Using wide tow Quad point sources for high resolution seismic and accurate AVO measurements in the Barents Sea

Per Eivind Dhelie*, Vidar Danielsen, Jan Erik Lie, Simen Jenvin Støen, Anna Dustira, Lundin Energy Norway
Mark Ackers, Evgeniya Shelavina, Paul Gannon, Tor Atle Wicklund, Spirit Energy Norway
Karen Dancer, Cally Spendlove, Abid Riaz, DownUnder GeoSolutions
Stian Schjelderup, Sval Energi (previously Spirit)

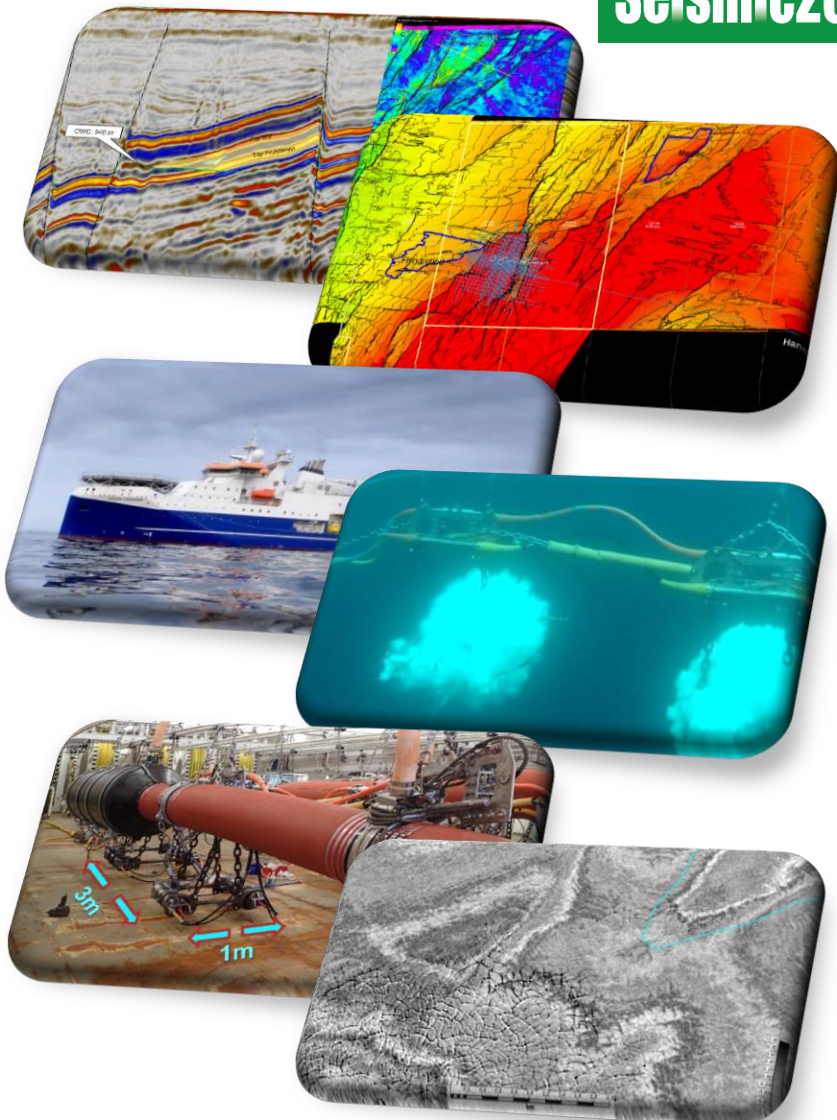
Thursday 17th of September 2020
SPE International, UK, Virtual Event
The Role of Seismic in Unlocking Value in The Energy Mix; "Technology"
14:30 PM – 14:55 PM

Seismic2020

For online viewers – contact me:
ped@lnas.no
LinkedIn

Outline

- Background
  - Geology, license, petroleum systems
  - Geophysical challenges & AVO
- Acquisition Solution – HalfSeis
  - Design, Source, Receivers
  - Planning & Performing the acquisition
- Results
  - Imaging with ultra high density
  - AVO
- Conclusions



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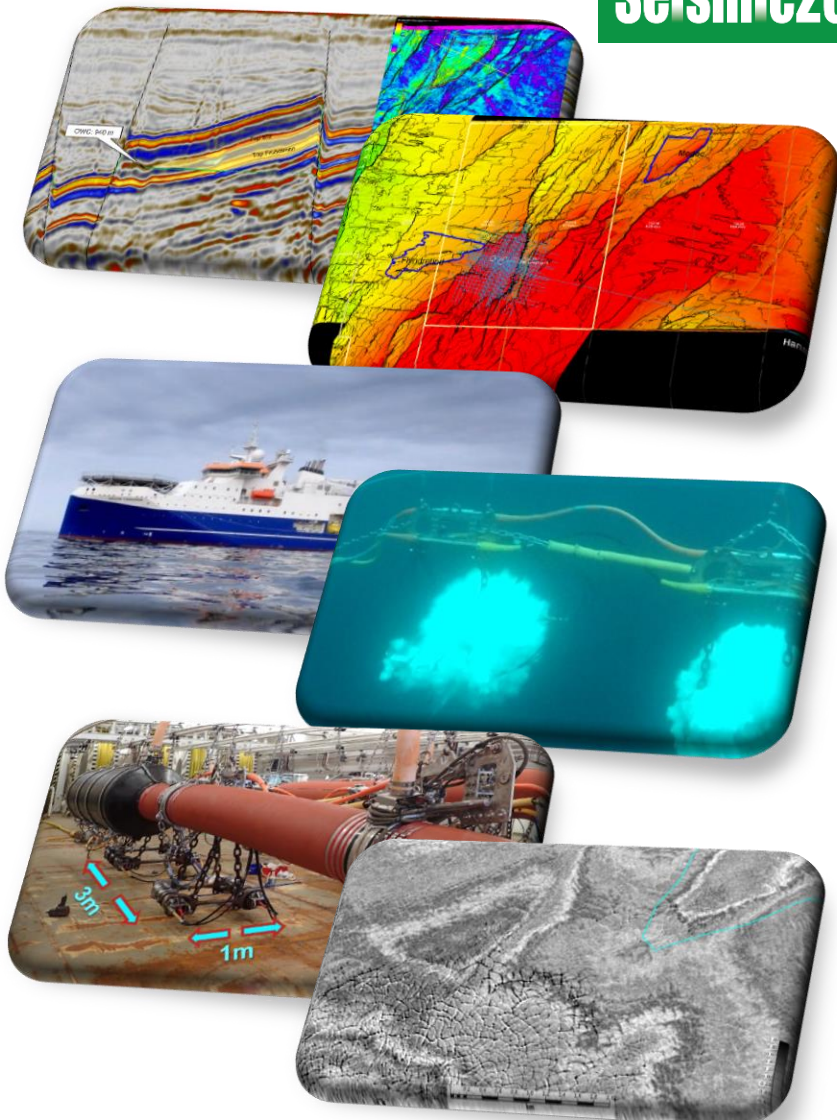
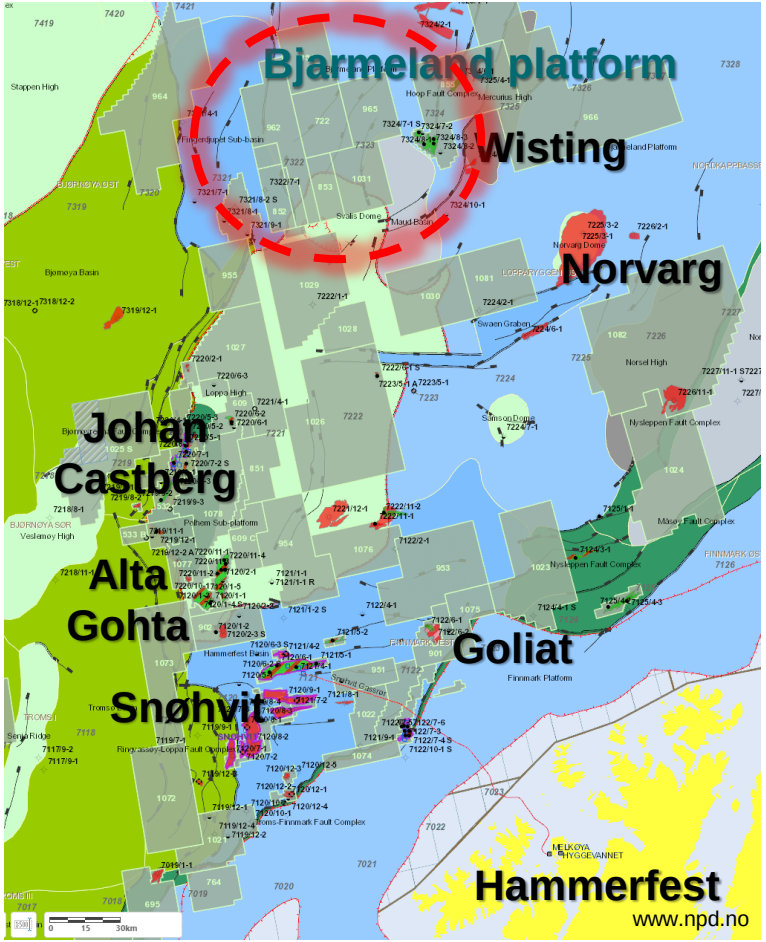
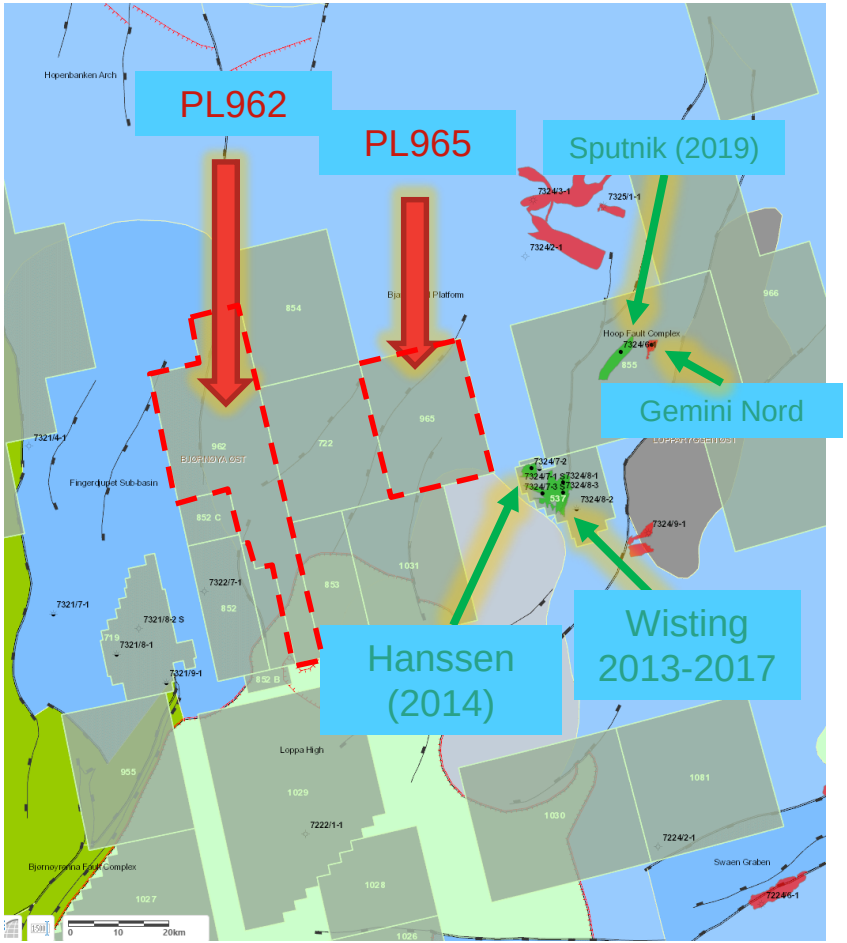
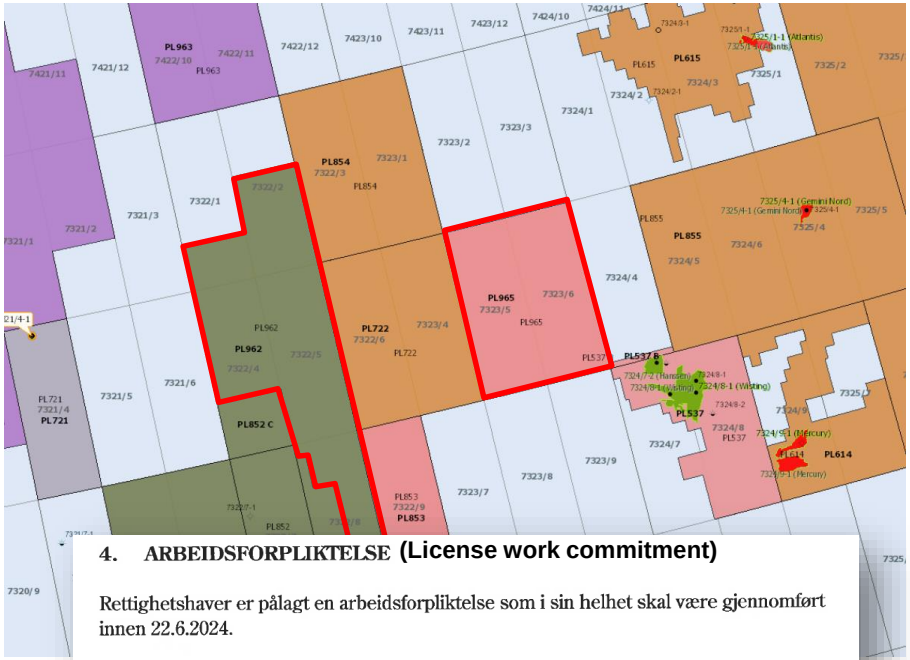


Barents Sea – Where are we I



Barents Sea – Where are we II – 24th round – Hope…area☺





4. ARBEIDSFORPLIKTELSE (License work commitment)

Rettighetshaver er pålagt en arbeidsforpliktelse som i sin helhet skal være gjennomført innen 22.6.2024.

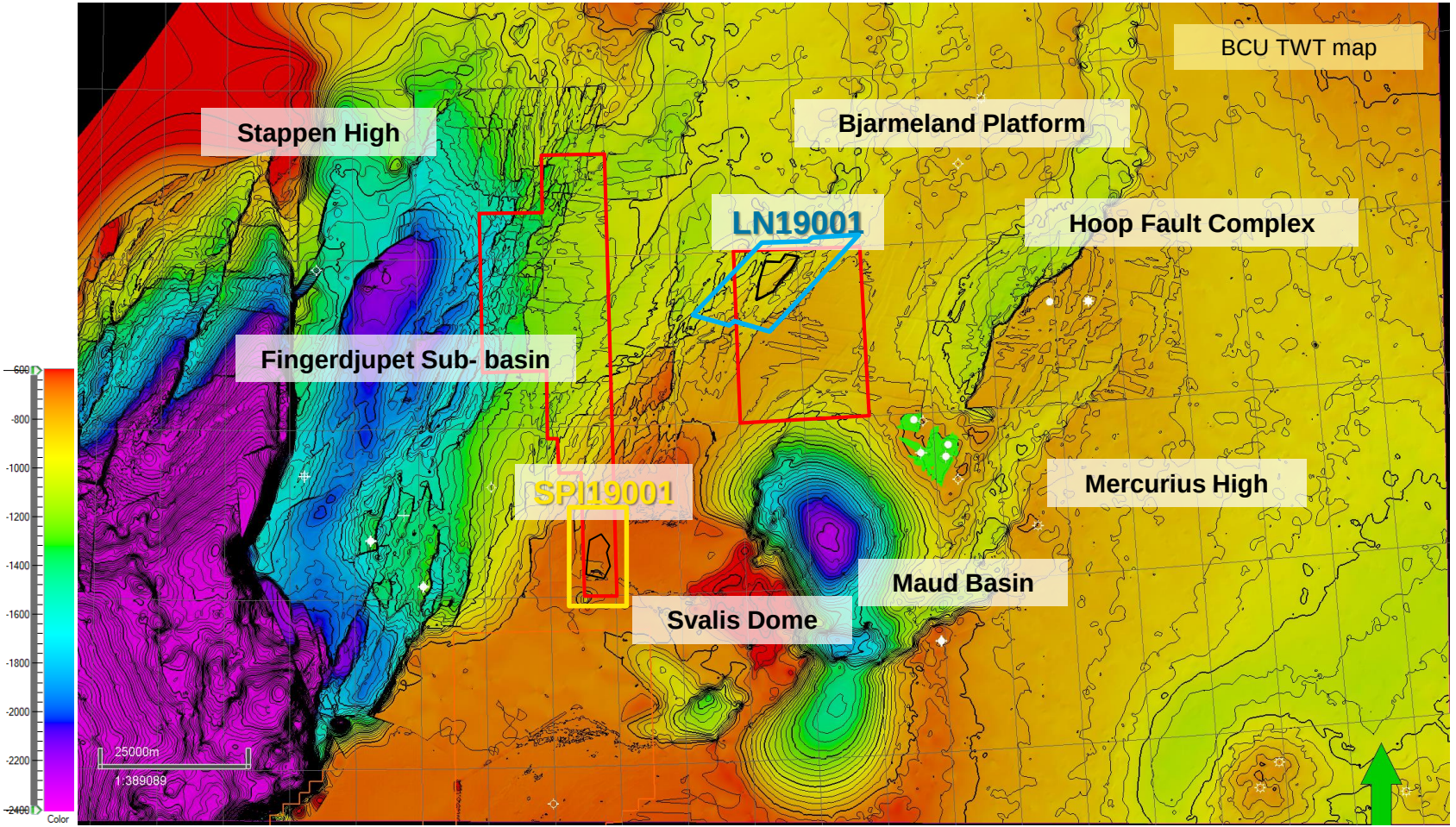
Om arbeidsforpliktelsen og gjennomføringen av denne gjelder følgende:

a) Rettighetshaver skal innen 3 år fra tildelingstidspunktet samle inn ny 3D-seismikk (Høyoppløslig seismikk) og gjennomføre EM-mulighetsstudie.

«shall acquire new 3D high res seismic»

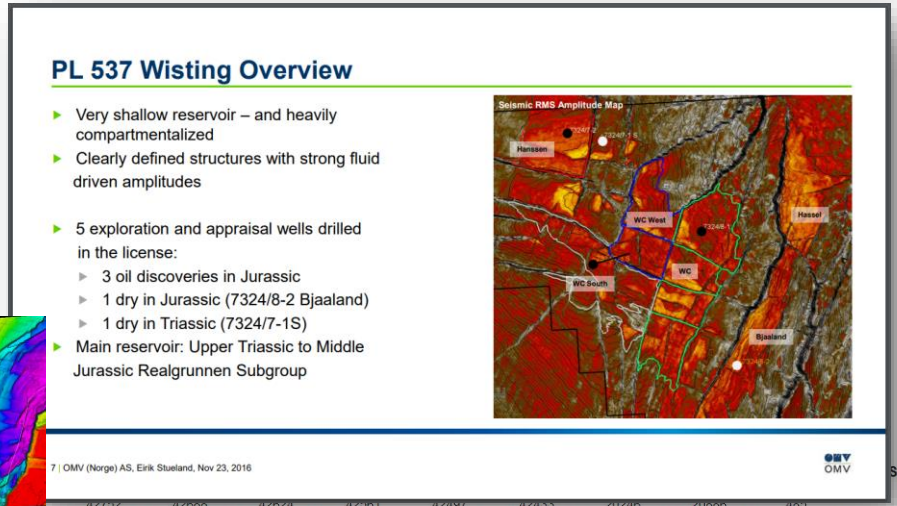
b) Rettighetshaver skal innen 3 år fra tildelingstidspunktet vedta om det skal bores en undersøkelsesbrønn. Vedtak om boring fattes i medhold av Avtale for petroleumsvirksomhet artikkel 3.2. Dersom det fattes vedtak om boring av undersøkelsesbrønnen, videreføres utvinningstillatelsen. Boring av undersøkelsesbrønn skal i sin helhet være gjennomført innen 5 år fra tildelingstidspunktet.

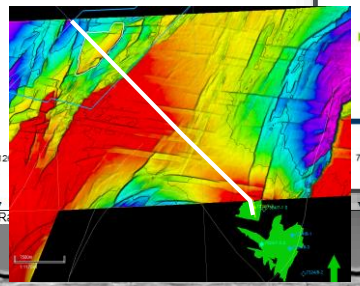
Barents Sea – Where are we III

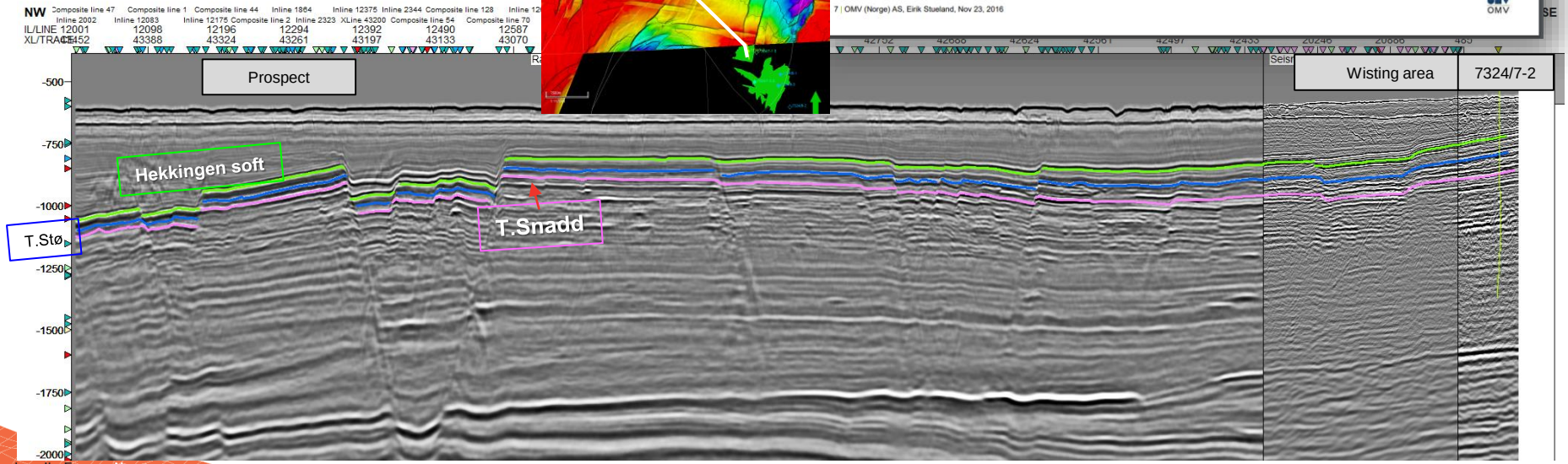


The link to Wisting and high resolution seismic

- Extensive data coverage:
  - Large 3D surveys
  - Abundance of 2D data
  - Several campaigns of high-res site-survey 2D data

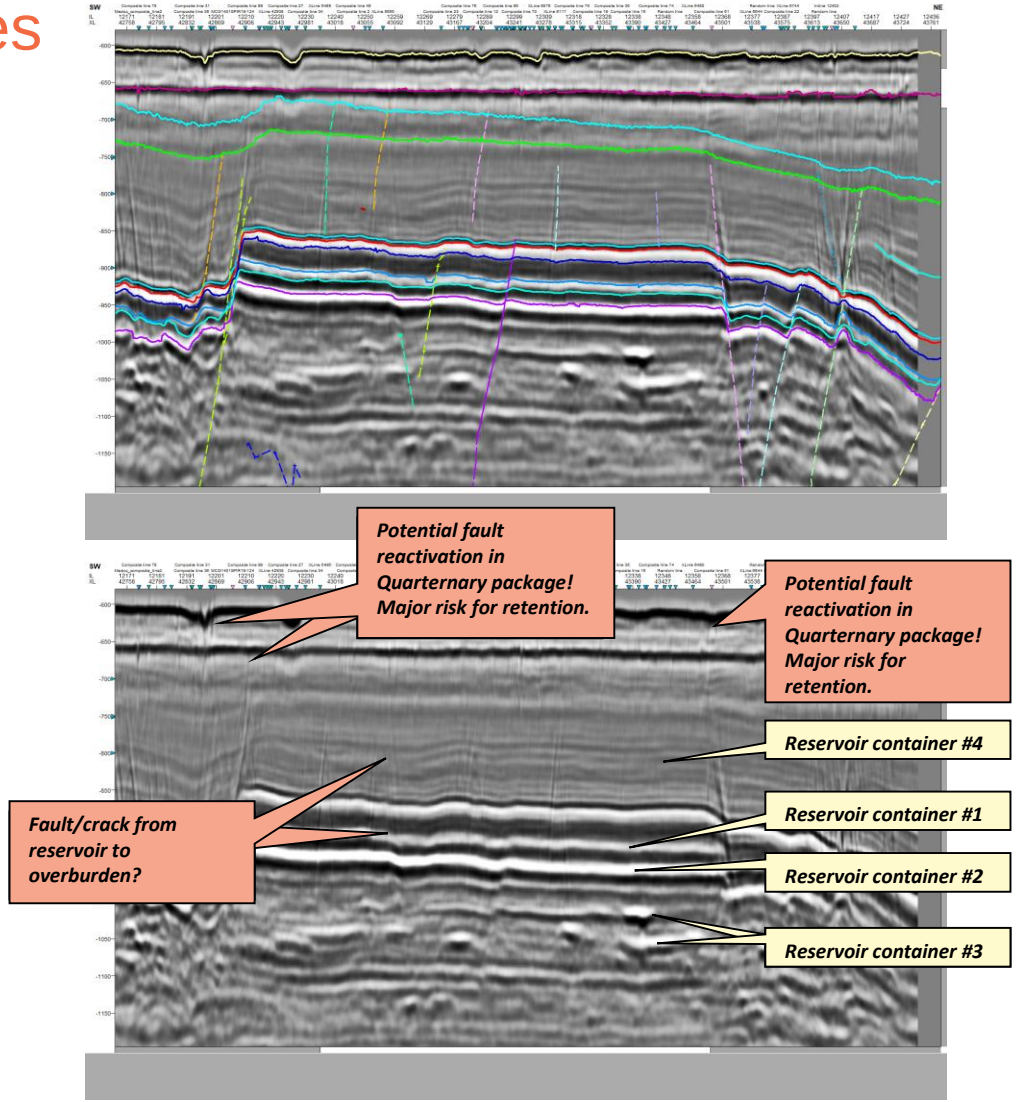




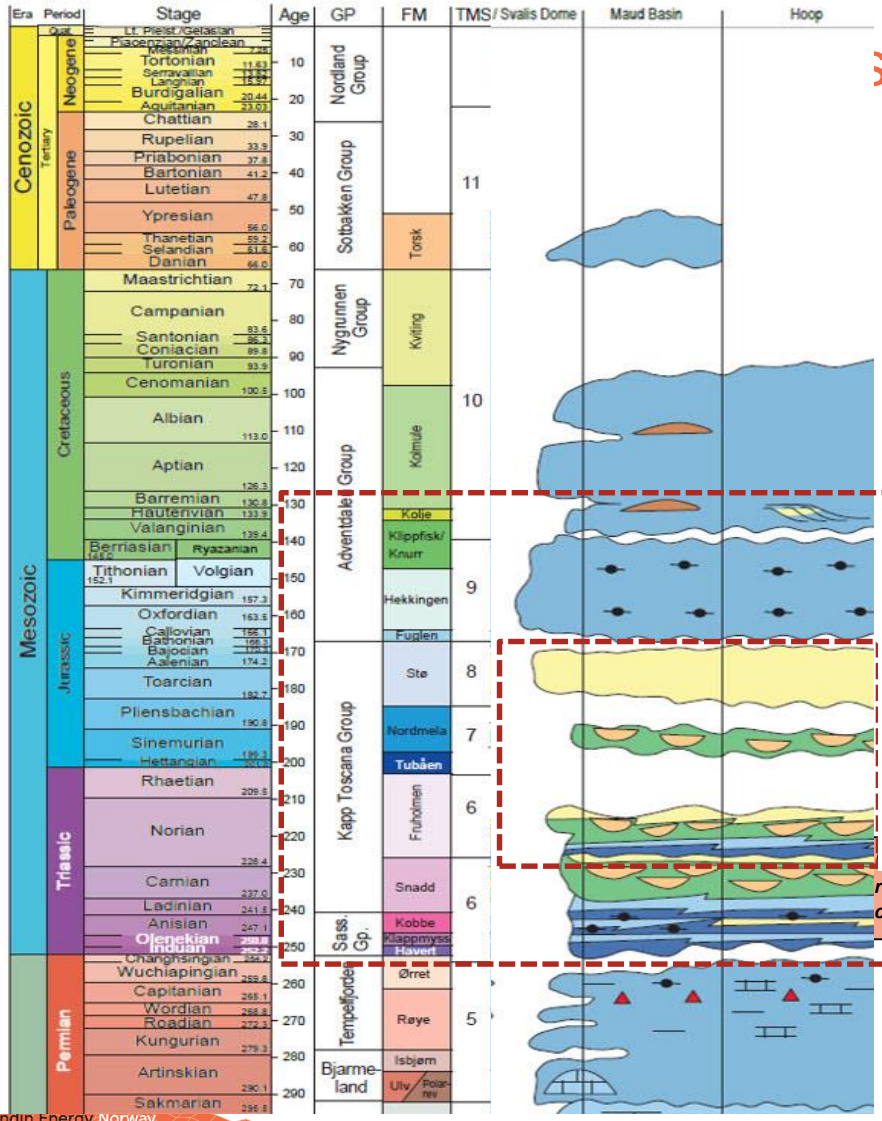


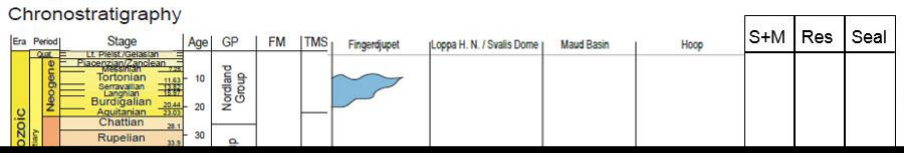
Reservoir Driven Challenges

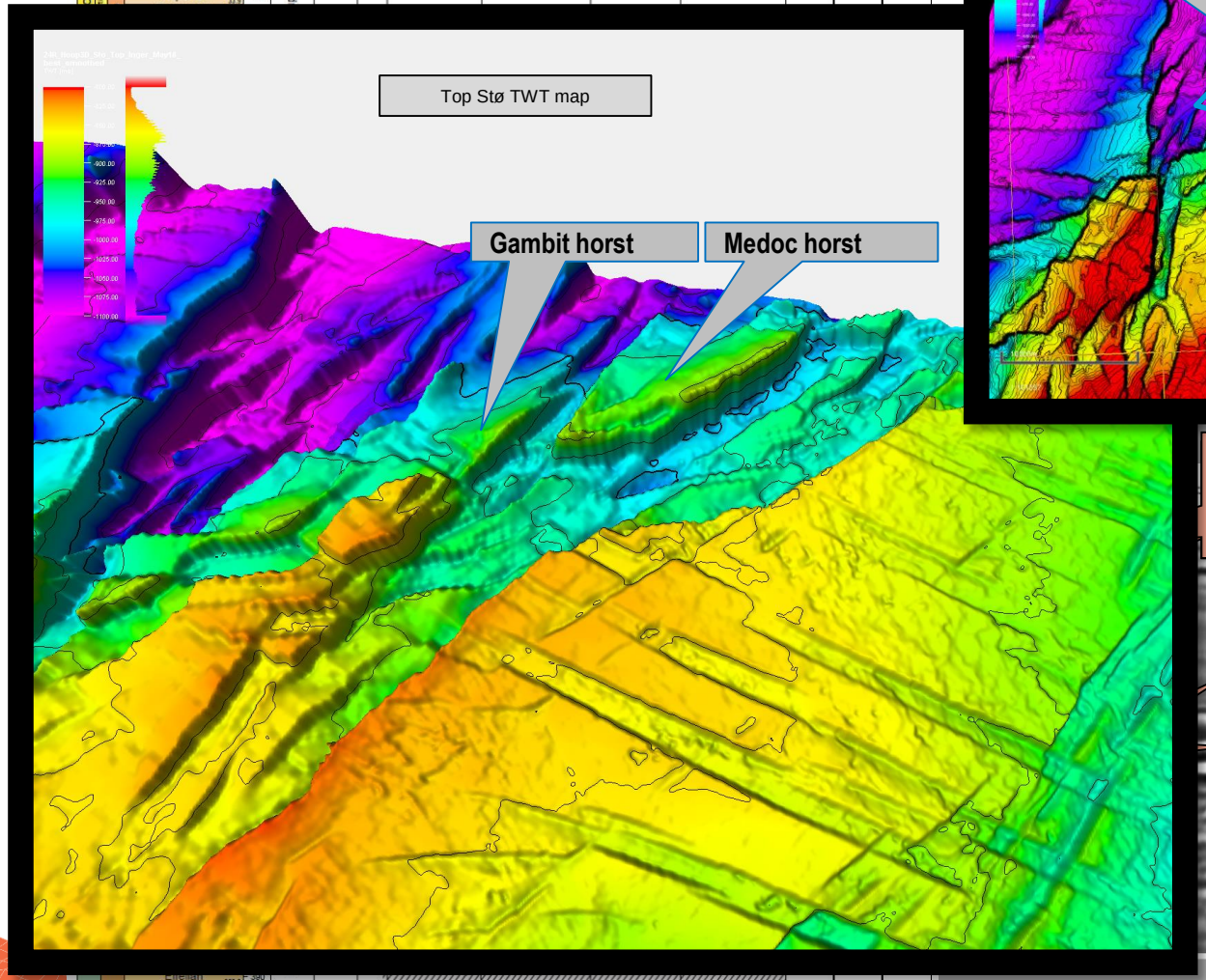
- The Maud basin is depocenter for most prospective reservoir sequence in this part of the Barents Sea
- Reservoir stratigraphy is thinning towards west (prospect area)
- We need to “see” the reservoir architecture to improve understanding and reduce risk
- Looking for flat-events – sign of moving hydrocarbons
- Where do you set the base reservoir pick? Direct economic impact

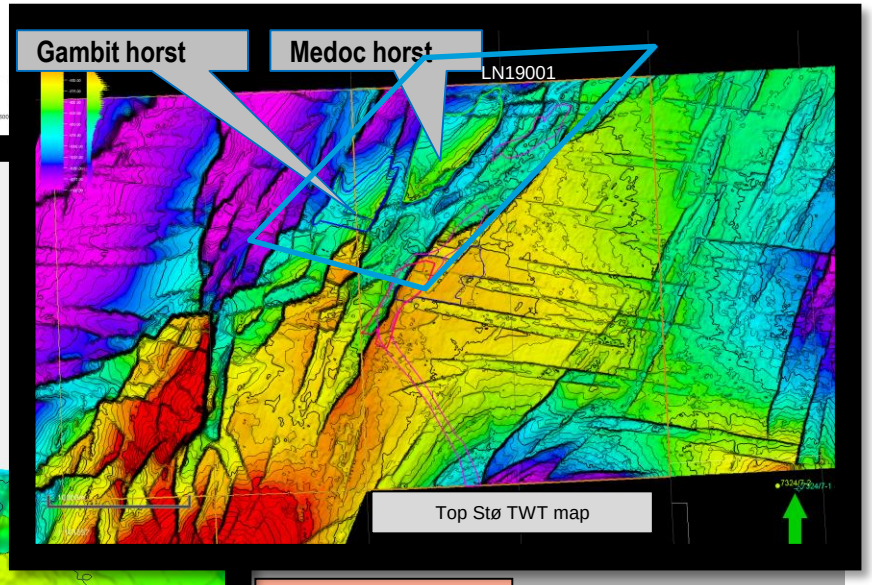


Chronostratigraphy




Chronostratigraphy
Era
Period
Stage
Age
GP
FM
TMS
Fingerdjupet
Loppa H. N. / Svalis Dome
Maud Basin
Hoop
S+M
Res
Seal
Neogene
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
10
20
30
Nordland Group


Top Stø TWT map
Gambit horst
Medoc horst


Gambit horst
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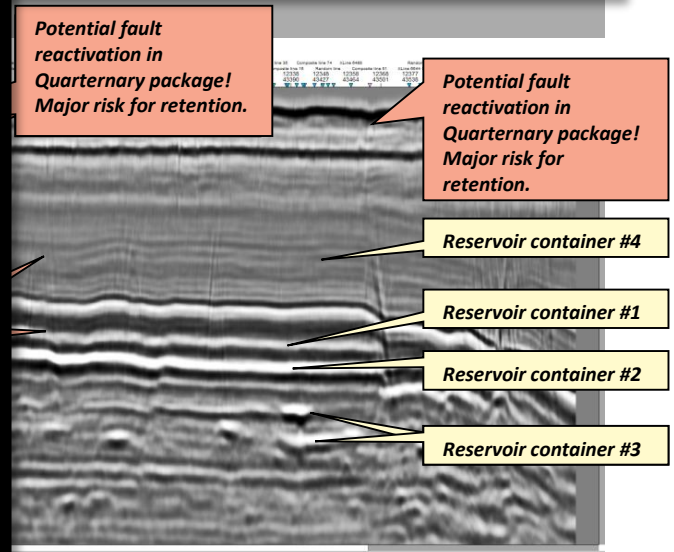
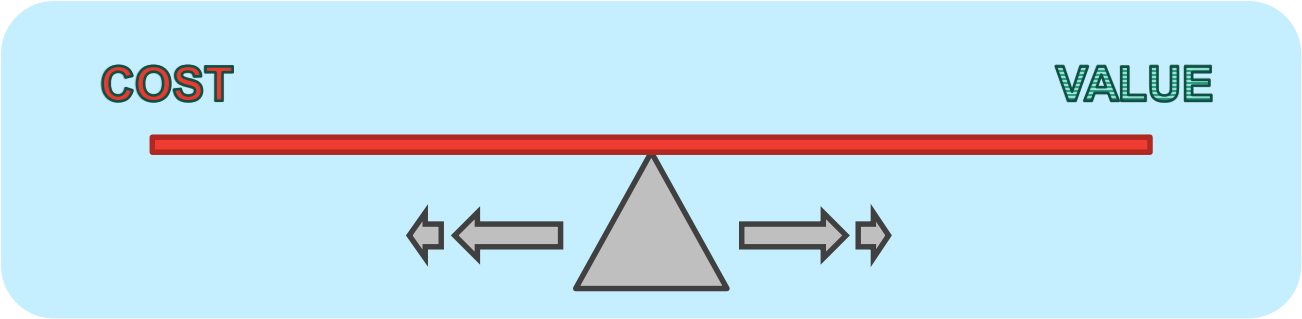
LN19001
Top Stø TWT map


Potential fault reactivation in Quarternary package! Major risk for retention.
Potential fault reactivation in Quarternary package! Major risk for retention.
Reservoir container #4
Reservoir container #1
Reservoir container #2
Reservoir container #3

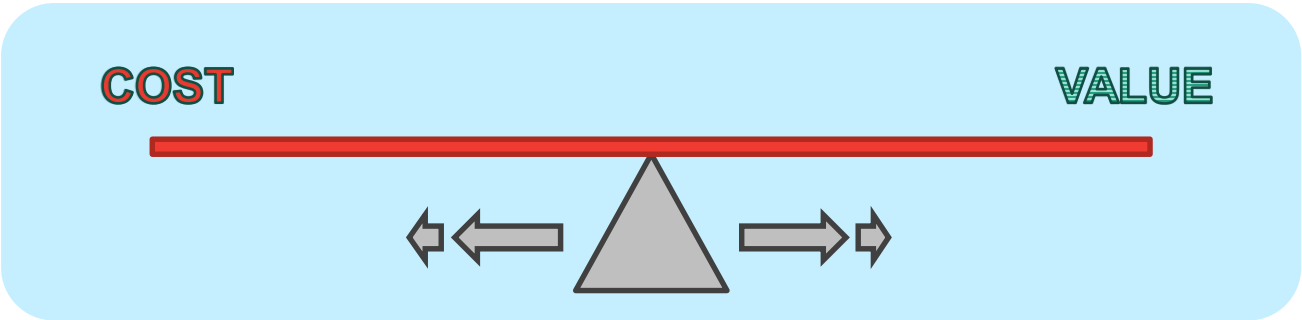
Geophysical Challenges

- Temporal resolution > Both higher and lower frequencies
- Spatial resolution > Smaller bins – more focused source point
- Sharp faulting > Low frequencies – and deghosting (source & rec)
- Definition > High trace density – lots of shots and receivers
- Stubborn Multiples > High fold & sampling, near & far offsets
- AVO/DHI > Requires close to zero offsets & far offsets
- Prospect survey > Cost efficient for ~200 km^2 (not a large survey)
- Pre-PDO > Limited funds available to obtain needed data



Survey Objectives:

- To acquire and obtain:
  1. a very high resolution survey, both spatially and temporally
  2. a close to zero-offset dataset – by having the sources spread out wide and as close as possible to the front of the streamers
  3. a good quality low noise dataset with the streamers/receivers towed deep
  4. a high signal to noise dataset with high fold data, with many sources (4) and shot as frequent as possible (6.25m SPI)
  5. a seismic survey using a small focused point source to obtain very high crisp detail in the seismic image



- Quad small point source
- Multimeasurement Streamers
- Deep quiet noise free tow, 15m
- 6.25m SPI, 4m source depth
- Zero offset acquisition <20m
- Ultra high density, 1.56 x 3.12m
- Source separation 33m
- 50m streamer separation
- 8 on 6 preplot for reduced noise
- 1.5 – 204Hz continuous recording
- Natural dither only
- Shot-by-shot far field compensation

Amazon Conqueror

SHEARWATER

- Quad small point source
- Multimeasurement Streamers
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10th September 2019

Shearwater GeoServices awarded Isometrix projects by Lundin Norway and Spirit Energy Norway.

Shearwater GeoServices Holding AS ("Shearwater") is pleased to announce the award of a master services agreement by Lundin Norway AS ("Lundin"), and new **Iso***metrix* seismic acquisition projects for Lundin and Spirit Energy Norway AS ("Spirit Energy") in the Barents Sea, Norway.

Both projects are Flexisource quad-source Isometrix projects with 50m streamer separation which will deliver a true 3D deghosted high-resolution Isogrid dataset. The marine acquisition surveys will be carried out by the Amazon Conqueror, starting in Q3. The Lundin award is under the new multi-year master services agreement and covers approximately 180 sq. km at license PL965. The project for Spirit Energy covers 130 sq. km and is at license block PL962.

"In addition to the unique Isometrix streamer technology, we have redesigned the source configuration down to a very small point source of only 1m by 3m. Combined with wide tow and four of the small focused sources, we believe we will obtain a super-high resolution image with almost zero-offsets as well as give us accurate amplitude versus offset measurements for reservoir property prediction" comments Per Eivind Dhelie, Senior Geophysicist in Lundin.

"This novel hybrid acquisition setup, which combines elements from 3D marine and site-survey operations will deliver a very high-resolution dataset that we believe will enable high fidelity imaging of our target", comments Mark Ackers, Senior Geophysicist in Spirit Energy.

"The combination of our Amazon class vessel and Isometrix multi-sensor technology gives our clients access to the industry's most technologically advanced and efficient platform for marine seismic acquisition," said Irene Waage Basili, the CEO of Shearwater GeoServices. *"We are truly excited by Lundin and Spirit Energy choosing our Isometrix technology and the Amazon Conqueror for their surveys."*

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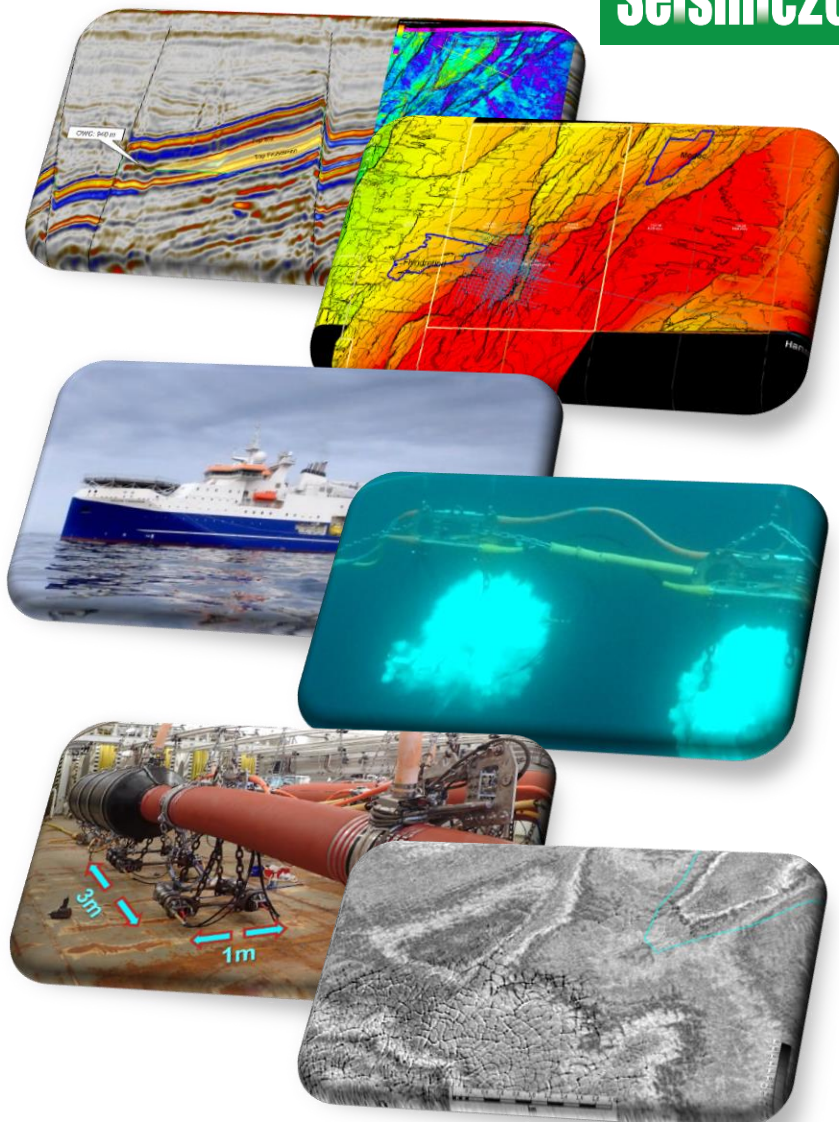
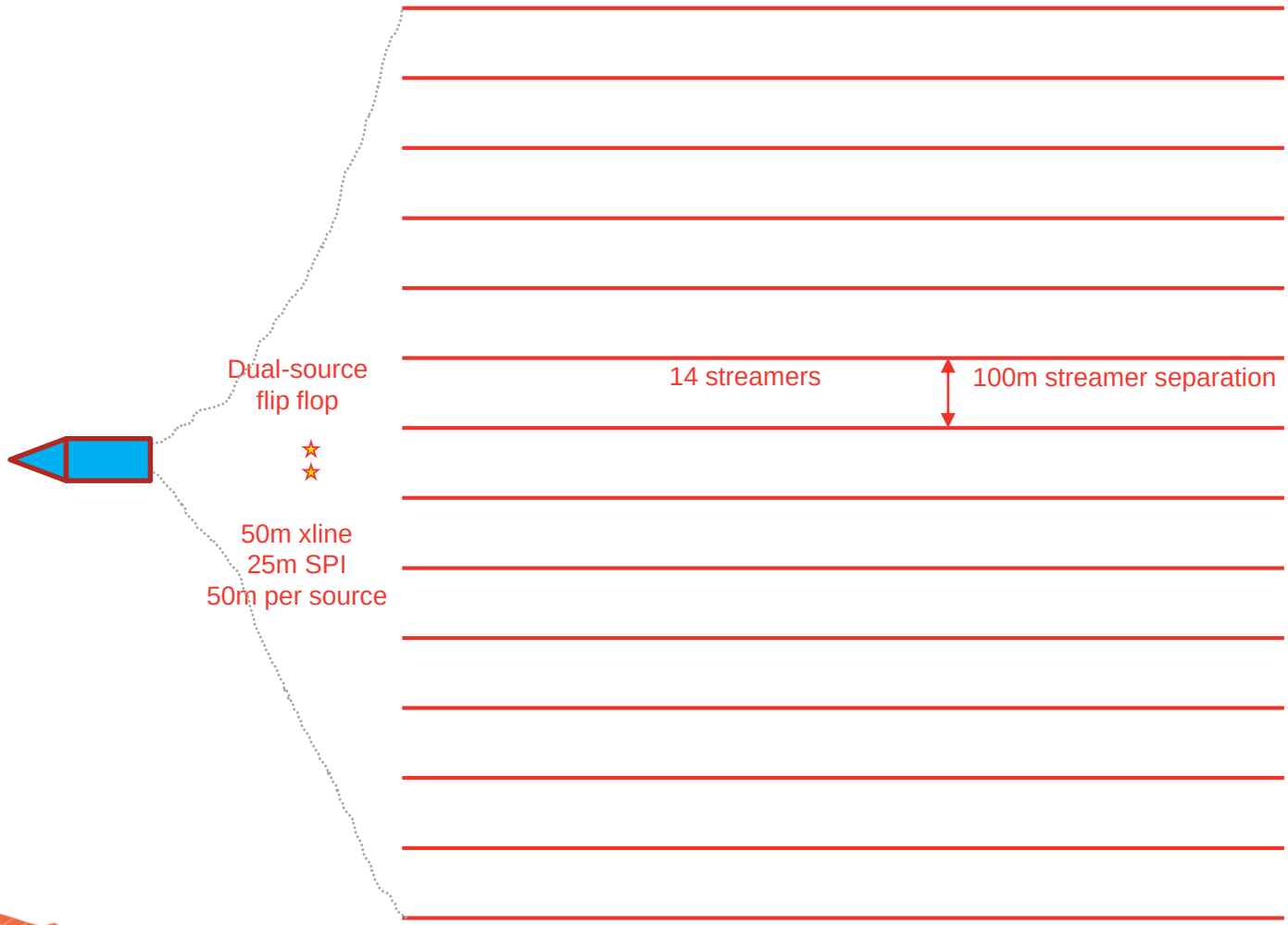


A conventional big cool spread – (that does not work….)



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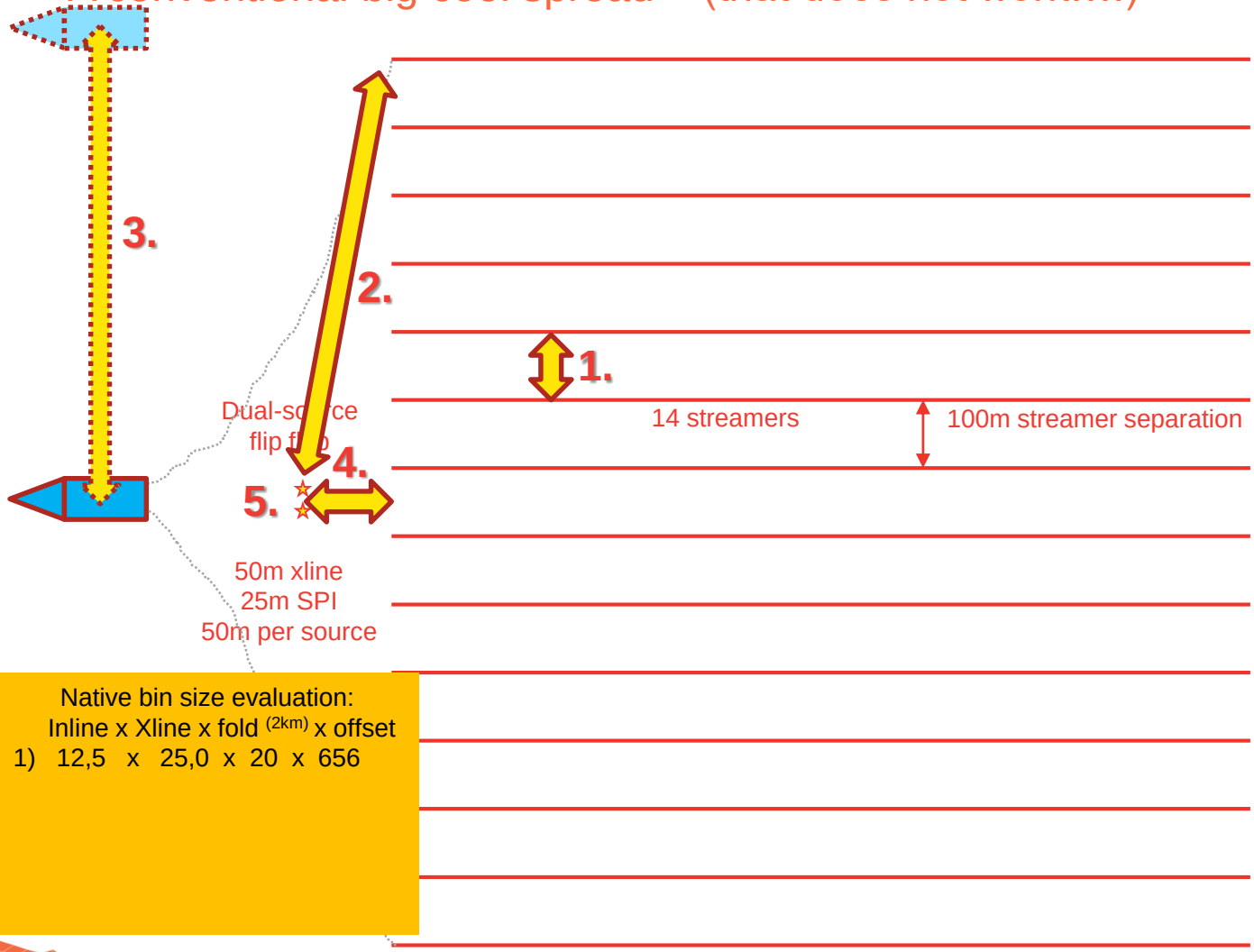
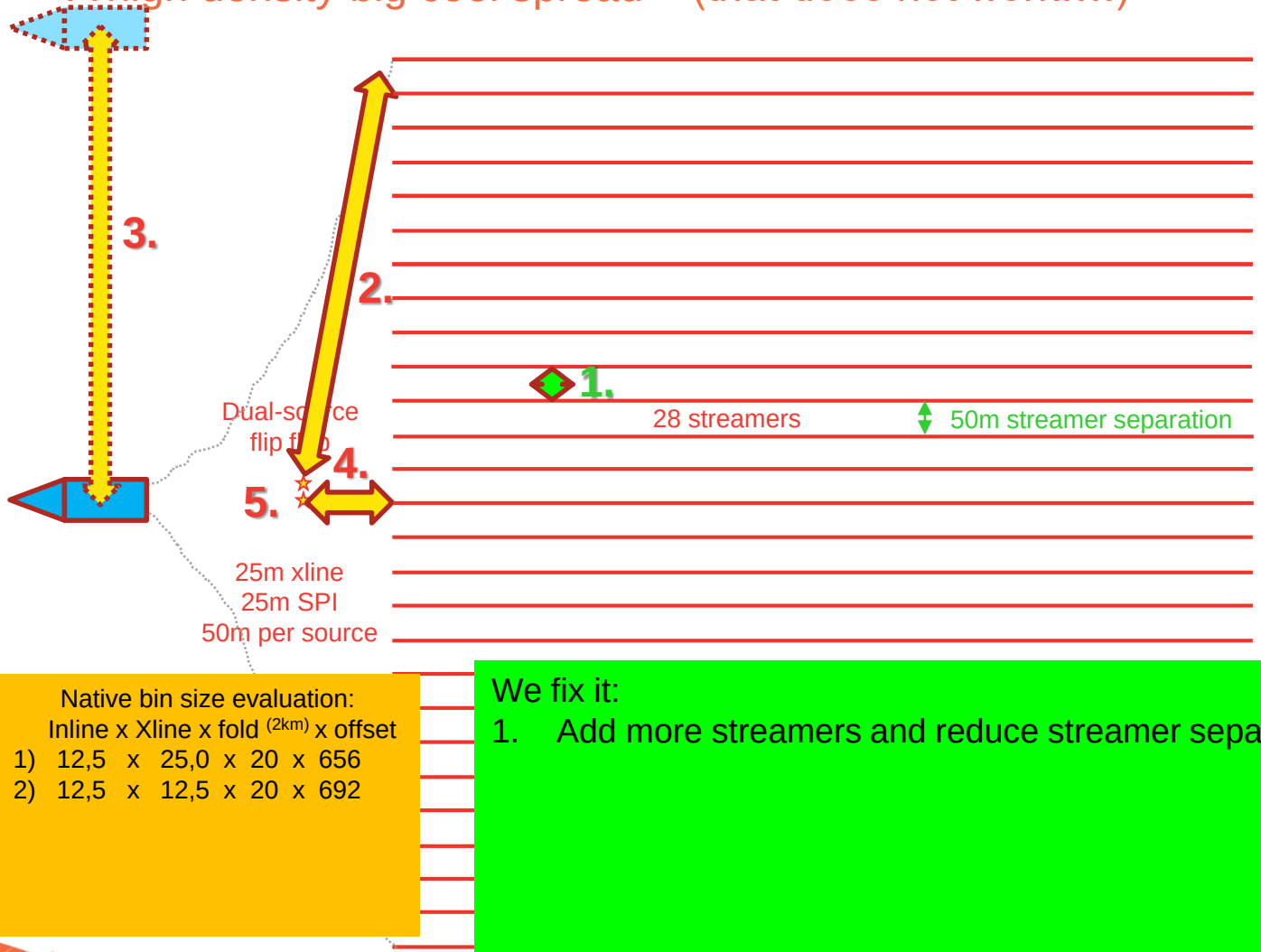


Native bin size evaluation:
Inline x Xline x fold (2km) x offset
1) 12,5 x 25,0 x 20 x 656

Key issues:
1. Too large xline sampling
2. Way too long distance to outer streamers
3. Shot line spacing of 700m
4. Too far nominal near offset
5. Too sparse shot grid

A high density big cool spread – (that does not work….)



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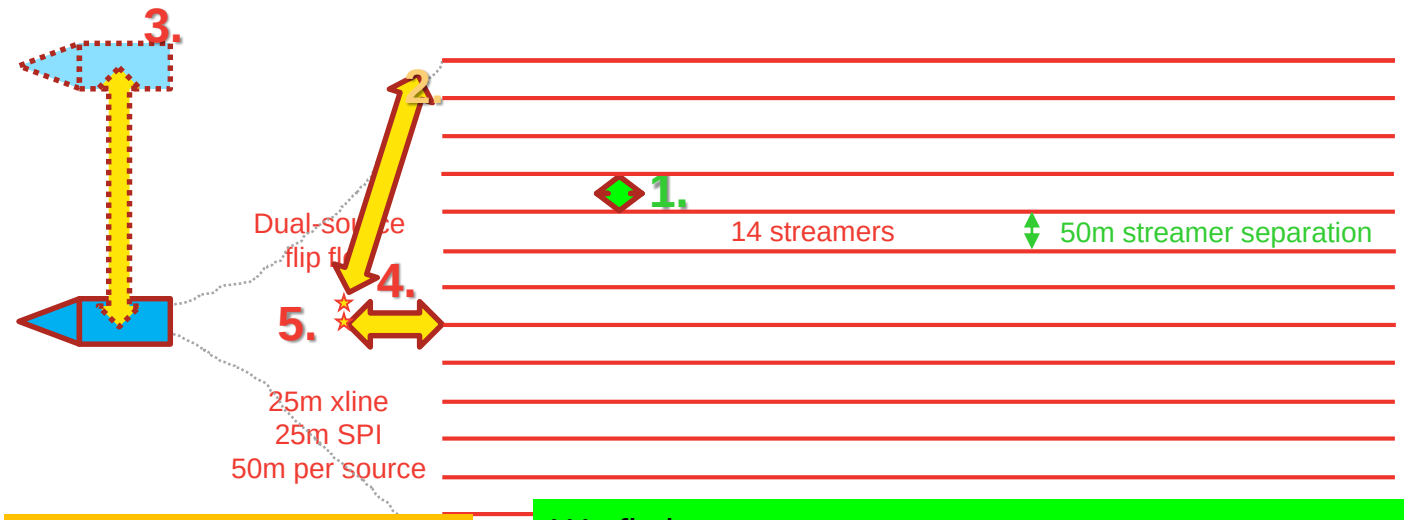
Native bin size evaluation:
Inline x Xline x fold (2km) x offset

1) 12,5 x 25,0 x 20 x 656
2) 12,5 x 12,5 x 20 x 692

We fix it:

1. Add more streamers and reduce streamer separation

A high density cool spread – (that does not work….)



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Native bin size evaluation:

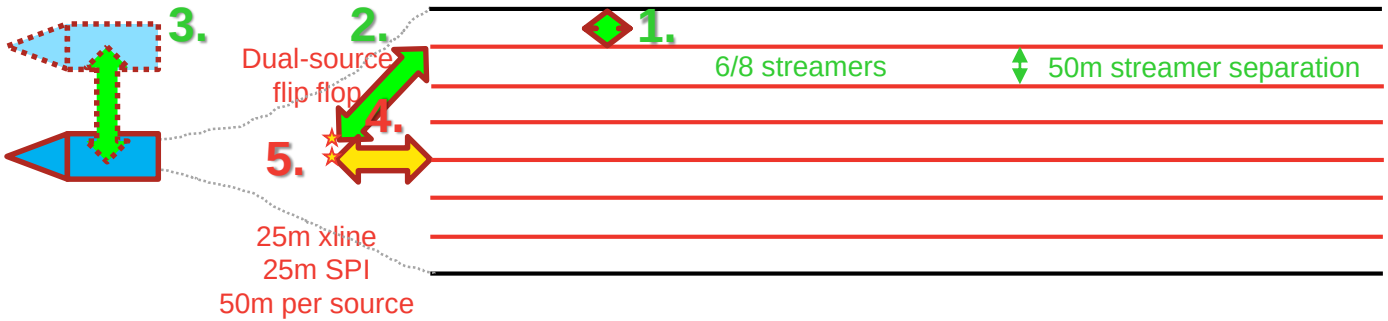
Inline x Xline x fold $^{(2km)}$ x offset

1) 12,5 x 25,0 x 20 x 656
2) 12,5 x 12,5 x 20 x 692
3) 12,5 x 12,5 x 20 x 371

We fix it:

1. Add more streamers and reduce streamer separation
2. Have to reduce the total width of the spread and number of streamers
3. Helps from point 2 – still uneven shot line spacing and very large – not enough – we need the outer streamers much closer to the sources

A high density spread – (that does ~~not~~ work….)



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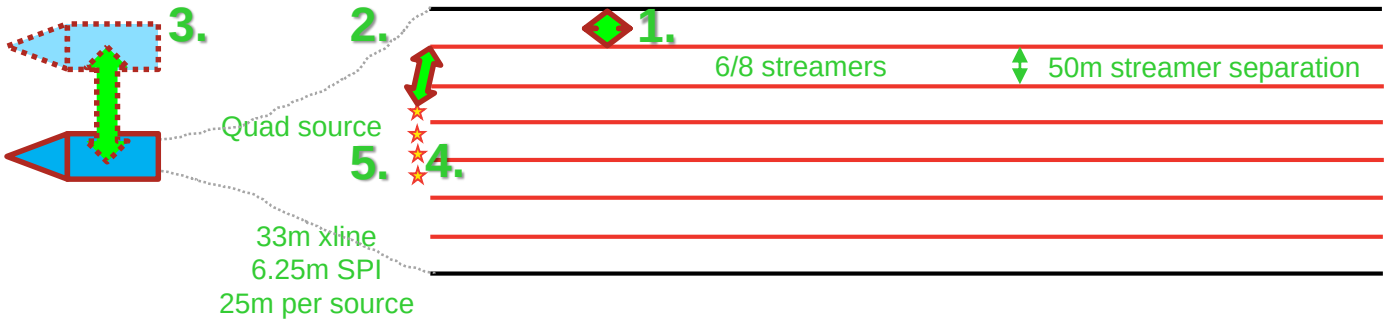
Inline x Xline x fold $^{(2km)}$ x offset

1) 12,5 x 25,0 x 20 x 656
2) 12,5 x 12,5 x 20 x 692
3) 12,5 x 12,5 x 20 x 371
4) 12,5 x 12,5 x 20 x 229

We fix it:

1. Add more streamers and reduce streamer separation
2. Have to reduce the total width of the spread and number of streamers
3. Helps from point 2 – still uneven shot line spacing and very large

A HalfSeis spread – that does work ☺



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2) 12,5 x 12,5 x 20 x 692
3) 12,5 x 12,5 x 20 x 371
4) 12,5 x 12,5 x 20 x 229
5) 1,56 x 3,125 x 40 x 77

Isometrix

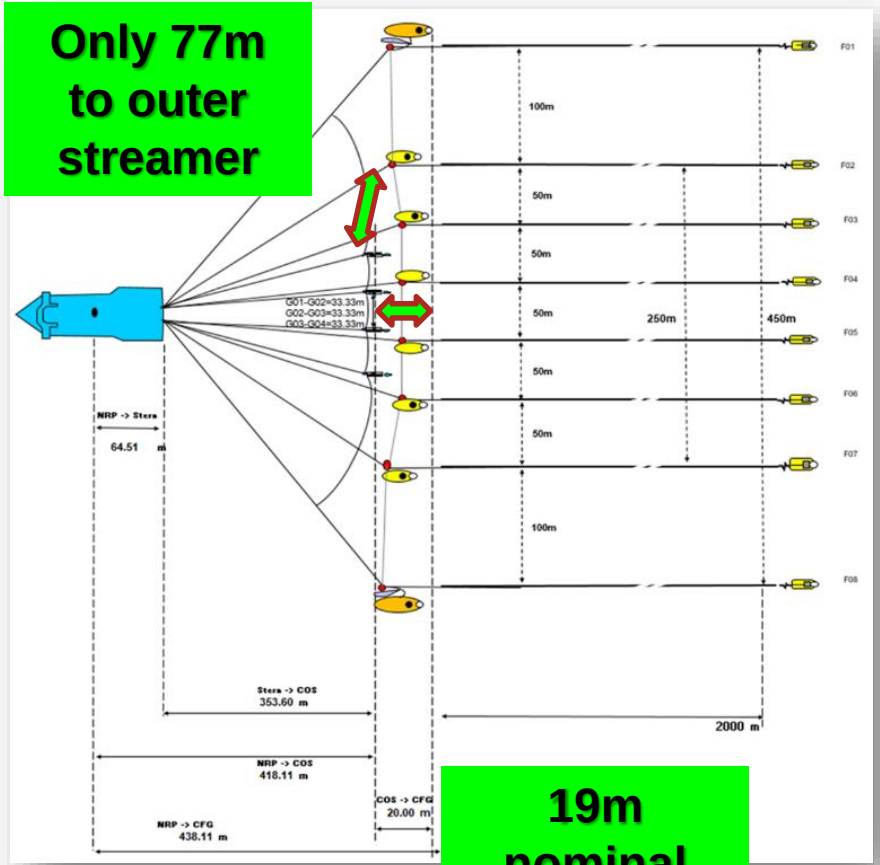
We fix it:

1. Add more streamers and reduce streamer separation
2. Have to reduce the total width of the spread and number of streamers
3. Helps from point 2 – still uneven shot line spacing and very large
4. Move sources closer to streamer fronts…. Not that easy….
5. Add more sources – twice as many

Acquisition configuration – details

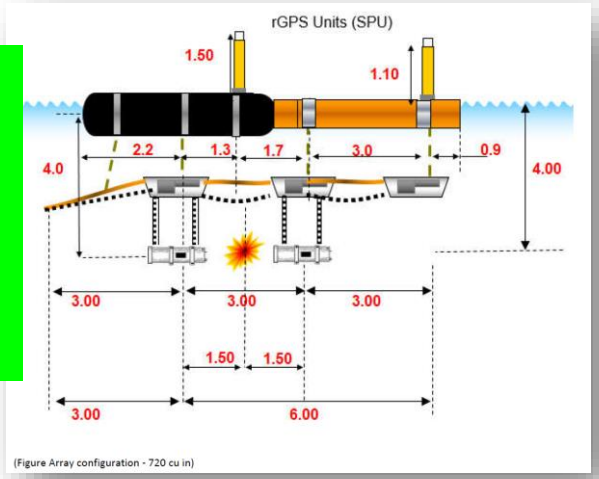
Lundin Energy Norway

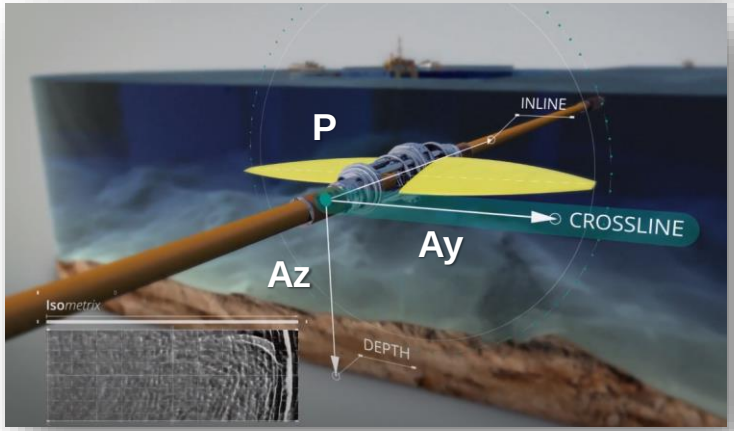
Only 77m to outer streamer



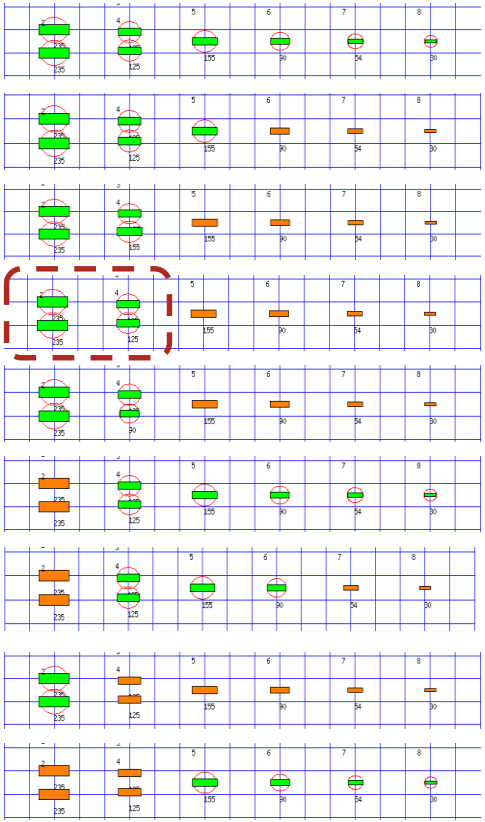
19m nominal near offset

Ultra compact small point source of 1x3m 720 in^3 4m Full near-field recording system





Re-designing the source - alternatives



1049 cuin

875 cuin

750 cuin

720 cuin

685 cuin

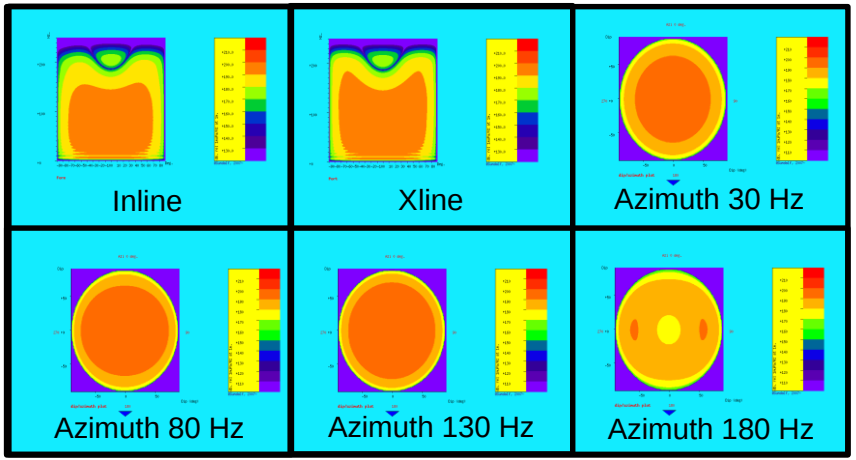
579 cuin

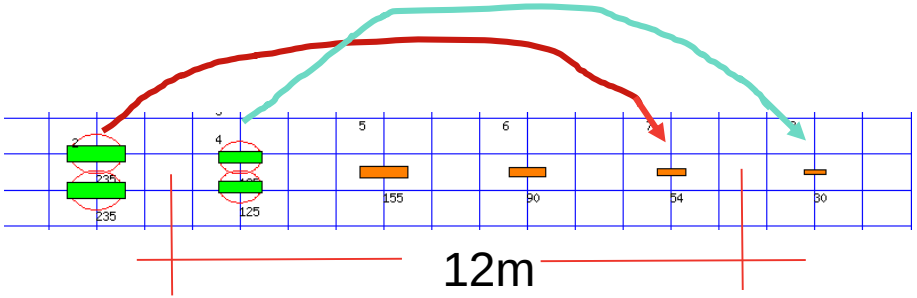
495 cuin

470 cuin

329 cuin

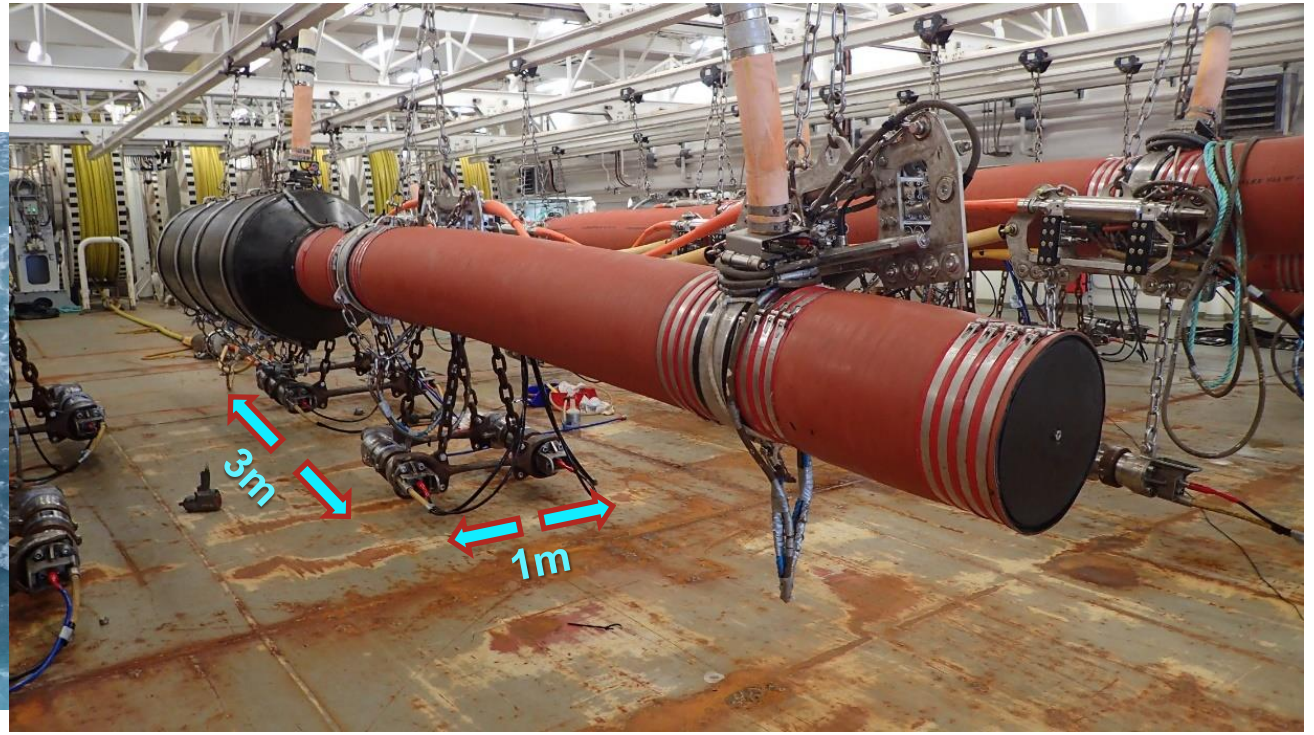
Directivity modeling for the 720in^3 source





Possible reduction of nominal near offset by -12m. This can be achieved by moving the two front cluster to the back of the gun string.

1st time we do a full rebuild of the sources



Reducing the physical length of the source allowed the front of the streamers to be moved much closer to the tail of the source. Had only ~5m clearance to streamer fronts.

Photo taken onboard the Amazon Conqueror, Oct 5th 2019

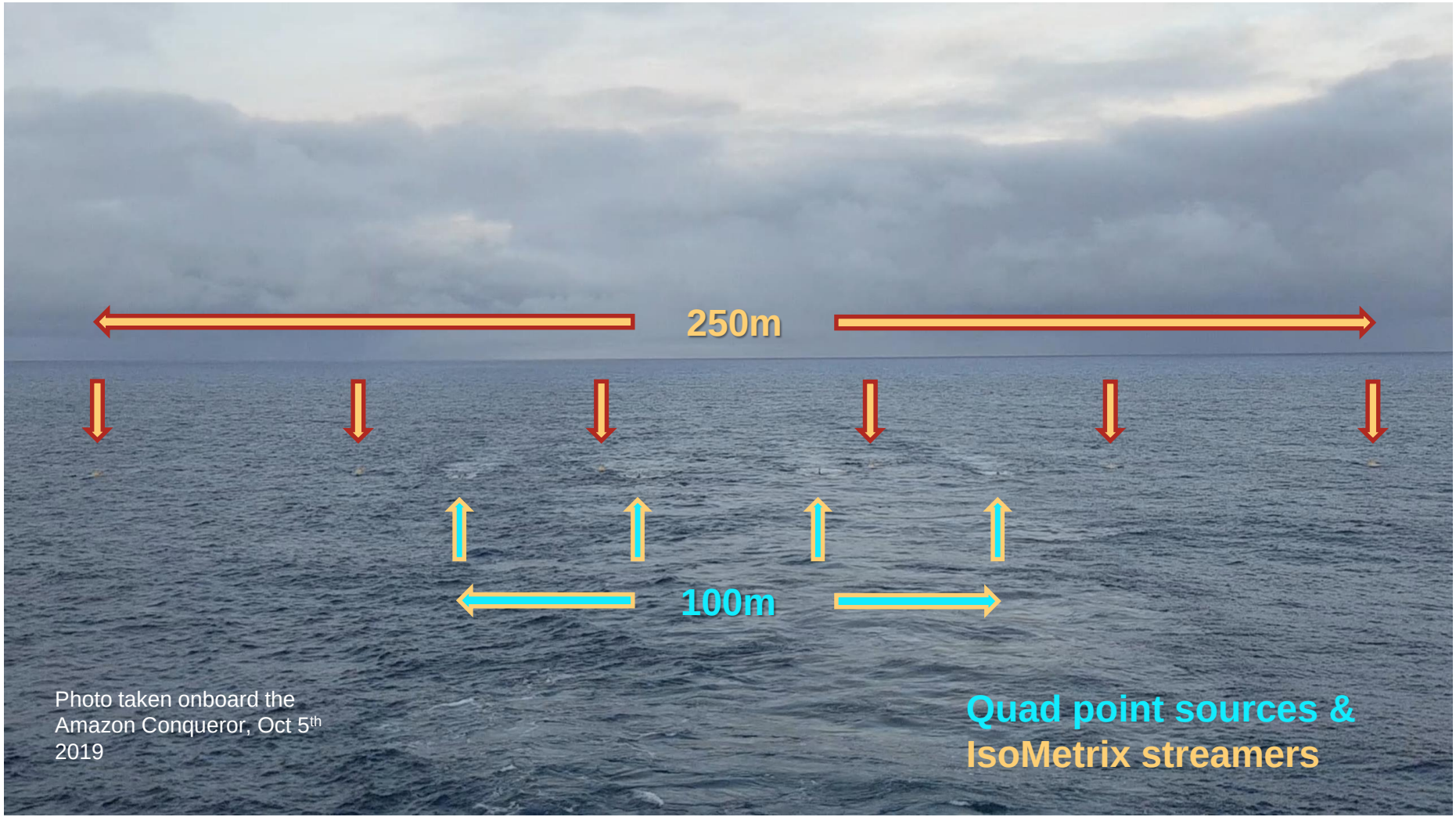
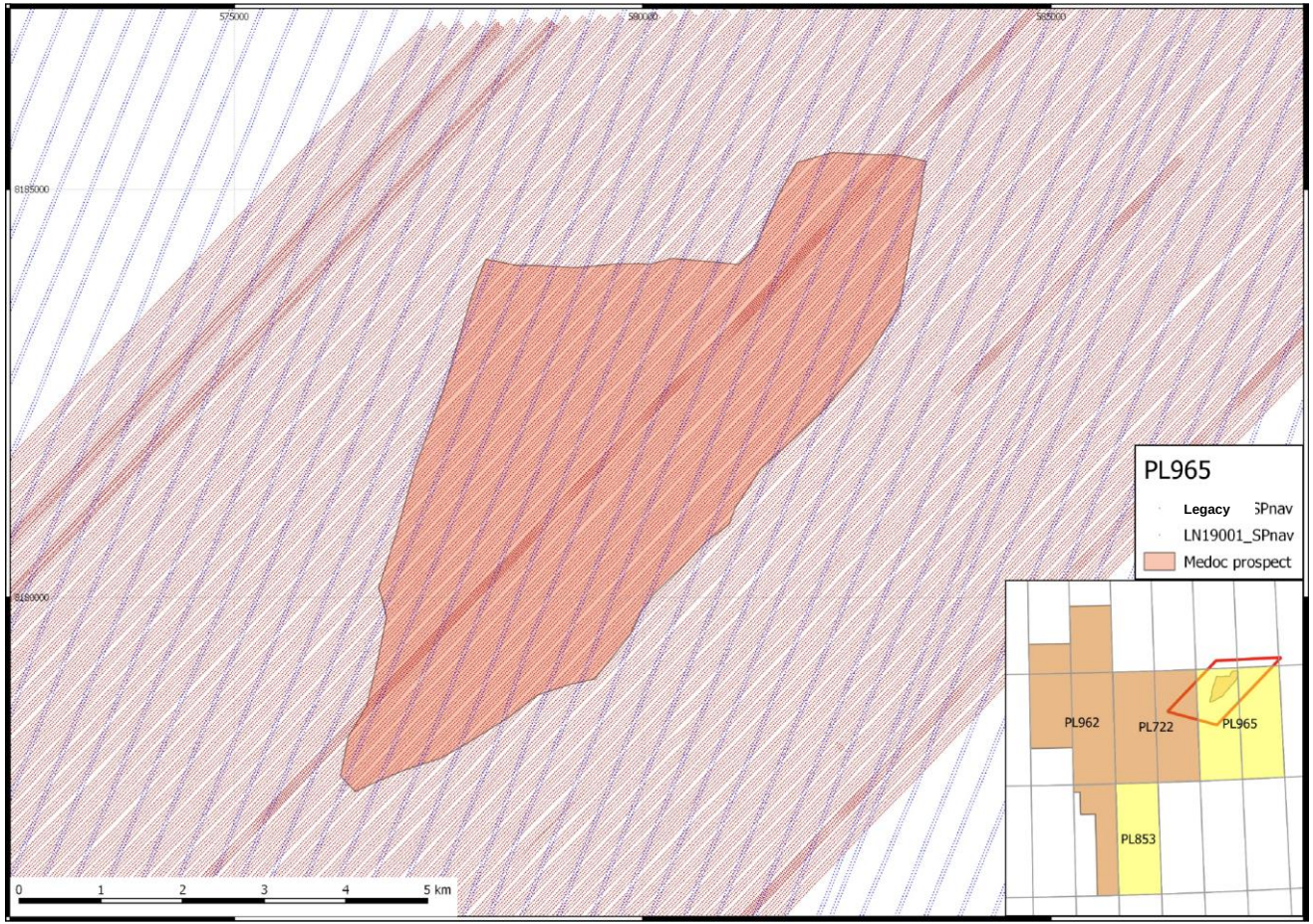


Photo taken onboard the Amazon Conqueror, Oct 5th 2019

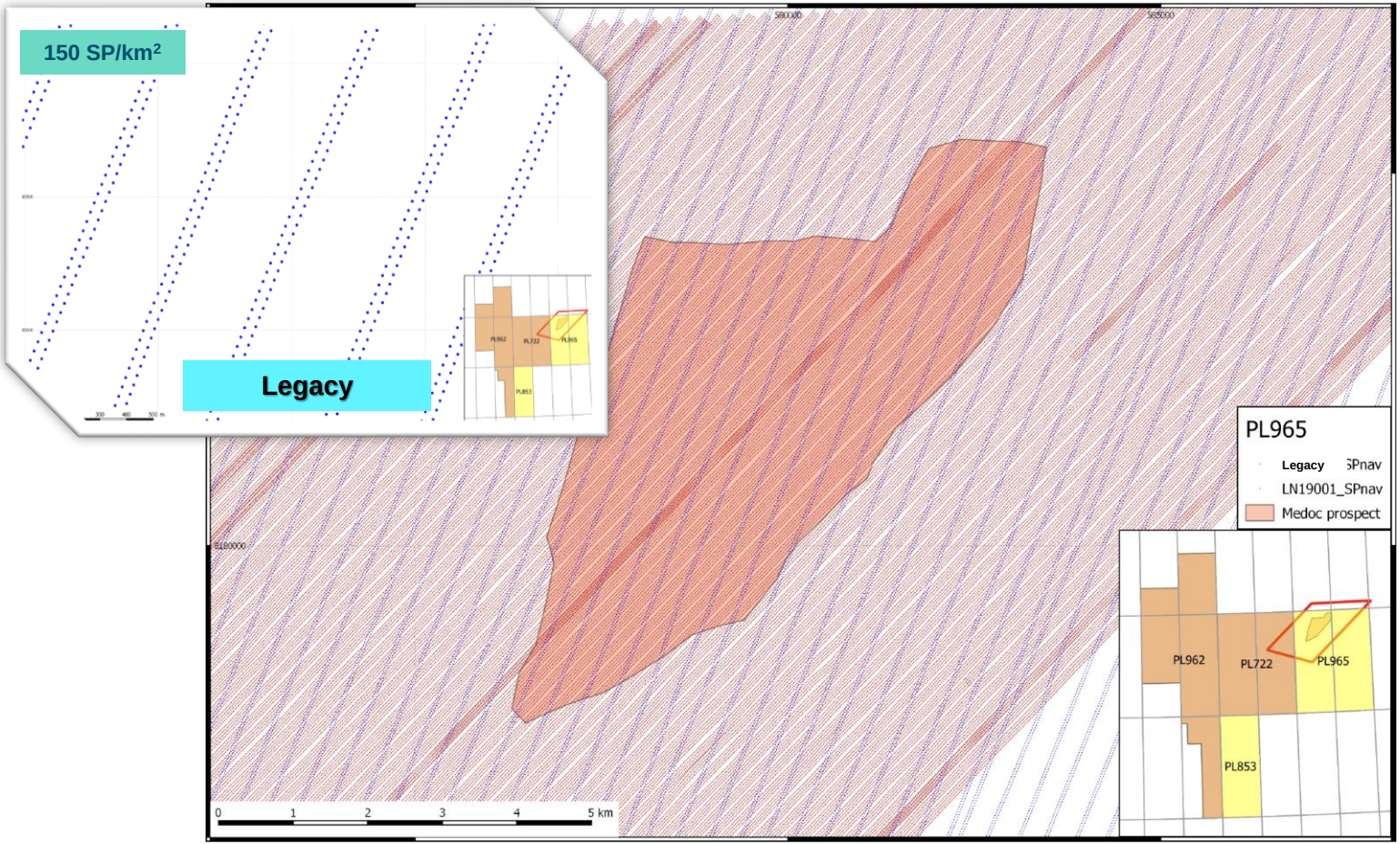
Quad point sources & IsoMetrix streamers

Shot line density – more or less even



This is «after the fact = post plot»

Shot line density – more or less even



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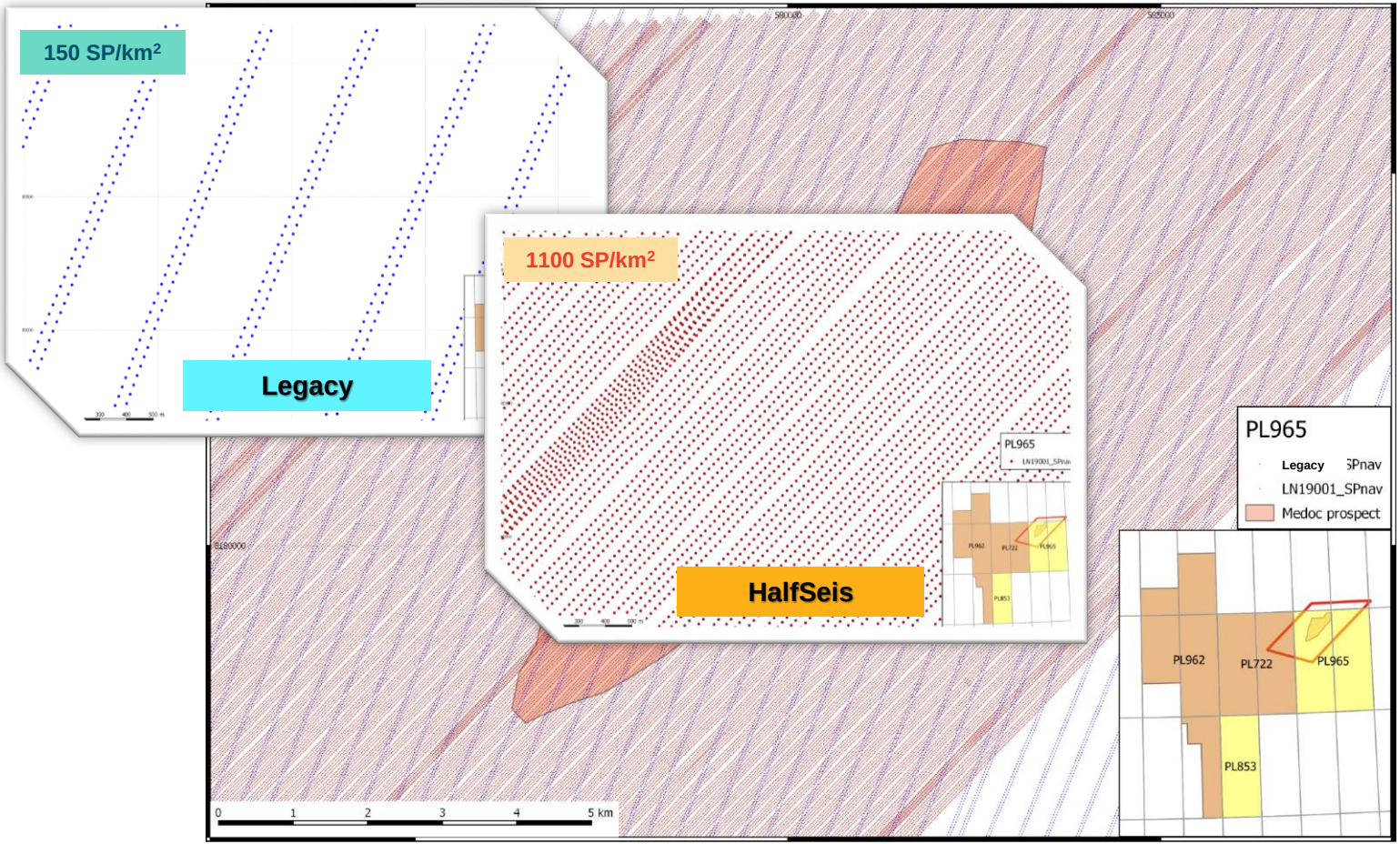

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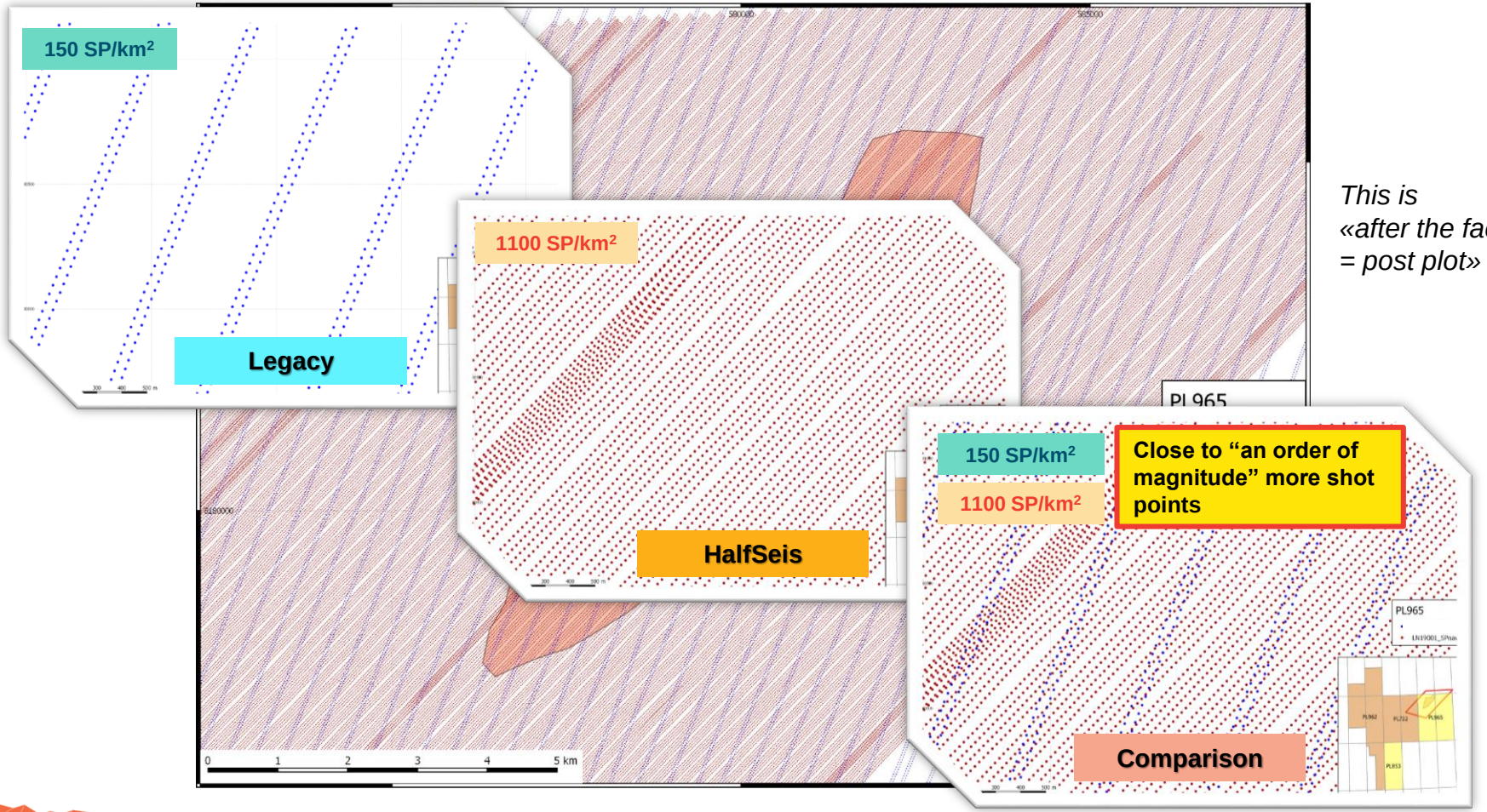

This is «after the fact = post plot»

Video of compact point-source in action

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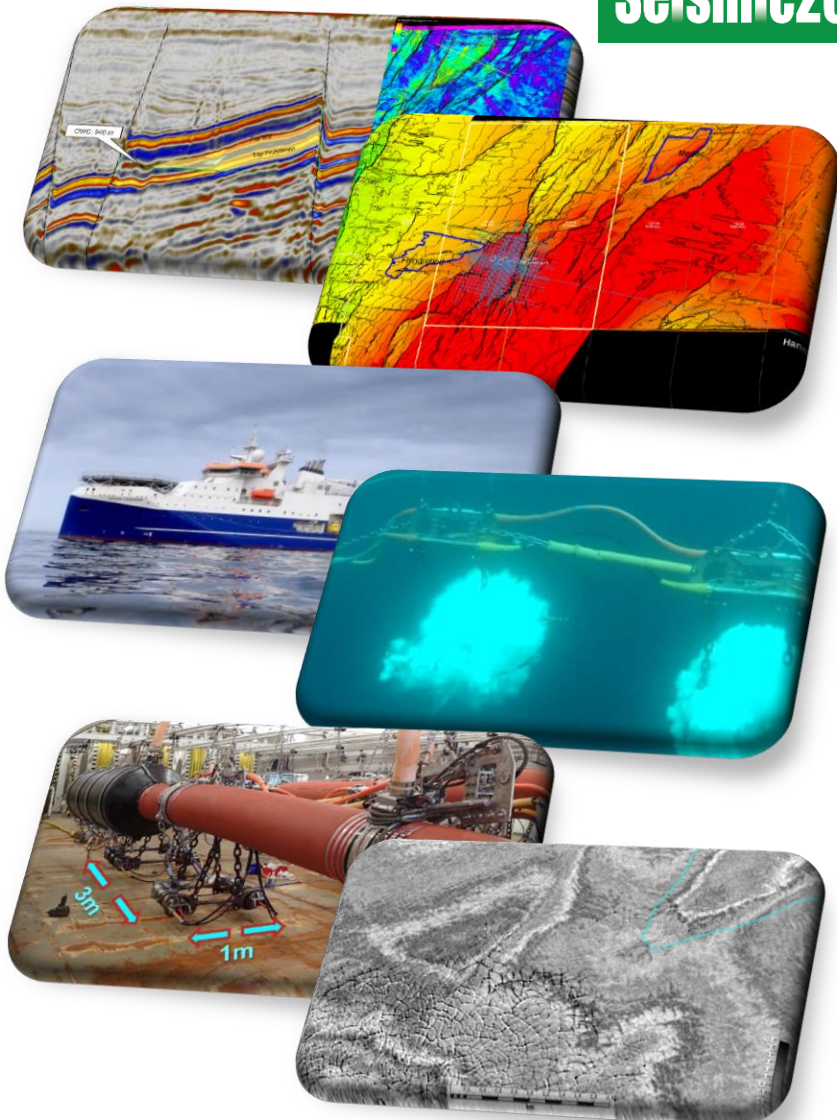
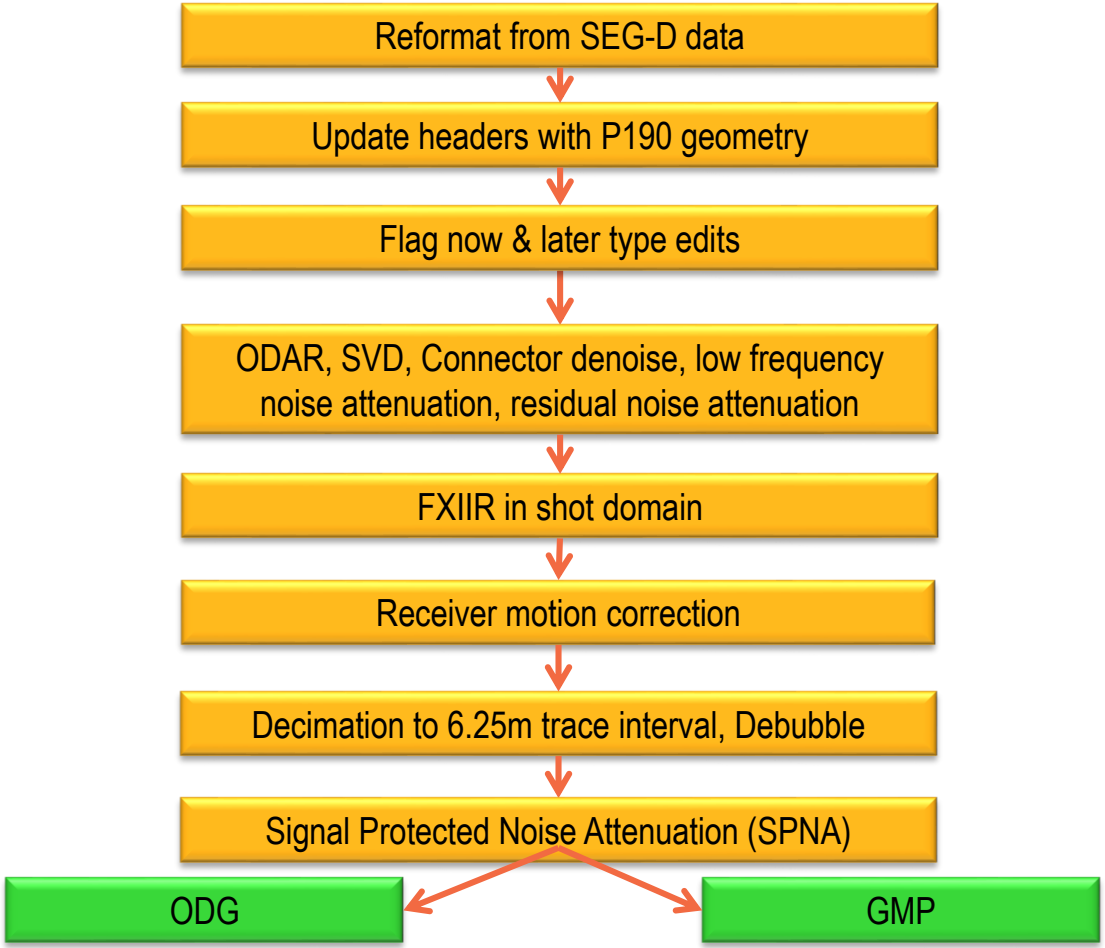
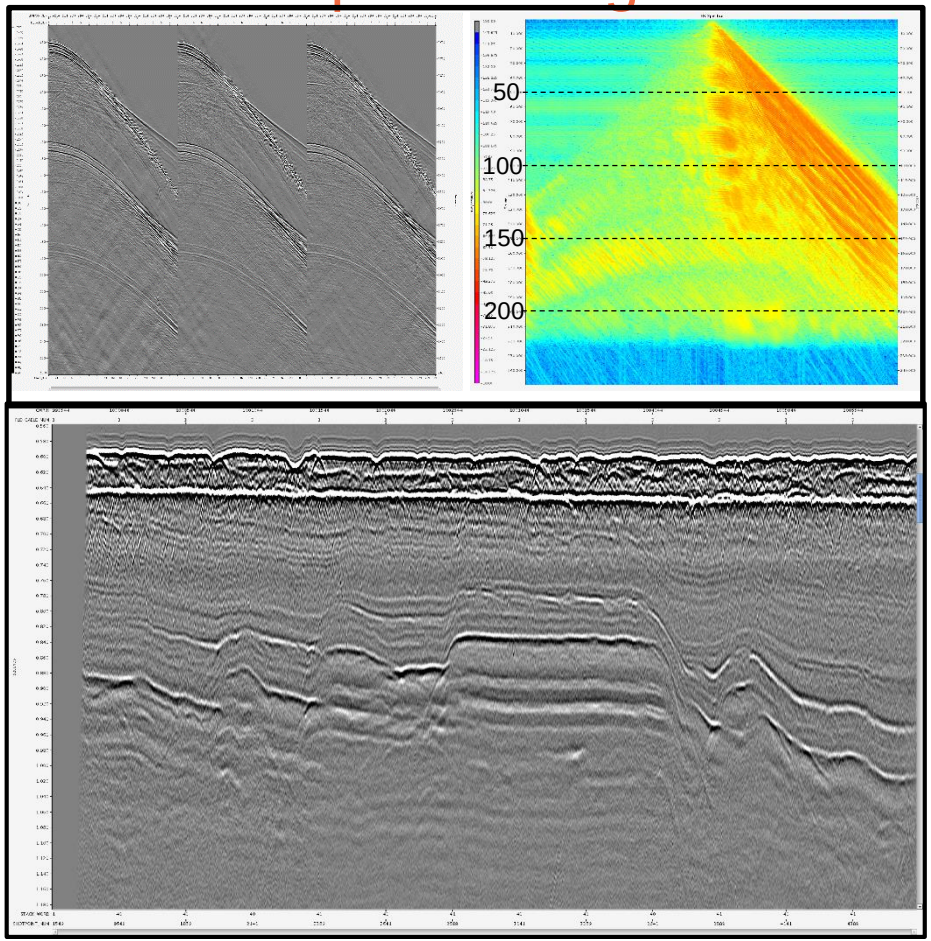
  - Imaging with ultra high density
  - AVO
- Conclusions

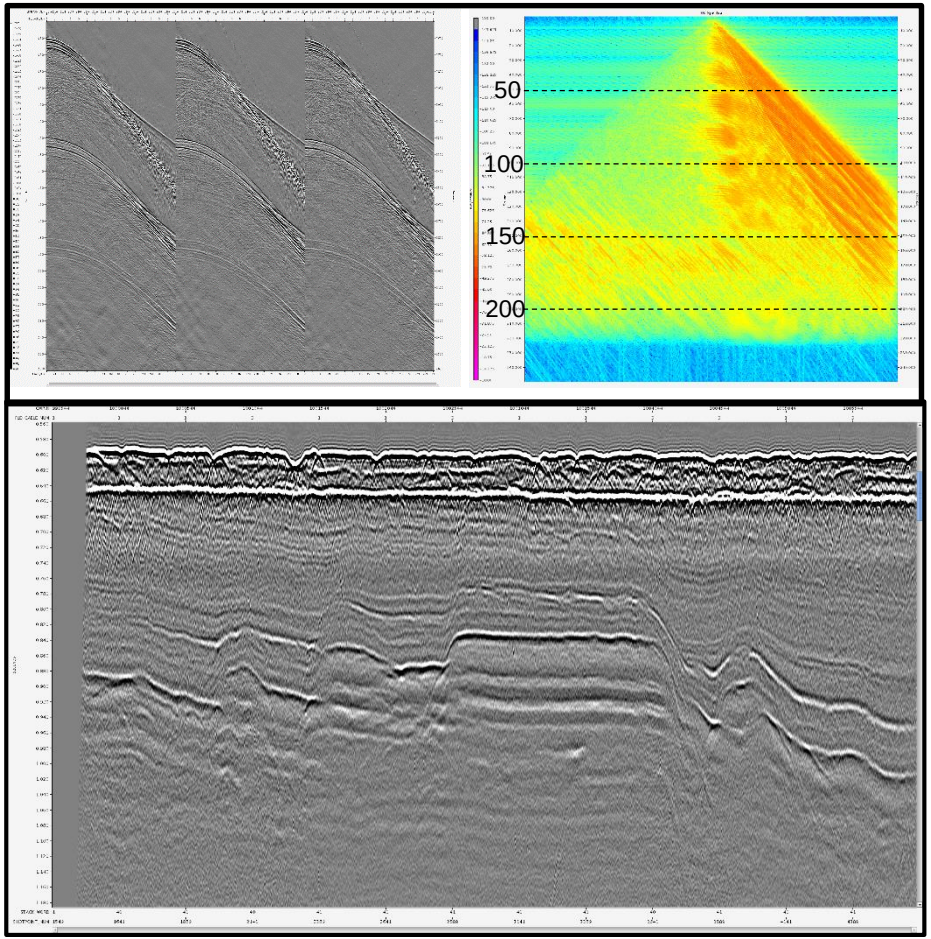


Seismic processing – 1 – Onboard



Seismic processing – 1 – Onboard

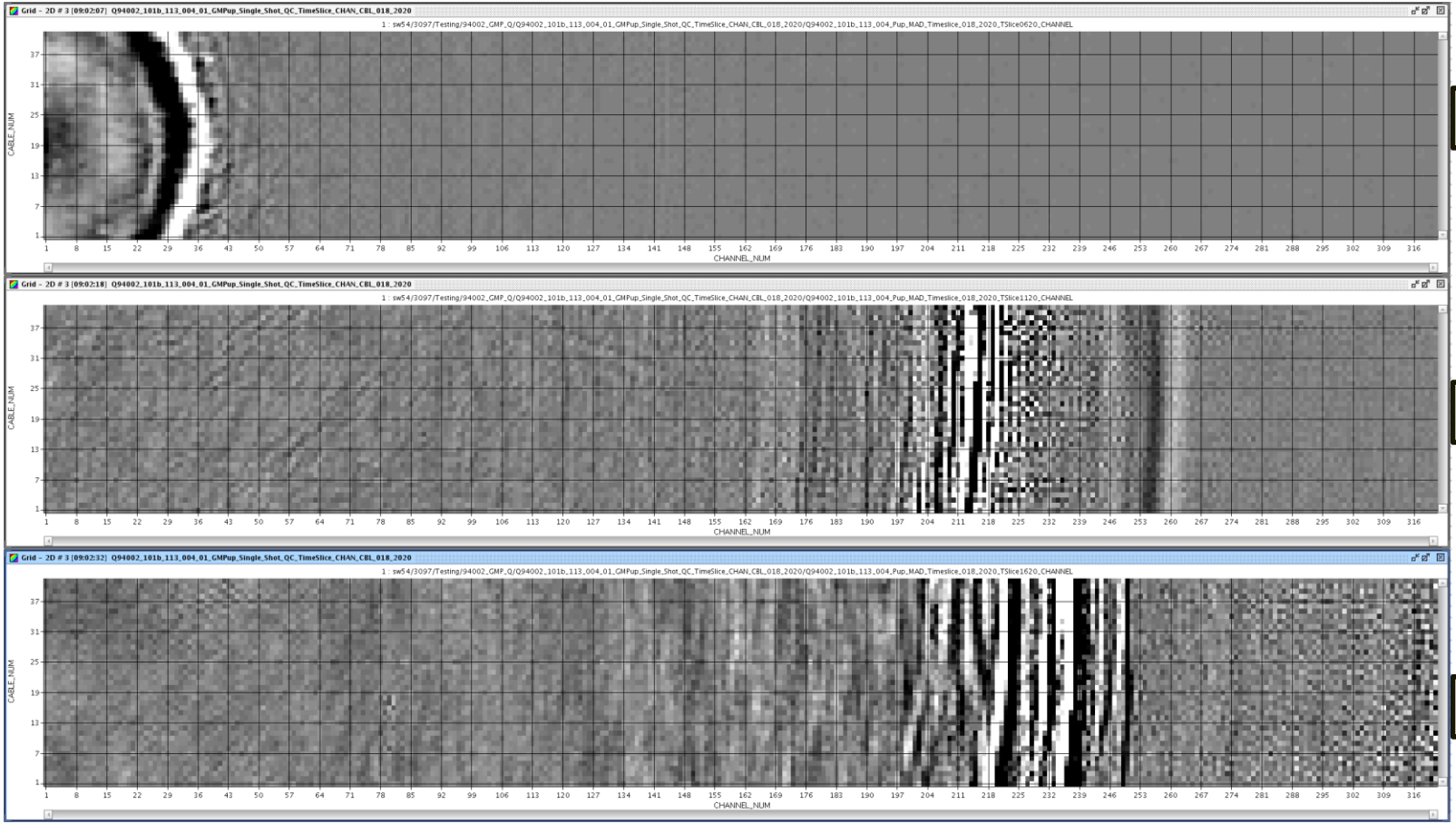




ODG

GMP

Seismic processing – 1 – Onboard – GMP Pup



620 ms

1120 ms

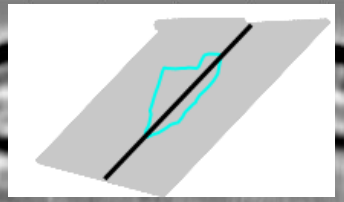
1620 ms

From 6 to 41 cables

Seismic processing – 2 – Onshore

Read GMP 41 cable data	Regularization	Trim statics
Tidal correction	Invers Q phase	High-frequency diffr denoise
K-filter and cable drop,21	Velocity Model Building	Inverse Q amp
Denoise 2 pass	High-res Radon demultiple	Full Stack (0-35)
Dug Broad (source)	Post reg denoise	Angle stacks 0-50 (step 10)
NFH shot-by-shot designature	KPreSTM	Post stack denoise
Gun scaling	High Density Vel Analysis	Spectral shaping
3D SRME	Residual Moveout Correction	Time variant band-pass filter
SI removal	Post mig radon	WBT mute
Pre-reg denoise	Linear Noise Attenuation	SEG-Y output

Legacy - Inline



IL 1,920

4,700 4,800 4,900 5,000 5,100 5,200 5,300 5,400 5,500 5,600 5,700 5,800 5,900 6,000 6,100 6,200 6,300 6,400 6,500 6,600 6,700 6,800 6,900 7,000

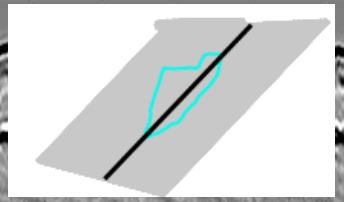
TWT (ms)

700 800 900 1,000 1,100 1,200

0 1,000 2,000 3,000

metres

HalfSeis - Inline



IL 1,920

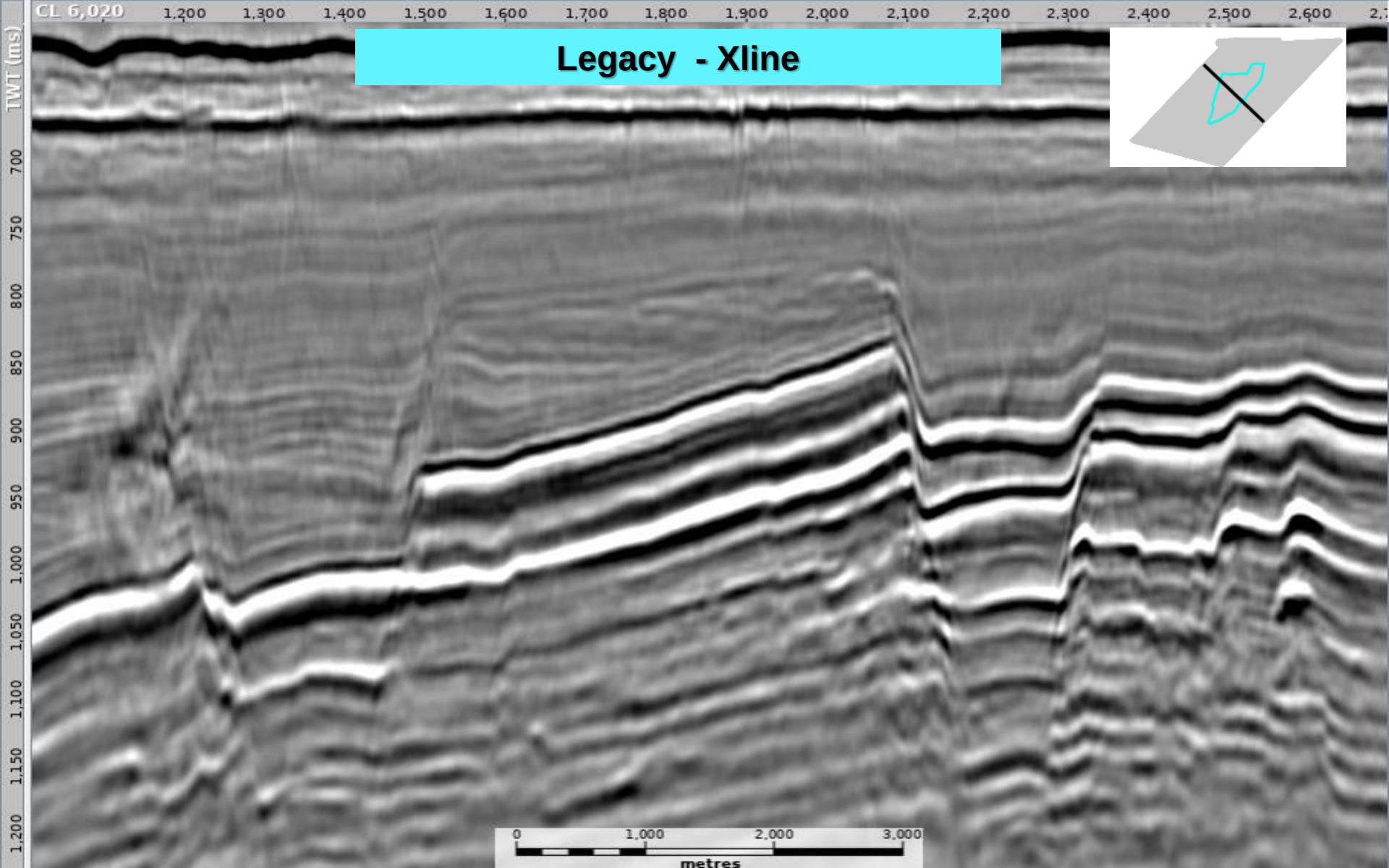
4,700 4,800 4,900 5,000 5,100 5,200 5,300 5,400 5,500 5,600 5,700 5,800 5,900 6,000 6,100 6,200 6,300 6,400 6,500 6,600 6,700 6,800 6,900 7,000

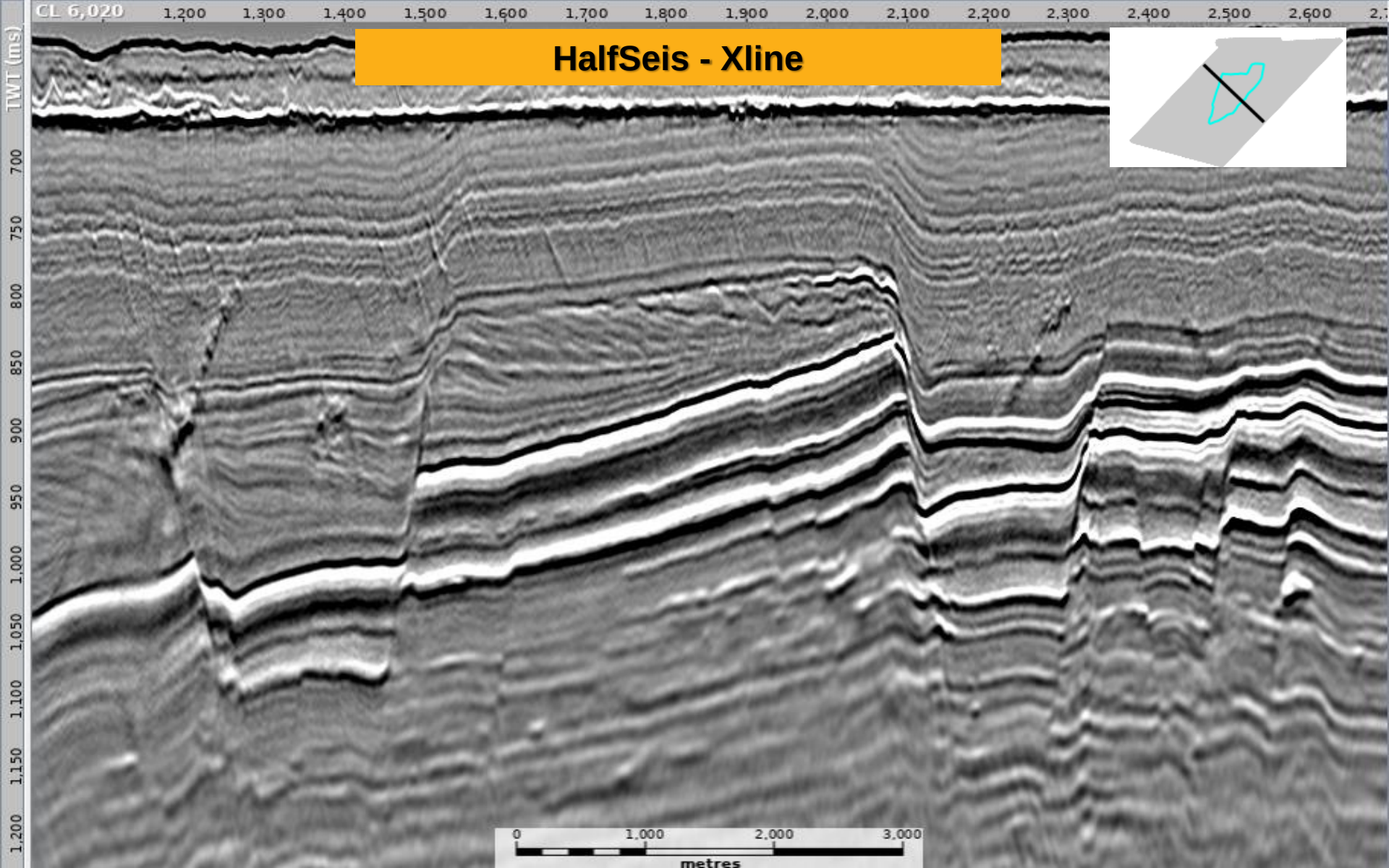
TWT (ms)

700 800 900 1,000 1,100 1,200

0 1,000 2,000 3,000

metres

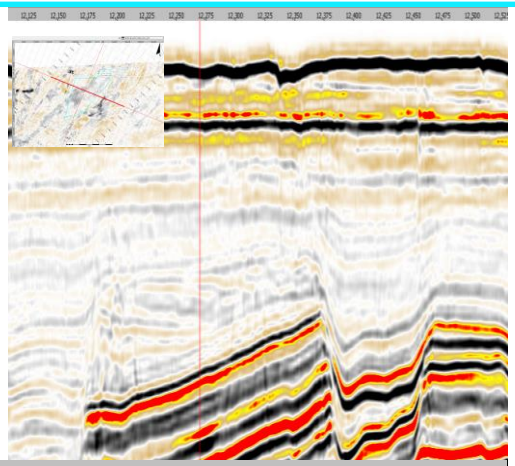

Legacy - Xline
CL 6,020
1,200
1,300
1,400
1,500
1,600
1,700
1,800
1,900
2,000
2,100
2,200
2,300
2,400
2,500
2,600
TWT (ms)
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
0
1,000
2,000
3,000
metres


HalfSeis - Xline
CL 6,020
1,200
1,300
1,400
1,500
1,600
1,700
1,800
1,900
2,000
2,100
2,200
2,300
2,400
2,500
2,600
TWT (ms)
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
0
1,000
2,000
3,000
metres

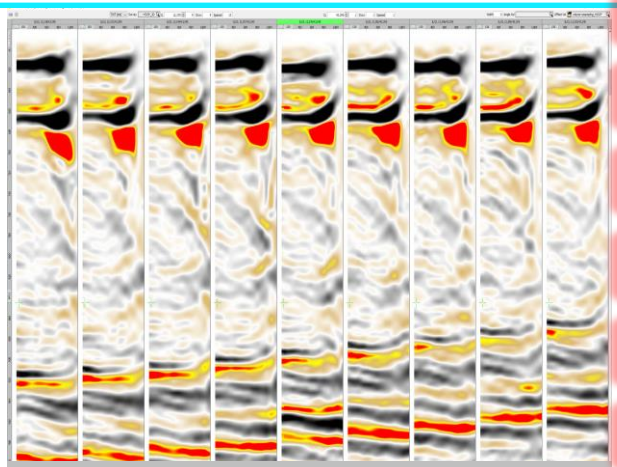
AVO compliant – 0-45˚ at all target levels

Lundin Energy Norway

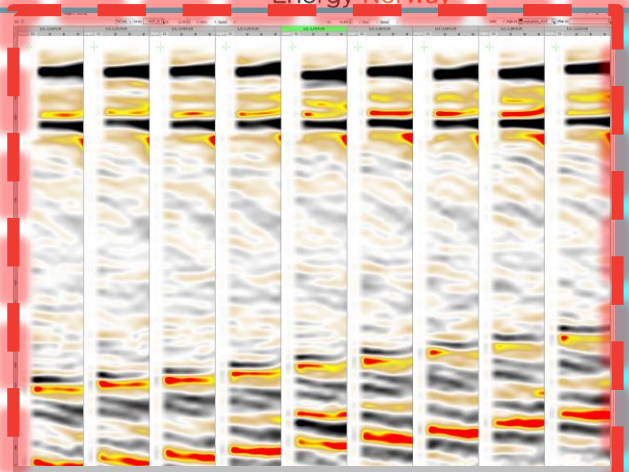
Legacy



Stack



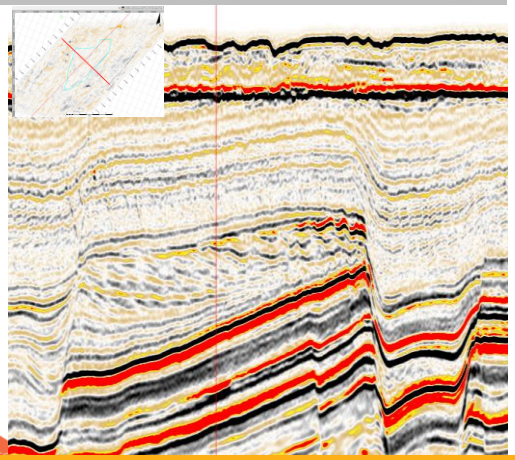
Offset gathers – 0-1100m

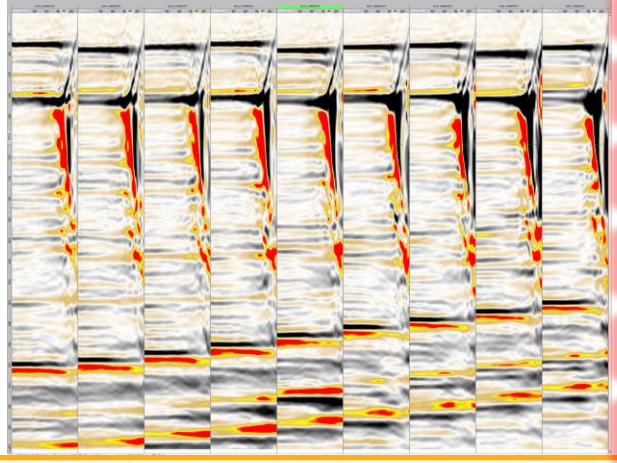


Angle gathers – 0-45˚

Legacy

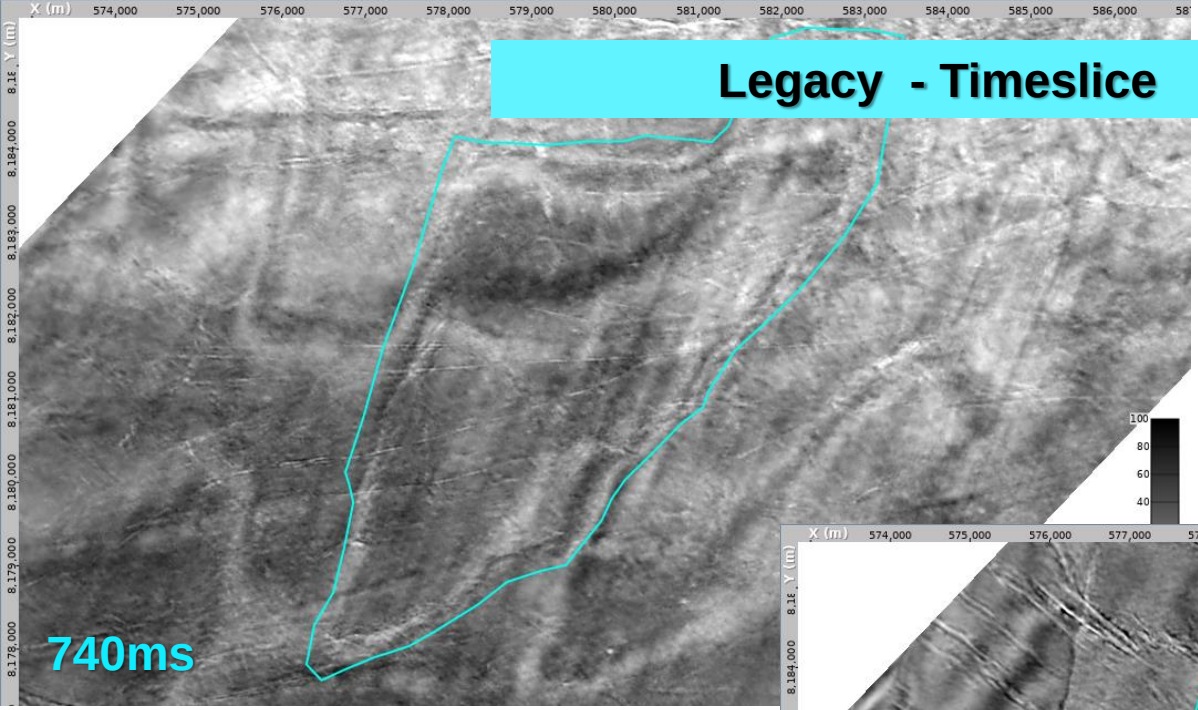
HalfSeis

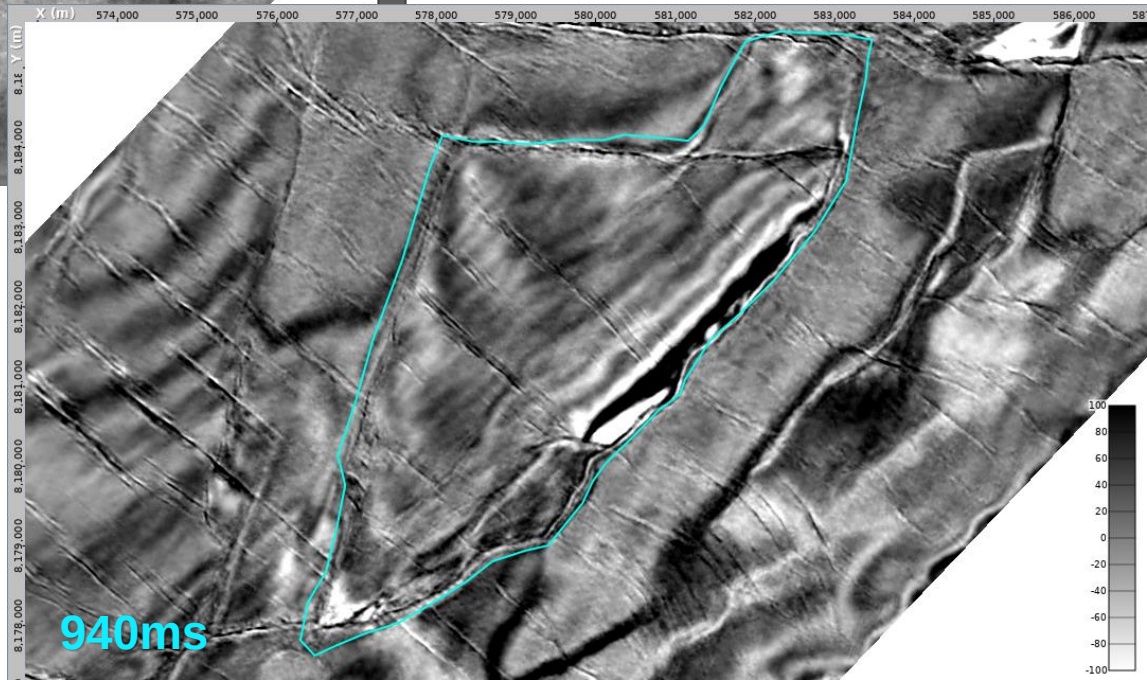




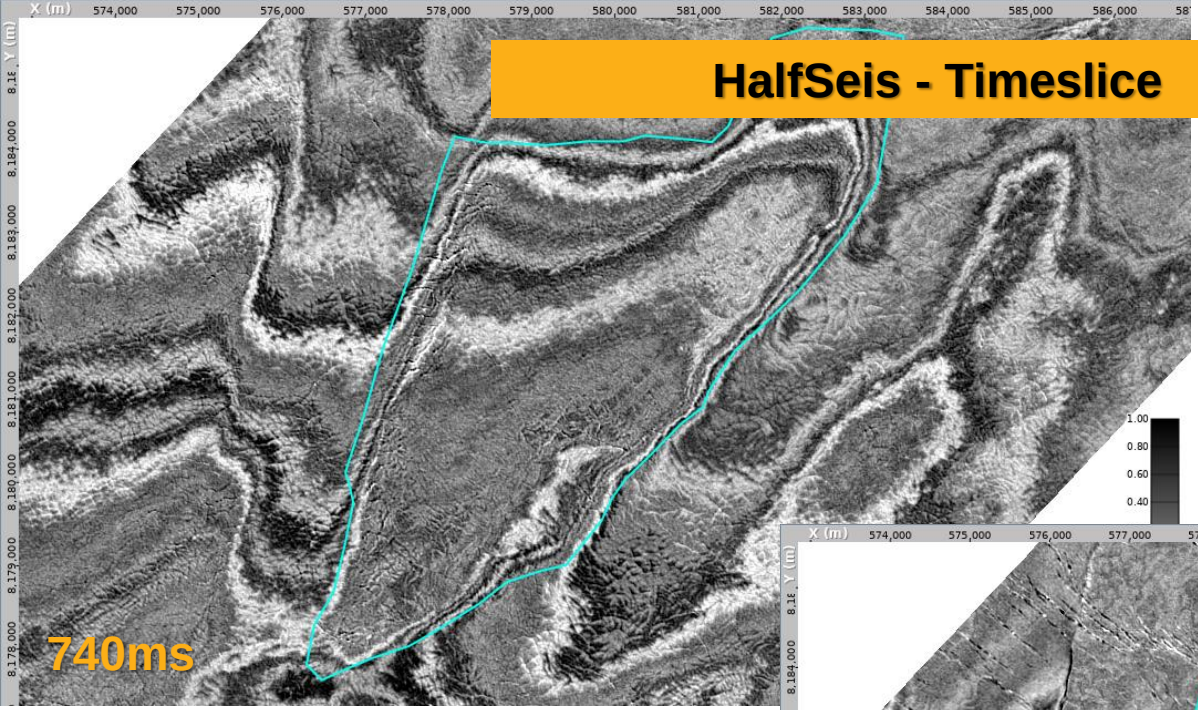
HalfSeis

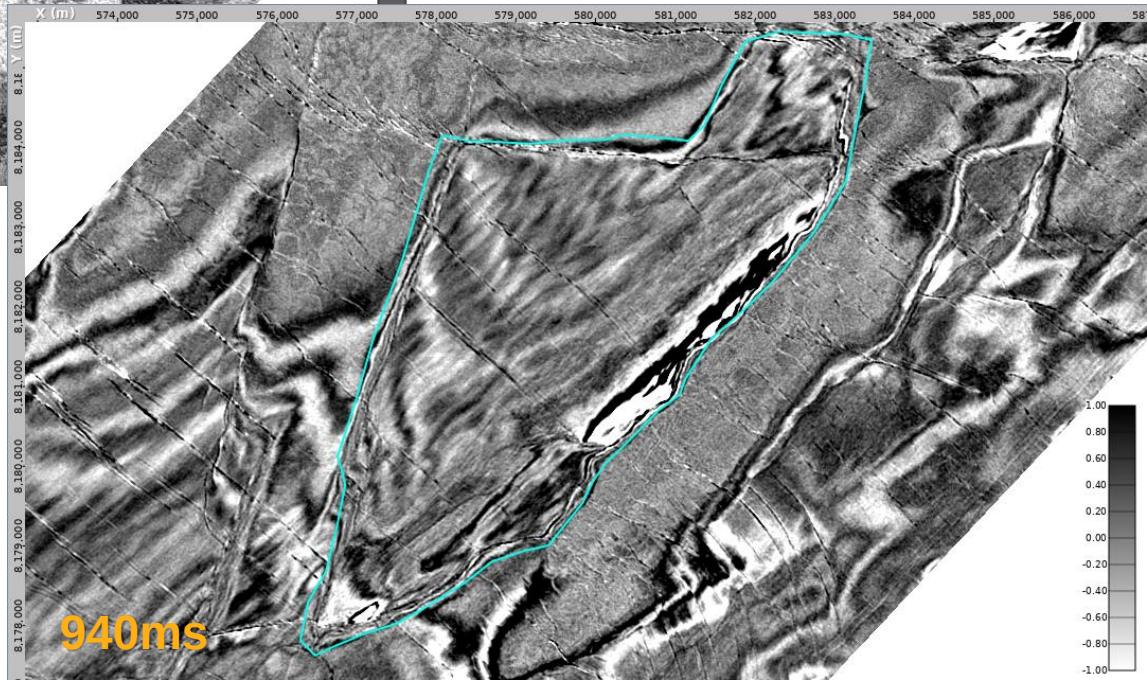
Legacy - Timeslice



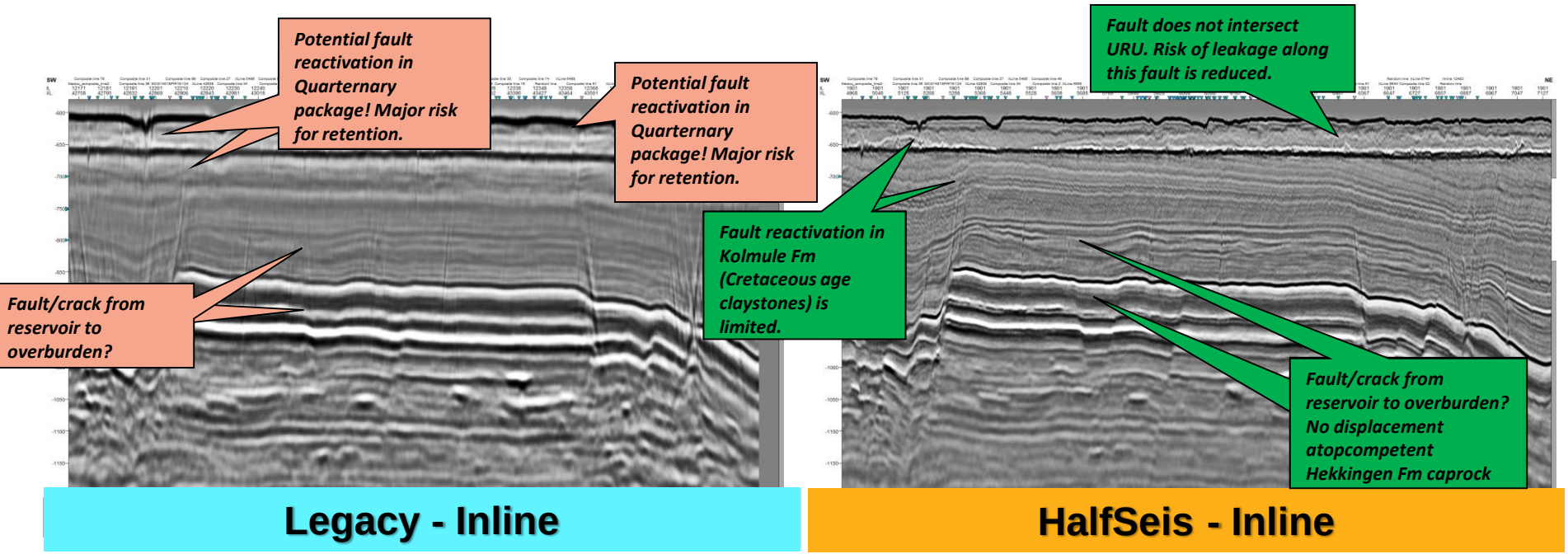


HalfSeis - Timeslice





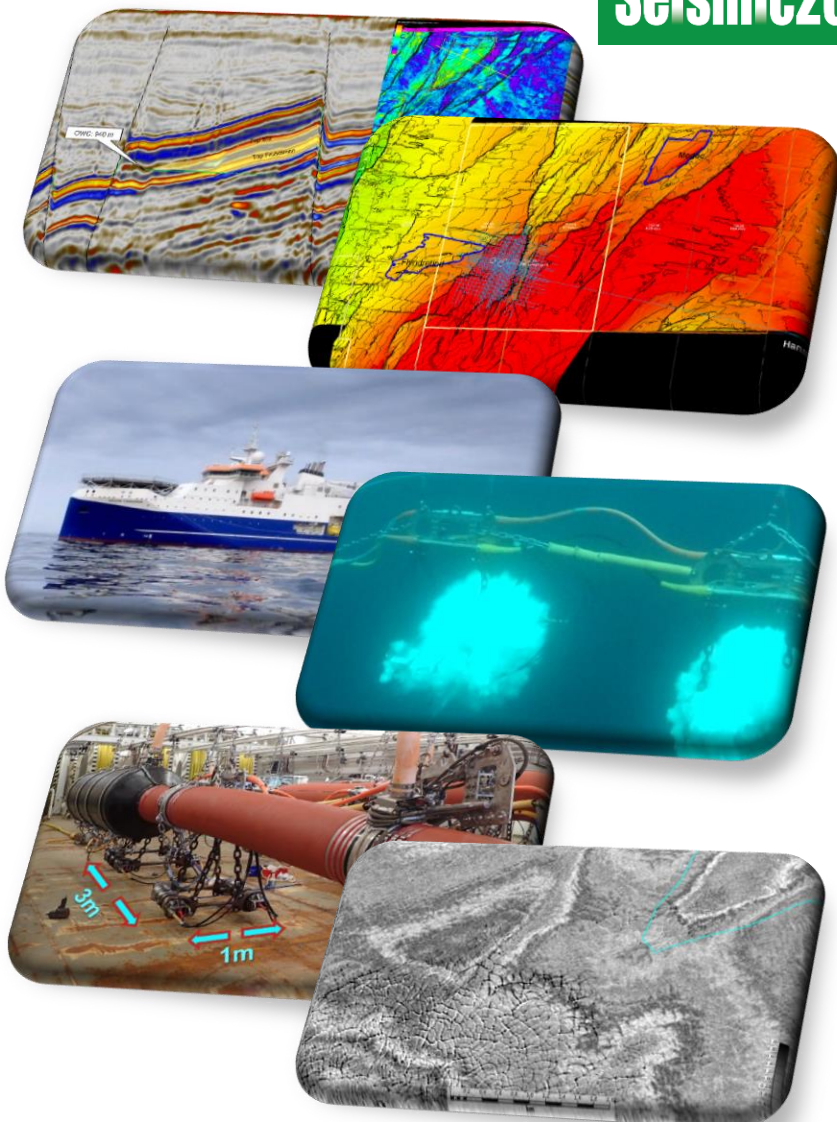
Returning to our challenge



The new high-resolution seismic is really doing the job in solving the pre-defined challenges

Outline

- Background
  - Geology, license, petroleum systems
  - Geophysical challenges & AVO
- Acquisition Solution – HalfSeis
  - Design, Source, Receivers
  - Planning & Performing the acquisition
- Results
  - Imaging with ultra high density
  - AVO
- Conclusions



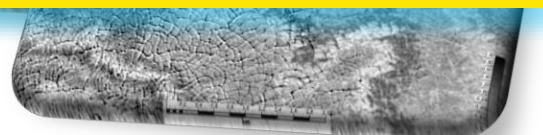
Outline

Well – just before we conclude, I'd like to address
two key items not covered so far:

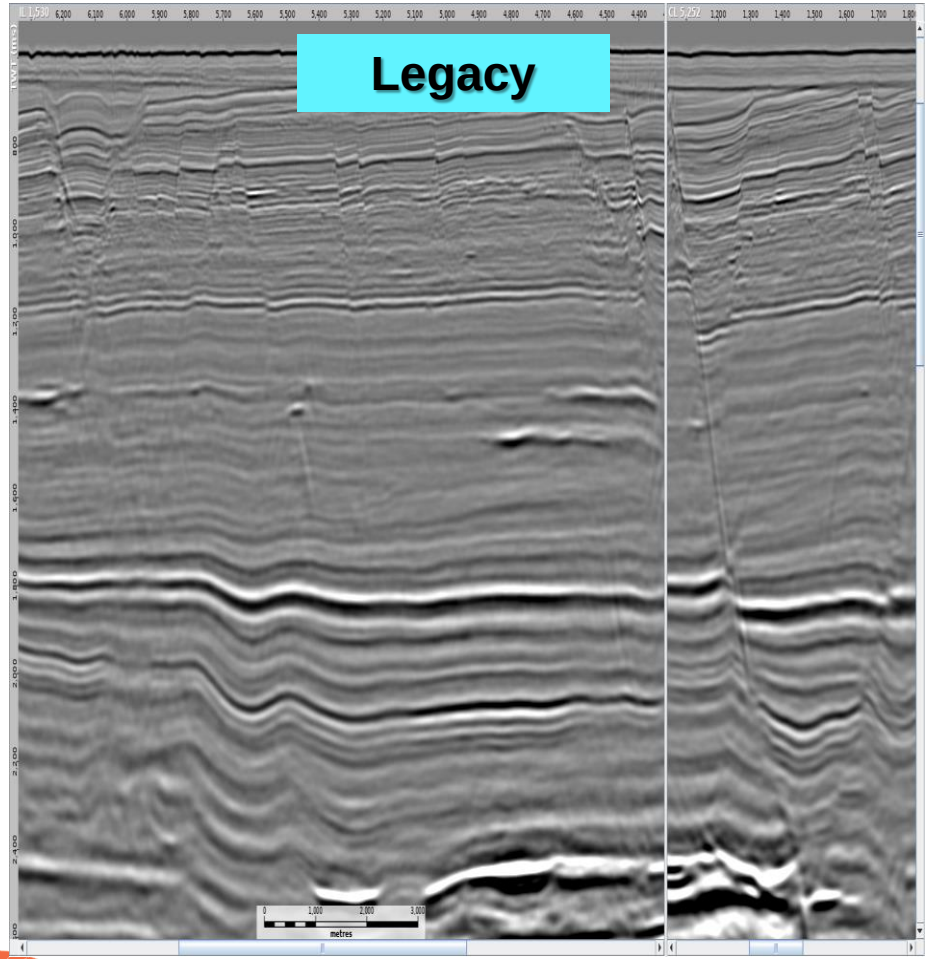
1) You only have 2km offset – what about Velocity Model Building = FWI

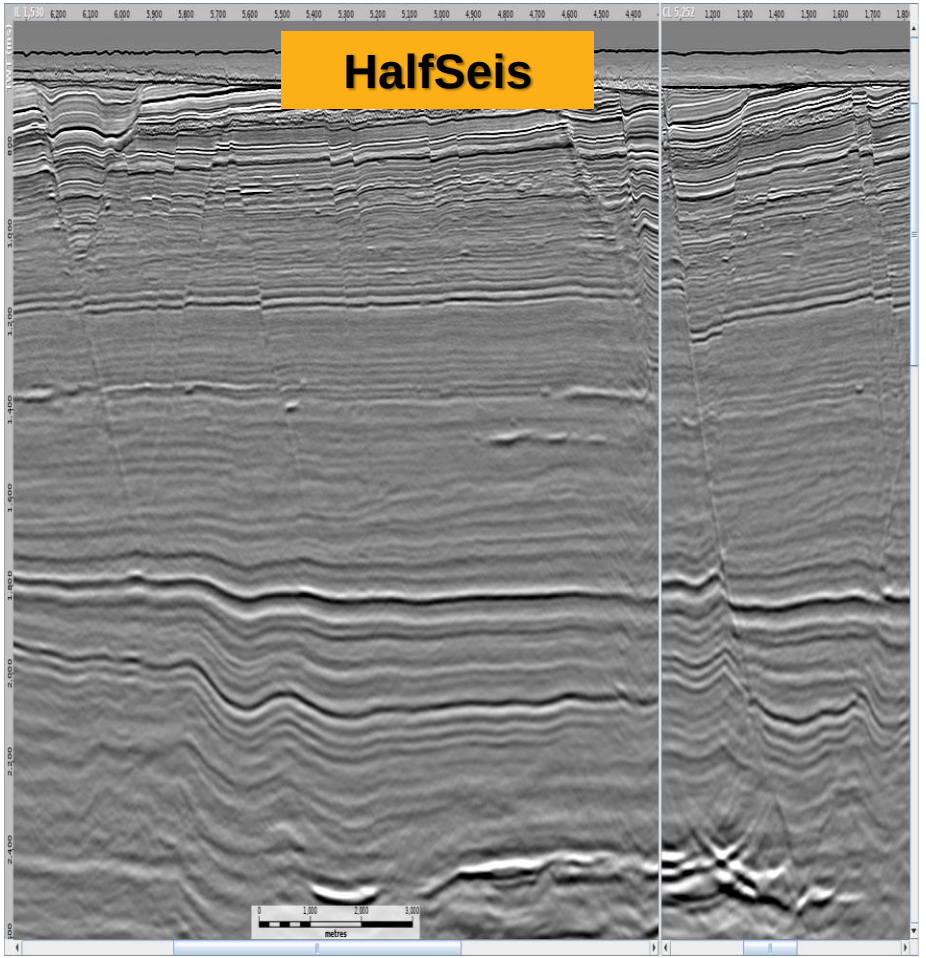
and

2) You had 6.25m shot interval and very small source output, 720 in^3;
Can you image deep with this data?



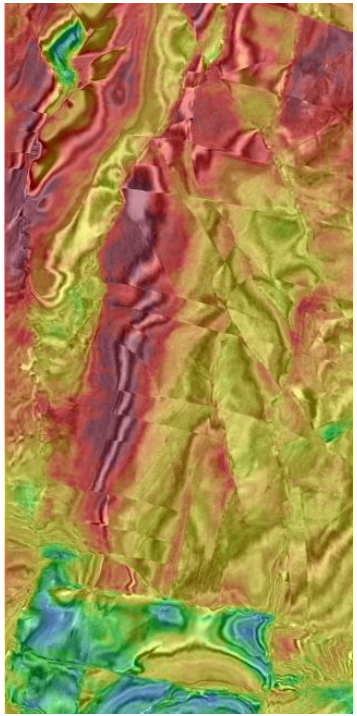
We have NO problems to image > 4km deep



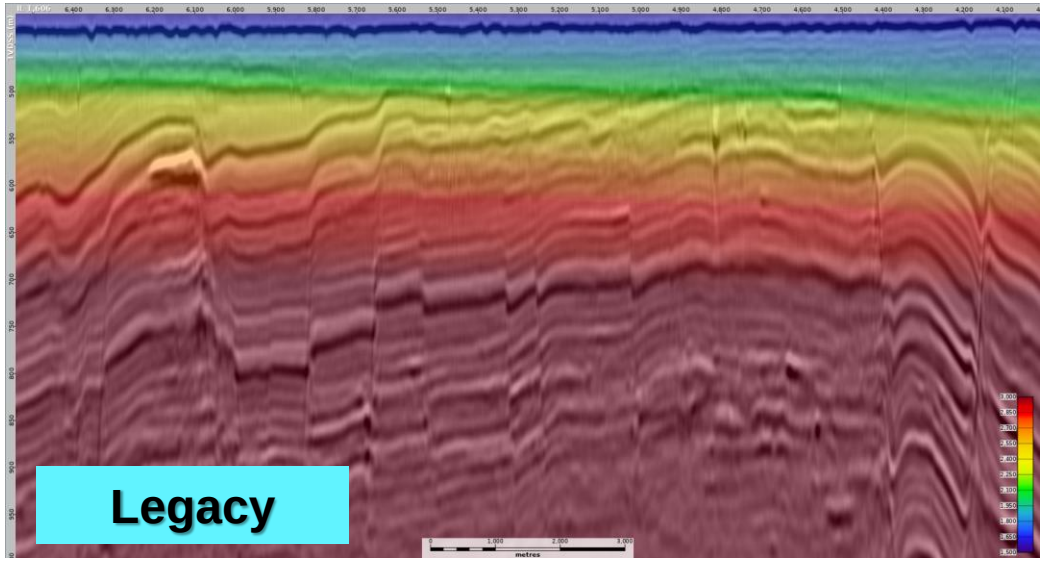


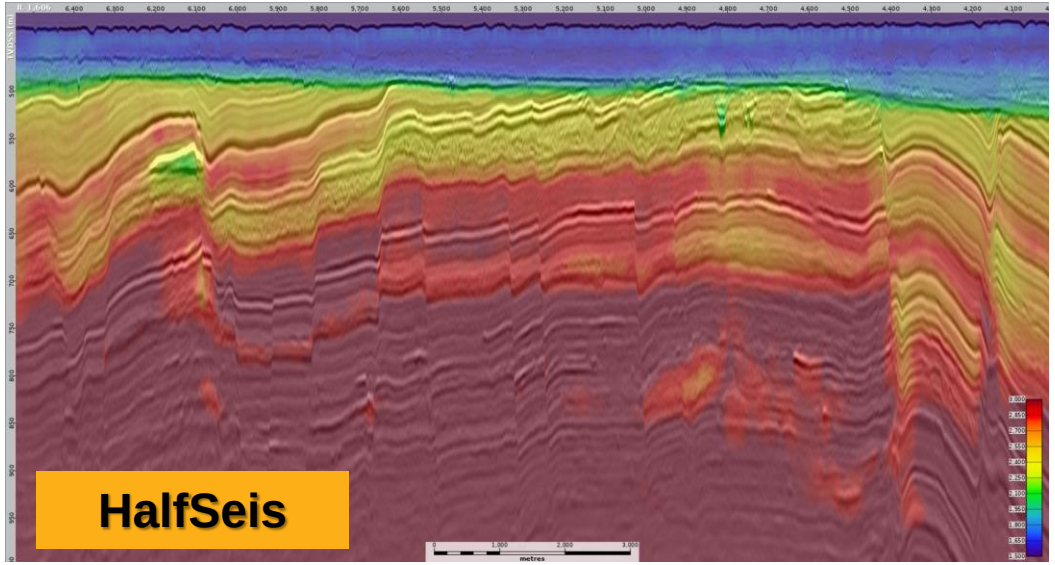
FWI – 24Hz

Legacy



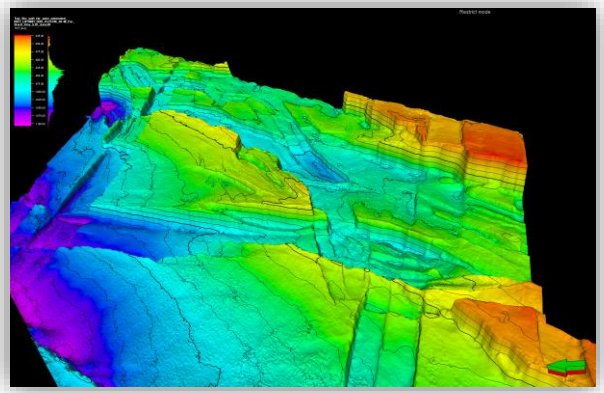
HalfSeis

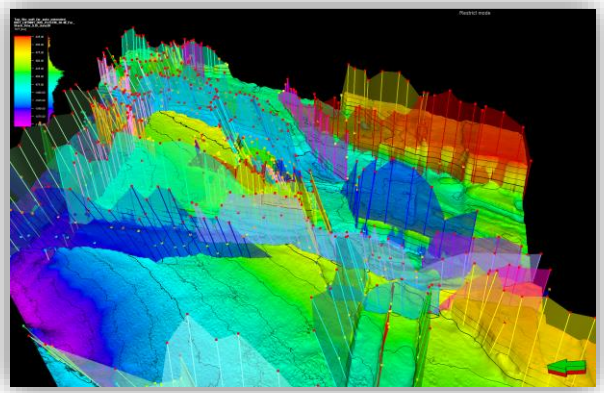




Conclusions

- A seismic acquisition and image project has been undertaken involving very specific and clear goals stated upfront.
- The project involved:
  - re-designing the seismic towing configuration – to get close to zero offsets
  - re-design and rebuilding of four sources into small efficient point sources
  - acquisition using multisensor recording system to allow for full deghosting
- The new seismic allows us to:
  - Image reservoir architecture in high resolution at multiple target levels & pick the top and base reservoir
  - Fault reactivation and retention control is vastly improved
  - The data can and will be used for shallow hazard gas detection (no need for any further 2D site survey acquisition)
  - AVO can now confidently be performed on all these “shallow targets”.





Acknowledgements

The authors would like to emphasis the joint collaborative effort between Spirit Energy and Lundin Energy Norway that led to the successful planning, execution and processing of these new high resolution datasets across PL962 and PL965.

We would also like to thank the crew on-board the Amazon Conqueror for their swift adaptation and willingness to redesign and rebuild the source arrays.

Thanks to Lundin Energy Norway and PL965 and PL962 license partner Spirit Energy Norway for permission to share this work. Special thanks to the Spirit Exploration team in Stavanger for excellent teamwork.

None of this work would have been possible without the excellent collaboration with our Lundin Harstad team!

And last but not least – a big thanks to Dug and Karen Dancer for the superb work on processing and imaging these datasets