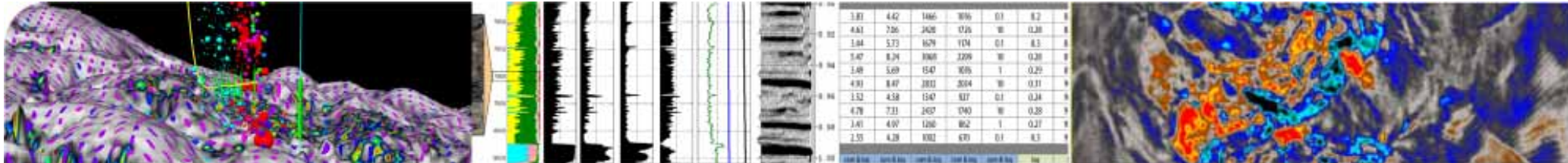


Extraordinary results. By any measure.



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



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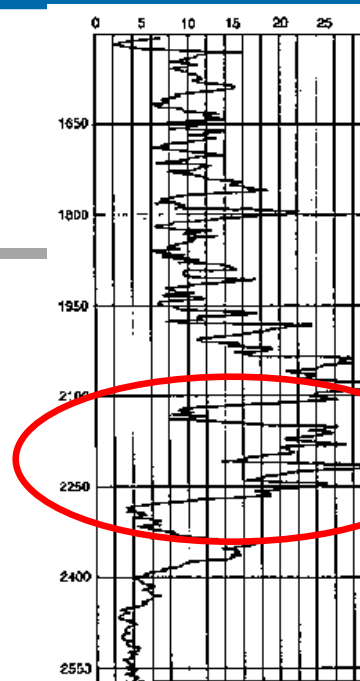
EM came first....



1912

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

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



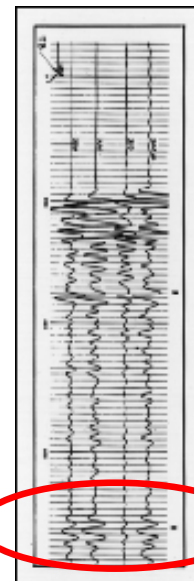
1927

“There is probably oil just below 1950 feet.”

First reflection seismic data recorded

1934

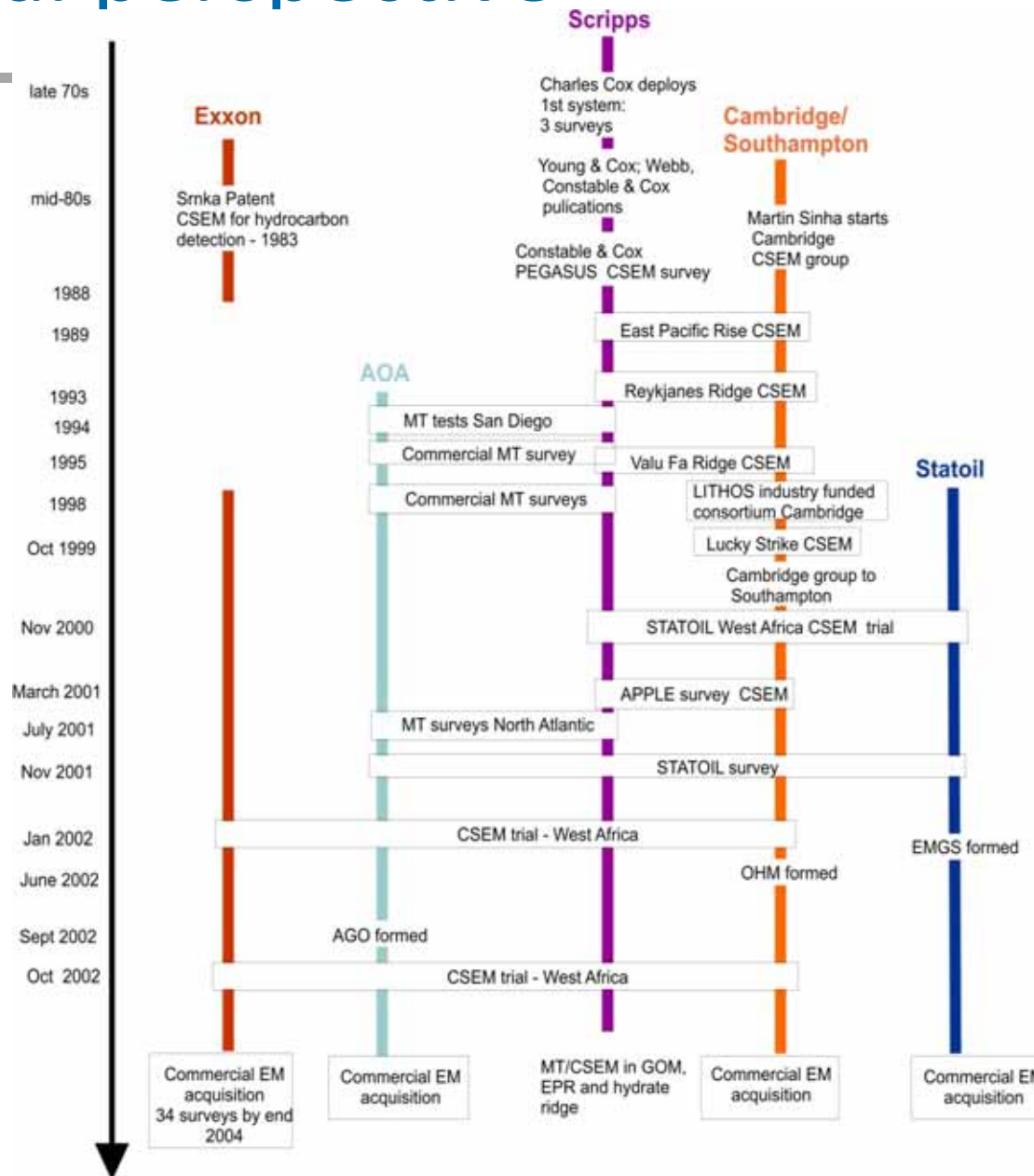
First electrical resistivity well log is recorded in Pechelbronn, France (image above is first well log in USA, 1929, Kern Co.)



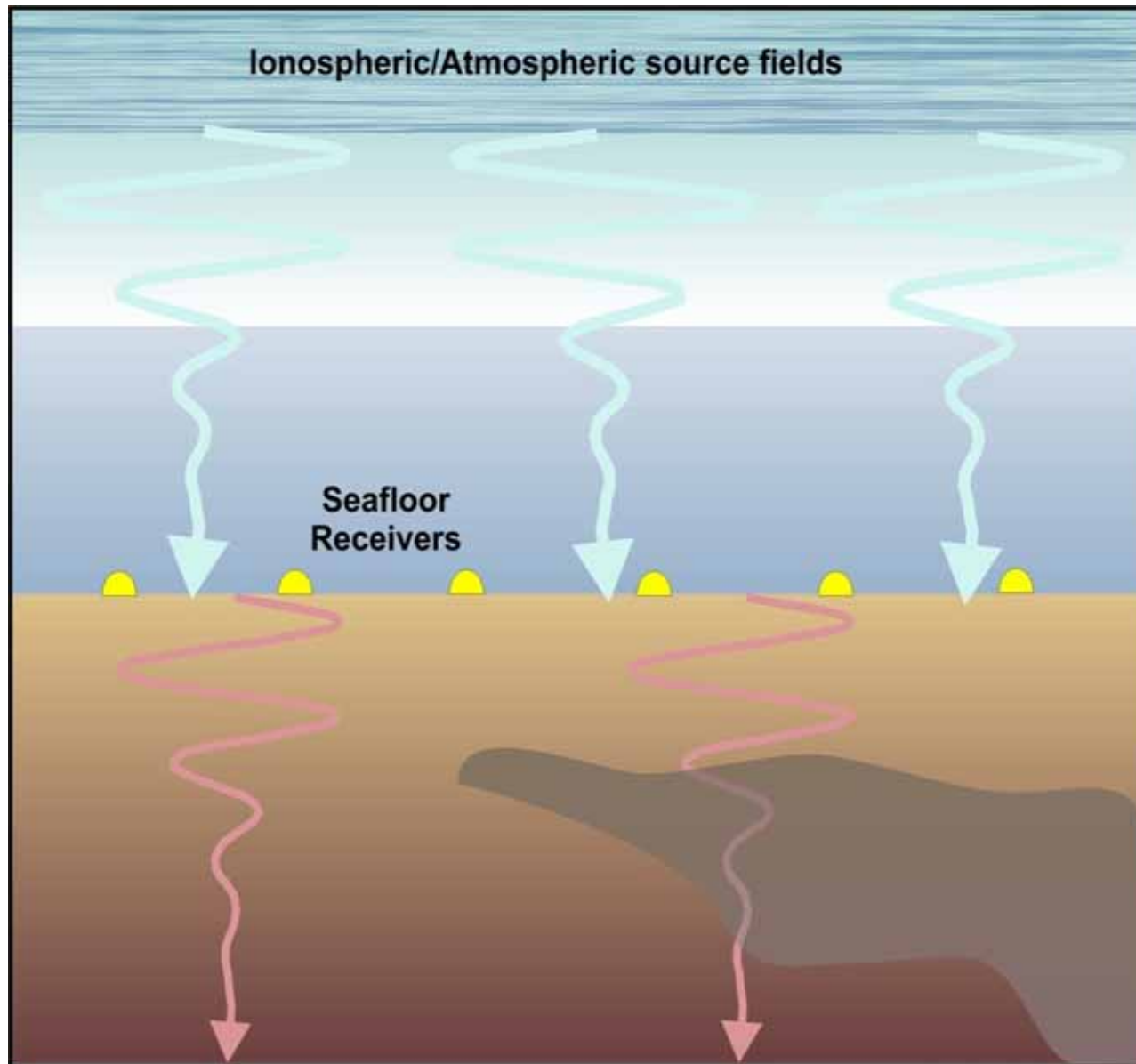
“There is different rock down there somewhere.”

Extraordinary results. By any measure.

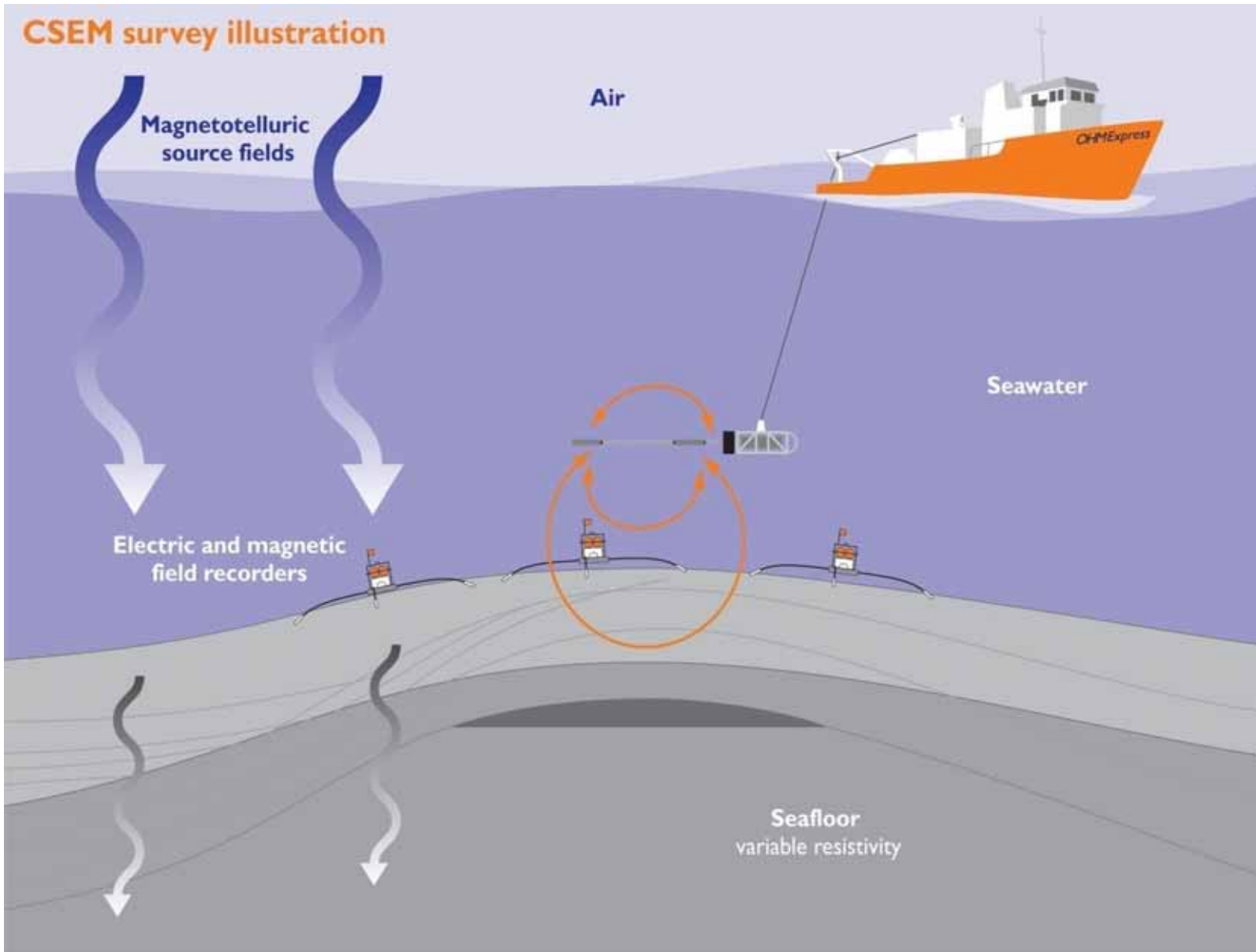
Historical perspective



Marine Magnetotelluric - MT



Controlled Source ElectroMagnetics - CSEM

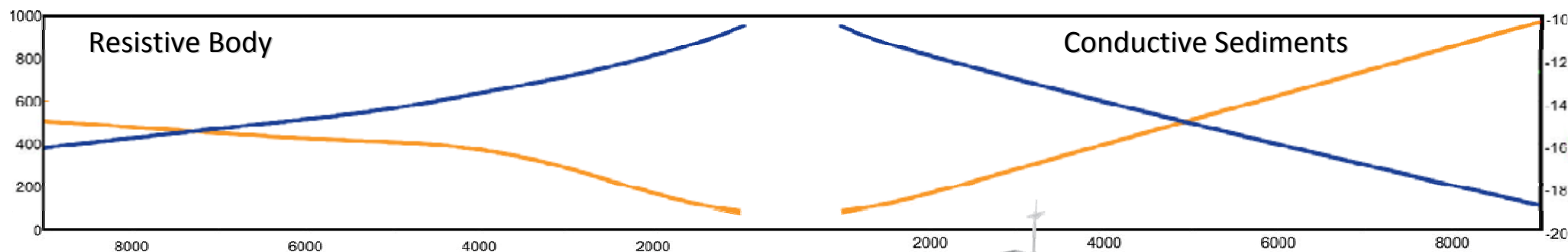


CSEM – Two Basic Measurements



Phase

Electric Field Strength



Sea Water

Reservoir (Resistive body)

Conductive Sediments

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

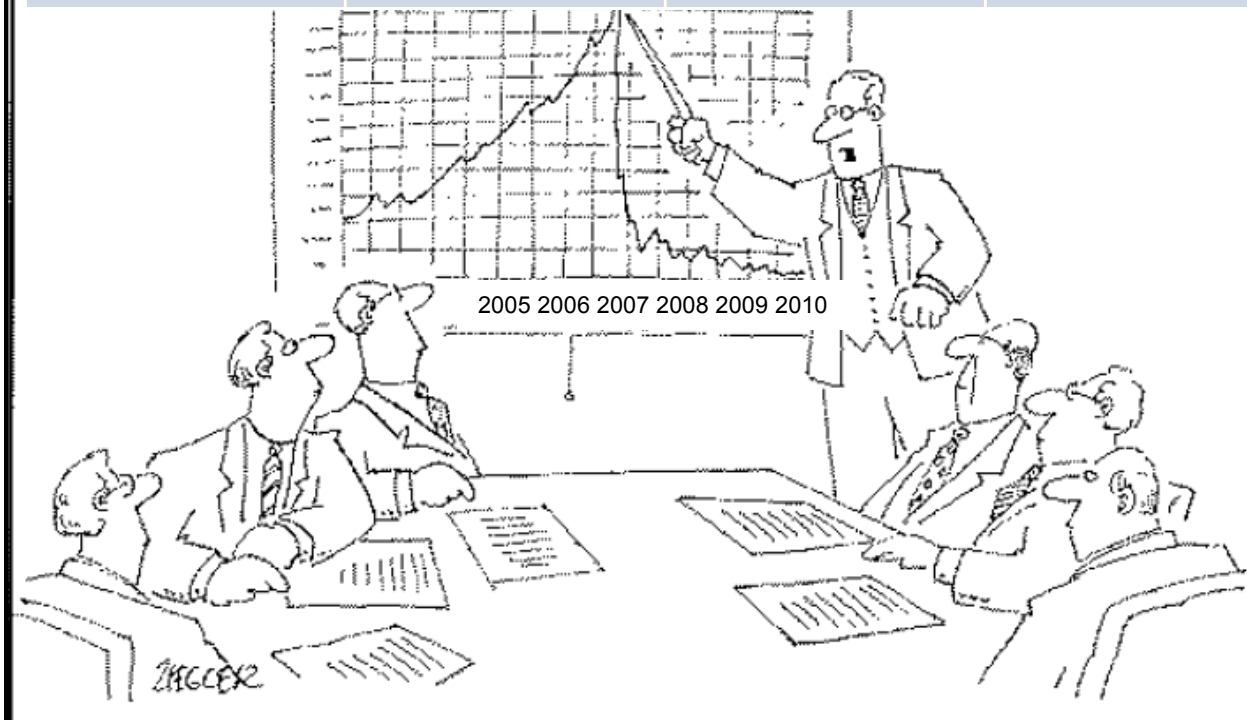
Agenda



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“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

**Stop exploring.
Start finding.**

The last 20 years have seen huge advances in exploration technology. But success rates continue to decline.

It's been a hit-and-miss affair
In its pursuit of new hydrocarbons, the exploration industry has relied on indirect evidence.

Traditional exploration workflows, which evaluate petroleum systems, source rocks, seals and structures, are good at establishing the locations where hydrocarbons can exist.

But, amg's award-winning seabed-logging technology is able to show whether hydrocarbons do exist.

The new standard
Today, with more than 200 commercial surveys recorded, seabed logging is revolutionising how the industry finds hydrocarbons.

Seabed logging is enabling new exploration strategies such as scanning frontier and mature regions for new leads. These strategies are delivering prospects earlier than traditional methods. And operators continue to use seabed logging to rank prospects before they commit further resources.

It's hardly surprising then, that every day more and more exploration professionals are building seabed logging into their workflows. Indeed, right now over 35 leading operators worldwide are using seabed logging to evaluate existing prospects – and to find new ones.

Improving the workflow
Seabed logging remotely measures subsurface resistivity contrasts. Of course, as formation resistivity is the industry's most effective hydrocarbon indicator and has been for the past 75 years, it makes perfect sense to include seabed logging in the exploration workflow.

Finding hydrocarbons™

Seabed logging
Winner of 2007 E&P 2006 Special Merit Award for Engineering Innovation

Market adoption/growth barriers: CSEM



CSEM considered to be “expensive” compared to seismic:

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

S
ms

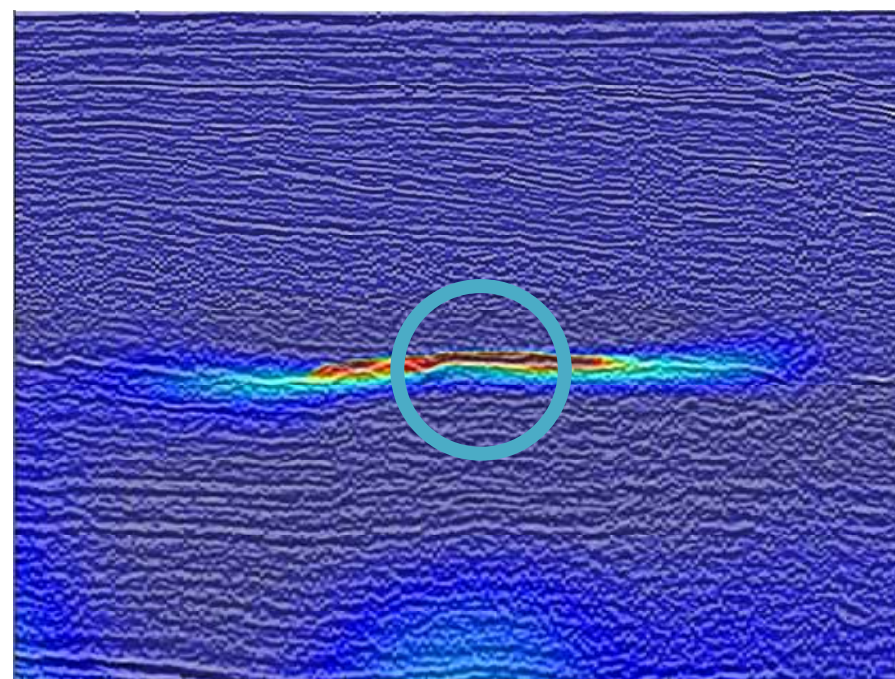
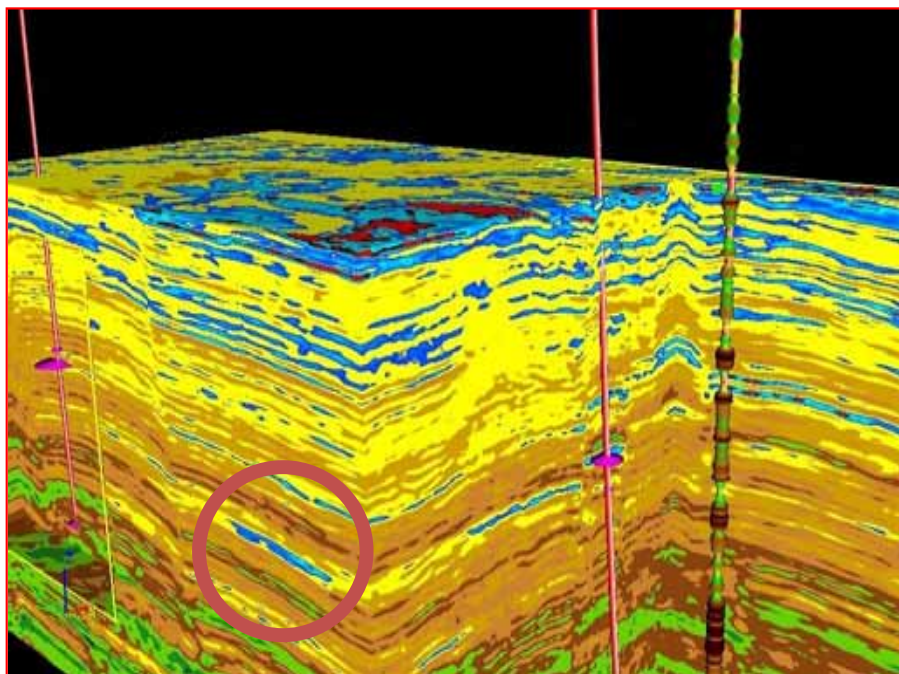
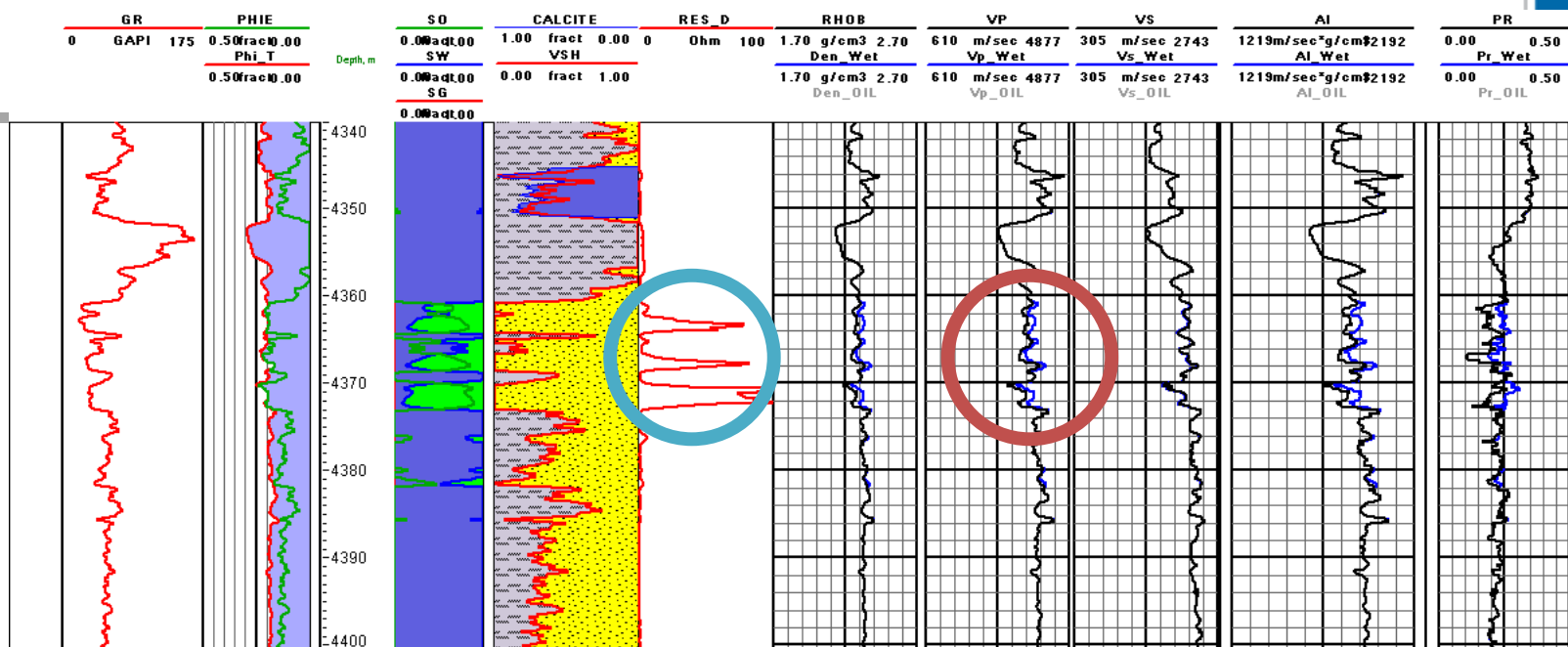
Better, faster, cheaper!

Agenda



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 1. **Norwegian Sea Gas Reservoir**
 2. **Fluid in a Chalk interval**
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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.

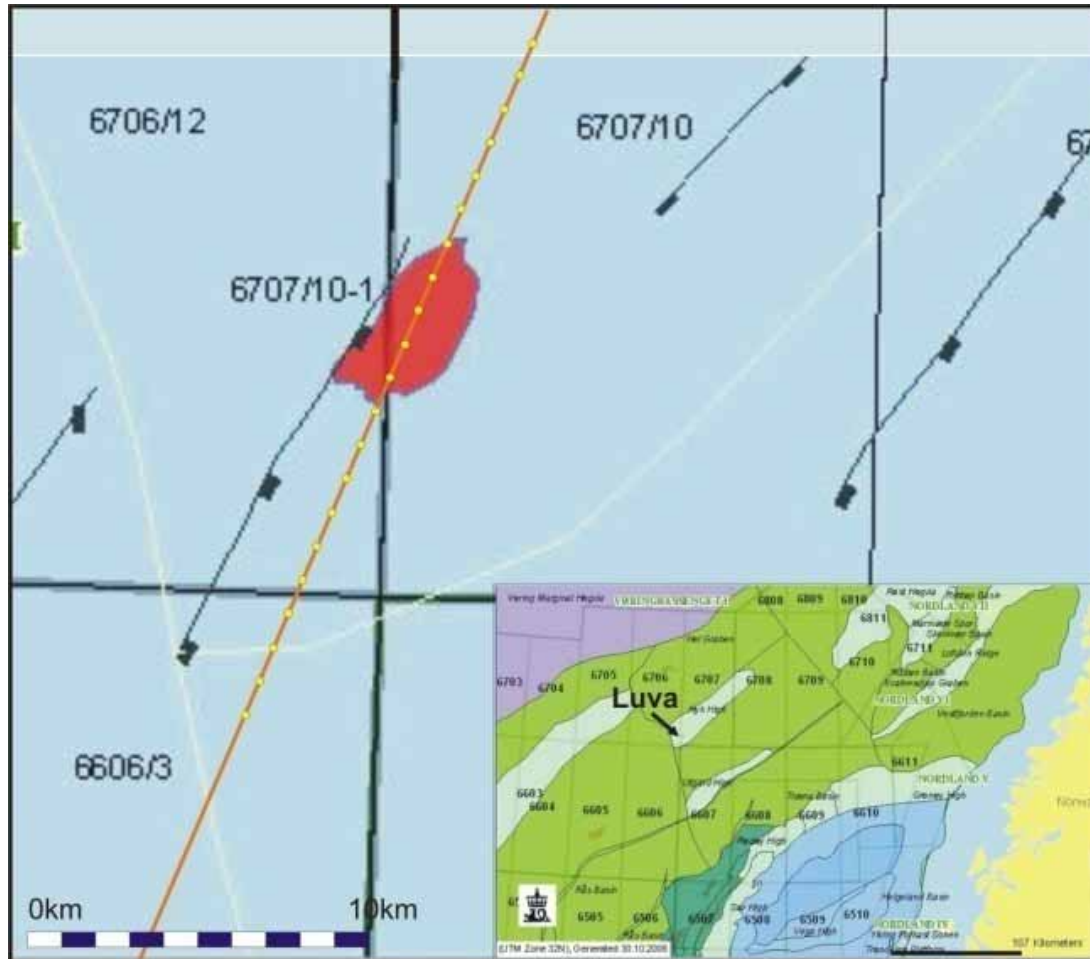
So we need to use the right tool (or tools) for the job....

Agenda



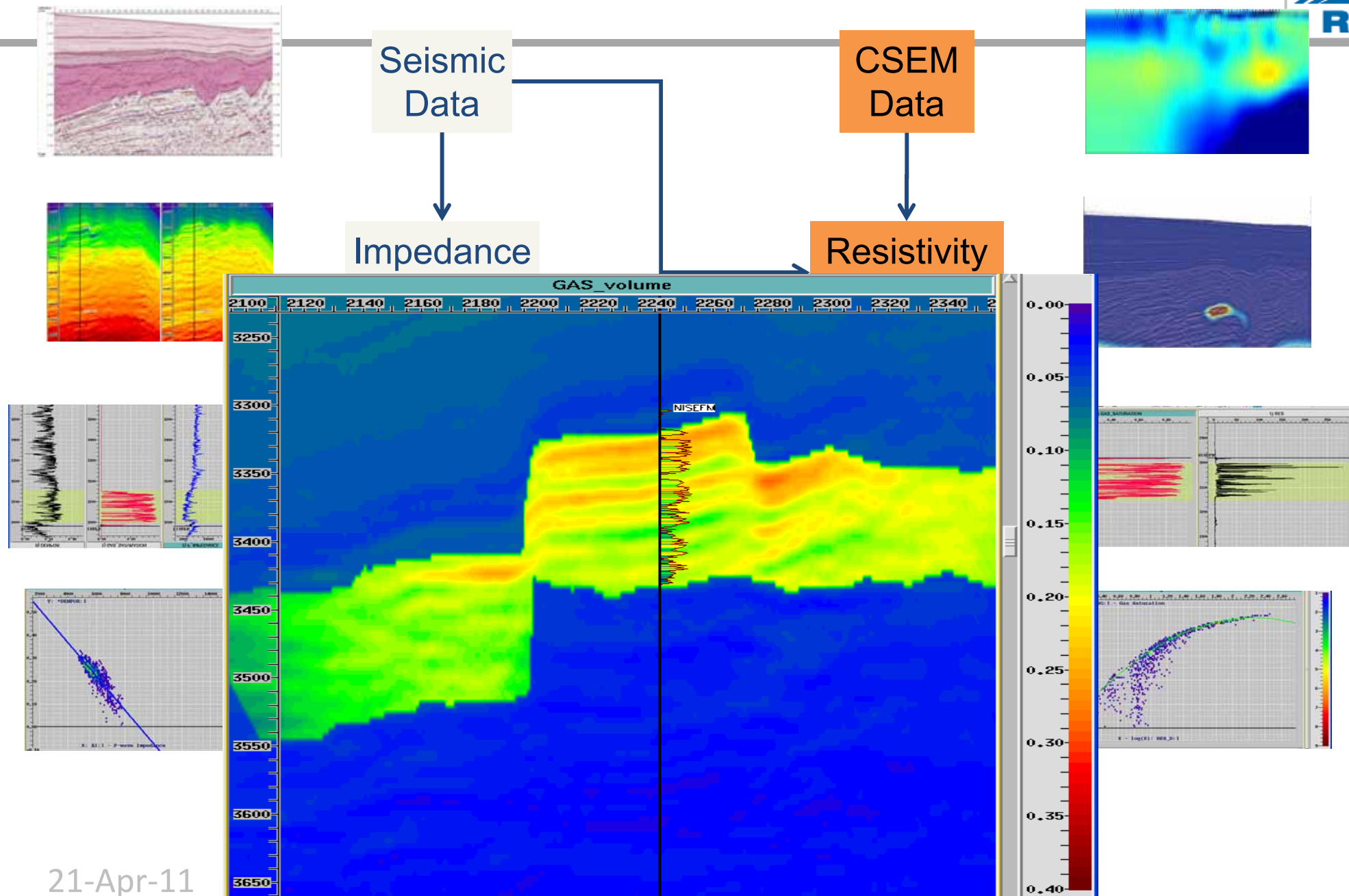
- An introduction to marine EM methods
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Appraisal



- 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



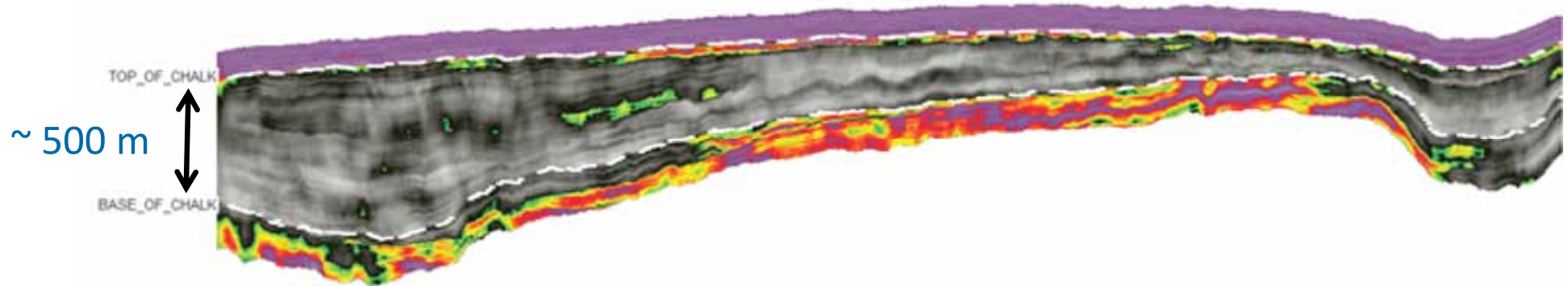
21-Apr-11

Agenda



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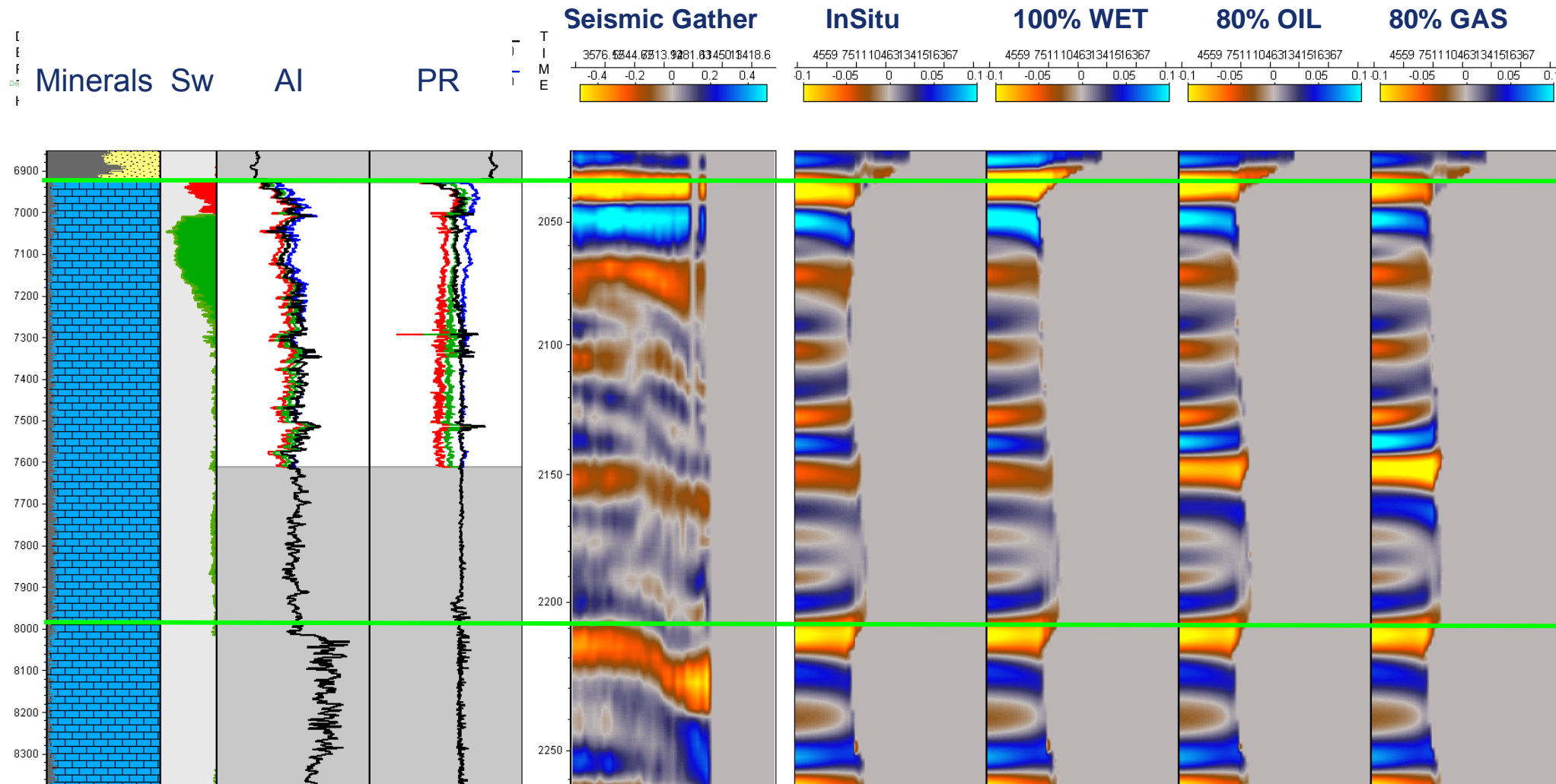
What is the fluid within a North Sea Chalk ?



- 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

Gassmann fluid substitution

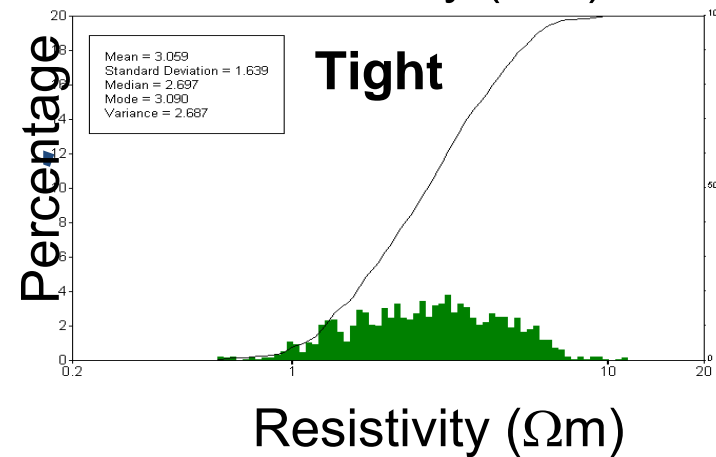
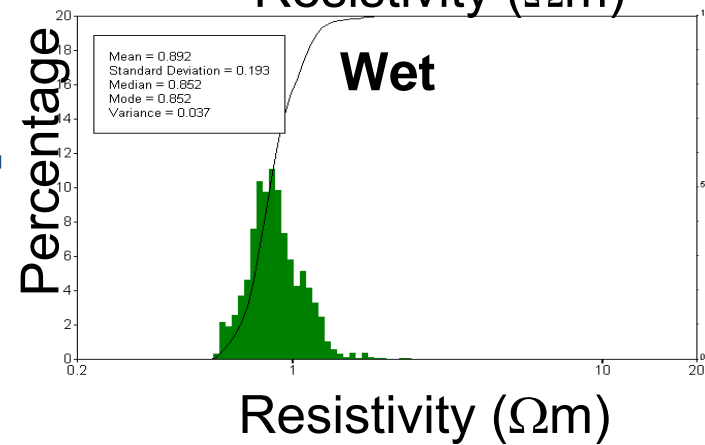
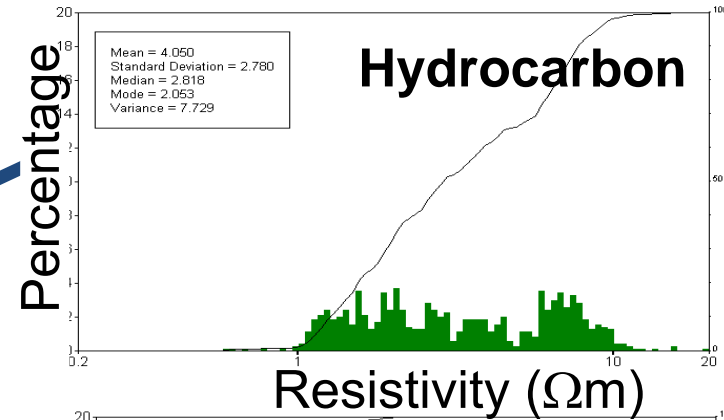
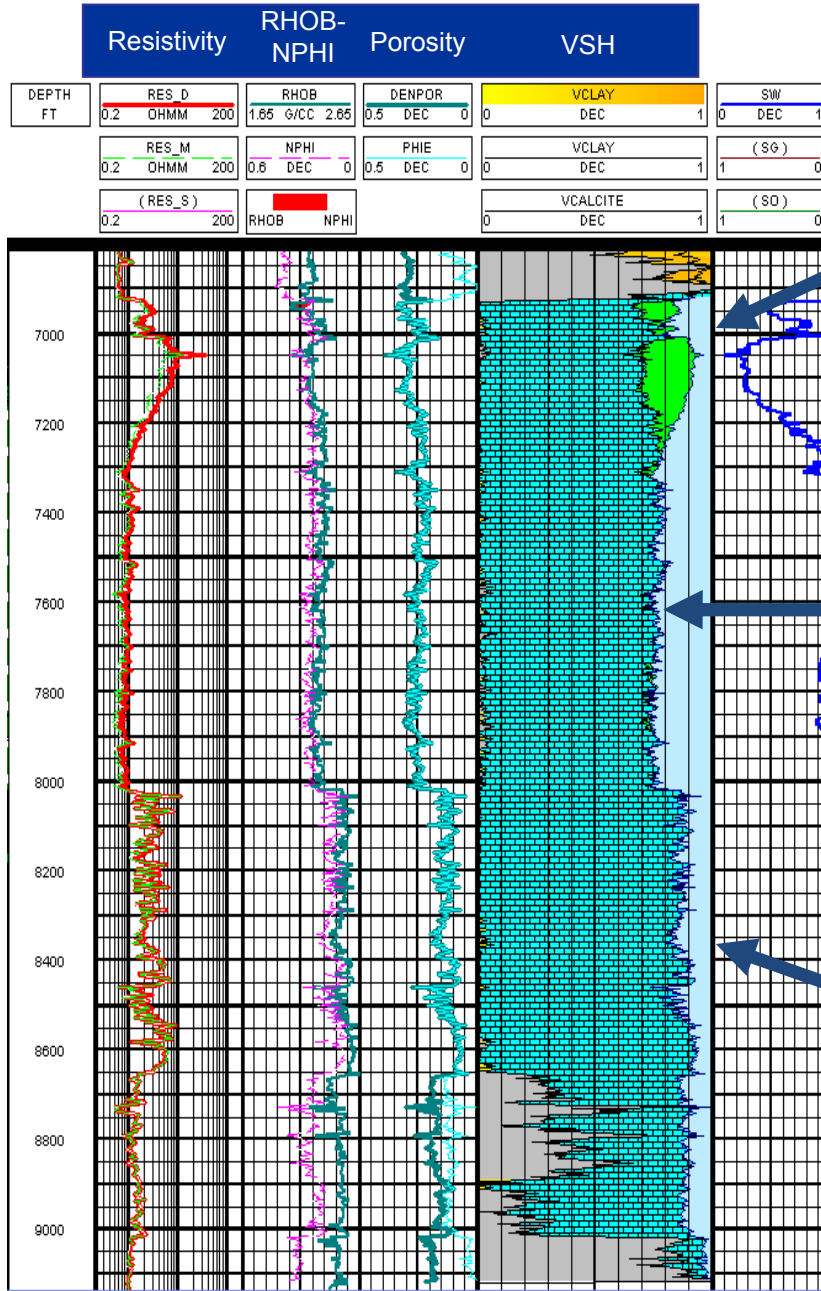


Data courtesy Maersk Oil, Shell and Chevron

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Extraordinary results. By any measure.

Chalk resistivity



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

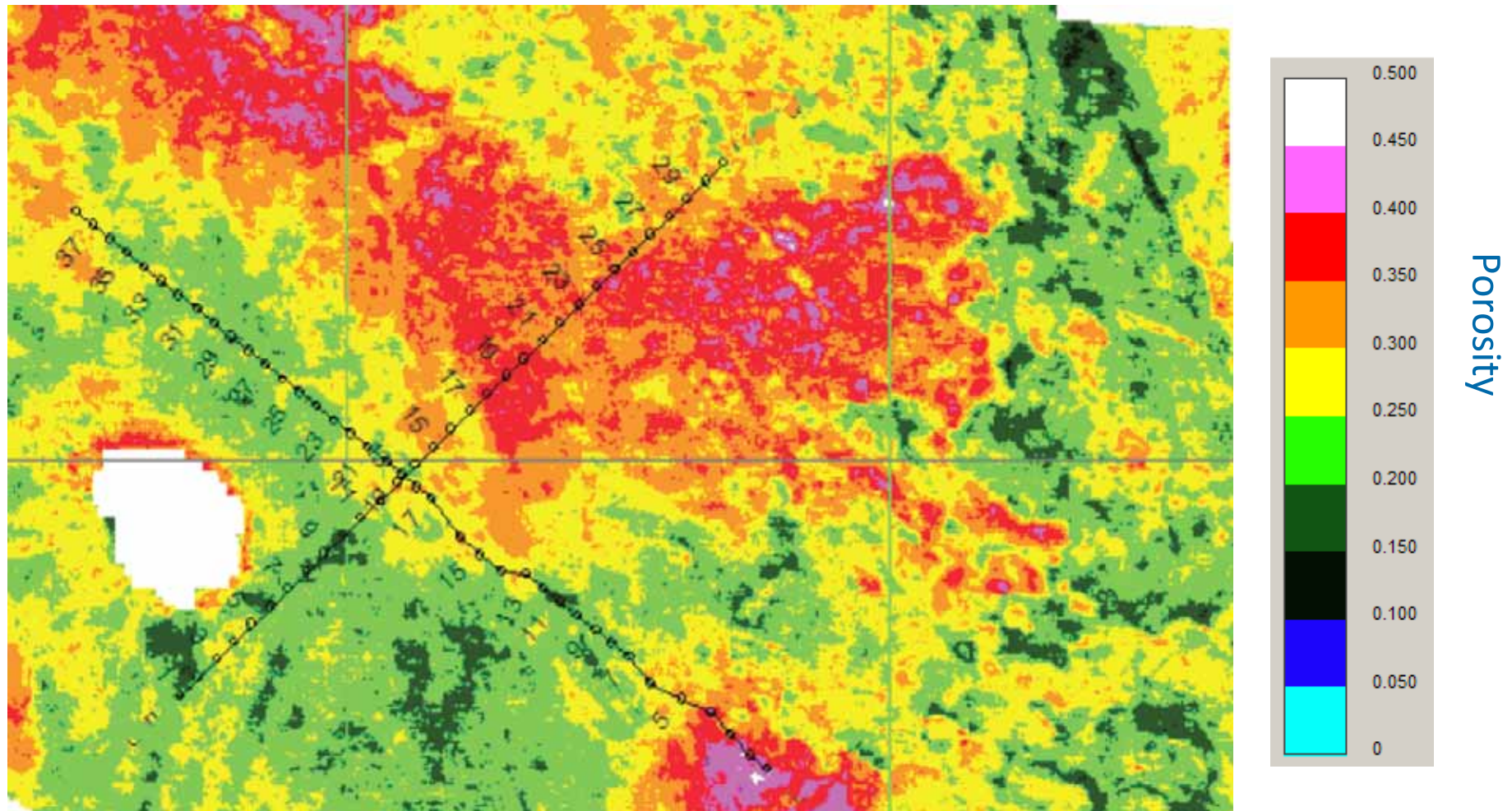


Use seismic to
determine
porosity...



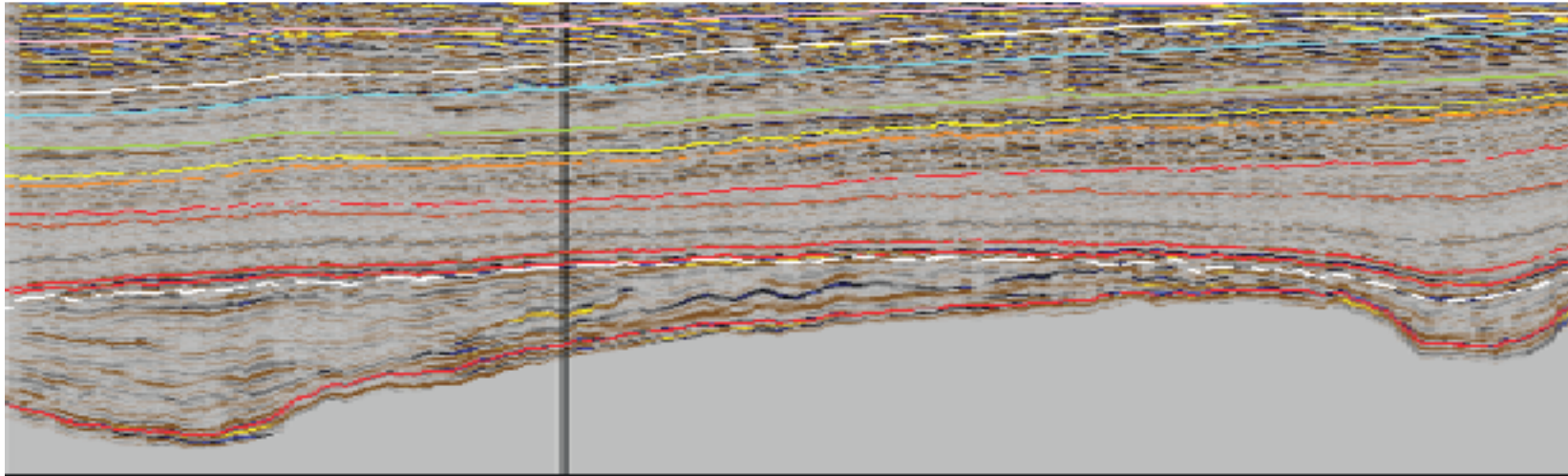
...then use CSEM to
determine the fluid
content

Porosity derived from seismic inversion



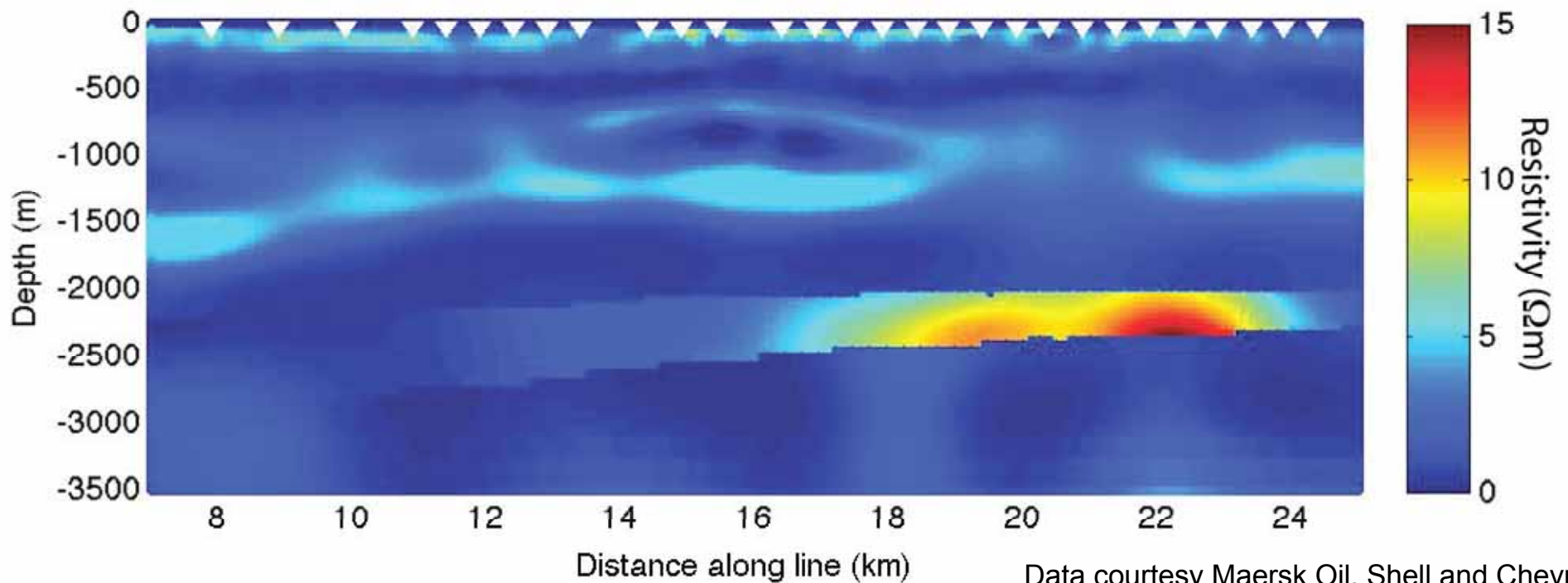
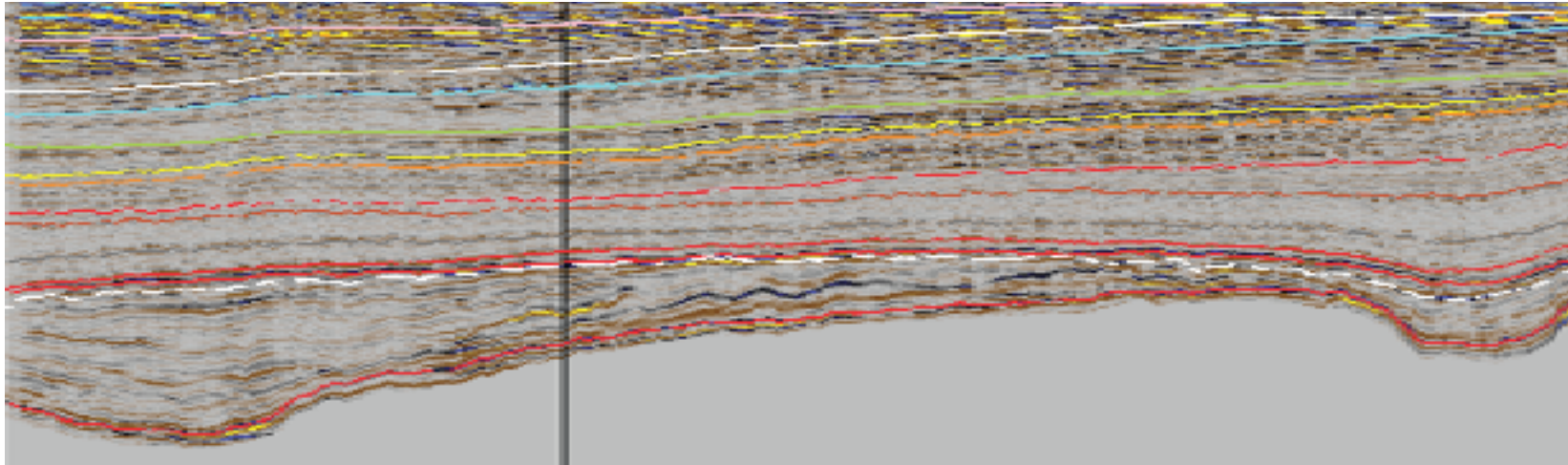
Average porosity in the top 24m of the chalk: can find the reservoirs but not the content

2D constrained inversion



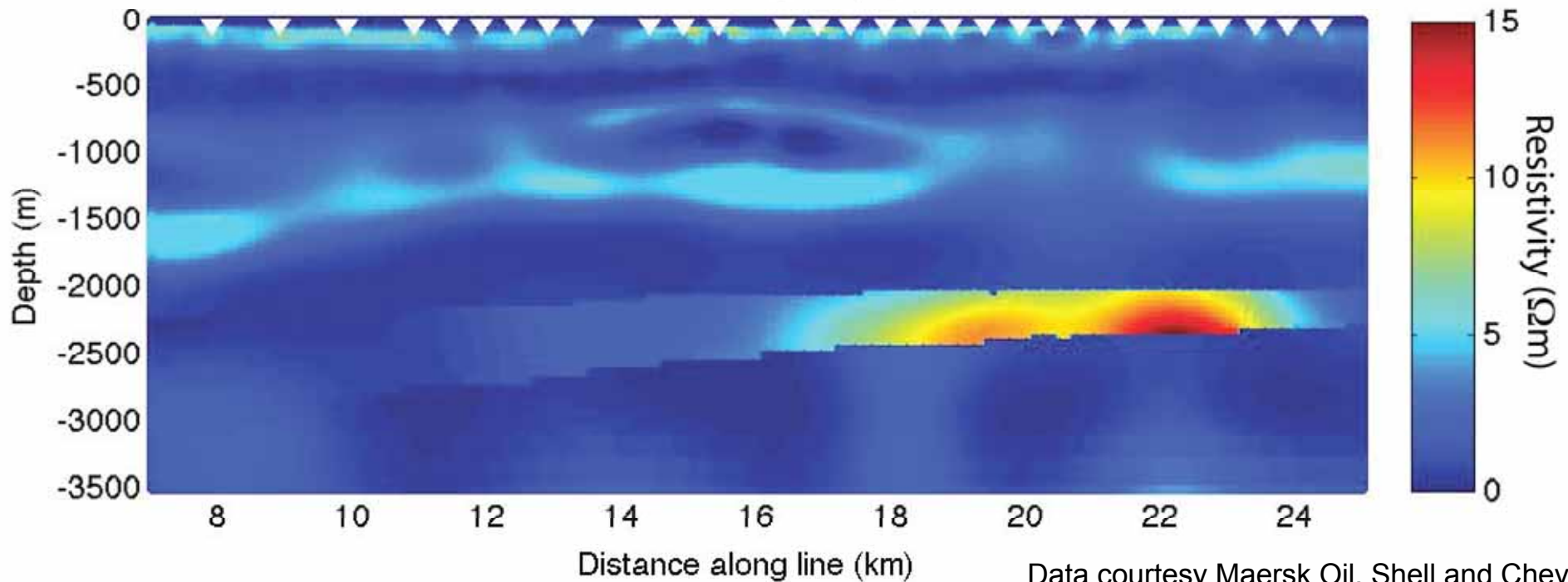
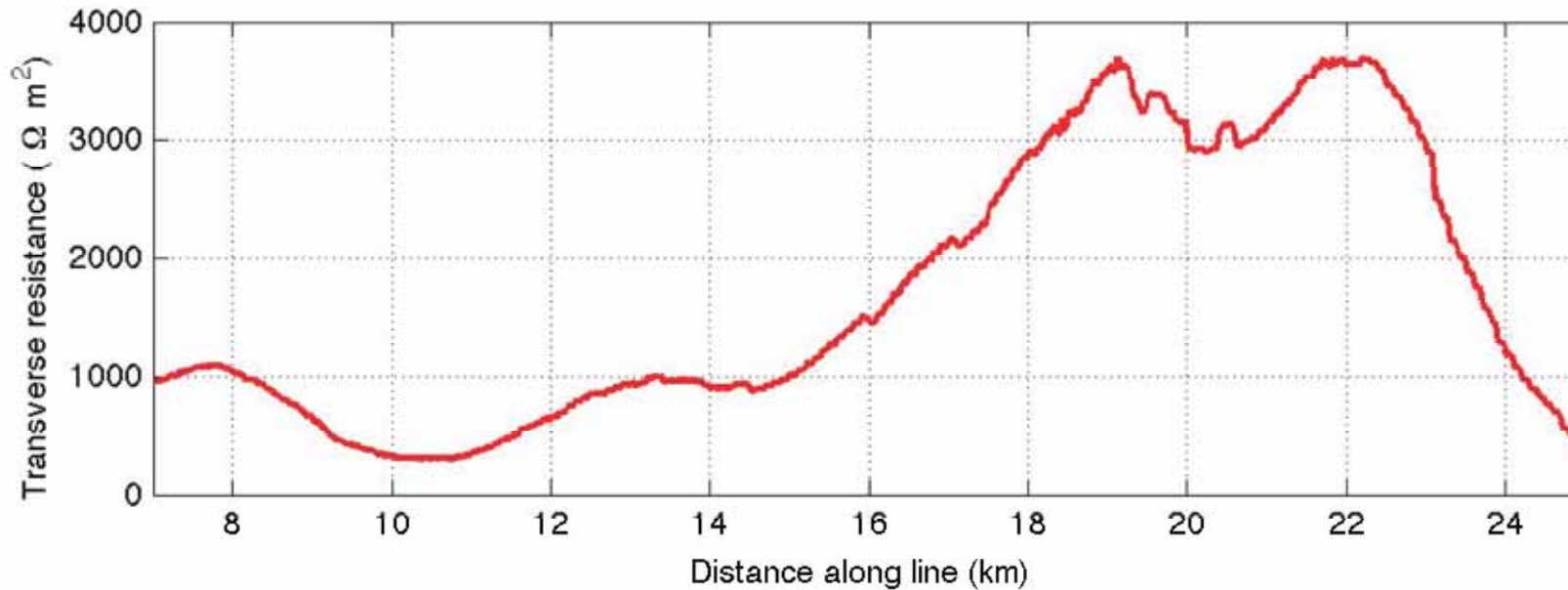
- CSEM data alone has poor structural resolution
- Use the seismic structure to constrain the CSEM inversion by allowing breaks in smoothness at top and bottom chalk.
- In each case invert 0.05Hz, 0.25Hz and 0.6Hz amplitude and phase

2D constrained inversion



Data courtesy Maersk Oil, Shell and Chevron.

Transverse resistance

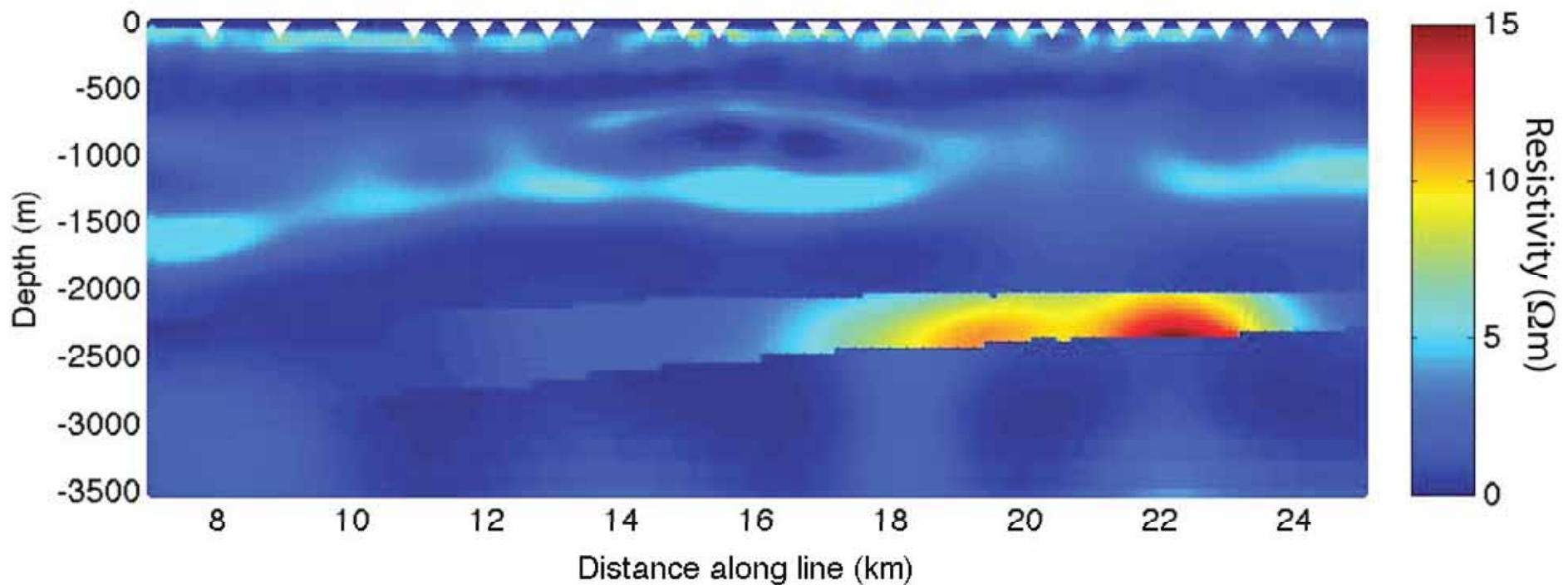


Data courtesy Maersk Oil, Shell and Chevron.

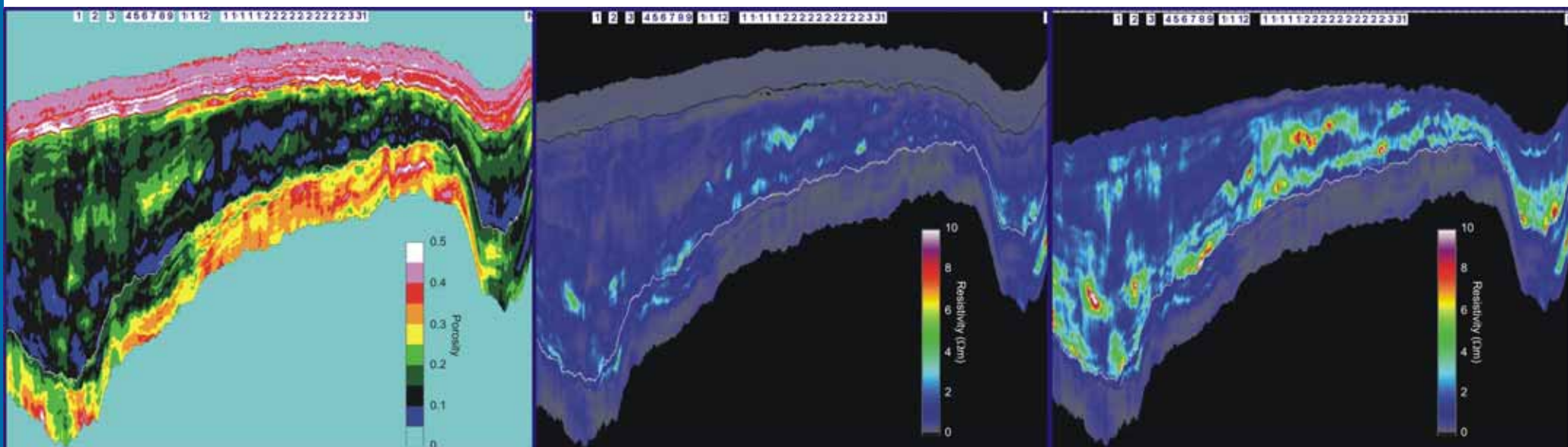
Is the increase in resistivity related to...



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



Chalk Resistivity Sections: based on seismic



$R_w = 0.03758 \, \Omega\text{m}$ in Chalk

$R_w = 0.08 \, \Omega\text{m}$ in Chalk

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

100% water saturation

R_w and m from well log calibration

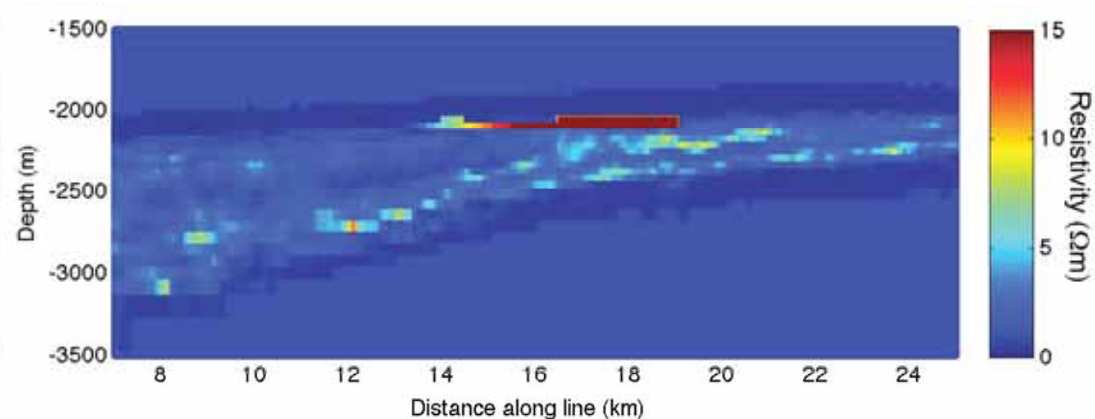
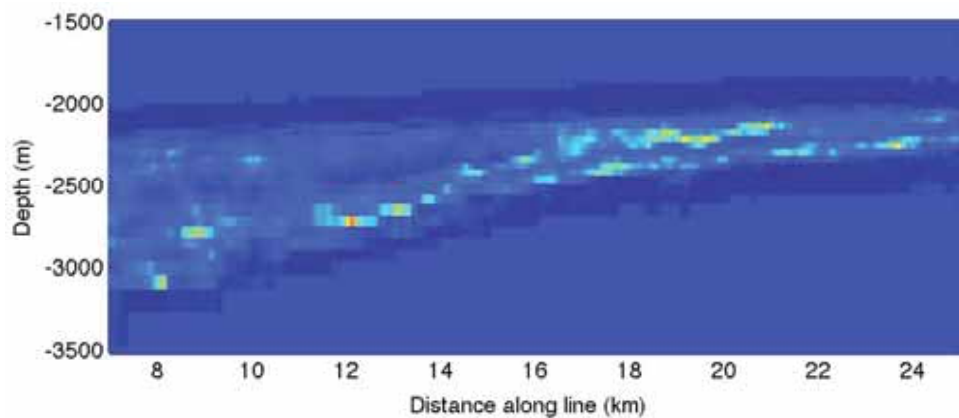
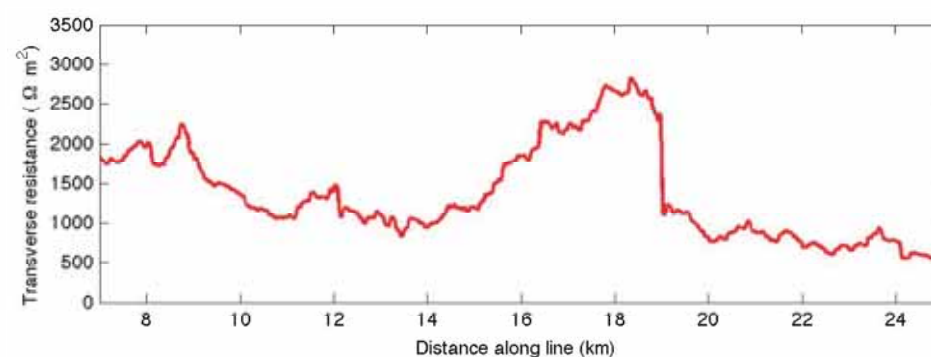
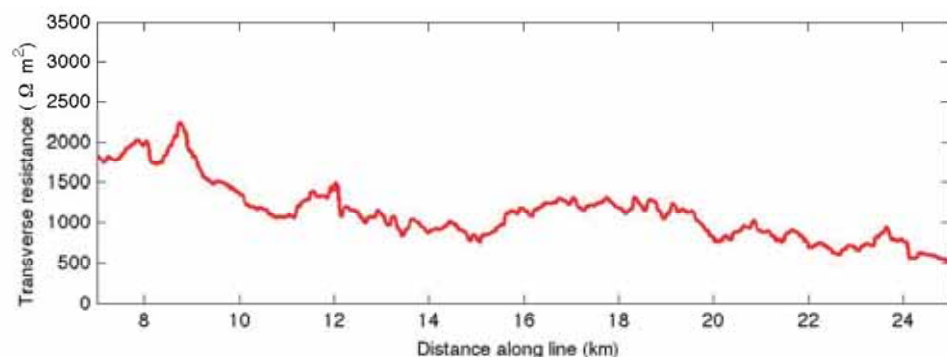
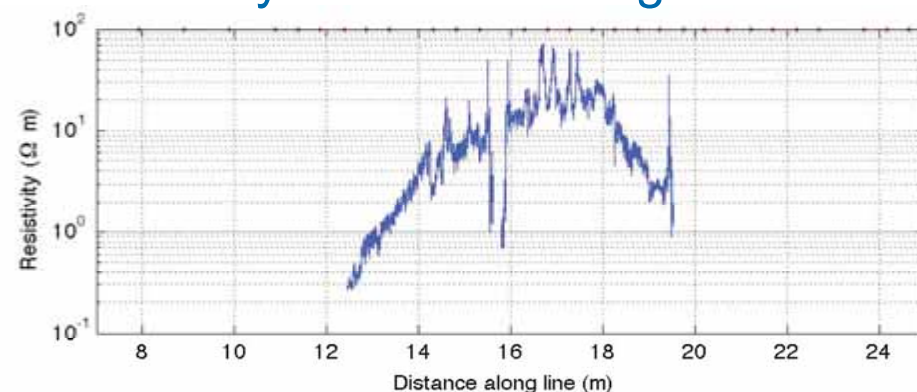
Porosity from seismic.

Transverse resistance: seismically derived model

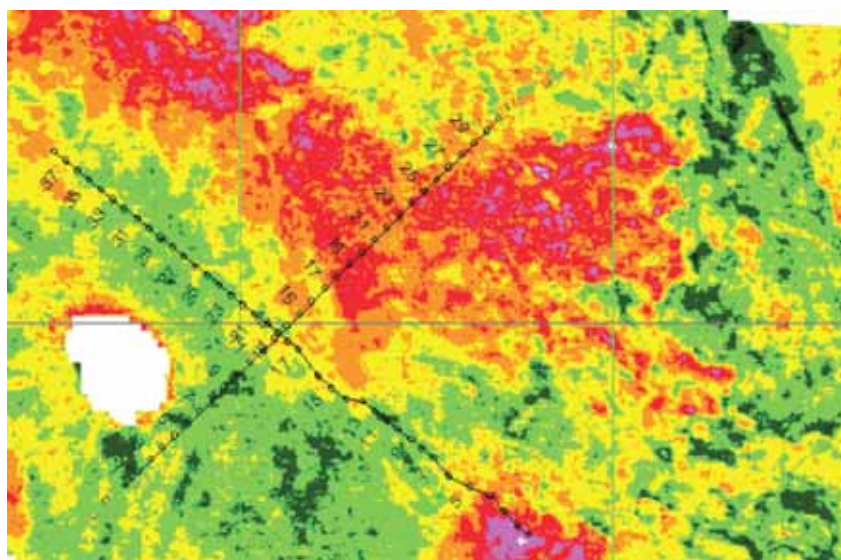
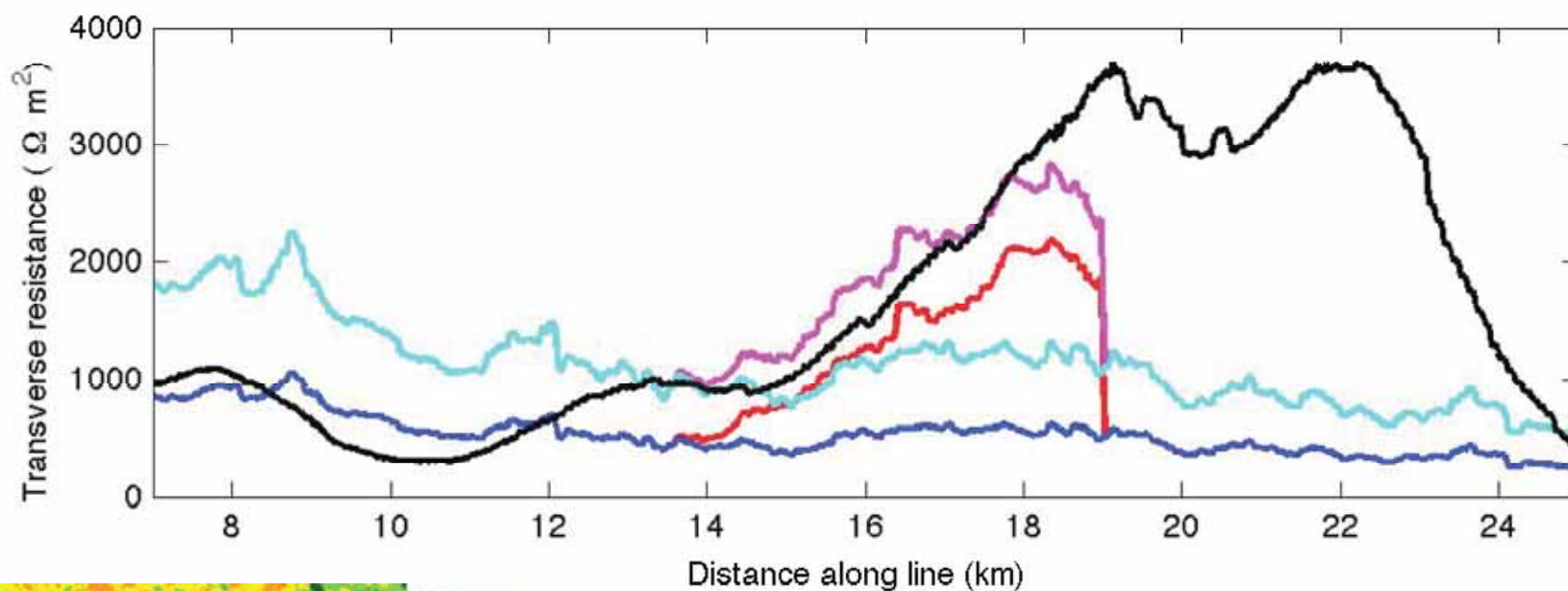


Hydrocarbon charged

100% water saturated



Comparing CSEM and seismically derived resistivity...



Seismic + well log derived

Water
saturated

Hydrocarbon
saturated

— High baseline

—

— Low baseline

—

Agenda

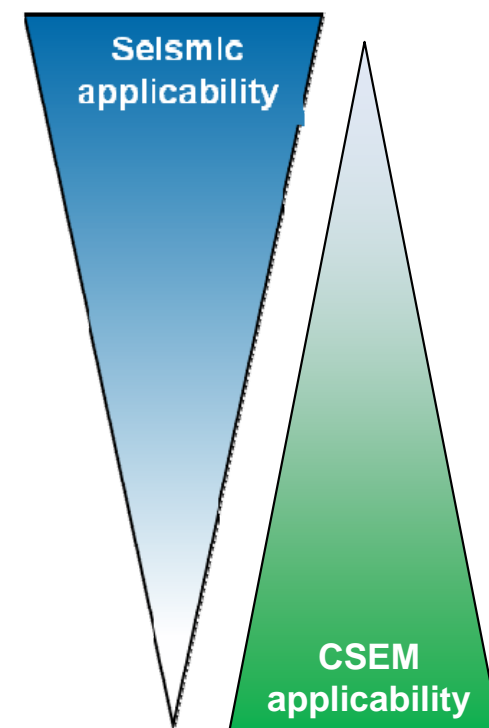


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Seismic & CSEM together!



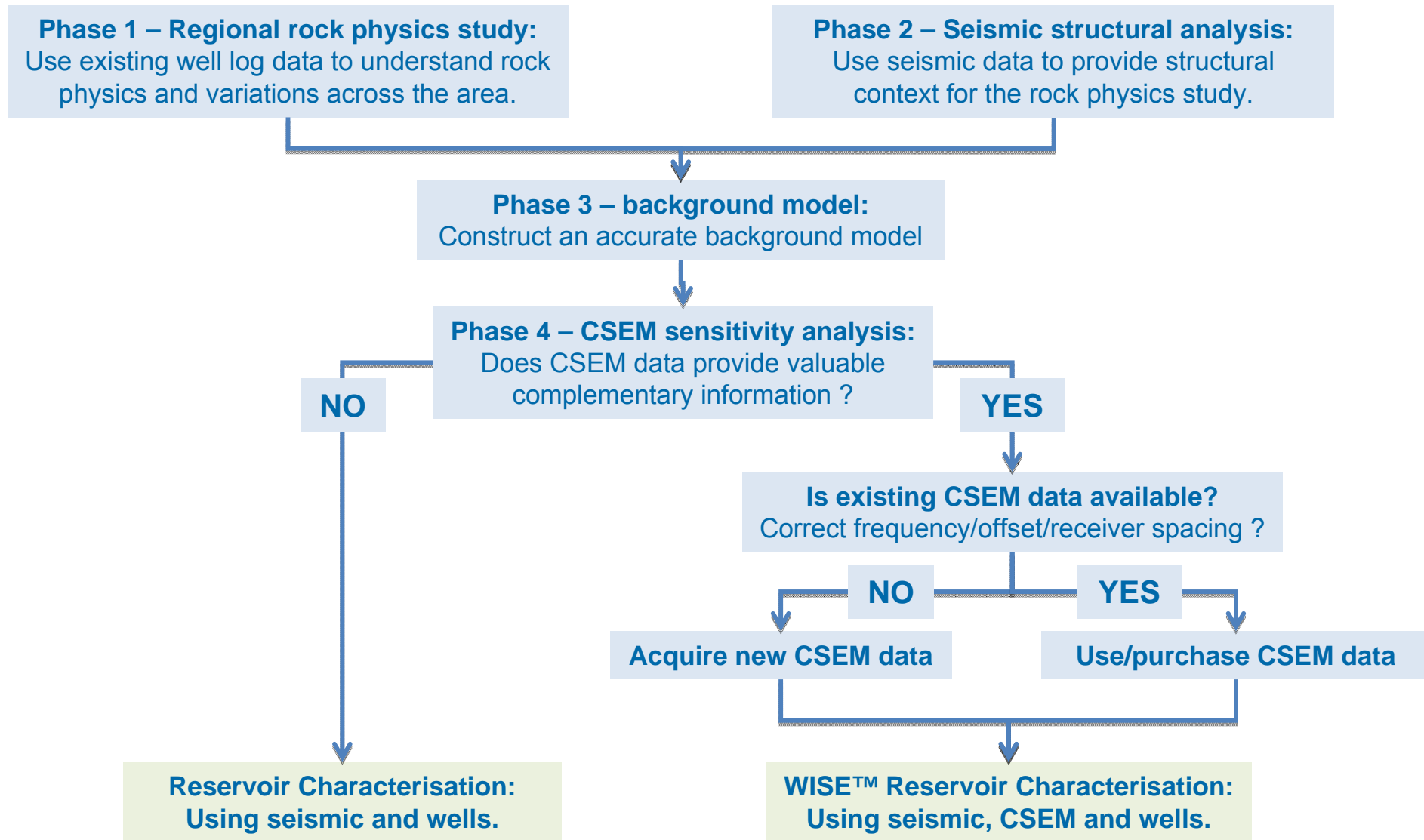
	Seismic availability?	Well availability?	CSEM interpretation risk
Frontier Exploration	None	None	High
Exploration	Sparse 2D, maybe 3D	None or limited	Model dependent
Appraisal	3D	Several	Low
Monitoring	3D/4D	Many	Low



Where does CSEM data fit ?



Objective: understand the geology and prospectivity of an area

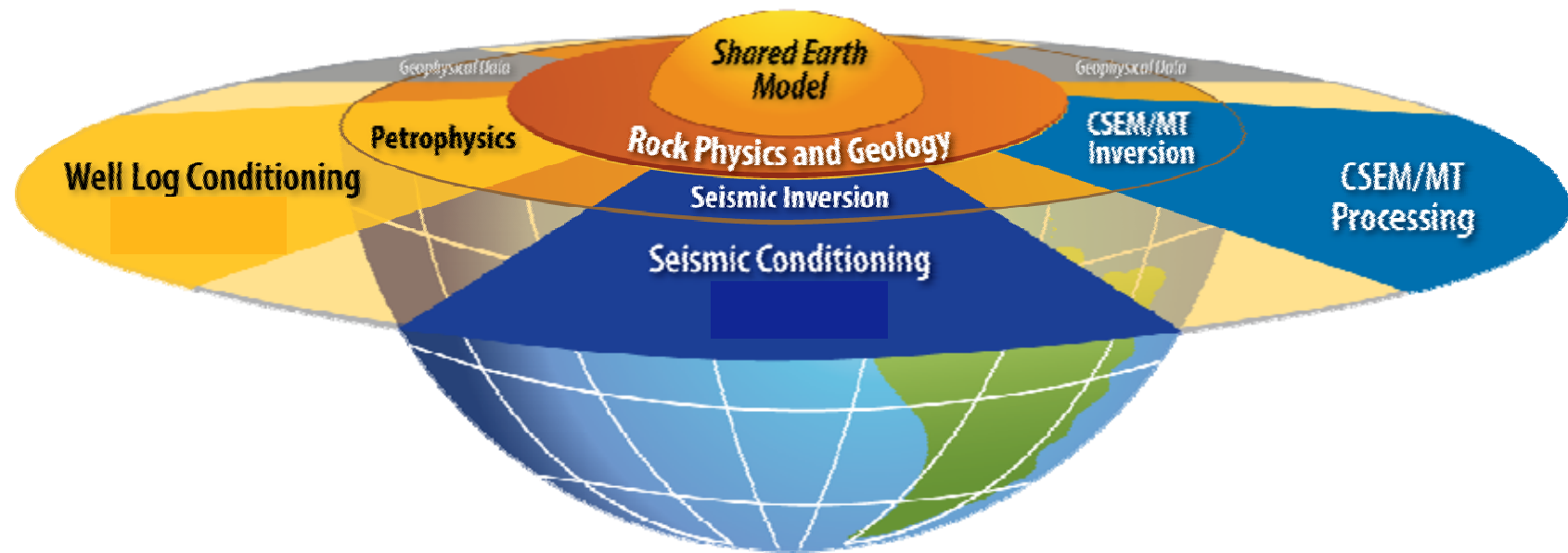


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Summary



- 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”



The screenshot shows the SEG Honorary Lecture library website. The header includes the SEG logo, a world map, and navigation links: SEG, DIGITAL LIBRARY, FOUNDATION, 中国, Donate, Careers, Community, Shop, and Register. Below the header, the text reads "Society of Exploration Geophysicists" and "The international society of applied geophysics". A search bar is present on the right. The main content area is titled "Honorary Lecture library" and is sponsored by Shell. It describes the SEG Honorary Lecture Program, which began in 2006 and is aligned with six geographical regions. It states that because of Shell's investment in the SEG Foundation, these lectures are recorded for online viewing. Users must be an SEG member to view these videos, with links to log in or become a member. A link is provided to view Distinguished Lecture presentations. A note indicates that videos are best viewed in Internet Explorer. Three lecture presentations are listed:

- Lucy MacGregor, 2011 Europe**
Integrating well logs, seismic, and CSEM data for reservoir characterization
- Aldo Vesnaver, 2010 Europe**
Talking and listening to reservoirs
- Ben Clennell, 2010 Pacific South**
Electrical properties of sedimentary rocks from DC to dielectric frequencies

<http://www.seg.org/education/misc/hlibrary>

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!