Towed Streamer EM – Beyond Resistivity

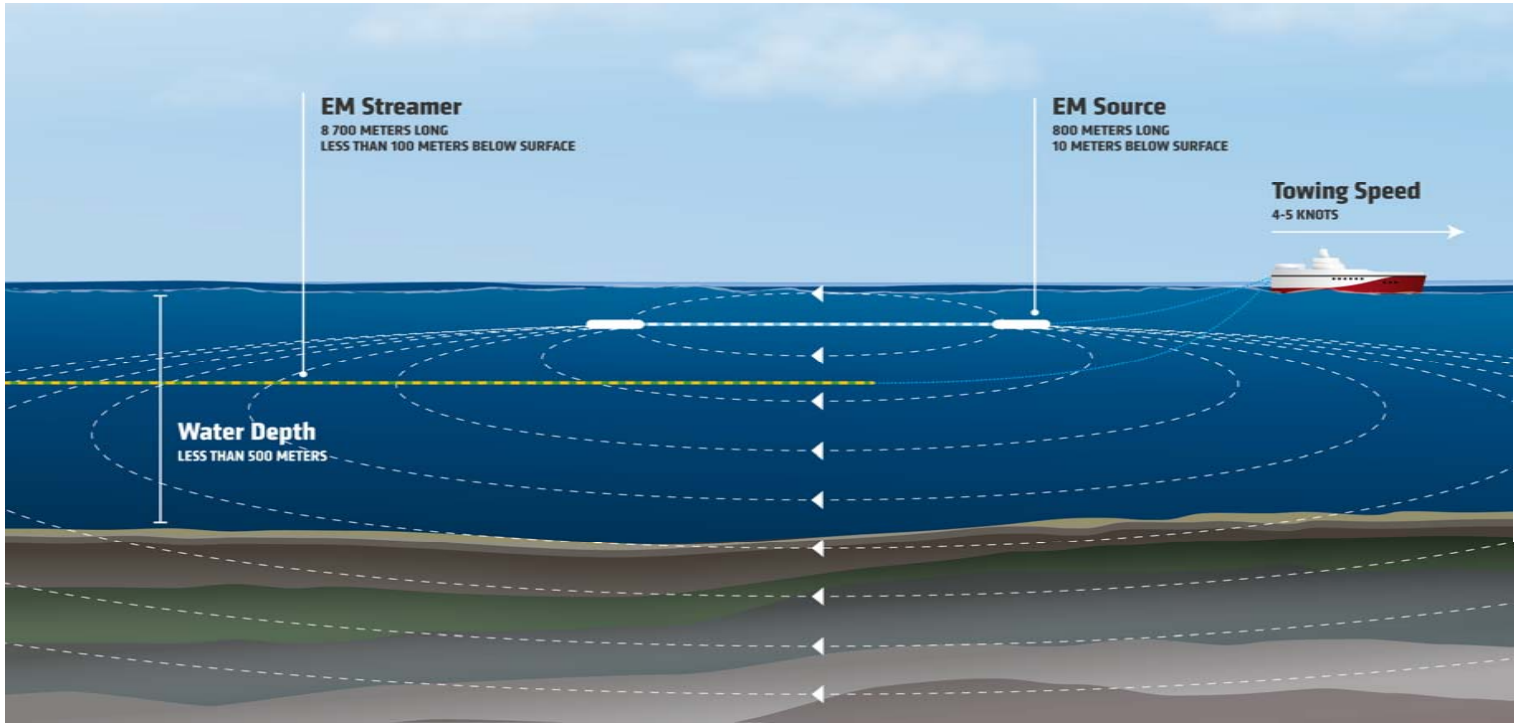
Finding Petroleum – New Geophysical Technologies – London, 24th February 2016

Joshua May – Sales and Marketing Manager

Agenda

- Introduction to TSEM
- Operations
- TSEM advantages and applications
- Inversion + seismic and EM integration
- A word on data density
- Application – Establishing saturation of shallow gas
- Application – Frontier exploration / prospect de-risking
- Application – Near field exploration
- Examples and integrated interpretation

Towed Streamer EM Operations



Current is injected into a dipole source that generates an EM field

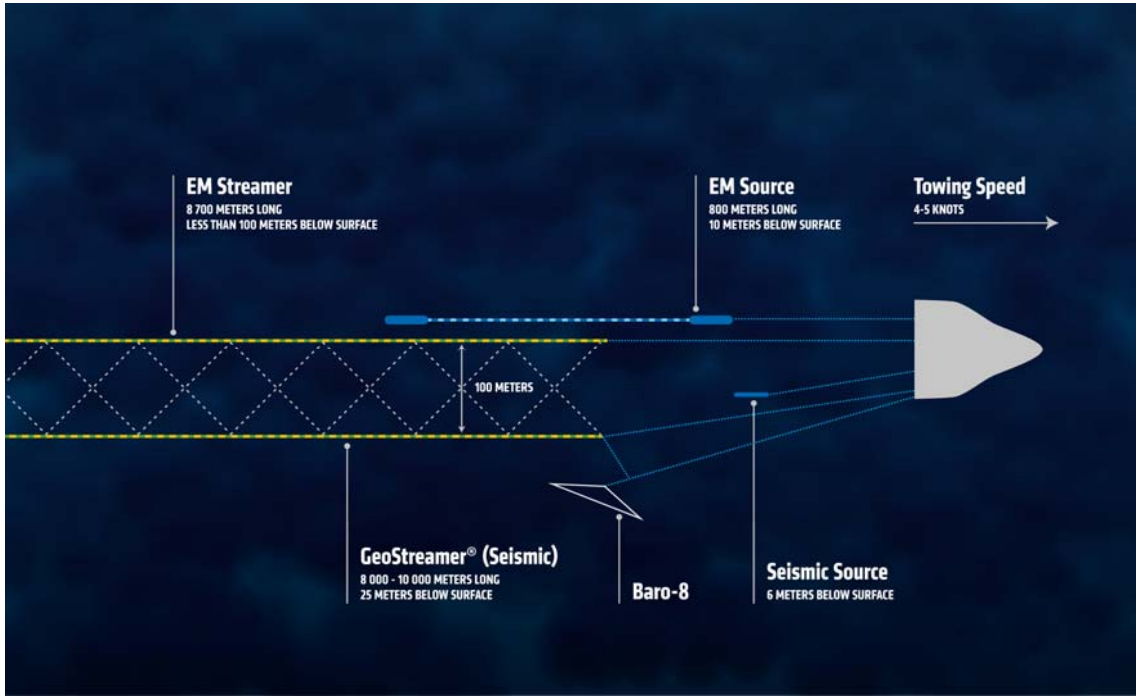
The field penetrates the sub-surface and is distorted by the presence of resistive bodies

Measurements (voltage) are made by the receivers at various offsets from the source

Amplitude and phase responses of the Earth are recovered which can be transformed into sub-surface resistivity models through a process of inversion

Hydrocarbons are typically characterized by high resistivity

Simultaneous GeoStreamer and EM Operations

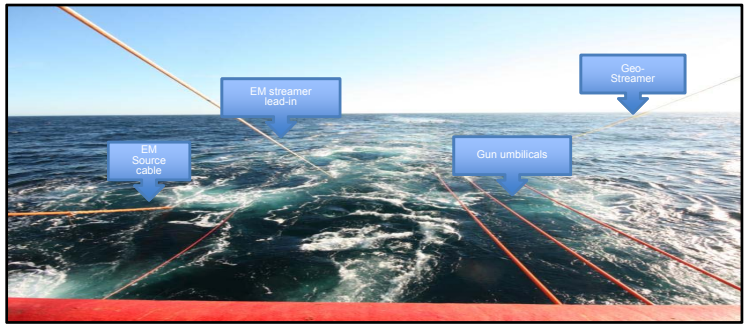


2.5D EM

Line spacing >1.5km, delivers 2.5D resistivity sections

3D EM

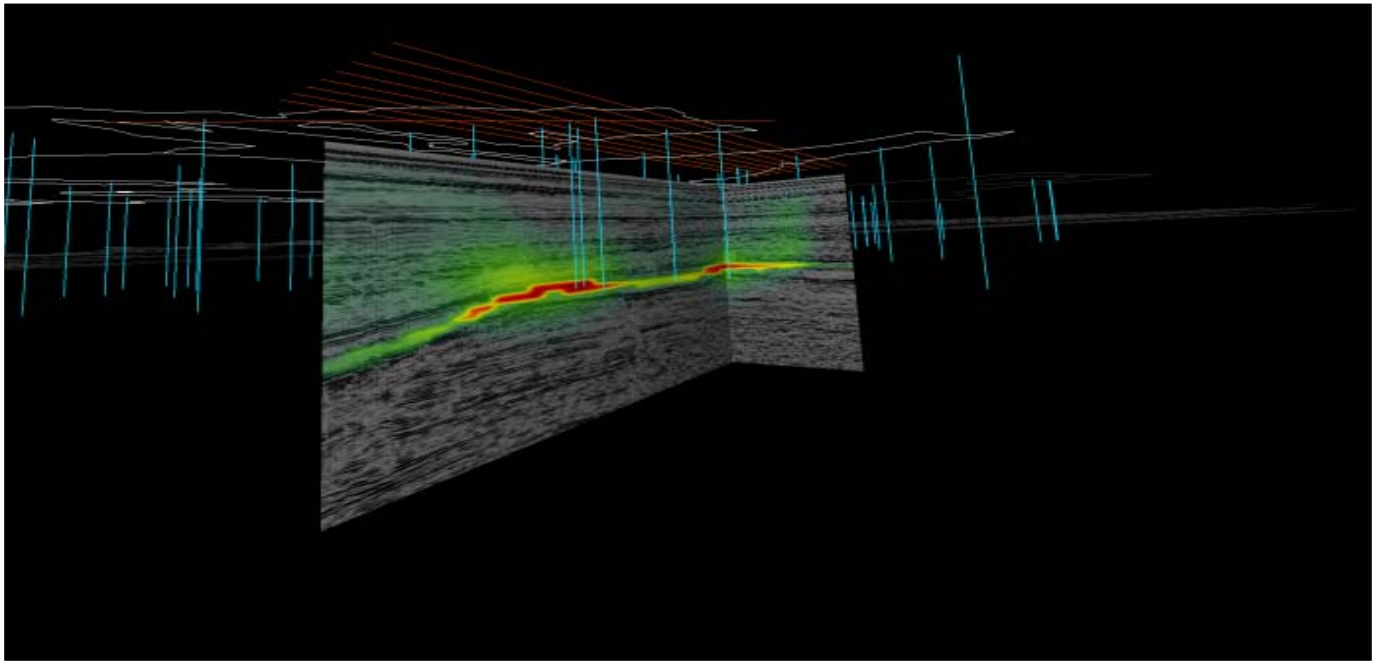
Line spacing <1.5km, delivers 2.5D resistivity sections and 3D resistivity volume(s)

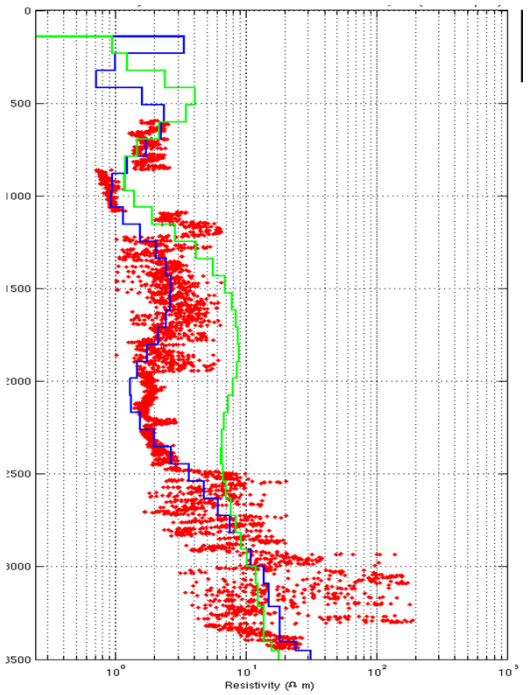


Simultaneous acquisition of 2D GeoStreamer and Towed Streamer EM from back deck of Nordic Explorer, 2013

Controlled Source Electromagnetics (CSEM)

Aim – determine resistivity away from the well





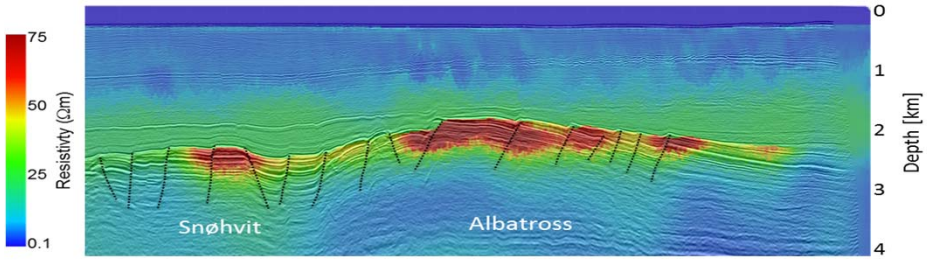
Advantages of Towed Streamer EM

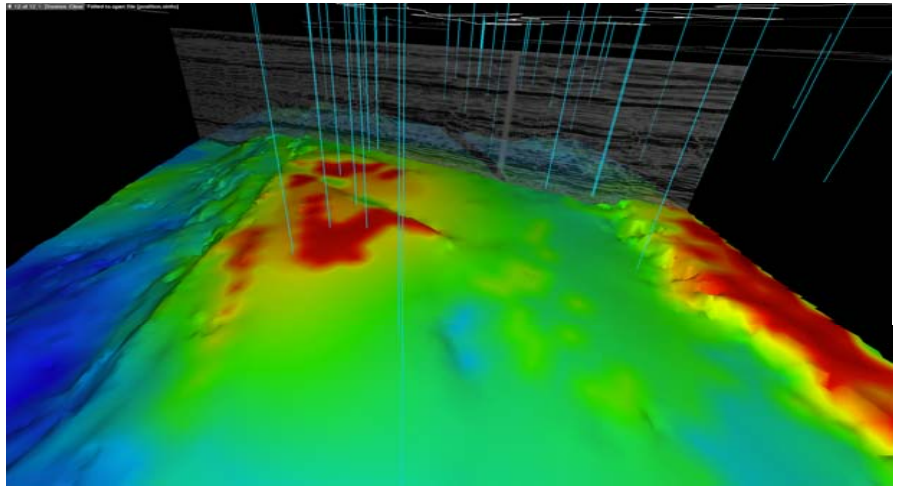
Towed Streamer EM is based on a standard 2D seismic system

- Can be deployed from virtually any seismic vessel
- Does not require an EM dedicated crew
- Acquisition speed is the same as Towed Streamer Seismic
- Enables simultaneous acquisition of EM and GeoStreamer
- Realtime QC and onboard processing of data

- Streamer has dense receiver spacing resulting in superior data density
- Receivers are towed through a homogeneous water layer so less sensitive to localized anomalies on the seabed

Commercial Benefits | Geophysical Benefits

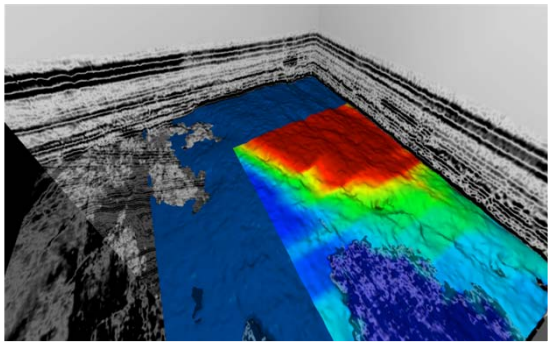




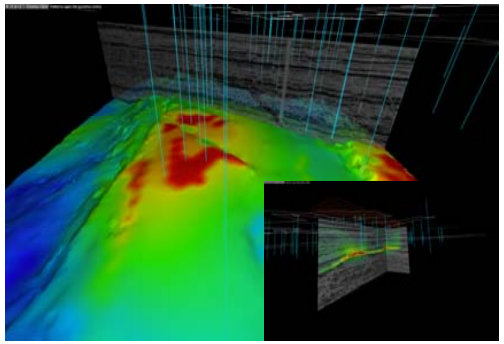
TSEM – Applications

- Regional-Scale Exploration in Frontier Areas
- Near-Field Exploration in Mature Areas – Reduce cost per barrel / extend field life / delay decommissioning
- Estimate Gas Saturation – Determine commerciality of prospect / 4D / prospect ranking
- Shallow Gas (Hazard) Detection – Mitigate drilling hazards (reduce associated costs) / improve understanding of field dynamics
- Characterization of the Overburden
- Detection of Gas Hydrates (in up to 1250m water depth)

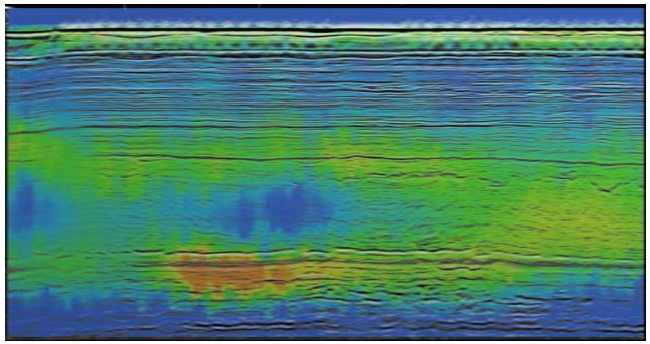
Data Examples: Detection of Known Reservoirs



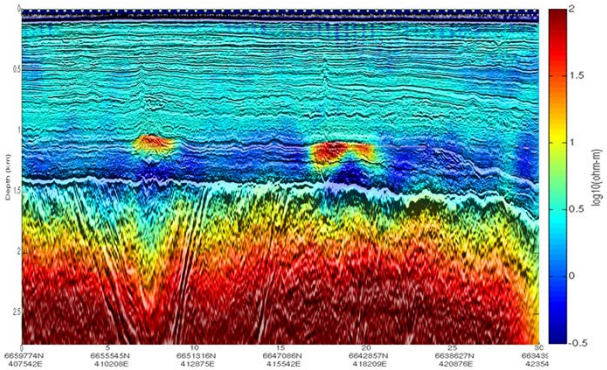
Peon, North Sea



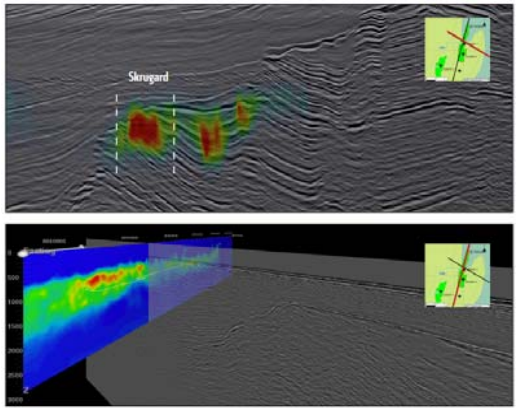
Troll, North Sea



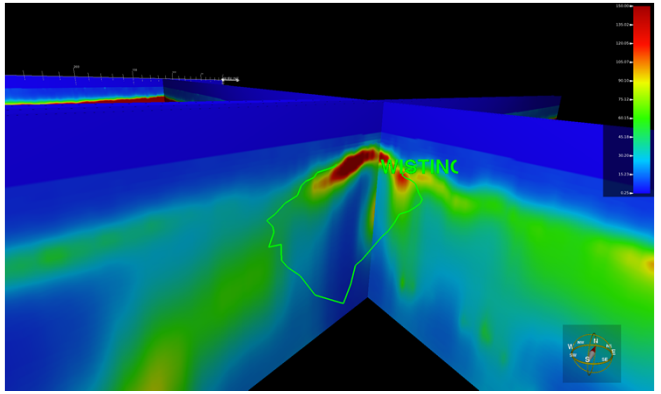
Alvheim, North Sea



Bressay & Bentley, North Sea



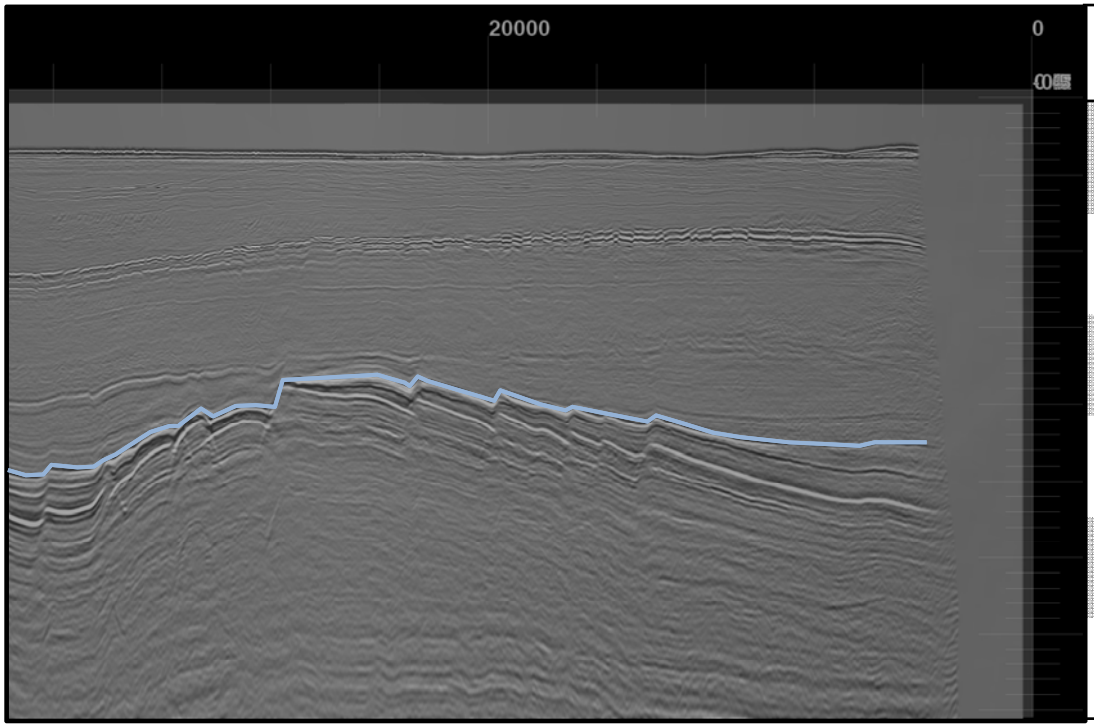
Skrugard, Barents Sea



Wisting, Barents Sea

How is that Value Extracted (e.g. Block / Prospect Evaluation)?

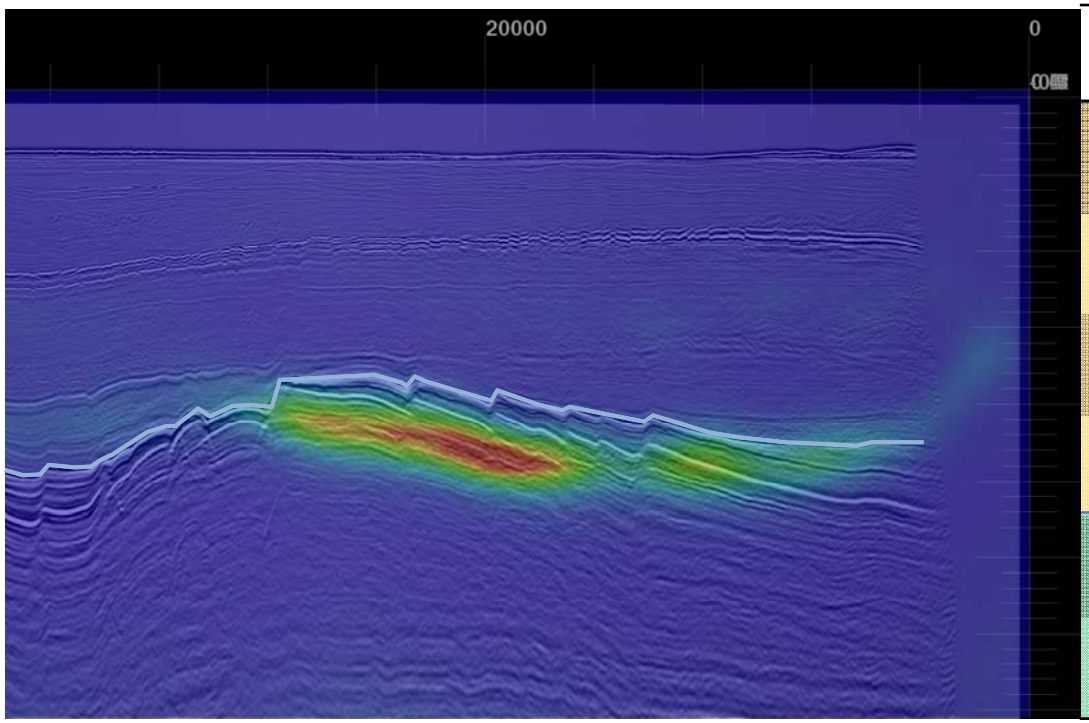
Interpretation & Integration



	Seismic	EM
Trap	✓	
Reservoir	✓	
Seal		
Charge		
Gross Rock Volume	✓	
Hydrocarbon Volume		

Nice structure (in the correct setting)

Block / Prospect Evaluation
Interpretation & Integration

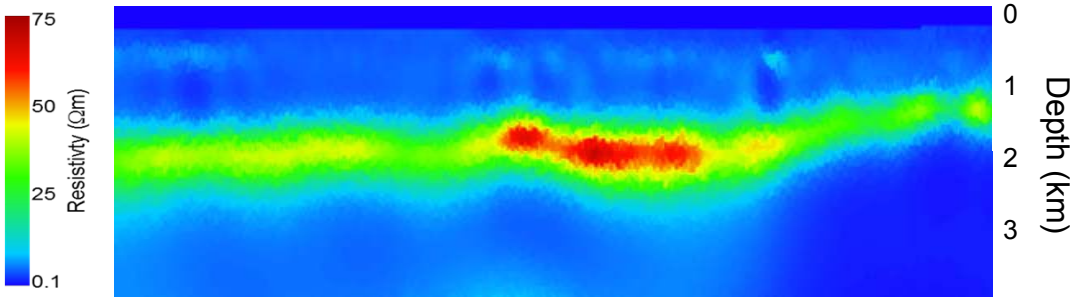


Nice Structure + Resistivity Anomaly

	Seismic	EM
Trap	✓	
Reservoir	✓	
Seal		✓
Charge		✓
Gross Rock Volume	✓	
Hydrocarbon Volume		✓

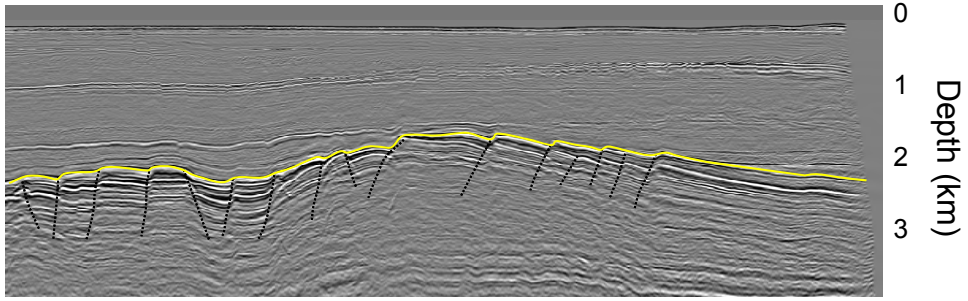
Prospect	Commercial Prospect

Seismically Guided Inversion



Unconstrained Inversion

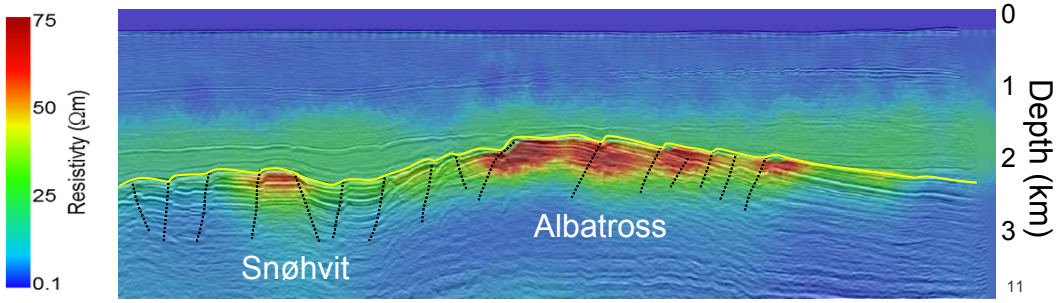
+



Seismic Interpretation

Section length is 44 km

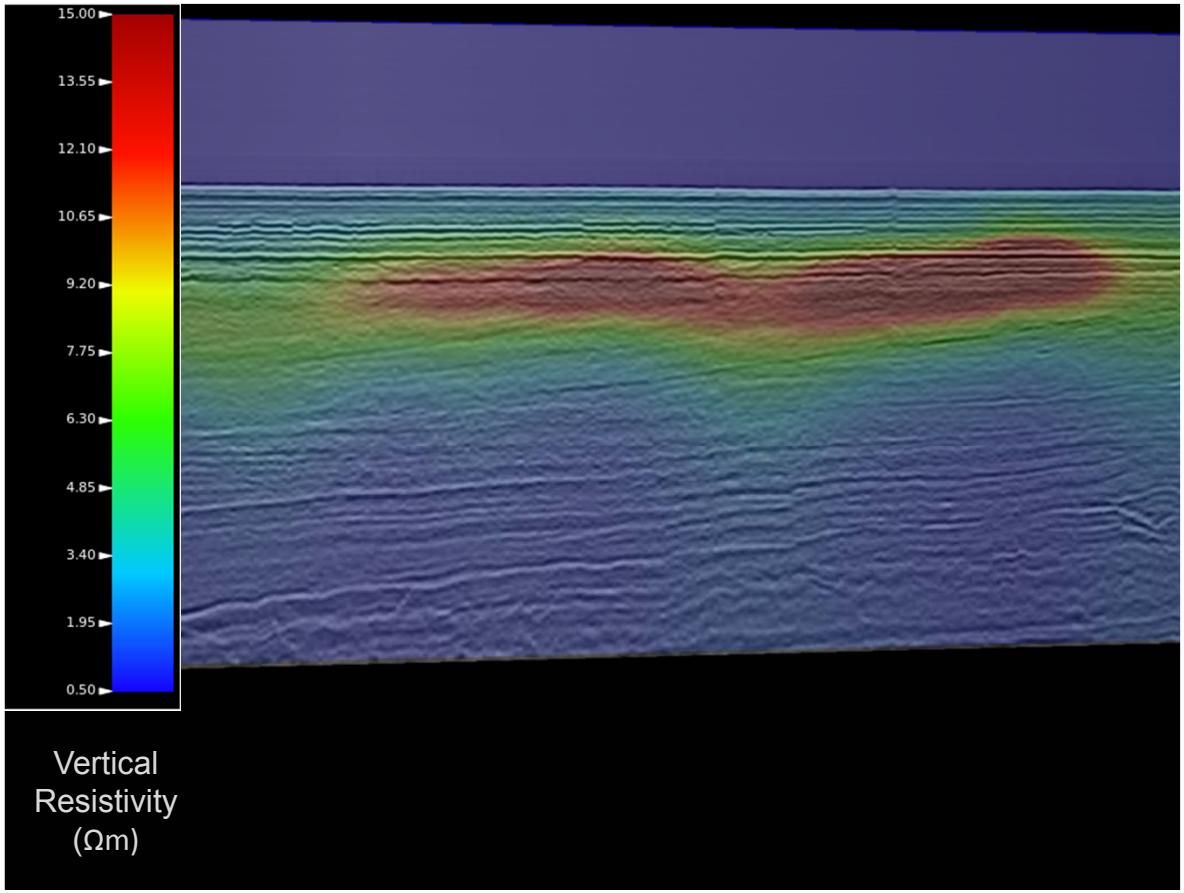
= **Seismically Guided Inversion**

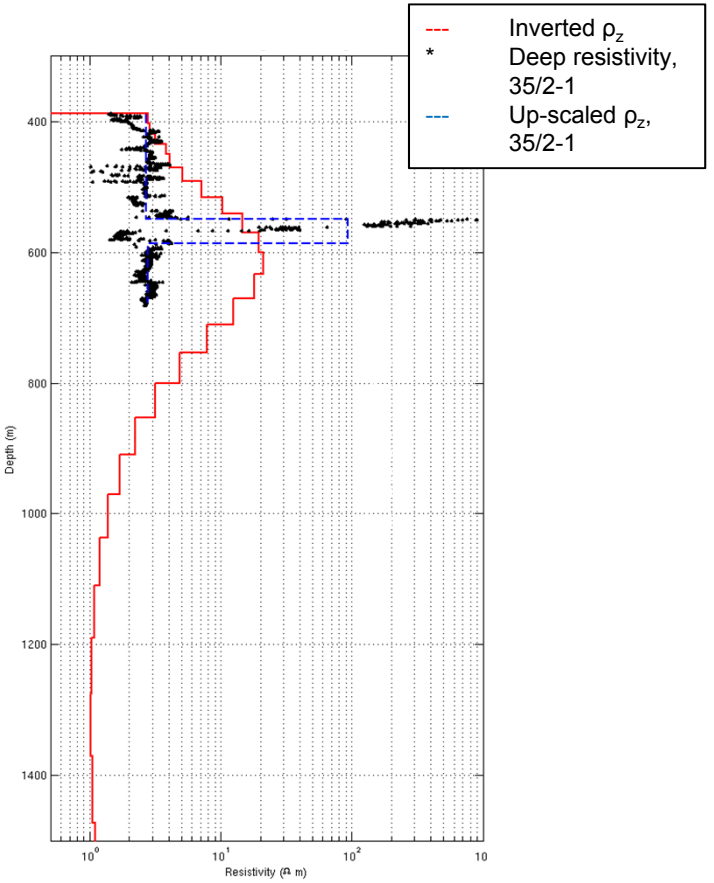


Further work: Constrained Inversion

Tie to seismic and well

Unconstrained inversion

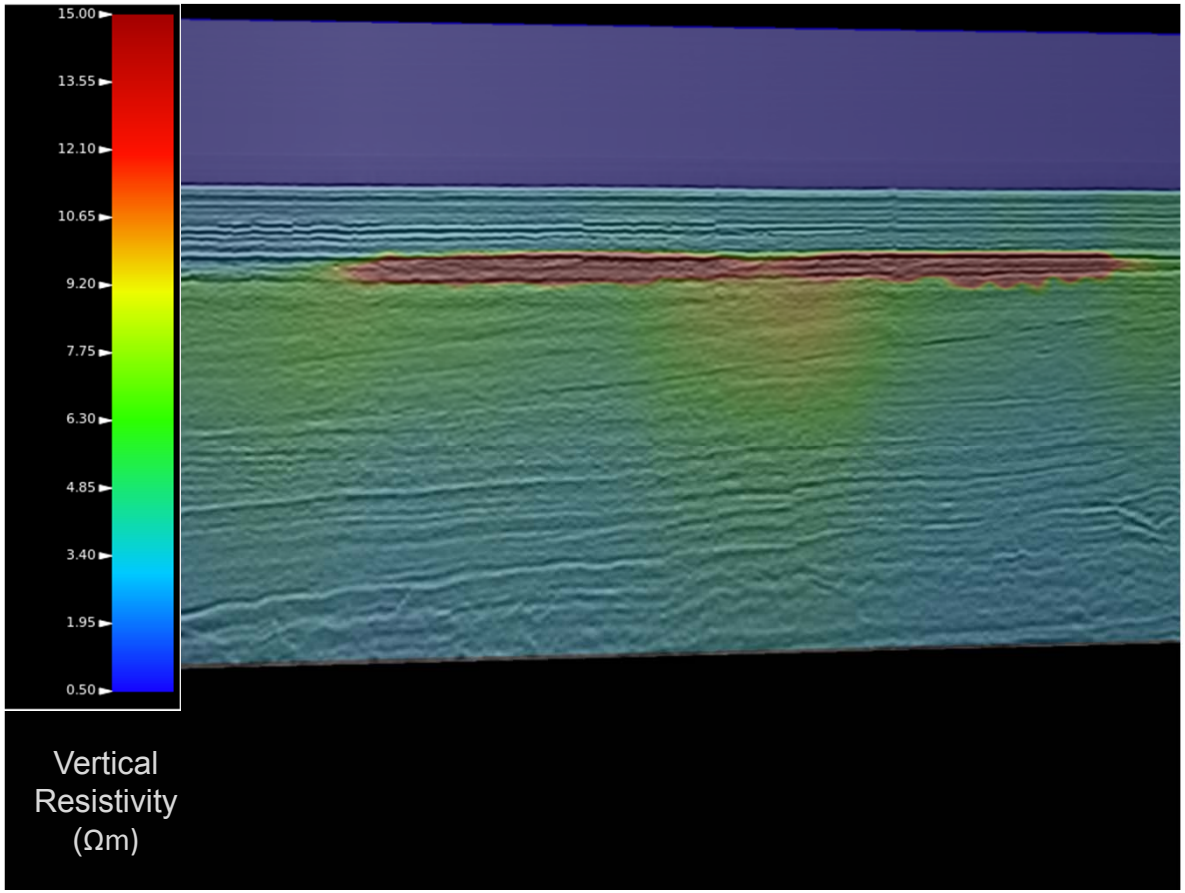


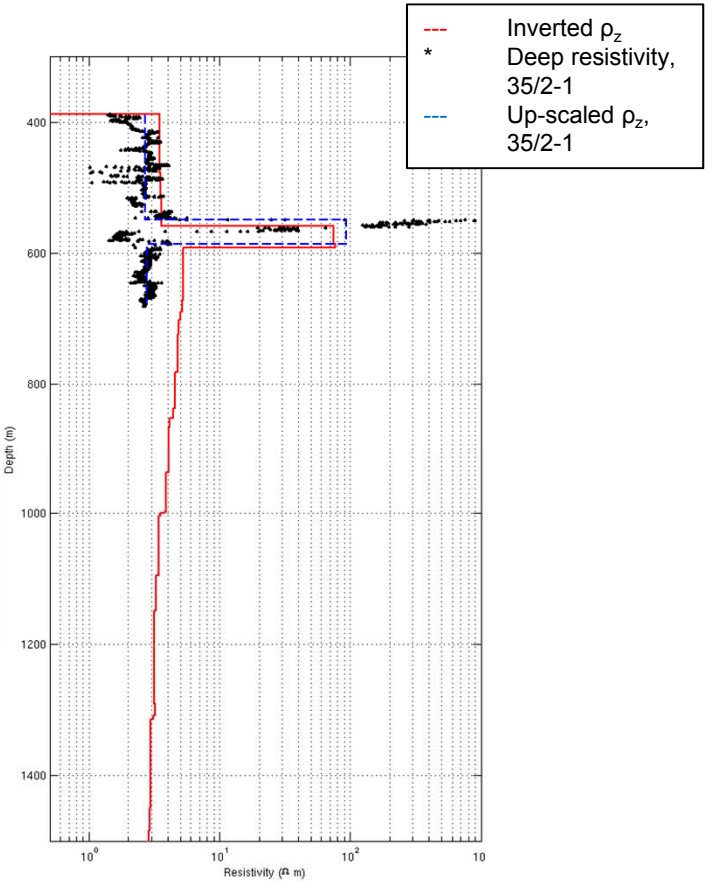


Further work: Constrained Inversion

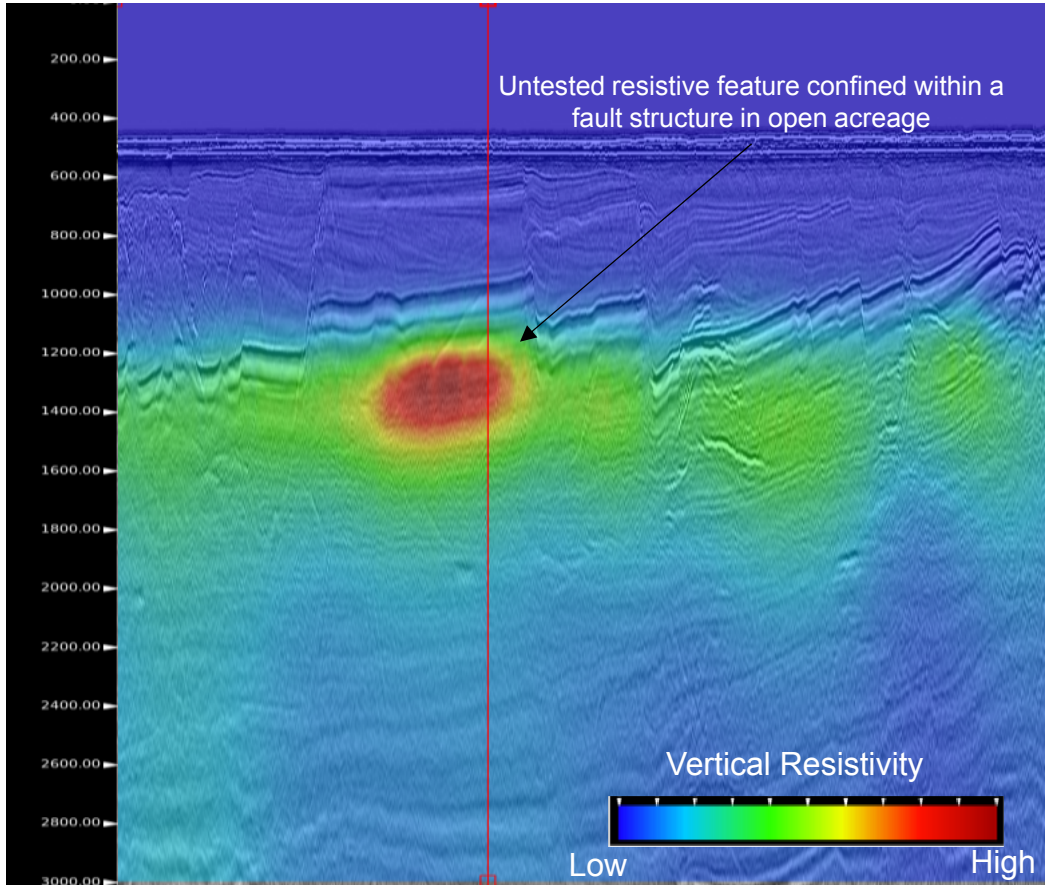
Tie to seismic and well

Seismically guided inversion





Data density – Enables more Challenging Prospects to be Characterised



High data density on both the source and receiver side:

- 72 receiver pairs in EM streamer
- EM source sweep every 250 m

Can enable, in conjunction with seismic:

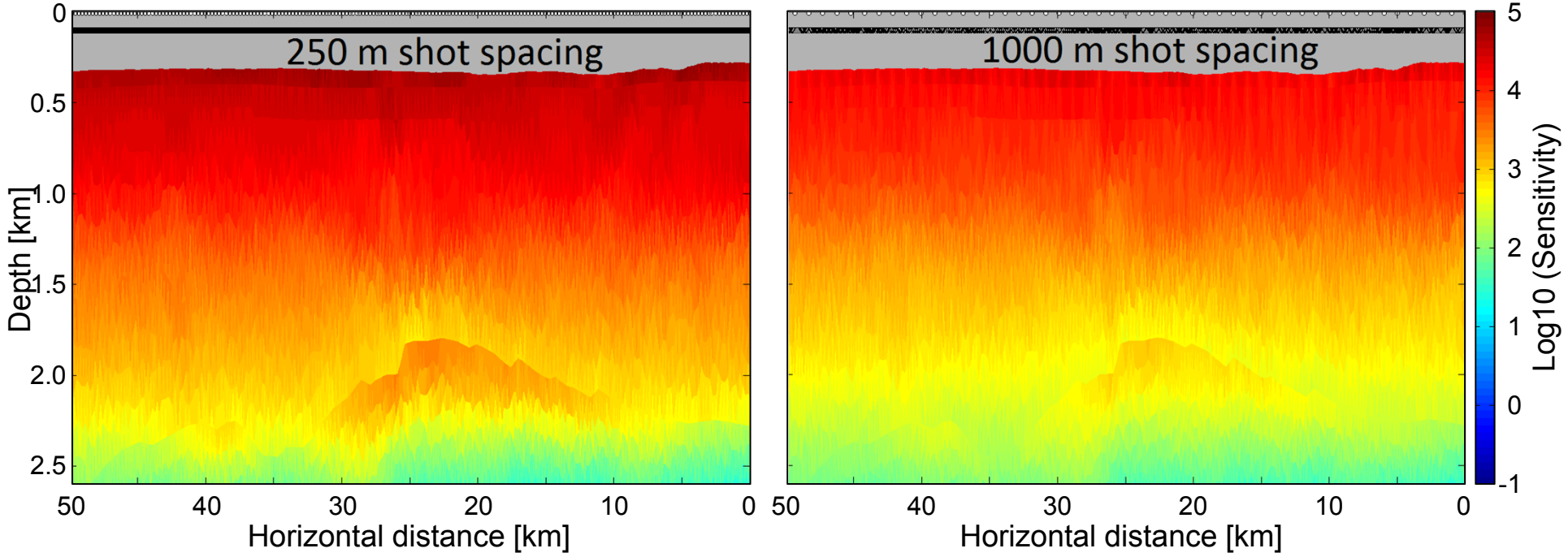
1. Distinction between charged and non-charged resistive reservoir; chalk for example

2. Higher resolution than traditional EM acquisition systems

3. Estimation of gas saturation

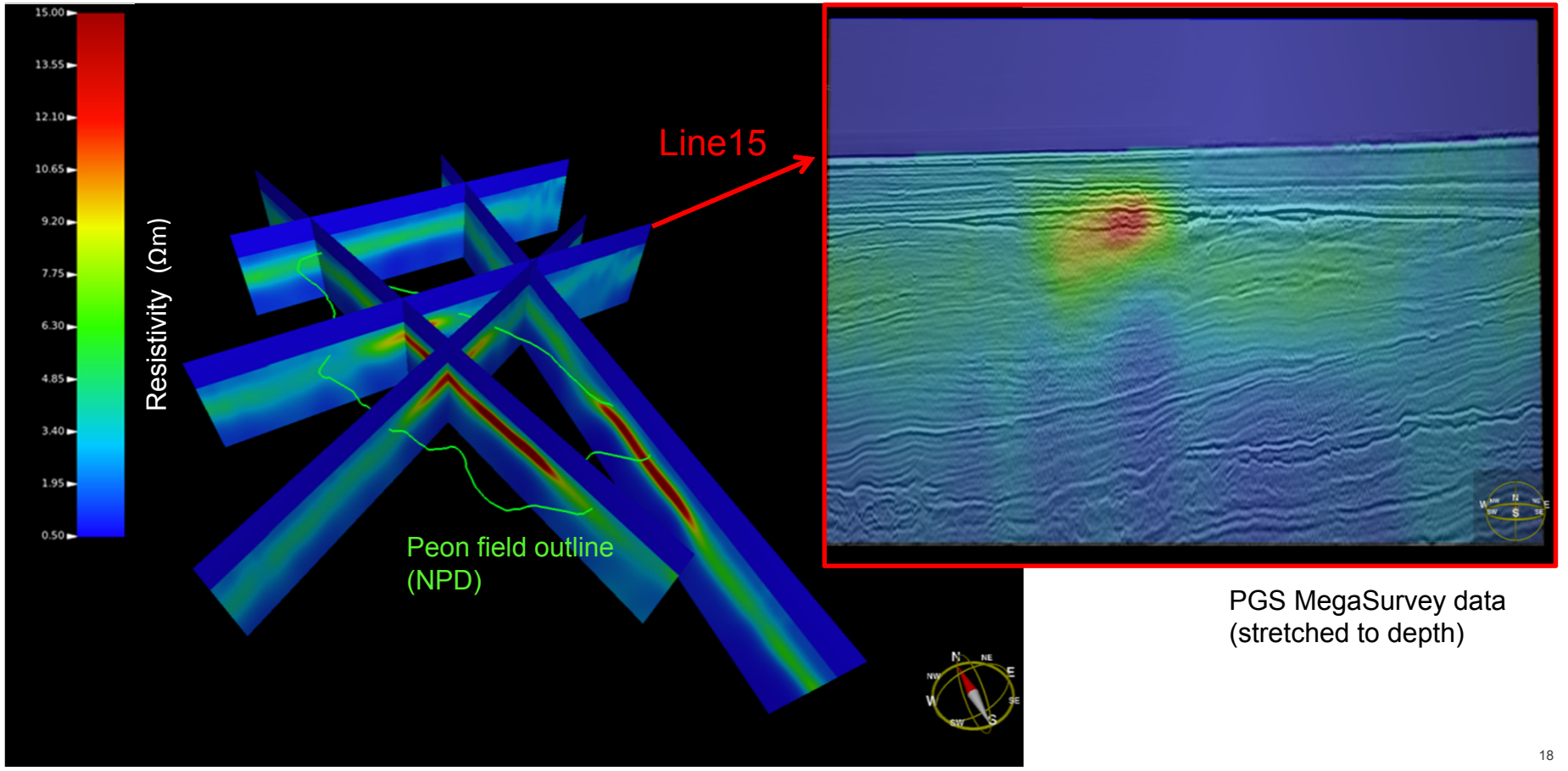
Geophysical Benefits

Increased Data Density = Increased Sensitivity



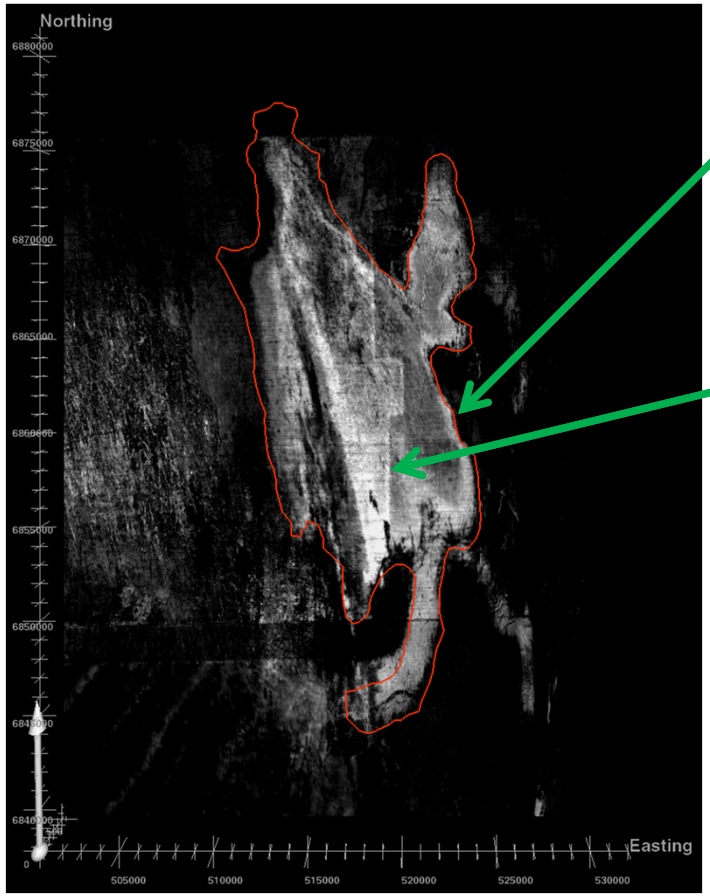
Peon 2010

Unconstrained Inversion, Vertical Resistivity Sections



PGS MegaSurvey data
(stretched to depth)

Peon – A case study in using EM to derive gas saturation levels



Peon gas reservoir outline in red showing seismic amplitudes between a 535 and 575 m window (Outline source: www.npd.no/en/)

Note areas of high RMS seismic amplitude within the reservoir indicating the presence of gas

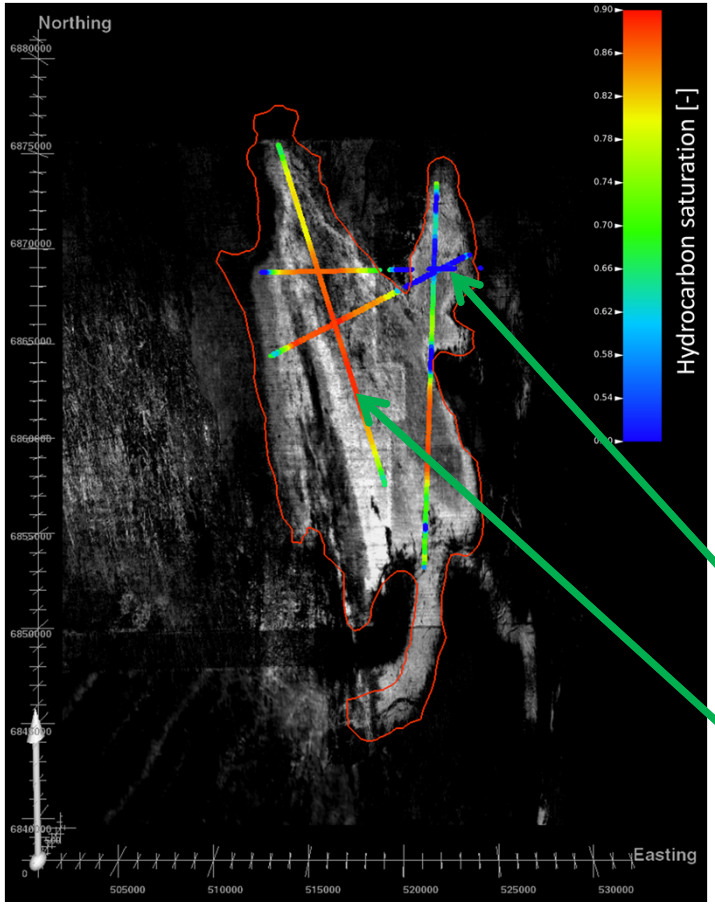
RMS amplitudes are fairly evenly distributed within the reservoir (the slight difference between East and West is due to use of merged seismic data)

From the seismic alone we do not have an understanding of the level of gas saturation

Saturation information is essential in:

1. Determining commerciality of a field
2. Understanding potential drilling hazards
3. Monitoring changes over time – 4D

Peon – A case study in using EM to derive gas saturation levels



Peon gas reservoir outline in red showing EM inverted saturation overlaid on seismic amplitudes between a 535 and 575 m window (Outline source: www.npd.no/en/)

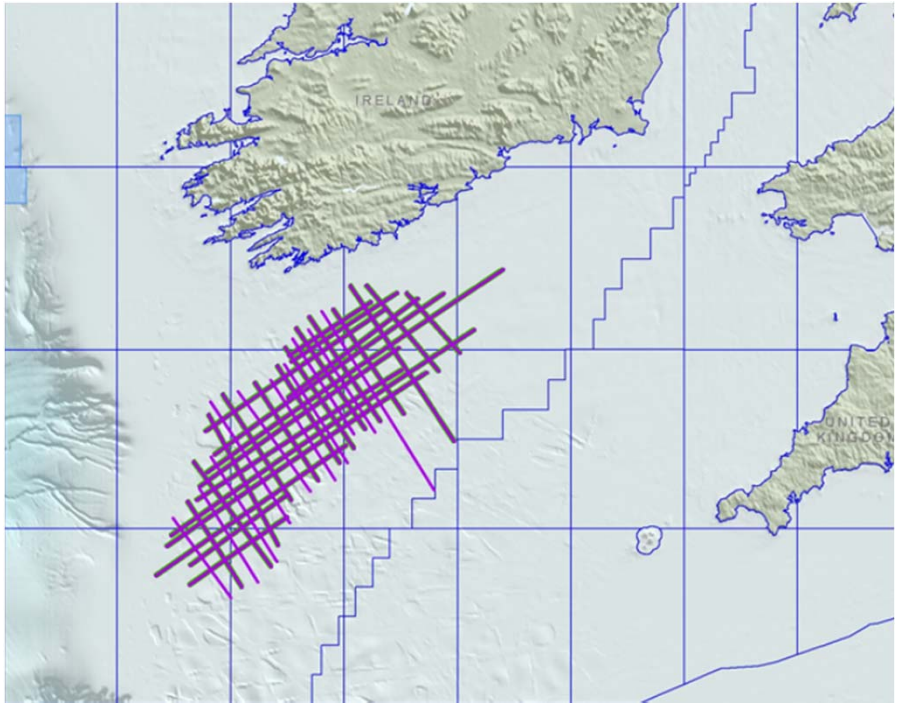
Note the fairly even distribution of RMS amplitude values within the reservoir outline

This is in contrast to the clear and significant differences in gas saturation shown by the EM data

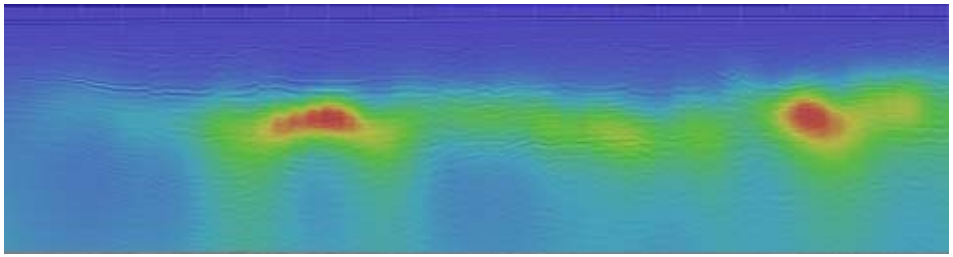
In the North East where RMS amplitudes are similar to the rest of the reservoir, the EM derived saturation is very low

RMS amplitudes similar to those in the North East are seen in the centre of the reservoir, where EM derived gas saturation is high

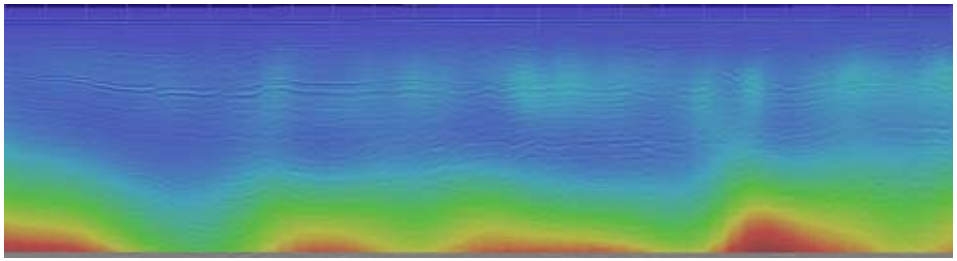
Regional Scale Exploration in Fastnet Basin



Vertical Resistivity (sensitivity to thin resistors)



Horizontal Resistivity (sensitivity to large-scale structures)



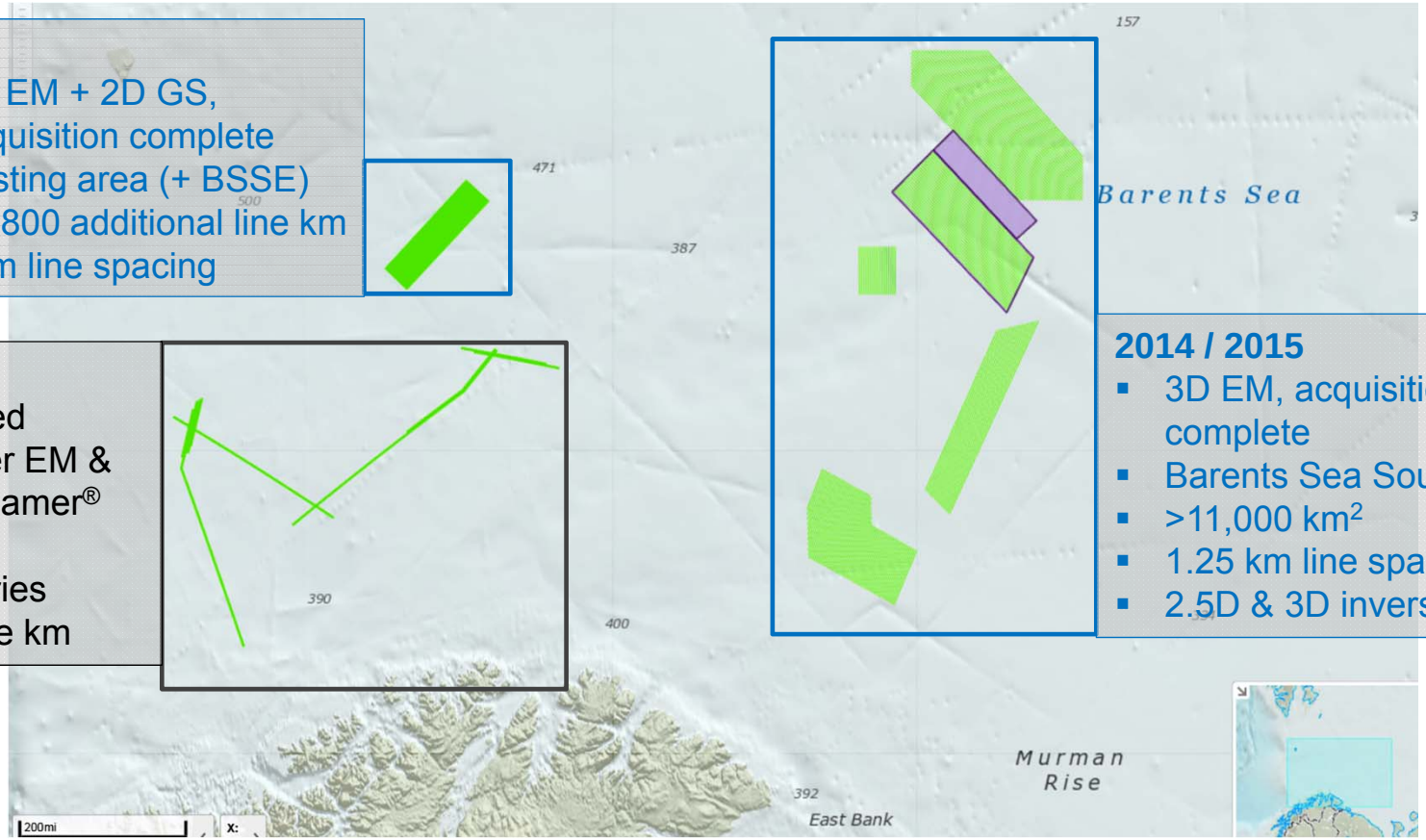
Large scale frontier exploration – All FNT 2013 EM data recently re-inverted using updated 2.5D code, seismically guided inversion examples using three horizons over Barryroe discovery available for data show

Barents Sea - Towed Streamer EM Data Coverage

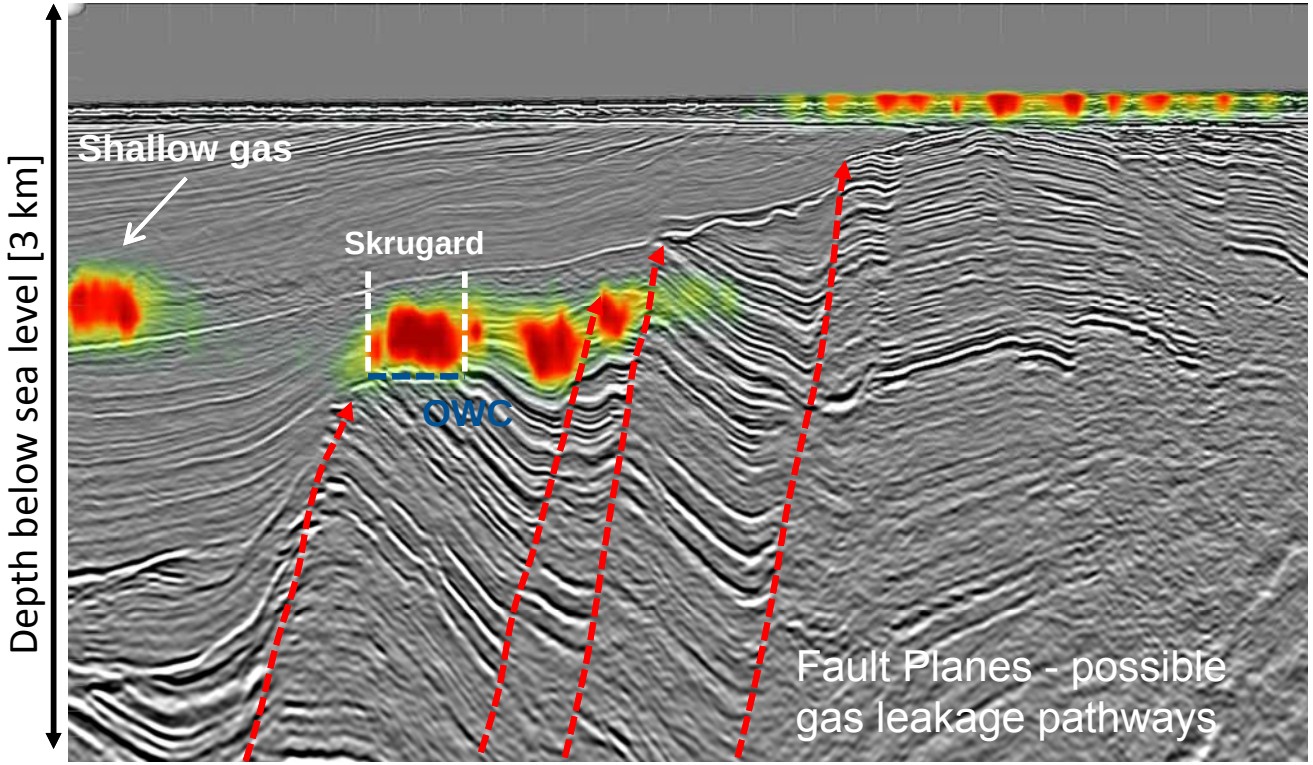
2015
- 3D EM + 2D GS, acquisition complete
- Wisting area (+ BSSE)
- >3,800 additional line km
- 1km line spacing

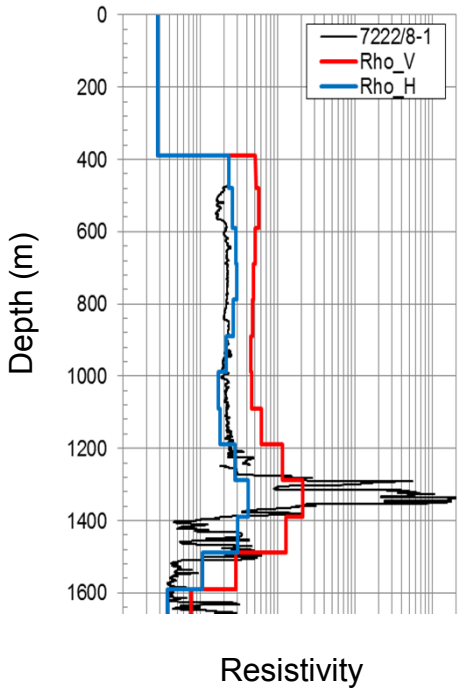
2013
- 2D Towed Streamer EM & GeoStreamer®
- Tie to discoveries
- ~850 line km

2014 / 2015
- 3D EM, acquisition complete
- Barents Sea South East
- >11,000 km^2
- 1.25 km line spacing
- 2.5D & 3D inversion



Barents Sea Proof of Concept – Johan Castberg (Skrugard) Area

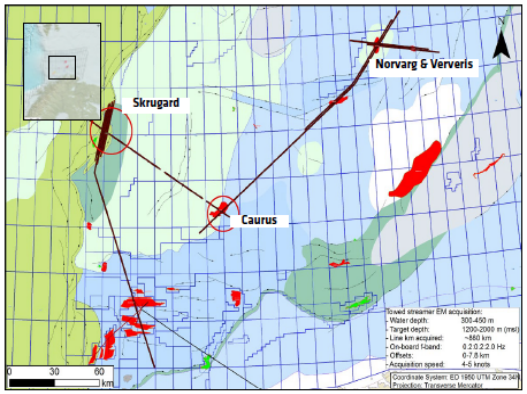




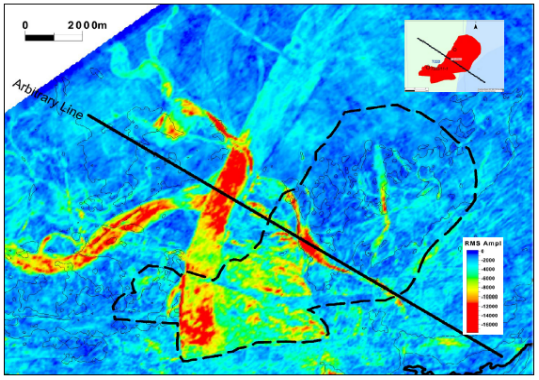
Barents Sea - Near Field Exploration

Joint interpretation of the resistivity and seismic data highlight interesting anomalies outside of the known HC reservoirs:

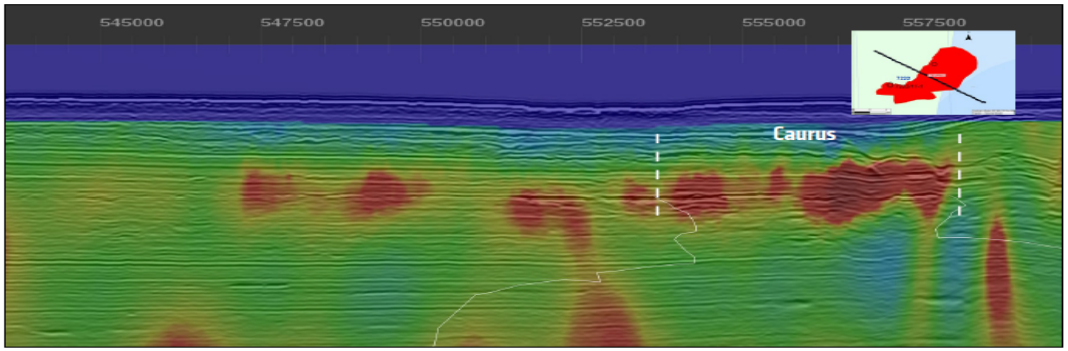
- Seismic attribute on Top Snadd shows strong anomalies at 700-800m depth
- These anomalies are within and out-with the main Caurus field outline
- EM anisotropy anomalies correspond well to the seismic anomalies



Location map



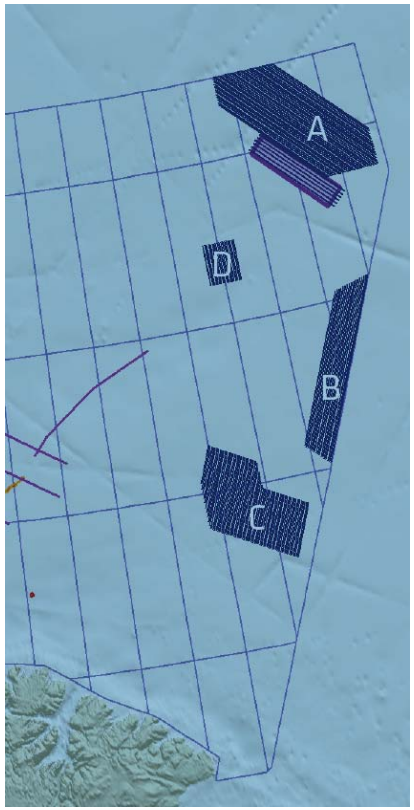
Seismic attributes (RMS)



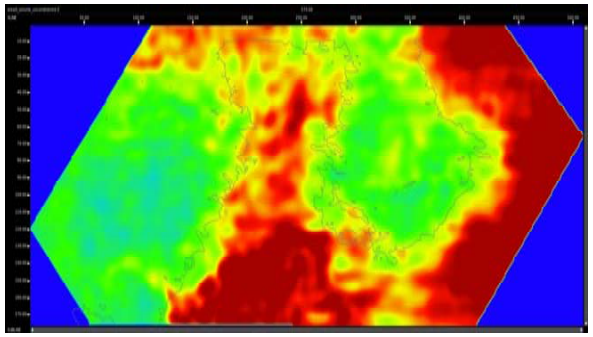
Apparent anisotropy from 2.5D inversion

Regional-Scale Exploration in Barents Sea SE – Unconstrained Inversions

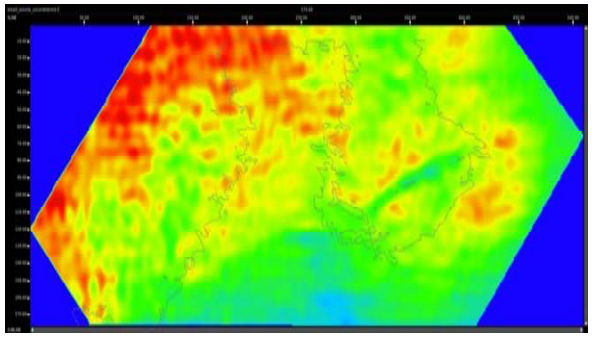
Barents Sea SE

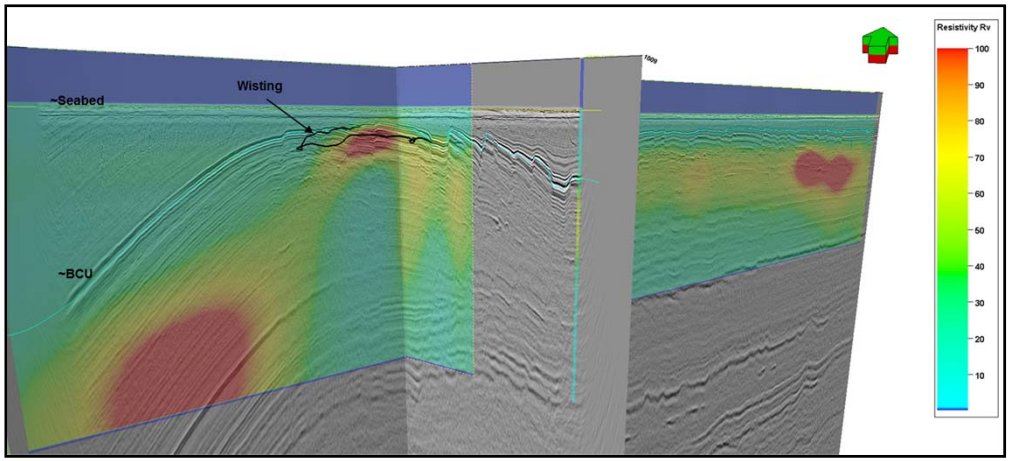


Horizontal Resistivity – depth slice



Vertical Resistivity – depth slice

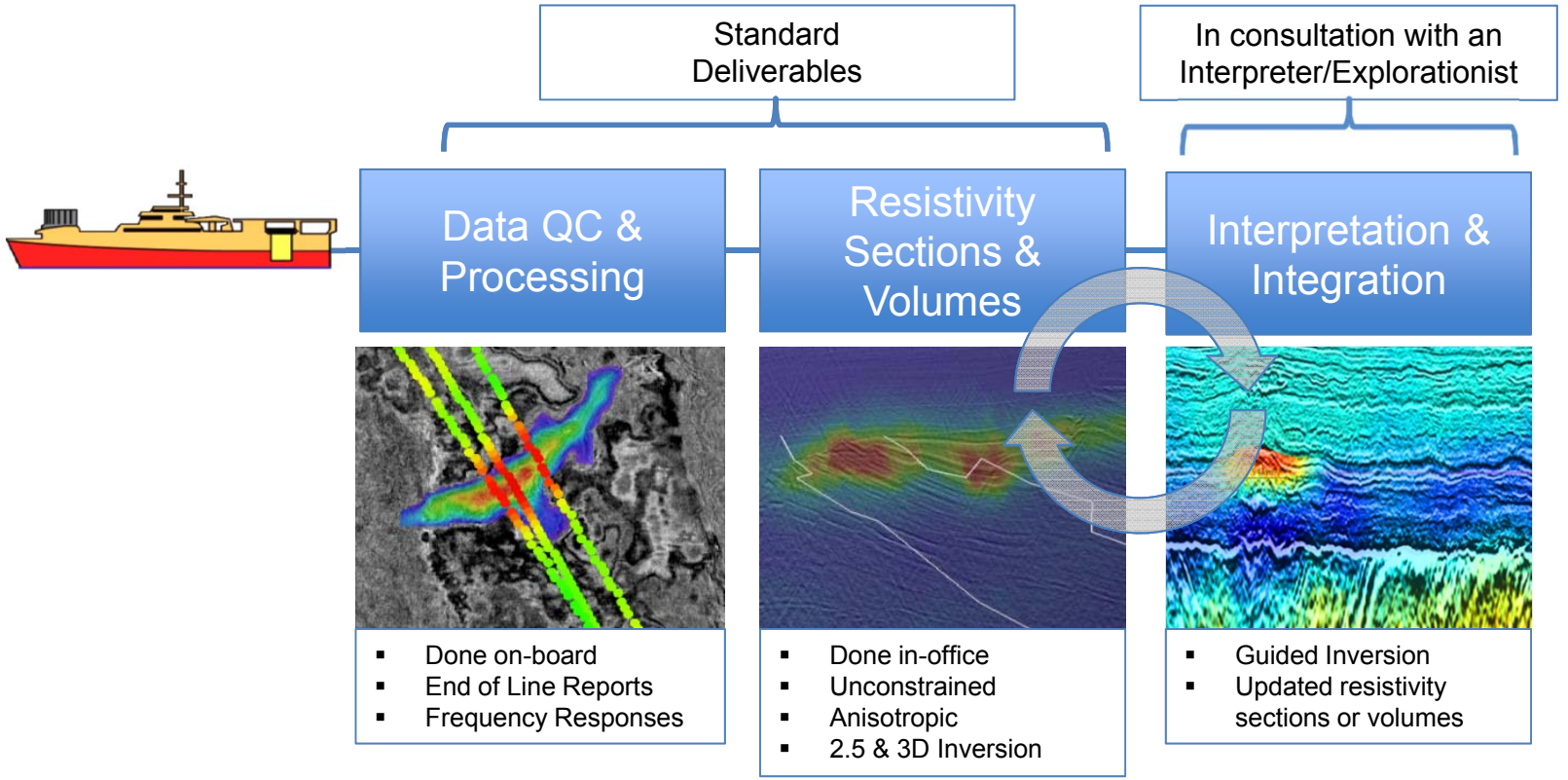




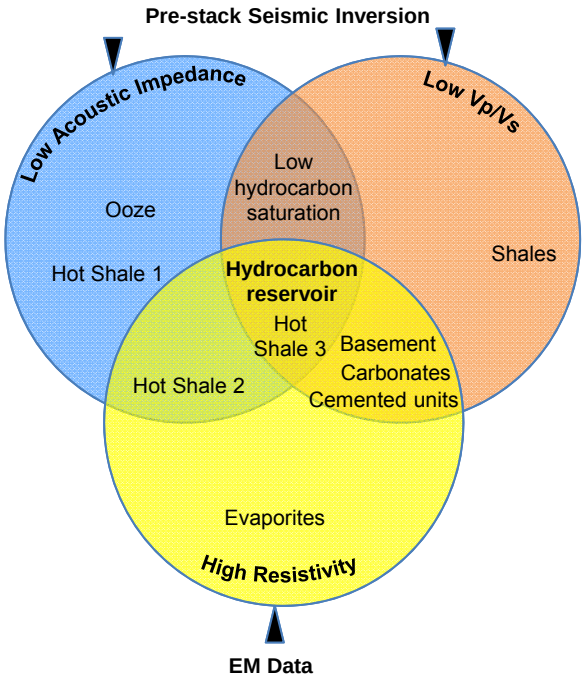
Vertical Resistivity – depth section, Wisting, Barents Sea

Towed Streamer EM

Determination of sub-surface resistivity

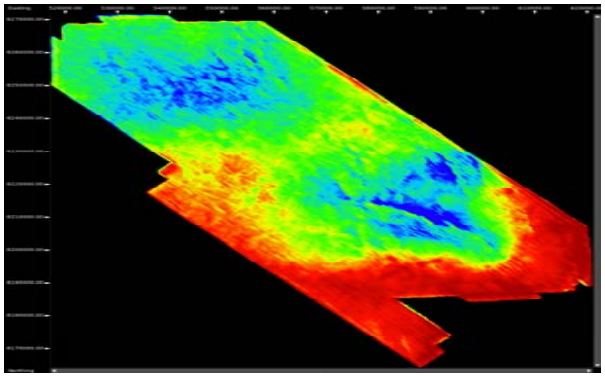


Integrated Interpretation of EM and GeoStreamer Data

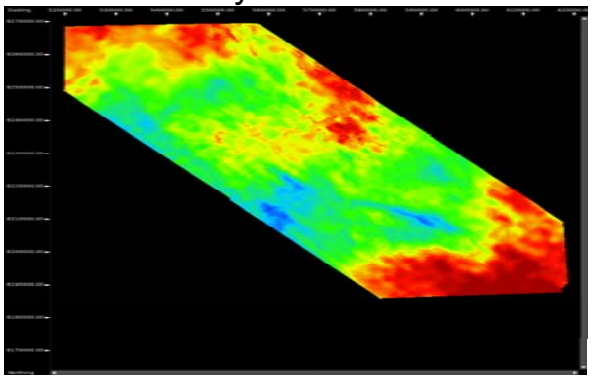


The Wisting oil discovery: Using CSEM and seismic attributes?
Tor Veggeland, Bente Flakstad Vold, Richard Olstad and Andre Janke;
Tullow Oil Norge AS

Seismic Velocity



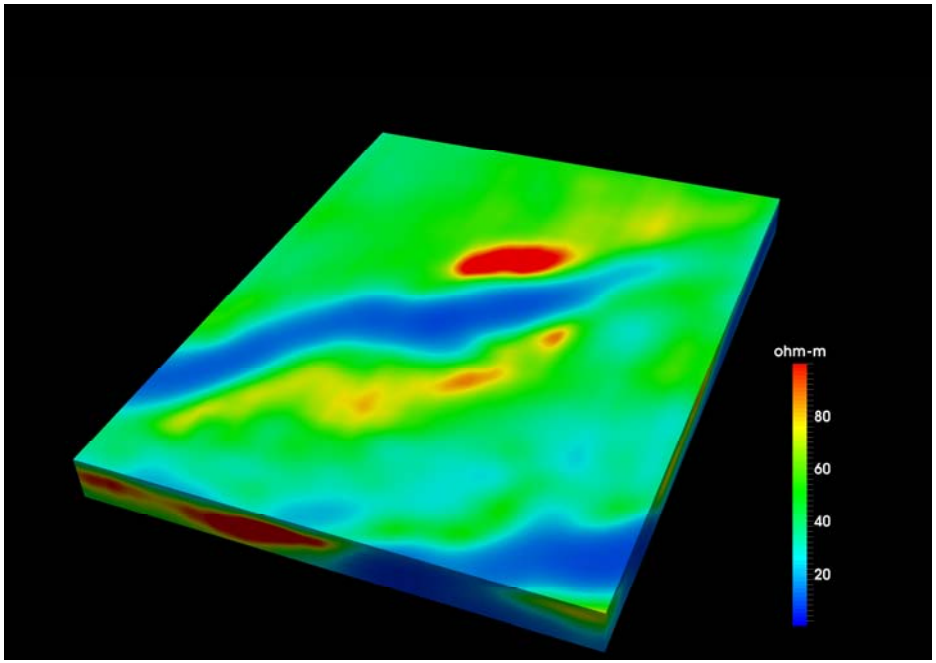
EM Resistivity



Summary – Value added by Towed Streamer EM

De-risk prospects from both a charge and saturation perspective – improve near field potential and extend the life of existing infrastructure

- High density marine CSEM data can now be acquired on a regional-scale as well as prospect-scale
- Unconstrained anisotropic inversion of Towed Streamer EM data enables resistivity determination that matches resistivity measured in the well
- The addition of seismic information can further enhance the results from EM inversion
- Resistivity information from inversion should always be interpreted with seismic data



3D unconstrained resistivity volume from the Barents Sea, ~600 sq km