Hybrid Streamer and OBN surveys – BGP's Recent Experience

Dr Chris Walker
Chief Geophysicist

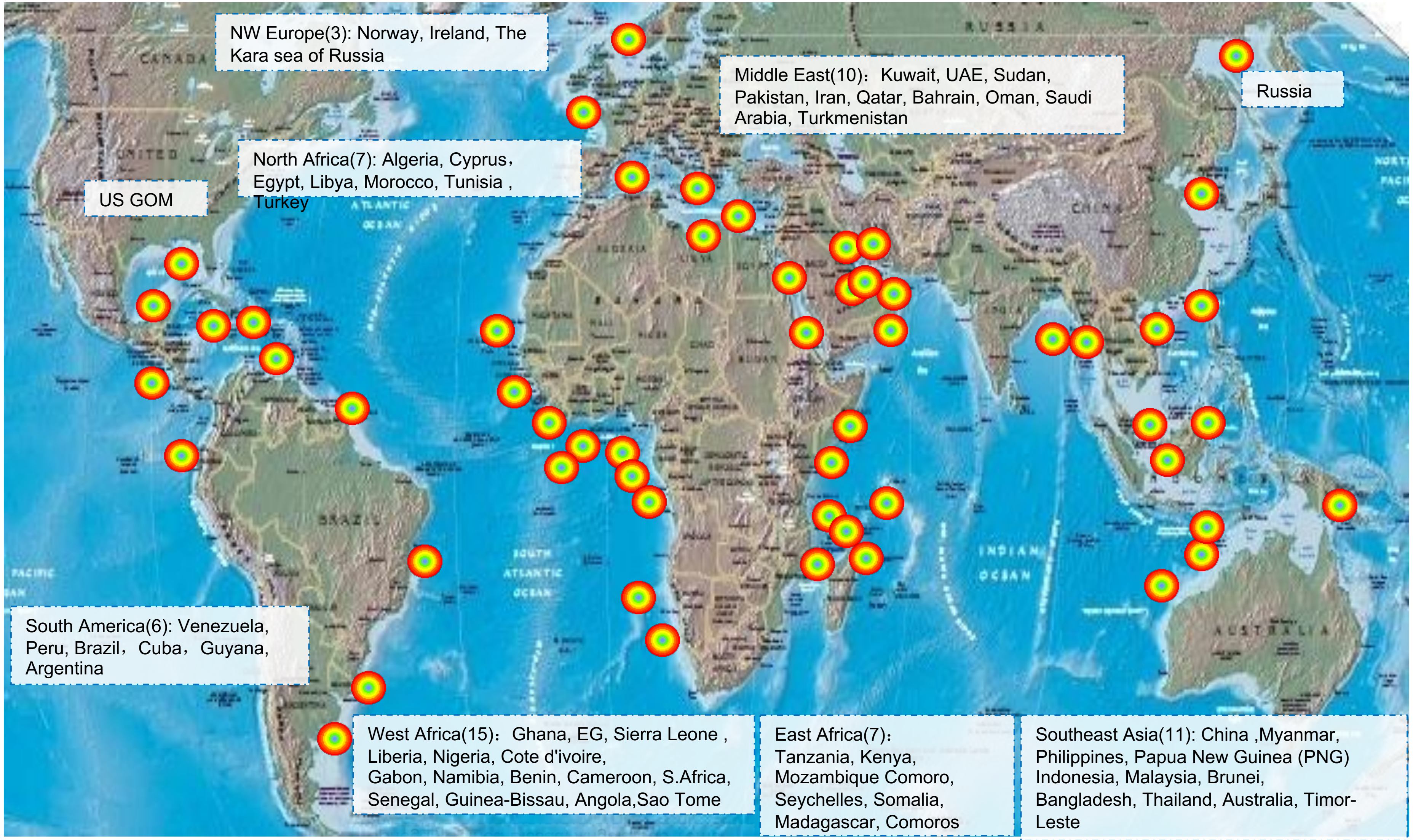
BGP Offshore

Hybrid Streamer and OBN surveys – BGP's Recent Experience

- Introduction
- Brunei Shell Hybrid 4D
- NCS Q35 Hybrid 3D
- Conclusions/Questions

Worldwide Operations

More than 60 countries, 280+ projects - 121 OBS, 144 Streamer, 16 Multi-Client - 80 clients



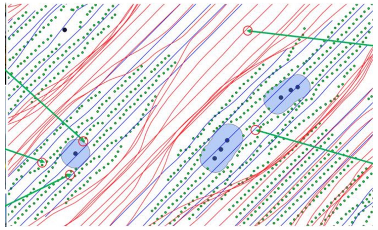
Client Base

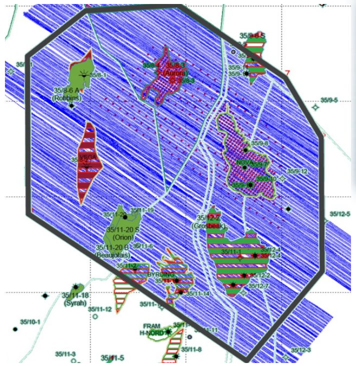
Major NOCs

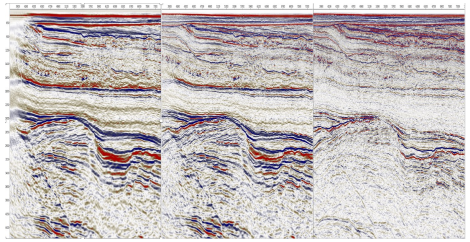
Major IOCs

Others

BGP Offshore: The world's most experienced OBN service provider







Streamer & OBN Imaging

BGP Innovator – Hybrid Vessel

9 x Ocean-going shooting vessels

100,000 Nodes

7 x Ocean-going Node handling vessels

7 x OBN crews

30+ Shallow water Node vessels

20,000 sqkm of OBN Backlog

20+ Shallow water Shooting vessels

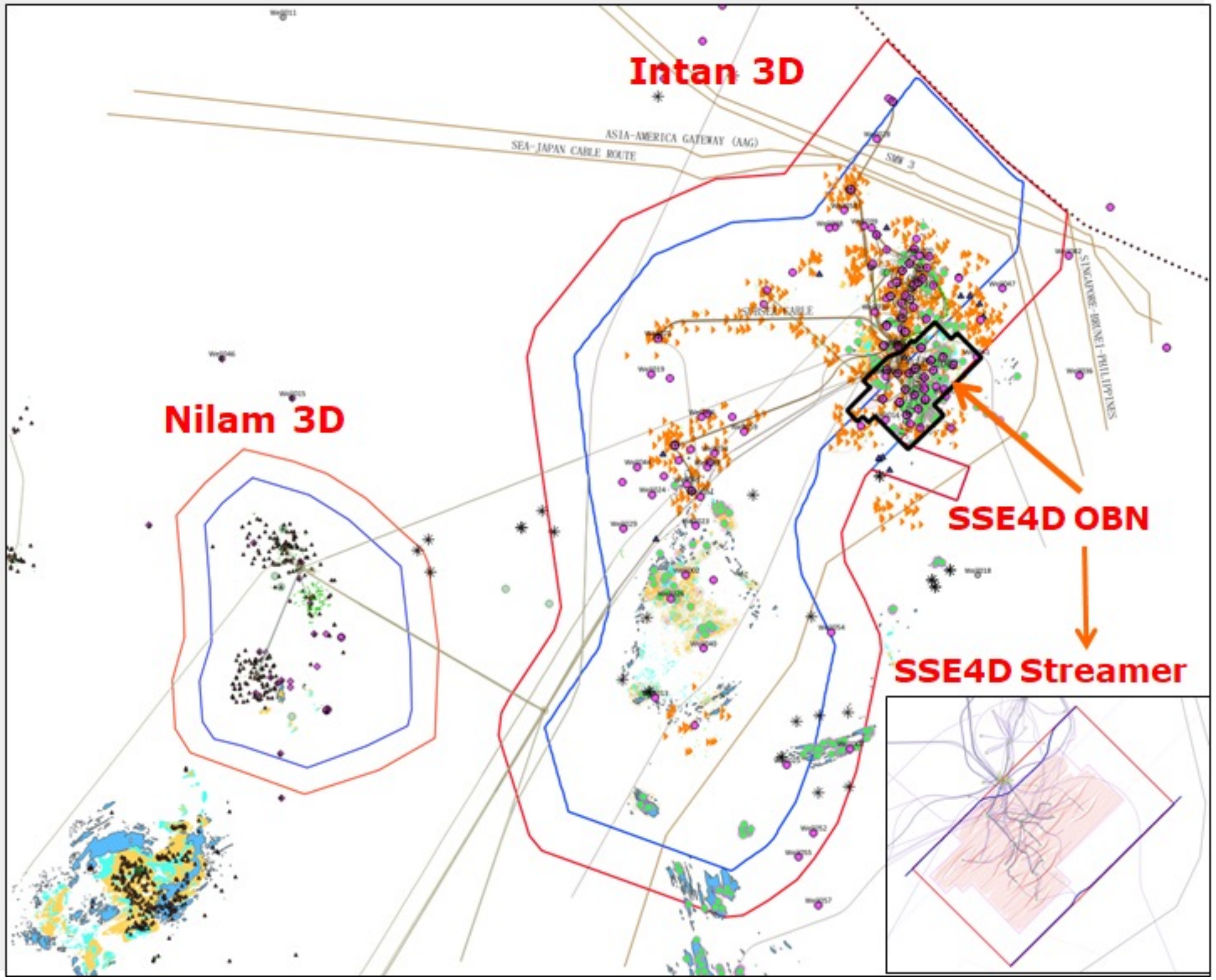
Hybrid Streamer and OBN surveys – BGP's Recent Experience

- Introduction
- Brunei Shell Hybrid 4D
- NCS Q35 Hybrid 3D
- Conclusions/Questions

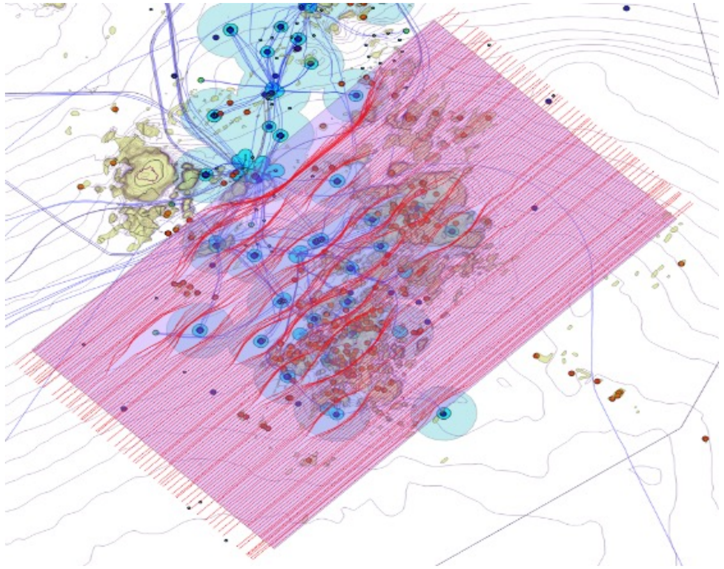
Brunei Shell Hybrid OBN/Streamer 4D Survey

Total work program:

- Intan
- SSE 4D OBN
- Nilam
- SSE 4D Streamer



Brunei Shell Hybrid 4D

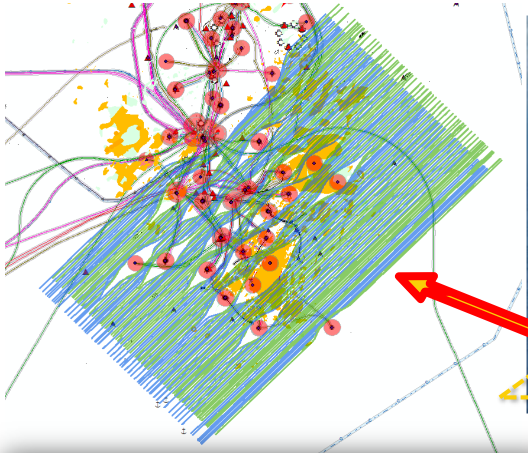


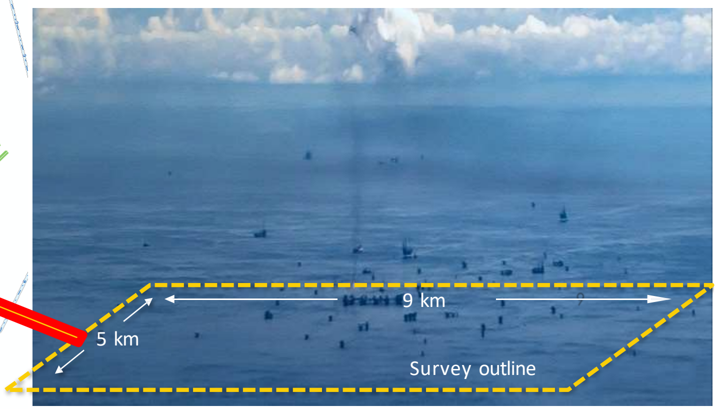
Brunei Shell Hybrid 4D

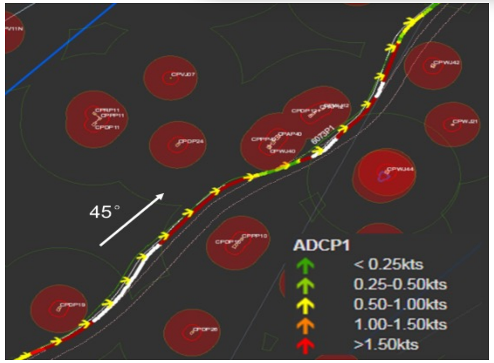
Survey Overview – The world's most difficult 4D project?

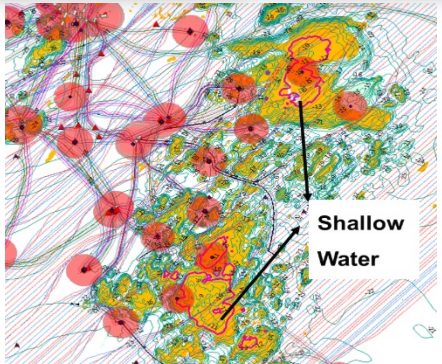
Challenges:

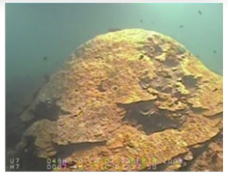
- 45 km^2 survey area
- 25 platforms
- SIMOPS
- Weather / Strong current
- Shallow water / Coral area

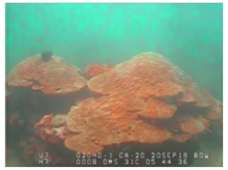




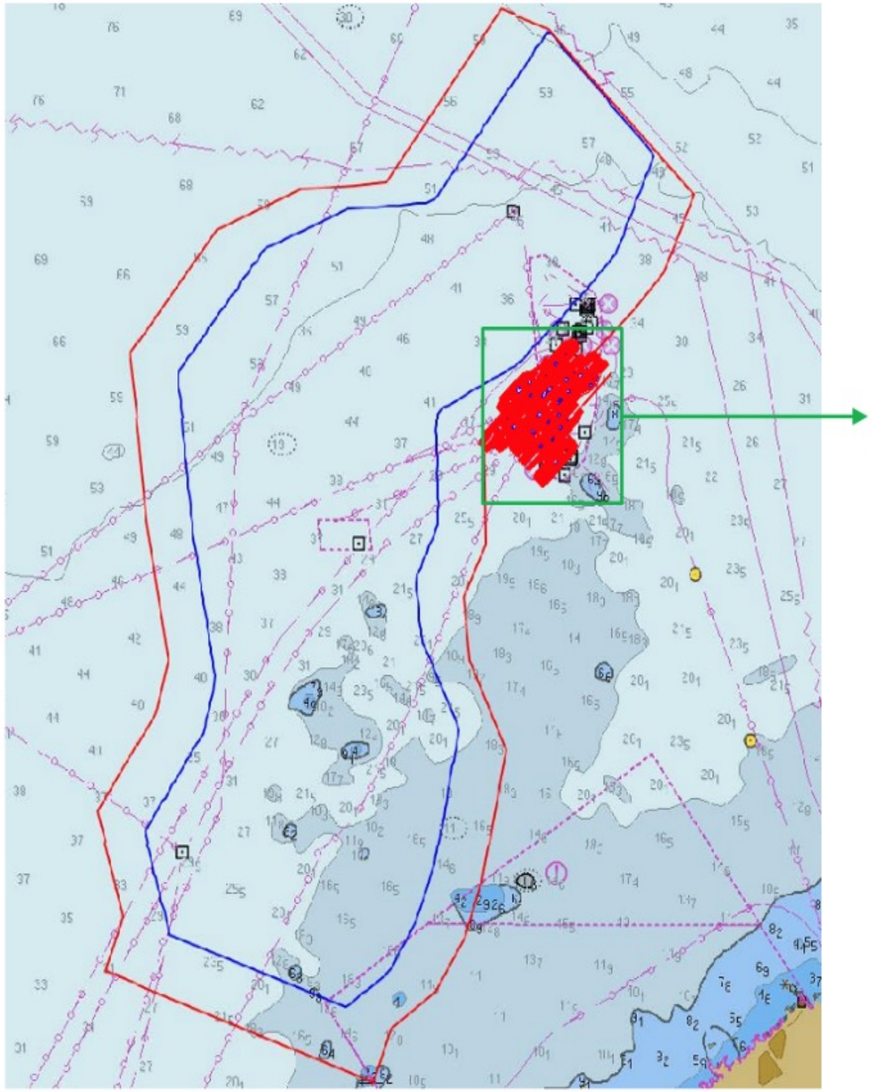


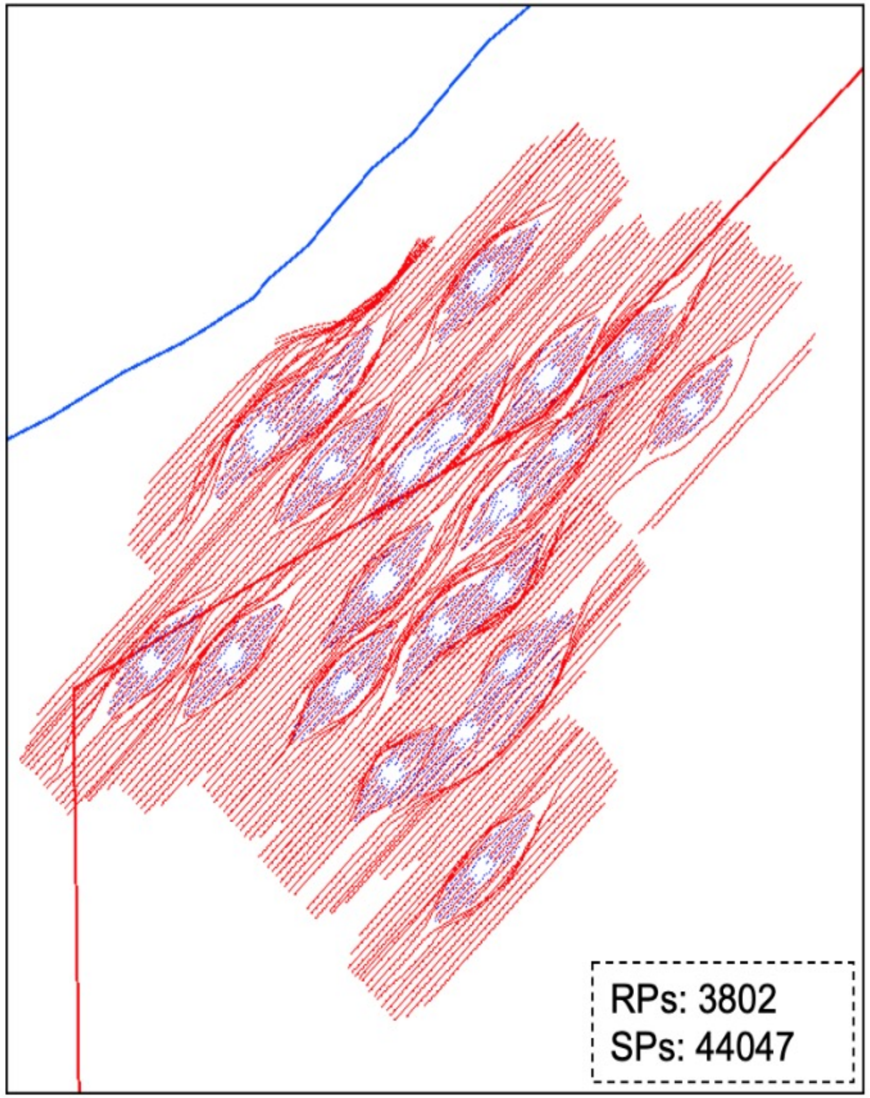




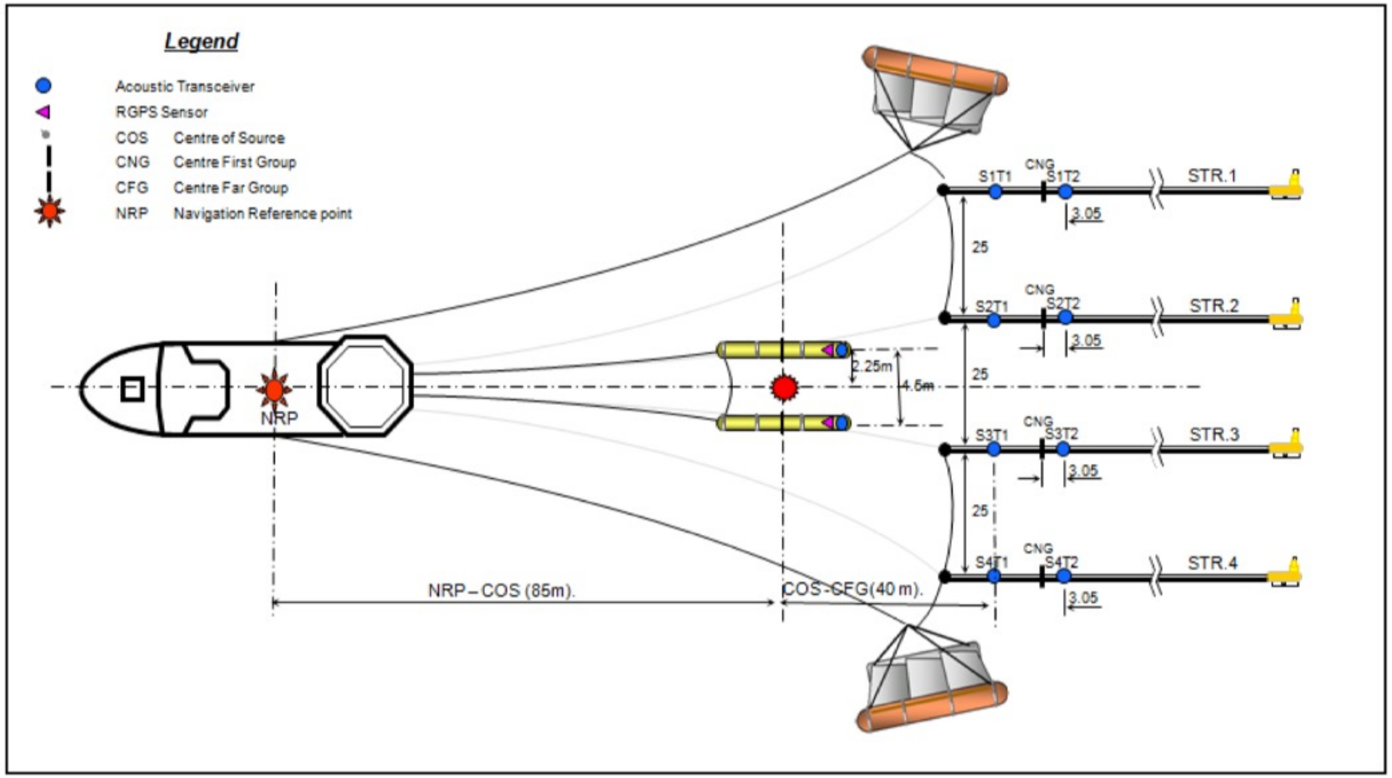


Brunei Shell Hybrid 4D

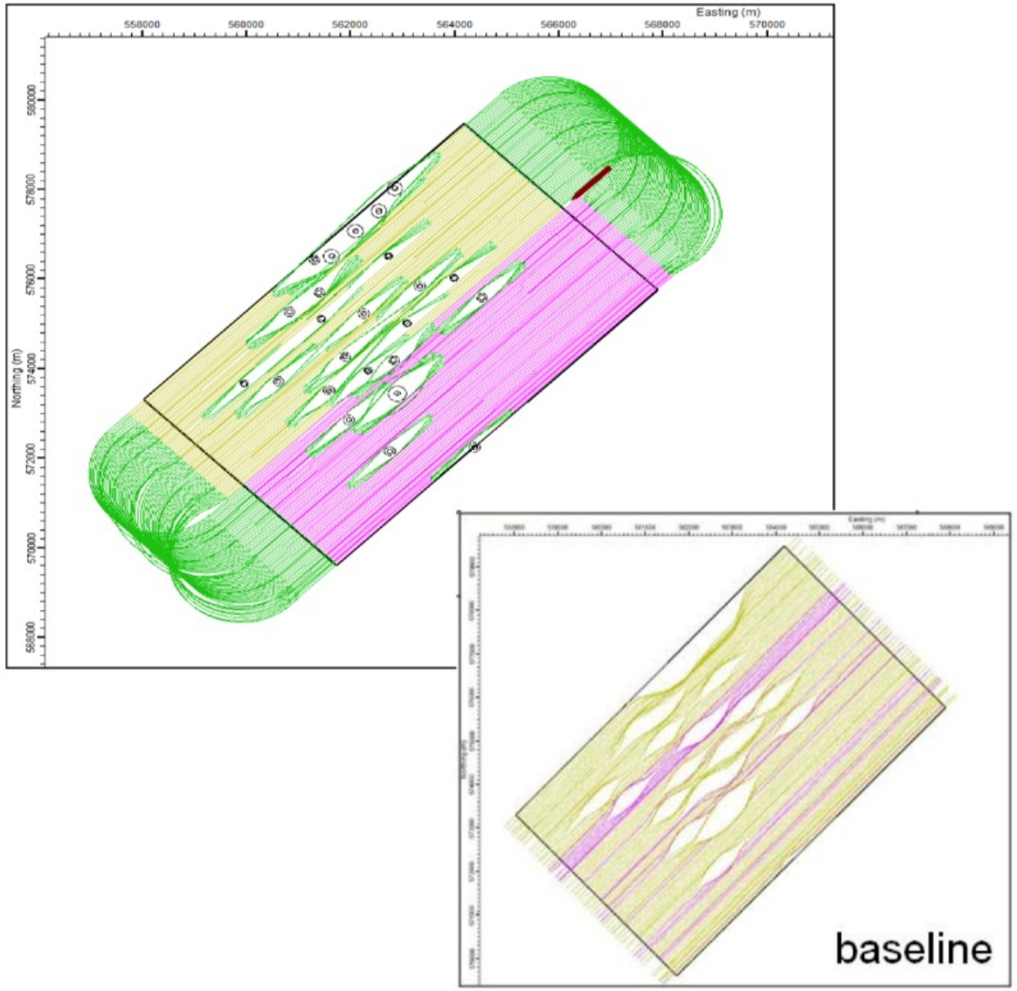




Brunei Shell Hybrid 4D

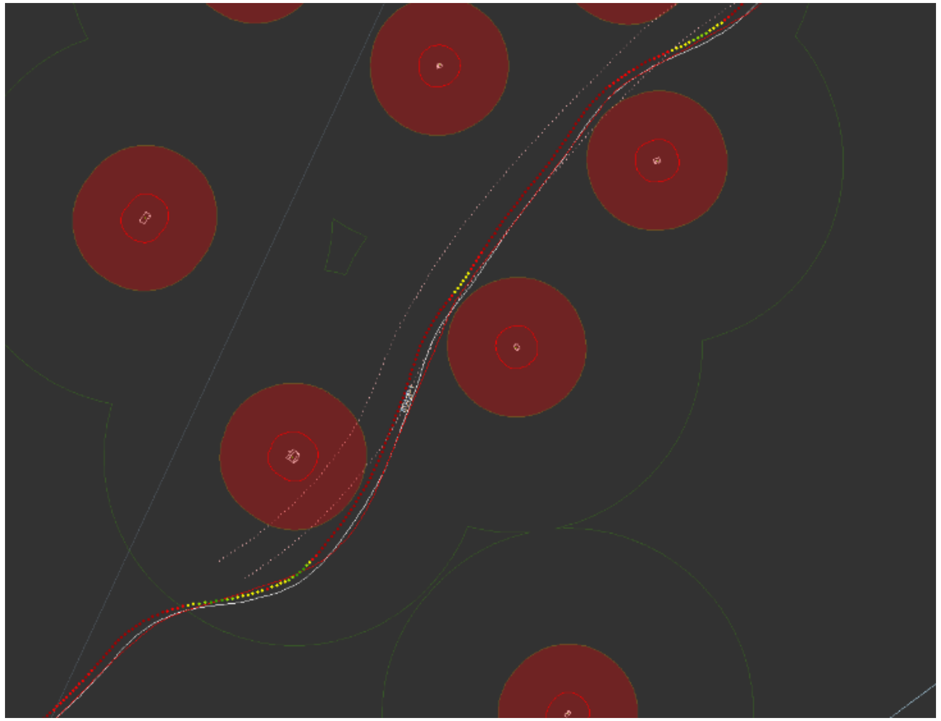


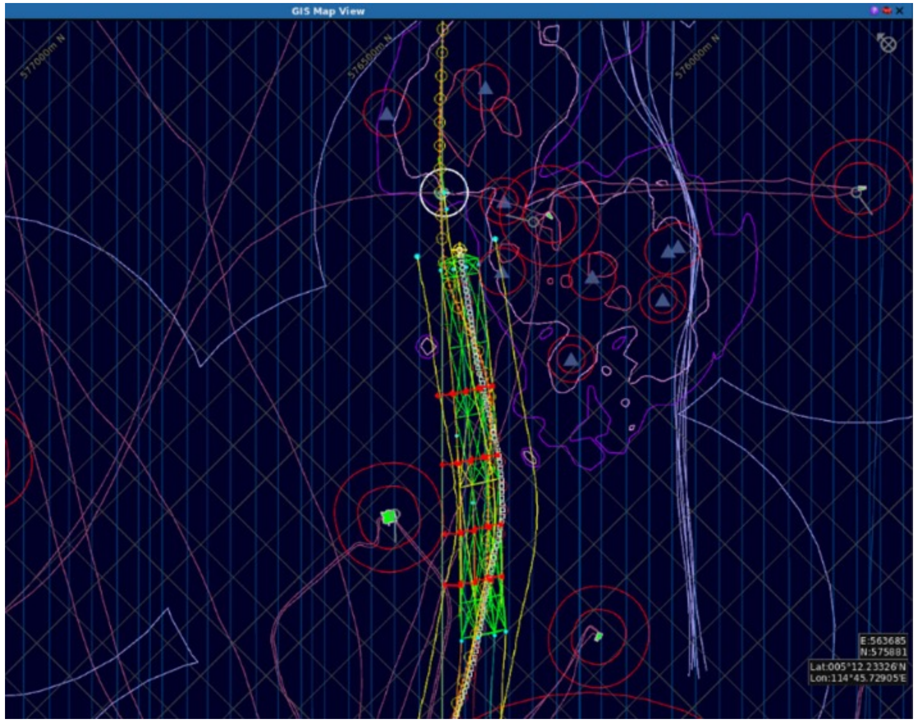
Streamer & Gun towing configuration



Brunei Shell Hybrid 4D

Close pass obstacles and shallow water area

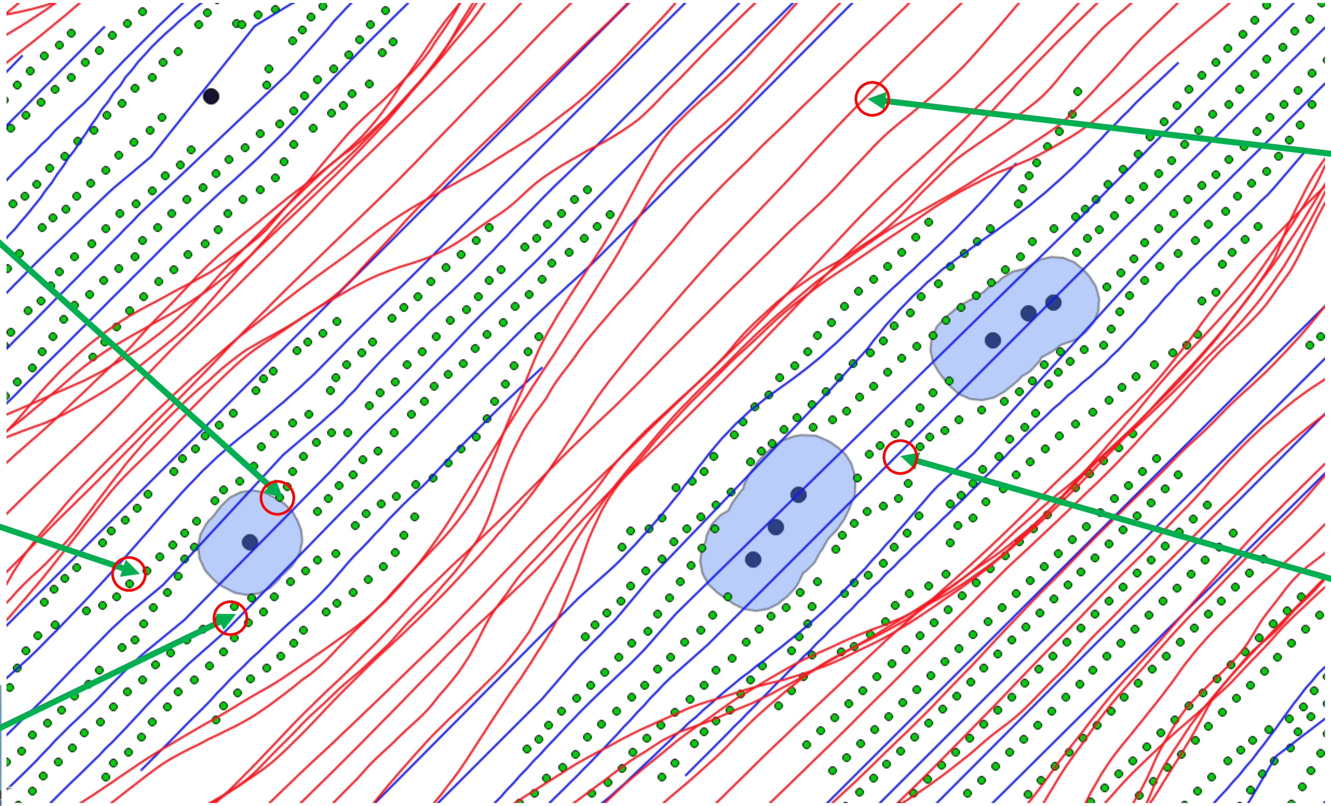




- 25 Platforms and 2 shallow water areas
- Number of close passes – 1184
- 50m steel-to-steel separation
- Max 13 close passes in 40 minutes

Brunei Shell Hybrid 4D

OBN 4D



① Node very close to platform deployed by ROV

② Nodes in shallow water area by shallow node vessel

③ Other nodes by deep water node vessel

④ “Open” area shots using deep source vessel

⑤ Shots close to platforms using shallow source vessel

Brunei Shell Hybrid 4D

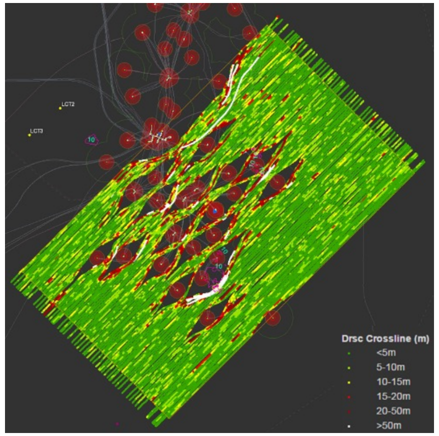
Inline/Crossline/Radial Source Repeatability – extreme deviations removed					
	Mean	% in 2m	% in 4m	% in 6m	% in 10m
Inline	0.2m	99.9	99.9	100	100
Crossline	5.3m	29.2	52.8	69.5	87.0
Radial	5.3m	28.9	52.7	69.5	86.9

Feather Statistics (°)	
Min	-28.46
Mean	-0.16
Max	31.95
Median	-0.37
SD	5.71

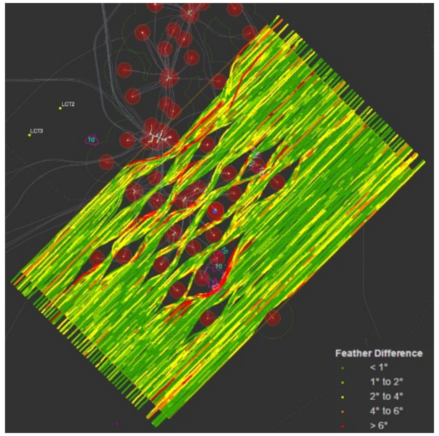
Good Feather match, Mostly < 1° outside congested area.

Brunei Shell Hybrid 4D

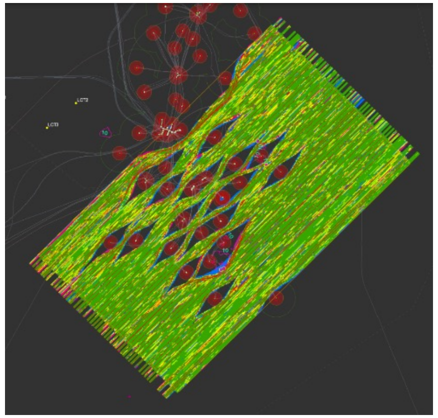
4D Repeatability



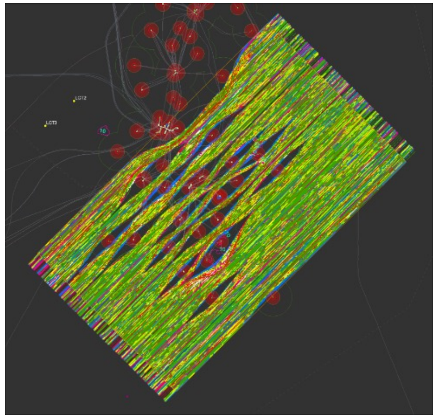
Dsrc crossline



Feather difference



DsrcDrx at near offset



DsrcDrx at far offset

- Source repeatability: Good adherence to preplot, 87% shot point crossline difference from preplot < 10m
- Feather repeatability: Good feather match, mostly < 1 degree outside of congested area
- Coverage of monitor is better than baseline
- Achieved excellent overall 4D repeatability considering the challenges of the survey area.

Conclusions

- Undershooting using nodes provides improved coverage compared to that delivered using a second shooting vessel especially for near offsets

- For towed streamer 4D in a heavily congested oilfield the use of a “digital twin” to rehearse multi-obstruction close pass operations proved invaluable from both an HSE and coverage perspective

- Node deployment using inspection class ROVs improves near offset coverage

Hybrid Streamer and OBN surveys – BGP's Recent Experience

- Introduction
- Brunei Shell Hybrid 4D
- NCS Q35 Hybrid 3D
- Conclusions/Questions

Q35 Hybrid 3D

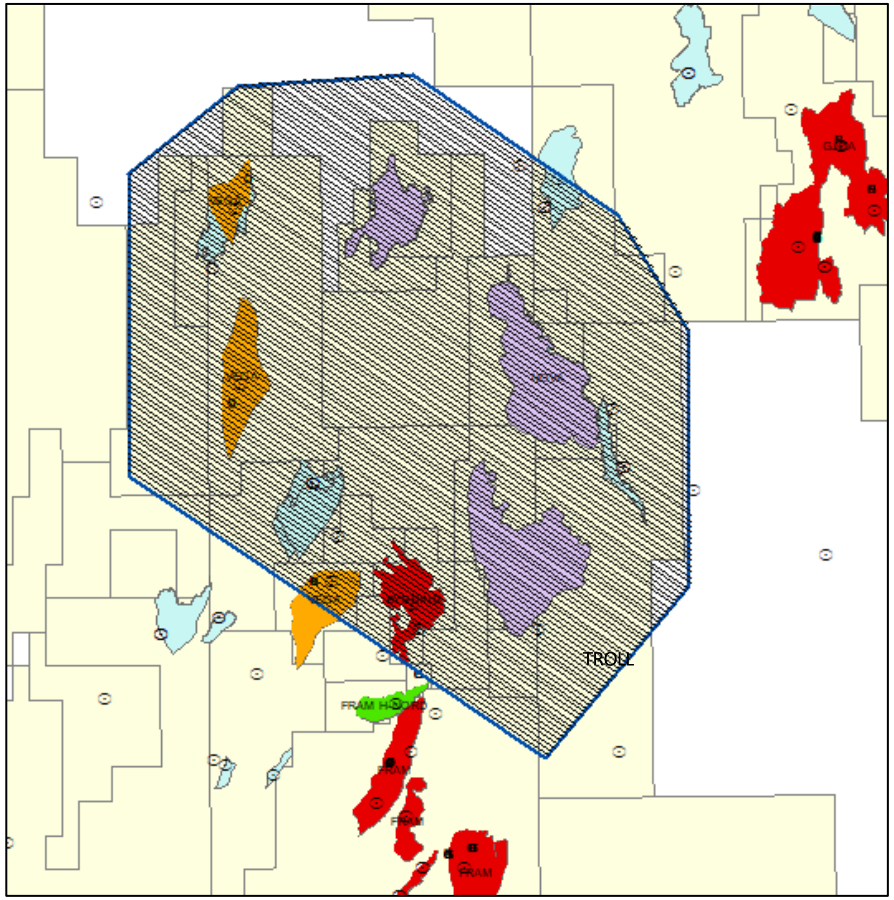
- Introduction
- Norway Quad-35 OBN survey
- Quad-35 FWI and FWI Imaging

Q35 Hybrid 3D

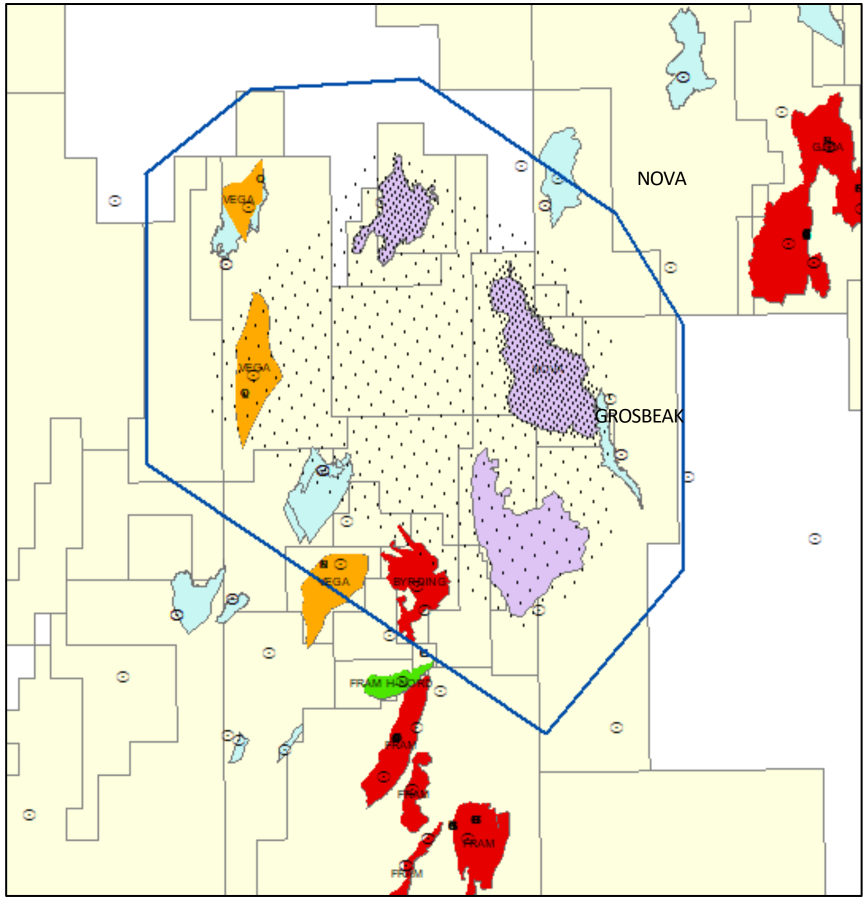
- In 2020 BGP Offshore acquired the world’s first combined, simultaneously acquired ultra-high density streamer and node Multi-Client 3D Survey in the Q35 area offshore Norway
- The project was conceived by Geoex MCG and Seismic Partner and was executed by a consortium of companies:-
  - BGP Offshore – *3D streamer acquisition*
  - Reach Subsea – *node deployment and recovery*
  - MagseisFairfield – *node provider*
  - DUG – *Streamer Data Processing*
- In addition to DUG’s “conventional” 3D processing, BGP R&D in Houston imaged the OBN data through 50Hz RTM using compressive sensing based wavefield reconstruction to generate a shot carpet from the streamer shots

Q35: Hybrid Streamer / Node Survey

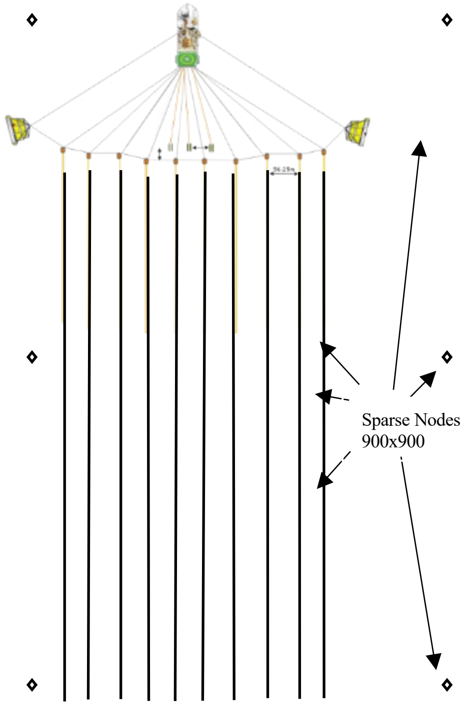
102 streamer SAIL LINES



982 NODES

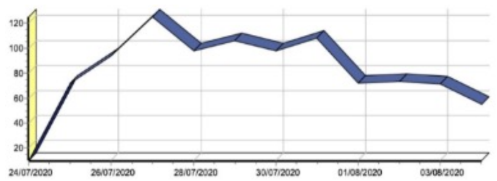


Q35: Hybrid Streamer / Node Survey

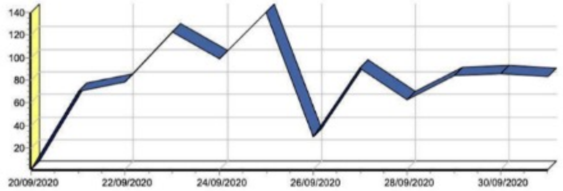


Long endurance nodes placed on the seafloor for entire duration of the survey

Source grid:	75:75:75 x 31.25
FWI node grid:	900m x 900m over entire area
Imaging node grid:	300m x 300m node over areas of interest
Source:	3x2000 cu in [flip/flop/flap]
Source separation:	75m
SP interval flip to flip:	31.25m between same source
SP interval flip/flop/flap:	10.416m
Streamer:	10x8000m
Streamer Separation:	56.25m
Record Length:	10sec [extracted from continuous recording]
Bin size [crossline x inline]:	9.375m x 6.25m
Fold:	128

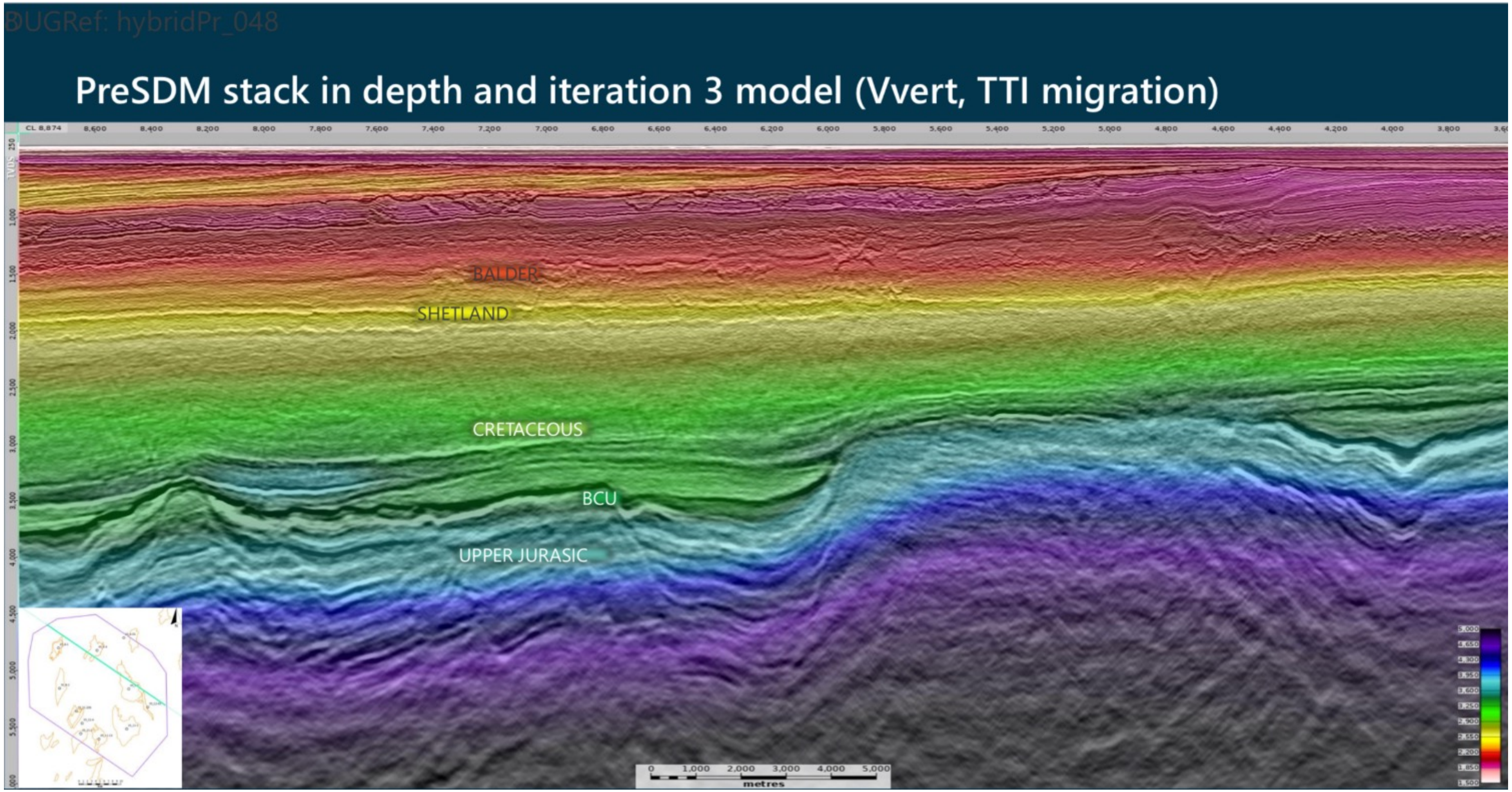


Node Deployment

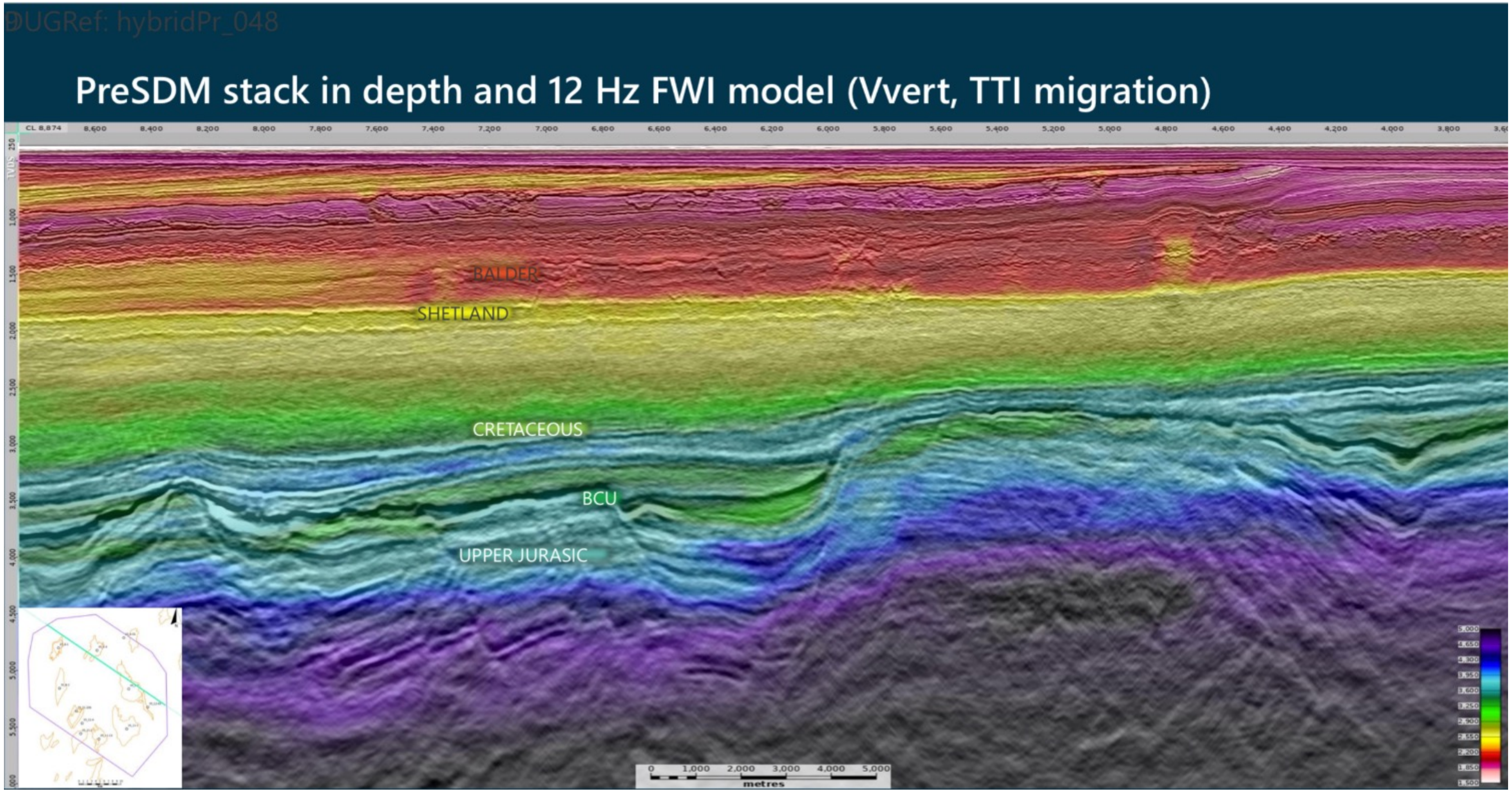


Node Recovery

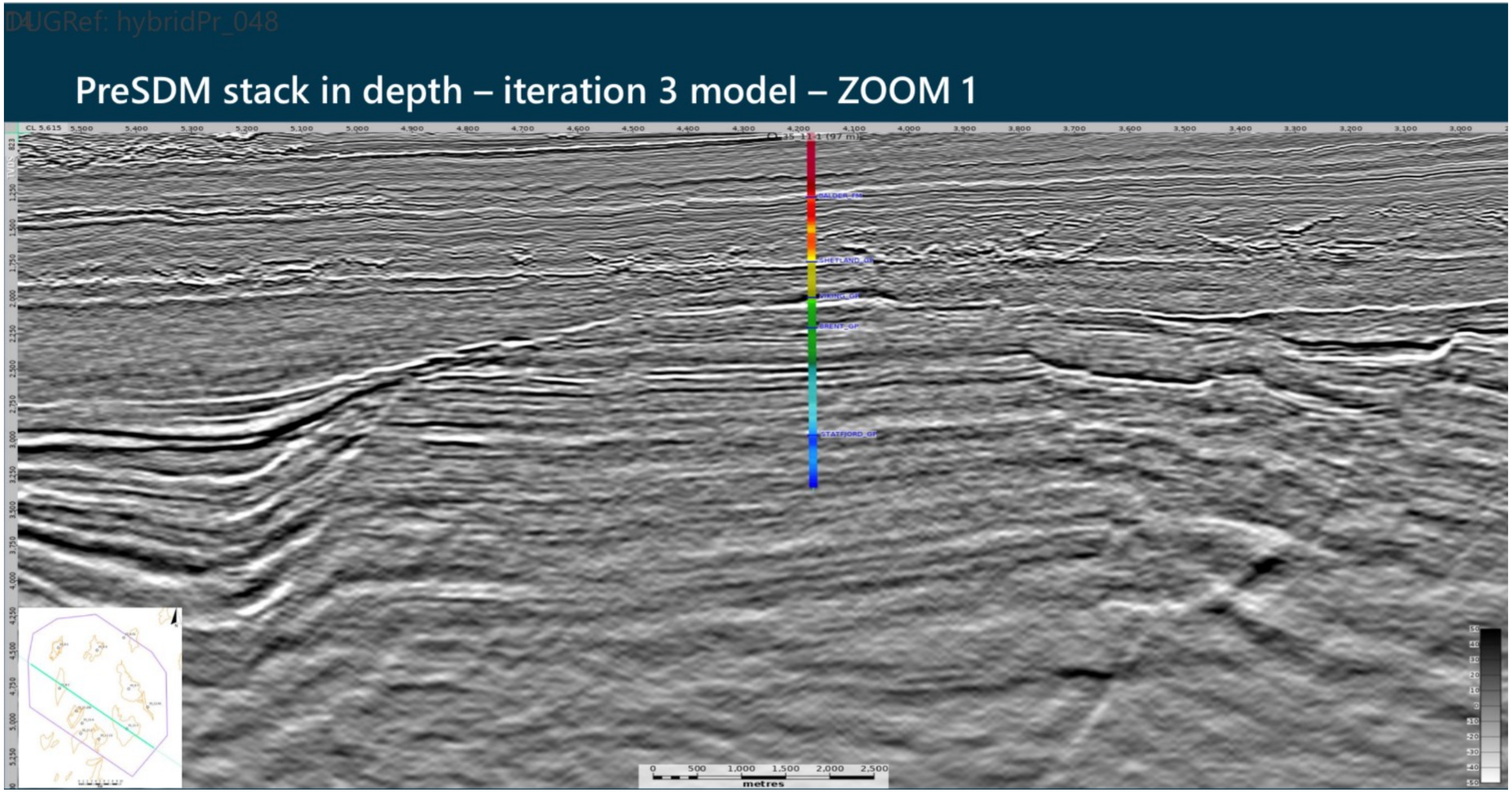
Q35: Hybrid Streamer / Node Survey



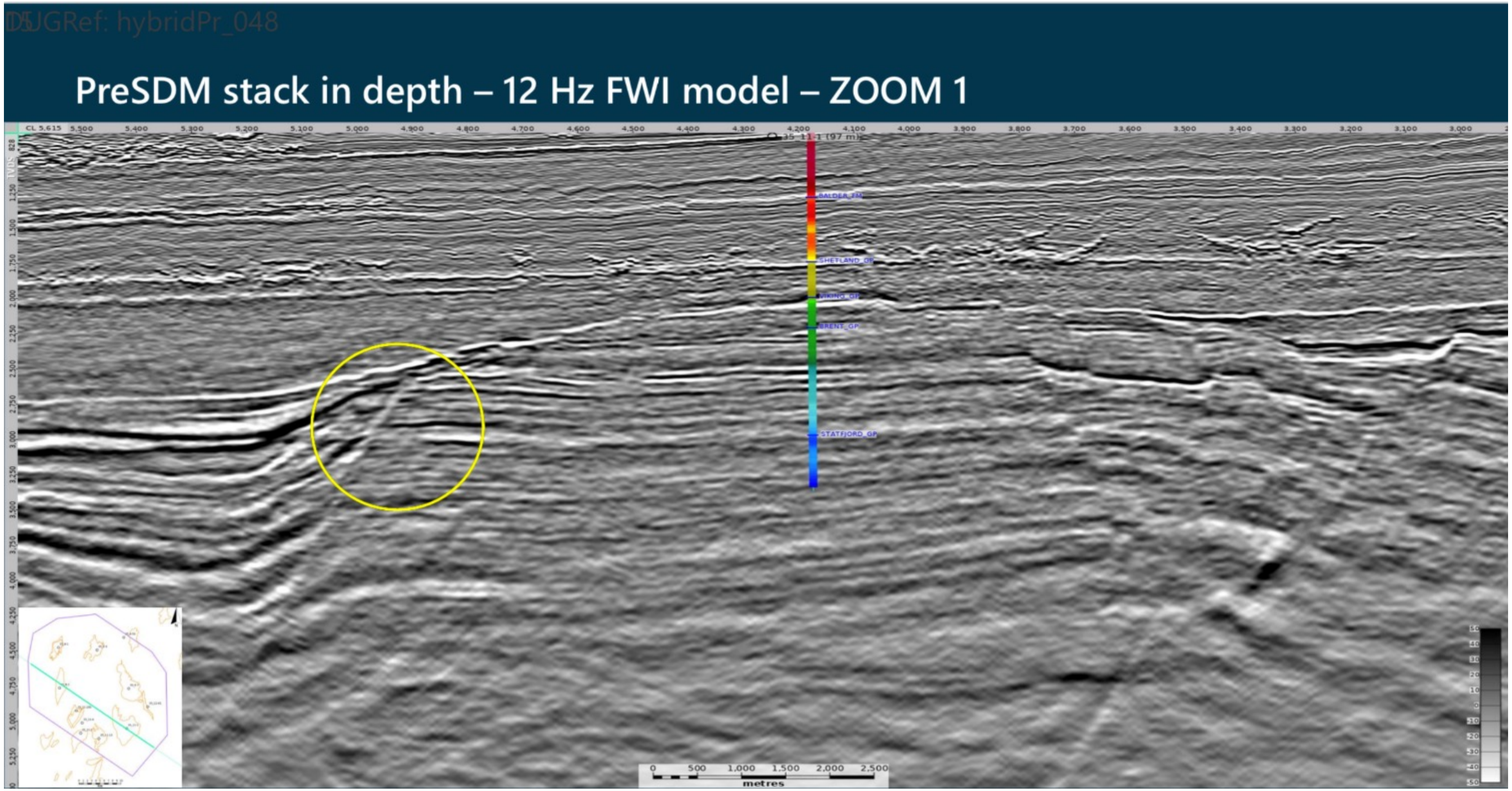
Q35: Hybrid Streamer / Node Survey



Q35: Hybrid Streamer / Node Survey



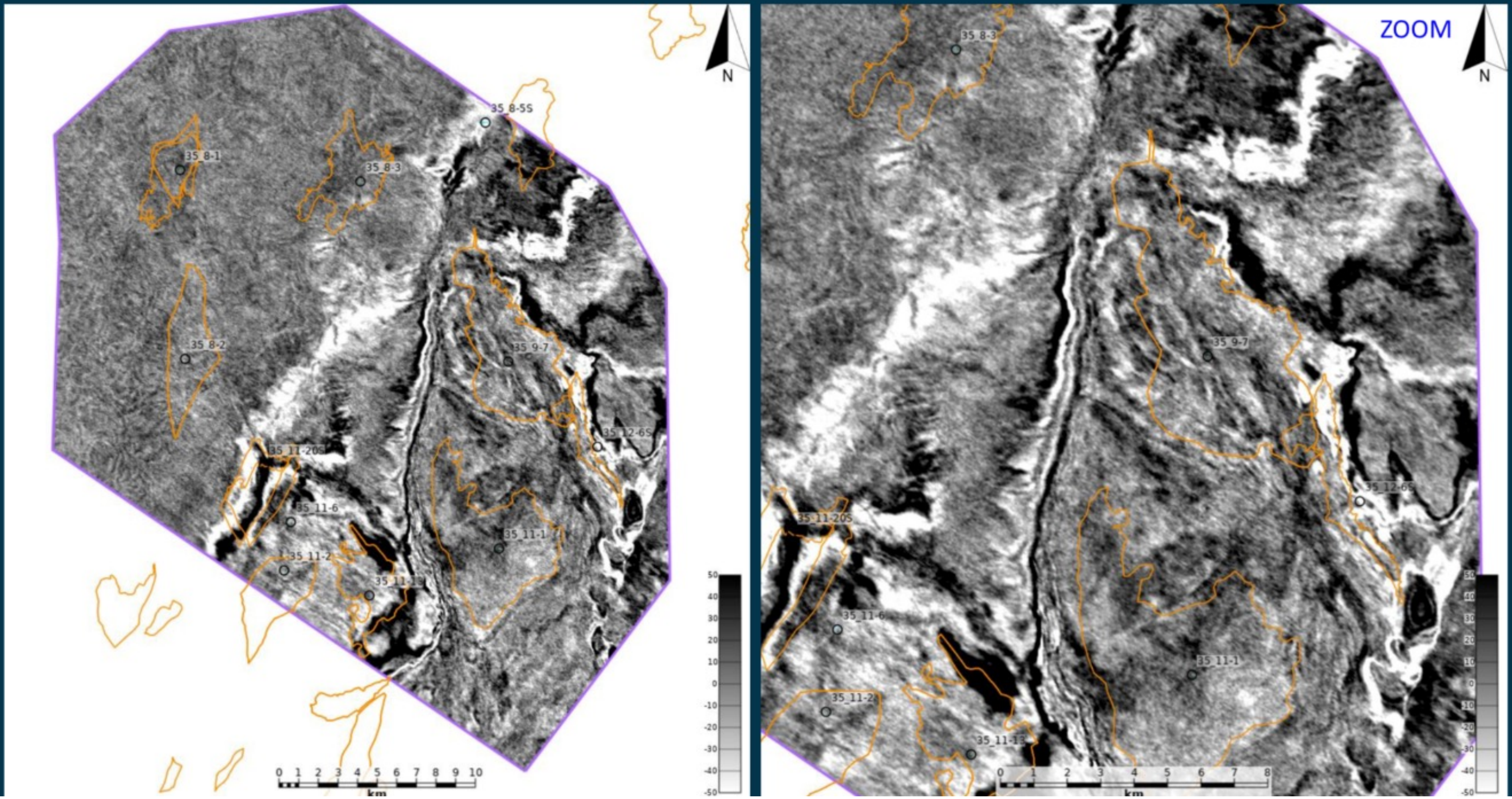
Q35: Hybrid Streamer / Node Survey



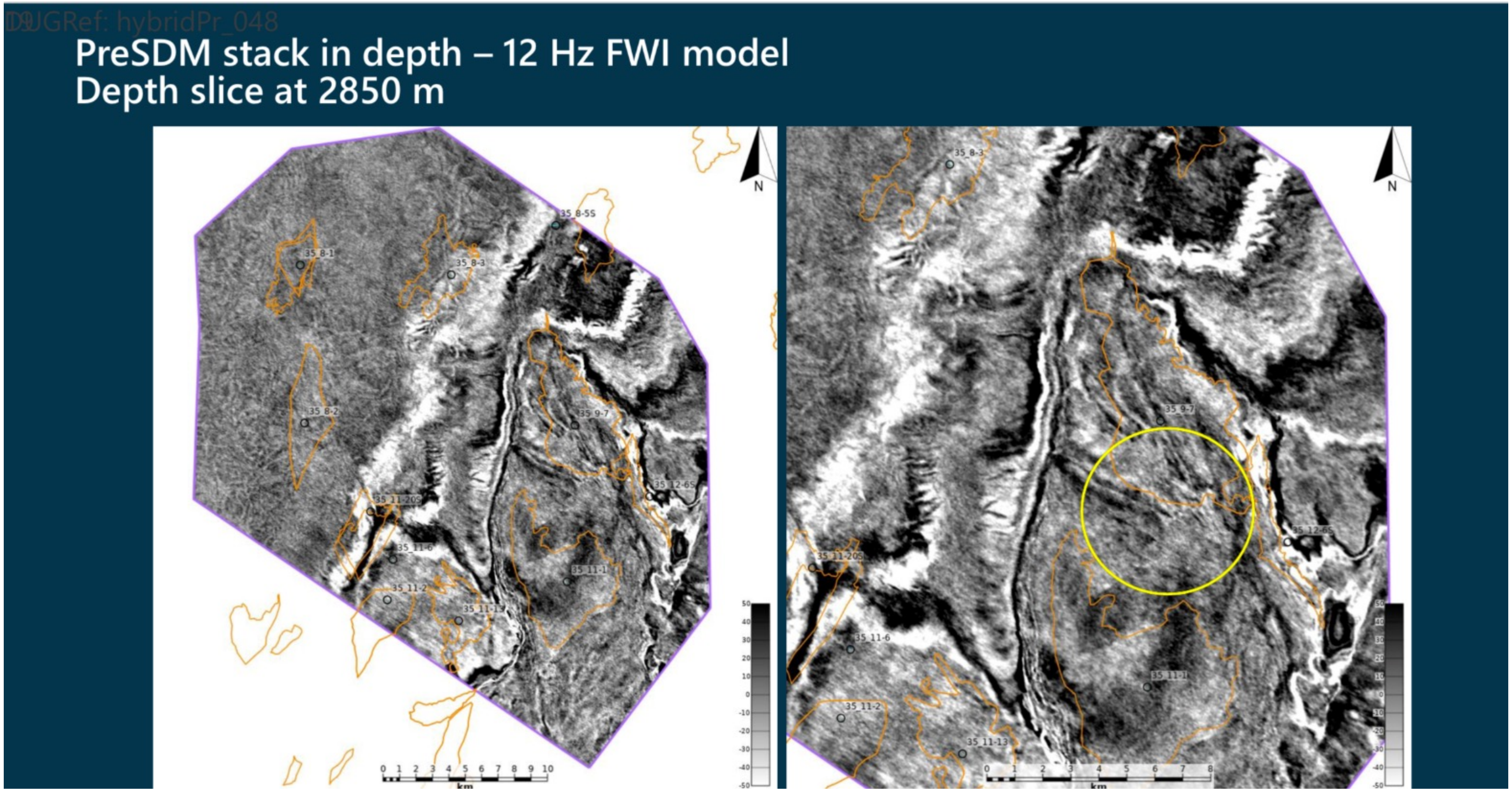
Q35: Hybrid Streamer / Node Survey

DUGRef: hybridPr_048

PreSDM stack in depth – iteration 3 model
Depth slice at 2850 m

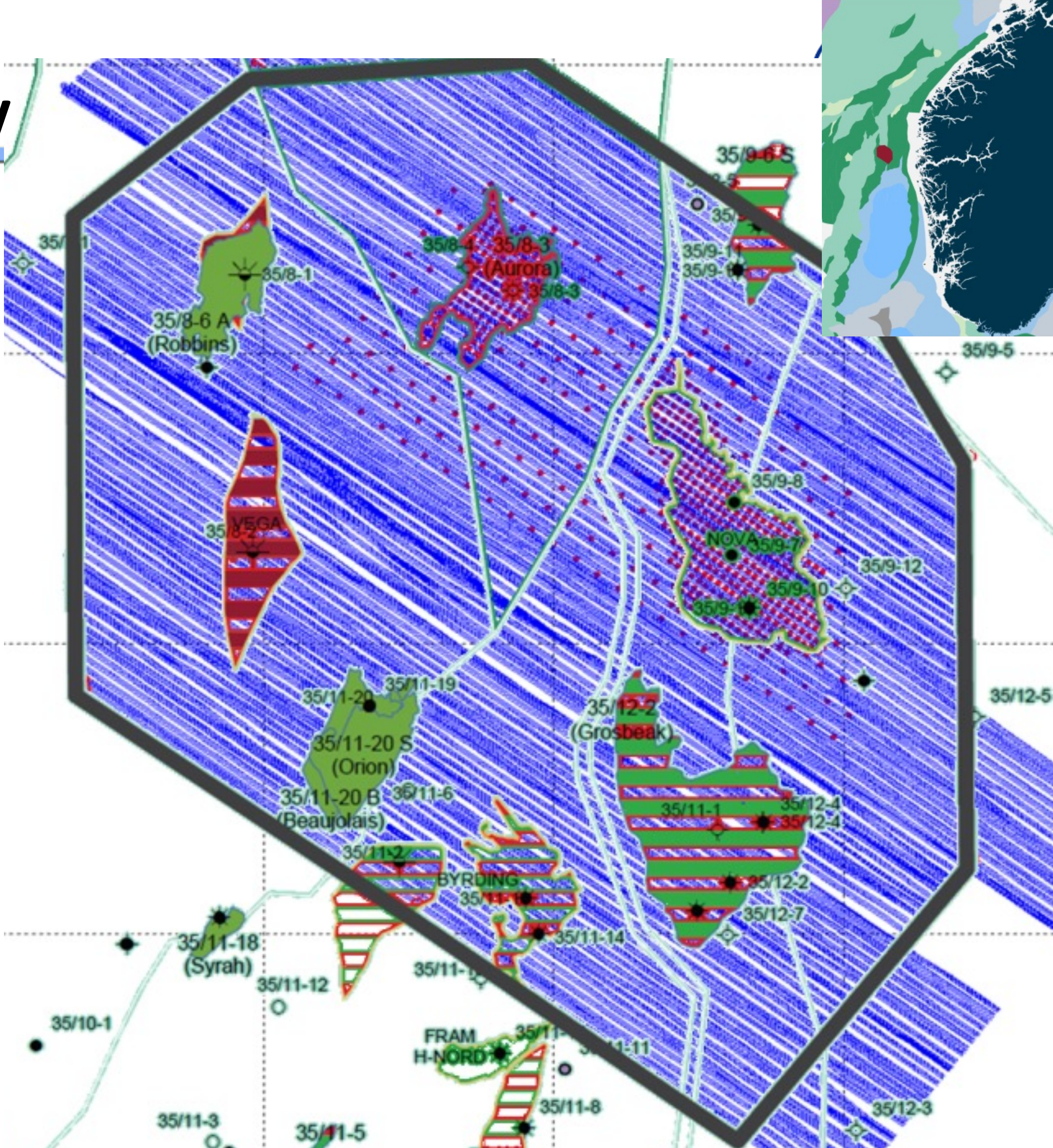


Q35: Hybrid Streamer / Node Survey



Q35: Hybrid streamer/node survey

- ~370m water depth
- Simultaneous recording with streamer – only streamer shots acquired
- 900m x 900m OBN grid, with local in-fill to 300m x 300m grid
- Partially blended triple source shooting; up to 30 km offset
- Input: subset of OBN and streamer data
- OBN FWI up to 25Hz
    - Max frequency progression: 5Hz, 6Hz, …, 20Hz, 25Hz
- OBN processing, up to Up / Down separation and demultiple
- OBN RTM up to 50Hz (Up and Down)
- **FWI Image**: combination of FWI reflectivity with RTM
- **Hybrid Image**: combination of OBN FWI Image with streamer PSDM



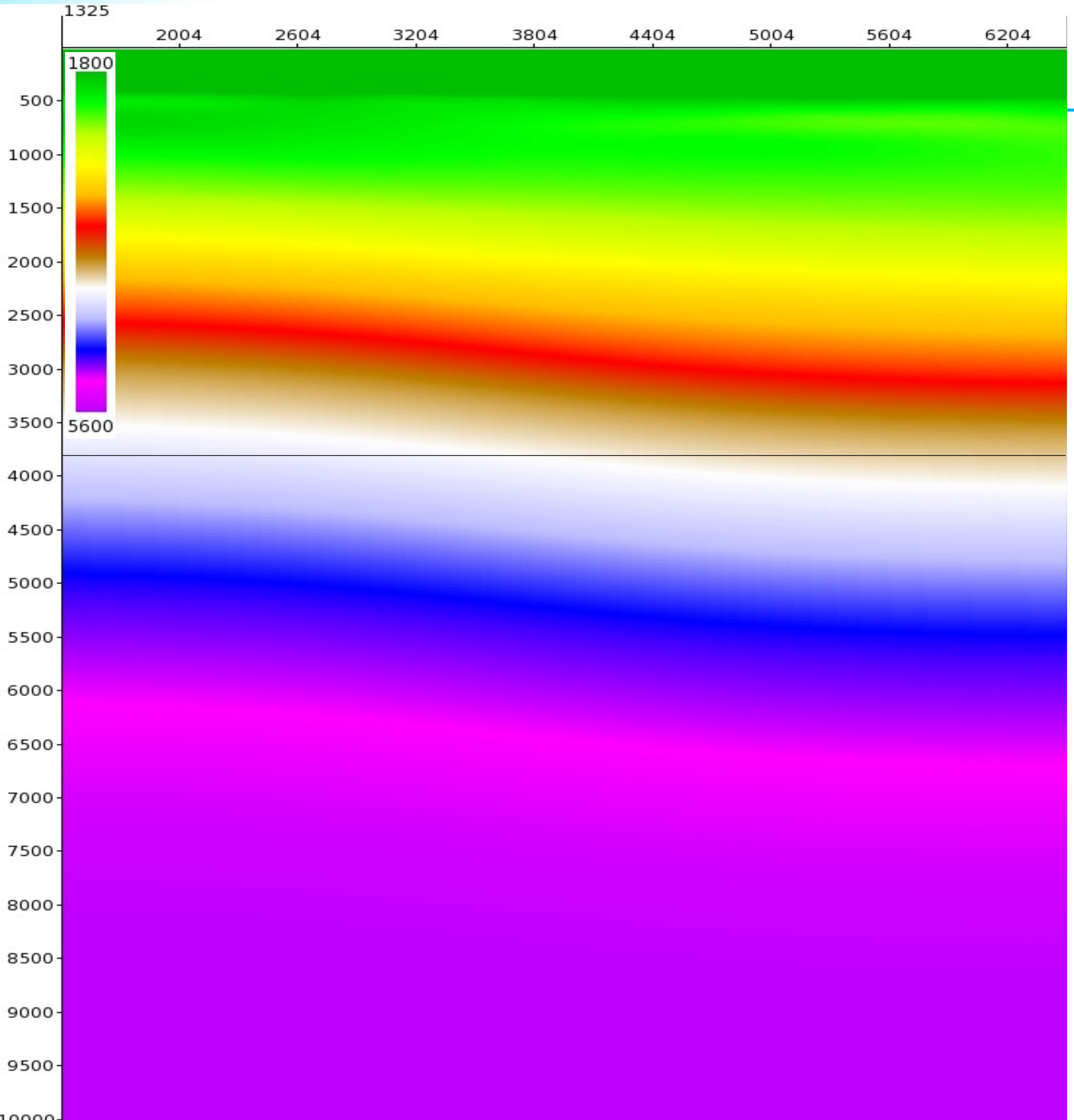
Full Waveform Inversion

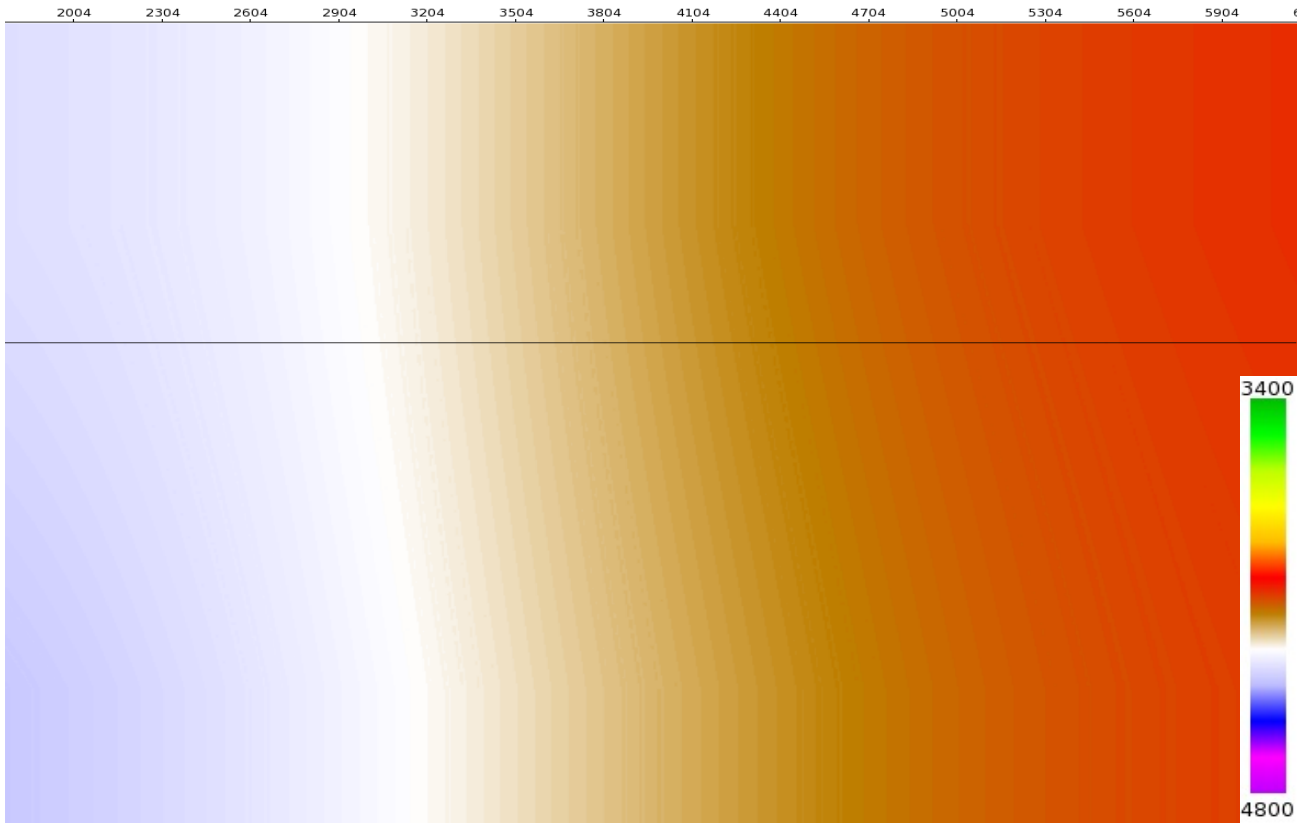
- FWI adjusts the earth model and wavelets so that the modeled synthetic data better match the observed data

- As such, any part of the data that we can model, we do not need to remove
  - Ghosts, multiples, source signature, etc. do not need to be removed
  - We generally start with the raw data for FWI

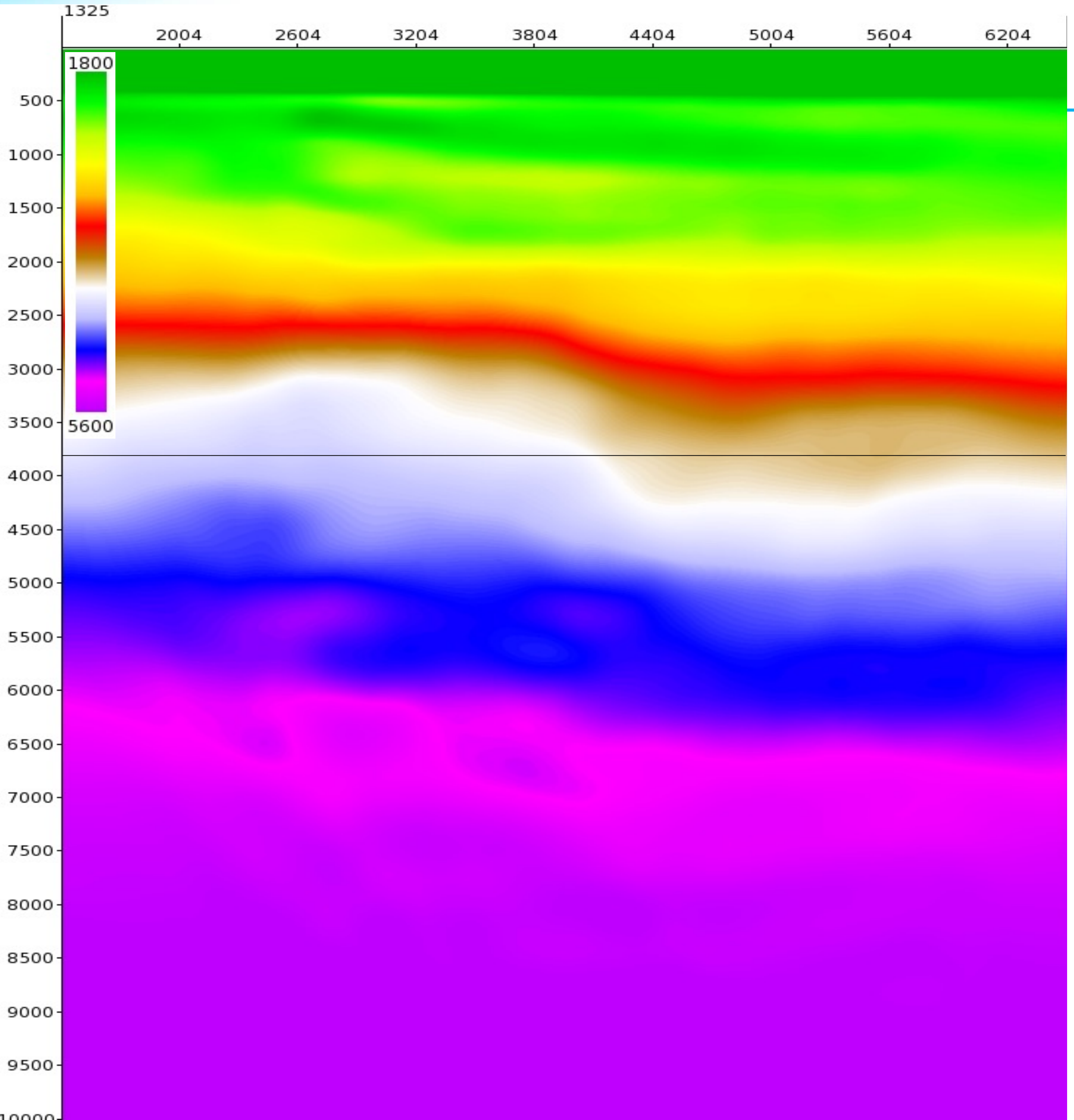
- Due to presence of long offsets, we can start with a very simple model, e.g. heavily smoothed stack velocities

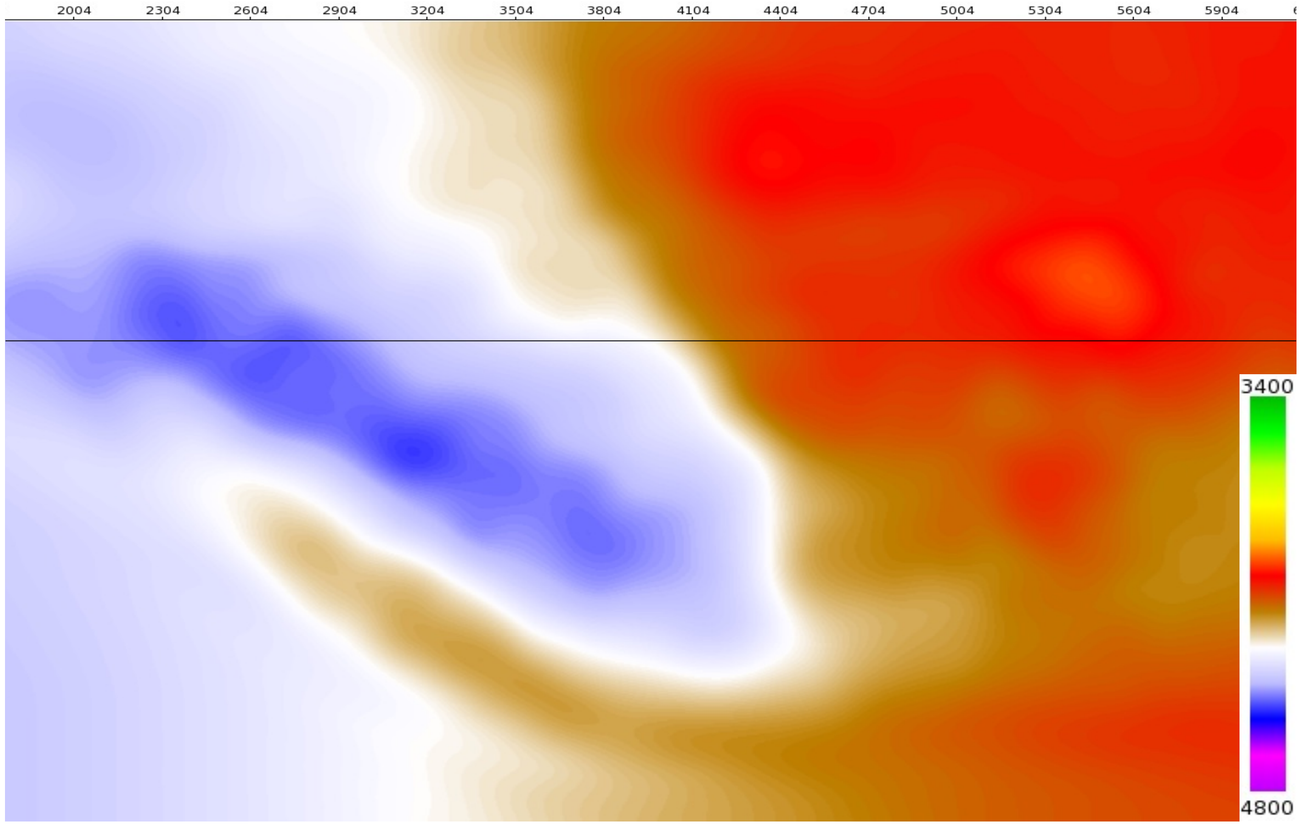
L1325 and Z=3800m slice: initial velocities



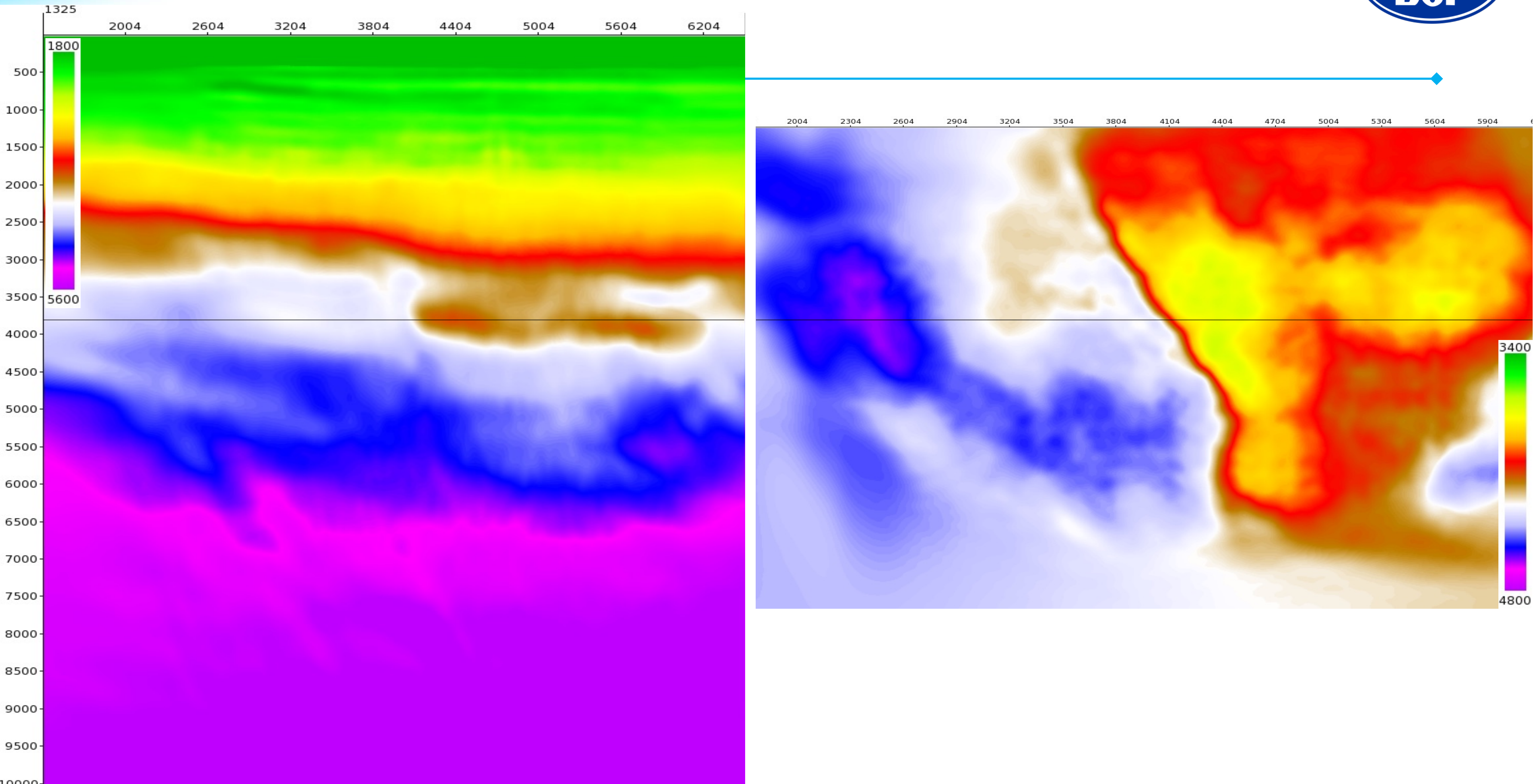


L1325 and Z=3800m slice: FWI 5Hz

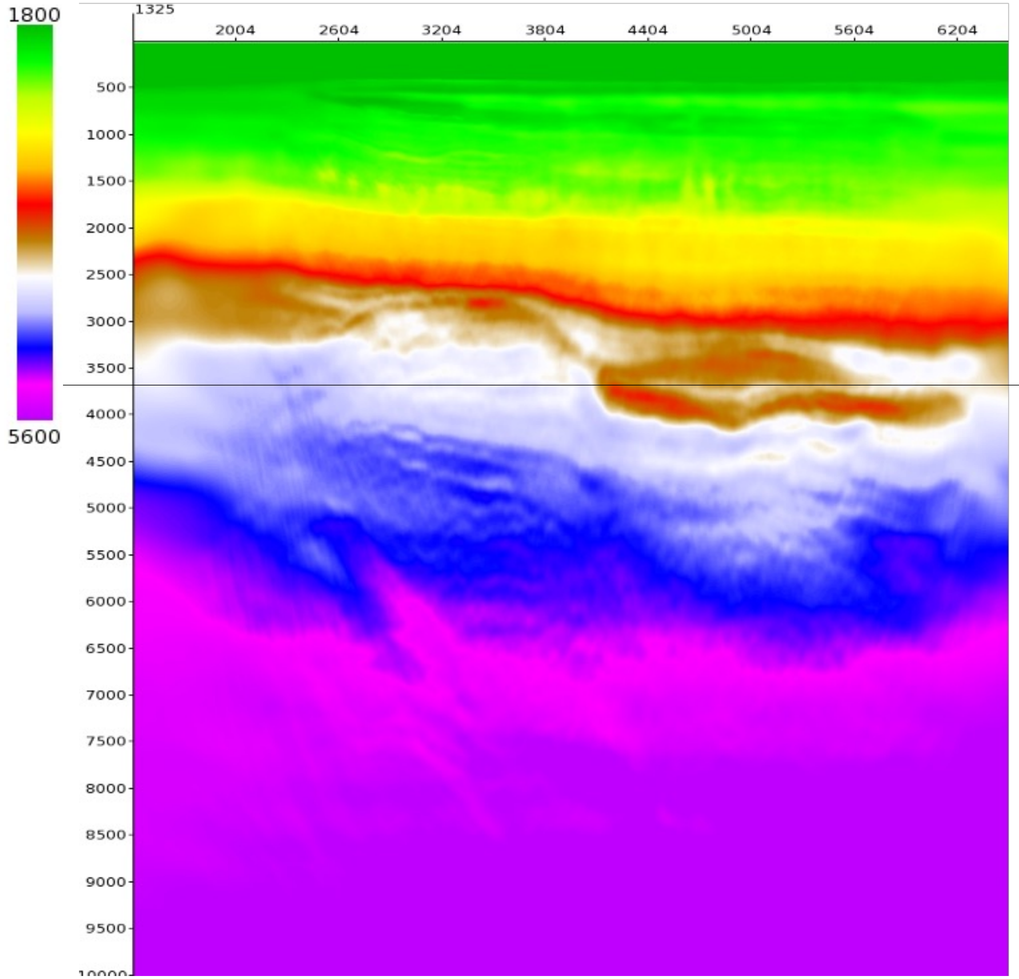


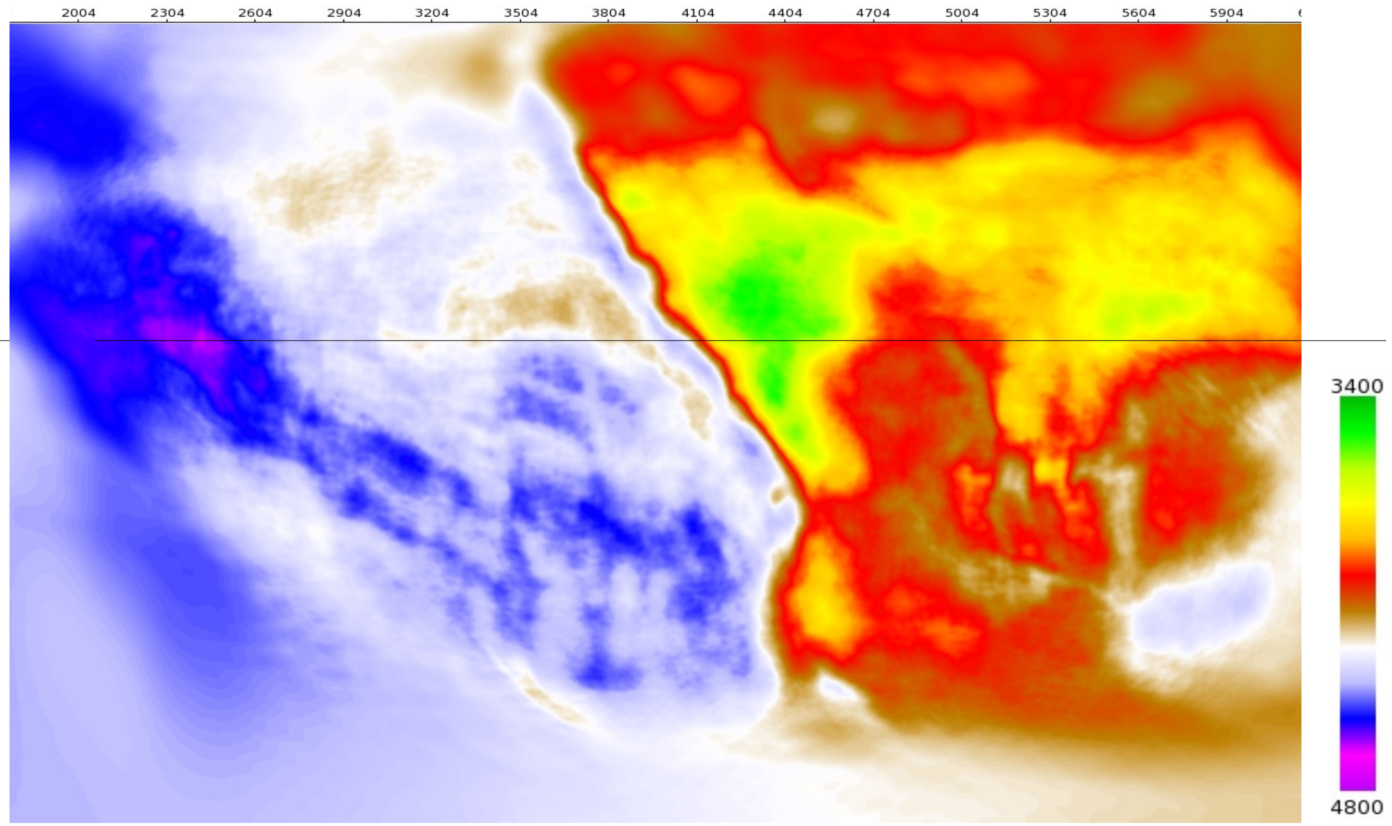


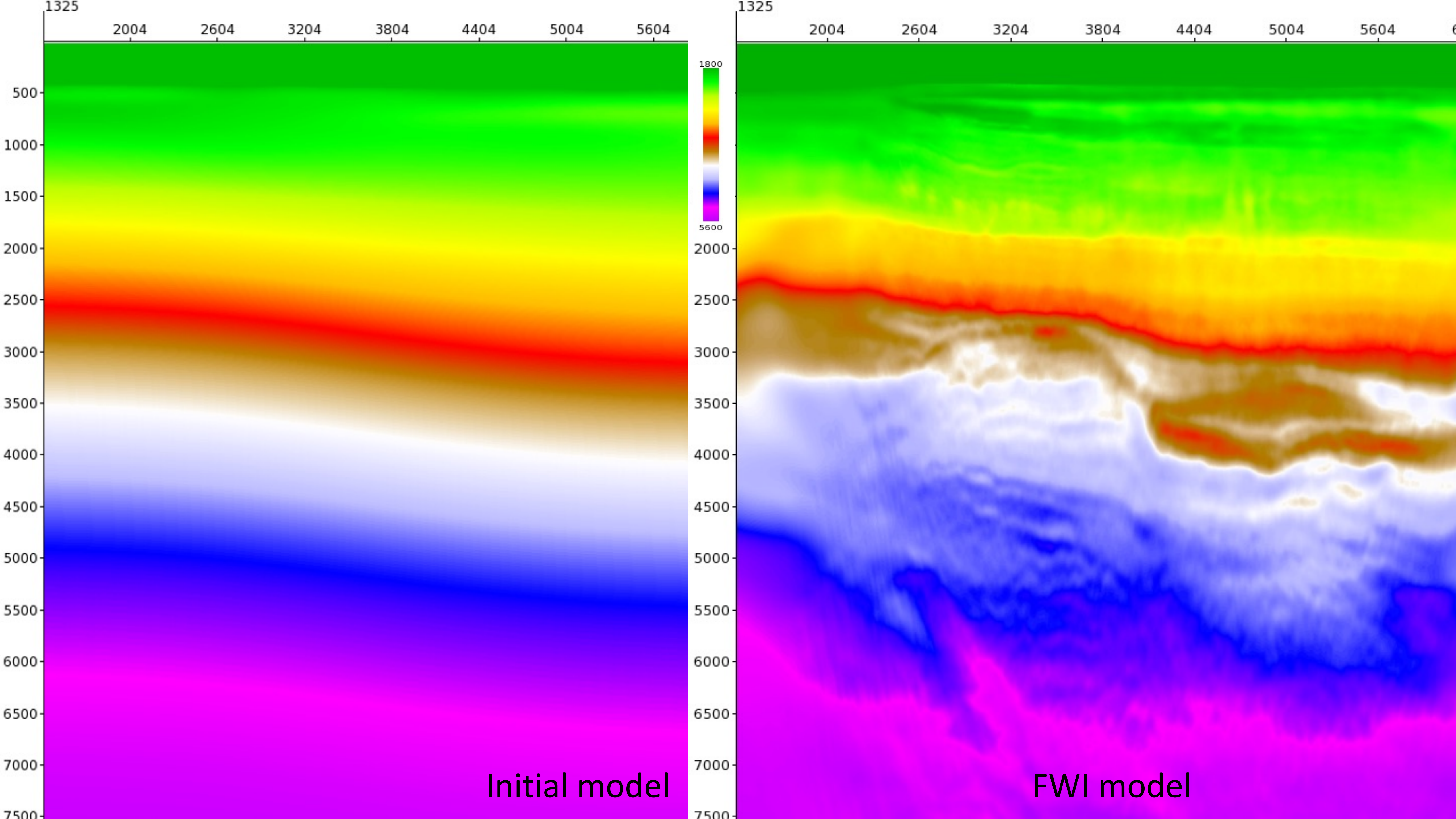
L1325 and Z=3800m slice: FWI 8Hz



L1325 and Z=3800m slice: FWI 25Hz

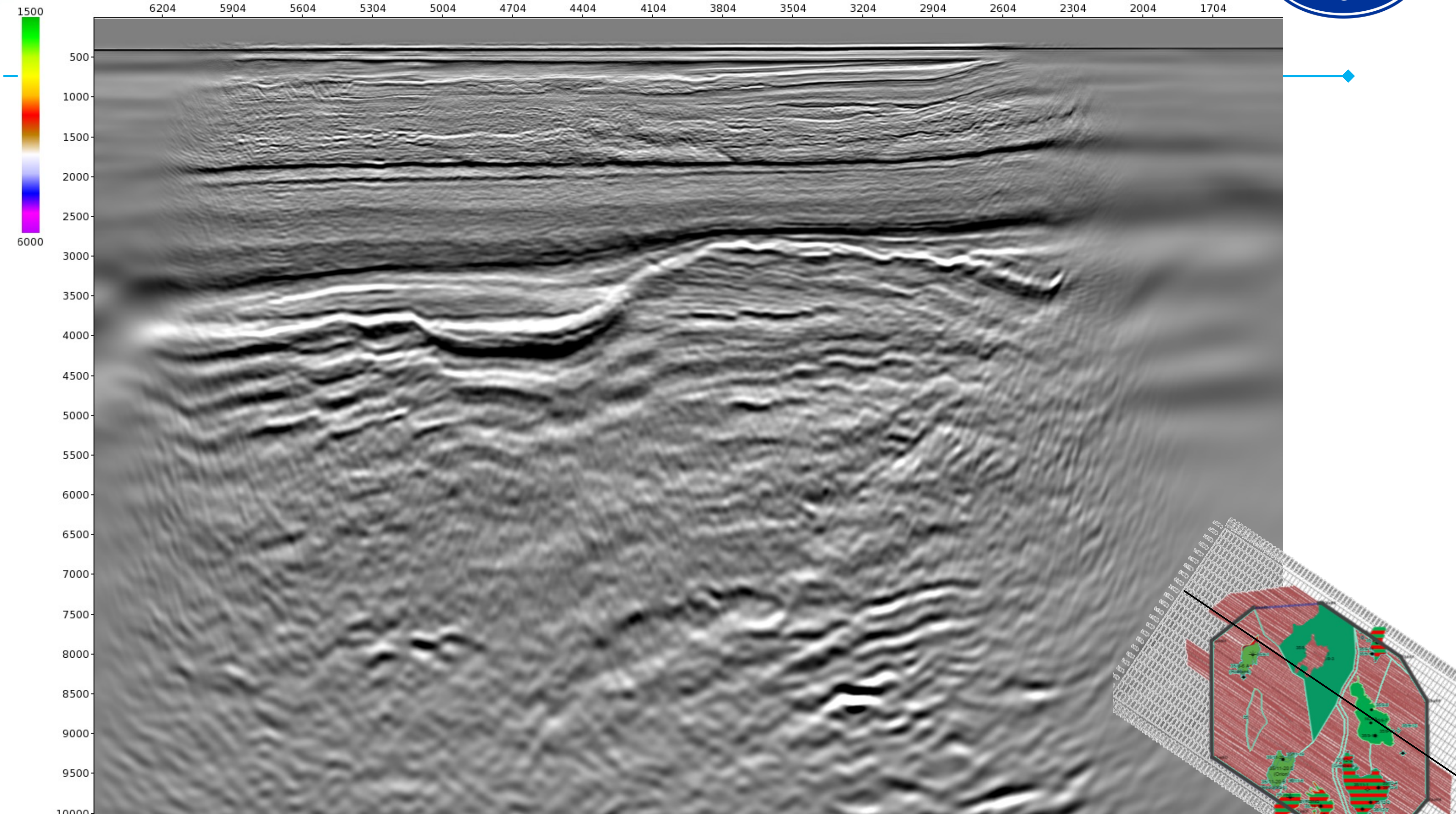




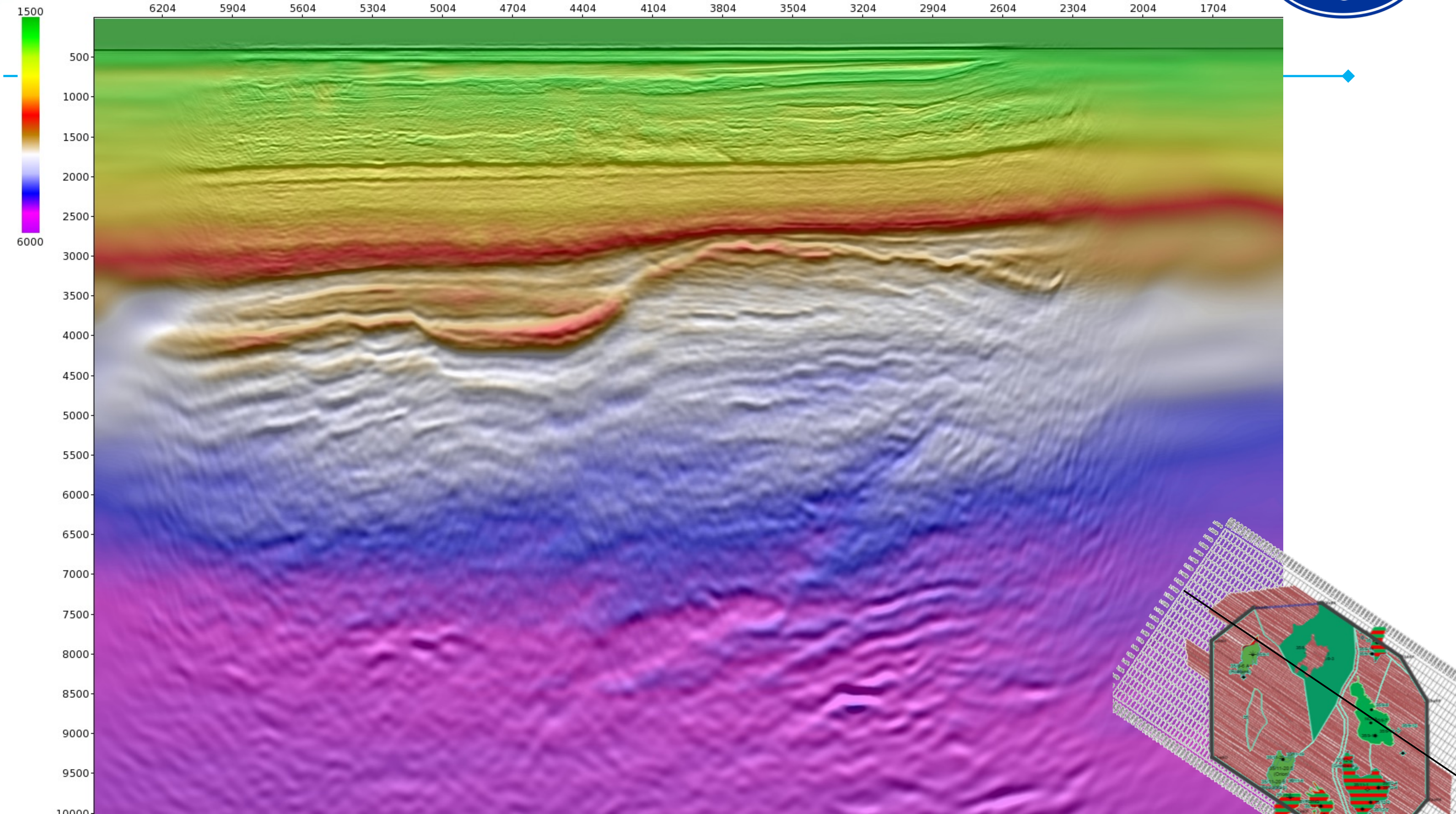


1325
2004
2604
3204
3804
4404
5004
5604
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
1800
5600
Initial model
FWI model

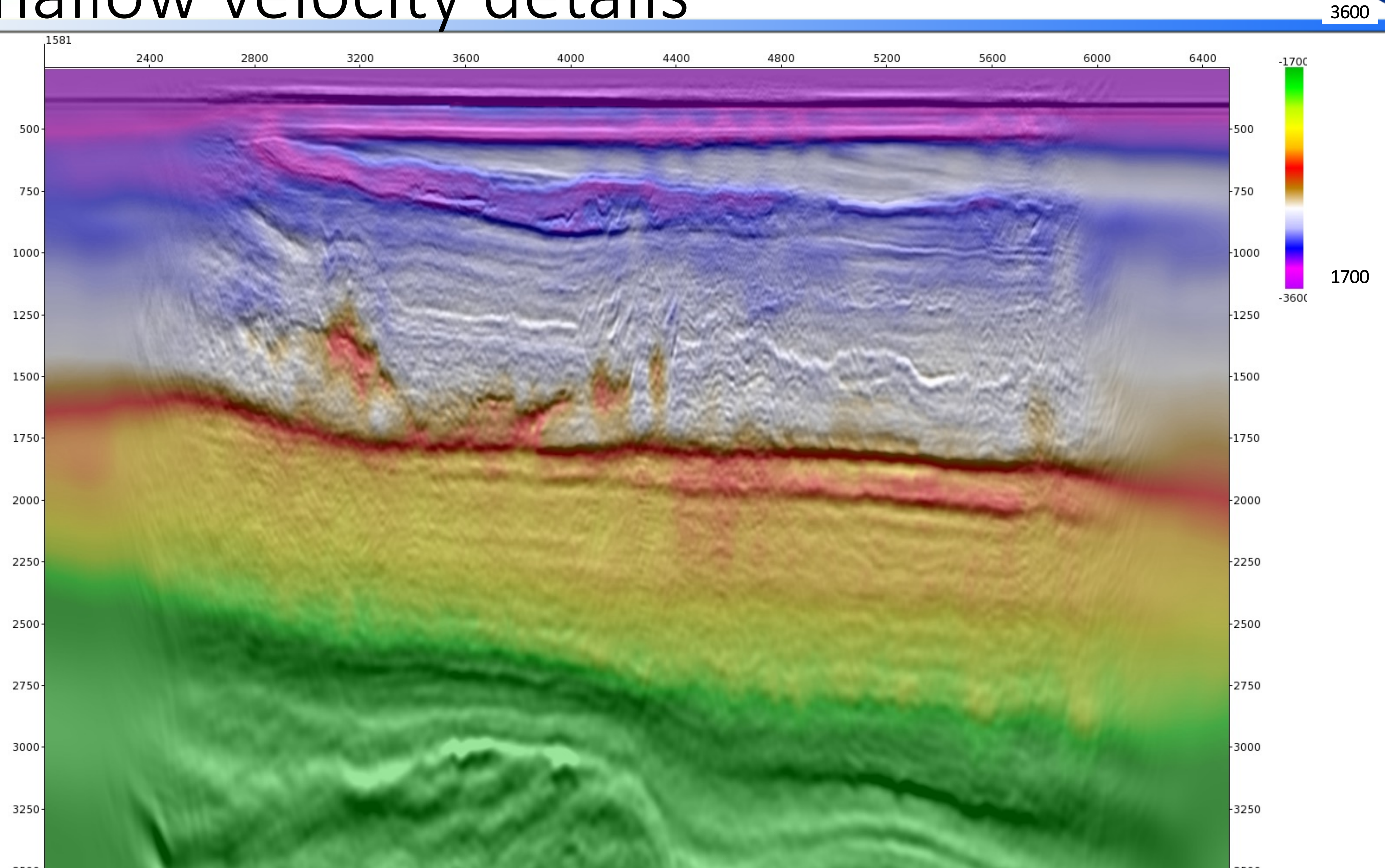
L1451 BGP OBN Image



L1451 BGP OBN FWI velocities



Shallow velocity details

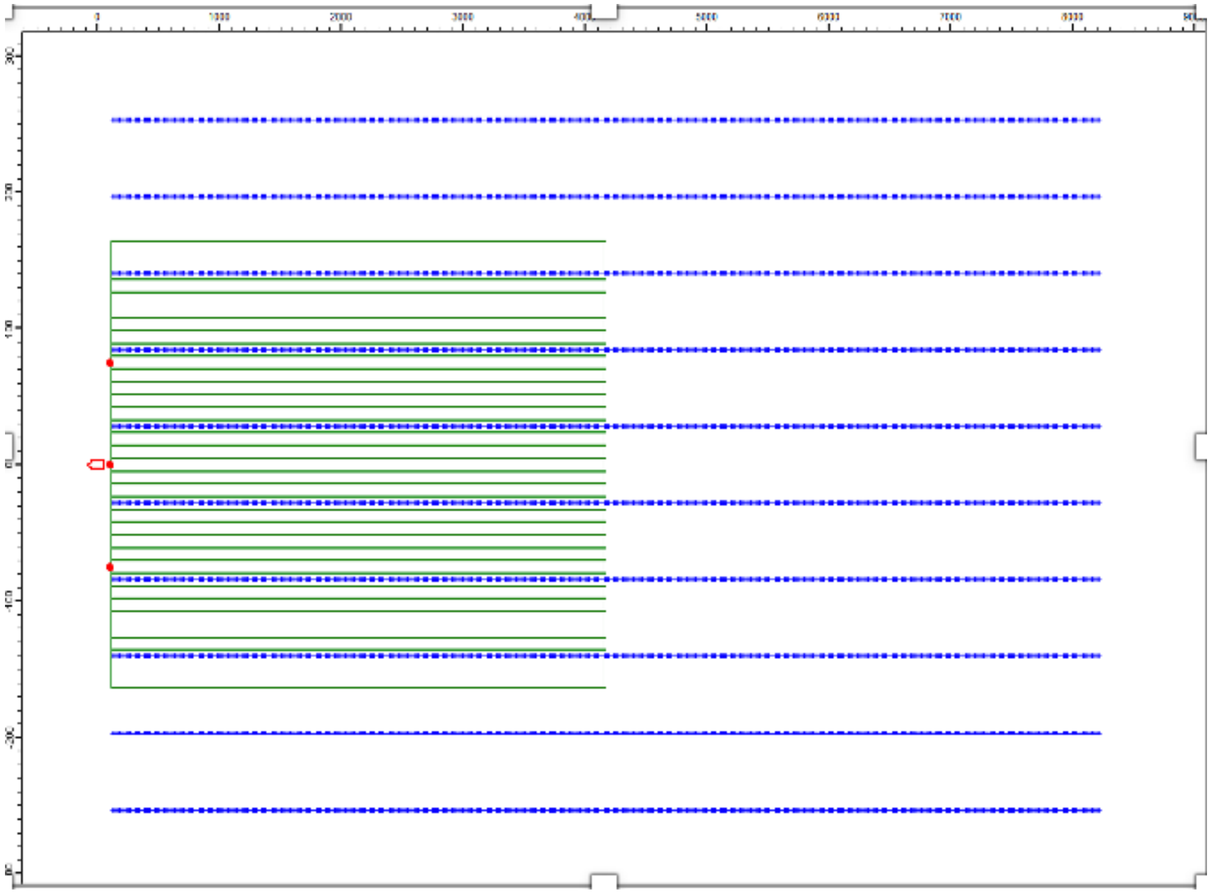


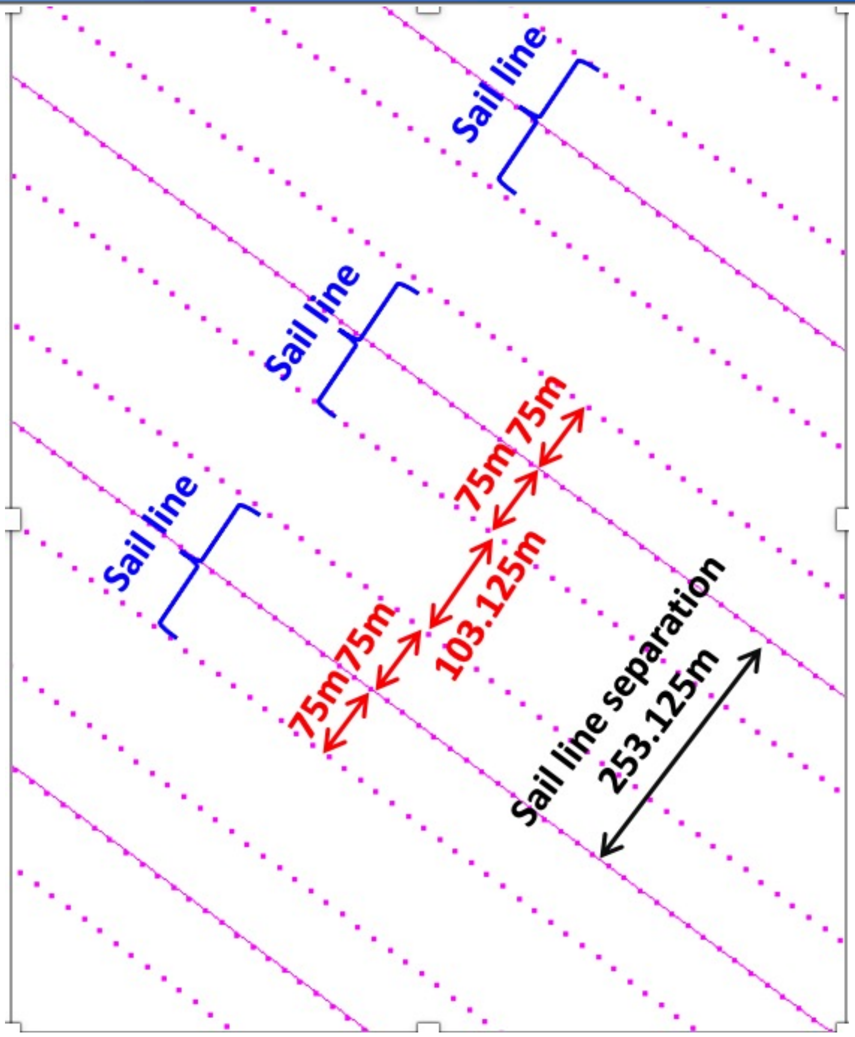
CS Reconstruction of Source Geometry

- Triple source streamer-optimized shooting results in irregular source point distribution, particularly in the cross-line direction
- For processes such as WE multiple prediction and U/D decon, source geometry regularization and interpolation is highly beneficial

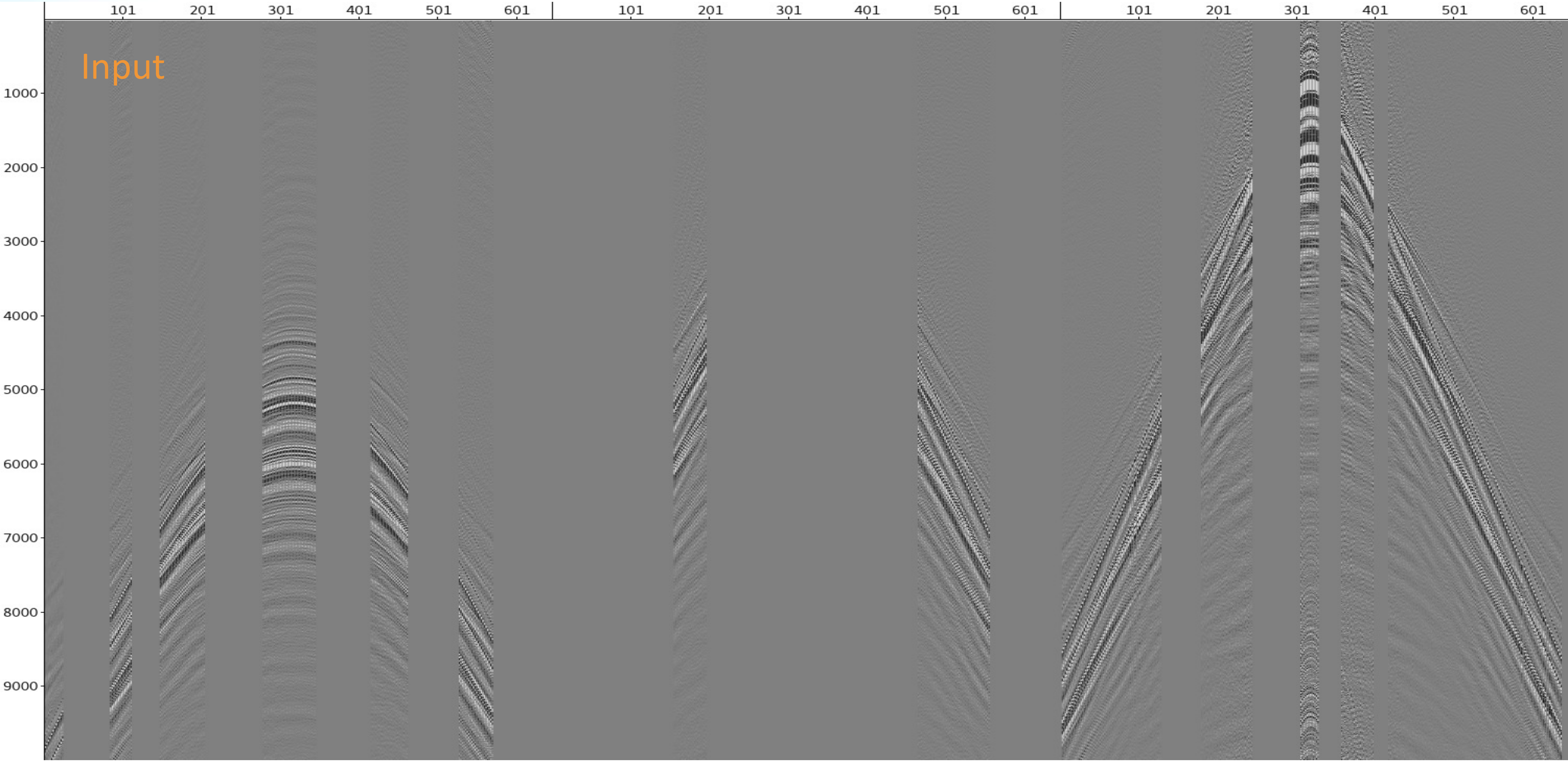
- Average input source spacing is 31.25 m by 88.2 m
- We choose CS Recon output spacing at 15.625 m by 29.4 m, a 2x3 interpolation
  - This grid will still alias the water column direct arrivals at 25Hz in the cross line direction and at 48Hz in the inline direction
- CSR methods
  - WC-CSR: 1-d wavelet (T) and 2-d curvelet (XY) transform domain L1 sparsity constrained interpolation
  - FC-CSR: 1-d Fourier (T) and 2-d curvelet (XY) transform domain L1 sparsity constrained interpolation

Q35: Hybrid streamer/node survey

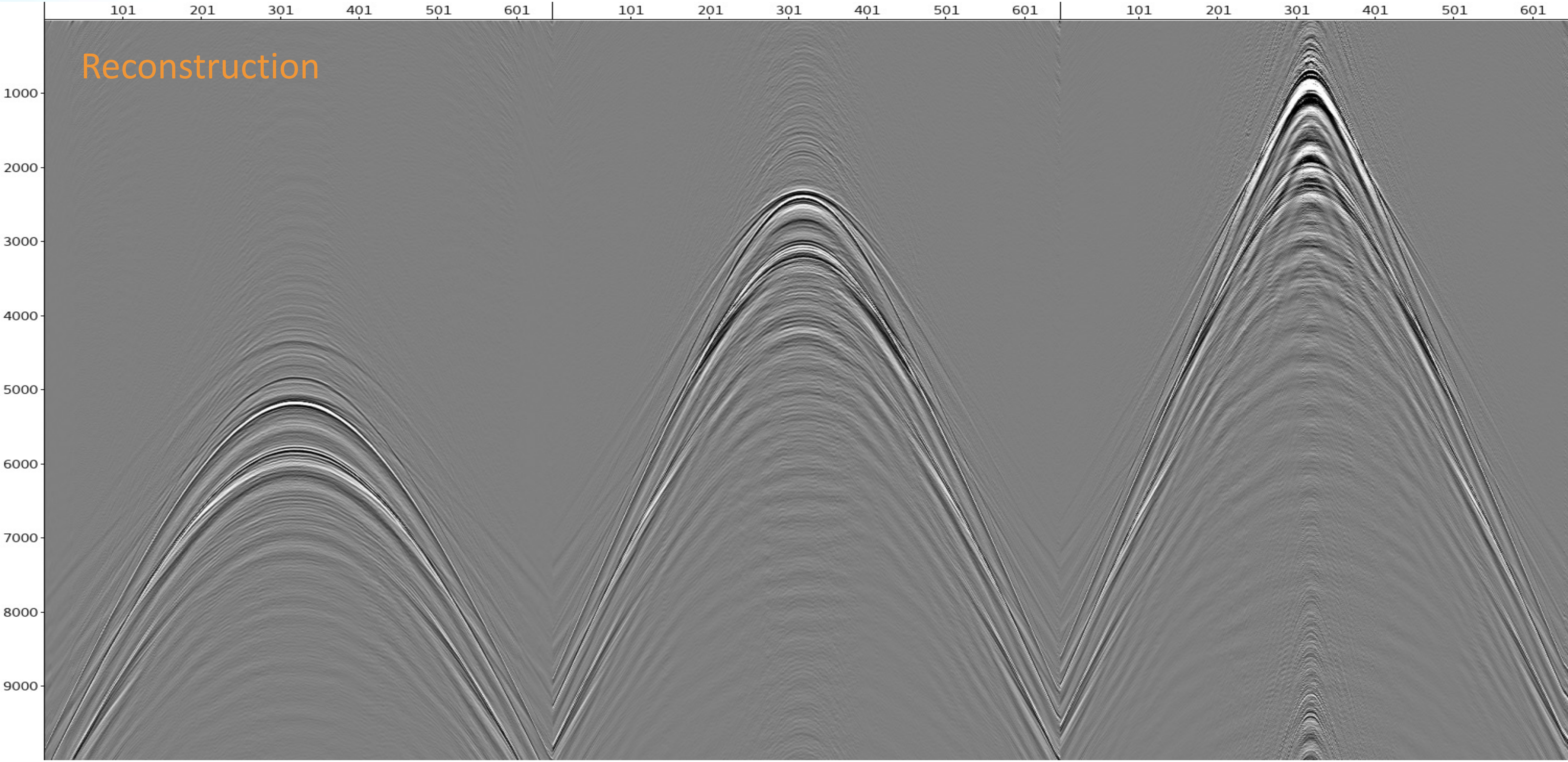




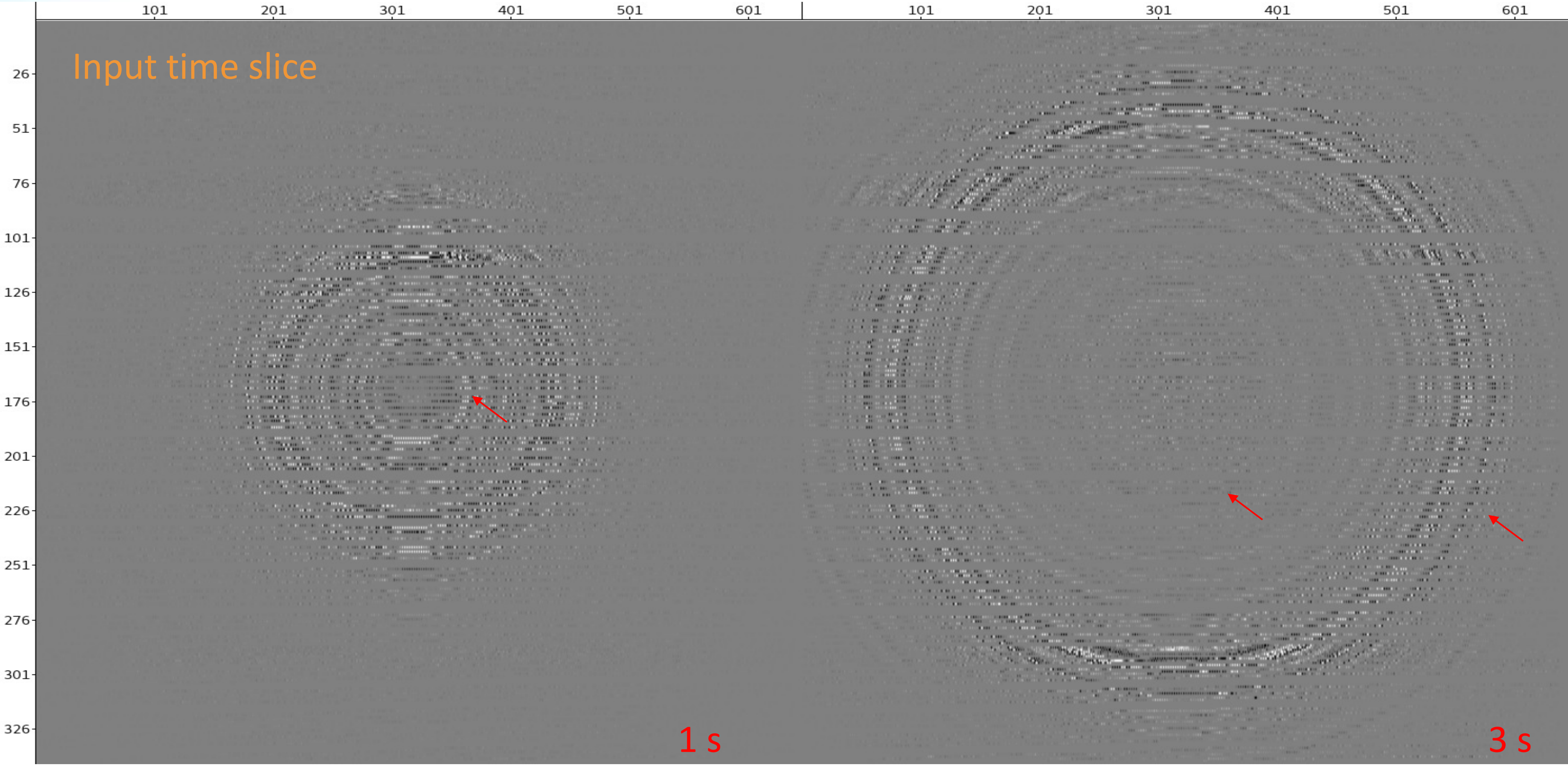
Q35 OBN common-receiver gather



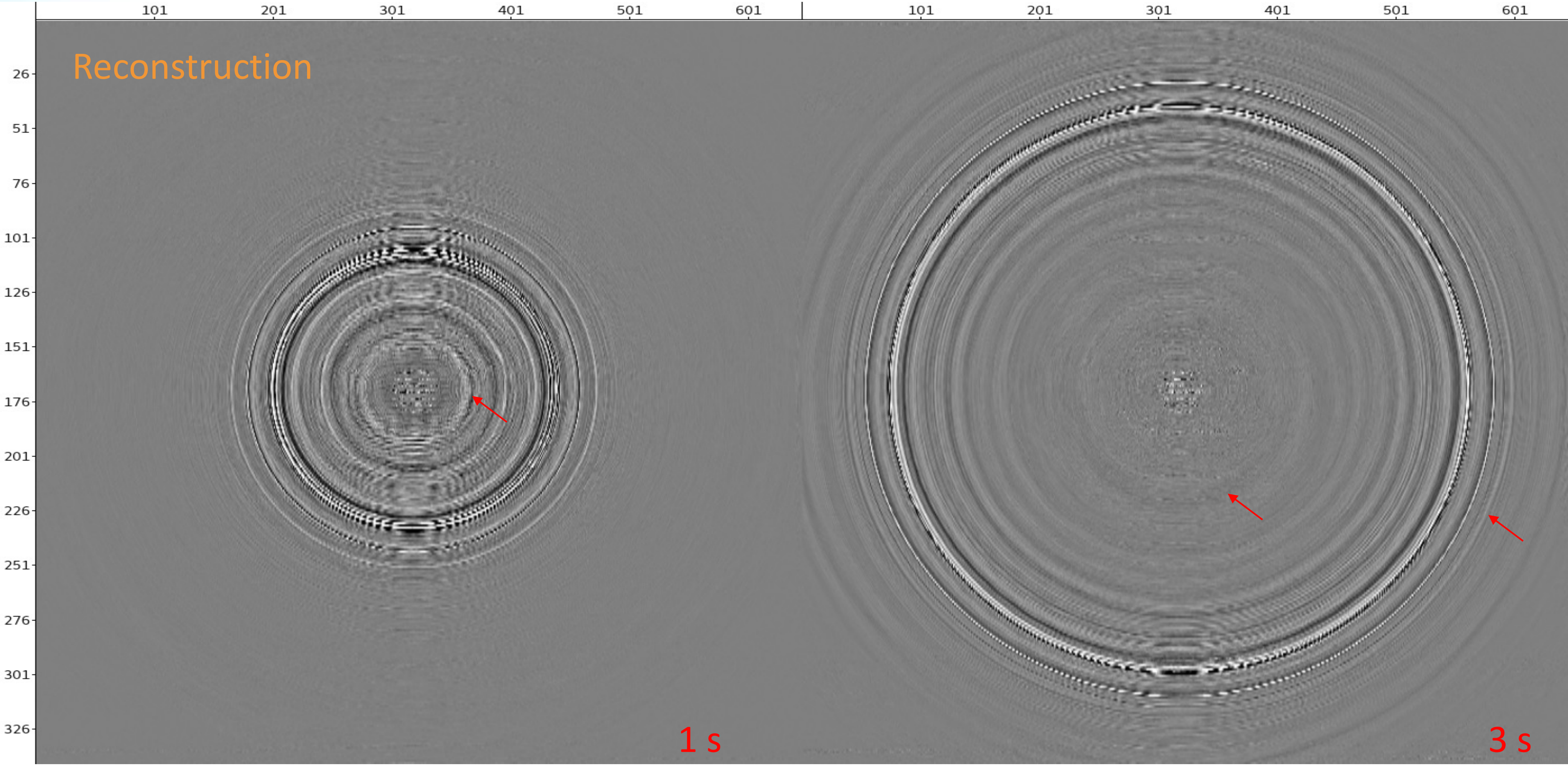
Q35 OBN common-receiver gather



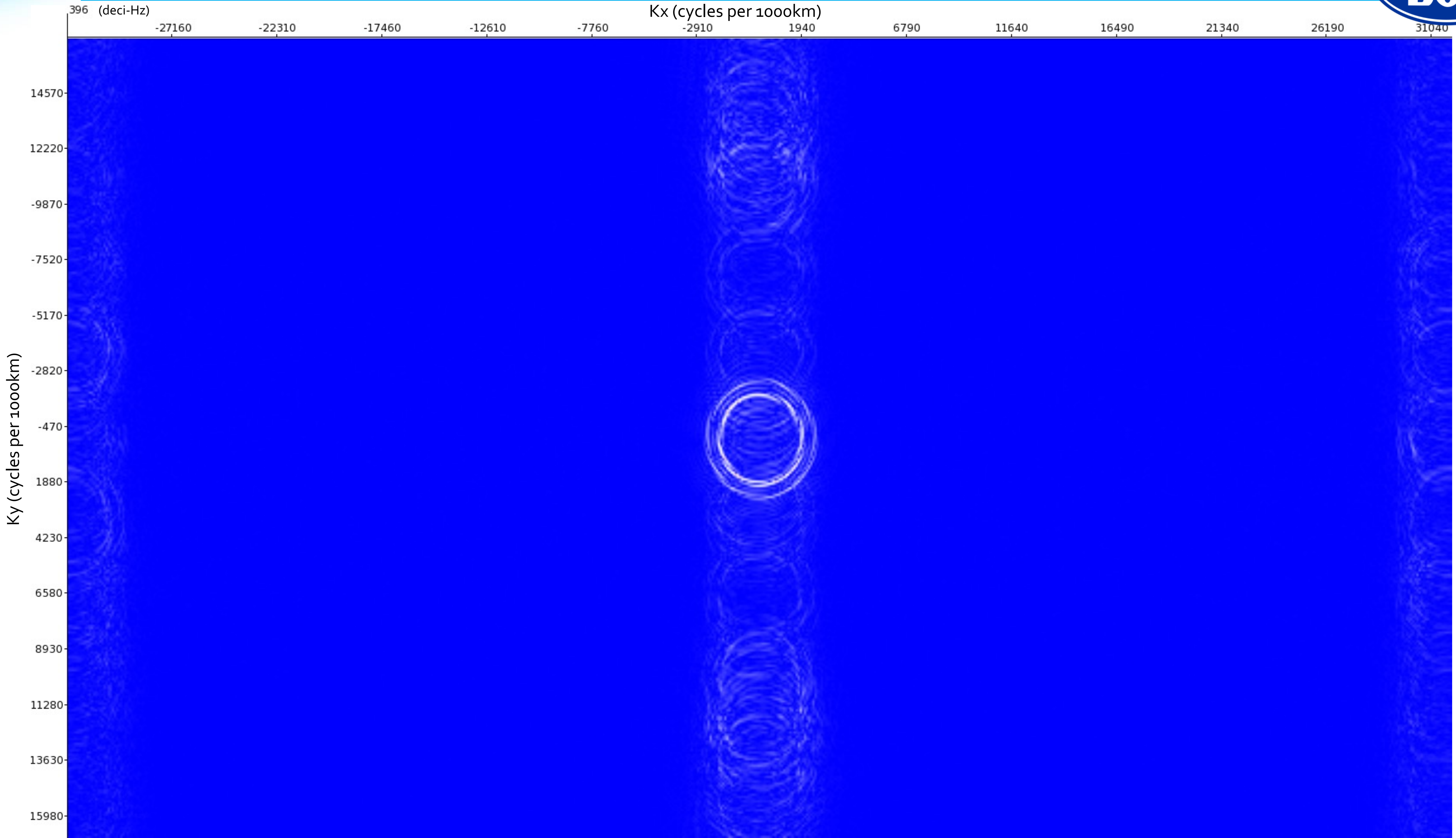
Q35 OBN common-receiver data



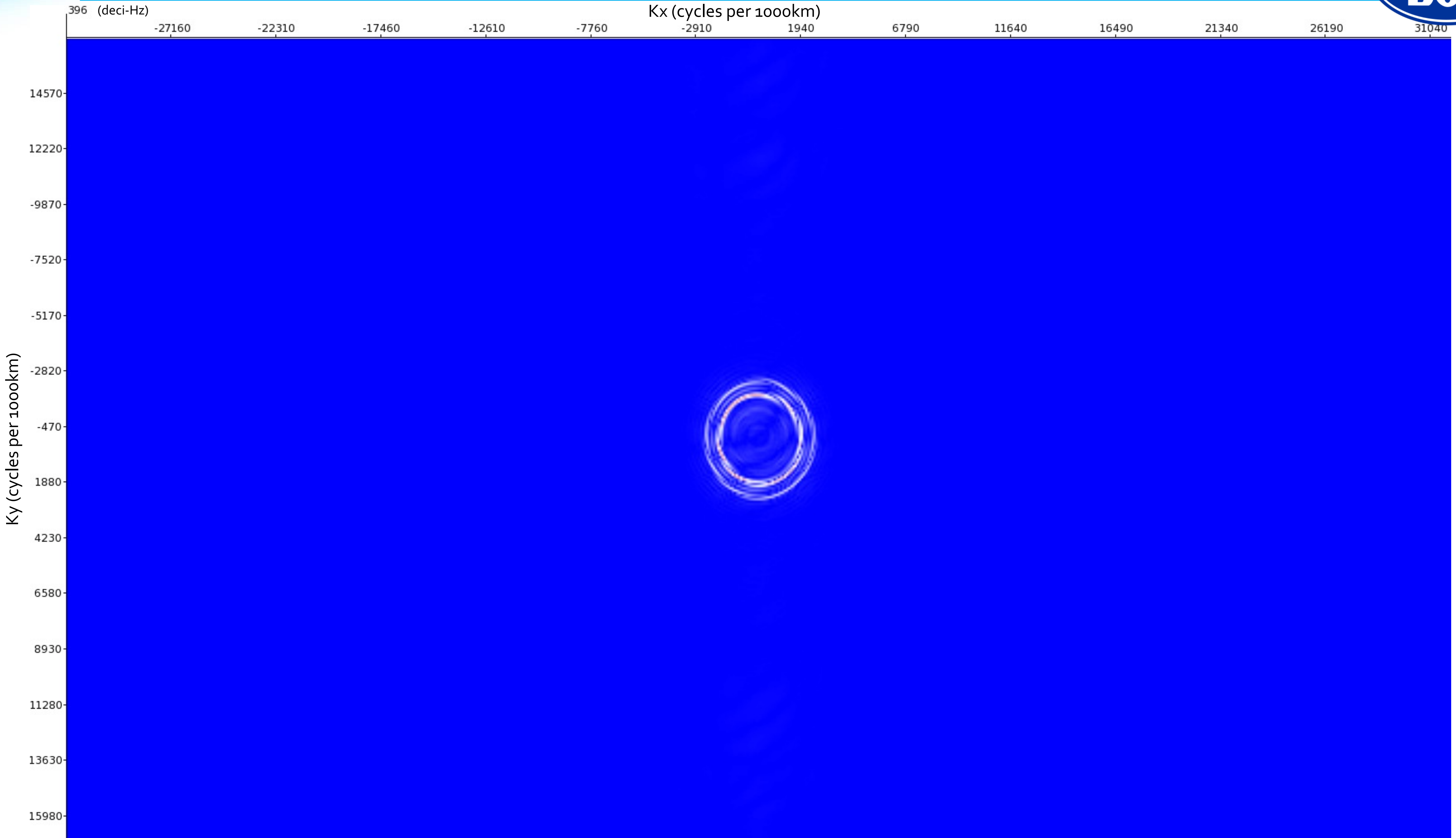
Q35 OBN common-receiver data



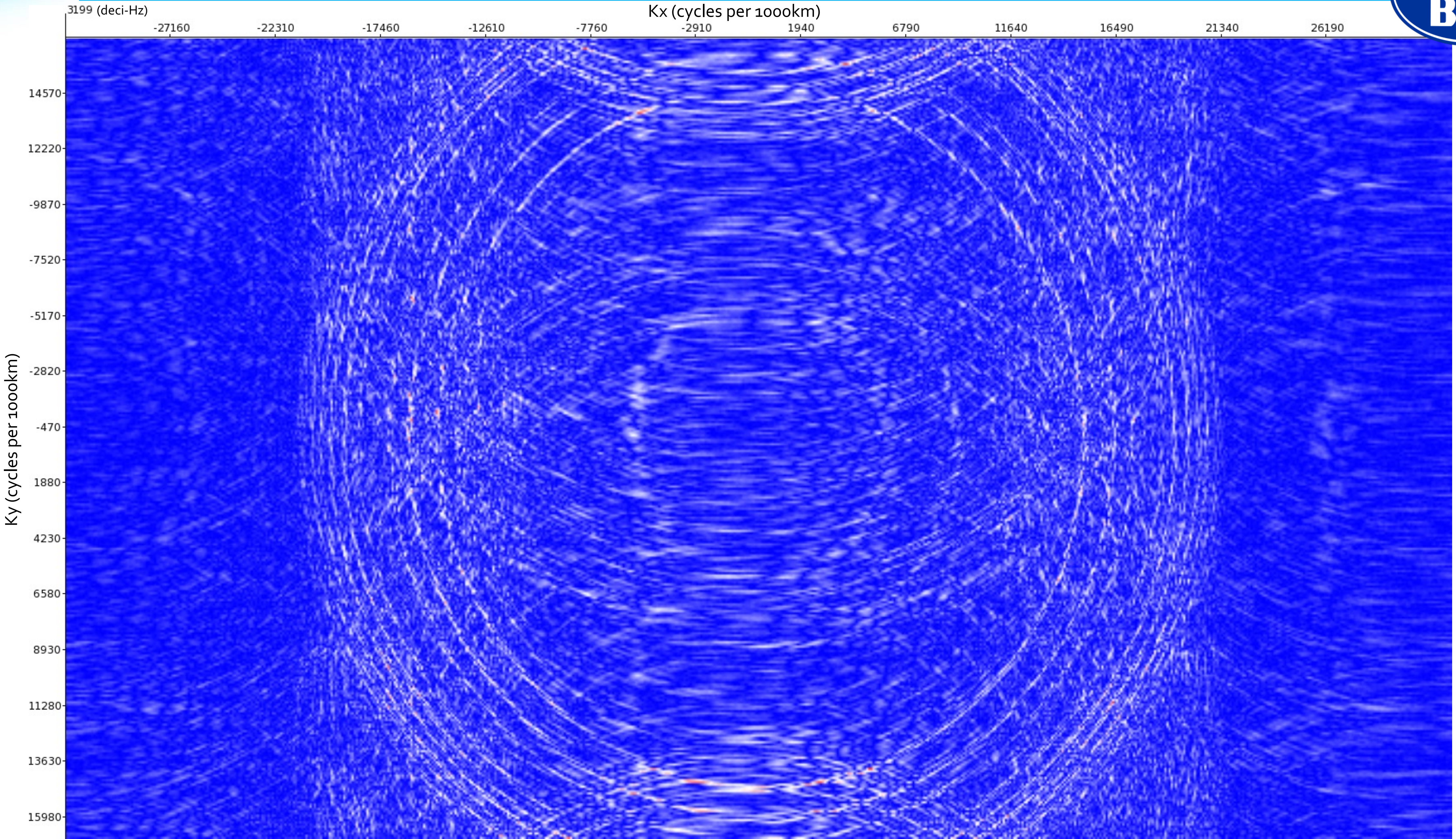
Q35 OBN FKK amplitude: 4Hz before reconstruction



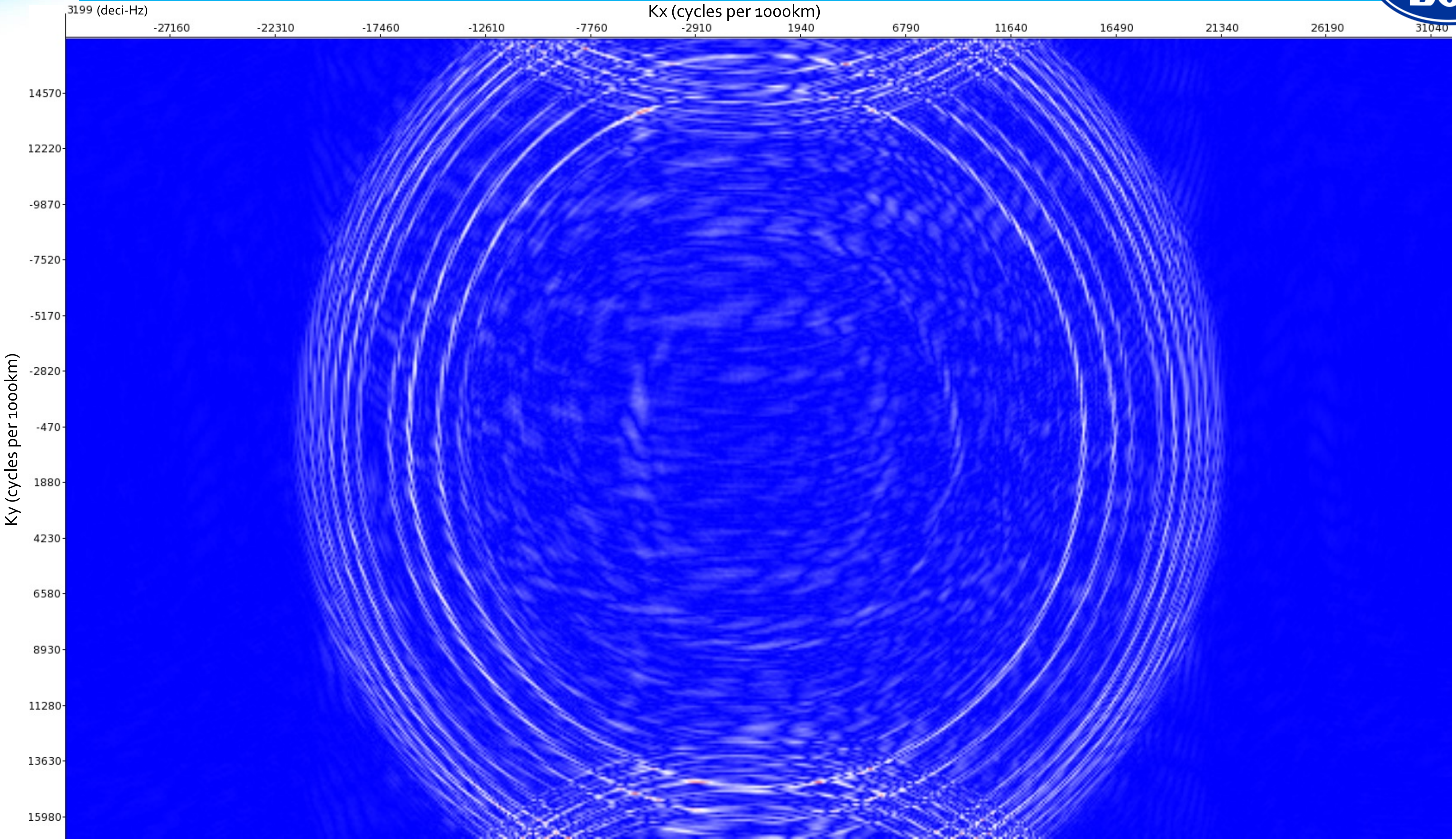
Q35 OBN FKK amplitude: 4Hz after WC-CSRecon



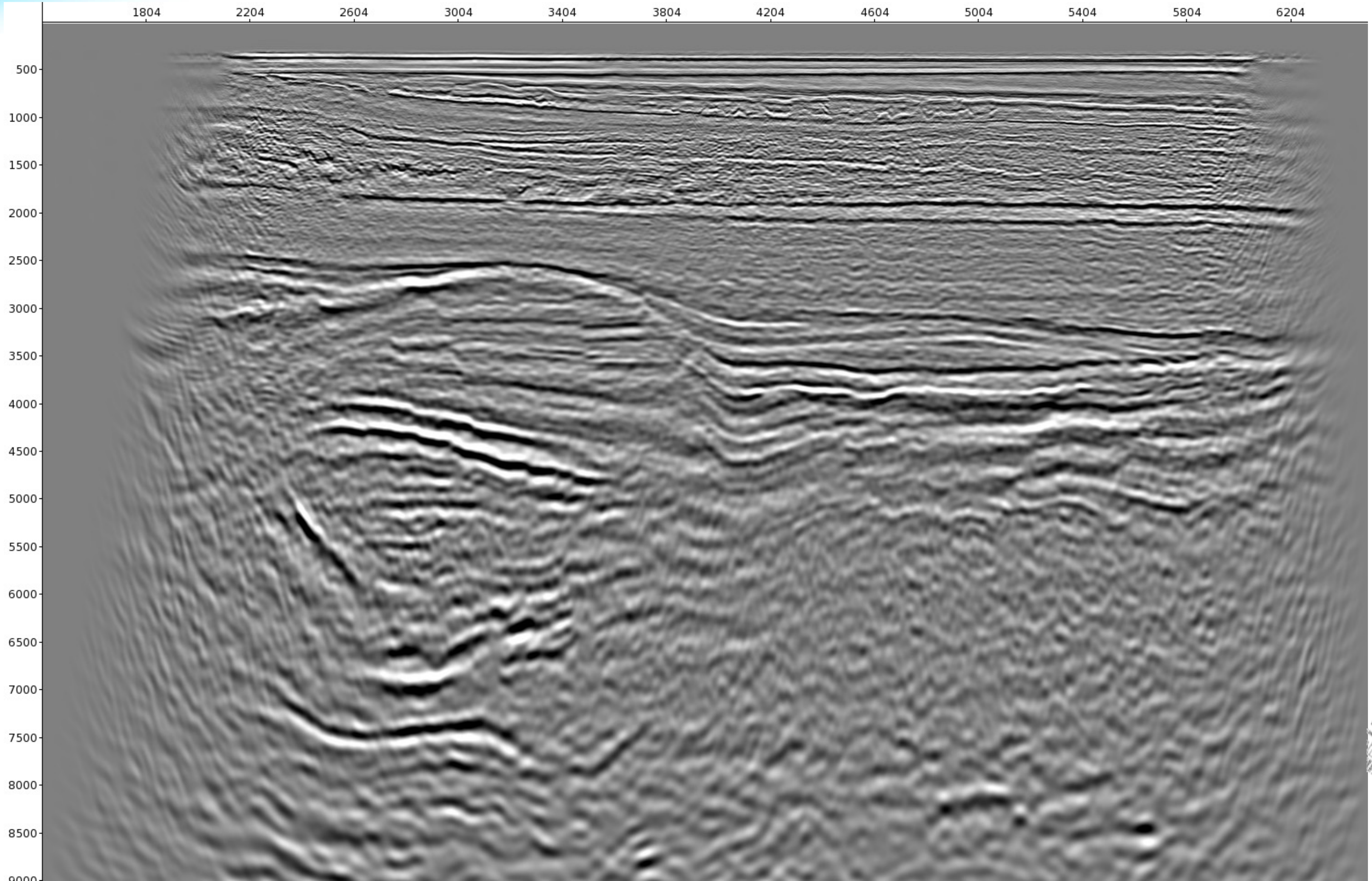
Q35 OBN FKK amplitude: 32Hz before reconstruction

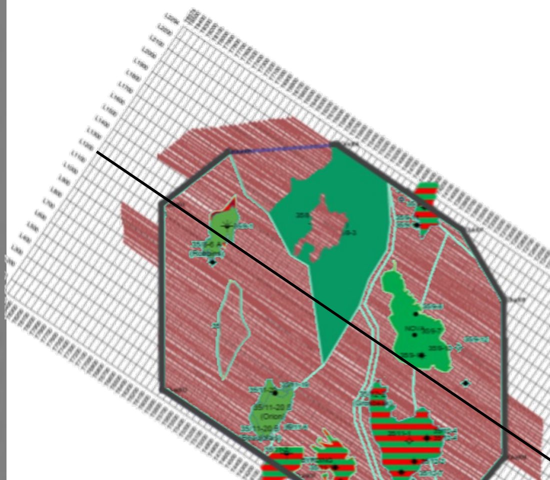


Q35 OBN FKK amplitude: 32Hz after WC-CSRecon

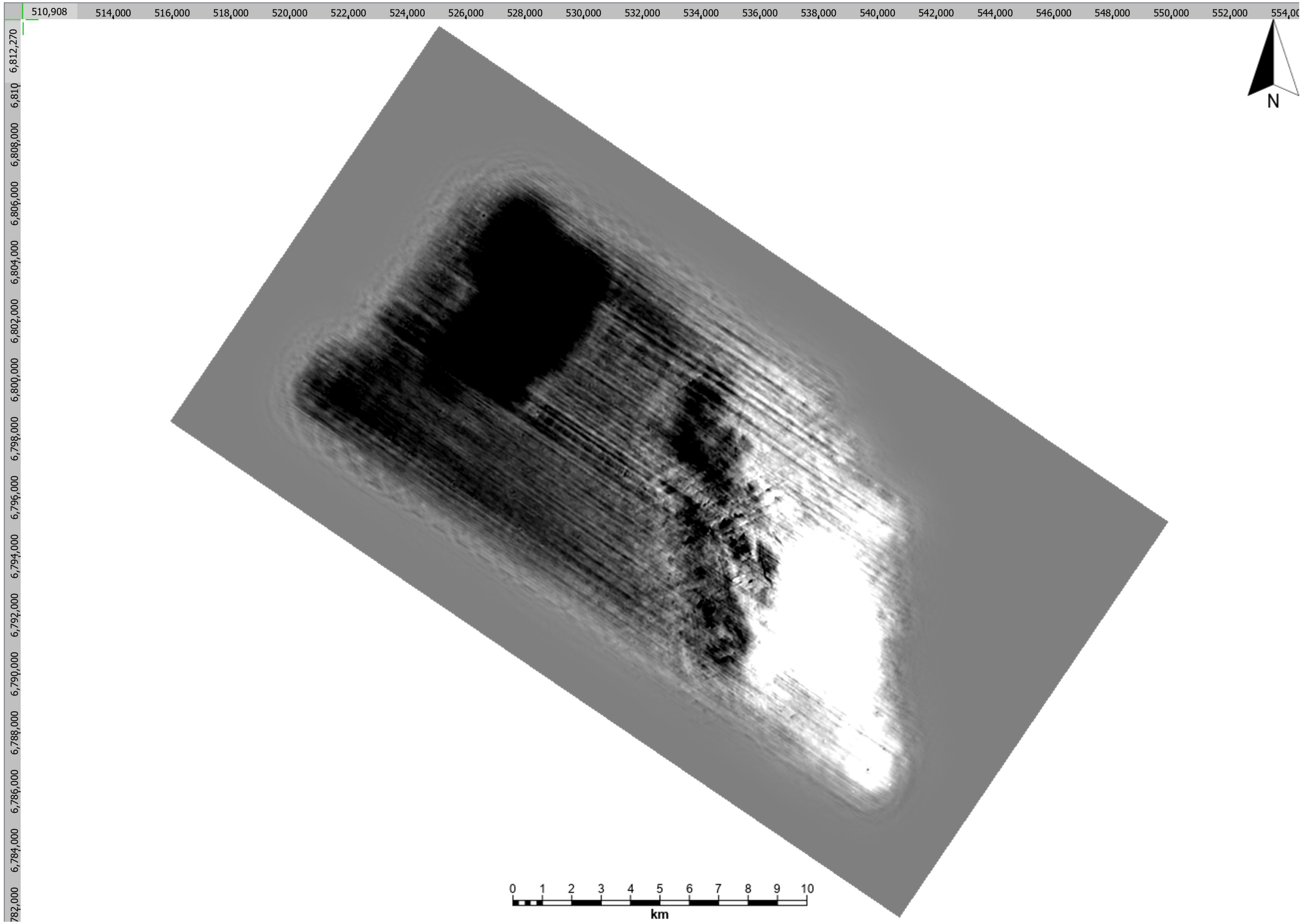


L1201 OBN RTM

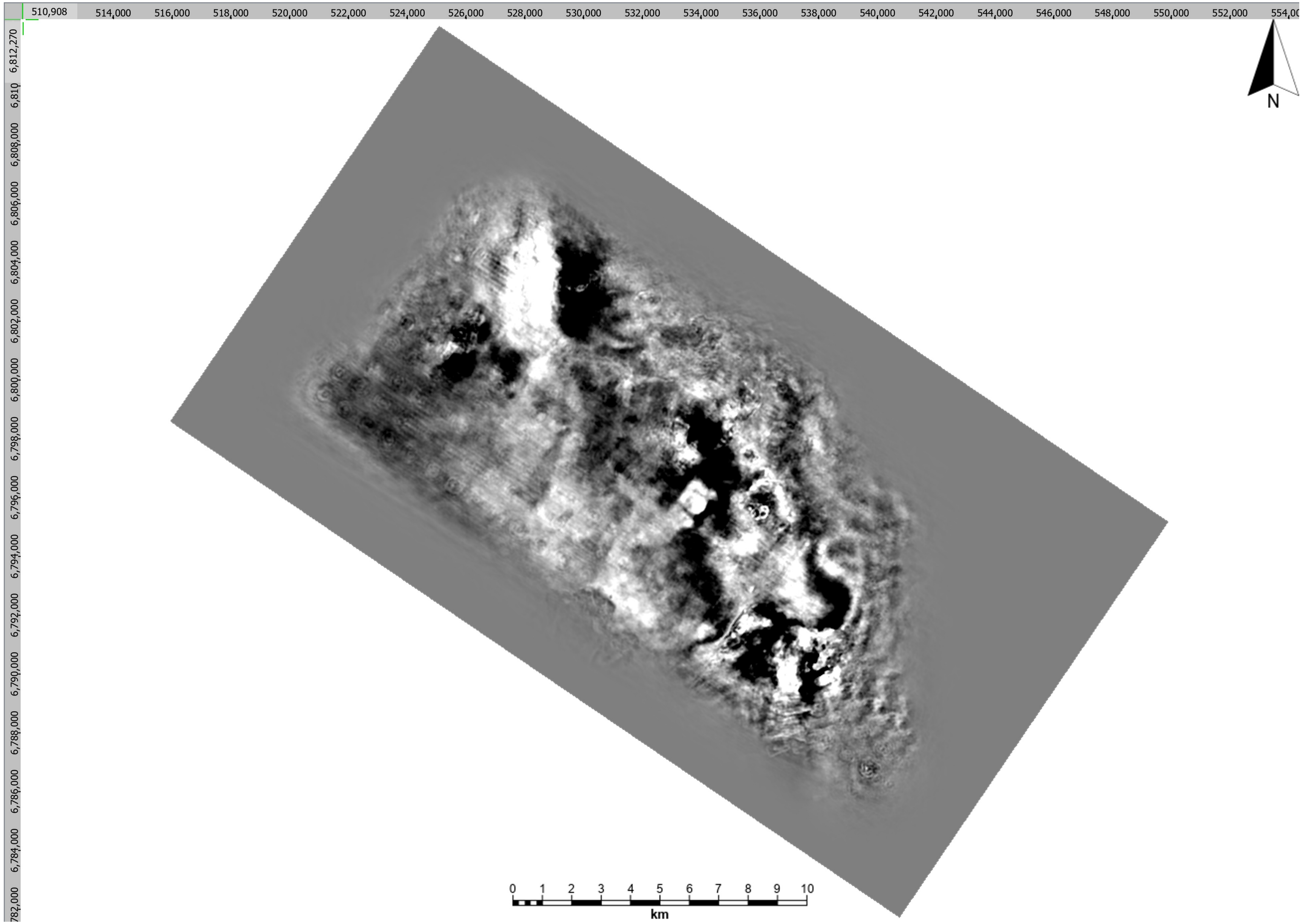




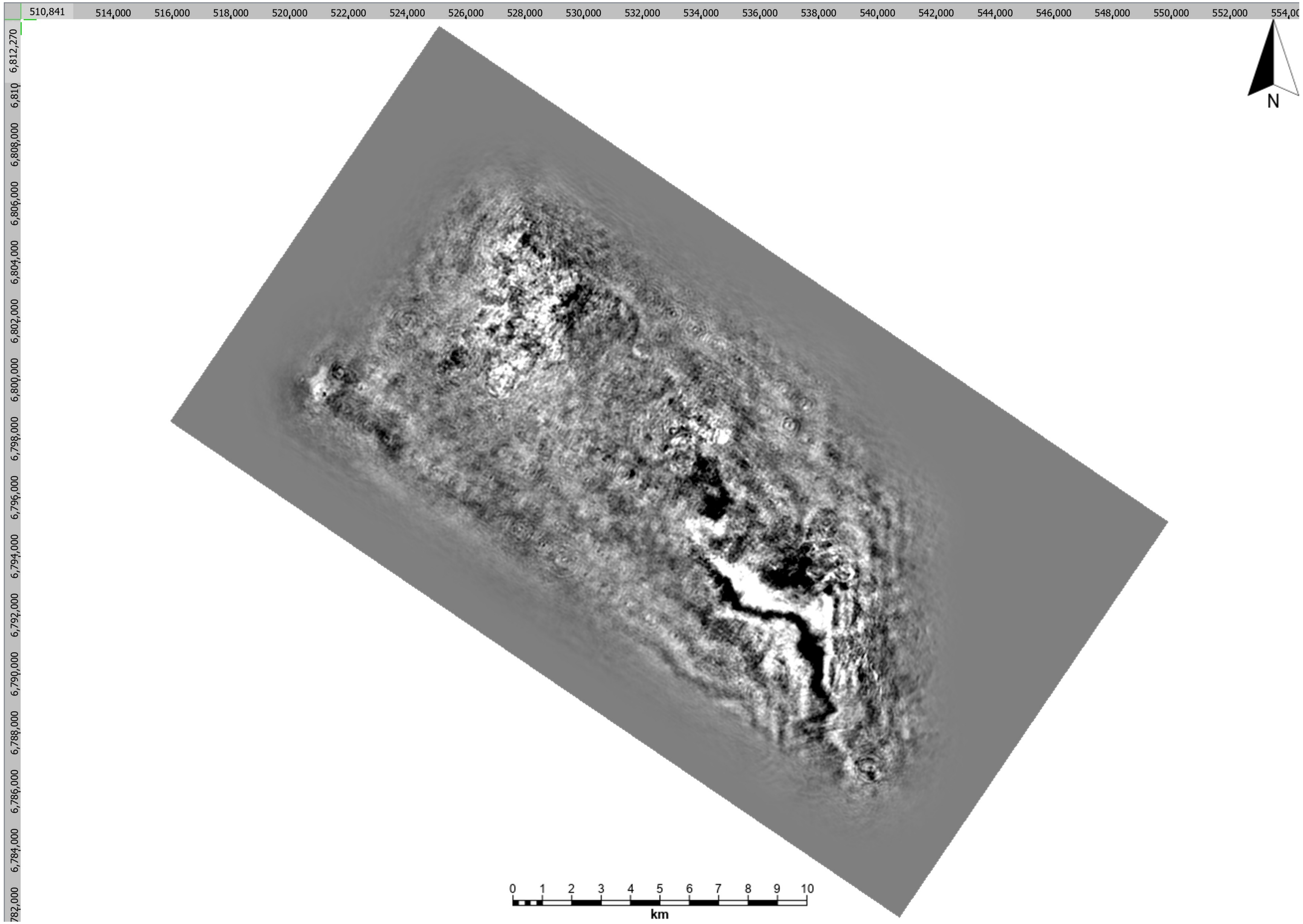
OBN RTM Depth Slice – 375m



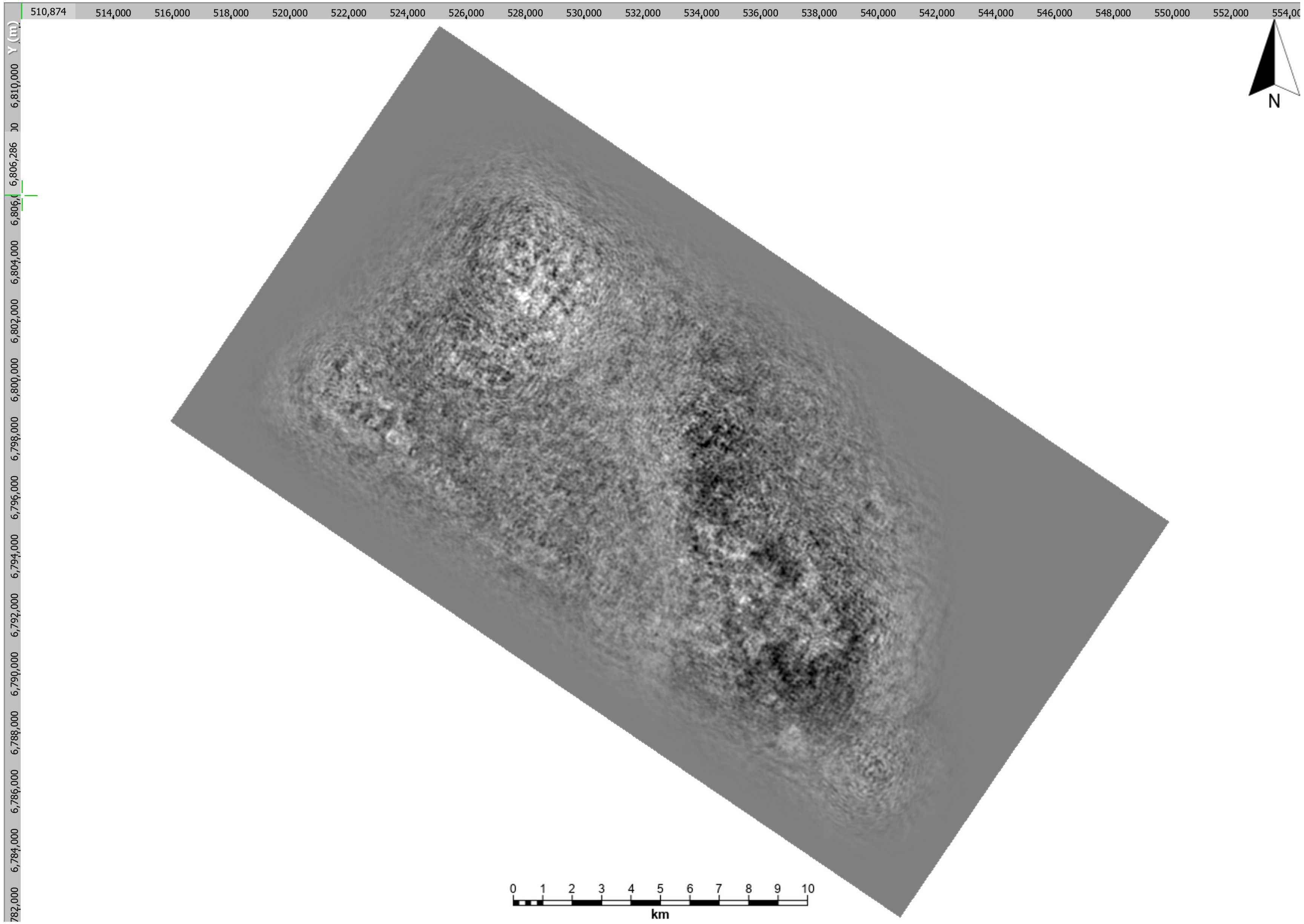
OBN RTM Depth Slice – 750m



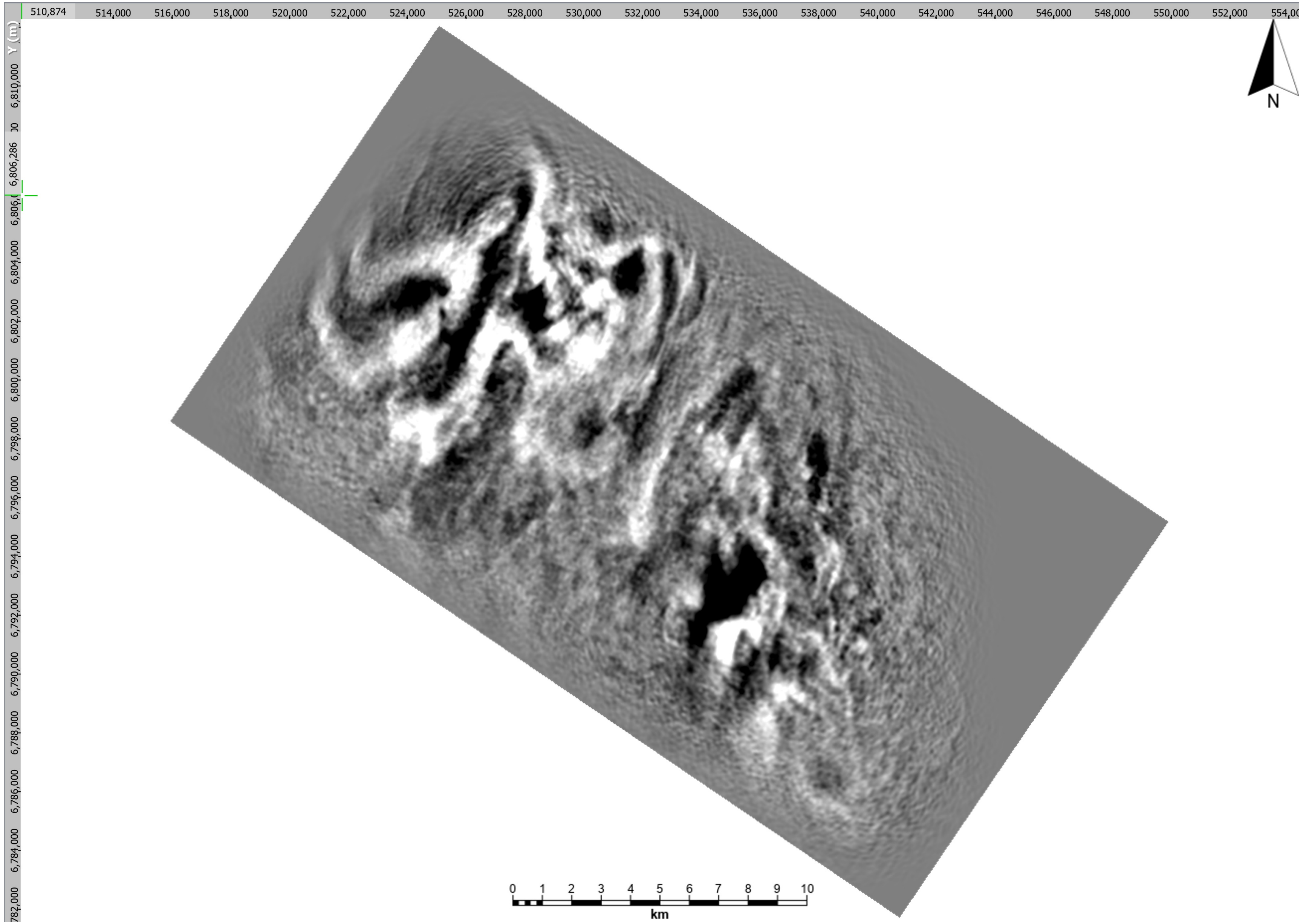
OBN RTM Depth Slice – 1150m



OBN RTM Depth Slice – 2250m



OBN RTM Depth Slice – 4750m

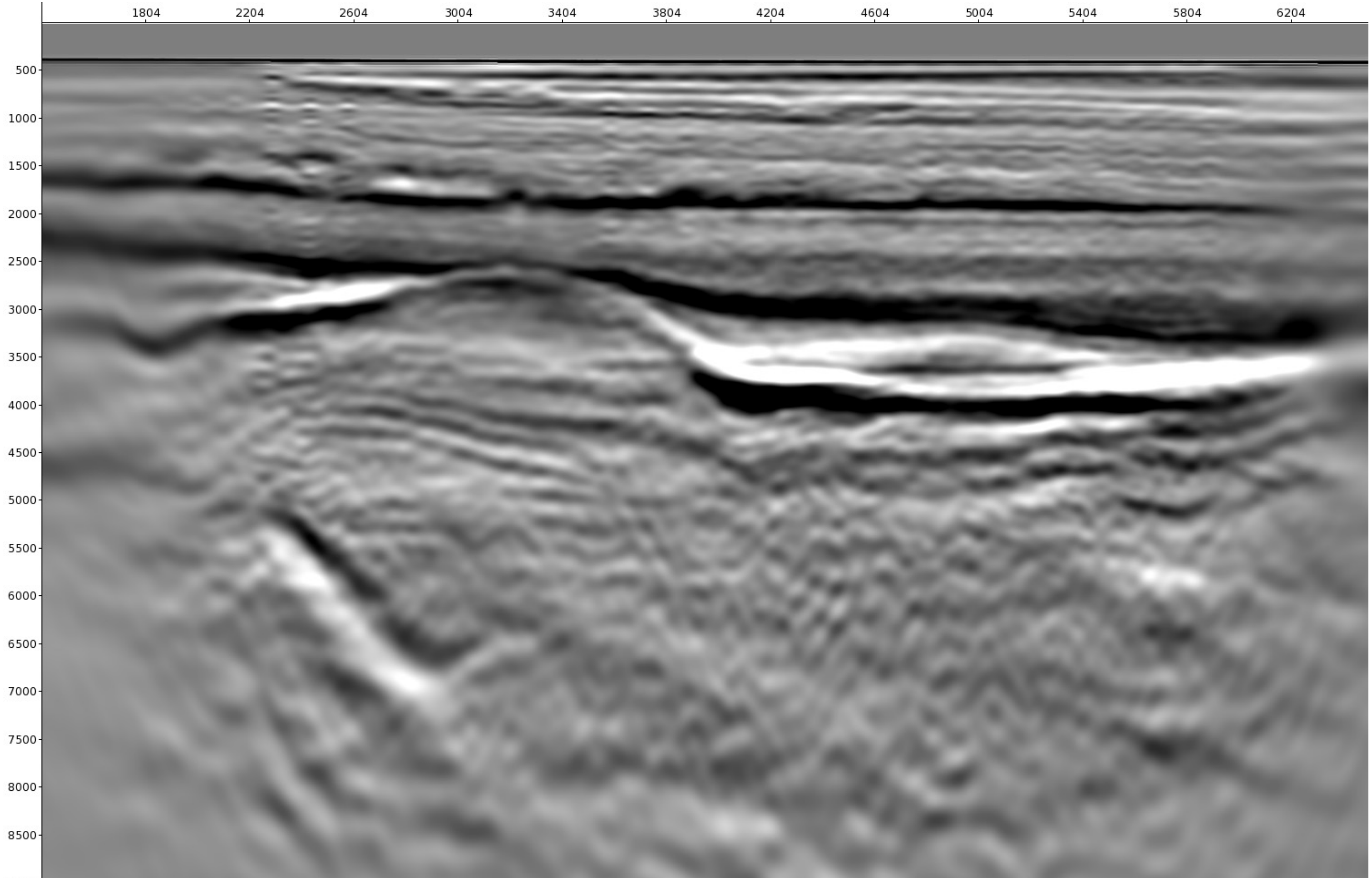


Full Wavefield Imaging

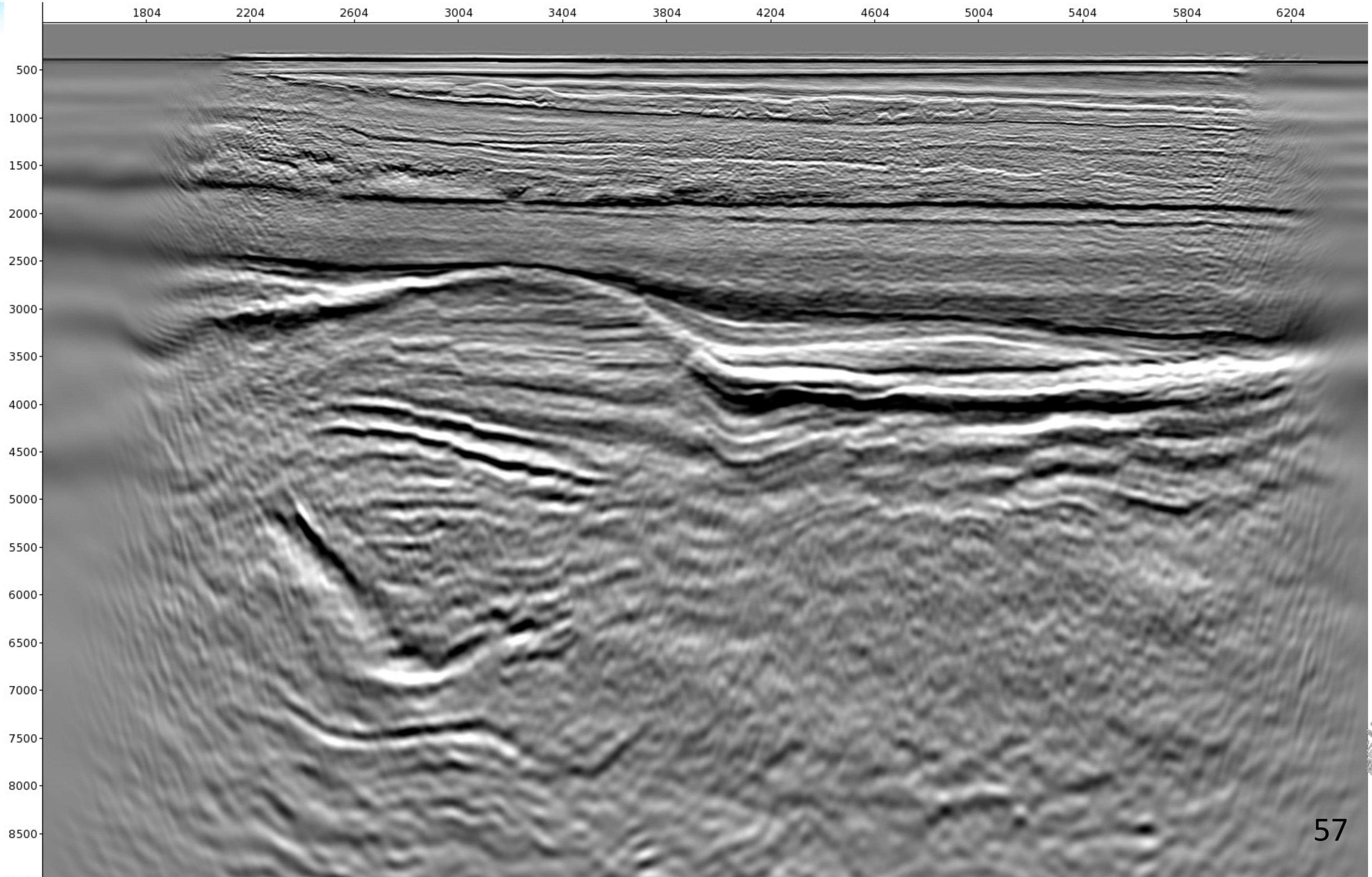
- To fill in low frequencies missing from seismic data
  - Migration works under the 1st-order Born scattering framework, a linear scheme. It images only pre-critical reflections, and cannot create frequencies (wavenumbers) not present in the seismic waves
  - FWI uses the full wavefield to form the image in a nonlinear inversion scheme, and can create in the image frequencies (wavenumbers) that do not exist in the propagating seismic waves

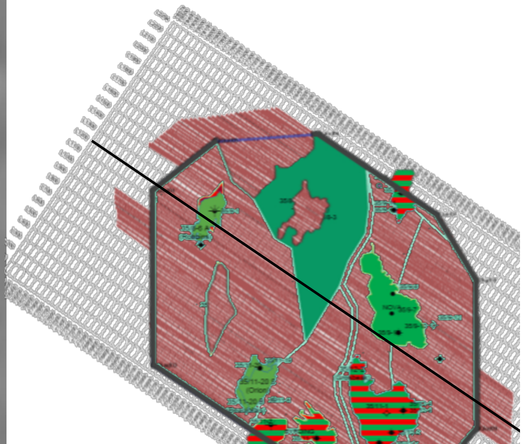
- Vertical reflectivity is extracted from the FWI model and blended with the PSDM image

L1201 OBN FWI Reflectivity Image

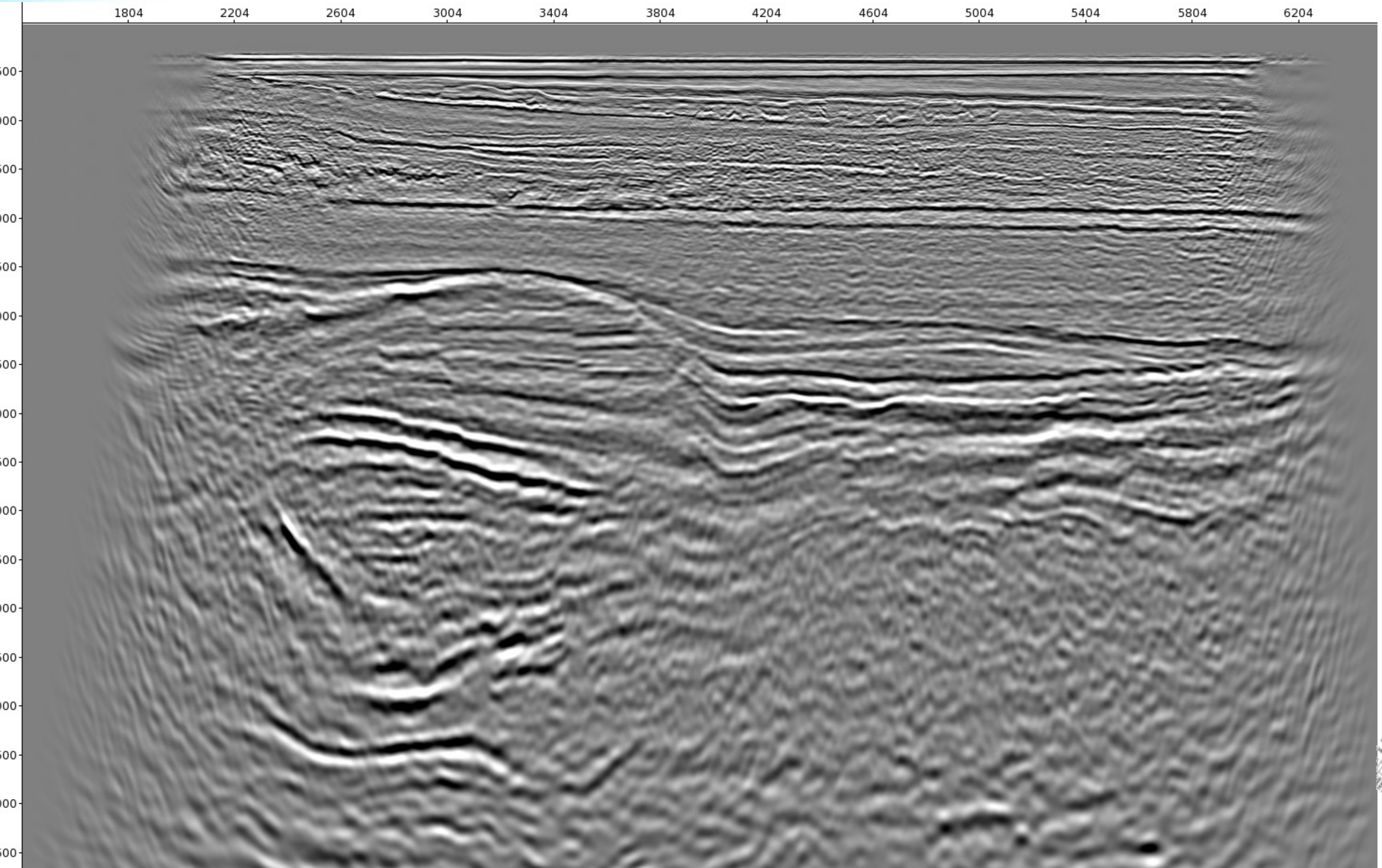


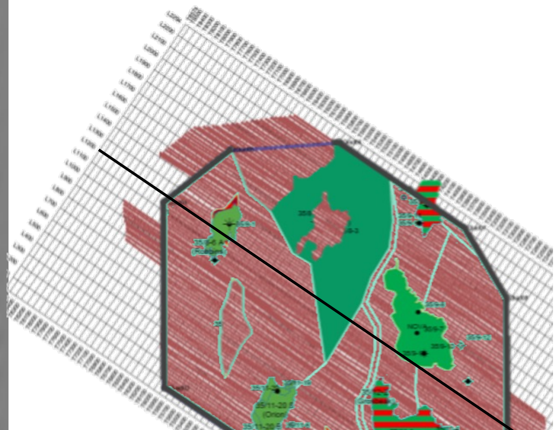
L1201 OBN RTM + FWI Reflectivity Image



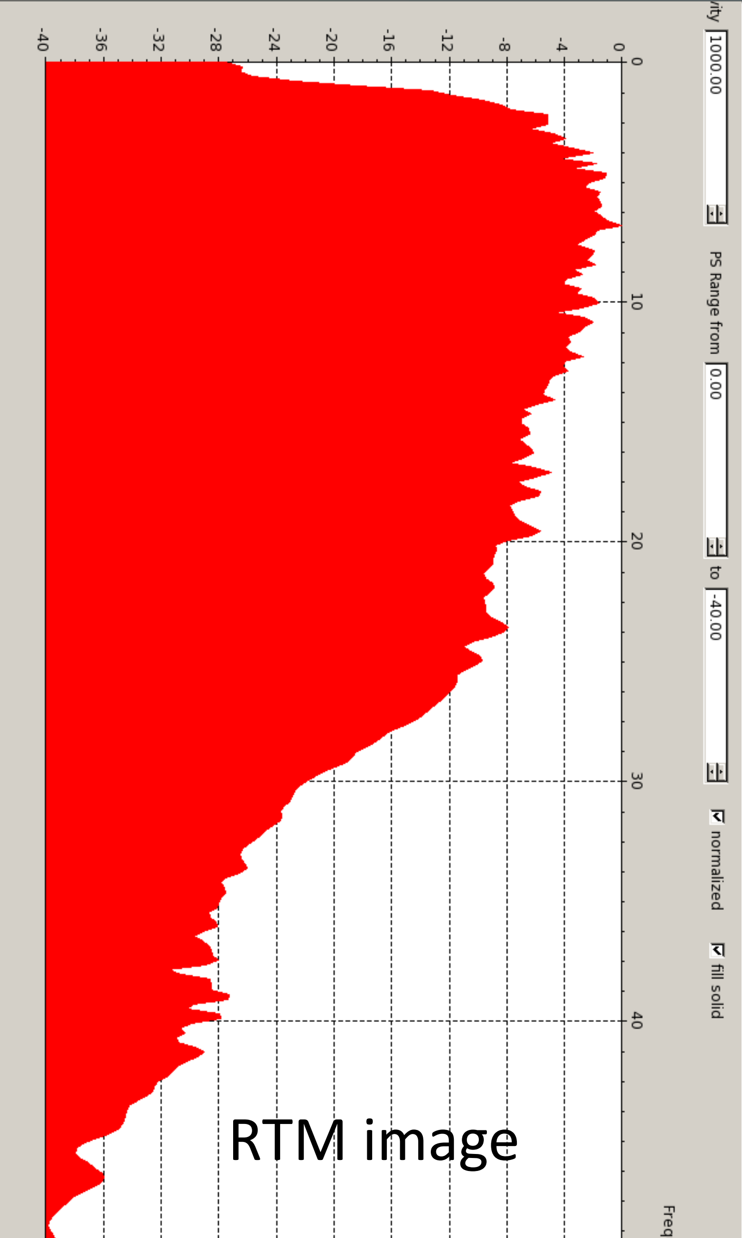


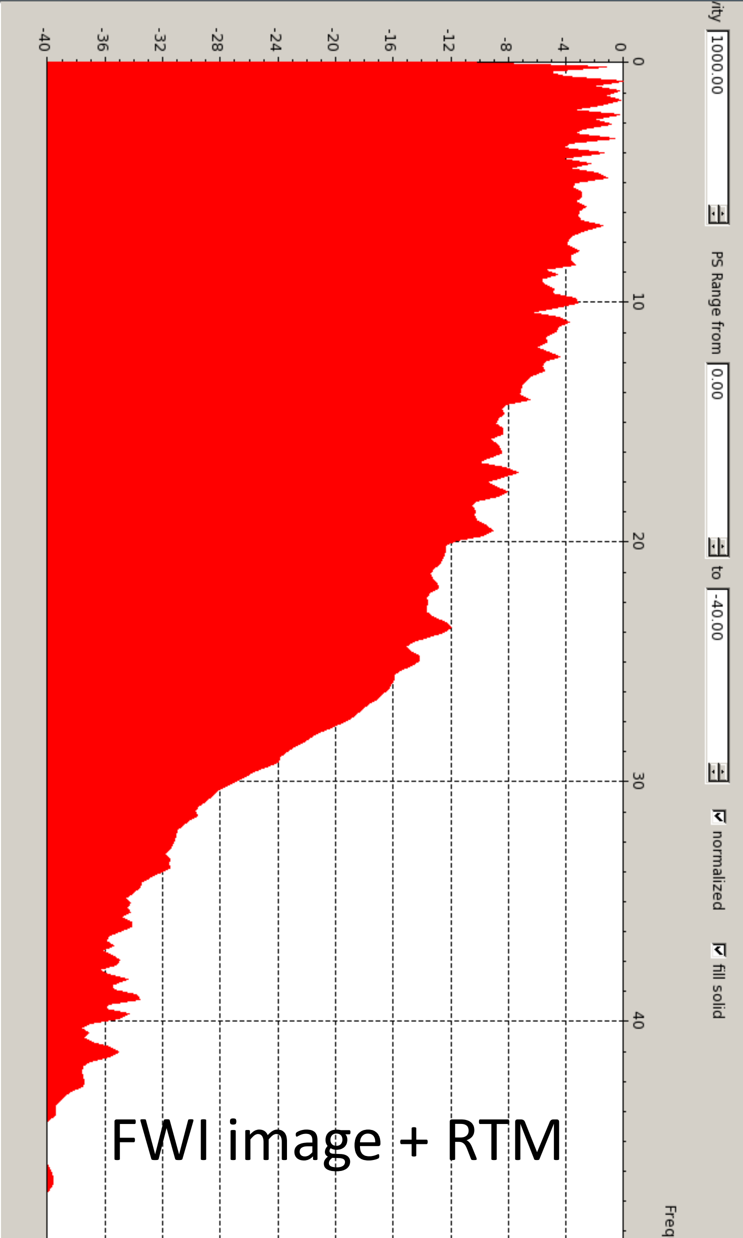
L1201 OBN RTM



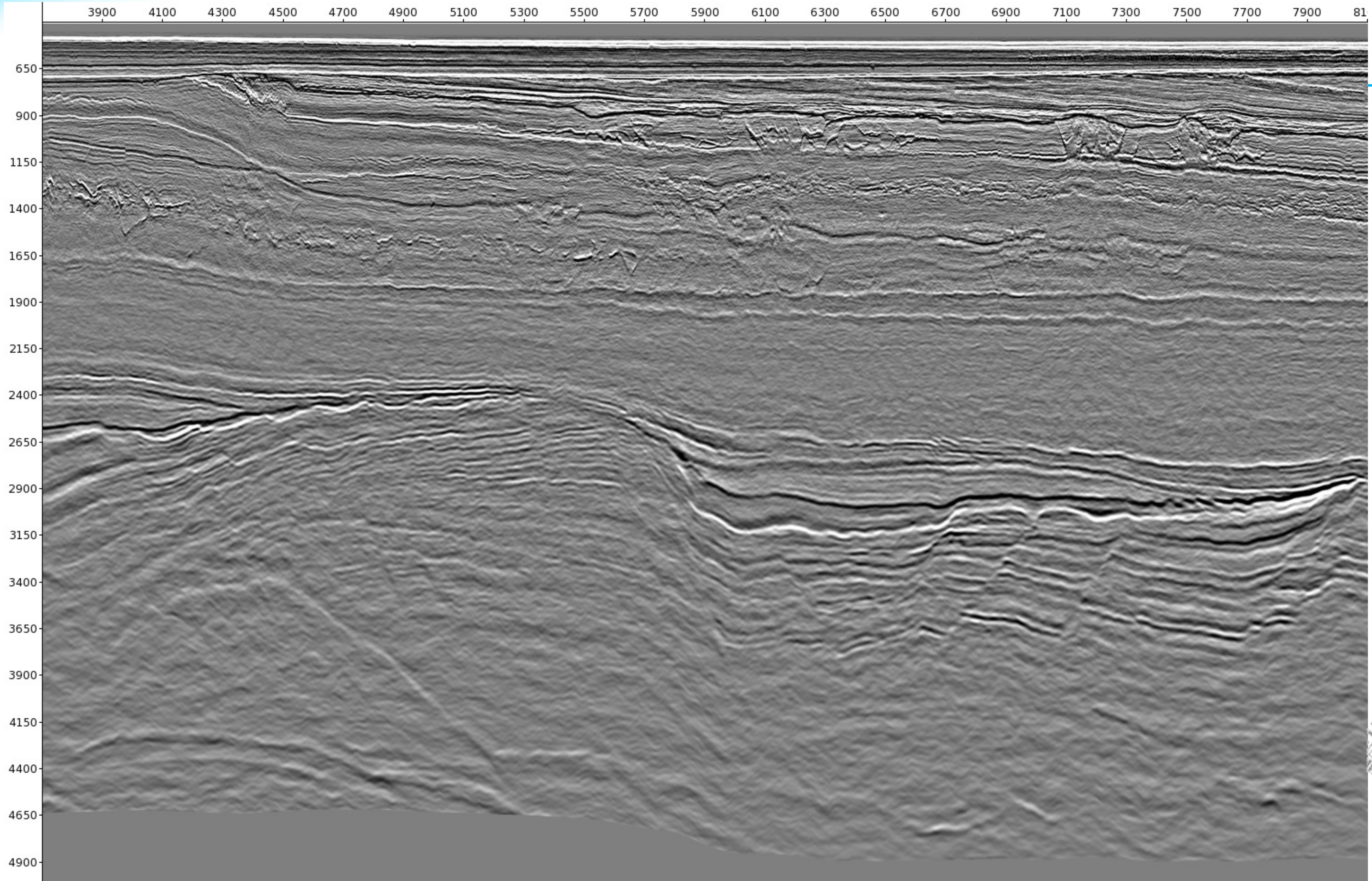


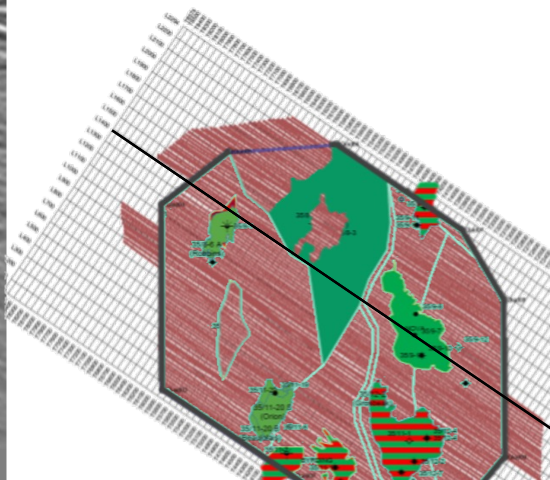
Depth domain spectra comparison



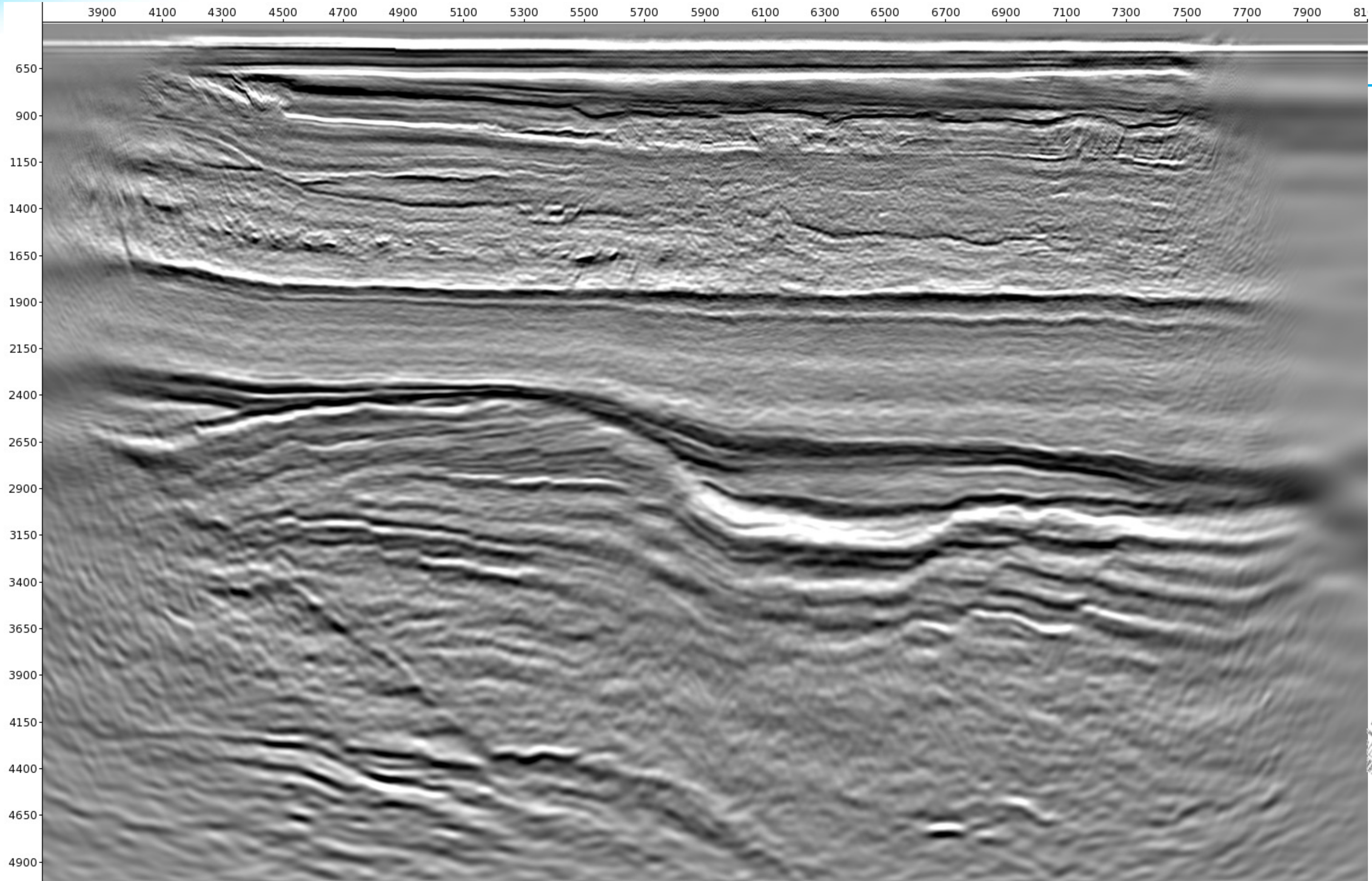


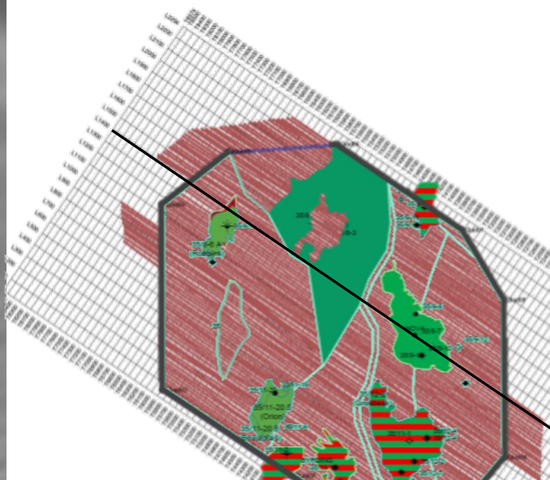
Streamer PSDM



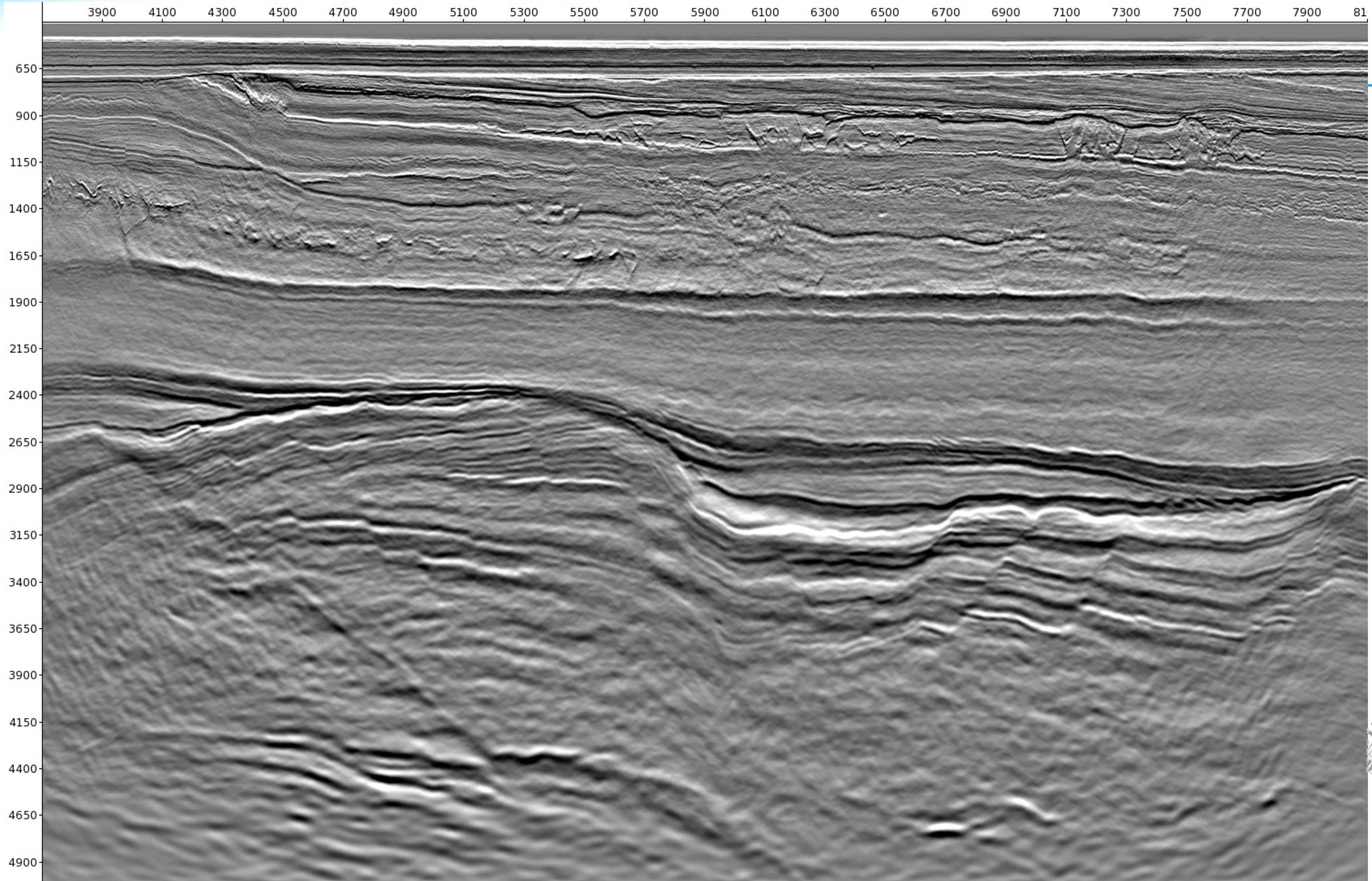


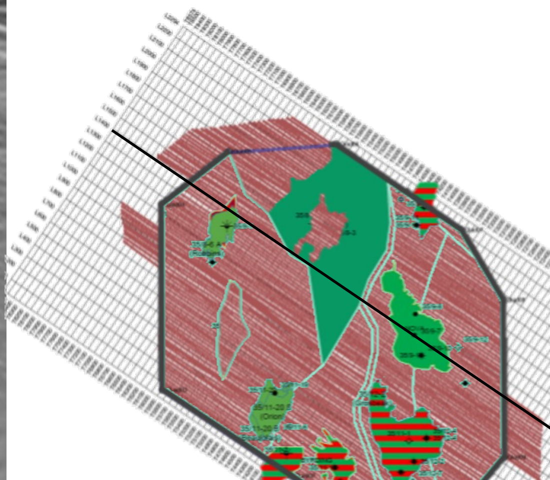
OBN RTM + FWI Image



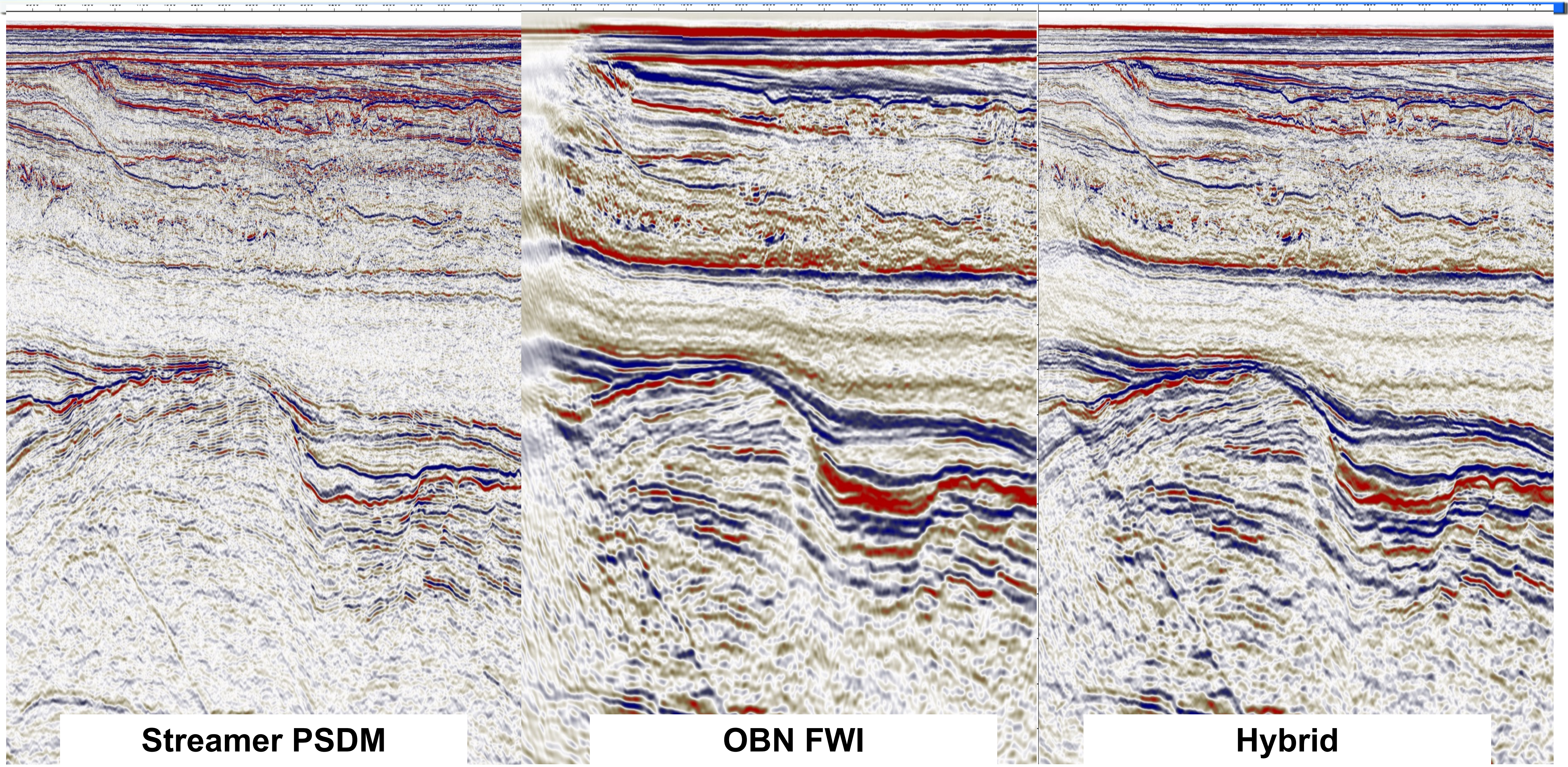


Hybrid Image: Streamer PSDM+OBN RTM+FWI Image





Hybrid Streamer / Node Acquisition



Conclusions

- OBN data provide valuable velocity information due to long offsets which improves streamer data imaging
- FWI is capable of building the velocity model from very simple initial models, and can provide structurally conforming velocity details
- The reflectivity information present in the highly detailed FWI model is complimentary to that in the seismic image, and fills in the low frequencies missing from the latter
- CS-based wavefield reconstruction is able to generate a virtual shot carpet from the non-uniform streamer shots allowing a 50Hz RTM OBN data volume to be imaged using sparse nodes/streamer shots

Conclusions

- Hybrid streamer/OBN surveys offer improved subsurface imaging by improving coverage in congested oilfield surveys and higher resolution FWI velocity models resulting from the longer offsets delivered from the nodes

- Improved wavefield reconstruction methods allow imaging of OBN data using the non-uniform shot coverage from a multi-streamer vessel

- Lower cost node deployment and recovery methods – “drop and pop” nodes - are currently being investigated/trialed to lower the costs of such surveys. For nodes-for-velocities surveys precise node deployment to a regular grid is not required

Acknowledgements

- The author would like to thank Geoex MCG/Seismic Partner for conceiving and implementing this innovative project; BGP Offshore and the other acquisition partners, Reach Offshore and MagseisFairfield, for acquiring the data at the height of the Covid pandemic; BGP Processing R&D for supporting the imaging of the OBN data in Houston and BGP Inc for permission to present these results

QUESTIONS?