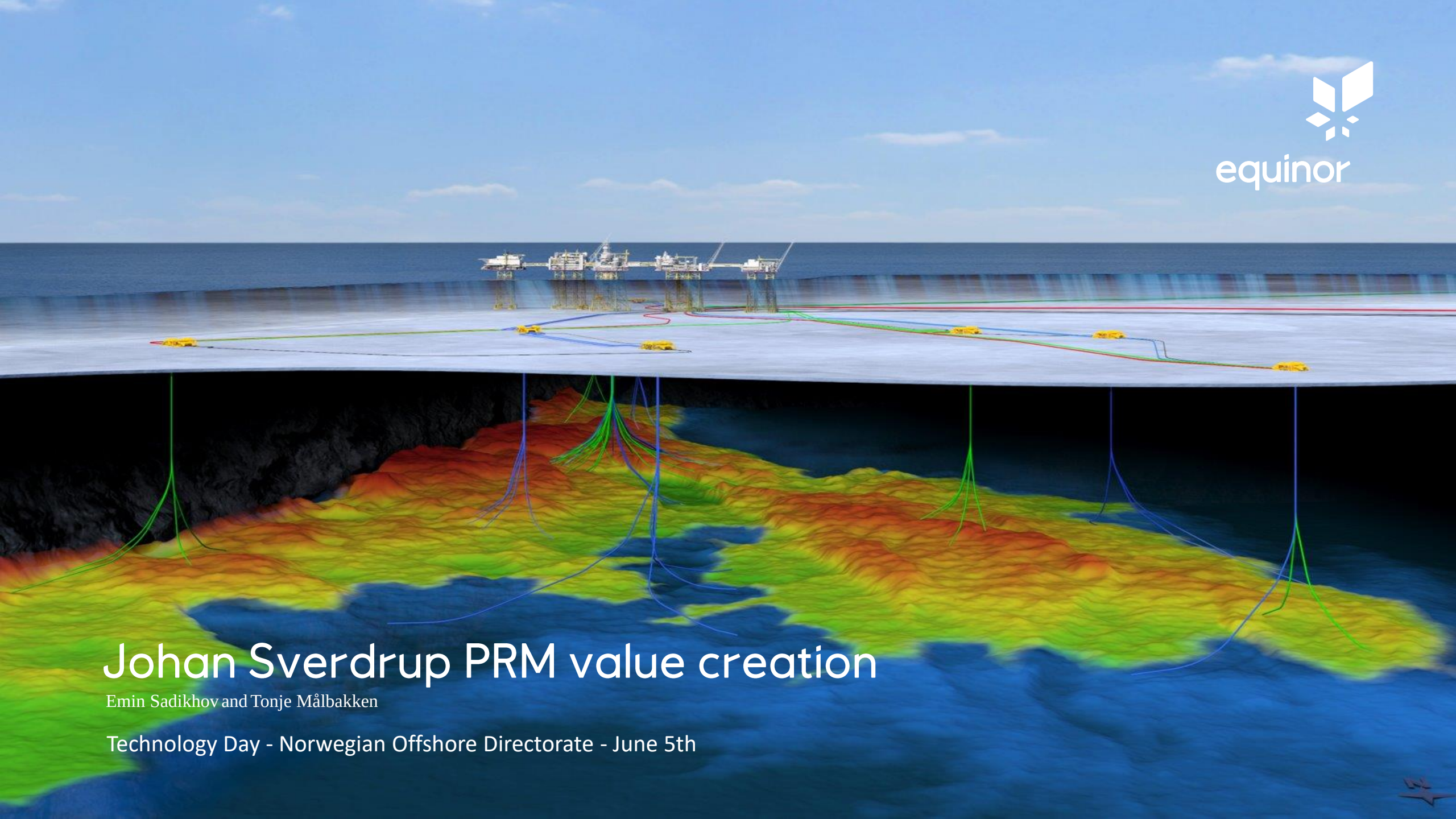


Johan Sverdrup PRM value creation

Emin Sadikhov and Tonje Målbakken

Technology Day - Norwegian Offshore Directorate - June 5th

Presentation outline

- Field introduction
- Johan Sverdrup reservoir monitoring
  - In wells
  - Permanent Reservoir Monitoring (PRM) giving 4D seismic data
- Example of value creation from 4D seismic data
- PRM
  - Business drivers
  - Equinor PRM Portfolio
  - Technology testing and applications
- Summary

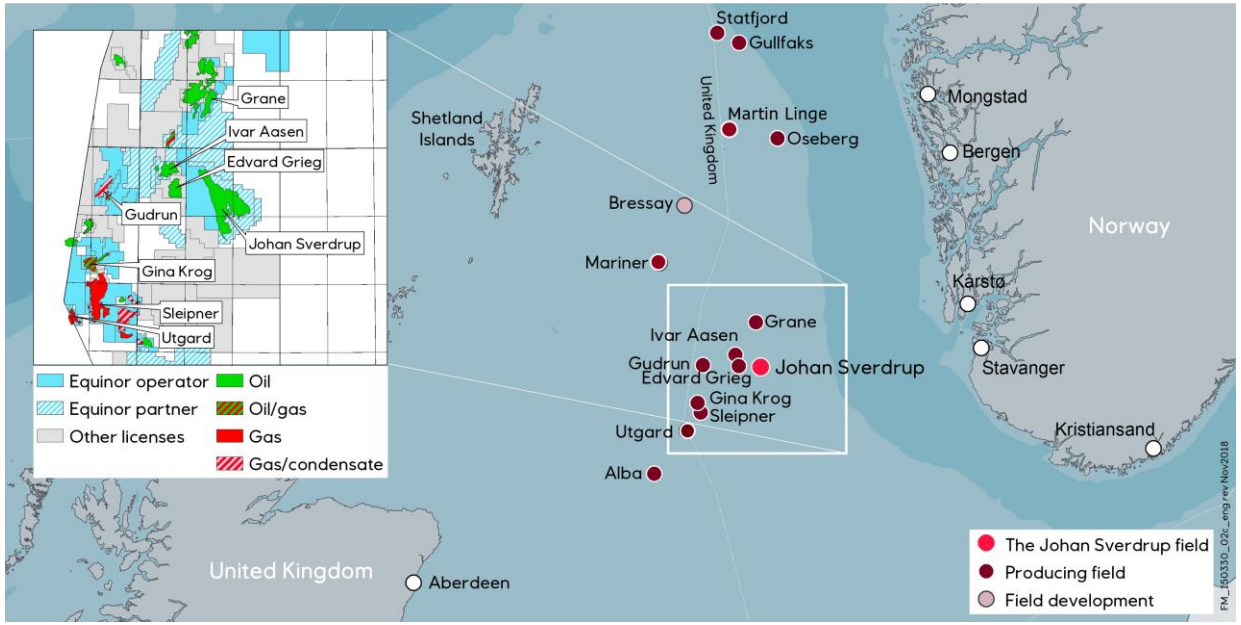
Johan Sverdrup - field introduction

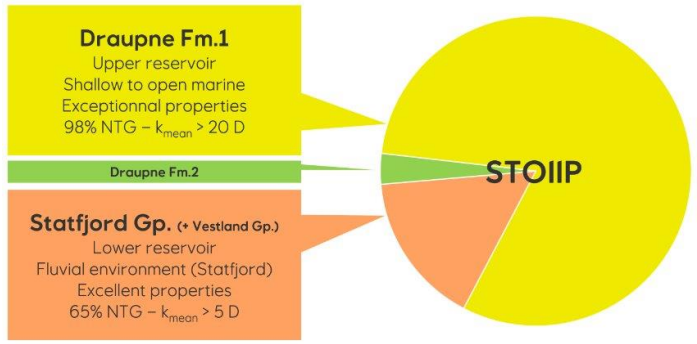
Located at Utsira High ~160 km west of Stavanger. Start-up: October 2019

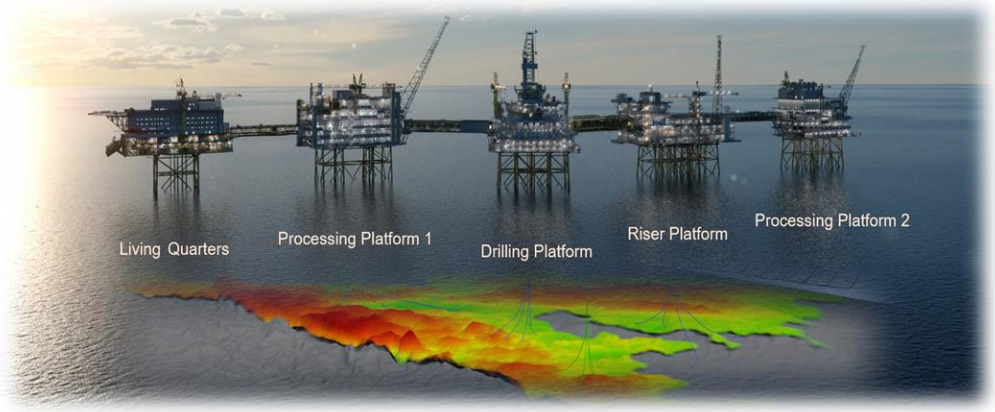
General	
Reservoir apex	~ 1800 m TVD MSL
Water depth	~ 110 meter
FWL	1922 - 1934 m TVD MSL
Area	~ 200 km^2
Pressure	Hydrostatic
Age	Jurassic and Late Triassic (main reservoir)
Recoverable resources	2.2 – 3.2 billion boe

Reservoir facts	
Reservoir quality	Multi-Darcy permeability Porosity ~ 25 - 30% No gas cap

Drainage strategy	
Water injection	Pressure maintenance by voidage replacement

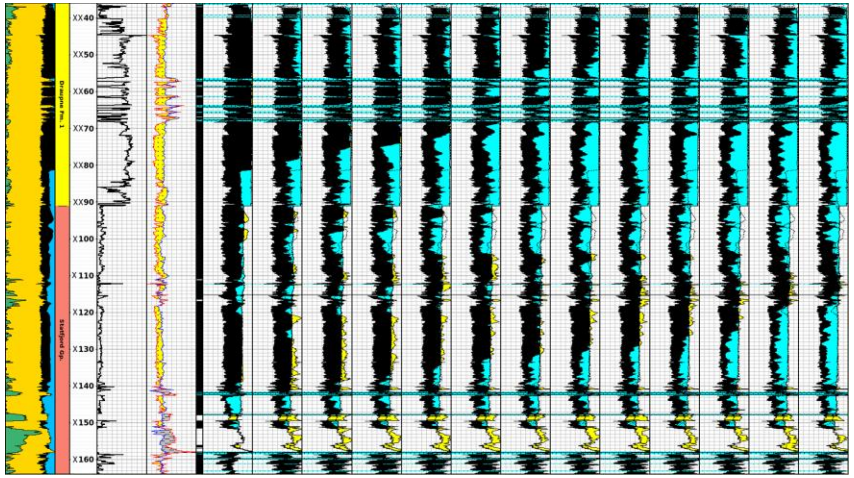




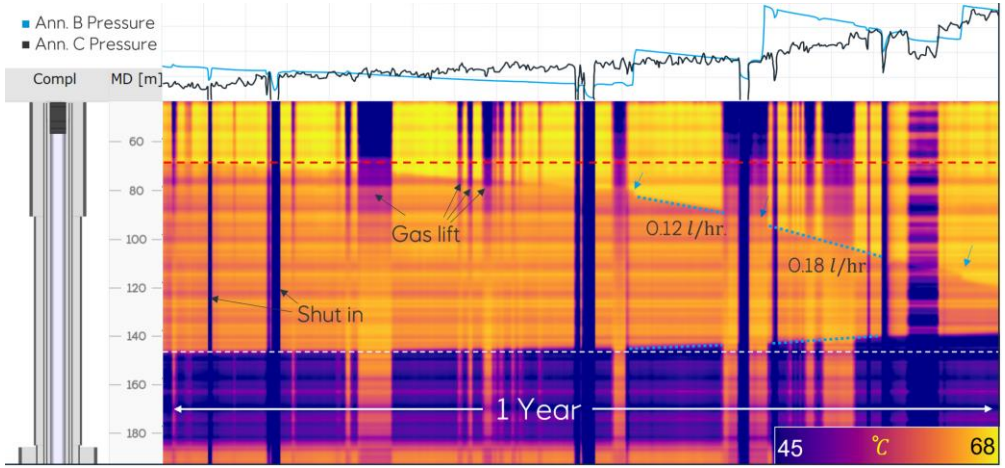


Johan Sverdrup - reservoir monitoring - in wells

- Repeated saturation logging (Pulsar)
  - Monitoring fluid changes
- Continuous pressure measurements (down-hole)
  - Voidage control
- Production/Injection logs
  - Safe injection
  - Reservoir performance
- Tracer injection/production and well chemistry analysis
  - Connectivity between wells
- Fiber
  - Distributed Temperature Sensing (DTS)
  - Distributed Acoustic Sensing (DAS)

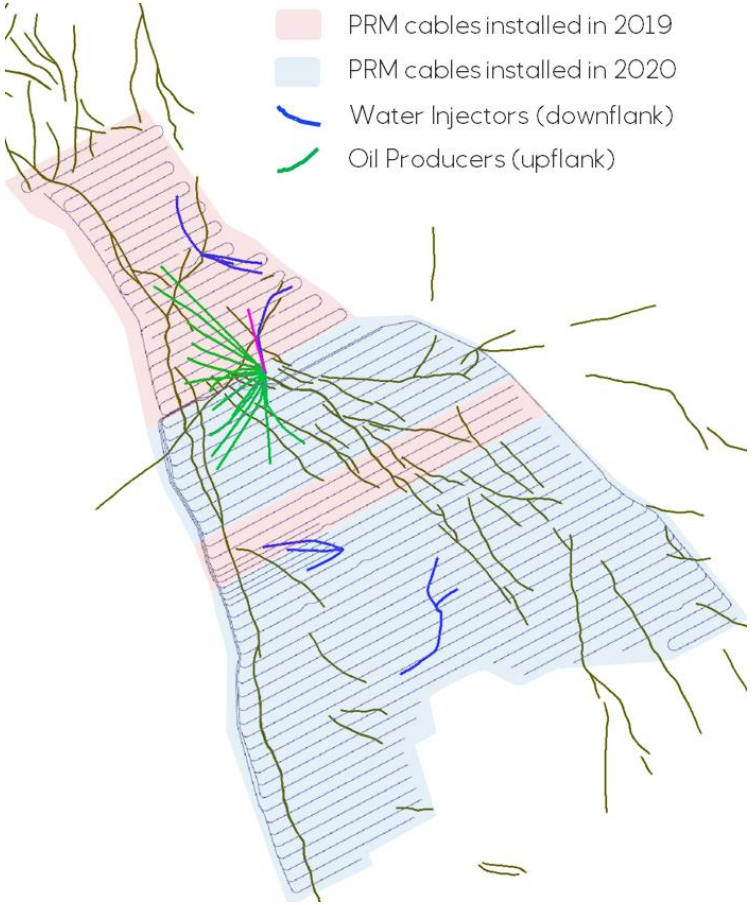


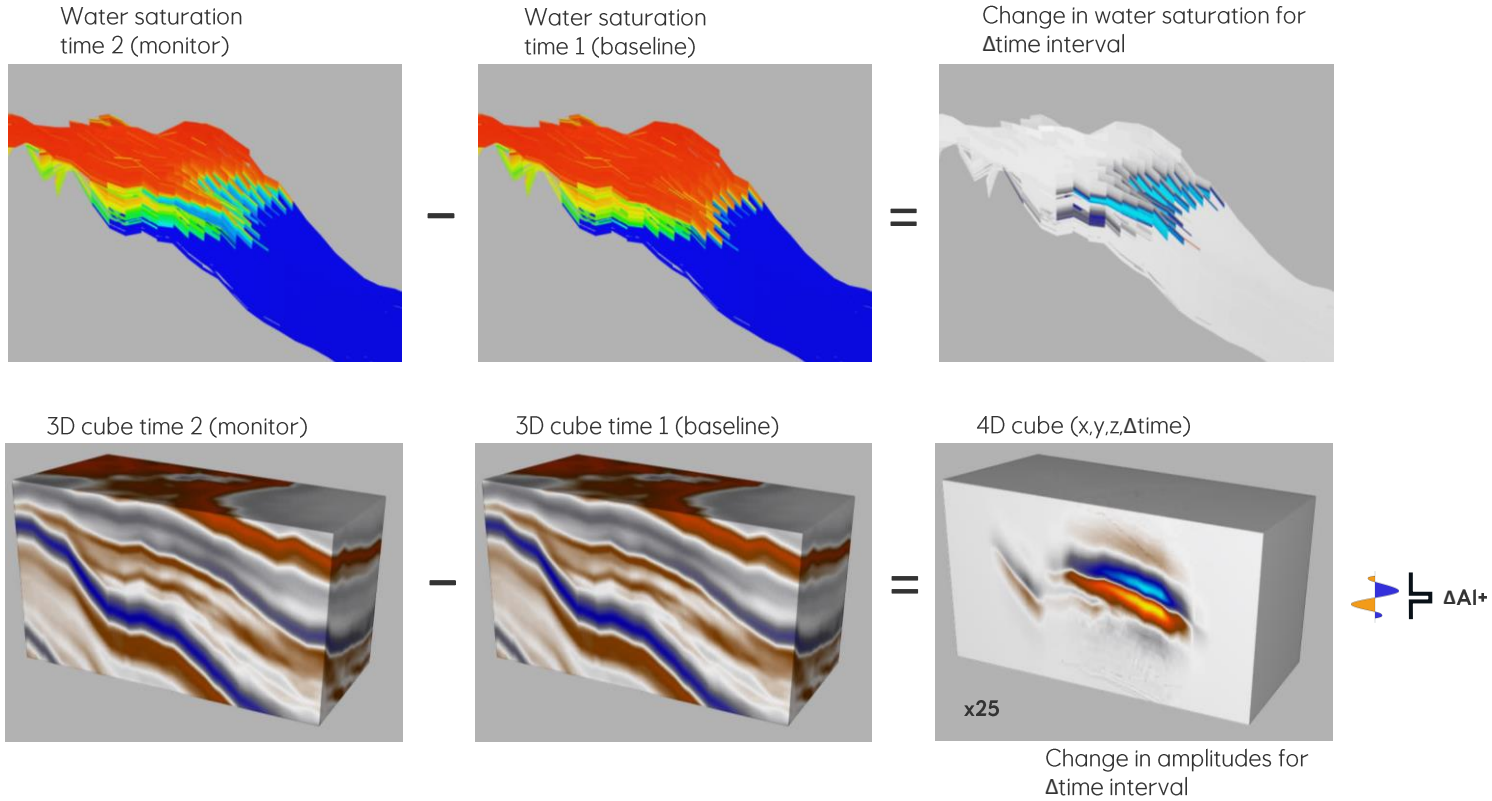
Open hole saturation profile (left), horizontal permeability profile (linear scale), density / neutron logs and saturation profiles from (Fortier, B., et al. SPWLA 65th Annual Logging Symposium, May 18-22, 2024).



DTS data from a 1-year period recorded in an oil producing well with occasional gas lift.
(Haavik, Kjetil E.. "Annuli Liquid-Level Surveillance Using Distributed Fiber-Optic Sensing Data." SPE J. 29 (2024): 1195–1209).

Johan Sverdrup - reservoir monitoring - fieldwide with 4D seismic data





- **P**ermanent **R**eservoir **M**onitoring system installed 2019-2020 for monitoring reservoir behavior with time-lapse (4D) seismic.
- Water replacing oil is seen as +ΔAI (hardening) in the 4D seismic data.

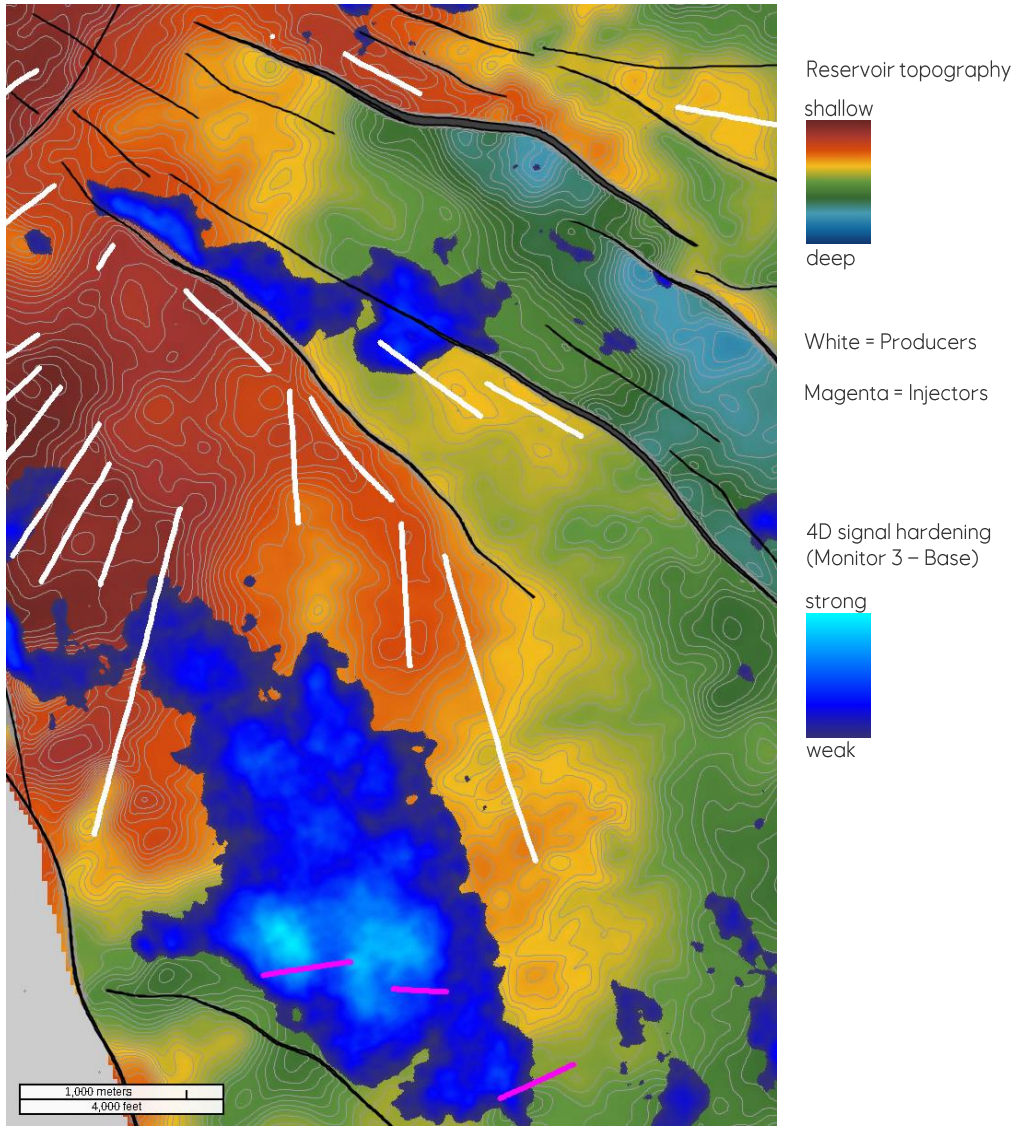
Johan Sverdrup – example - value of 4D seismic monitoring

- In general:
  - Injectors are placed down-flank
  - Producers are placed up-flank
  - Large distance between injectors and producers to delay water breakthrough.

- Value of 4D seismic monitoring:
  - Strong 4D signal = preferential pathways for the injected water.
  - Weak and/or absence of 4D signal = areas with poorer sweep.

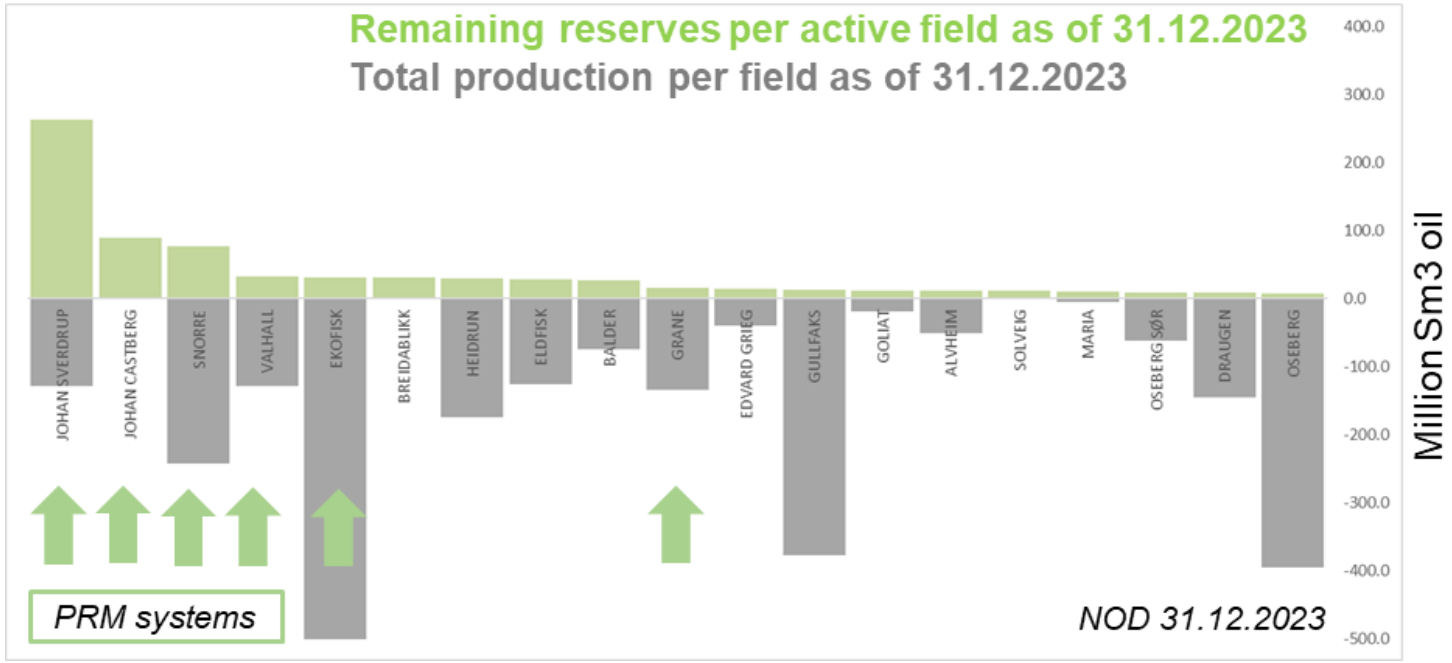
- The 4D seismic data gives possibility to assess reservoir behavior in areas outside of well control.

- Locations for infill wells (both injectors and producers) are based on 4D seismic data in combination with data from in-well monitoring.

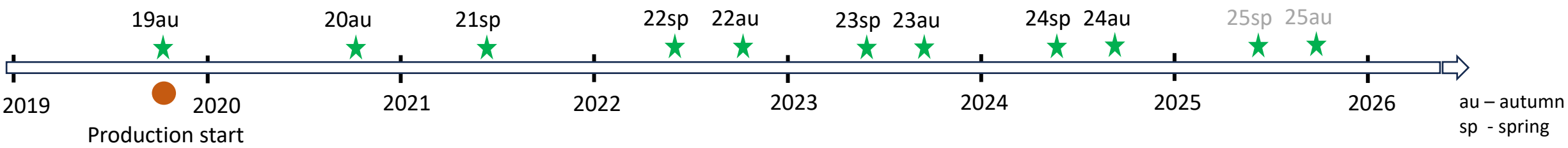


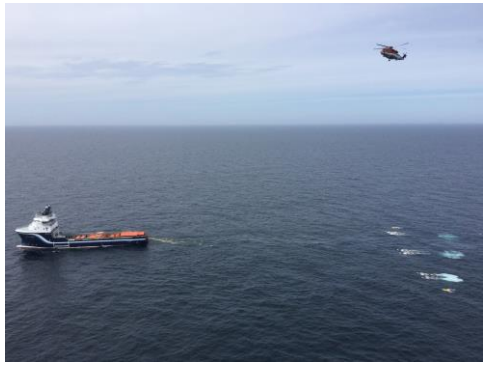
Permanent Reservoir Monitoring business drivers

- Important IOR tool
- Frequently repeated monitoring surveys
- High repeatability with early time-lapse insights



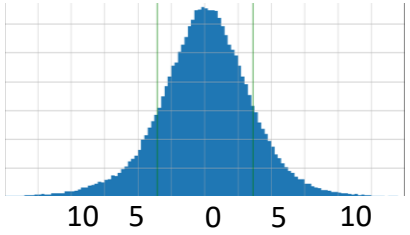
Permanent Reservoir Monitoring Johan Sverdrup





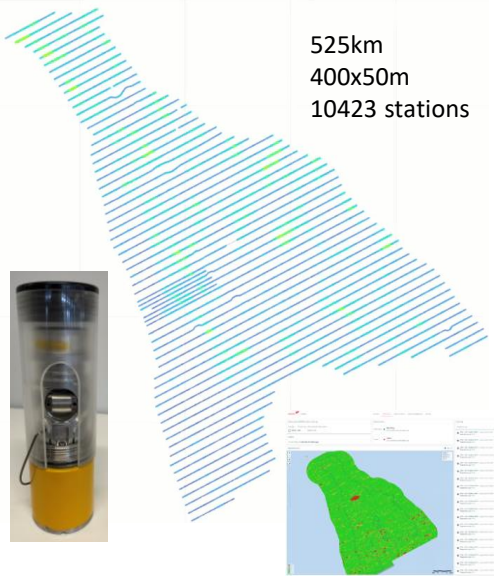
12.5x50m triple Bolt eSource

Xline std: 3.6m/Inline std: 0.3 m

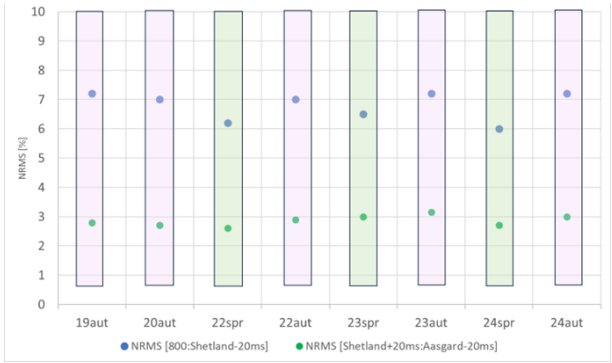


Earthquake March 2022

525km
400x50m
10423 stations

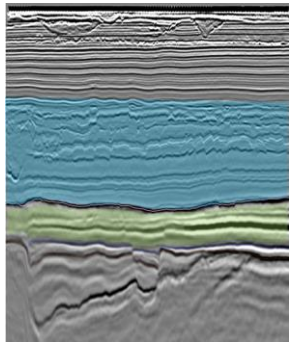


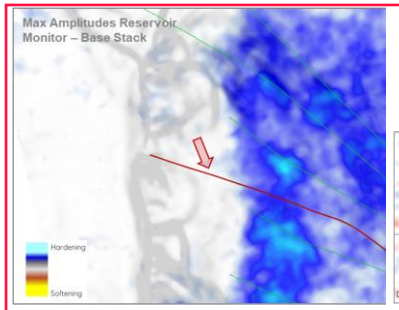
- ASAQC – Automated acquisition QC and interface management
- Real time cloud based data access/storage



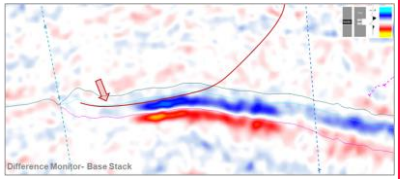
Spring-Autumn | Spring - Spring

- Fast turnaround: 3 wks
- High data quality
- Streamlined processing sequence
- High resolution velocity model



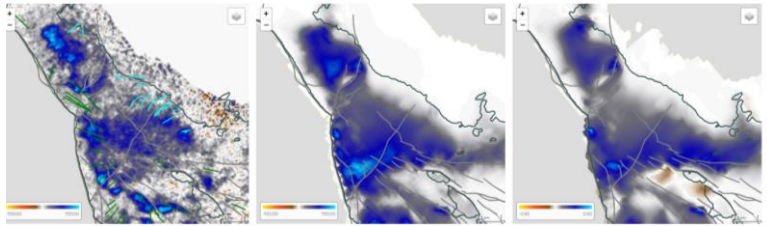


- New target identification
- Accelerated production



Courtial, et al, EAGE 2024

Multi-disciplinary dataviews

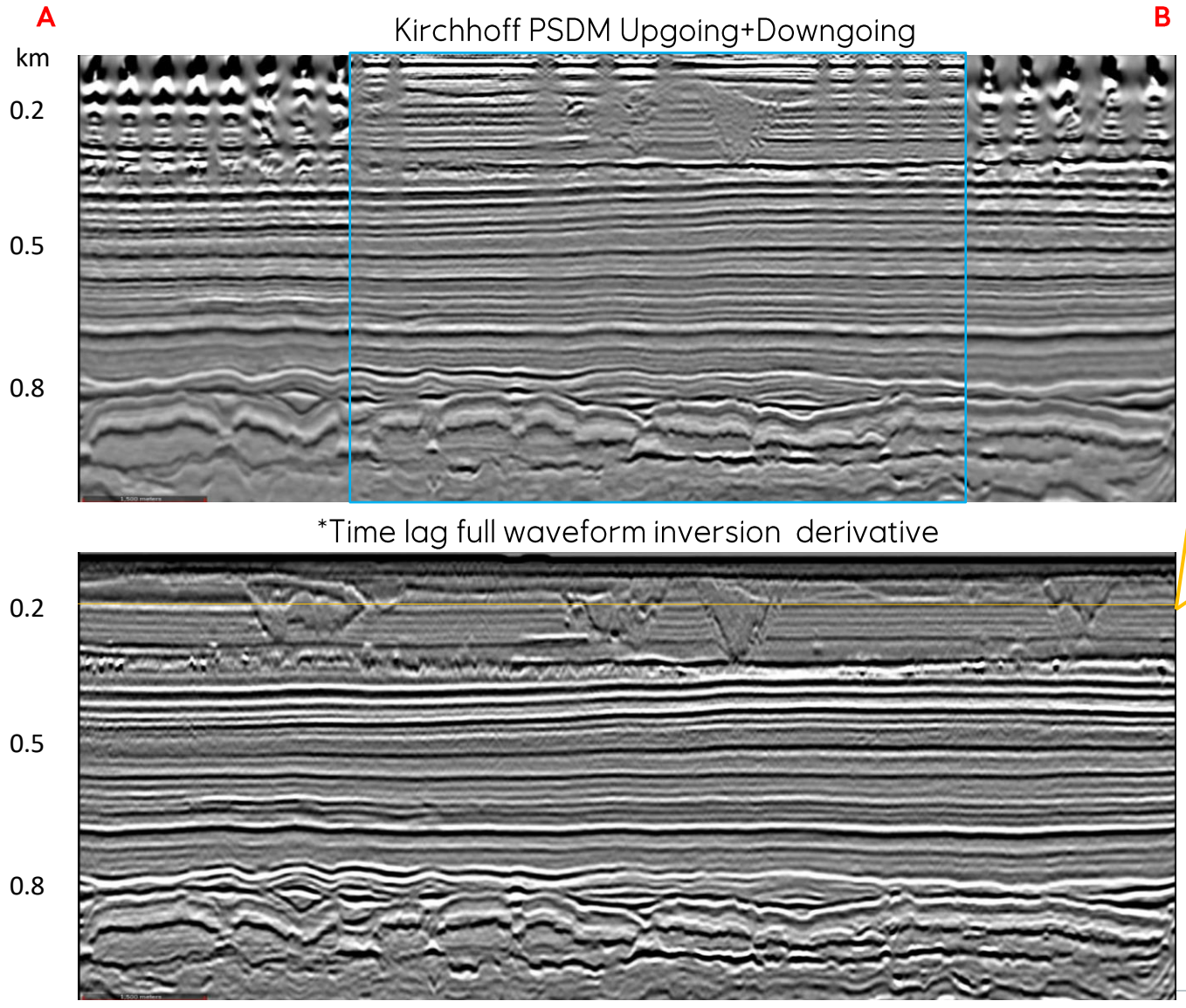


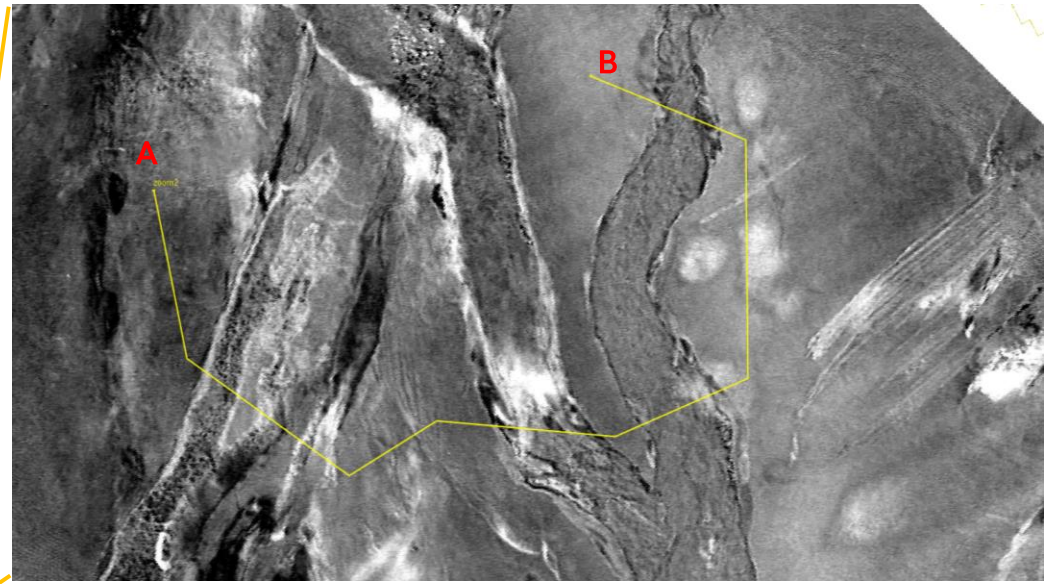
Observed Amp map Mon-base

Model Amp map Mon-base

Model Swater Mon-base

PRM potential for shallow overburden monitoring





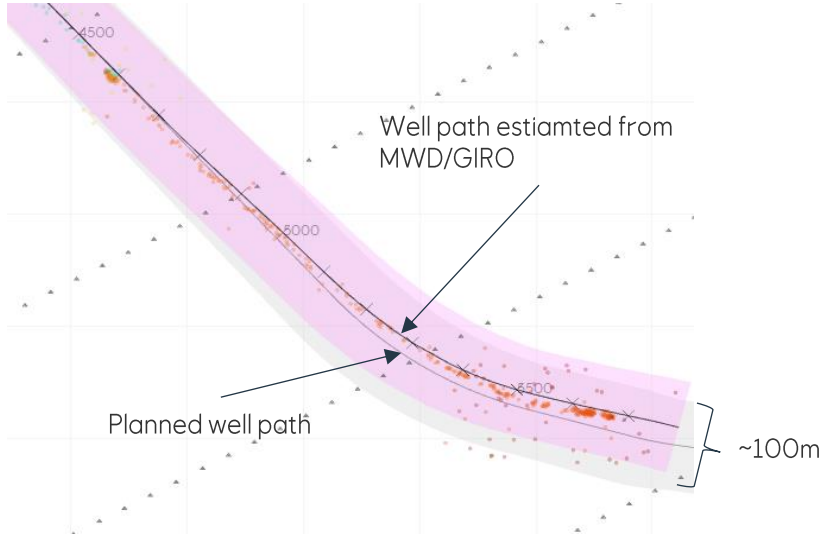
depth slice at 200m

- Several solutions evaluated for monitoring
  - Mirror/Multiple imaging
  - Full wave form inversion imaging

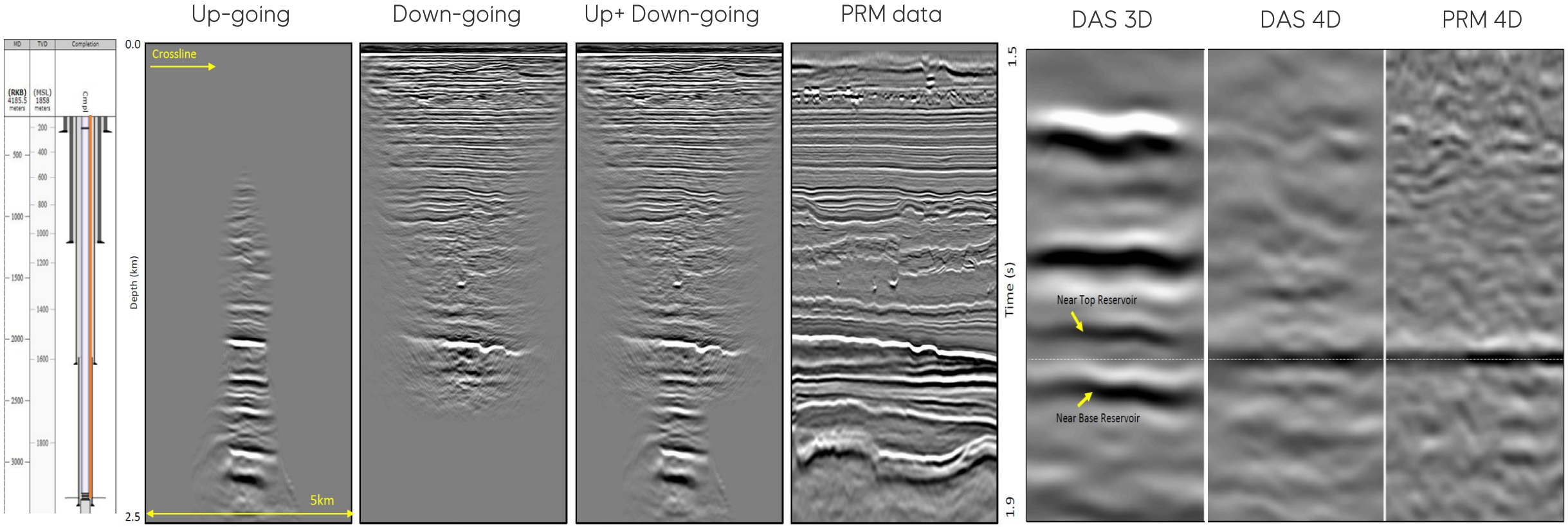
Sadikhov et al, EAGE 2024

PRM passive data is continuously utilized

- Noise measurements
- PRM system monitoring
- Microseismic detection
  - Drillbit monitoring
  - Injection/fracturing monitoring
  - Characterization of near well bore noise/fluid losses, etc.
  - Drill bit imaging
- Earthquake recordings

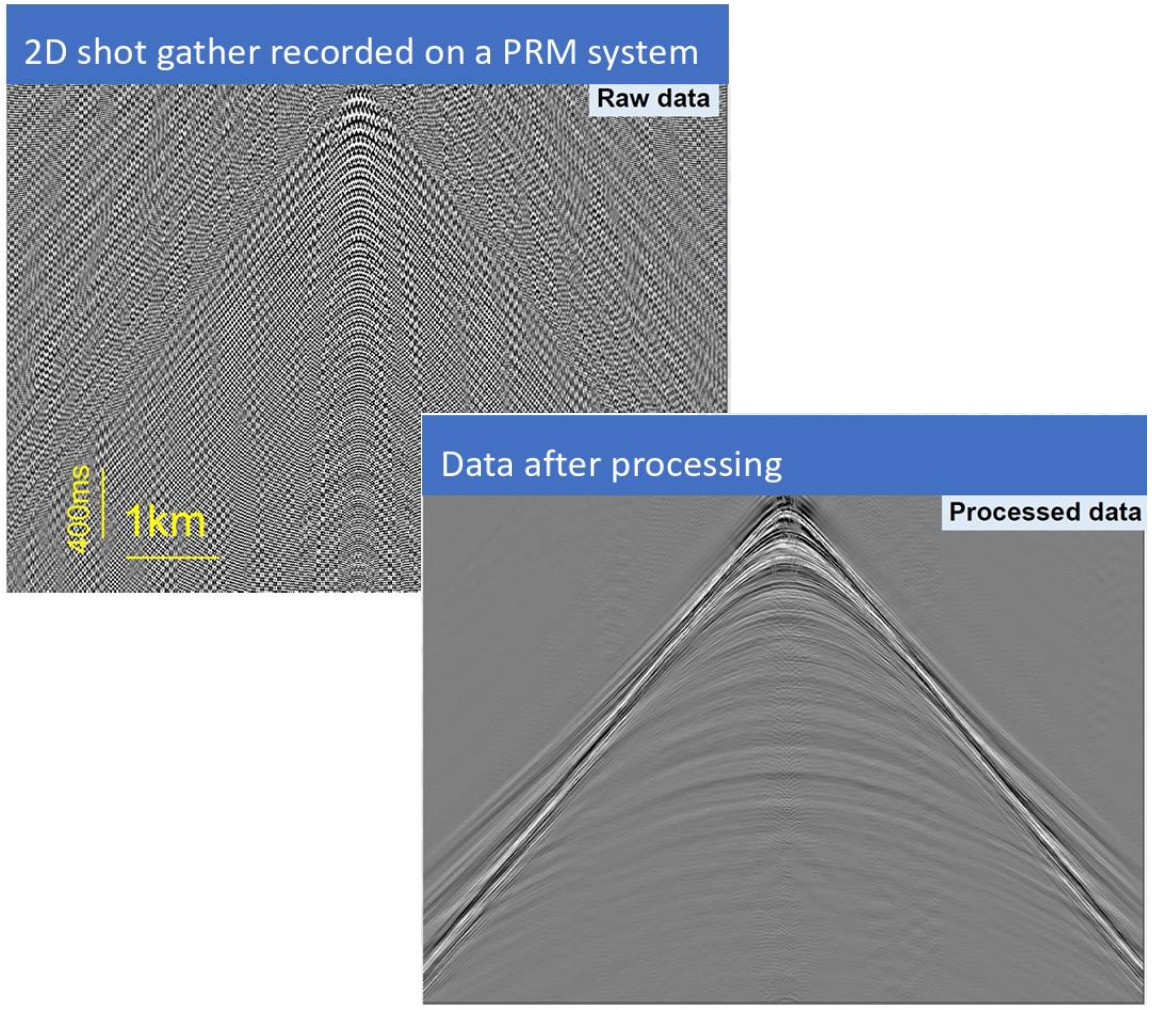


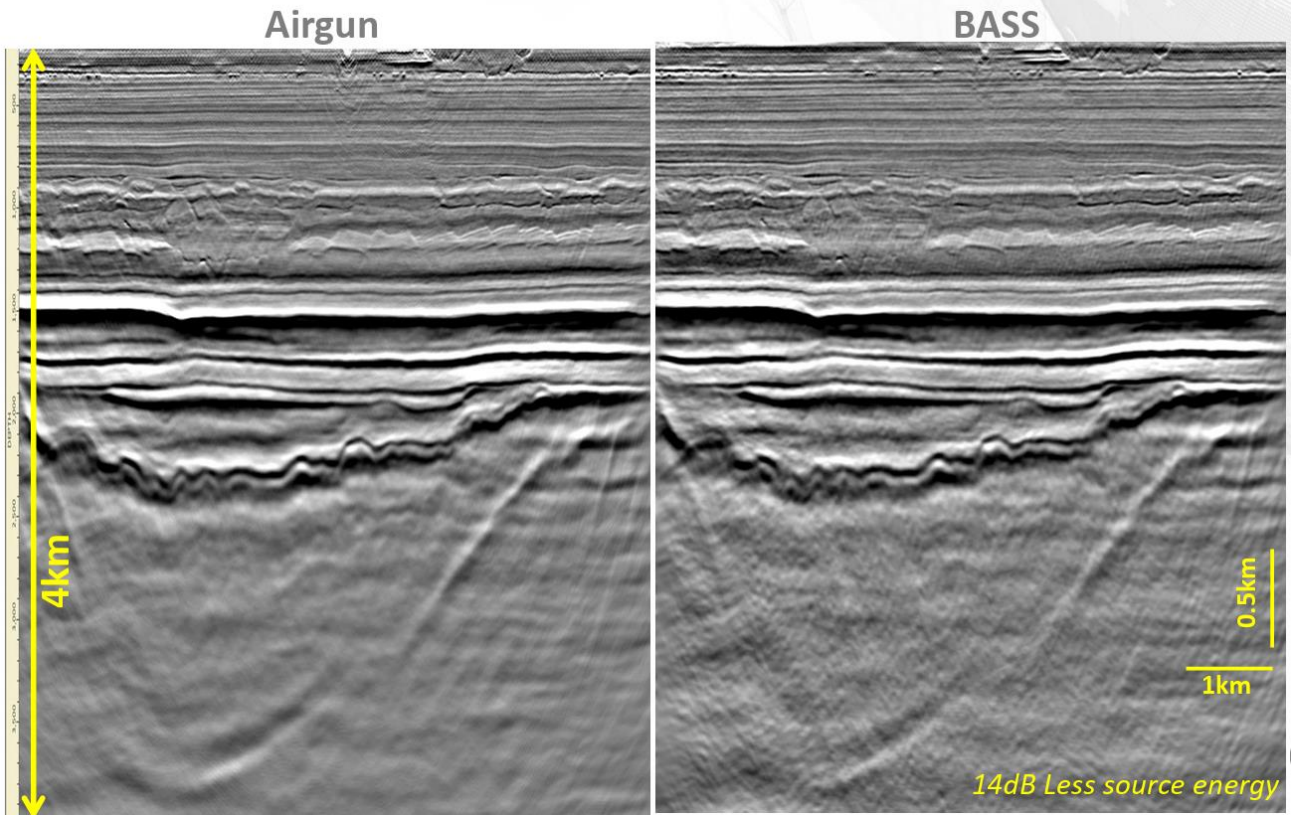
PRM testing ground – DAS VSP - Distributed Acoustic Sensing



Olsen et al EAGE 2023, Galyga, et al, EAGE 2023, Liao, et al, EAGE 2024

PRM testing ground – BASS Marine Vibrator

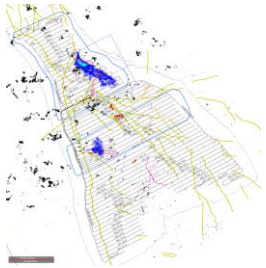




Work performed by MV BASS JV

JafarGandomi et al, EAGE 2024

Summary of PRM value creation

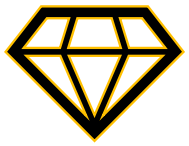


PRM gives high quality 4D seismic data:

- The 4D seismic data reveals subsurface reservoir behavior in areas outside of well control
- The 4D seismic data is important for optimal placement of infill wells, leading to better drainage of the subsurface reservoir

Integration:

- Dynamic time lapse information utilized together with other data sets to support reservoir management decisions



Technology applications

- Efficient operations and high quality data provided by PRM system
- Further developmet and testing of new solutions in the PRM system

The authors would like to thank the Johan Sverdrup license operator Equinor ASA and partners Petoro AS, Aker BP ASA, and TotalEnergies EP Norge AS for their permission to share these results. The views and opinions expressed in this abstract are those of the operator and are not necessarily shared by the license partners.

A special thanks to TGS, ASN and the Viridien PRM processing team for their dedication and the high data quality delivered.

Big thanks to our colleagues in Equinor, Johan Sverdrup asset, Geophysical operations, Seismic Imaging and Processing, Telecom, Equinor Research

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