Acknowledgements

Marine electromagnetic group at GEOMAR (Marion Jegen, Sebastian Hölz, Malte Sommer), RWE Dea, FUGRO, BP, SUGAR Phase I & II, BMBF, University of Tromso, Academia Sinica, Blue Mining Project

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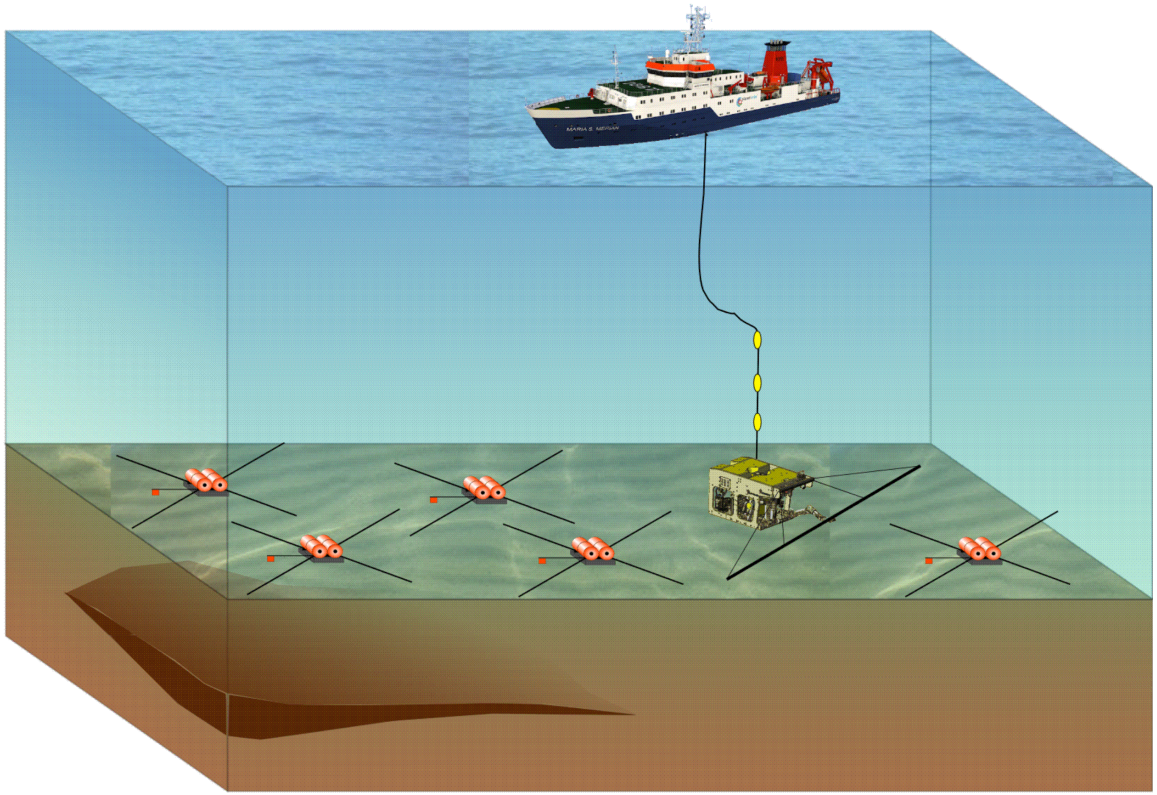
GEOMAR marine CSEM system (“Sputnik”, “3DEM”)



Method suitable for small scale targets
Can be used on sites with rugged bathymetry
Two transmitter polarizations using ROV
Highly 3D coverage of seafloor

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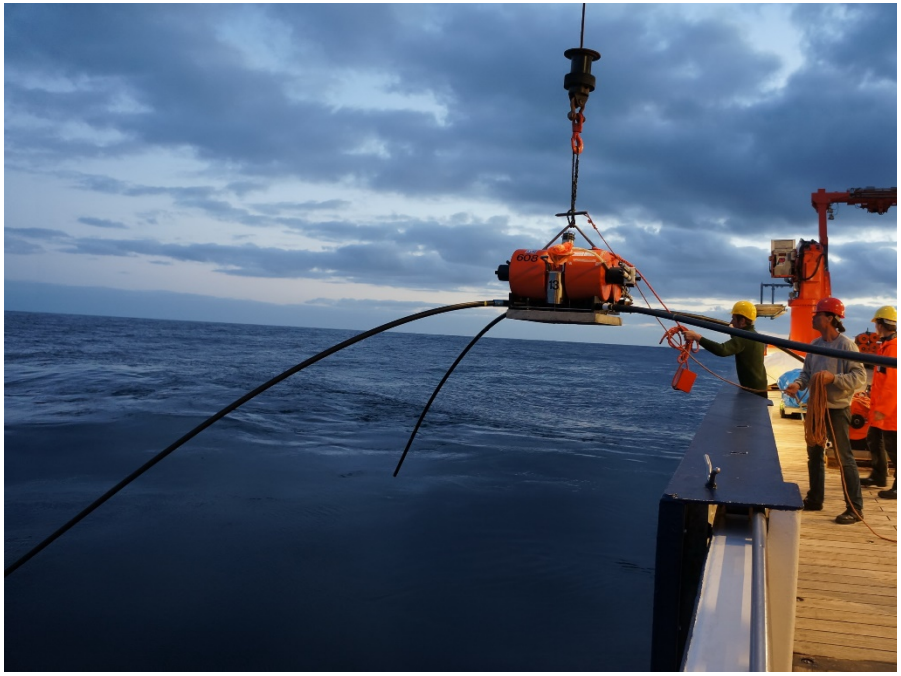
Transmitter & receiver deployment



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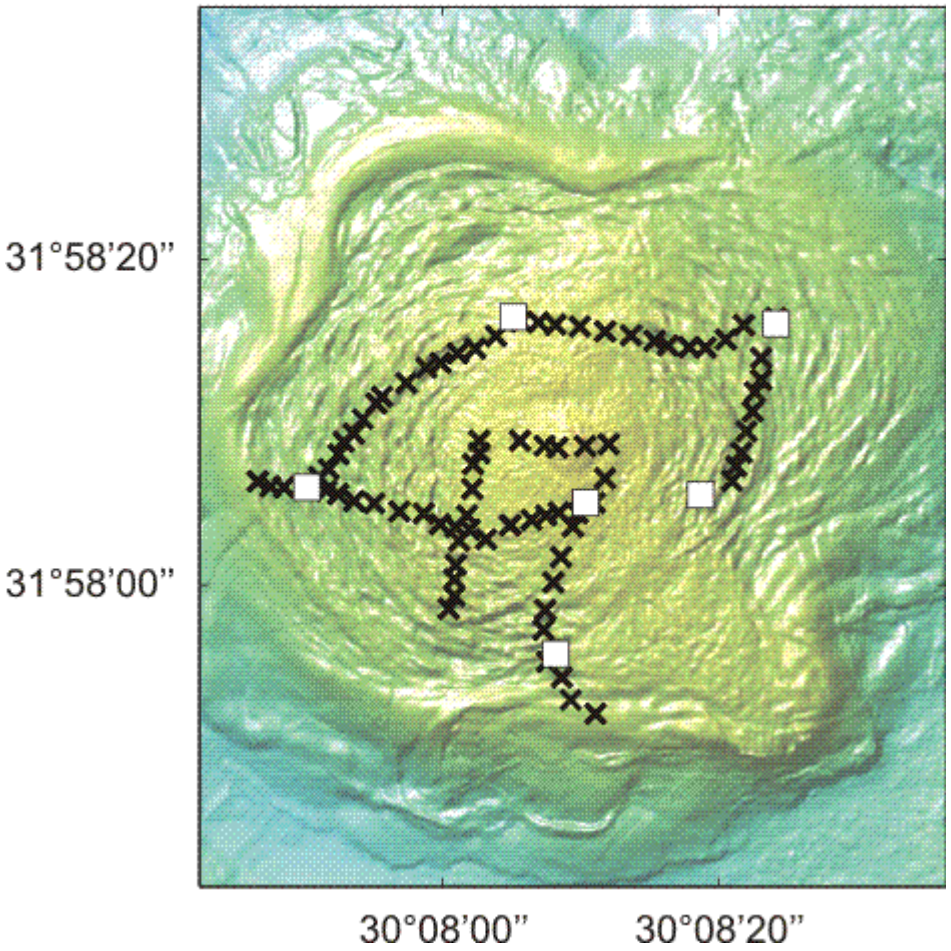
Station map



Bathymetry from
Feseker et al. (2010)

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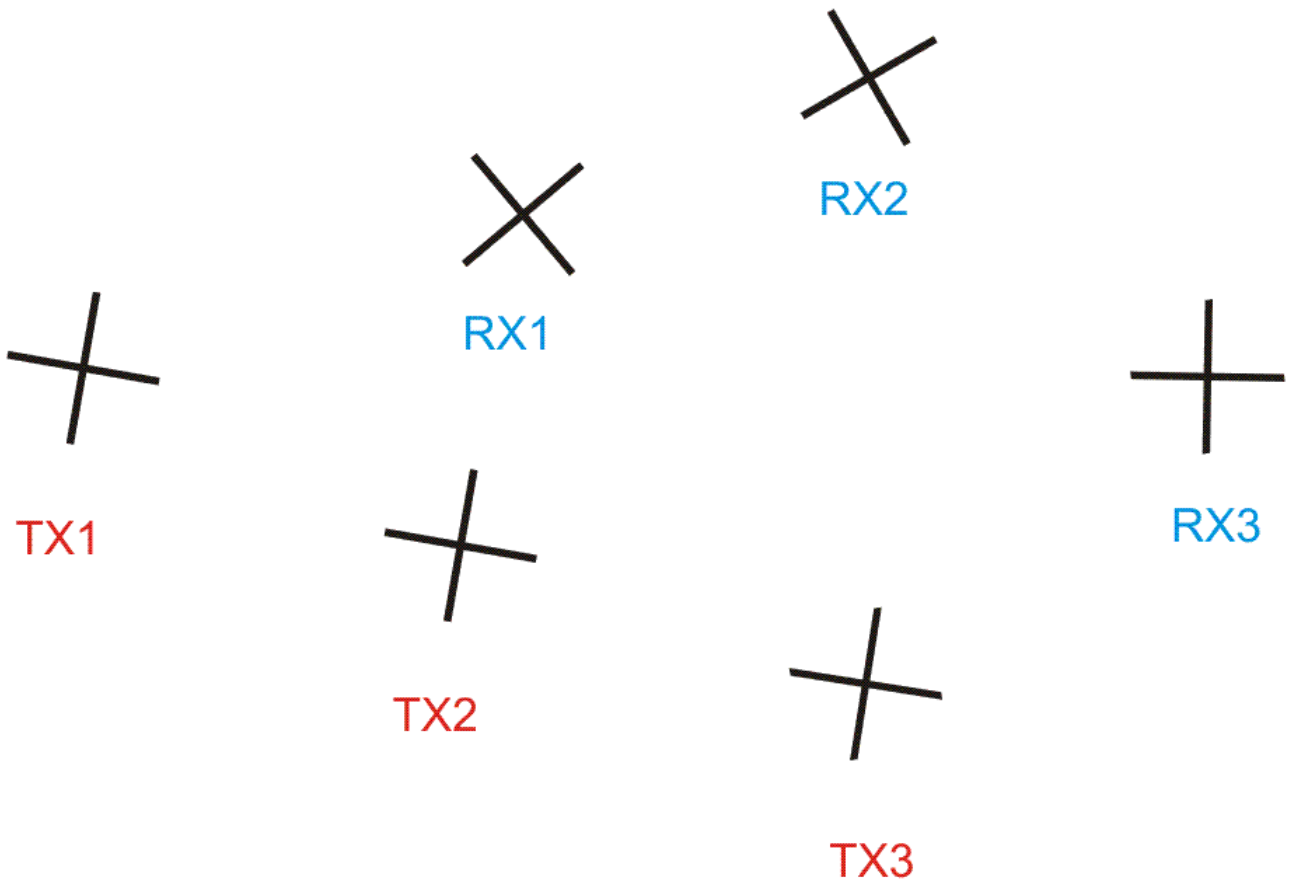
A geometric mess!



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A rotational invariant?

TX1

RX1

$$E_{inv} = \det \begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix}$$

MINES GEOMAR

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MINES GEOMAR

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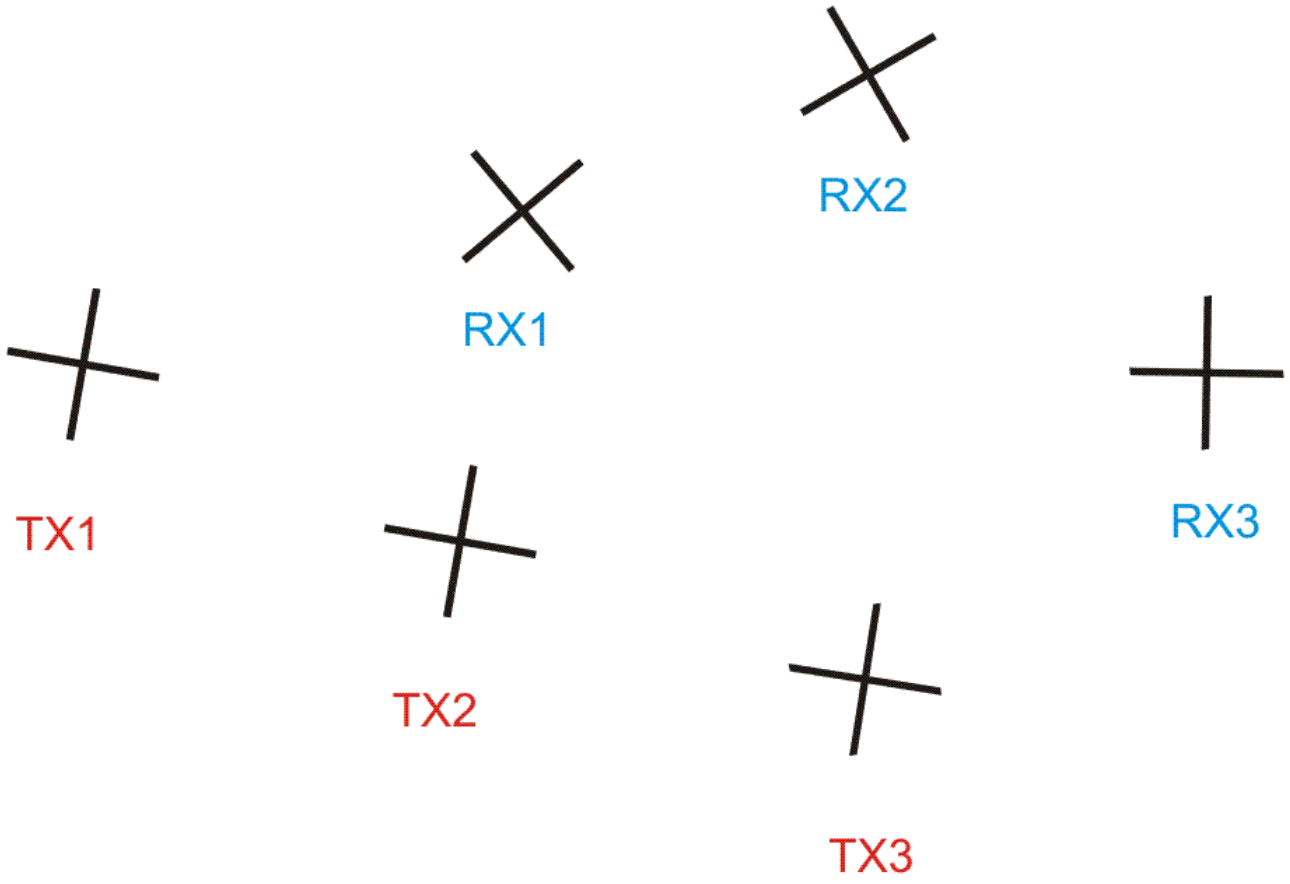
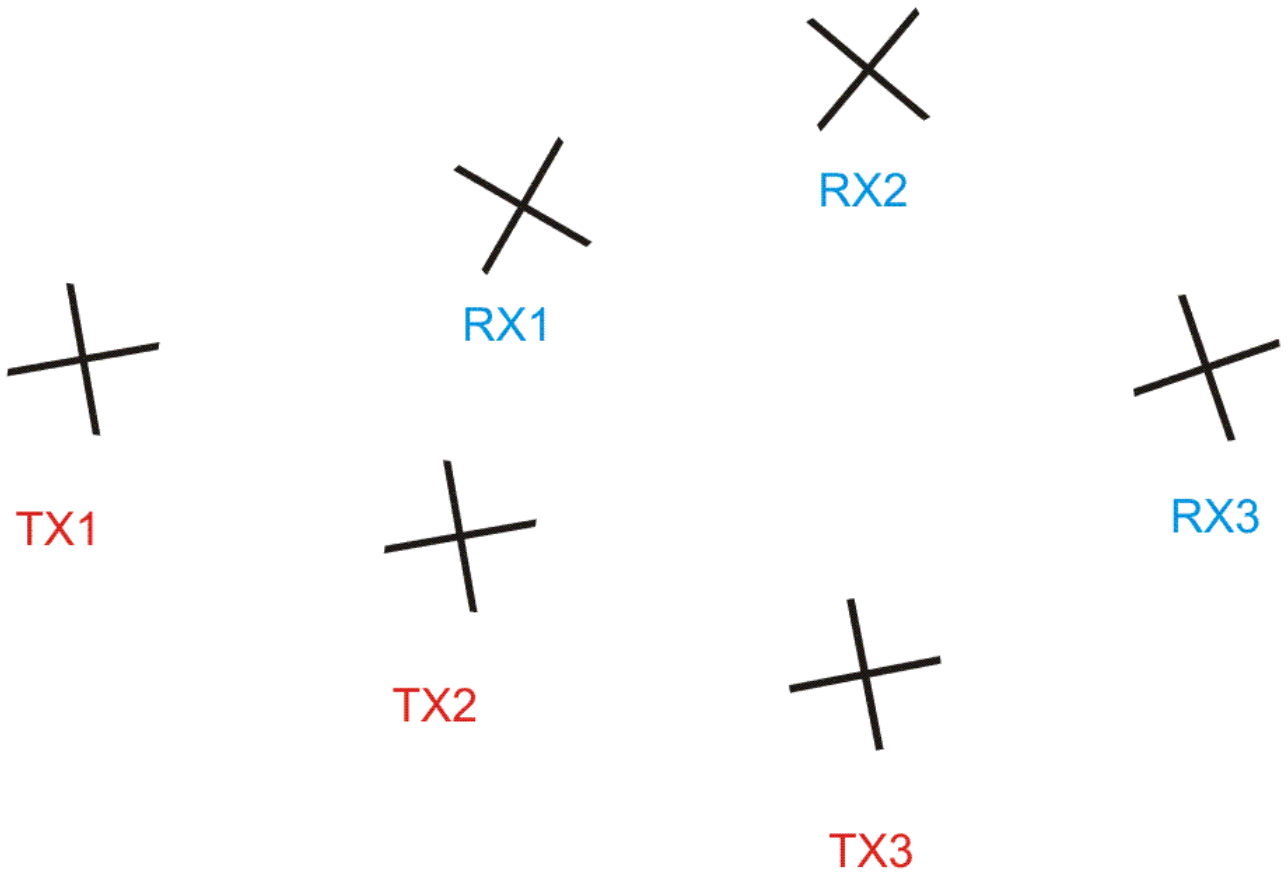
Transformed data now does not depend on rotation

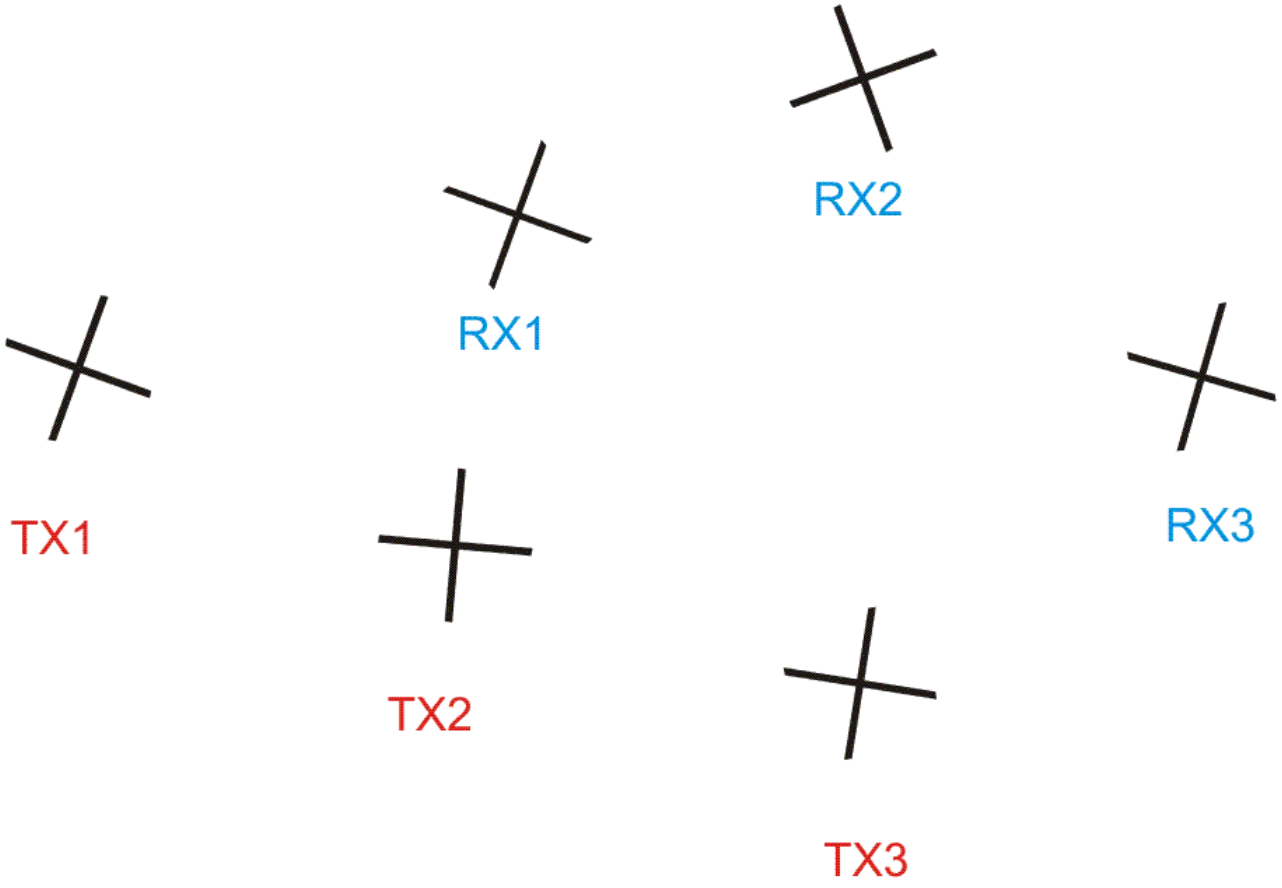


Transformed data now does not depend on rotation



MINES GEOMAR

Transformed data now does not depend on rotation



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Dimensional analysis

$$\nabla^2 \boldsymbol{E} = \mu\sigma \, \partial \boldsymbol{E} / \partial t$$

$[1/L^2]$ $\qquad$ $[1/t]$

$$\tau = \frac{\mu\sigma r^2}{c} \quad \rightarrow \quad \boxed{\rho_a = \mu r^2 / \tau c}$$

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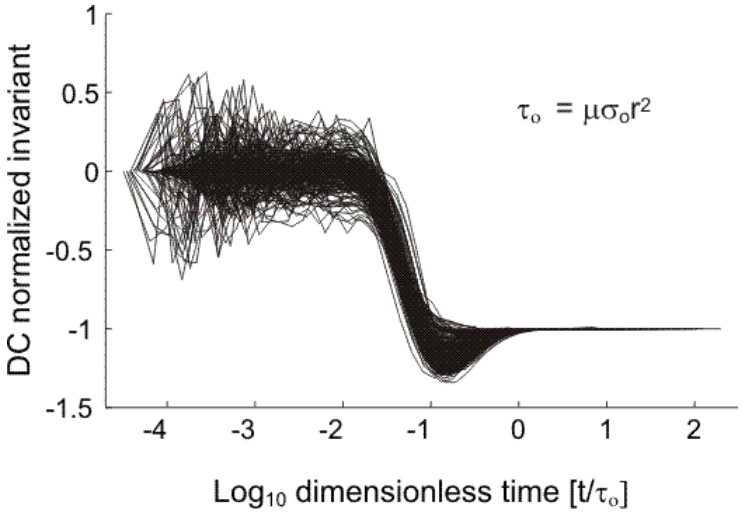
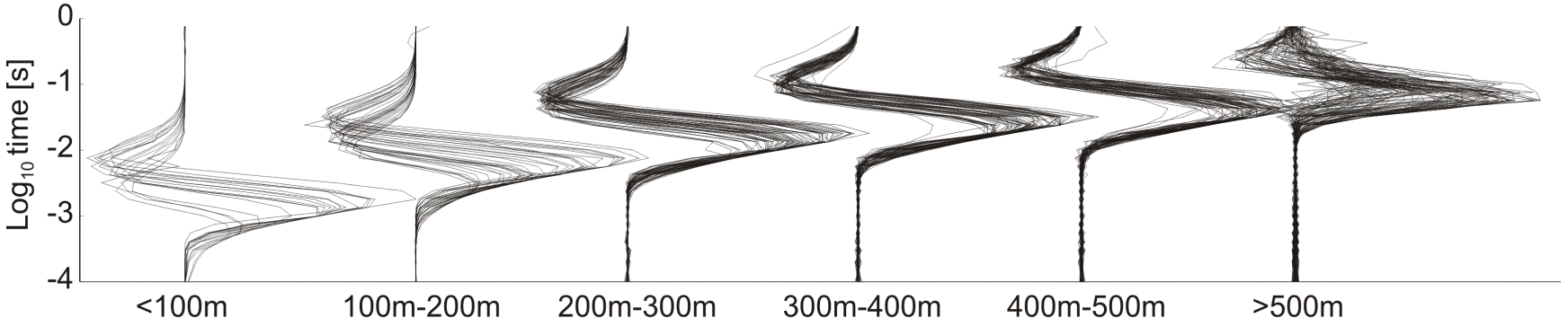
Real data from the mud volcano



Top: Invariants normalized in time and amplitude, all offsets

Bottom: Derivatives of invariants, binned by offset, muted at early time



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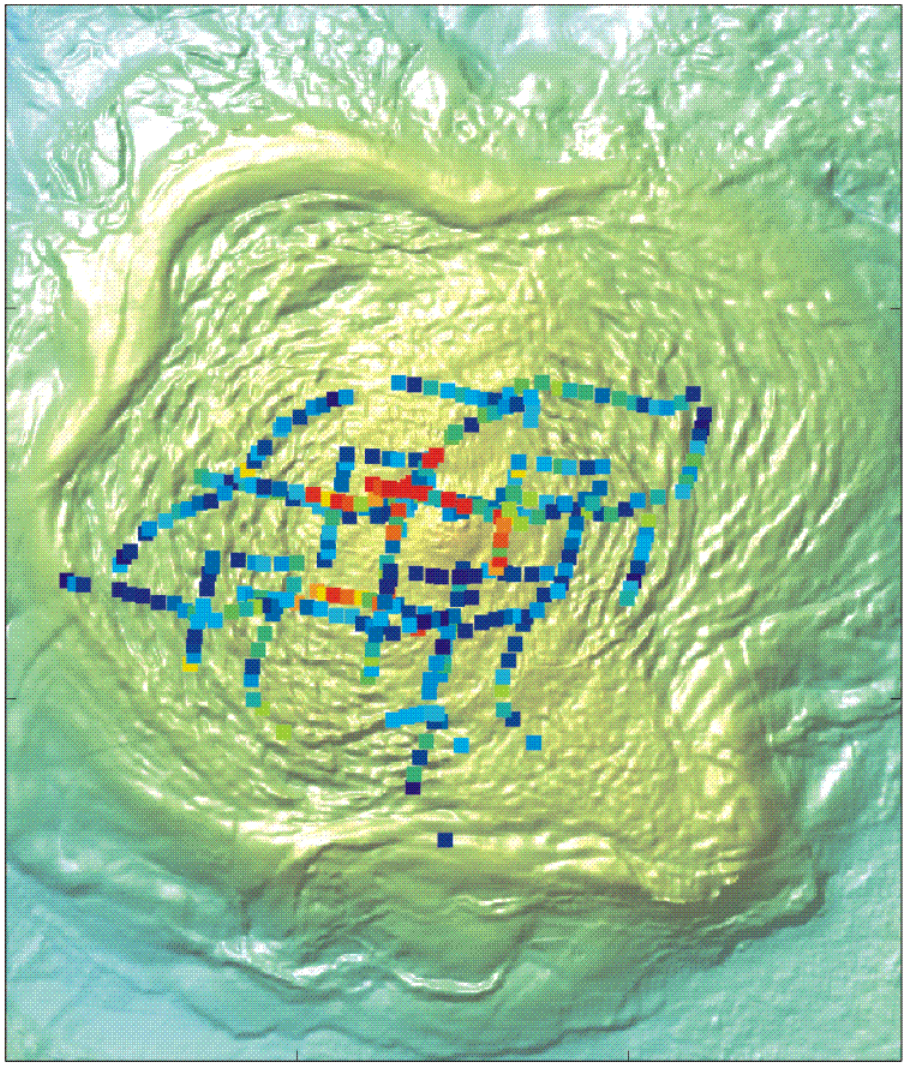
All offsets



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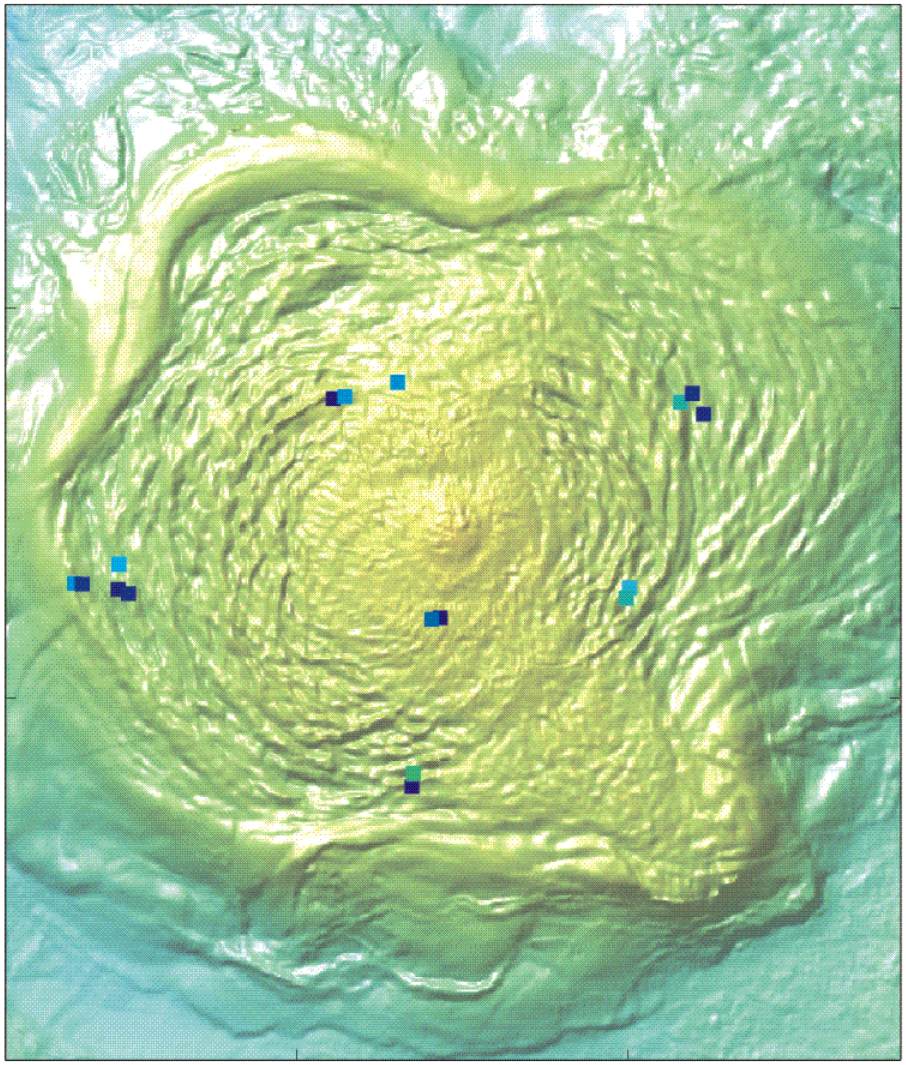
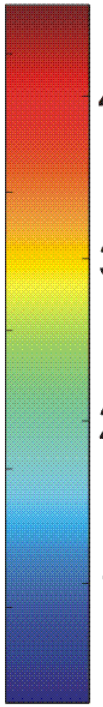
<100m



Apparent resistivity [Ω·m]



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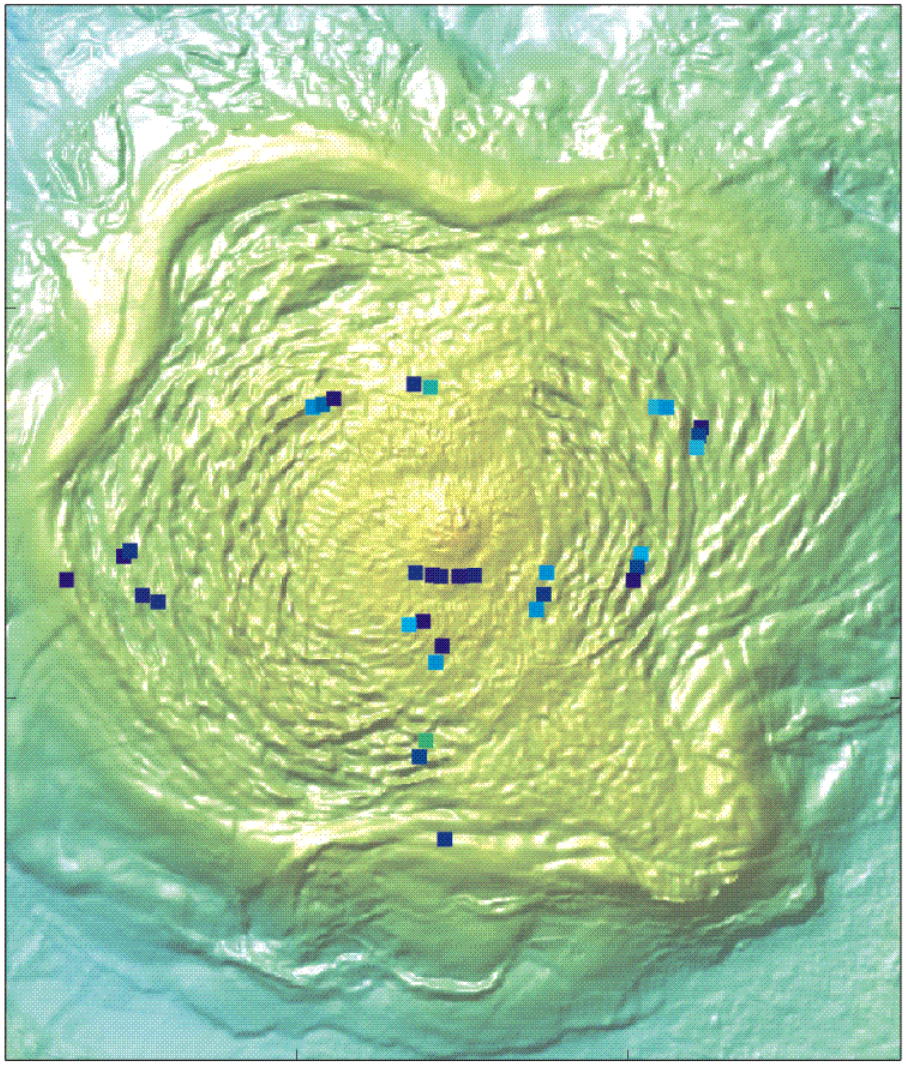
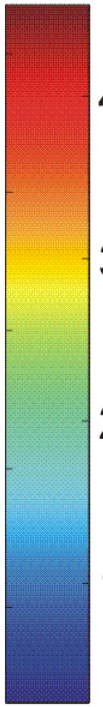
100m to 200m



Apparent resistivity [Ω·m]



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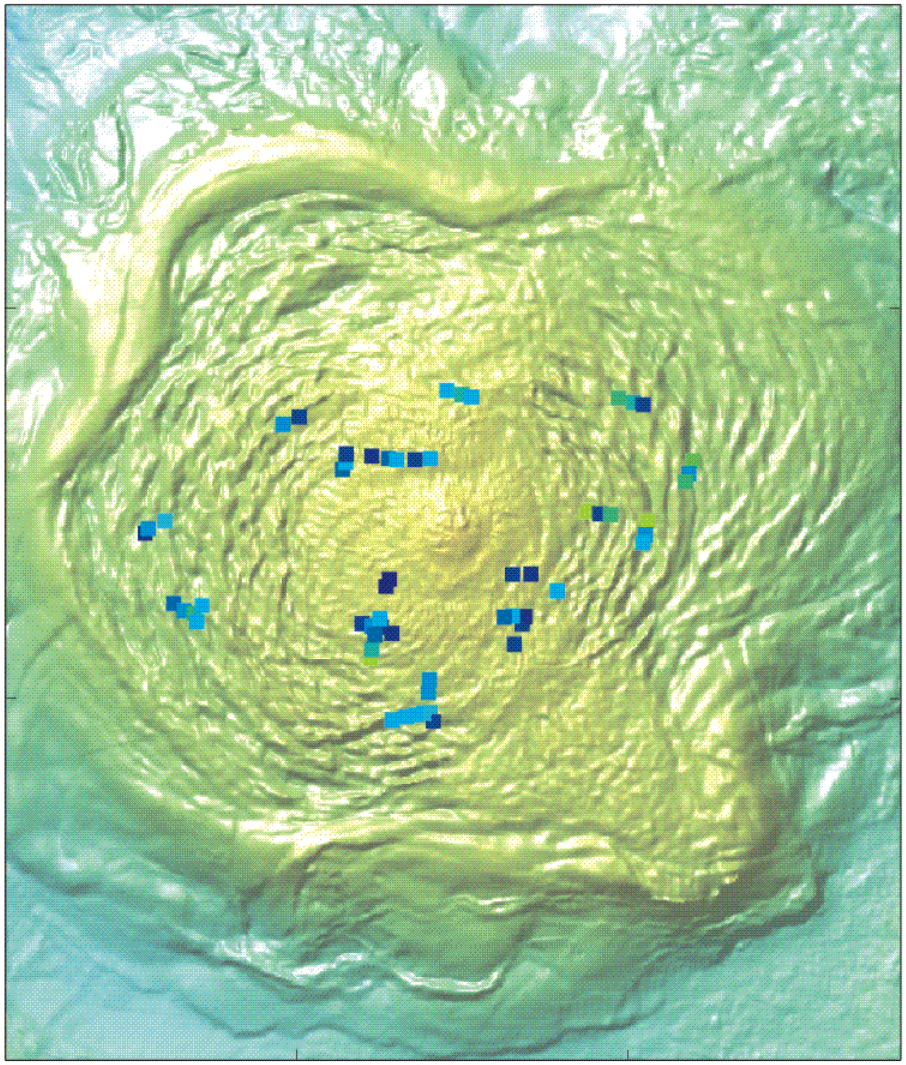
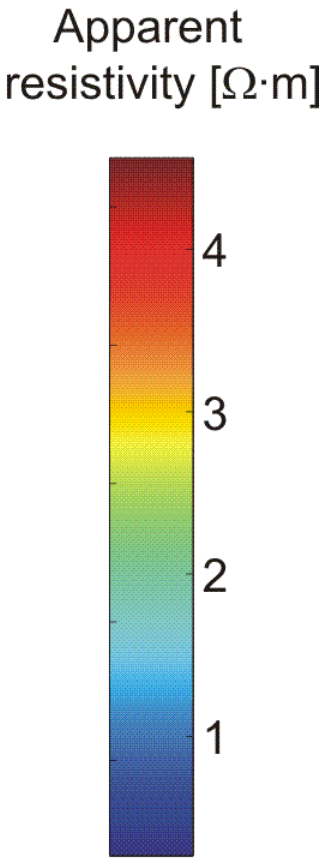
200m to 300m





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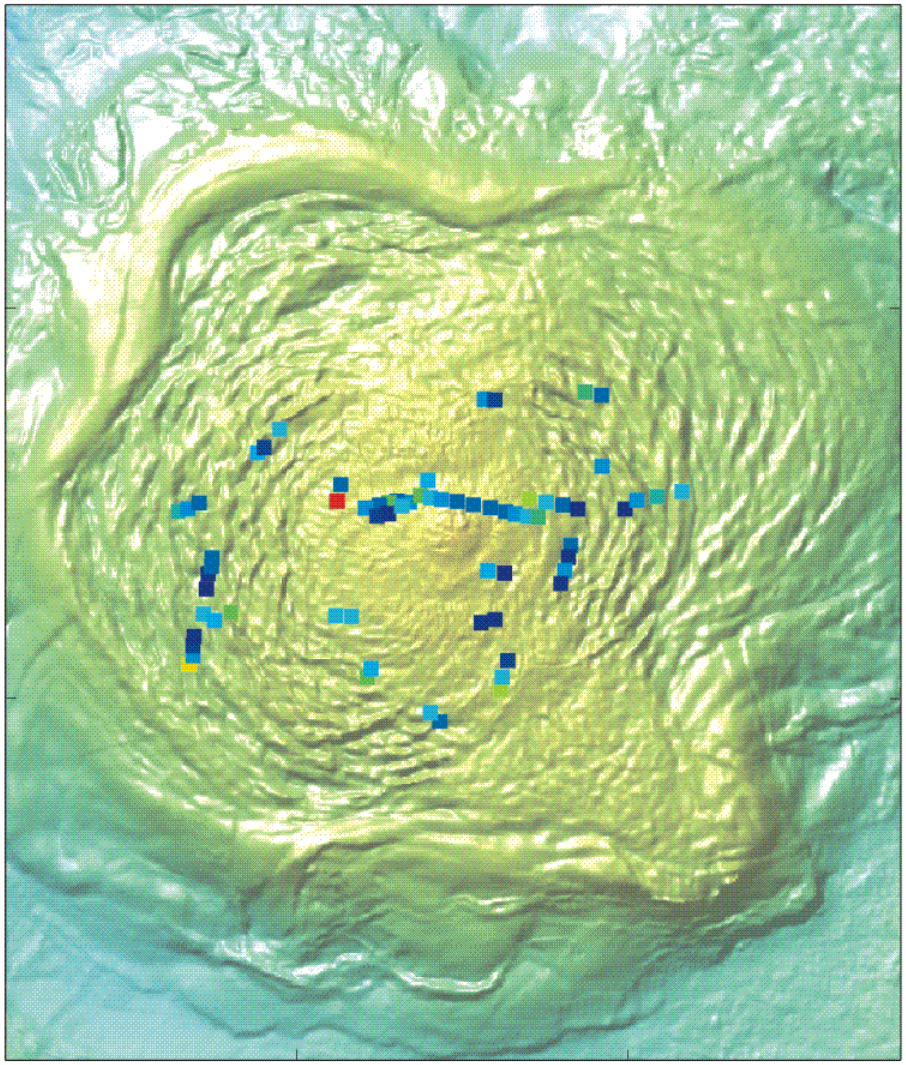
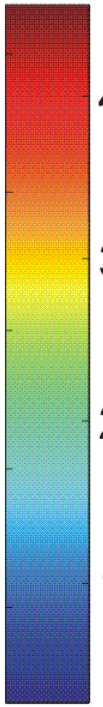
300m to 400m



Apparent resistivity [Ω·m]



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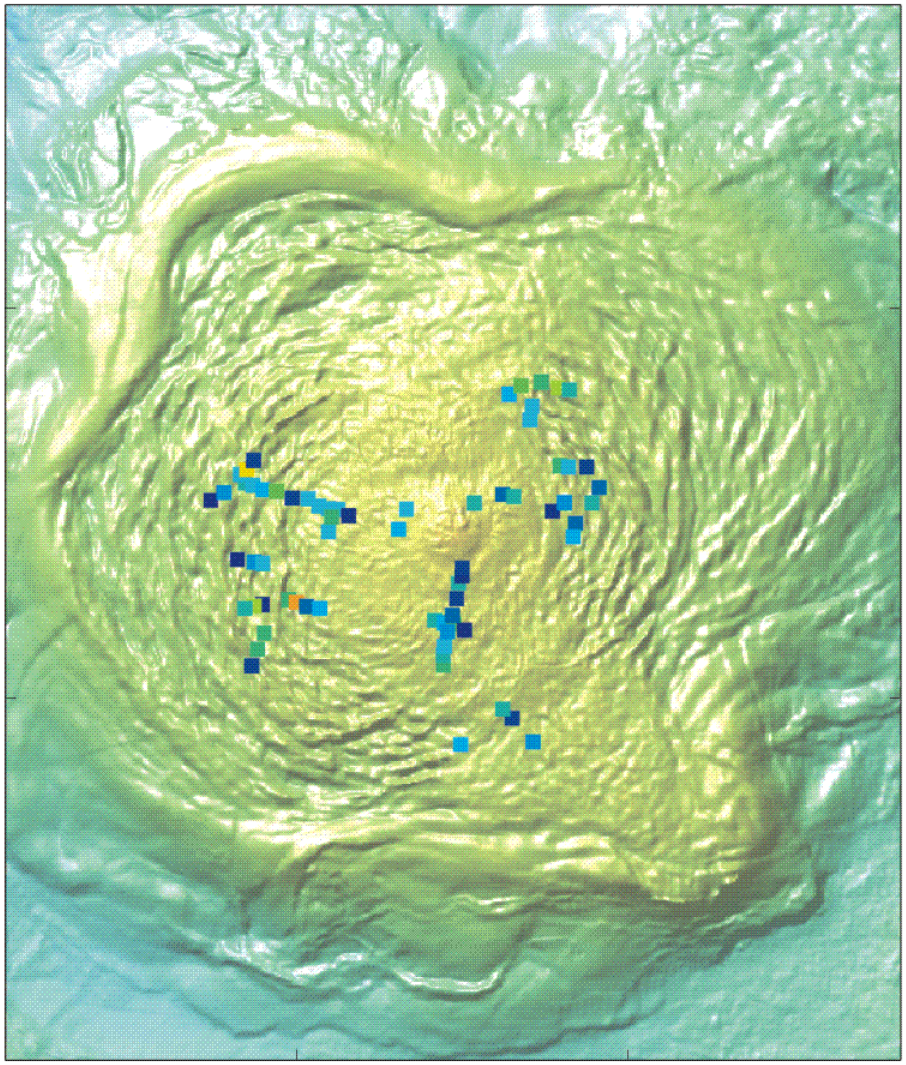
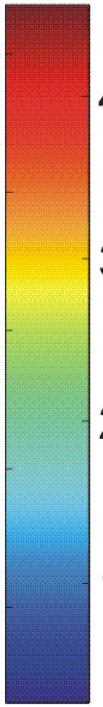
400m to 500m



Apparent resistivity [Ω·m]



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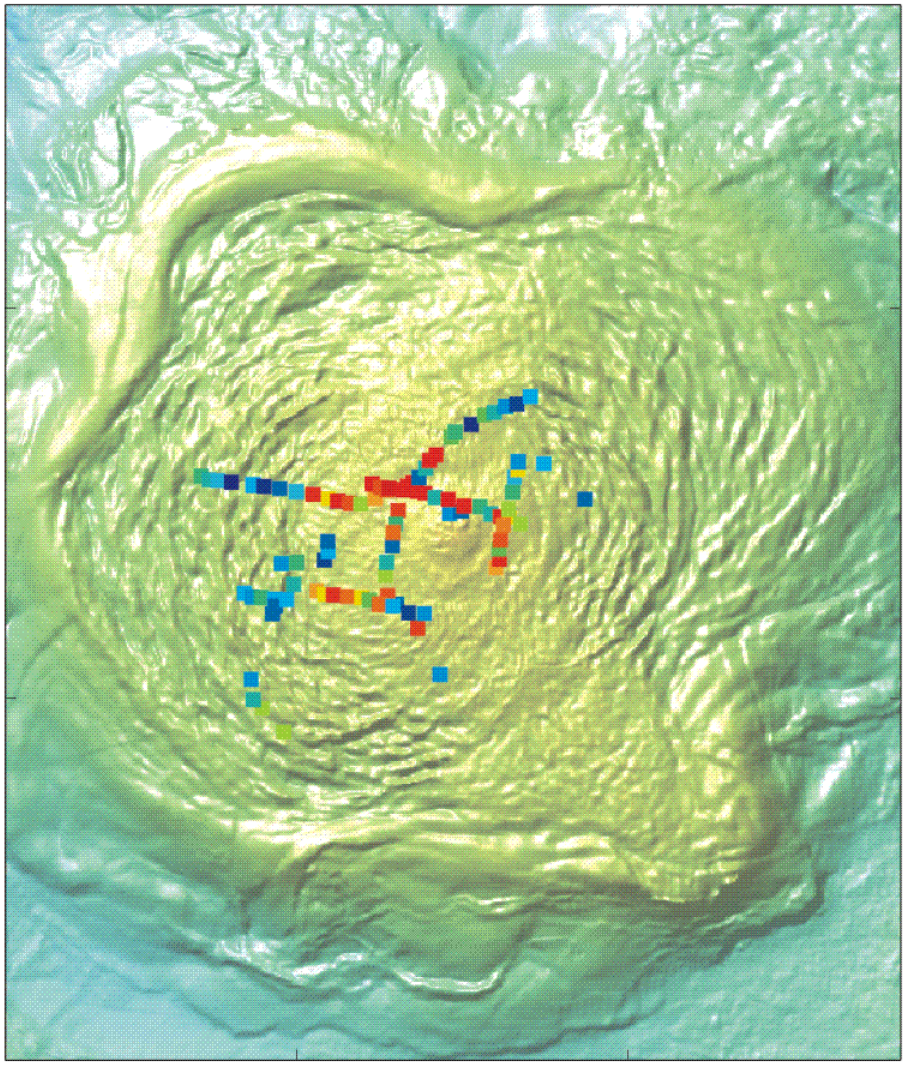
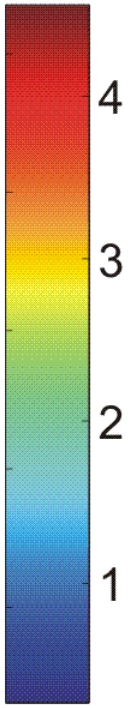
>500m



Apparent resistivity [Ω·m]



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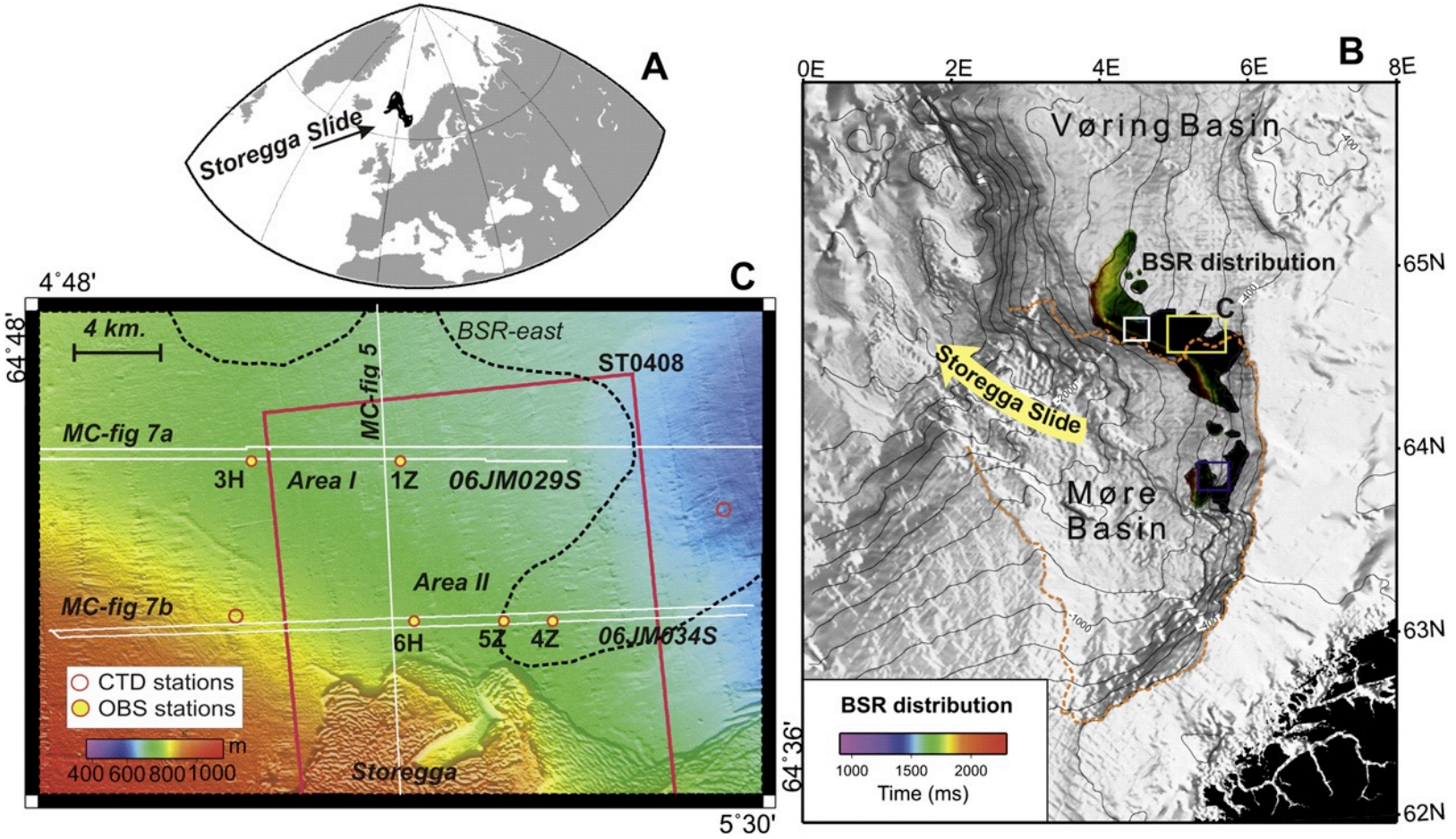
Example 5: hydrates offshore Mid-Norway



(Plaza-Faverola et al. 2010)

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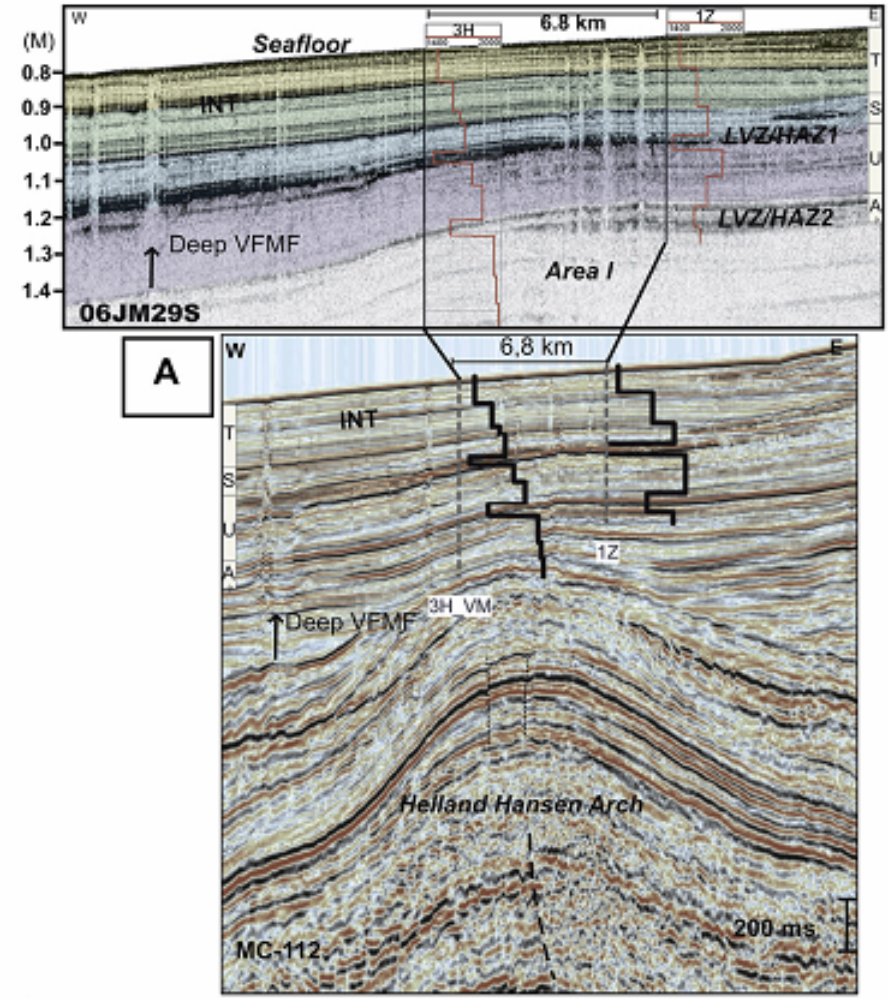
High resolution 3D seismic and OBS profiles



(Plaza-Faverola et al. 2010)

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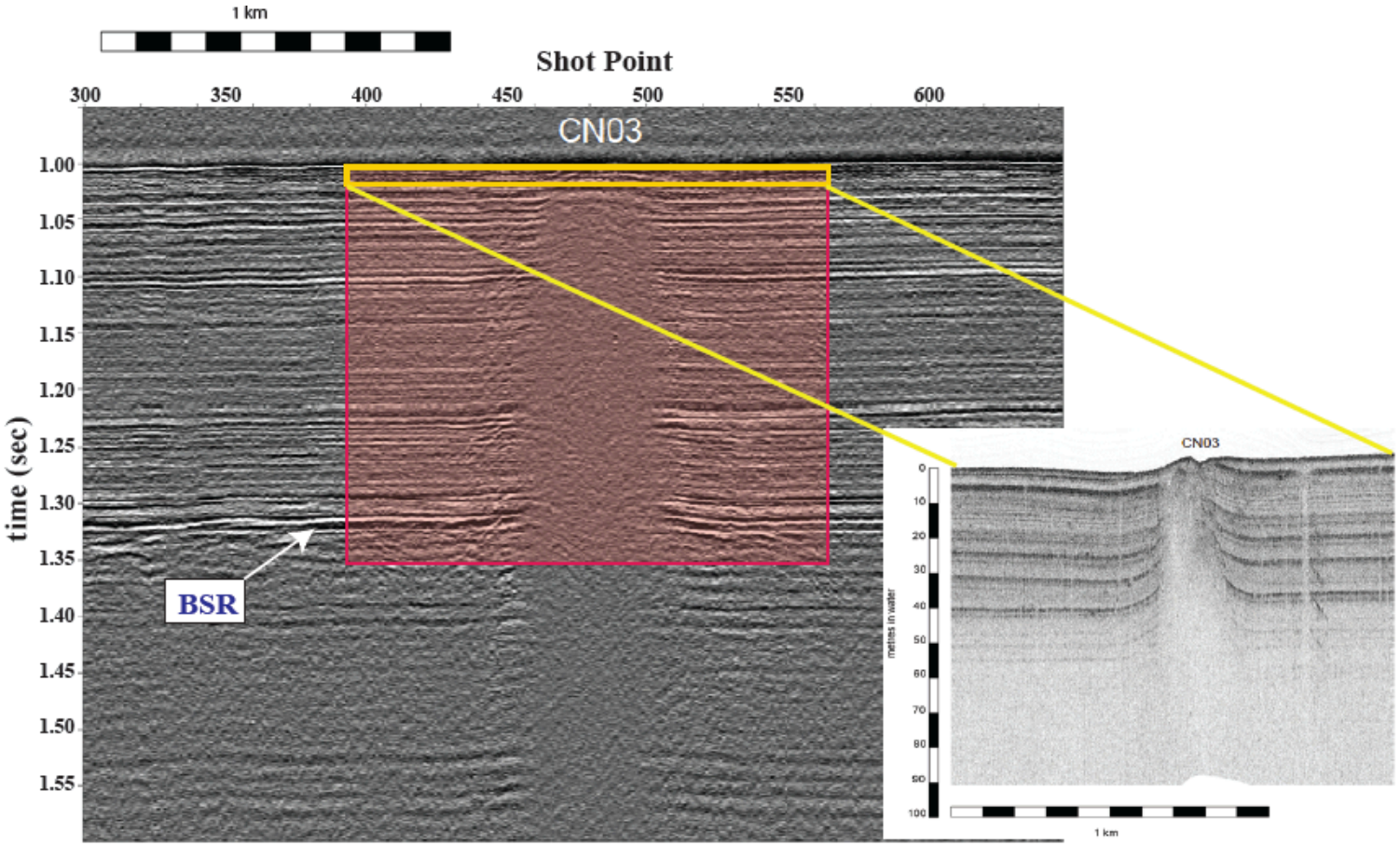
Vertical chimney features from seismic



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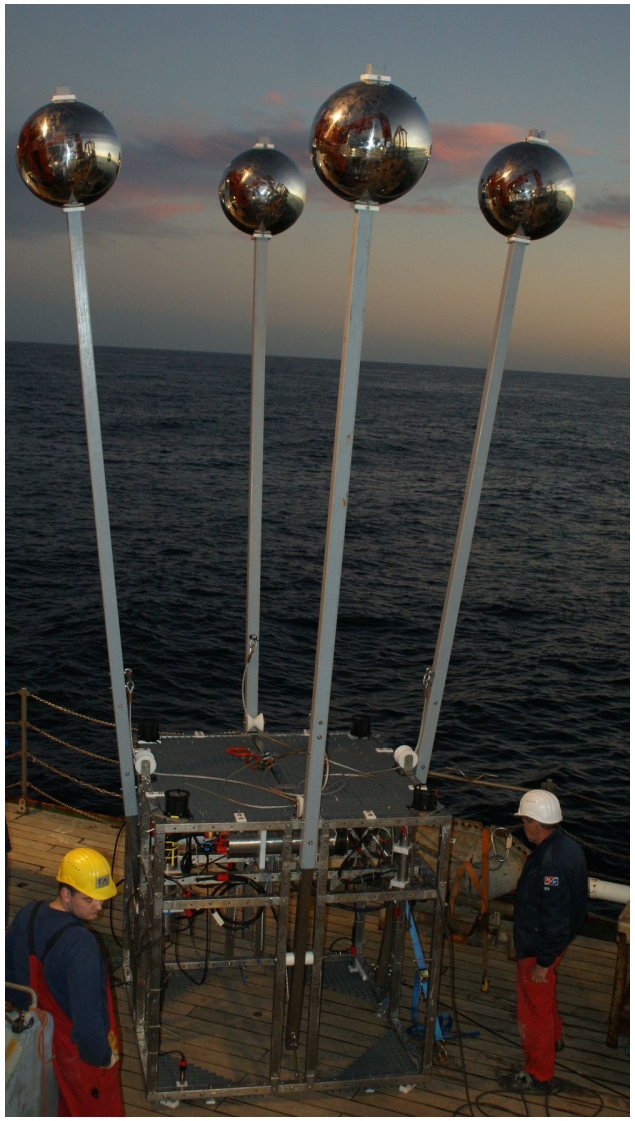
New type of source deployment



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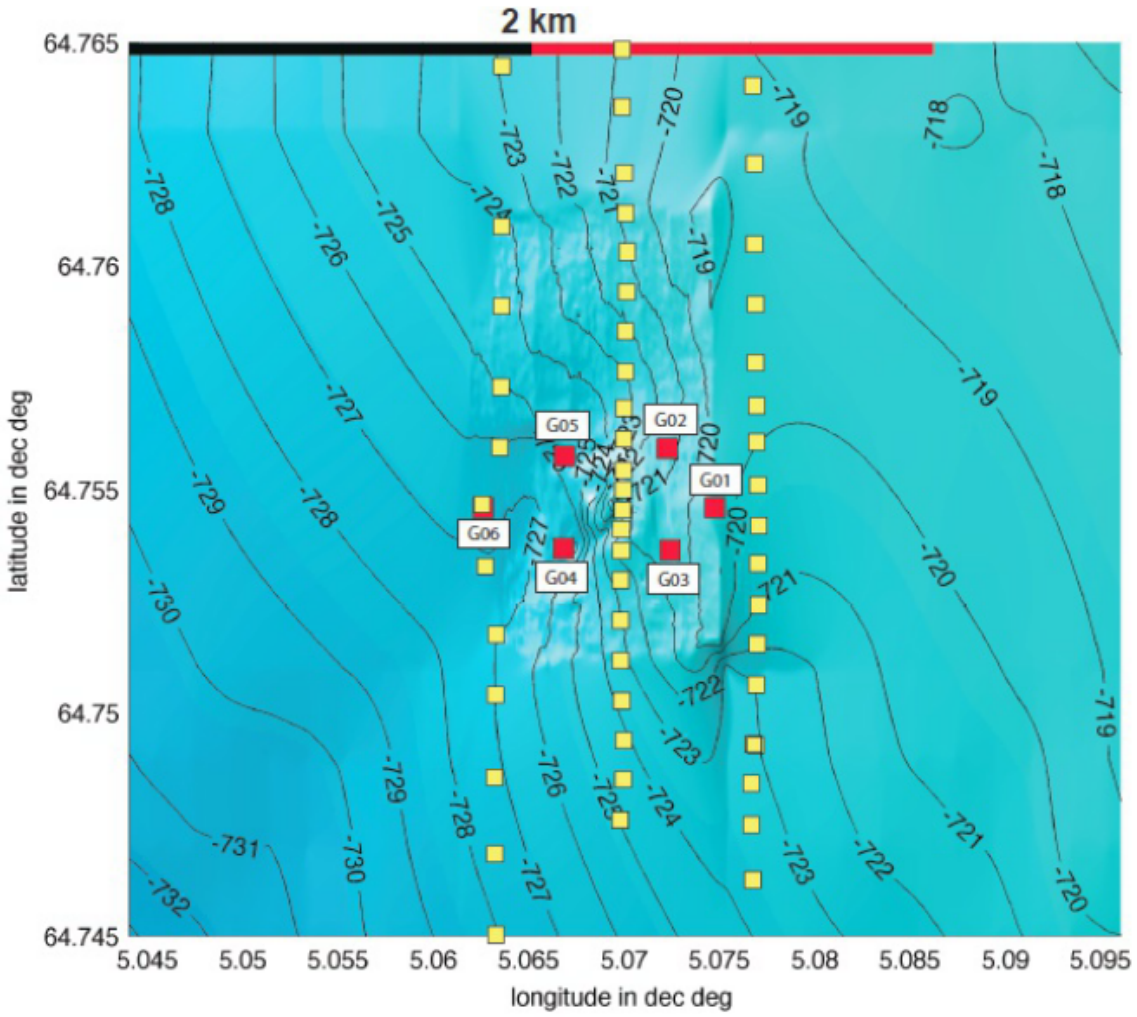
2012 Norway survey map



… receivers centred around hydrate vent

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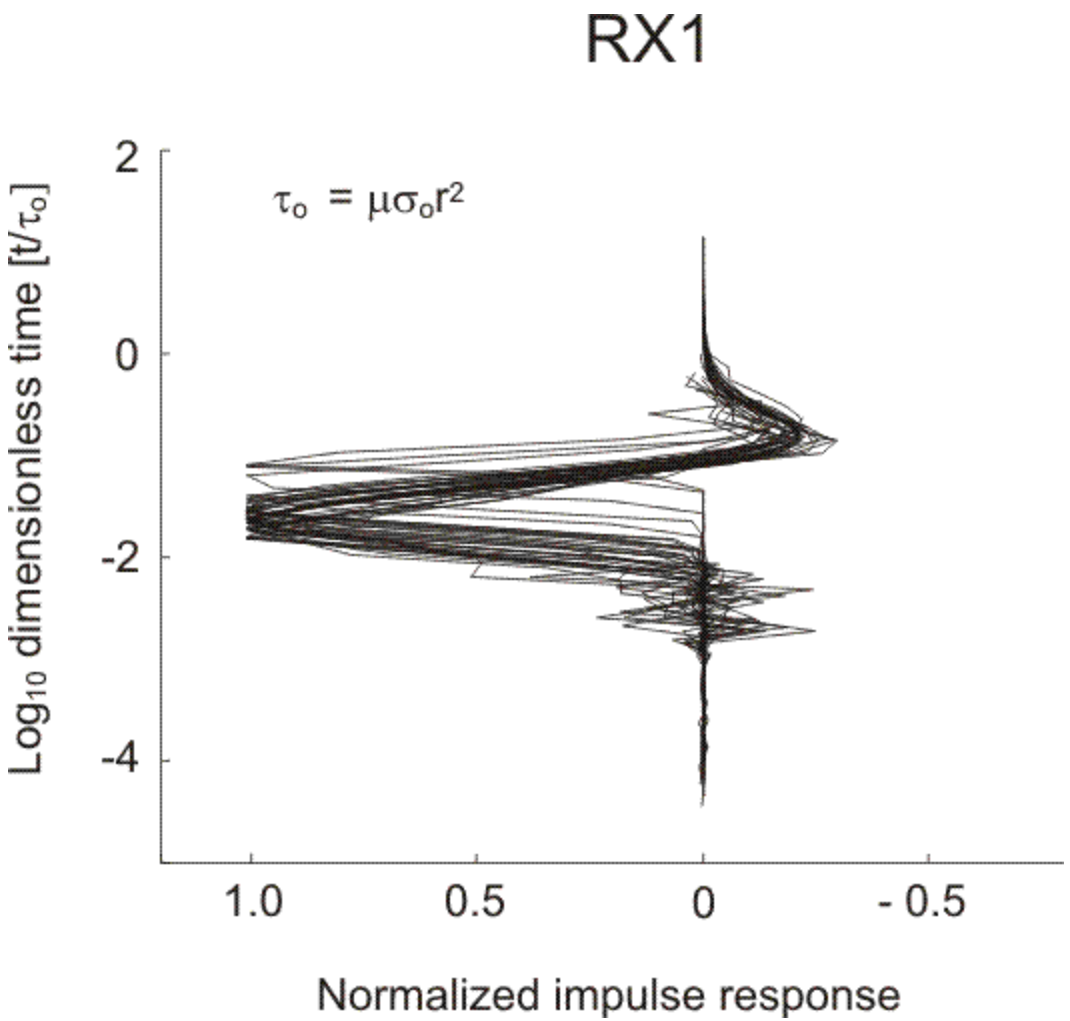
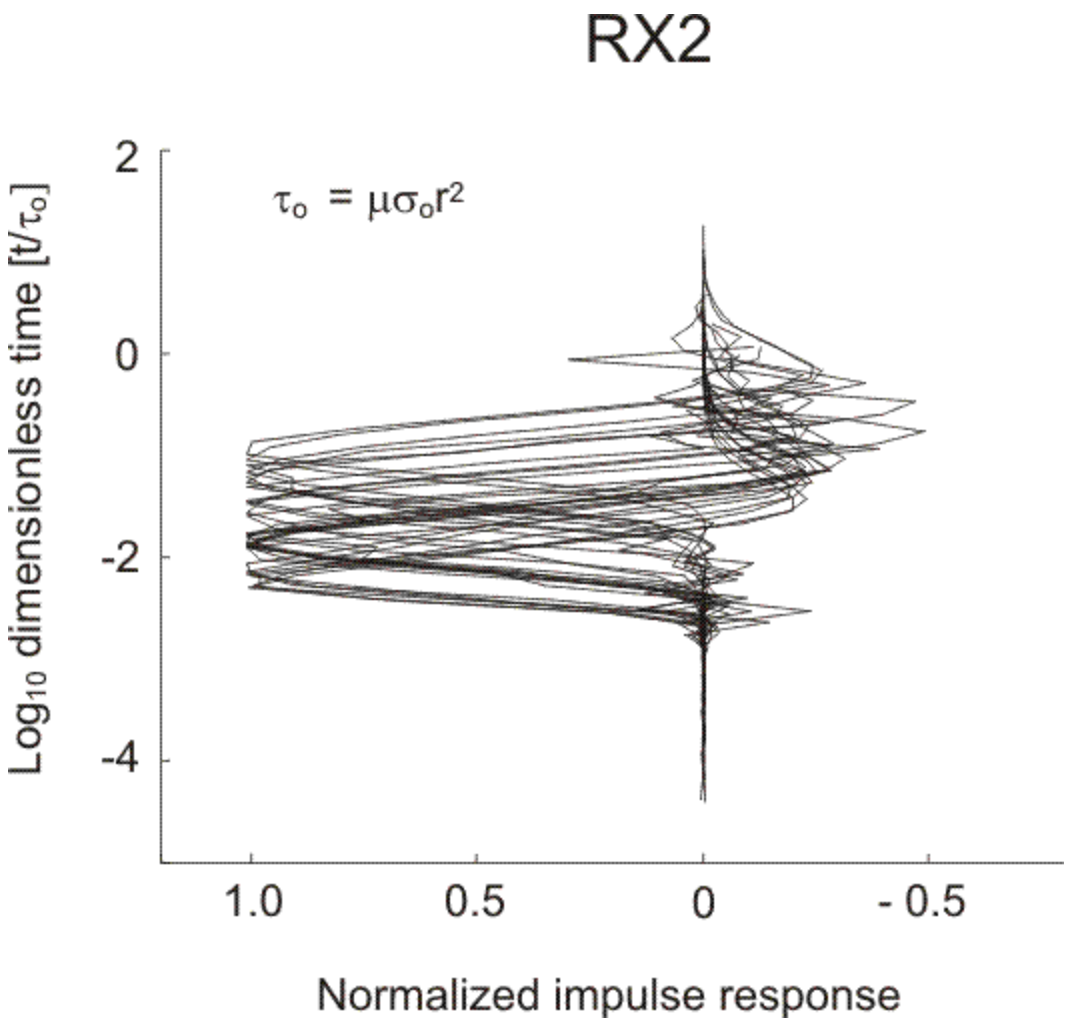
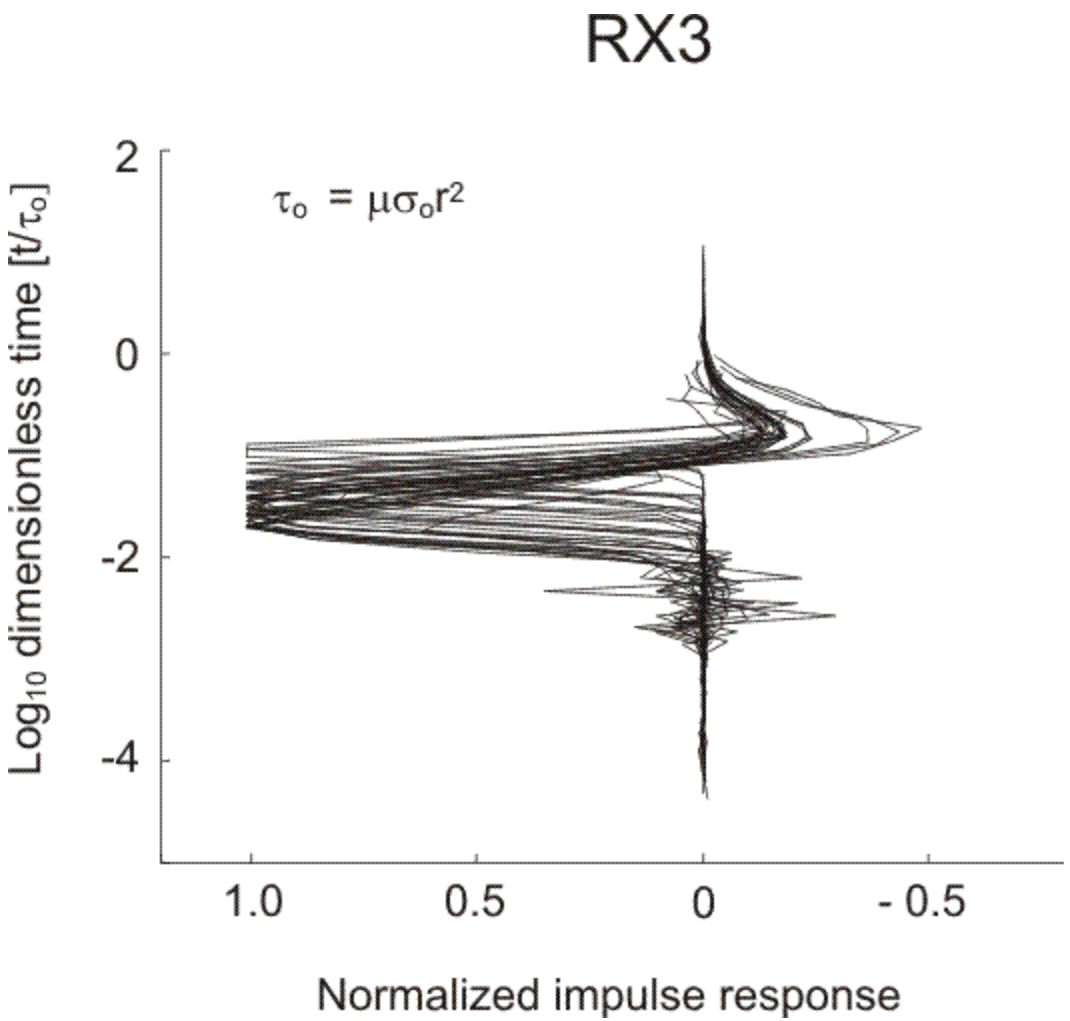


MINES GEOMAR



MINES GEOMAR



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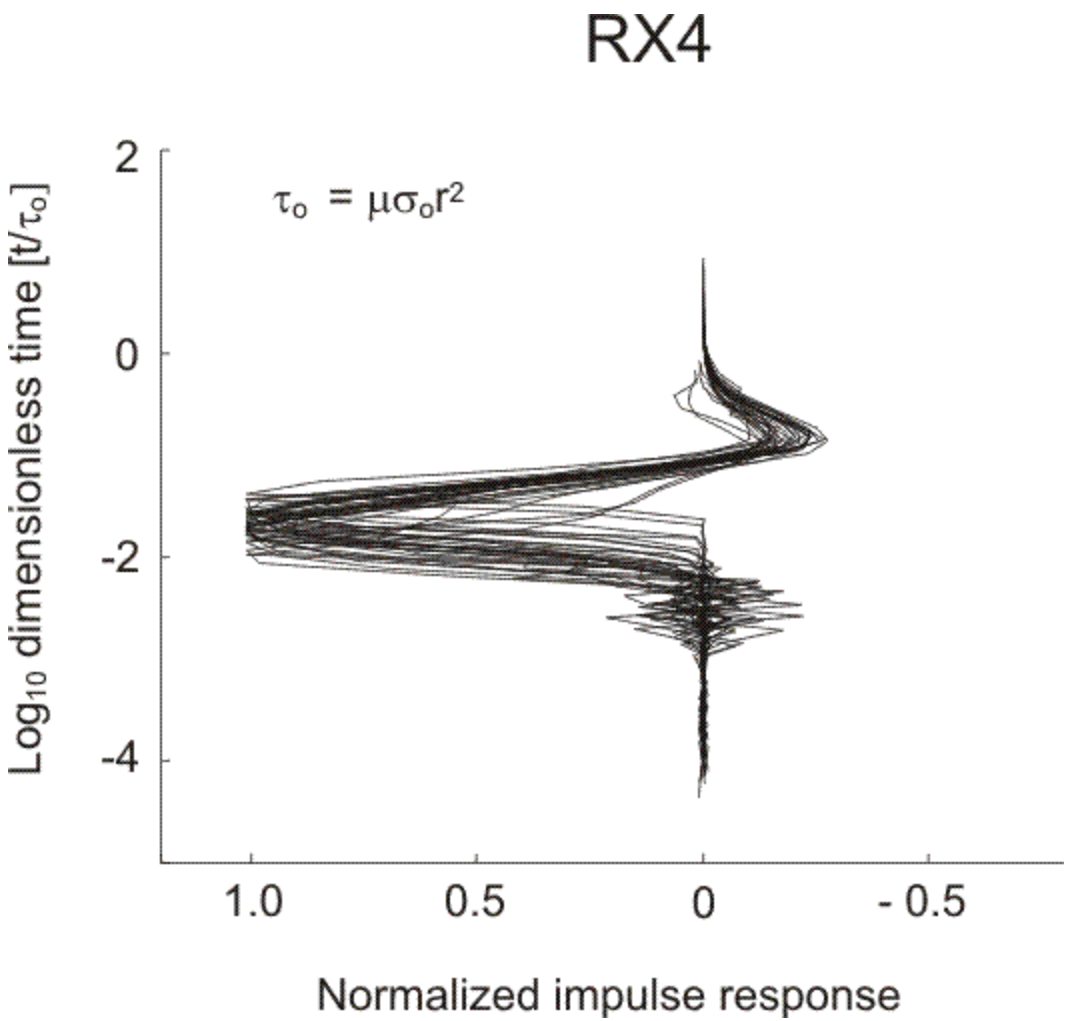
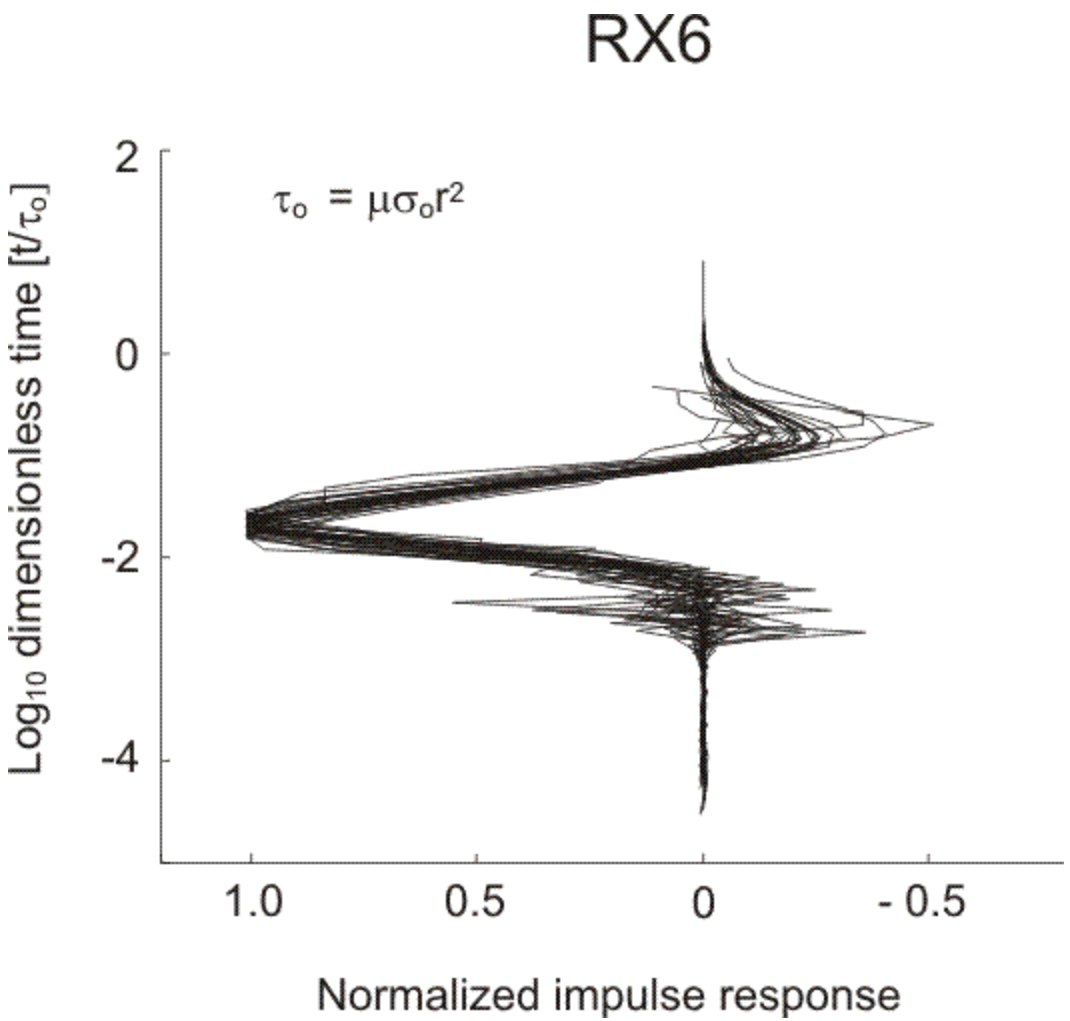

RX4
$\tau_o = \mu\sigma_o r^2$
Log_{10} dimensionless time [t/τ_o]
2
0
-2
-4
1.0
0.5
0
- 0.5
Normalized impulse response



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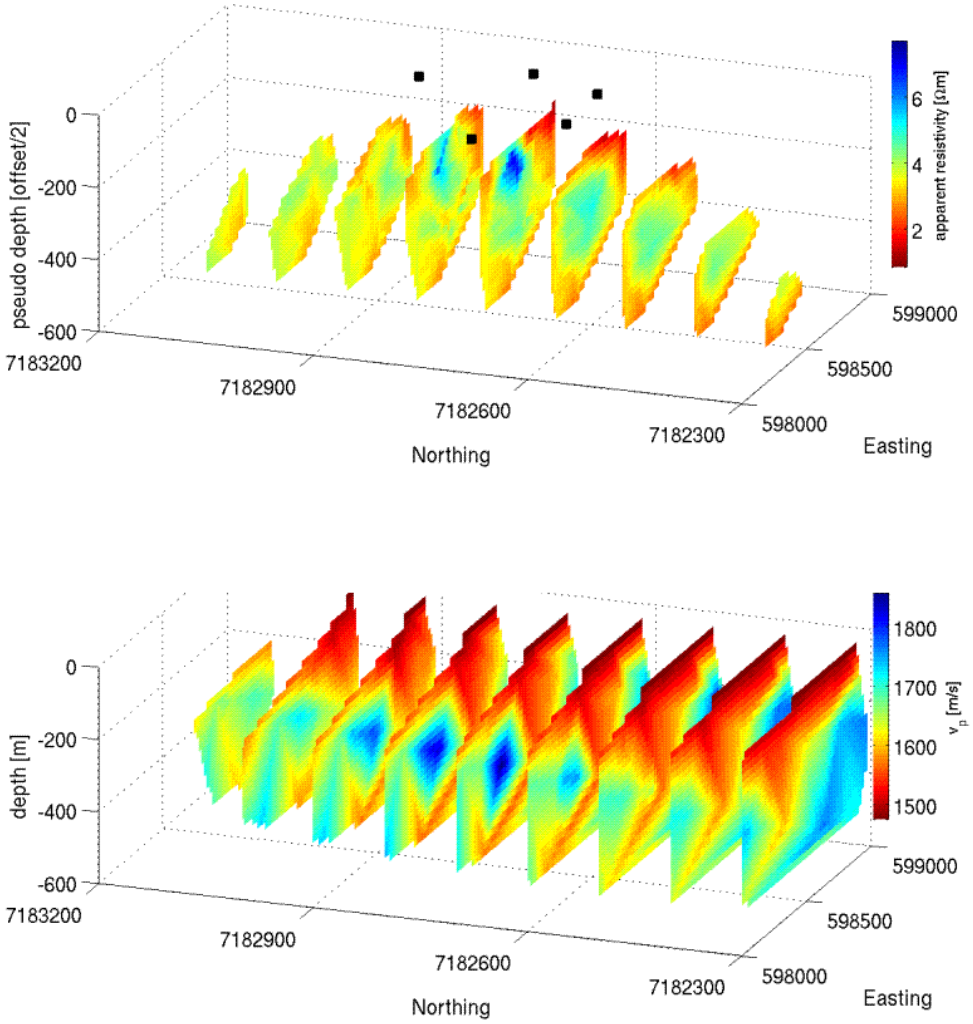
Comparison of apparent resistivities to OBS velocities



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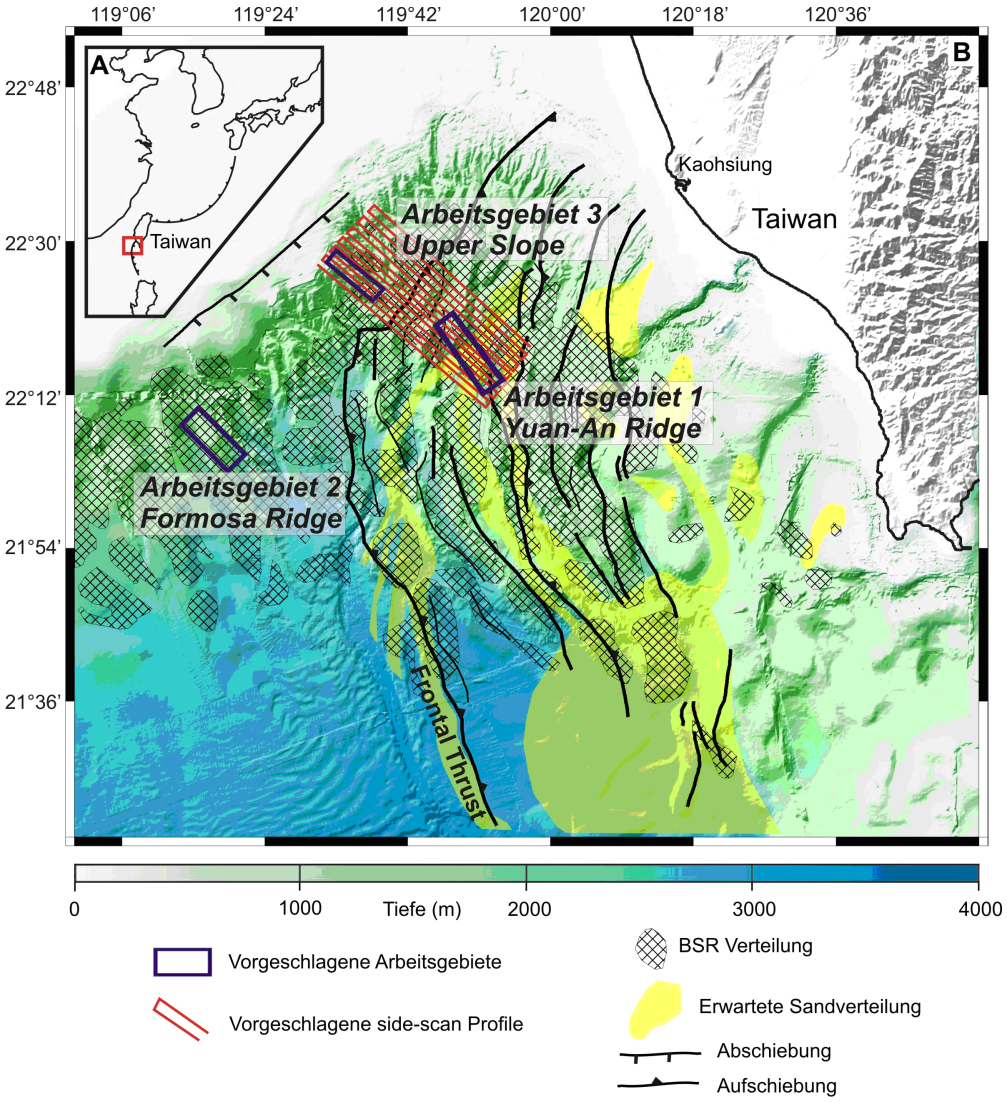
Example 6: Hydrates offshore Taiwan



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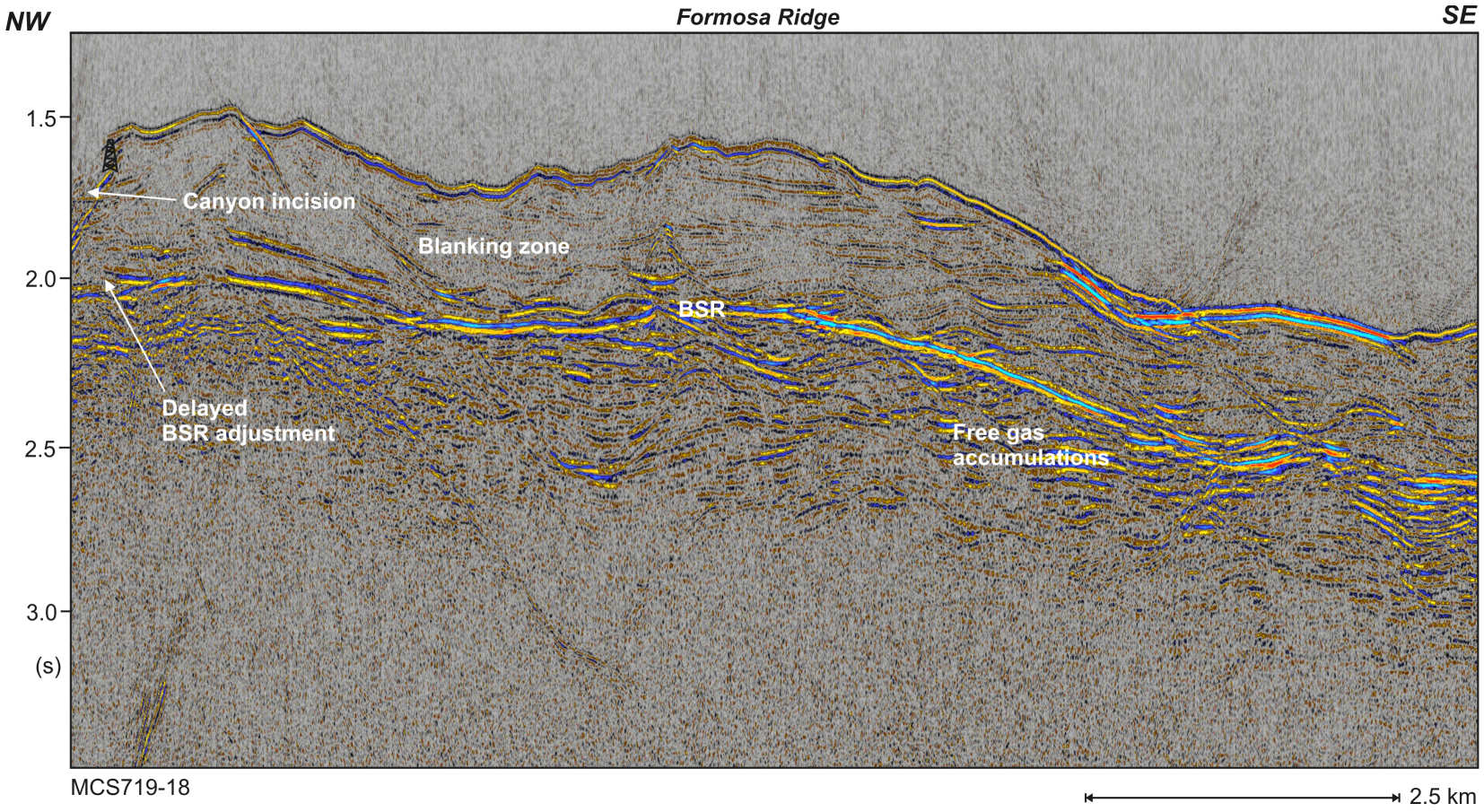
Previous seismic evidence of hydrates in numerous locations



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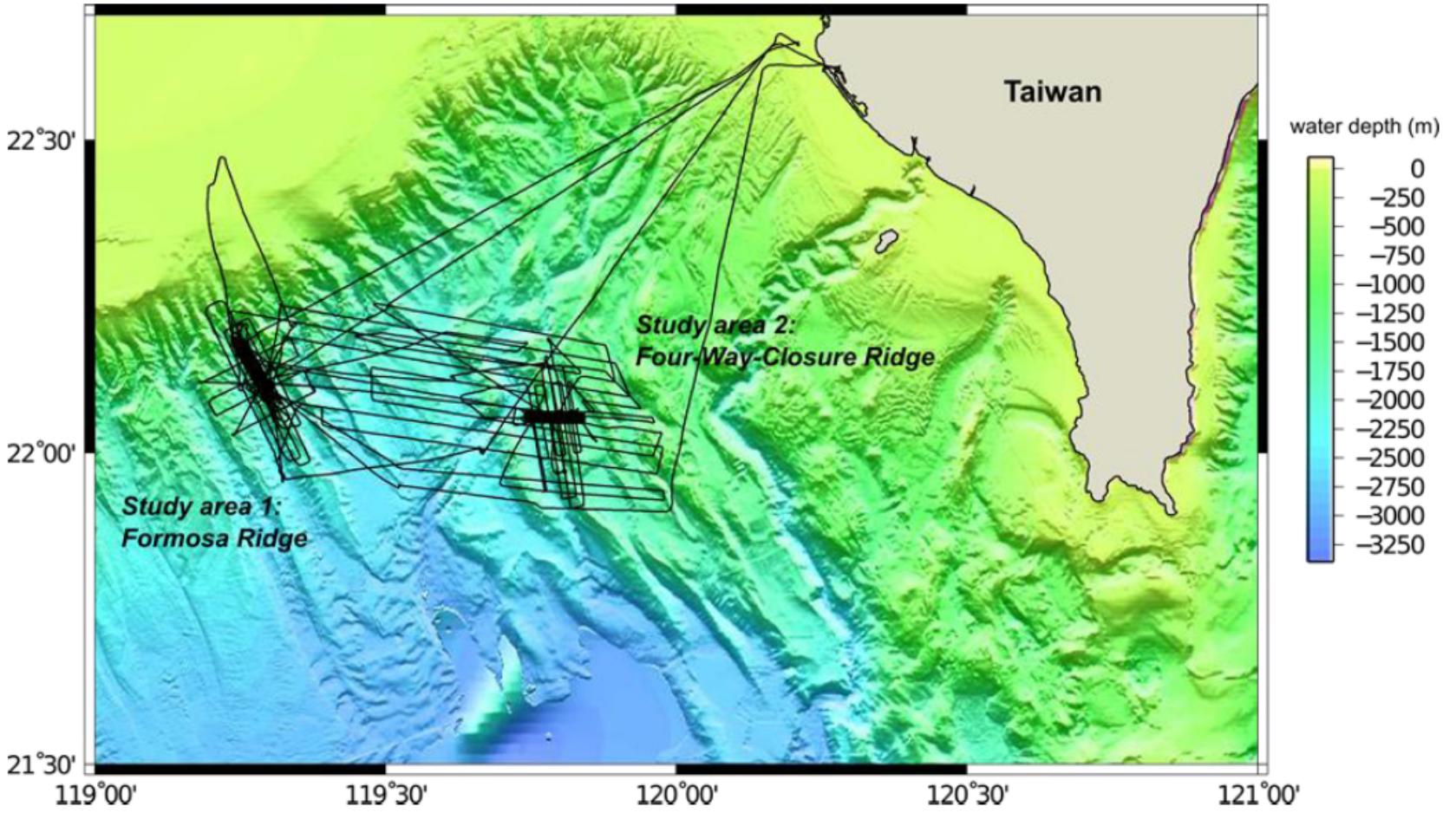
Cruise SO227: Kaohsiung 2-4-13 to Kaohsiung 2-5-13



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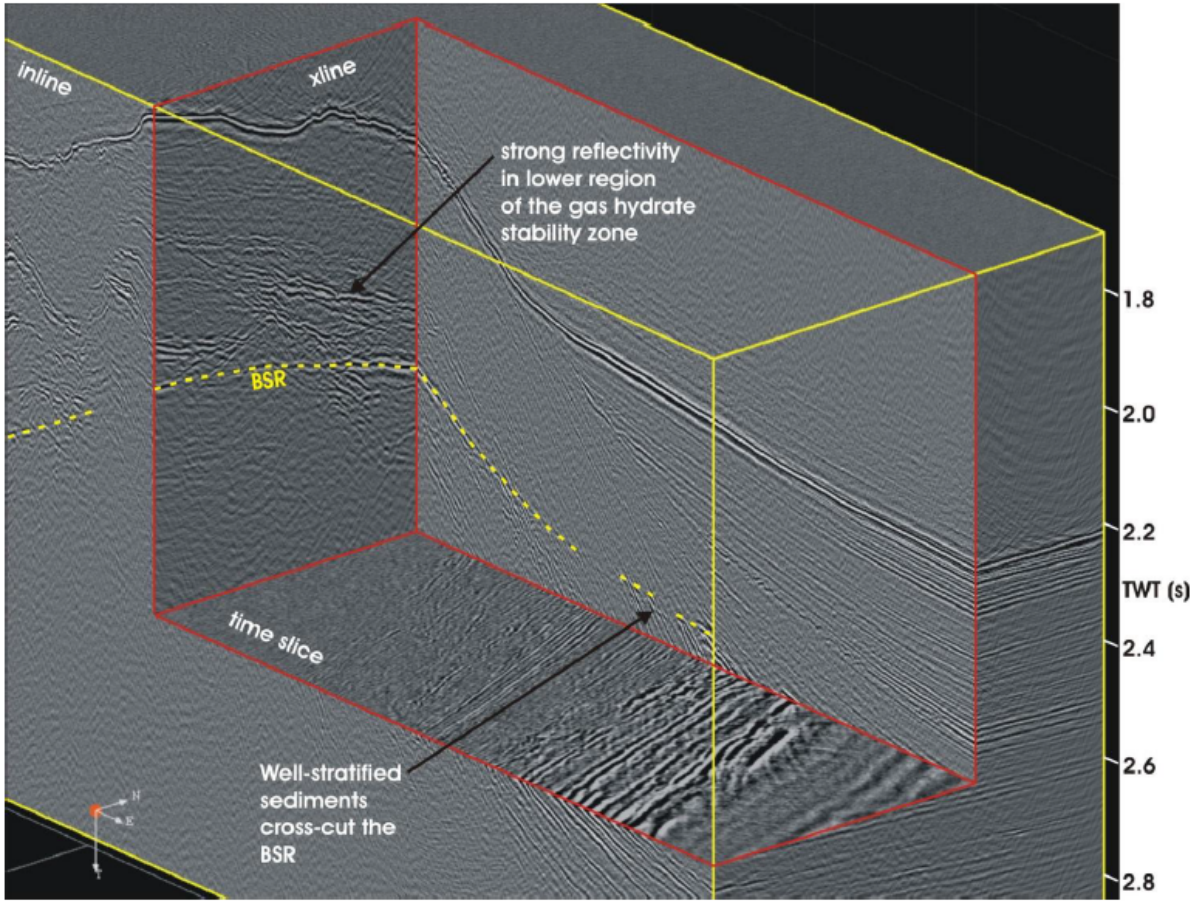
High resolution P-cable seismic evidence of hydrate at Four-Way-Closure.



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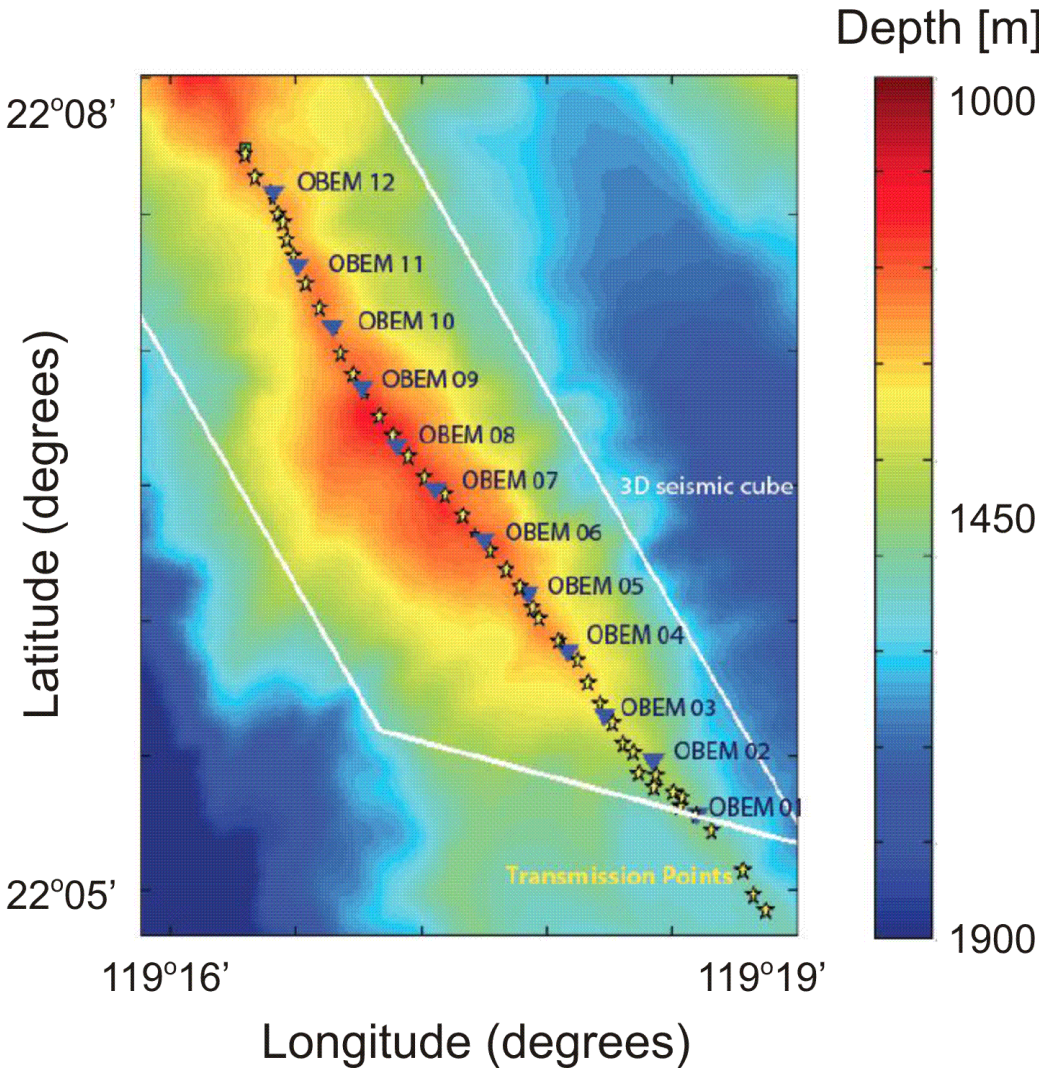
Formosa ridge CSEM survey line



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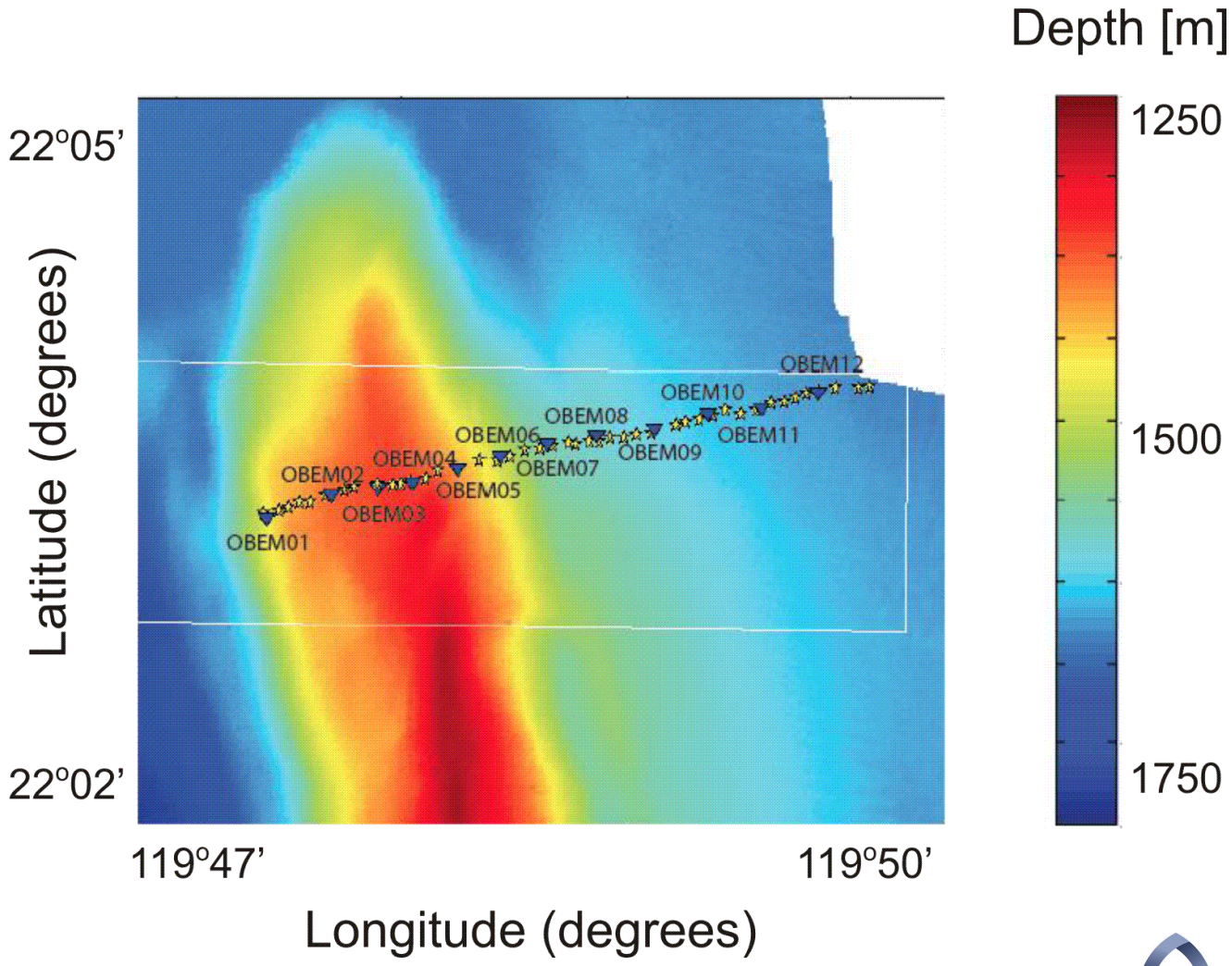
Four-Way-Closure CSEM survey line



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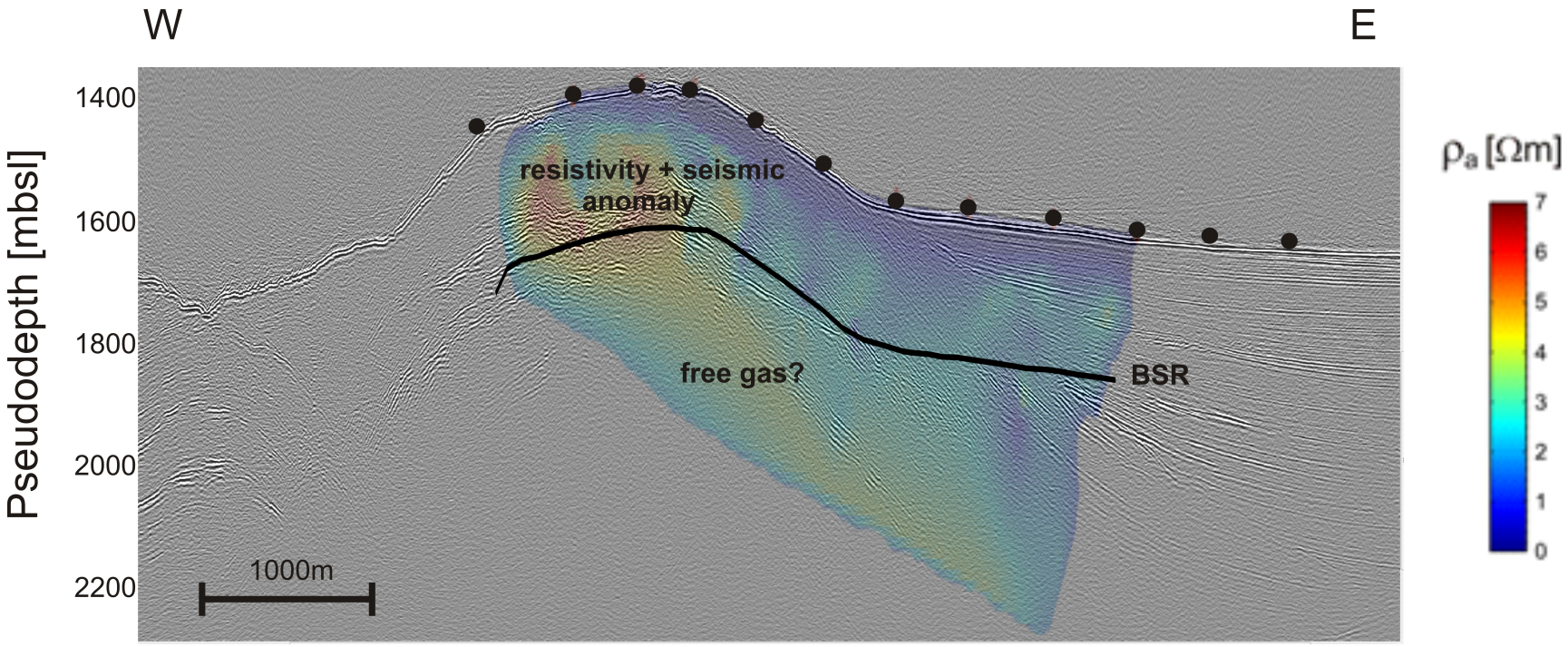
First attempt to compare 3D seismic and resistivity

Not a proper comparison!!!



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