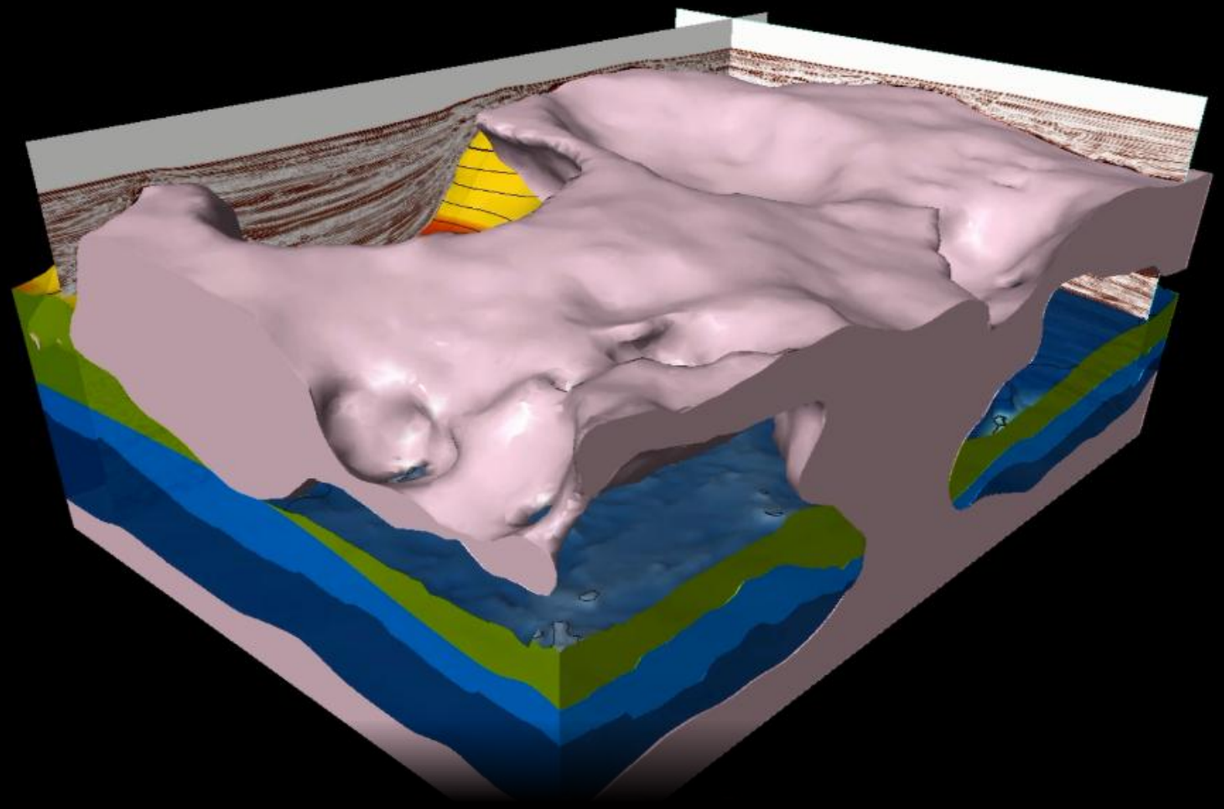
Subsalt seismic imaging; Recent advances and the way forward



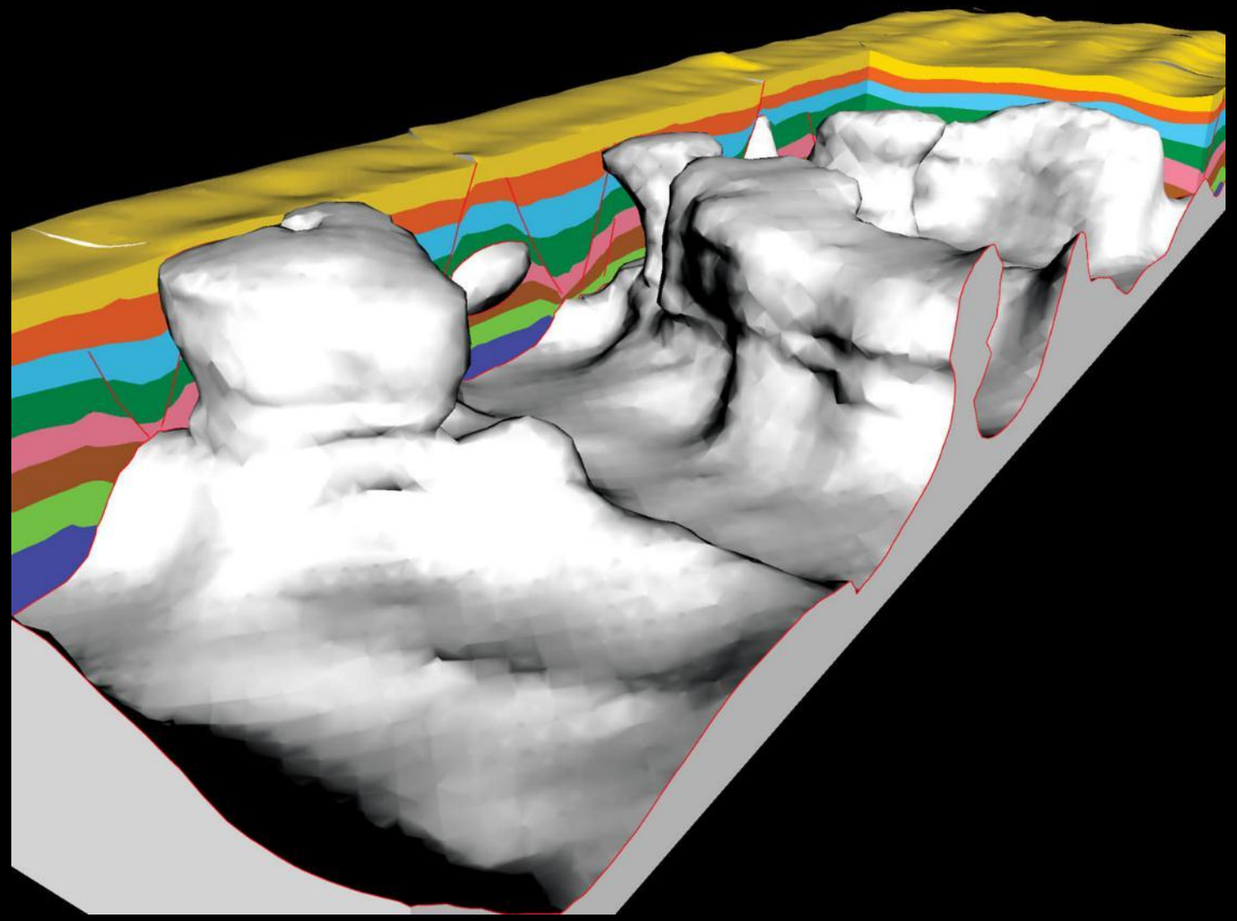
Presented by Tim Brice, WesternGeco

Contributors: Jerry Kapoor, Nick Moldoveanu, Chris Cunnell, Stuart Papworth, Denis Vigh

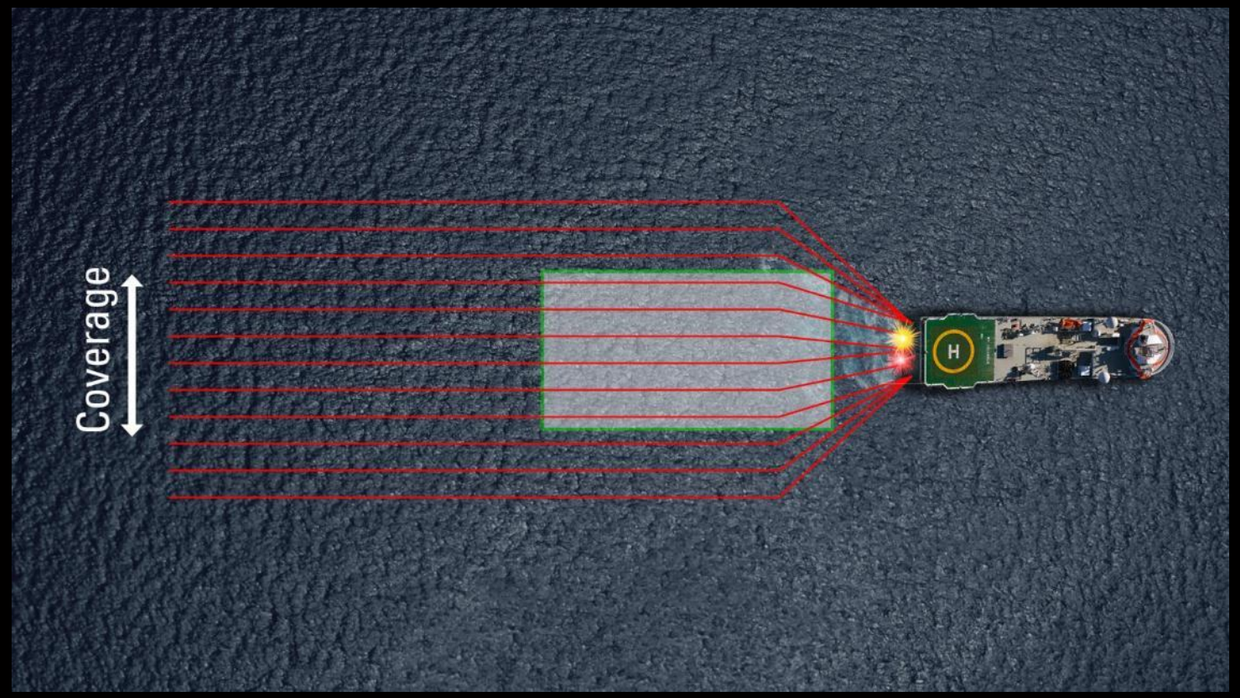
WesternGeco

Outline

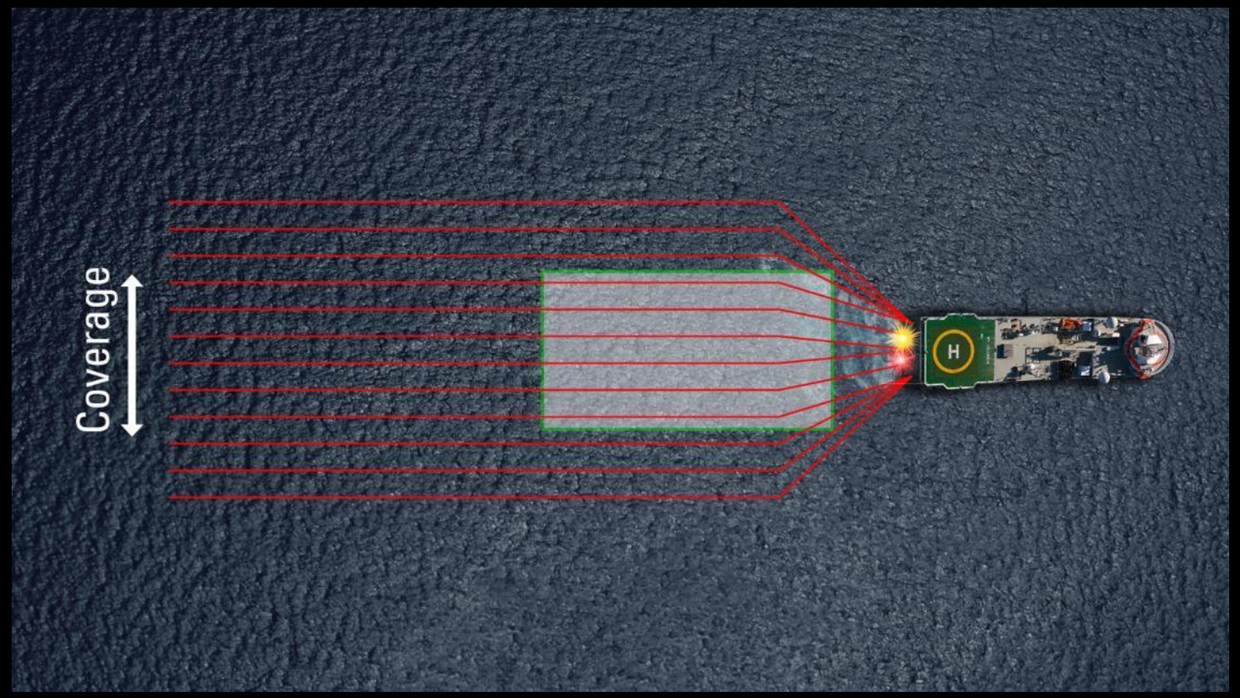
- Recent advances
  - Acquisition technology
  - Processing/imaging technology
- Nordkapp Basin survey
- The way forward

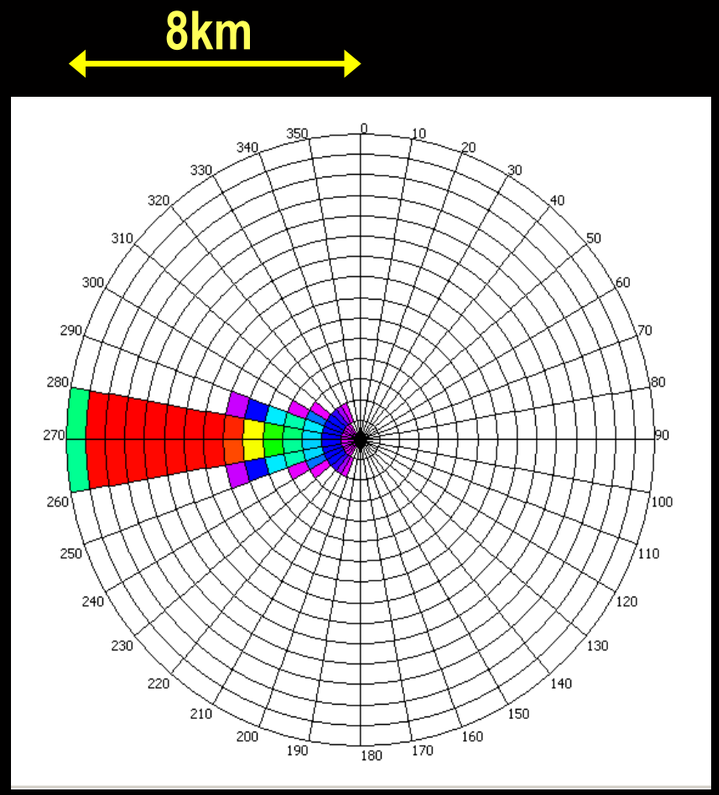


Marine towed streamer acquisition



Streamer acquisition offset and azimuth

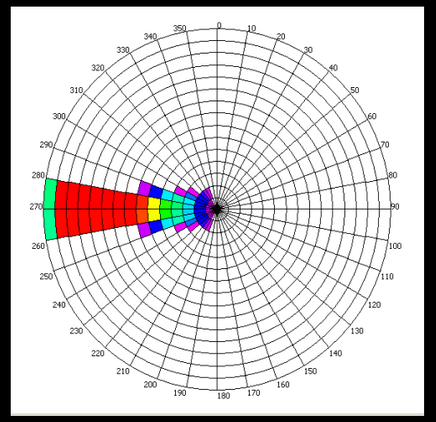




Seismic data acquisition designs azimuth and offset

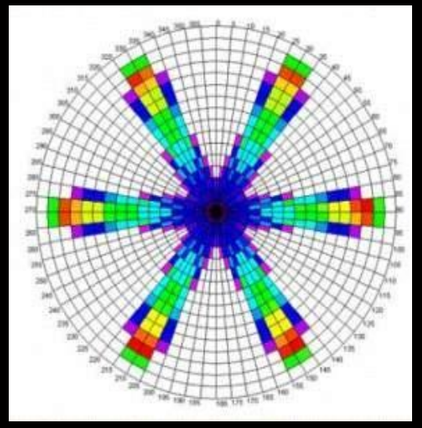
Narrow Azimuth

NAZ Pre 2005



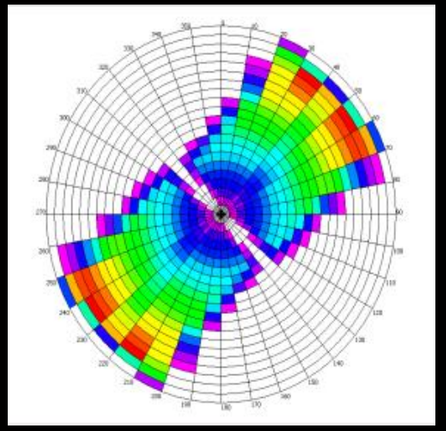
Multi Azimuth

MAZ Pre 2005



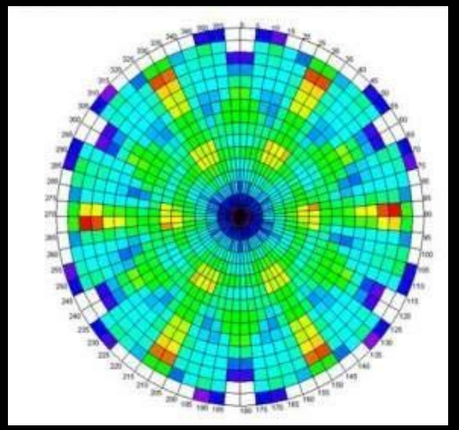
Wide Azimuth

WAZ 2005



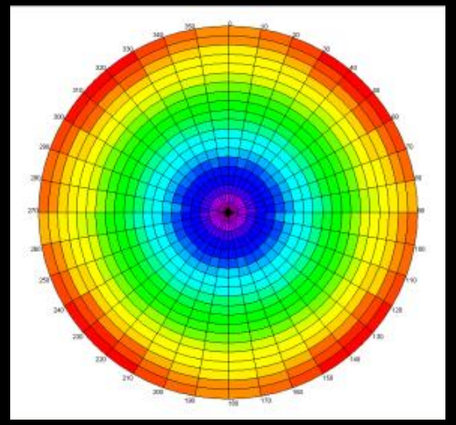
Rich Azimuth

RAZ 2006

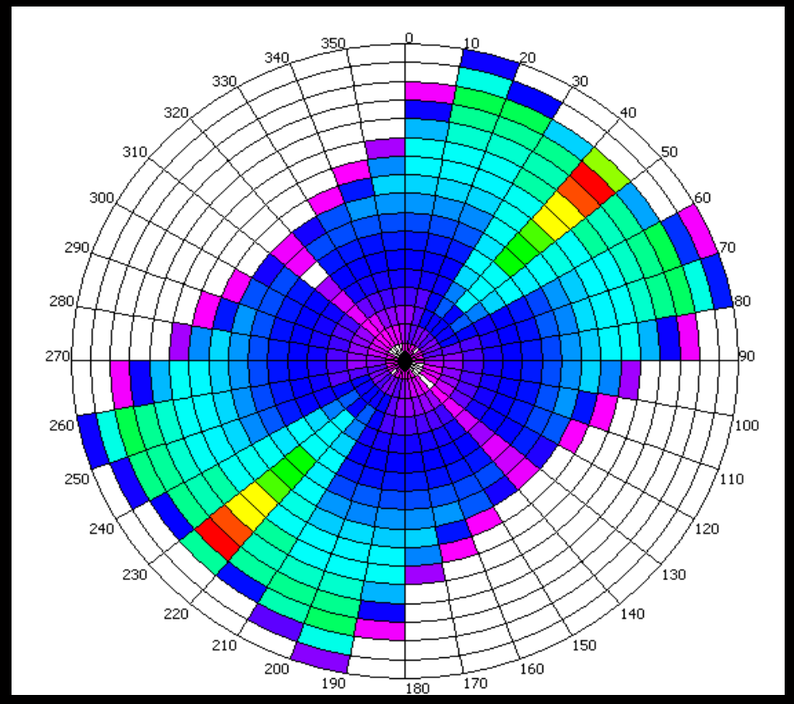


Full Azimuth

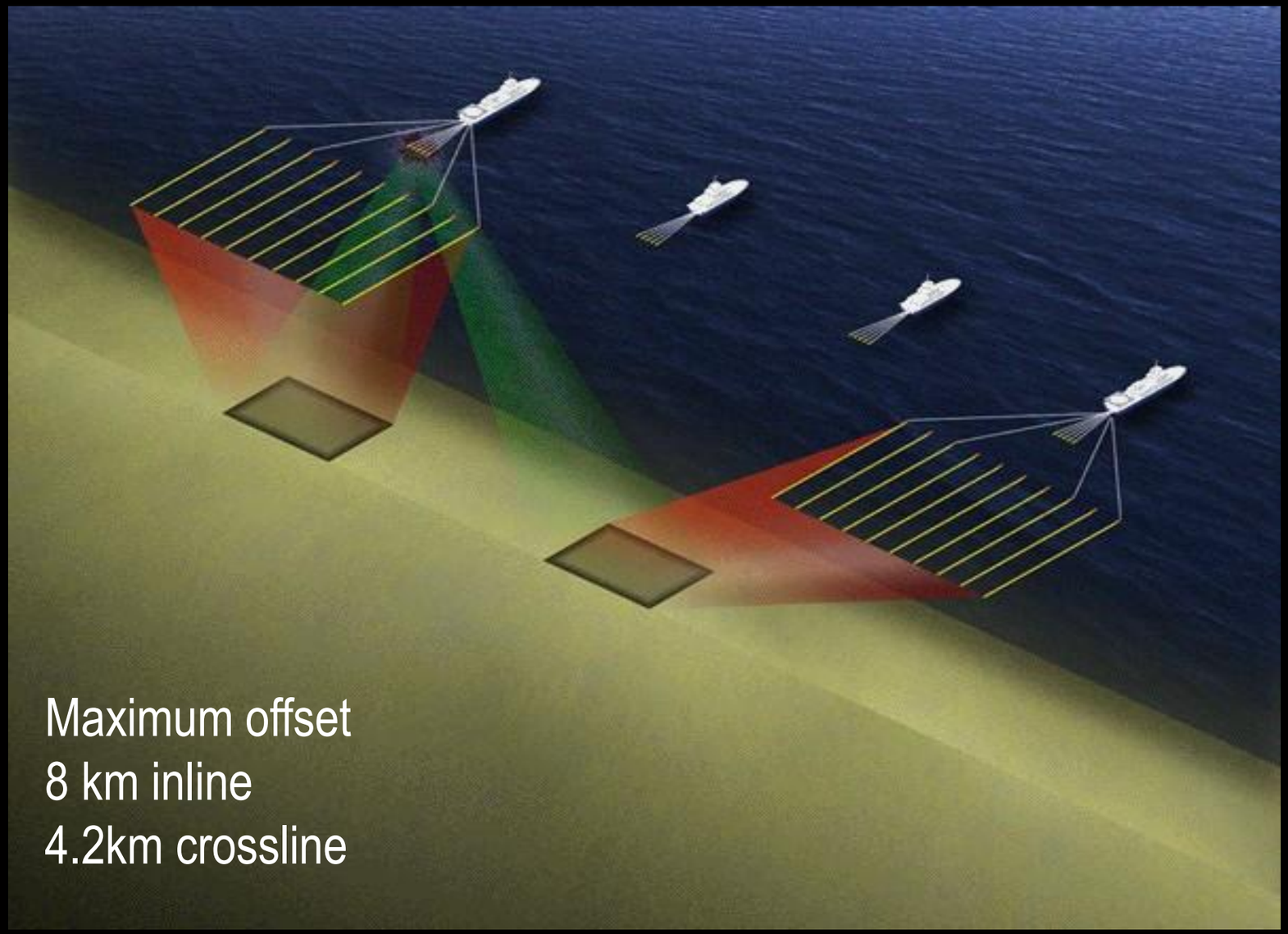
FAZ 2009



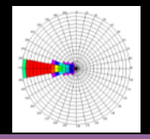
Parallel acquisition geometries for wide azimuth acquisition

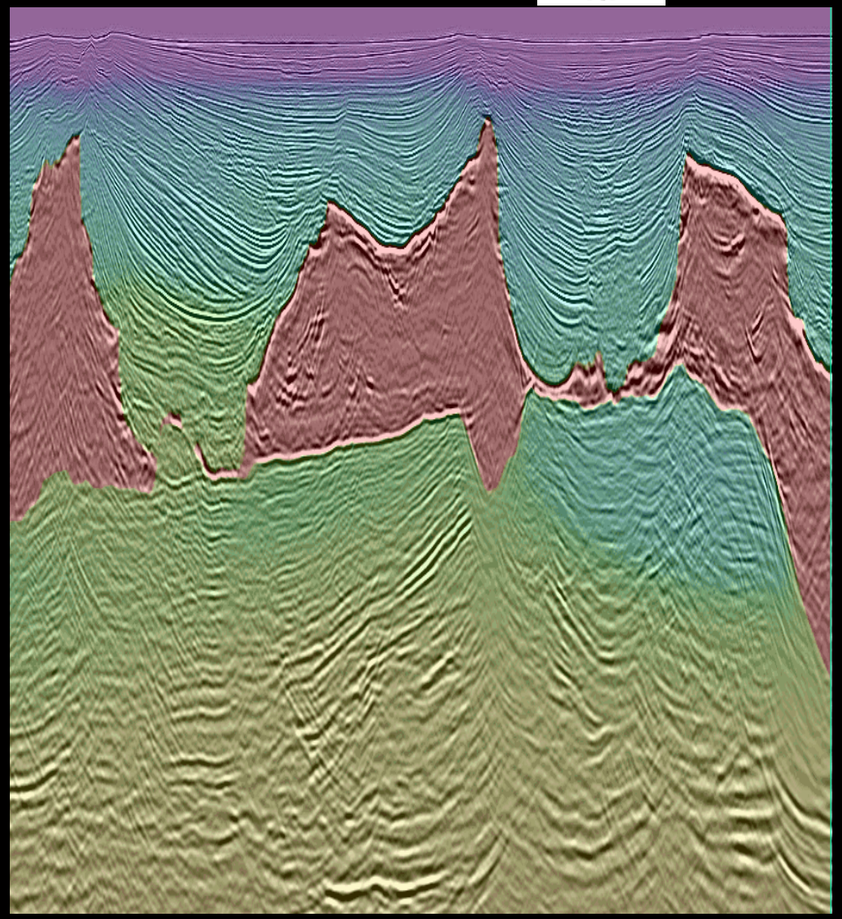


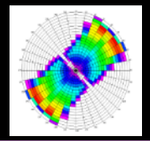
Azimuth and offset Coverage

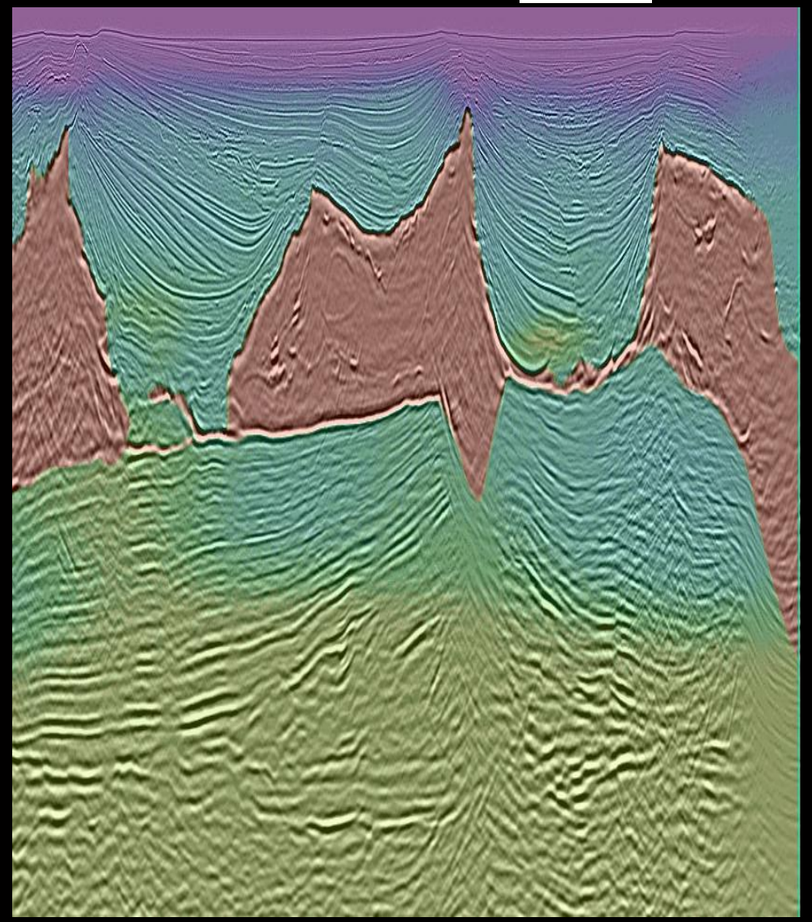


Imaging improvements

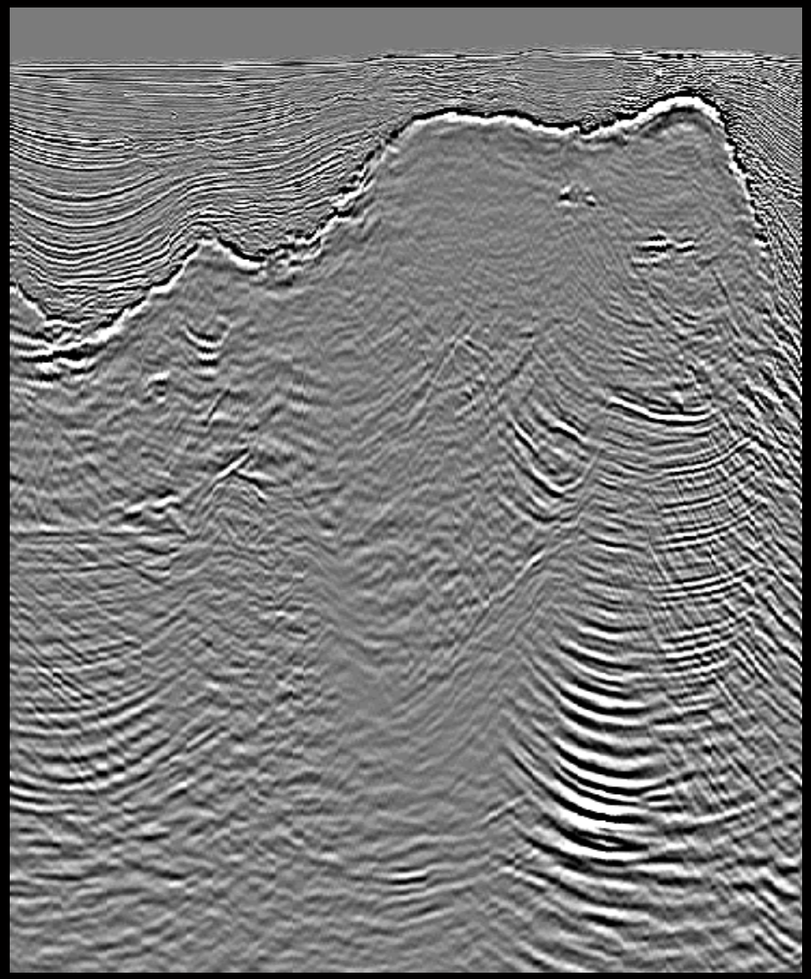
2005 NAZ 



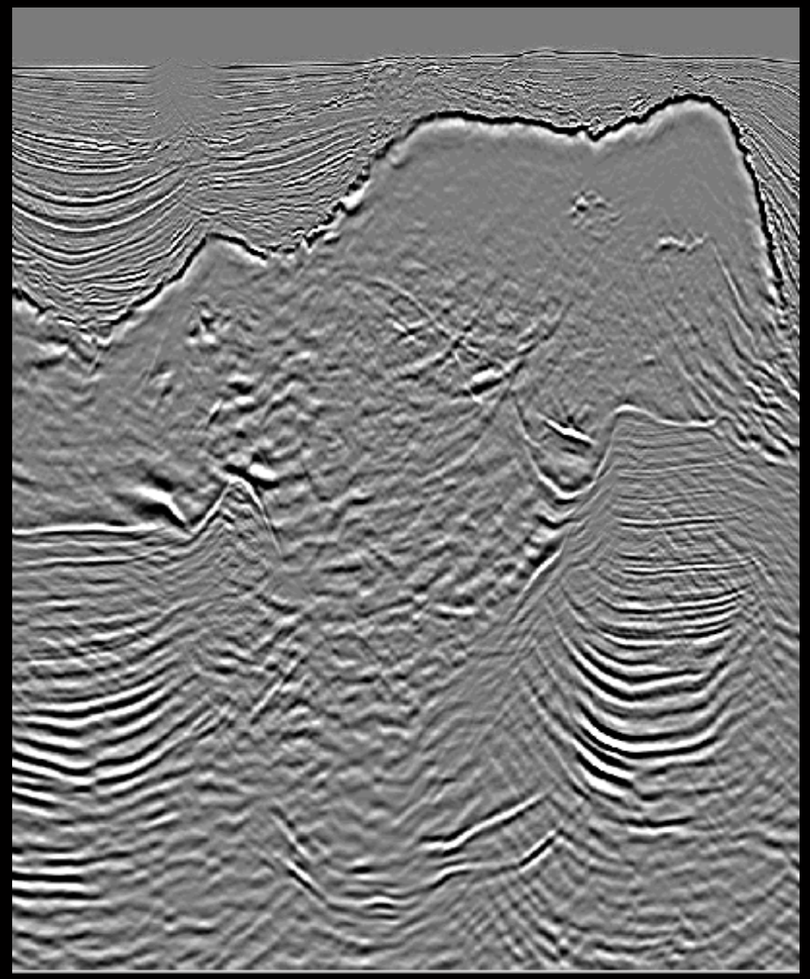
2008 WAZ 



Imaging improvements



NAZ

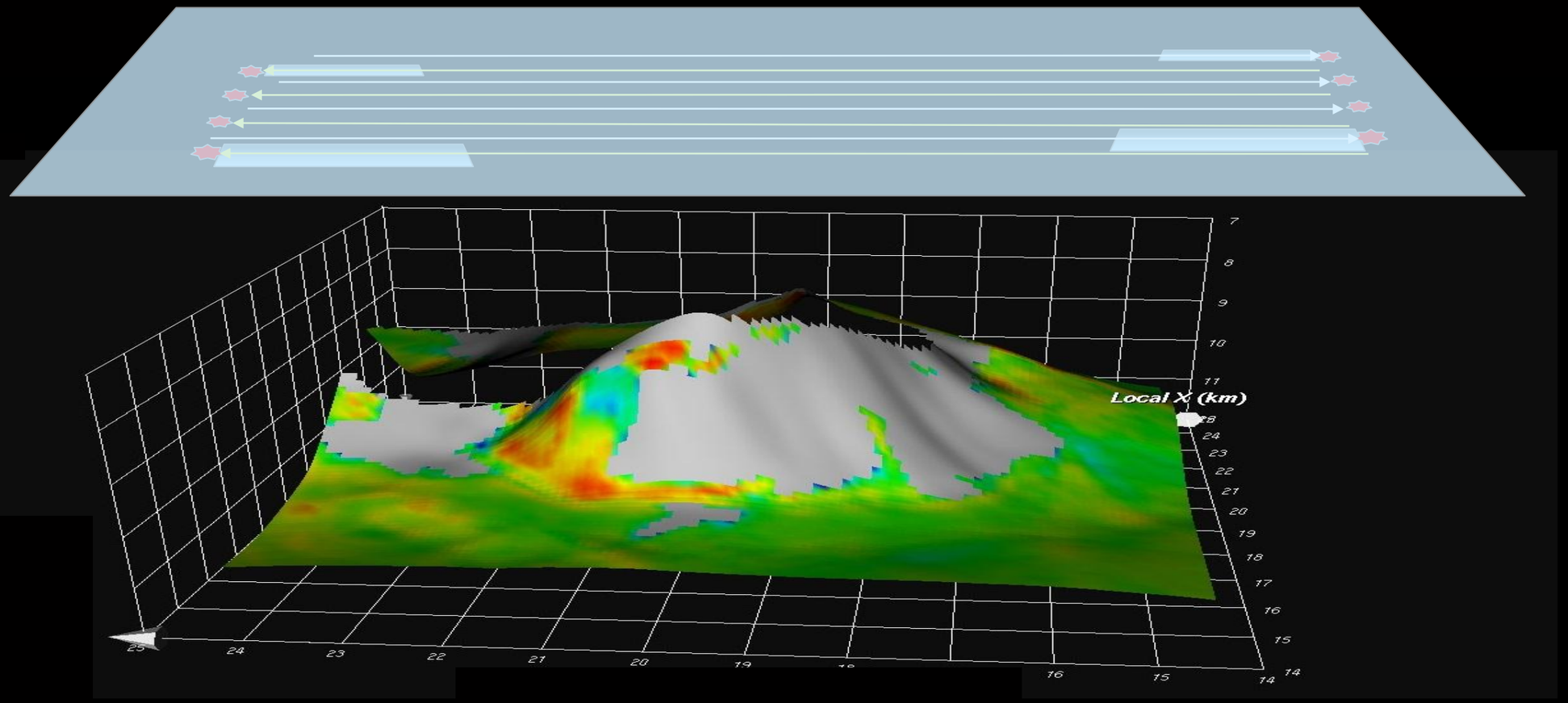


WAZ
2006

Ray trace modeling study

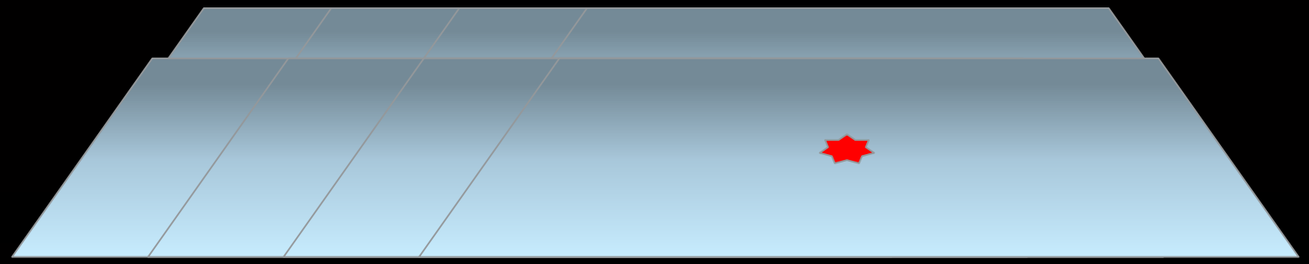
Ray trace modeling study

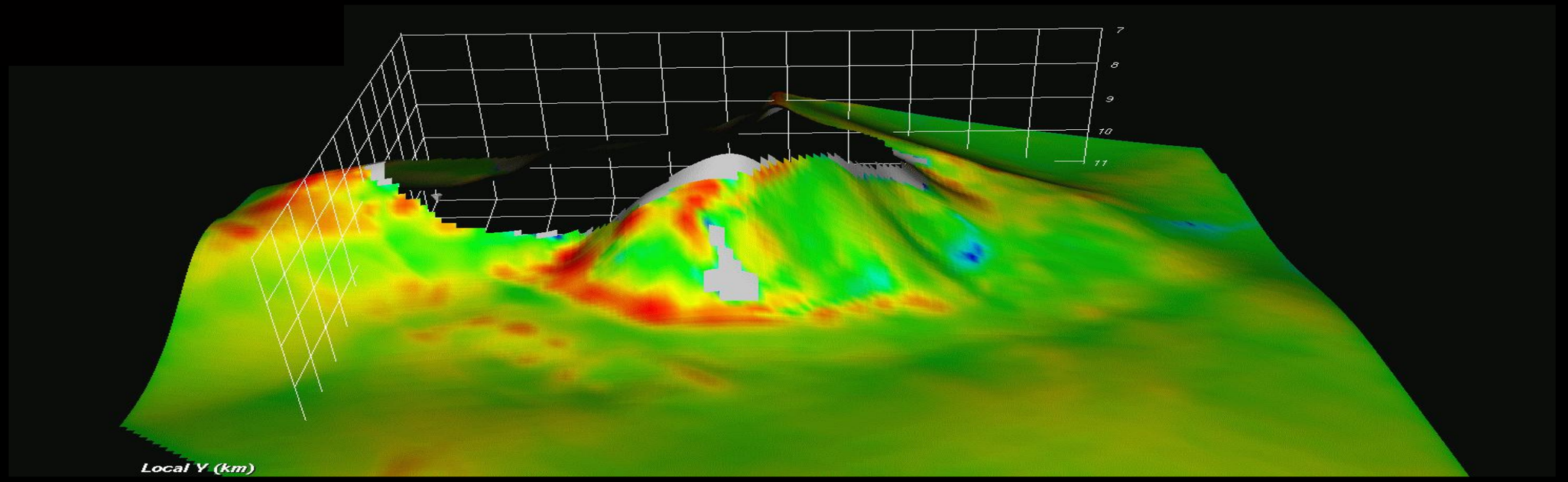
WAZ acquisition



Ray trace modeling study

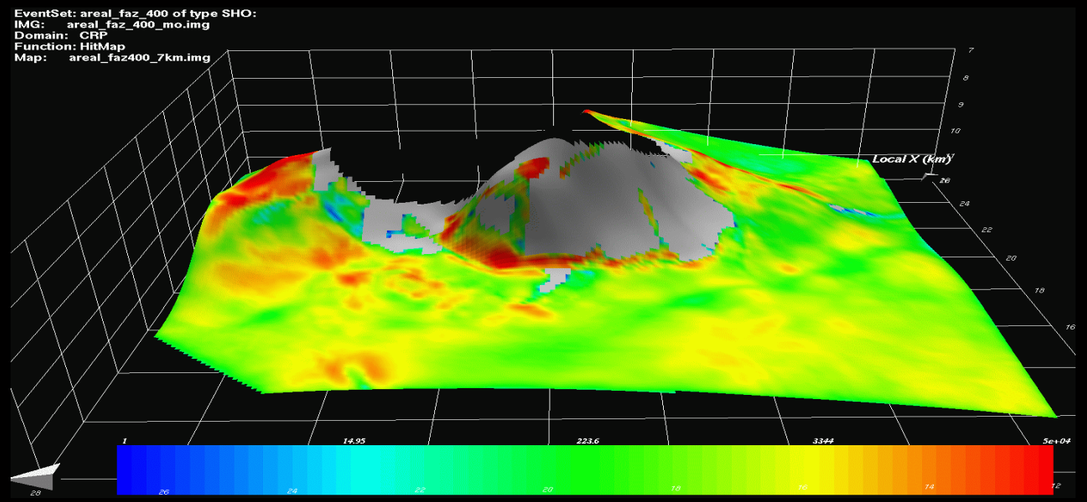
Areal geometry



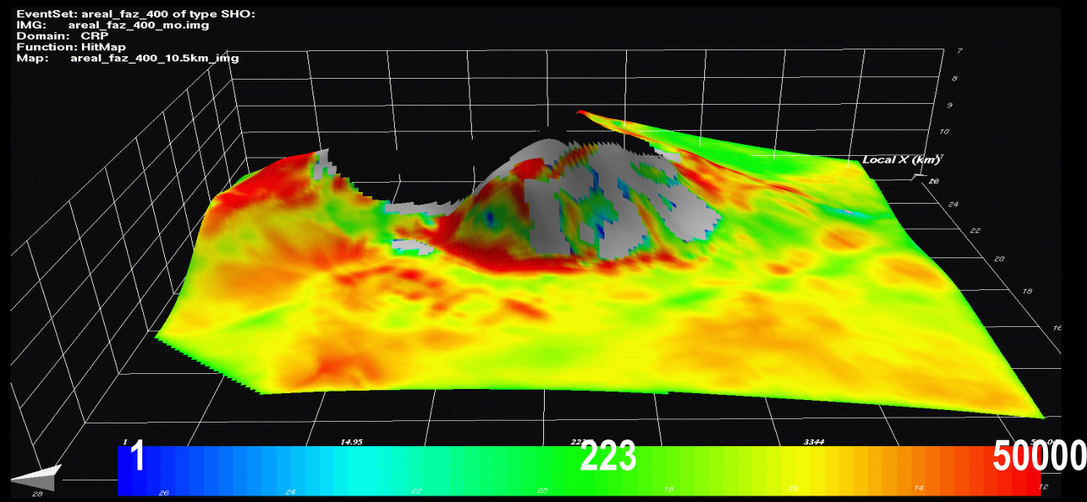


Illumination maps for full azimuth geometries

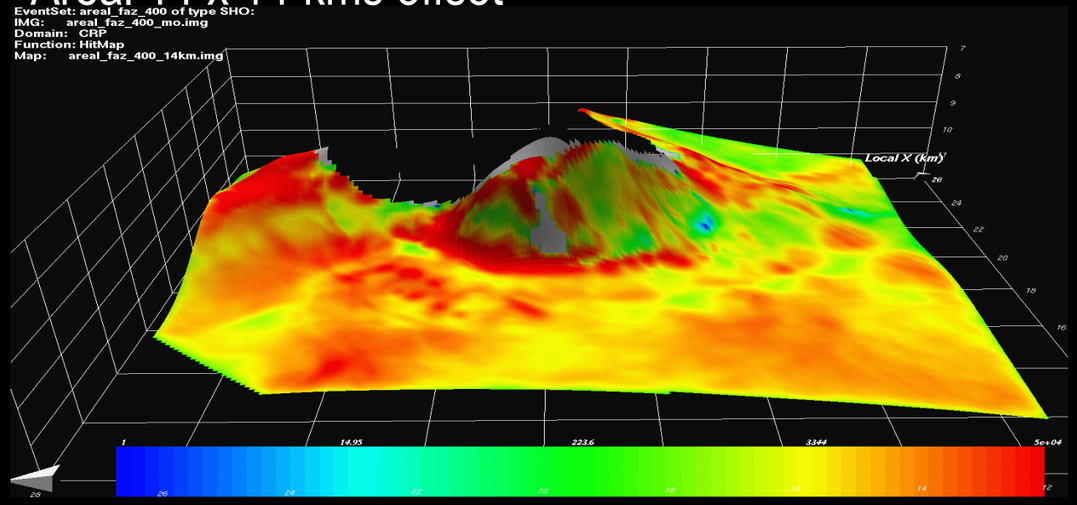
Areal 7x7 kms offset



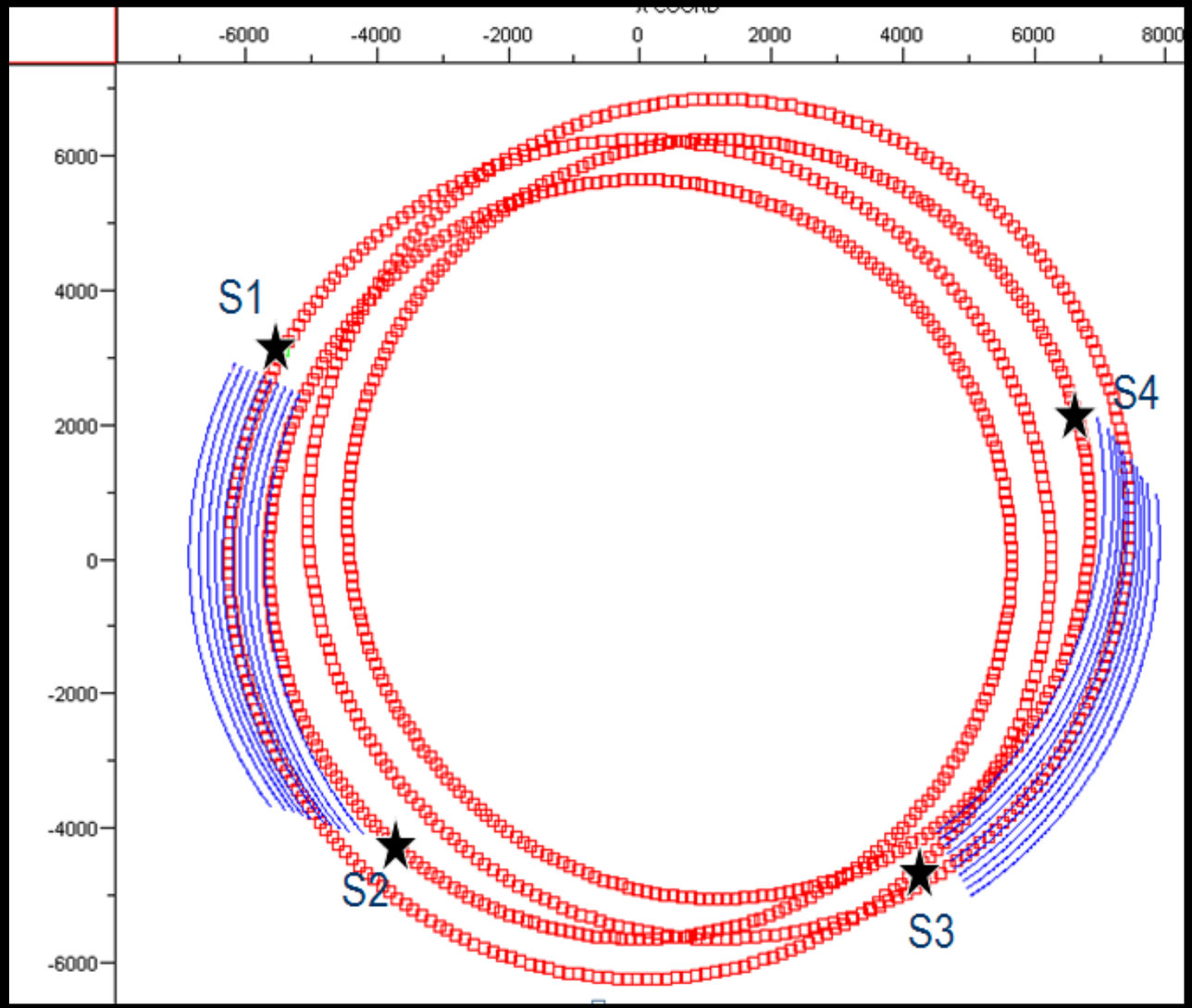
Areal 10.5 x 10.5 kms offset

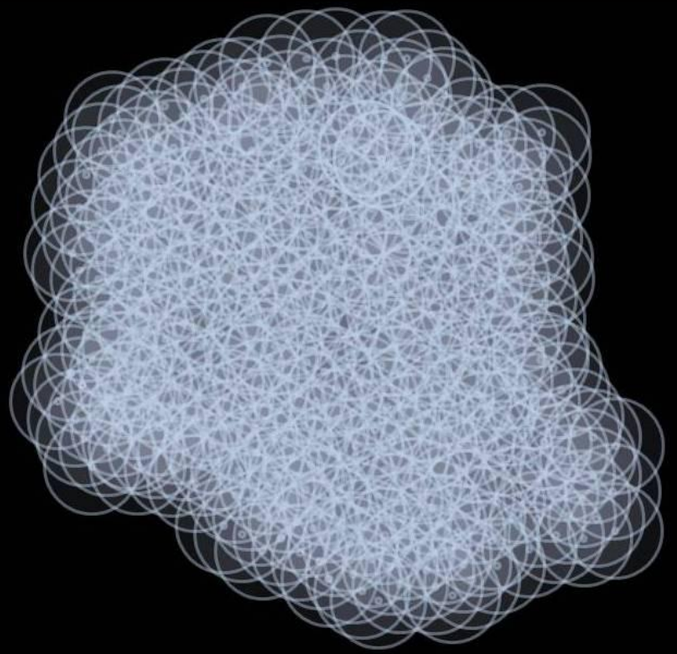


Areal 14 x 14 kms offset

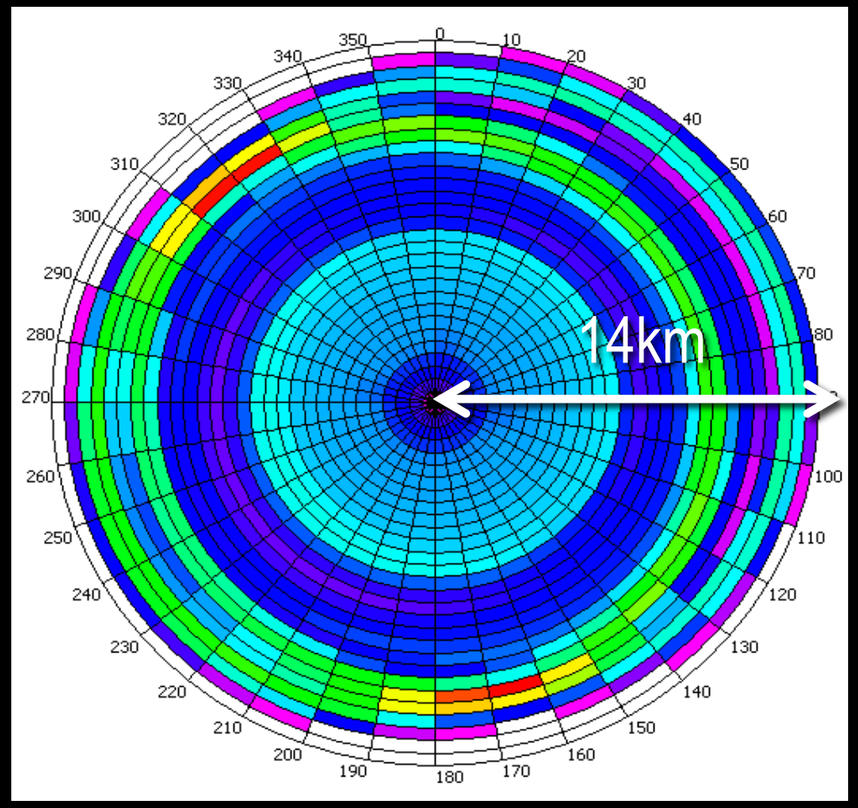


Dual coil design



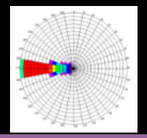


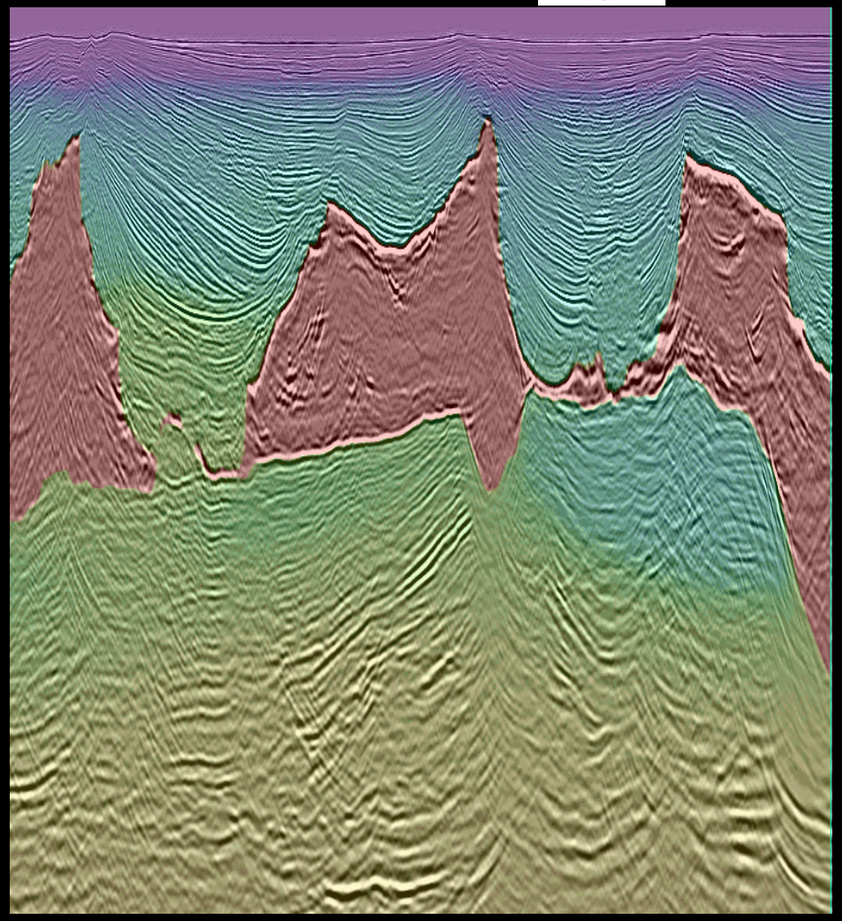
Dual Coil geometry for full azimuth long offset acquisition

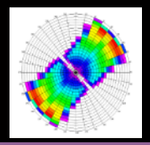


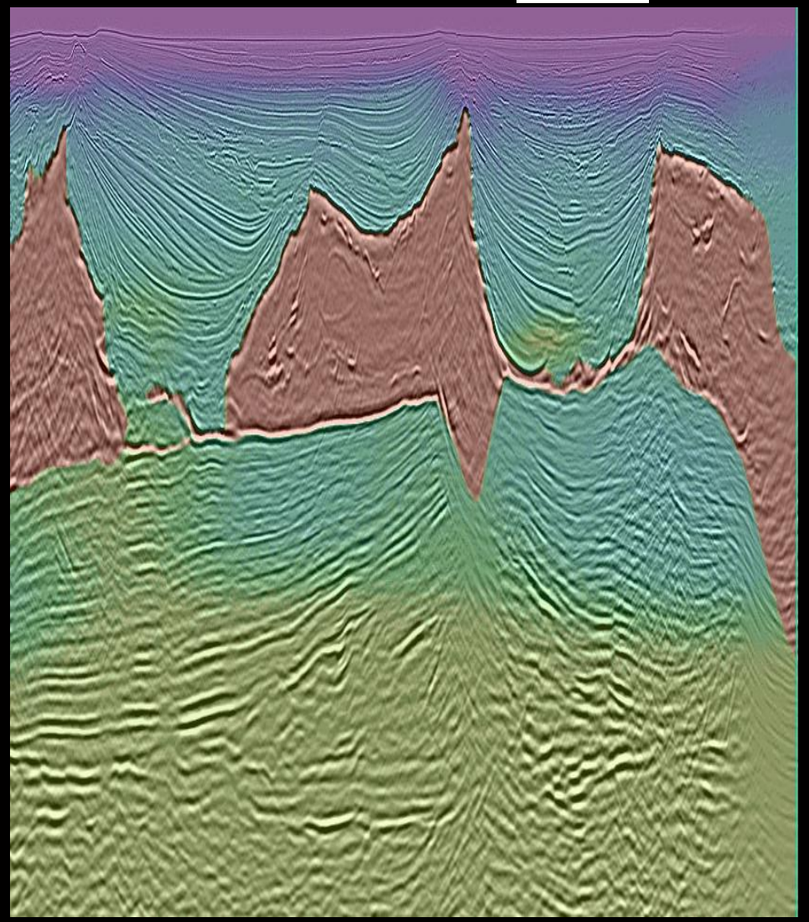
Azimuth and offset Coverage

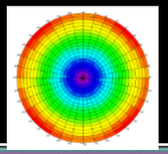
Imaging improvements

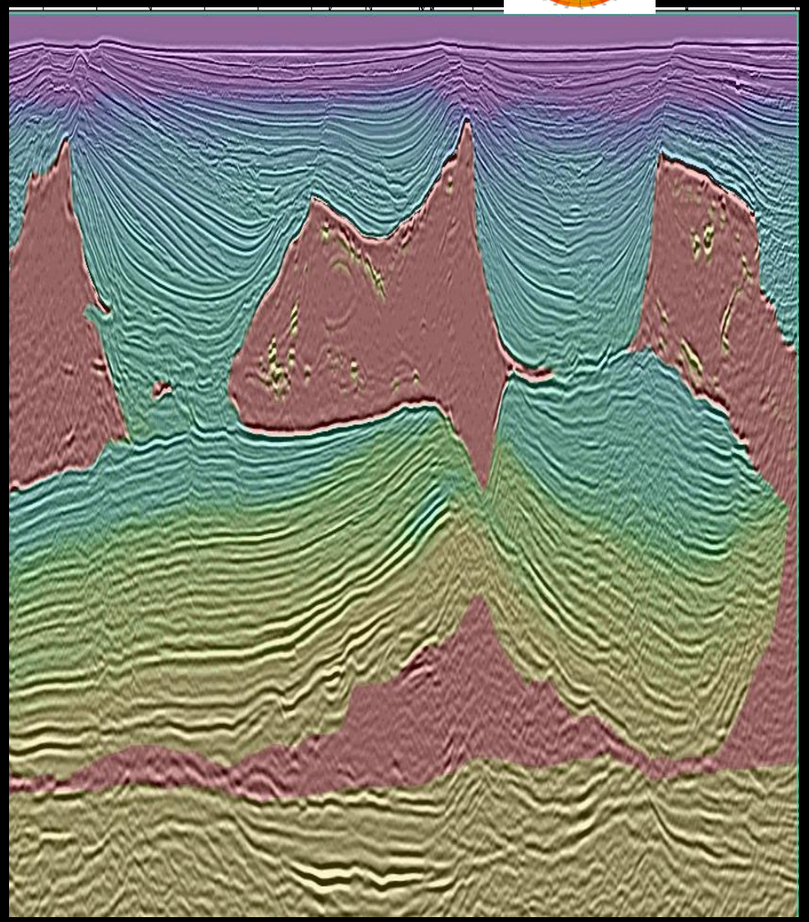
2005 NAZ 



2008 WAZ 

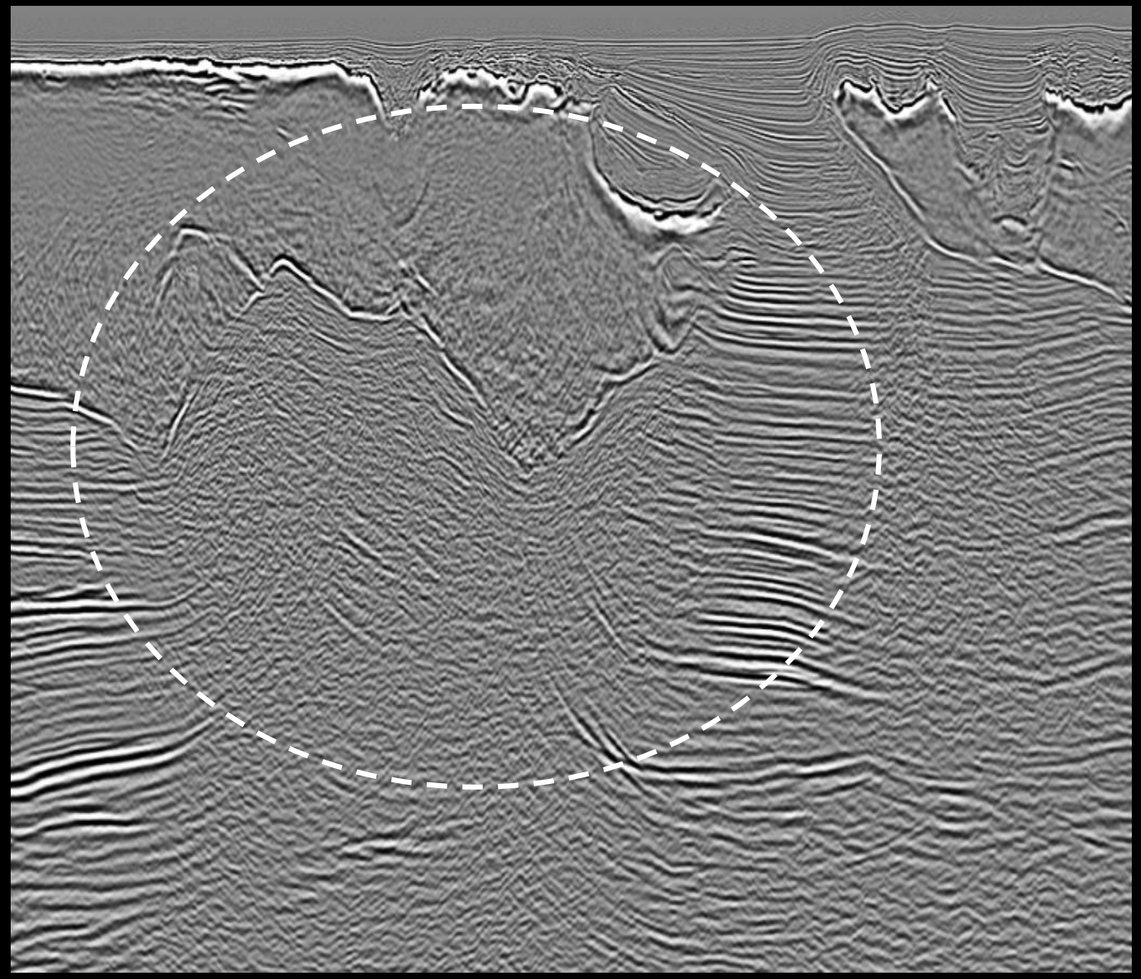


2013 Dual Coil 

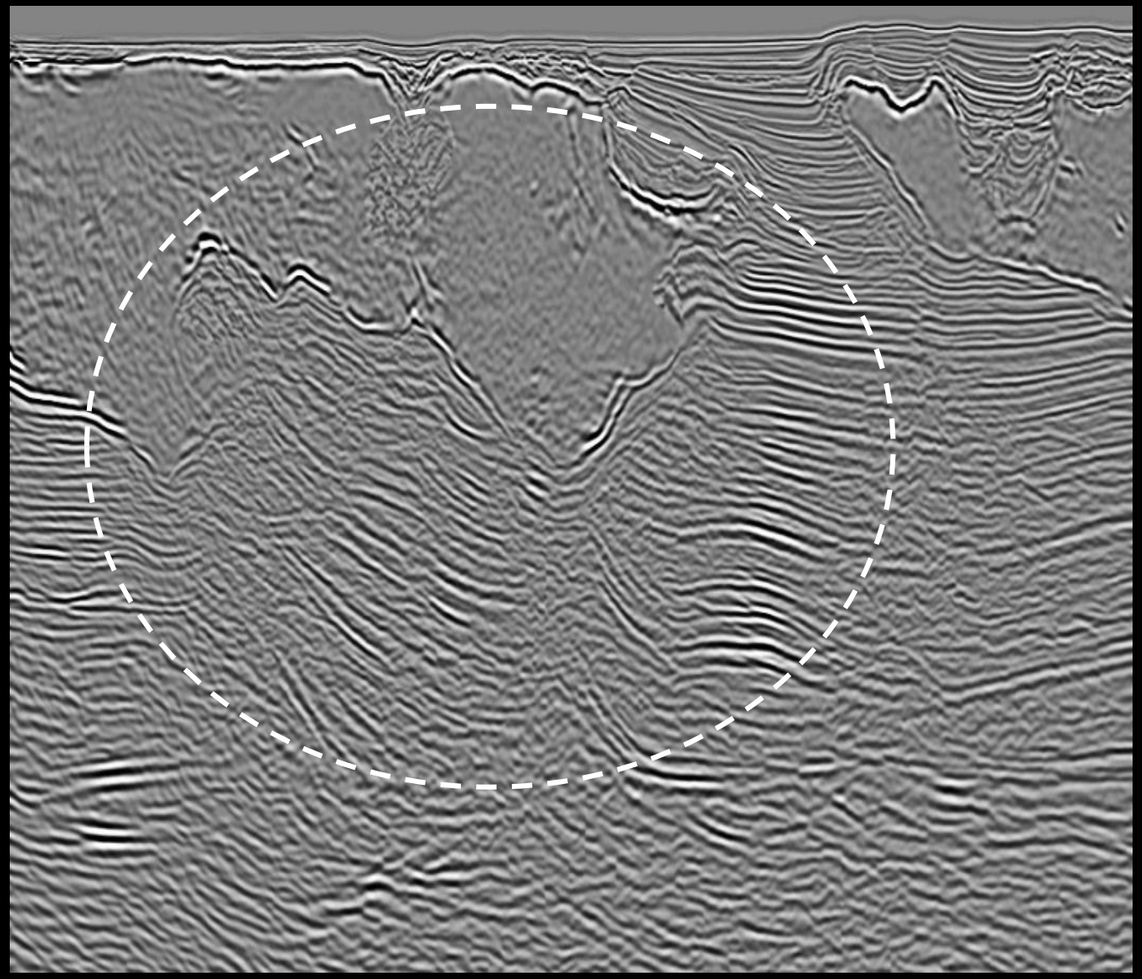


Better illumination with Dual Coil

Wide azimuth

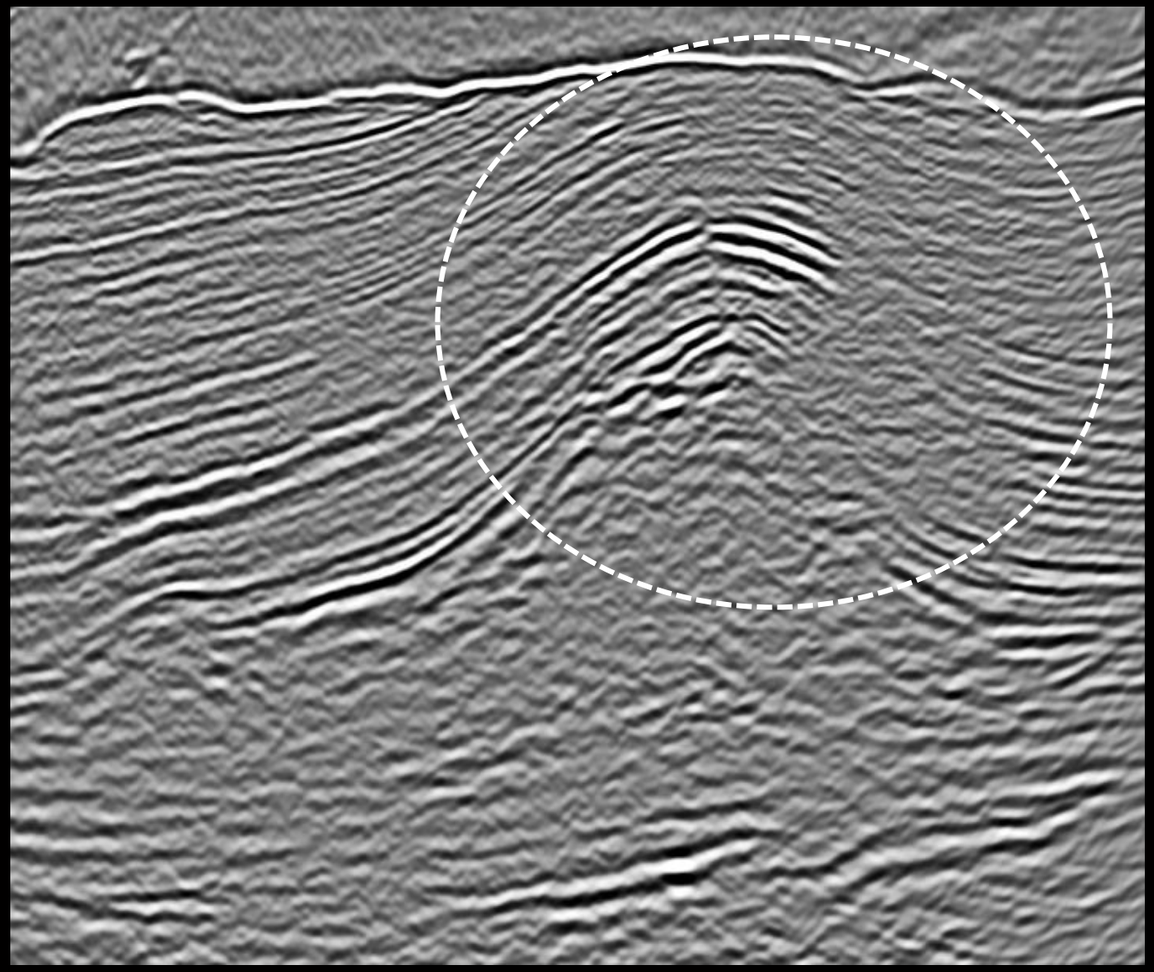


Full azimuth, long offset

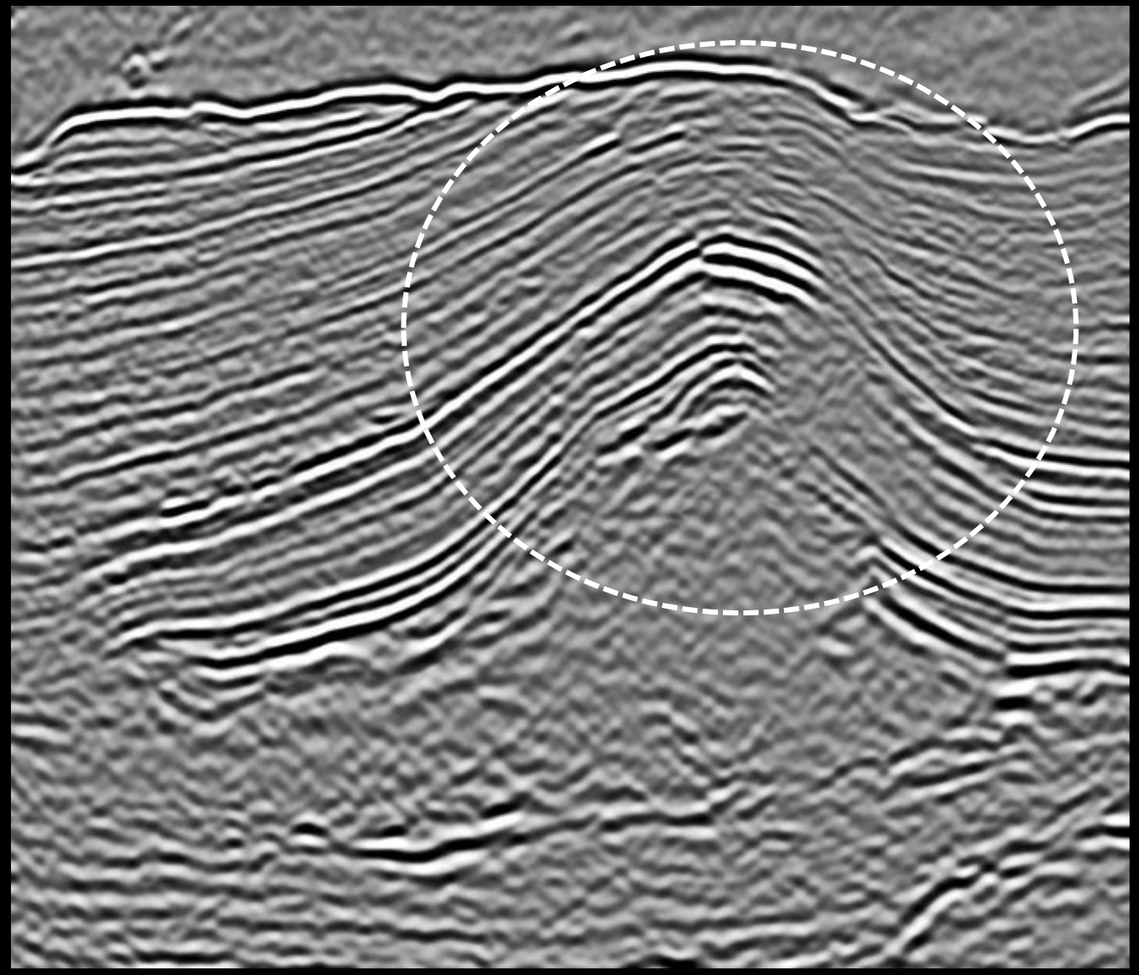


Better illumination with Dual Coil

Wide azimuth

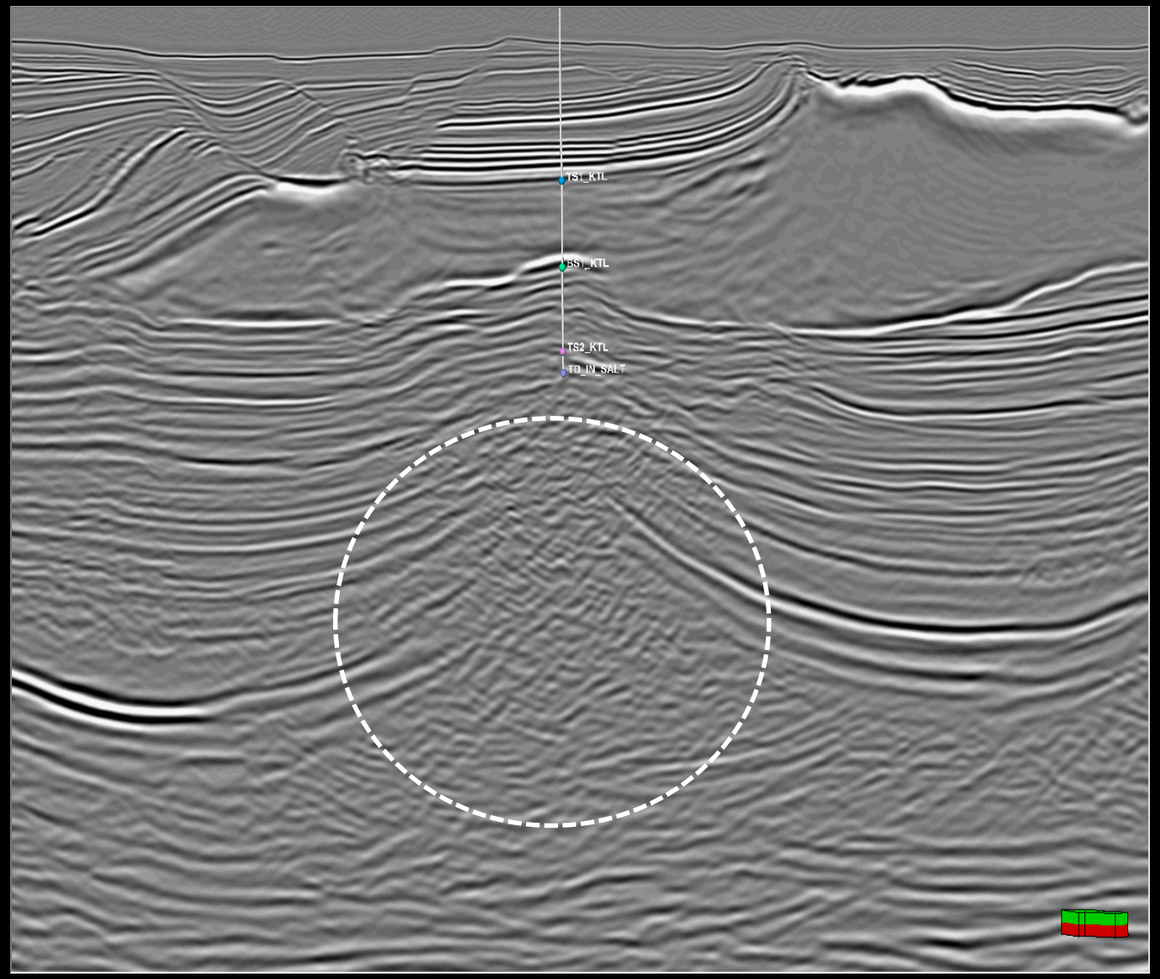


Full azimuth, long offset

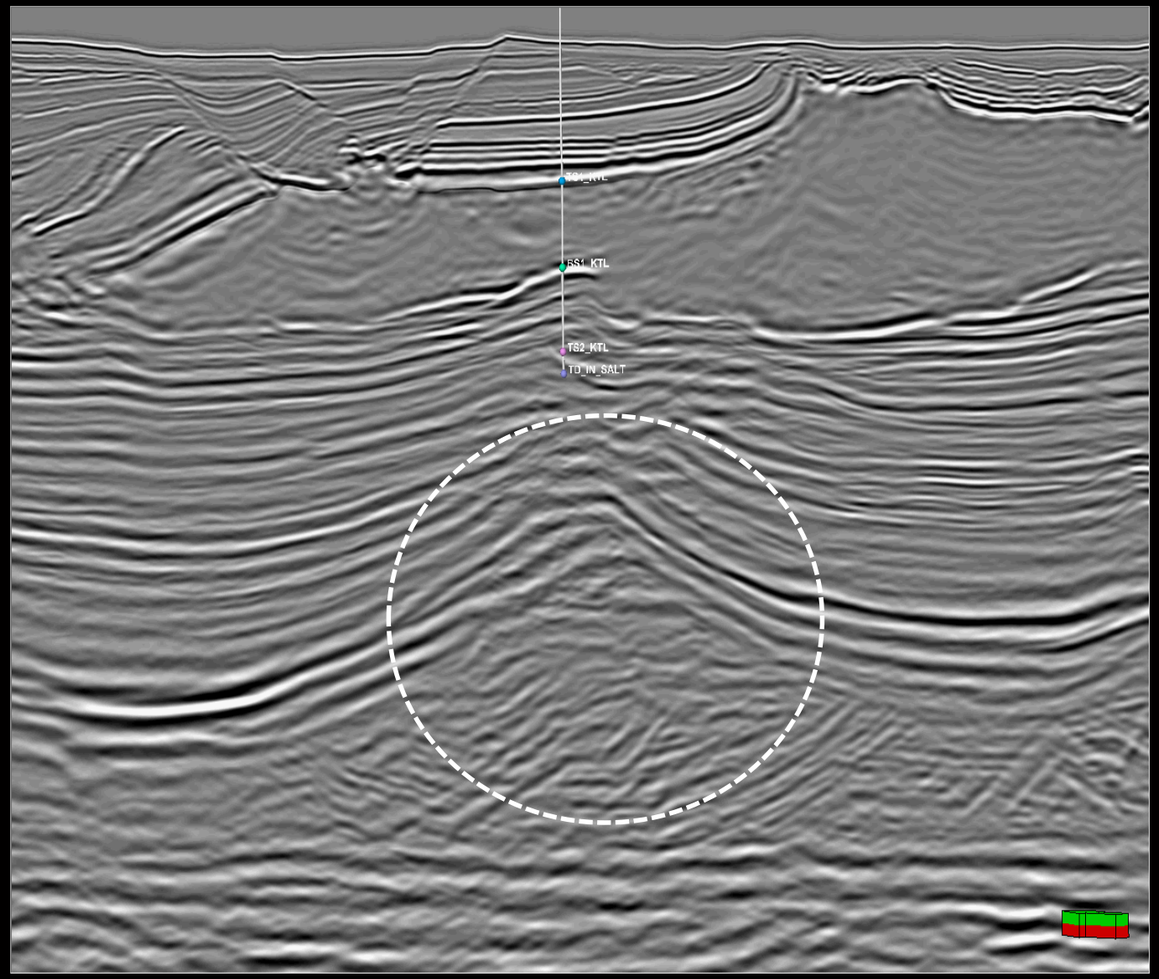


Better illumination with Dual Coil

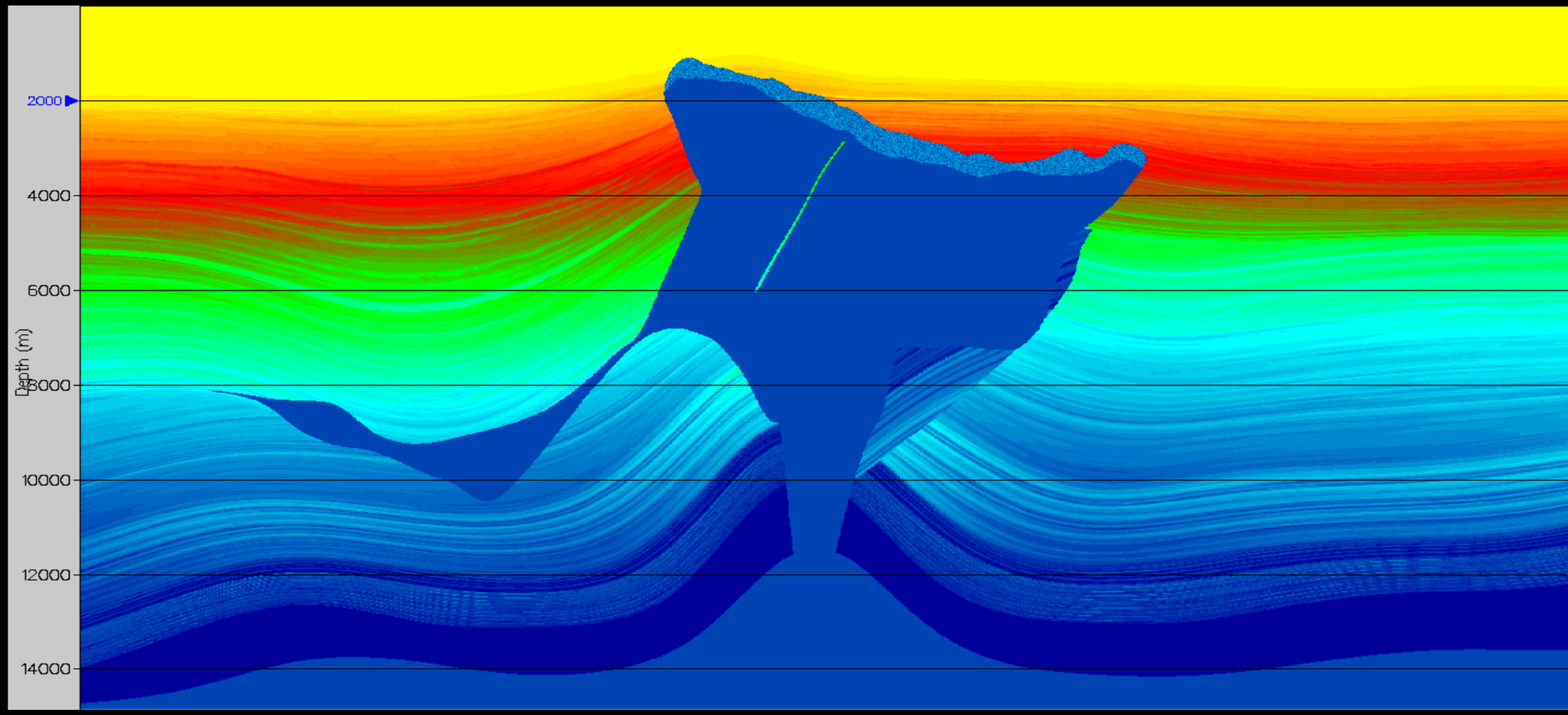
Wide azimuth



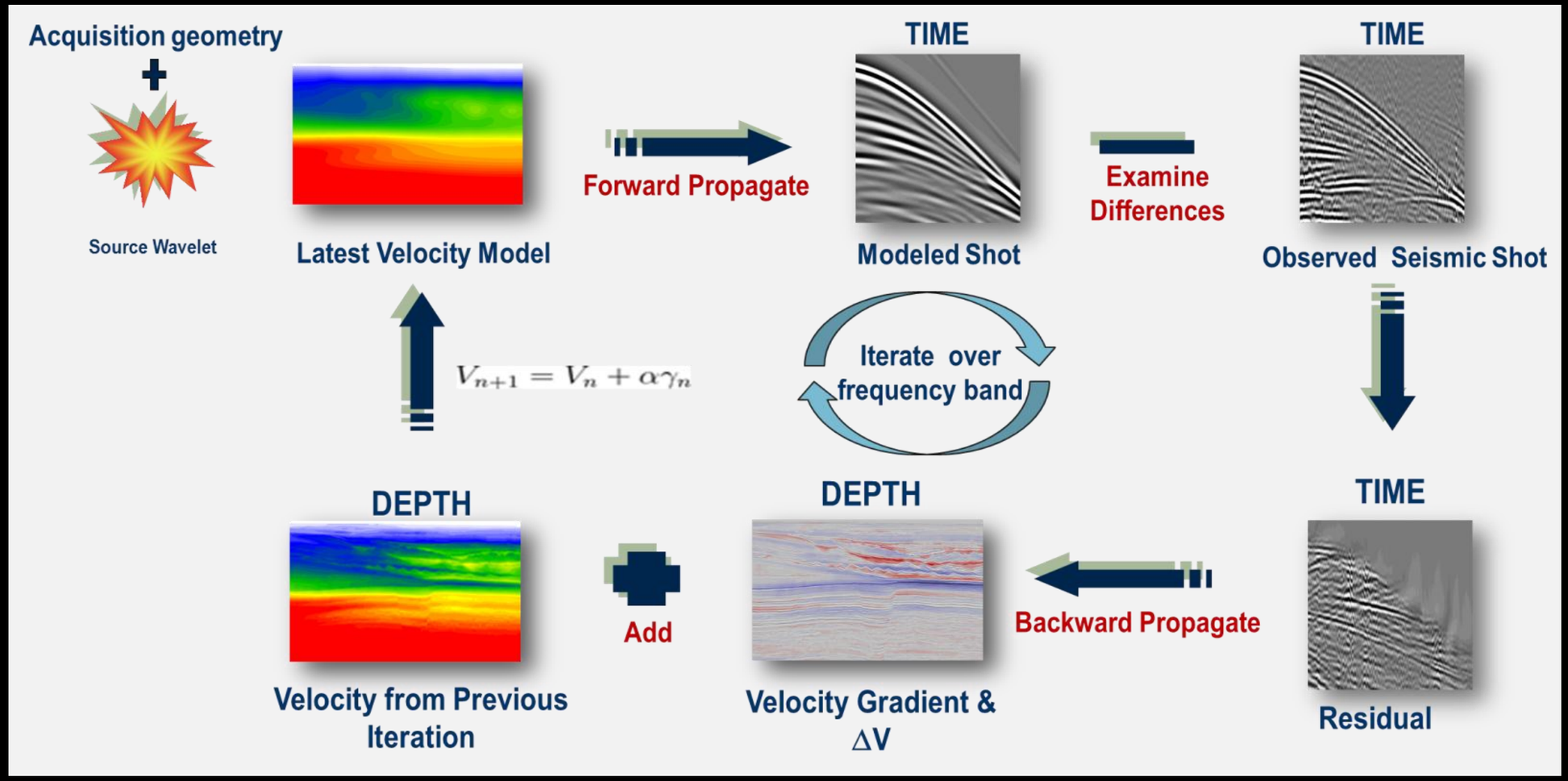
Full azimuth long offset



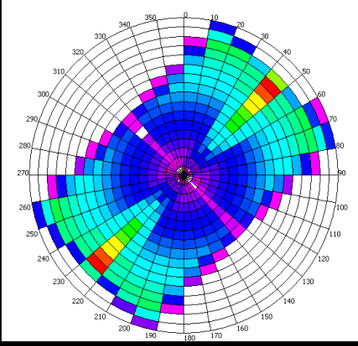
Data Processing – Model building & imaging

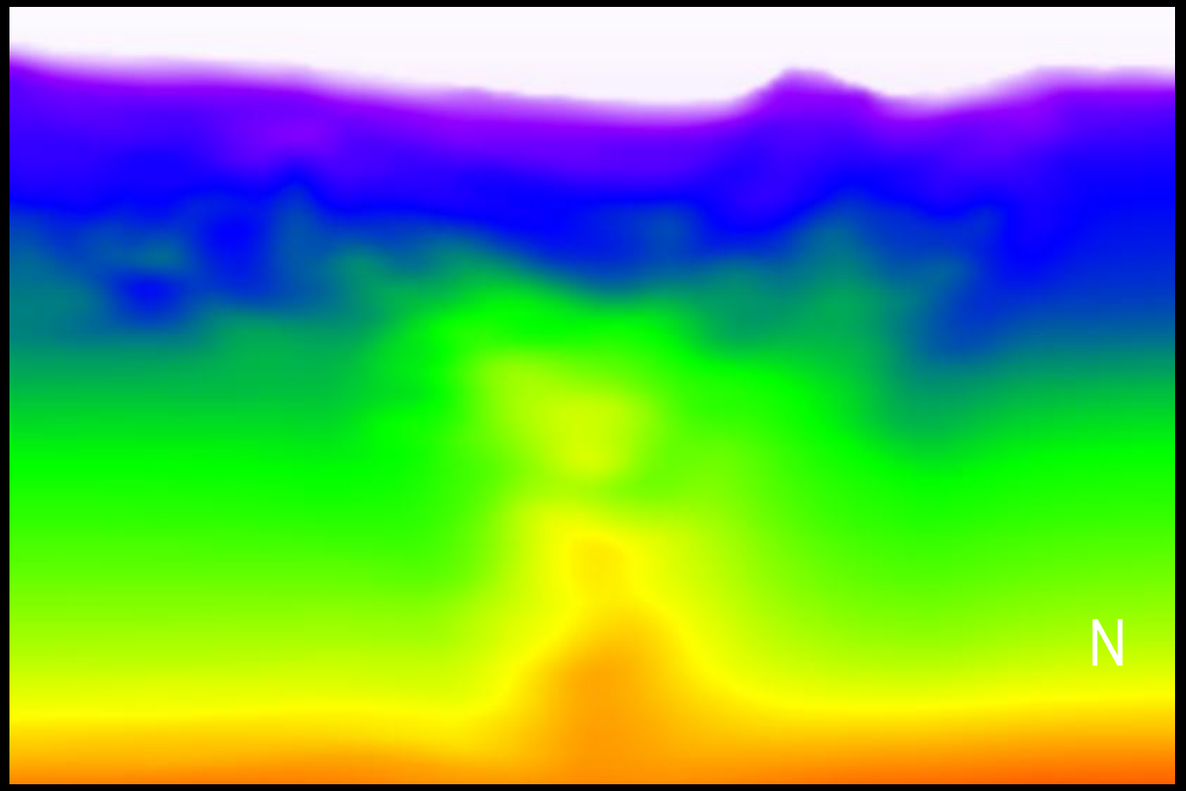


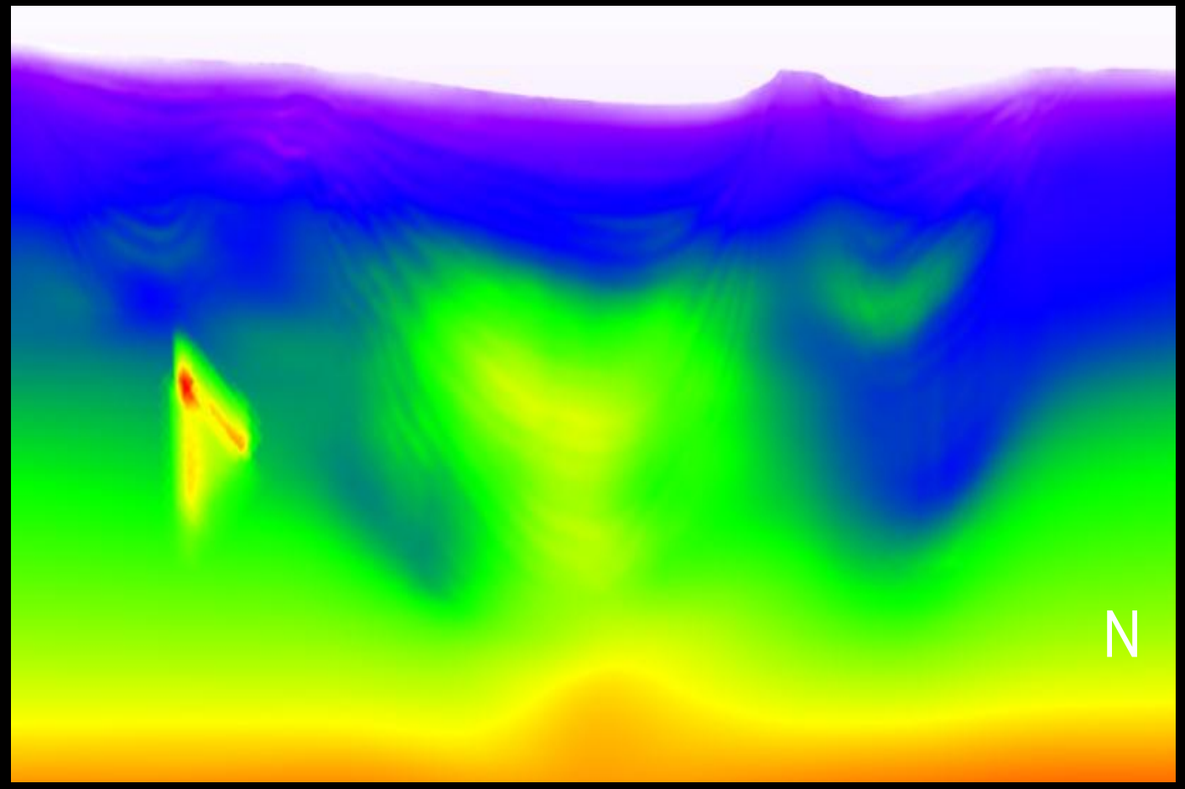
Full waveform inversion

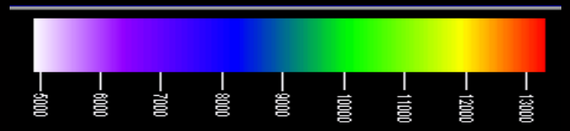


Improved velocity detail with FWI

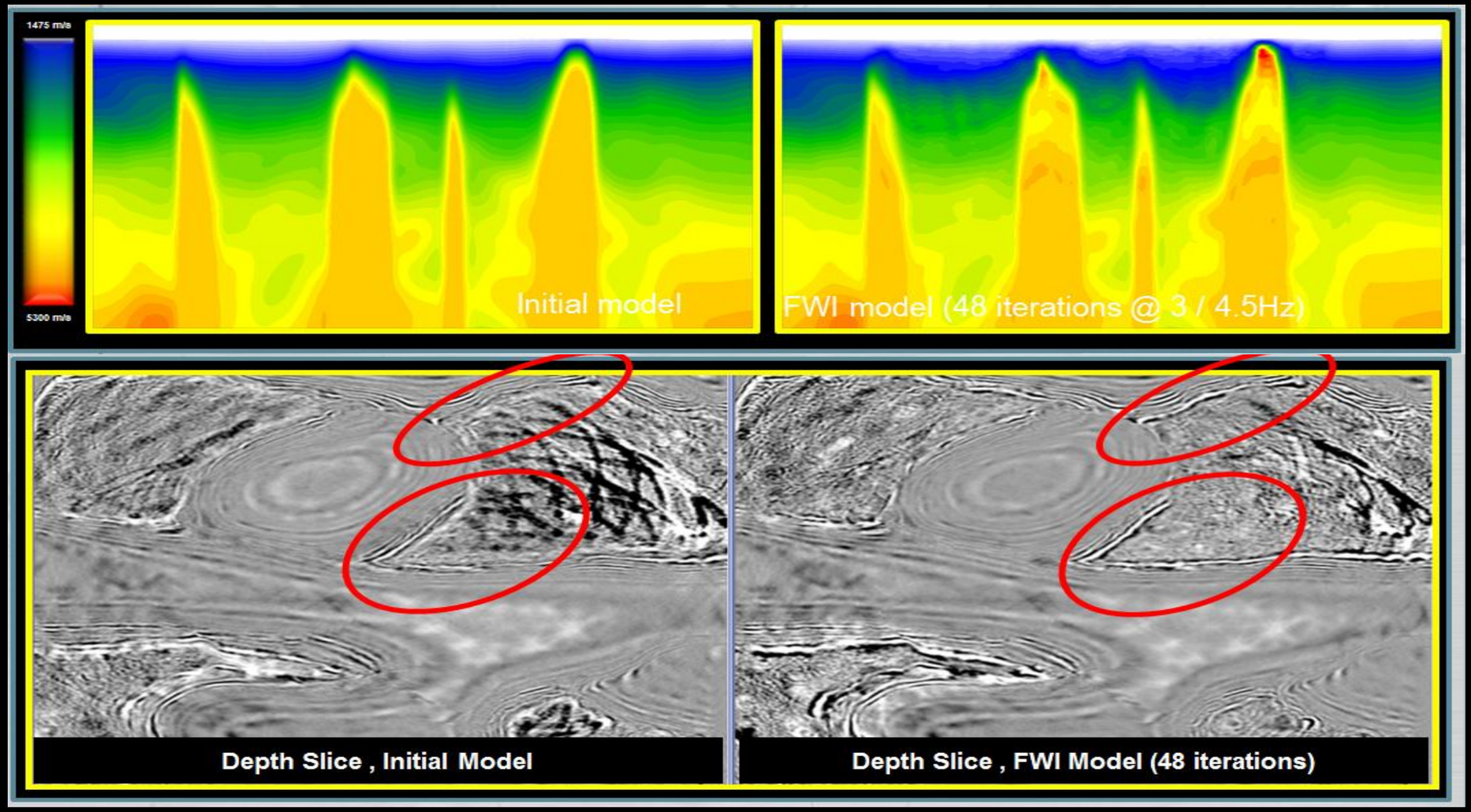




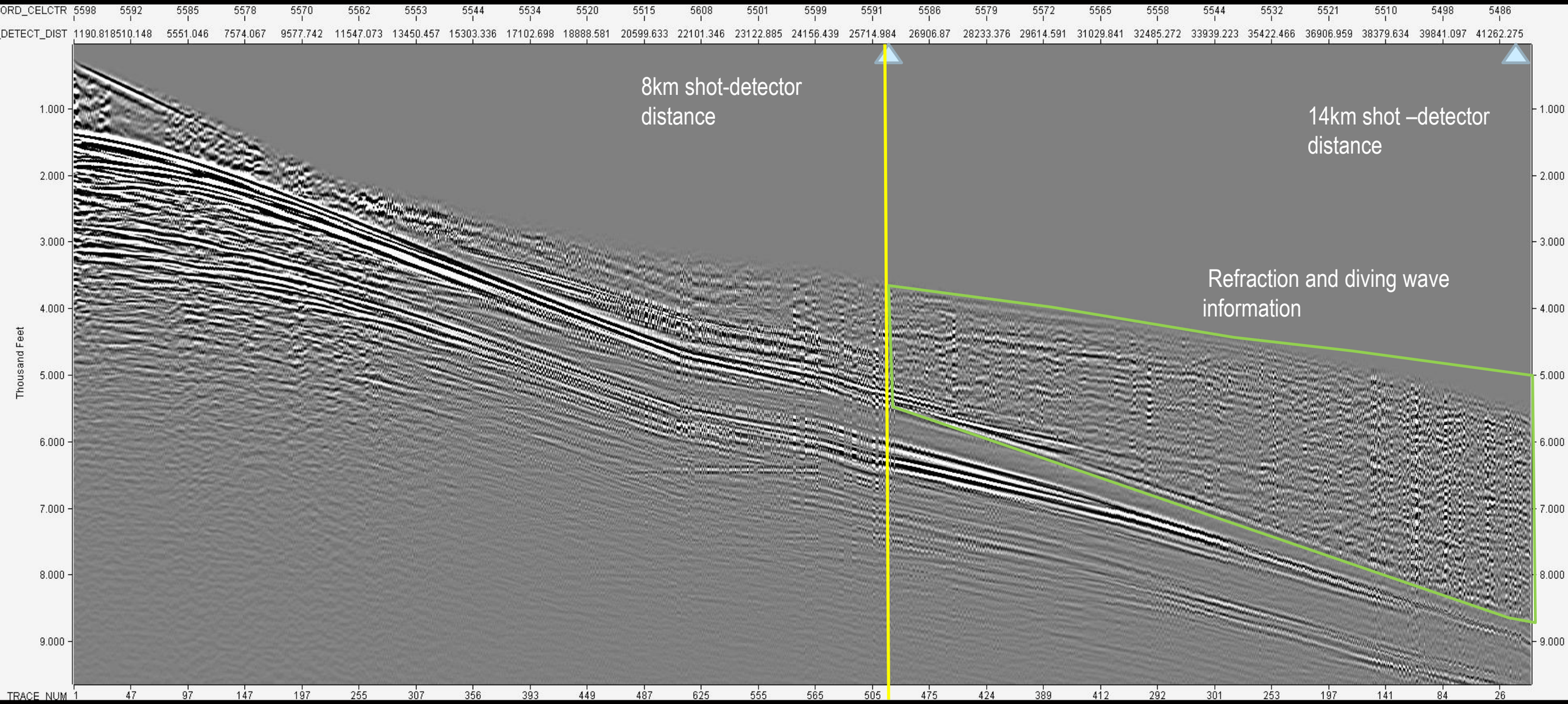




FWI in the Barents Sea
Example from Nordkapp Salt body



Long offset for full waveform inversion



Reverse Time Migration

High-end pre-stack depth migration

- Two-way wave propagation in Time based on numerical solution of two-way wave equation
- Source/Receiver wavefield propagated independently from actual depth
- Handling all aspect of wave propagation, including prismatic & diving waves, hence no dip limit

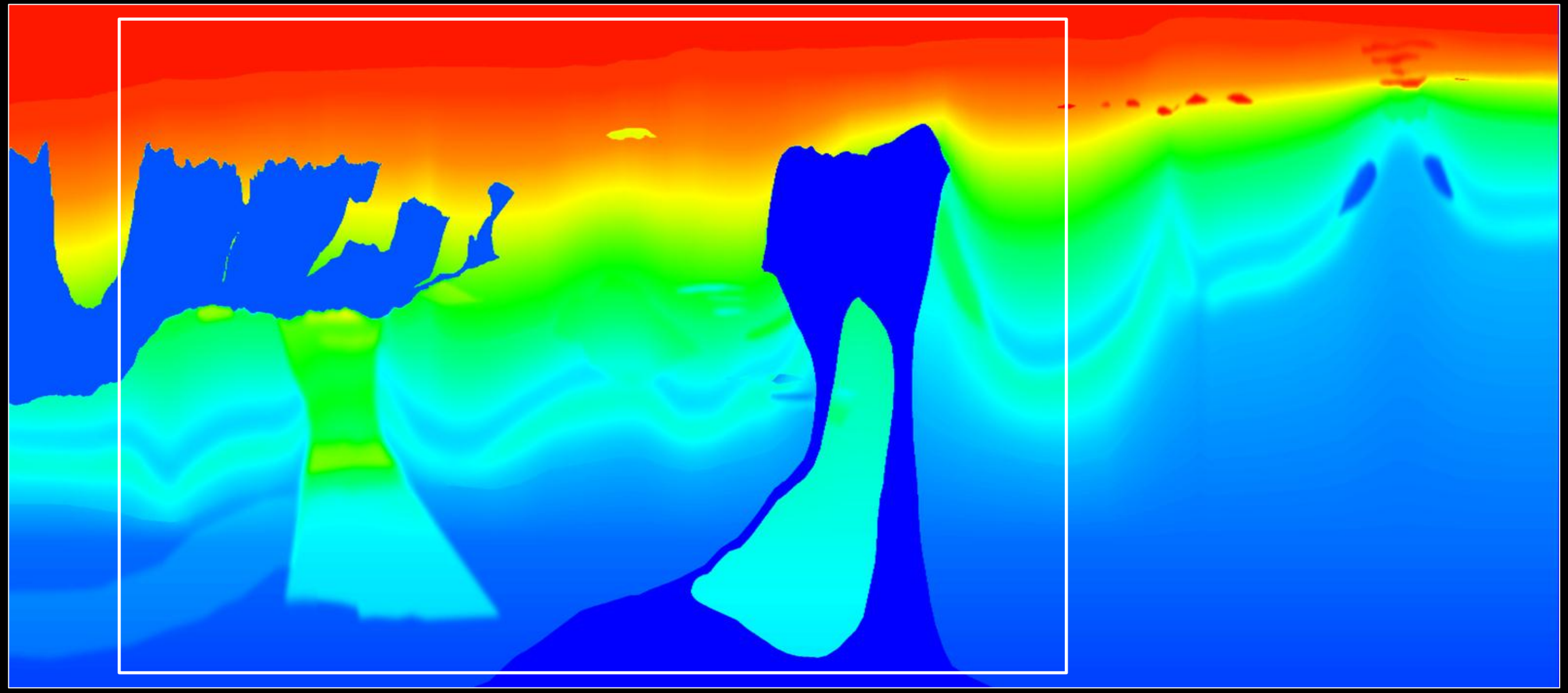
Imaging in areas of the greatest complexity

- Subsalt images
- Overhanging salt, steep flanks of salt bodies and steep channels
- Imaging under very complex shallow sections

Handles Complex Velocity Models

- Isotropic, Anisotropic (VTI, TTI and orthorhombic) velocity models
- Supports highly detailed models
- Handles large velocity contrasts within models

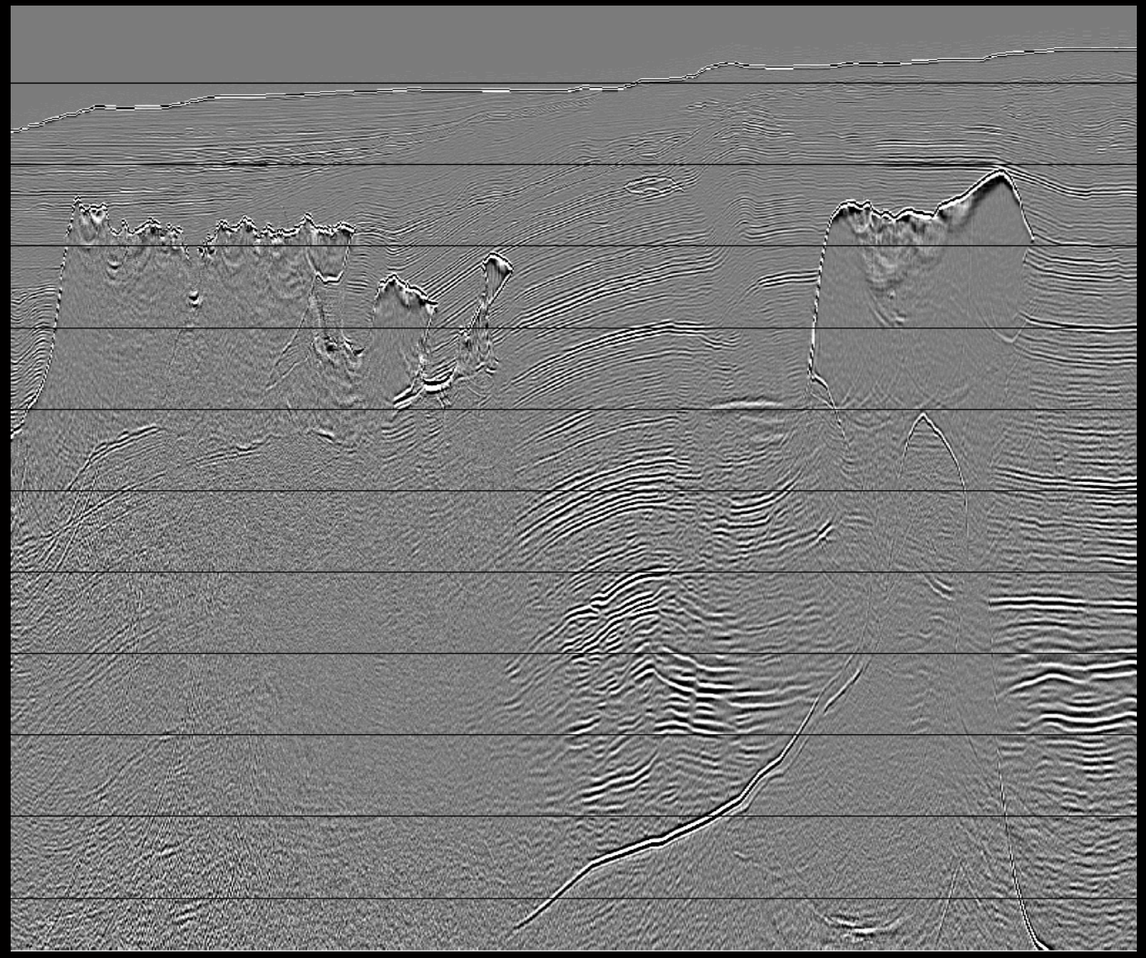
BP EAGE 2004 Model



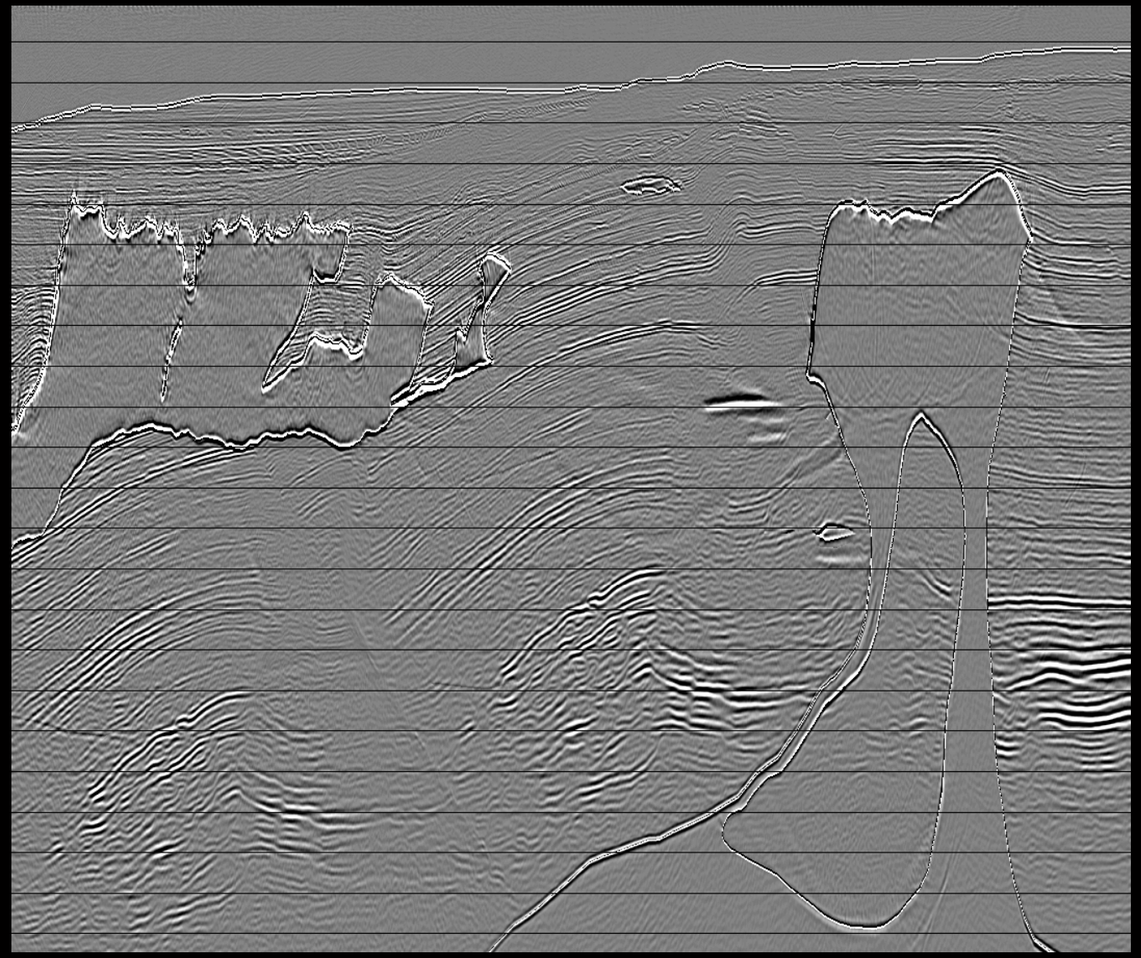
Migrated Image Space

Migration Algorithm comparisons

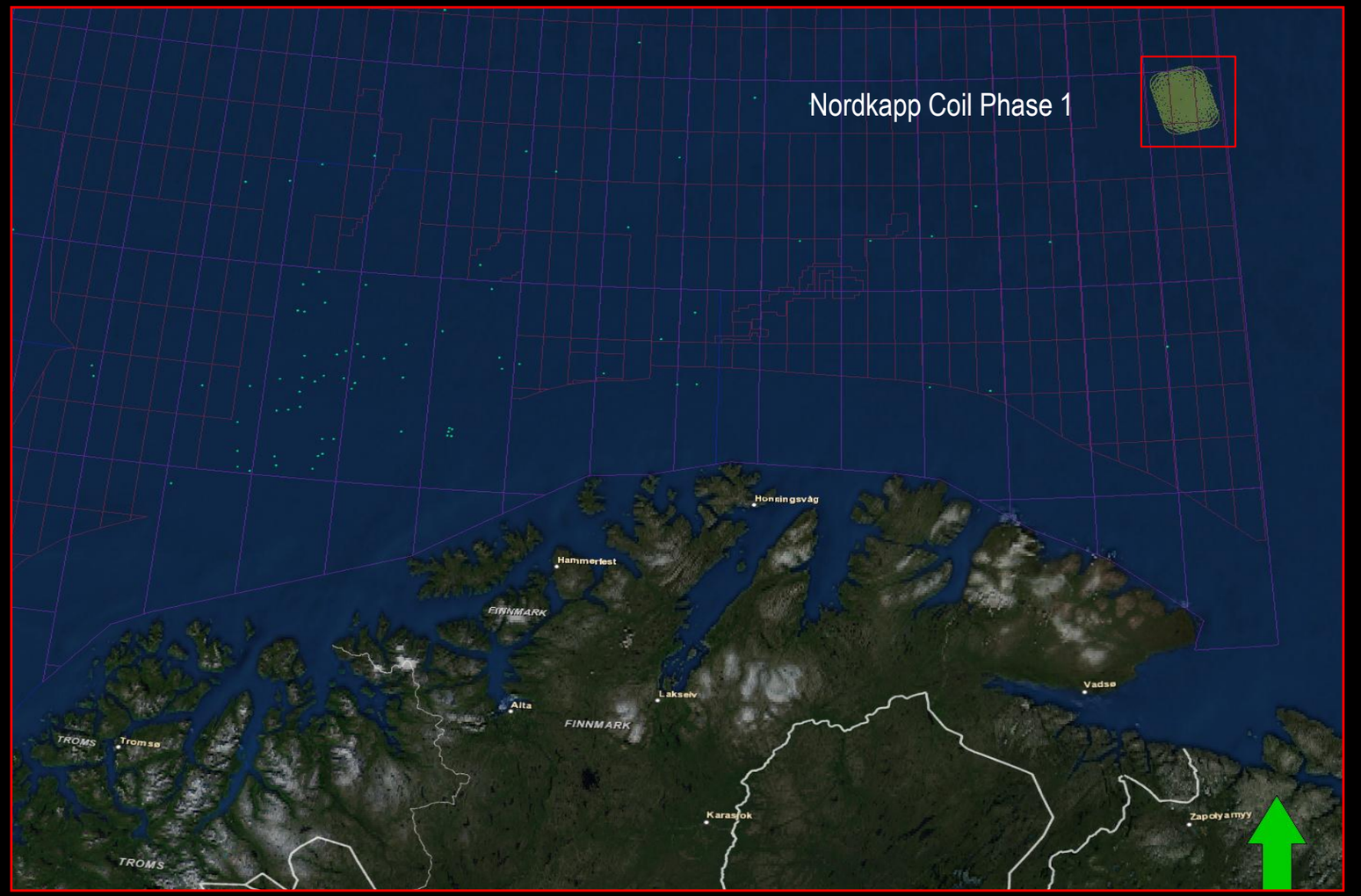
Kirchhoff



RTM

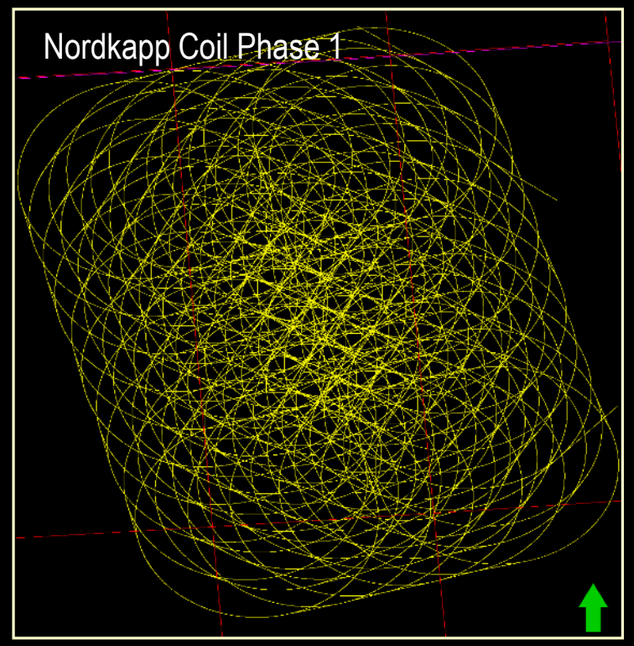


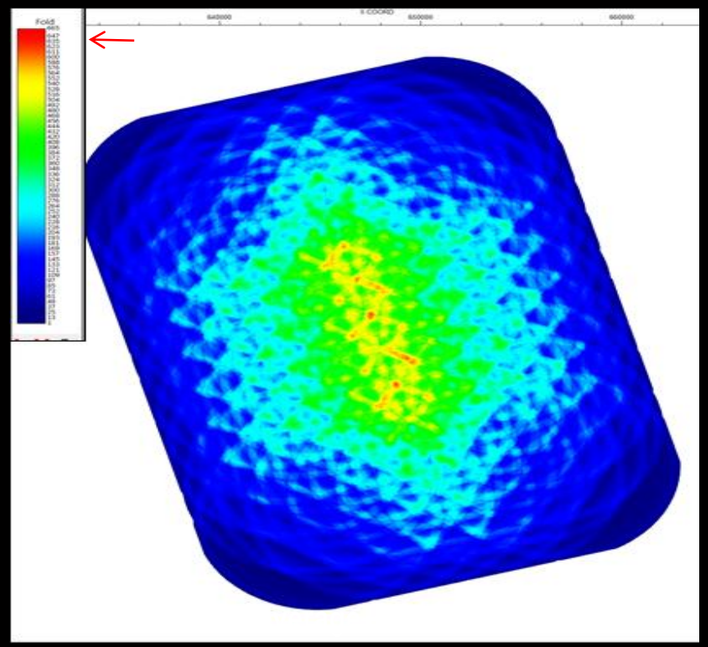
Location – Nordkapp Basin Block 7231

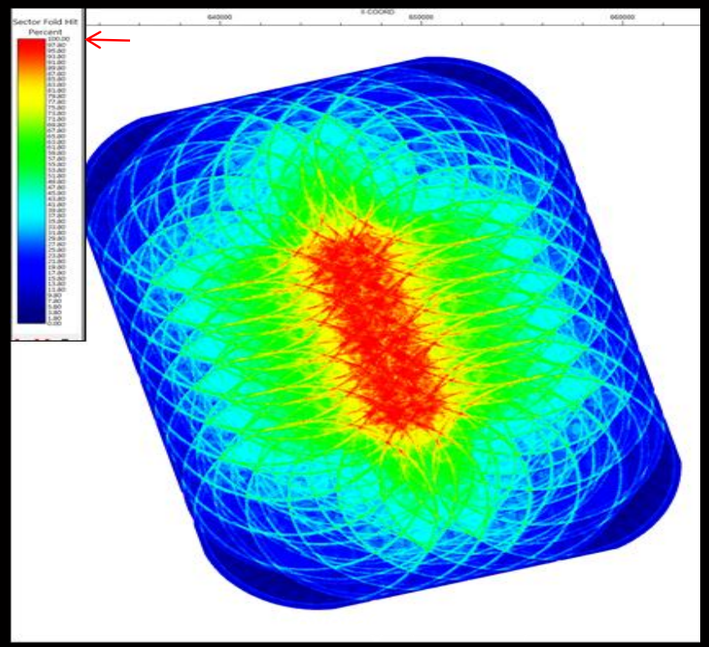


Acquisition Summary

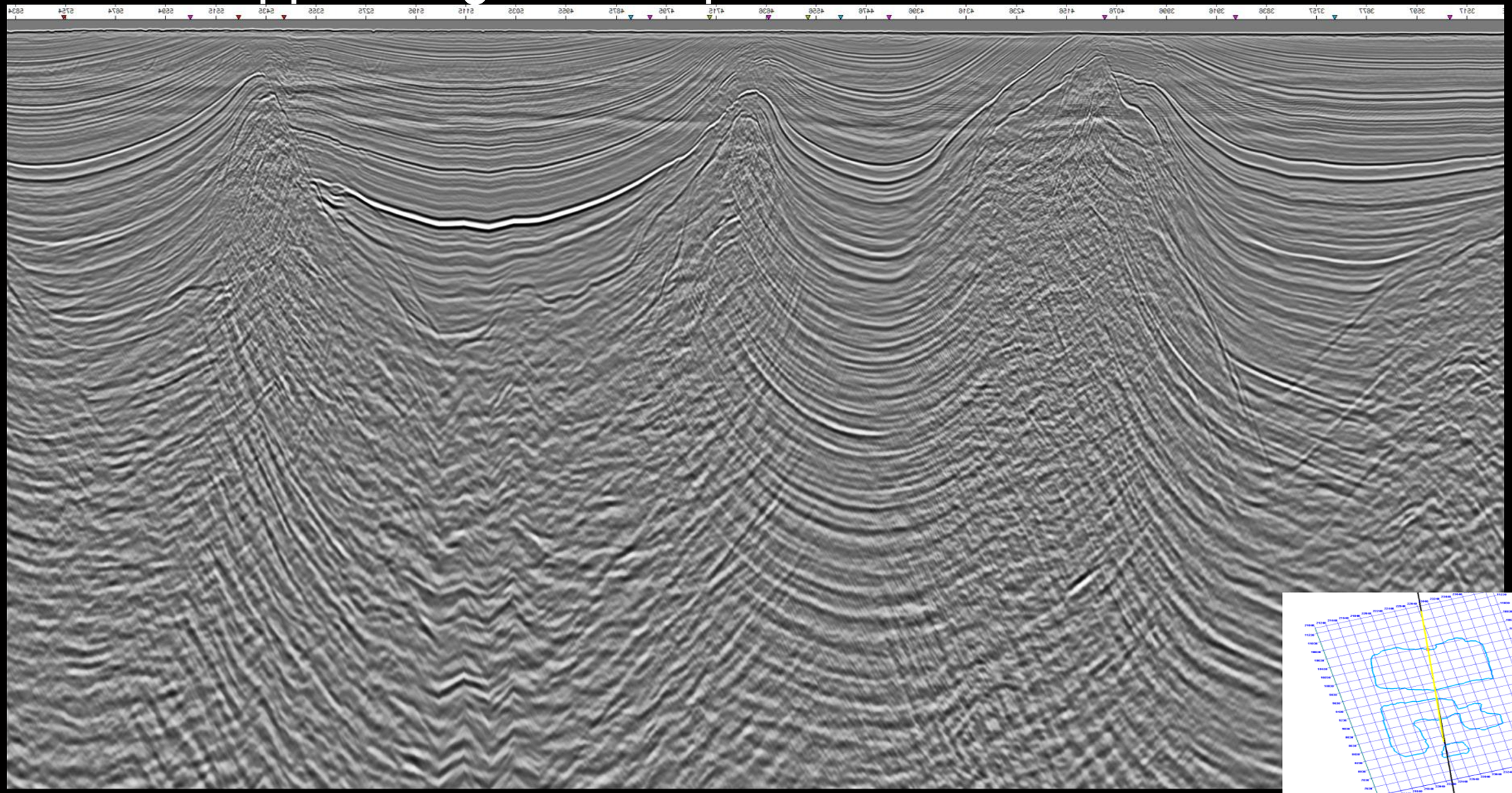
- Full Azimuth - Single Vessel Coil
- High Fold – 8km maximum offset

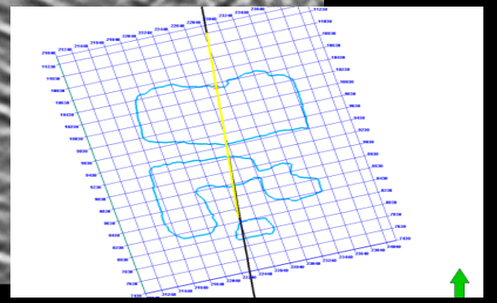




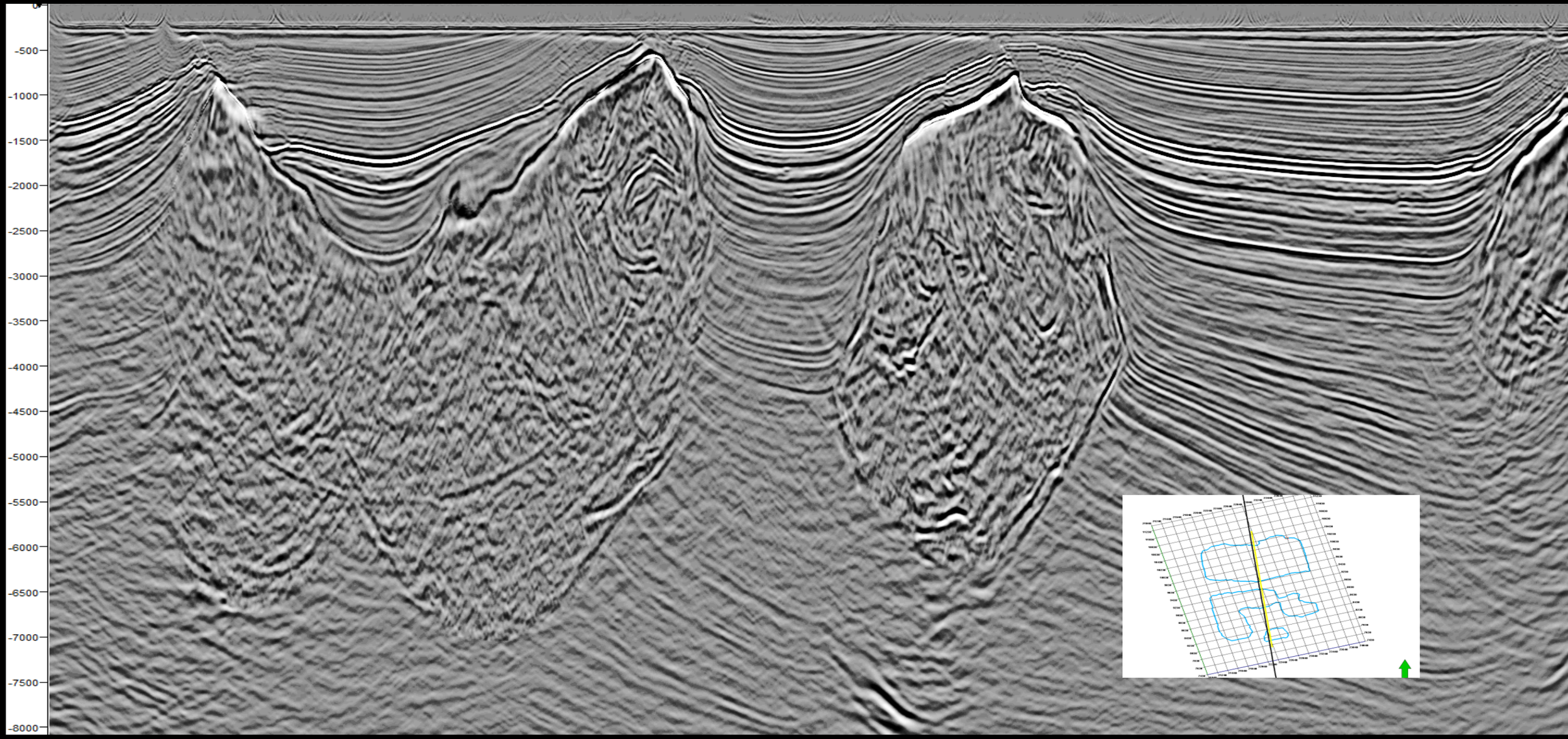


Nordkapp Vintage 2D acquisition

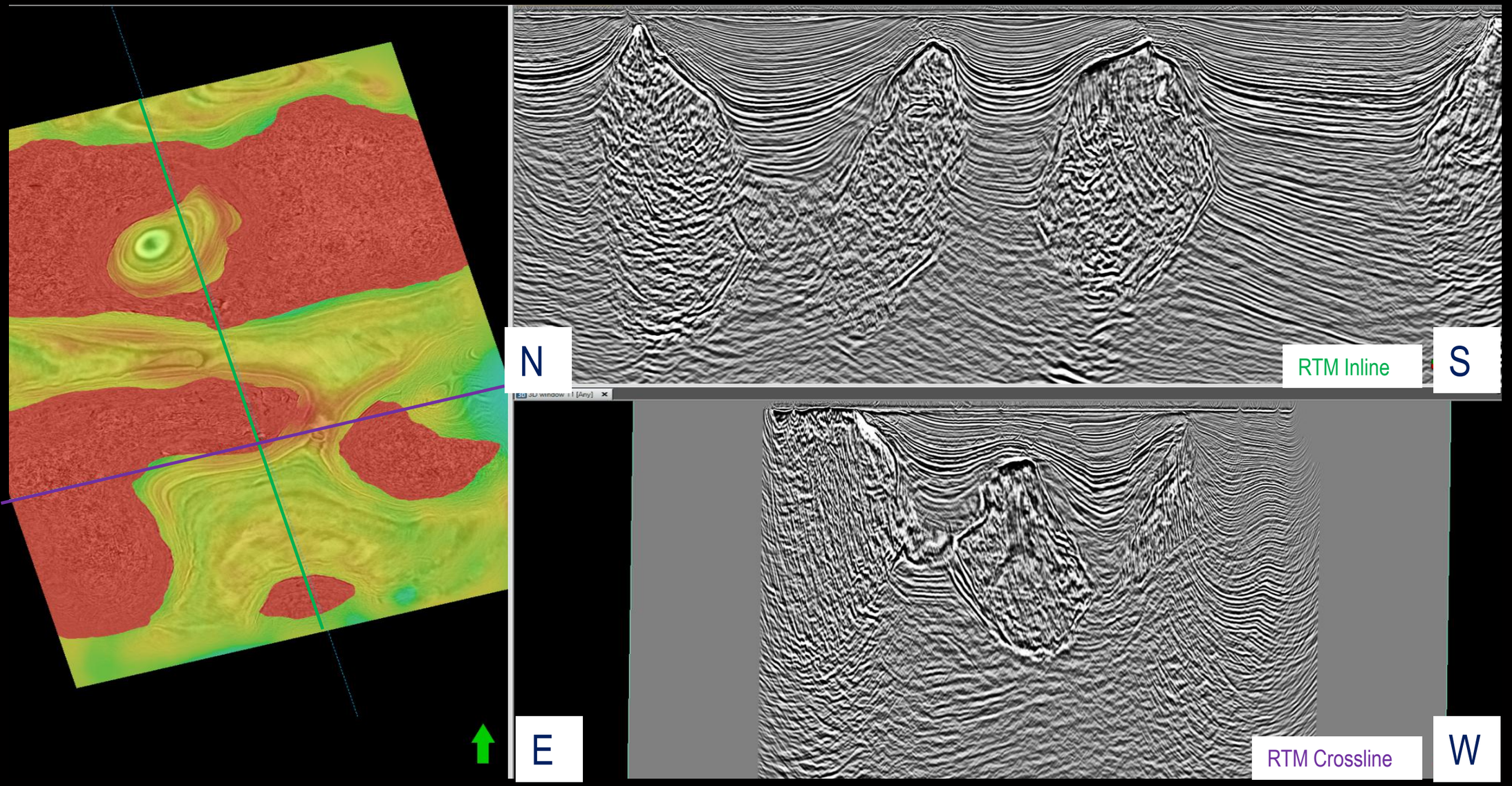




Nordkapp 2012 Single vessel ObliQ broadband COIL acquisition



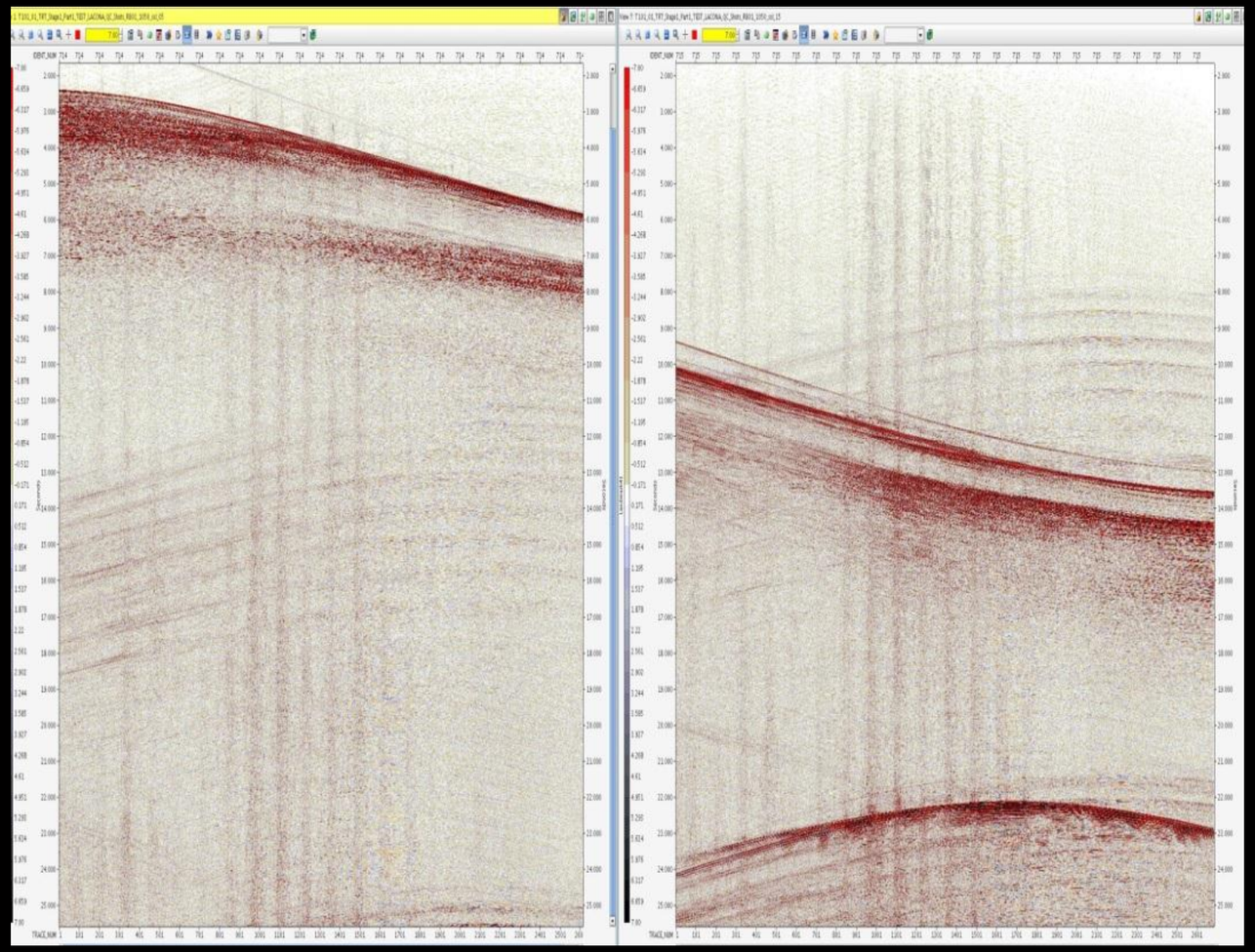
Optimised Weighted Stack – Salt Bodies

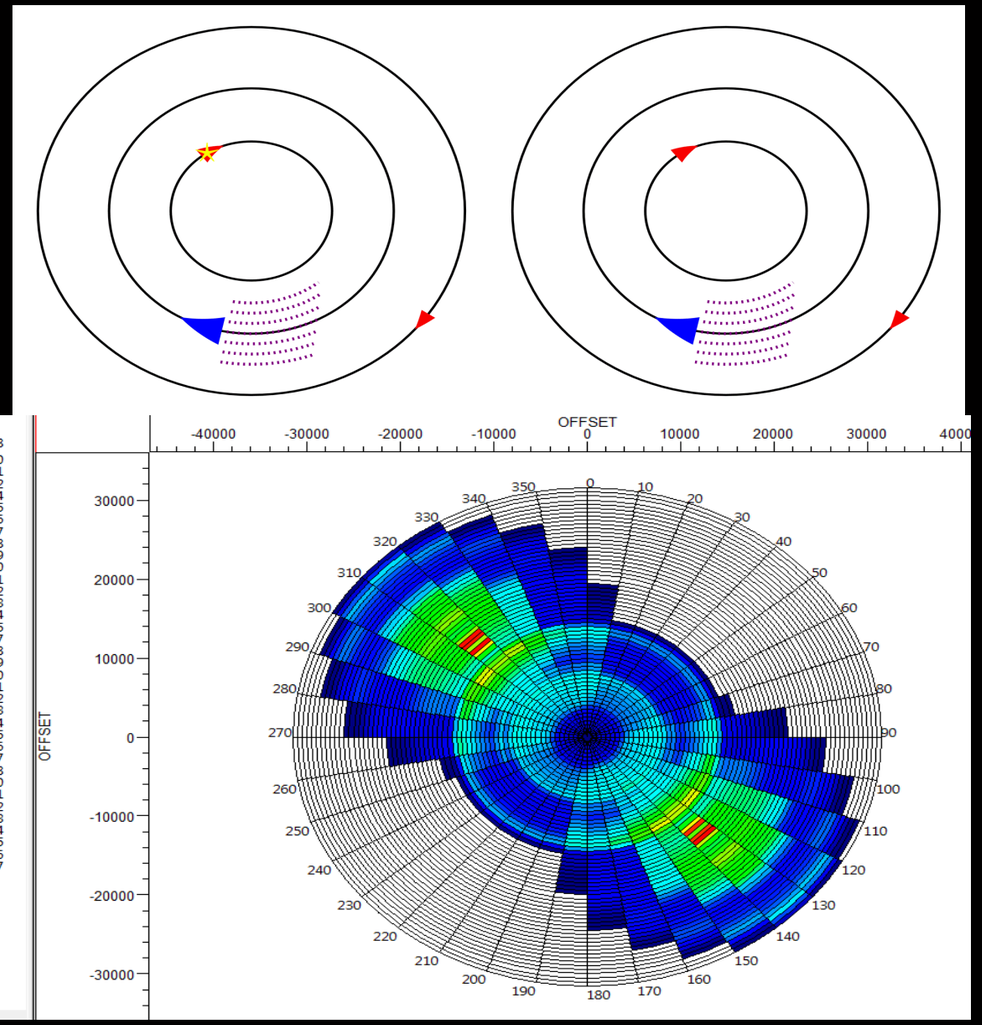


Future Directions

- Improvements in spatial and temporal seismic resolution and amplitude accuracy
  - Dense seismic sampling and ultra long offsets
  - Improved seismic sources
  - Implementing imaging algorithms from acoustic to elastic
  - Joint migration (including multiples) and inversion
- Reservoir characterization
  - Elastic rock properties
  - Pore properties
  - Fracture characterization
  - Permanent monitoring

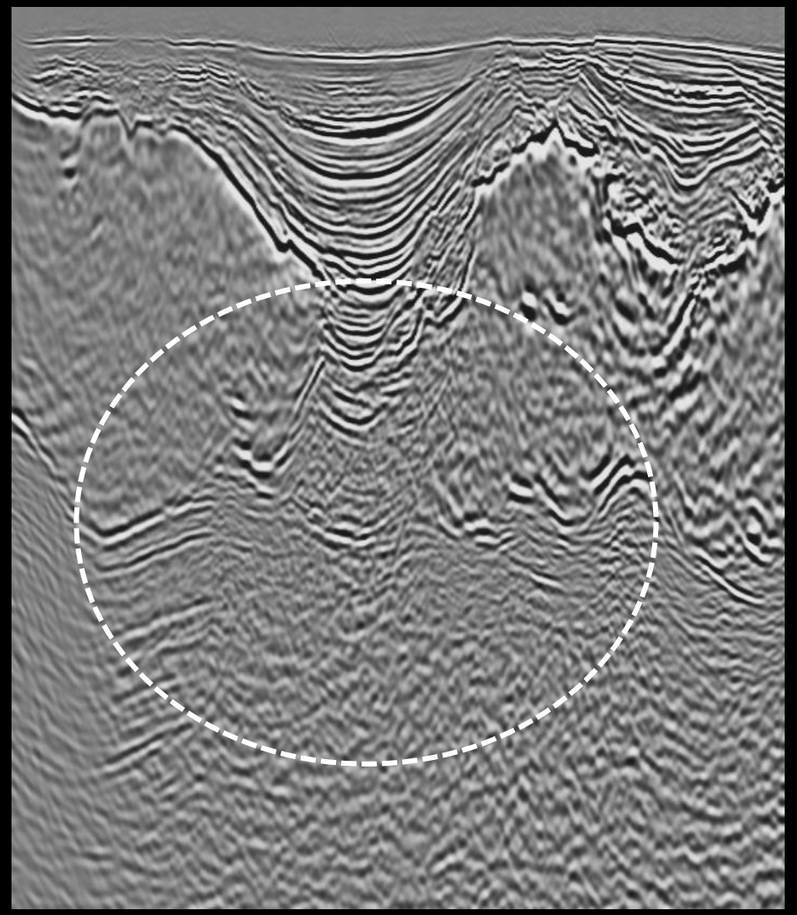
New acquisition test : 2 recording vessels and 6 sources
29 Km maximum offset and continuous recording



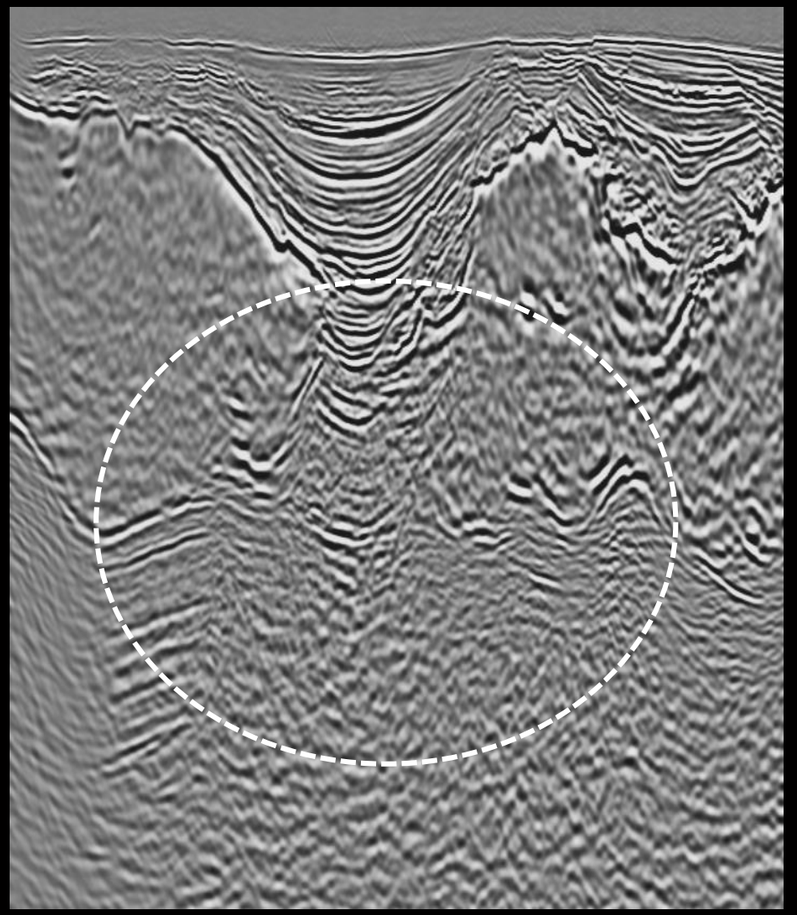


Subsalt imaging improvements with 29 kms offset test data

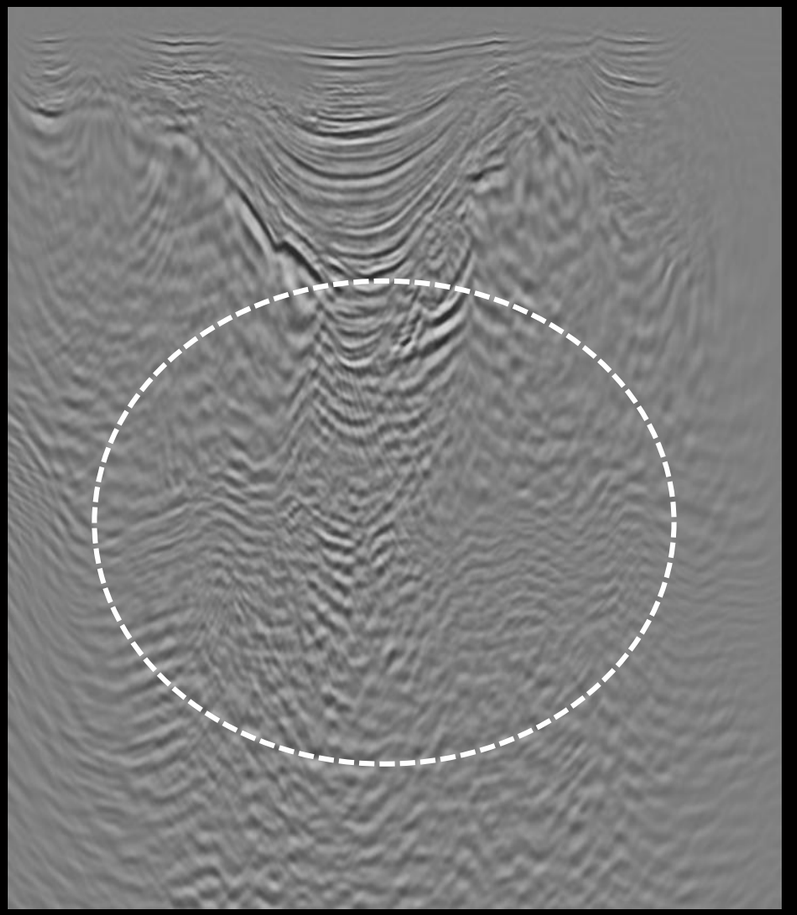
2x4 Dual COIL



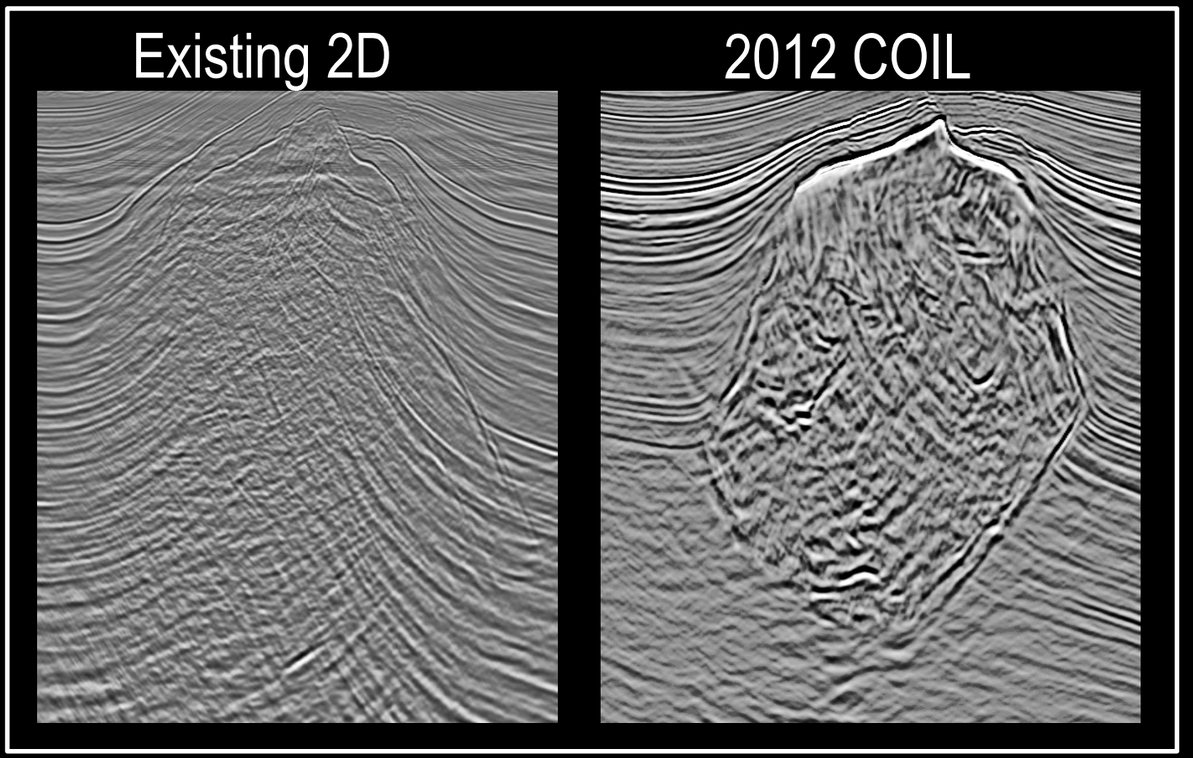
2x4 Dual Coil plus 2x6 test



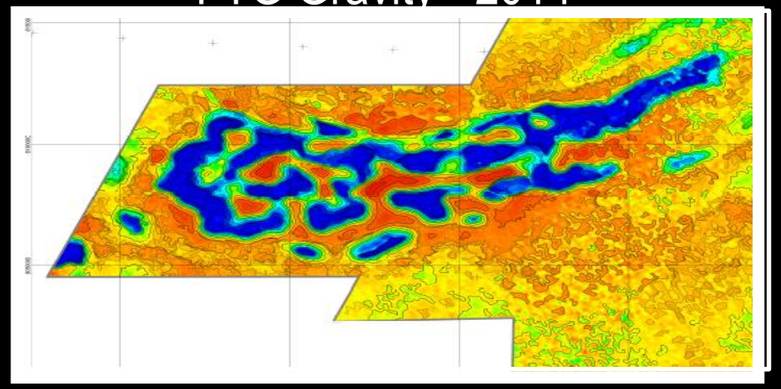
2x6 Dual Coil Long-offset contribution



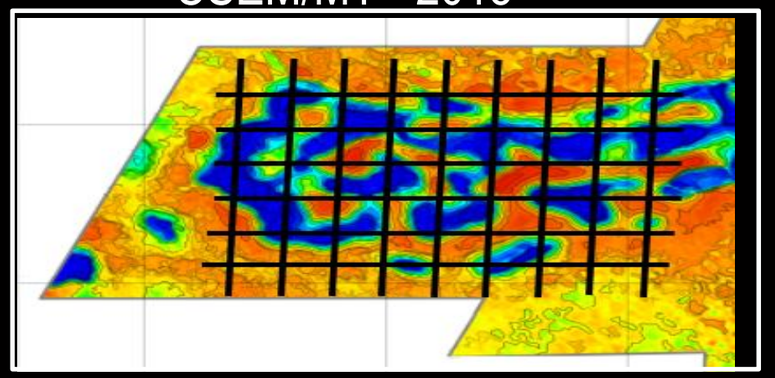
Unlocking the Nordkapp Basin
A four year plan



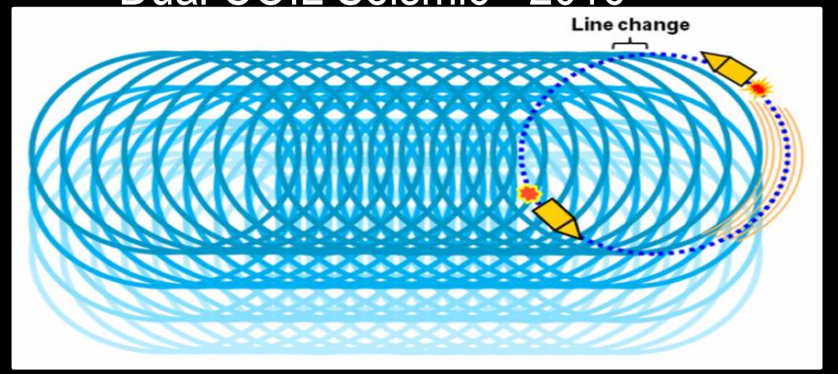
FTG Gravity - 2014



CSEM/MT - 2015



Dual COIL Seismic - 2016

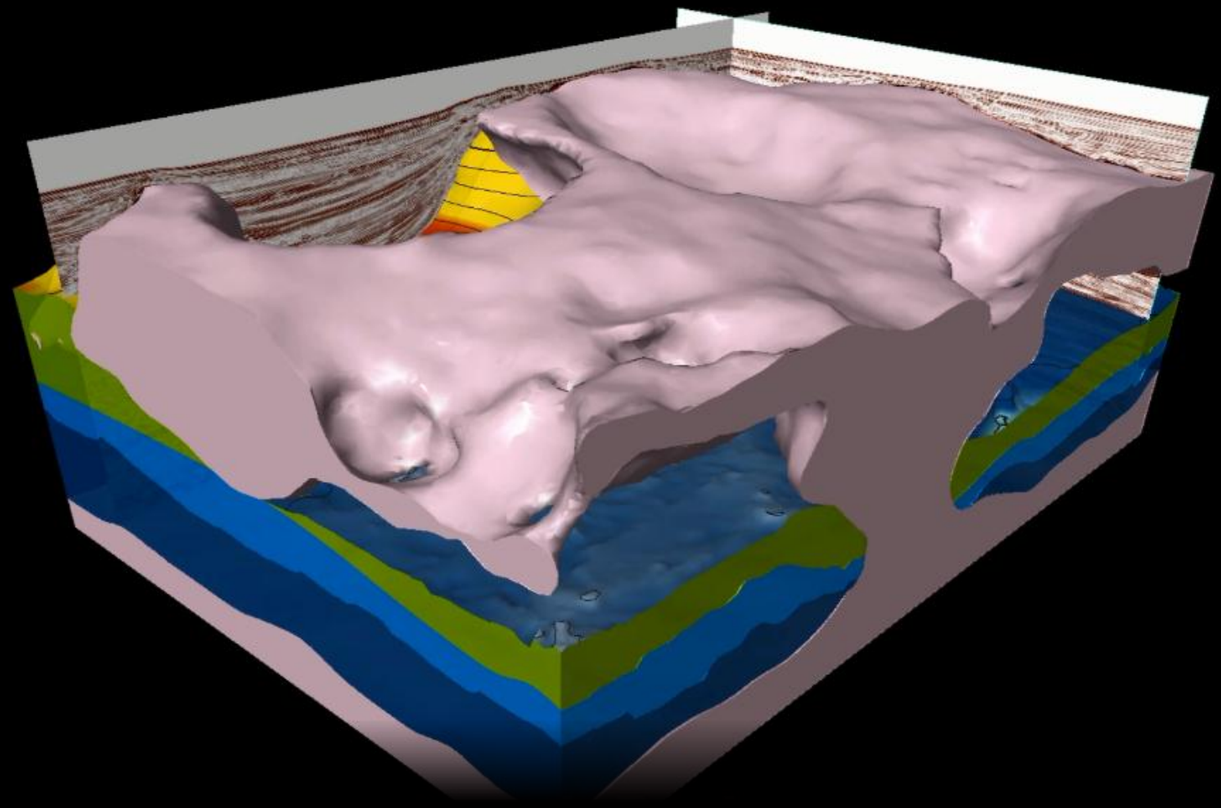


The pathway to subsalt

Resolve the overburden ➡

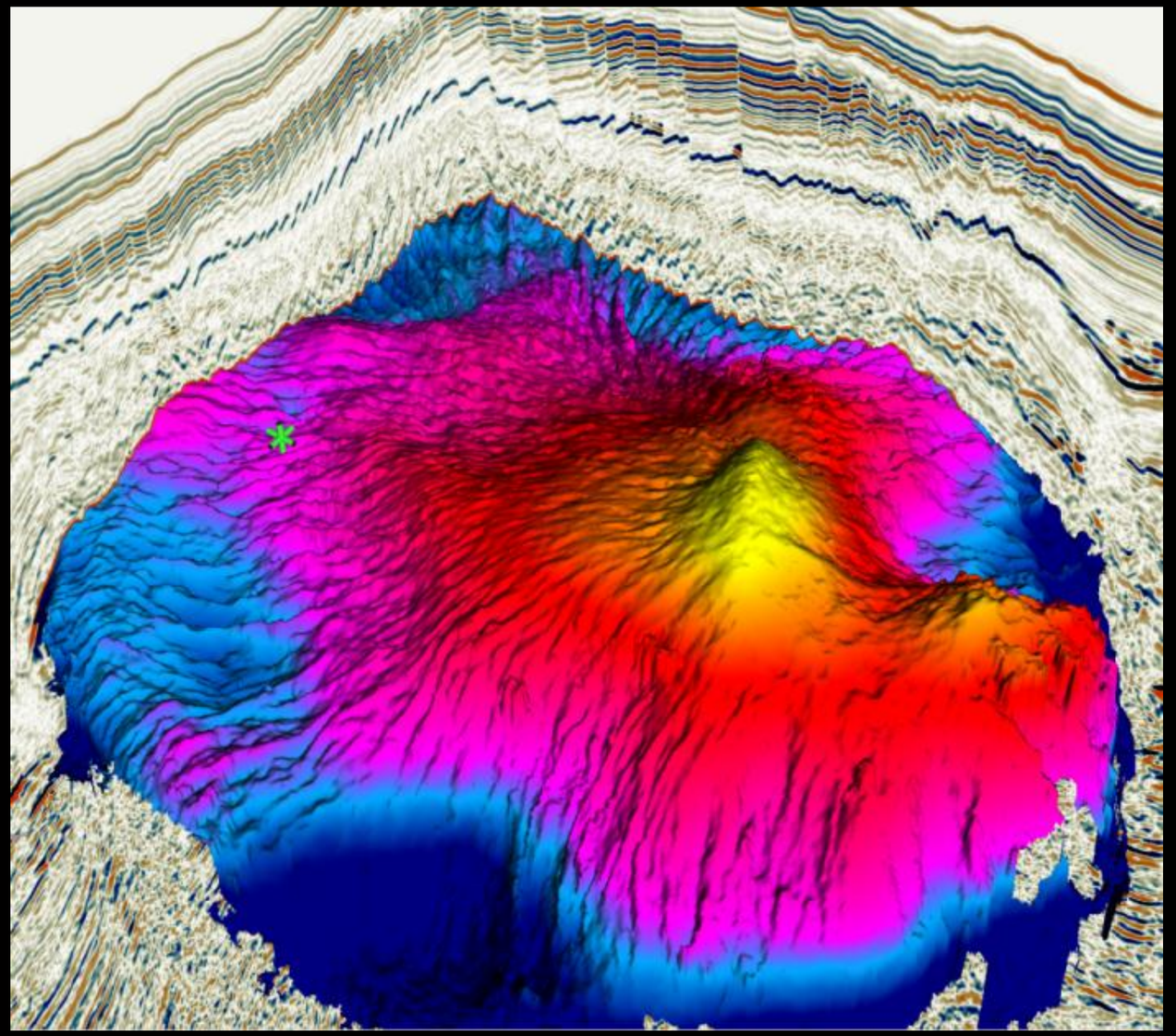
Define the salt ➡

Image subsalt ➡



Refine top-salt

- Rugose top-salt
- Top defines base
- Spatial sampling for accurate interpretation?



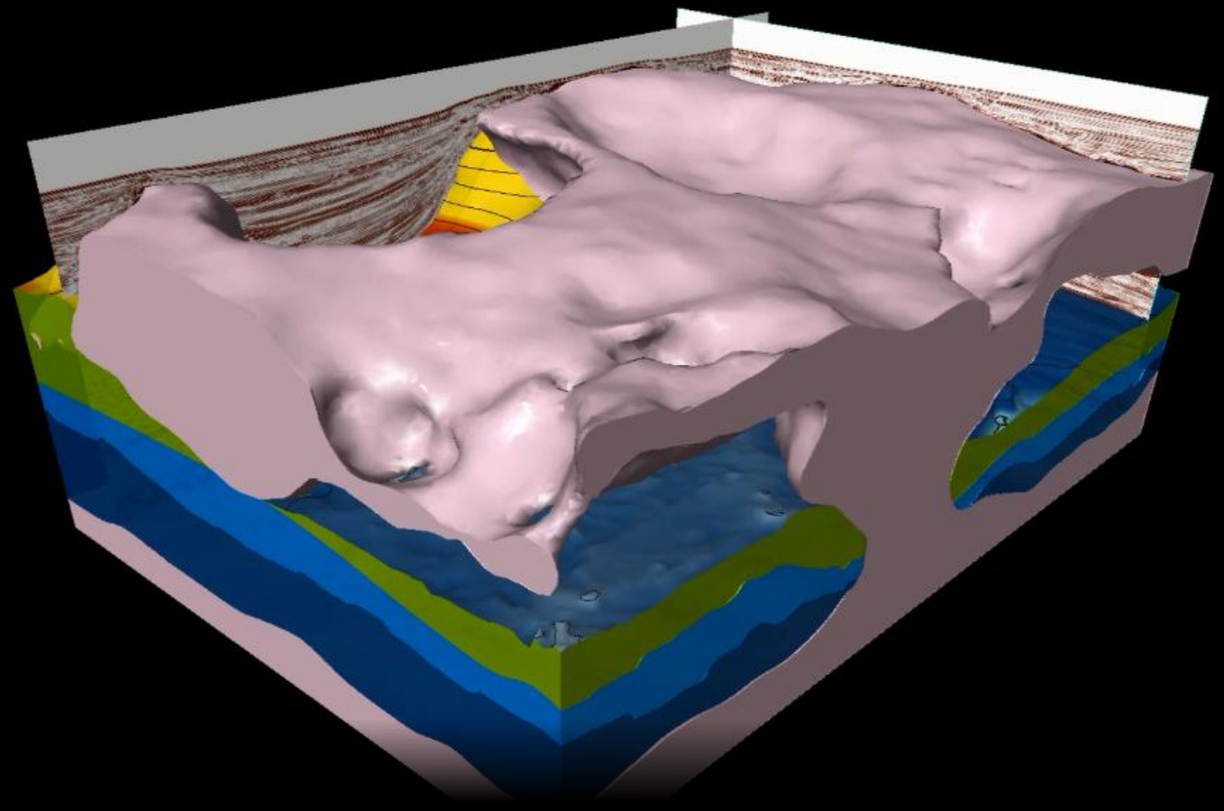
Conclusions

- Acquire full azimuth, long offset broadband data
- Multi-vessel coil shooting can generate very efficiently full azimuth, long and ultra-long offset data
- Build accurate earth models with FWI
- Image with RTM
- Keep improving both acquisition and processing technologies

- **Benefits for exploration, appraisal and development**
  - Salt-sediment interface & areas of steep dip
  - Event continuity & fault definition
  - Confidence in well planning and placement
  - Less uncertainty in volumetric calculations
  - Understanding possible reservoir compartmentalization

Thank you

Acknowledgments to Jerry Kapoor, Nick Moldoveanu, Chris Cunnell, Stuart Papworth, Denis Vigh



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