Università di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE SM62

Percorso Esplorazione Geologica

Anno accademico 2023 - 2024

Geologia Marina 953SM

Parte IV

Modulo 4.3
Indicatori di movimento di fluidi: chimneys, pockmarks, vents…

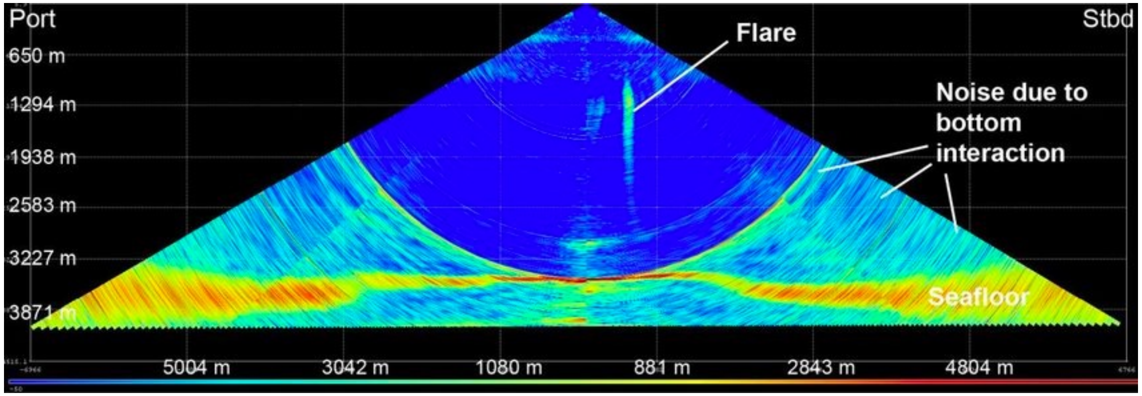
Docente
A. Camerlenghi

Outline

Review of main mechanisms of fluid flow:

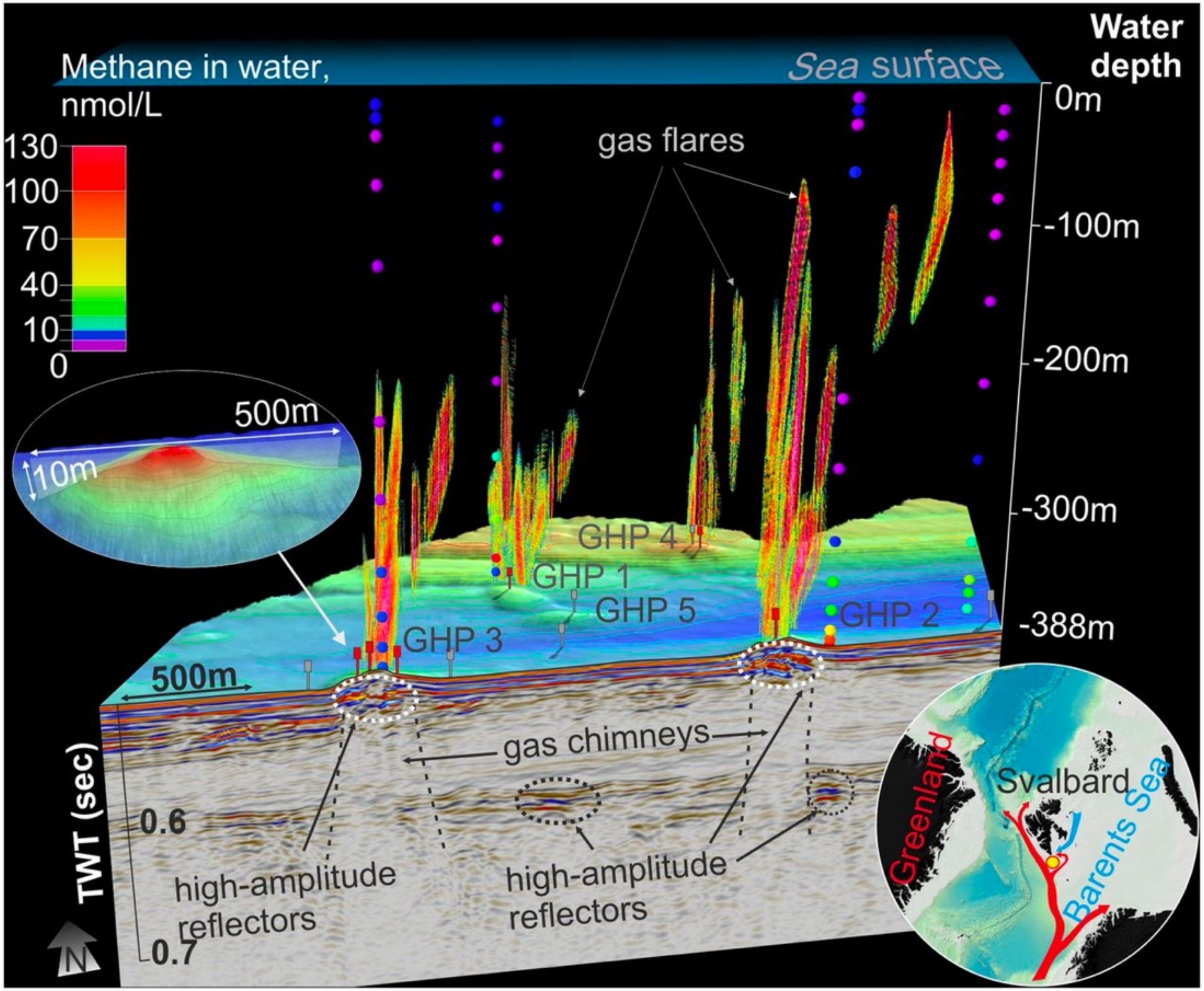
- Mud diapirs and mud volcanoes
- **Gas chimneys**
- **Pockmarks**
- **Seafloor vents in general**
- **Polygonal fault systems**
- **Diagenetic fronts**
- Gas hydrates

The data from the multibeam sonar can be used to investigate the water column

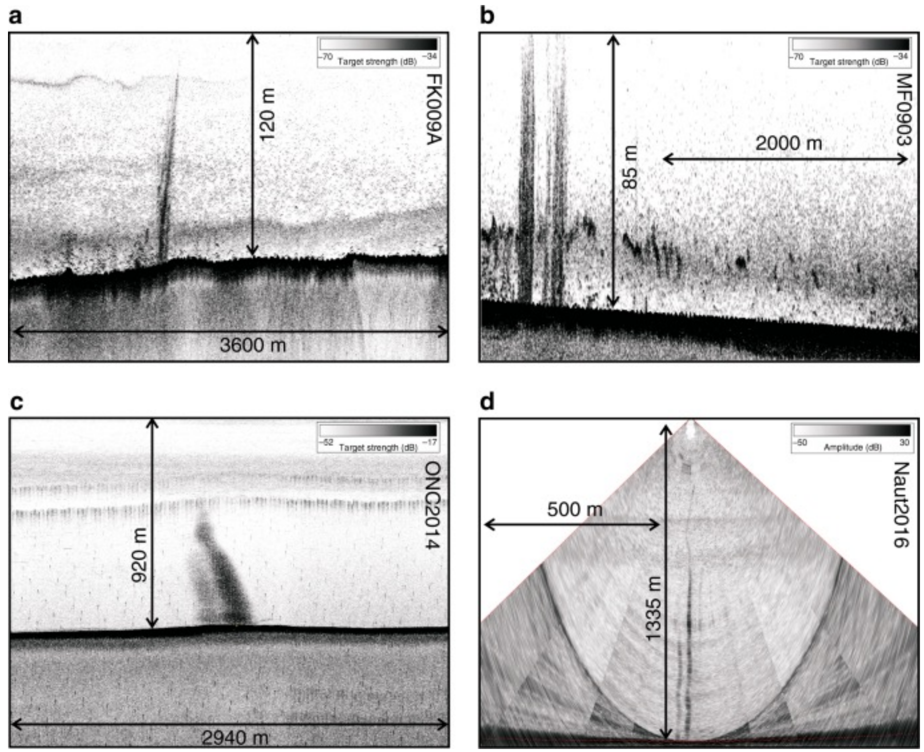


Screenshot of a multibeam swath showing a hydroacoustic flare that is caused by a gas plume of rising gas bubbles.

Sahling et al., 2016. Biogeosciences DOI:10.5194/bg-2016-101



Serov et al., 2016 PNAS https://doi.org/10.1073/pnas.1619288114



Riedel et al., 2018. Nat Communications. https://doi.org/10.1038/s41467-018-05736-x

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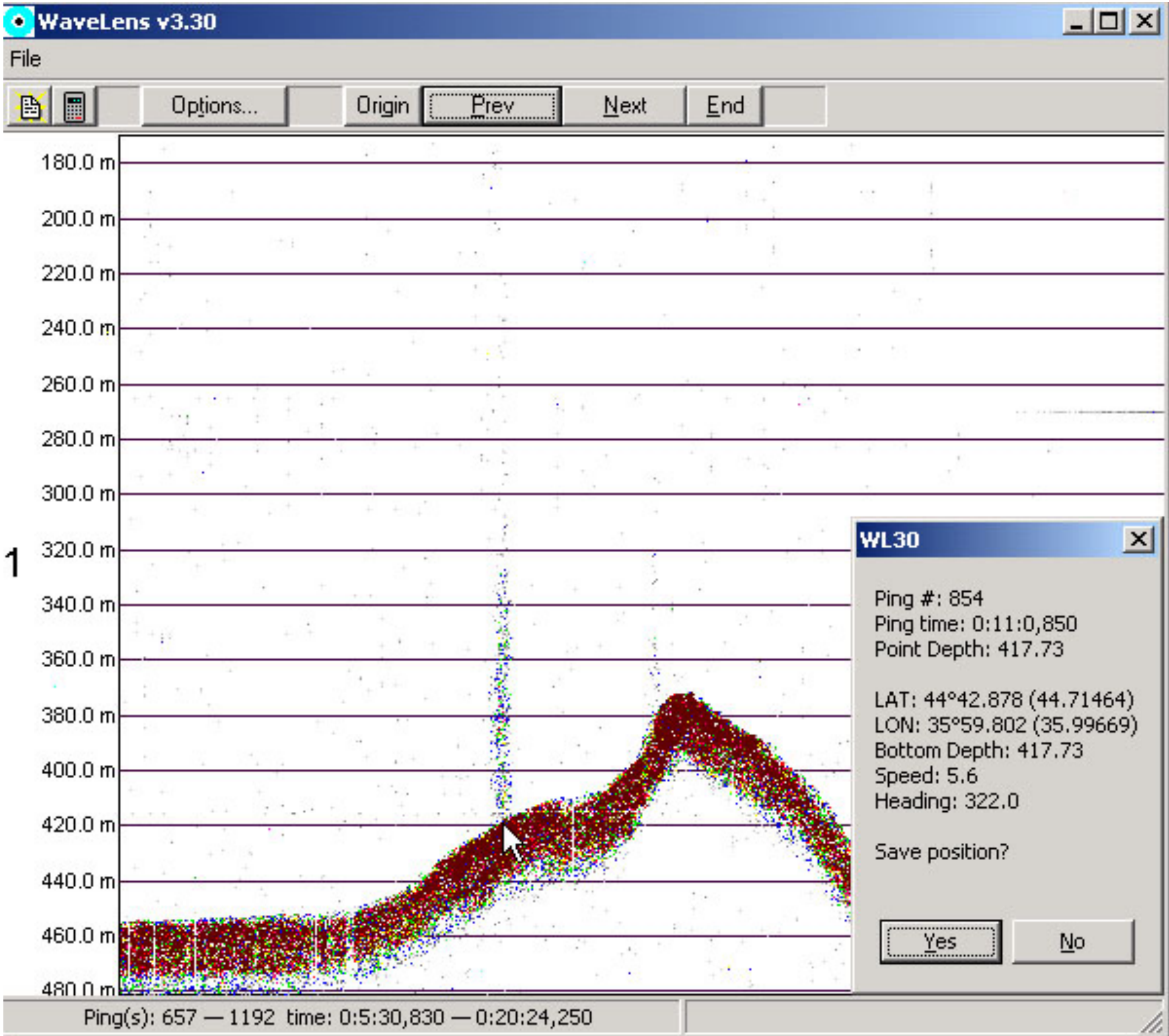
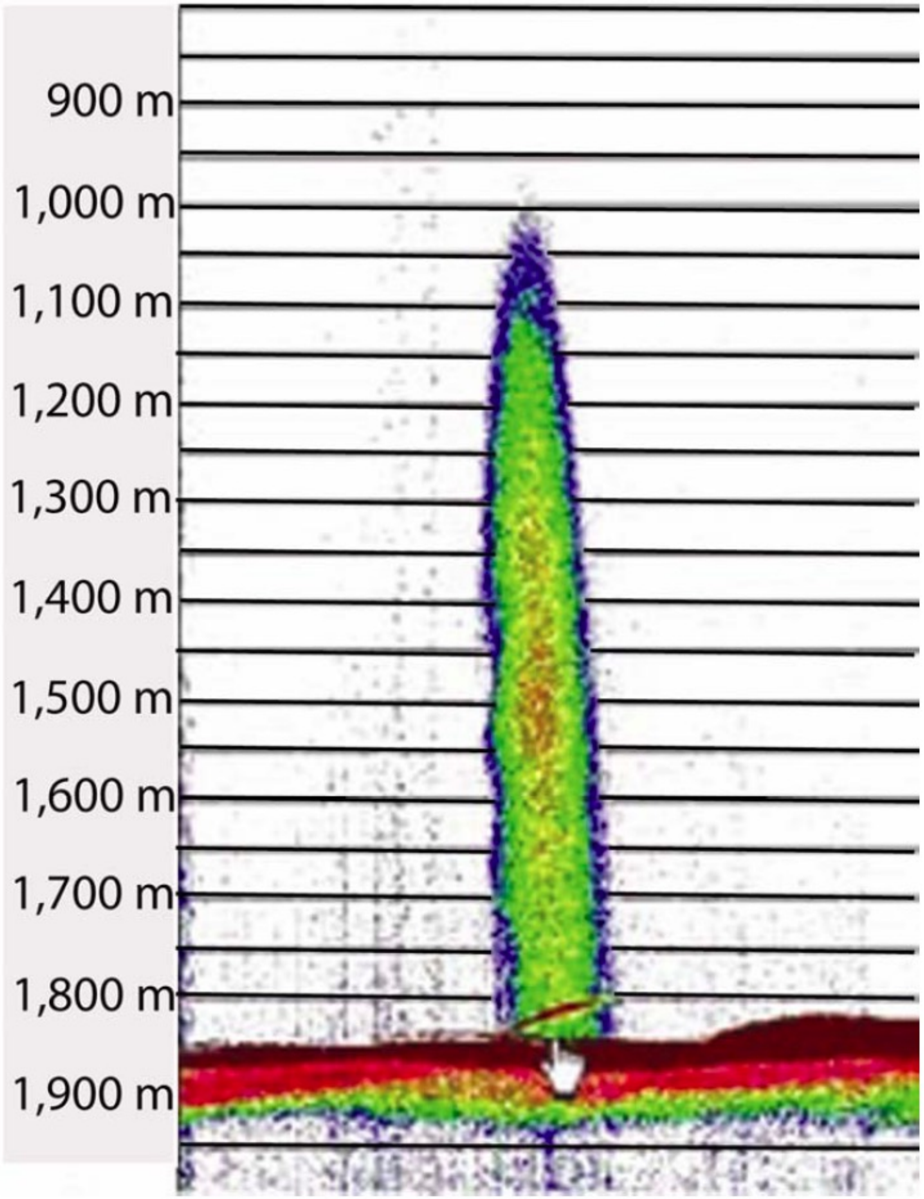
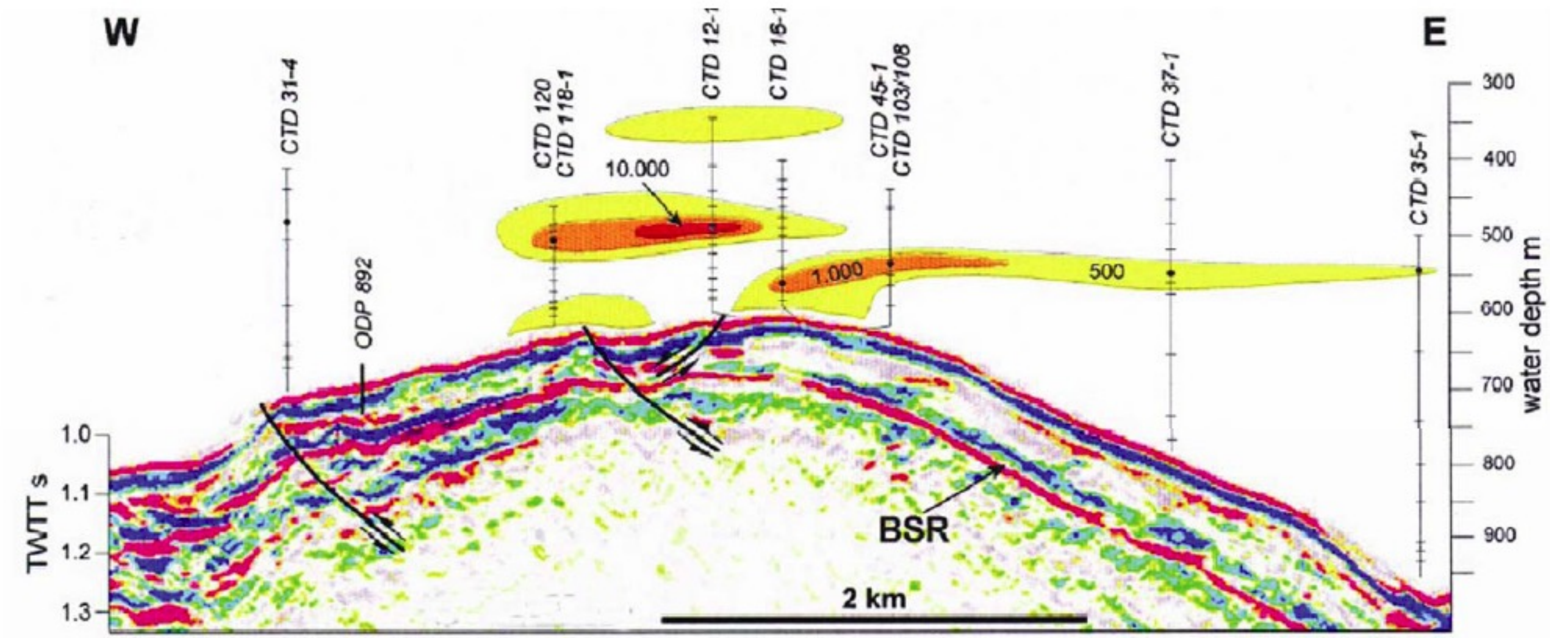


G. Bohrmann, Initial results from M52/1 **MARGASCH**

Judd and Hovland, 2007. *Seabed Fluid Flow.*

Parametric echo sounder image of a 'flare' (intense water column targetcaused by vigorous gas seepage) rising 850 m from the seabed in the NW BlackSea.





Methane concentration in the seawater from methane sensors on CTD casts

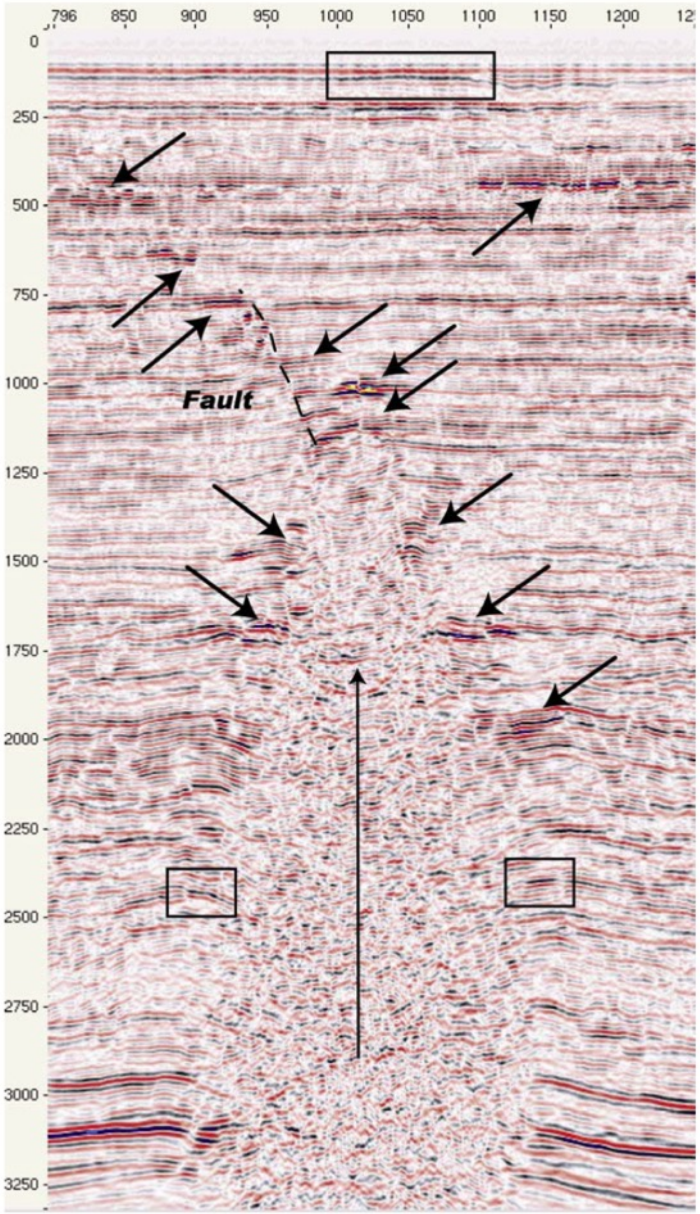
Gas chimneys are vertical zones in some way or other have been 'disturbed' by previous or on-going gas migration.

Exactly what has caused this acoustically-detecteddisturbance is still unknown, although it is believed thatsmall (metre-sized) parcels of trapped gas and slightlydisplaced sediments may be involved. In many cases, rather than a distinct chimney, gas may be present as an amorphous cloud.

Gas accumulations provoke a high acoustic impedance contrast >>>>High reflectivity.

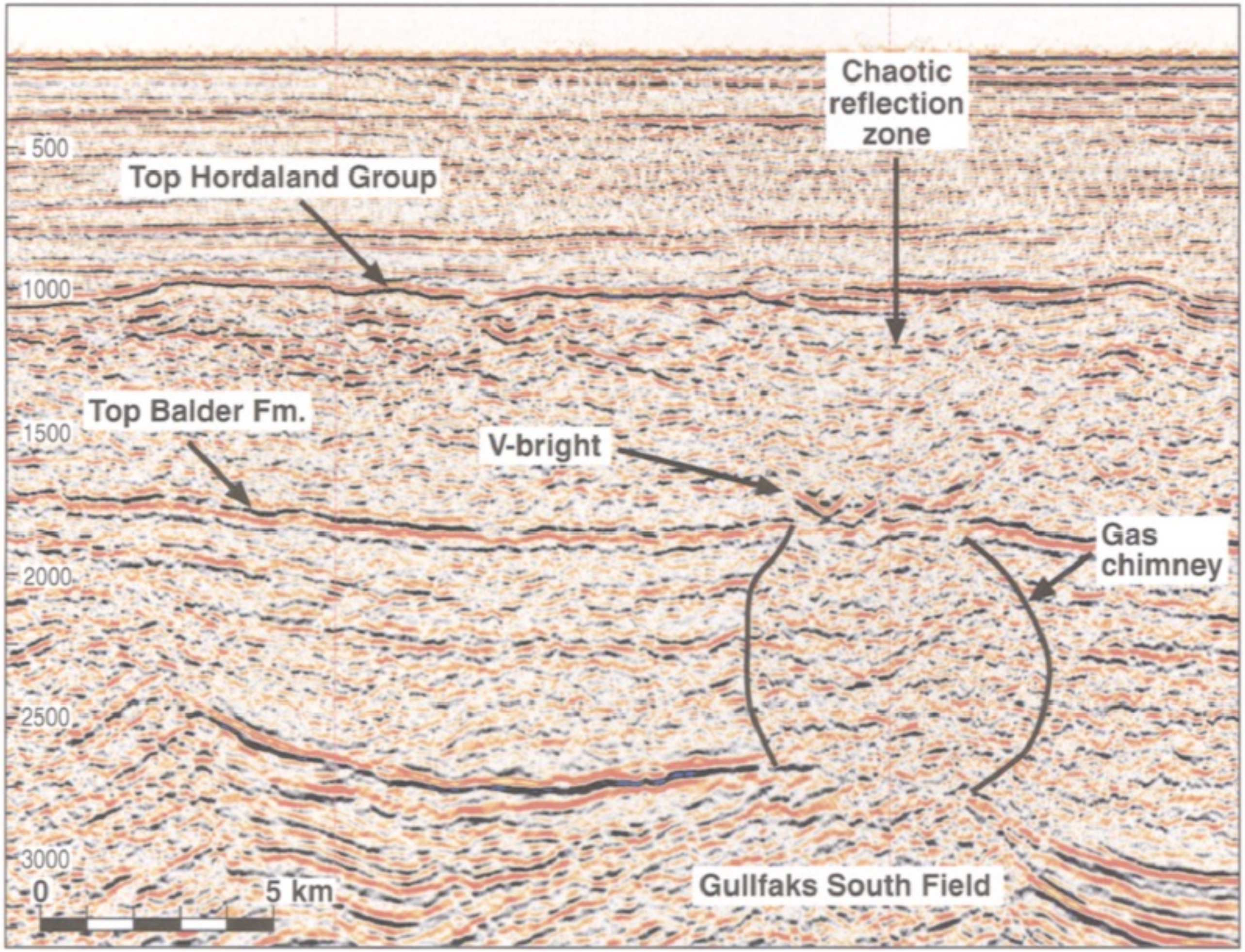
- **Enhanced seismic reflections**
- **Bright spots**
- **Flat spots**
- **Acoustic blanking**
- **Columnar disturbances, gas chimneys, pipes**
- **BSR (in case of gas hydrates)**

Judd and Hovland, 2007. *Seabed Fluid Flow.*

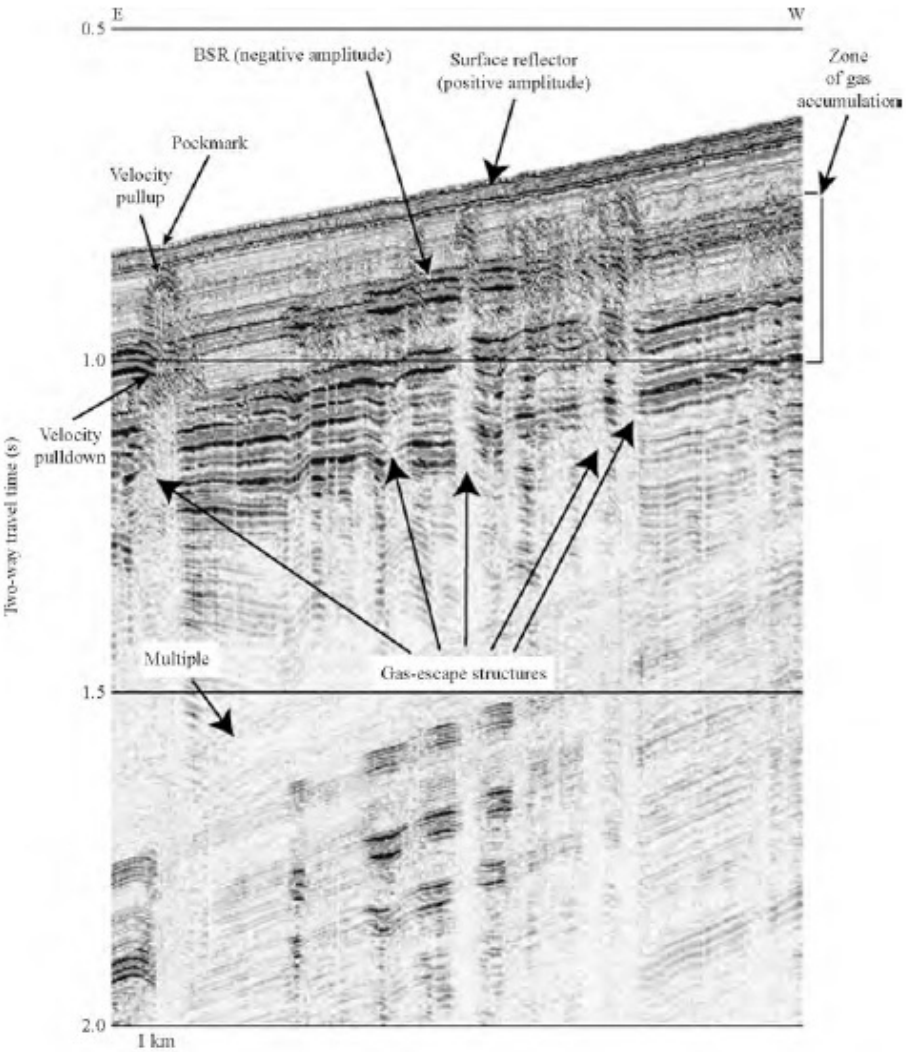


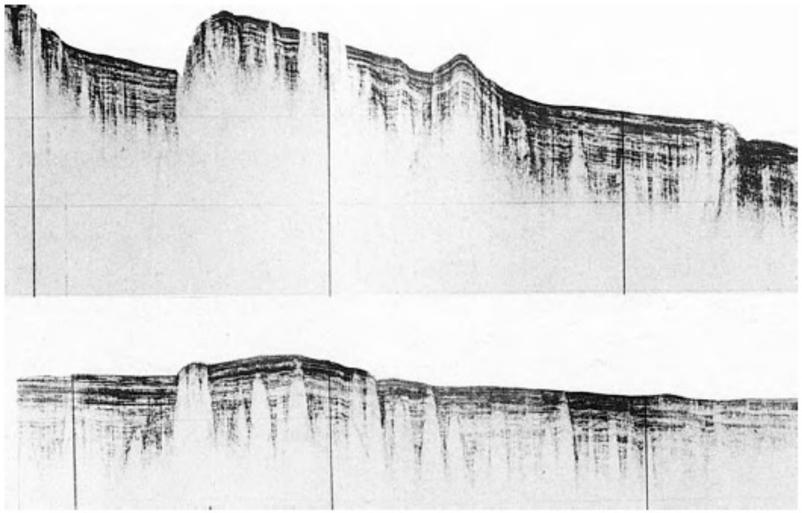
Seismic section across the Tommeliten Delta structure, a saltpiercement diapir. The noisy zone is interpreted as a gas chimney through whichgas rises vertically (as indicated by the large arrow). Some gas escapes laterally toproduce brightening of adjacent reflectors, and reducing the acoustic velocity (*vp*) toproduce 'pull down' (examples are in the rectangles).

Judd & Hovland 2007

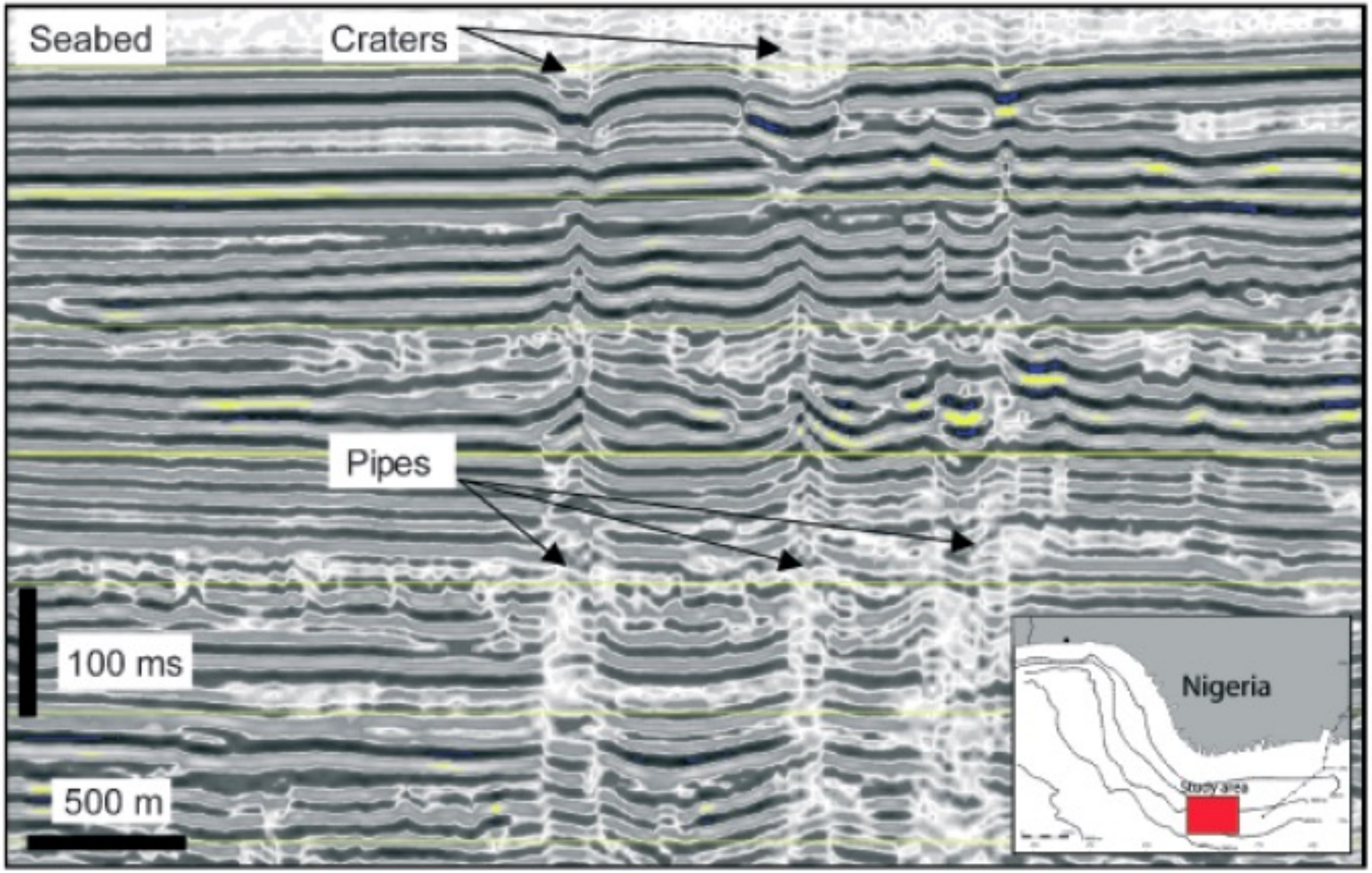


Løseth et al., 2003

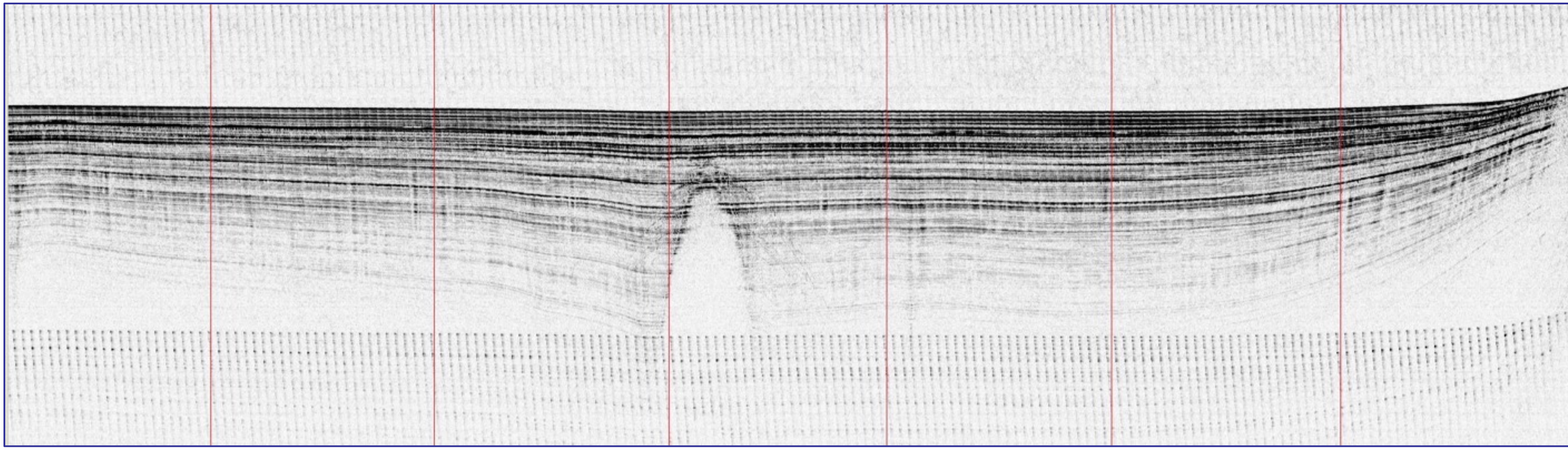


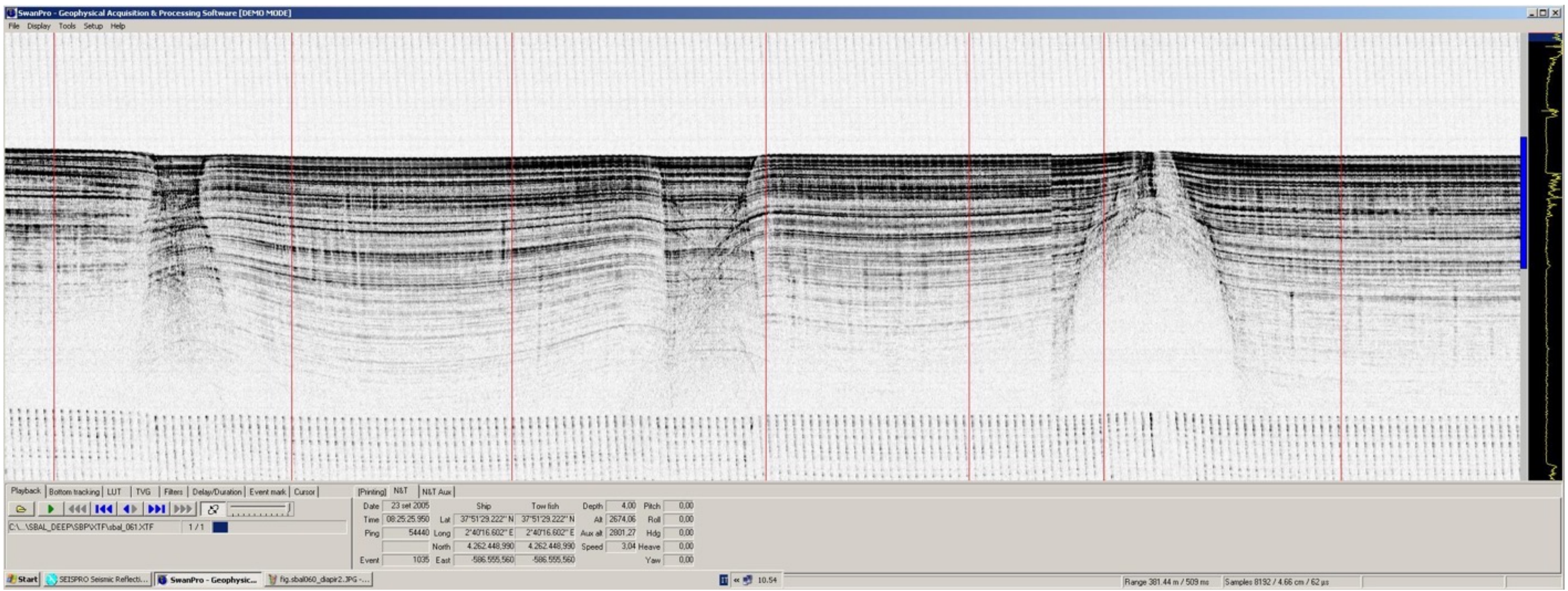


Judd & Hovland 2007



Cartwright and Huuse, Basin Research (2005) 17, 1–20,





Cruise SBALDEEP - Camerlenghi et al., submitted

Pockmarks are shallow seabed depressions, typically several tens of metres across and a few metres deep.

Generally, they are formed in soft, fine-grained seabed sediments by the escape of fluids (gas or water, but mainly methane) into the water column.

Judd and Hovland, 2007. ***Seabed Fluid Flow.***

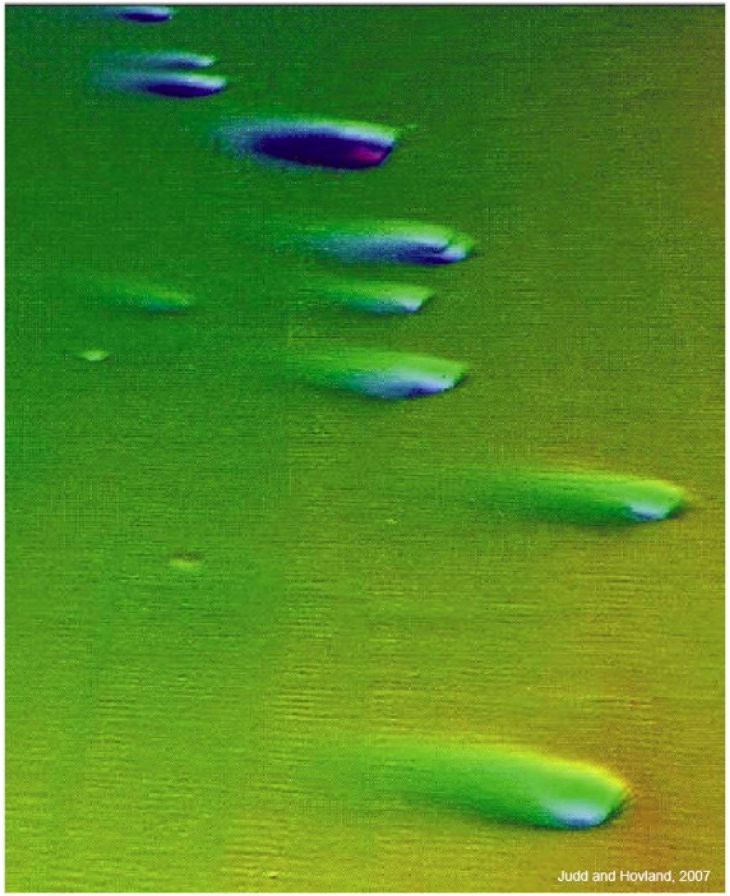


Figure 2.6: Assymetric pockmarks, Witch Ground Basin, UK North Sea. Multi-beam echo sounder image [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]

Judd and Hovland, 2007. ***Seabed Fluid Flow.***

Figure 2.3: Typical North Sea pockmarks, Witch Ground Basin, UK North Sea. Multi-beam echo sounder image [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]

Judd & Hovland 2007

Judd and Hovland, 2007. ***Seabed Fluid Flow.***

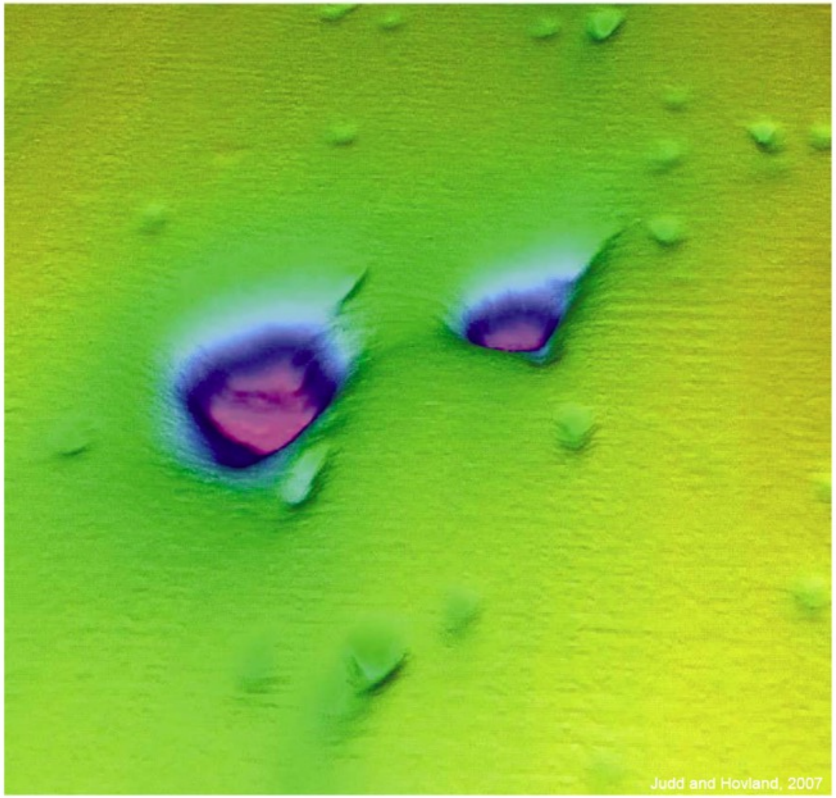


Figure 2.40: MBES image of the *Scanner* pockmark, Block UK15/25, North Sea. [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]

Judd and Hovland, 2007. ***Seabed Fluid Flow.***

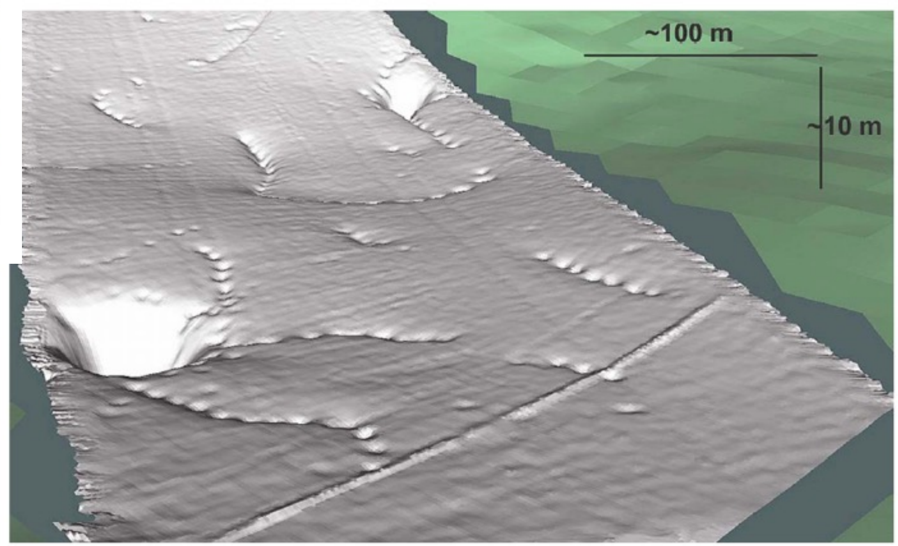


Figure 2.8: MBES image of pockmark strings in the Norwegian Sea. These strings have no preferred orientation, and some lead to (or from) large standard pockmarks. The 26 inch Haltenpipe pipeline is visible on the lower part of the image.

Judd & Hovland 2007

Judd and Hovland, 2007. *Seabed Fluid Flow.*

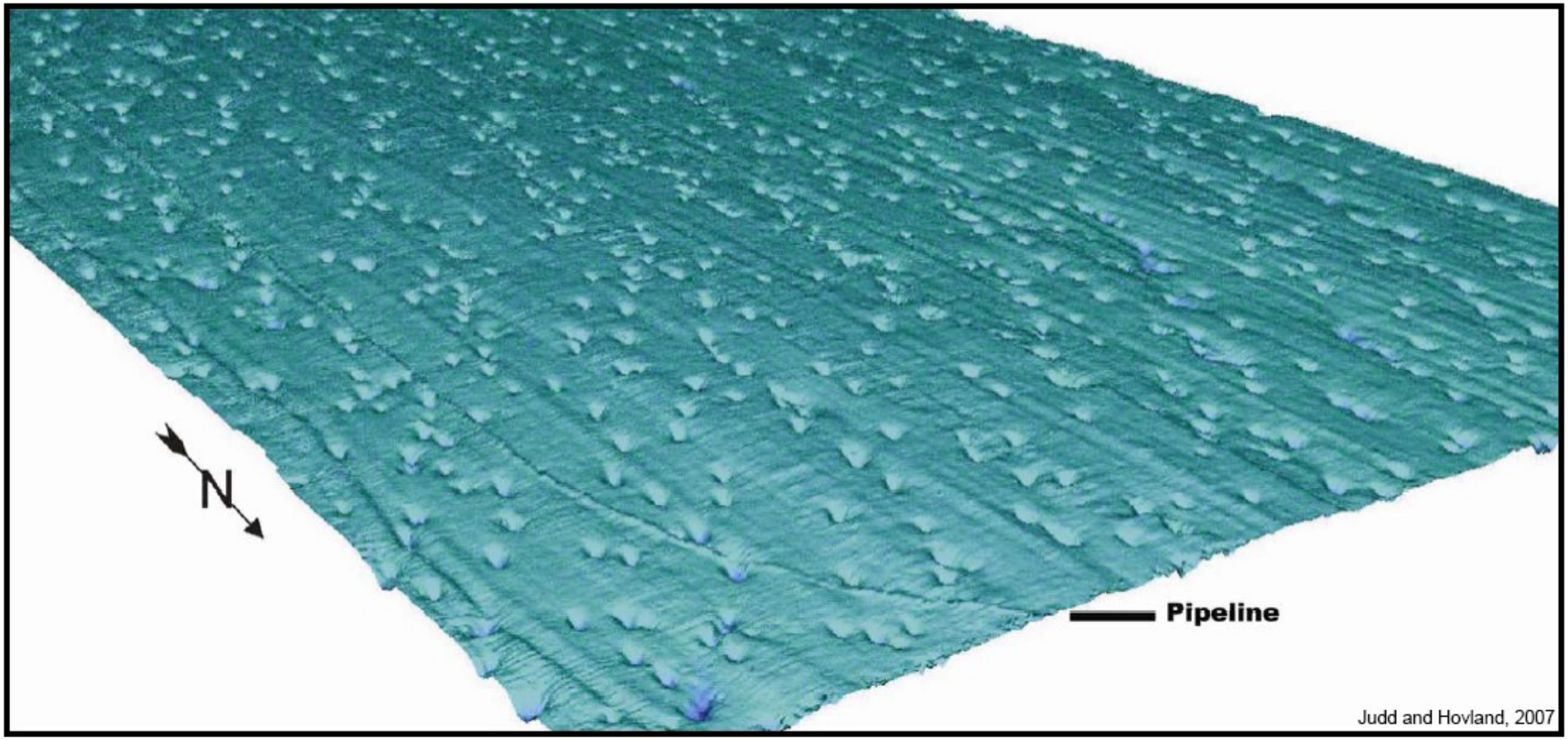


Figure 2.16: Pockmarks in the northern part of the South Fladen Pockmark Study Area; MBES survey, 2001. The pipeline (Scott-Forties Unity pipeline; 24 inch, 61 cm, diameter) gives an idea of the scale. [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]

Judd & Hovland 2007

Judd and Hovland, 2007. *Seabed Fluid Flow.*

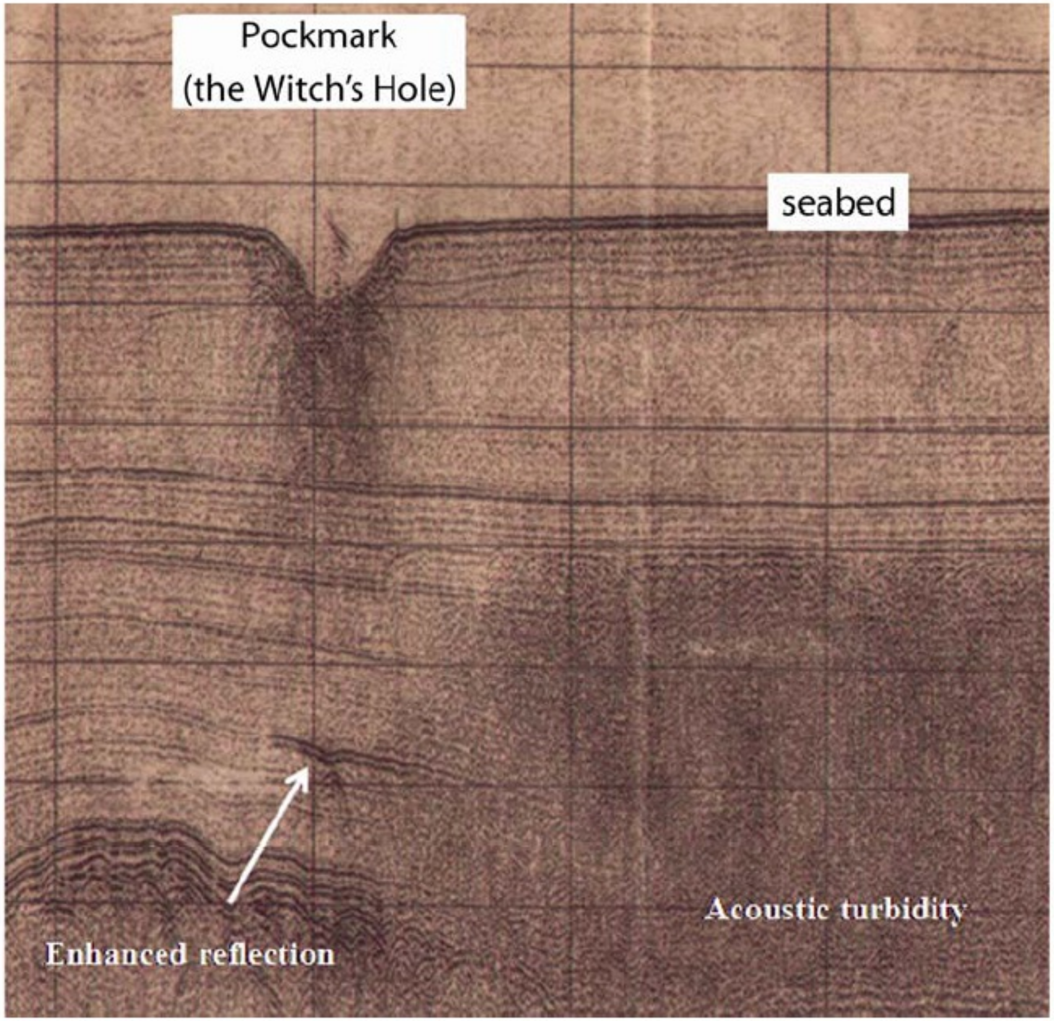


Figure 2.19: Boomer profile across the Witch's Hole, an unusual pockmark in the South Fladen area. [Reproduced by permission of the British Geological Survey. © NERC. All rights reserved. IPR/67-34C.]

Judd and Hovland, 2007. ***Seabed Fluid Flow.***

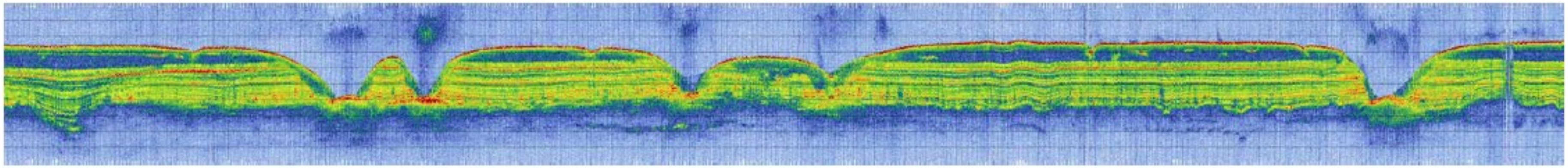
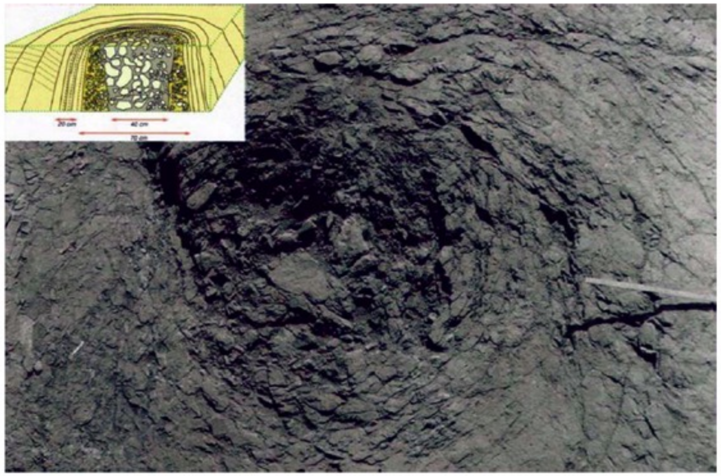


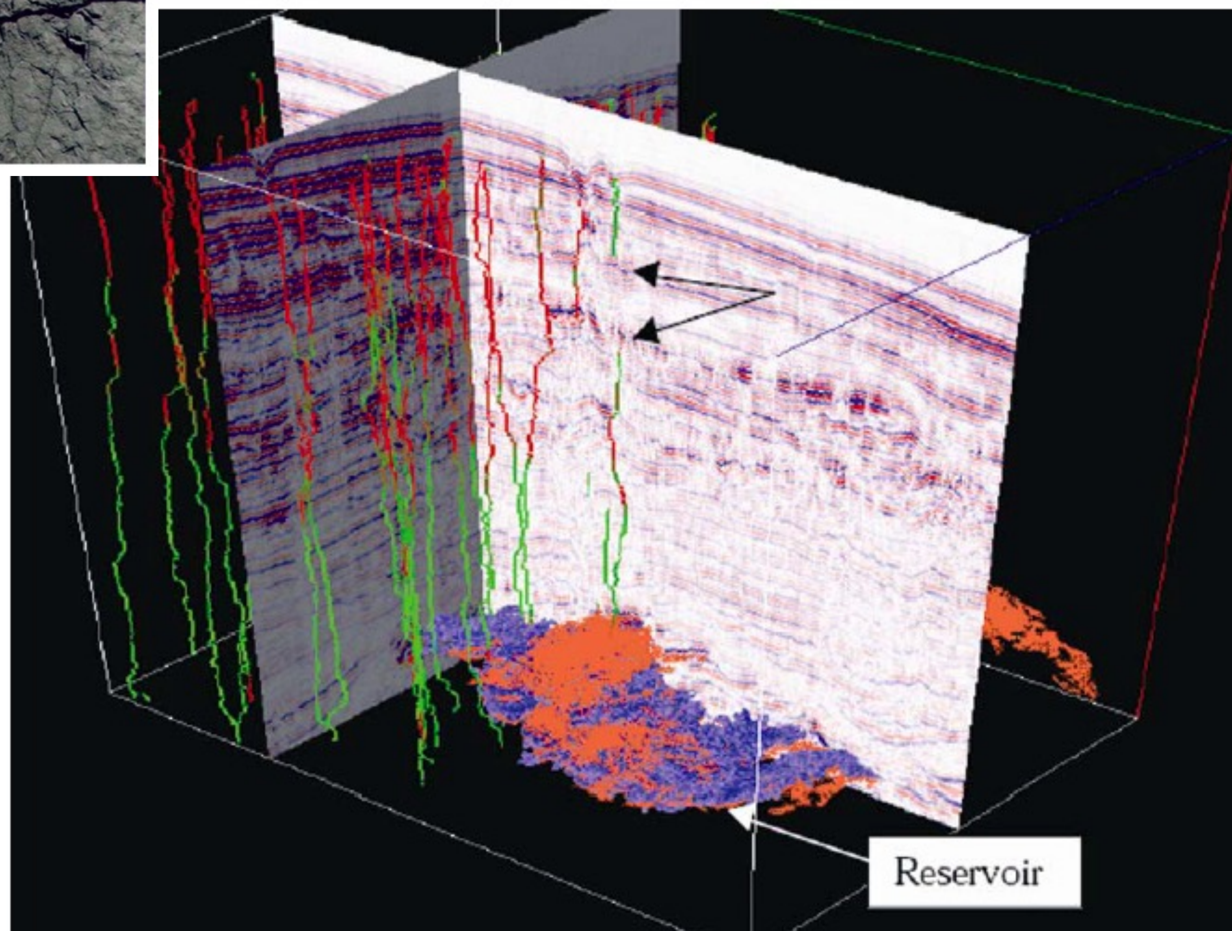
Figure 2.44: Seep plumes from the Scanner (left), Scotia (centre), and Challenger (right) pockmarks, Block UK15/25, North Sea acquired during the Heincke 180 cruise, October 2002 (Alfred Wegener Institute) using the parametric sediment echo sounder system (SES-2000DS) developed at Rostock University, Germany; this scan shows depths from 140 to 190 m. [courtesy of Gerdt Wendt, University of Rostock.]

Judd & Hovland 2007

Judd and Hovland, 2007. *Seabed Fluid Flow.*



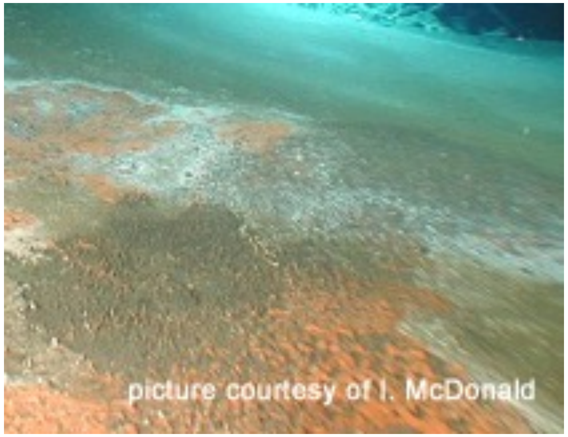
Judd and Hovland, 2007. *Seabed Fluid Flow.*



Judd & Hovland 2007

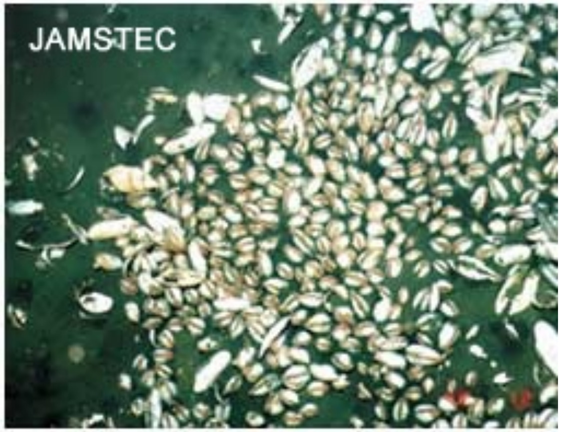
Chemosynthetic organisms at cold seeps

Free-living filamentous sulfur bacteria: *Beggiatoa*



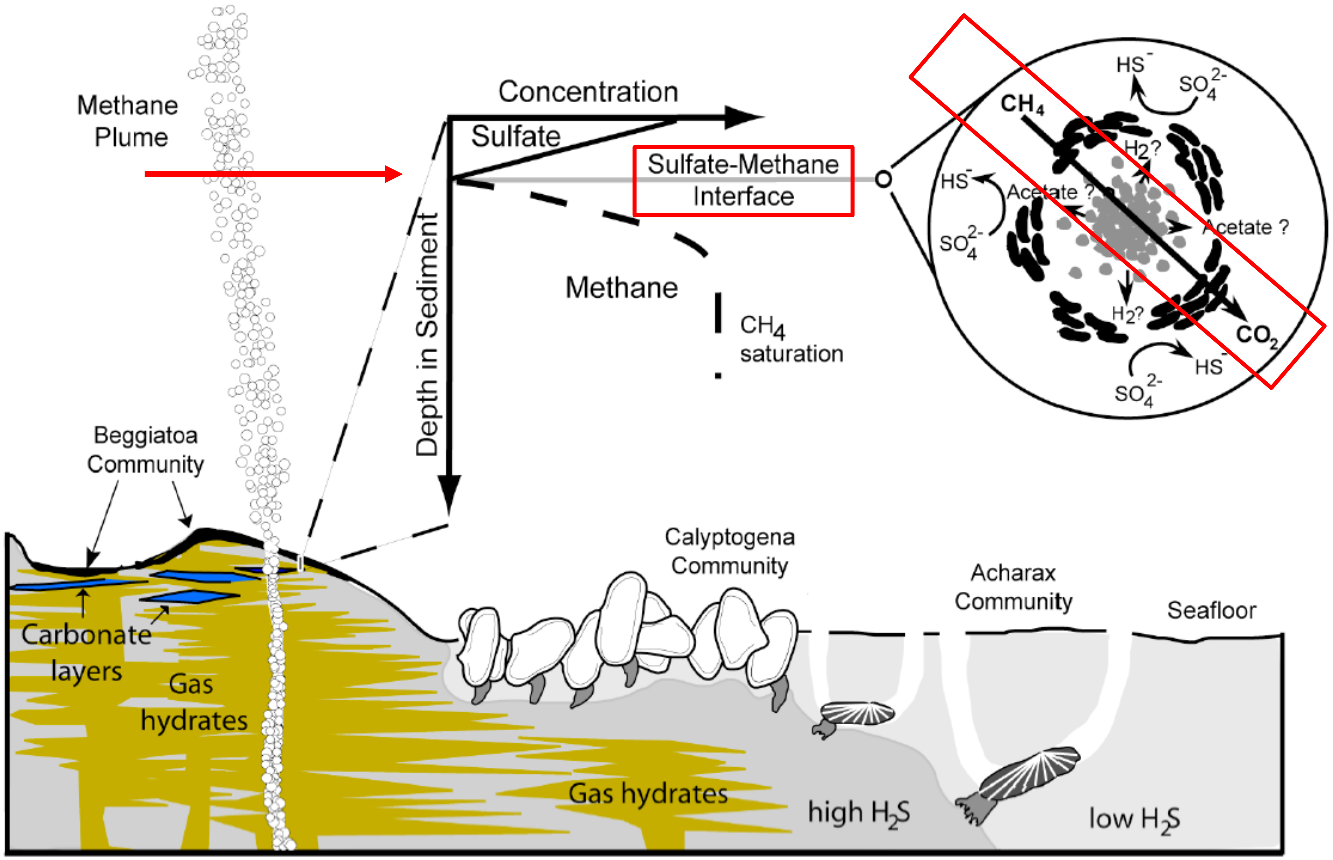
tube worms: *Lamellibrachia*

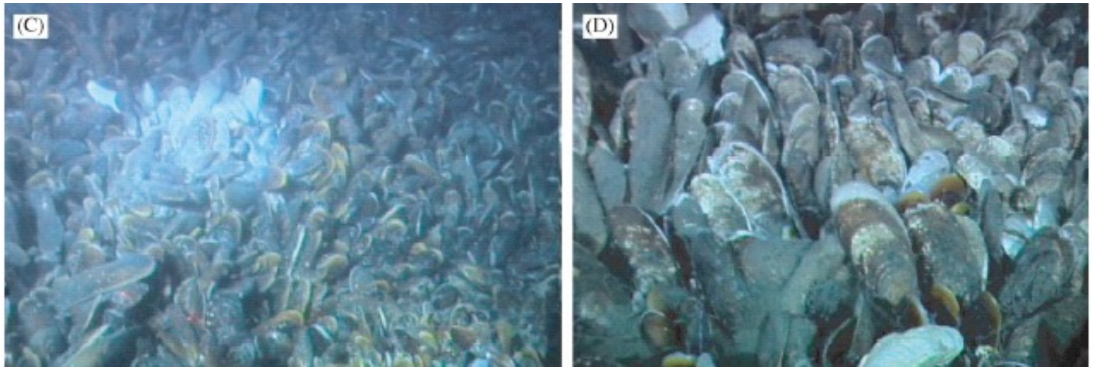
clams: *Calyptogena*



mussels: *Bathimodiolus*

mussels: *Acharax / Solemya*

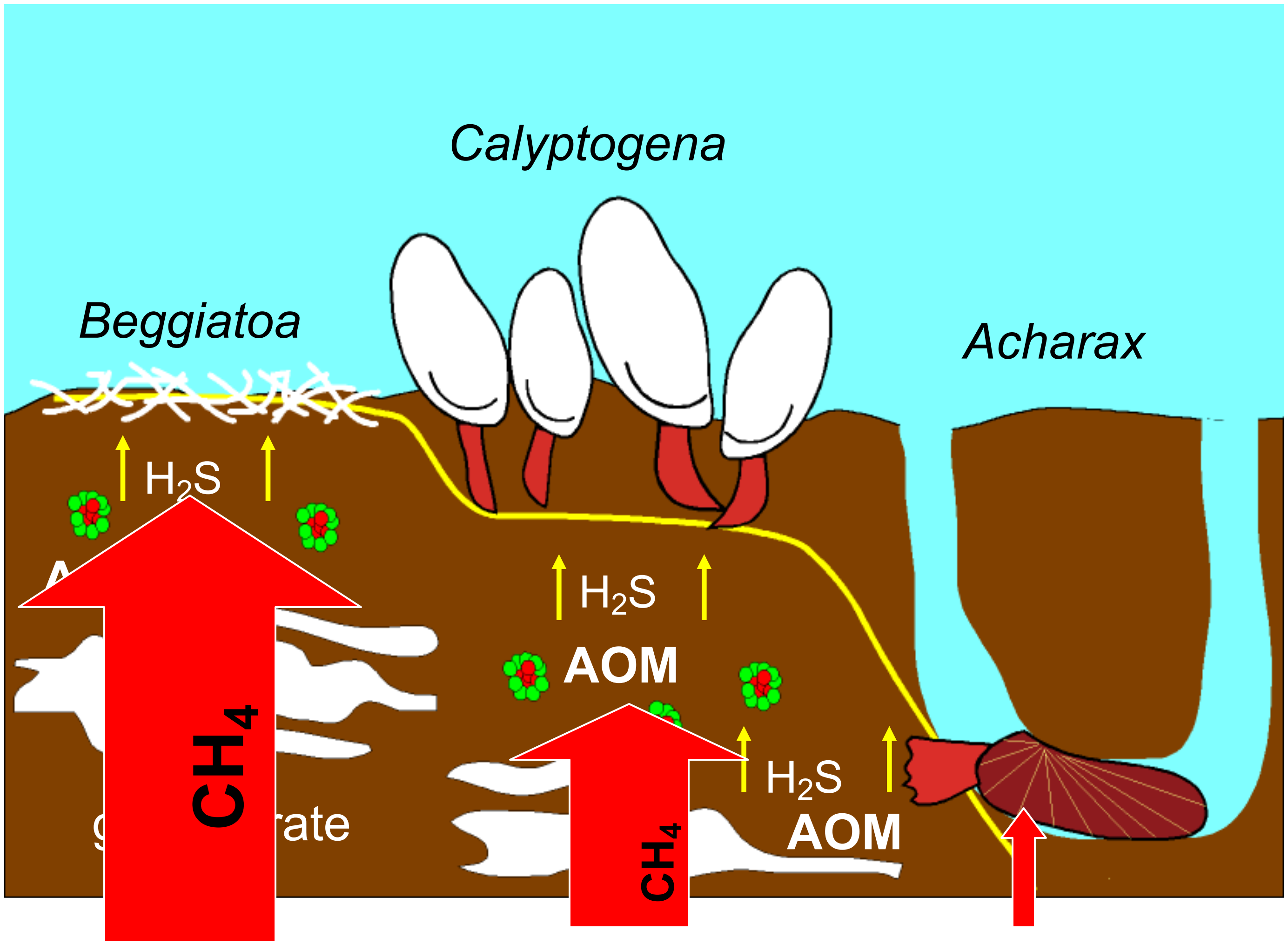




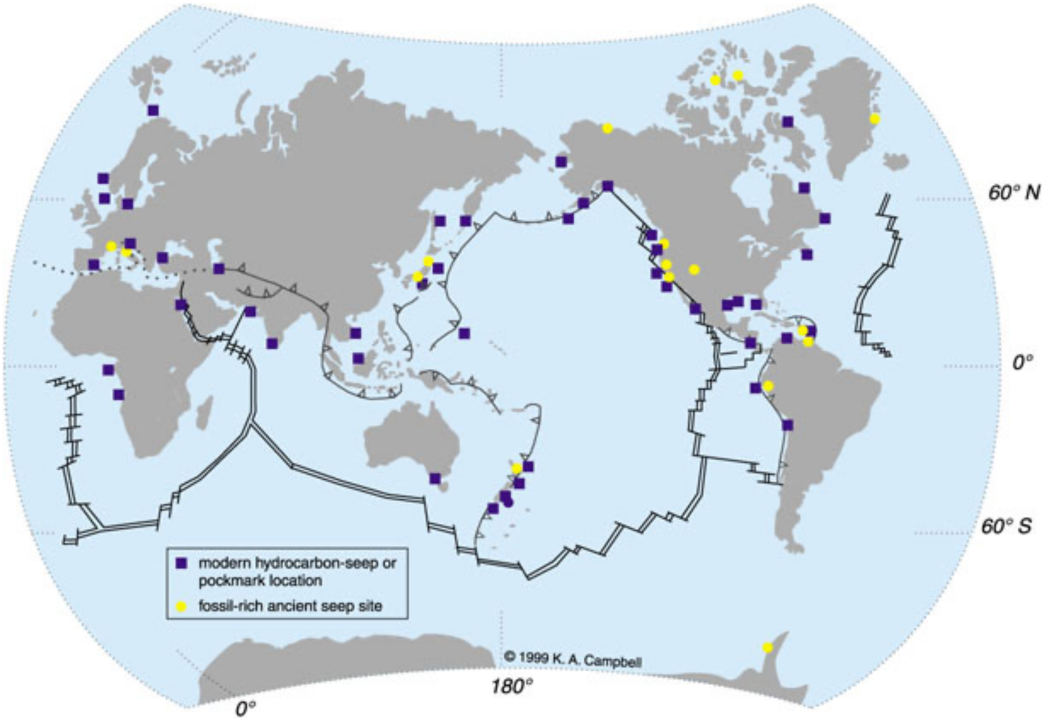
Bathymodiolus heckerae mussel beds. (A) Juvenile and adult mussels at Marker 'E'. (B) Dead mussels and octopus. (C) Extensive bed of live mussels of relatively uniform size, partially covered by bacterial mats, at Marker 'B'. (D) Dead mussels at the eastward periphery of Marker 'B'. (E) Mussels with a chiridotid holothurian and Alvinocaris sp. (F) Mussels with Alvinocaris sp. And ophiuroids. Scale bars: A–D : 10 cm, E; F : 5 cm.

Van Dover et al. (2003). *Deep Sea Research*

Gradient of chemosynthetic communities



AOM Algogenic Organic Matter



Authigenic Carbonates:

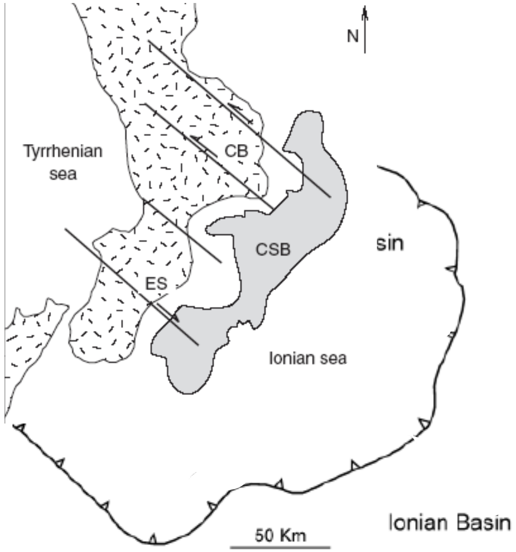
Isotopically light

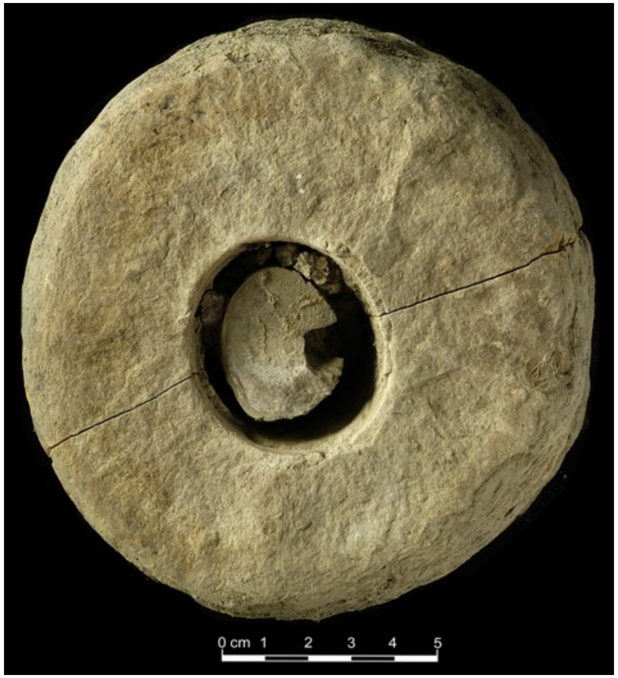
Organic markers indicate presence of methane oxidizers

Serve as habitat for bottom fish (e.g. rock fish)

Jensen *et al*., 1992

Fossil carbonate chimneys (PobitiKAmani, Bulgaria) Judd &, Hovland 2006





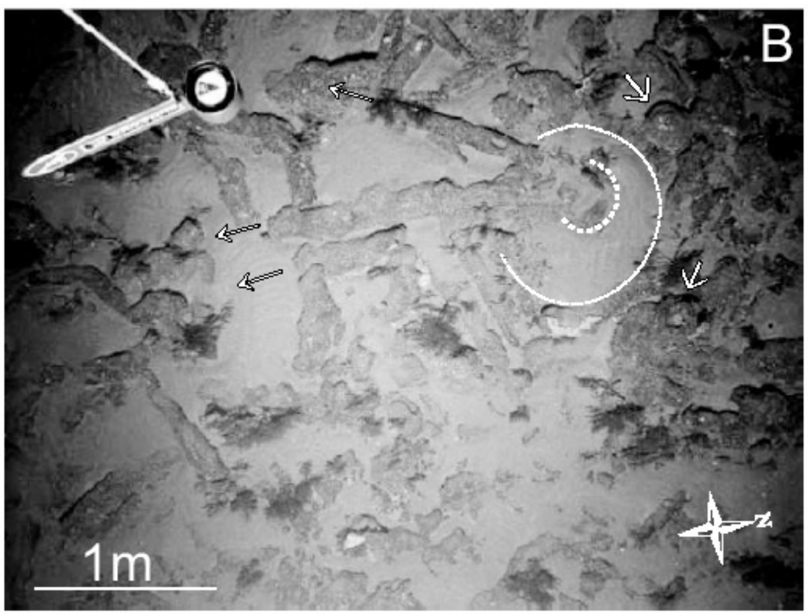
Courtesy, Domenico Rio, University of Parma

FOSSIL DEWATERING CHIMNEYS IN PLIOCENE MARLS, CROTONE BASIN

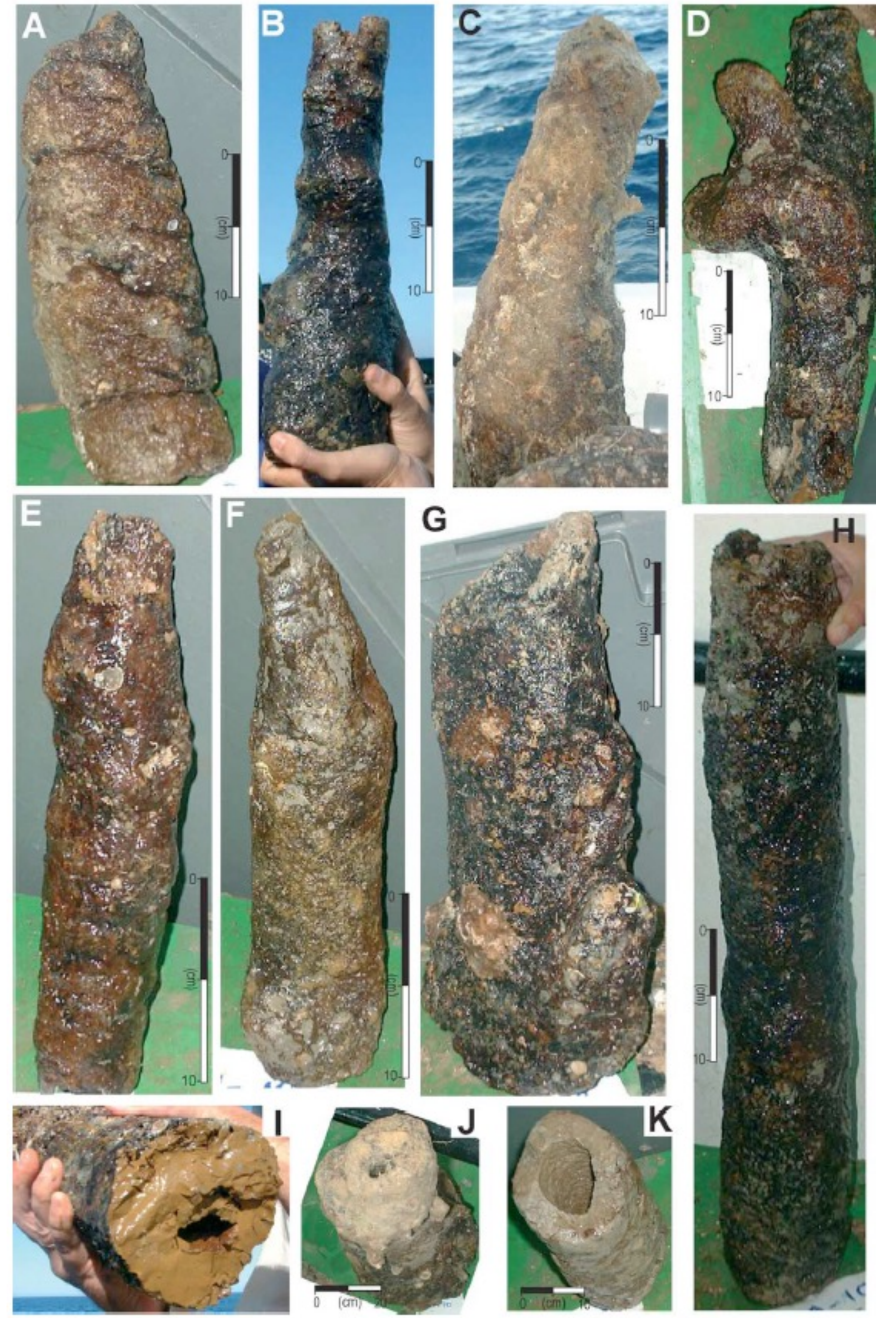
Pipe-like chimneys in Gulf of Cadiz Mud Volcanoes

Composed of authigenic carbonates with iron oxides.

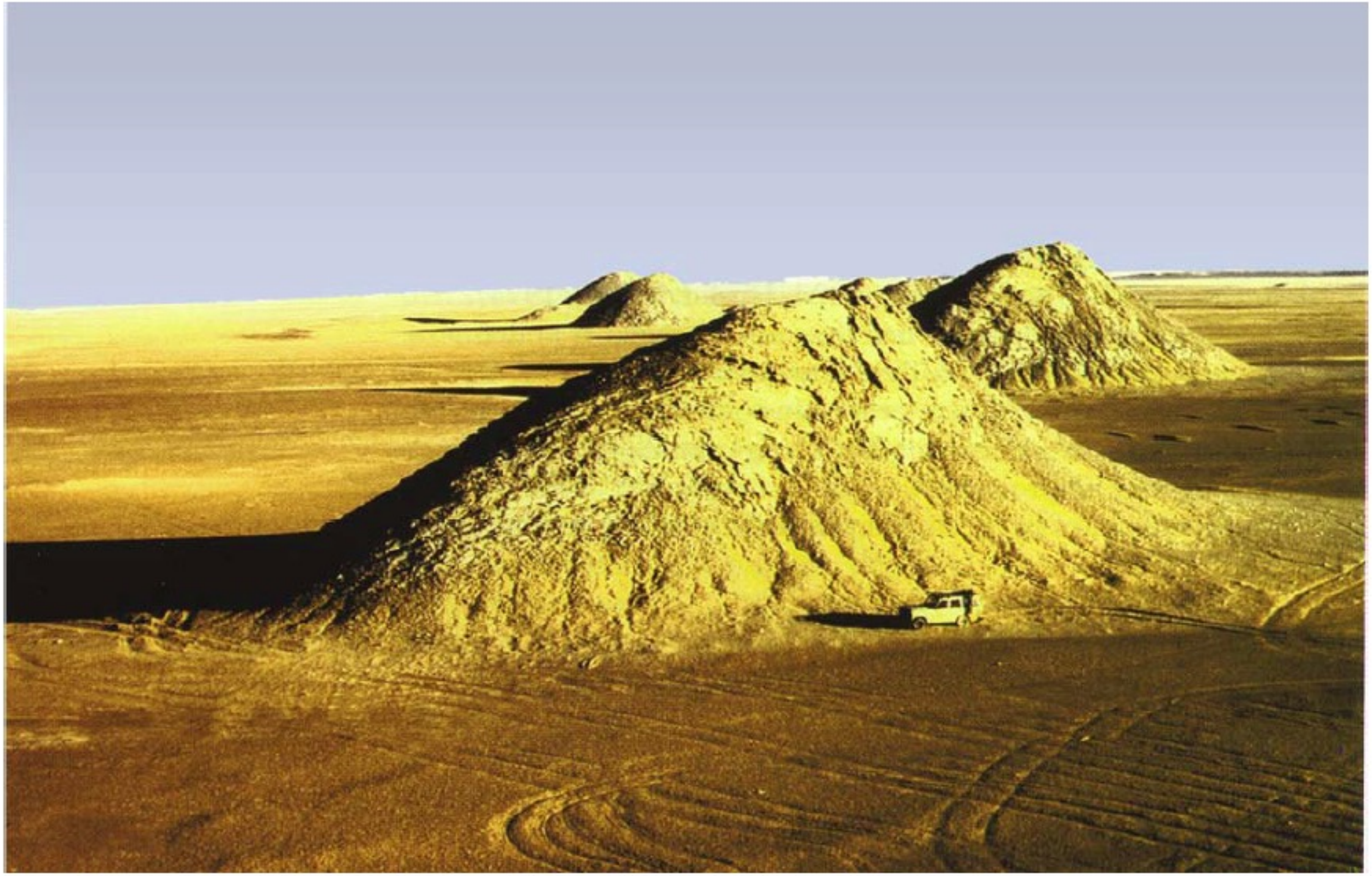
Carbonates are moderately depleted in ^{13}C, ranging from - 46‰ to -20 ‰ PDB



Diaz del Rio al., Marine Geology 195 (2003) 177-200



Judd and Hovland, 2007. *Seabed Fluid Flow.*



Judd & Hovland, 2007

Anaerobic oxidation of methane (AOM) via sulfate reduction.

Microbial consortia of **methanotrophic archaea** and **sulfate-reducing bacteria** identified on gas hydrate-bearing samples (Boetius et al. 2000).

The archaea oxidize methane:

$\mathbf{CH_4} + 2H_2O >>> \mathbf{CO_2} + 4H_2$

And sulfate reducing bacteria may act as indicated by the reaction:

$\mathbf{SO_4^{2-}} + CH_3COOH + 2H^+ >>> 2\mathbf{CO_2} + H_2S + 2H_2O$

$\mathbf{CH_4} + SO_4^{2-} >>> \mathbf{HCO_3^-} + HS^- + H_2O$

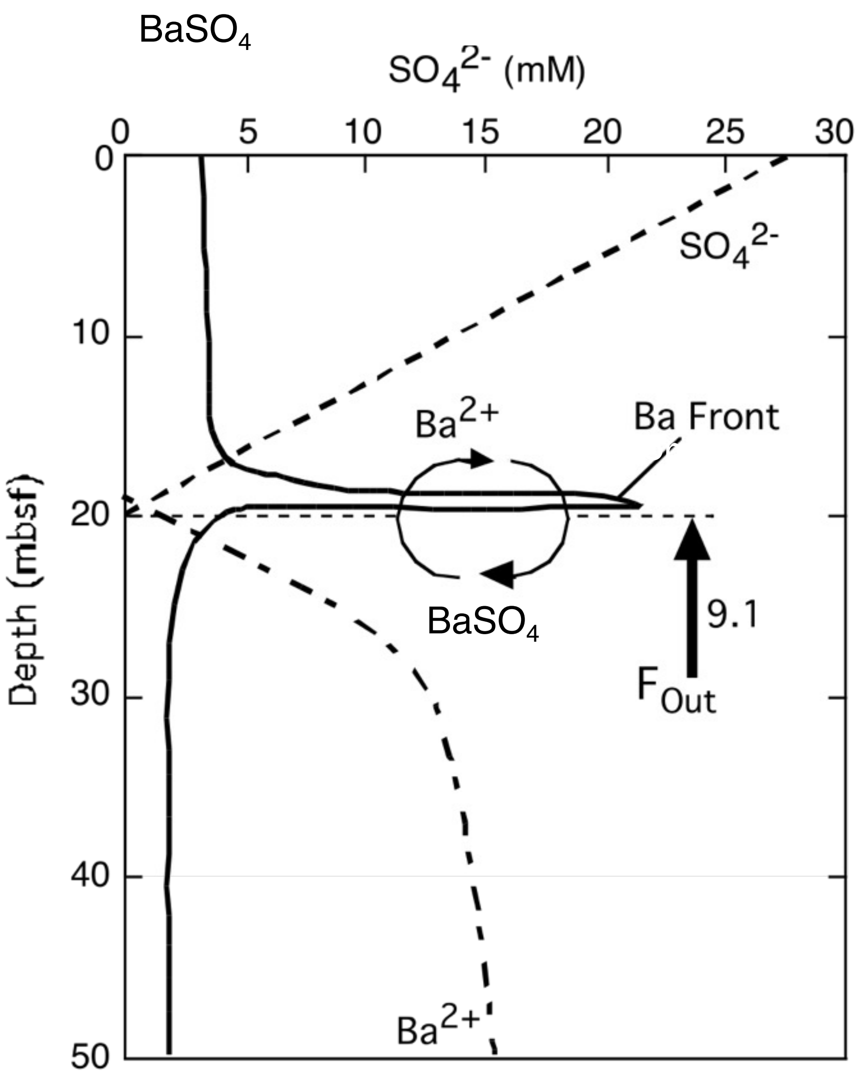
Bicarbonate ion

Authigenic carbonate precipitation
Methane-derived Calcium Carbonate

$$HCO_{3-} \quad + \quad OH^{-} \quad + \quad Ca^{2+} \quad \rightarrow \quad CaCO_3 + H_20 + C0_2$$

Bicarbonate from bacterial action	alkaline seawater	calcium ions present in seawater	calcium carbonate deposited

$BaSO_{4(s)}$ (Barite) <----> $Ba^{2+}_{(aq)} + SO_4^{2-}_{(aq)}$



Coupled Sulfate / Barium Profiles

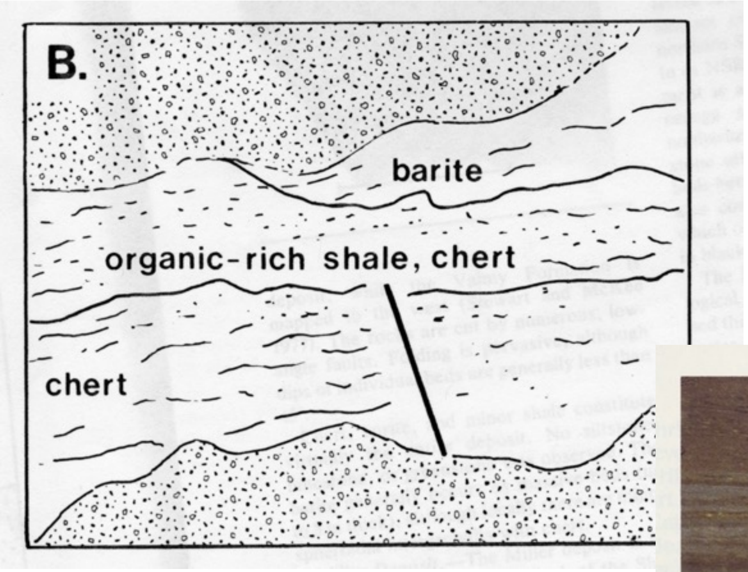
1. High concentrations of barite in pelagic sediments underlying high productivity waters are thought to result from **biologically mediated precipitation of barium sulfate within the water column.**

2. In organic-rich, rapidly accumulating sediment, sulfate is consumed by microbial reduction of organic carbon. **Barite is dissolved under conditions of sulfate depletion leading to high barium concentrations in the pore fluids.**

3. **When barium-rich fluids discharge at the seafloor, barite forms by reaction with seawater sulfate**, forming “cold-seep barite” deposits.

Paleozoic Bedded barites from Nevada, Arkansas, Mexico and South China are associated with:

- Organic shales
- Chert and phosphorite
- Some carbonate



Cold seep barites along continental margins are associated with:

- Organic-rich facies
- Opal-rich sediments
- Phosphorites
- Some carbonates

Jewell and Stallard, J. Geol., 99, 1991

ODP Leg 112

Polygonal Faults

'an array of layer-bound extensional faults within a mainly fine-grained stratigraphic interval that exhibit a diverse range of fault strikes which partially or fully intersect to form a polygonal pattern in map view'

• This type of fault has only been recognized in packages that are predominately composed of fine-grainedsediments.

• The local stress regime operative at the time when polygonal faults grow can exert a significant influence onstrike and on the organisation of the fault array as a whole.

Cartwright et al., 2003.

Polygonal Faults. Geometry

- Polygonal faults systems develop in tiers. Faults in one tier may partially interconnect with those in adjacent tiers by cross-propagation of a sub-set of the total fault population, but the majority of the faults in the separate tiers are contained wholly within individual tiers.

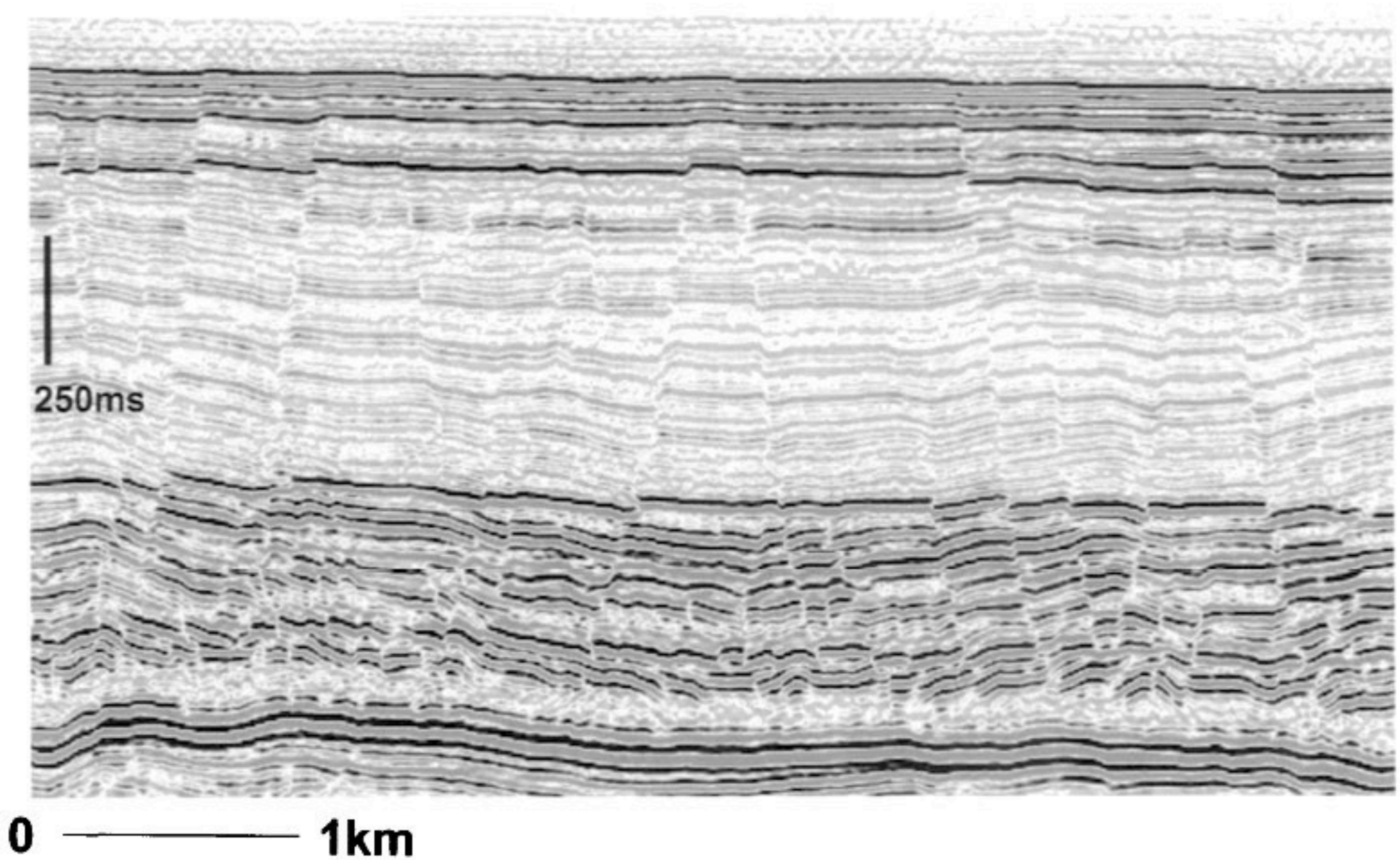
- They range in fault trace length from 100 m to several kilometres and extend vertically across discrete layers from a few tens of metres to over one kilometre in thickness.

- Polygonal faults can be planar or listric

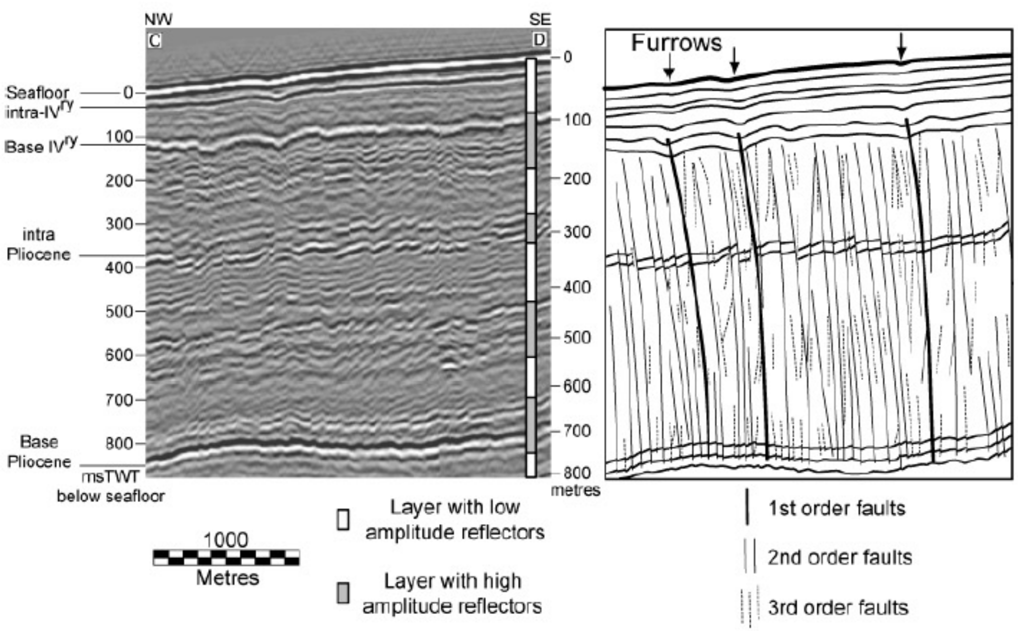
- Faults are characterized by a large range of fault strikes. Where strikes are almost randomly oriented, a classical polygonal plan form geometry results. Variations in the basic polygonal plan form can arise from regional slope, tectonic context, or basement topography, or from intrinsic variation in the physical properties or the thickness of the deforming interval.

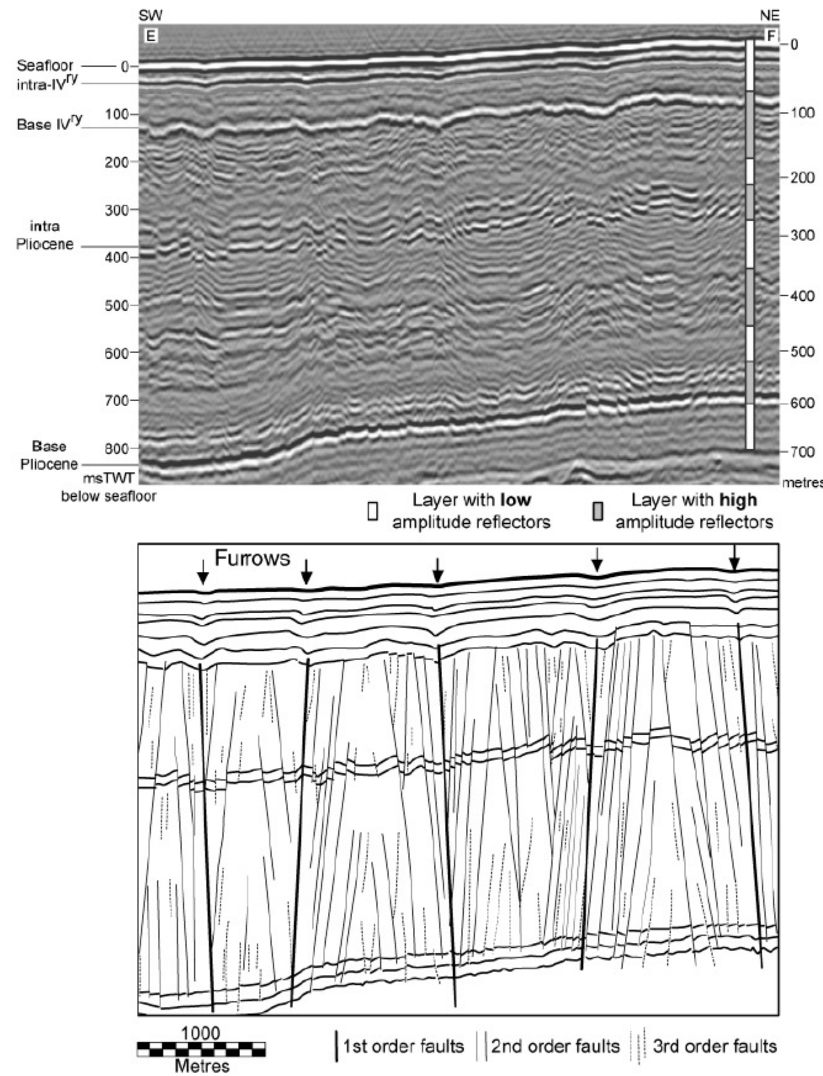
- Three-dimensional geometry of polygonal fault systems is invariably complex and difficult to appreciate from simple 2D cross-sections.

Cartwright et al., 2003.

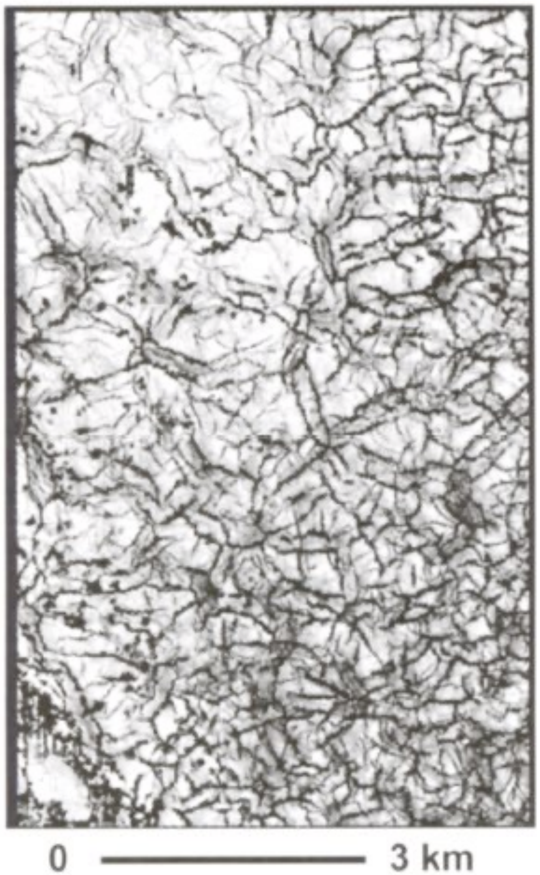


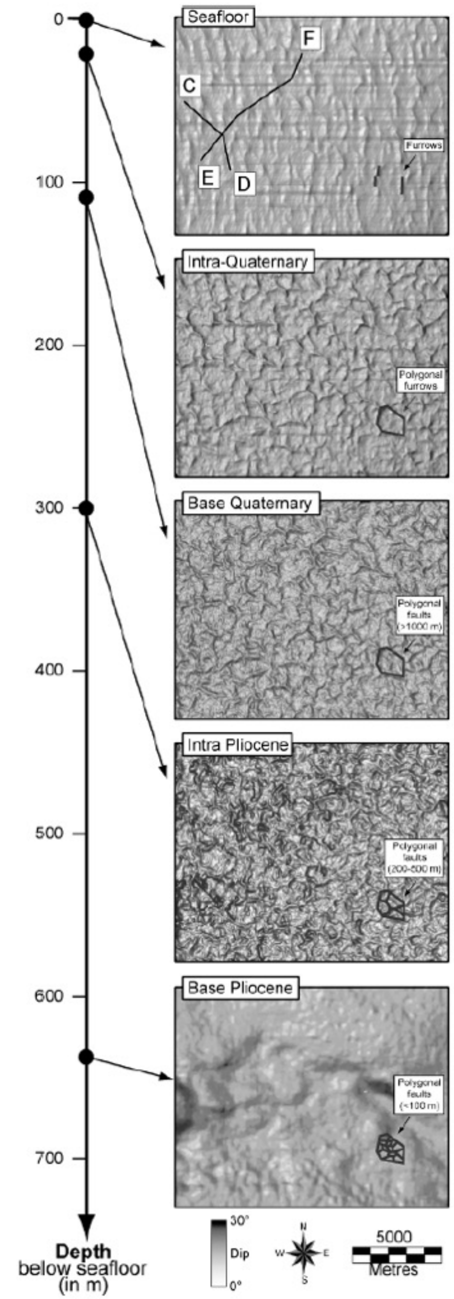
Cartwright et al., 2003.



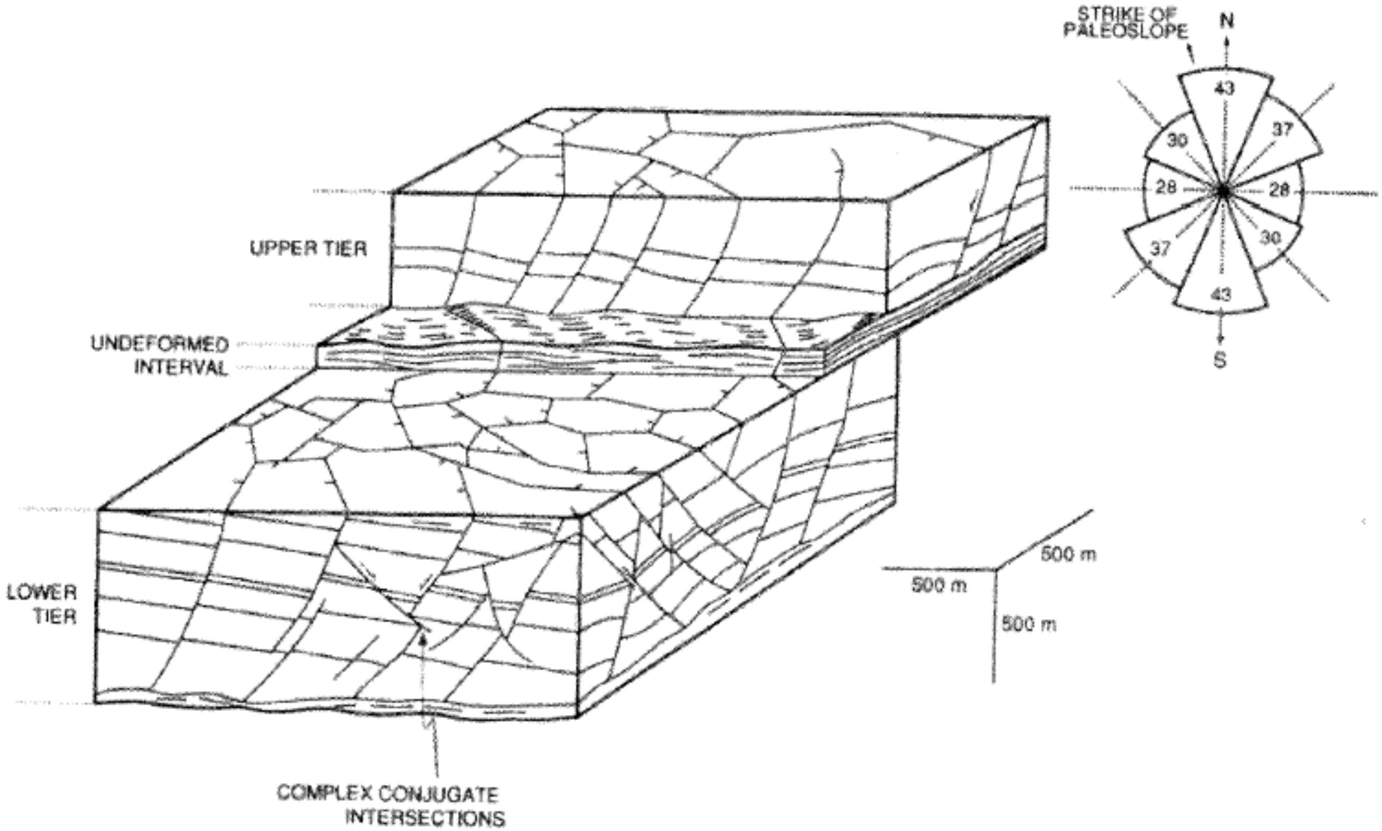


Gay et al., Basin Research (2004) 16, 101-116





Cartwright et al., 2003.



Cartwright et al., 2003

Polygonal Faults. Genetic mechanisms

Gravity sliding-collapse NO

Sliding down a slope, with a basal detachment at the boundary would imply iso-orientation, and basal contraction.

Density Inversion (Such as Henriet)

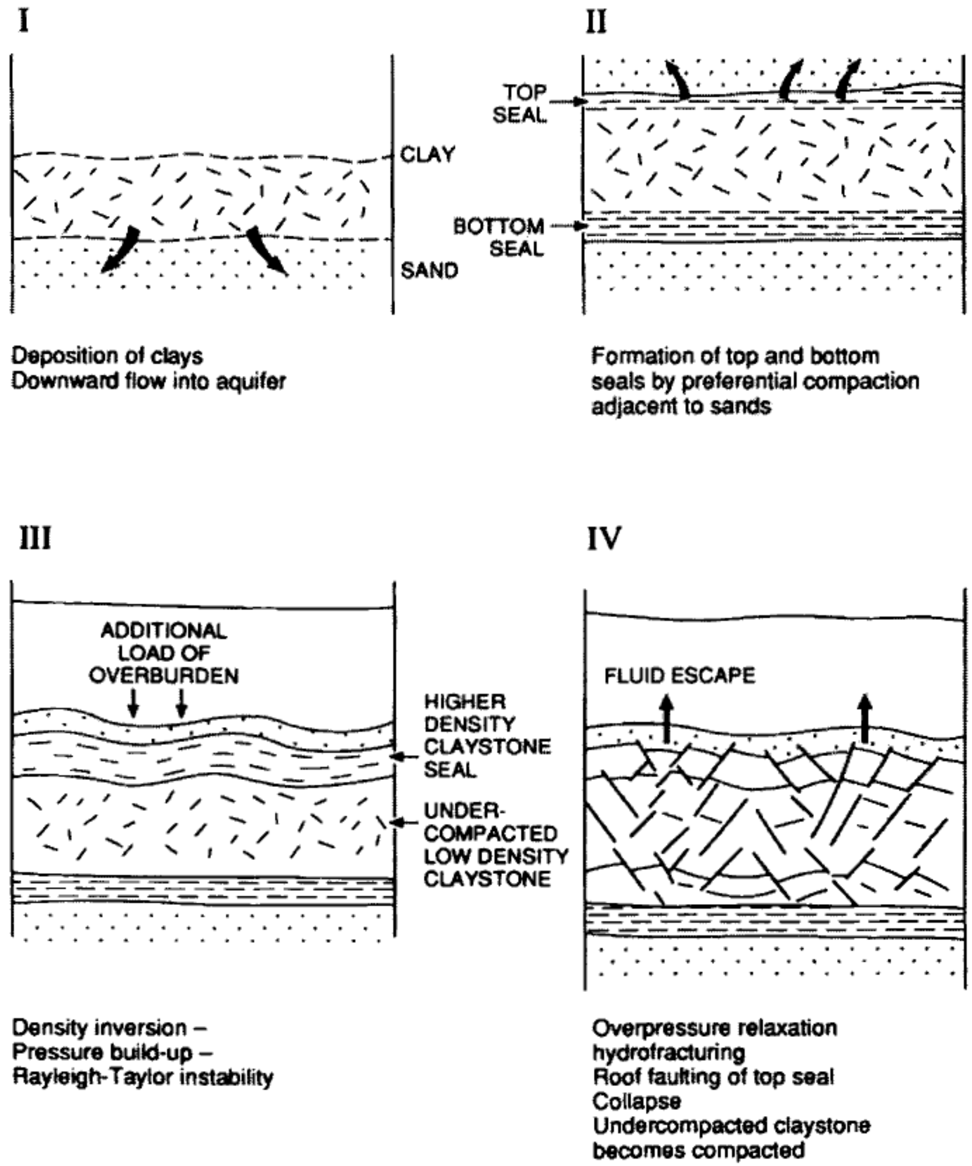
Density inversion should produce folding (like in salt diapirs), whicha are not always observed.

Syneresis

- Syneresis is a spontaneous contraction (shrinkage) without evaporation, but is a process that is specifically restricted to gels.
- Gels are a framework of colloidal particles, and the primary condition for gel formation is the very fine size range of the constituent particles (clay size range).
- Ultra-fine grained sediments in which all polygonal falt sysytems form, fall into the range of colloidal materials

Cartwright et al., 2003.

Density inversion model
For polygonal fault systems
Henriet et al., 1989.



Cartwright et al., 2003

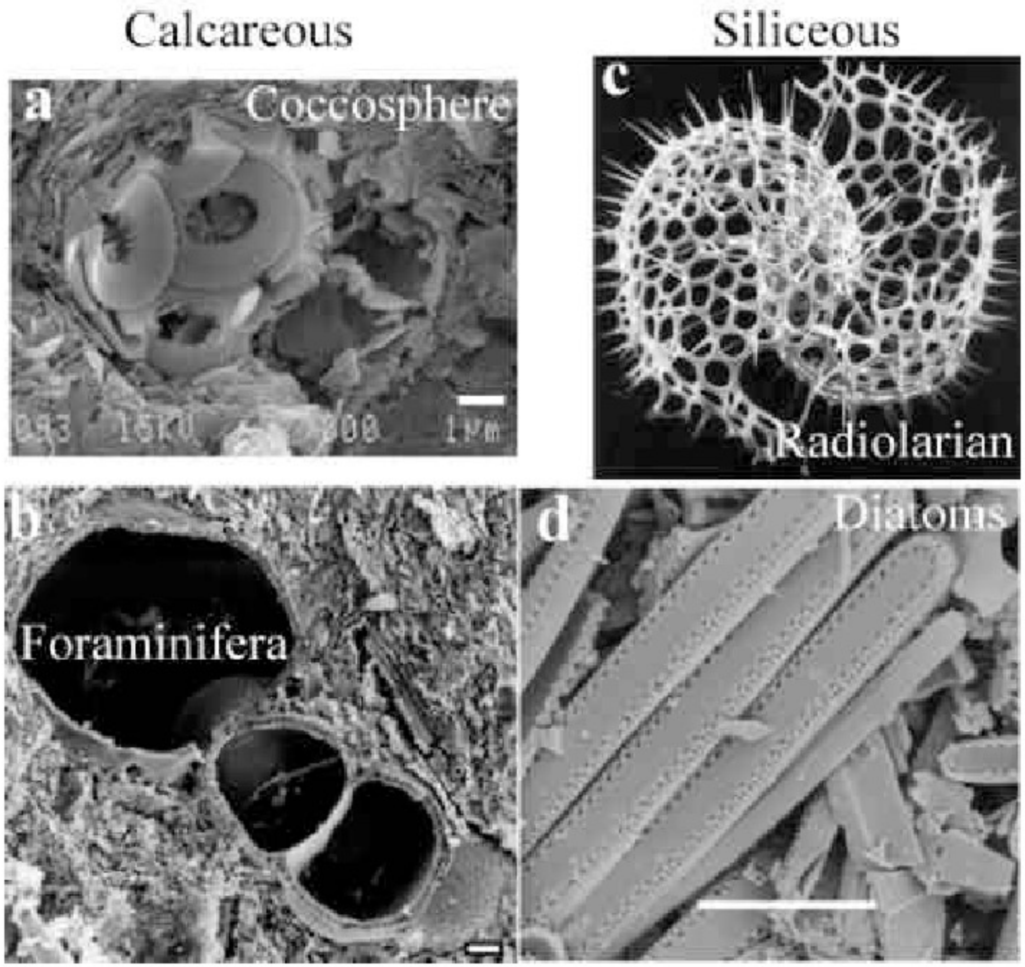
FOSSILIFEROUS SOILS

-They trap water and introduce a significant bias on index properties, and diatoms microfossils in particular can play a significant role on physico-chemical properties of soil because of their potentially large specific surface area.

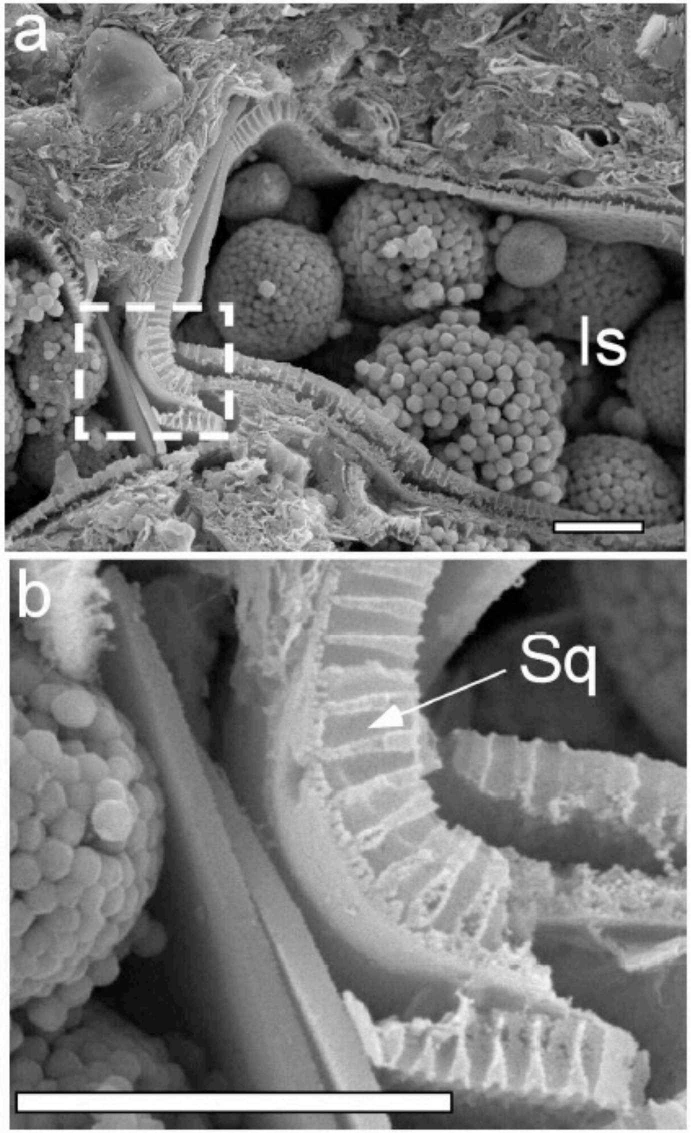
-They can provide delayed compressibility or a sudden increase in compressibility once the yield strength of the microfossil is exceeded.

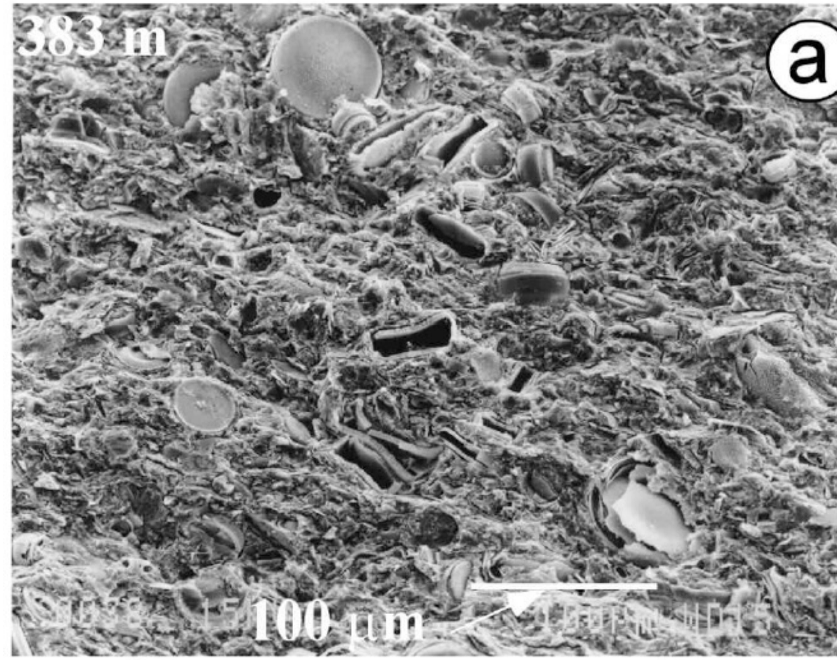
- They influence the frictional behavior of soils by their size and shape.

Locat & Tanaka, 2001; Tanaka & Locat, 1999



Locat & Tanaka, 2001; Tanaka & Locat, 1999

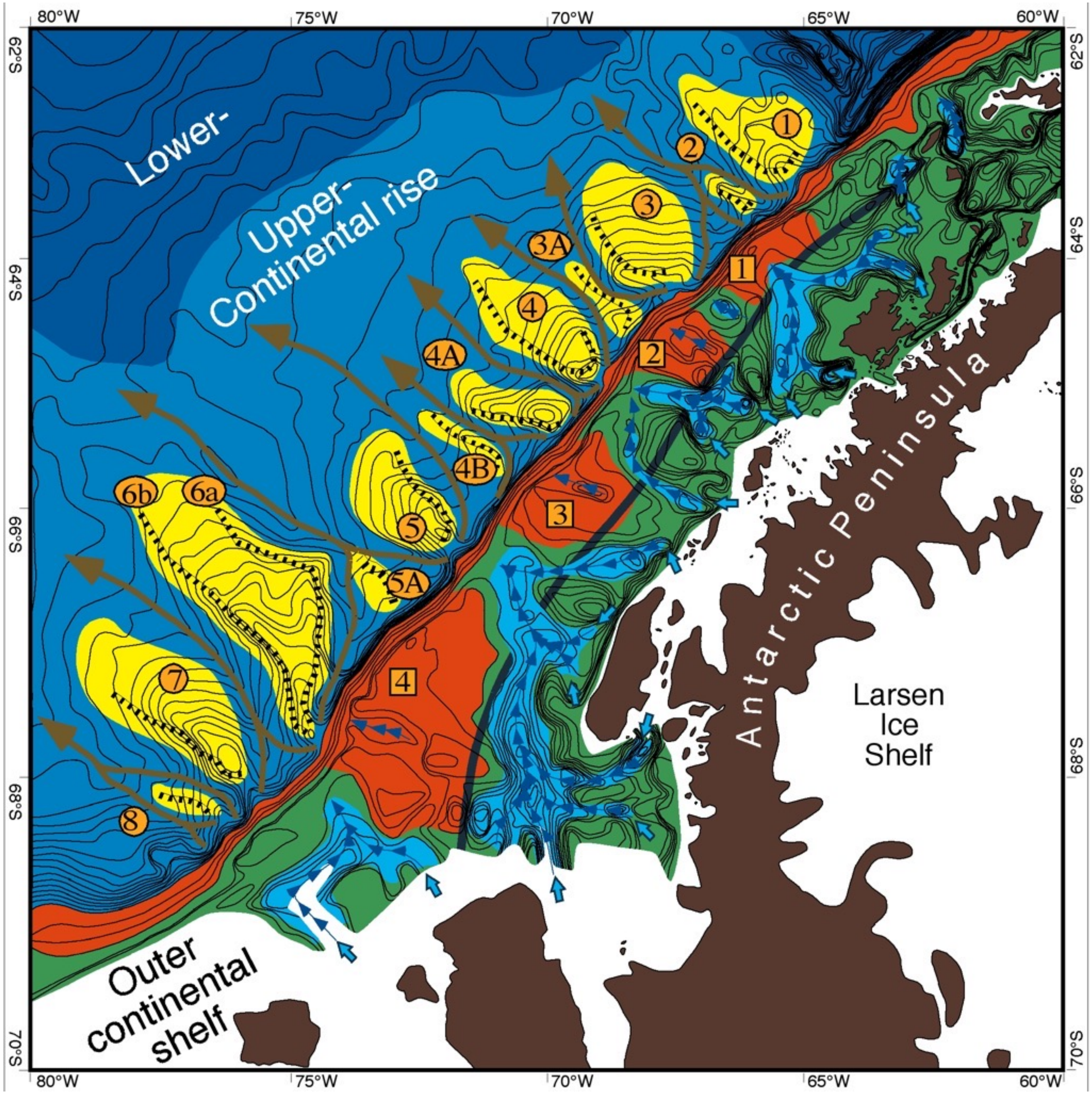




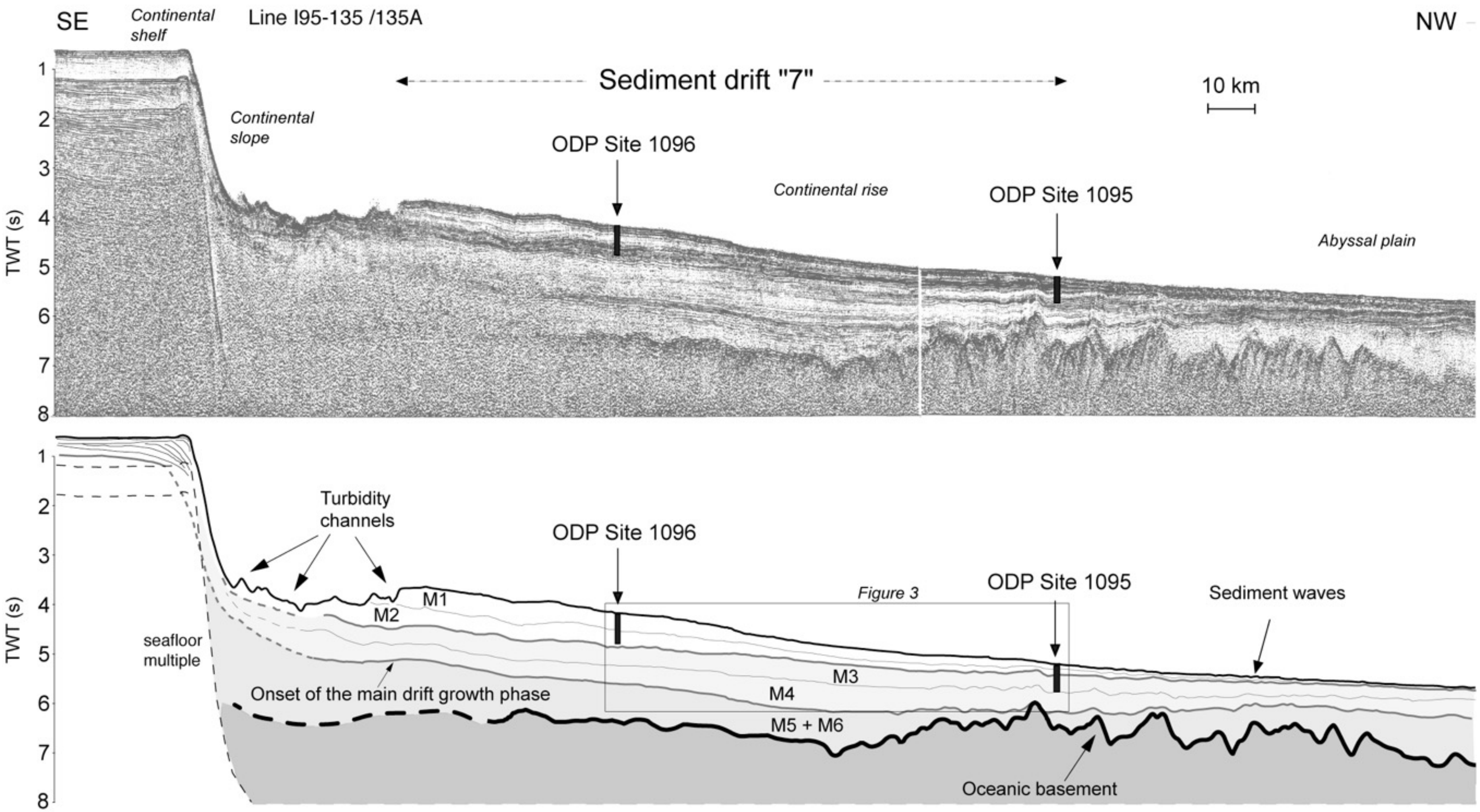
Distribution of diatoms in a consolidated sediment taken at a depth of 383 m at the site of Kansai airport.

Intra-skeletal (Is, a) and skeletal (Sq, b) porosity of microfossils.

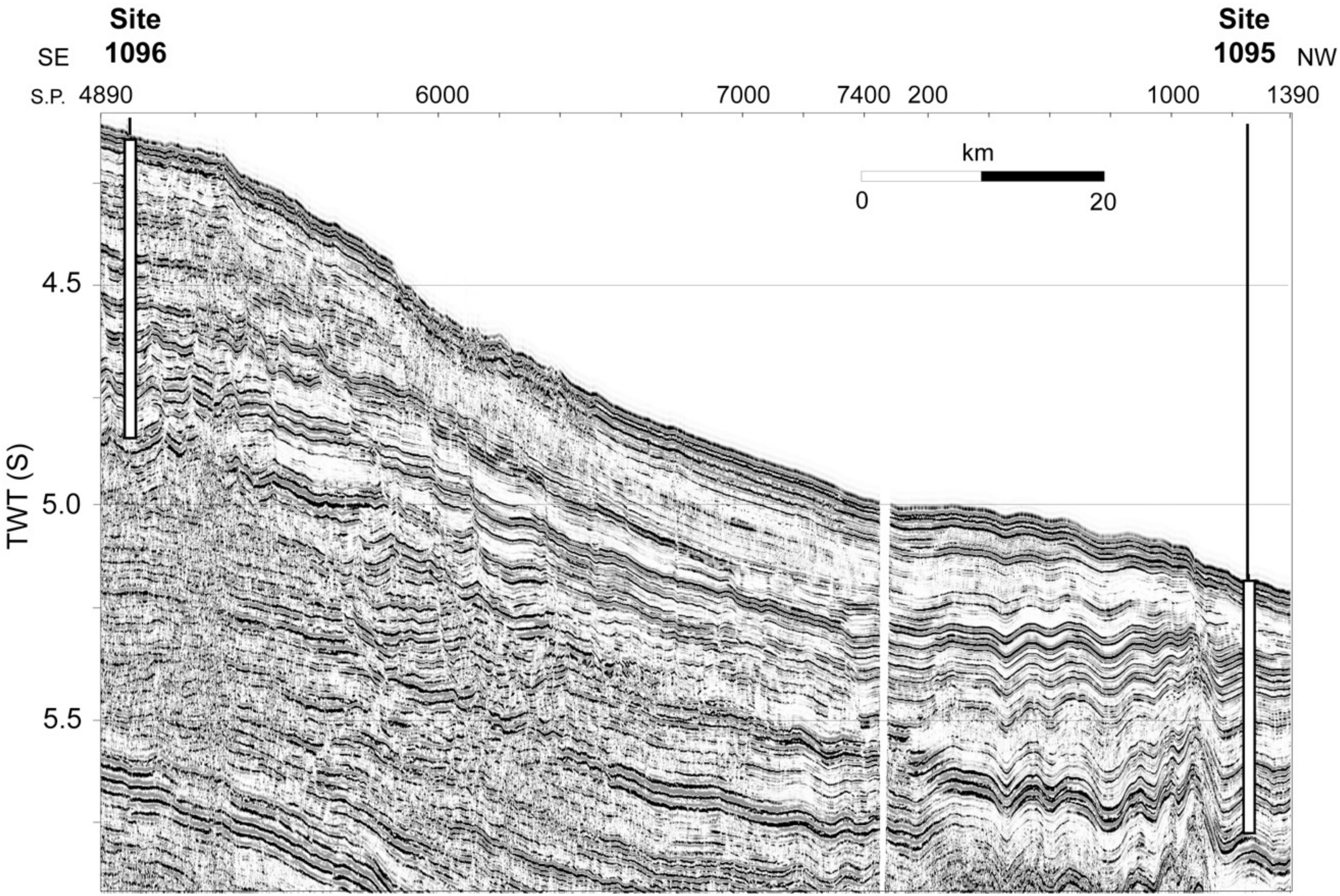
Locat & Tanaka, 2001; Tanaka & Locat, 1999



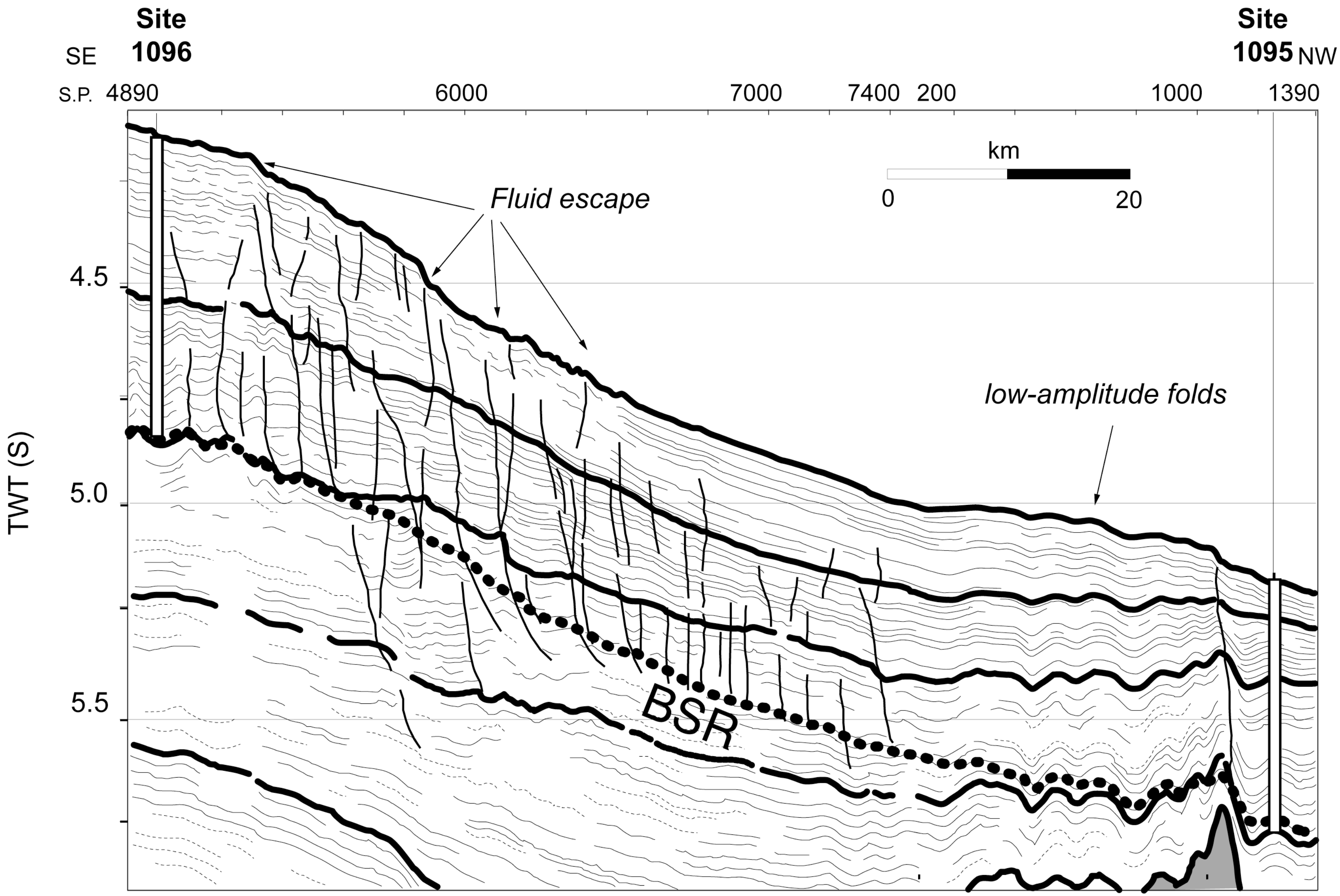
Rebesco et al. (1998), Terra Antartica, 5(4), 715-725



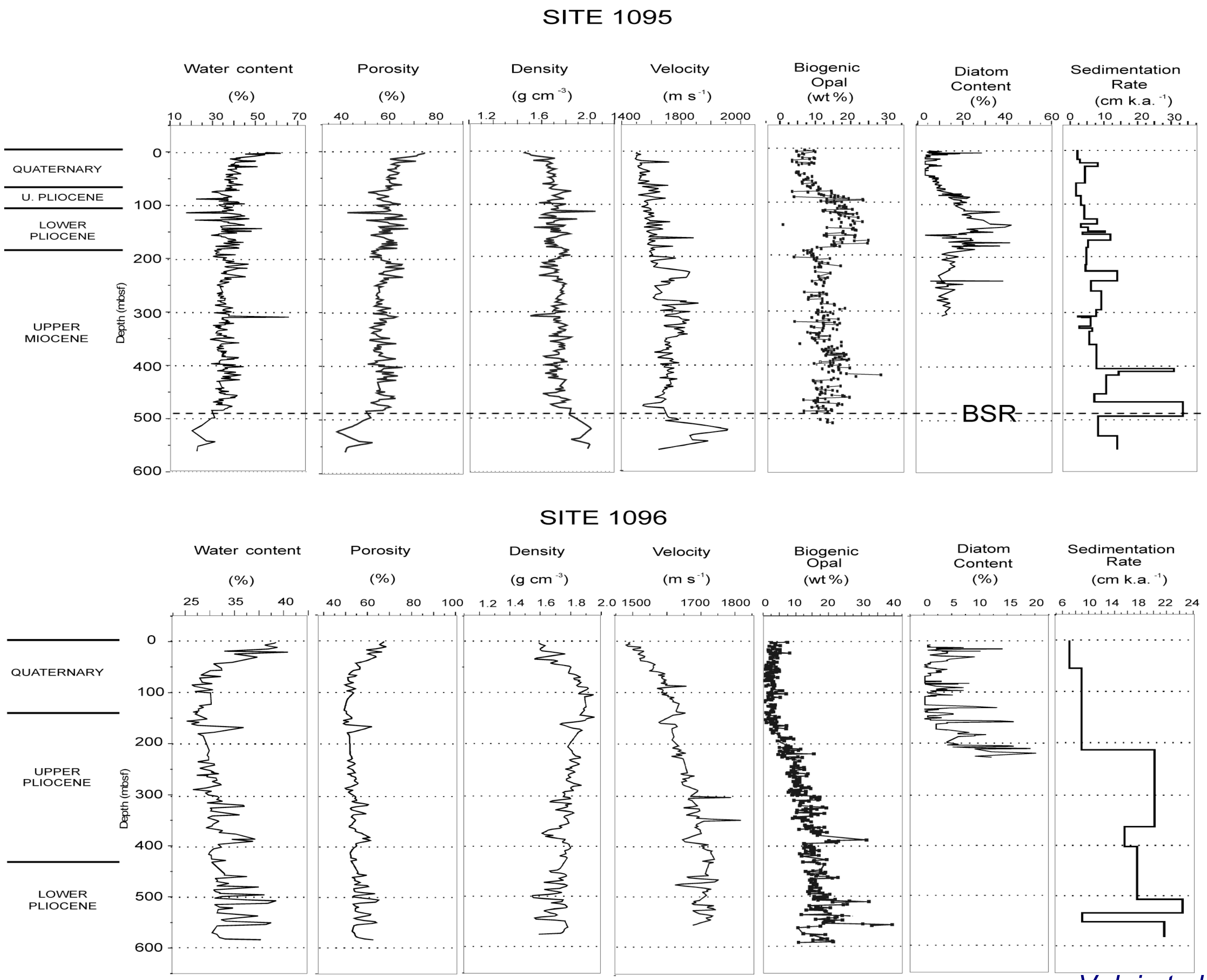
Volpi et al., 2003



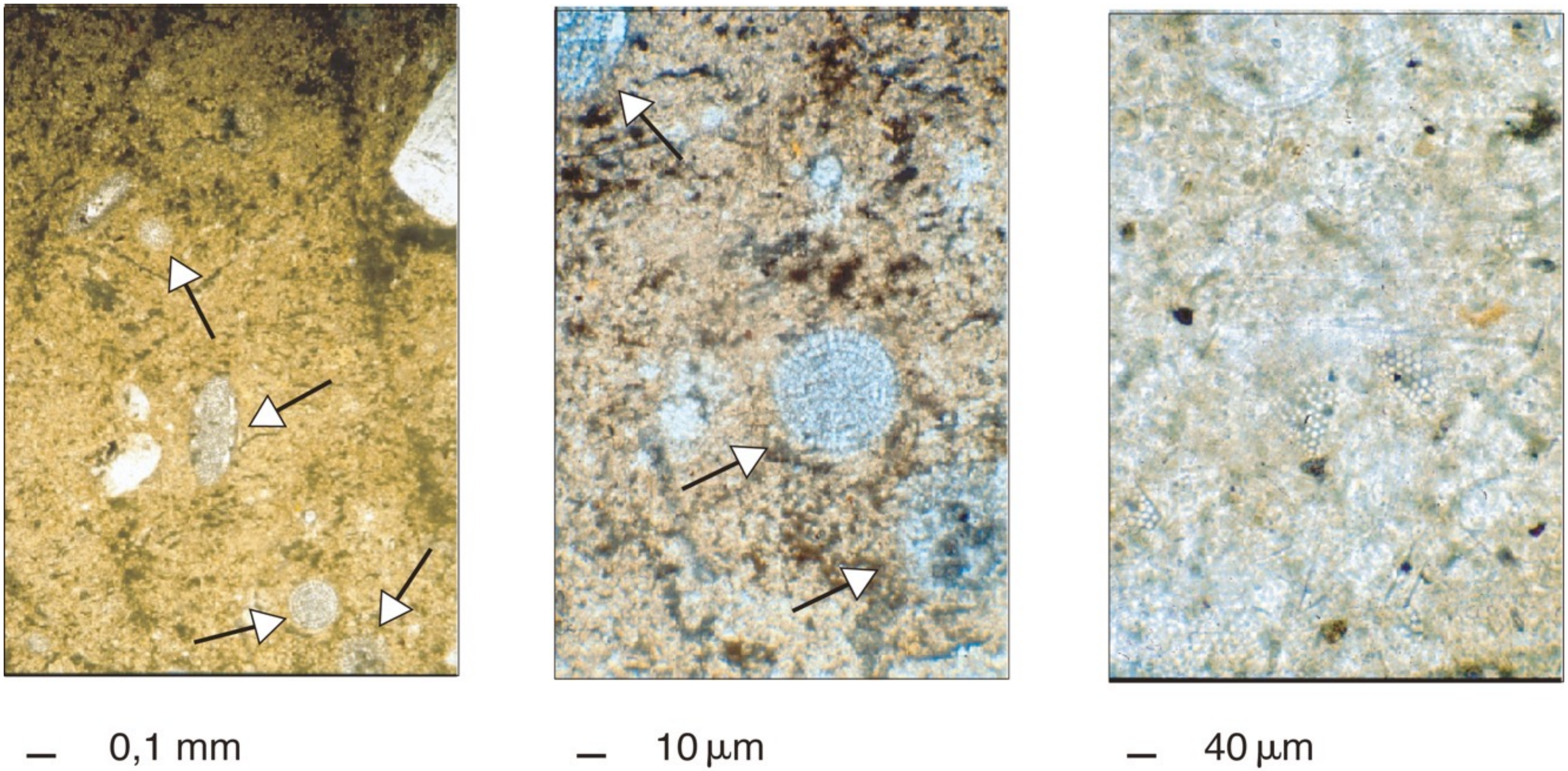
Volpi et al., 2003



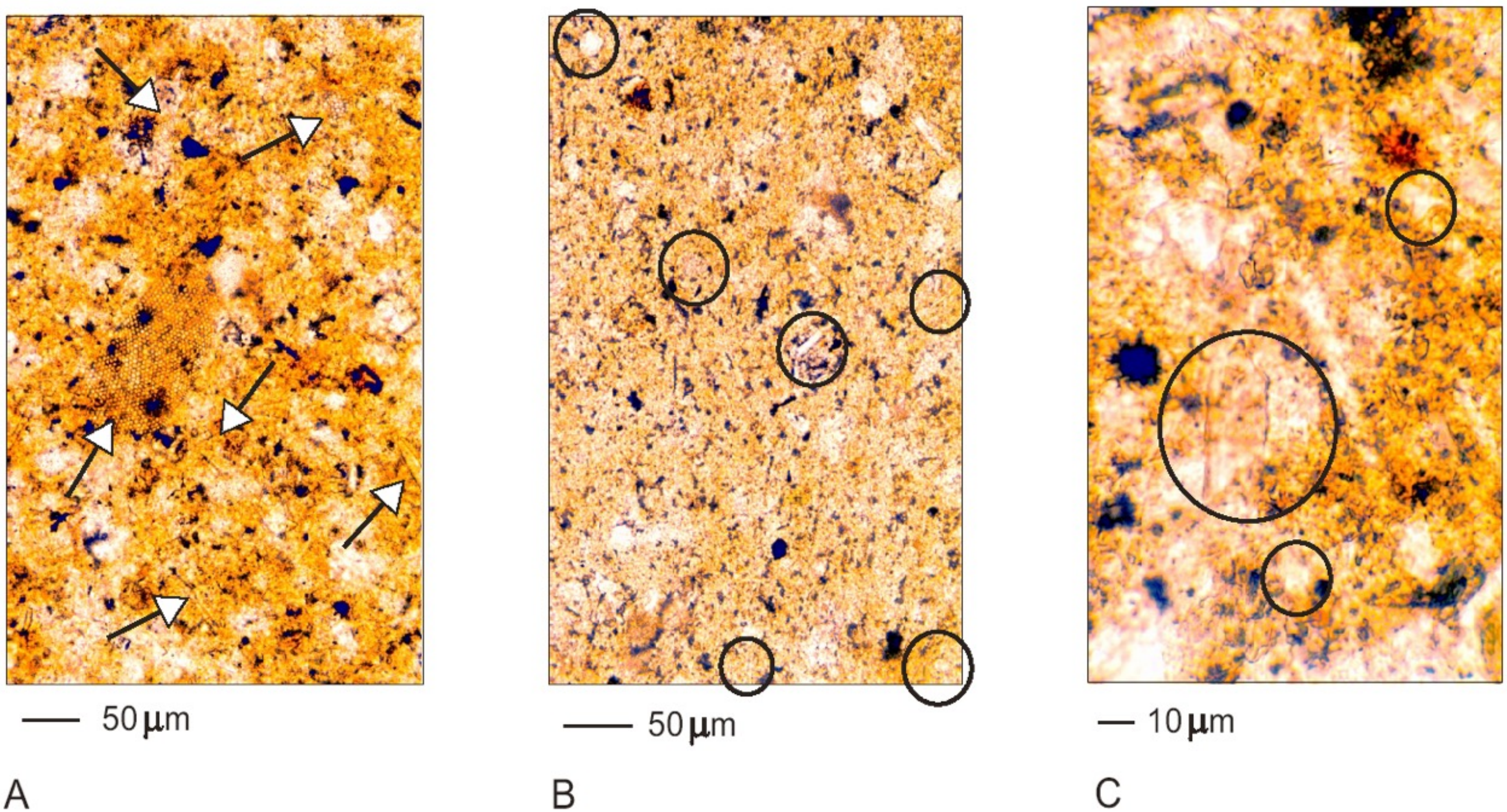
Volpi et al., 2003



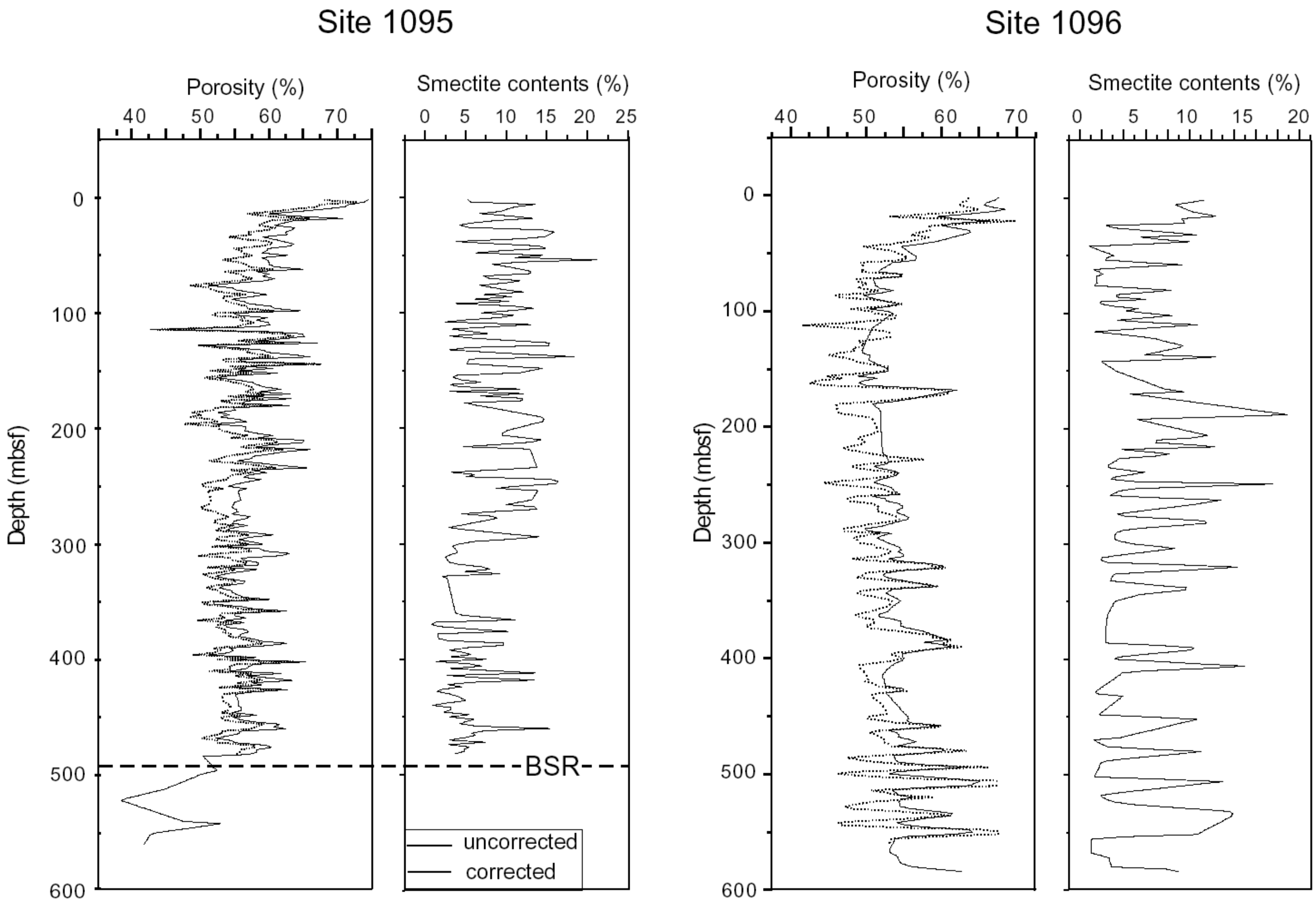
Volpi et al., 2003



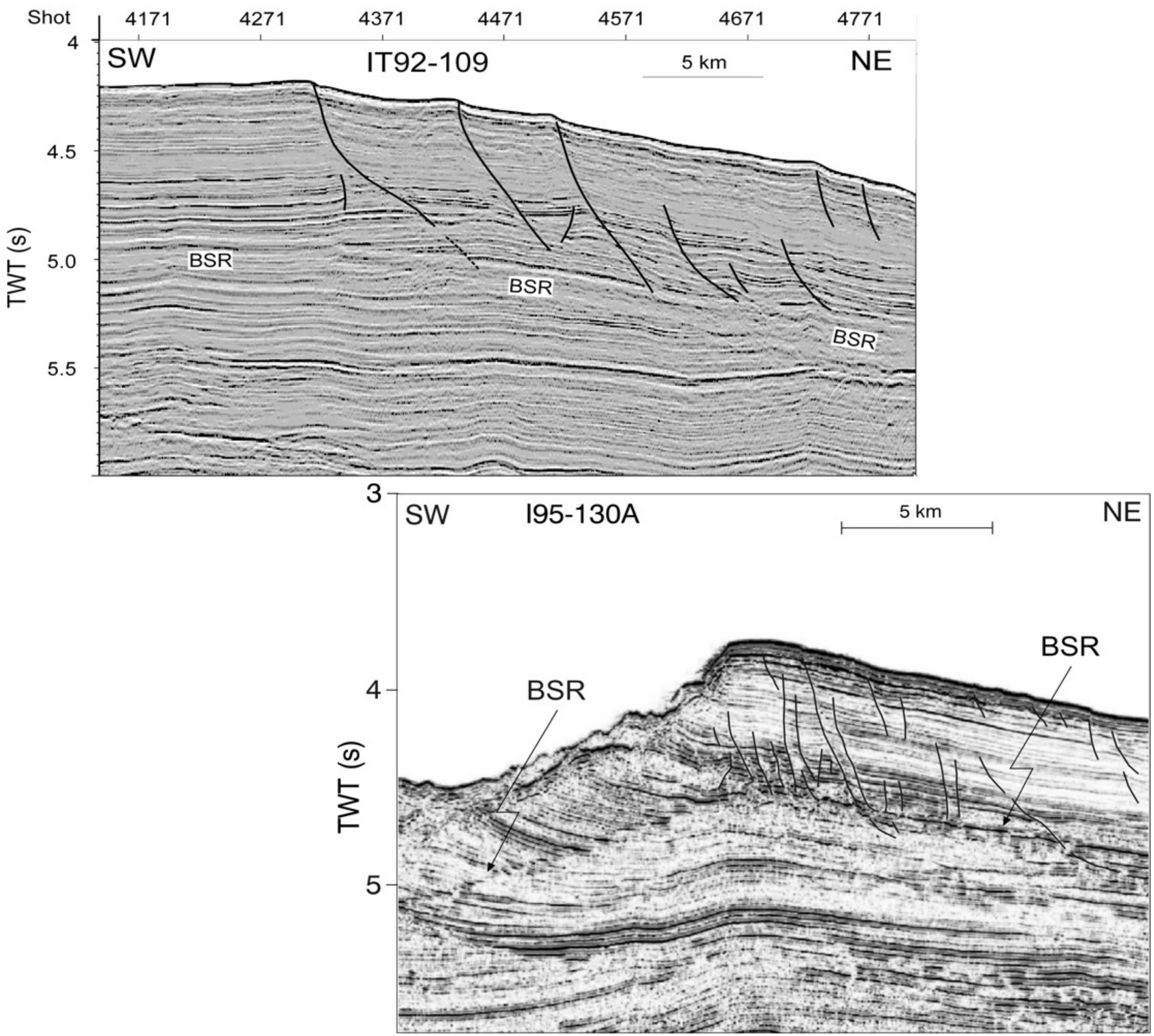
Volpi et al., 2003



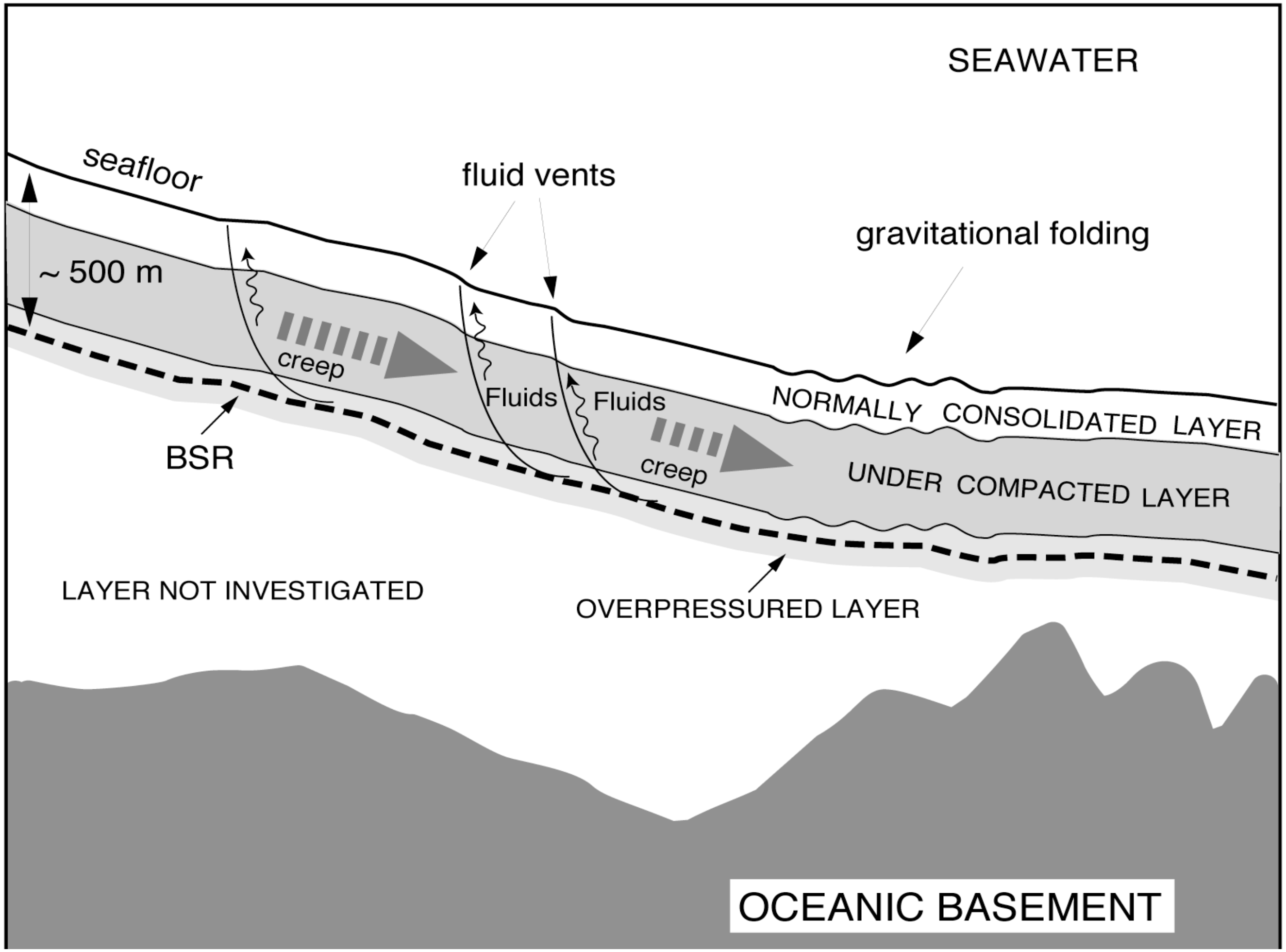
Volpi et al., 2003



Volpi et al., 2003



Volpi et al., 2003



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Conclusions:

- Due to their shape and strengths, microfossils affect significantly the physical properties and mechanical behavior of marine sediments:

- Microfossil-rich sediments retain porosity with depth.

-They resist consolidation until a threshold value of applied stress, exceeded which the rigid structure of the sediment collapses.

- Micro-structural collapse may trigger overpressure in the pore fluids, and weakness of the sediment (decreased effective stress).

- Diagenesis may act in two ways:

_ Cementation contributed to strengthening of the sediment.
_ Opal A to C/T transformation acts as a micro-structural collapse

- Microfossil rich sediments, and oozes in particular, are candidate sediments to provide weakness surfaces in submarine slopes.

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