Ulisses

UNIVERSITY OF LISBON
INTERDISCIPLINARY STUDIES
ON SUSTAINABLE ENVIRONMENT AND SEAS

Looking into the ocean with geophysics

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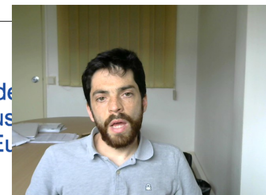
Geophysics

DEFINITION (from the '*Encyclopedia dictionary of Applied Geophyscis, R. Sheriff*')

1) The Application of physical principles to studies of the Earth.

2) The study of the Earth by quantitative physical methods by *seismic reflection* and *refraction*, *magnetic*, *electrical*, *electromagnetic* and *radioactive* methods.



Geophysics

Global Geophysics
study of the entire Earth's structure

Regionalized studies
stuctures of the mantle

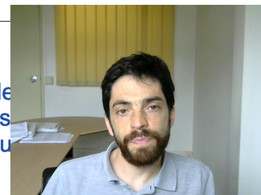
Localized studies
basin-scale
environmental Geophysics
engineering studies

Decrease in resolution
Increase in depth penetration

Method	Measured parameter	Operative physical property
Seismic	Travel times of reflected/refracted seismic waves	Density and elastic moduli, which determine the propagation velocity of seismic waves
Gravity	Spatial variations in the strength of the gravitational field of the Earth	Density
Magnetic	Spatial variations in the strength of the geomagnetic field	Magnetic susceptibility and remanence
Electrical		
Resistivity	Earth resistance	Electrical conductivity
Induced polarization	Polarization voltages or frequency-dependent ground resistance	Electrical capacitance
Self-potential	Electrical potentials	Electrical conductivity
Electromagnetic	Response to electromagnetic radiation	Electrical conductivity and inductance
Radar	Travel times of reflected radar pulses	Dielectric constant

Kearey et al. 2002

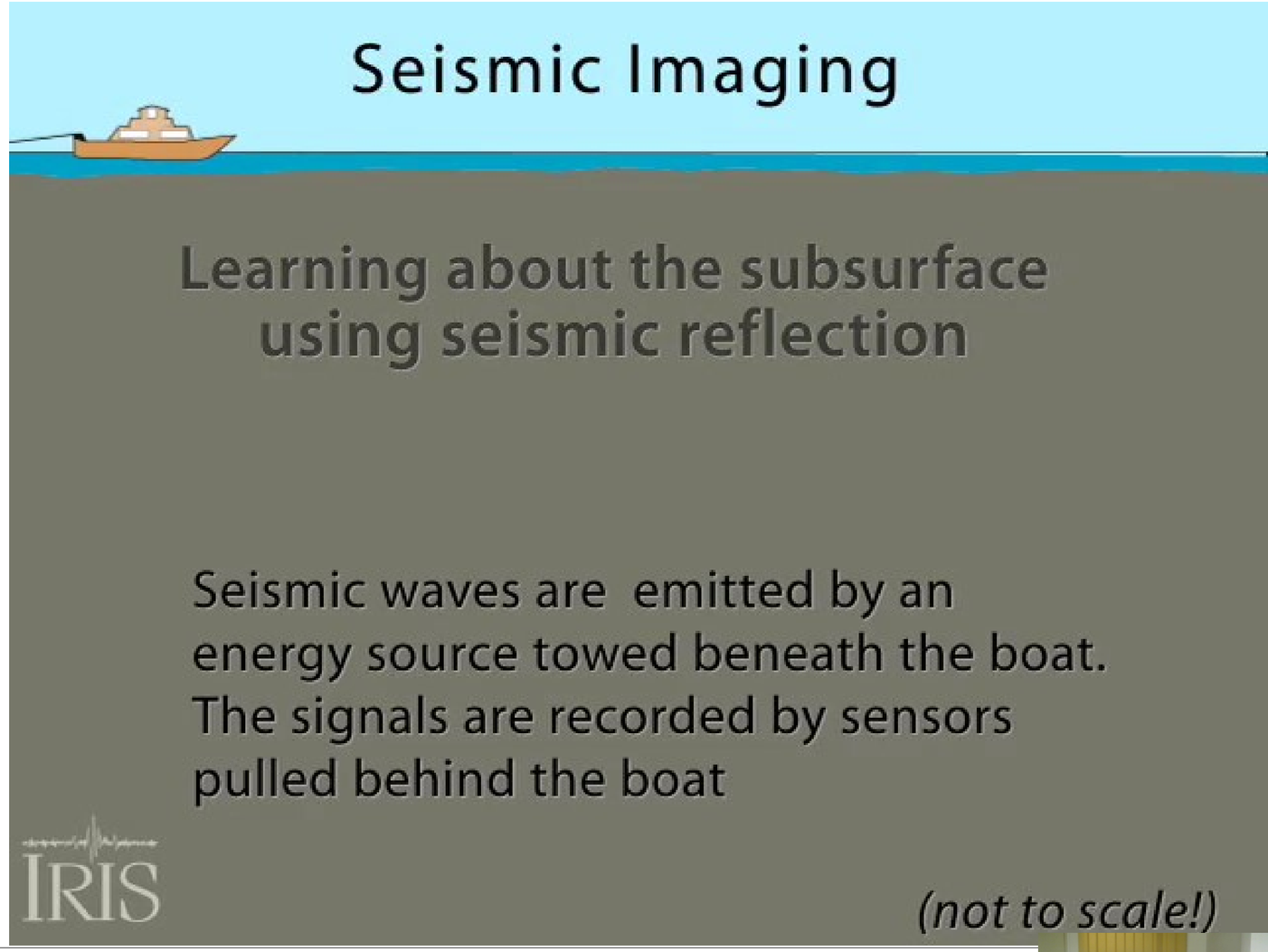
The study of the ***solid*** and ***liquid*** Earth



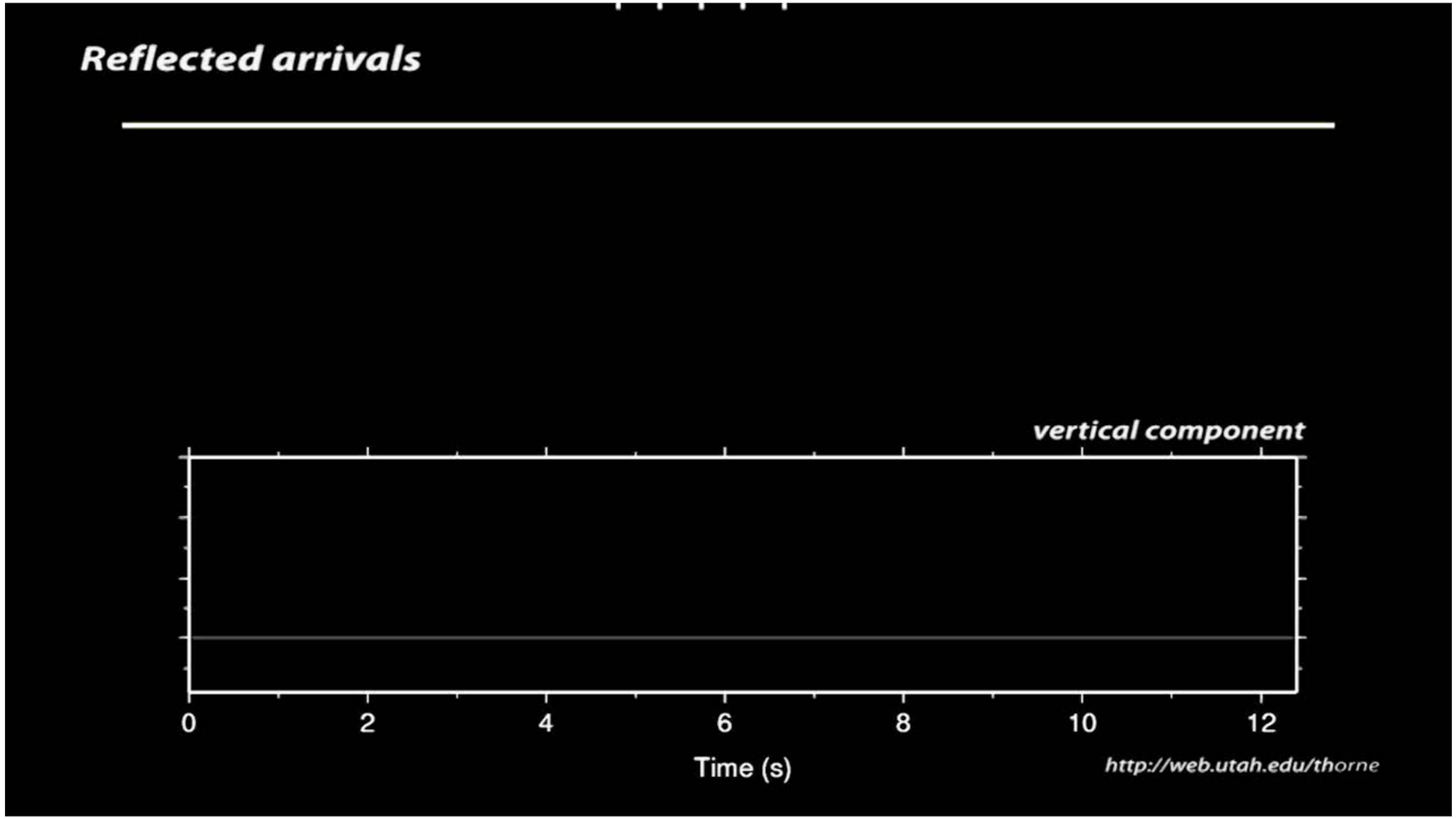
Seismic reflection

Most used method in exploration. It is based on the propagation of compressional waves in Earth's subsurface which are reflect at the interface between geologic layers with different elastic properties.

Allows the interpretation of the stratigraphy and structural geology of a given basin.



Seismic reflection

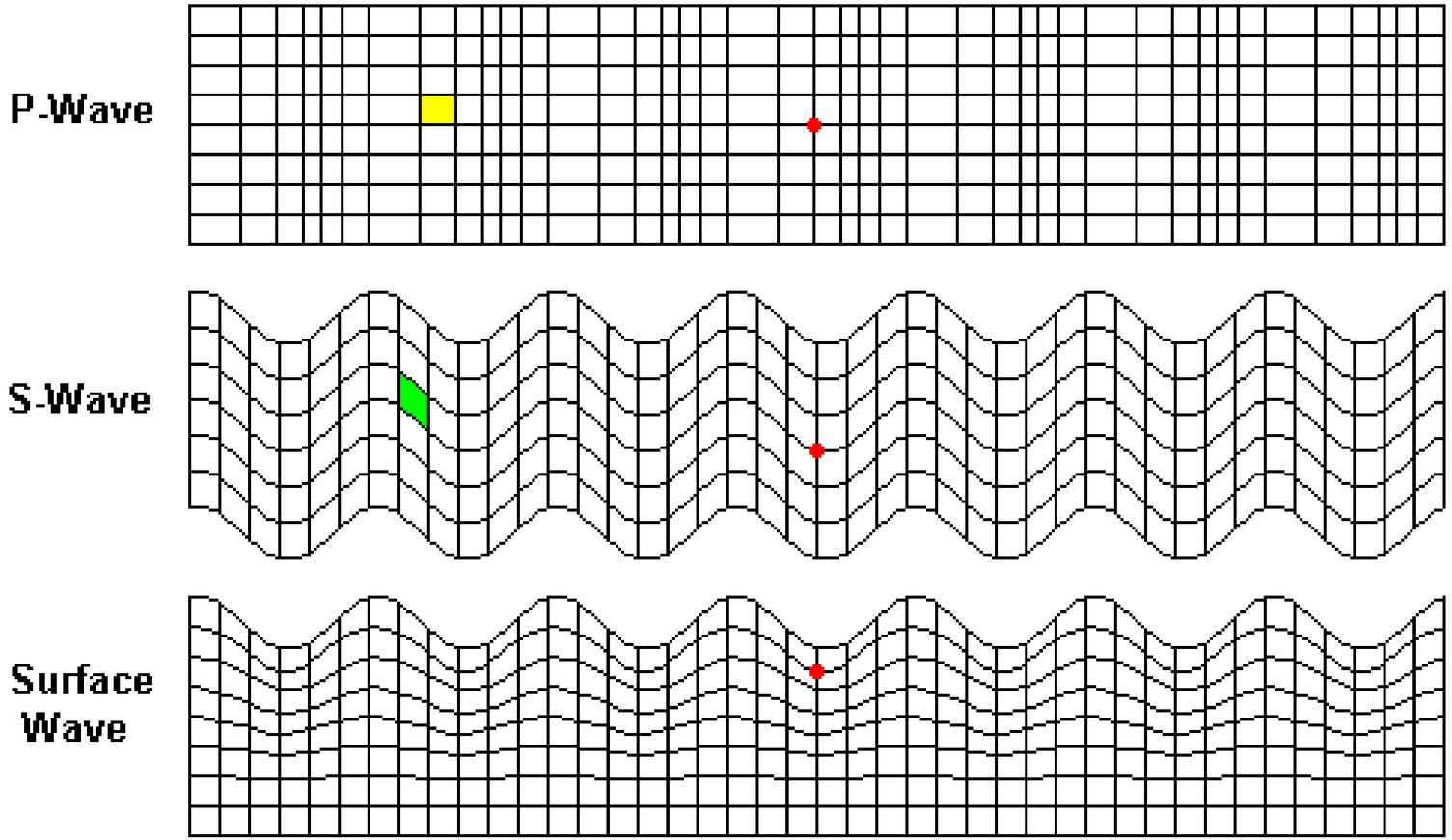


Seismic reflection: *types of waves*

There are 2 main types of waves:

- Surface waves;

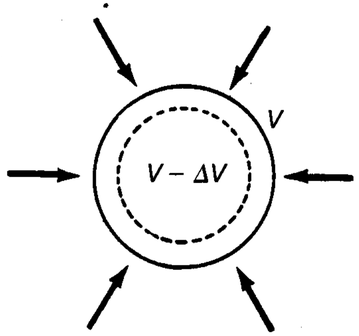
- Body waves.



Seismic reflection: *types of waves*

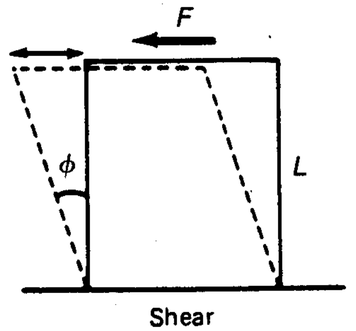
The seismic energy travels within the subsurface as elastic waves. Its velocity depends on the intrinsic properties of the subsurface geology: density and dynamic modulus (K, or μ).

Bulk Modulus (k)



$$k = \frac{1}{\kappa} = \frac{P}{\Delta V / V}$$

Shear Modulus (μ)



$$\mu = \frac{\tau}{\tan\theta}$$

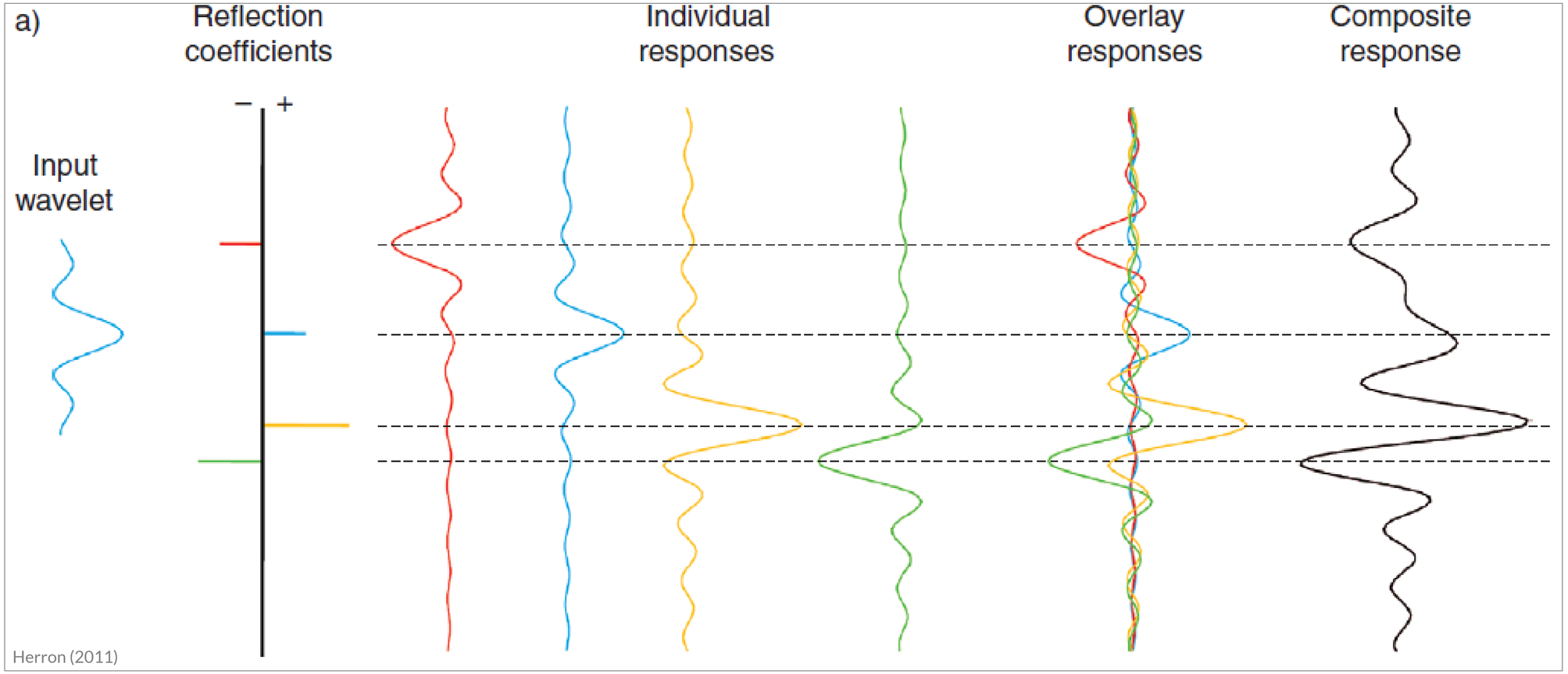
P-wave velocity (Vp)

$$v_p = \sqrt{\frac{k + \frac{4\mu}{3}}{\rho}}$$

S-wave velocity (Vs)

$$v_s = \sqrt{\frac{\mu}{\rho}}$$

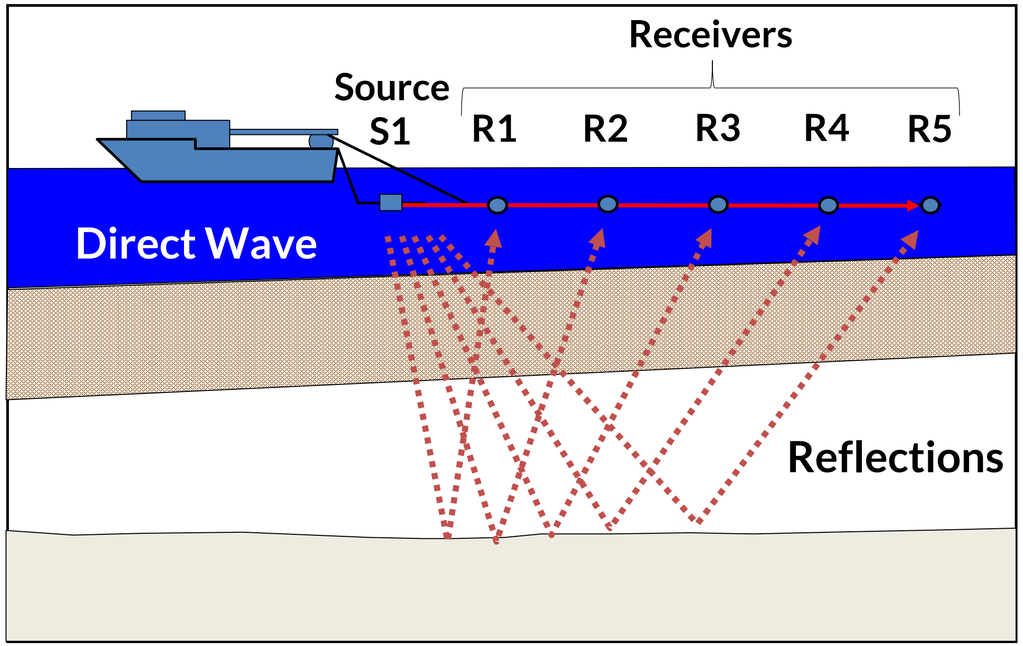
Seismic reflection

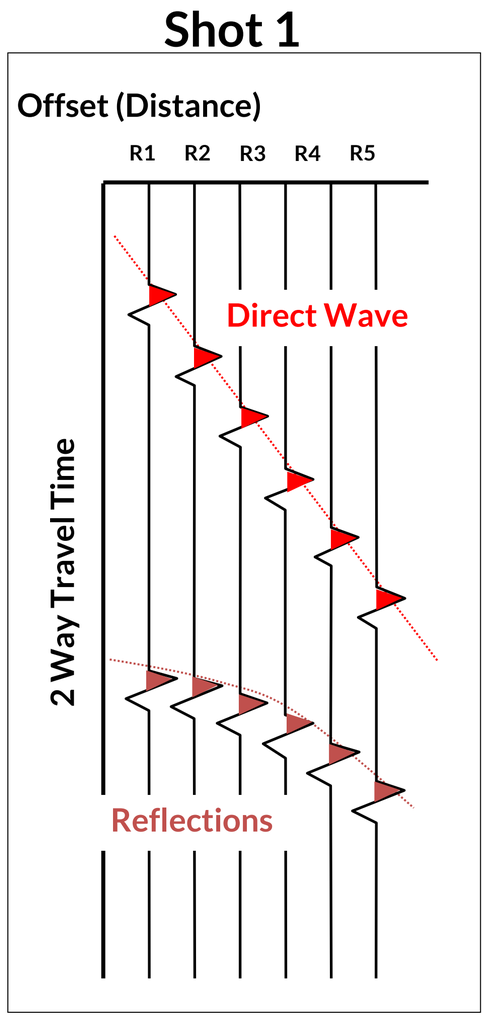


$$\text{Acoustic Impedance (Ip)} = \text{Vp} \cdot \rho$$

$$\text{Reflection Coefficients} = \frac{\text{Ip}_2 - \text{Ip}_1}{\text{Ip}_1 + \text{Ip}_2}\text{, for normal incidence}$$

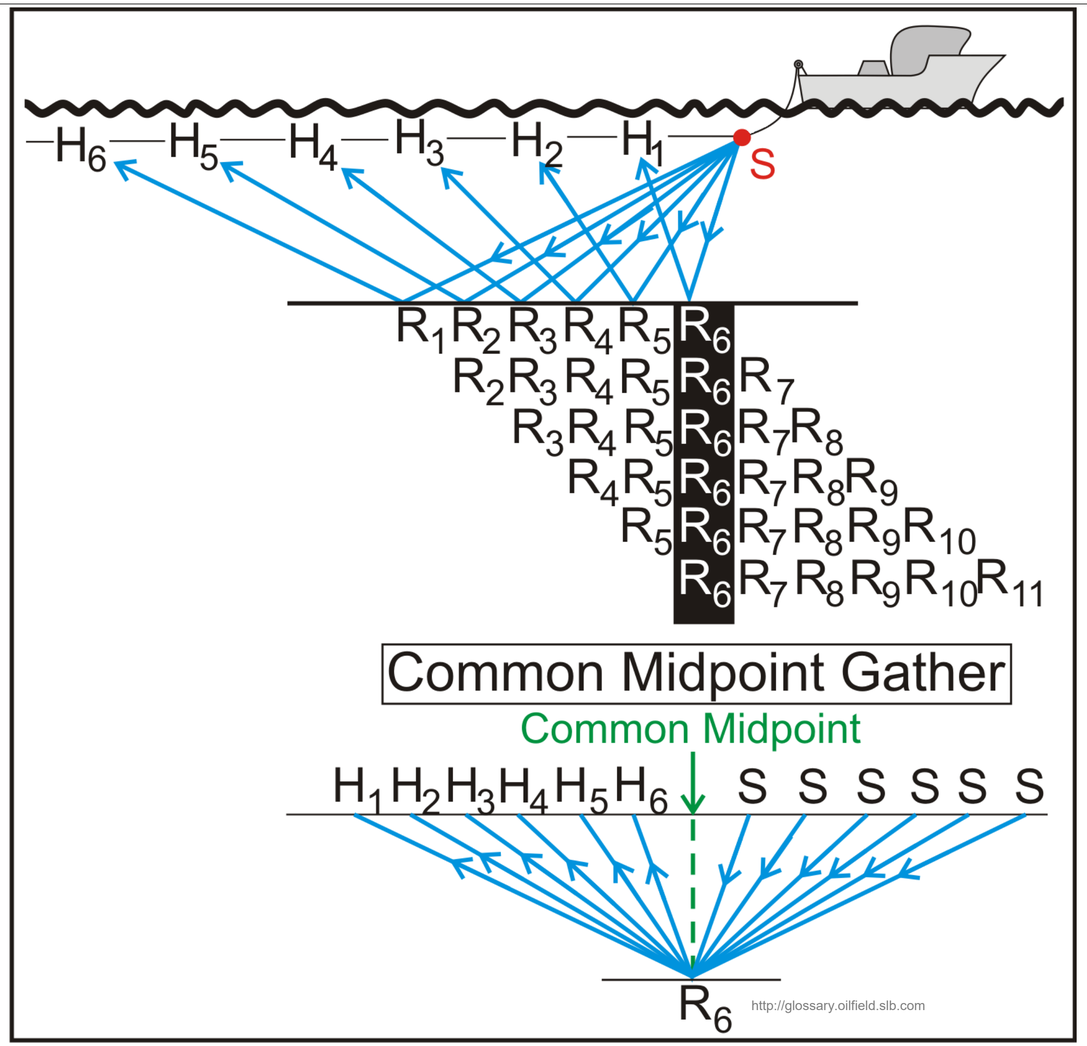
Seismic reflection: *acquisition and processing*



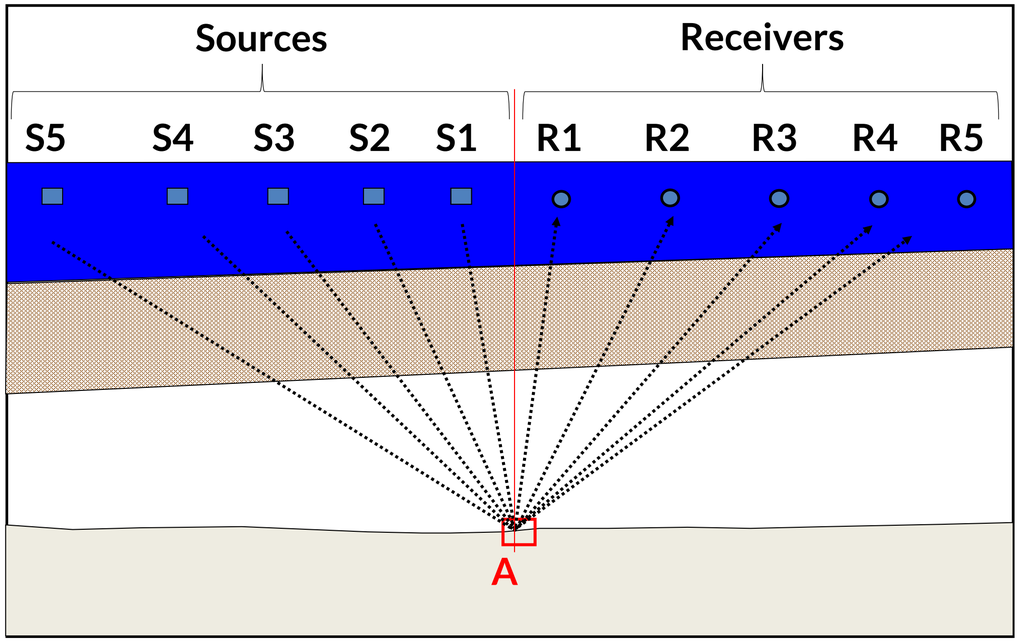


F.W Schroeder '04

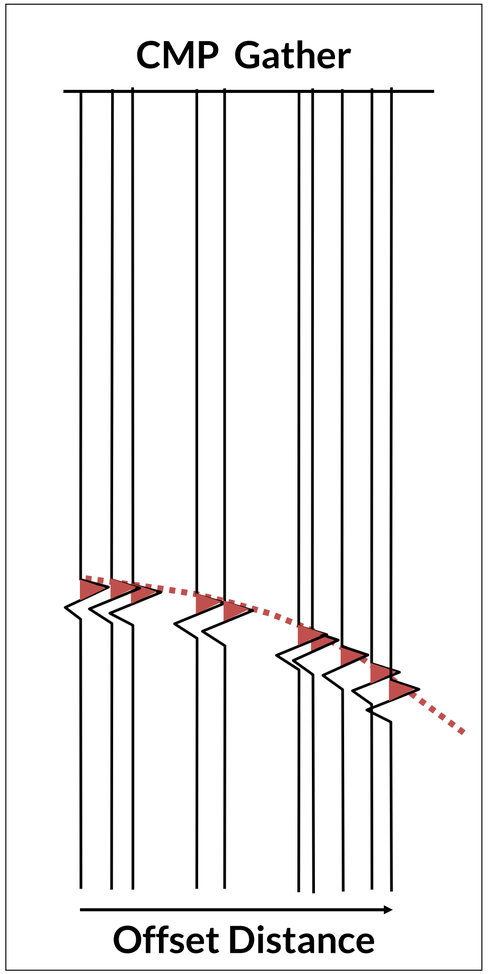
Seismic reflection: *acquisition and processing*



Seismic reflection: *acquisition and processing*

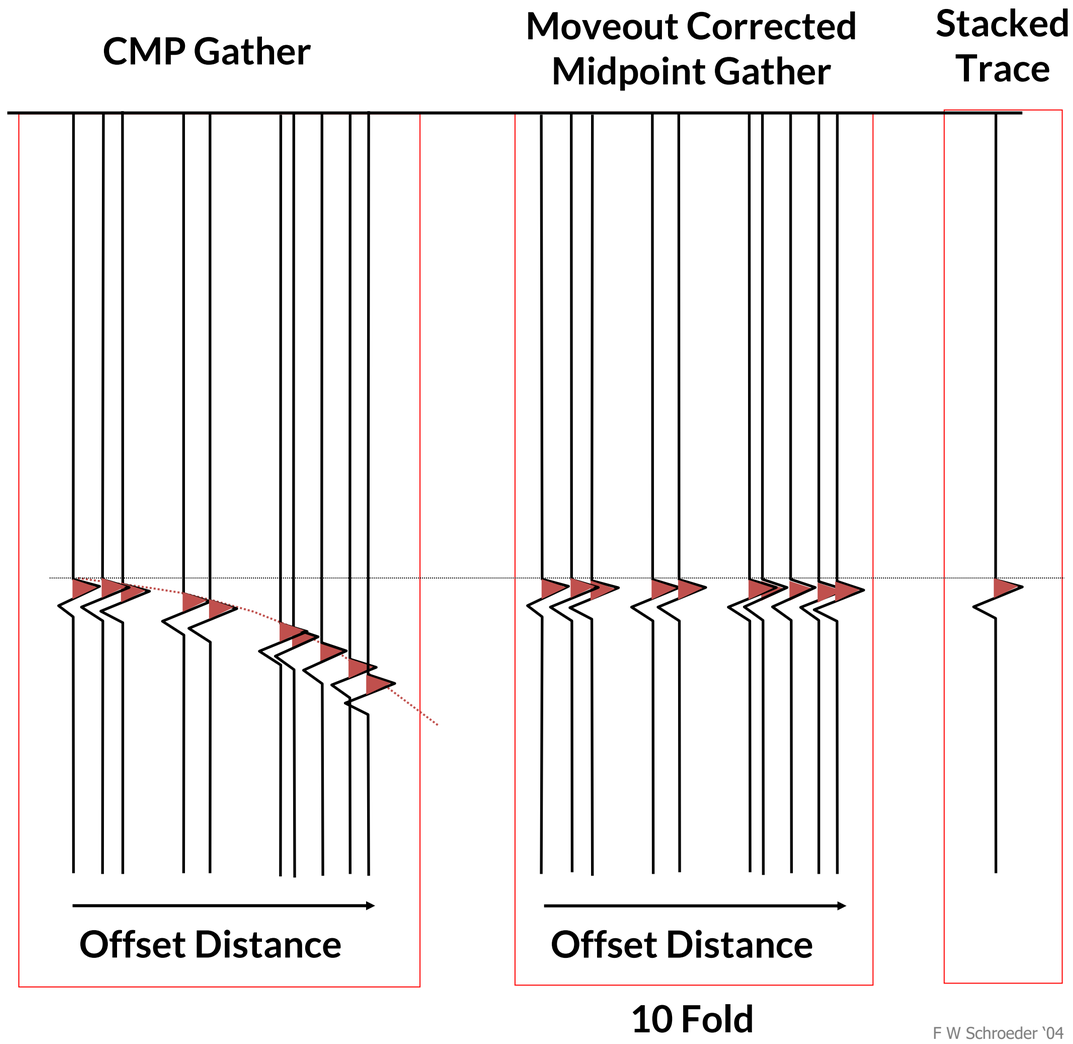


For Point A



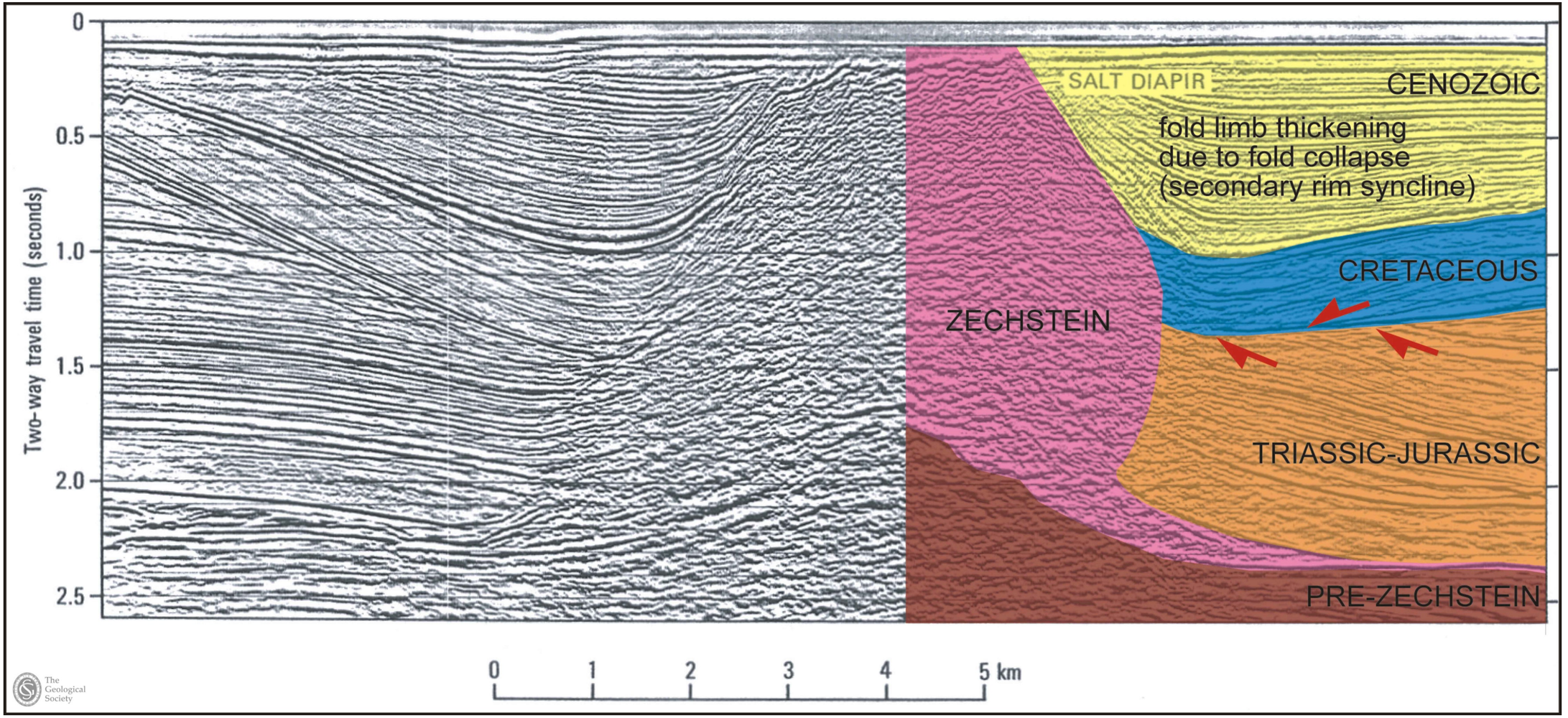
F W Schroeder '04

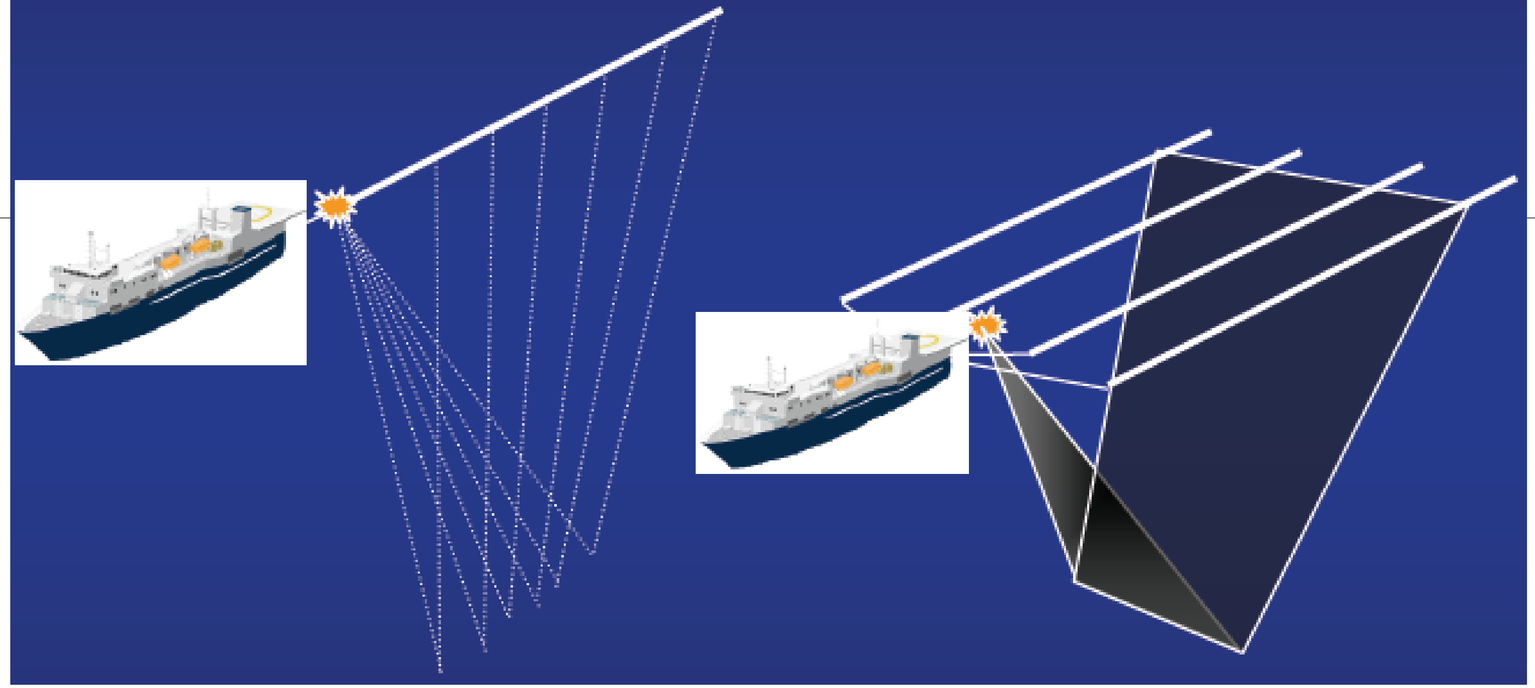
Seismic reflection: *acquisition and processing*



F W Schroeder '04

Seismic reflection data

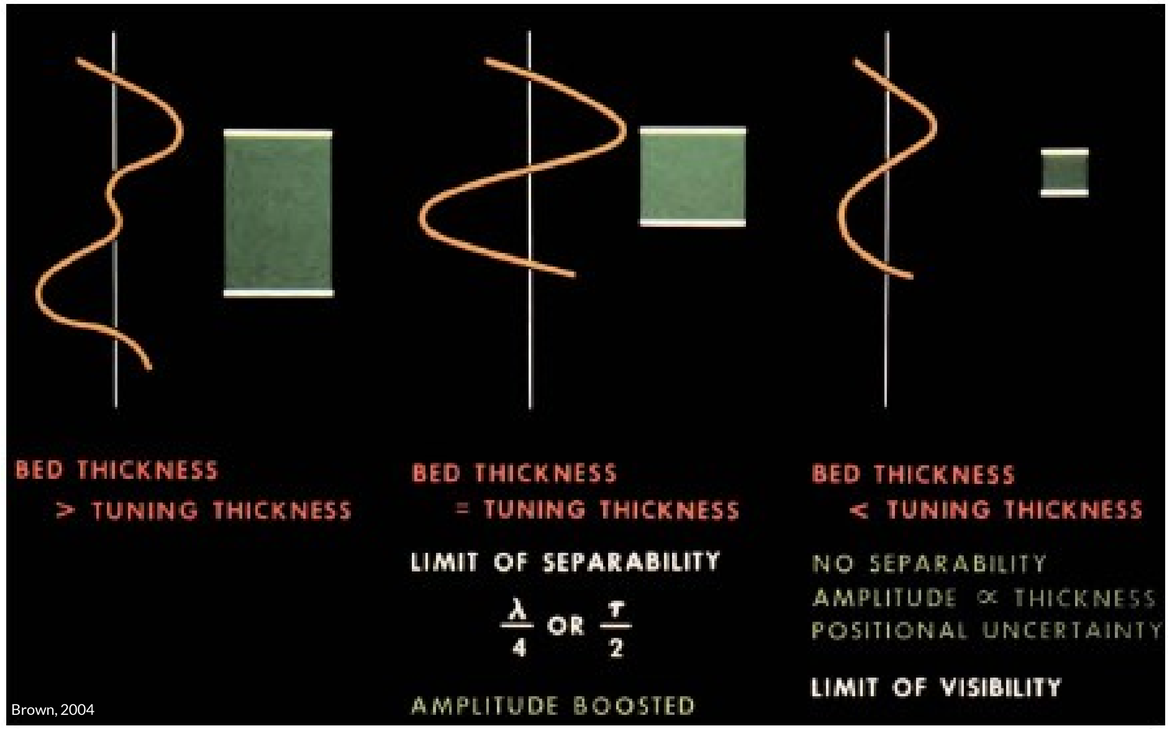


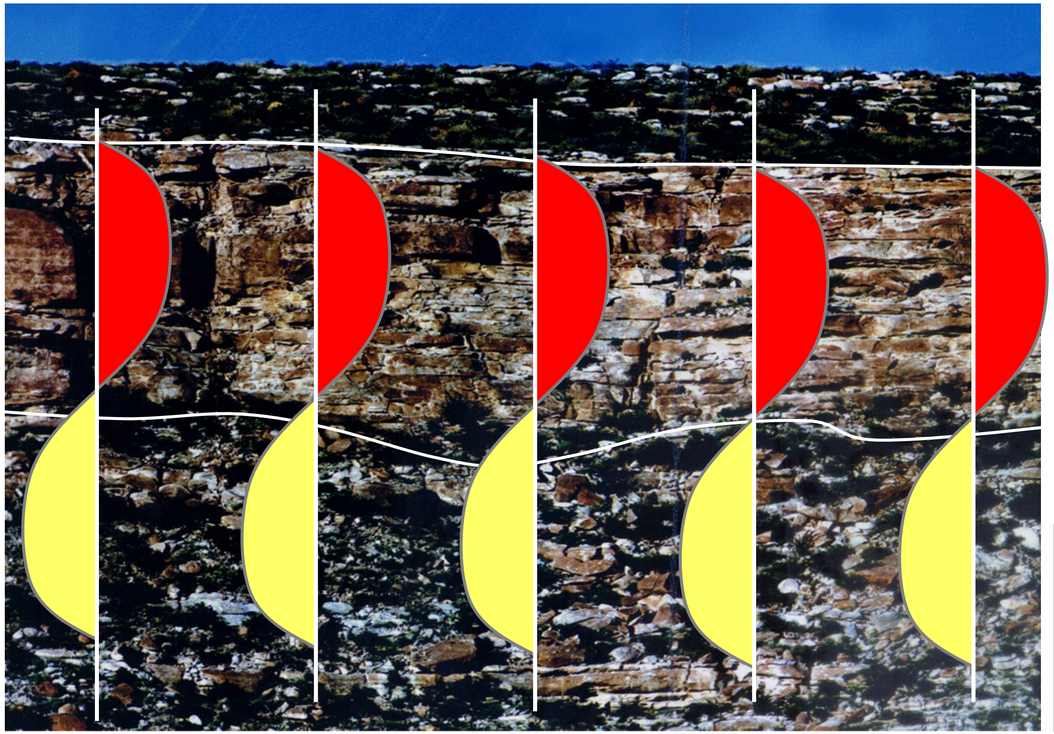


- Lower costs;
- Low S/N Ratio;
- Illumination along the same path;
- Frequently used in regional studies.

- Higher costs;
- Higher S/N Ratio;
- Illumination along the same path *(Narrow-Azimuth)*;
- Frequently used for prospect ID and Characterization.

Seismic reflection: *resolution*

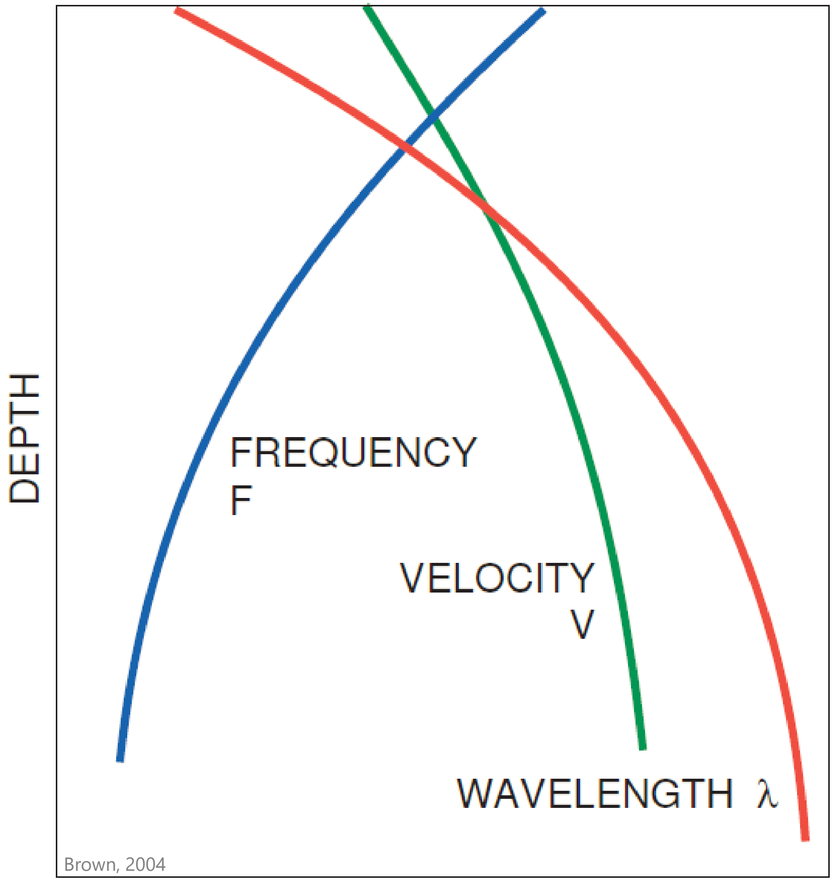




F W Schroeder '04

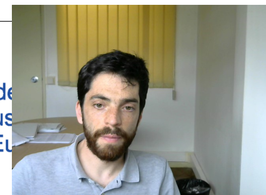
Seismic reflection: *resolution*

$$\lambda = \frac{V}{F}$$



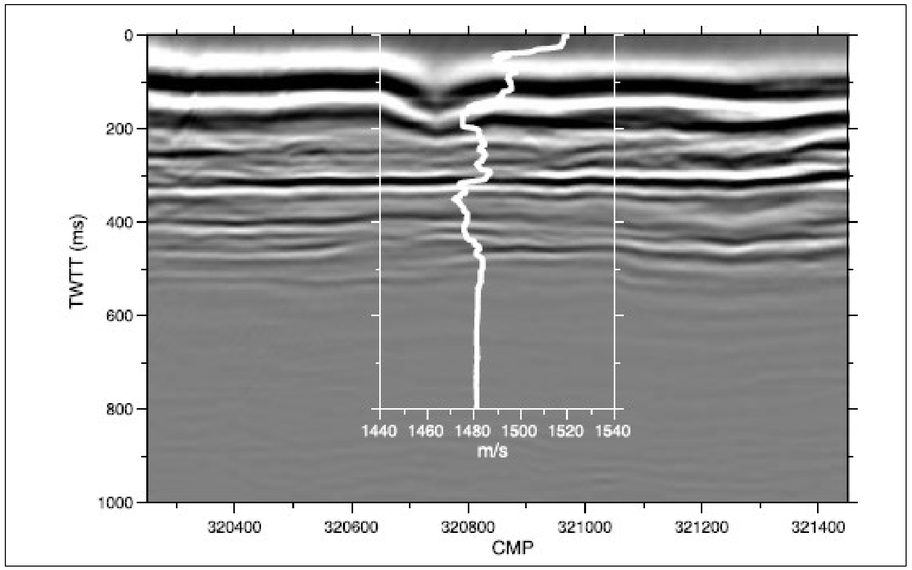
Brown, 2004

What about the ocean?



Seismic oceanography (SO)

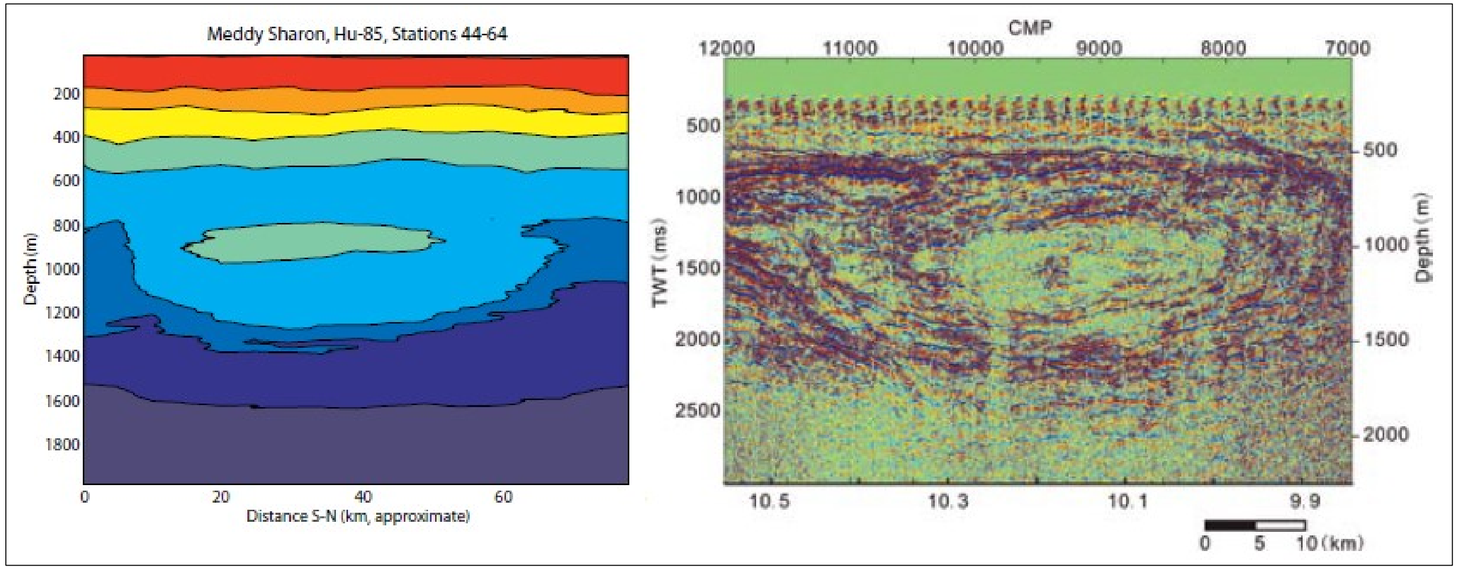
- Seismic reflection sections from the water column
- Qualitative interpretation of oceanic structures
- Imaging of the meso and submesoscales



Holbrook et al. 2003

Conventional data

SO



Ruddick et al. 2009

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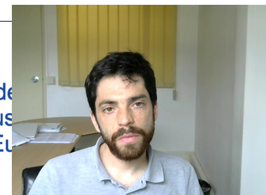
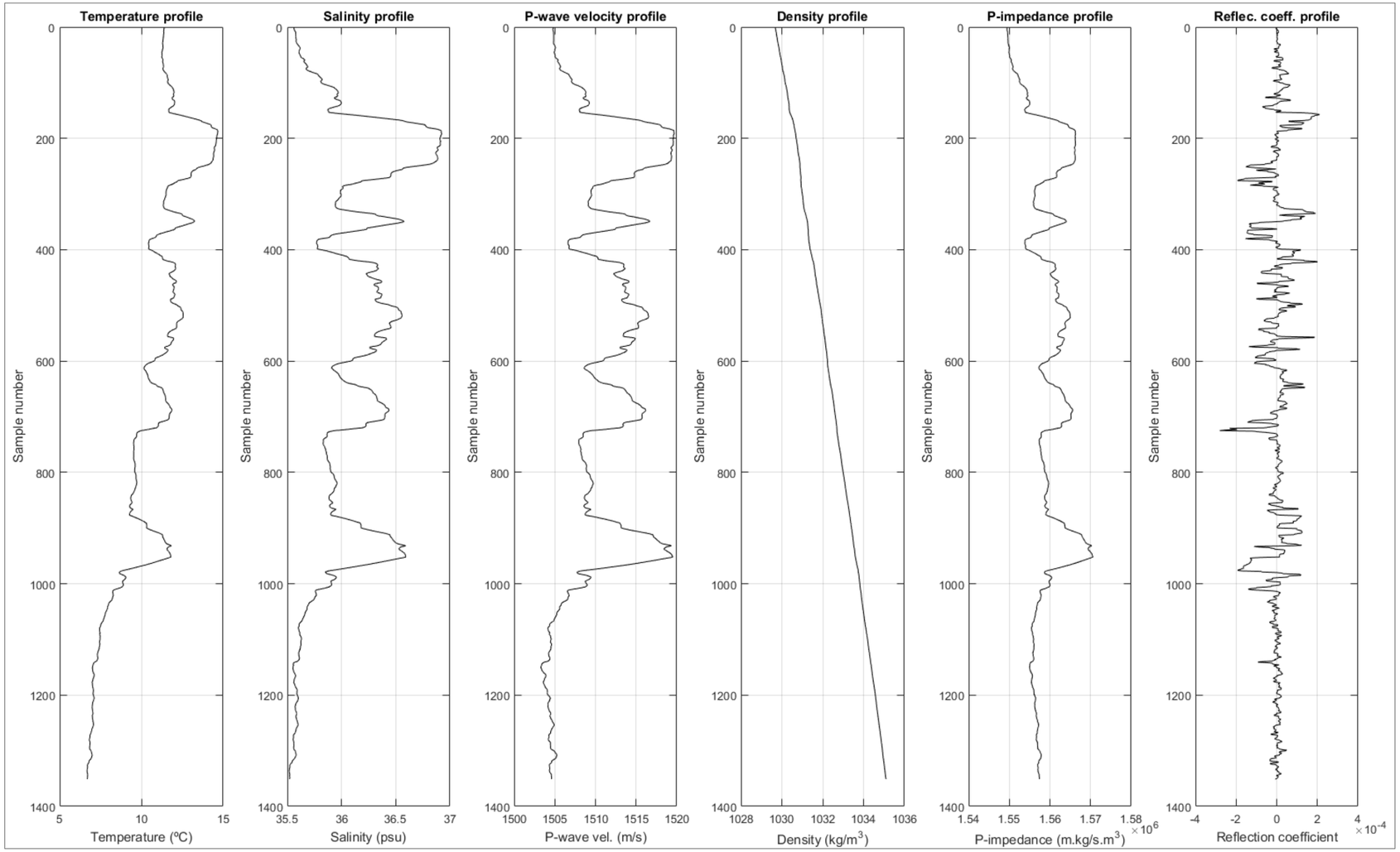
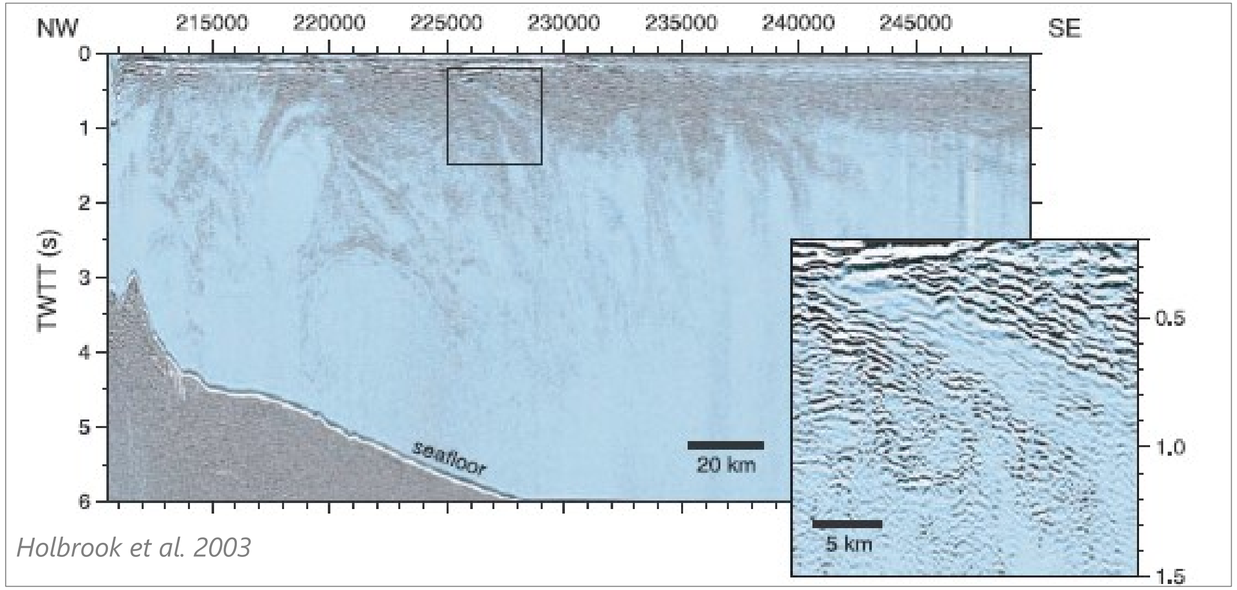


Seismic oceanography (SO)

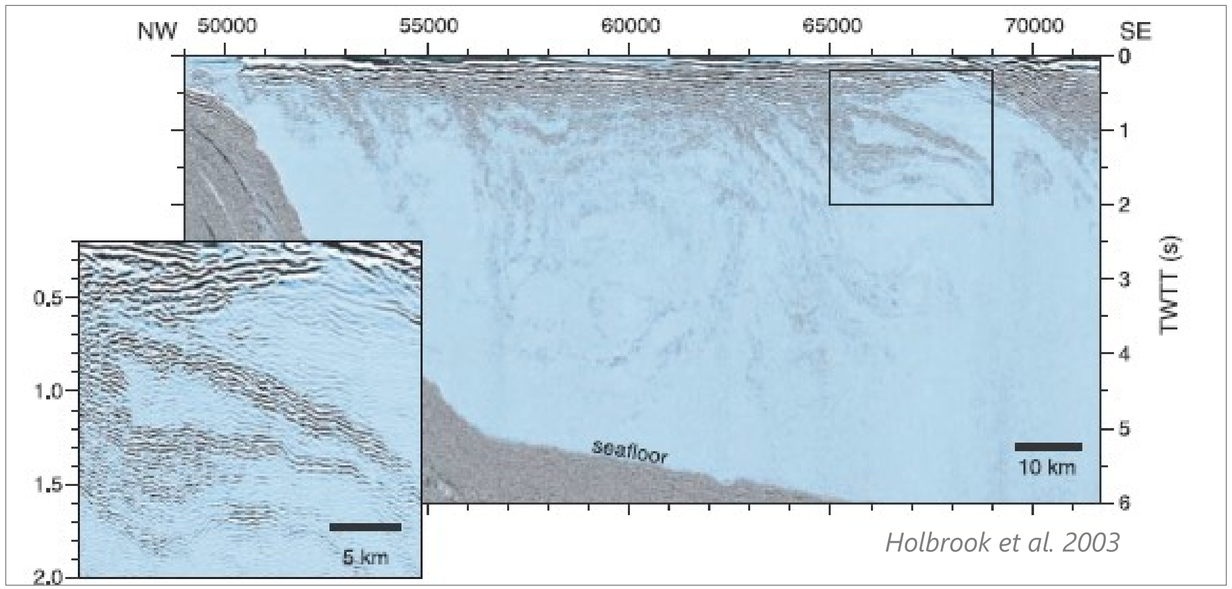


Additional information on synthetic seismic calculation *Ruddick et al. (2009)*

Seismic oceanography (SO)

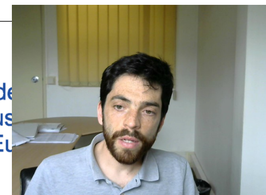


Holbrook et al. 2003

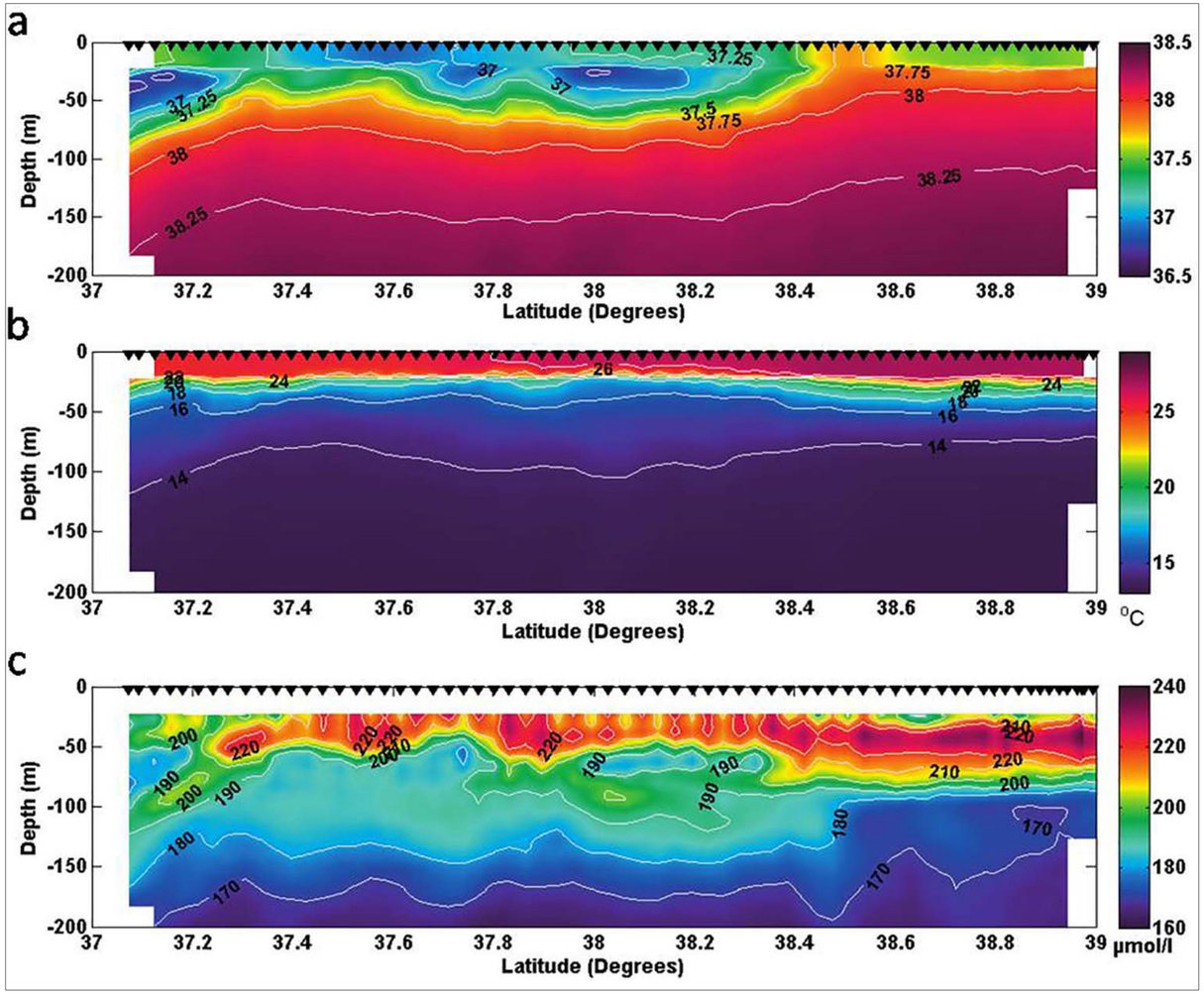


Holbrook et al. 2003

- Seismic reflection sections from the water column
- Imaging of the meso and submesoscales (O (1km))
- Qualitative interpretation of termohaline structure



Ocean models

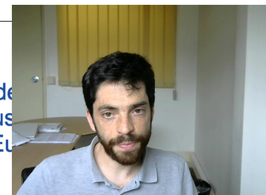


Temperature

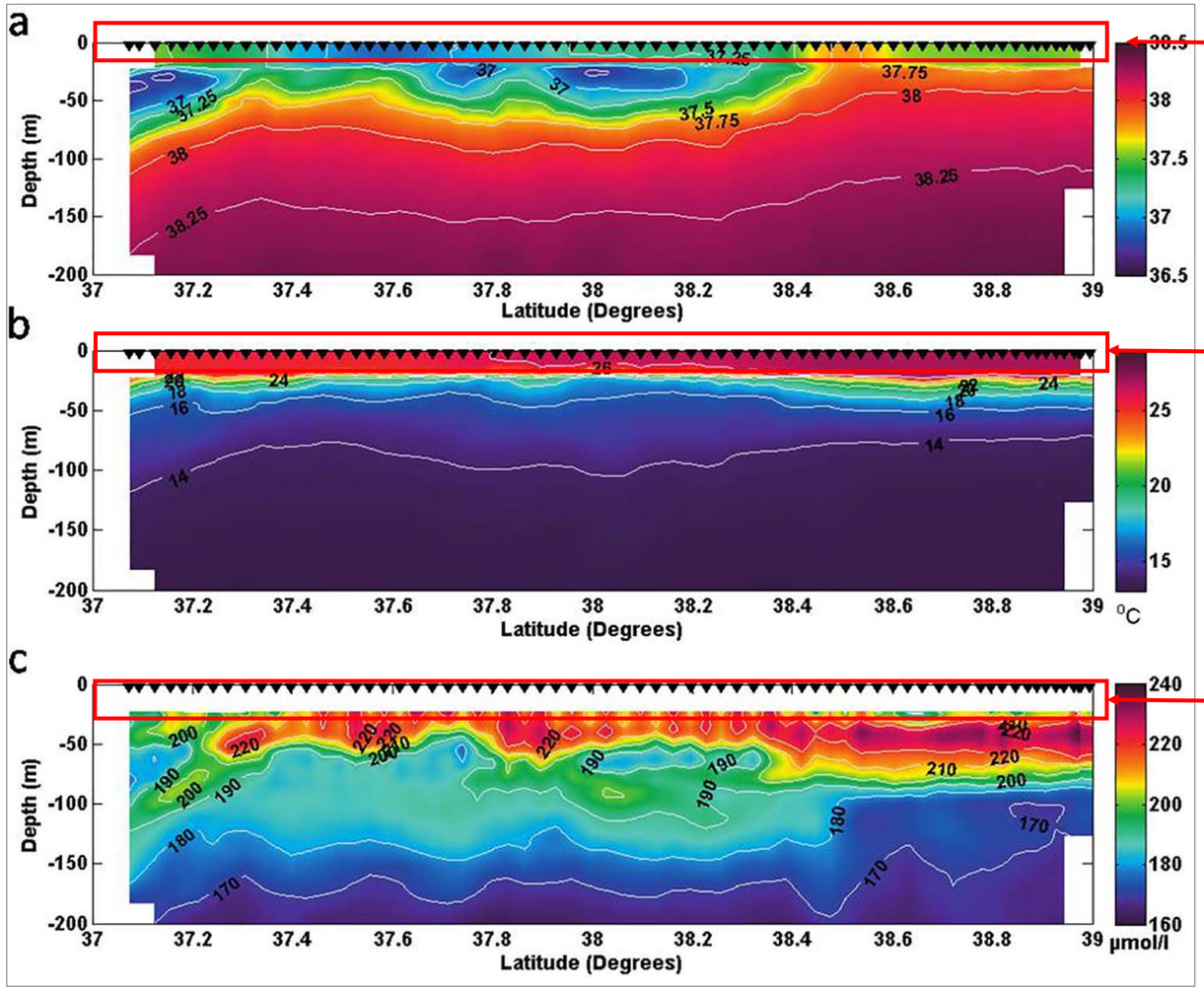
Salinity

O_2 concentration

Aulicino et al. 2018



Ocean models



Direct observations
(experimental data)

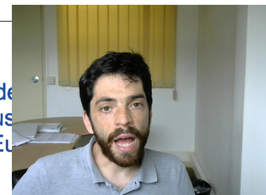
Temperature

Direct observations
(experimental data)

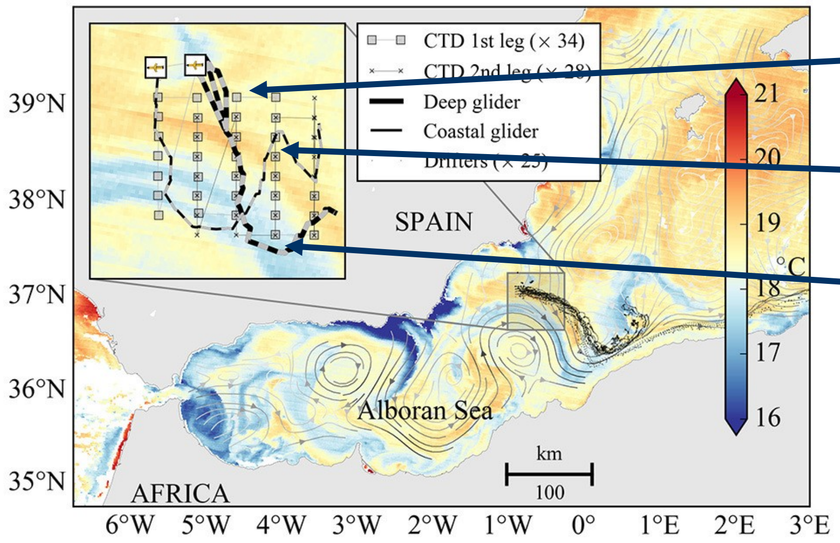
Salinity

Direct observations
(experimental data)

O_2 concentration



Ocean models

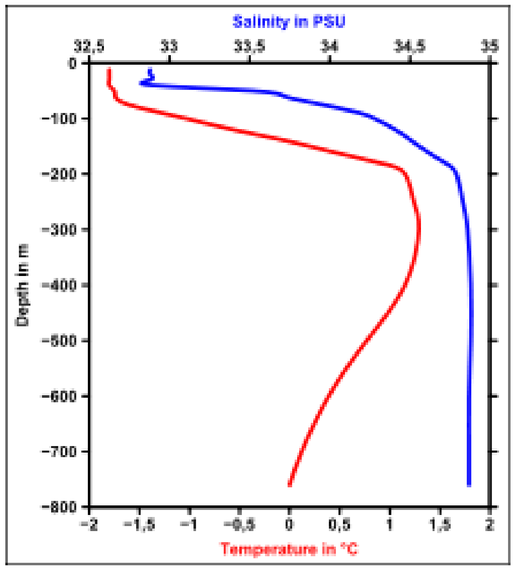


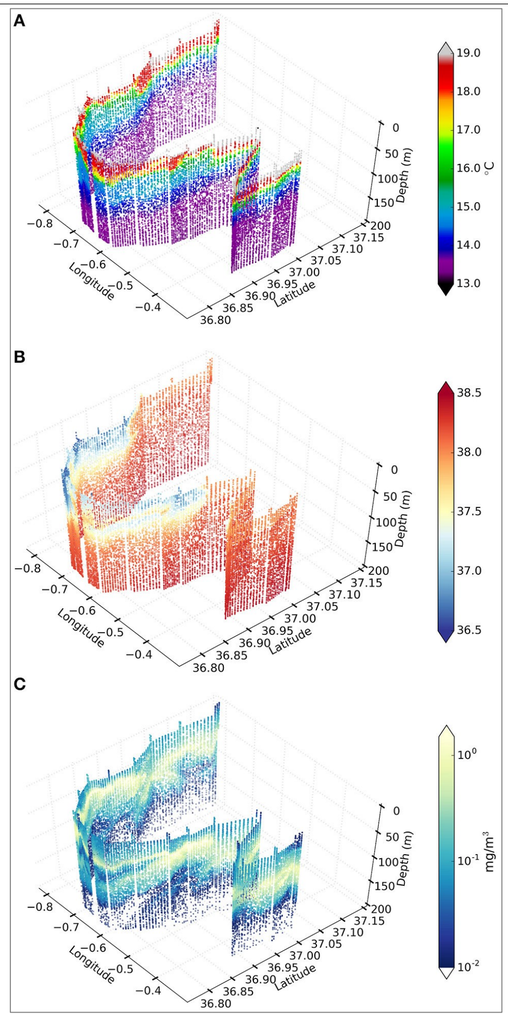
Pascual et al. 2017

Topography maps (Satellite)

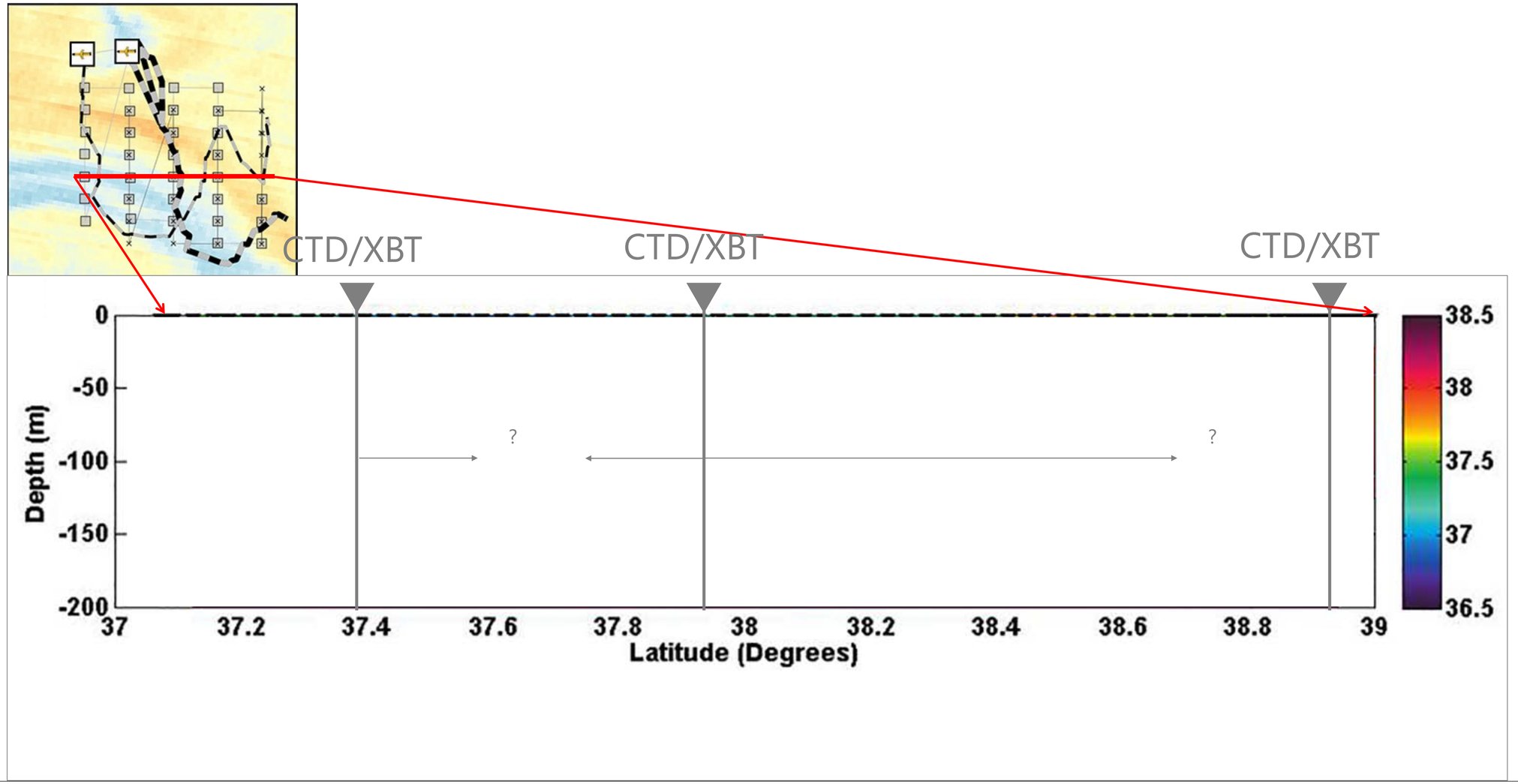
Direct measurements (CTD)

Gliders





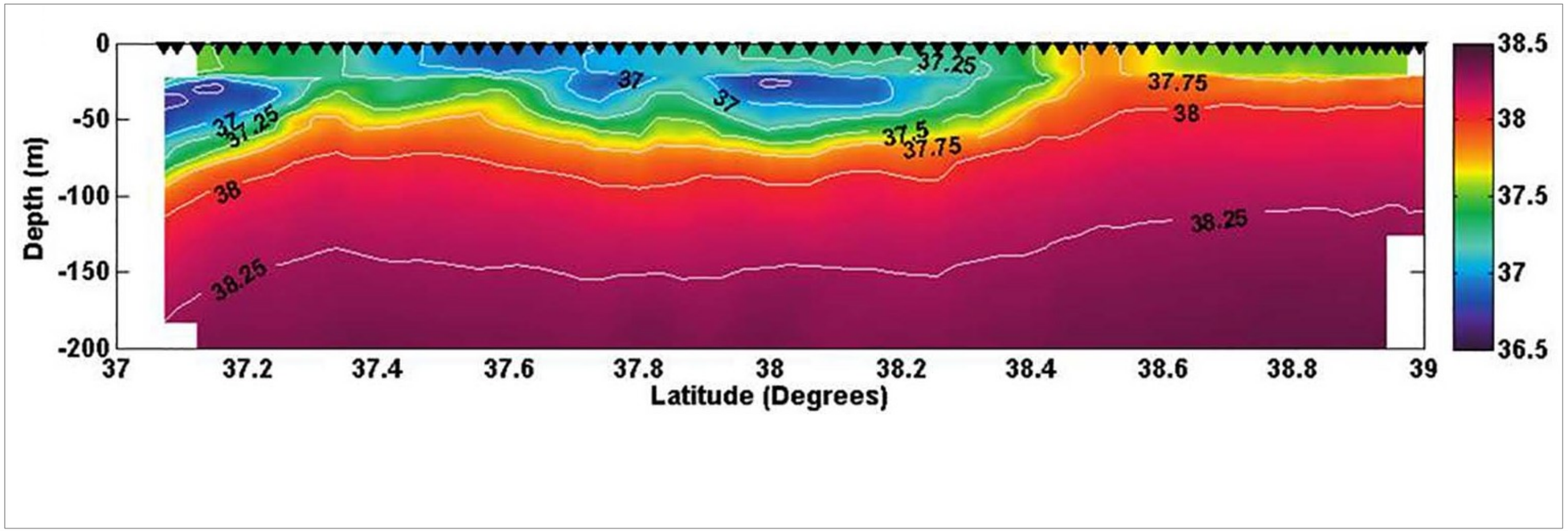
Ocean models



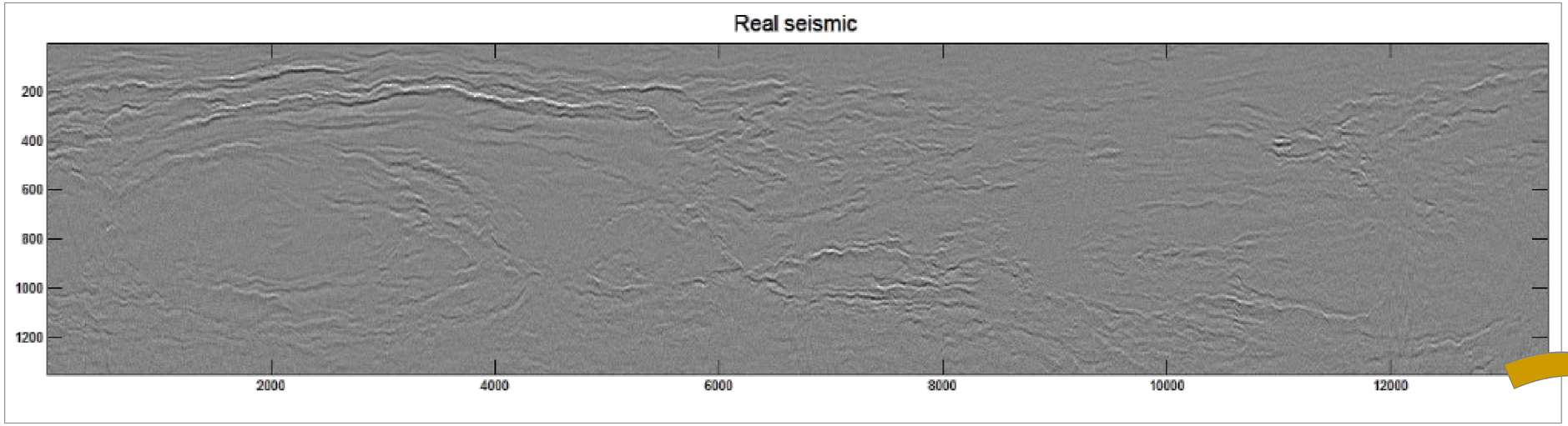
Ocean models

Conventional interpolation approaches (*kriging*)

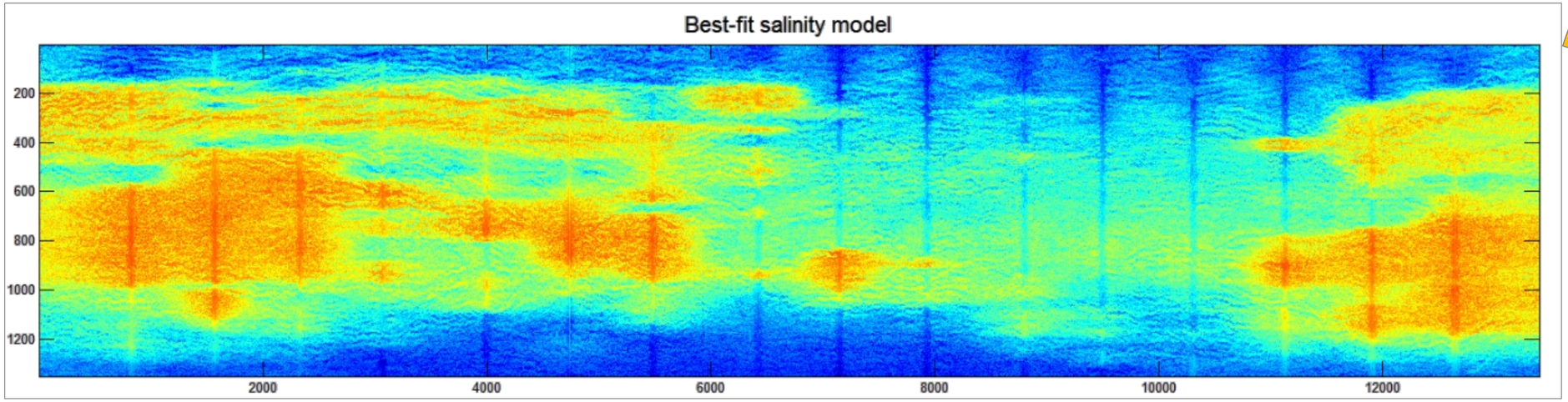
- Smooth representations
- Low spatial resolution
- Highly uncertain
- Depend on assumption about the spatial continuity pattern

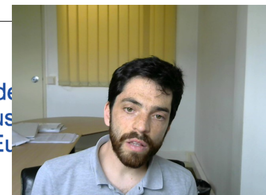


Seismic oceanography inversion



?





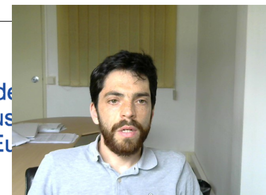
Seismic oceanography inversion

Traditional technique in subsurface modelling and characterization (oil and gas industry)

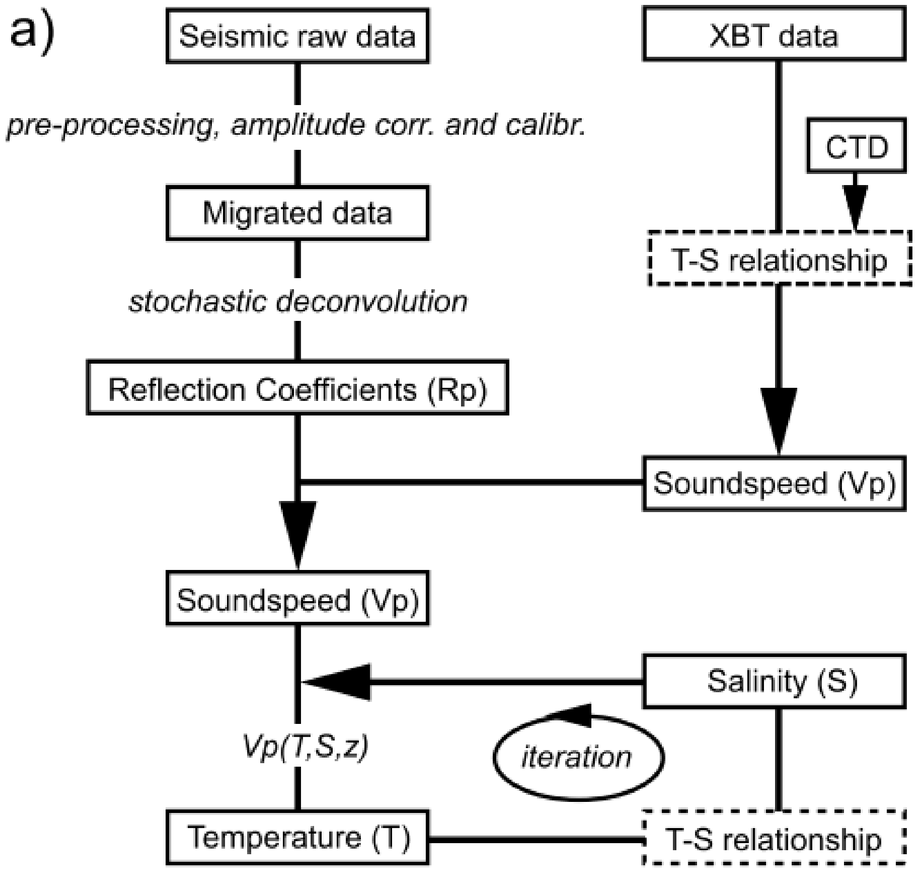
Seismic inverse problems infer the subsurface elastic properties (e.g. density and P-wave and S-wave vel.) from a set of indirect measurements:

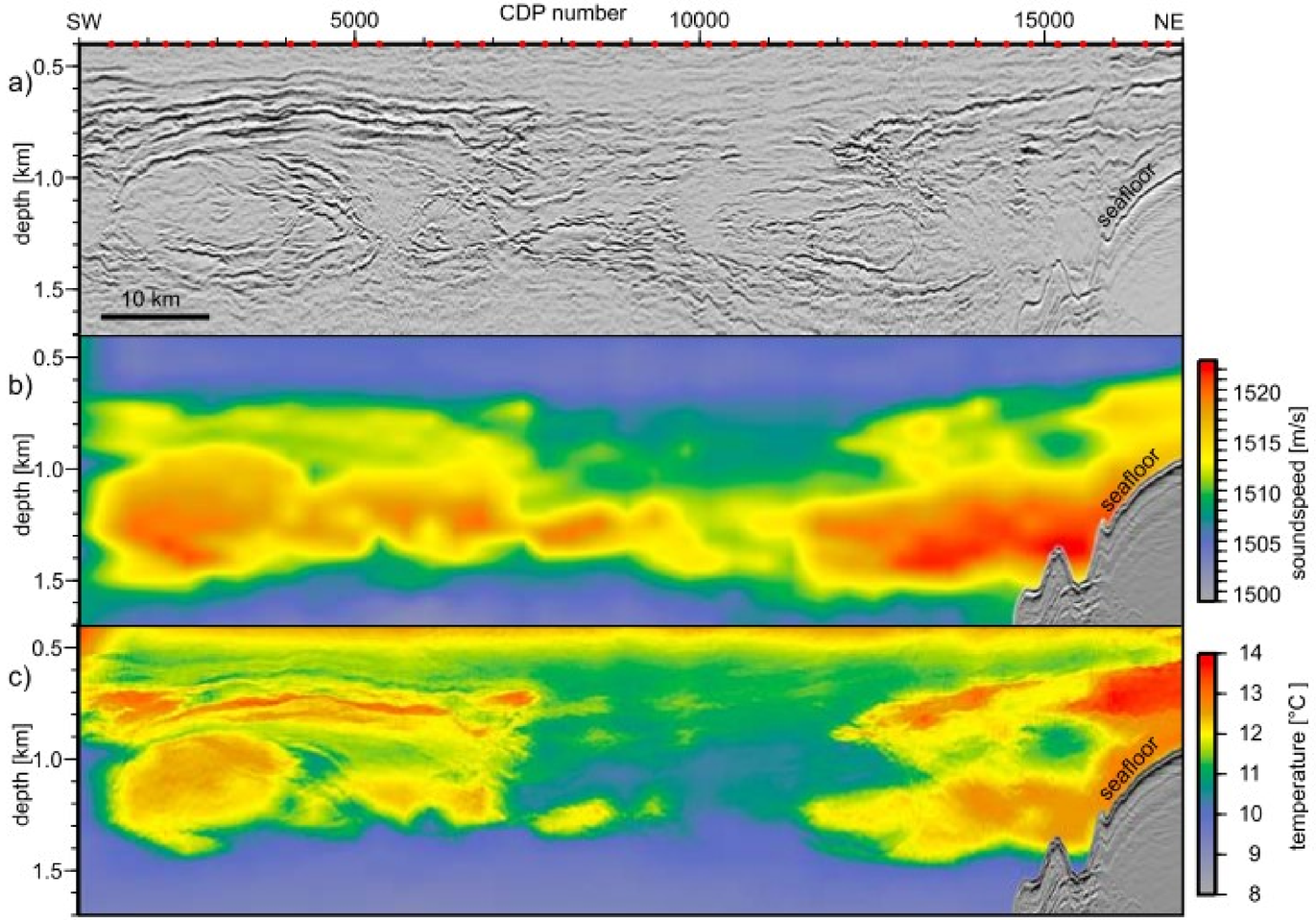
$$\mathbf{m} = F^{-1}(\mathbf{d}_{obs}) + \mathbf{e}$$

Nonlinear, ill-posed with non-unique solution



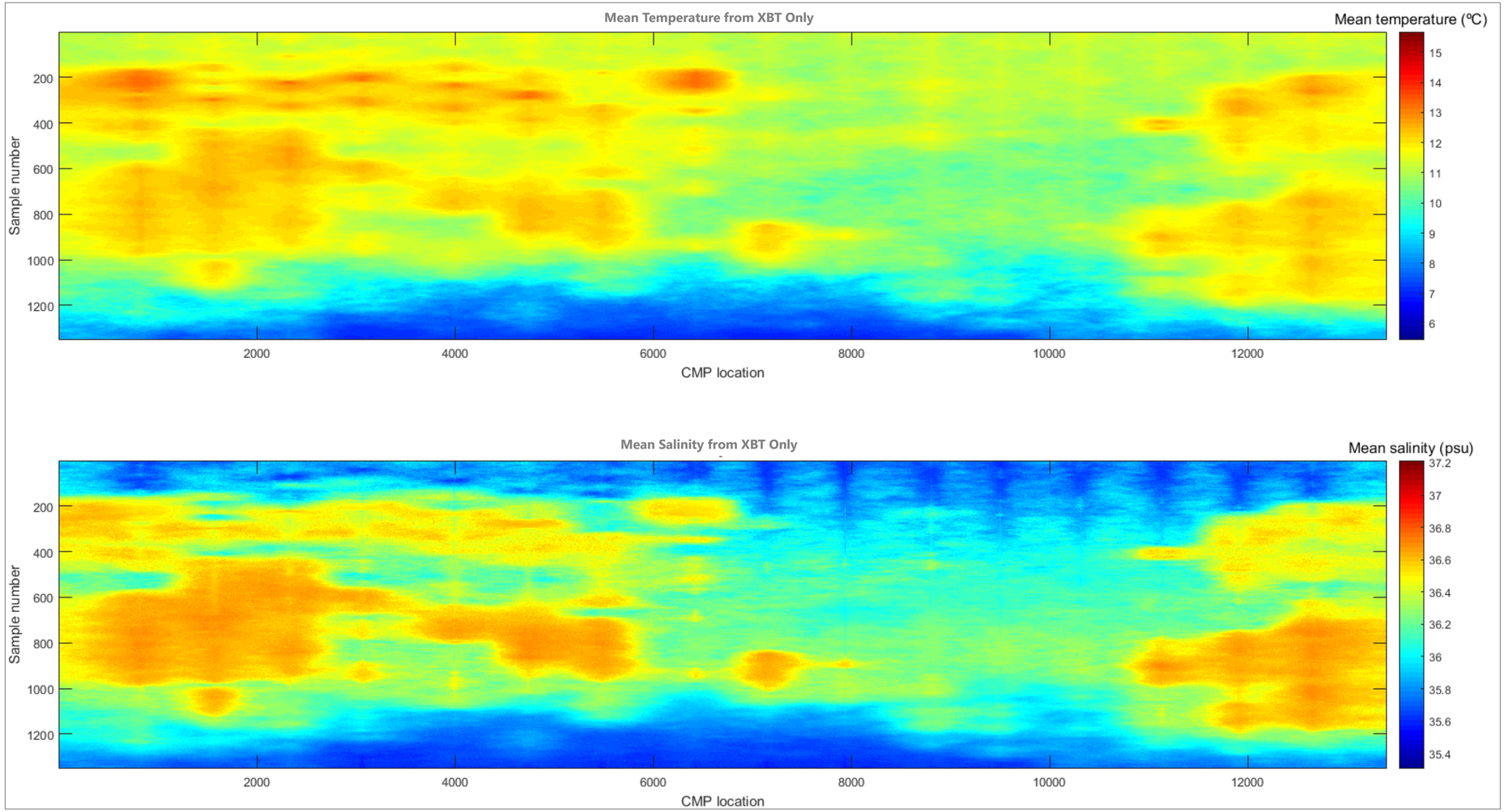
Seismic oceanography inversion



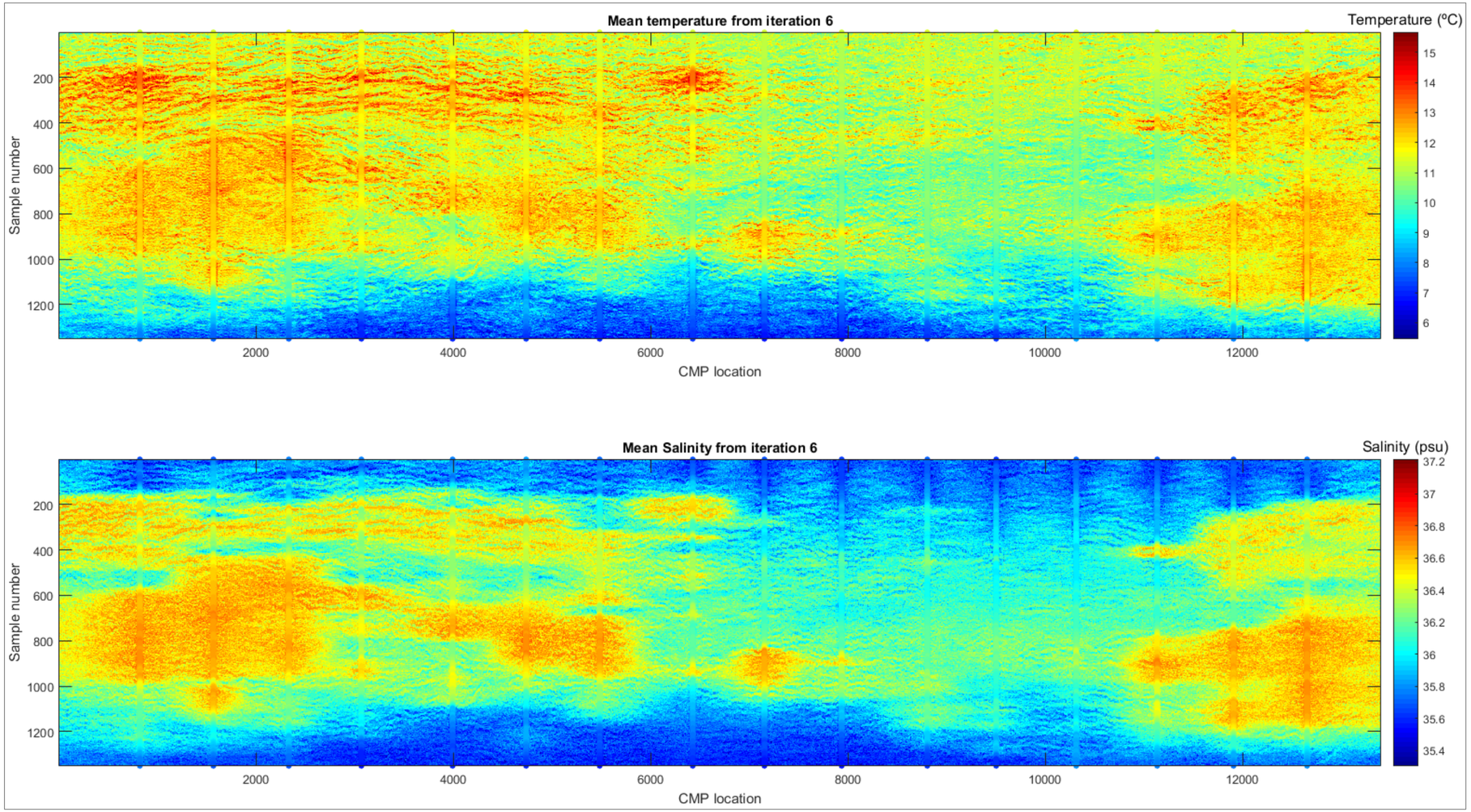


Papenberg et al. 2010

Seismic oceanography inversion

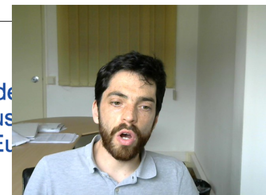


Seismic oceanography inversion

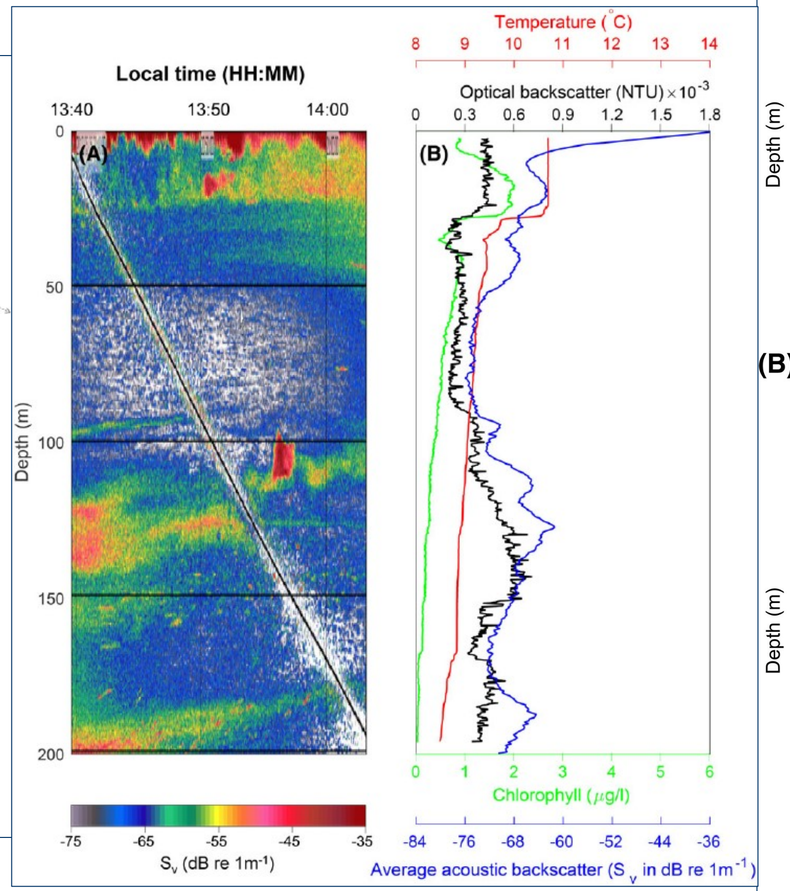


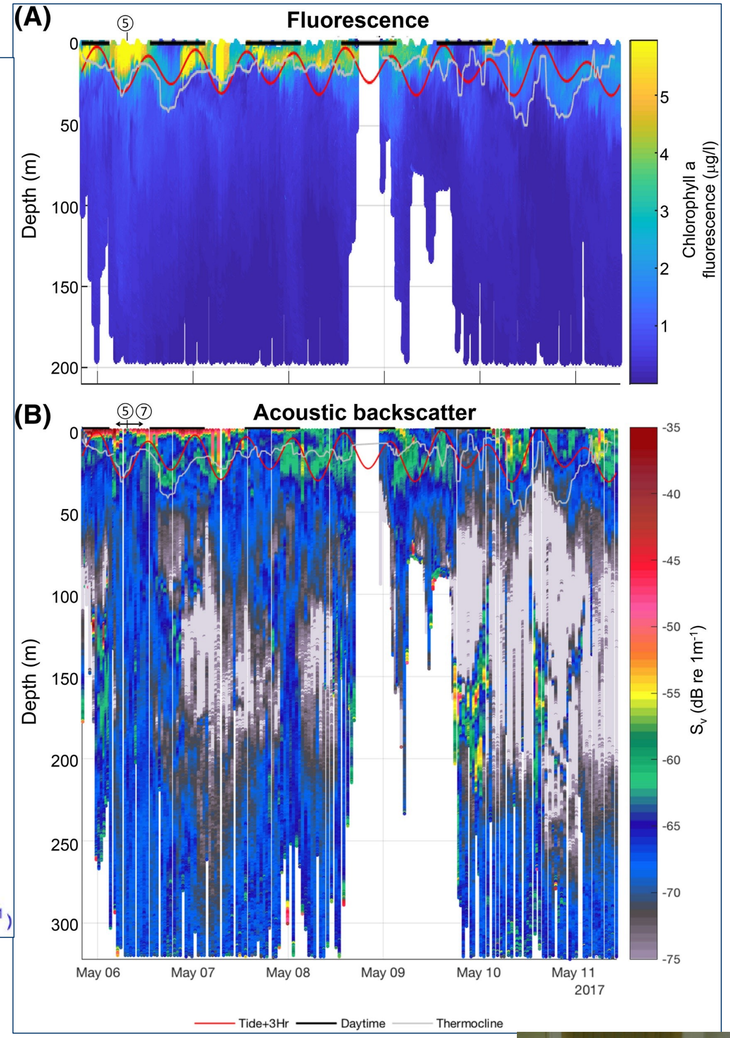
Azevedo et al. 2018

What about the µPs?

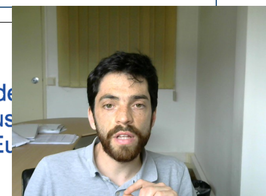


Ultra-high resolution acoustic data





Benoit-Bird et al. 2018

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