Mapping Gas Hydrate using Electromagnetic Methods

Steven Constable

Scripps Institution of Oceanography

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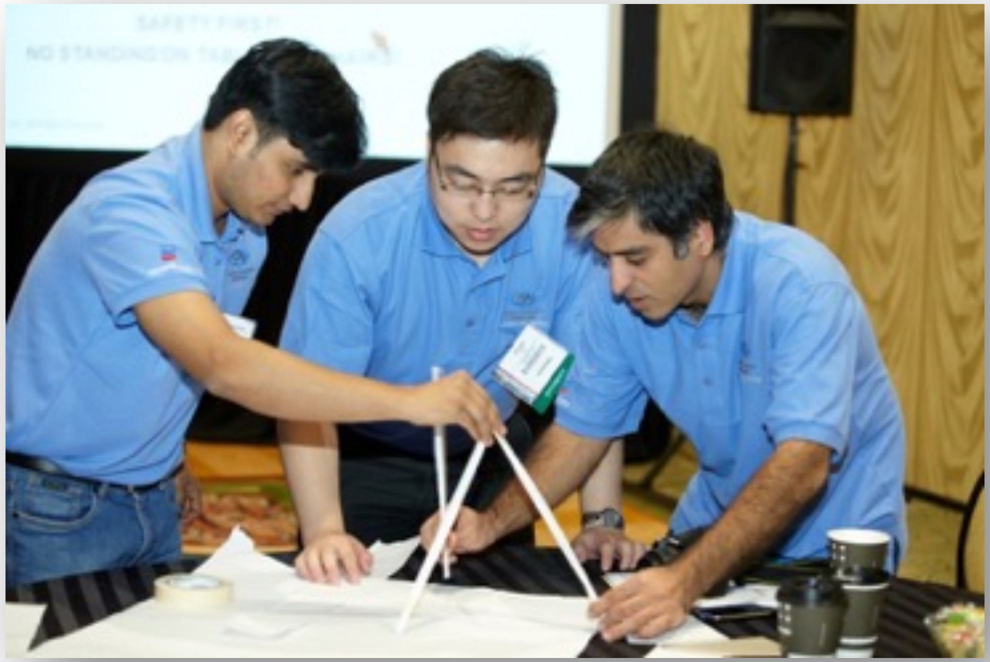

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March 2013:

SECTIONS HOME SEARCH

The New York Times

GLOBAL BUSINESS

An Energy Coup for Japan: 'Flammable Ice'

By **HIROKO TABUCHI** MARCH 12, 2013

Gas flames being expelled from a burner in a deep-sea drilling vessel in the Pacific off Japan. Jogmec, via European Pressphoto Agency

Email

TOKYO — Japan said Tuesday that it had extracted gas from offshore deposits of methane hydrate — sometimes called "flammable ice" — a breakthrough that officials

Hydrate: the What, the Where, and the Why

Laboratory studies of hydrate electrical conductivity

Marine EM methods

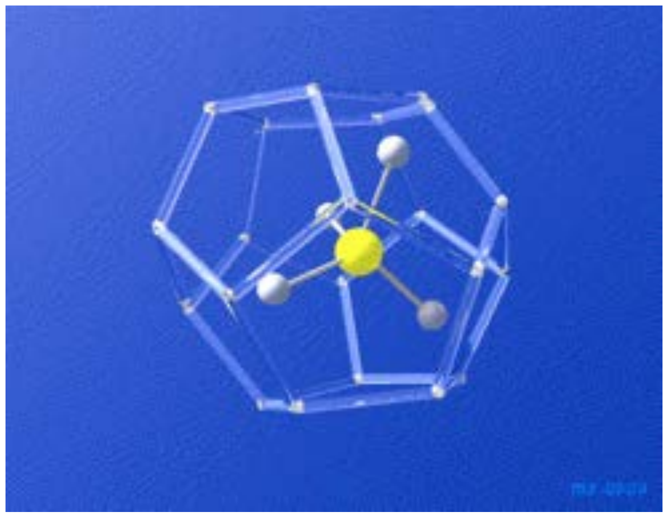
Hydrate Ridge experiment

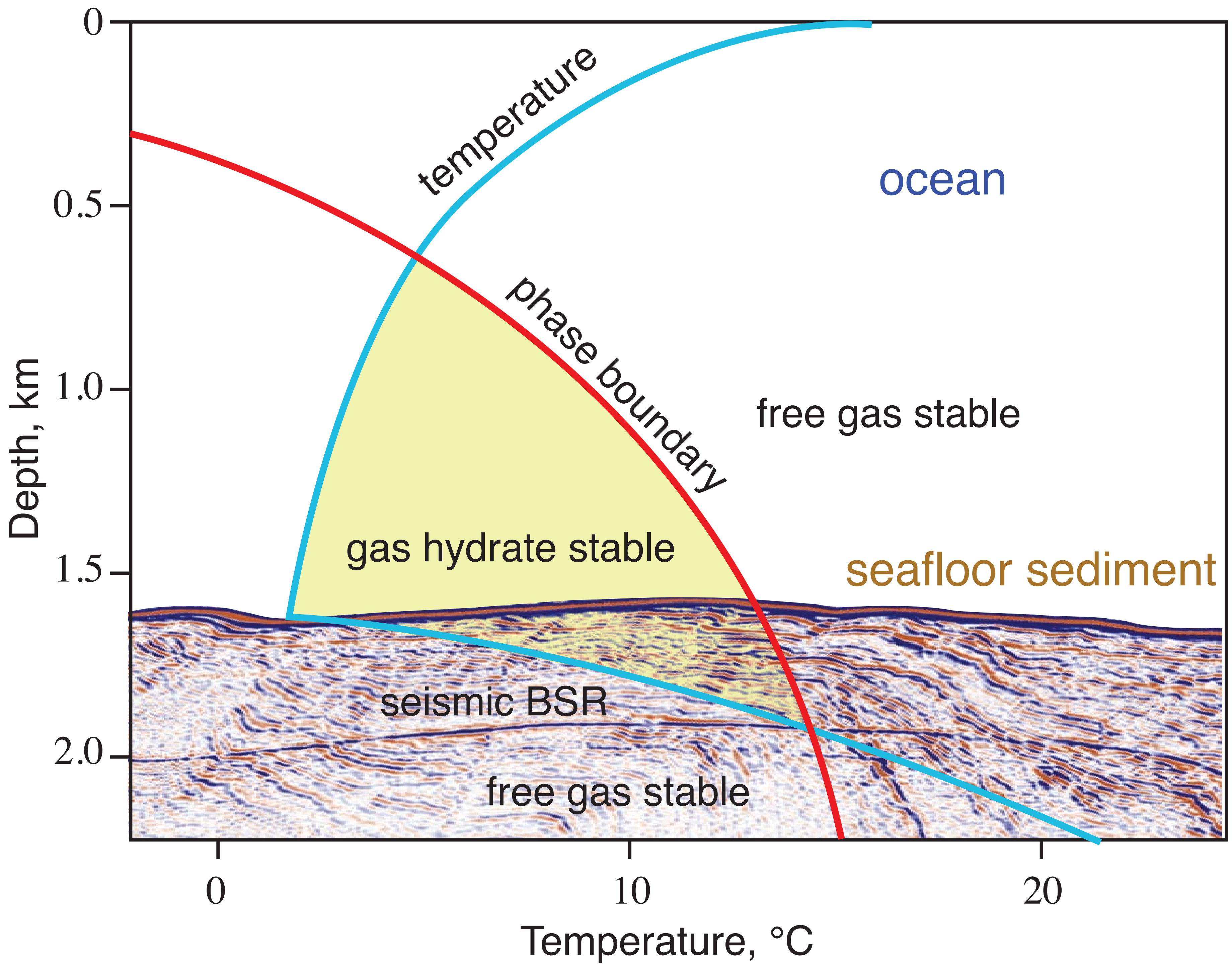
The Vulcans

2015 San Diego Trough tests

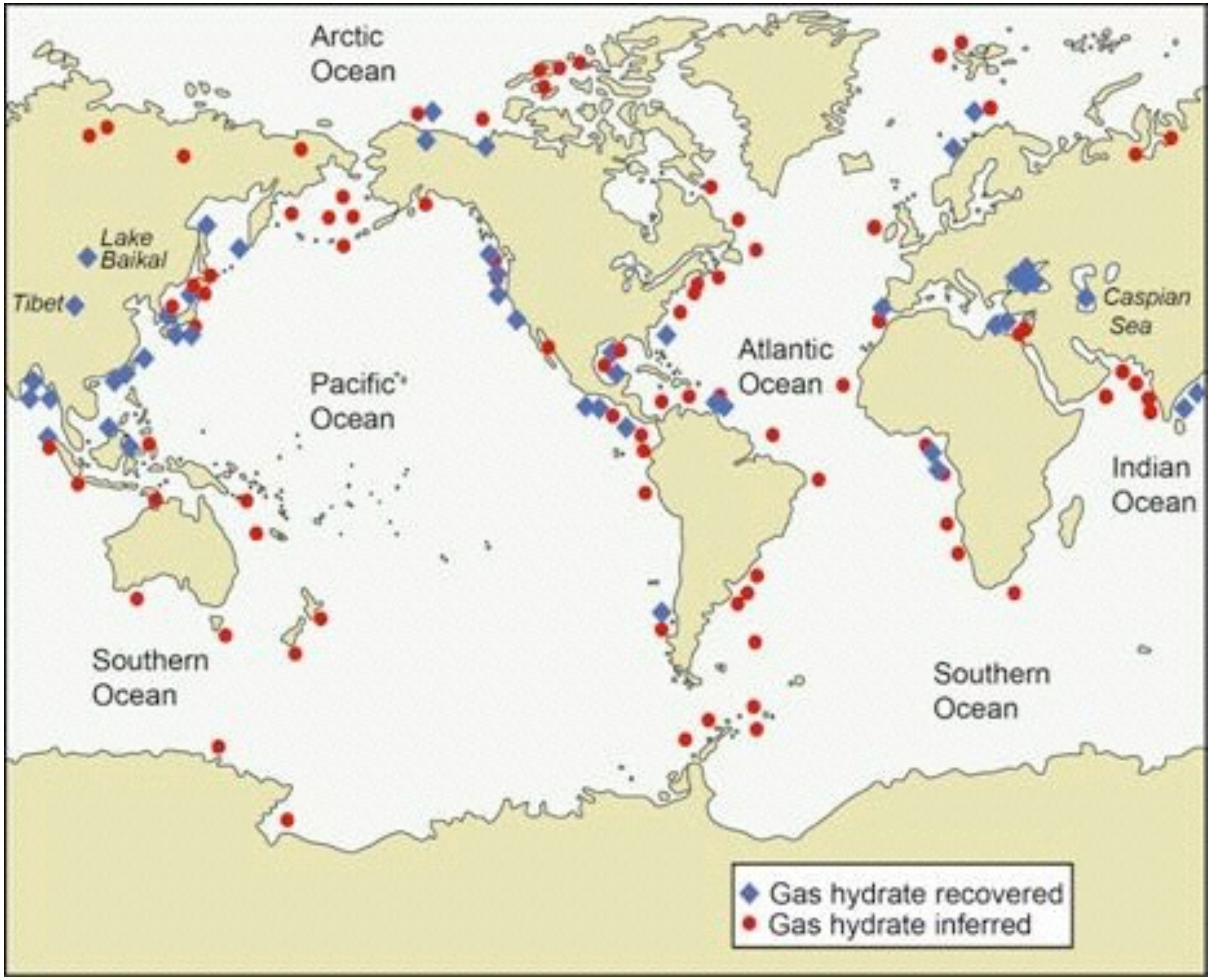
Concluding remarks

What:




ocean
temperature
phase boundary
free gas stable
gas hydrate stable
seafloor sediment
seismic BSR
free gas stable
Depth, km
0
0.5
1.0
1.5
2.0
0
10
20
Temperature, °C

Where:



US Geological Survey

Why:

It is a hazard to drilling and infrastructure

It is viewed by some as a potential energy source

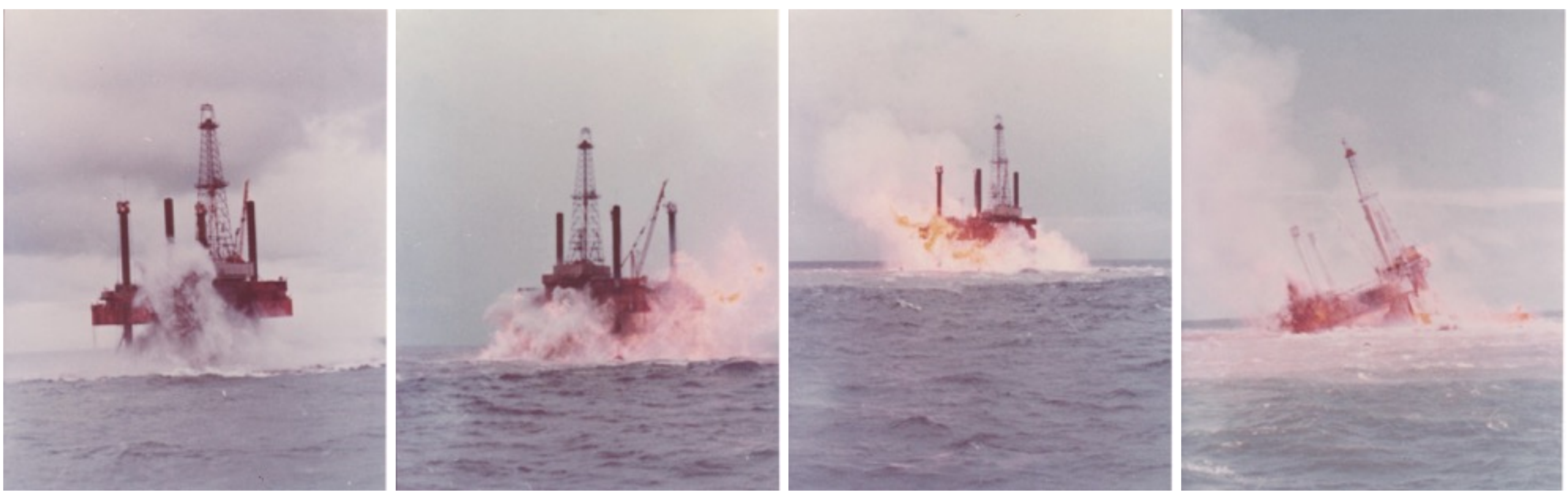
Methane release may play a role in climate change

Is a significant part of the global carbon cycle

Hydrate may play a role in marine CO2 sequestration

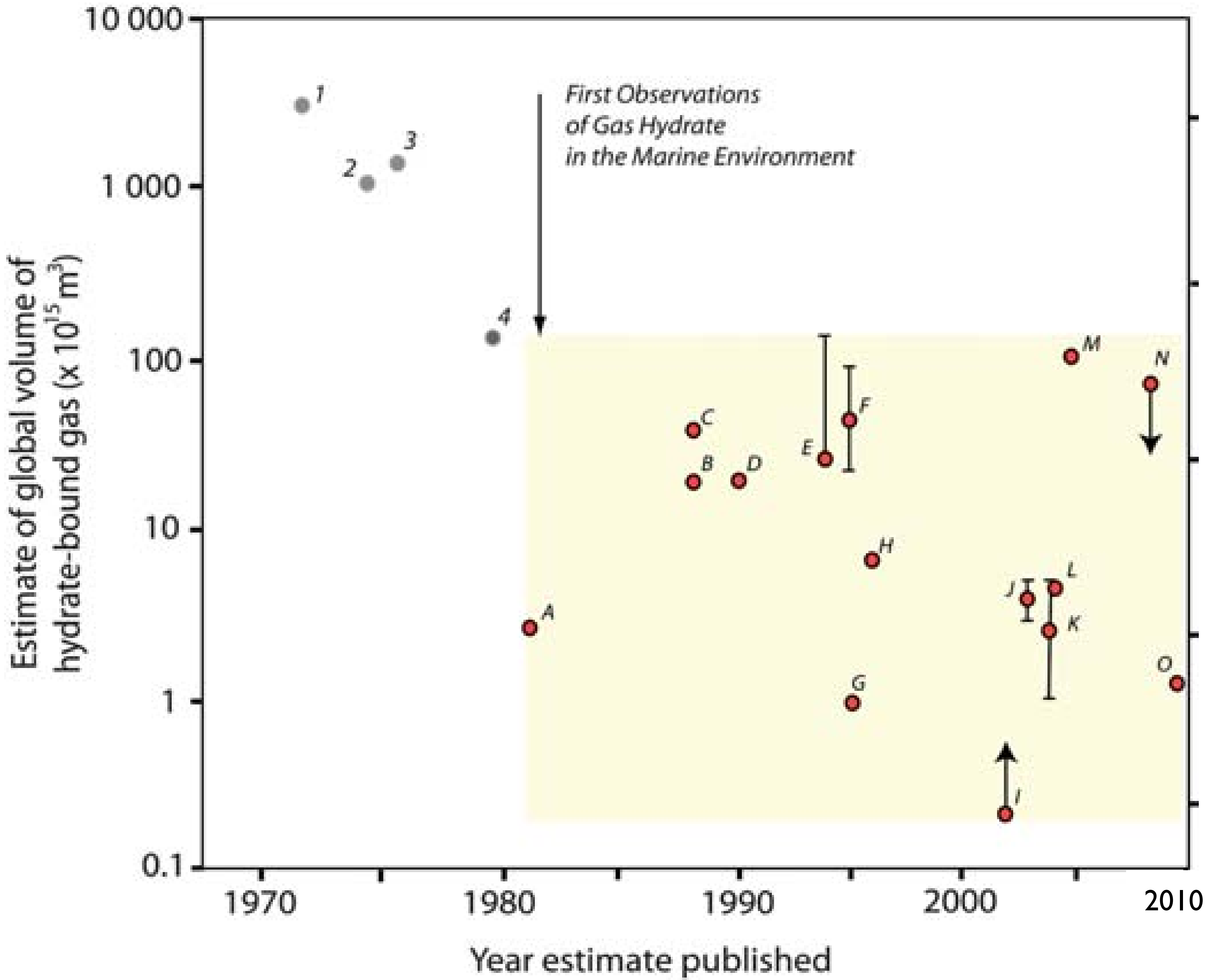
It can confound interpretation of marine EM for exploration

There is a lot of it



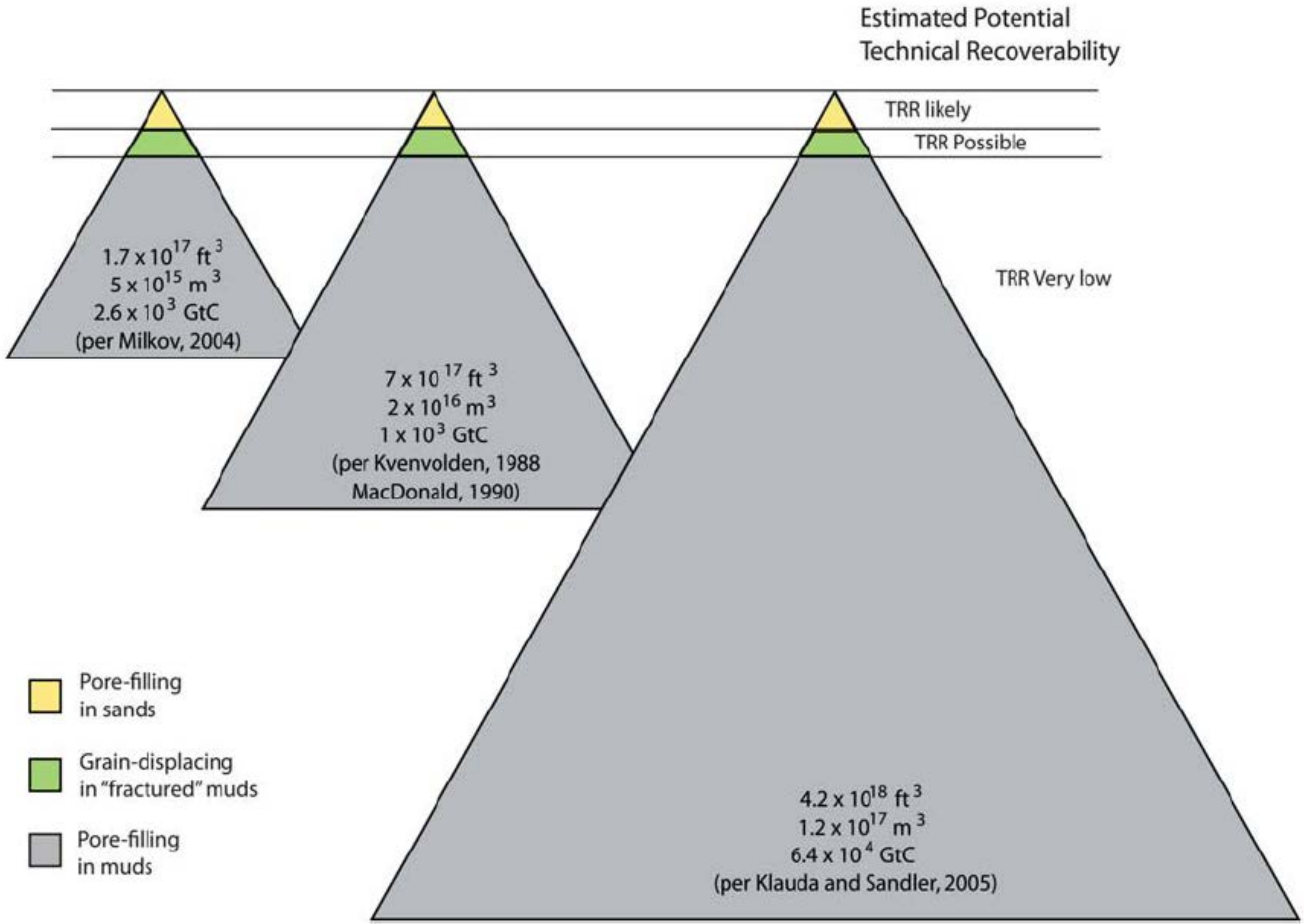
Photos courtesy Arnold Orange

A lot, but, global volume is highly uncertain:



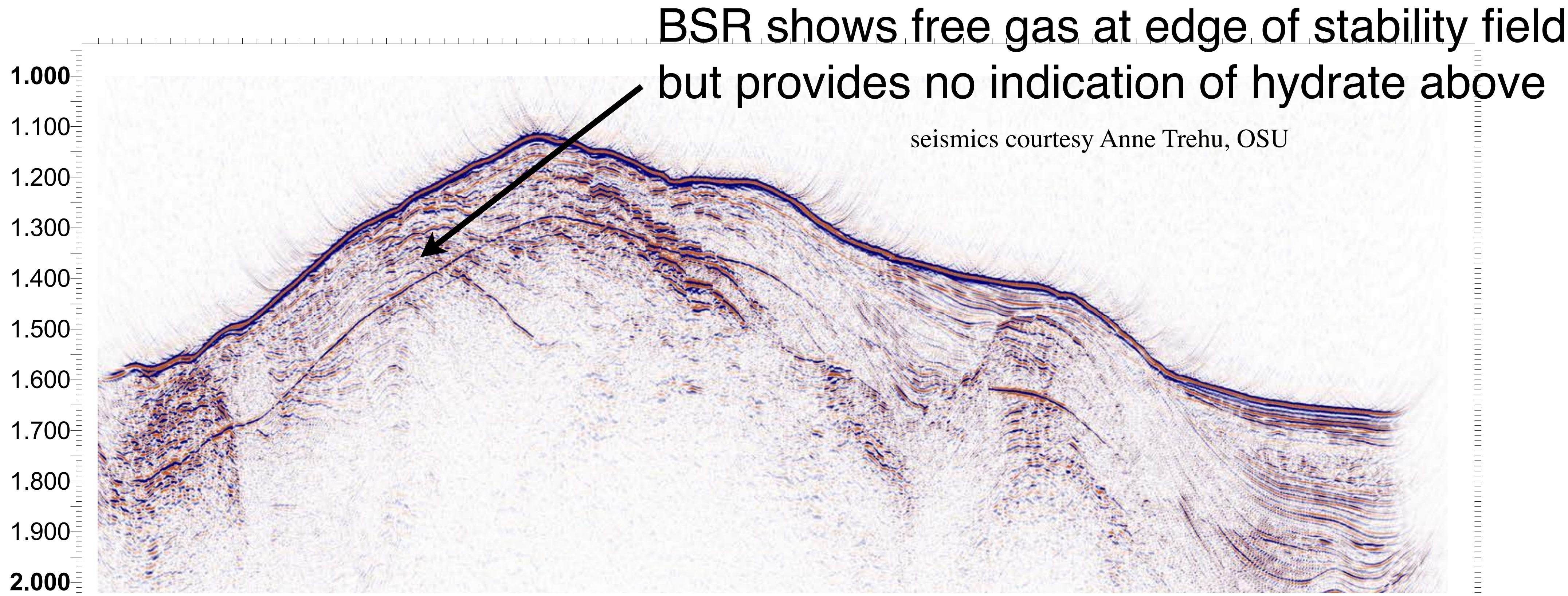
Boswell and Collett, 2011, and Milkov 2004

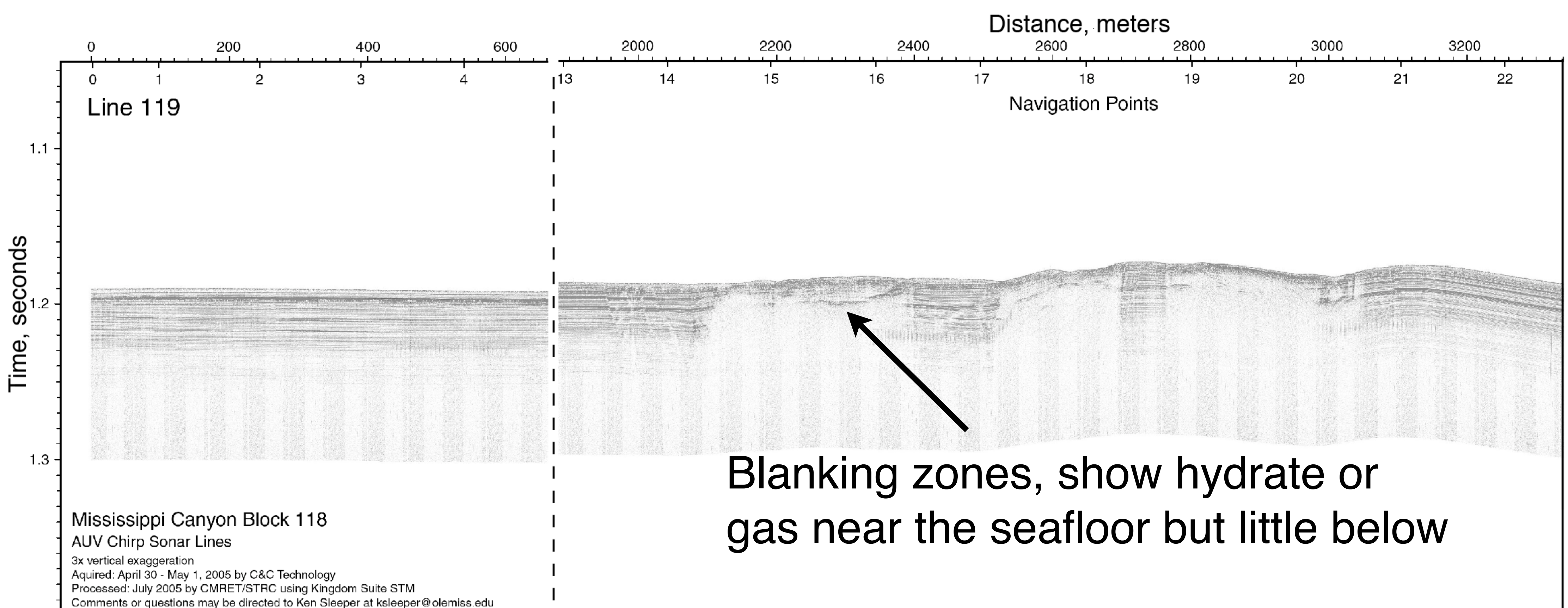
The hydrate resource pyramid.



Boswell and Collett, 2011

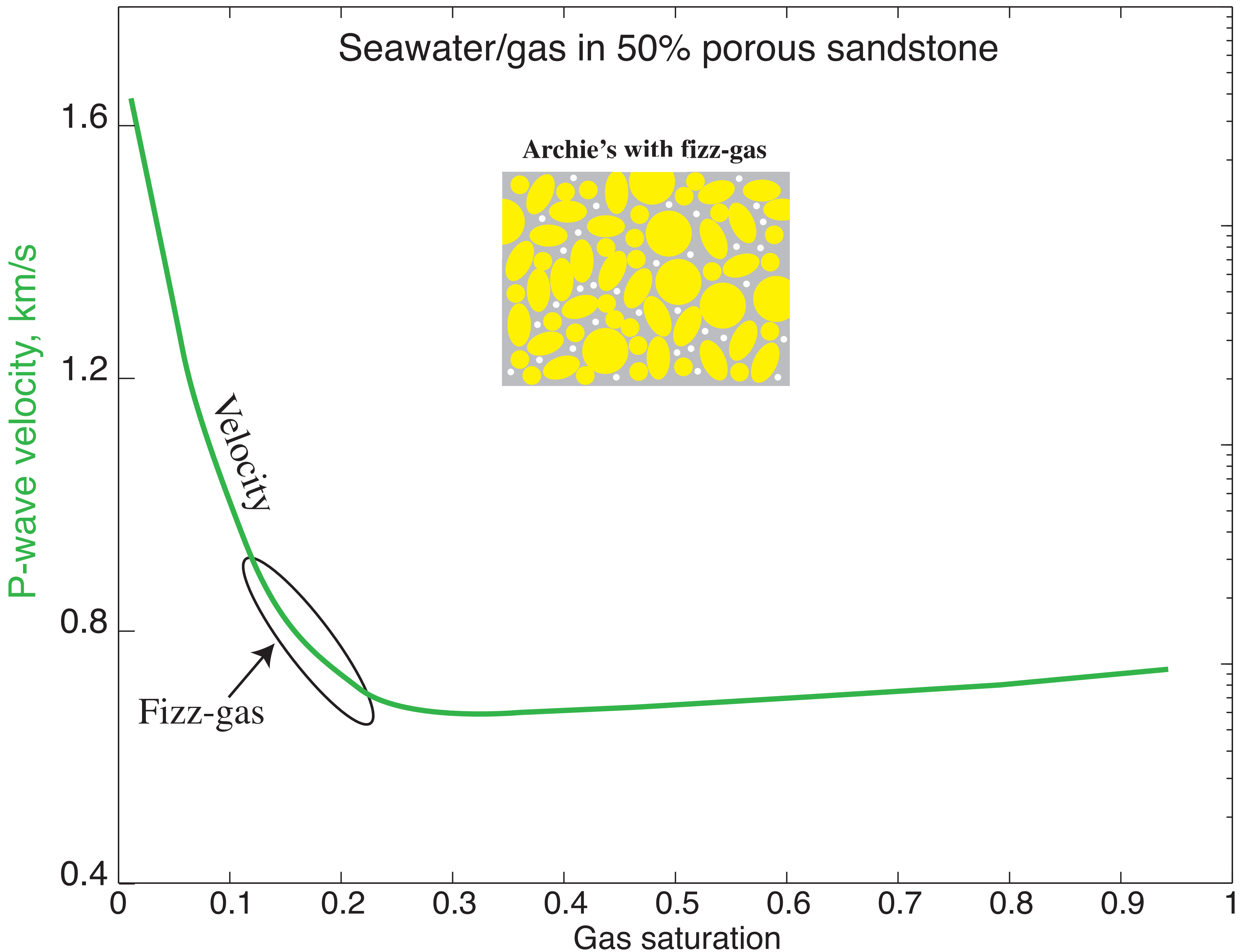
Quantification of hydrate volume using seismic methods is difficult.



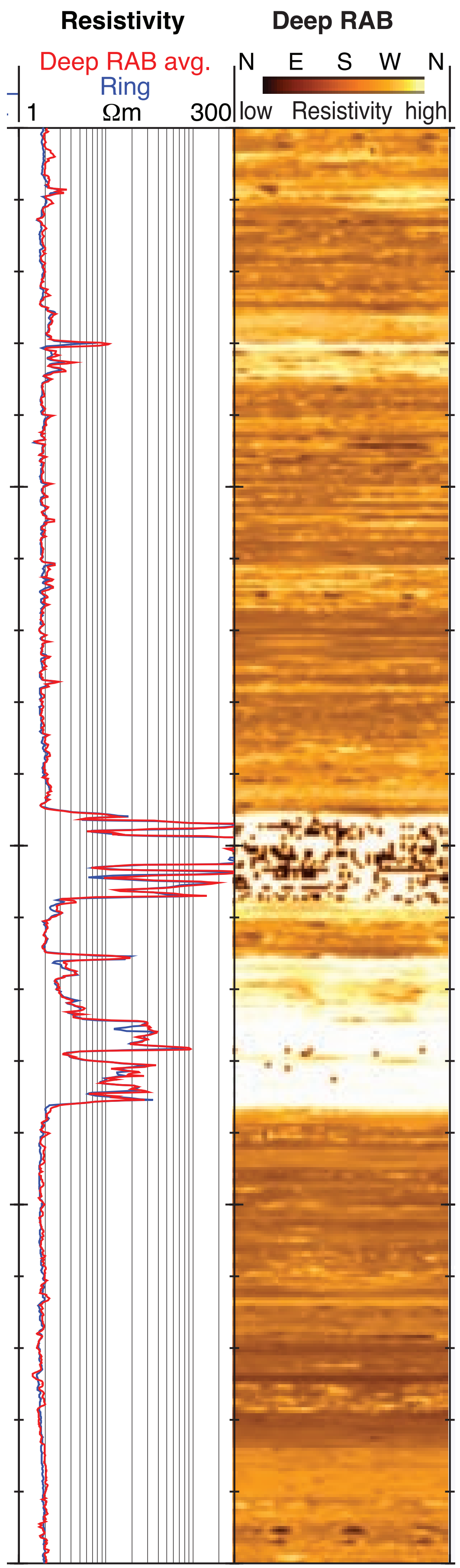


Ken Sleeper

The BSR reflection is associated with small amounts of free gas - similar to the "fizz-gas" problem in hydrocarbon exploration.



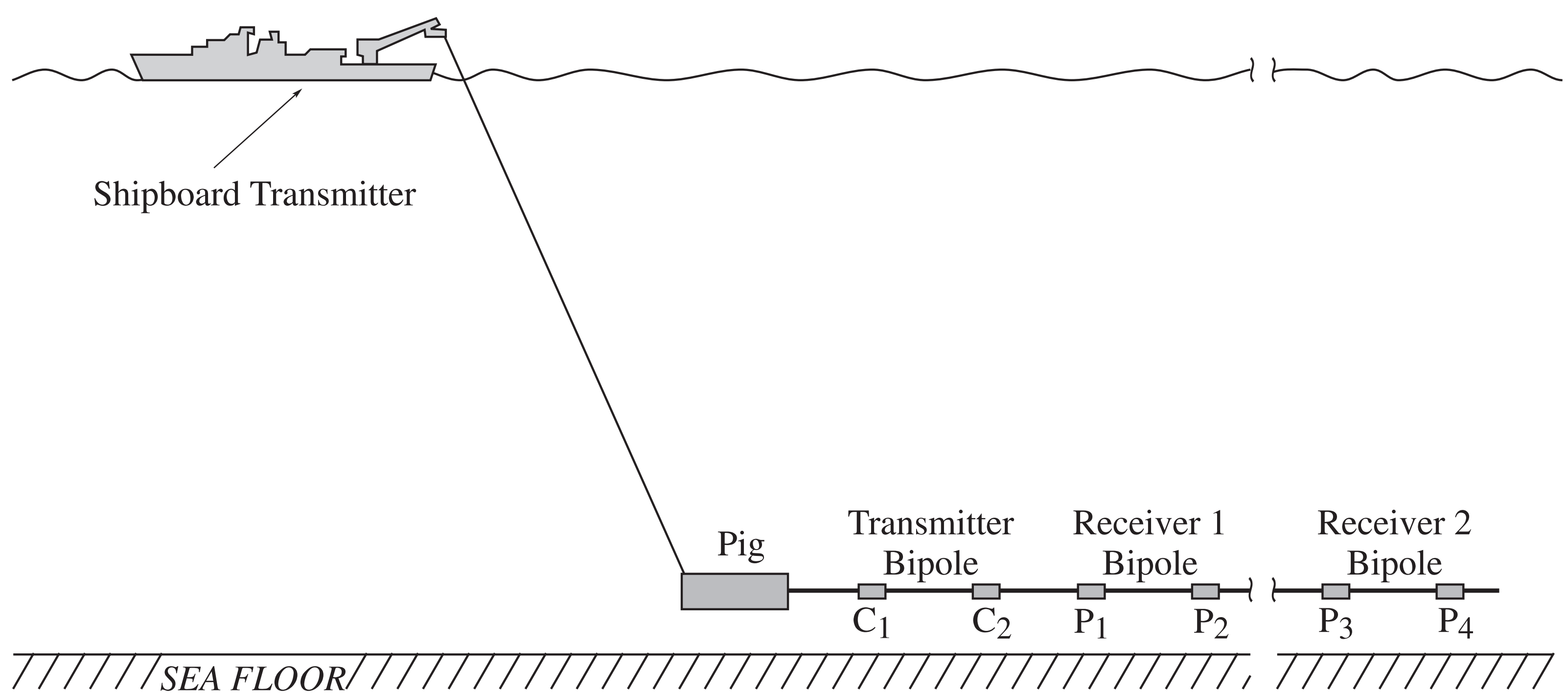
Hydrate is electrically resistive, and so is a target for electromagnetic methods.



GEOPHYSICS, VOL. 62, NO. 1 (JANUARY-FEBRUARY 1997); P. 63–74, 10 FIGS., 2 TABLES.

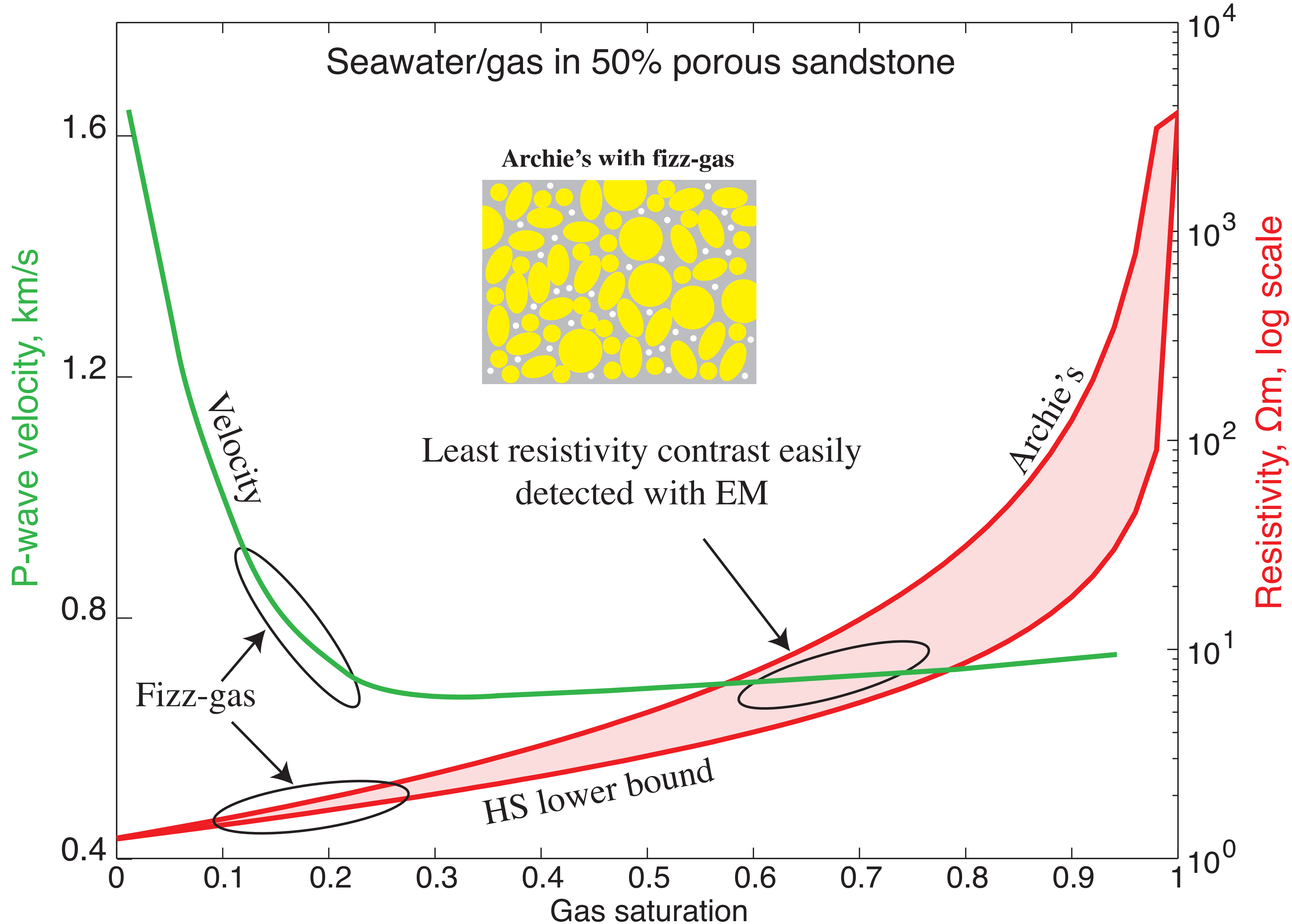
On the resource evaluation of marine gas hydrate deposits using sea-floor transient electric dipole-dipole methods

R. Nigel Edwards*



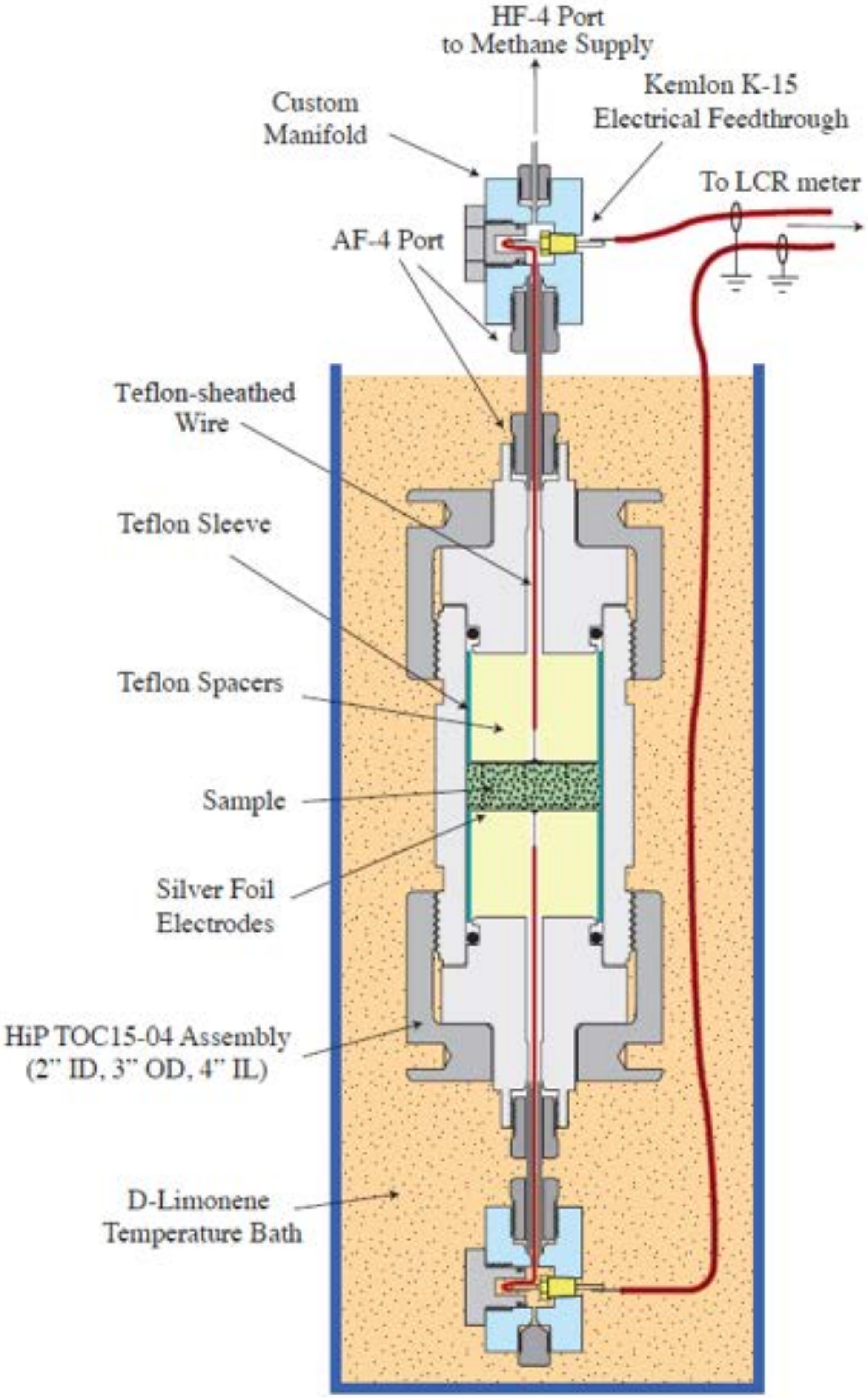
Logs from Walker Ridge 313-H, from Boswell et al., Fire In the Ice Summer 2009

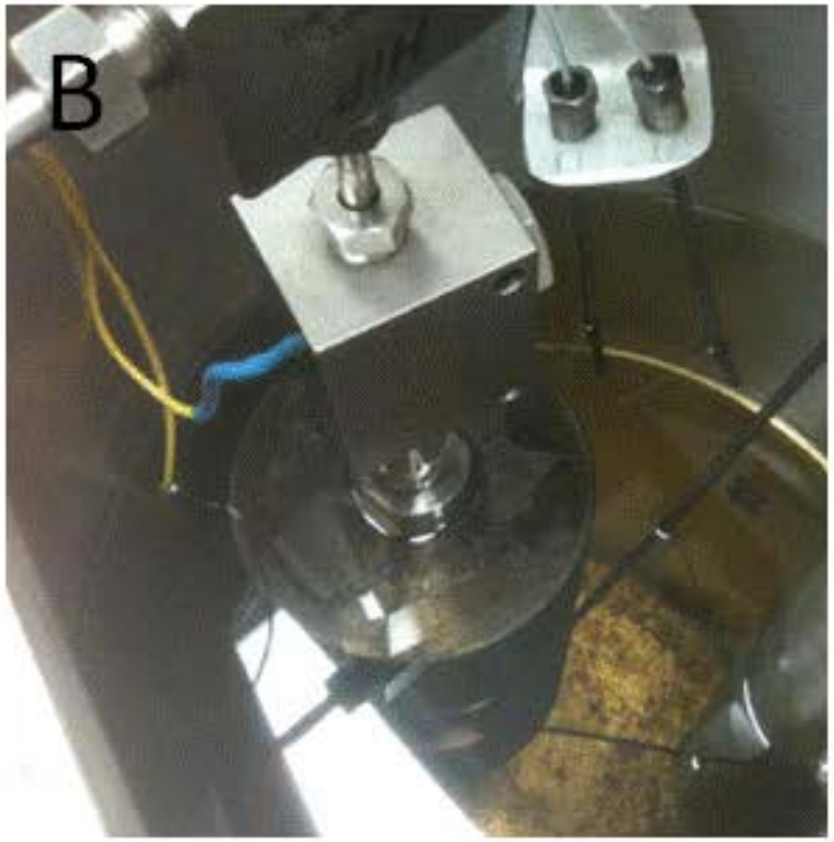
Hydrate/gas concentrations have to be high to generate an electrical signature - EM is a good tool to find the top of the pyramid.

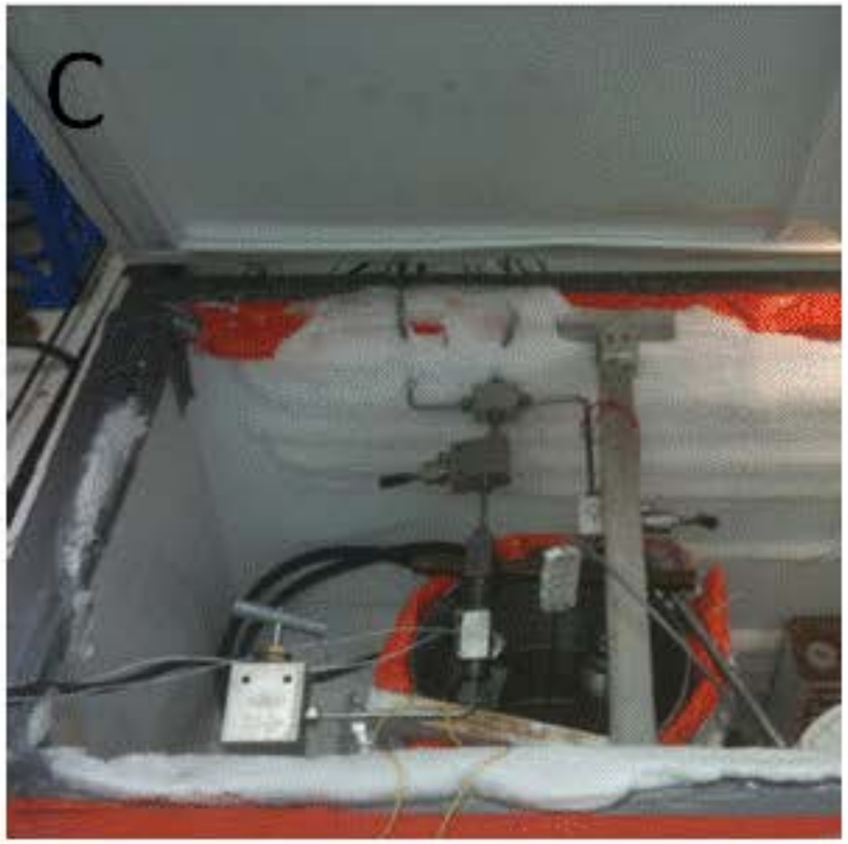


Laboratory studies of hydrate conductivity

Apparatus to synthesize methane hydrate in a conductivity cell.

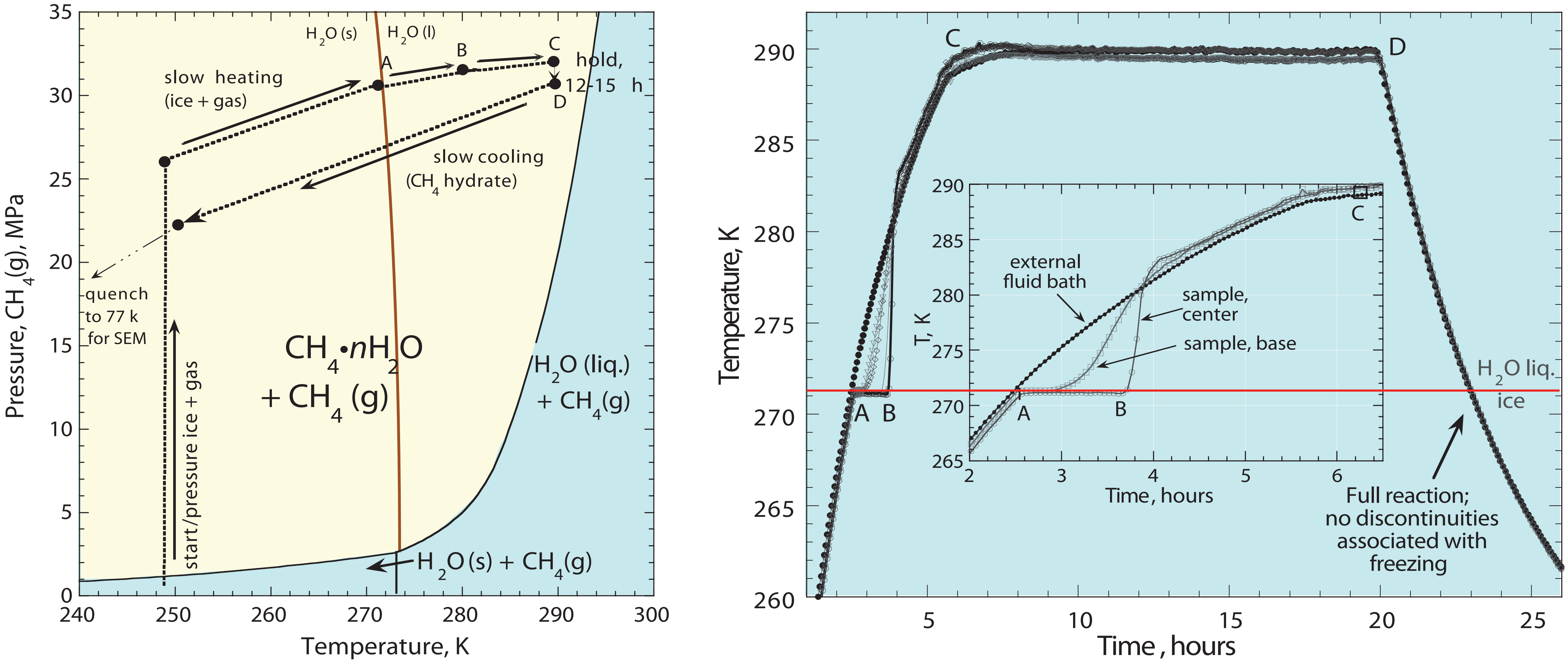






Du Frane et al., 2011

Synthesis of Methane Hydrate:



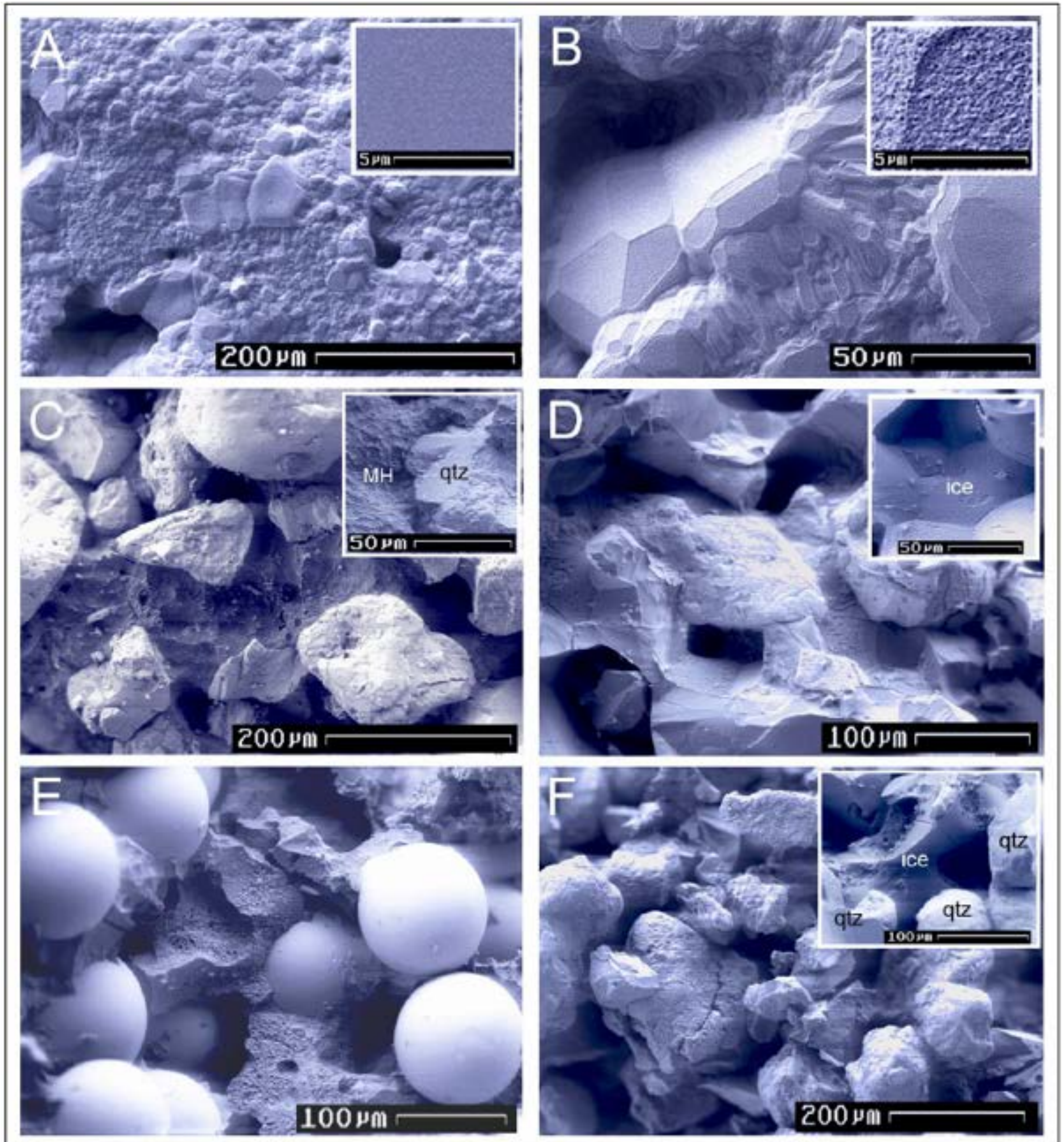
Stern et al., Am. Min. (2004)

Cryo-SEM is used to assess grain characteristics and phase distribution.

100 vol% CH_4 hydrate

50 vol% CH_4 hydrate: 50 vol% Sand

50 vol% CH_4 hydrate: 50 vol% glass beads



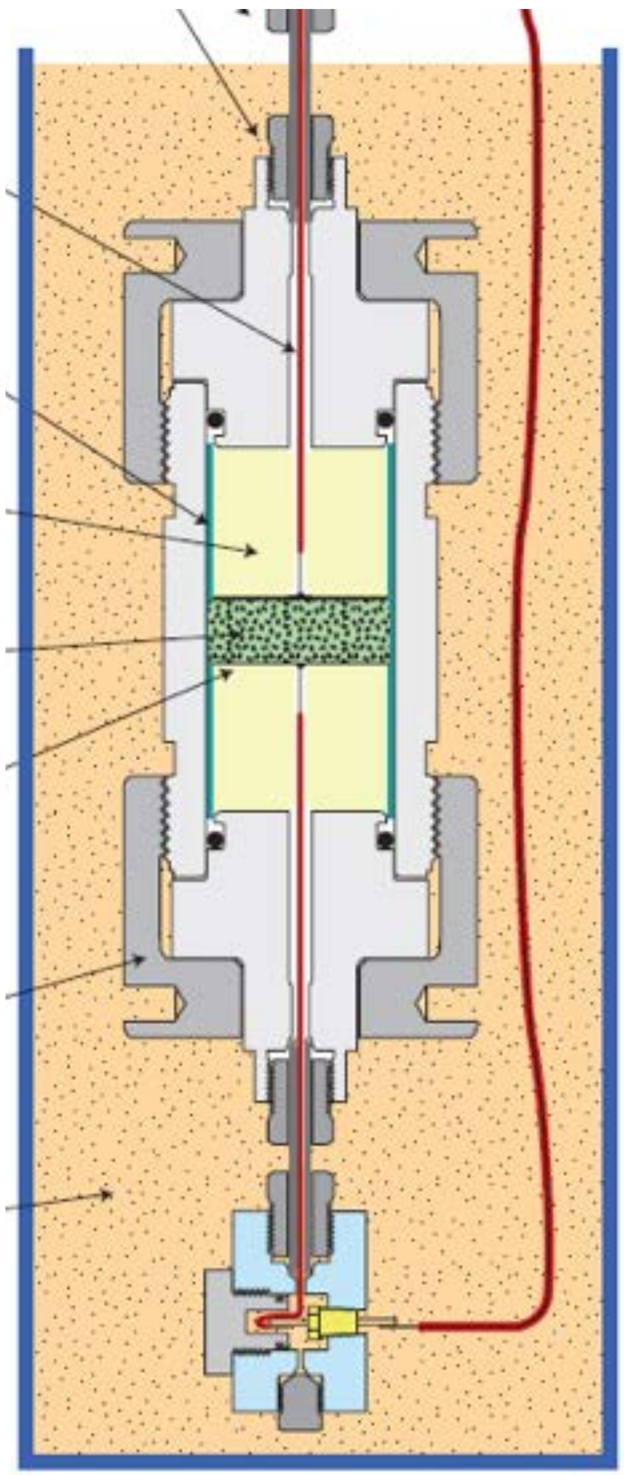
100 vol% CH_4 Hydrate

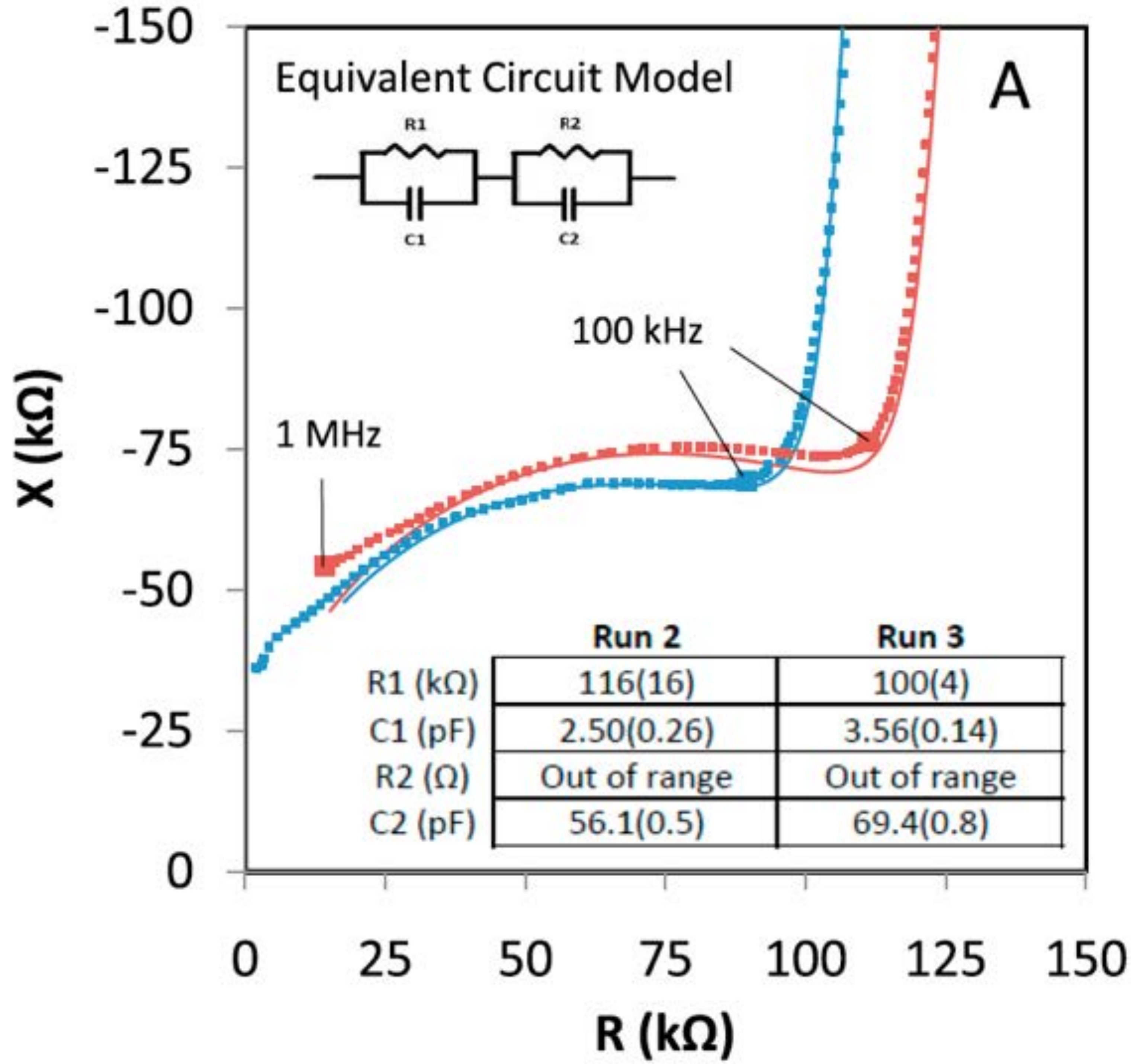
50 vol% ice: 50 vol% sand

10 vol% ice: 90 vol% sand

Du Frane et al., 2015

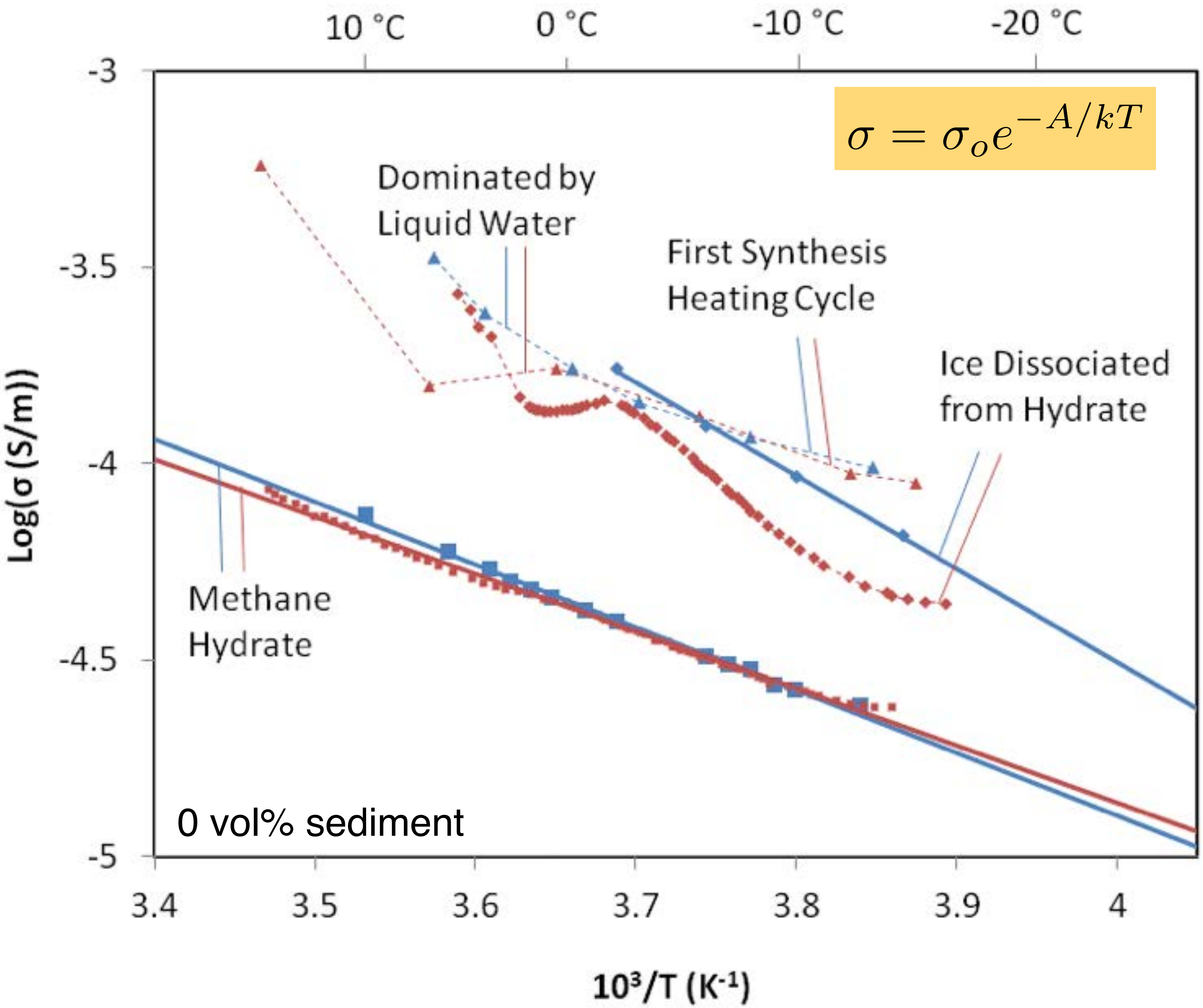
Impedance spectroscopy and equivalent circuit models allow removal of electrode effects:





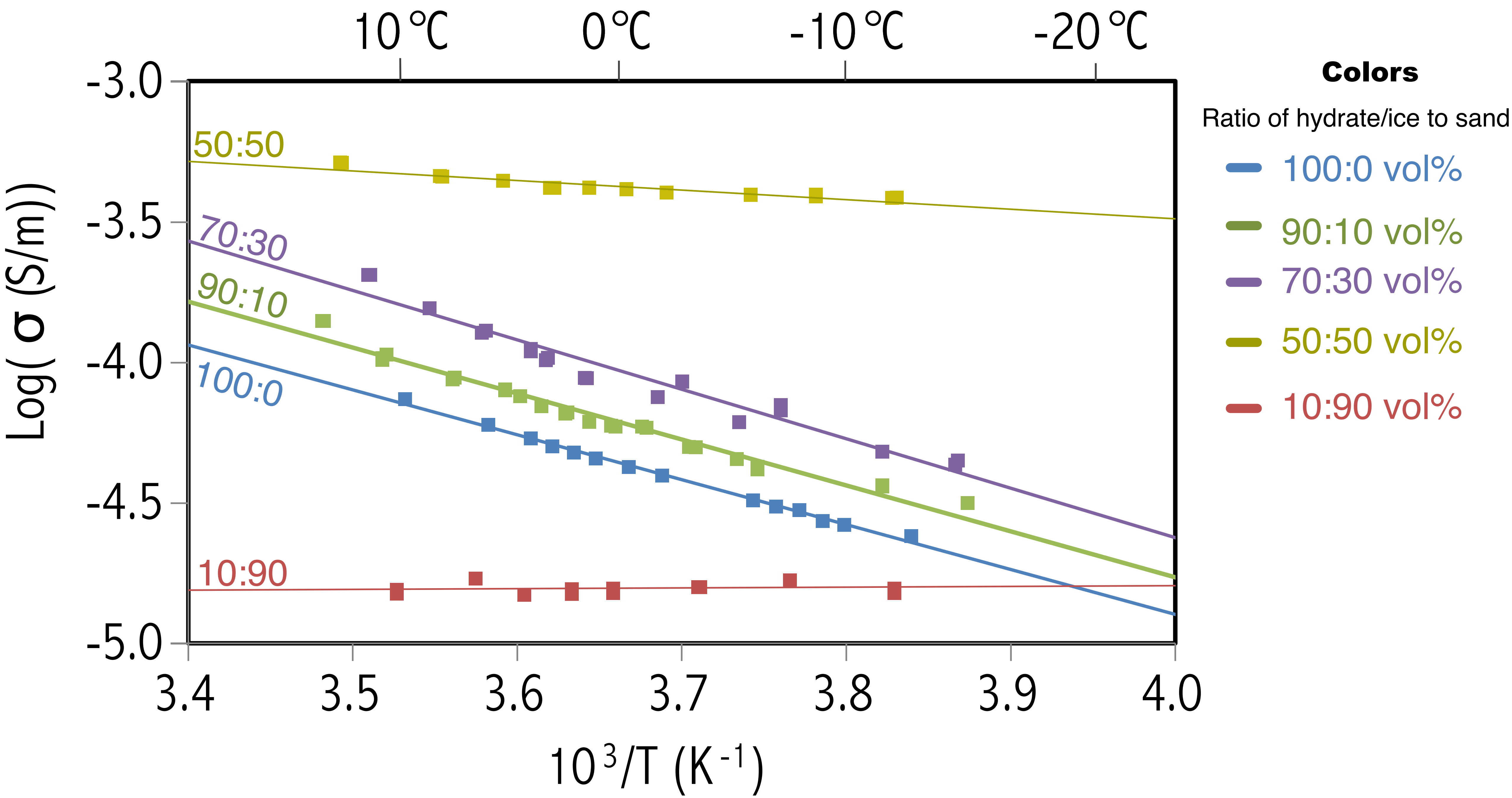
Du Frane et al., 2011

Pure hydrate conductivity is 3-4 times lower than ice and well fit by Arrhenius model.



Du Frane et al., 2011

Mixed with silica sand, hydrate conductivity goes up until a percolation threshold is reached. We think that impurities from the sand, probably K^+ and Cl^-, increase the charge carriers available in the hydrate.



Du Frane et al., 2015

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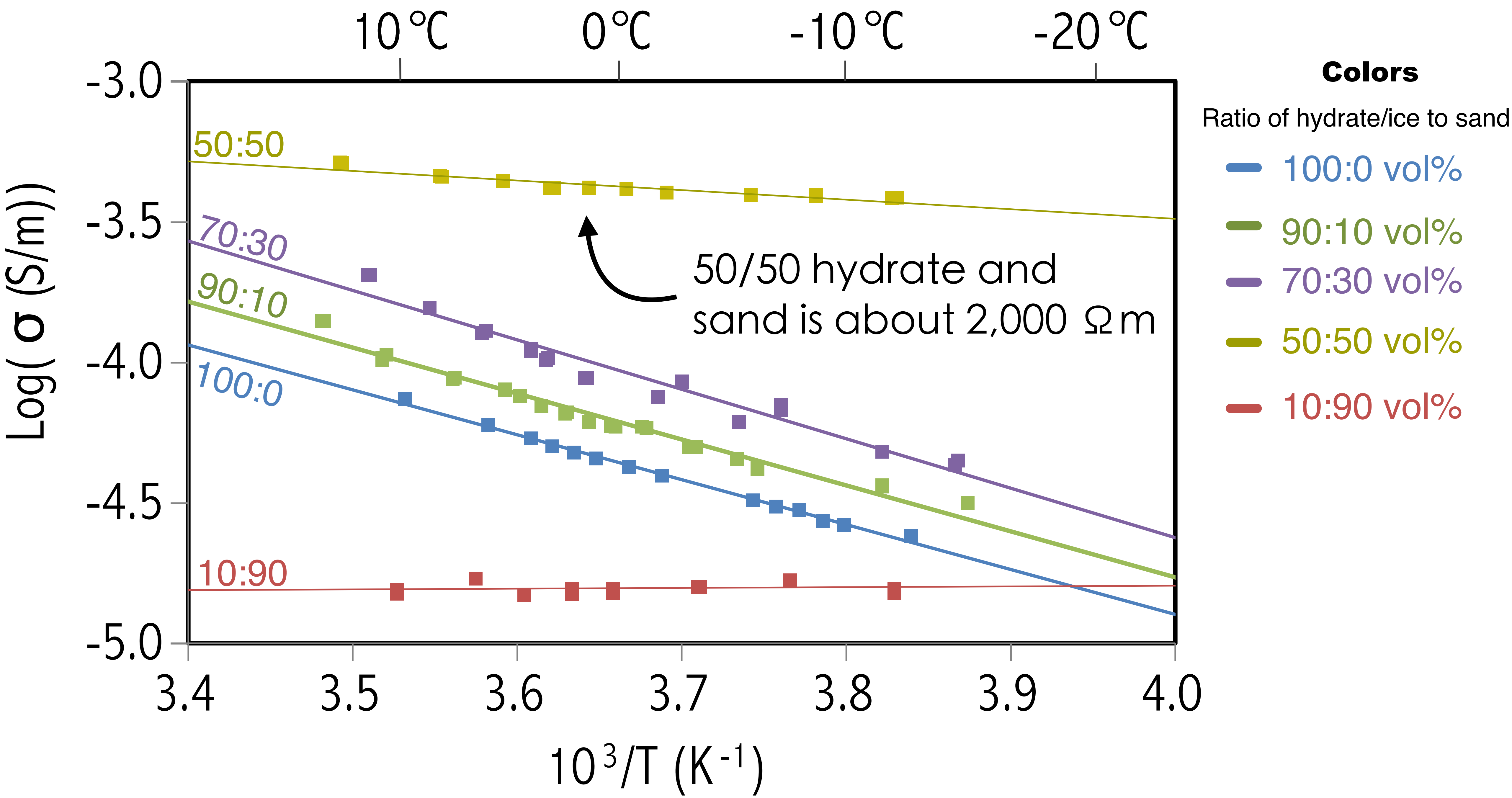
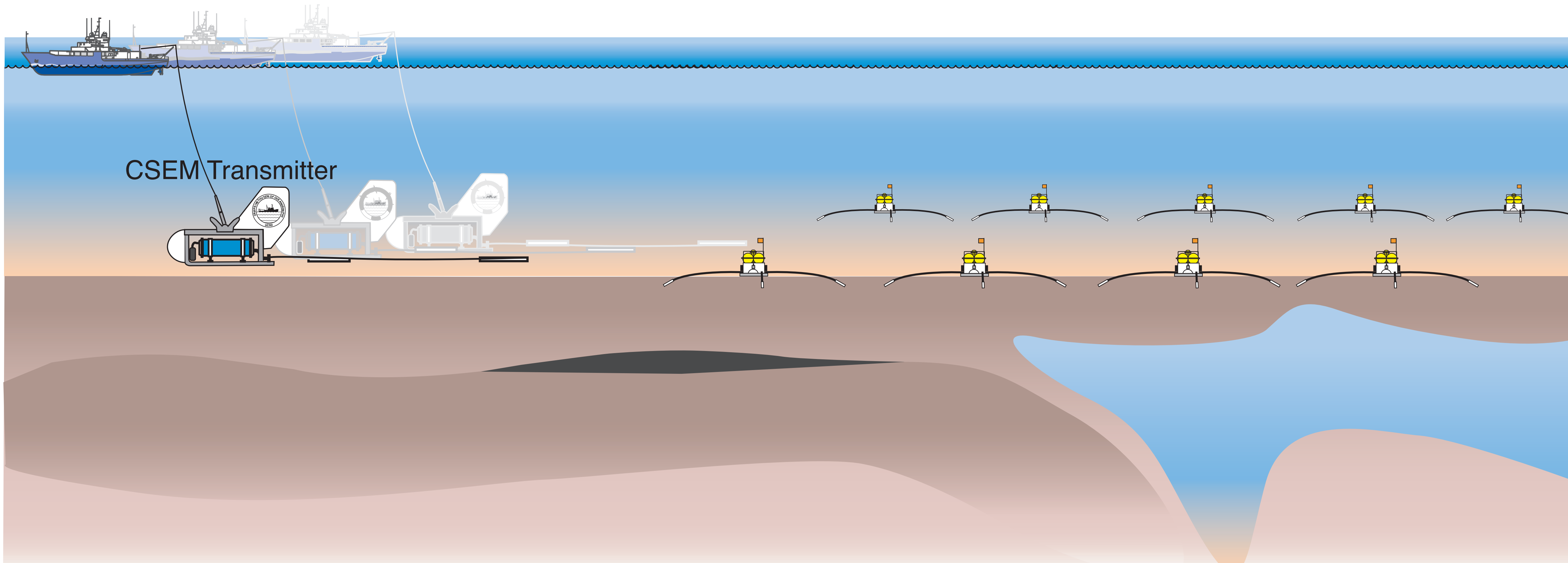
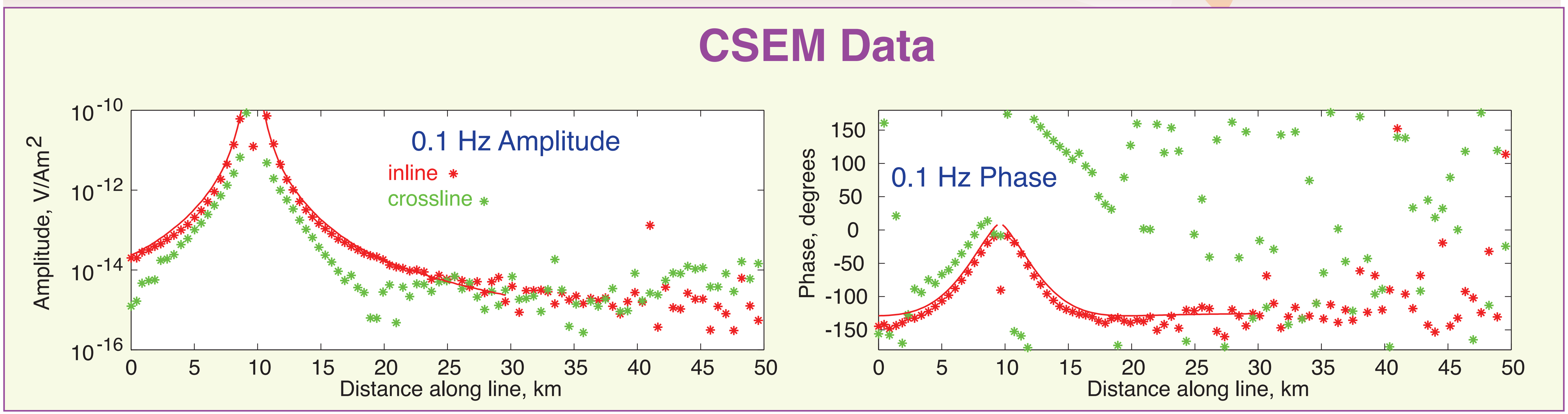


Du Frane et al., 2015

Marine CSEM Methods

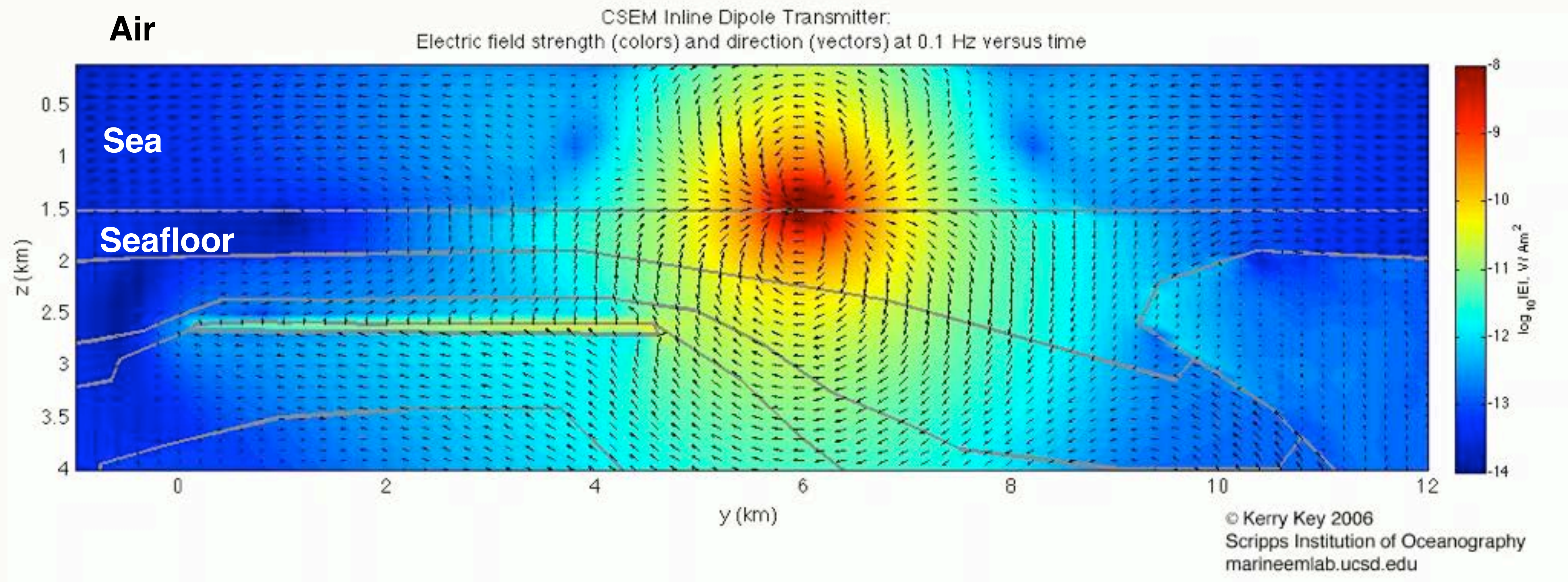
Controlled-source electromagnetic (CSEM) sounding:





Field amplitude and phase is measured as a function of frequency and source/receiver position.

With frequency domain CSEM, the entire air-sea-seafloor system is illuminated continuously. Energy propagates preferentially in resistive rocks.



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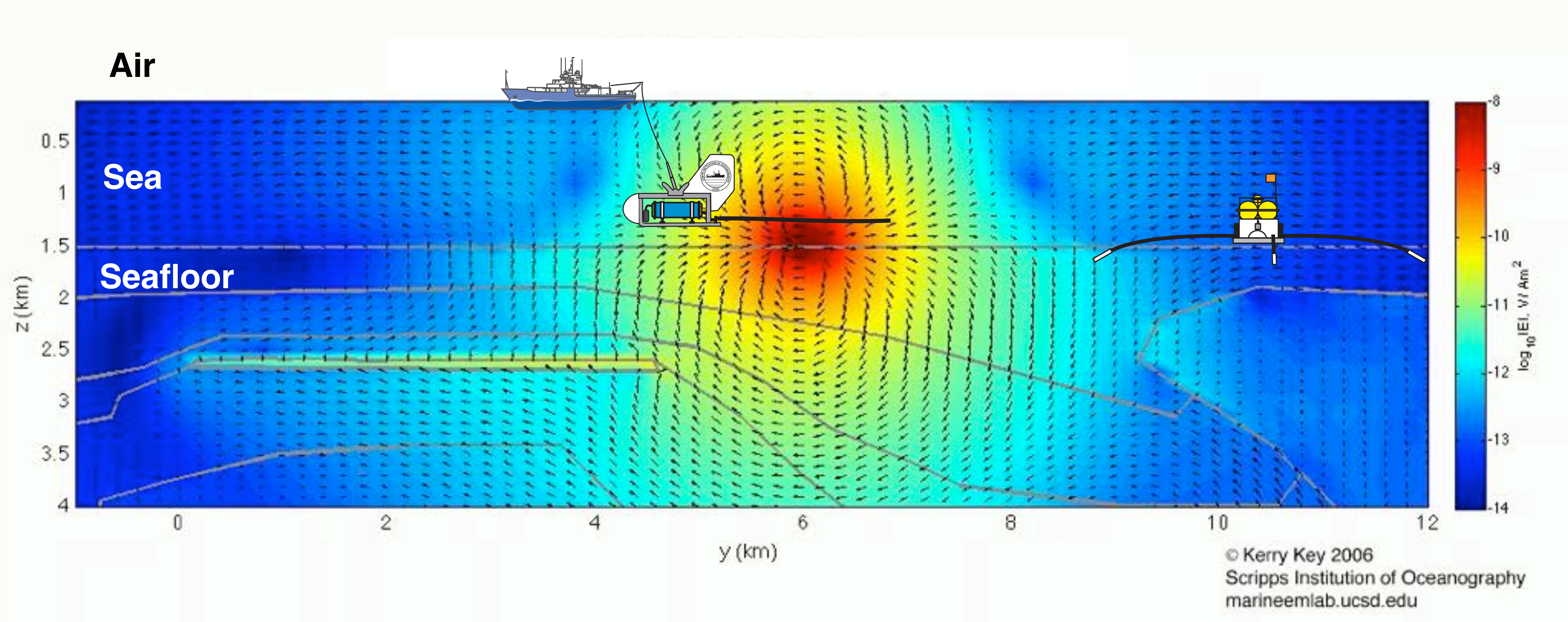


Amplitude and phase of the magnetic/electric fields on the seafloor can be used to infer geological structure to depths of several km.

The resolution of EM induction is between wave propagation and potential fields:

High frequency (megahertz)

Wave equation: Resolution ~ wavelength

Radar $\nabla^2 \mathbf{E} = \mu\sigma \frac{\partial \mathbf{E}}{\partial t} + \mu\epsilon \frac{\partial^2 \mathbf{E}}{\partial t^2}$

Seismics $\nabla^2 u = \epsilon \frac{\partial u}{\partial t} + \frac{1}{c^2} \frac{\partial^2 u}{\partial t^2}$

Mid frequency (0.001 - 1000 Hz)

Diffusion equation: Resolution ~ size/depth

Inductive EM $\nabla^2 \mathbf{E} = \mu\sigma \frac{\partial \mathbf{E}}{\partial t}$

Zero frequency

Laplace equation: Resolution ~ bounds only

DC Resistivity $\nabla^2 \mathbf{E} = 0$

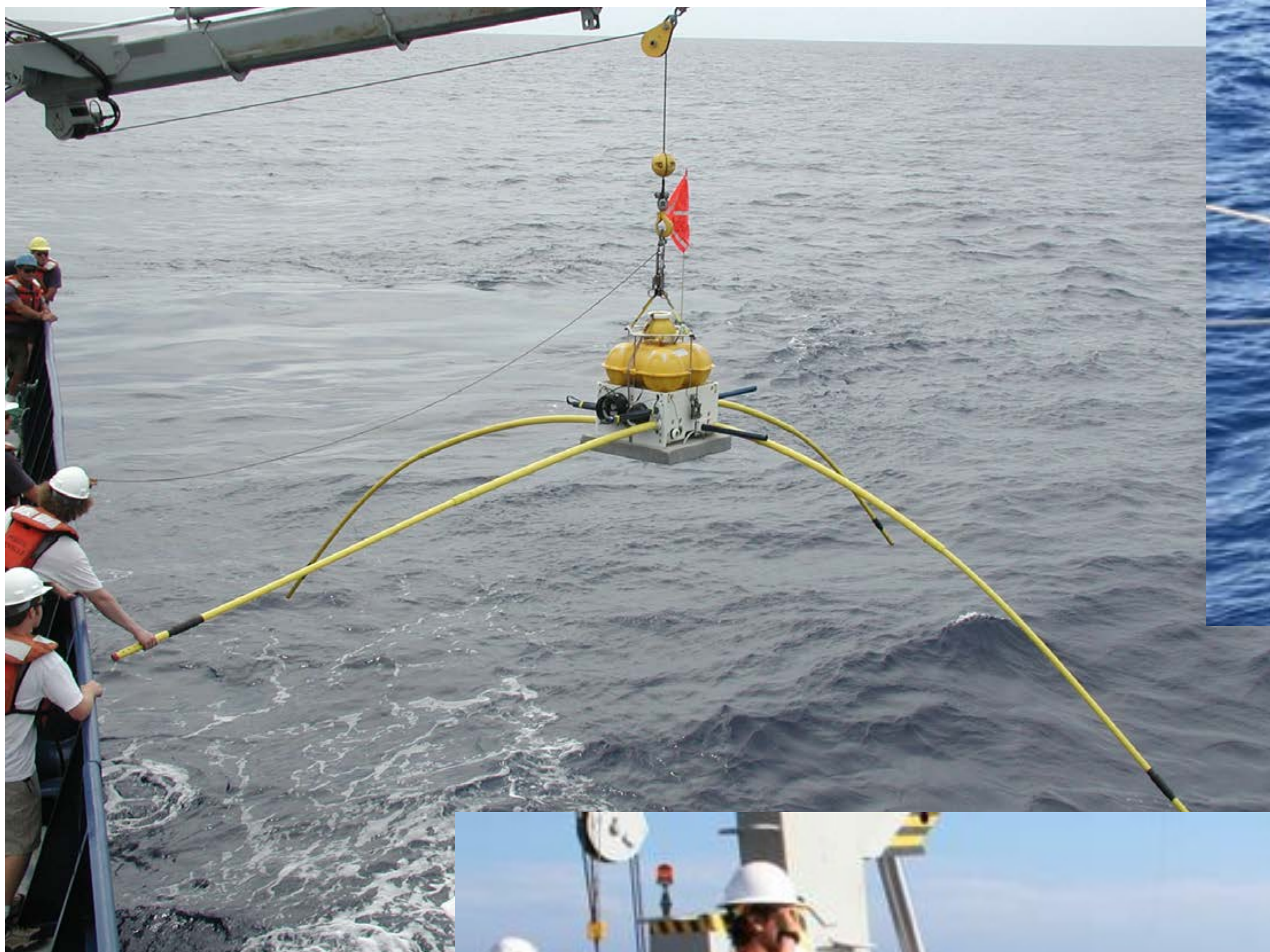
Gravity/ Magnetism $\nabla^2 U = 0$

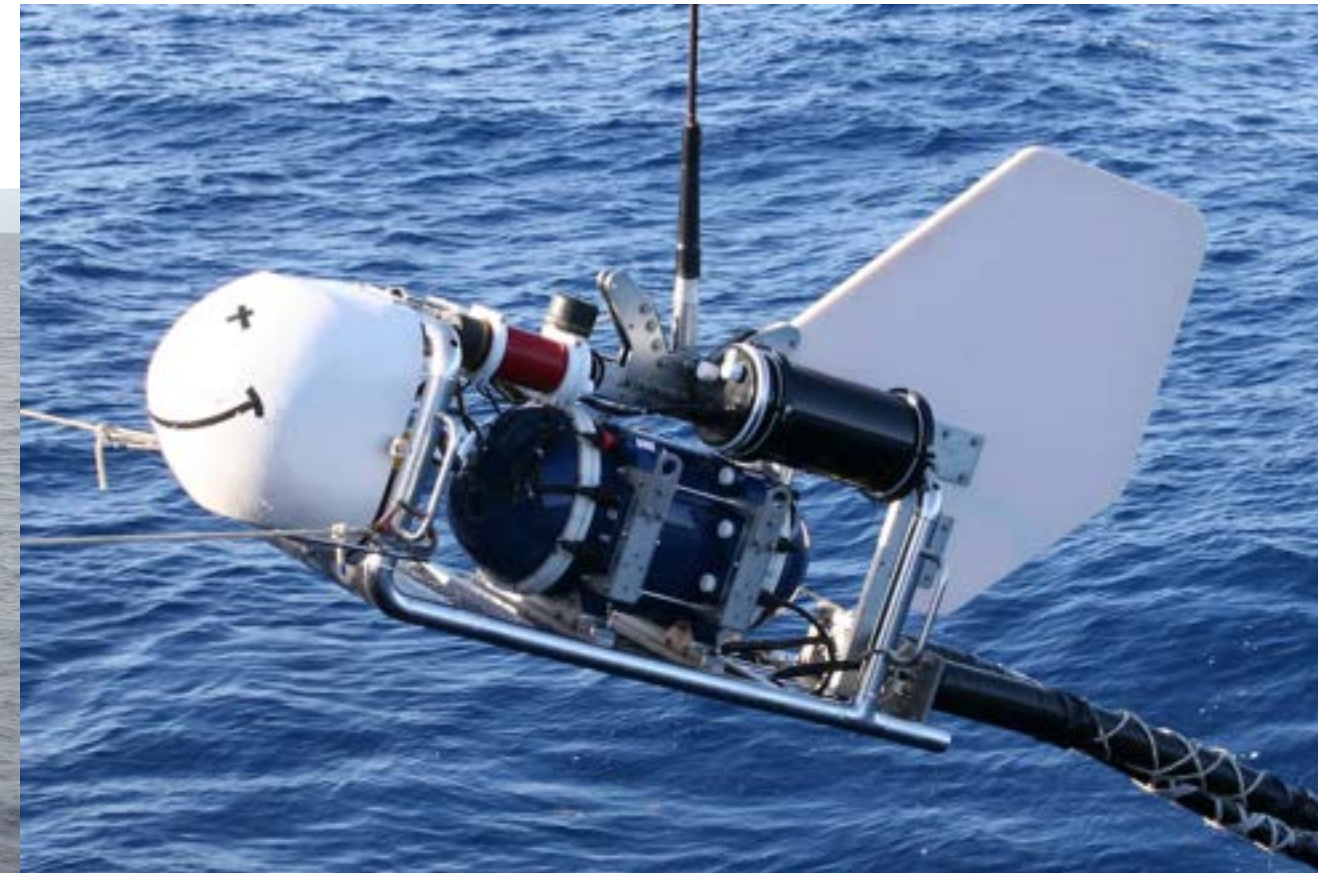
σ = electrical conductivity ~ $3 - 10^{-6}$ S/m

μ = magnetic permeability ~ $10^{-4} - 10^{-6}$ H/m

ϵ = electric permittivity ~ $10^{-9} - 10^{-11}$ F/m

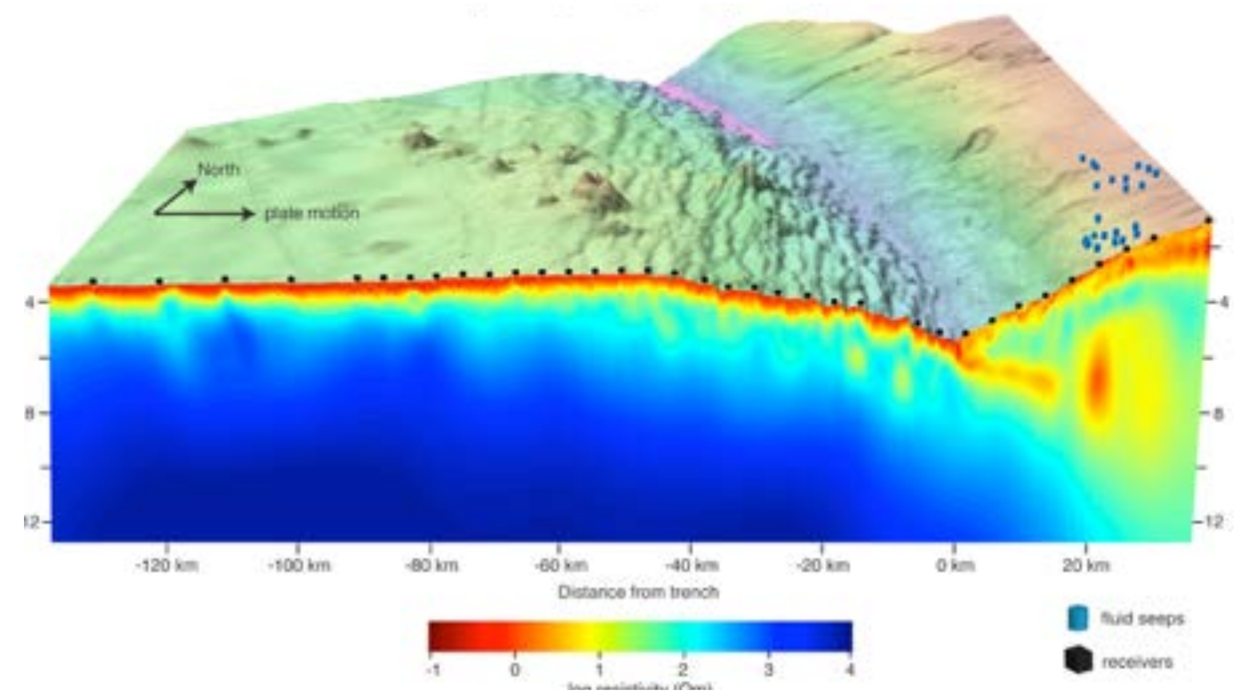
Instrumentation:





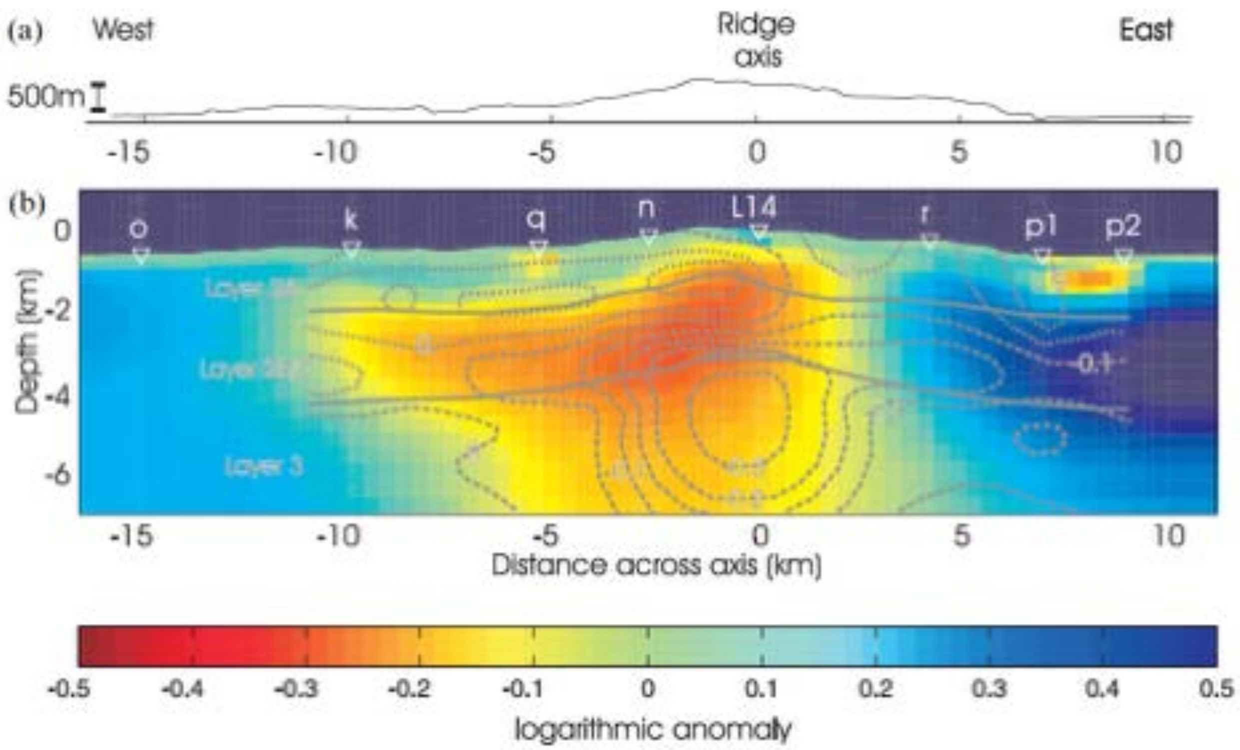
The many uses of marine CSEM:

Subduction zones



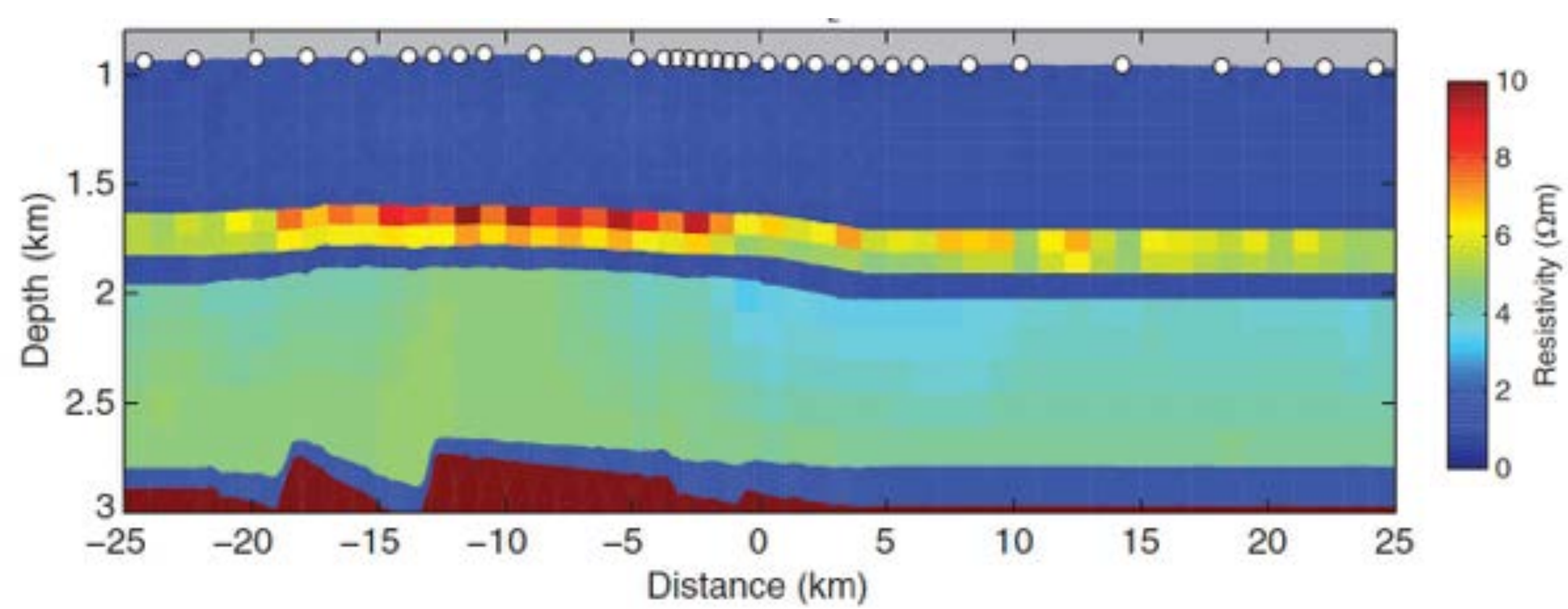
Naif, PhD thesis, 2015

Mid-ocean ridges



MacGregor et al., GJI, 2001

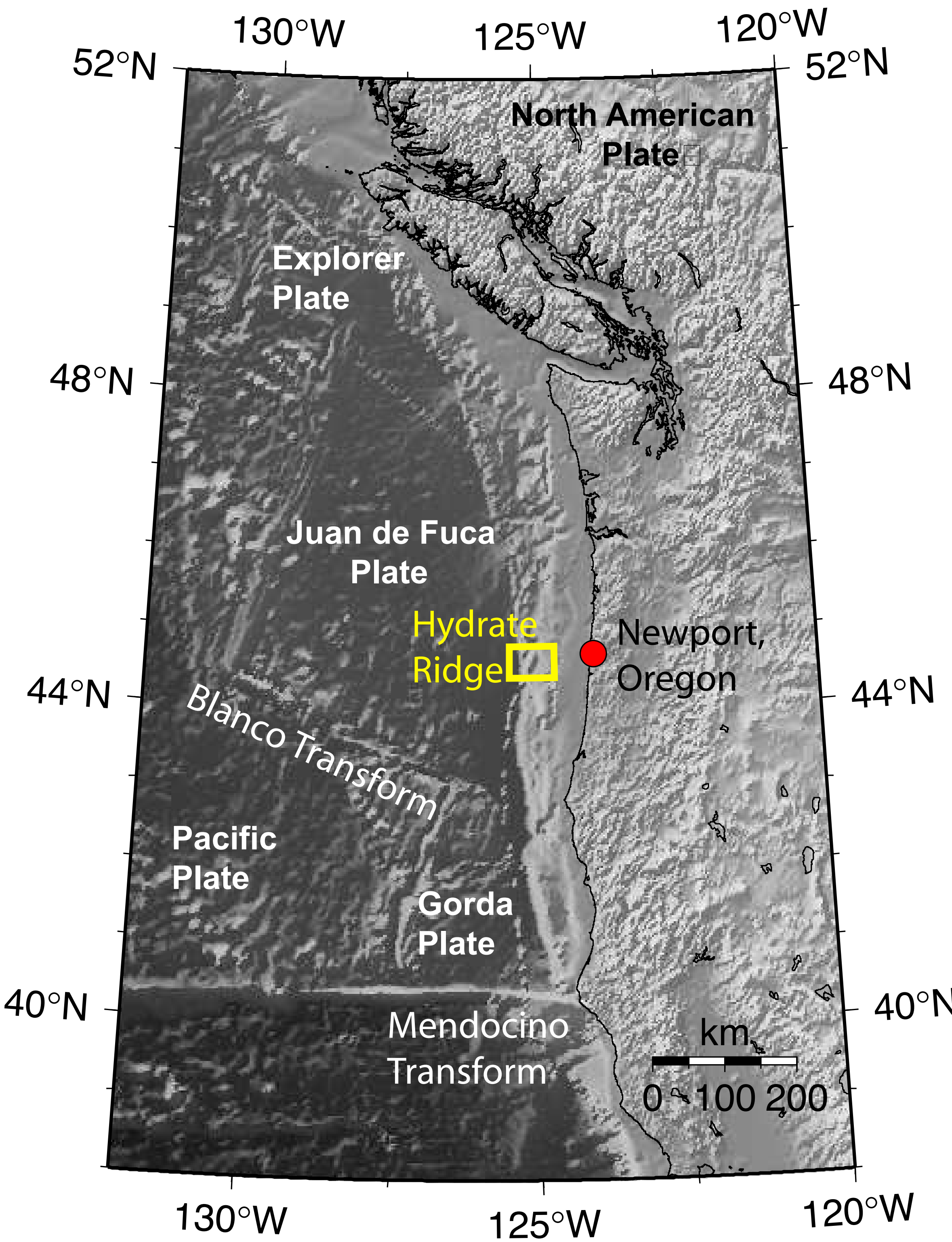
Oil and gas exploration

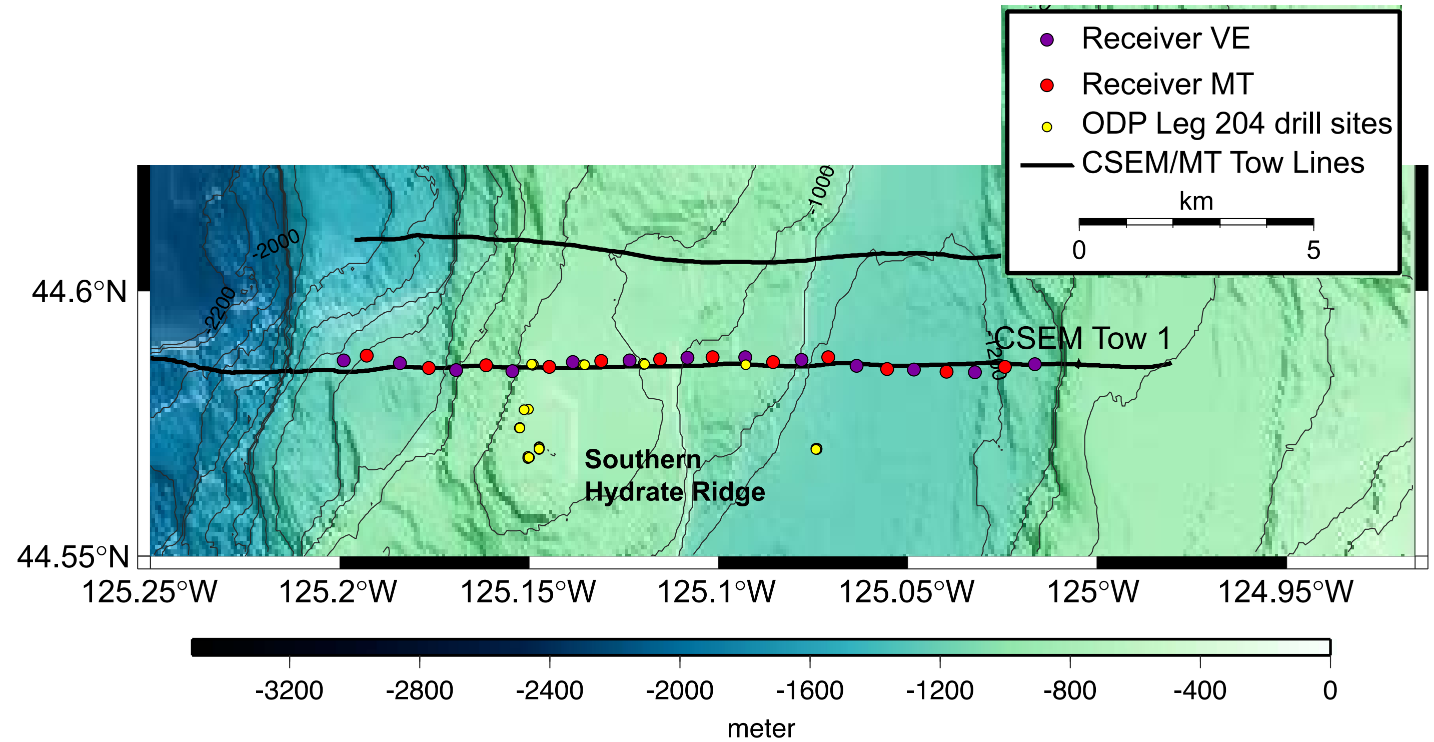


Myer et al., Geophysics, 2015

Hydrate Ridge Experiment

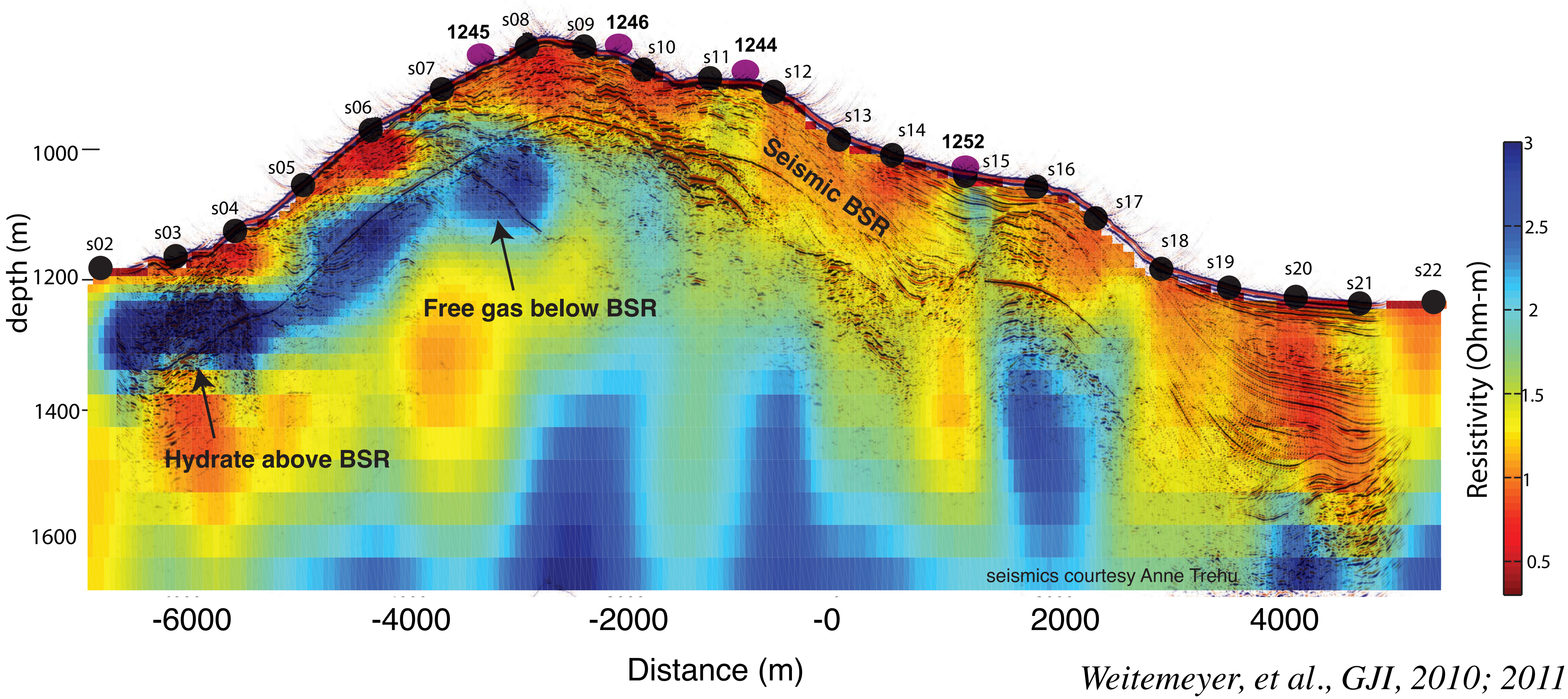
2004 pilot study at Hydrate Ridge





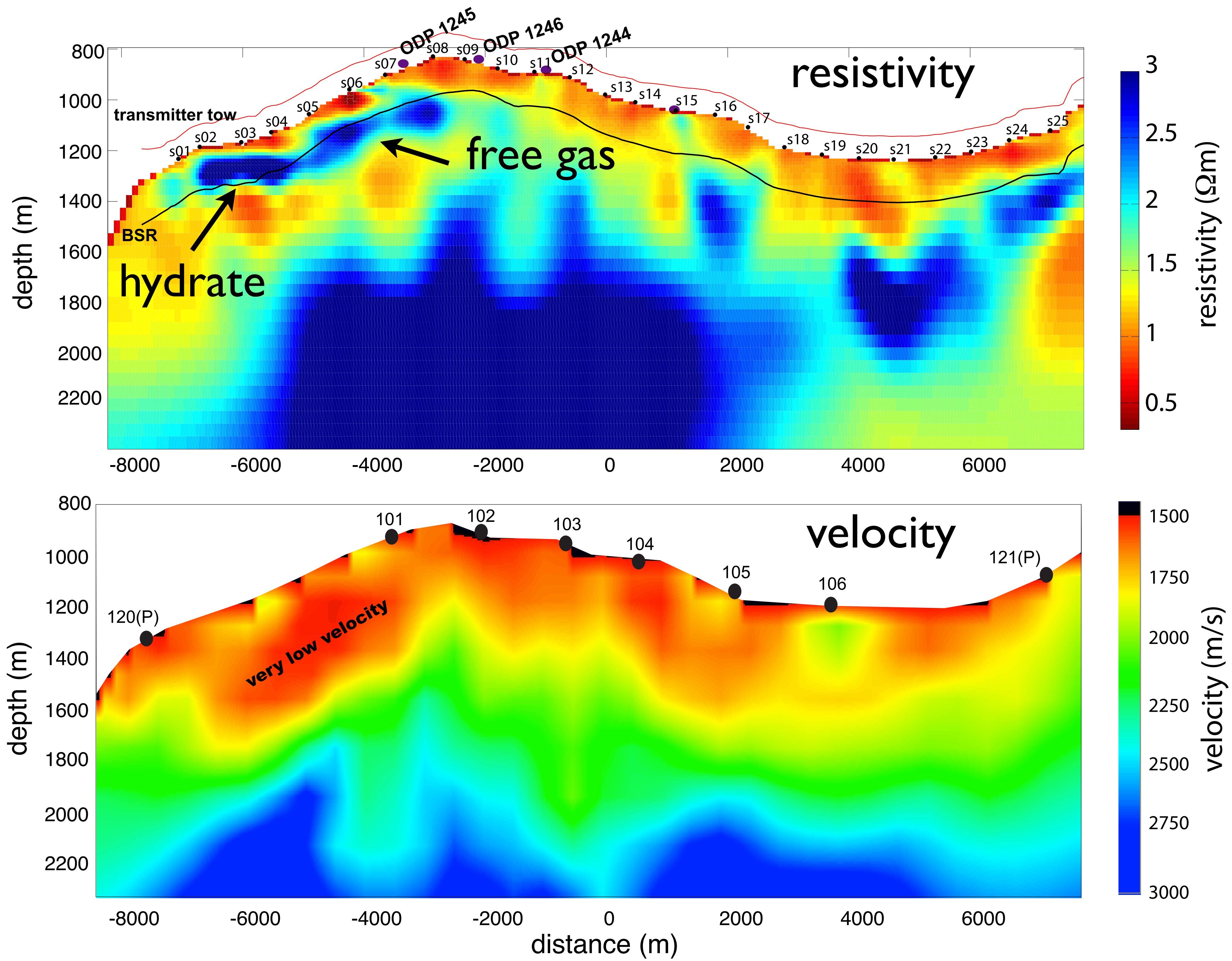
Weitemeyer et al., GJI, 2011

2D inversion, using Schlumberger's finite difference code



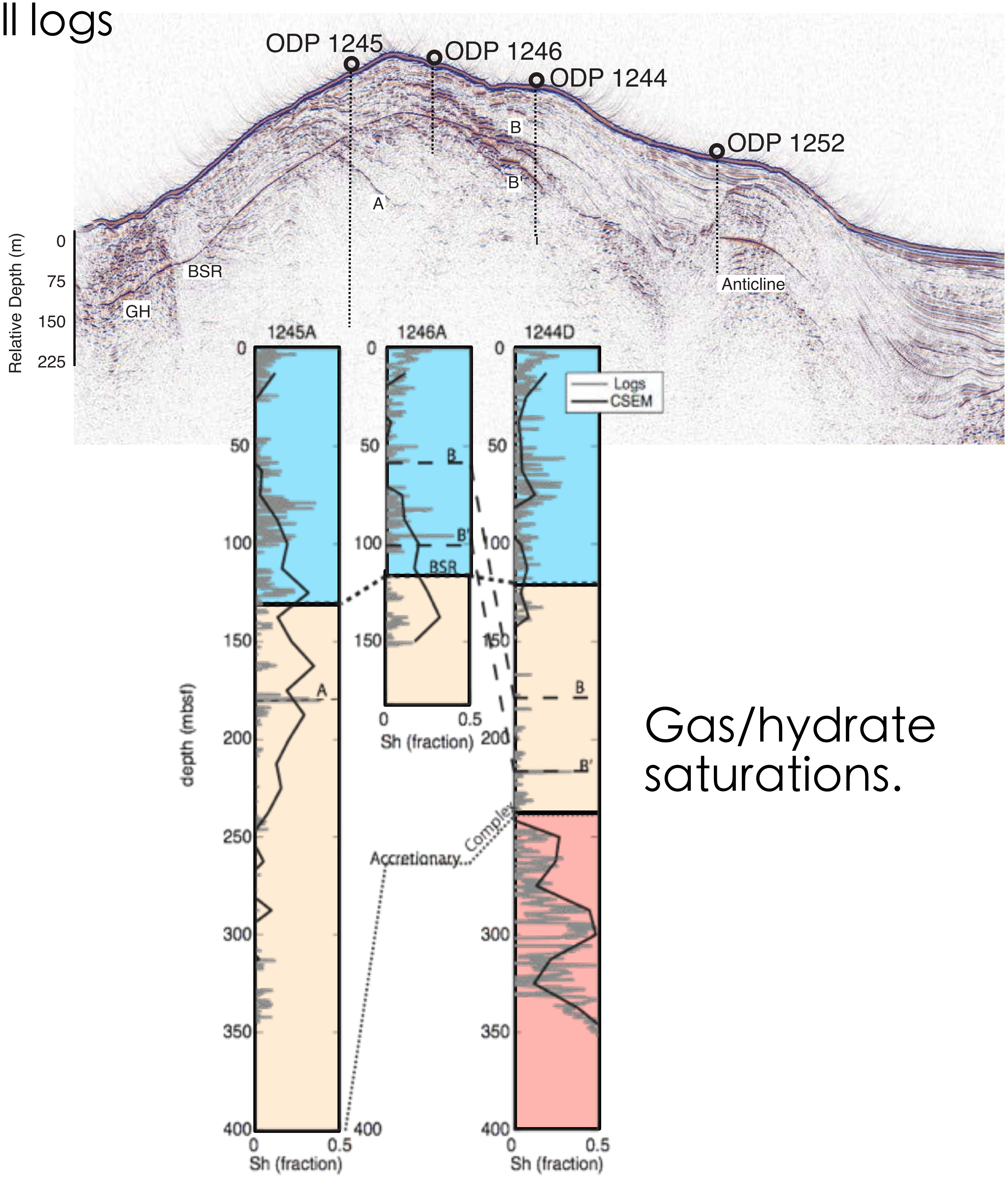
Weitemeyer, et al., GJI, 2010; 2011

High resistivity below the BSR corresponds to low seismic velocities -> free gas, while high resistivity above the BSR suggests hydrate.



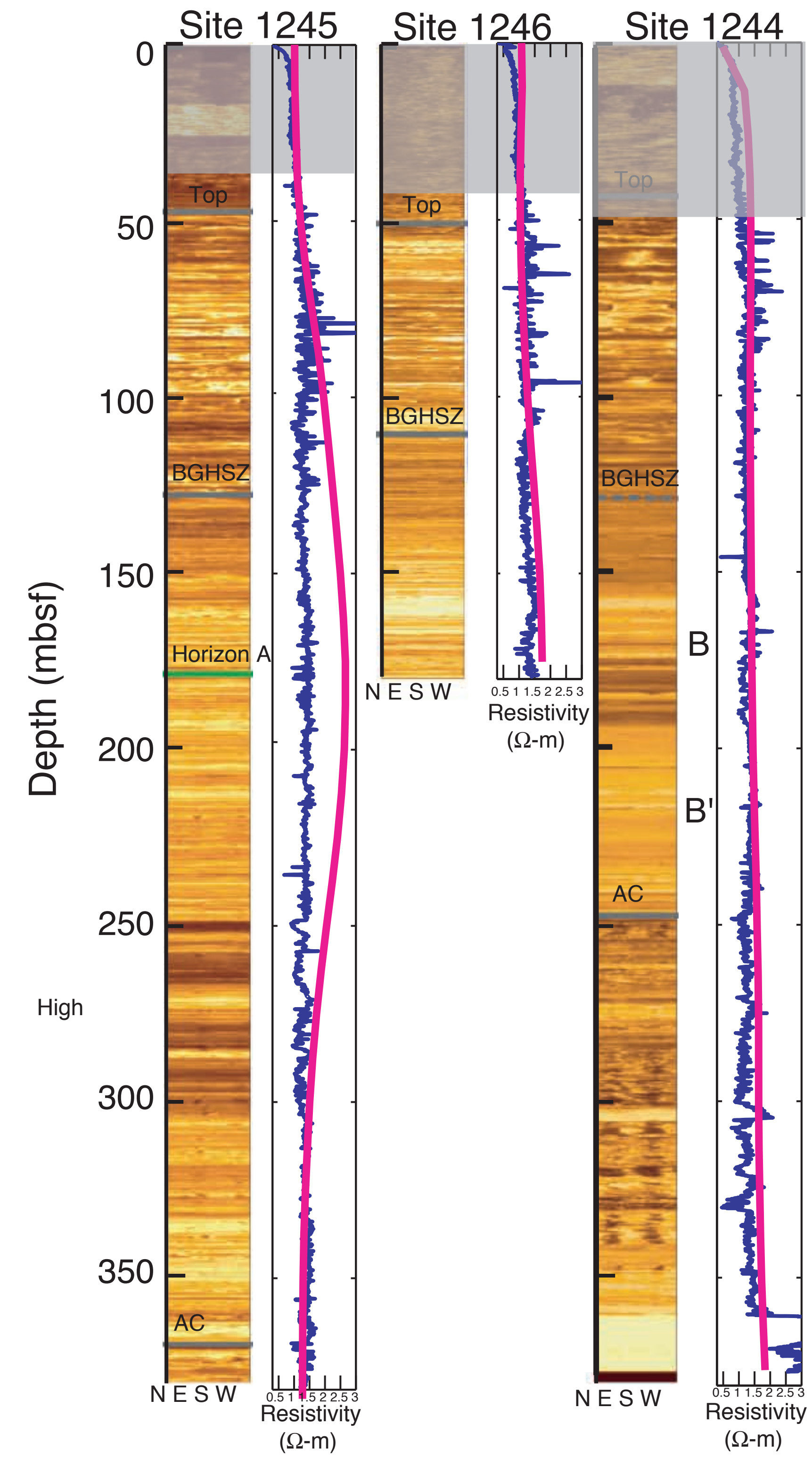
Weitemeyer, Constable and Tréhu, 2011

Comparison of inversion resistivities with well logs



Gas/hydrate saturations.

Resistivities



Shipboard Scientific Party Leg 204 (2003)

Weitemeyer, Constable and Tréhu, 2011

The Hydrate Ridge project was a success, but ...

There are a number of limitations with deployed seafloor receivers:

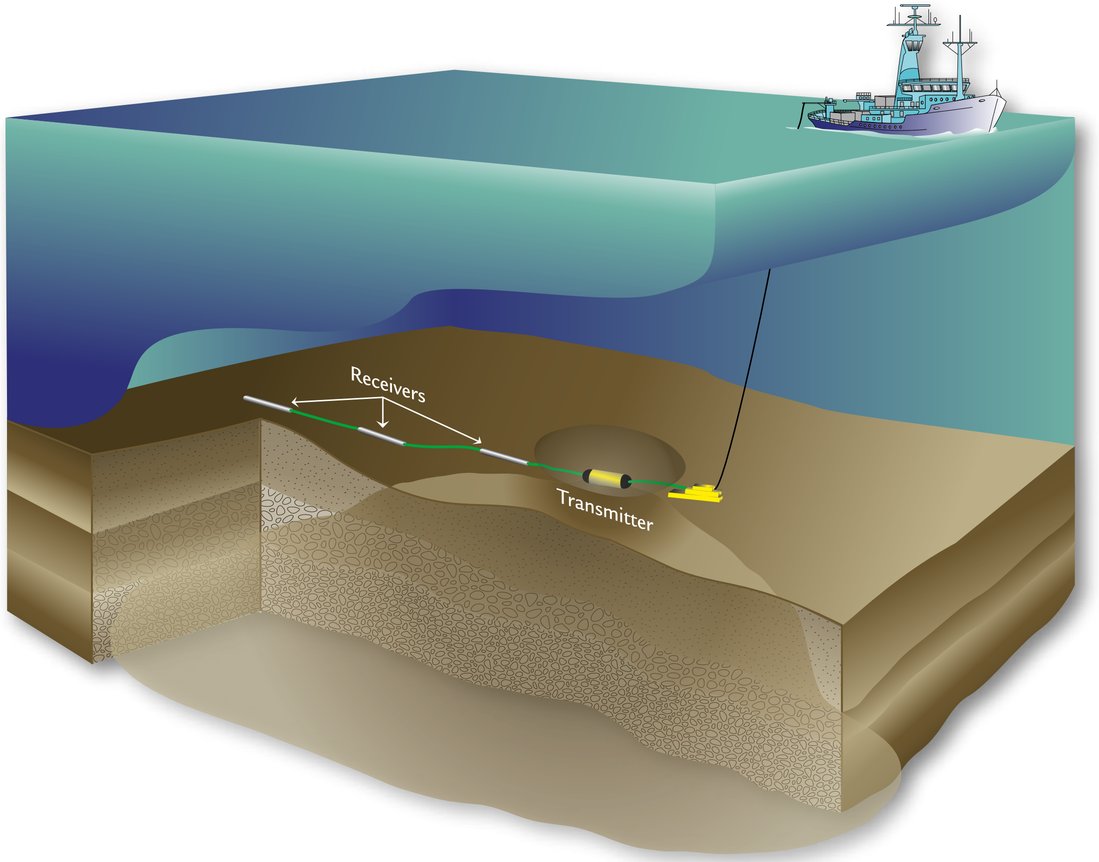
- Closely spaced receivers are costly in ship time and instruments
- Navigation errors increase with short source-receiver offsets
- There are still, inevitably, gaps in data coverage

This argues for a towed system.

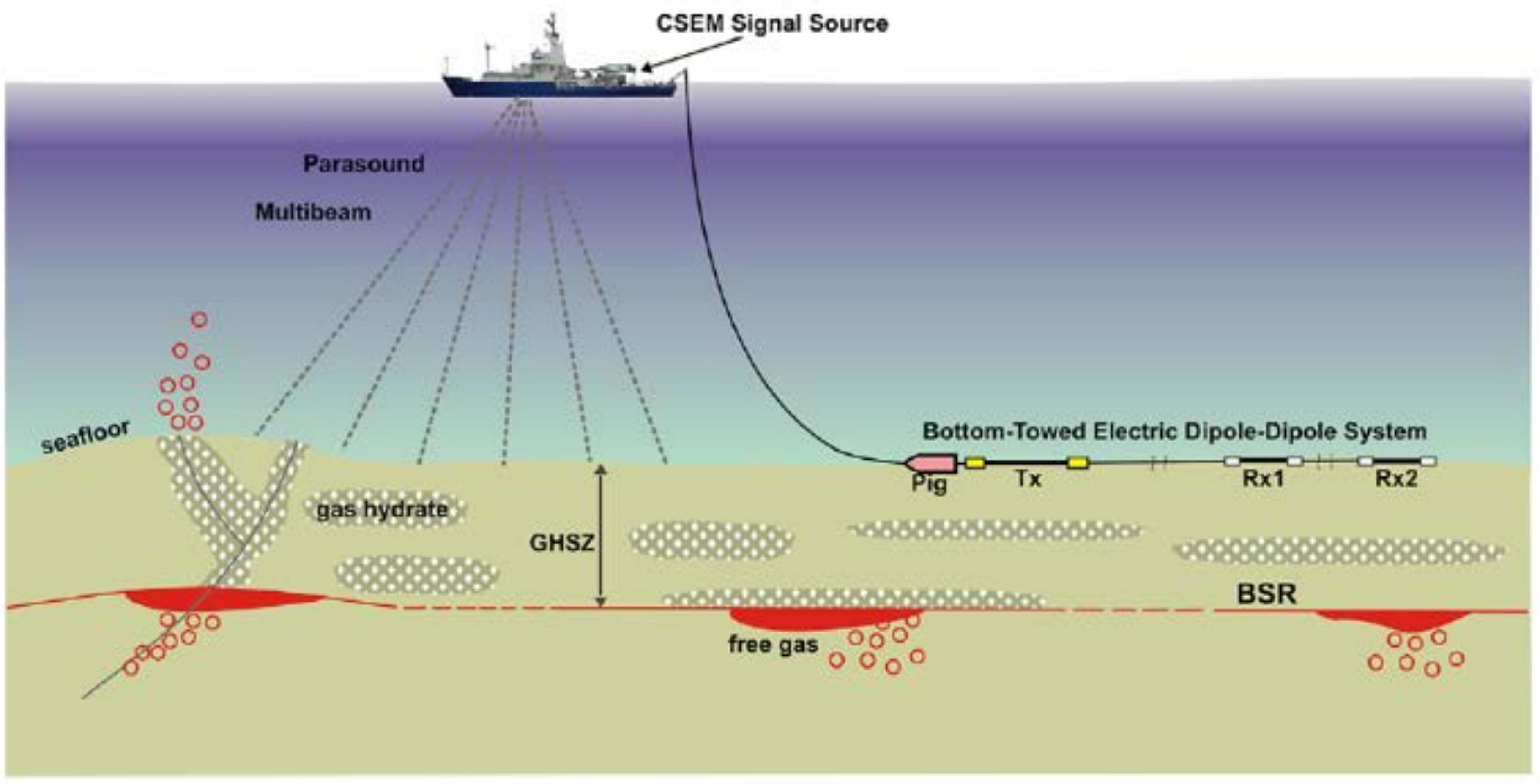
The Vulcans

Bottom-dragged systems exist but

- Source-receiver offsets are limited
- Noise is high
- Equipment losses are frequent
- Only inline data are possible

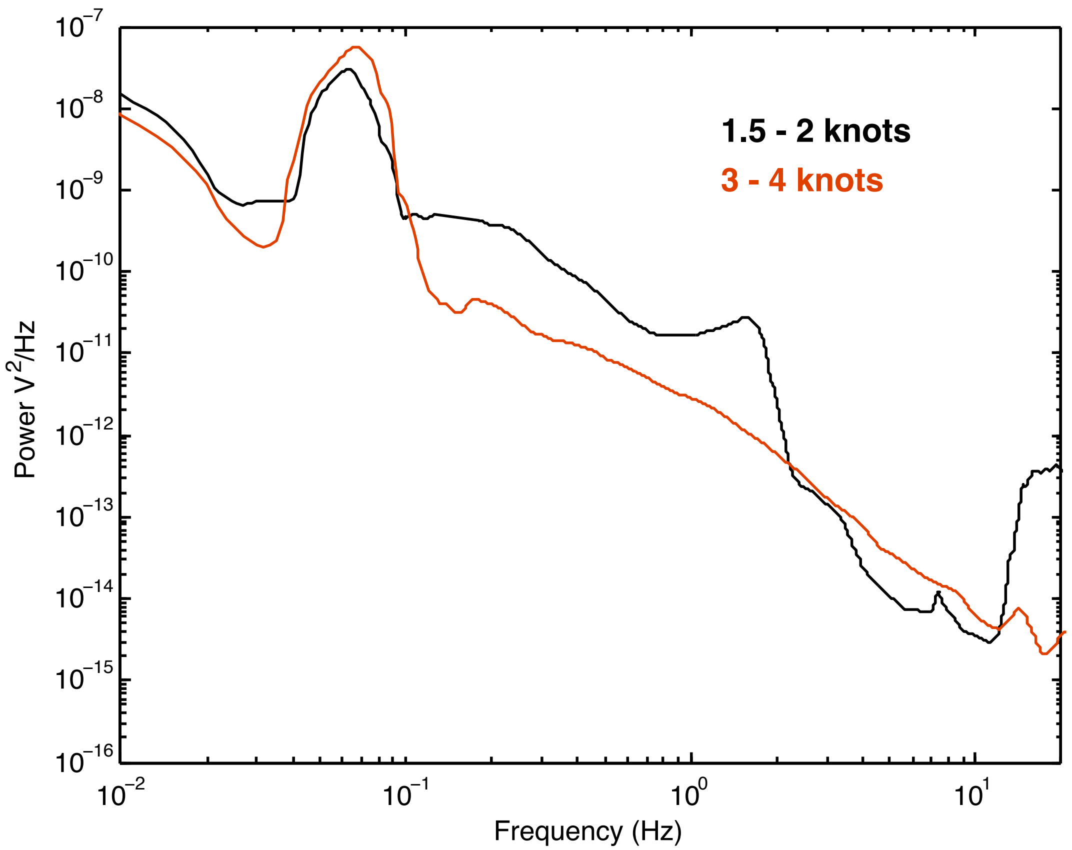


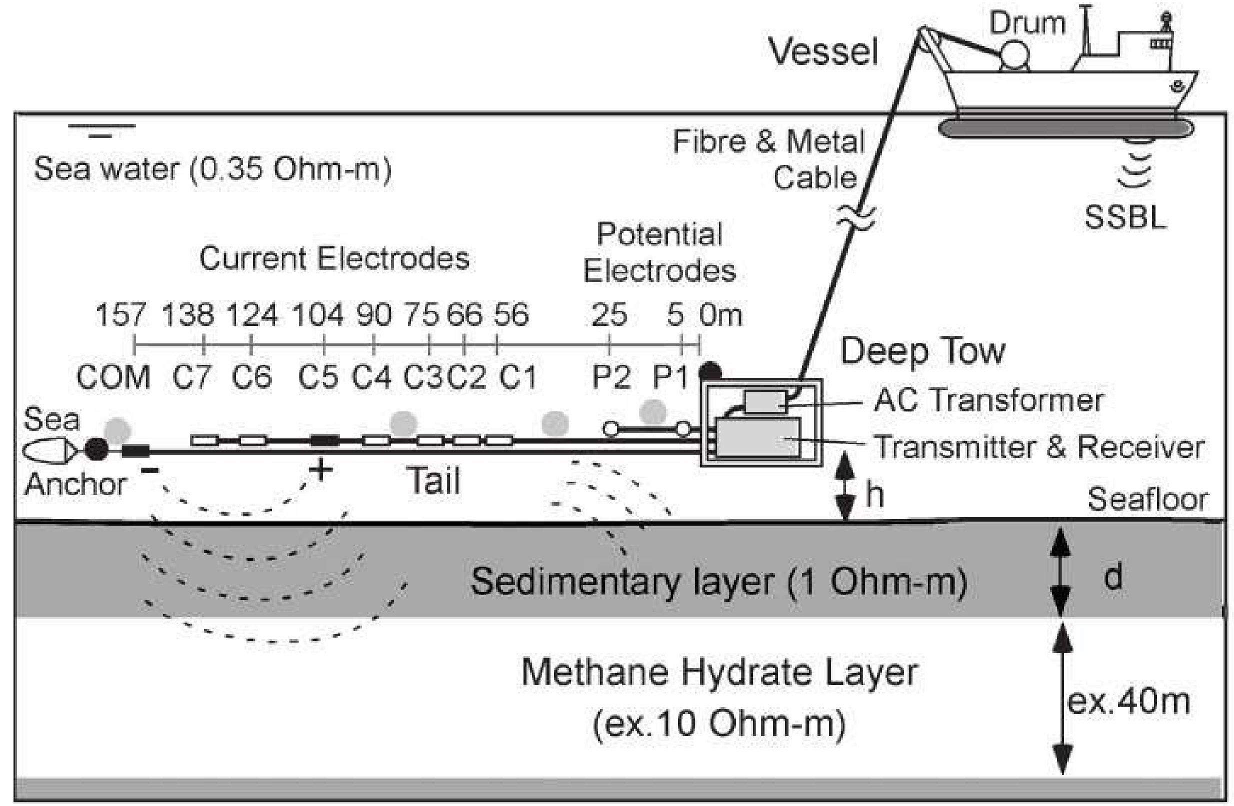
www.whoi.edu/cms/files/revans/2006/2/EM_System_7927.pdf



Schwalenberg, et al., 2010

The alternative is to fly an array above the seafloor.

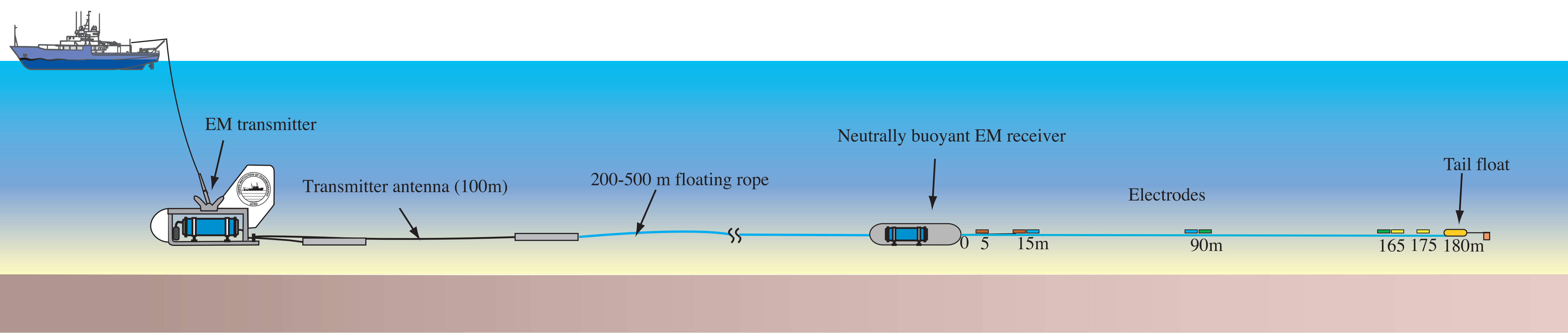




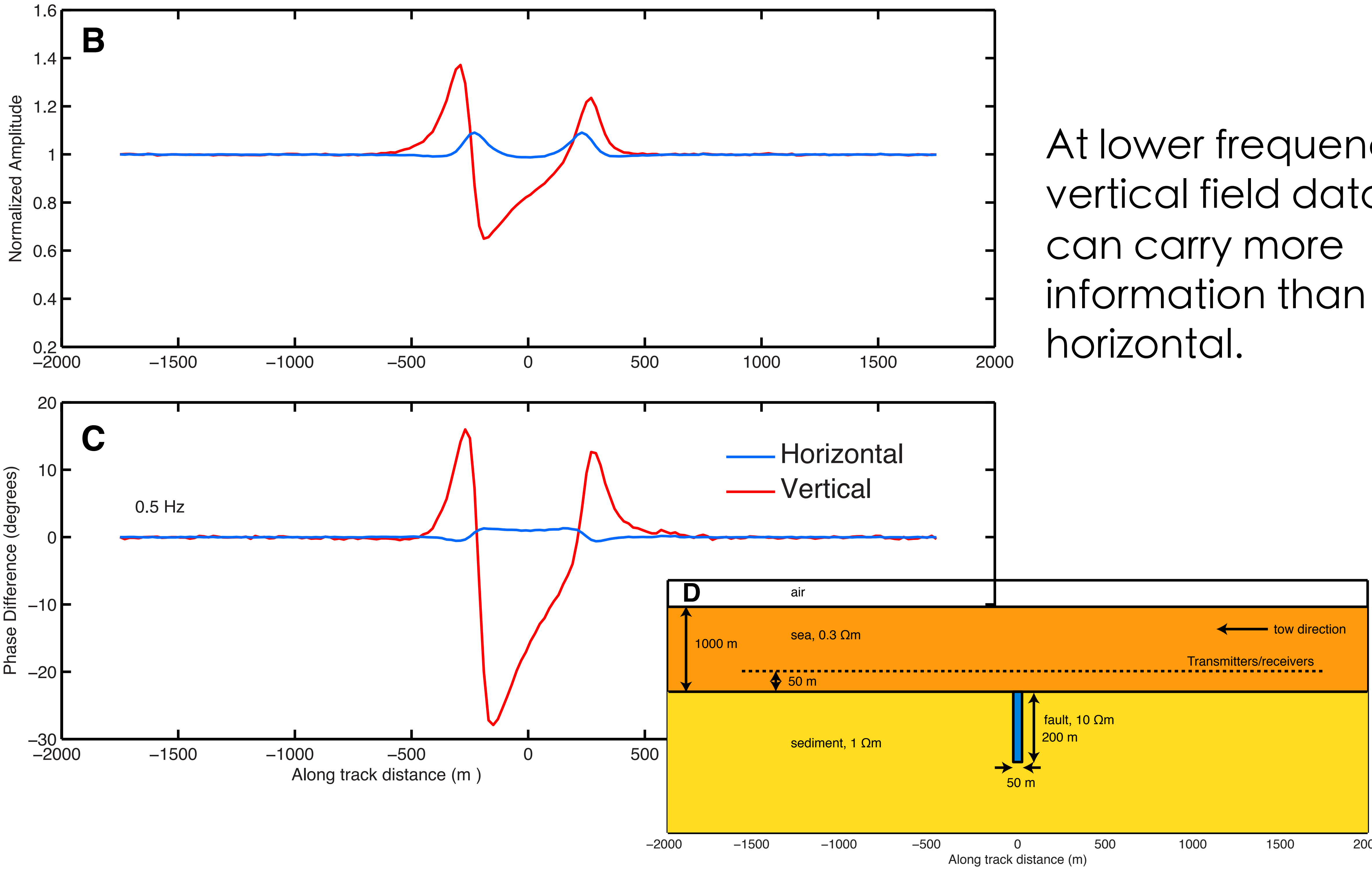
Goto, et al., 2009

But, noise induced by lateral motion of cable in Earth's magnetic field

$$\mathbf{E} = \mathbf{v} \times \mathbf{B}$$



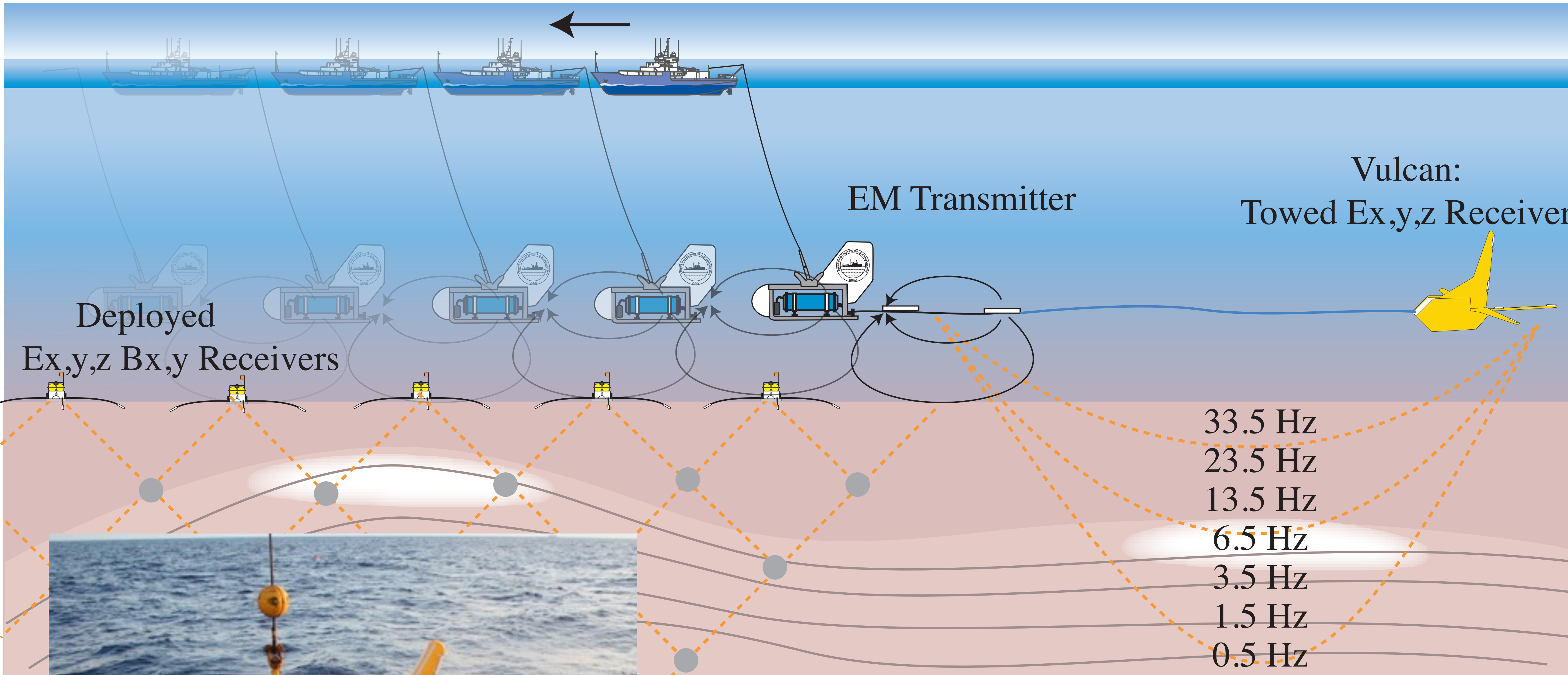
Our modeling also showed that it would be worth recording the vertical component of the electric field.

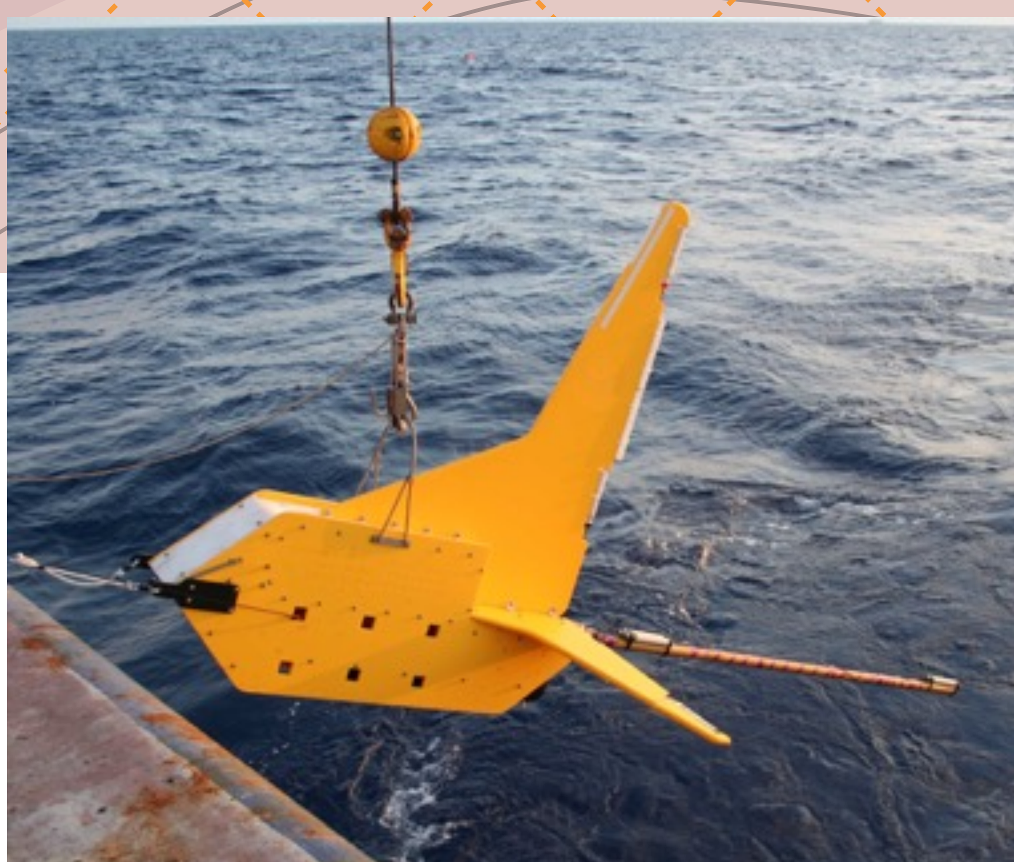


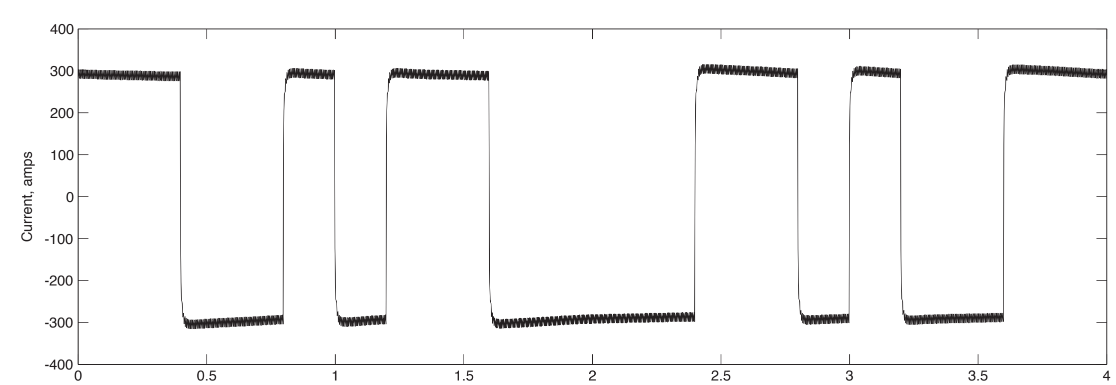
At lower frequencies, vertical field data can carry more information than horizontal.

0.5 Hz, 500 m offset, 50 m altitude

In 2007, we developed “Vulcan” for fixed offset frequency sounding.

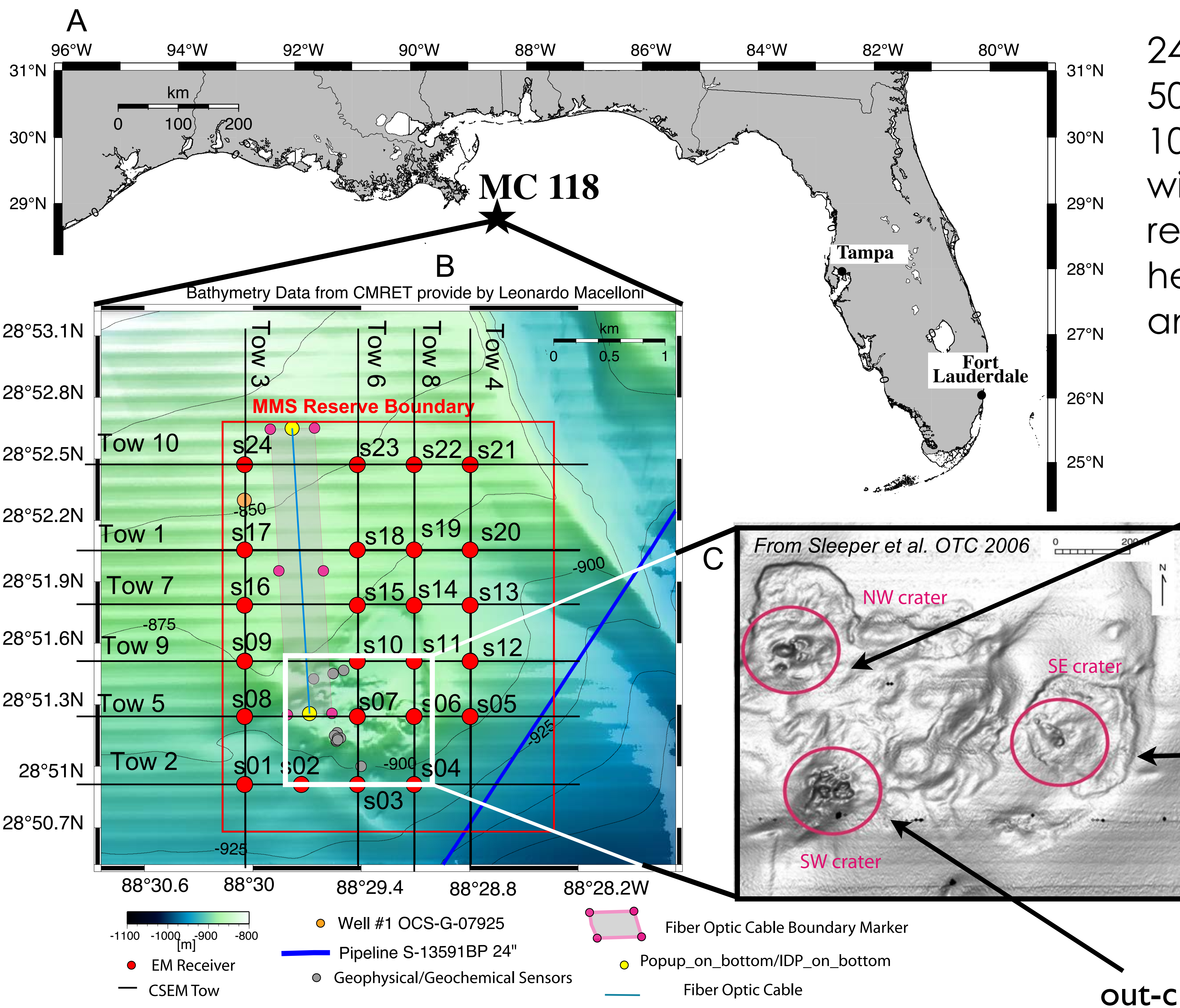






Waveform-D has a broad spectrum

MC 118, Gulf of Mexico using seafloor instruments and towed receiver:



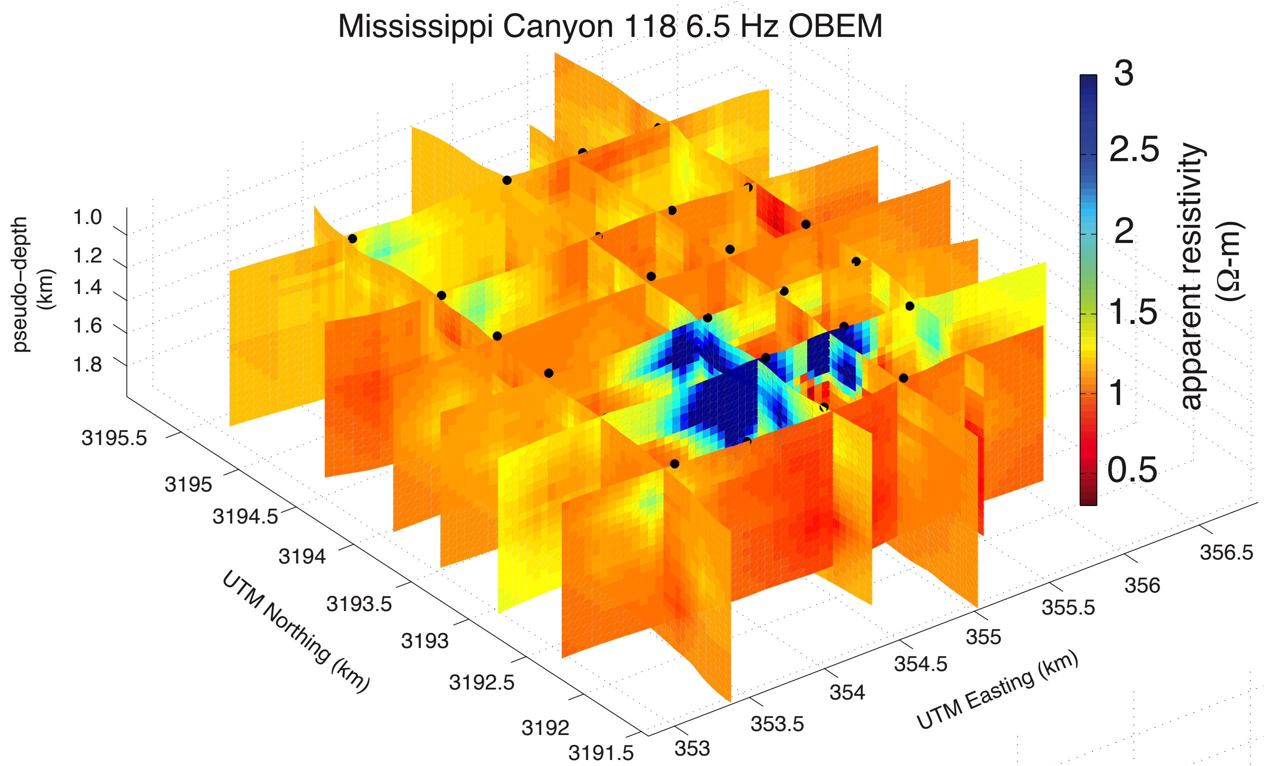
24 OBEM
500 m spacing
10 CSEM tows
with towed
receiver at a
height of 65 m
and 300 m offset.

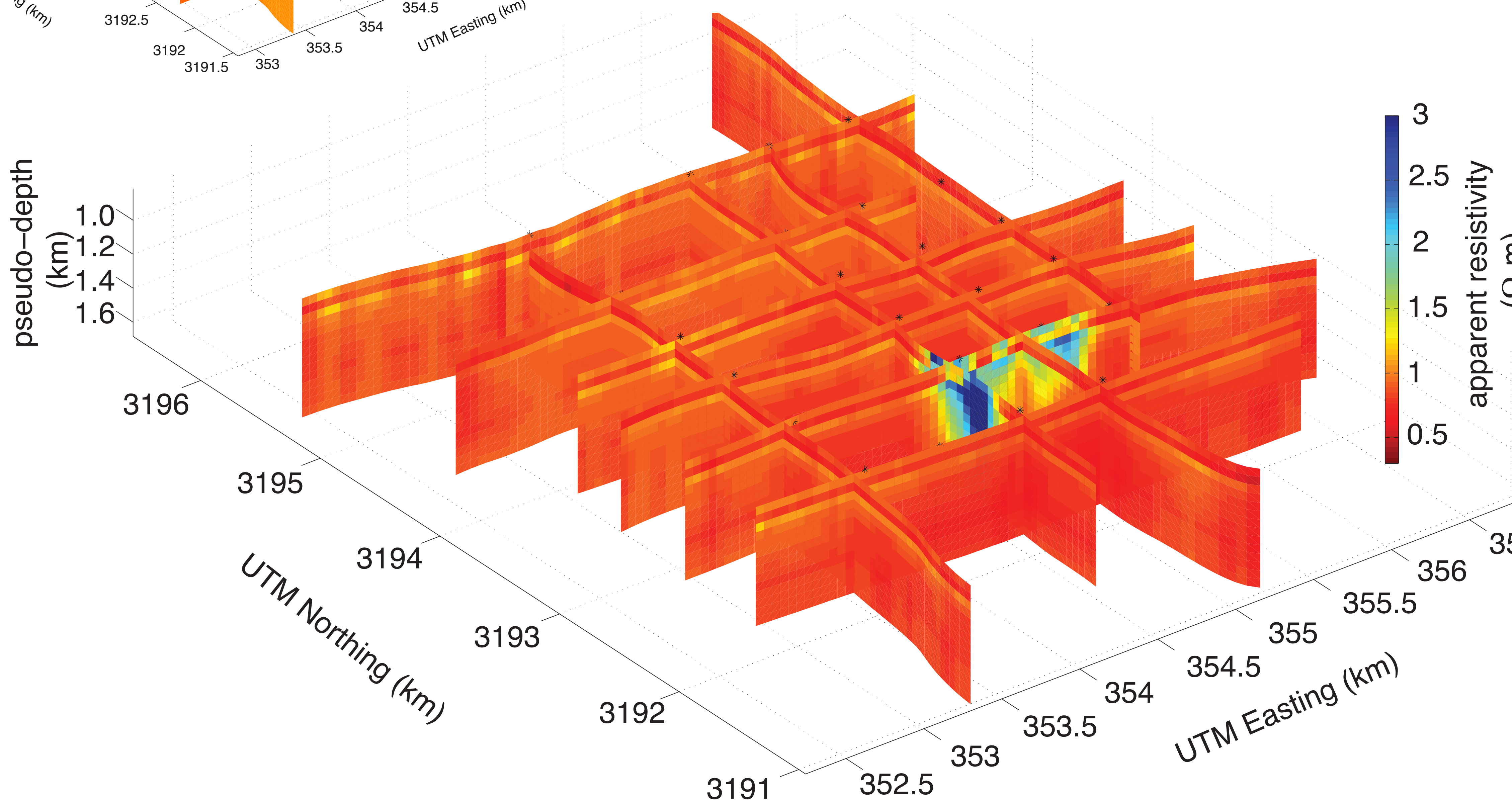
active, in proximity to super-saline waters

inactive clam graveyard

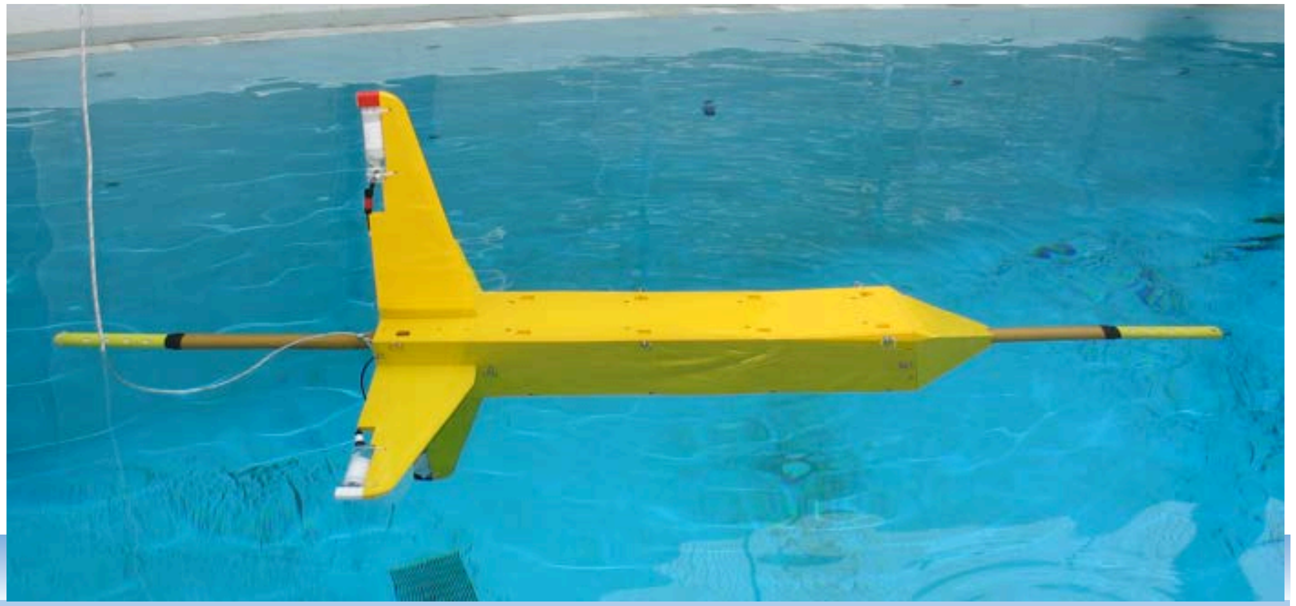
active, out-cropping hydrate

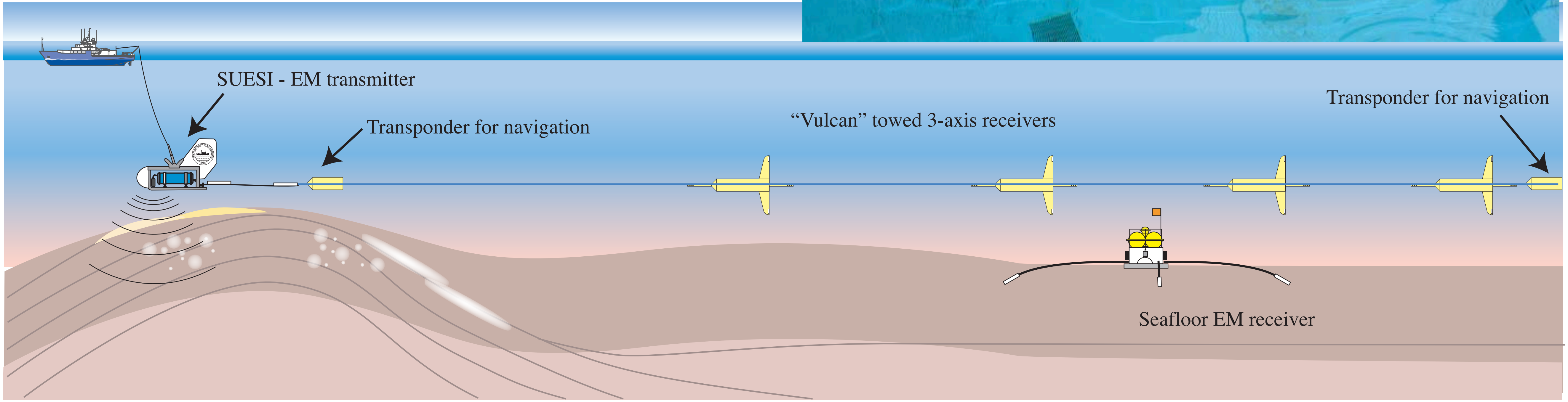
MC118 Vulcan apparent resistivity frequency sections are in good agreement with OBEM pseudosections





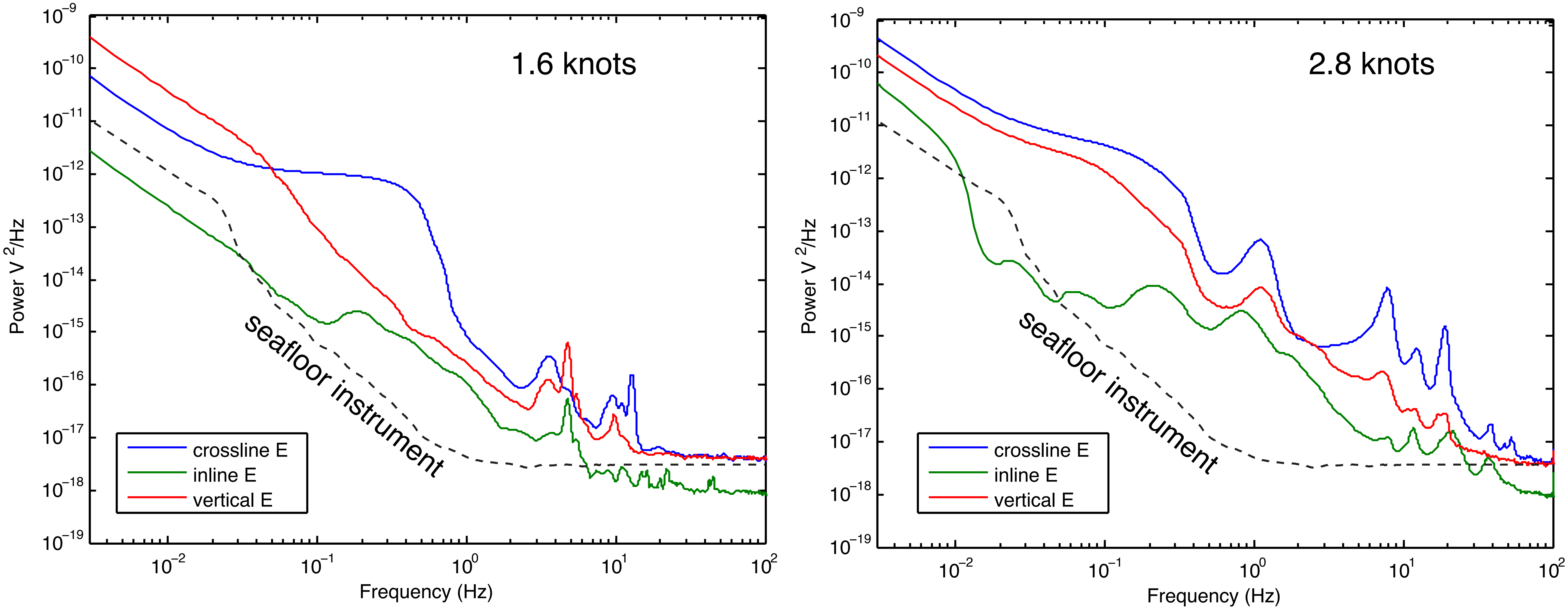
Under Fugro funding in 2011 we developed Vulcan Mk II





- Real-time depth telemetry
- Real-time data samples
- 3-axis accelerometer
- 1000+ meter offsets
- Timing pulse from transmitter

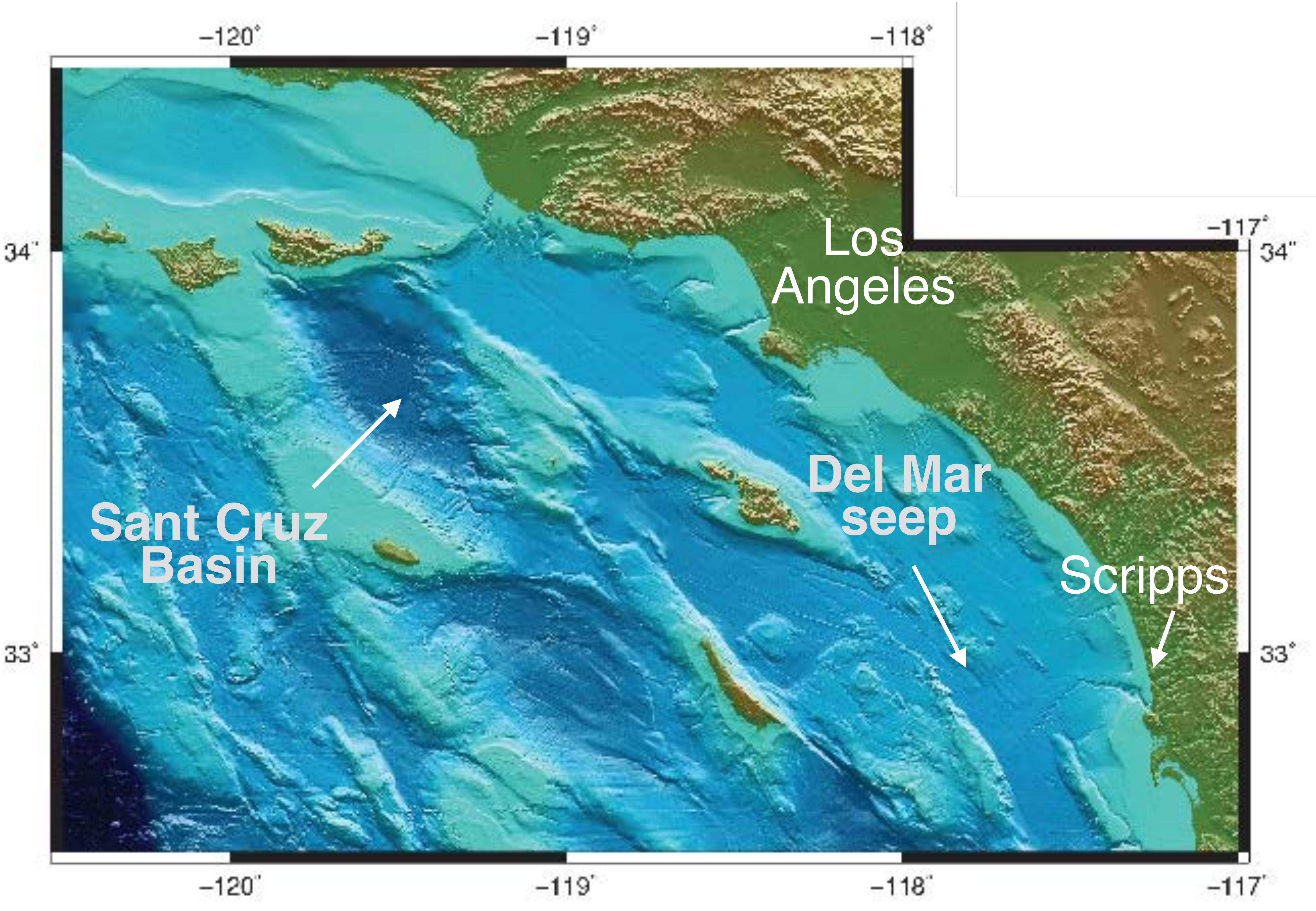
Voltage noise is comparable to our seafloor instrument. (But, dipoles are 5-10 times shorter.)



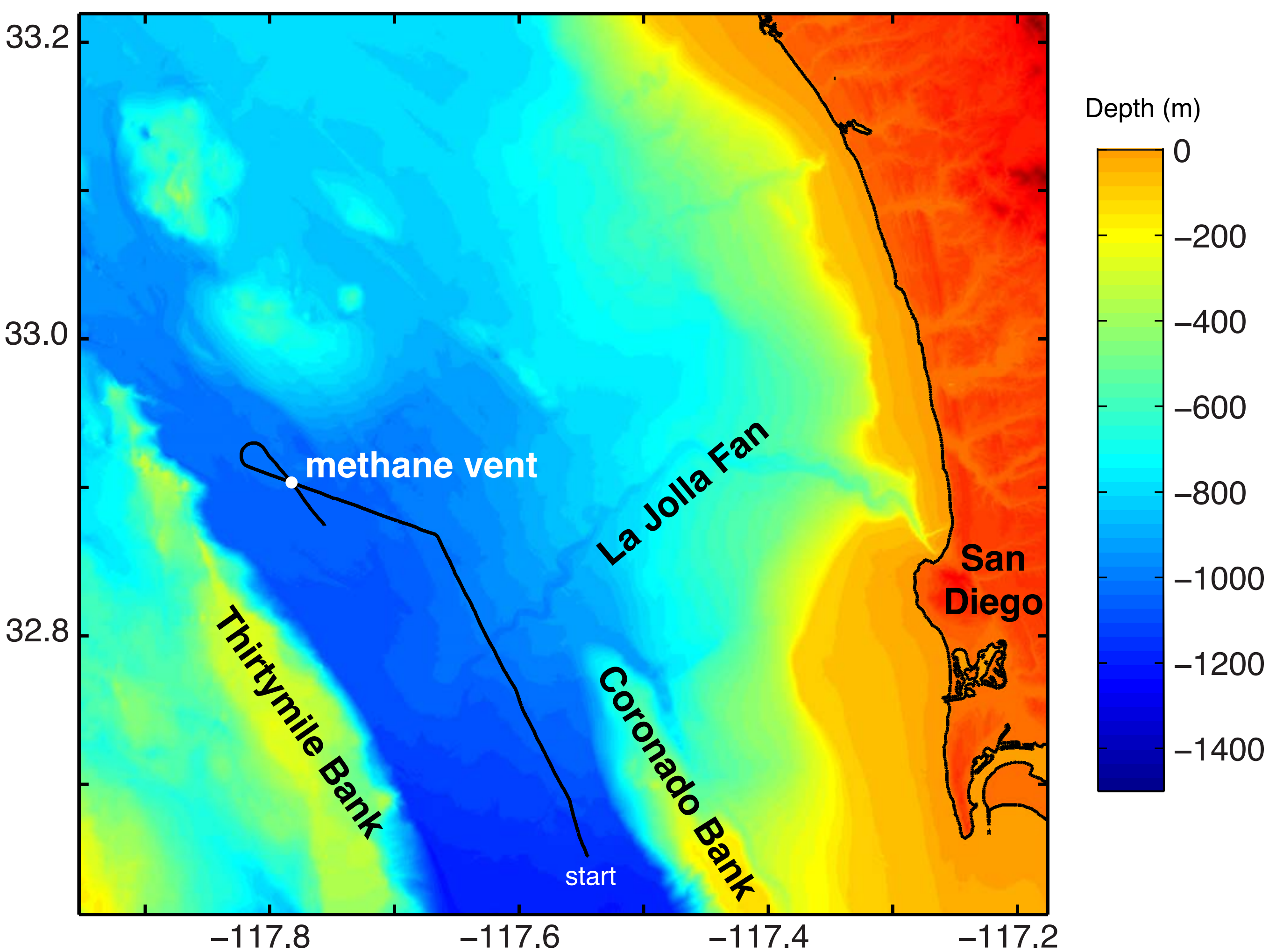
2015 Southern California Tests
A tale of two seeps

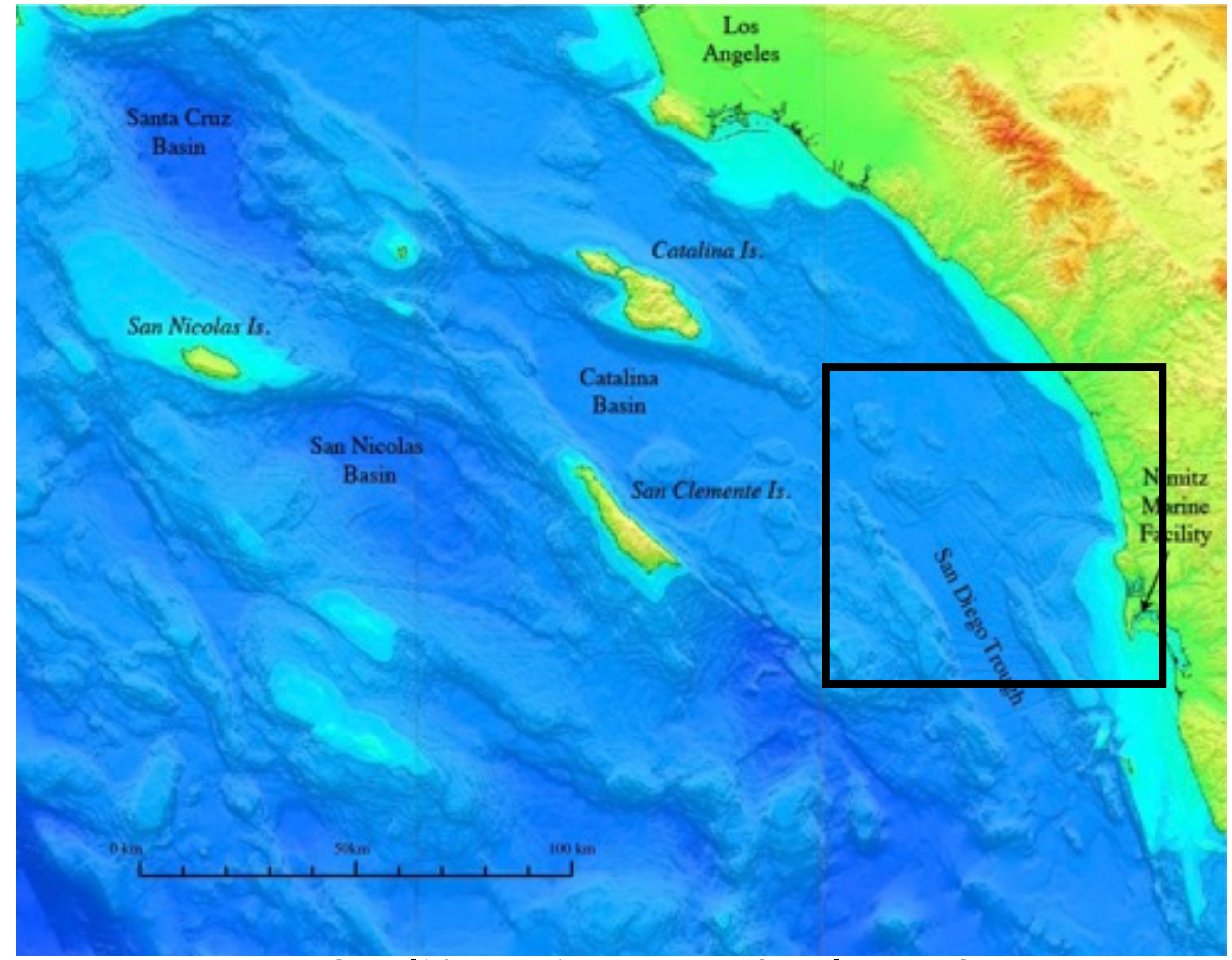
Work carried out by Peter Kannberg and supported by OFG and BOEM

We have carried out two surveys, one targeting a known methane vent called the Del Mar seep, and one covering most of the Santa Cruz Basin.

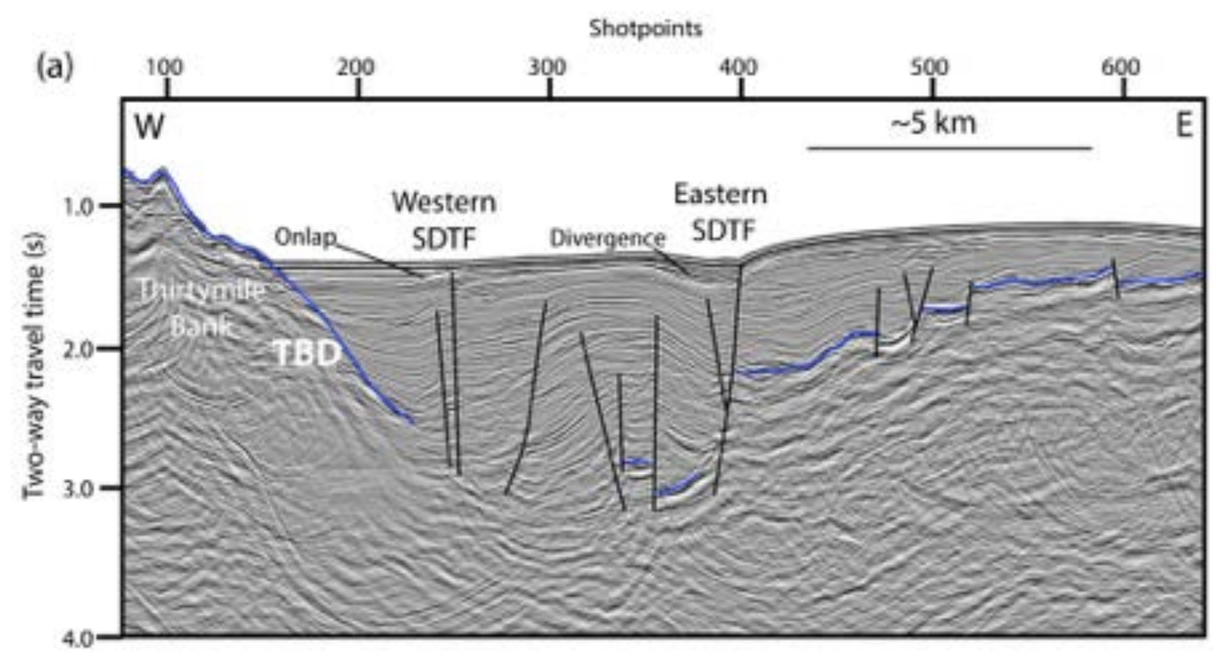


The Del Mar seep is a methane vent in the San Diego Trough, studied by Scripps students. It is in a pop-up structure bounded by two strands of the San Diego Trough Fault.



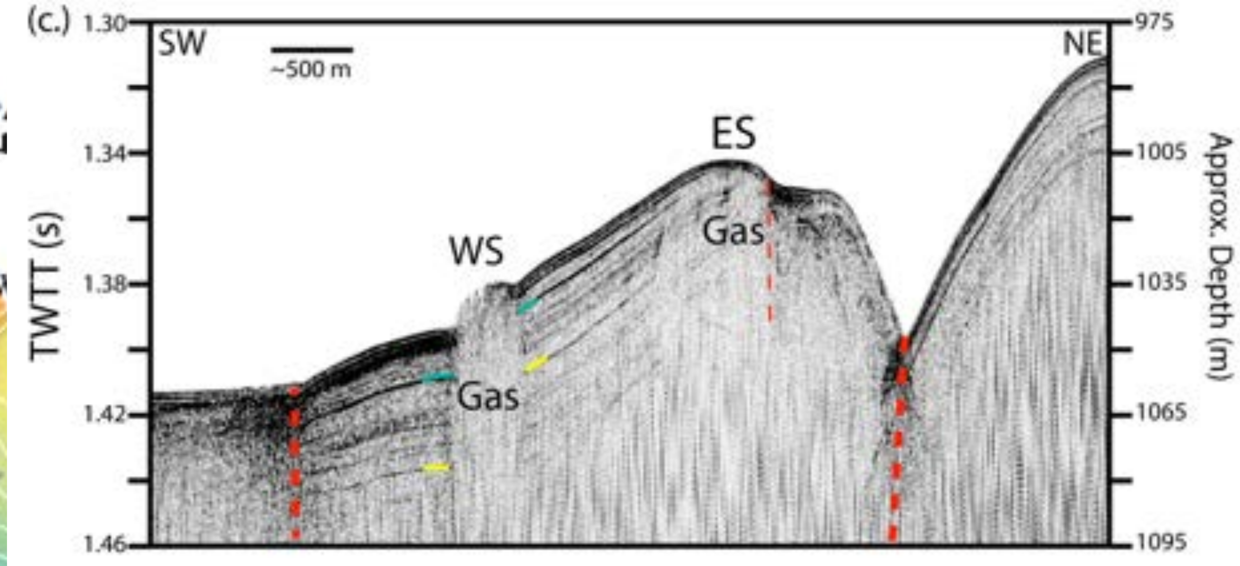


California Borderlands

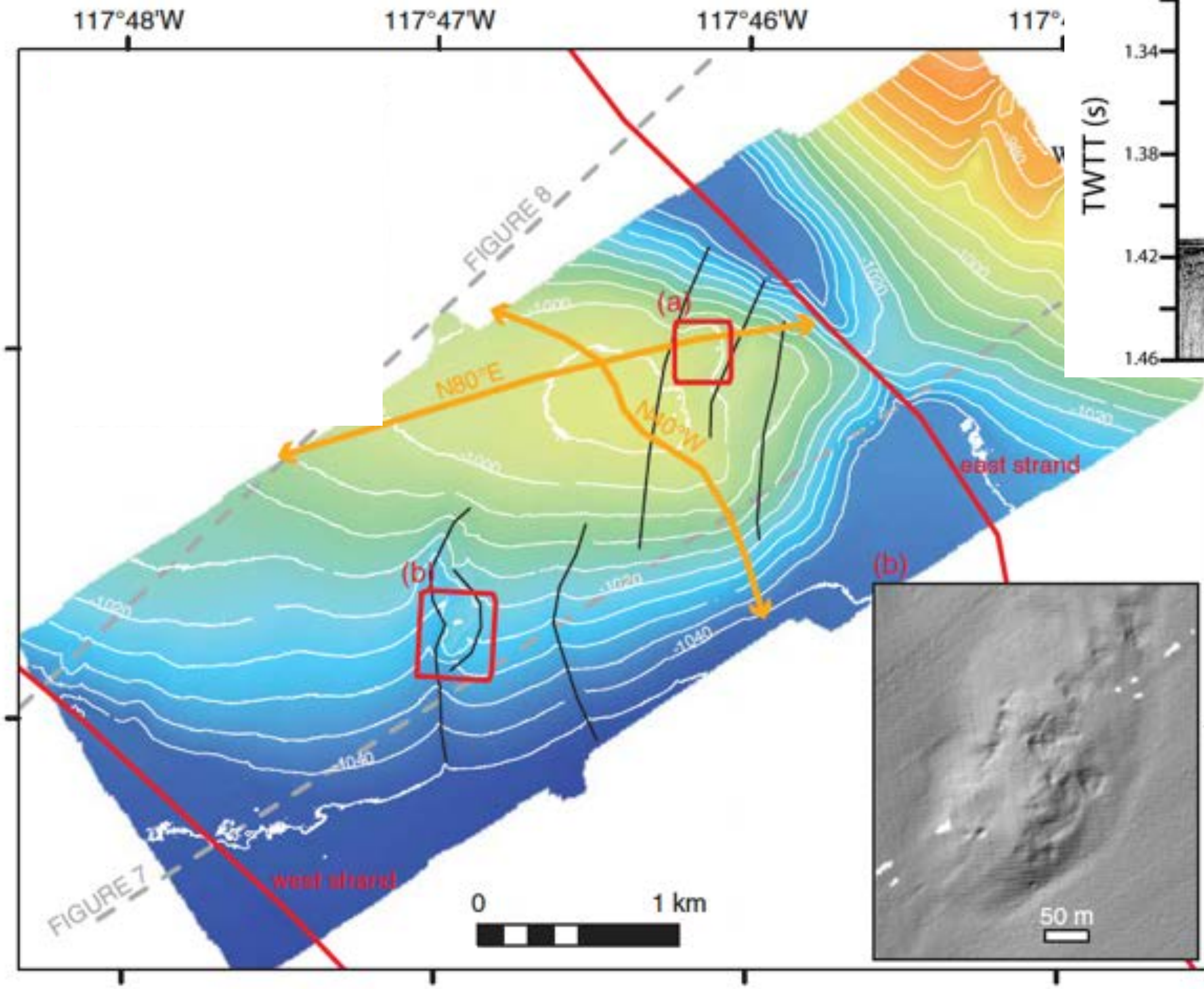


Maloney et al., 2015

Ryan et al. discovered this feature, in about 1,000 m water depth, and predicted fluid or methane venting, since confirmed by ROV dives and acoustics.

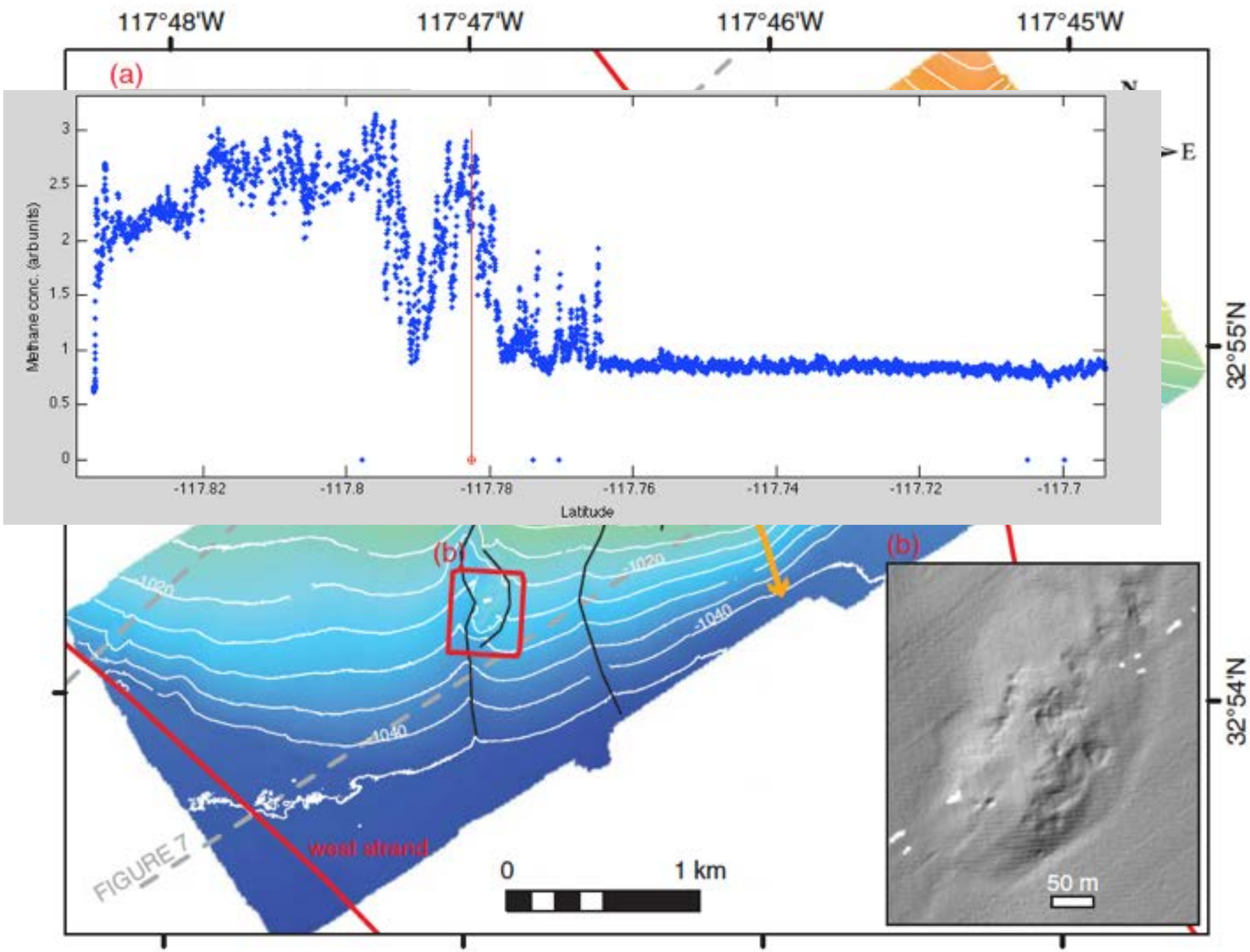


Maloney et al., 2015



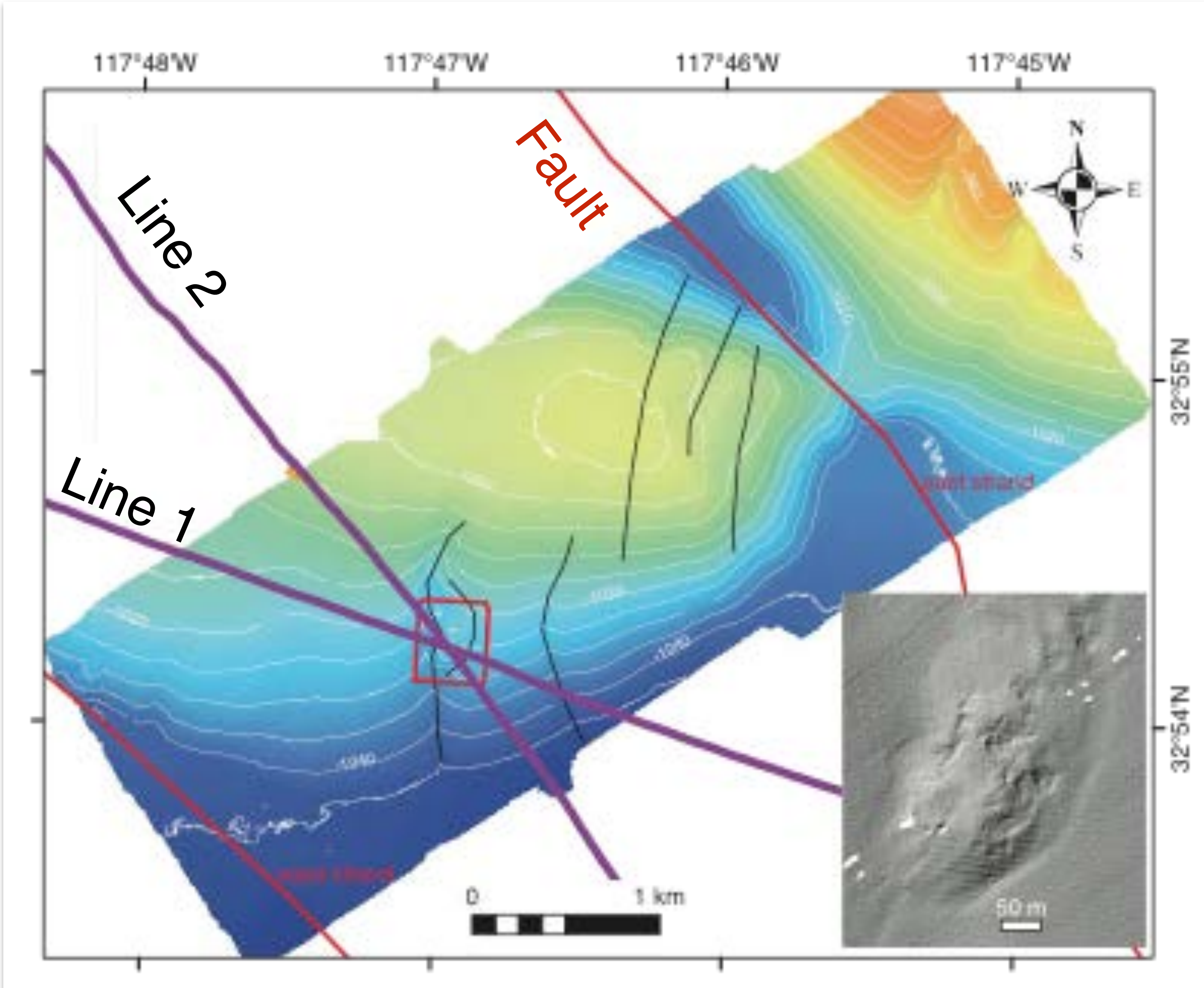
Ryan, et al., BSSA, 2012

We also obtained an uncalibrated signal on a Contros methane sensor during an earlier CSEM test.

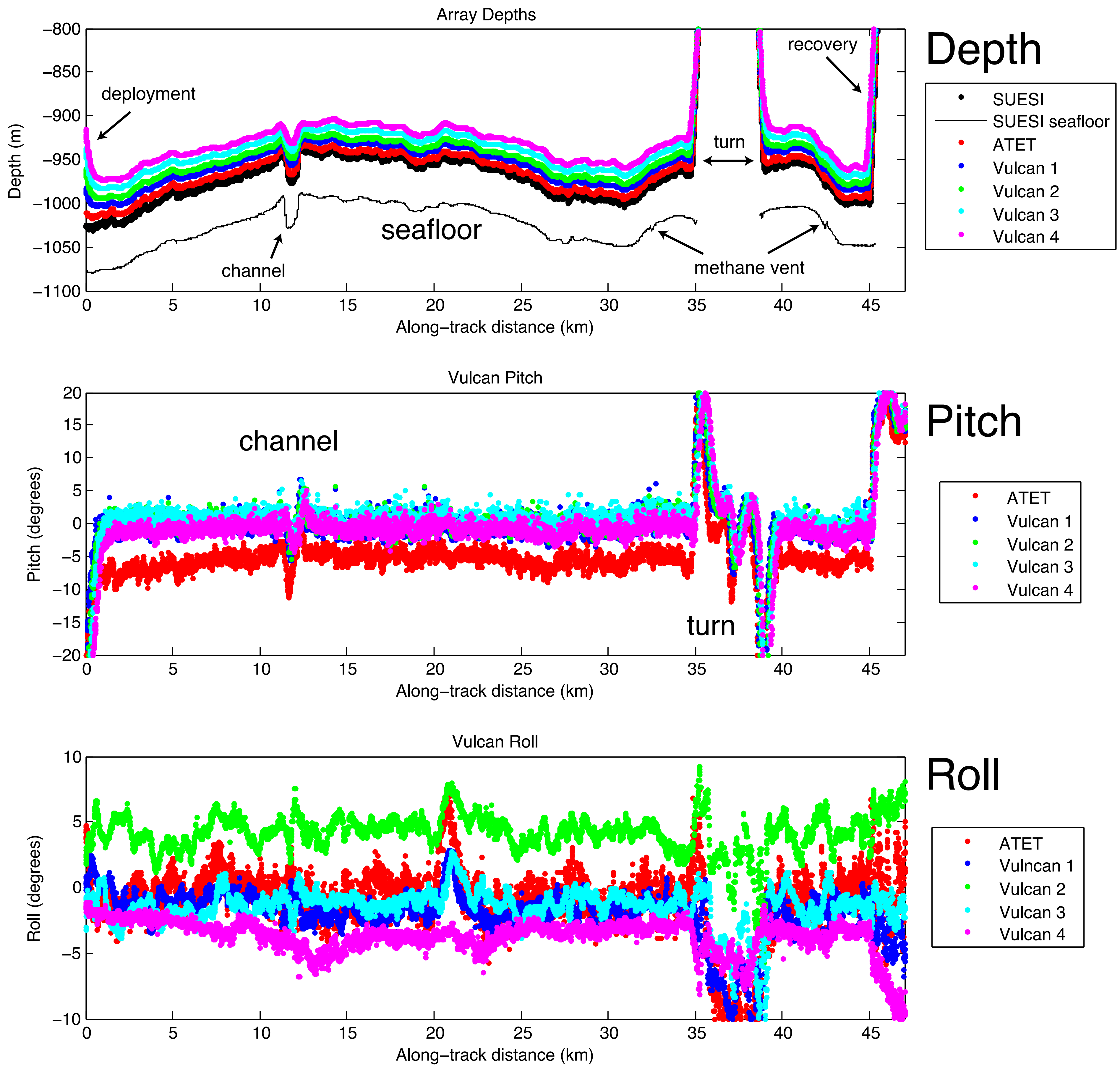


Ryan, et al., BSSA, 2012

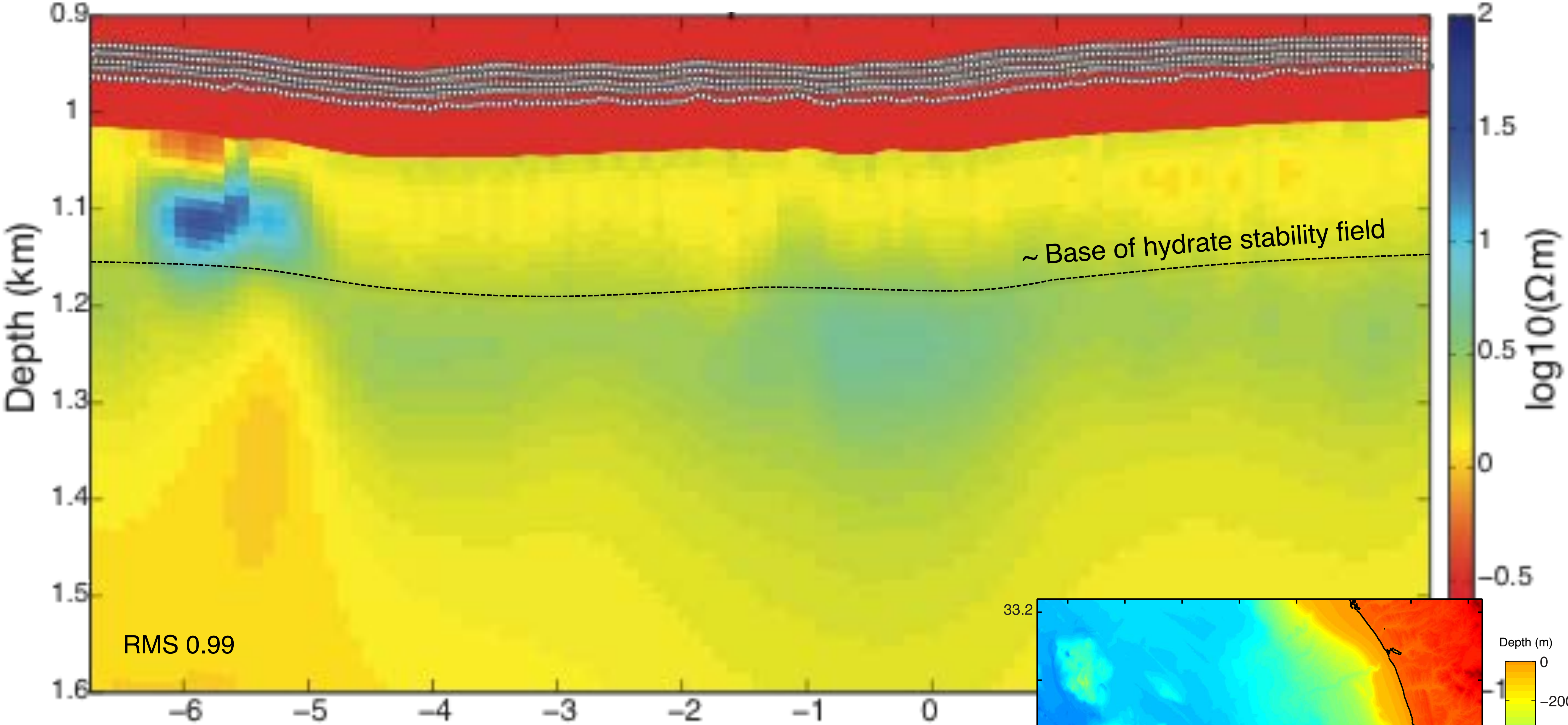
In March 2015 we towed across the vent with a 500 m Vulcan array, made a turn, and towed over it again.

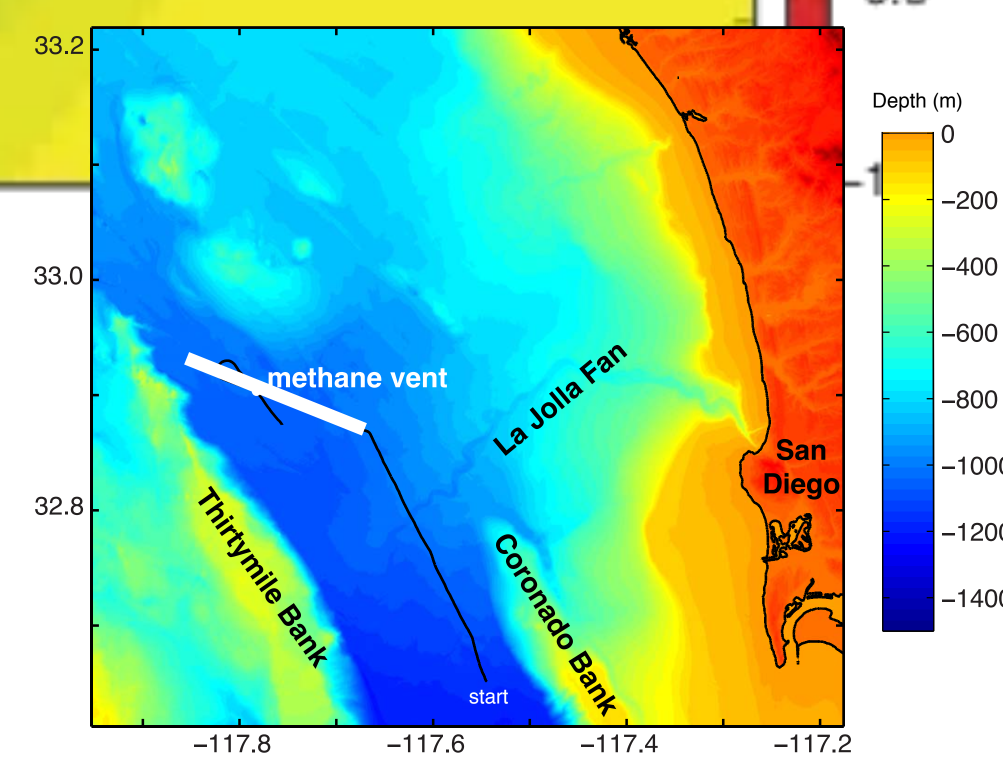


Navigation and stability of the receiver system is important.

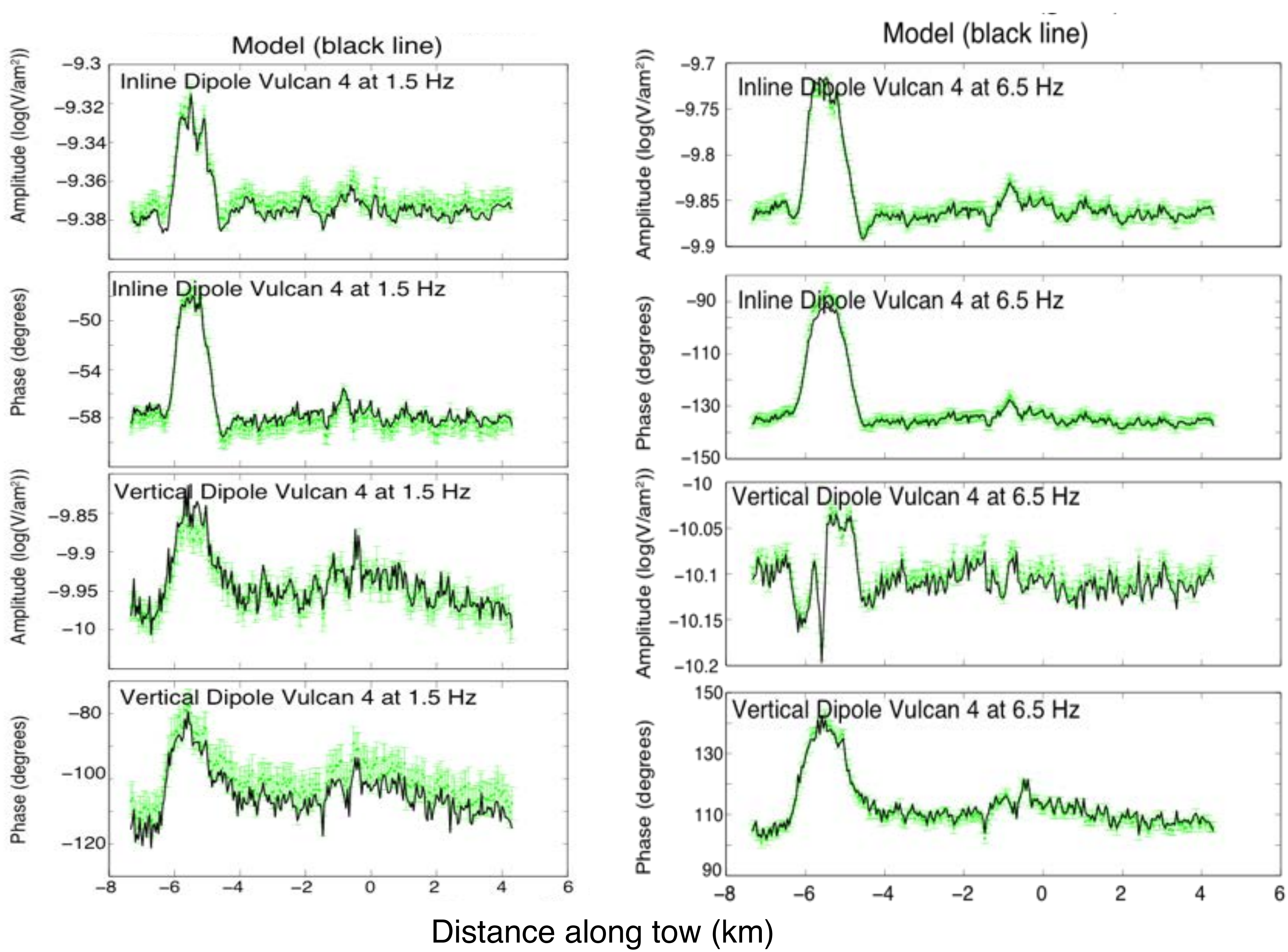


Line 1 inversion shows a uniform seafloor except in the seep area.

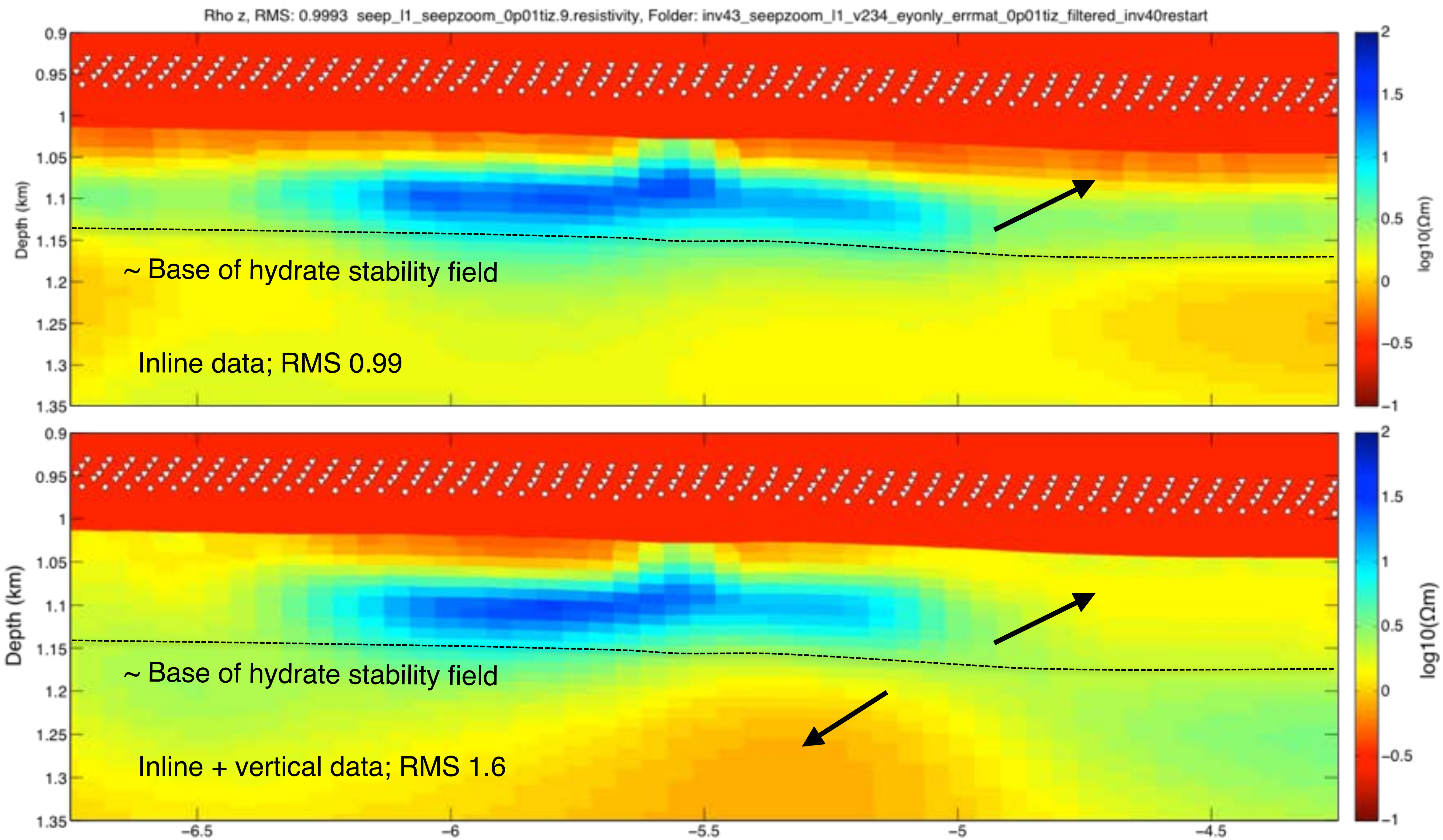




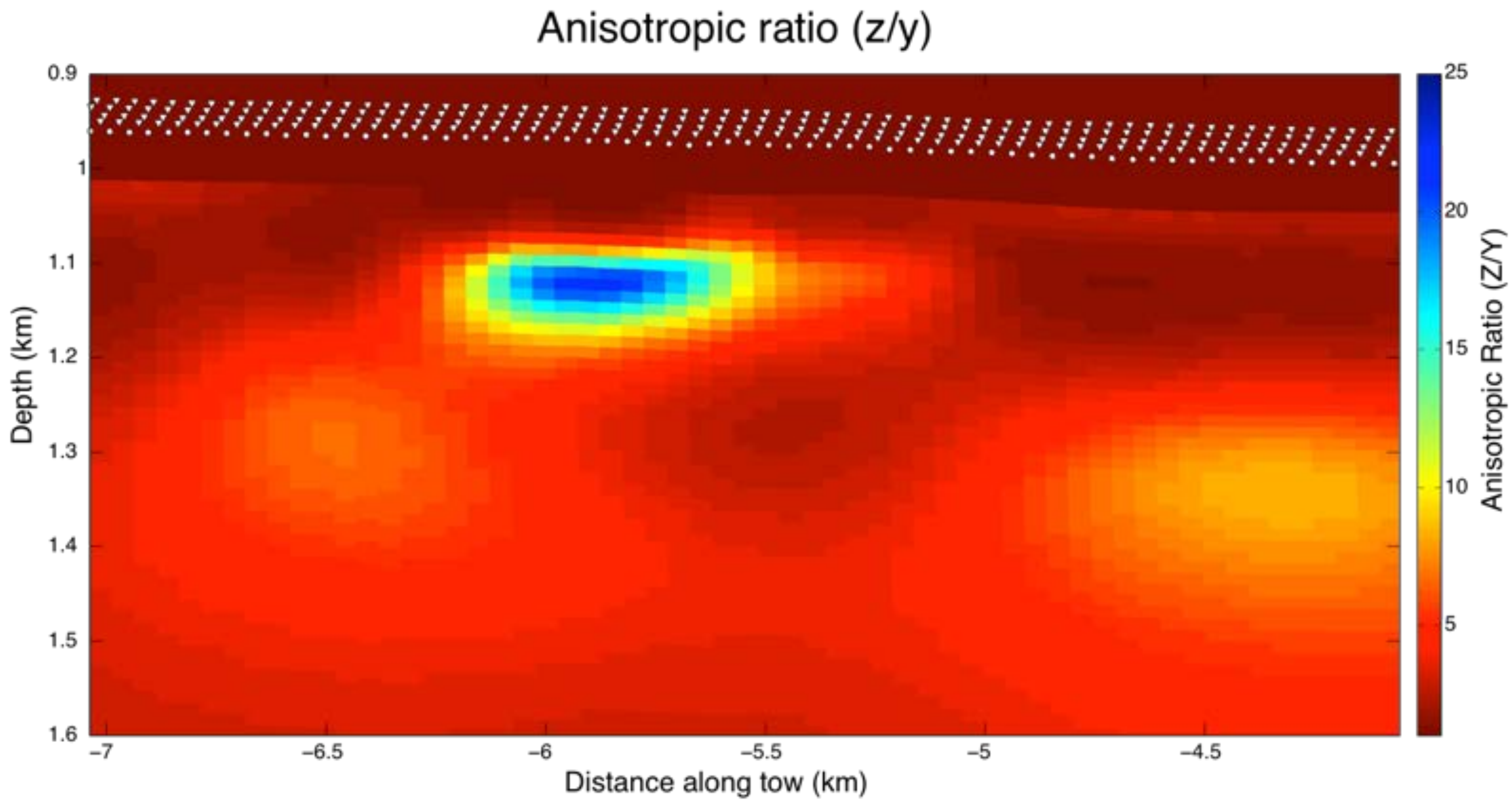
Frequencies of 1.5, 3.5, 6.5 Hz were fit for 3 Vulcans. Ey fits to 1% amplitude and 0.6° phase. As predicted, there is a strong low-frequency signal in Ez.



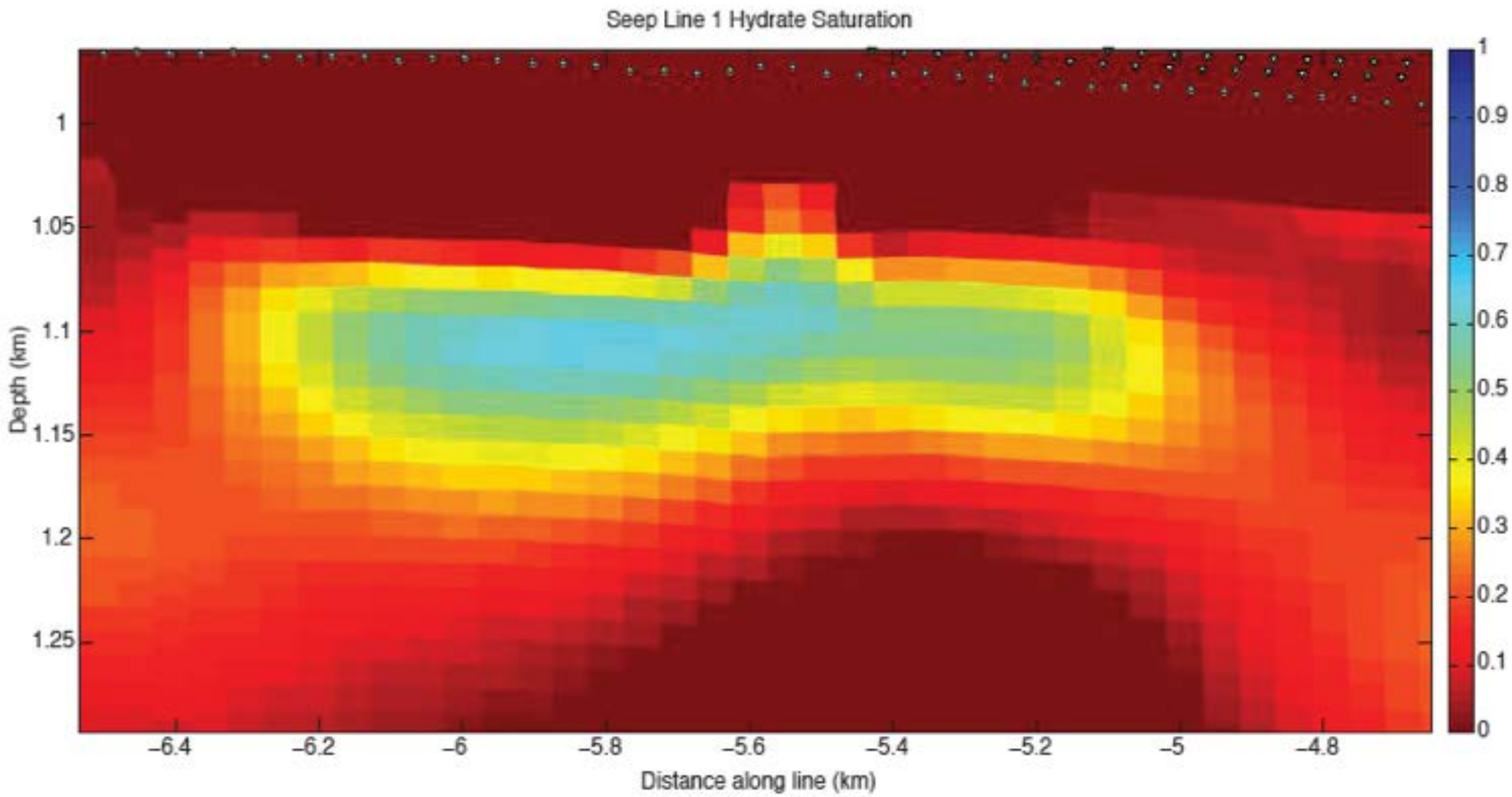
Addition of the vertical electric field data removes what appears to be a layering artifact and brings out a conductor that may be fluids feeding the vent.



Anisotropy (ratio of vertical to horizontal resistivities) is very high in the northern part of the region inferred to be gas hydrate.



Using Archie's Law, resistivity can be converted to hydrate saturation. Integrating saturation provides an estimate of 2 billion cubic meters of methane, or 0.07 tcf.

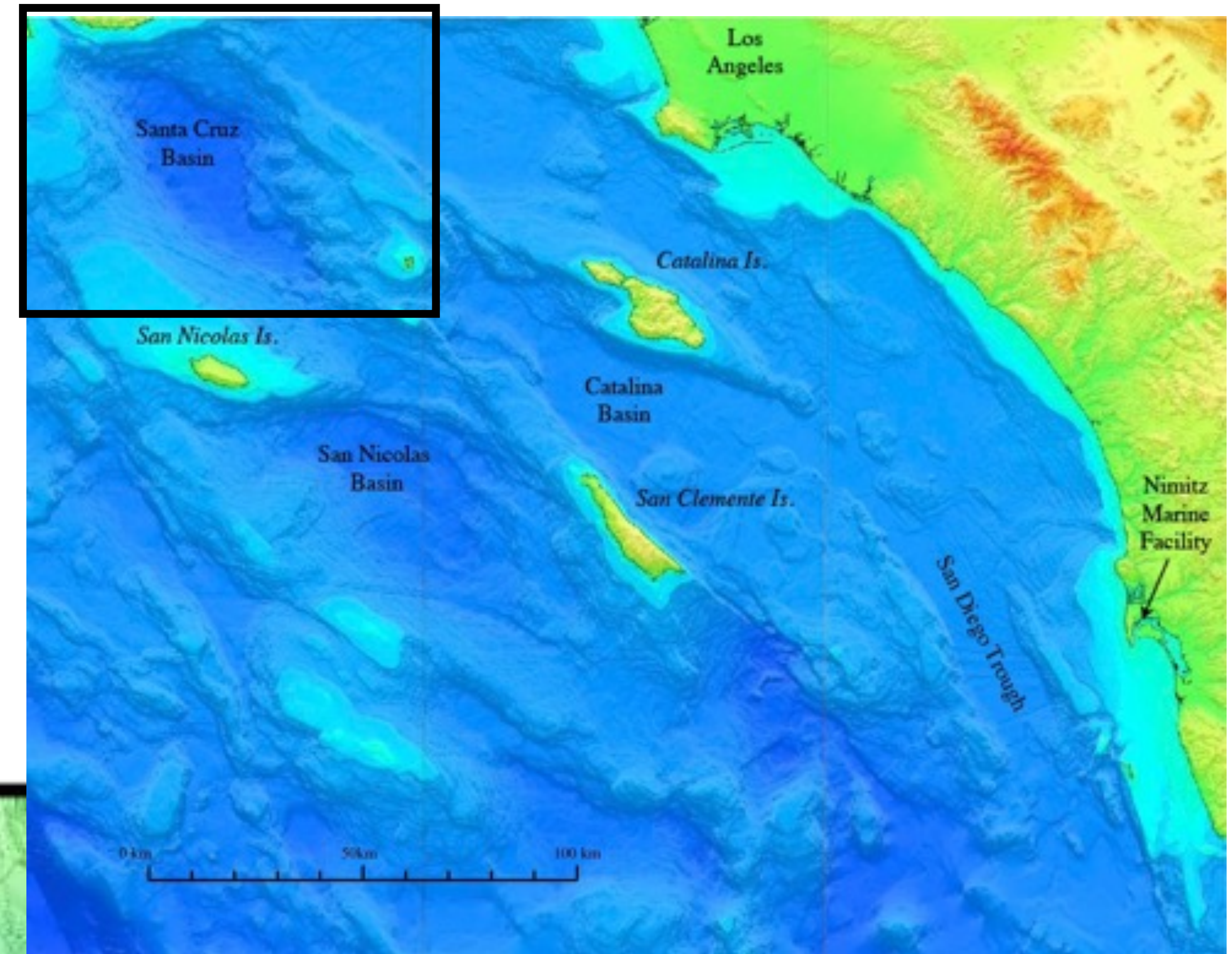


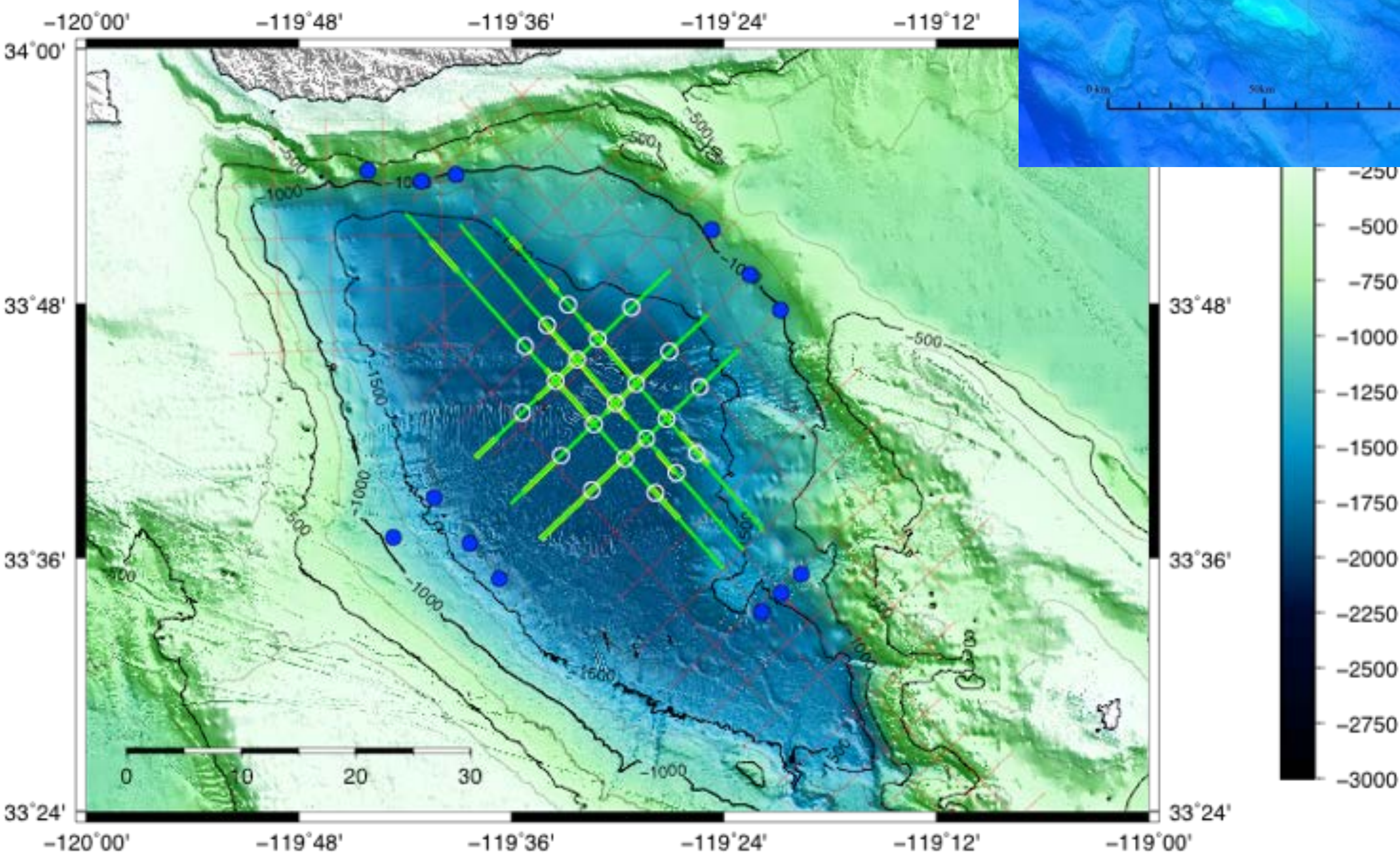
$$S_h = 1 - \left(\frac{aR_w}{\phi m R_t}\right)^{\frac{1}{n}}$$

where a=1, n=2, m=3, ϕ=0.5
Rw = 0.3Ωm, Rt = model resistivity

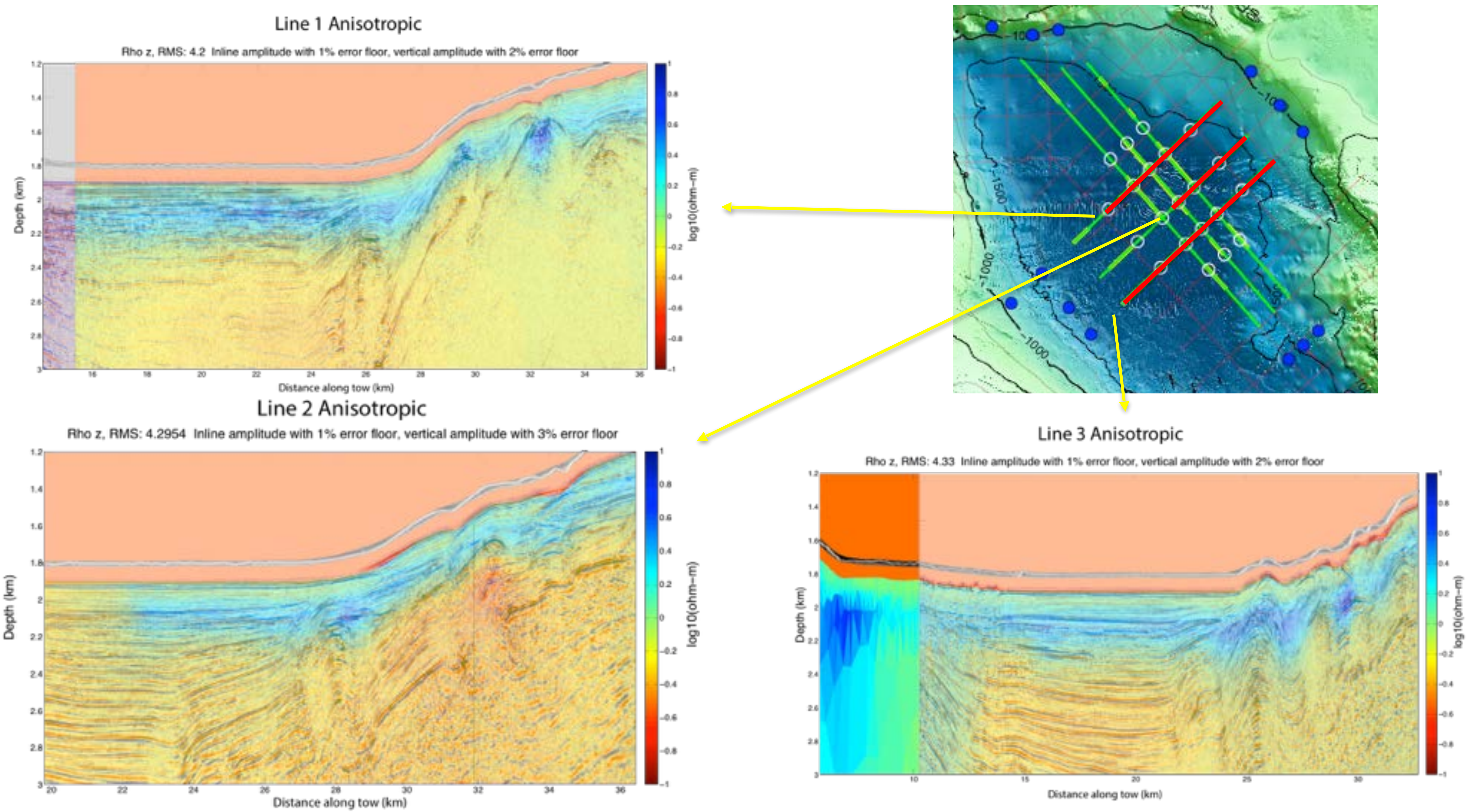
after Collet and Ladd, 2000

Santa Cruz Basin study: 21 seafloor receivers and 6 Vulcan tow lines. Water depths are over 2,000 m.

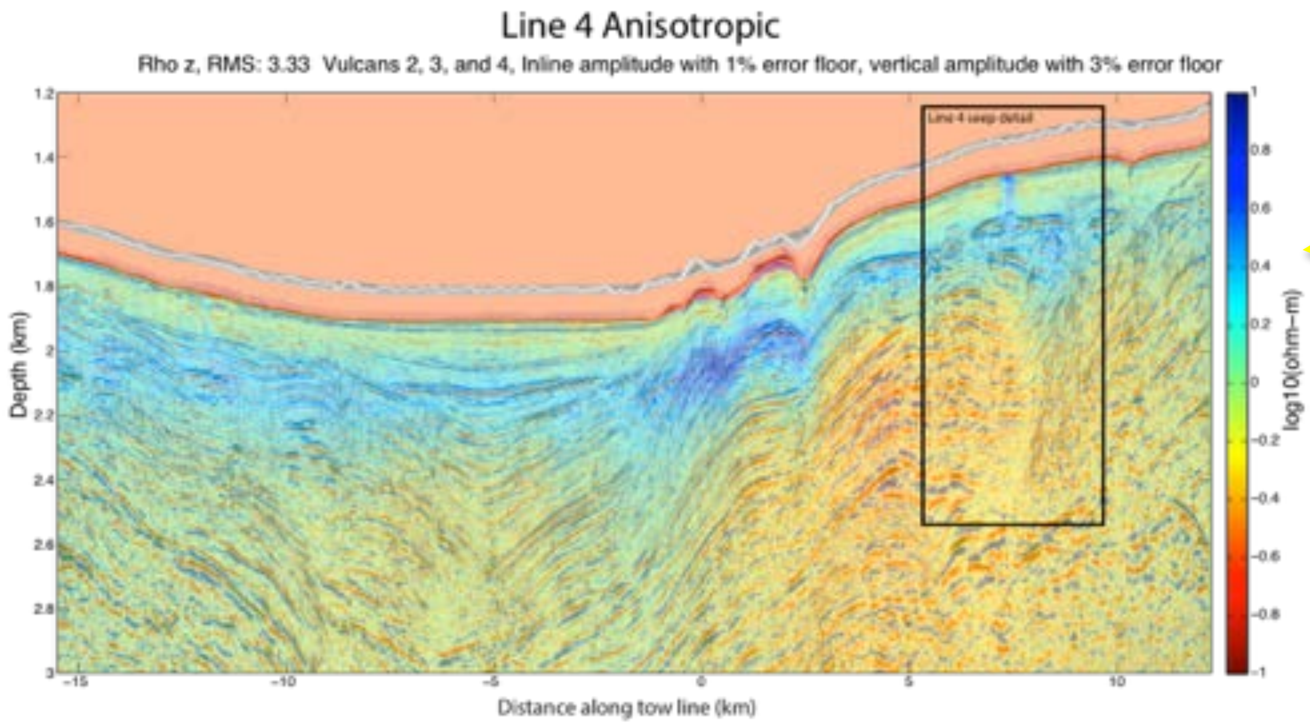


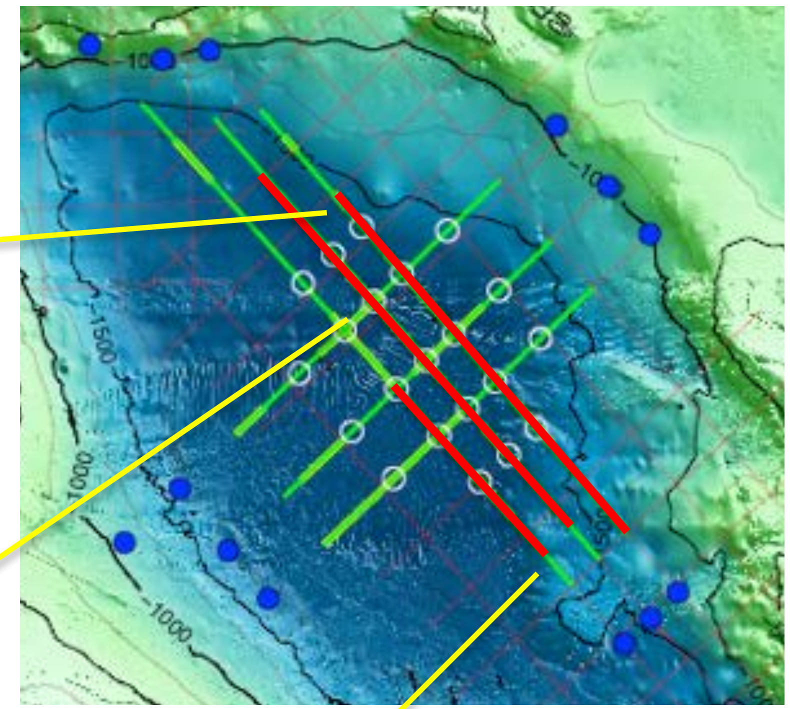


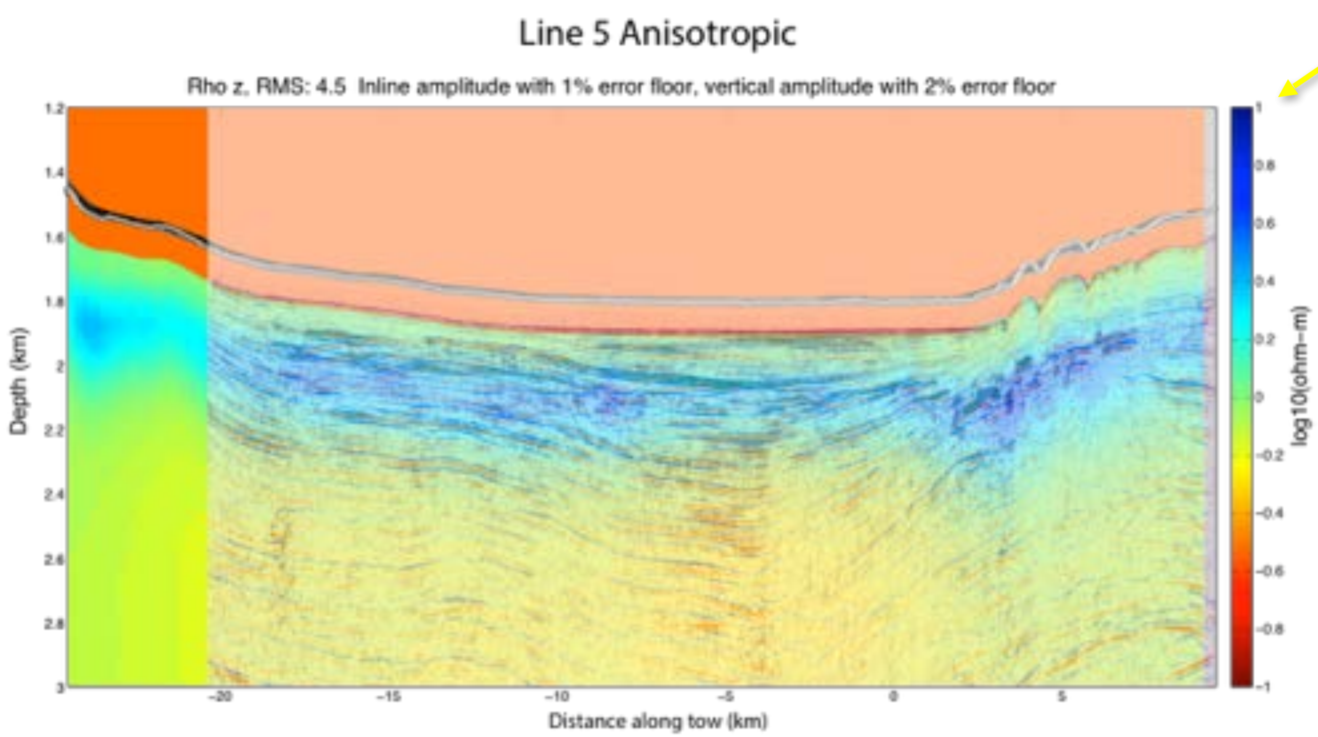
Highest resistivities appear to be on the flanks of the basin.

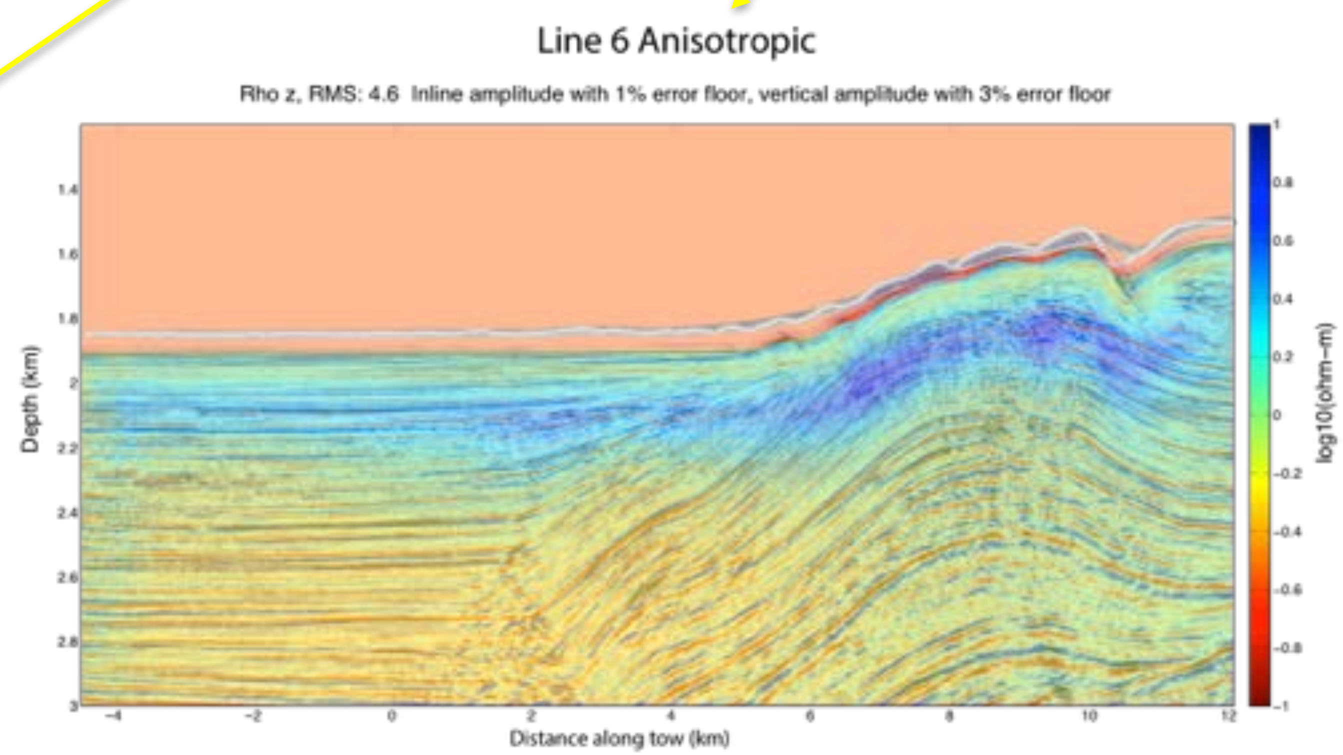


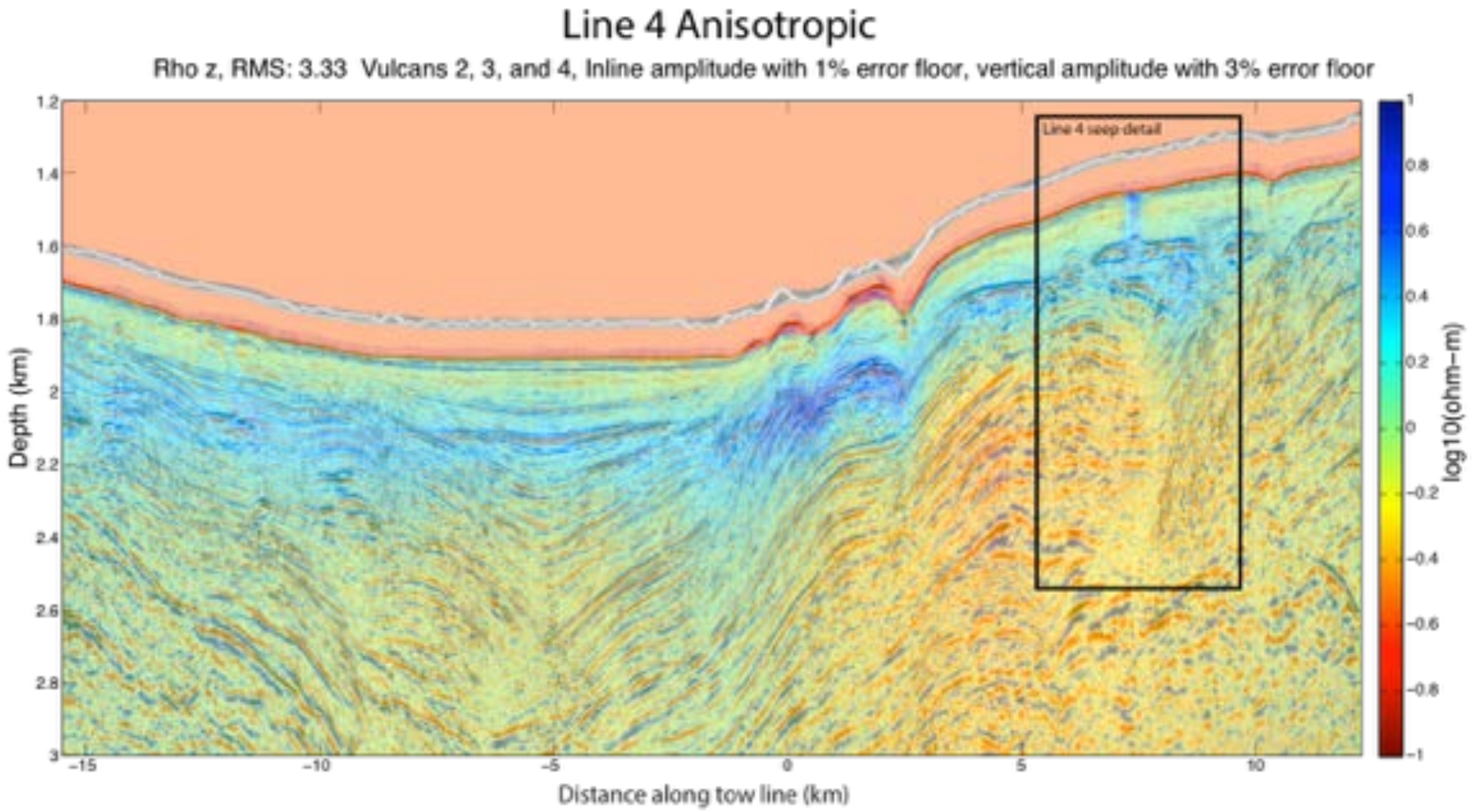
It looks as though we have discovered another seep.



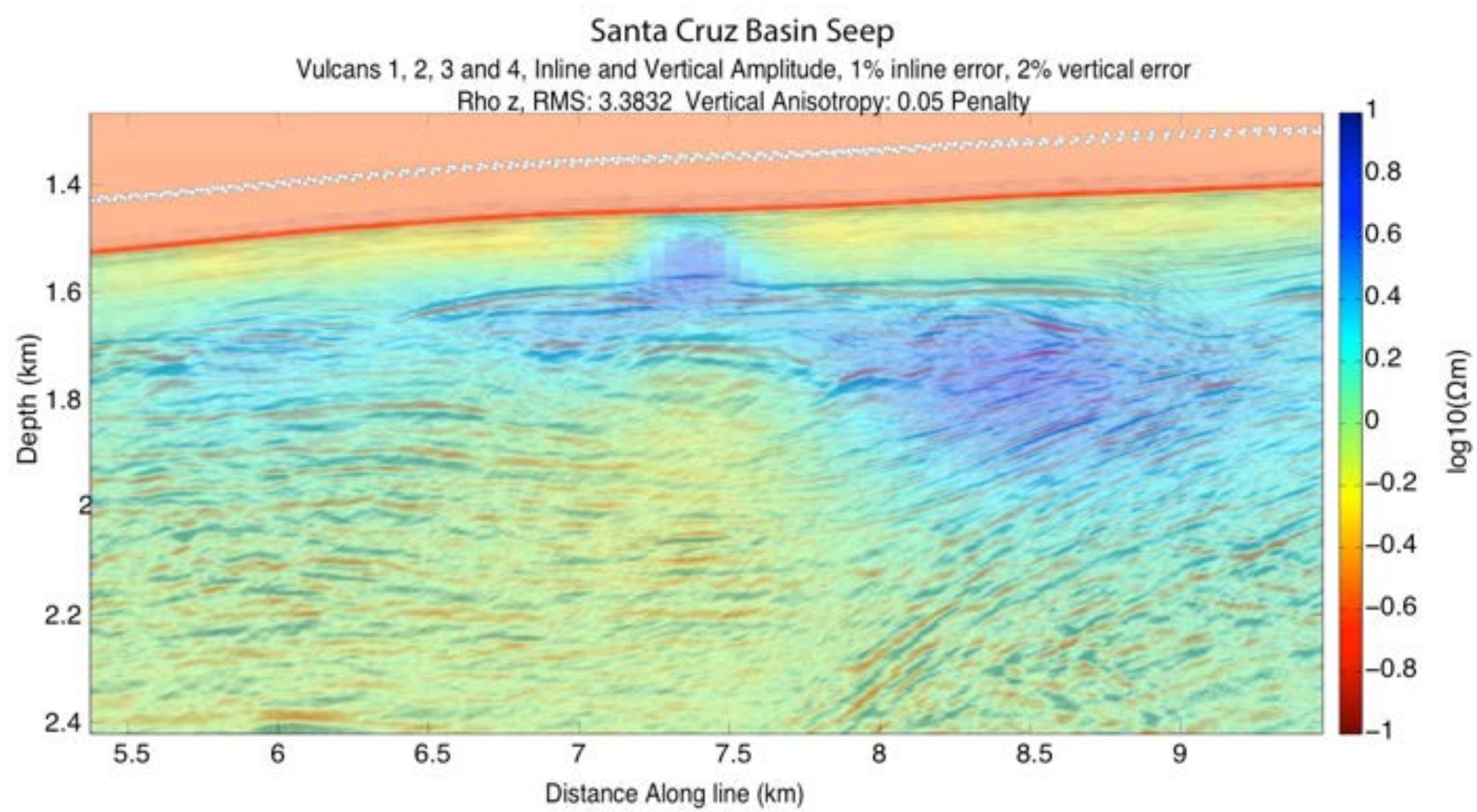






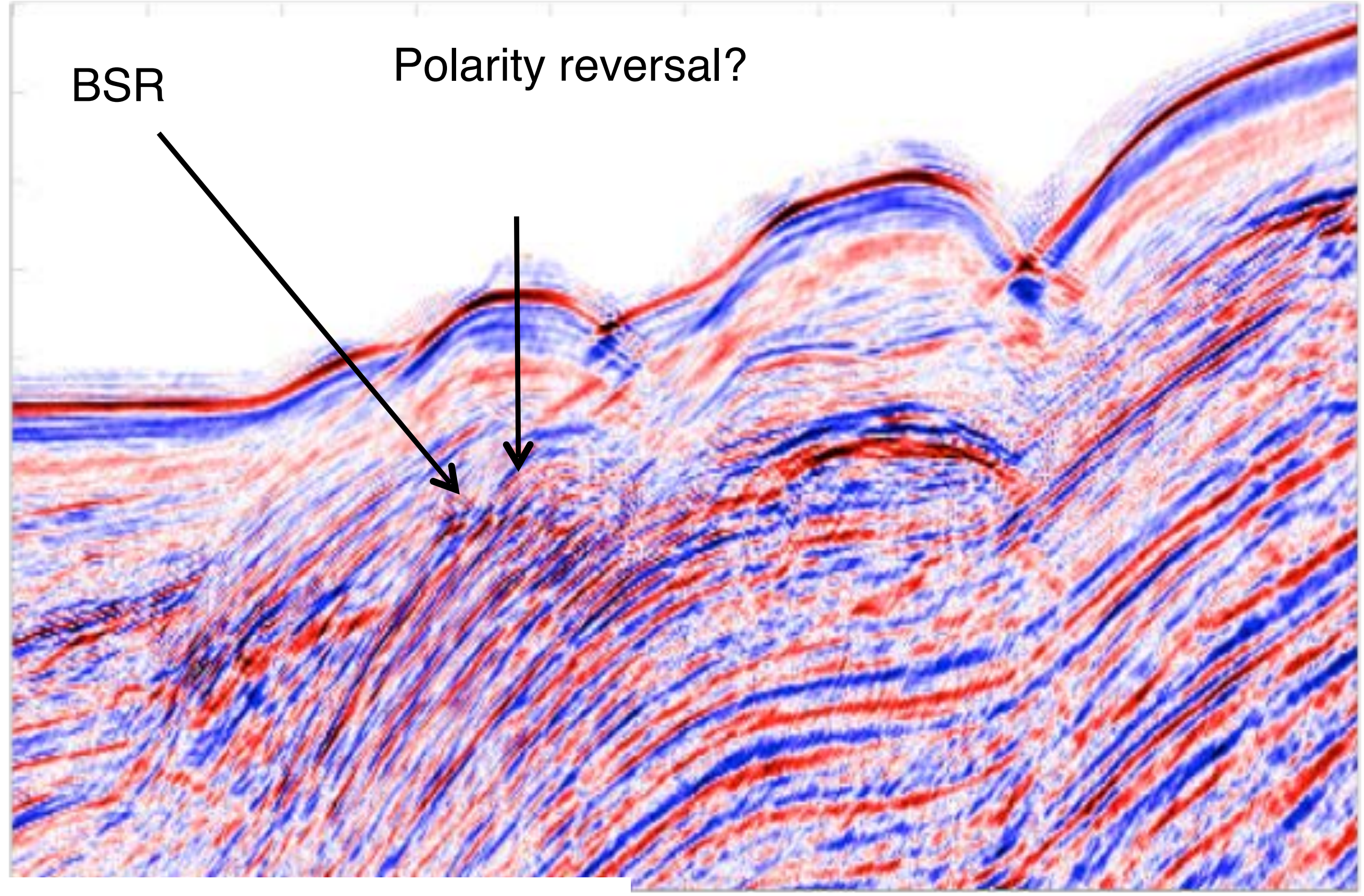


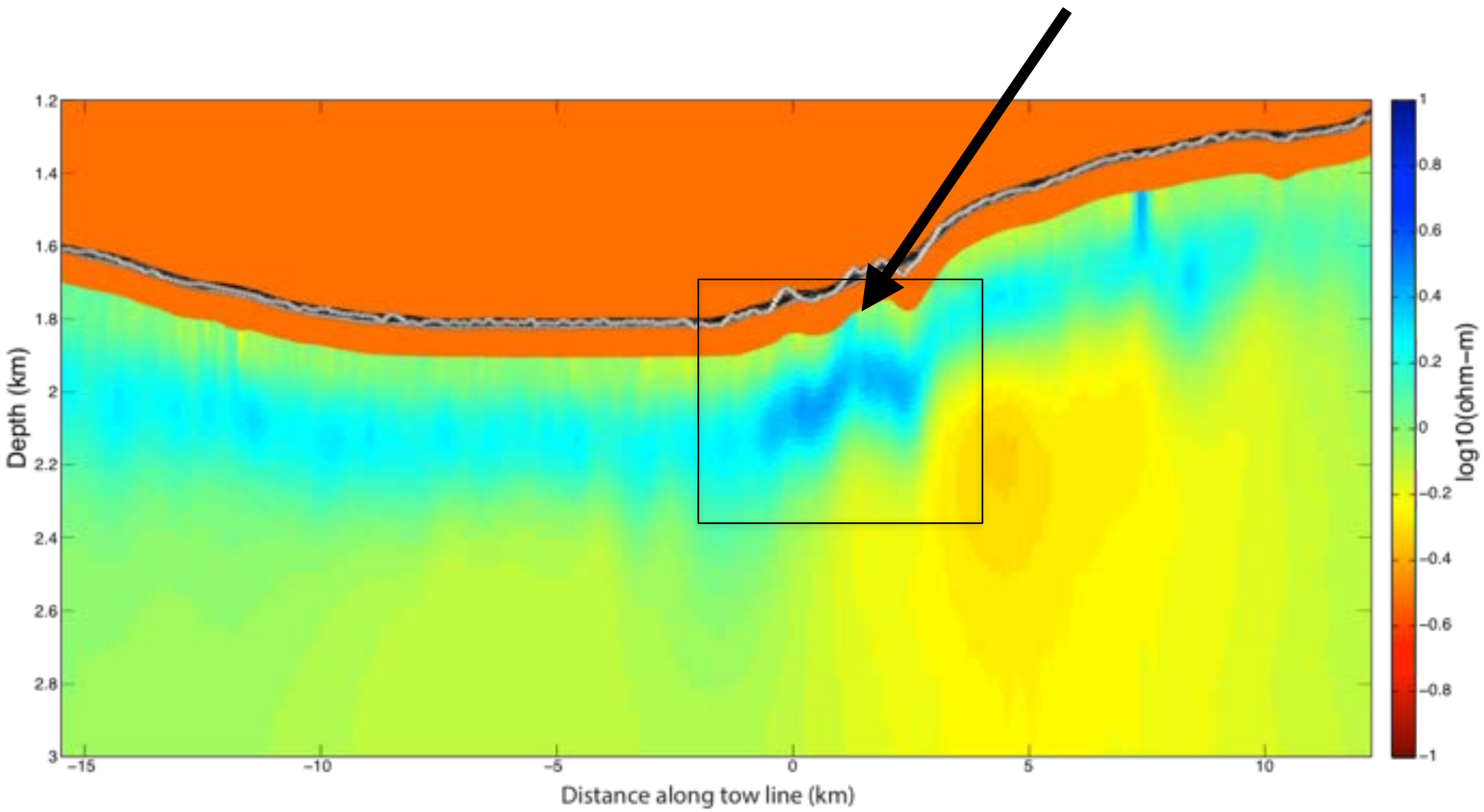
Line 4 seep.



~8 Ωm resistor lies entirely above the BSR, while a resistor to the east lies under (gas?)

Hydrate potential
- 10 degree dipping beds crossing the BSR
- seismic polarity reversal





March 2013

The New York Times

GLOBAL BUSINESS

An Energy Coup for Japan: 'Flammable Ice'

By HIROKO TABUCHI MARCH 12, 2013

Gas flames being expelled from a burner in a deep-sea drilling vessel in the Pacific off Japan. Jogmec, via European Pressphoto Agency

Email

TOKYO — Japan said Tuesday that it had extracted gas from offshore deposits of methane hydrate — sometimes called "flammable ice" — a breakthrough that officials

Over 1,000 line-km of Vulcan survey have been carried out off Japan as part of a national assessment of gas hydrate resources.

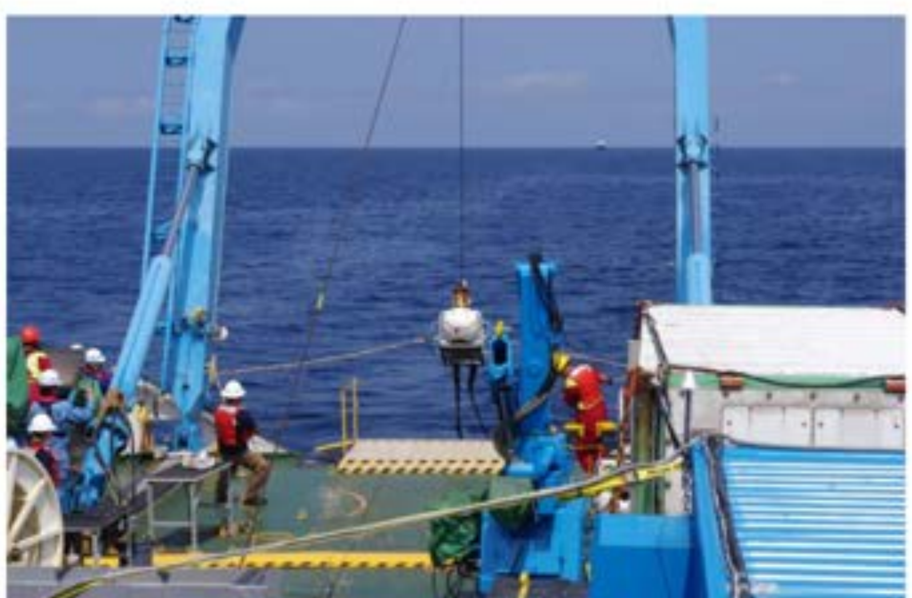
OFG Ocean Floor Geophysics Inc.
Ocean mining exploration services

PRESS RELEASE: Ocean Floor Geophysics Completes CSEM Gas Hydrate Survey in Japan

October 23rd, 2014

PRESS RELEASE: Ocean Floor Geophysics Completes CSEM Gas Hydrate Survey in Japan

Ocean Floor Geophysics Ltd. (OFG), in cooperation with Fukada Salvage and Marine Works Co. Ltd. (Fukada), has completed a high resolution CSEM survey of near surface gas hydrates using the Scripps Institution of Oceanography Vulcan system for the National Institute of Advanced Industrial Science and Technology (AIST) in Japanese waters. The survey comprises over 500 line kilometers of high resolution data collected using the Fukada vessel Shin Nichi Maru. Water depths were from 400 to 1100 meters. A 3D inversion of the EM data for an area of interest has been completed. The contract for the 3D inversion of the data for the entire survey area has also been awarded to OFG and will be completed in November this year. Fukada Salvage and Marine Works acted as prime contractor.



OFG Ocean Floor Geophysics Inc.
Ocean Mining Exploration Services

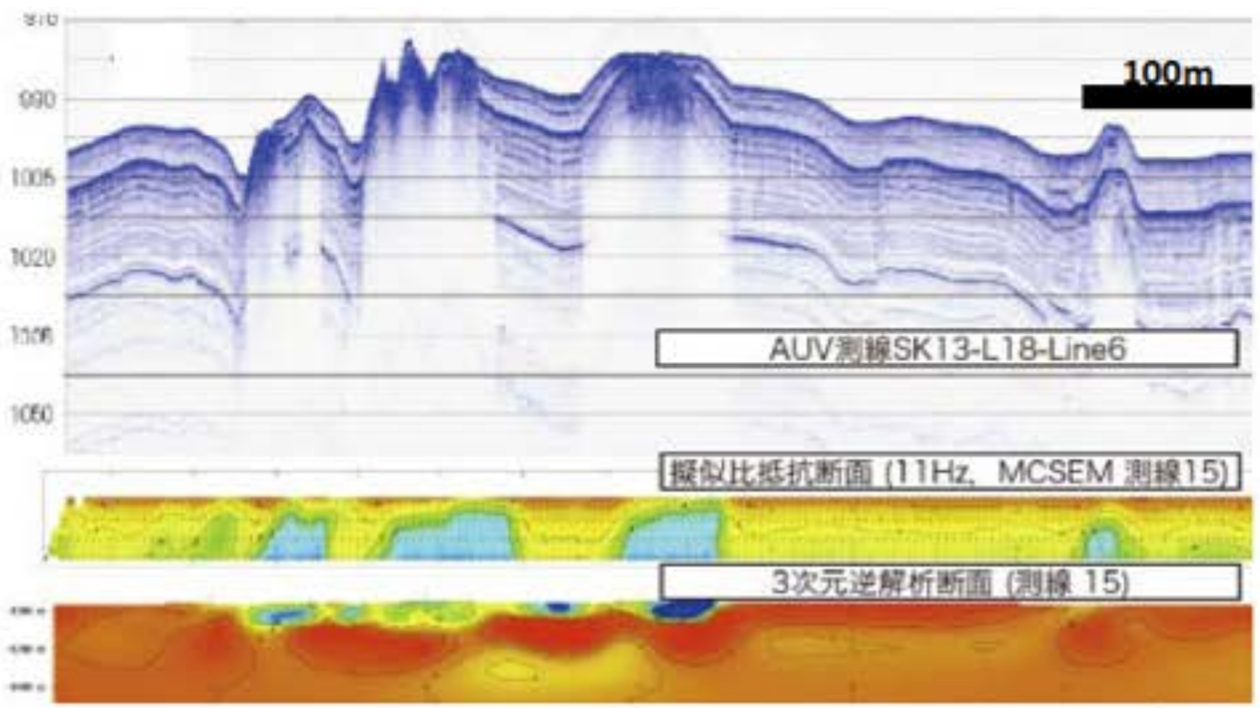
PRESS RELEASE: 2015 - Ocean Floor Geophysics Completes Another CSEM Gas Hydrate Survey in Japan

August 30th, 2015

PRESS RELEASE: Ocean Floor Geophysics Completes Another CSEM Gas Hydrate Survey in Japan

Ocean Floor Geophysics Ltd. (OFG), in cooperation with Fukada Salvage and Marine Works Co. Ltd. (Fukada), has completed another high resolution CSEM survey of near surface gas hydrates using the Scripps Institution of Oceanography Vulcan system for the National Institute of Advanced Industrial Science and Technology (AIST) in Japanese waters. Following the successful 3D CSEM survey and inversion models completed in 2014, the 2015 survey comprises over 670 line kilometers of high resolution data collected from the Fukada vessel Shin Nichi Maru. A 3D inversion of the EM data for an area of interest for this year's survey has been completed. The contract for the 3D inversion of the data for the entire 2015 survey area has also been awarded to OFG and will be completed in November this year. Fukada Salvage and Marine Works acted as prime contractor to AIST.

Inversion of the CSEM data will provide a better estimate of resource potential than is possible with seismic/acoustic data alone.



地形特異点（マウンド）海底下のガスチムニー構造（ブランキング）と高比抵抗部が一致する

資源エネルギー庁発表（2014.12.25）から

平成27年度も引き続き、広域調査等を実施するとともに、これまでの調査結果などを踏まえ、平成26年度と異なる地点において地質サンプル取得を含めた掘削調査の実施を予定している。

Research Consortium for Methane Hydrate Resources, Japan, 2015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京都本店

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