ConocoPhillips

Seismic while drilling –

Results of a test performed with the permanently installed seismic monitoring system on the seafloor at Ekofisk

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Project proposal/objectives (Octio)

Test processing of passive seismic recordings from Ekofisk LoFS array for the purpose of identifying seismoacoustic signals emanating from an active drill bit to locate the drilled well track and reflections ahead of the drill bit.

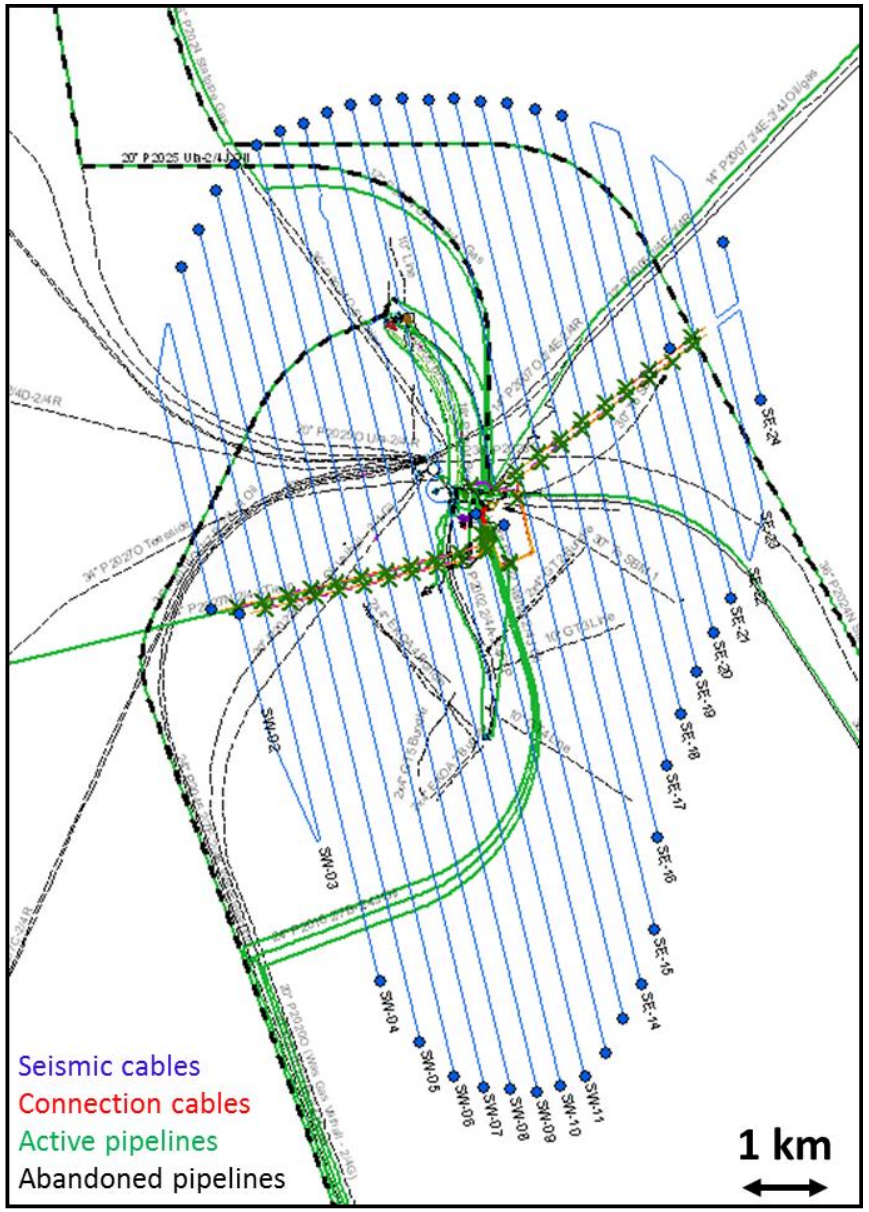
- To localize the drill bit with meter-level accuracy. This technique can provide a significant improvement in the position of well tracks compared to conventional downhole methods where the position uncertainty scales with measured depth. (DrillBit Positioning)

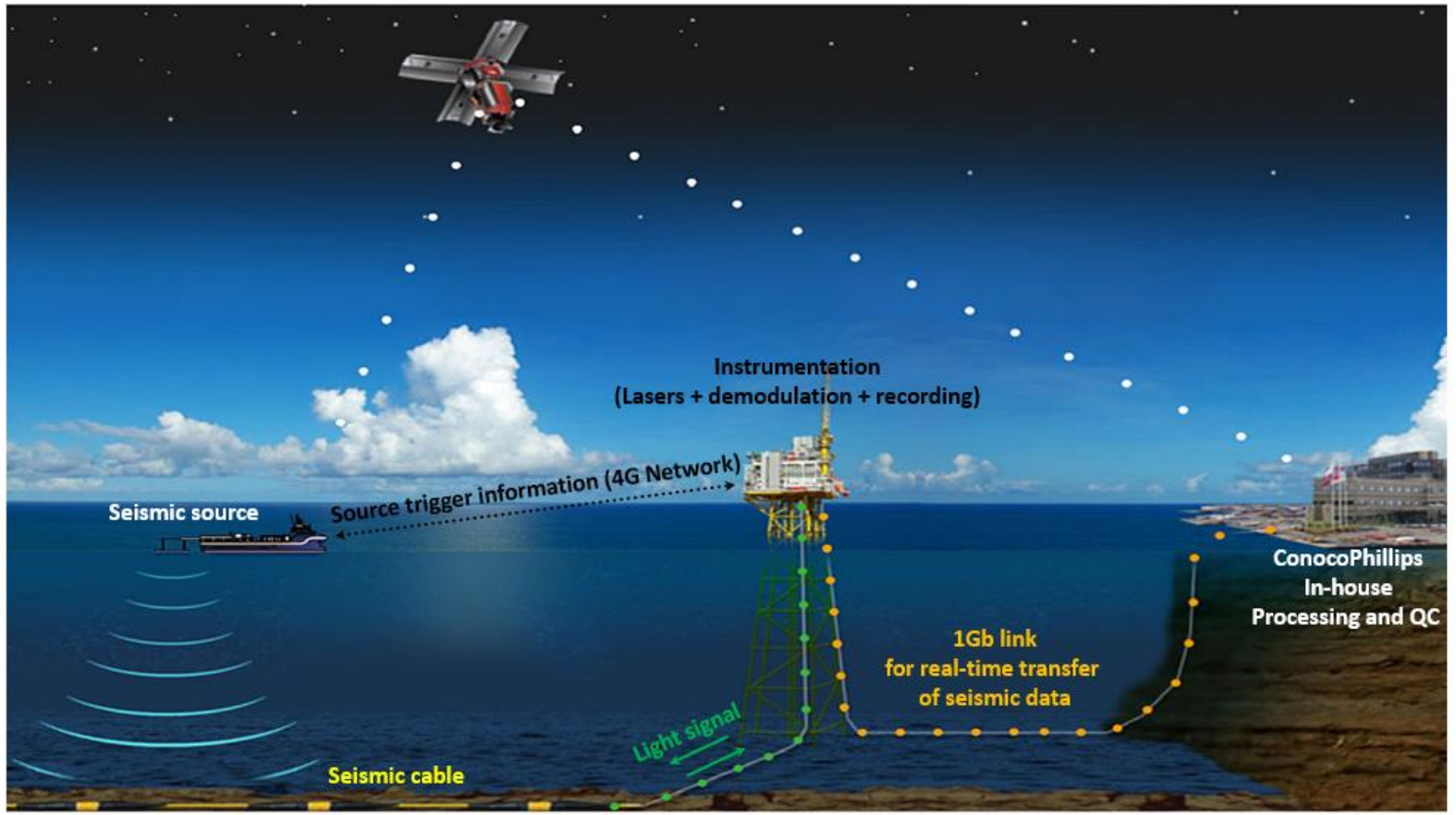
- To image the geology surrounding the drill-bit, through an analysis of reflections and diffractions. This is referred to as look-ahead* imaging and can be utilized to accurately navigate the drill bit with respect to reference horizons and other geological features. (Reverse VSP Imaging)

**Seismic look-ahead using the drill bit as a source is a mature technology (e.g., Poletto and Miranda, 2004).*

OCTIO

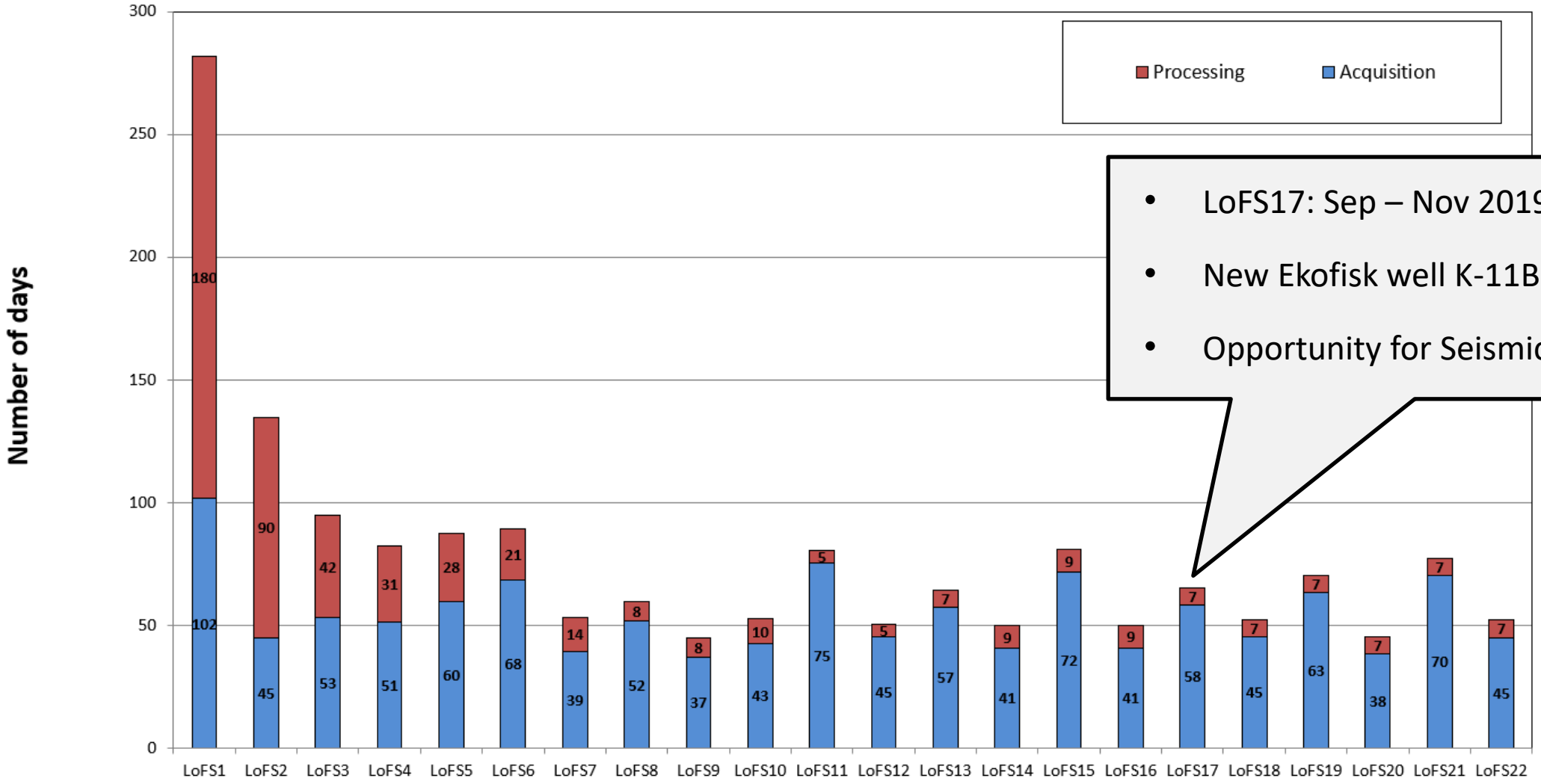
Ekofisk LoFS («Life of Field Seismic») system





- Optical system installed in 2010
- 3966 4C receiver locations
- 50m sensor interval
- 300m cable separation
- 98.5 % of sensor stations still working
- 22 surveys acquired so far

Ekofisk LoFS 4D seismic surveys

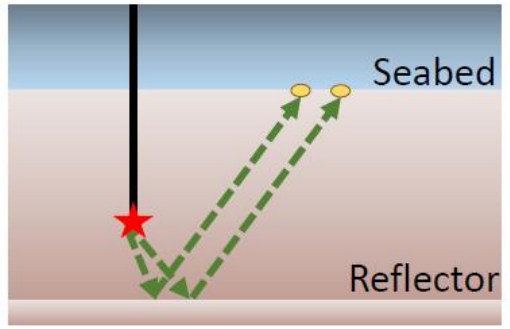


- LoFS17: Sep – Nov 2019
- New Ekofisk well K-11B being drilled
- Opportunity for Seismic While Drilling test

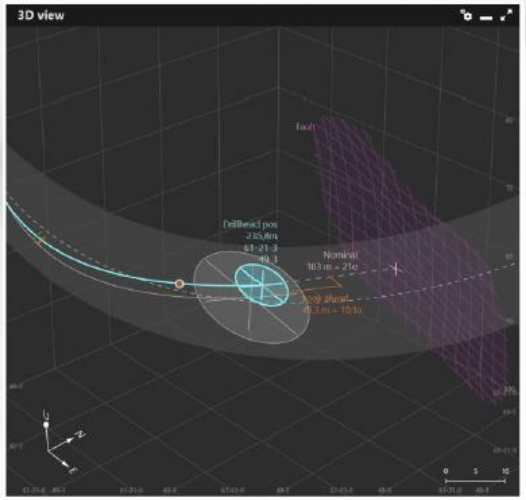
Look-ahead technology (Seismic While Drilling)

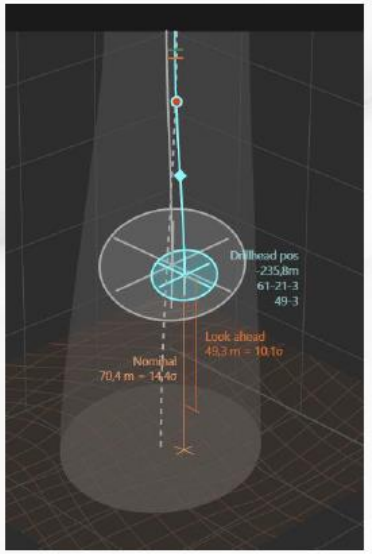
Applications: look-ahead

- **Principle:**
  - Use the drill-bit signal as a seismic source
  - Investigate reflections and diffractors to localize features with high accuracy ahead of the drill bit



- Features that can be imaged in front of bit:
  - Horizons (e.g. formation top)
  - Formation instabilities and possible mud losses
  - Over-pressured zones
  - Karst
  - Faults





- **Applications**
  - Optimize casing points
  - Identify hazards

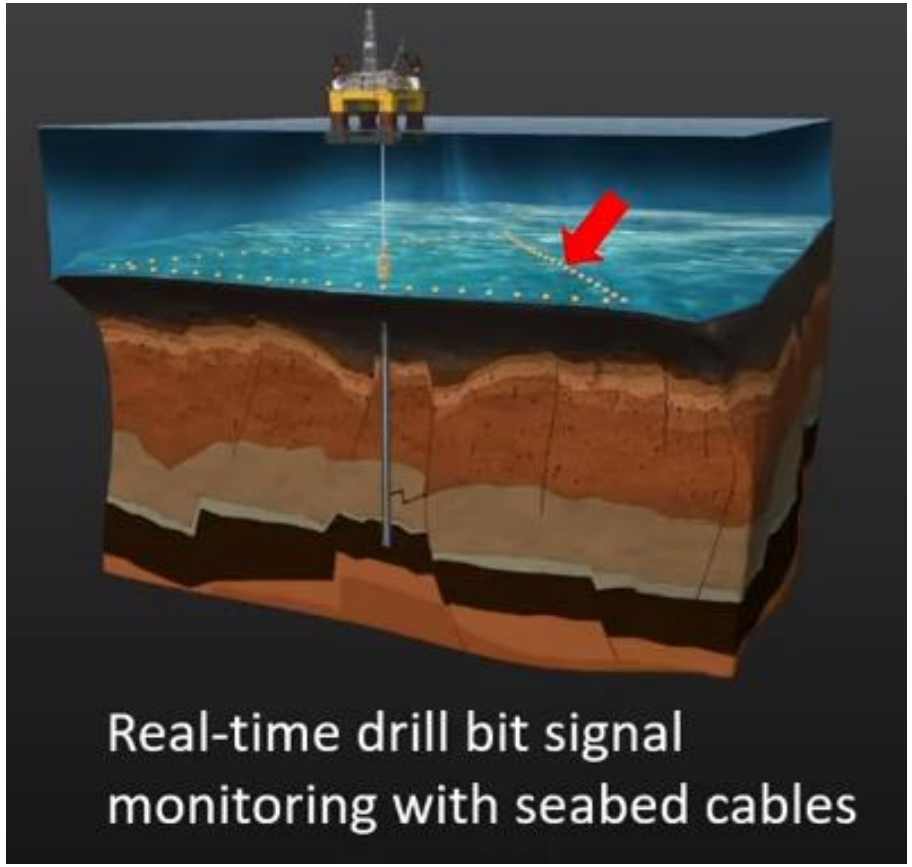
Look-ahead

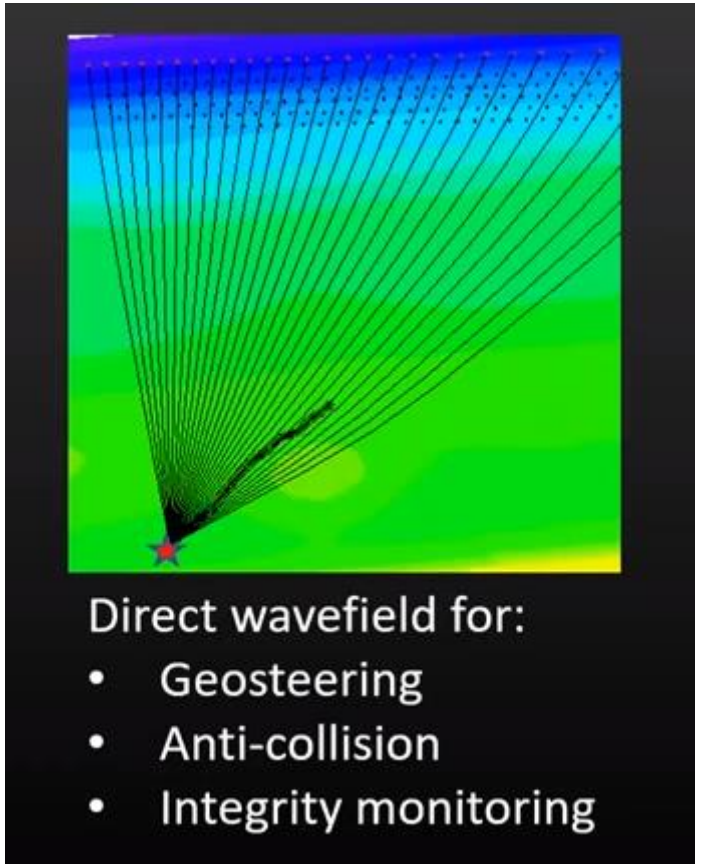
DrillBit

Seismic-While-Drilling

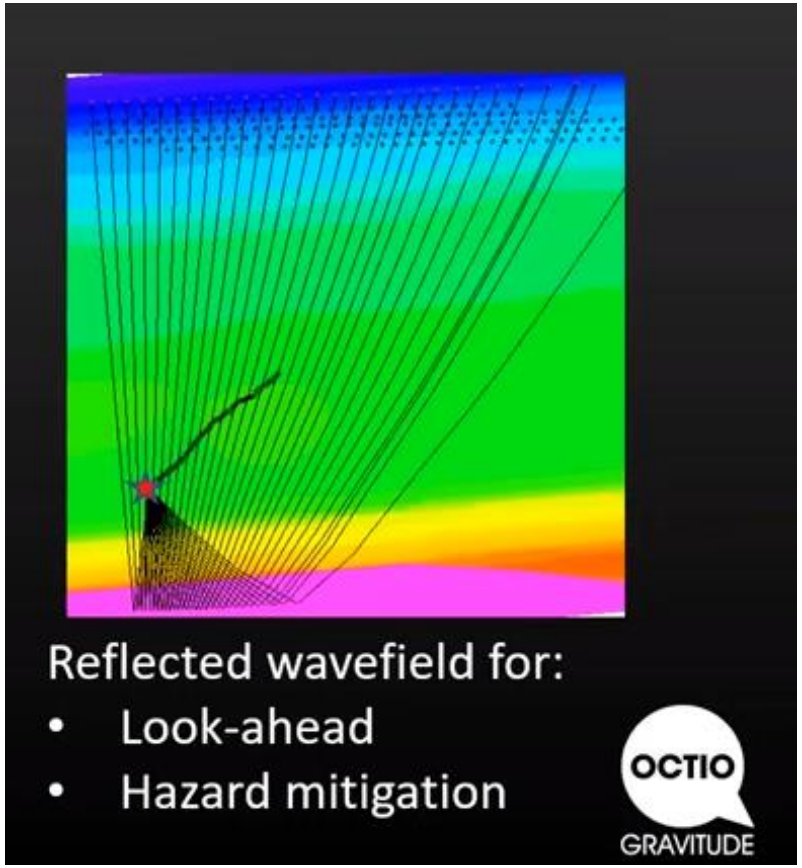
RVSP

Two types of wavefields obtained from DrillBit





DrillBit Positioning



Reverse VSP Imaging

DrillBit data acquisition

Plan:

- LoFS system in passive recording mode after end of LoFS17 survey
- Record drillbit from K-11B in reservoir section

Actual:

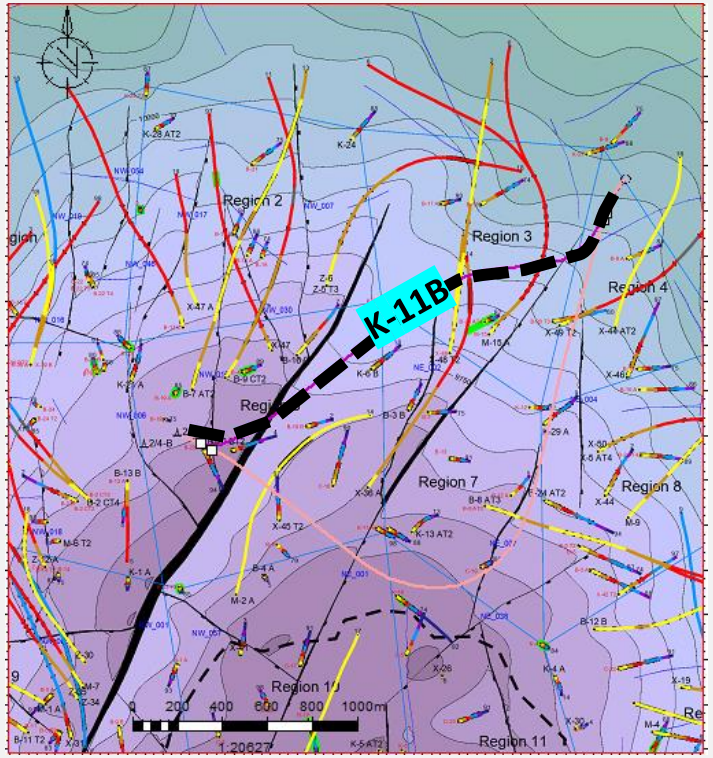
- LoFS system in passive mode during LoFS17 weather downtime
- Record drillbit from K-11B in overburden
- LoFS system failed during drilling of reservoir section

Data overview

Date/Time	Recording	Drilling	Depths (MD)
20191022 07:44 – 00:00 20191023 00:00 – 14:16	Active shots 9 sec	9:45-13:30, 15:00-00:00 00:00 – 14:16	2752 ft – 3628 ft 3628 ft – ca. 4700 ft
20191023 14:16- 00:00	Passive data 10 sec	14:16 – 00:00	4700 ft - 5481 ft
20191024 00:00 – 05:00	Passive data 10 sec	00:00-07:45	5481 ft - 6030 ft
20191028 00:00 - 15:21	Passive data – LF noise	No drilling	
20191102 04:30 - 00:00	outside drilling window	00:00-04:45	13033-13309ft
20191114 23:00 – 00:00	steps on ¼ of ITU's	No drilling	
20191115 00:00 – 23:59	steps on ¼ of ITU's – from 13:56 ½ of ITU's	01:45 - 00:00	13337 ft – 13683 ft
20191116 00:00 -03:00	steps on ½ of ITU's	00:00 - 03:00	13684-13889 (TD)

LoFS17 acquisition 18.09.2019 - 02.11.2019

Well information

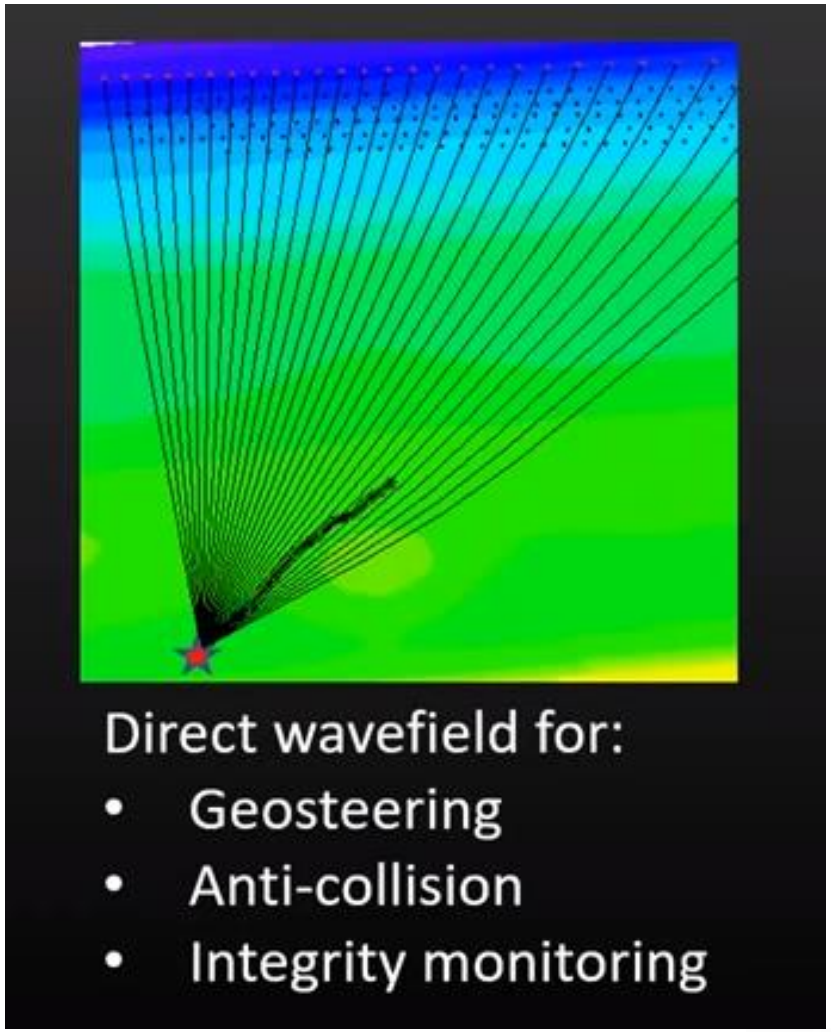


K-11B Deviated Ekofisk injector

- Kick off at 2700'MD
- Top Ekofisk at 13327' MD
- Reservoir length 1043' MD
- Planned TD at 14370' MD

Objective 1: DrillBit Positioning

- To localize the drill bit with meter-level accuracy. This technique can provide a significant improvement in the position of well tracks compared to conventional downhole methods where the position uncertainty scales with measured depth.



Relevant data and key processing steps

Date/Time	Recording	Drilling	Depths (MD)
10/23 14:16 – 10/24 05:00	Passive data 10 sec	14:16 – 05:00	4700 ft - 6030 ft
20191115 00:00 – 23:59	steps on ¼ of ITU's – from 13:56 ½ of ITU's	01:45 - 00:00	13337 ft – 13683 ft
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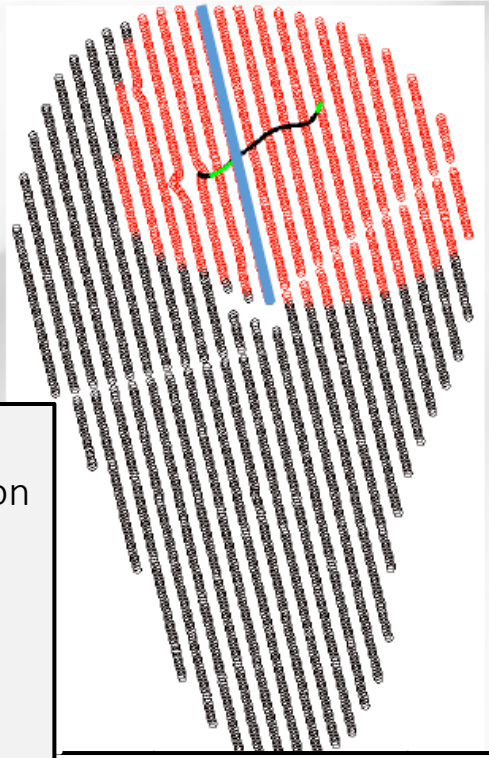
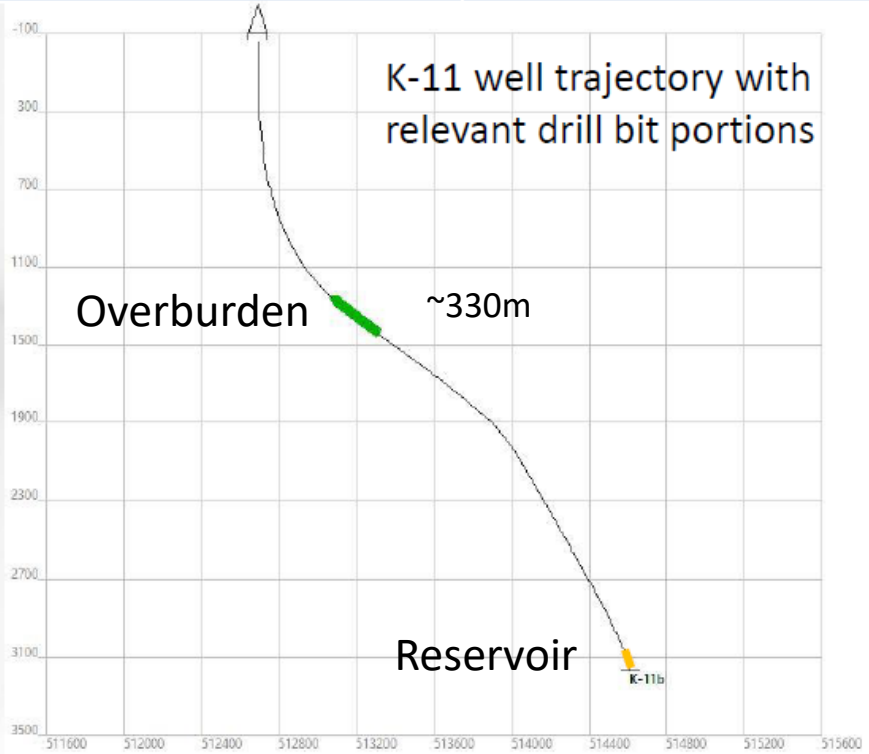
Node selection around K-11 well with line 24

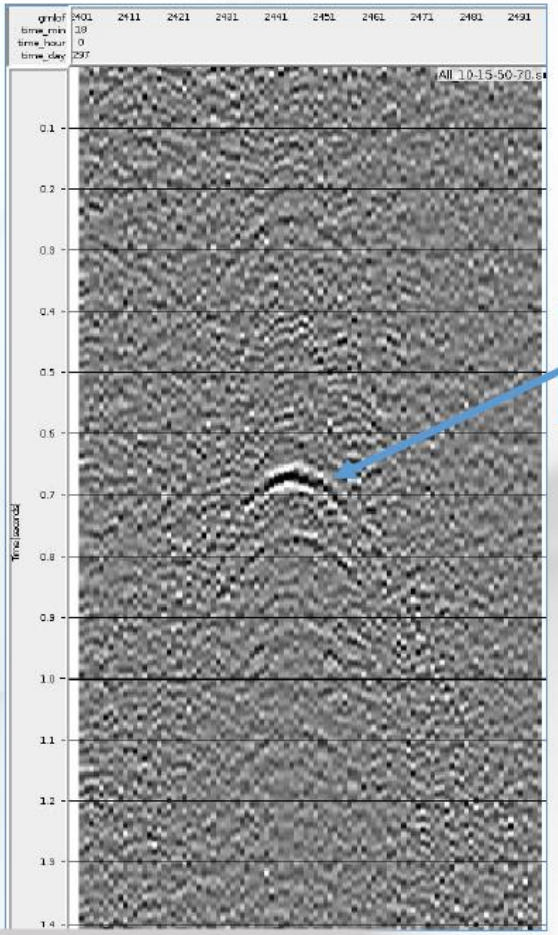




Key processing steps:

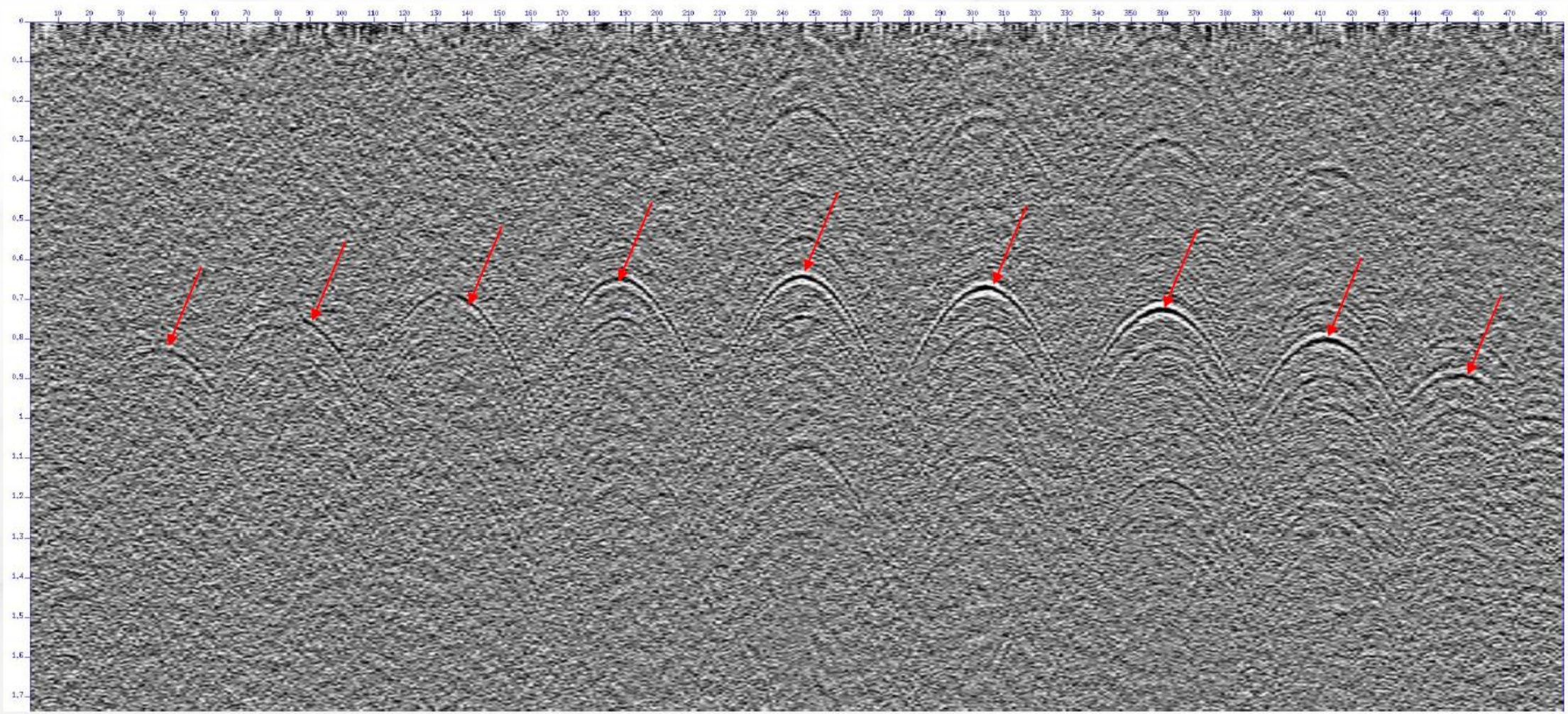
- Focused pilot extraction & evaluation
- Pilot correlation
- DrillBit location
- Single-node checkshot processing
- Multi-node checkshot processing (optional)

Initial drillbit signal line 24



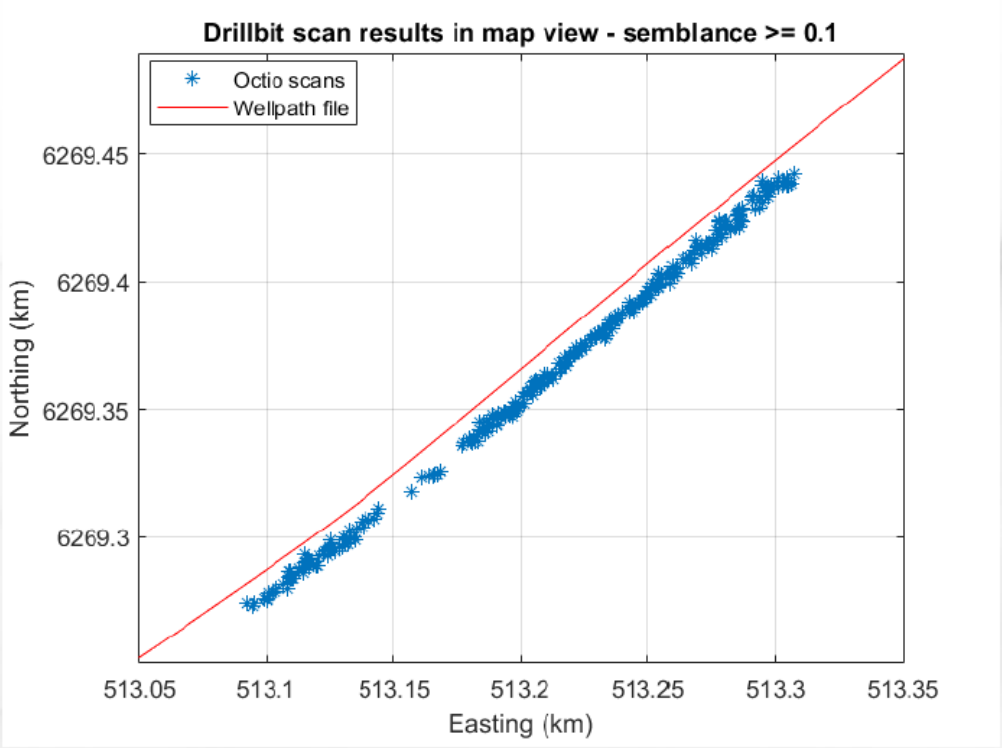
A drill bit signal has been identified
after initial denoise processing on line 24

DrillBit signal observed on most nodes

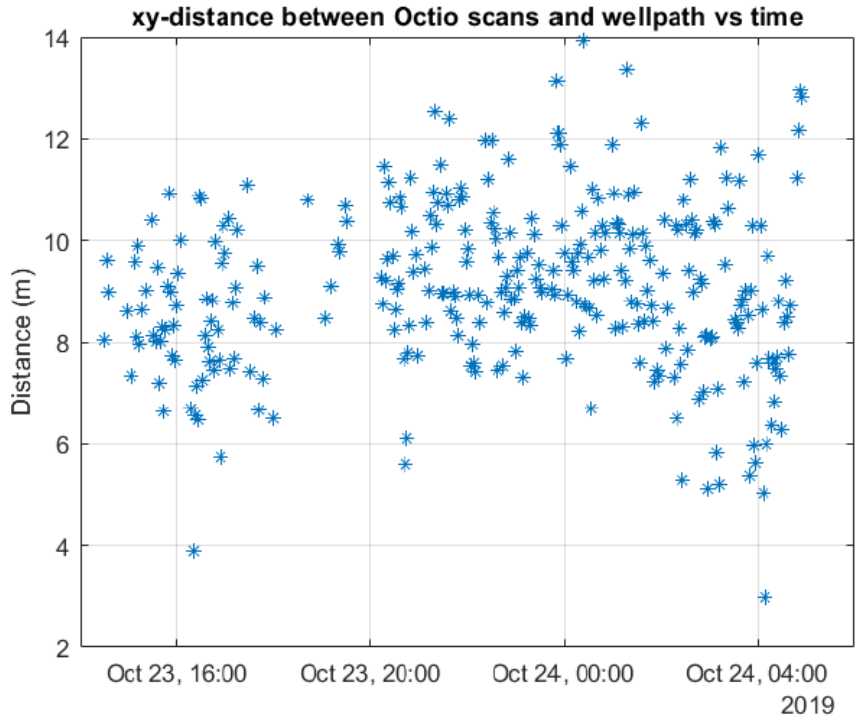


Drillbit location vs. well trajectory

Octio Scans
Proprietory software



Map view

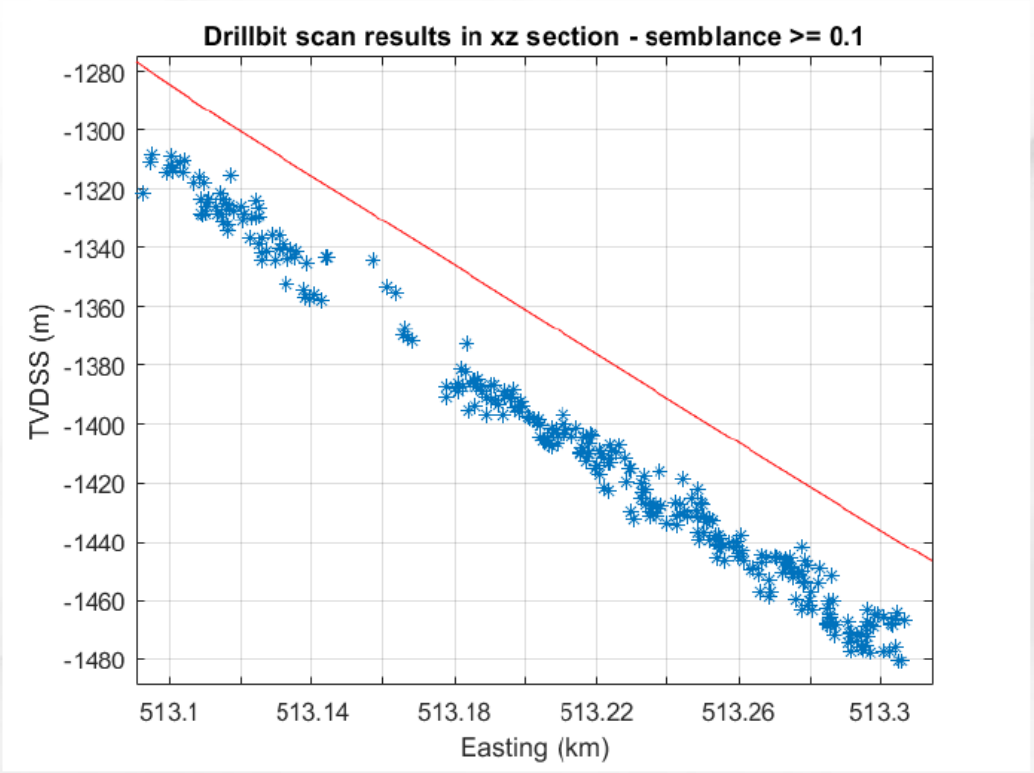


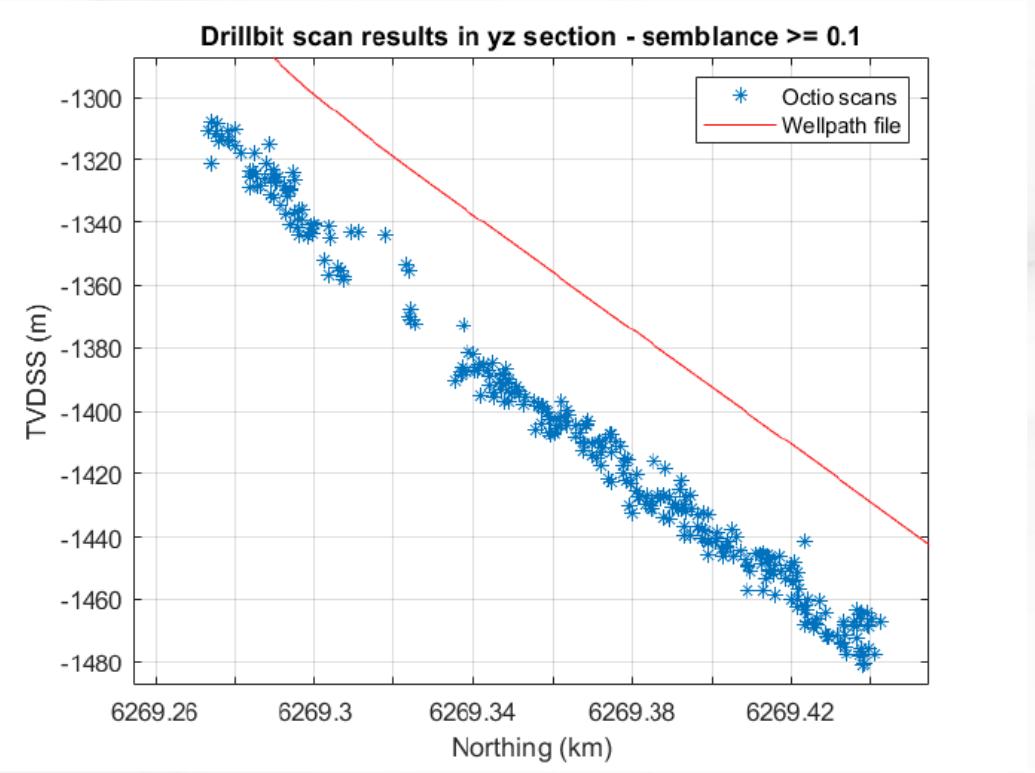
Difference between xy locations and trajectory
Is ca. +/- 3 m
But there is a slight bias.

DrillBit positioning results (cont.)

Drillbit location vs. well trajectory

Octio Scans
Proprietory software





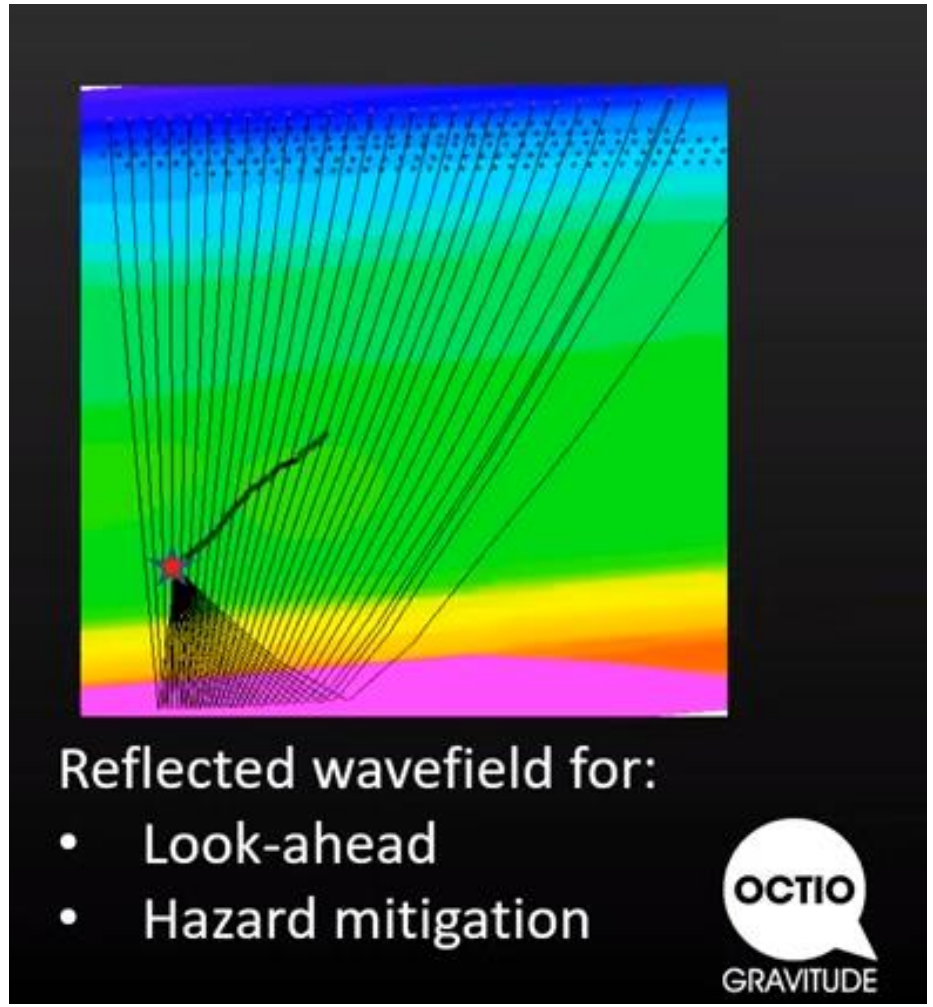
Our locations are ca. 40 m deeper than the provided well trajectory

Summary DrillBit location

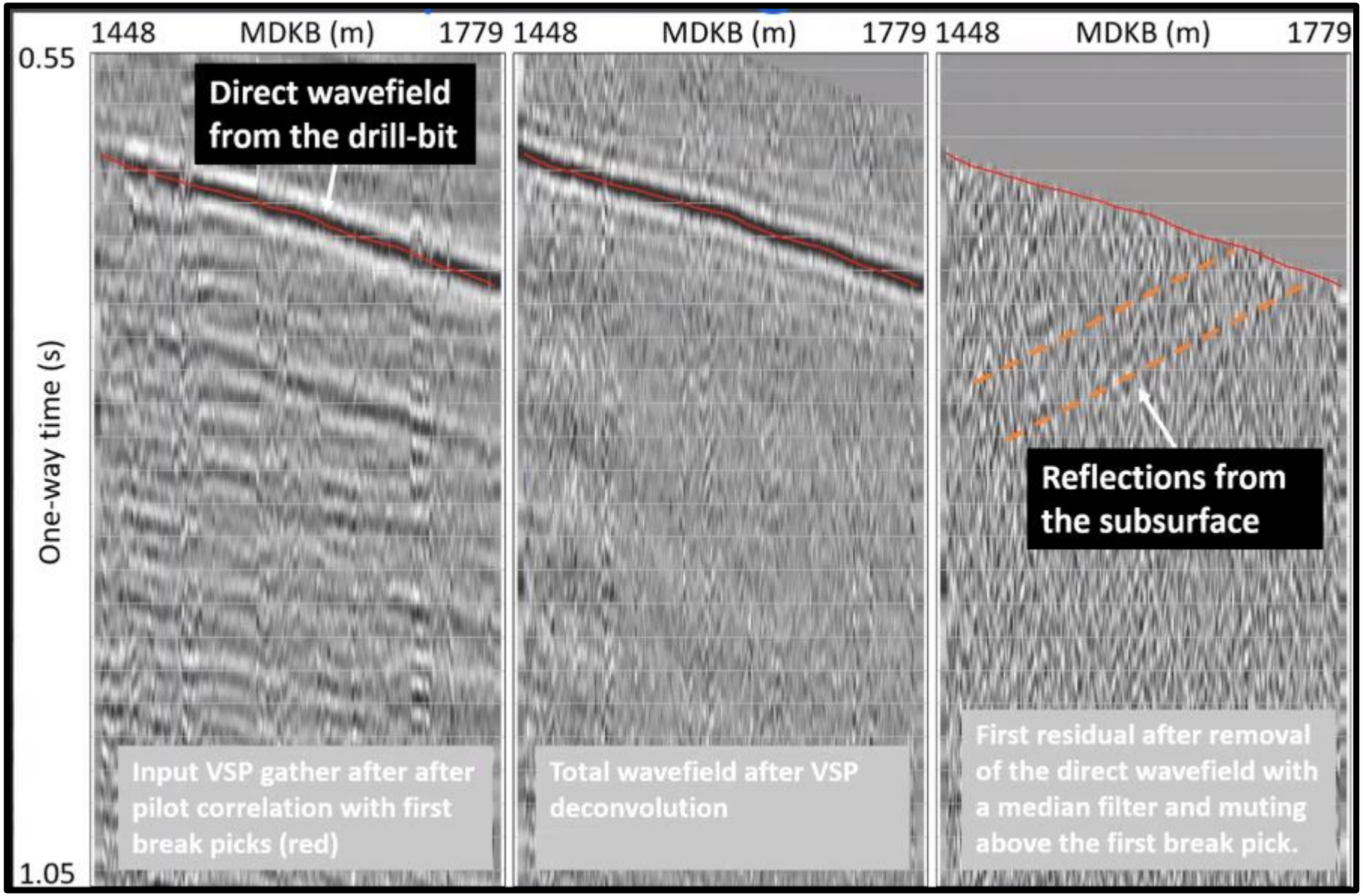
- Drillbit could be located with +/- 3 m accuracy horizontally.
- There is a bias in the data under investigation
  - Timing problem in the seismic headers? (UTC vs. CEST or other)
  - Is the deviation file as planned or as drilled?
  - Velocity model issues?
- Room for improvement in processing:
  - Deconvolution
  - Denoising during low semblance period
- SNR variations with offset/azimuth could be due to radiation pattern
  - Requires further investigation

Objective 2: Reverse VSP Imaging

- To image the geology surrounding the drill-bit, through an analysis of reflections and diffractions. This is referred to as look-ahead* imaging and can be utilized to accurately navigate the drill bit with respect to reference horizons and other geological features.



Look-ahead processing flow & reverse VSP



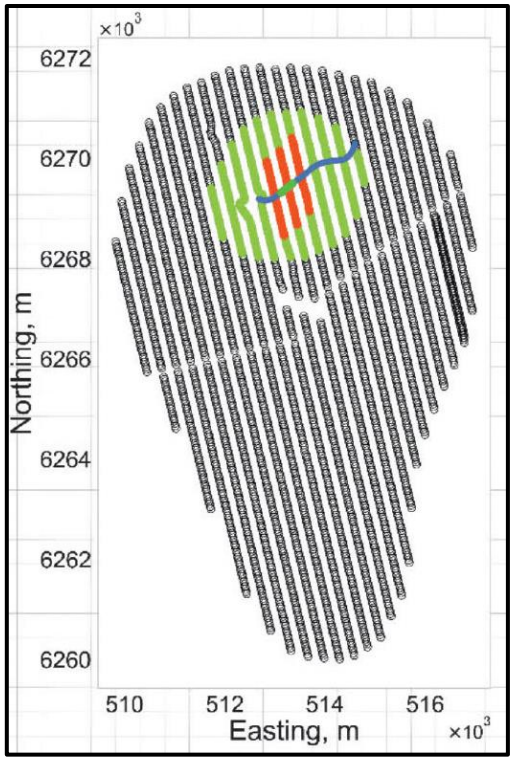


Figure 4 RVSP gather of one node approximately vertically above the borehole. Left (a): input VSP gather after pilot correlation with manual first break picks (red). Centre (b): Total wavefield after VSP deconvolution. Right (c): First residual after removal of the direct wavefield with a median filter and muting above the first break pick.

Setup for 3D VSP

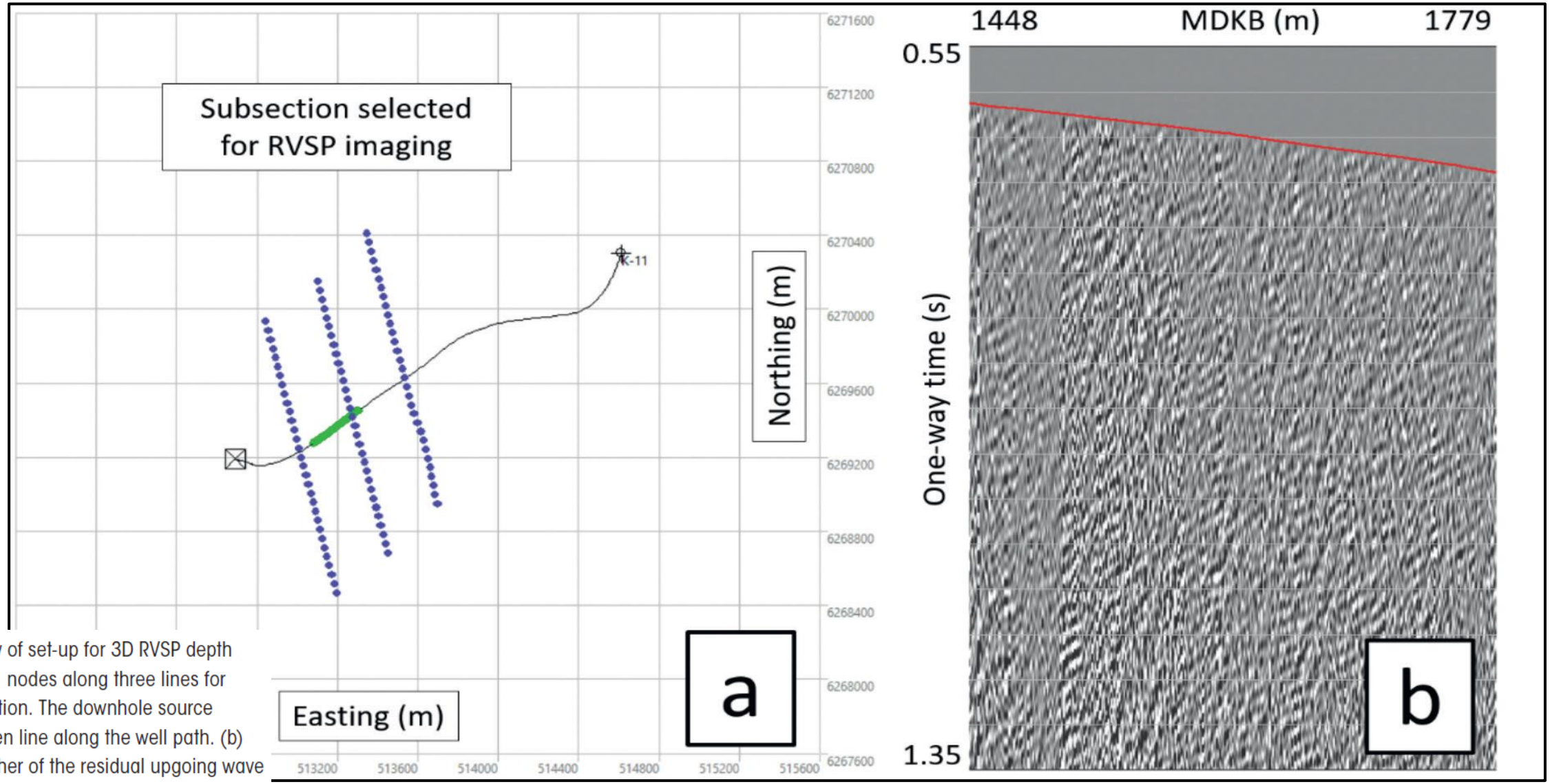


Figure 5 (a) Map view of set-up for 3D RVSP depth imaging. We select 91 nodes along three lines for processing and migration. The downhole source array is shown as green line along the well path. (b) Common-receiver gather of the residual upgoing wave field input to migration.

Reverse VSP imaging results

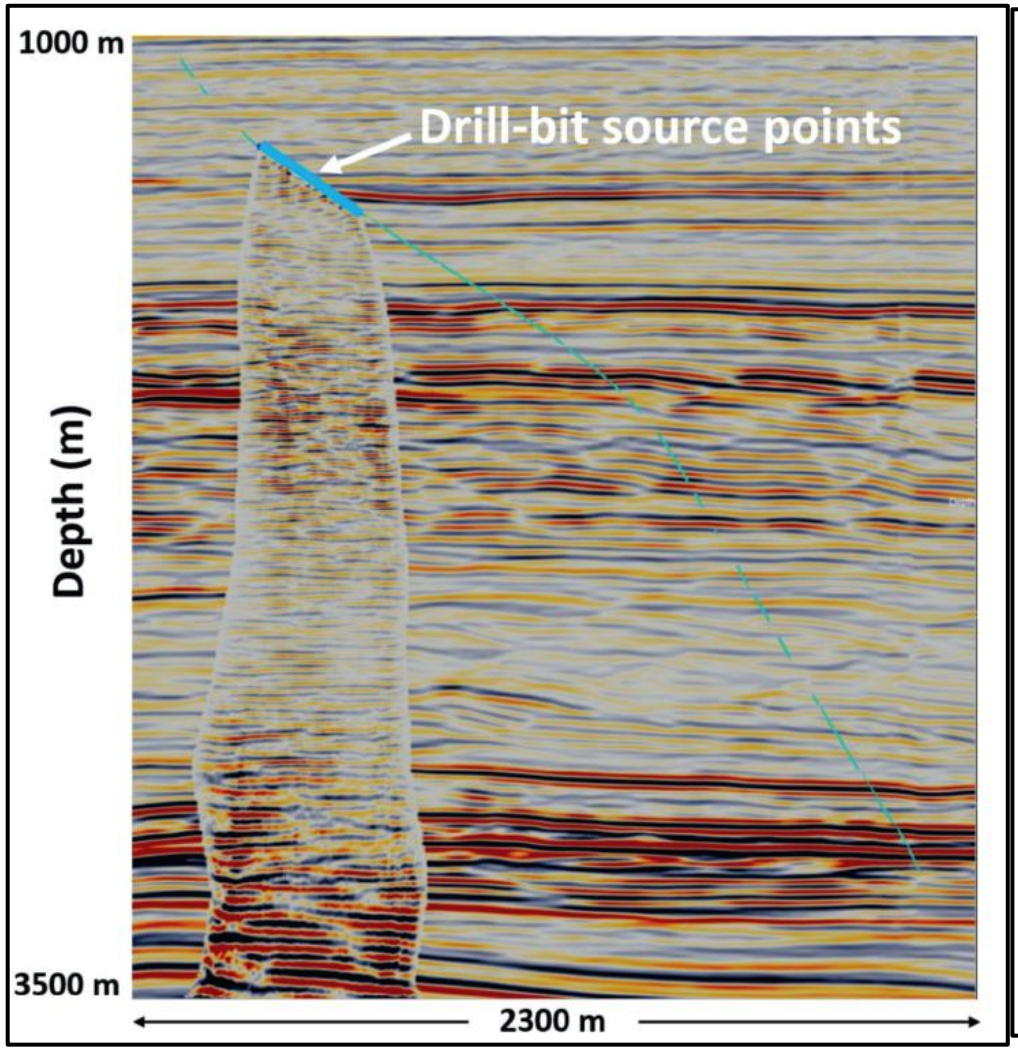


Figure 6 Seismic depth section along the well path with the corresponding line of the 3D RVSP image spliced in. The well path is indicated by the cyan line with the downhole source array highlighted by light blue thick line.

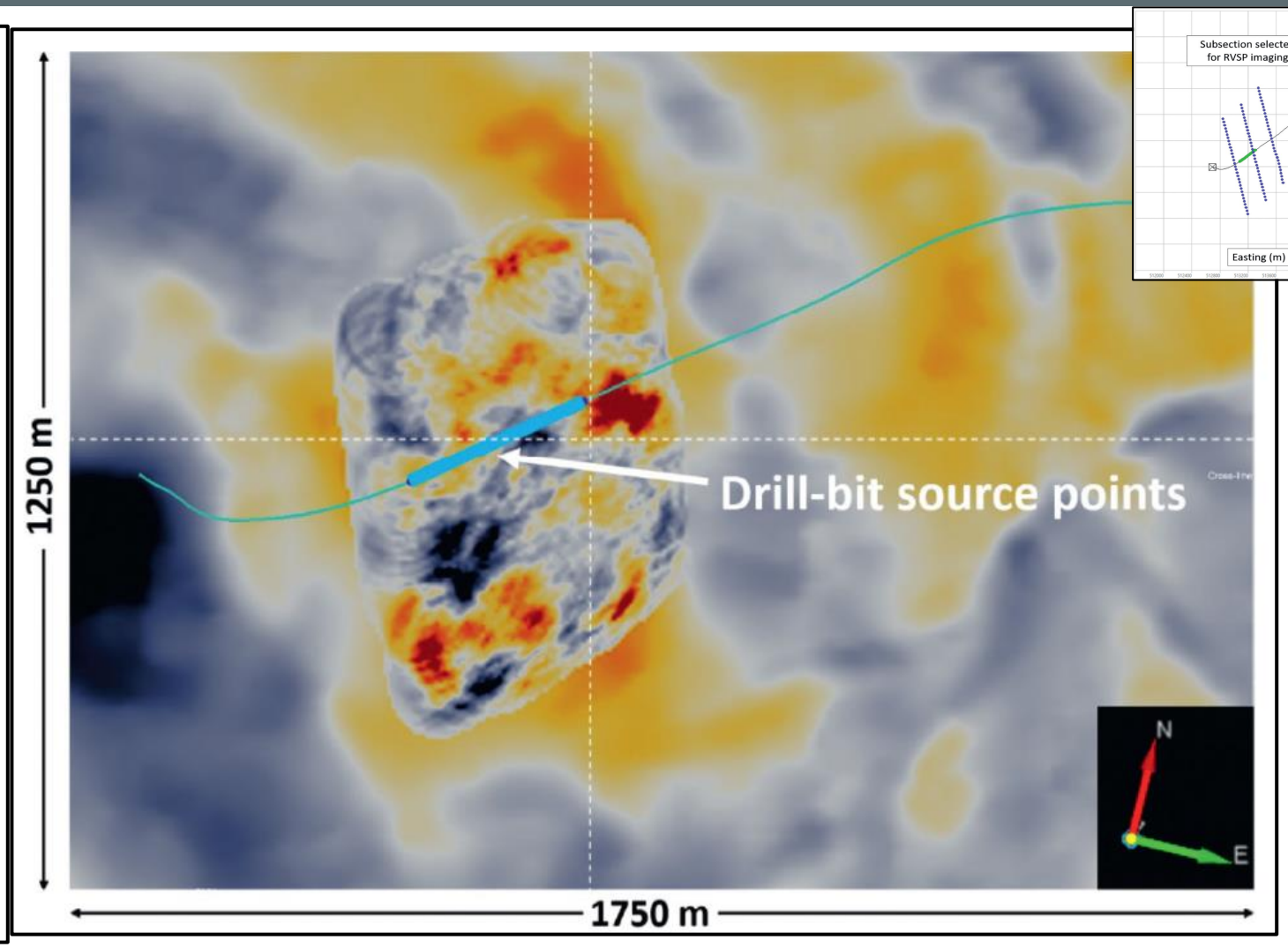
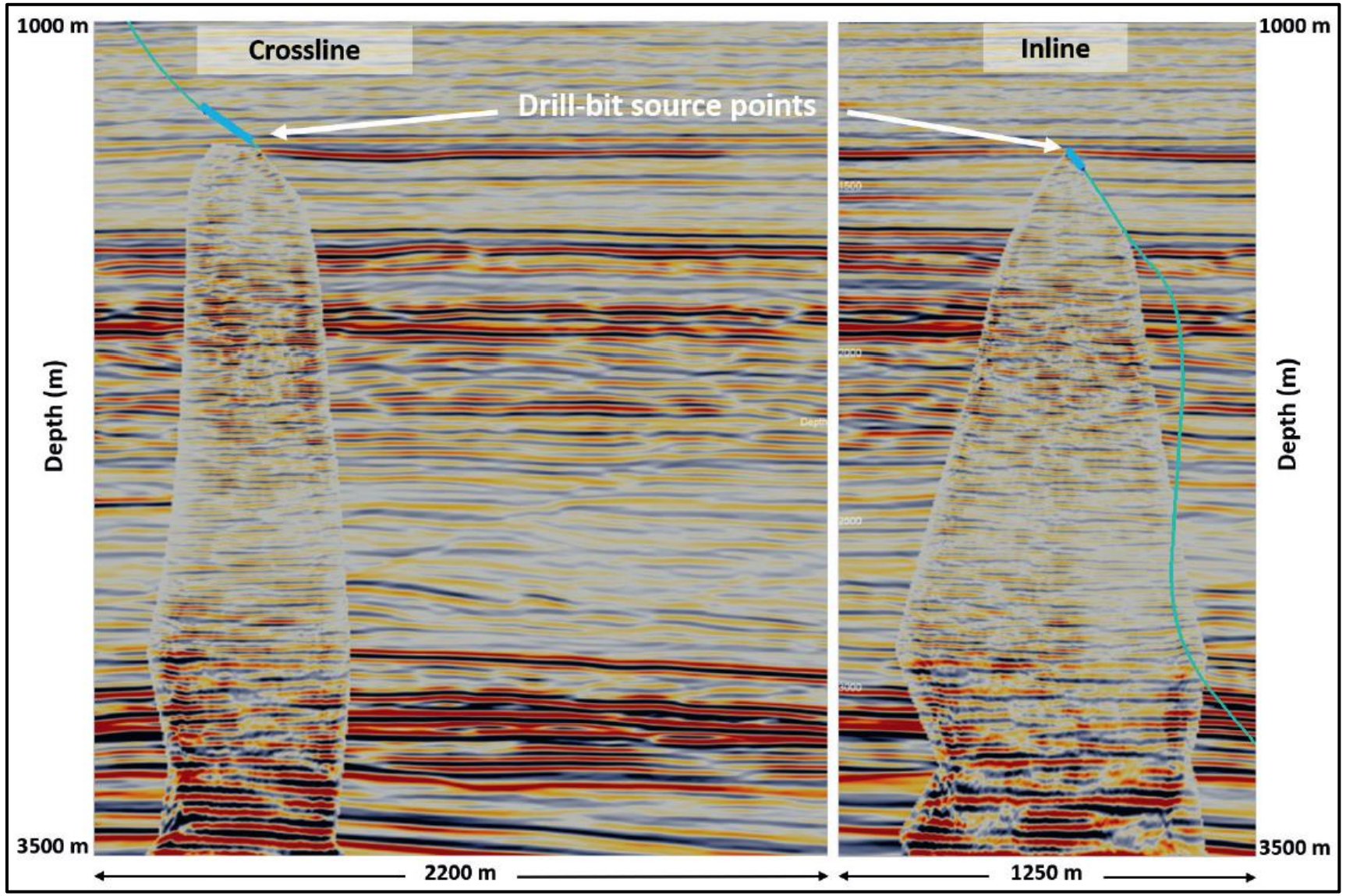


Figure 7 Depth slice of the spliced image at a depth of 2456 m, illustrating the lateral extent of the 3D RVSP image in relation to the well path. Dashed white lines indicate the location of the inline and crossline slices shown in Figure 8. We observe a good correspondence between the 3DRVSP and the background surface seismic image.

Reverse VSP imaging results (cont.)



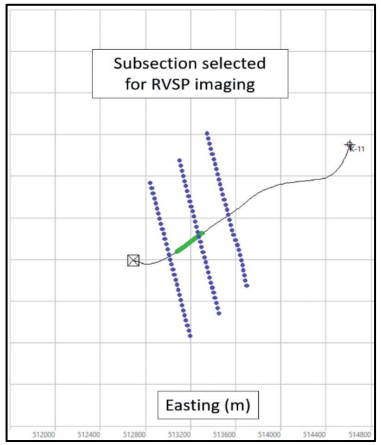


Figure 8 Inline (left) and crossline (right) section of the 3DRVSP image along the dashed lines shown in Figure 7. Well path and drill-bit source points are projected into the section for reference.

Conclusions

- DrillBit positioning is promising with some remaining uncertainties
- 3D image down to reservoir level obtained with reverse 3D VSP processing
- Real-time operations was not tested in this project
- Reservoir part was not included in this study due to data issues
- Can get VSP data at relatively low cost
- Potential to improve performance through better velocity model (anisotropy)

Path forward

- Another LoFS passive recording performed during drilling the entire reservoir section of X-20A
- LoFS system was utilized during 5 days of weather standby during acquisition of LoFS21 in Q4 2021
- Halliburton has proposed to perform a reverse VSP project on the data from this well
- Data can be made available to other qualified contractors