Offset and Azimuth Diversity
A Recipe for Complex Imaging

Eivind Fromyr and Chris Page, PGS*

Finding Petroleum

The Geological Society, Tuesday January 25, 2011

Outline

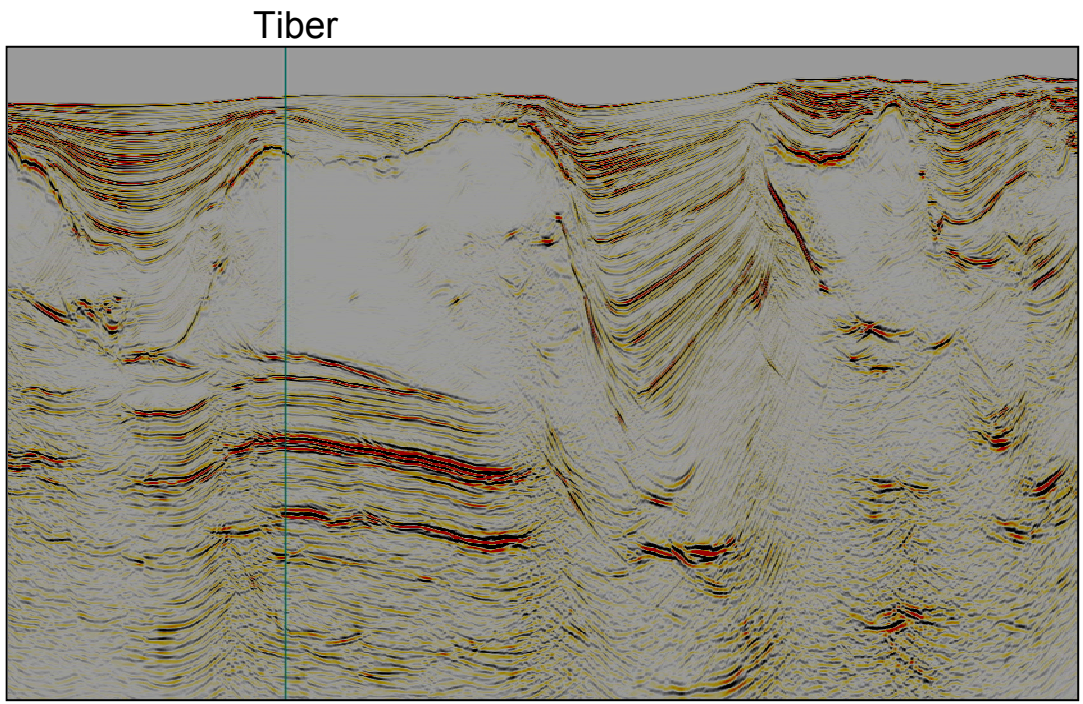
- ***Background***
- Wide Azimuth Acquisition Styles
- Crystal Phase I,II and III
- Some Aspects of Wide Azimuth Pre-Processing
- Data Examples
- Recent Developments
- Summary and Conclusions

Background

- Subsalt exploration has gained momentum due to a number of big discoveries
- Subsalt imaging has improved significantly with modern Depth Imaging Technology

- Challenges remain due to

  - Poor illumination from conventional acquisition geometries
  - The complex multiple wave-field limits the imaging quality

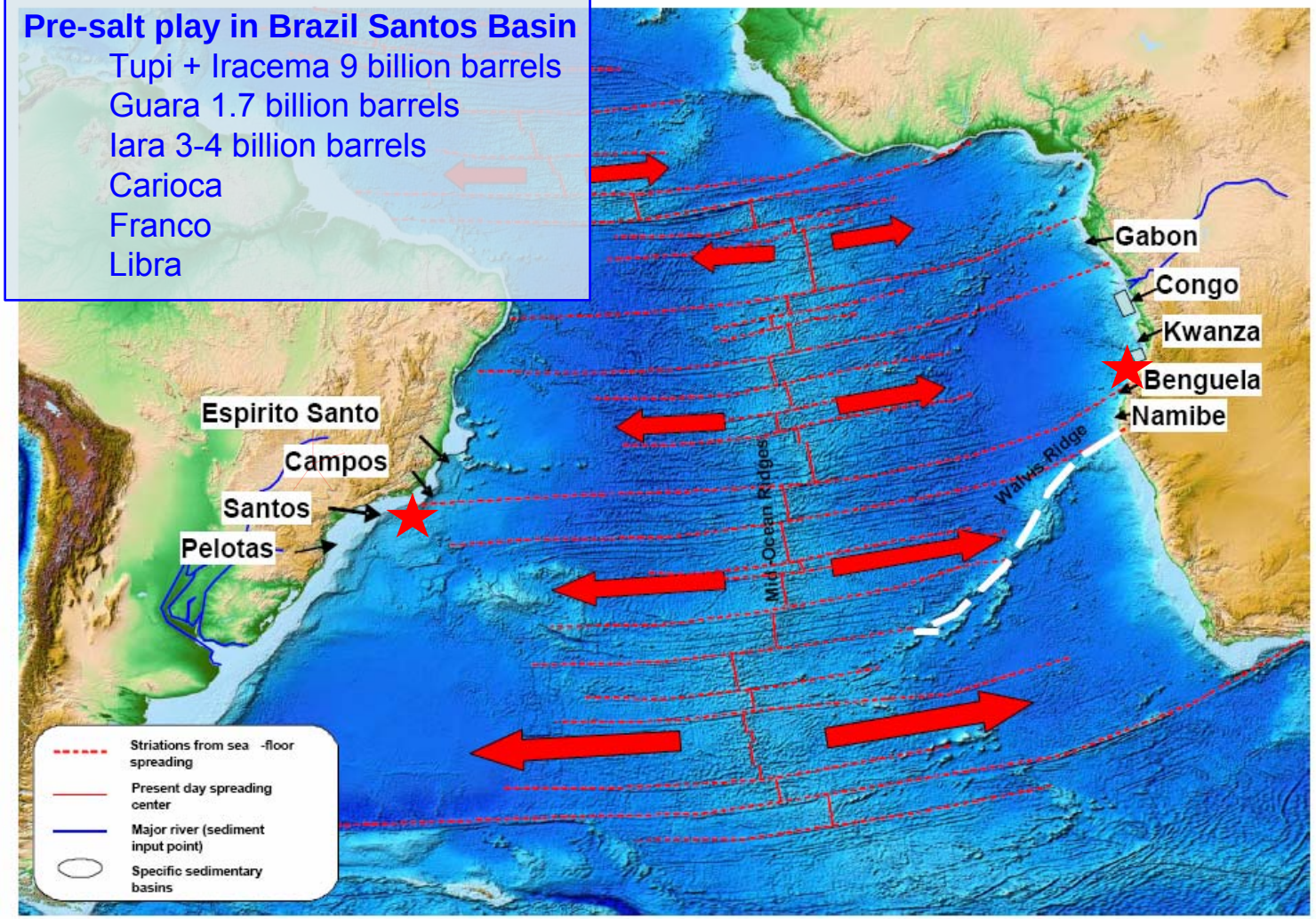


PSDM (WEM) of Conventional Streamer Data

South Atlantic Tectonics

Pre-salt play in Brazil Santos Basin

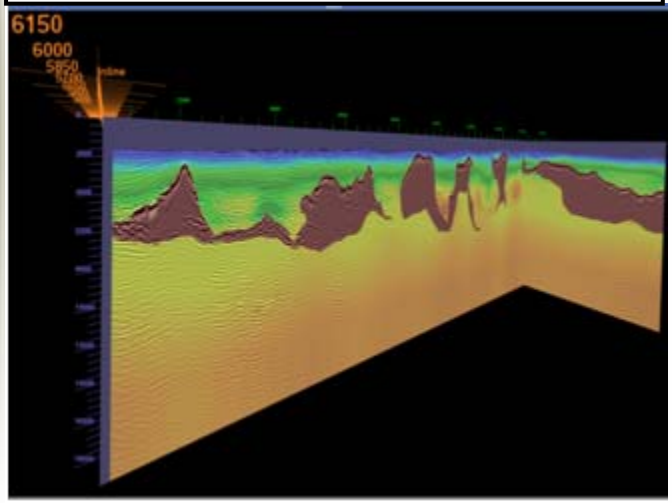
- Tupi + Iracema 9 billion barrels
- Guara 1.7 billion barrels
- Iara 3-4 billion barrels
- Carioca
- Franco
- Libra

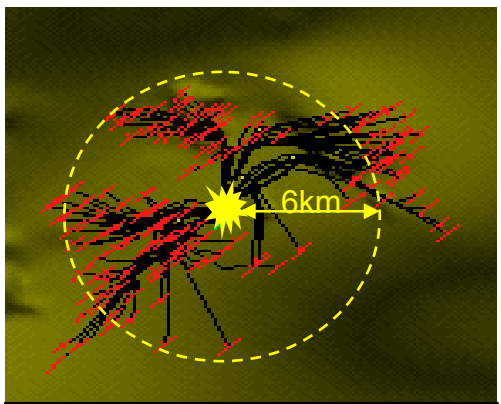


Source: Adapted by Bernstein from an original image: Amante, C. and B. W. Eakins, ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis, National Geophysical Data Center, NESDIS, NOAA, U.S. Department of Commerce, Boulder, CO, August 2008.

Wide Azimuth: *illumination*

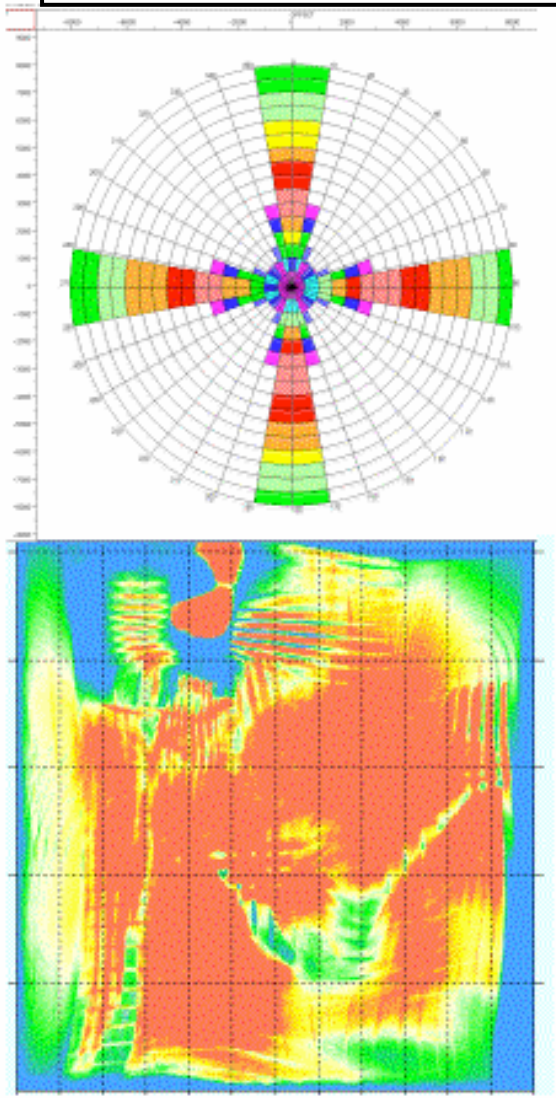
Complex Salt



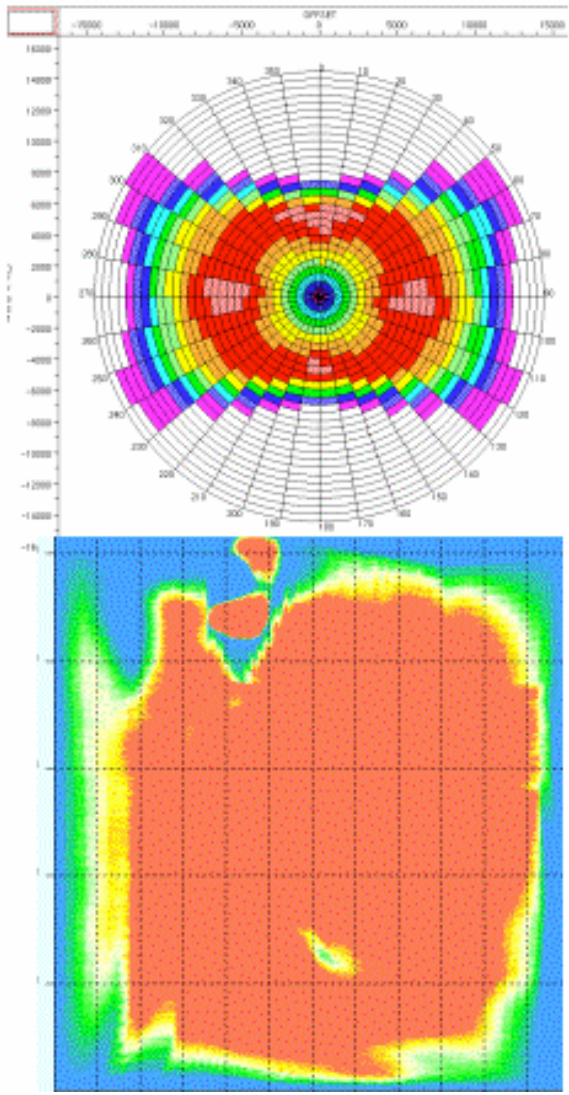


Scattering of energy

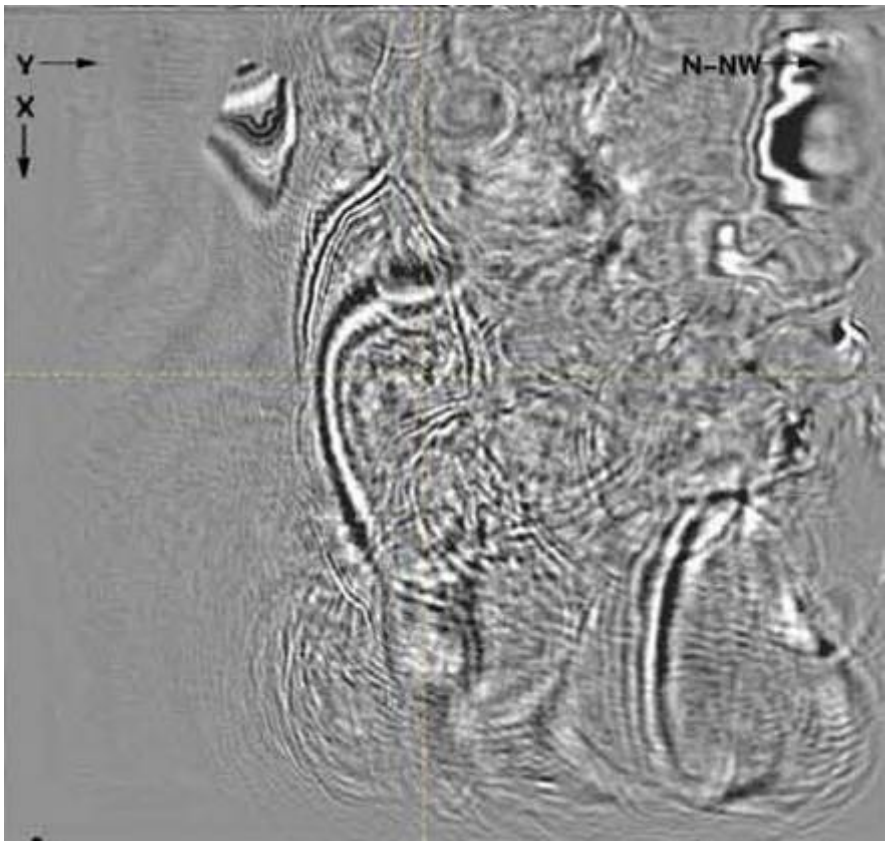
Narrow Dual Azimuth Illumination



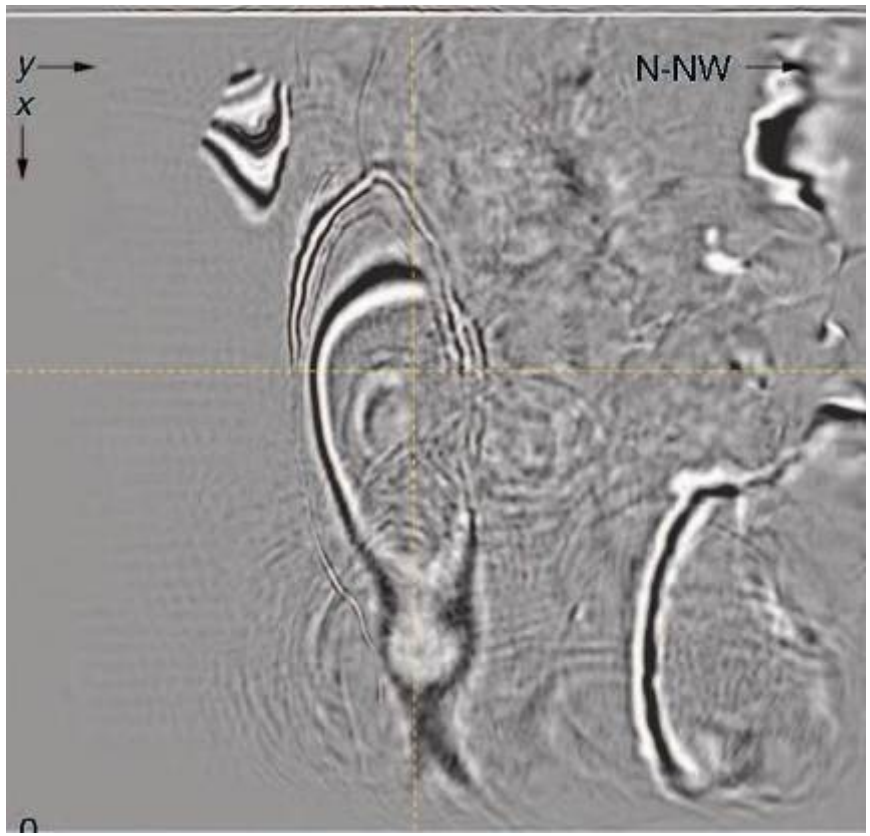
Wide Azimuth Illumination



Wide Azimuth: *multiple diffractions*



Narrow Azimuth Depth Slice

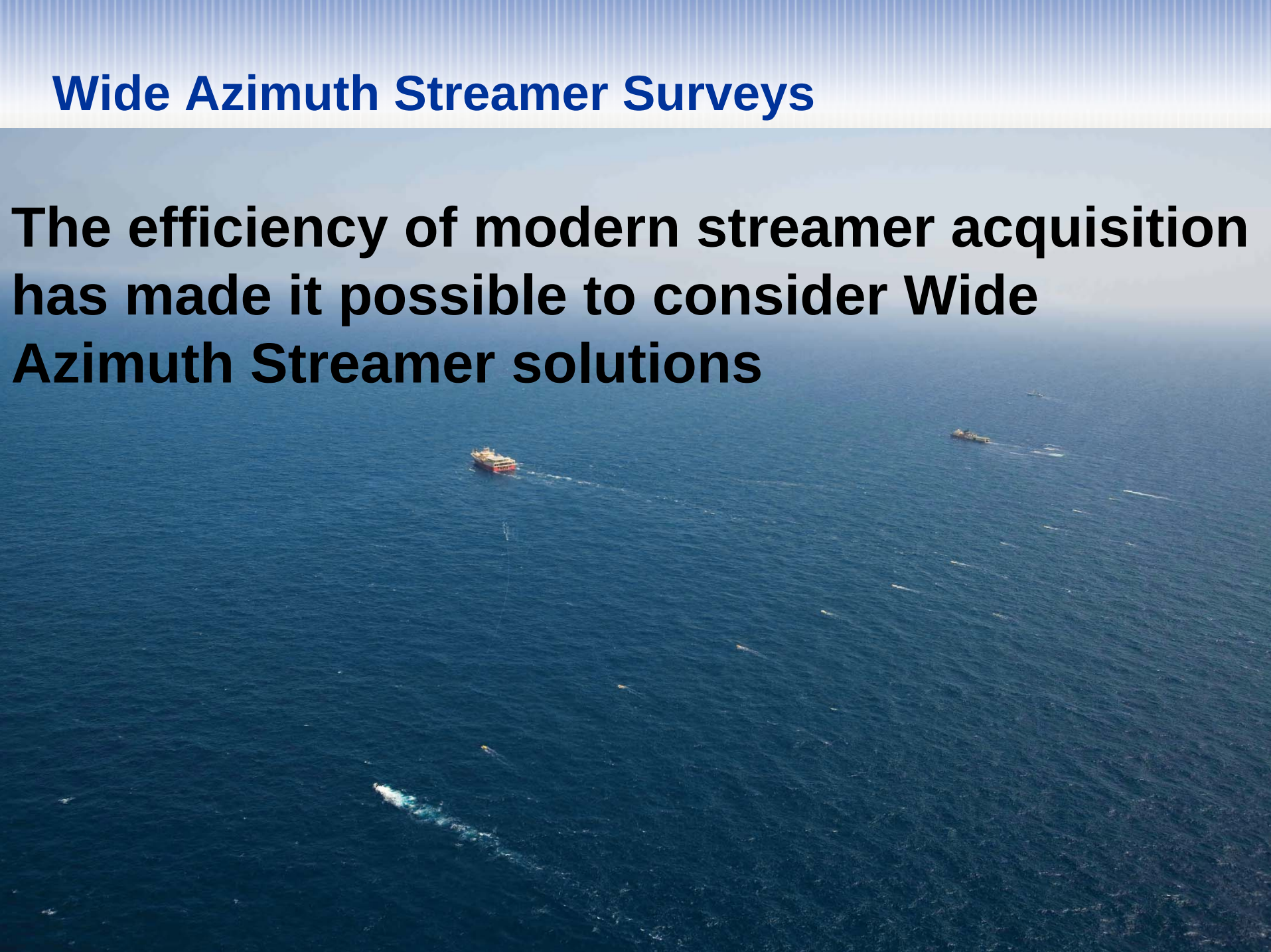


Wide Azimuth (2.4km) Depth Slice

Ref. Carl Regone "Using 3D finite-difference modelling to design wide azimuth surveys for improved subsalt imaging" , Geophysics, VOL 72, NO 5, 2007

Wide Azimuth Streamer Surveys

The efficiency of modern streamer acquisition has made it possible to consider Wide Azimuth Streamer solutions



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- ***Wide Azimuth Acquisition Styles***
- Crystal Phase I,II and III
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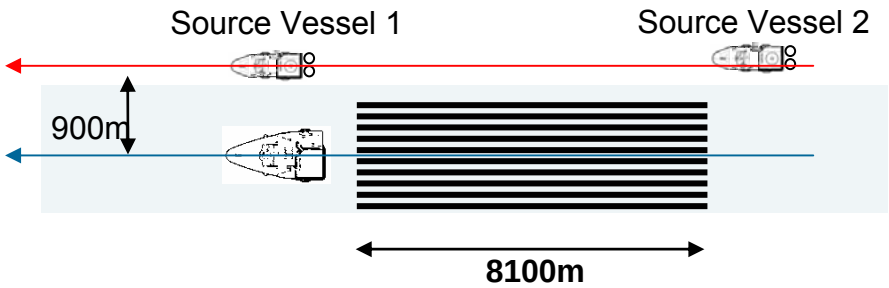
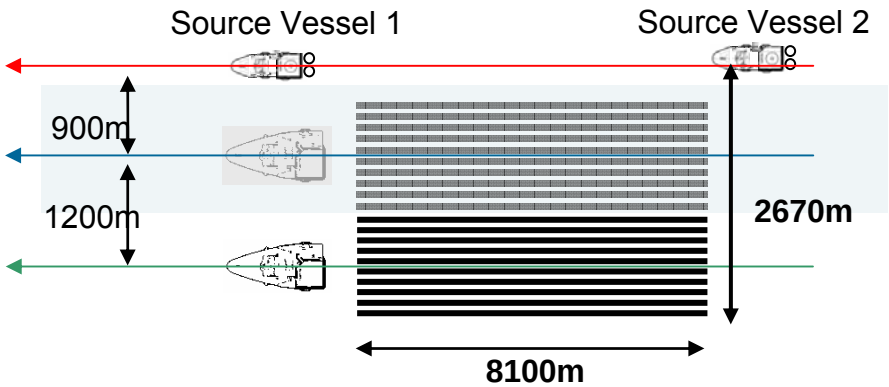
Wide Azimuth Geometry – Tile Template

First Sail-line
Near Cross-line Pass



Wide Azimuth Geometry – Tile Template

First Sail-line
Near and Far Cross-line Passes



Wide Azimuth Geometry – Tile Template

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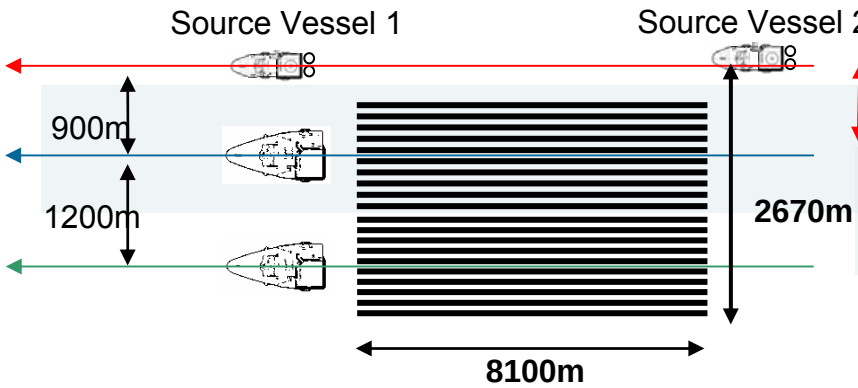
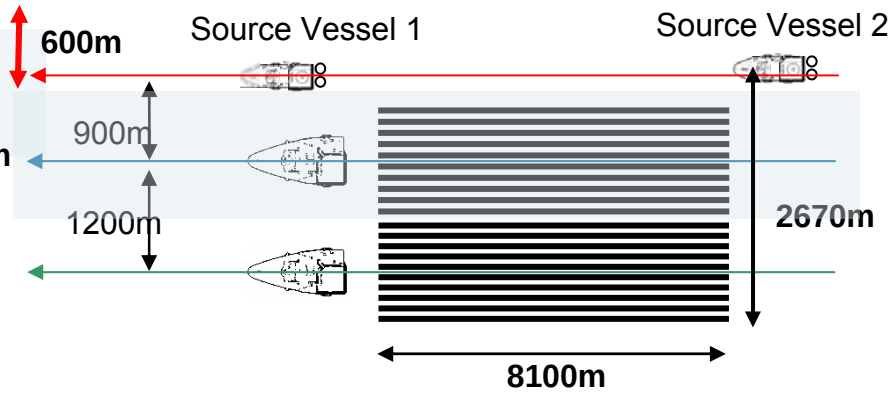


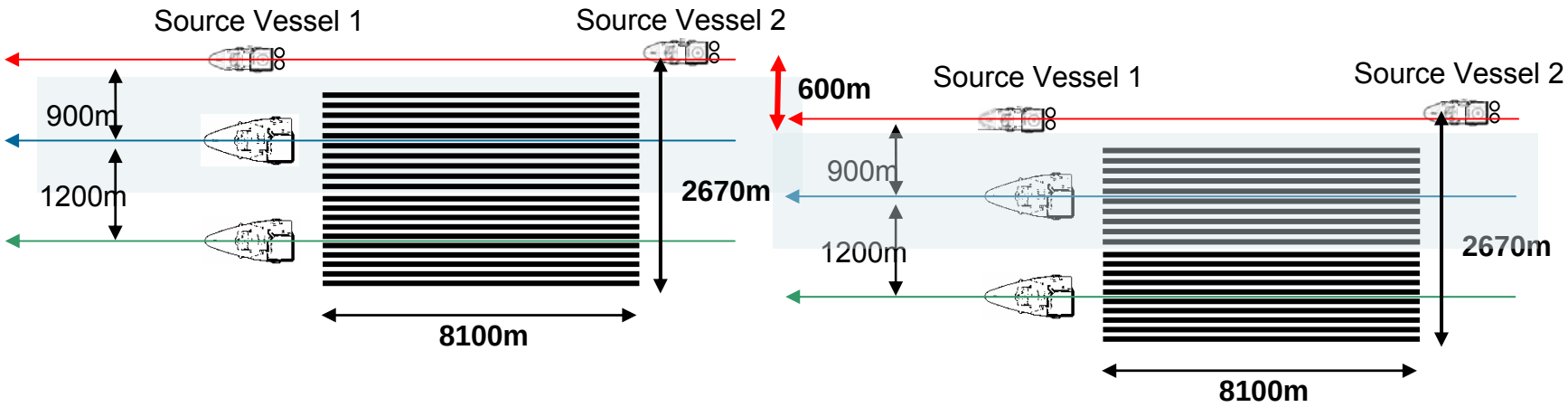
Second Sail-line
Near and Far Cross-line Passes



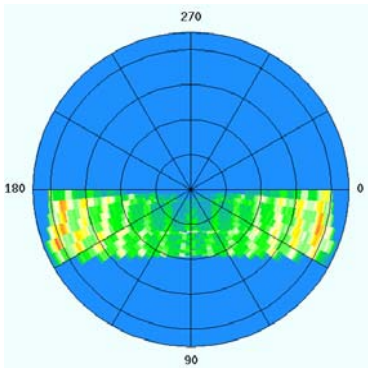
Wide Azimuth Geometry – Tile Template

First Sail-line
Near and Far Cross-line Passes

Second Sail-line
Near and Far Cross-line Passes



- **10 streamers, 8.1km length, 120m streamer separation**
- **2 dual sources each, 60.0m source separation**
  - **Front and Tail Source staggered**
  - **37.5m shot interval, 14 sec recording**
  - **Natural Acquisition bins 6.25m x 15.0m**
- **Source line separation 600m within each tile**

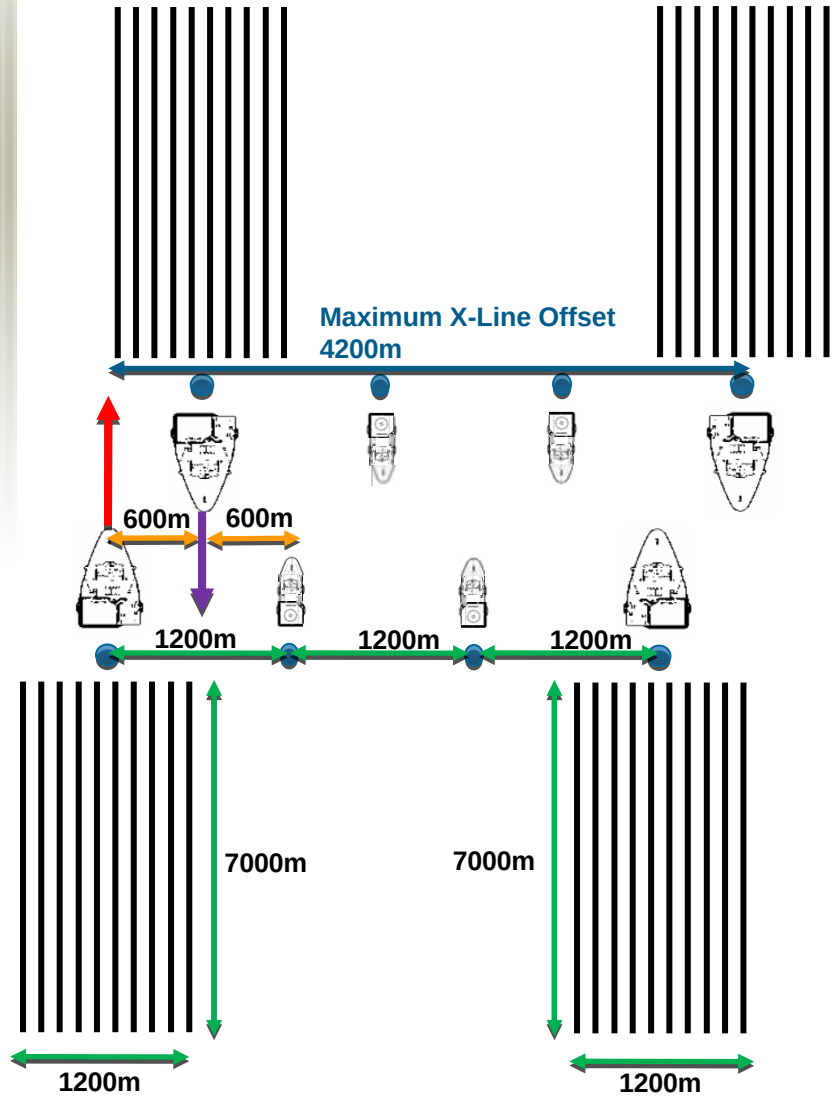


Subsurface Coverage

Nominal Fold 108 (6.25x30m)

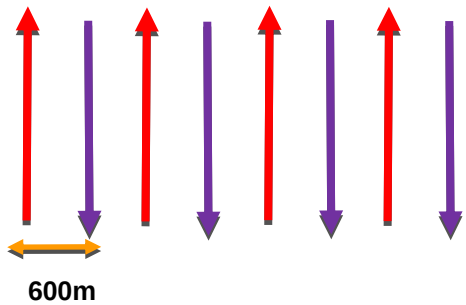
Cross-Line Fold : 2

Wide Azimuth Geometry - Dual Streamer Anti-parallel Template

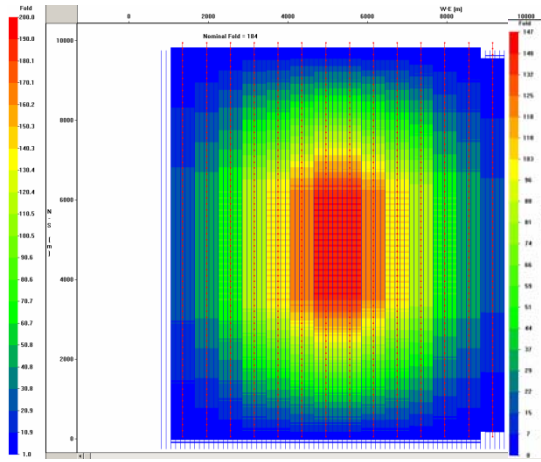


- 2x10 Streamers @120m
- Towing Depth 12m
- 4 single sources @ 9m
- 37.5m shot interval
- 14 sec recording
- Natural bin 6.25m x 60.0m
- Source line separation 600m

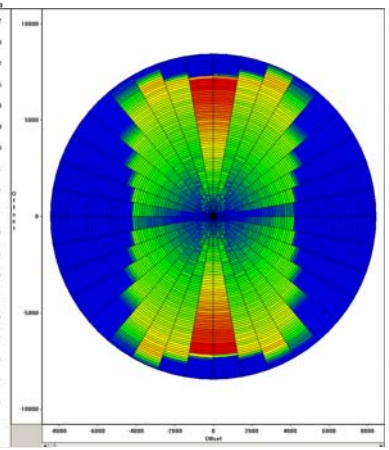
Shooting Pattern
600 m Separation
Antiparallel Directions



Fold



Offset-Azimuth Distribution

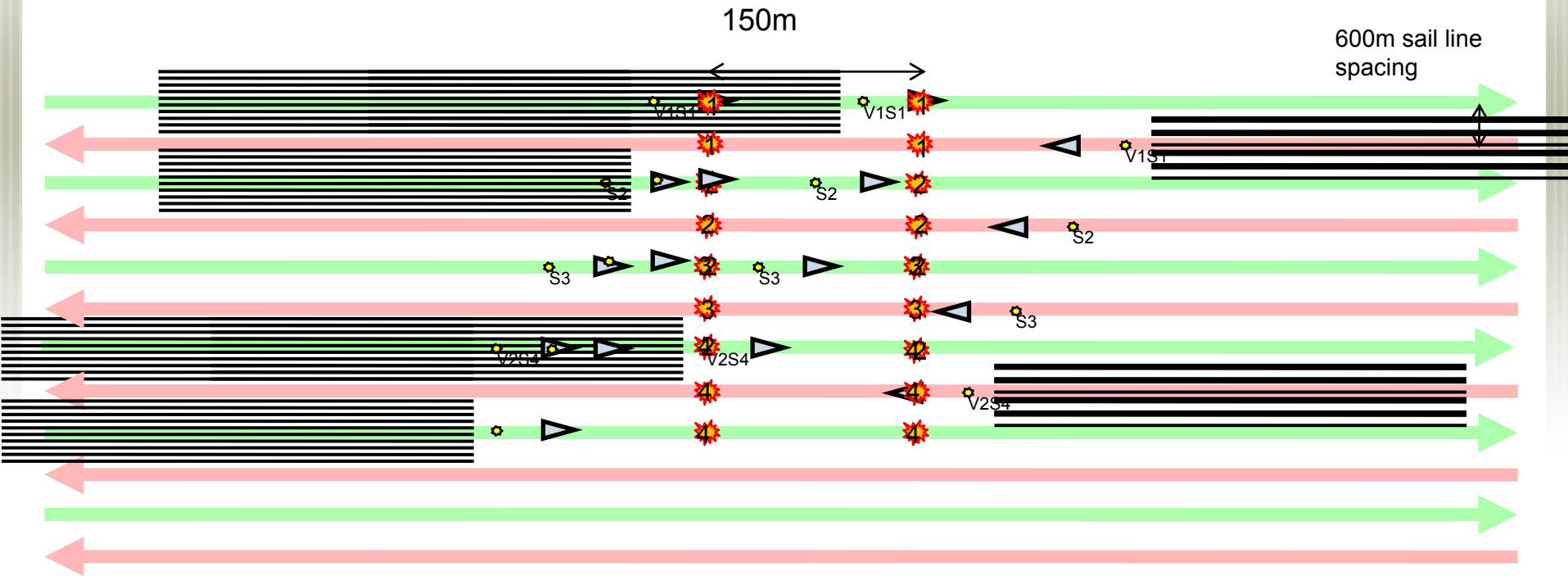


Subsurface Coverage

Nominal Fold 184 (6.25x60m)

Cross-Line Fold : 4

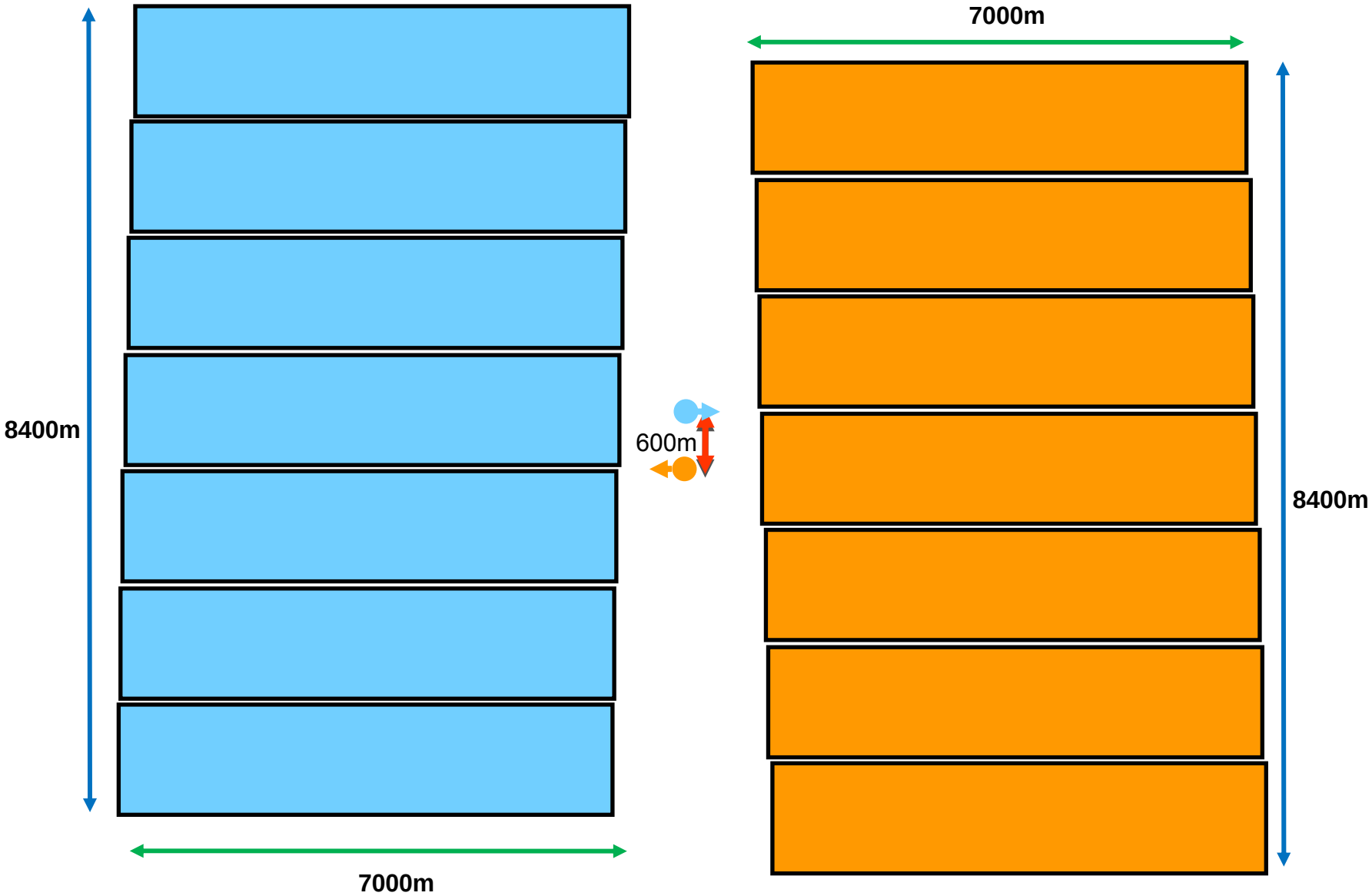
Crystal III WATS - Shooting Pattern (to be viewed in slide show) (not to scale)



Acquisition continues in this fashion so that each shot point is acquired 4 times i.e. once by each source vessel

This means that the data from each shot point can be gathered into super shots…

The SuperShot(s) or The Virtual Spread(s)



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- Some Aspects of Wide Azimuth Pre-Processing
- Data Examples
- Recent Developments
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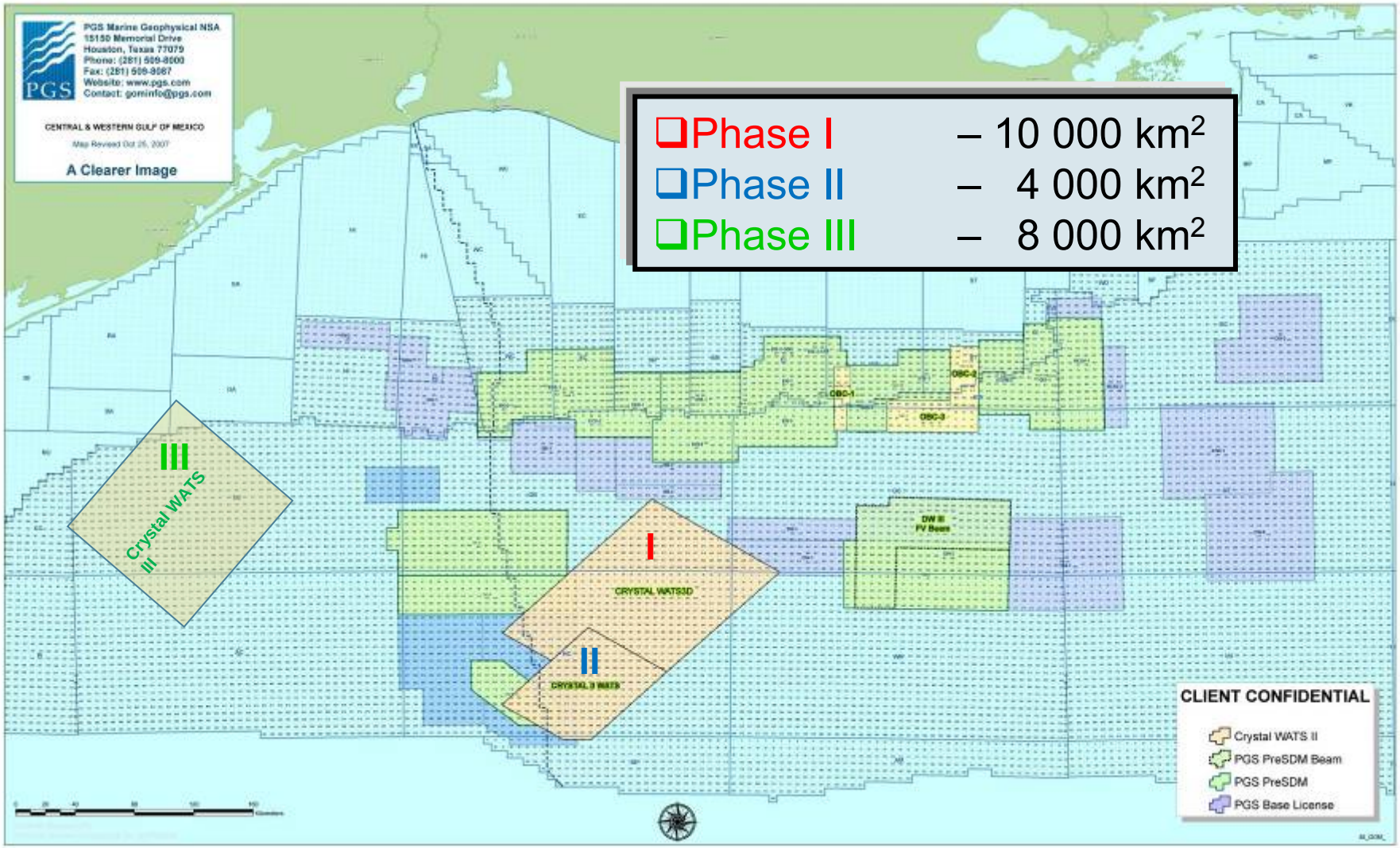
Crystal Surveys I,II,III – Gulf o Mexico



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Processing WATS Data

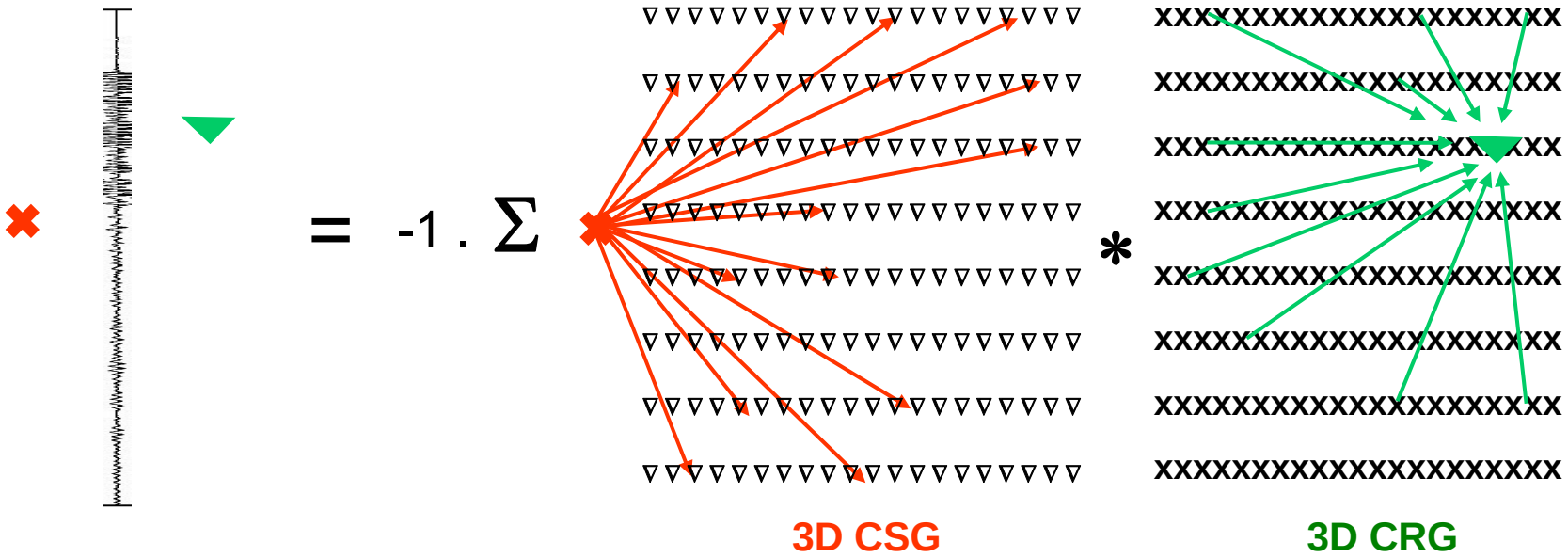
- Pre-processing
  - Source de-signature
  - De-bubble
  - Seismic interference attenuation
  - **True Azimuth 3DSRME**
  - Enhanced High Density Radon de-multiple
  - MDA
  - Water column statics

- **Velocity Depth Model Building**
  - **True Azimuth Tomography**

- Migration
  - Beam
  - Kirchhoff
  - Implicit Finite Difference – One Way
  - Reverse Time Migration

True-azimuth 3-D Surface-Related Multiple Prediction

For an arbitrary *source and receiver pair* (with azimuth) …



… 3D multiples are predicted by convolving 3D common shot gathers with 3D common receiver gathers at all ‘multiple contributions’ and summing the results!

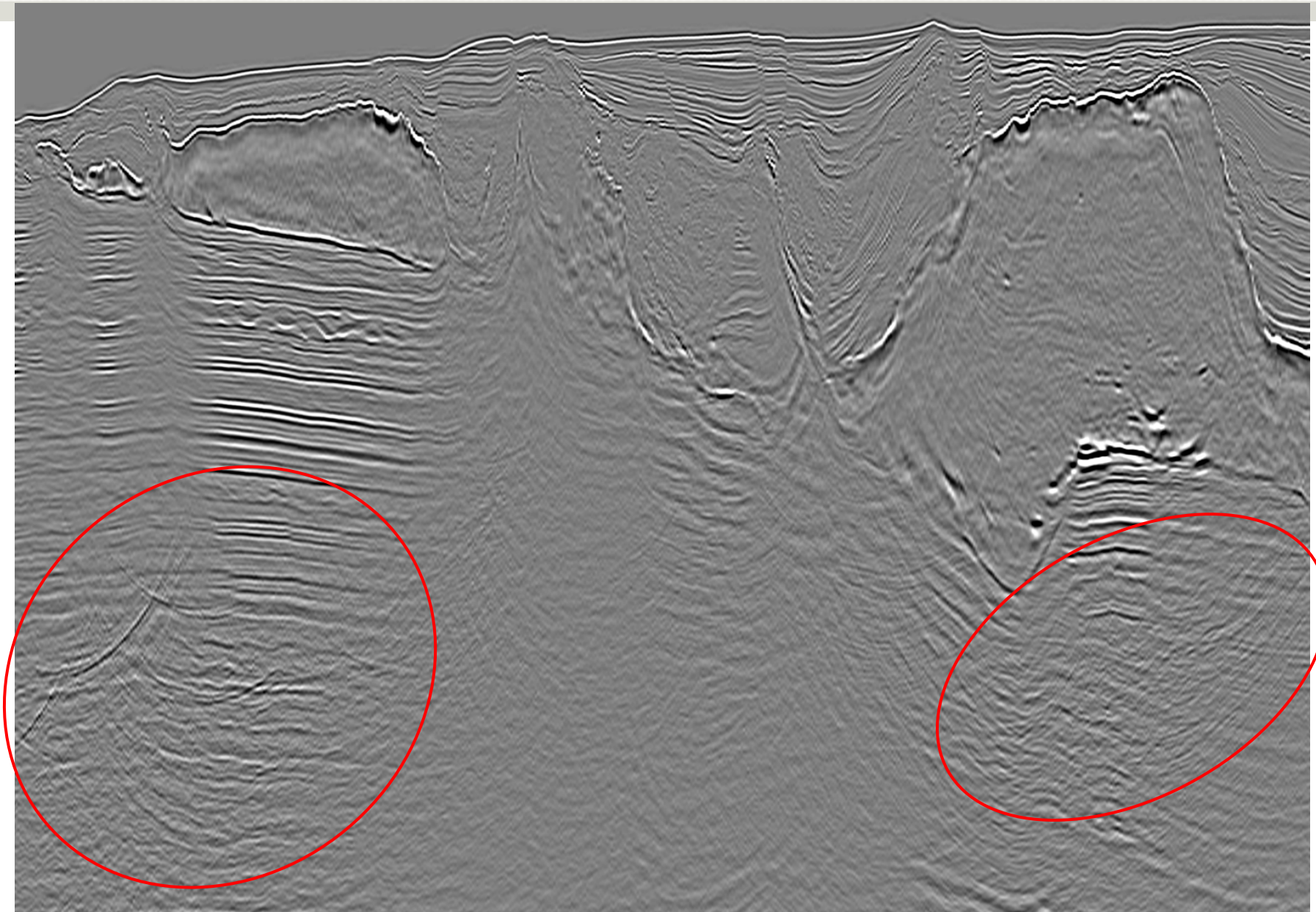
True-azimuth 3-D Surface-Related Multiple Prediction

The challenge in True-Azimuth 3-D SRME is to overcome

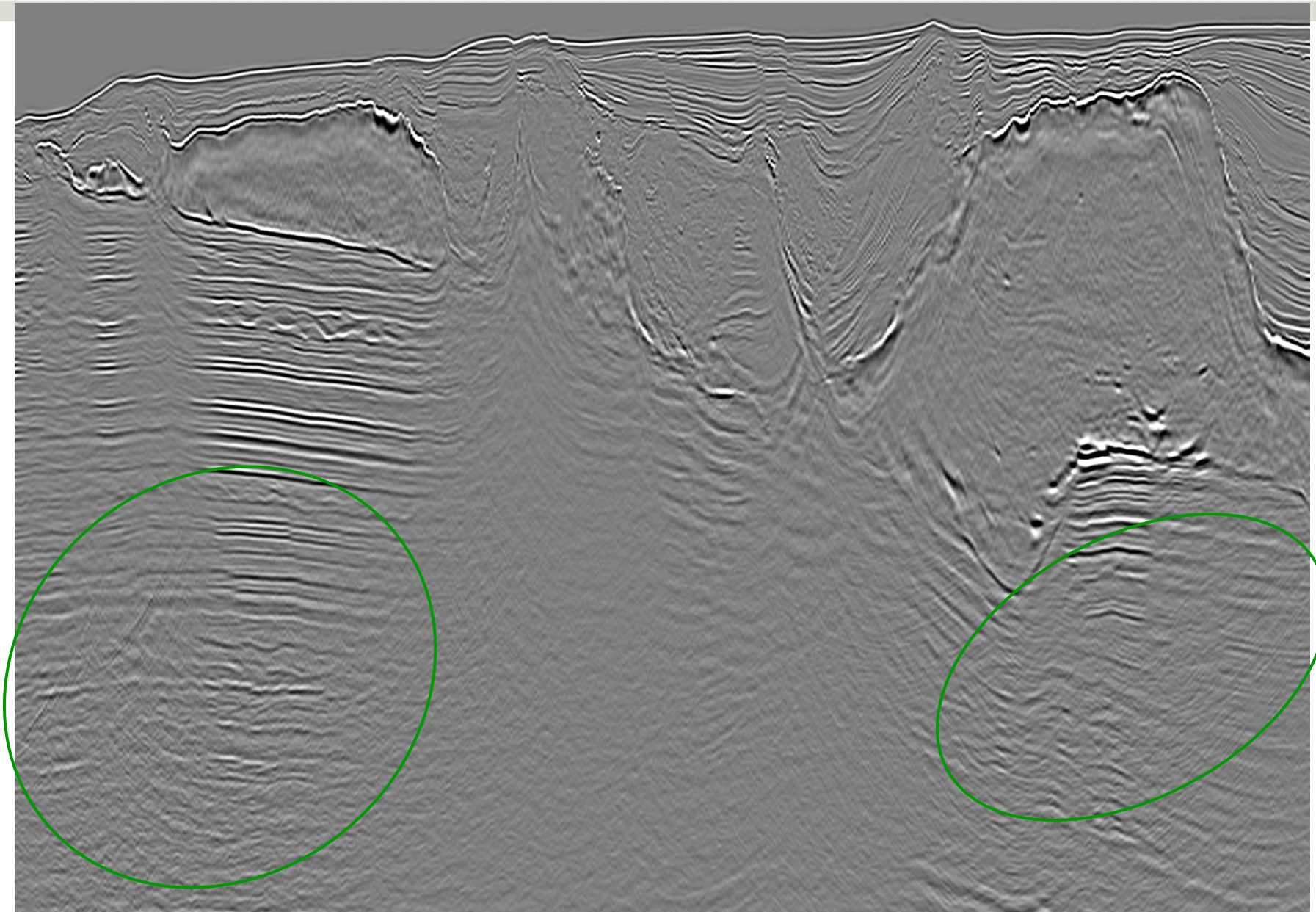
- The coarse sampling of cross-line sources & receivers
- The limited cross-line aperture of the receivers

using 3-D data reconstruction schemes.

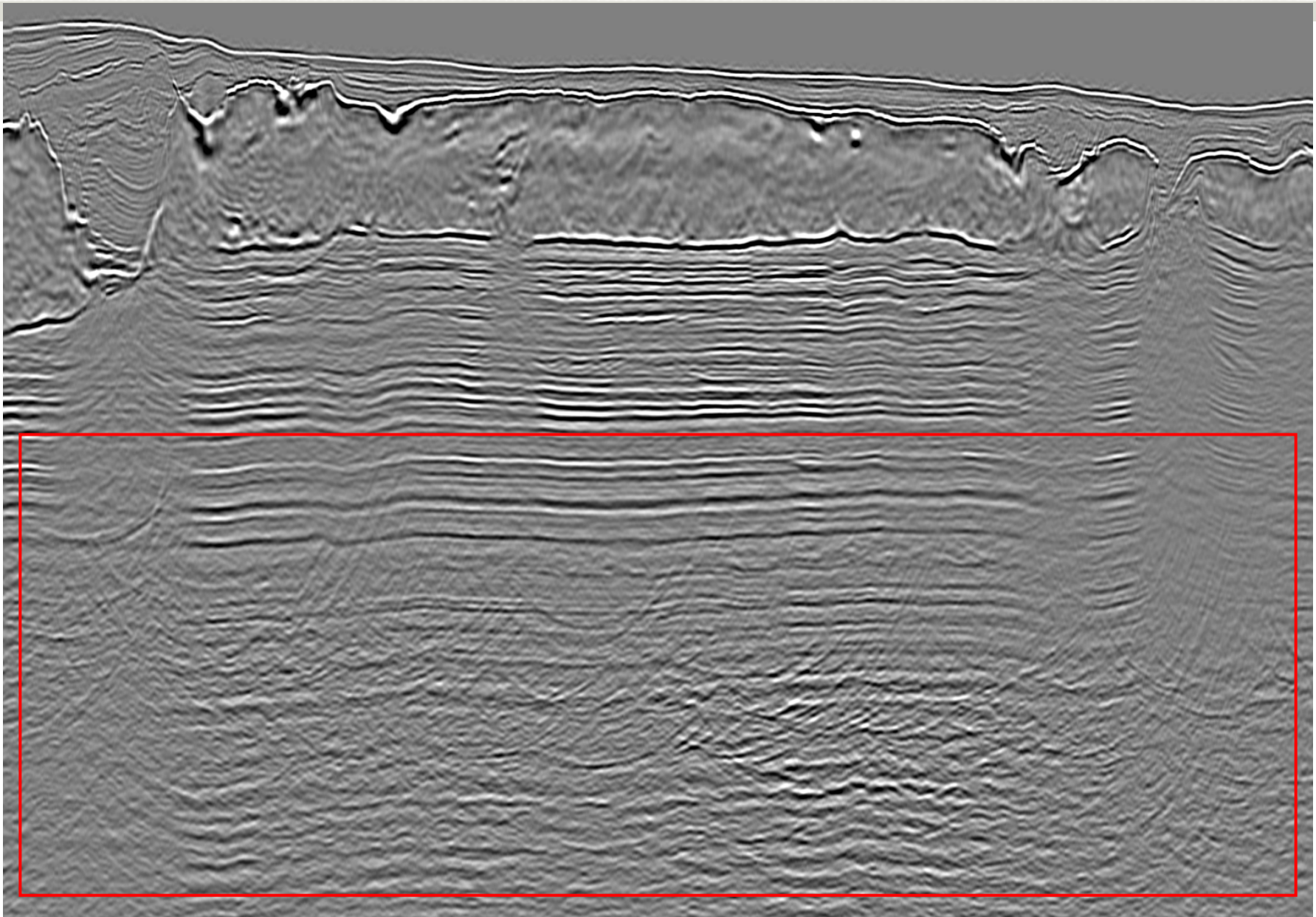
Crystal WATS: Radon only KPSDM Inline



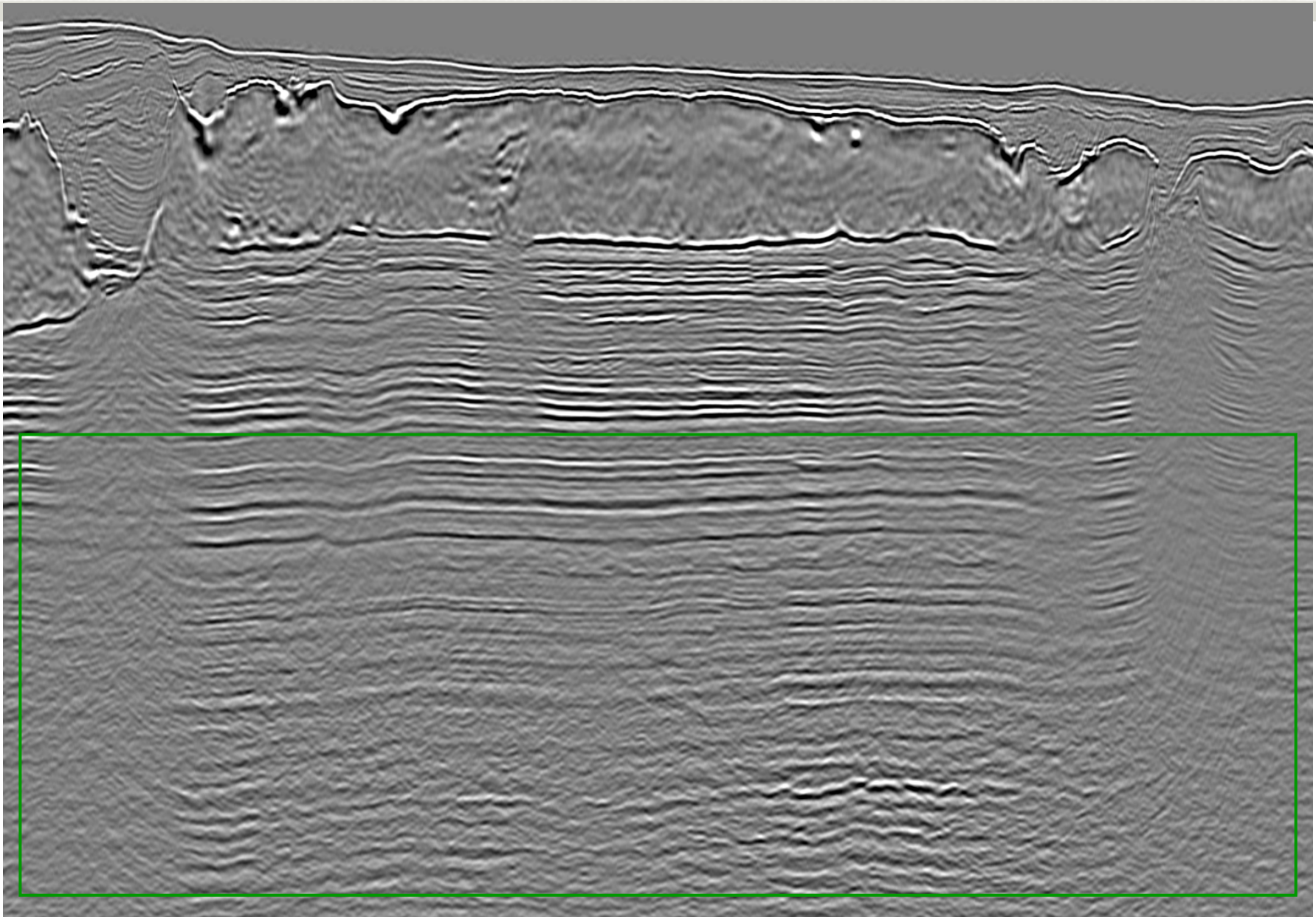
Crystal WATS: TA 3D SRME + Radon KPSDM Inline



Crystal WATS: Radon only KPSDM Xline

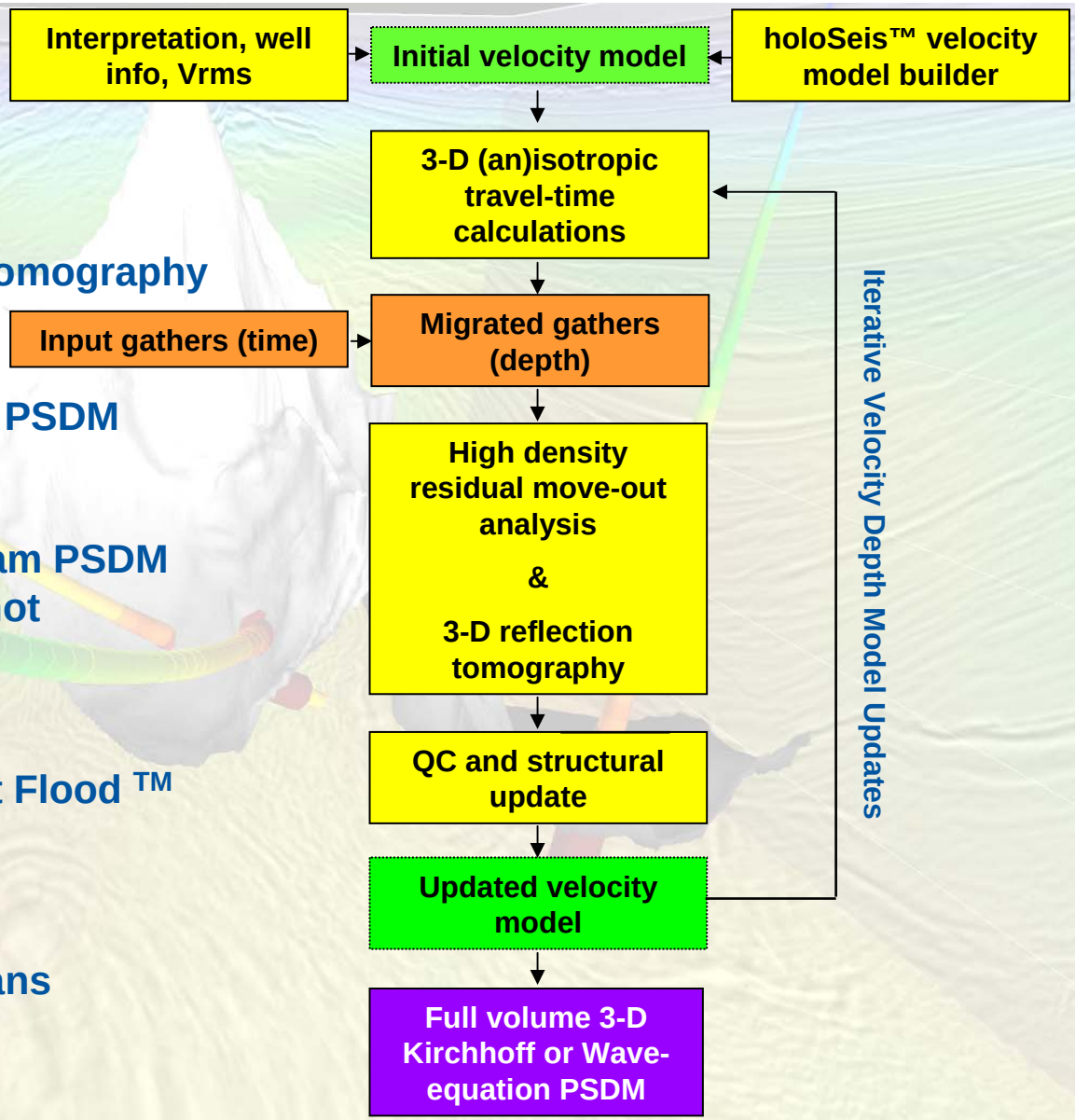


Crystal WATS: TA 3D SRME + Radon KPSDM Xline

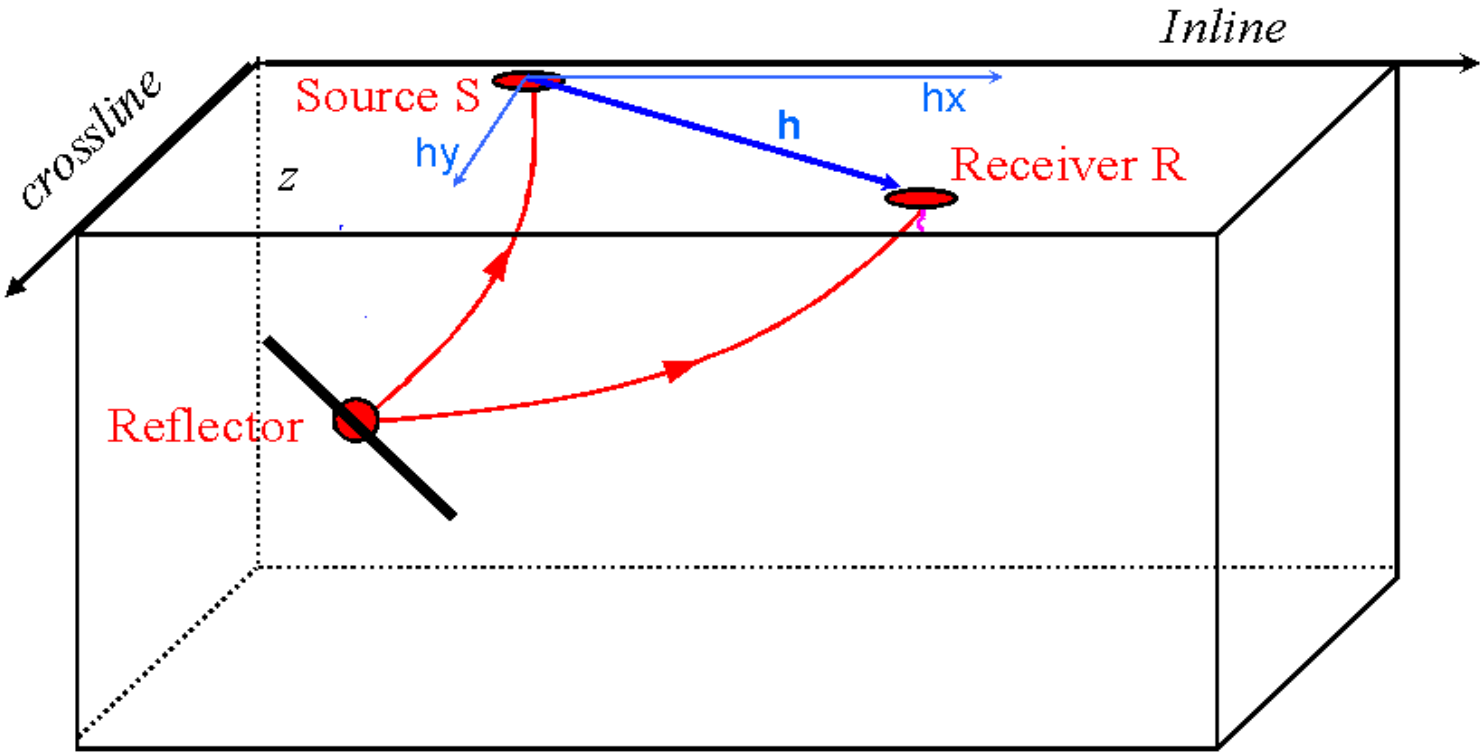


Velocity Depth Model Building

- Initial Velocity Depth Model
- Overburden
  - High Density Grid Based Tomography
- Top Salt Interpretation
  - Kirchhoff PSDM and Beam PSDM
- Salt Flood
  - Turning Ray-Kirchhoff, Beam PSDM
  - Wavefield Extrapolation Shot Migrations
- Salt Overhang Modeling
  - Using Beam PSDM – Smart Flood ™
- Sub-Salt Velocity Analysis
  - Subsalt-Tomography
  - WEM Sub-Salt Velocity Scans



Connecting the Acquisition Geometry to the Migrated Data



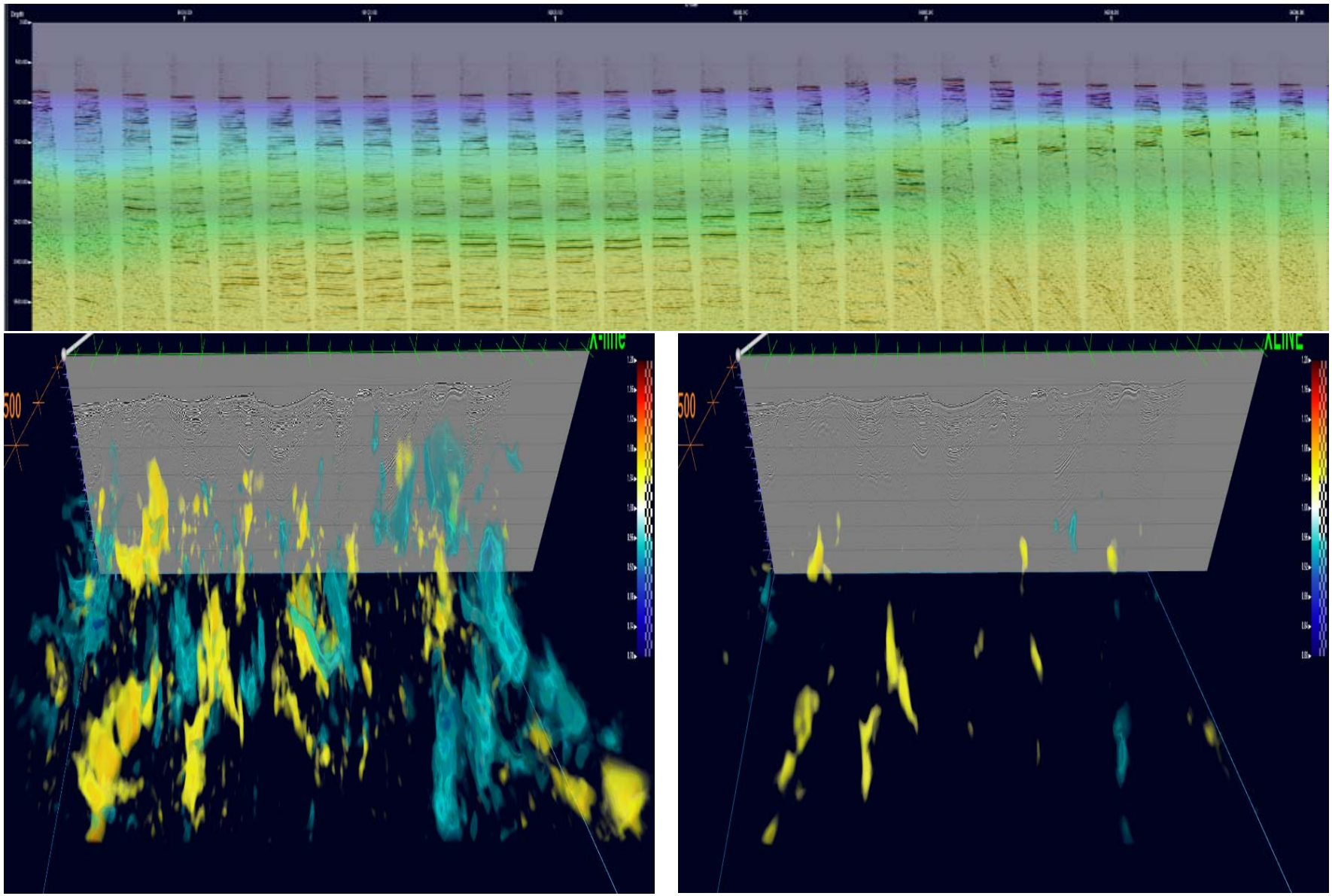
Input data binned in common vector offset

Geometry information (sx, sy, gx, gy, cvobin) of input data are stored in migration step and used in tomography

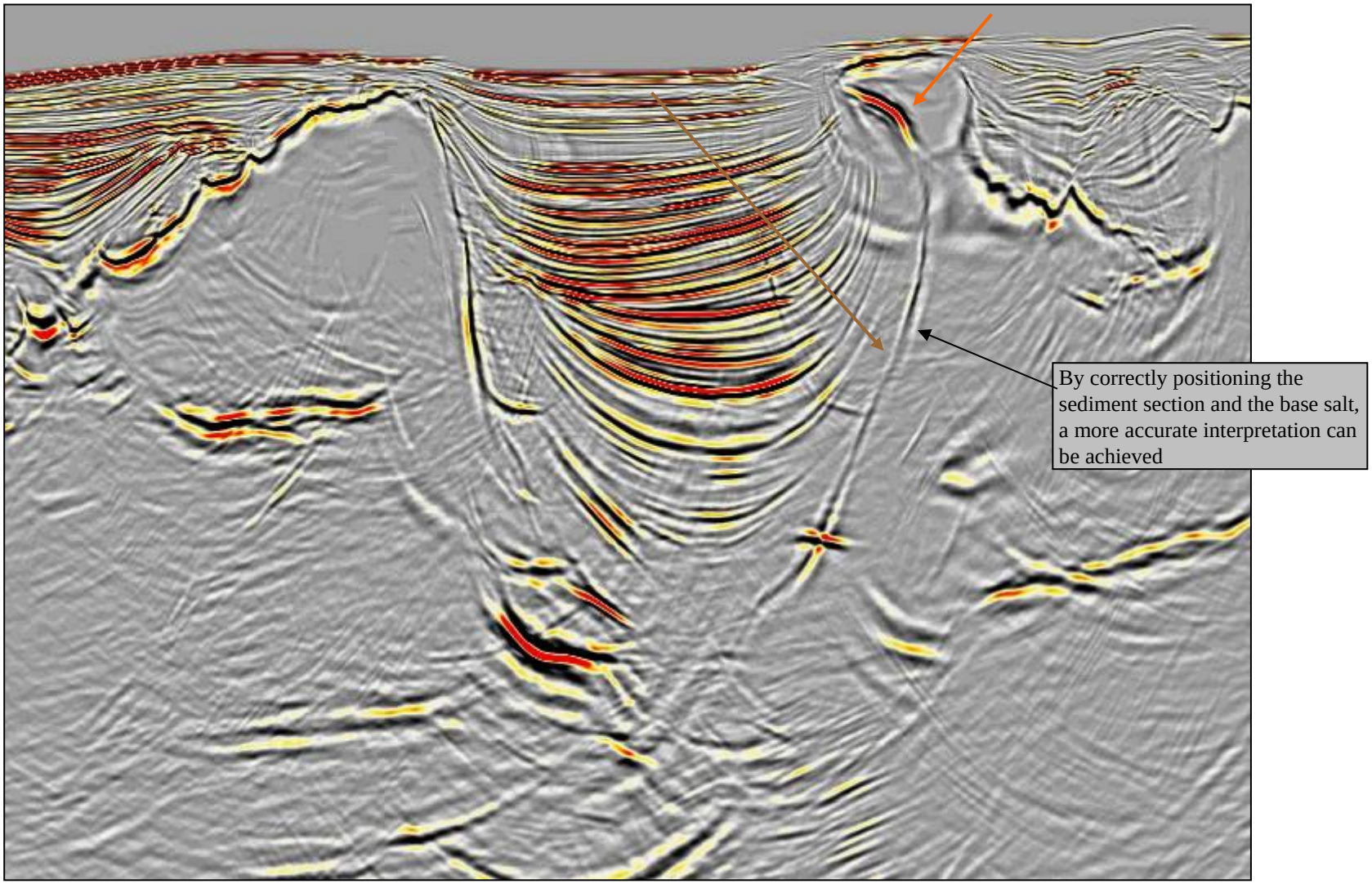
True Azimuth Tomography

- Input from either FastBeam or Kirchhoff migrations
- Operates on vector offsets; can handle NAZ, MAZ and WATS
- Multi-parameter RMO or direct Δz picking on gathers
- Uses acquisition geometry to connect migrated data with input data
- Inversion by pre-conditioned conjugate gradient solver

Crystal WATS – CRP gathers – 1st iteration / 3rd iteration



SmartFlood™ data – Gulf of Mexico



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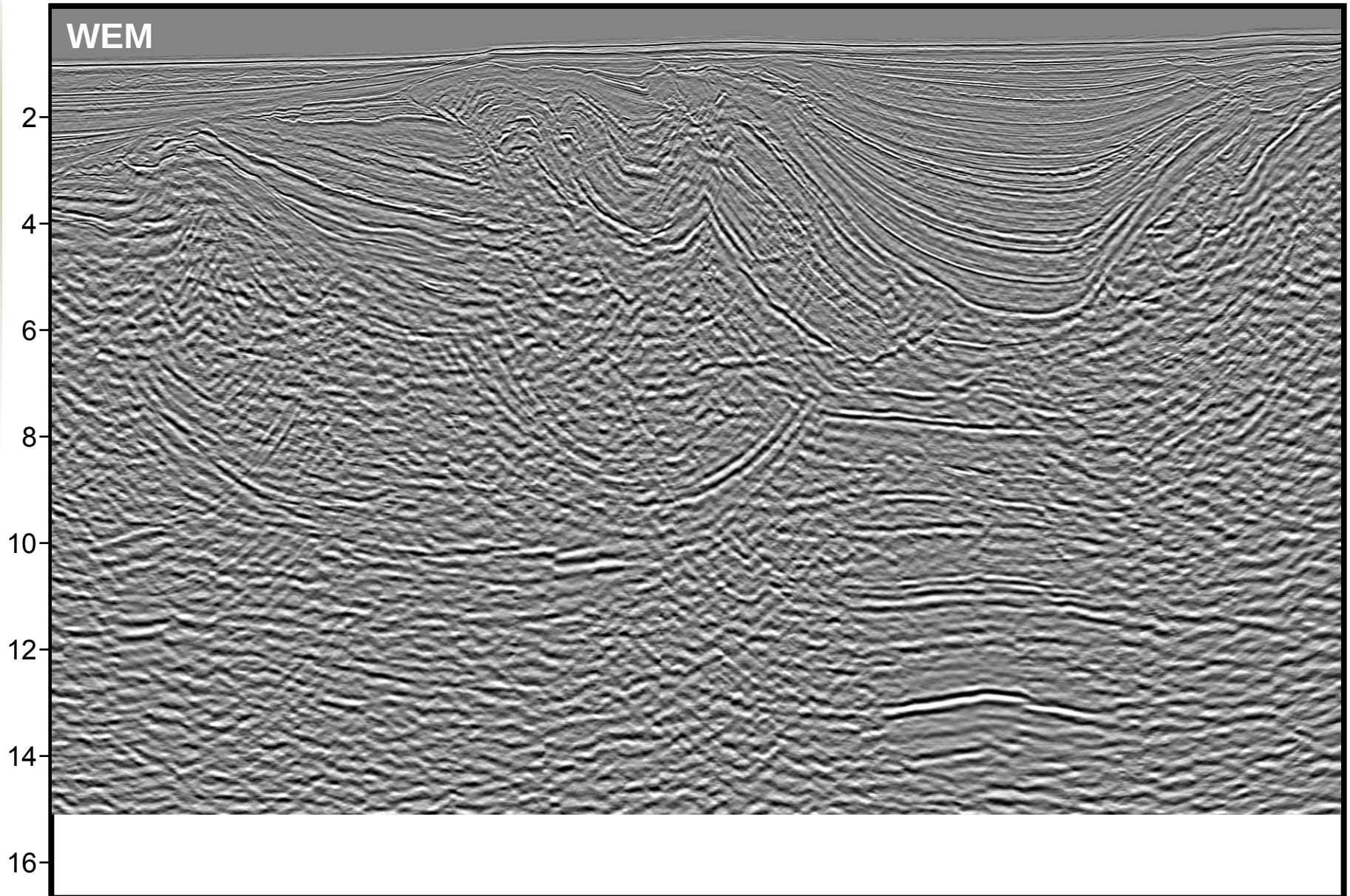
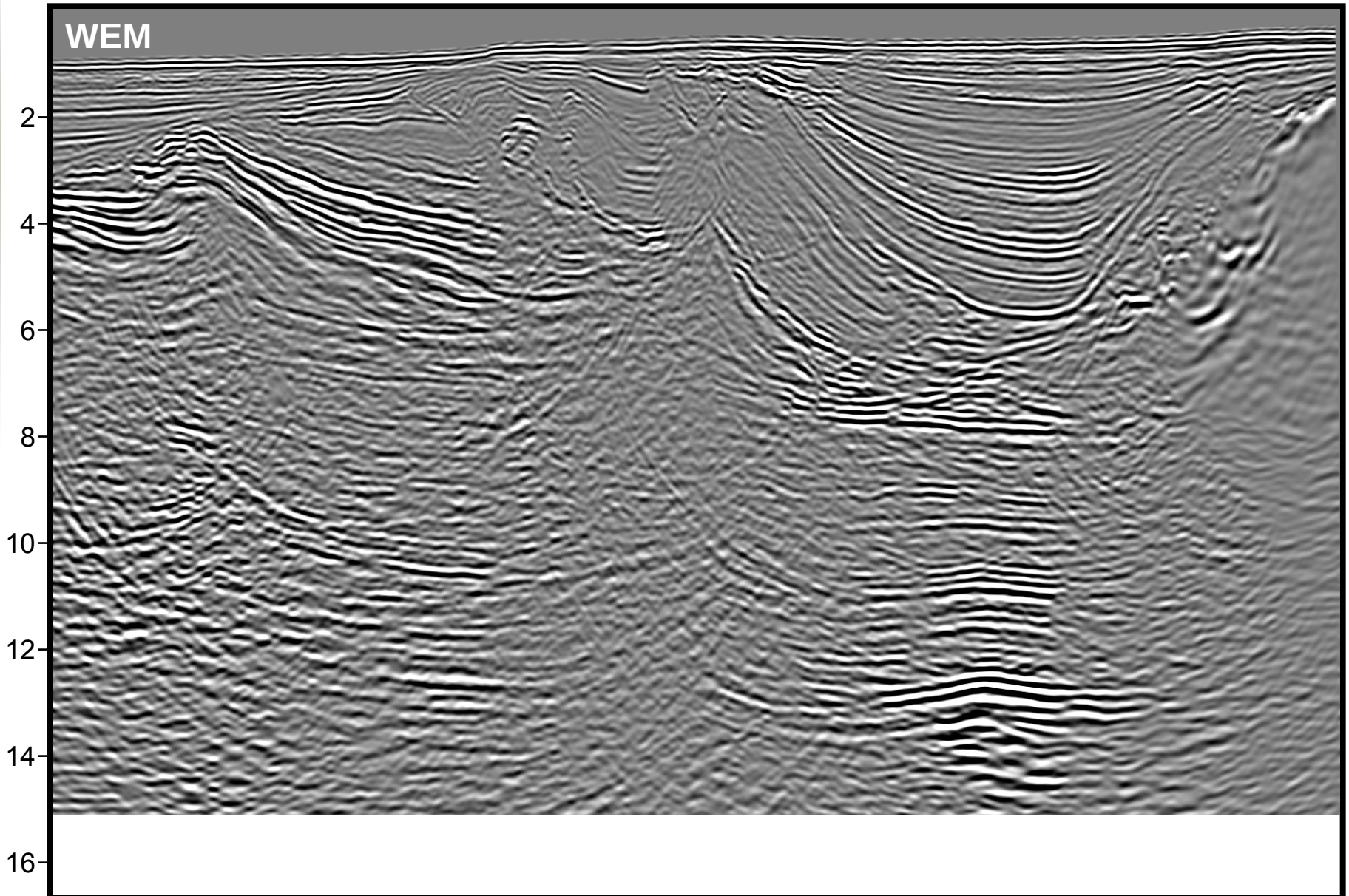
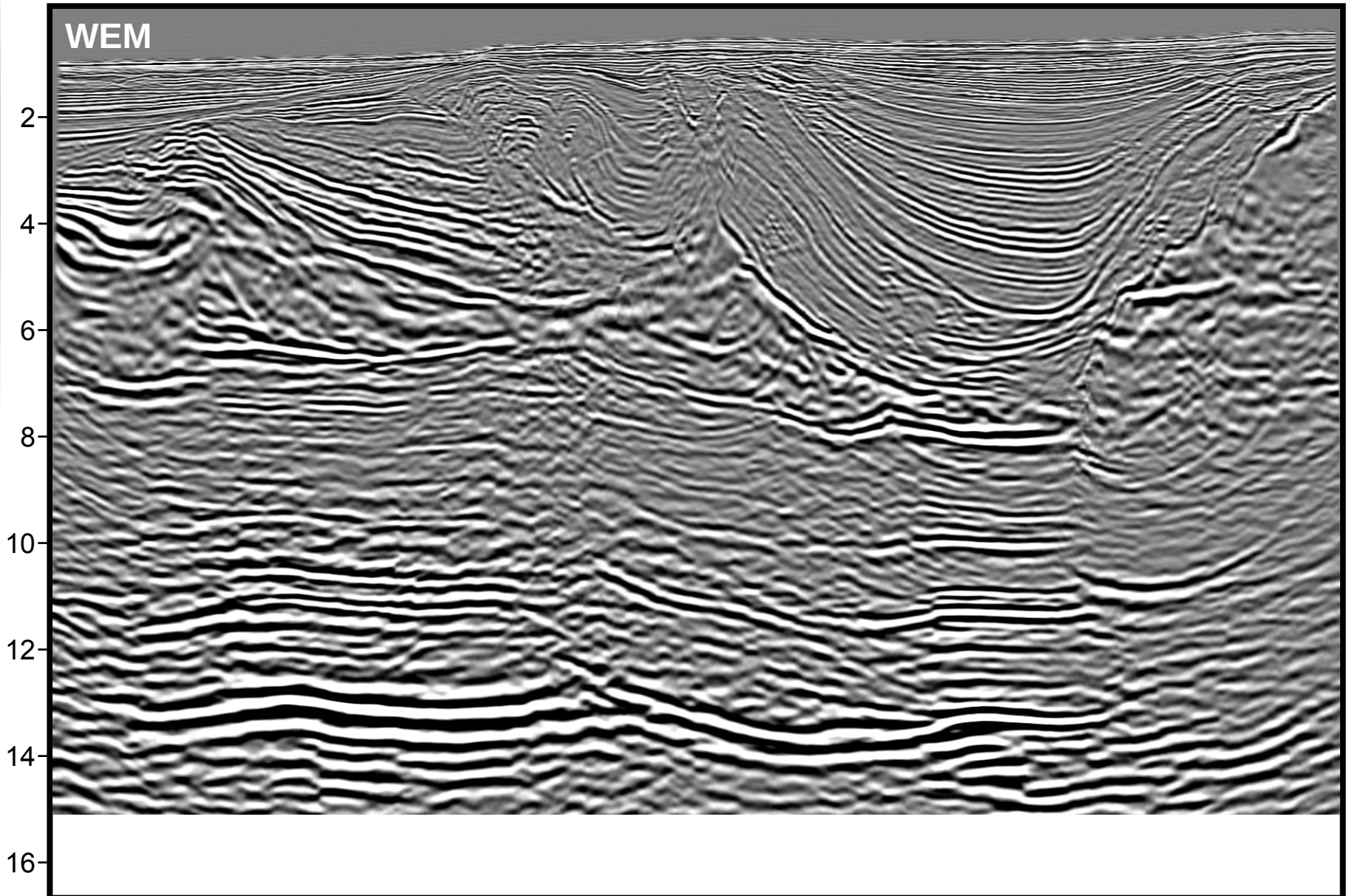
Legacy Narrow Azimuth Data



Wide Azimuth Data using NATS model - Fasttrack

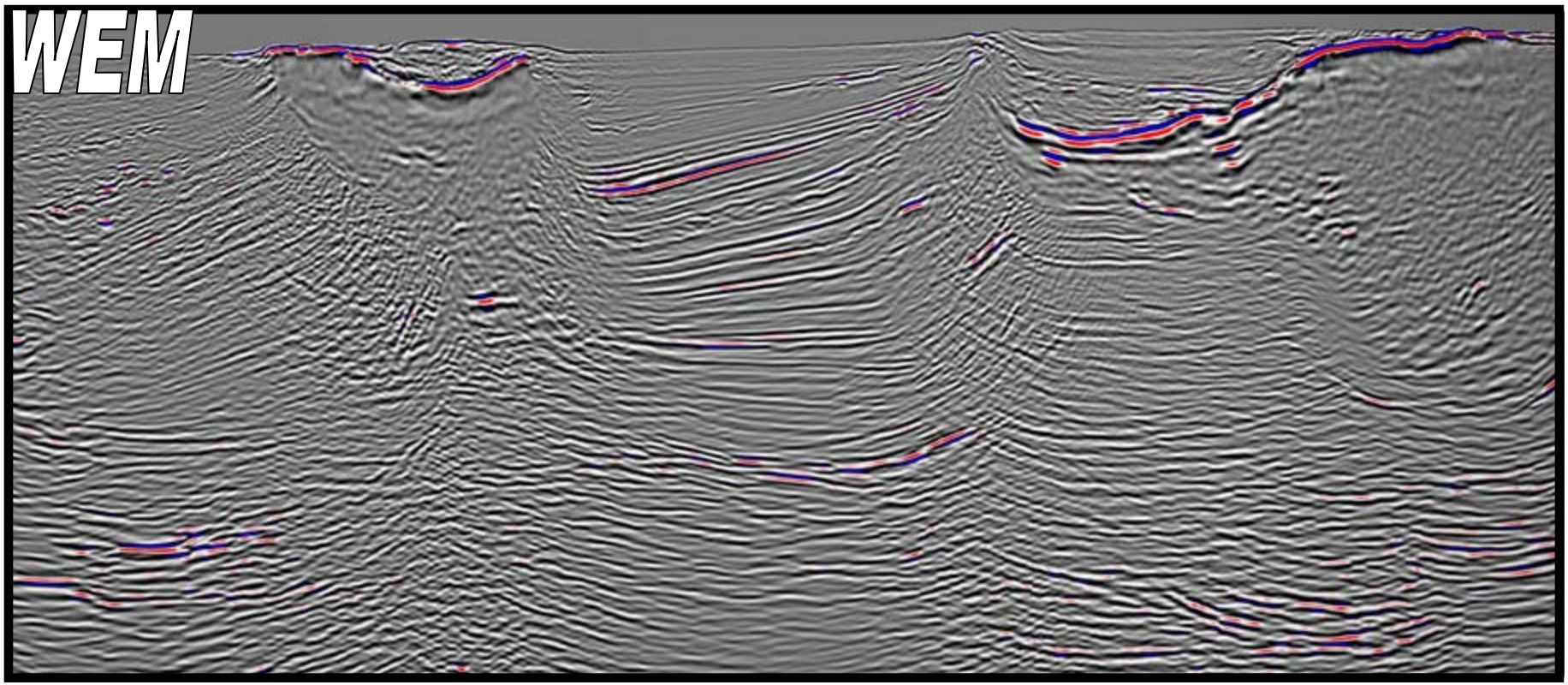


Wide Azimuth Data using WATS model



Further improvement

– Use of Reverse Time Migration
– Inclusion of Anisotropic information in the subsurface model



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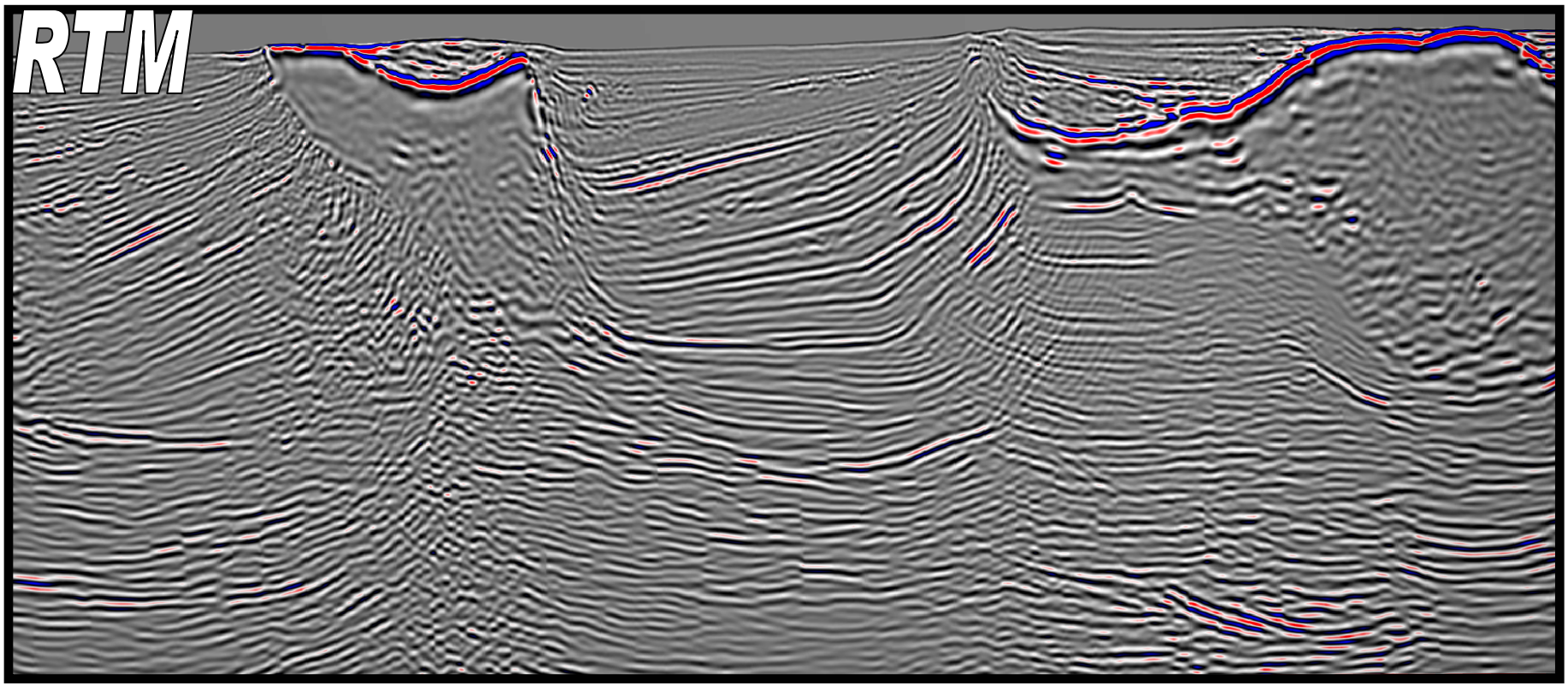

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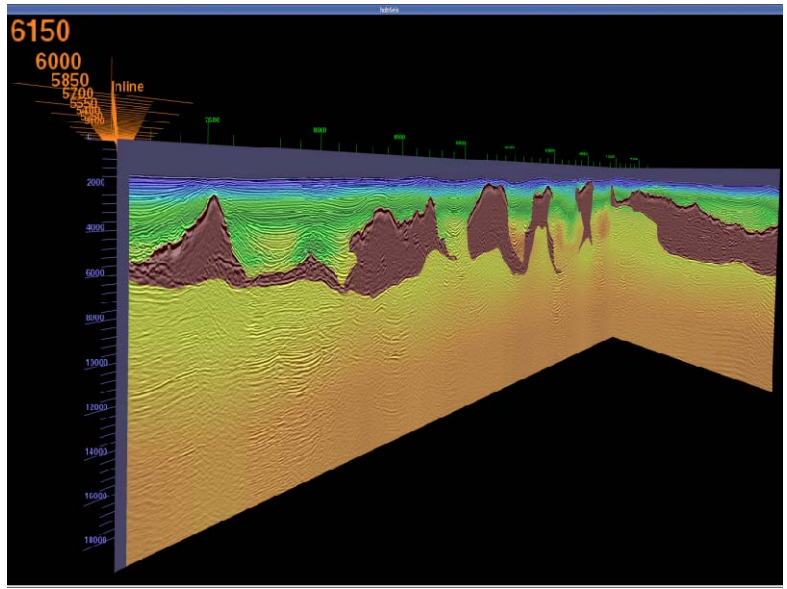
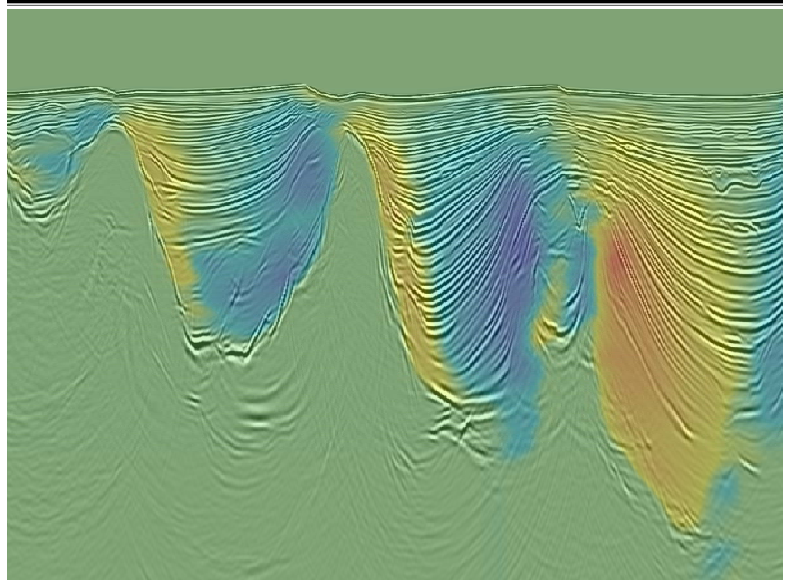
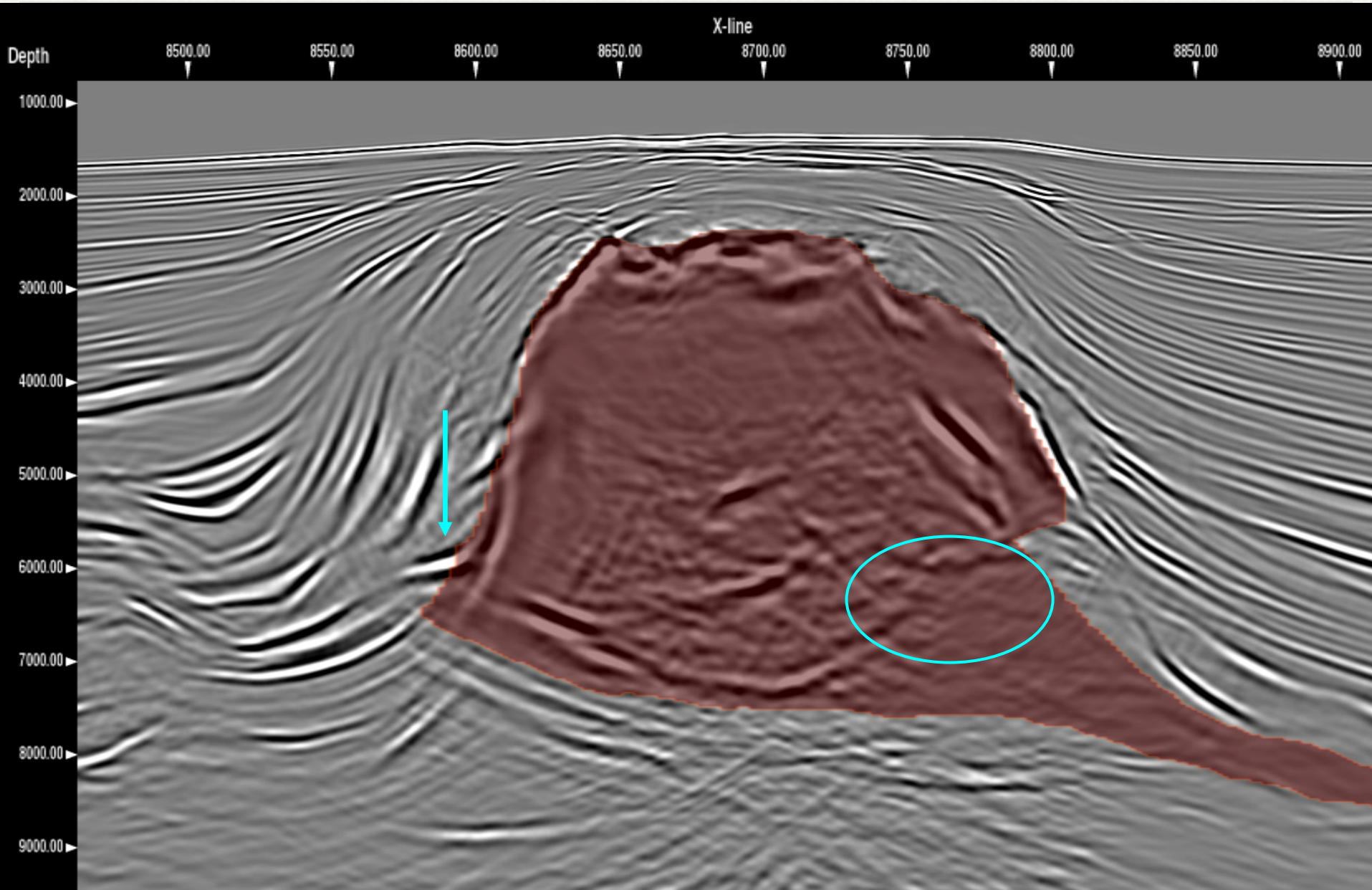
Current State of the Art Imaging Flow (2010)

- **Pre-processing;**
  - Source designation & de-bubble
  - Noise attenuation
  - True Azimuth 3DSRME
  - Enhanced HR Radon demultiple
  - Multiple Diffraction Attenuation
  - Water column statics
- **Velocity Depth Model Building;**
  - TTI sediment overburden modelling
  - True Azimuth Tomography
  - Multiple Salt body definition
  - Sub-Salt velocity analysis
- **Final Imaging;**
  - TTI RTM
  - TTI Beam

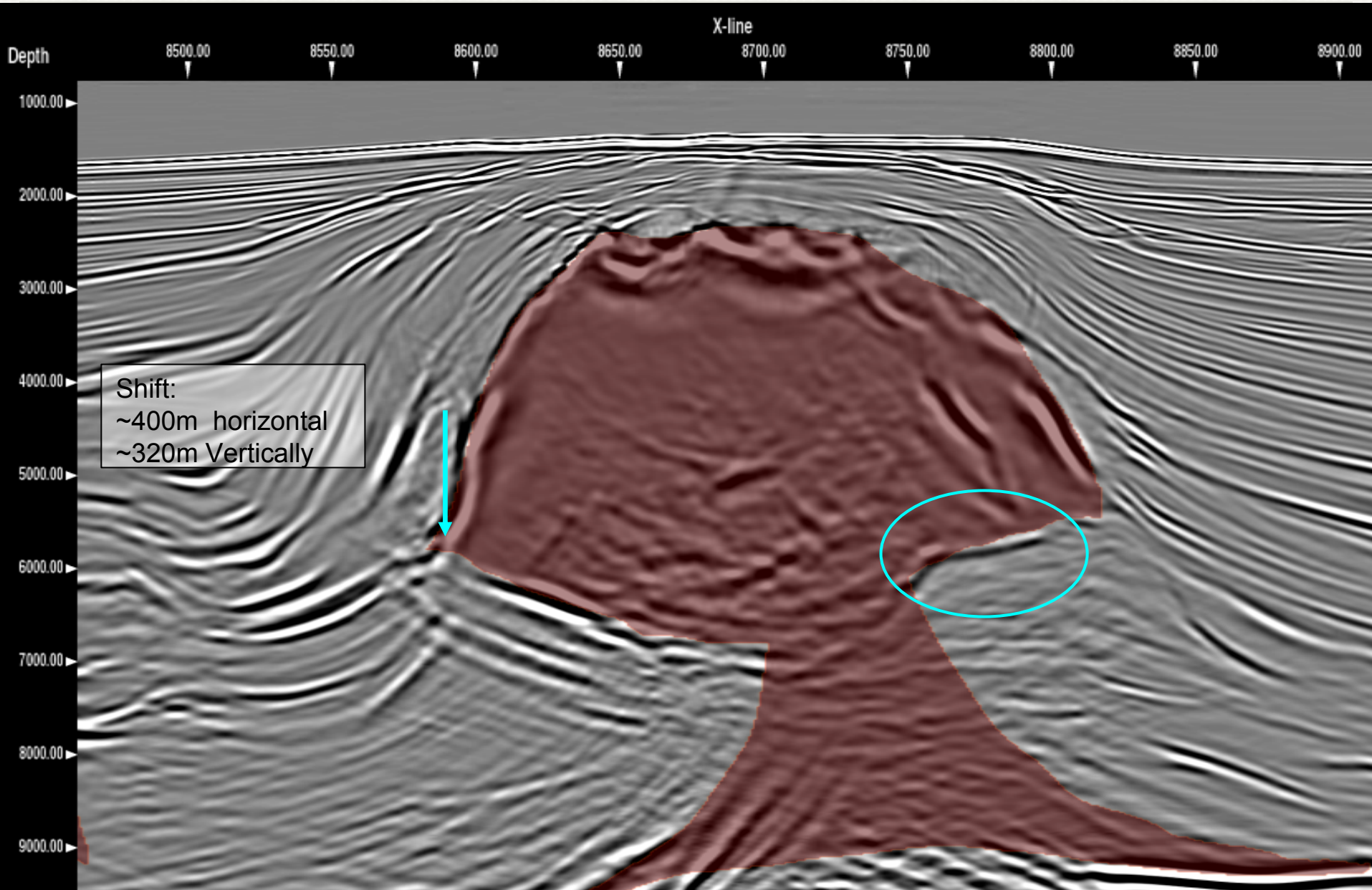




Isotropic RTM – Crystal WATS



TTI RTM – Crystal WATS



Conclusions

- Compared to Conventional Data Wide Azimuth has delivered
  - Improved illumination
  - Better multiple suppression
  - Better signal-to-noise ratio
- A Wide Azimuth Processing Flow includes
  - Wide Azimuth Tomography (TTI Compliant)
  - Wide Azimuth SRME
  - TTI Compliant Imaging using
    - Beam for fast model building
    - WEM
    - RTM for final image

Acknowledgements

- Thanks to PGS for permission to present the paper
- Finding Petroleum
- Many colleagues in PGS for their contribution

and

Thank You for Your Attention !