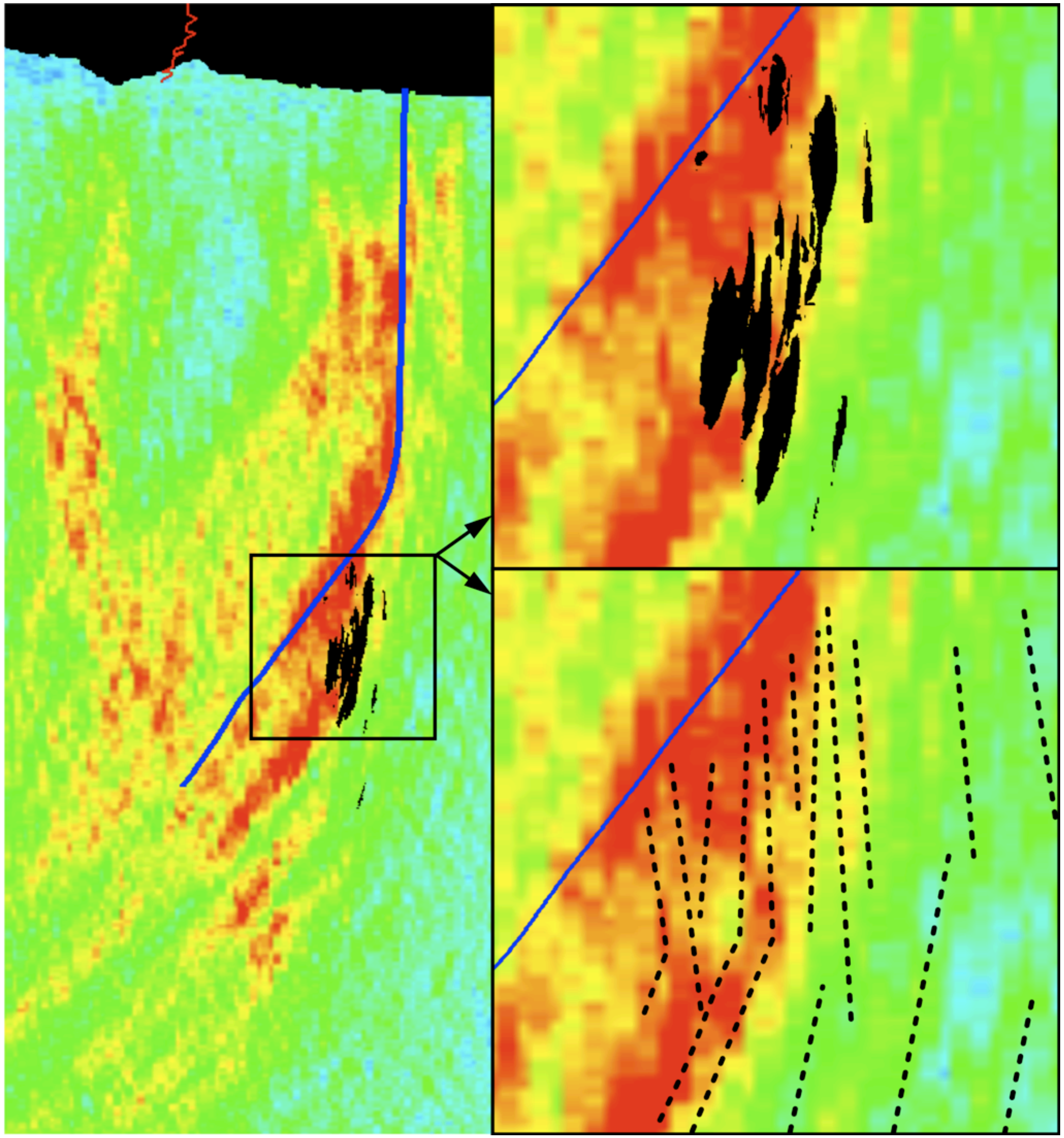
Comparison with surface seismic images



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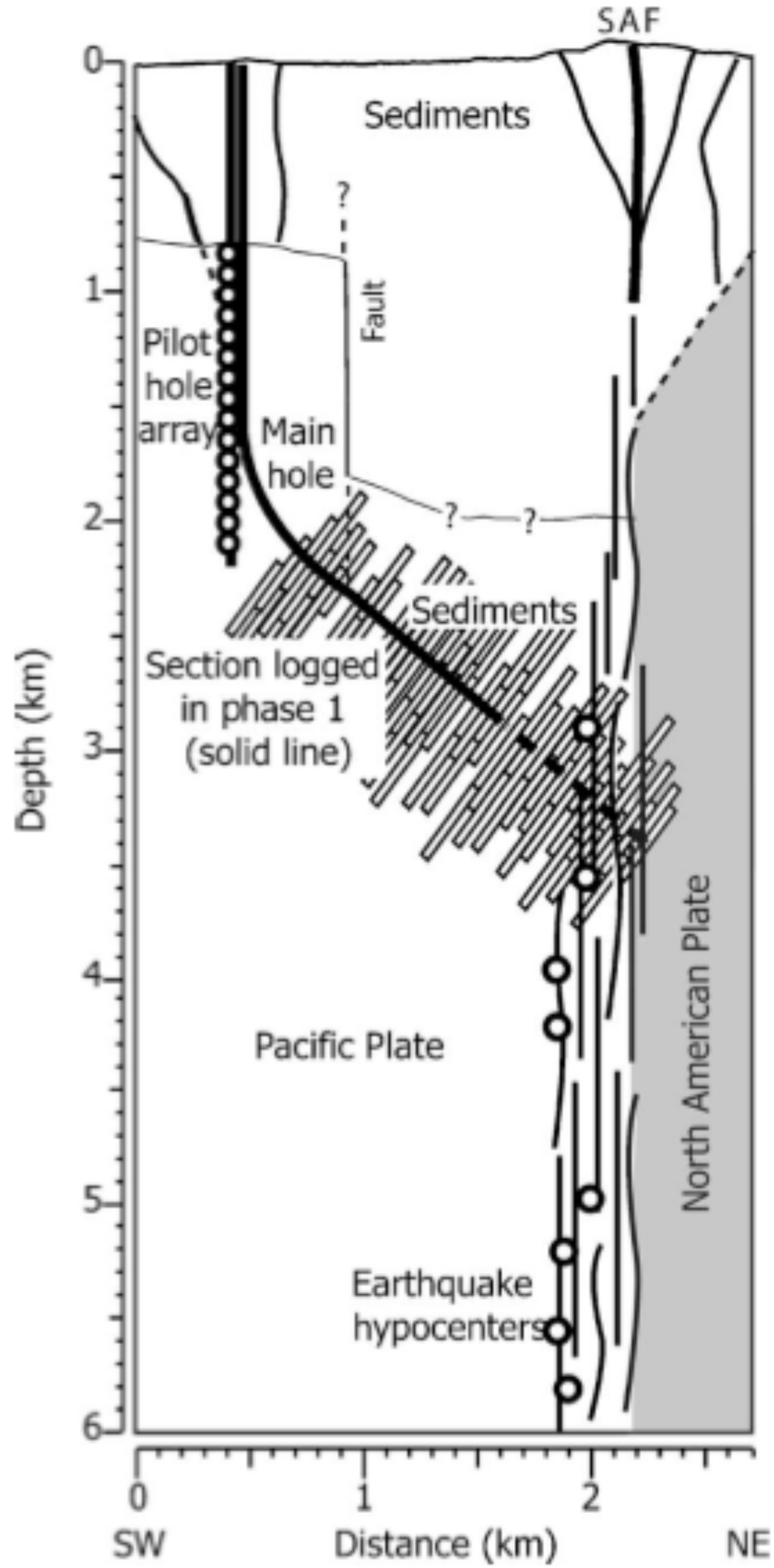
SAFOD: lithology

(Naomi L. Boness
and Mark D. Zoback, 2006)



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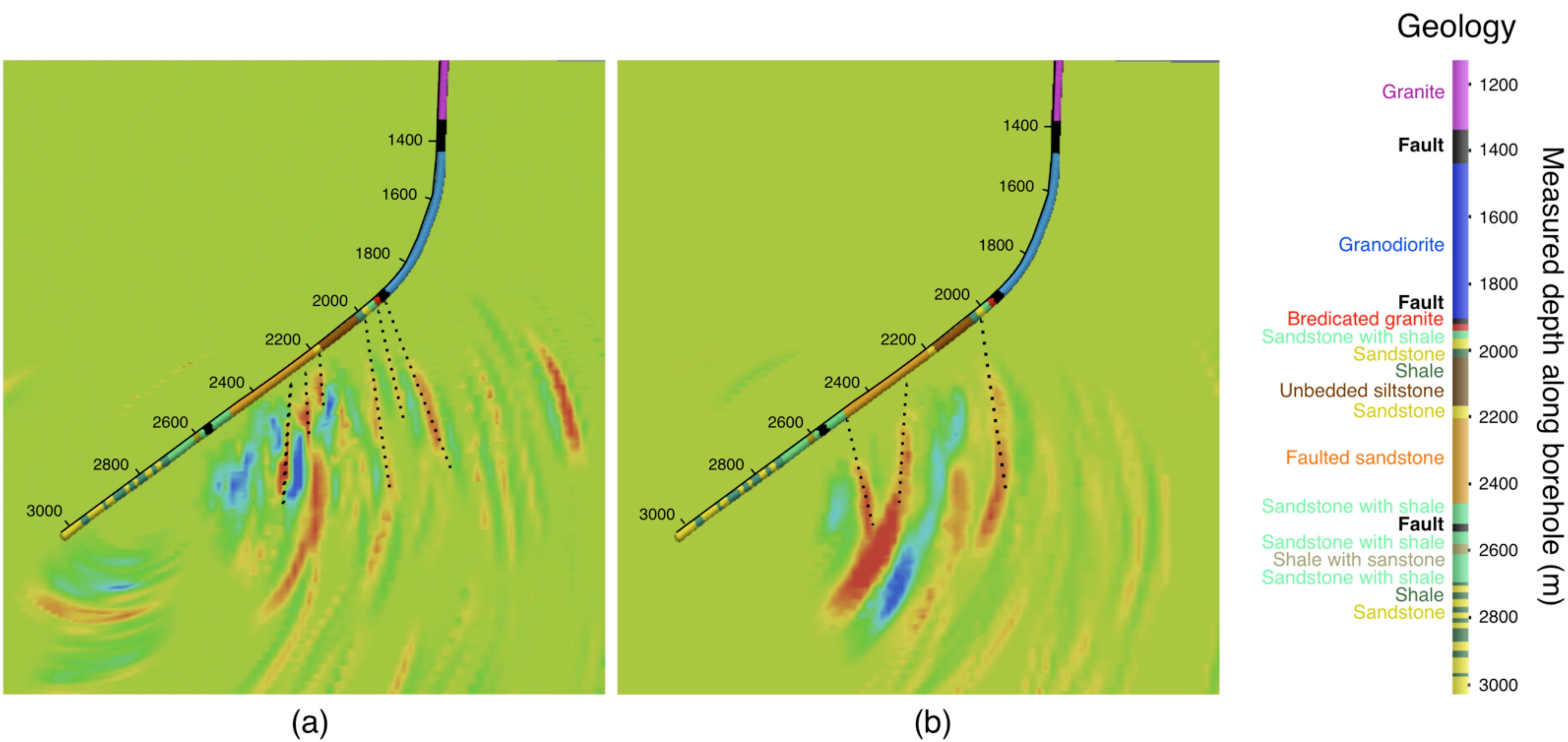
Correlation with lithology



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Summary & conclusions

1. We have presented **an approach for microseismicity imaging**:
   - using the obtained polarization of the P-wave first arrival, the hypocenter of the microseismic event is precisely located
   - then this event is treated as a "pseudo-active" seismic source and the reflections within the recorded wavefield are processed using a directional migration algorithm in order to construct a high resolution image in the close vicinity of the located hypocenter

2. **The method was applied to microseismic events recorded at SAFOD** and well-resolved images of a fault branch near the borehole were obtained.

3. **The comparison** of these findings with existing surface seismic reflection images as well as lithology shows **a quite satisfactory agreement**.

In summary, our results allow to obtain a spatial characterization of the complex internal structure of the SAF and can certainly be helpful for other studies which rely on this knowledge.