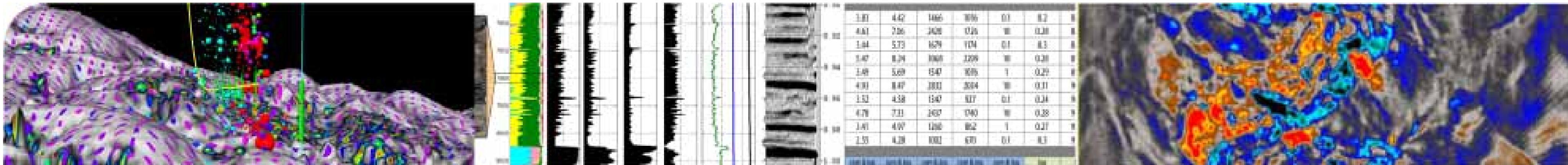
Extraordinary results. By any measure.



Integrating seismic, well and CSEM data

Richard Cooper, RSI

Business opportunities with subsurface data

20April 2011

Hallam Conference Centre, London

Agenda

- An introduction to marine EM methods
- The commercial story so far
- Case studies
- Where does CSEM fit within an overall exploration and exploitation strategy?
- Conclusion

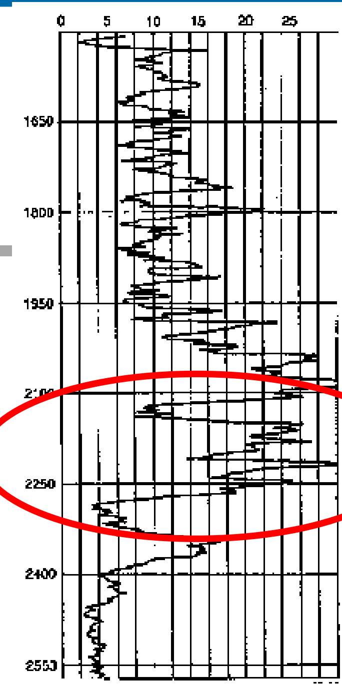
Agenda

- **An introduction to marine EM methods**
- The commercial story so far
- Case studies
- Where does CSEM fit within an overall exploration and exploitation strategy?
- Conclusion

EM came first….

1912

Schlumberger brothers begin performing surface resistivity surveys in Romania, Serbia, Canada, Union of South Africa, Belgian Congo, and USA



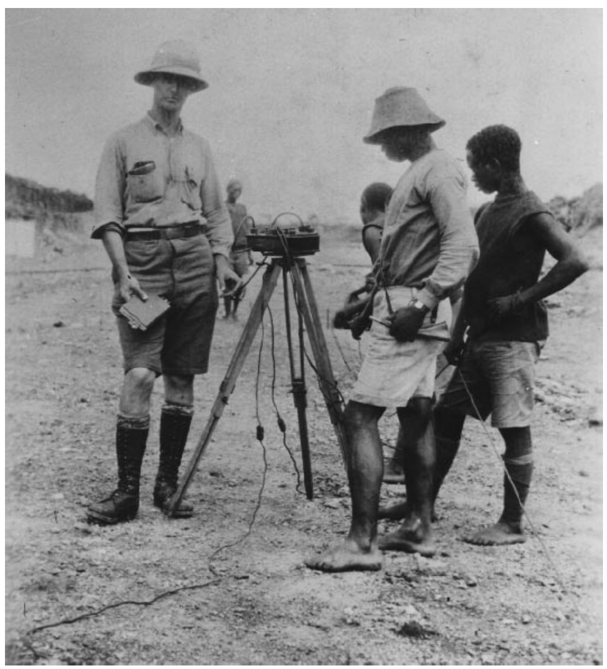
"There is probably oil just below 1950 feet."

1927

First reflection seismic data recorded

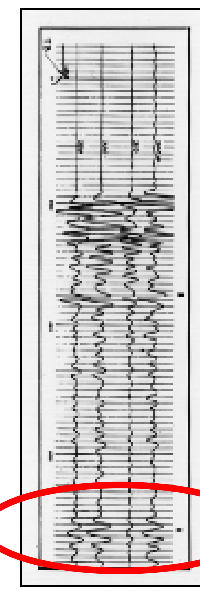
1934

Conrad Schlumberger conceived the revolutionary idea of using surface electrical measurements to map subsurface rock bodies

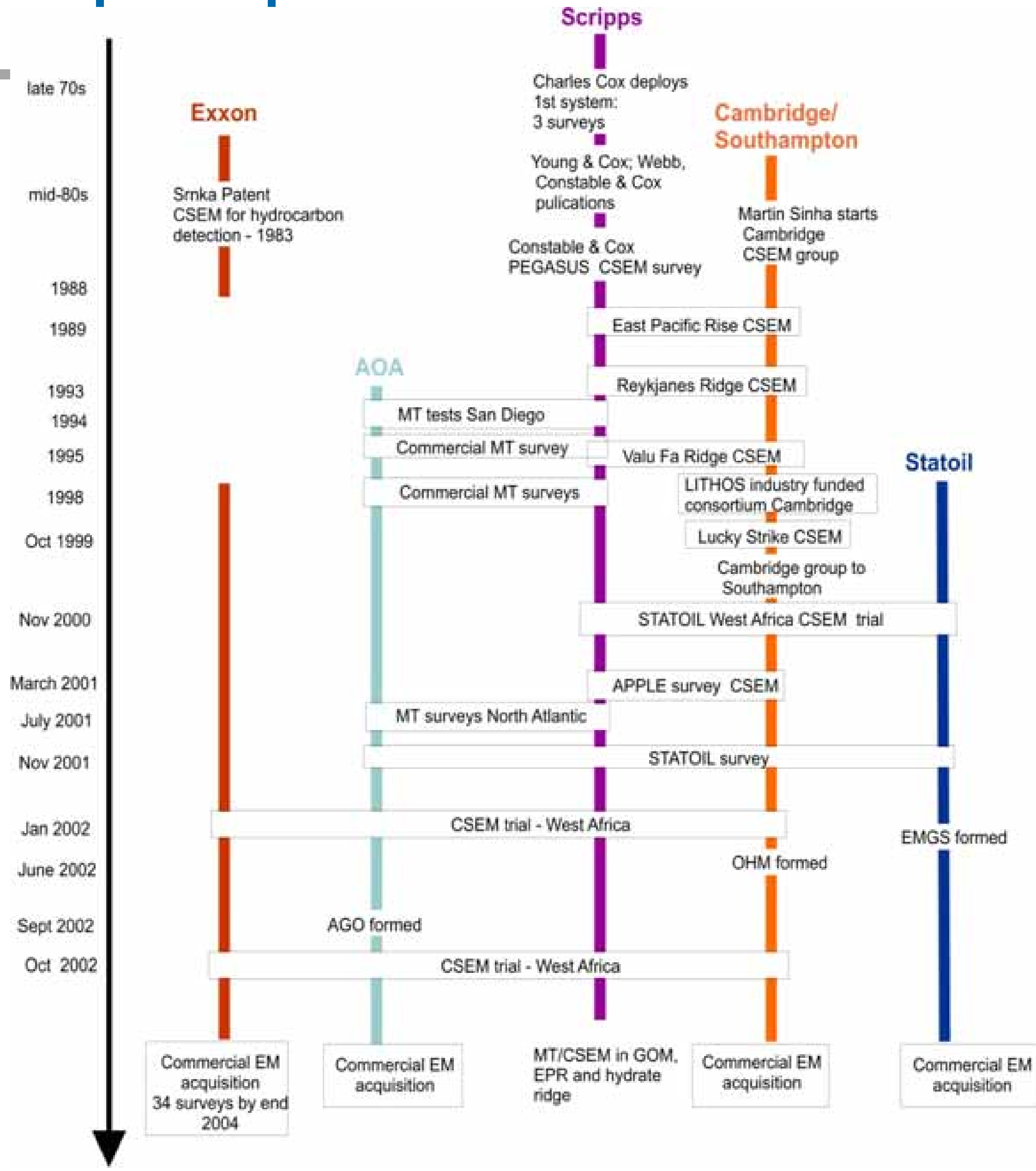


First electrical resistivity well log is recorded in Pechelbronn, France (image above is first well log in USA, 1929, Kern Co.)

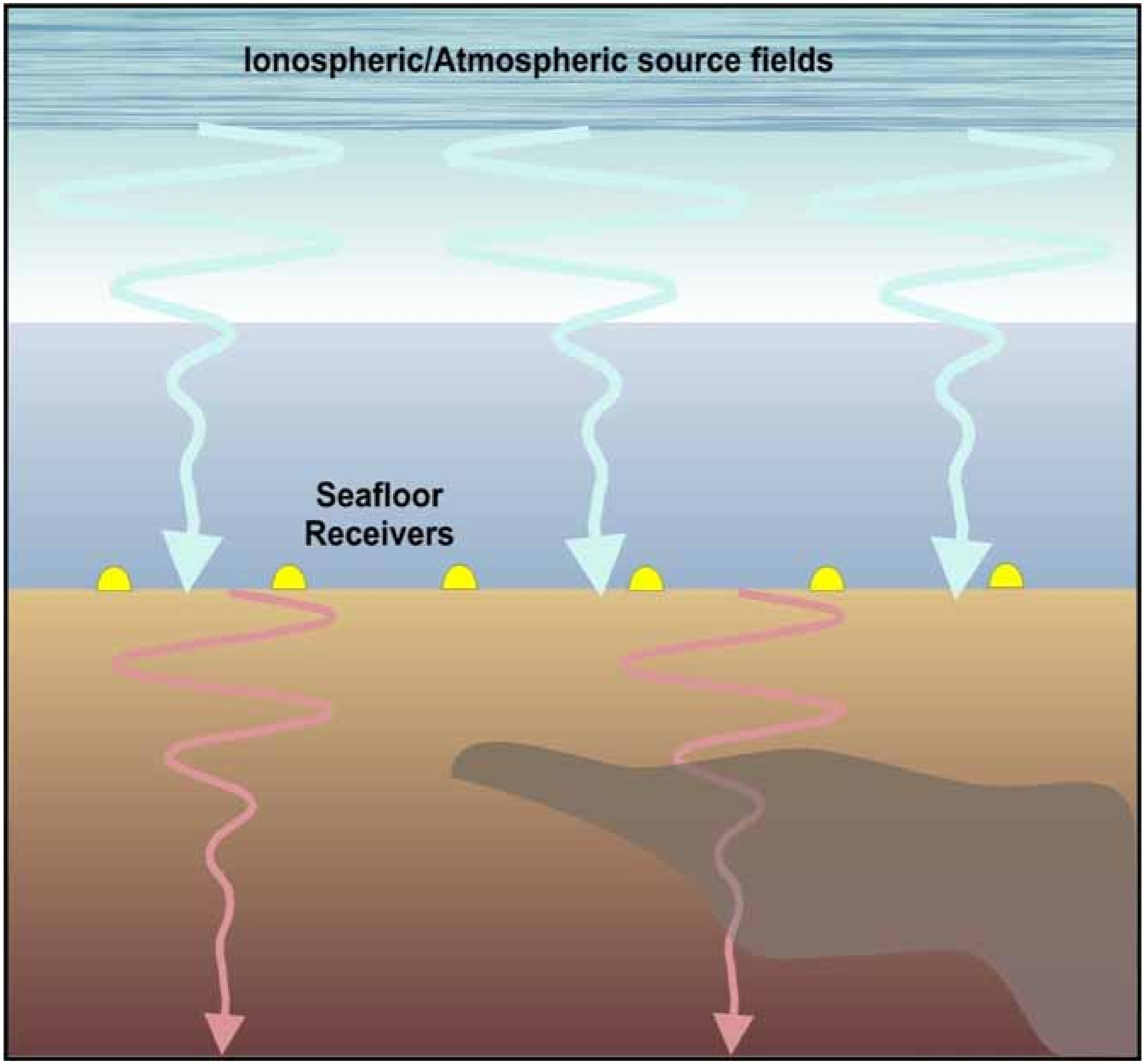
"There is different rock down there somewhere."



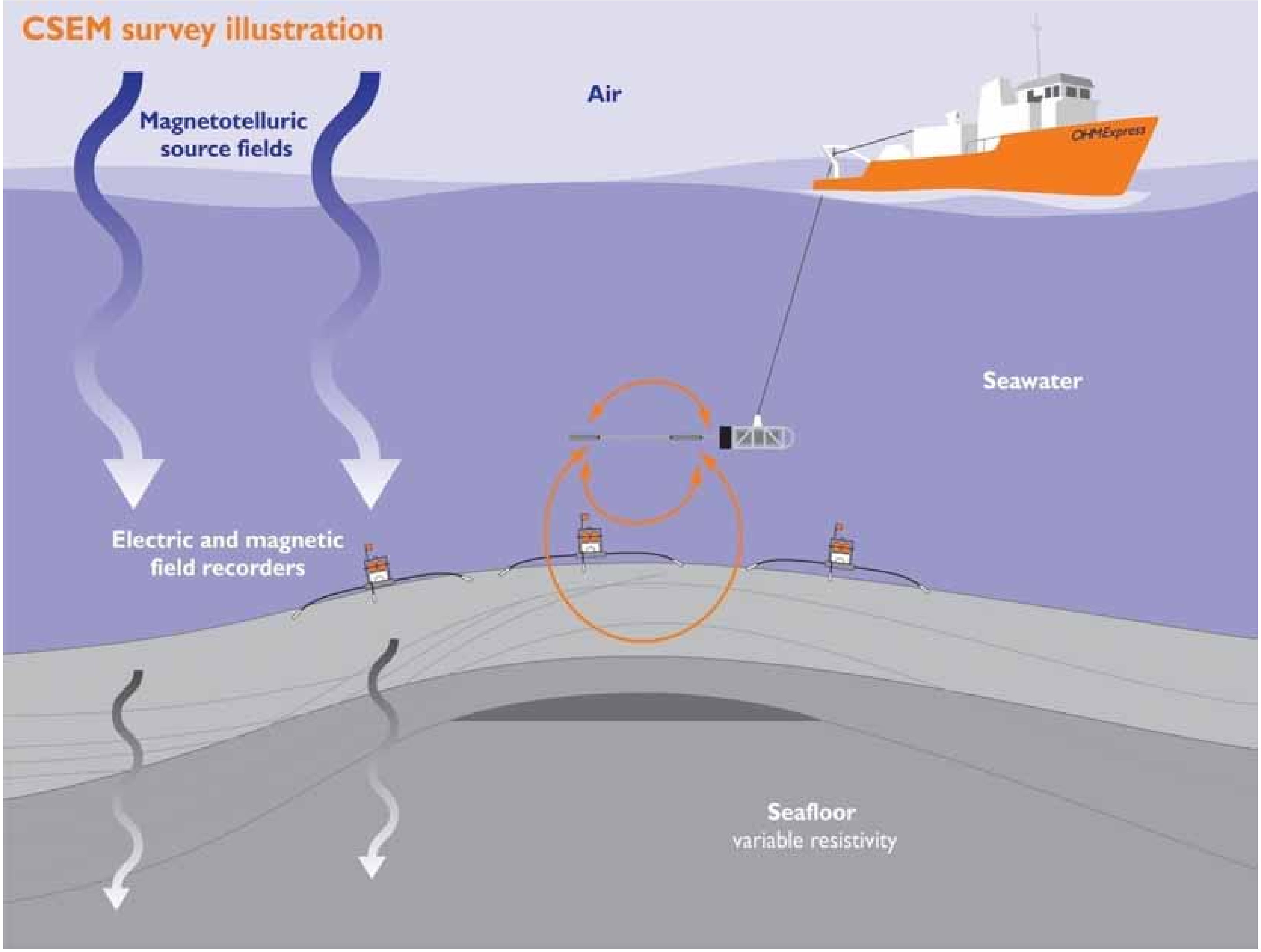
Historical perspective



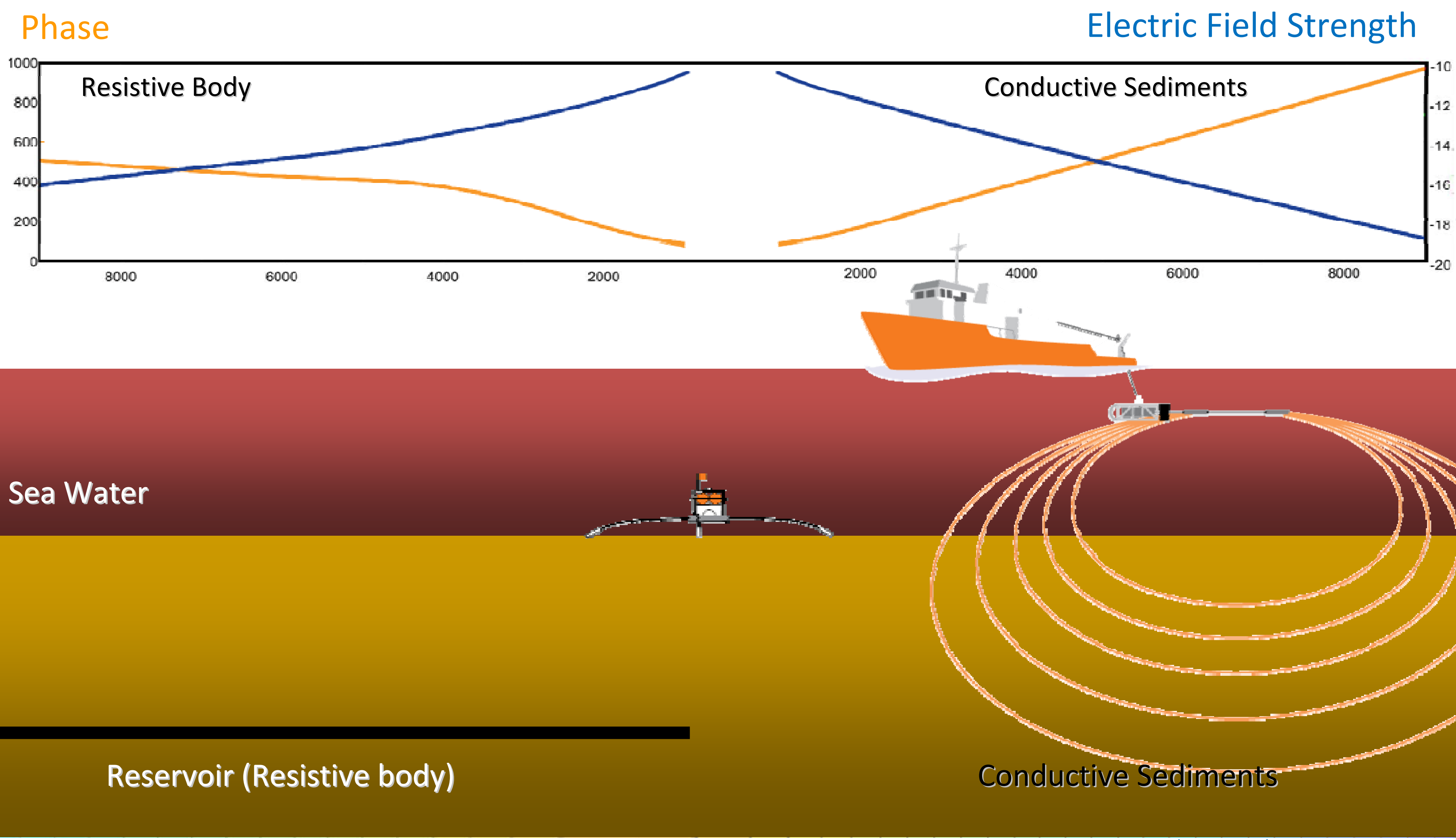
Marine Magnetotelluric - MT



Controlled Source ElectroMagnetics - CSEM



CSEM – Two Basic Measurements



Source

High powered dipole source with a moment in excess of 300,000 Am in the fundamental.

Receivers

Receivers detect and record electric and magnetic fields at the seafloor.

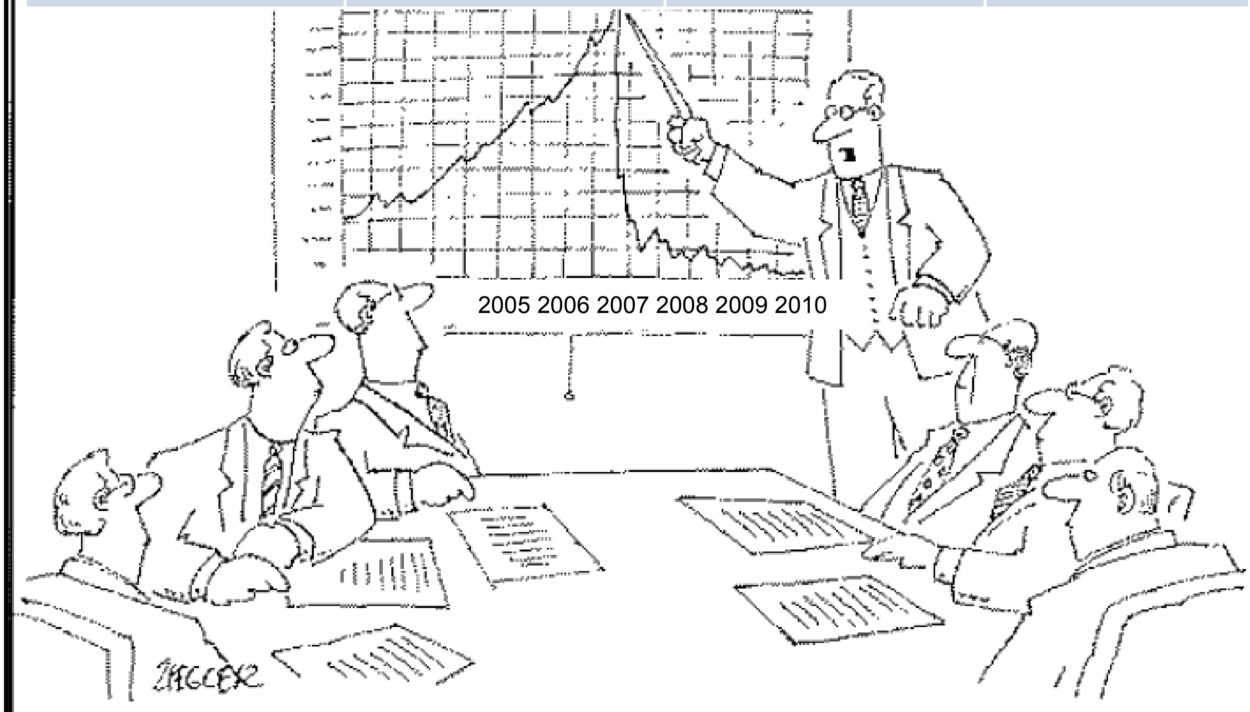
Deployed autonomously and recovered using acoustic release system

Agenda

- An introduction to marine EM methods
- **The commercial story so far**
- Case studies
- Where does CSEM fit within an overall exploration and exploitation strategy?
- Conclusion

“It was at this point, gentleman, that reality intruded”.

Market Cap	2007	2009	Change
emgs	$,1761 M	$83 M	(95)%
Mtem	$275 M	$0 M	(100)%
OHM	$ 190 M	$6 M	(96)%



The CSEM world in 2007…….what went wrong?

Great marketing; poor delivery: a fatal combination!

Incorrect statements:

- CSEM will replace seismic
- CSEM is a DHI

CSEM is not seismic

- Acquisition design critical
- Processing & interpretation technology immature; almost no commercial software
- Little in-house expertise or technology in oil & gas companies

Seismic Integration?

- Absolutely key

Market adoption/growth barriers: CSEM

CSEM considered to be "expensive" compared to seismic:

an seismic per unit area)
tile; just plain wrong!)

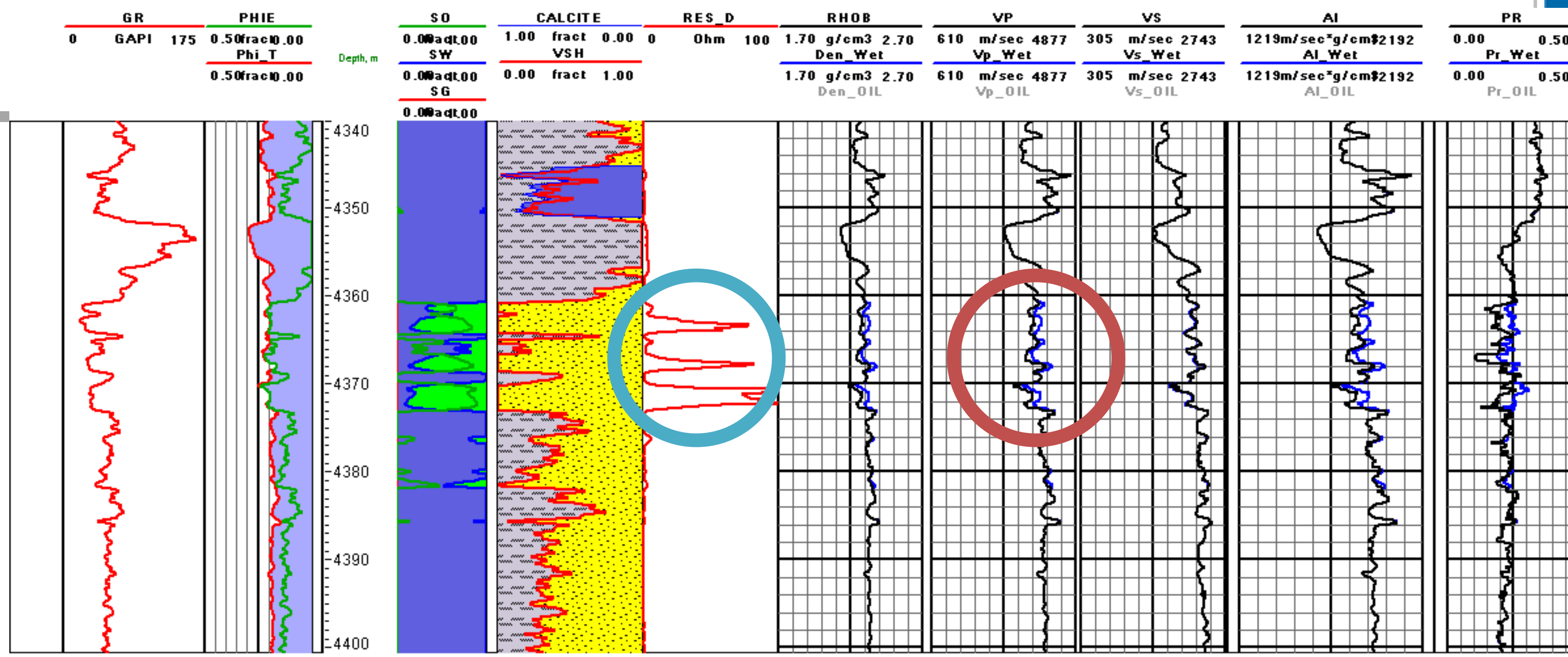
s
ems

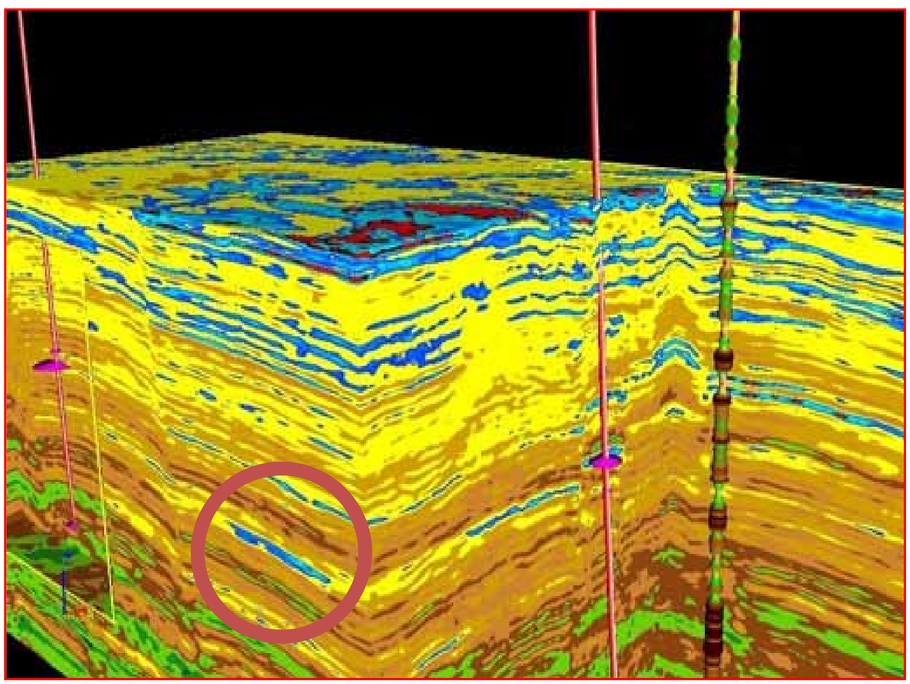
Better, faster, cheaper!

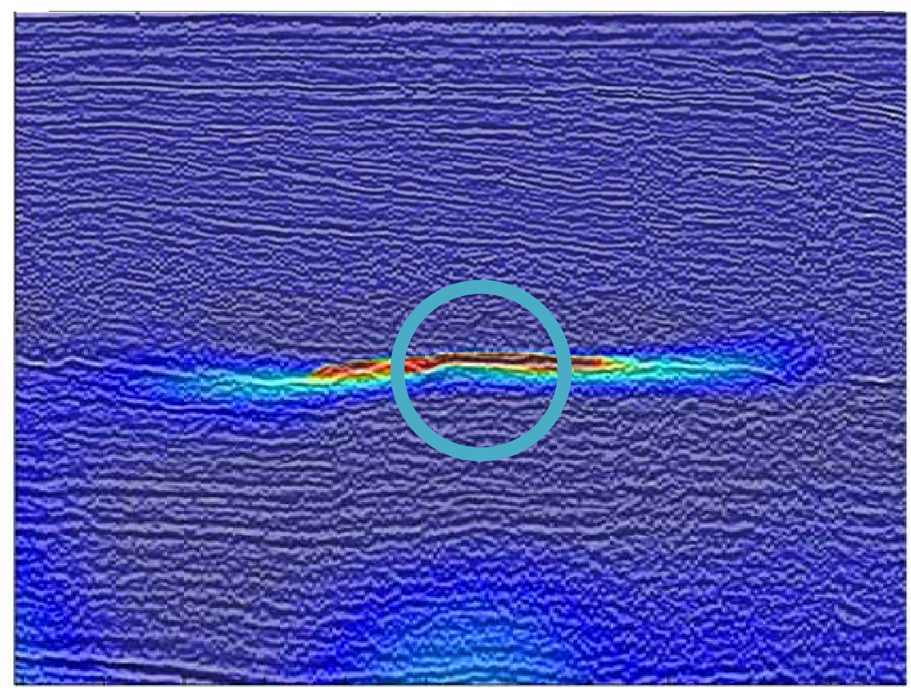
Agenda

- An introduction to marine EM methods
- The commercial story so far
- **Case studies**
    1. **Norwegian Sea Gas Reservoir**
    2. **Fluid in a Chalk interval**
- Where does CSEM fit within an overall exploration and exploitation strategy?
- Conclusion

Data integration is key







Each method has its strengths….

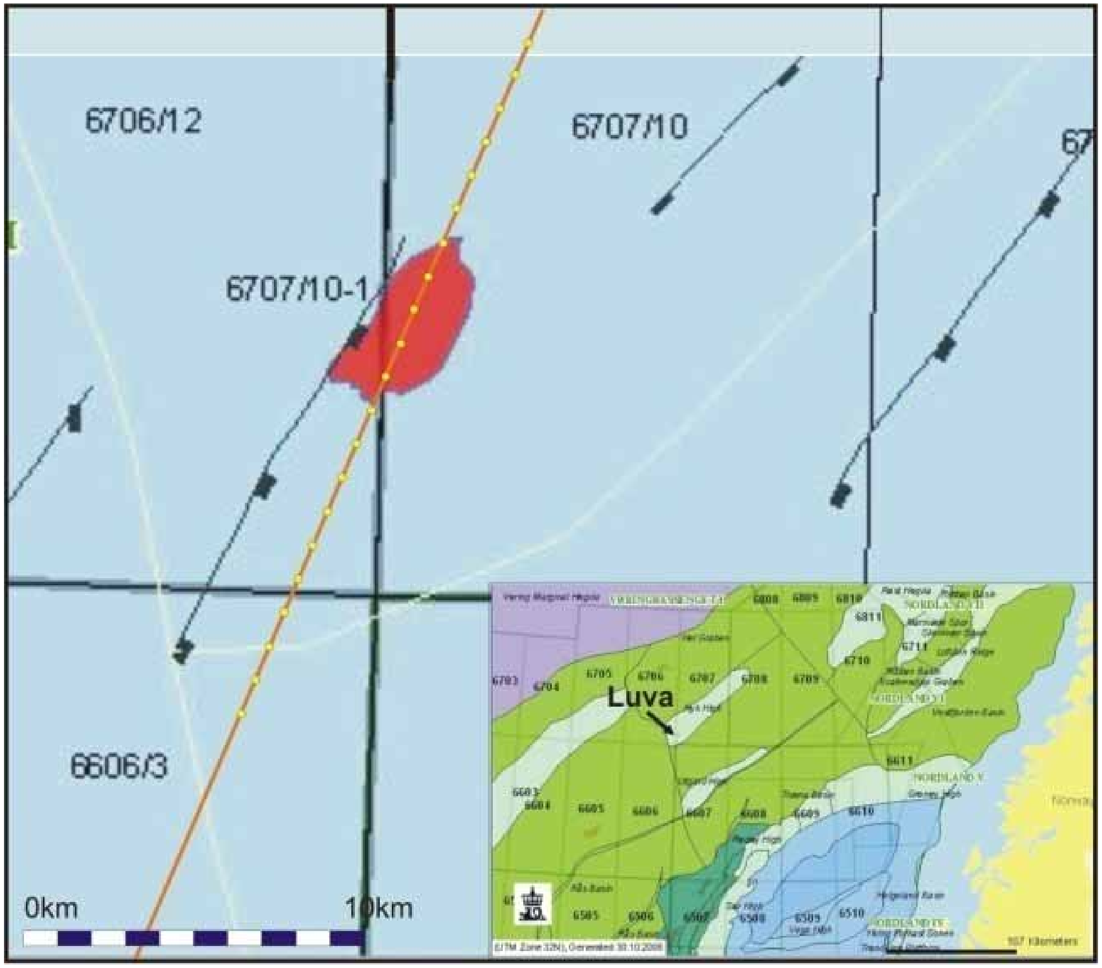
	CSEM	Seismic	Well data
Imaging structure			
Detecting fluids			
Determining mineralogy			
What can go wrong ?	**We measure resistivity, NOT hydrocarbons**	**AVO and amplitude anomalies may be caused by lithology variations. Saturation often difficult to determine**	**Severely undersampled laterally.**

So we need to use the right tool (or tools) for the job….

Agenda

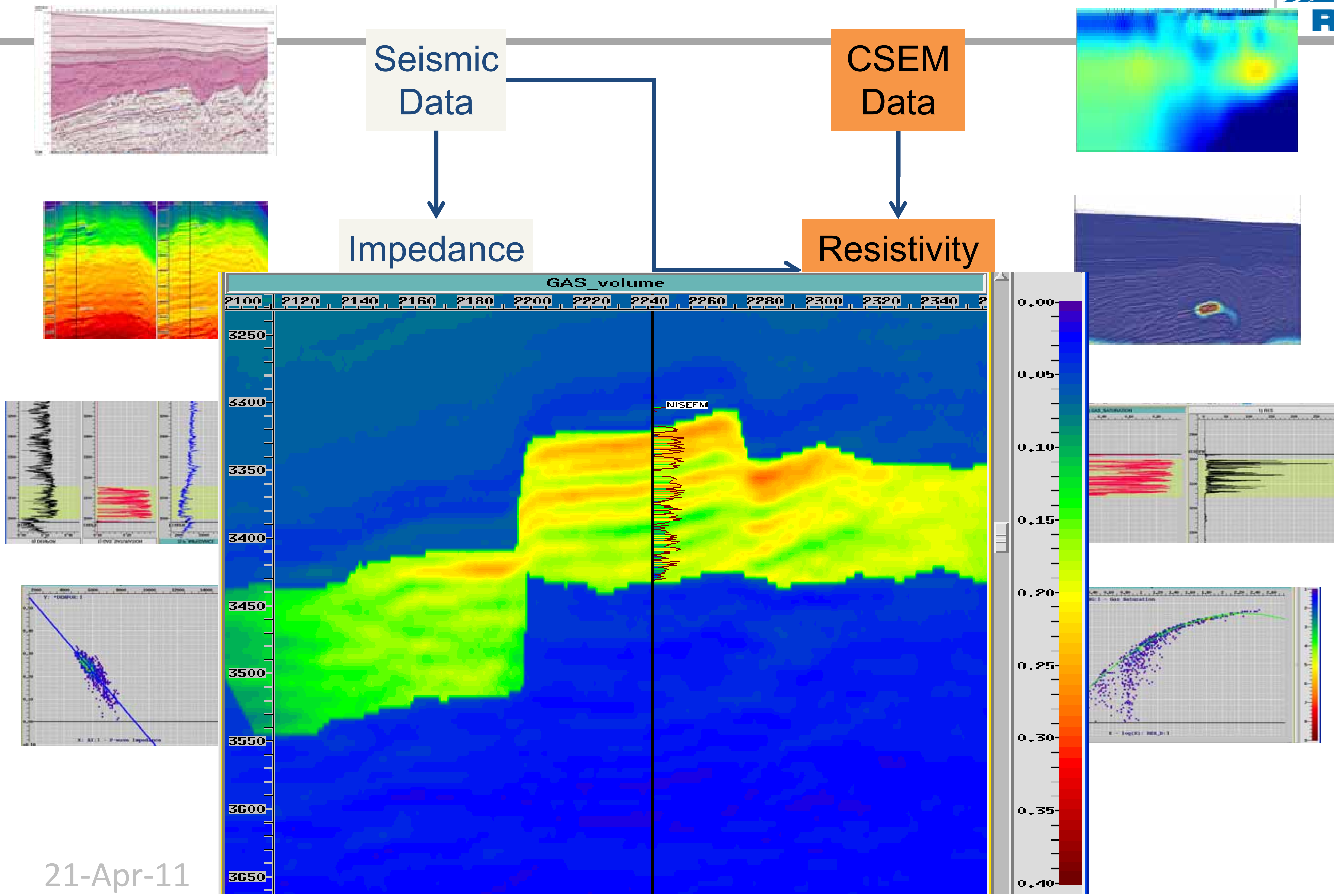
- An introduction to marine EM methods
- The commercial story so far
- **Case studies**
  1. ***Norwegian Sea Gas Reservoir***
  2. **Fluid in a Chalk interval**
- Where does CSEM fit within an overall exploration and exploitation strategy?
- Conclusion

Appraisal



- The Luva gas field lies on the Nyk High of the Voring Basin in the Norwegian Sea
- Water depth in the area is approximately 1300m
- OHM collected a CSEM survey over the field in October 2006

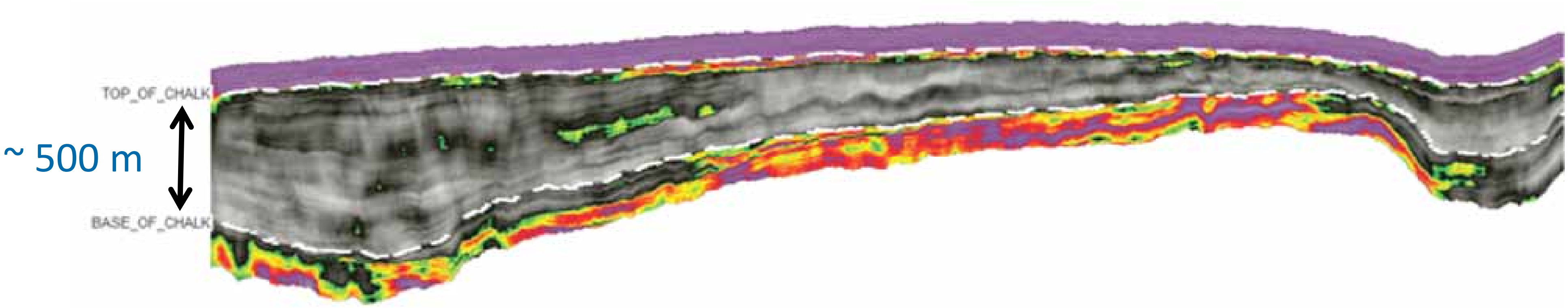
Appraisal – reservoir properties



Agenda

- An introduction to marine EM methods
- The commercial story so far
- **Case studies**
    1. **Norwegian Sea Gas Reservoir**
    2. ***Fluid in a Chalk interval***
- Where does CSEM fit within an overall exploration and exploitation strategy?
- Conclusion

What is the fluid within a North Sea Chalk ?

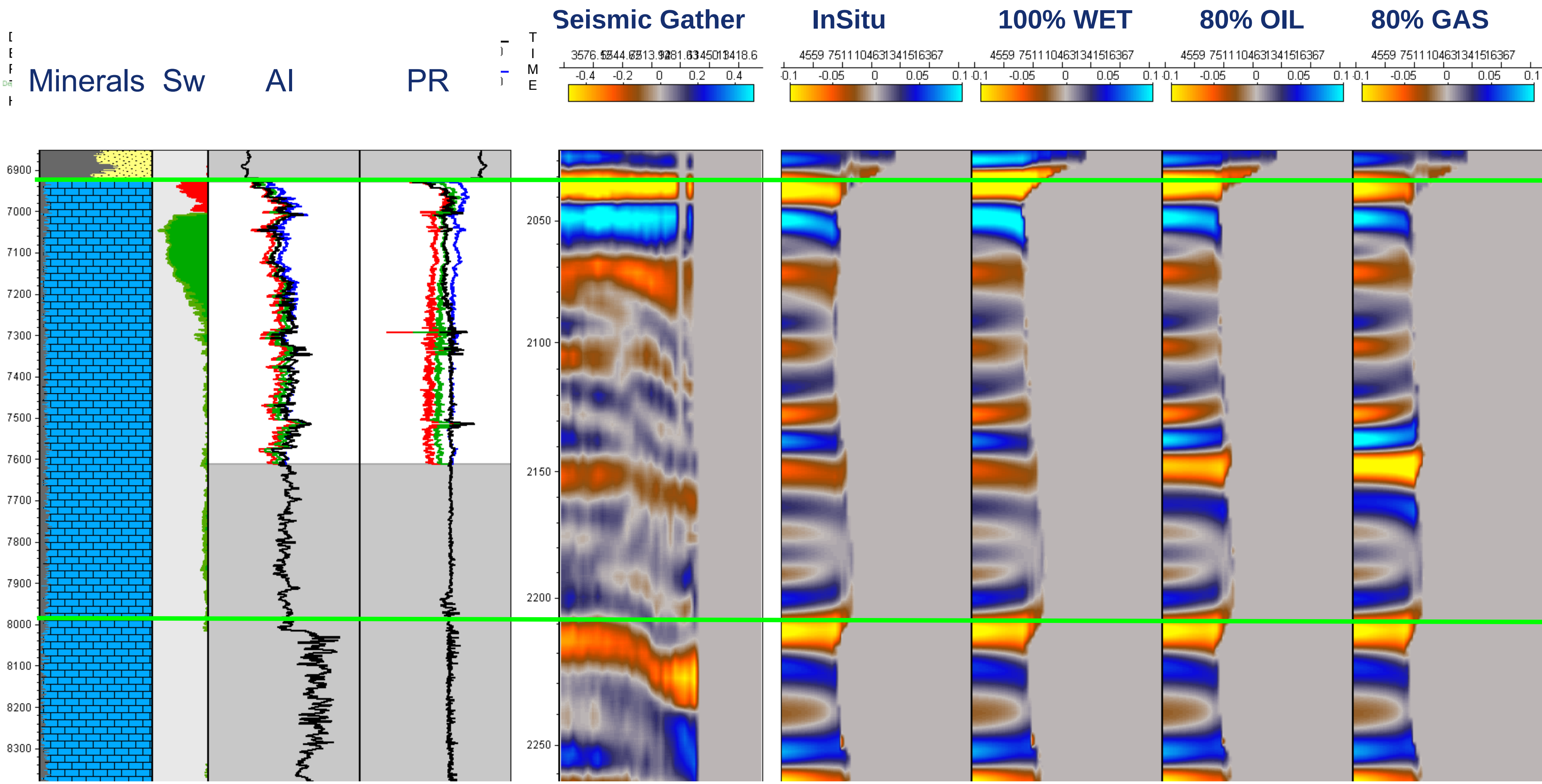


• Seismic inversion can be used to find porous zones, but determining the fluid content is difficult.

	Seismic
Tight	High impedance
Porous - wet	Low impedance
Porous – hydrocarbons	Low impedance

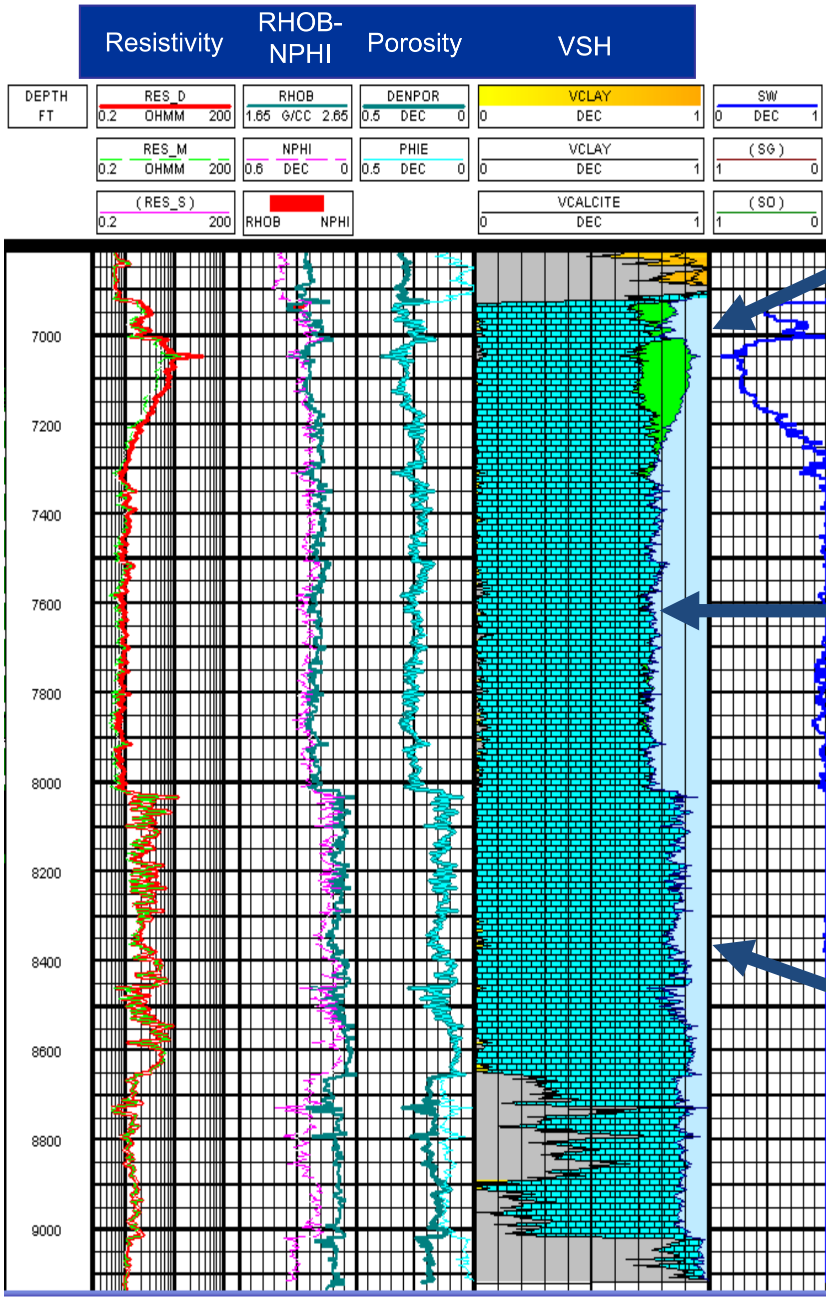
Data courtesy Maersk Oil, Shell and Chevron

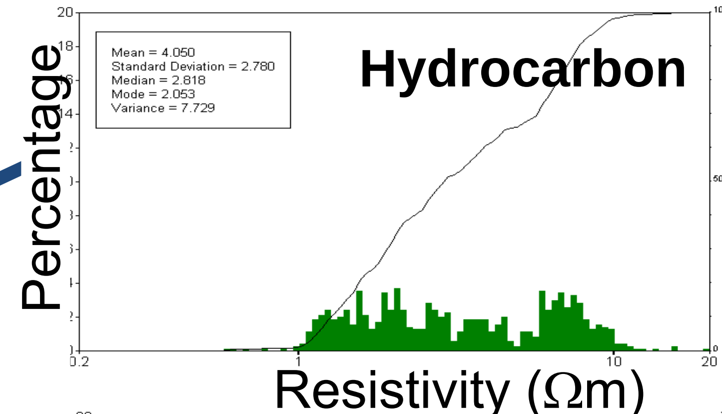
Gassmann fluid substitution

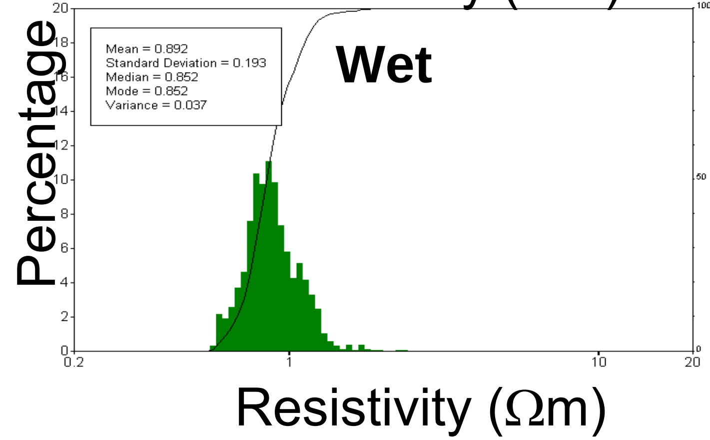


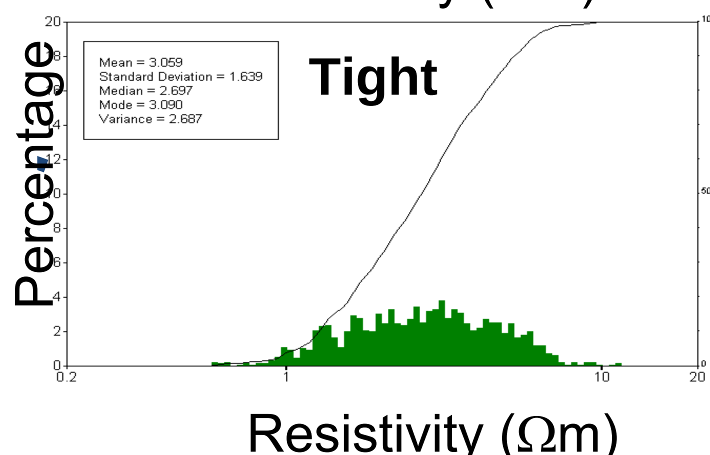
Data courtesy Maersk Oil, Shell and Chevron

Chalk resistivity









Data courtesy Maersk Oil, Shell and Chevron

Both seismic and CSEM data are needed…

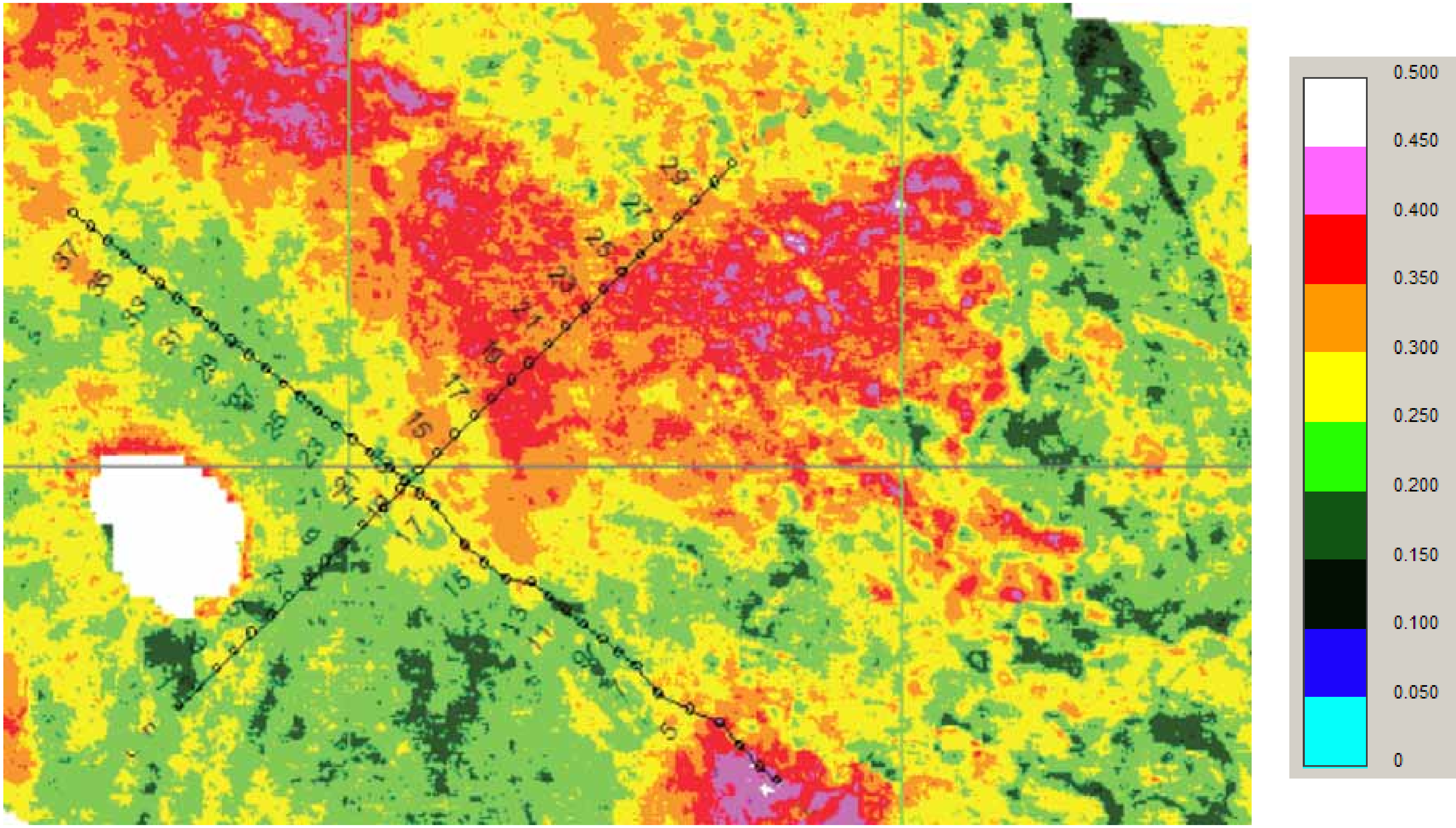
	Seismic	CSEM
Tight	High impedance	High resistivity
Porous - wet	Low impedance	Low resistivity
Porous – hydrocarbons	Low impedance	High resistivity

Use seismic to determine porosity…

…then use CSEM to determine the fluid content

Data courtesy Maersk Oil, Shell and Chevron

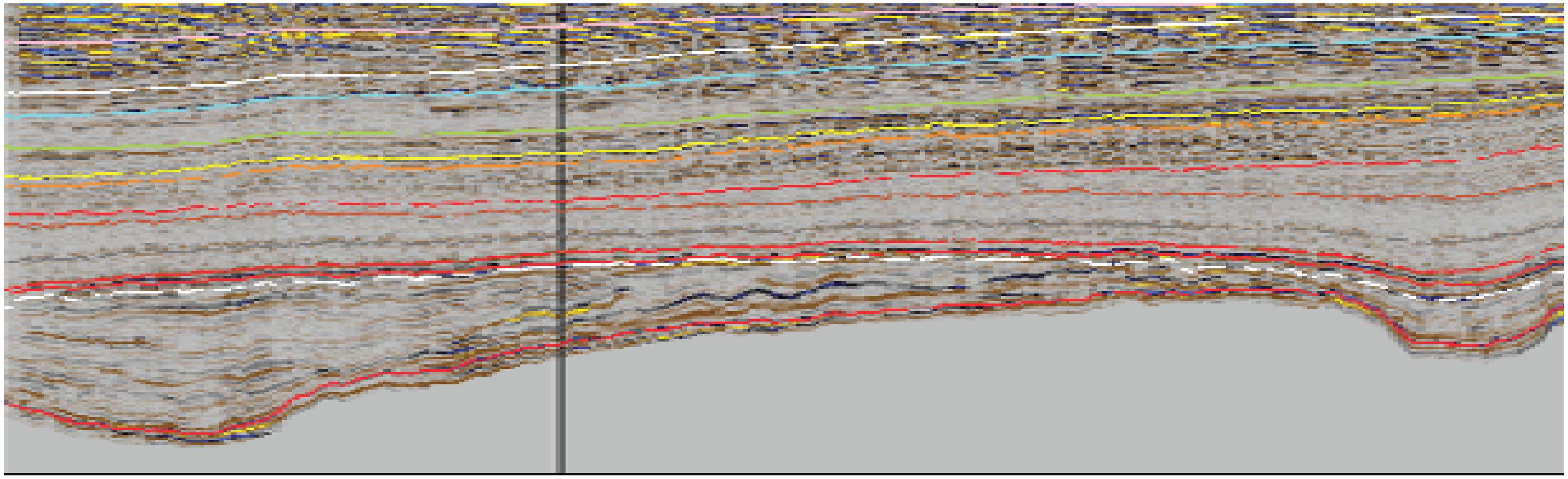
Porosity derived from seismic inversion



Average porosity in the top 24m of the chalk: can find the reservoirs but not the content

Data courtesy Maersk Oil, Shell and Chevron

2D constrained inversion



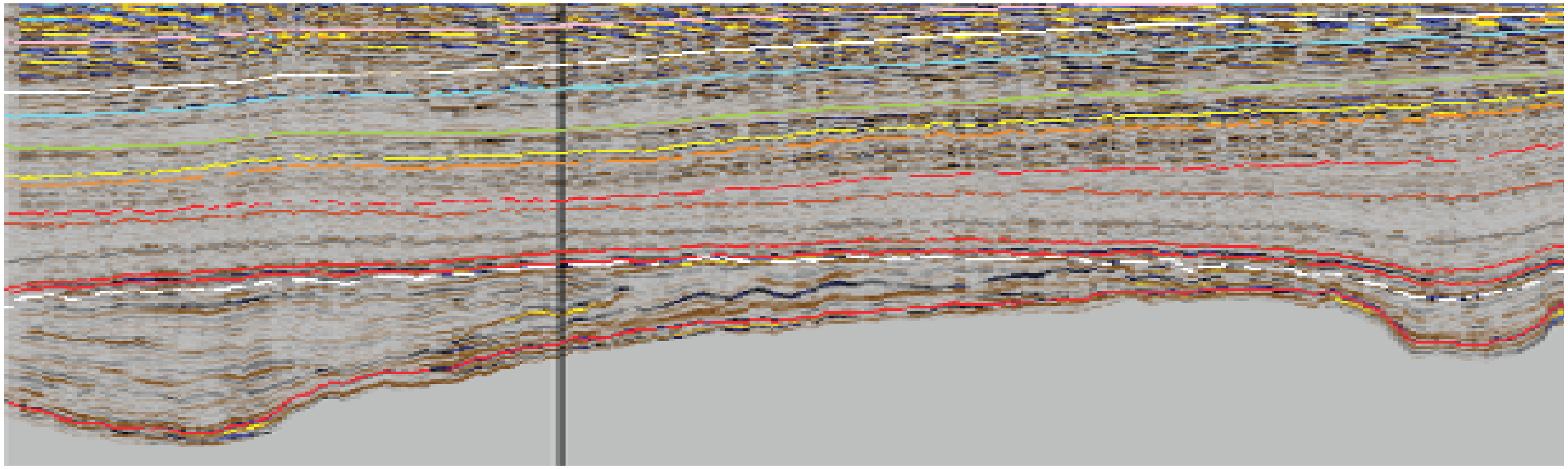
- **CSEM data alone has poor structural resolution**

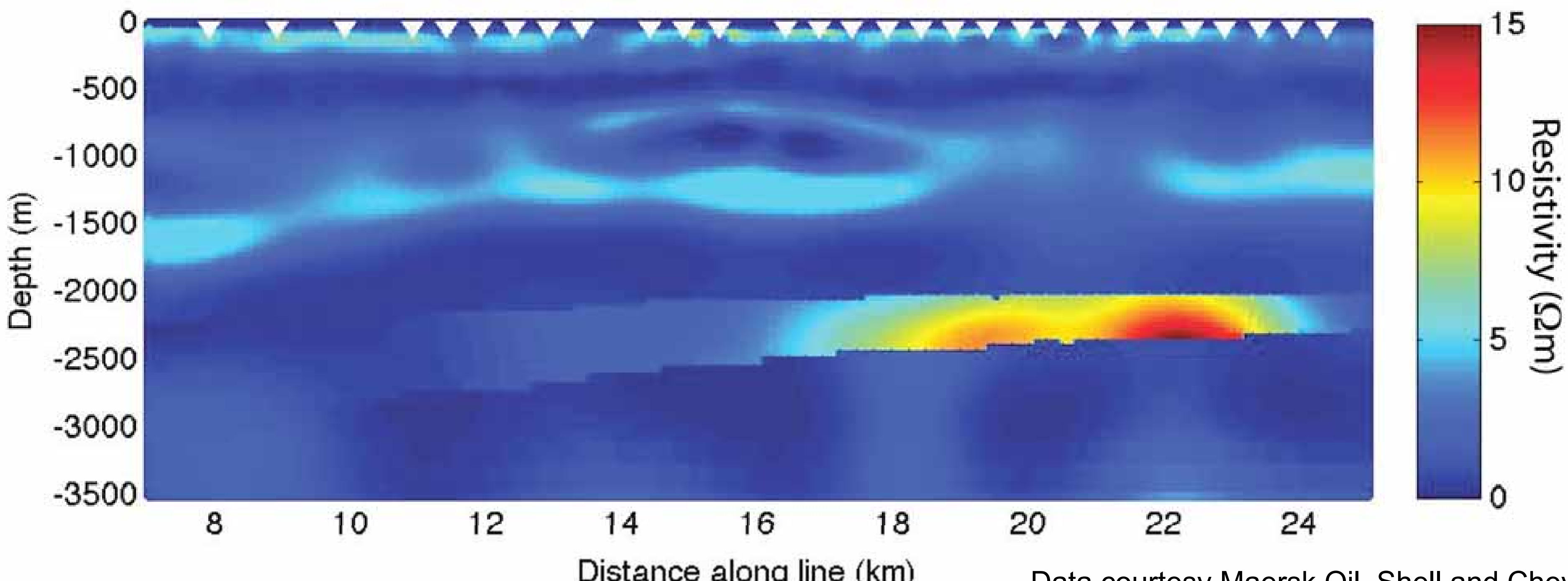
- **Use the seismic structure to constrain the CSEM inversion by allowing breaks in smoothness at top and bottom chalk.**

- **In each case invert 0.05Hz, 0.25Hz and 0.6Hz amplitude and phase**

Data courtesy Maersk Oil, Shell and Chevron

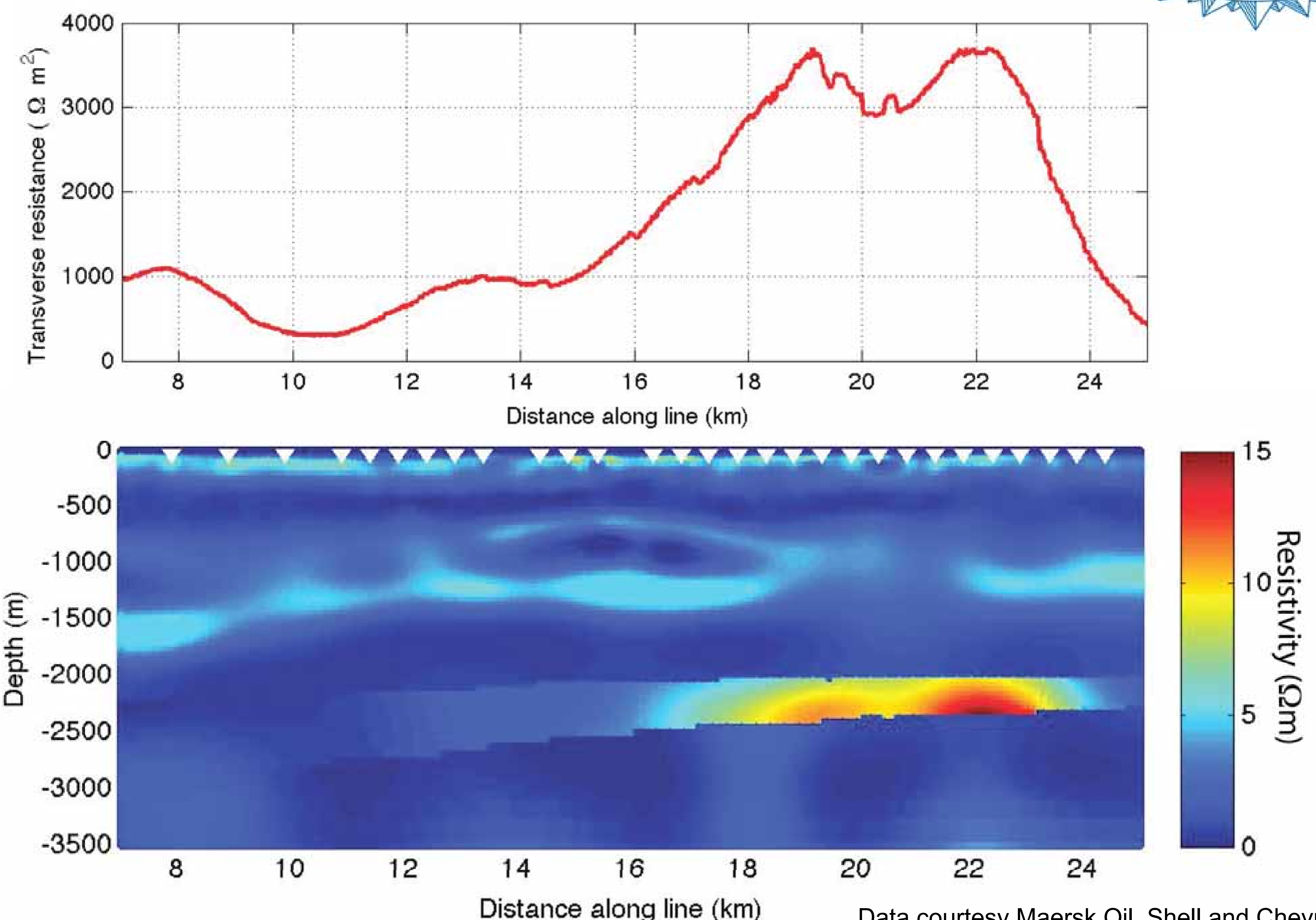
2D constrained inversion





Data courtesy Maersk Oil, Shell and Chevron

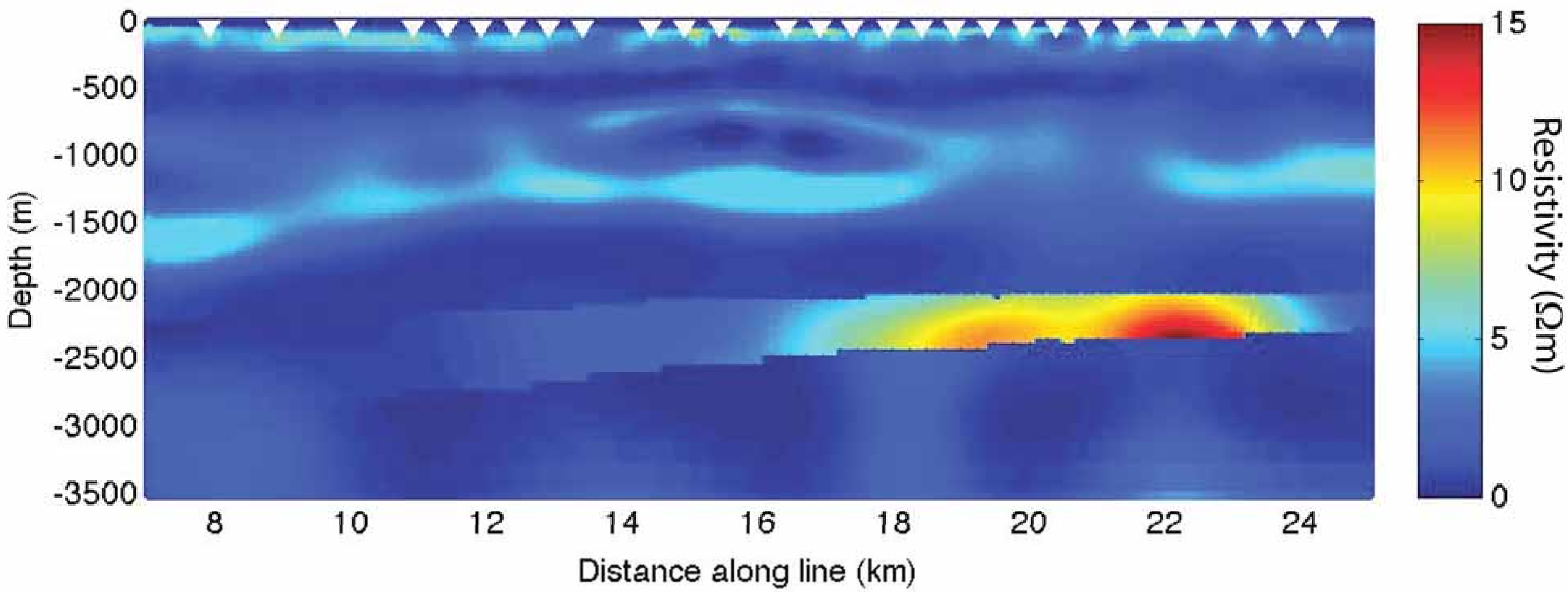
Transverse resistance



Data courtesy Maersk Oil, Shell and Chevron

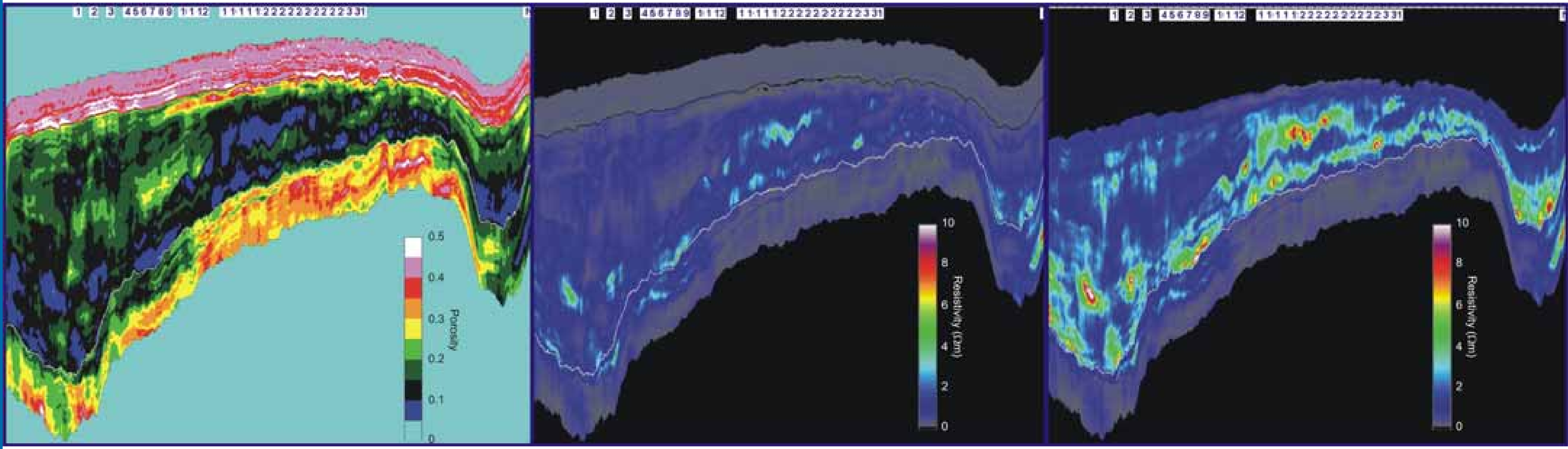
Is the increase in resistivity related to…

- Decreasing porosity ?
- Change in the chalk thickness ?
- Saturation changes ?



Data courtesy Maersk Oil, Shell and Chevron

Chalk Resistivity Sections: based on seismic



R_W = 0.03758 Ωm in Chalk

R_W = 0.08 Ωm in Chalk

100% water saturation

$$R_T = \frac{S_w^{-n} R_w}{a\,\Phi^m}$$

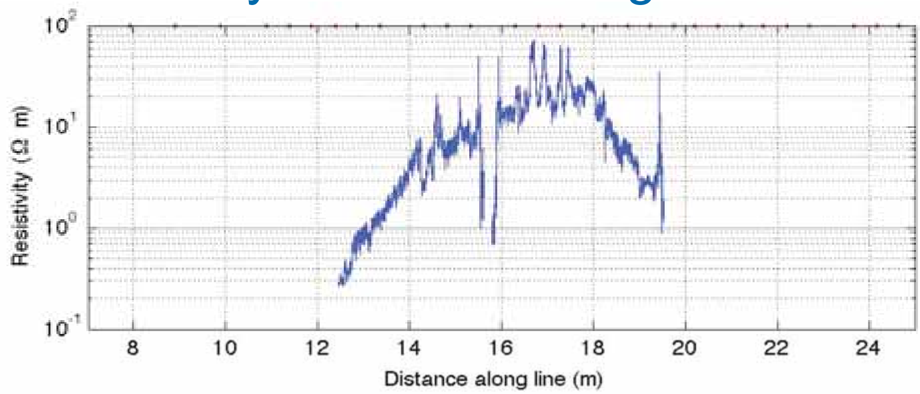
R_w and m from well log calibration

Porosity from seismic.

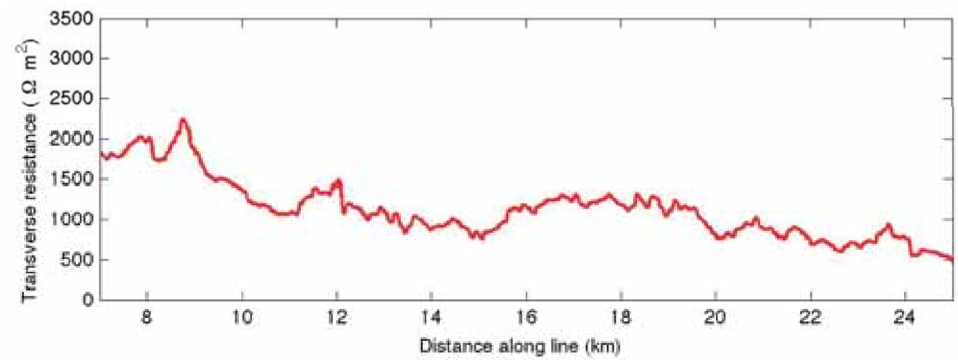
Data courtesy Maersk Oil, Shell and Chevron

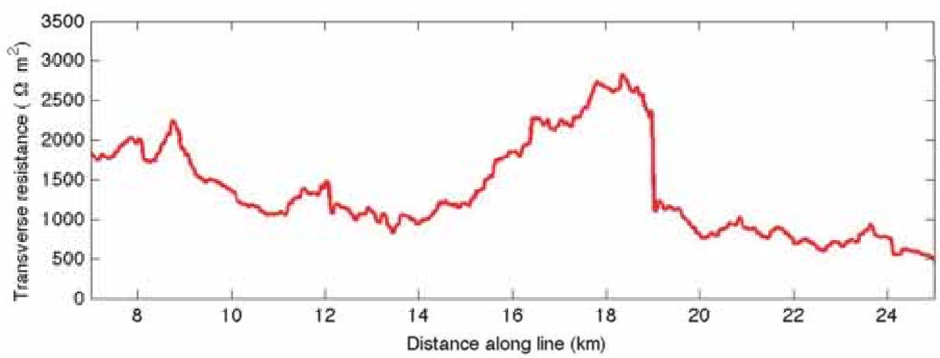
Transverse resistance: seismically derived model

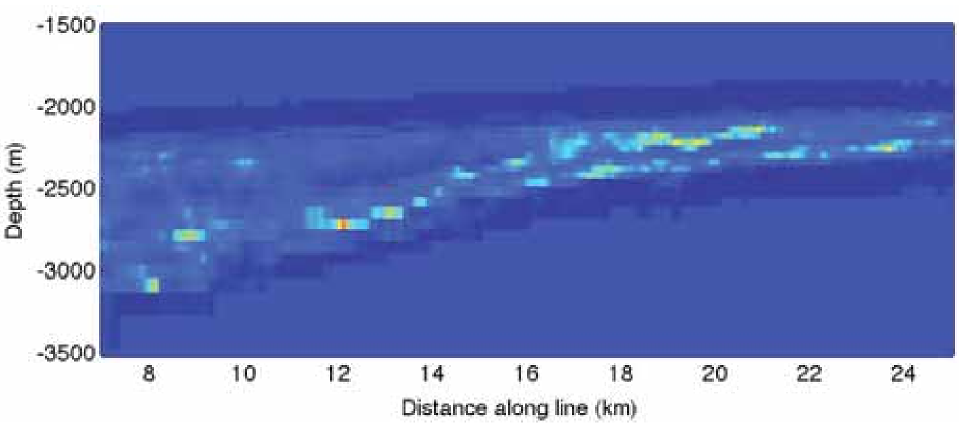
Hydrocarbon charged

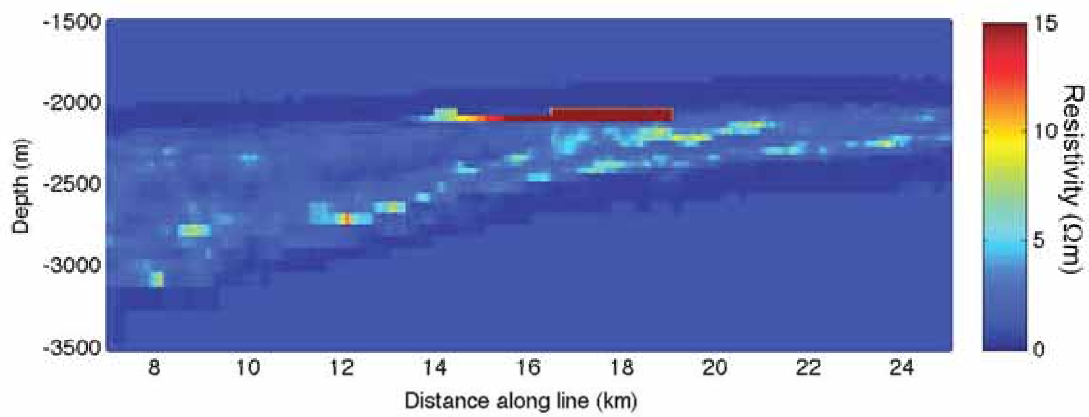


100% water saturated



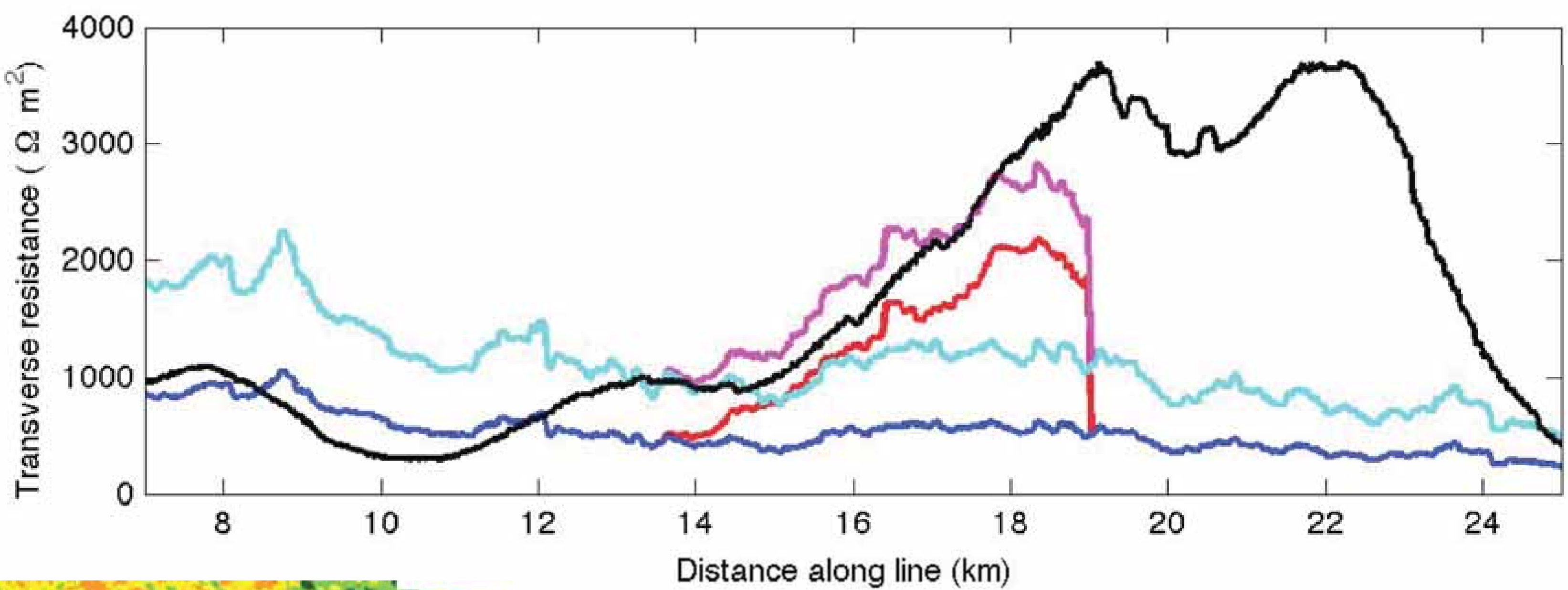


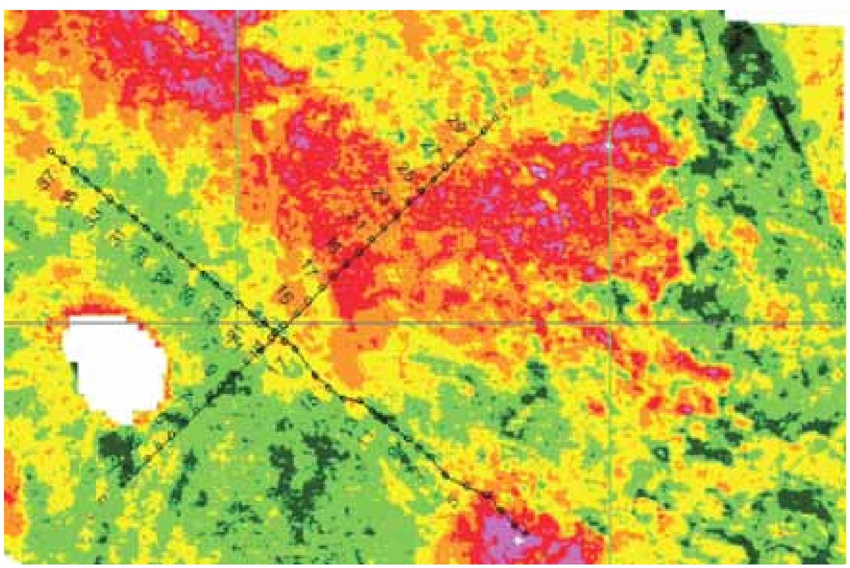




Data courtesy Maersk Oil, Shell and Chevron

Comparing CSEM and seismically derived resistivity…





Seismic + well log derived

	Water saturated	Hydrocarbon saturated
High baseline	(light blue line)	(pink line)
Low baseline	(blue line)	(red line)

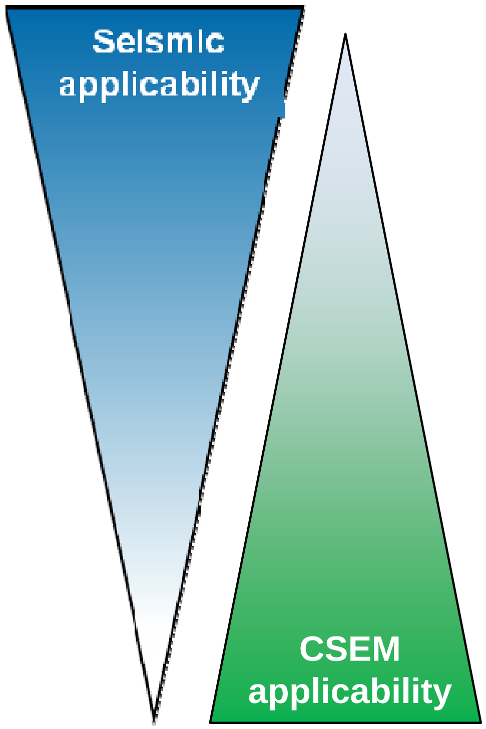
Data courtesy Maersk Oil, Shell and Chevron

Agenda

- An introduction to marine EM methods
- The commercial story so far
- Case studies
- **Where does CSEM fit within an overall exploration and exploitation strategy?**
- Conclusion

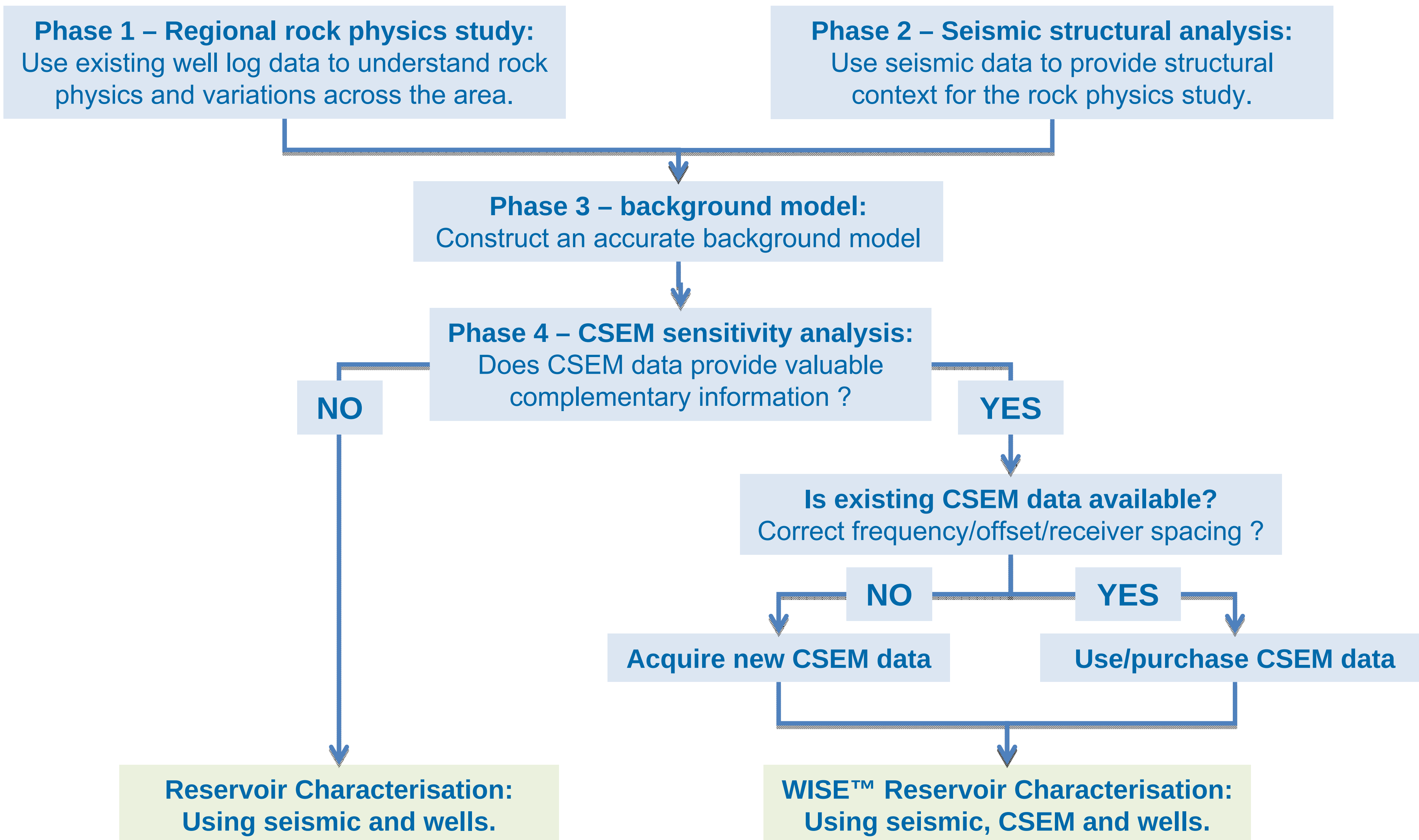
Seismic & CSEM together!

	Seismic availability?	Well availability?	CSEM interpretation risk
Frontier Exploration	None	None	High
Exploration	Sparse 2D, maybe 3D	None or limited	Model dependent
Appraisal	3D	Several	Low
Monitoring	3D/4D	Many	Low



Where does CSEM data fit ?

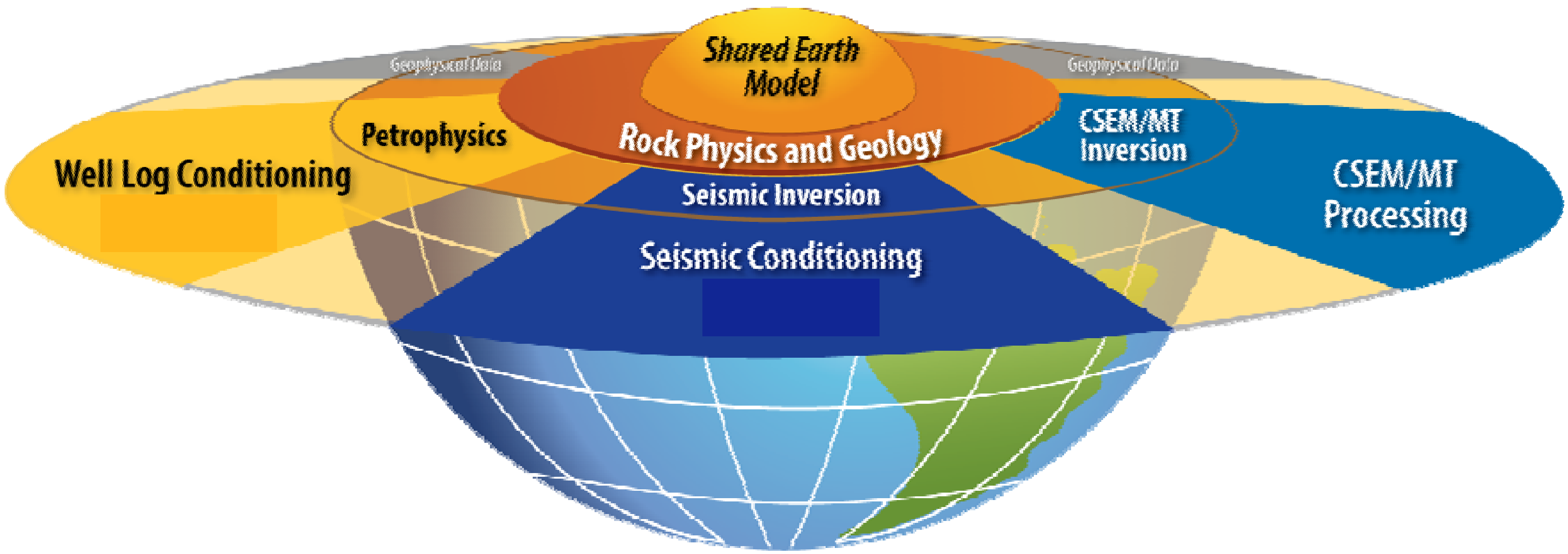
Objective: understand the geology and prospectivity of an area



Agenda

- An introduction to marine EM methods
- The commercial story so far
- Case studies
- Where does CSEM fit within an overall exploration and exploitation strategy?
- **Conclusion**

Summary



- Seismic is the “backbone” technology
- May not give all the answers?
- In cases where seismic is not the complete solution:
  - Can other geophysical methods help?
- Look towards:
  - CSEM
  - MT
  - Tensor Gravity

SEG 2011 European Lecture

"Integrating well logs, seismic and CSEM data for reservoir characterization"

http://www.seg.org/education/misc/hllibrary

Acknowledgements

My colleagues at RSI

OHM Ltd for data acquisition

SEG for permission to publish parts of the 2011 DL course

Maersk Oil, Shell, Chevron and Total for permission to show data

Thank You!