Università di Trieste
Corso di Laurea in Geologia

Anno accademico 2015 - 2016

Geologia Marina

Parte IV

Modulo 4.2 Indicatori di movimento di fluidi: Vulcani di Fango, chimneys, pockmarks, vents...

Docente
A. Camerlenghi

B2(1) - 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

Mud Volcanoes

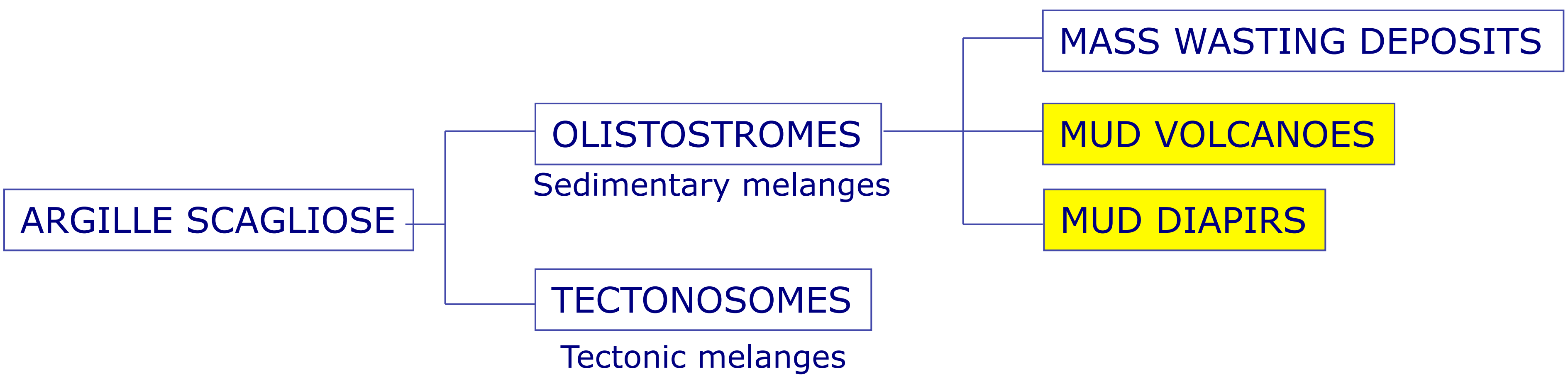
are **stacks of debris flow deposits** composed of fluid-rich, fine-grained sediments expelled on the Earth's surface or on the sea floor. During the ascent, the mud is able to carry litho-clasts of various size, shape, age, and composition.

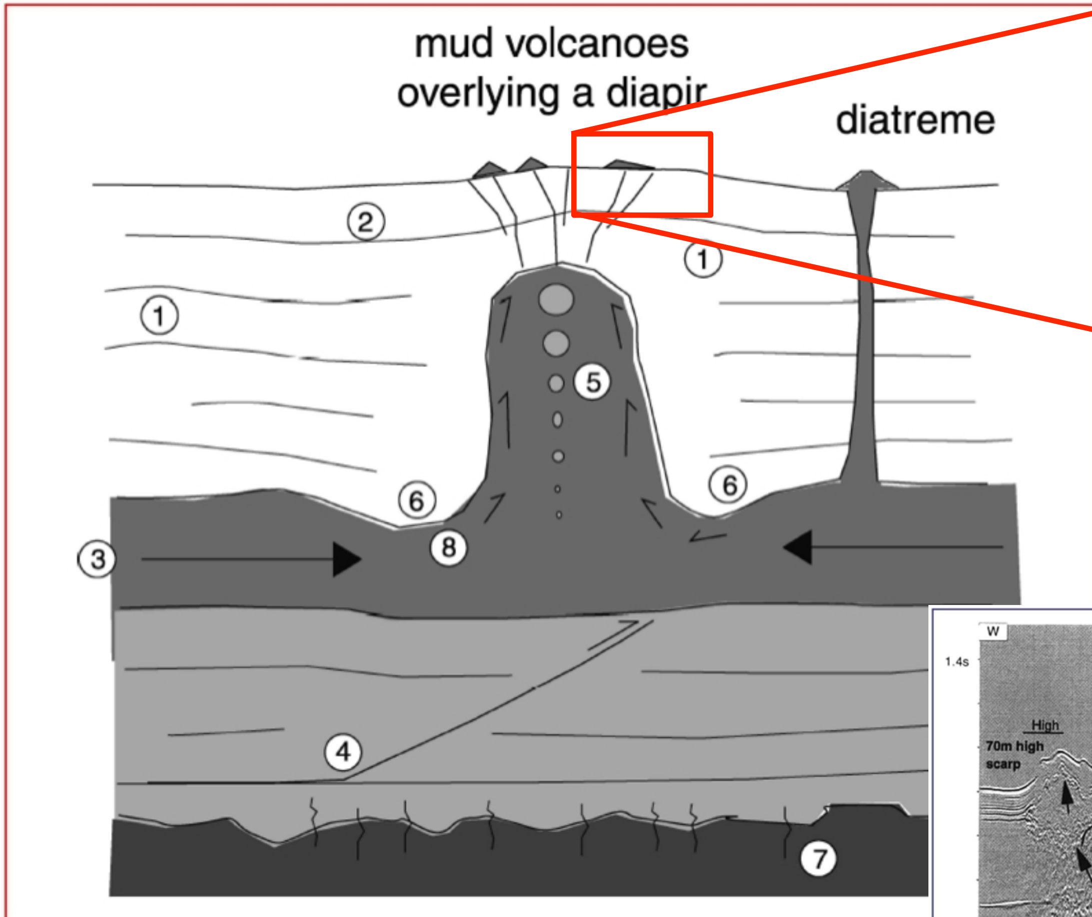
Mud volcanoes are often associated to **sedimentary diatremes** and **mud diapirs** (*shale diapirs, or clay diapirs*), all generated by subsurface overpressure of sedimentary (high accumulation rate), tectonic, or diagenetic origin following a state of **under-consolidation** in low-permeability sediments.

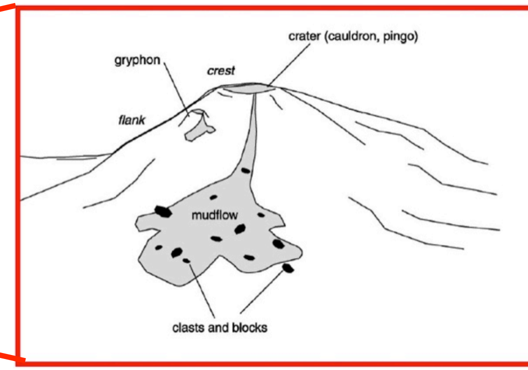
Although mud volcanoes occur in both divergent and convergent margins, they play an important role in the evolution of accretionary wedges, where they too participate in the **world wide controversy** about the origin and significance of **mèlanges.**

Olistostromes, or **sedimentary mèlanges:** uplifted and at times deformed **chaotic** sedimentary bodies (Cretaceous to Pliocene) originated by subacqueous mass gravitational processes, such as debris-flows, and submarine slides and/or mud volcanoes/diapirs.

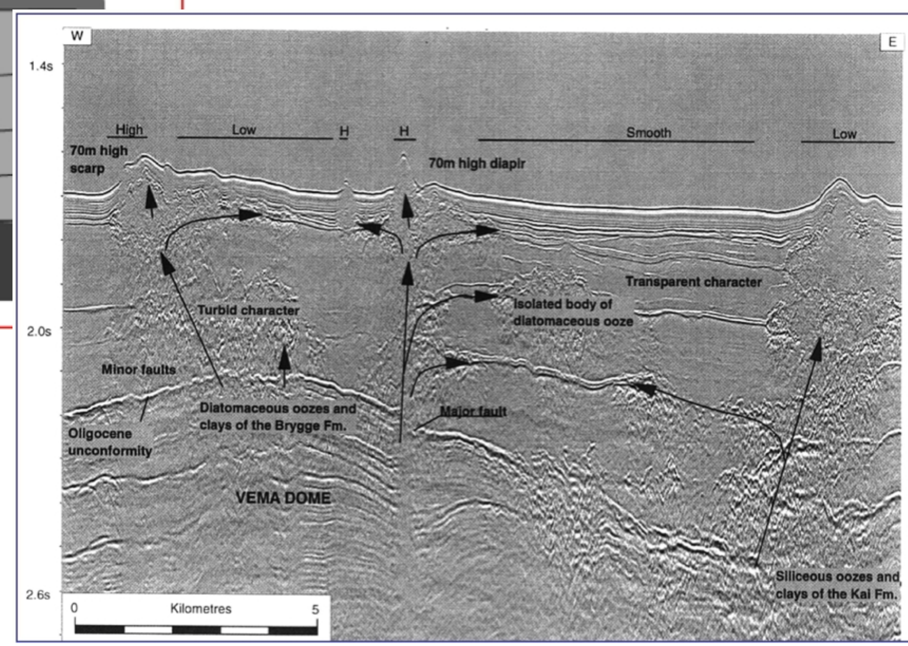
Tectonosomes, or **broken formations:** strongly deformed up to stratally disrupted Ligurian units, which retain their original stratigraphic coherence. They represent fossil, uplifted portions of the offscraping complexes of the Cretaceous-Eocene paleo-Apennine accretionary wedge.



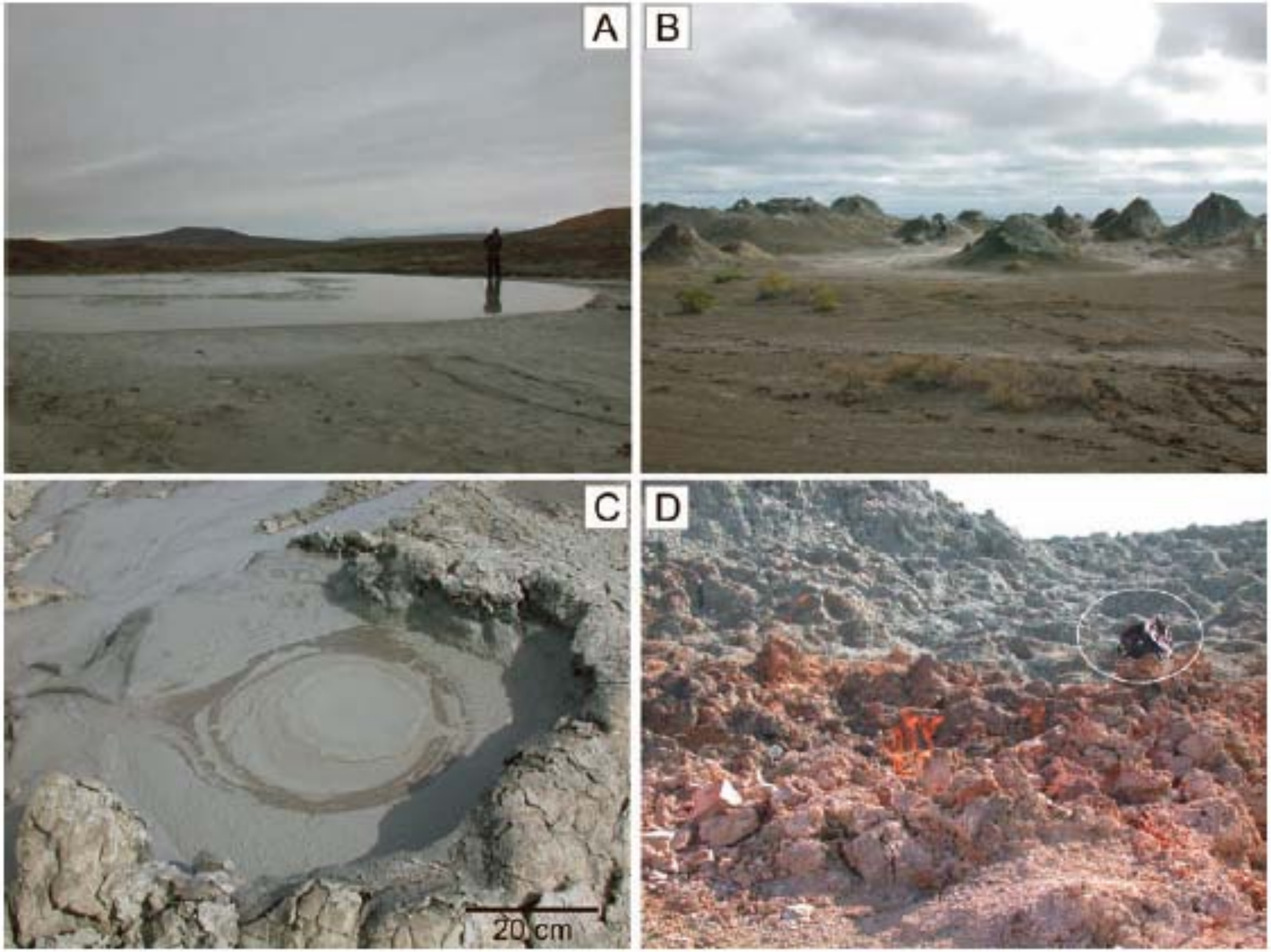




Kopf (2002)

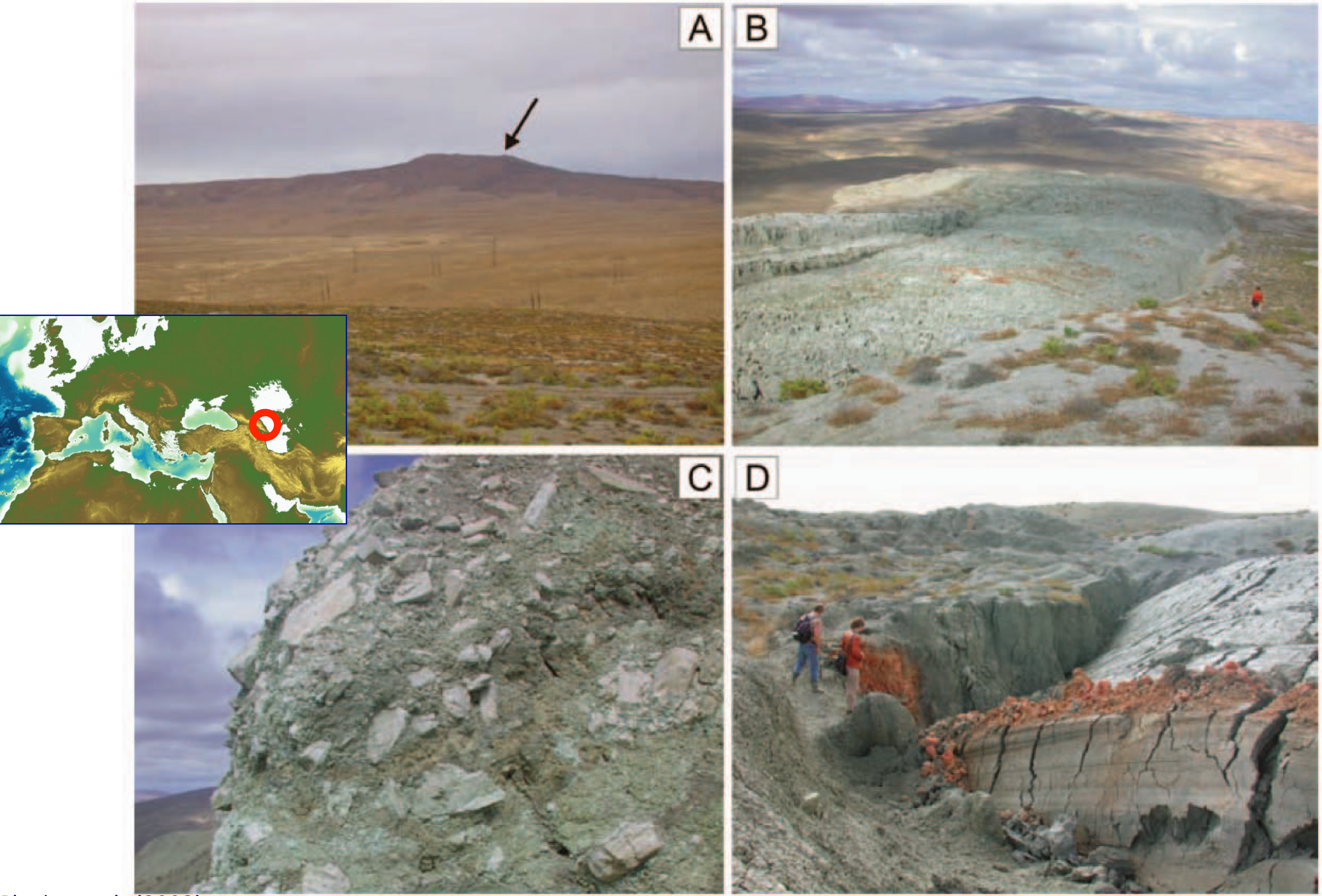


Hovland et al. (1998)



Seep structures and deposits on dormant mud volcanoes. A Salse A at the crater field of the Dashgil mud volcano, with the gryphon field to the west (B). C Hydrocarbons (black mud) in a gryphon at Bakhar. D Burning hydrocarbon gas in the vent at Lokbatan. The fire has been burning for more than a year since the October 2001 eruption (Figs. 2 and 3)

Planke et al (2003)



Planke et al (2003)

NATURAL FIRES OF AZERBEIJAN

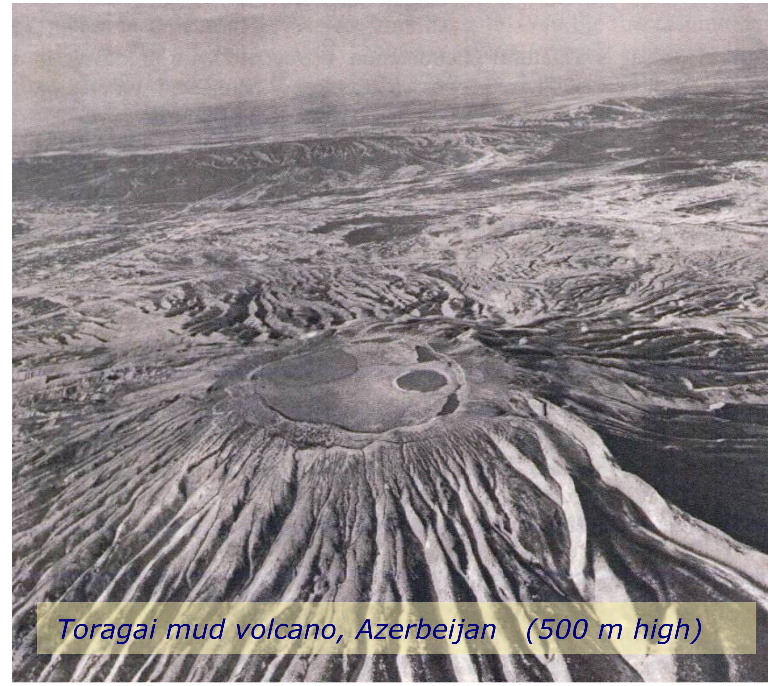
Marco Polo(?)

Images courtesy of Luis Piñero

The appearance of Zoroastrans in Azerbaijan and their cult of the eternal flame in the Temple of Fire of the Magi might be related to the fires from the mud volcanoes

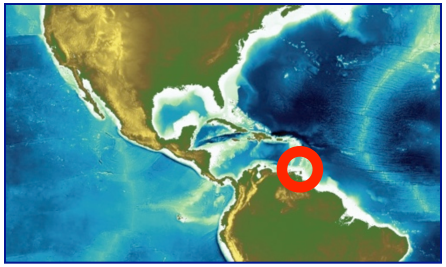
Planke et al. (2003)

Lokbatan Mud Volcano, Azerbeijan, 25 October 2001



Toragai mud volcano, Azerbeijan (500 m high)

Eruption Piparo, 22/2/1987

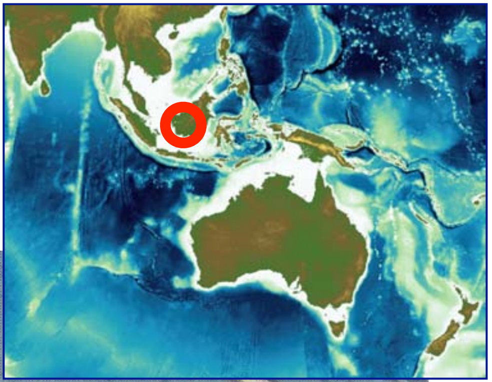


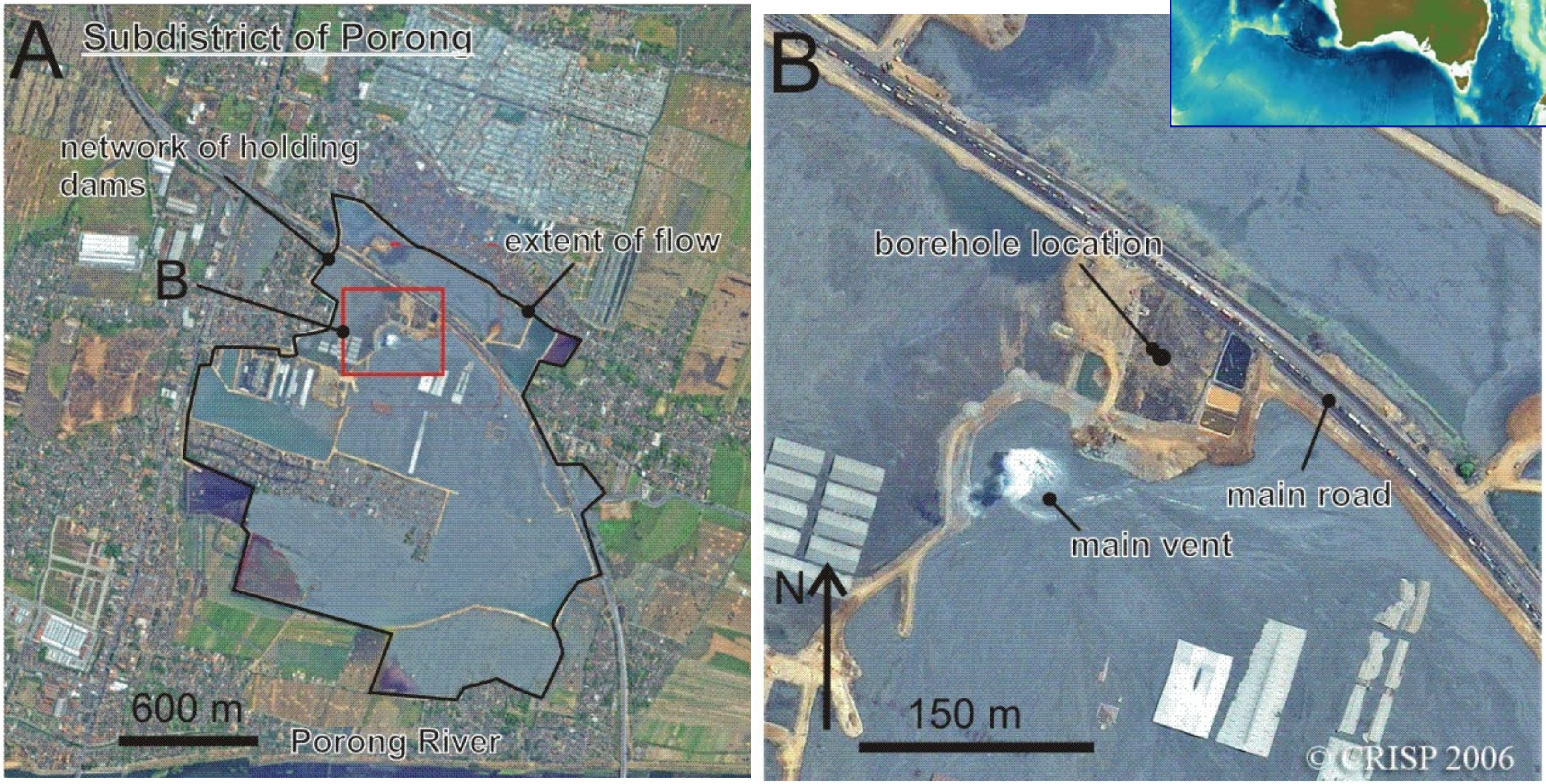
Piparo, Trinidad
22 Febbruary 1987

http://www.gstt.org/teaching/Devil's%20woodyard.htm


Sunday Guardian
• 25519
SUNDAY, FEBRUARY 23, 1997
$3
Taekwondo champion Cheryl-Ann Sankar is flying high — PAGE 19
SUNSHINE's Danella Callender cuddles up with teddy bear
Courtney Walsh is Windies captain against Indians – PAGE 6
Jeanille Bonterre is a shining star in ZONE
Volcano erupts
Mountain of mud leaves 31 Piparo families homeless
Trinidad Guardian
• 25520
MONDAY, FEBRUARY 24, 1997
$1.25
Volcano takes first life
Piparo resident dies after helping villagers
Mud mass
Piparo volcano erupts Page 3
Photos: STEPHEN AZIZ
TESTING THE MUD: Stepping lightly, Prime Minister Basdeo Panday examines the mud while visiting the site of the mud volcano which almost wiped out the entire Piparo Village in Central Trinidad last Saturday morning. Photo by TONY HOWELL.
Wed 26 Feb
Piparo villagers to be relocated
By LOUIS B HOMER
VICTIMS of the volcano eruption at Piparo are expected to be relocated either at Buen Intento, Stone Road Piparo, or a site on Ho-
Mosque, Prime Minister Basdeo Panday, who travelled by helicopter to the area, said the volcano eruption could be seen as another opportunity "to unite our people as one."
25 miles of roadway. Those listed for immediate attention are Piparo Guaracara Tabaquite Rd, Sisters Rd cho Road, Hoseinee Road, and Mayaro Road.

THE ENVIRONAMENTAL DISASTER OF THE MUD VOLCANOE TRIGGERED BY DRILLING FOR OIL IN JAVA: ISOLA DI GIAVA, MAY 29 2006

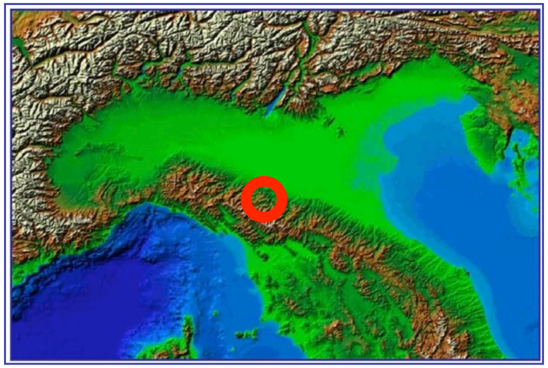




Davies, 2007, GSA-Today

SPIEGEL ONLINE International, Reuter

MUD VOLCANOES **SALSE DI NIRANO**, ITALY



How to recognize submarine mud volcanoes

1. Core samples showing 'mud breccia' containing sediments with a range of different ages, compositions and structures.
2. Strong backscatter on side-scan sonar records representing topographic features (craters, cones, mud flows, etc.).

To these we would add the following.

3. Evidence of gas seepage and associated features (bacterial mats, cold-seep communities or methanederived authigenic carbonate – MDAC).
4. High backscatter from ejected rock clasts, and/or from cold-seep communities and MDAC.
5. Seismic evidence of feeder channels and/or mud diapirs.
6. (For deep-water mud volcanoes) gas hydrates in an otherwise hydrate-free area.

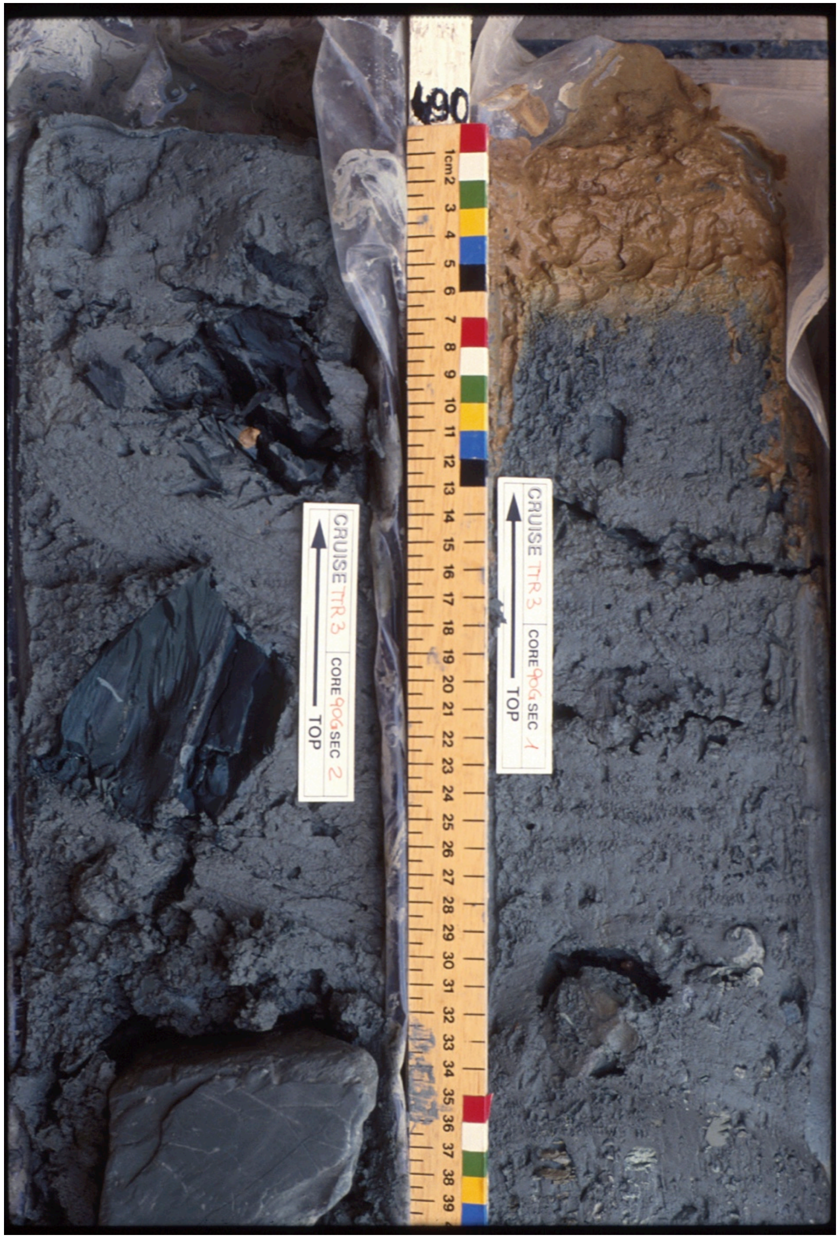
Classification of mud breccia from Mediterranea Sea mud volcanoes according to sedimentary facies

Lithotype or sedimentary facies	Description
A - MASSIVE	Matrix-supported clasts of soft to indurated marls. No size sorting observed in clasts and matrix.
MASSIVE A1	centimetric to pluri-centimetric clasts. Stiff matrix.
MASSIVE A2	millimetric clasts. Stiff matrix.
MASSIVE A3	mousse-like texture of the matrix produced by gas micro-vescicles
B - ORGANIZED	The mud breccia shows internal textural changes. The breccia can be either matrix- or clast-supported.
ORGANIZED B1	sub-horizontal (in sediment cores) bedding produced by thin layers of millimetric clasts sorted by size. No embricate structures observed.
ORGANIZED B2	upward graded grain-supported mud breccia. The matrix/clasts ratio increases upwards.
ORGANIZED B3	matrix supported mud breccia with patches (clouds) of different colors and composition.

(adapted from Camerlenghi et al., 1992 and Staffini et al., 1993).

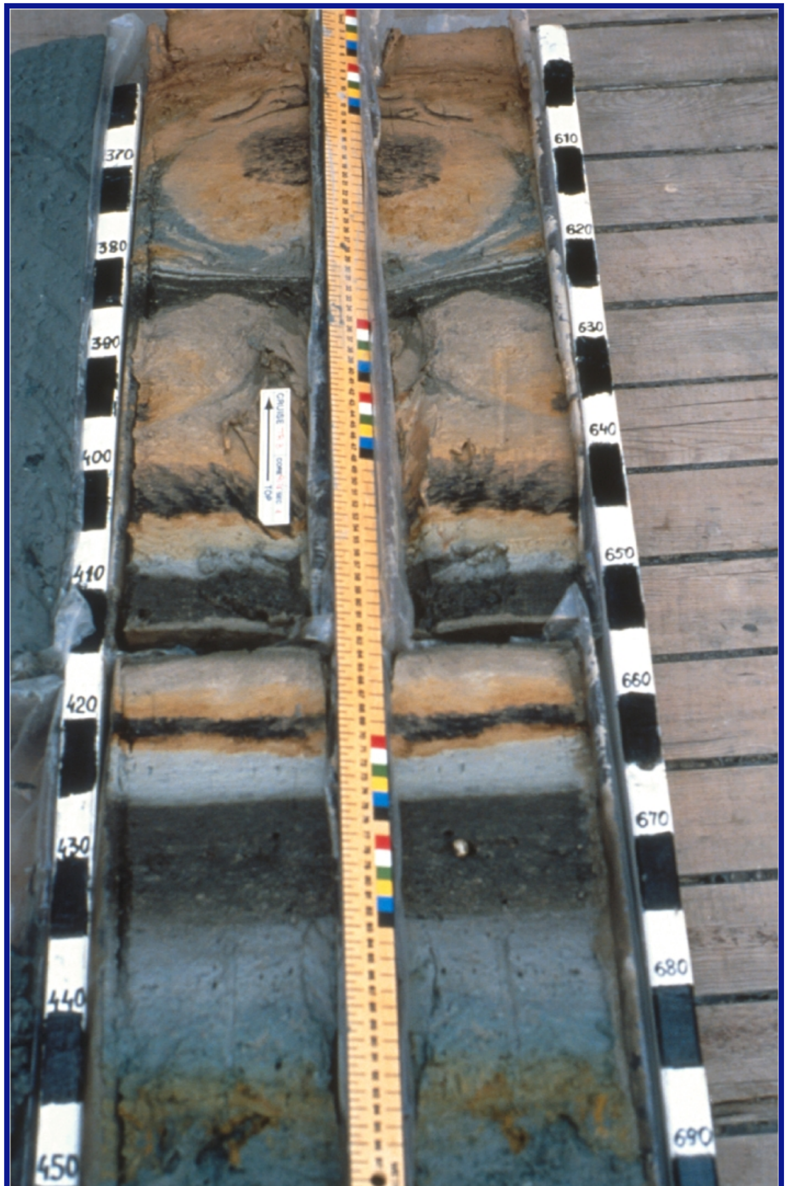
Dimitrov, 2002

Photo by Renata G. Lucchi



Clasts

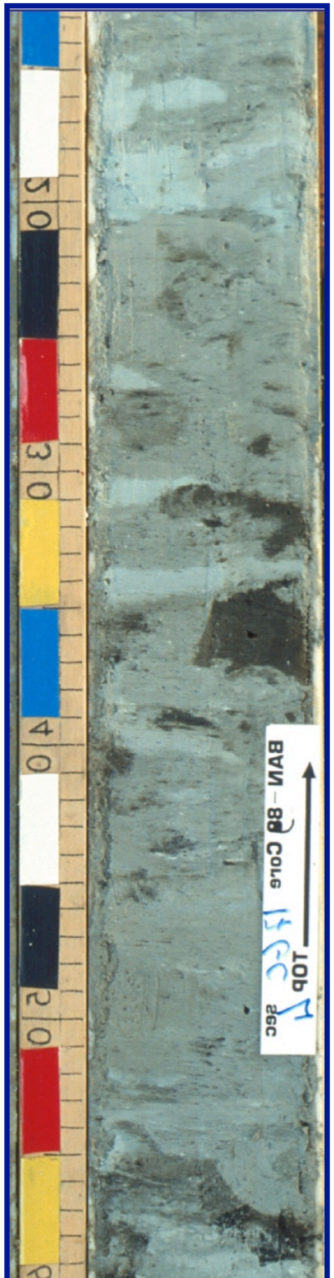
Courtesy Renata G. Lucchi



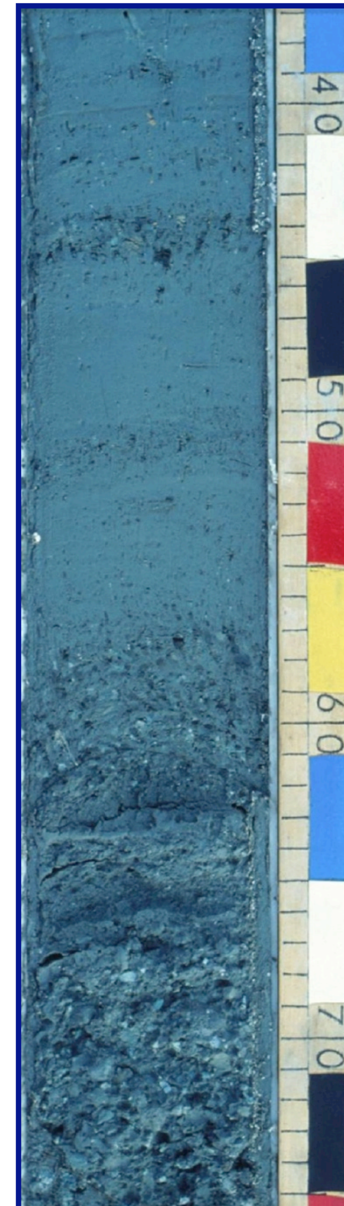
slumps

Photos by Renata G. Lucchi

Mud-breccia oxidized

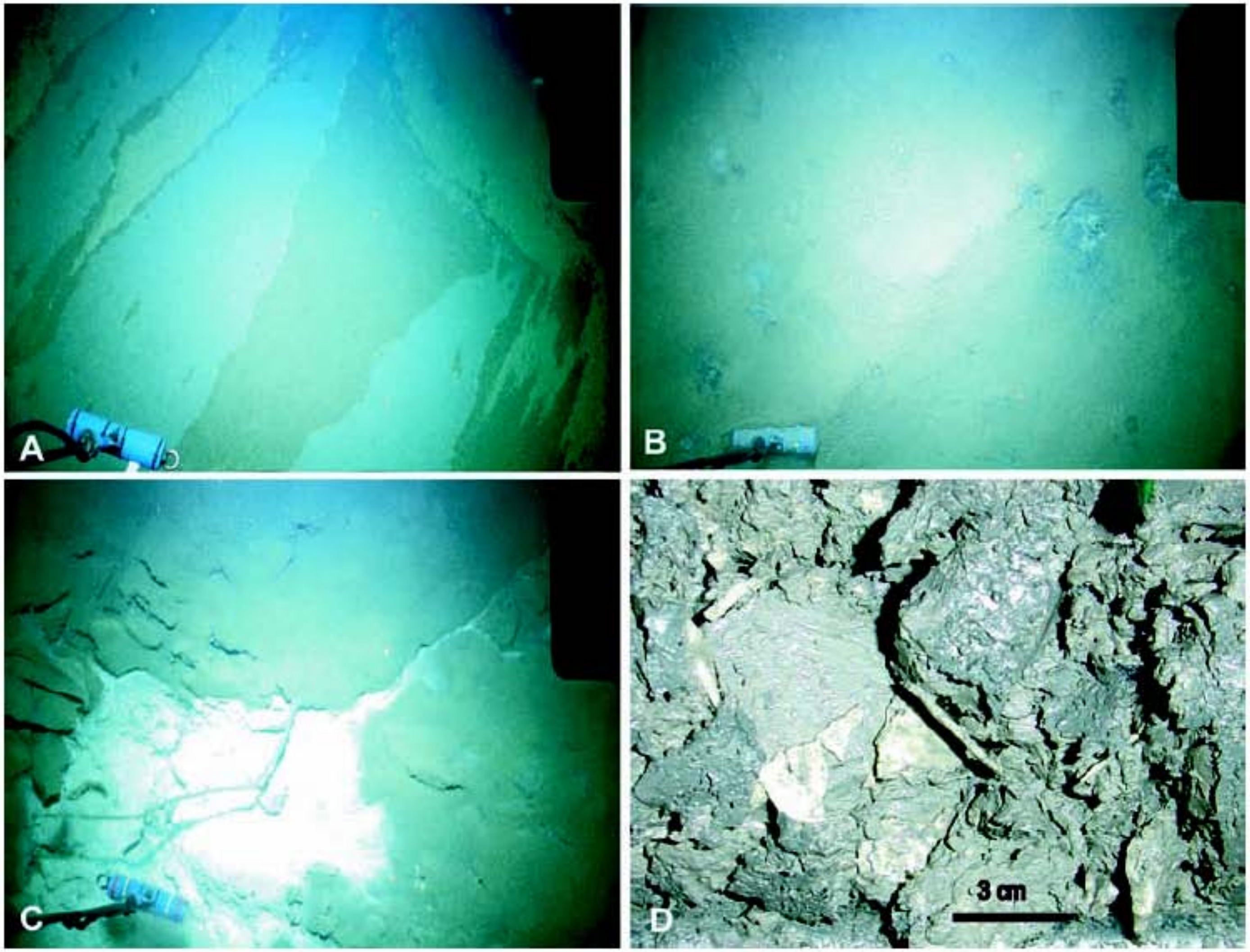


Mousse facies

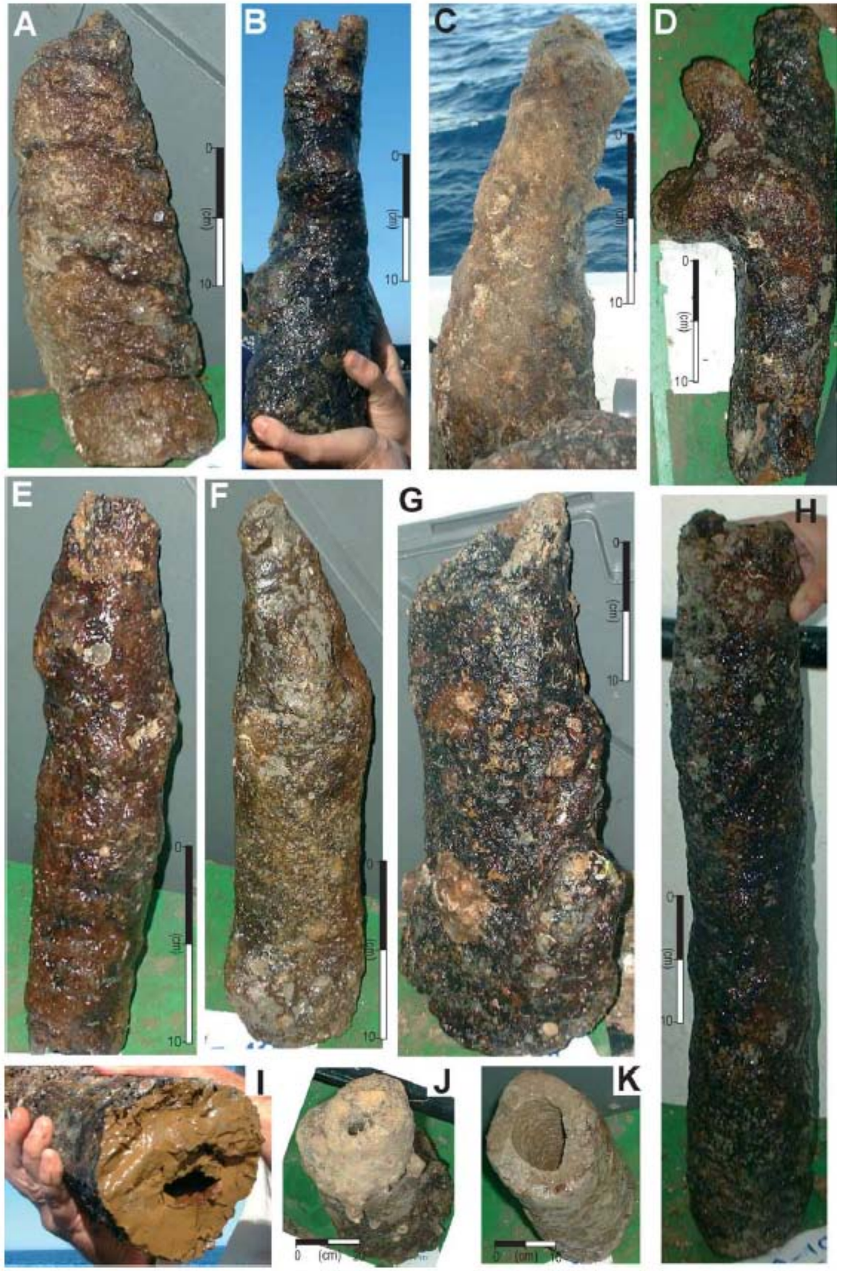


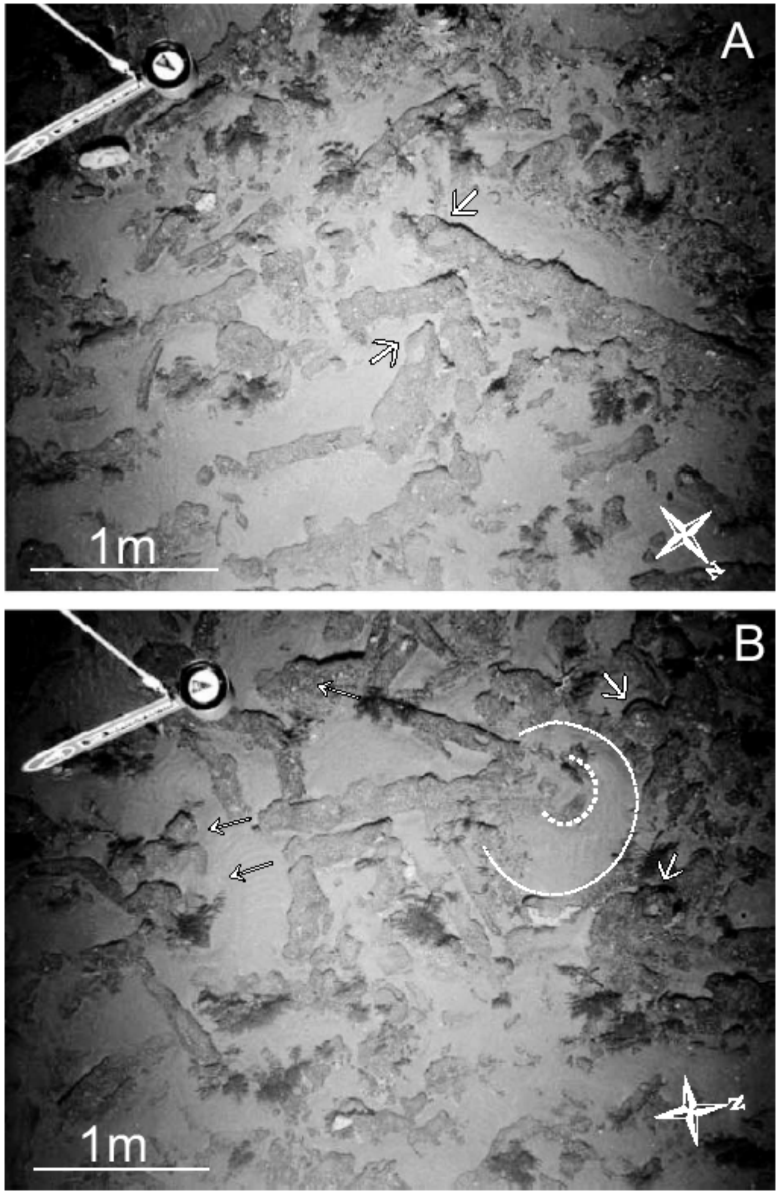
Organized facies

Fig. 4 Seafloor and sediment images from DMV (4A-C): **A** recent mud flow sheets from a seafloor fissure; **B** small vent sites from an area of seepage on DMV; **C** white bacterial mat in a seafloor crack on DMV; **D** fractured gas hydrate slabs in sediments from Odessa mudflow core M52/1-18



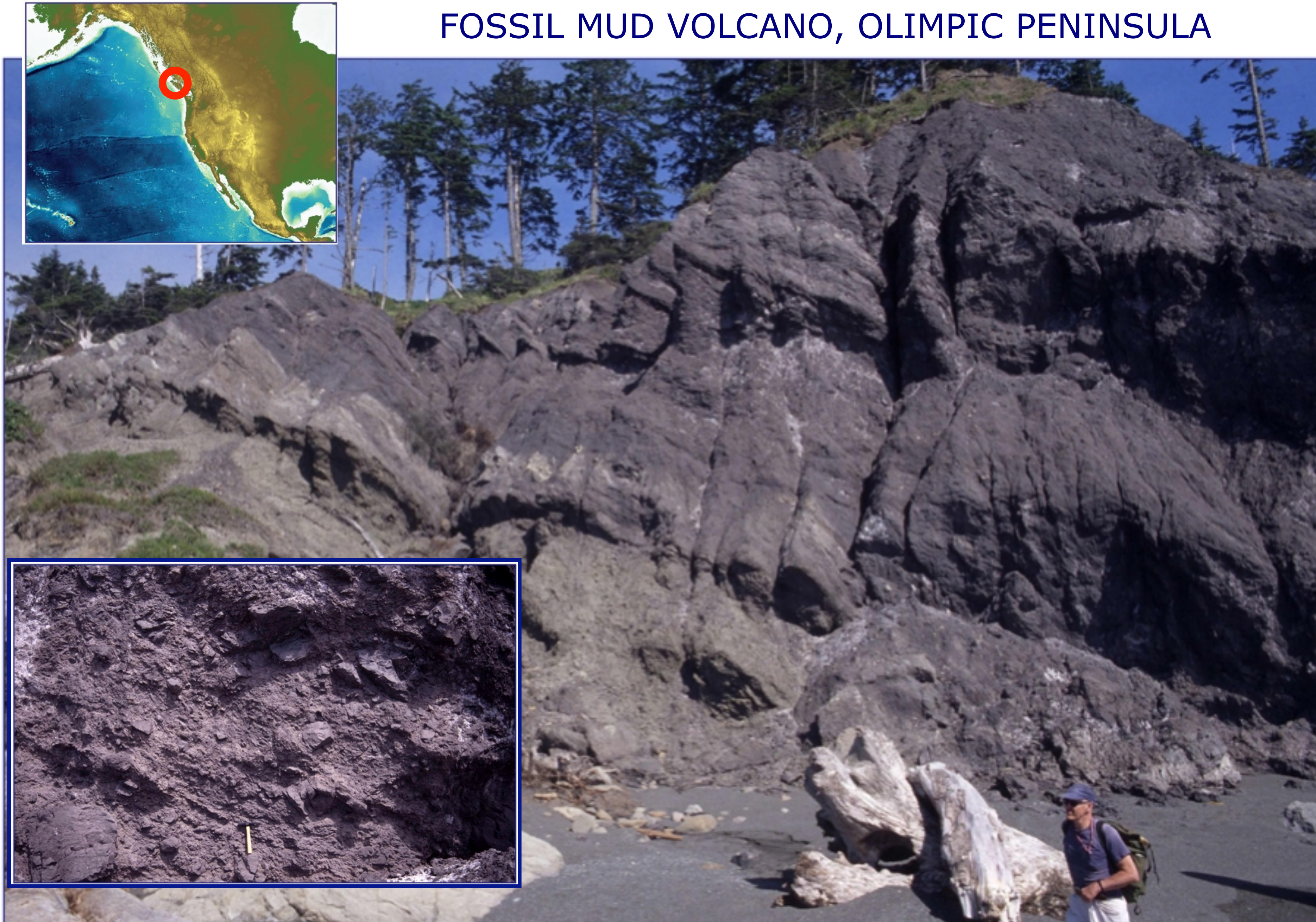
Bohrmann et al., Geo-Mar Lett (2003) 23: 239–249





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

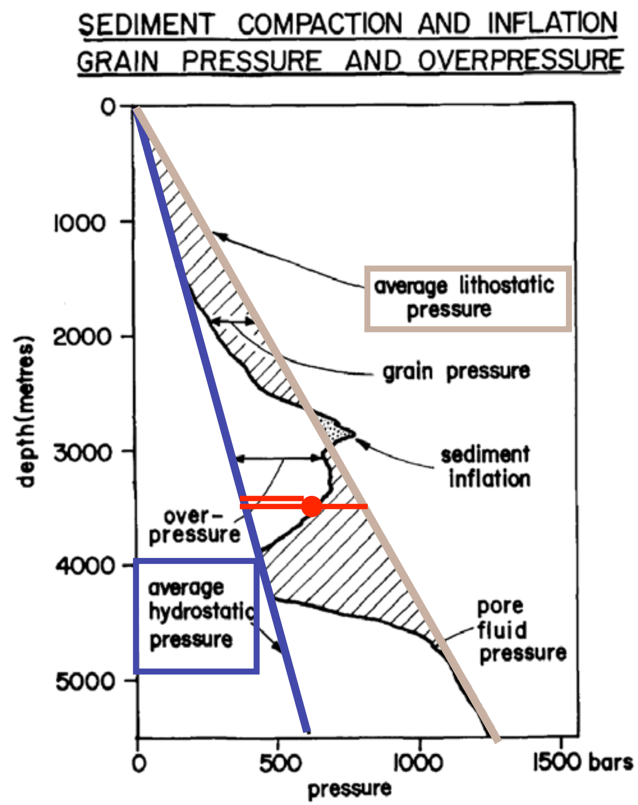
FOSSIL MUD VOLCANO, OLIMPIC PENINSULA



Degree of Overpressure

$$\lambda = (P_f - P_{hy}) / (P_d - P_{hy})$$

P_f = Pore pressure
P_{hy} = Hydrostatic Pressure
P_d = Total Stress

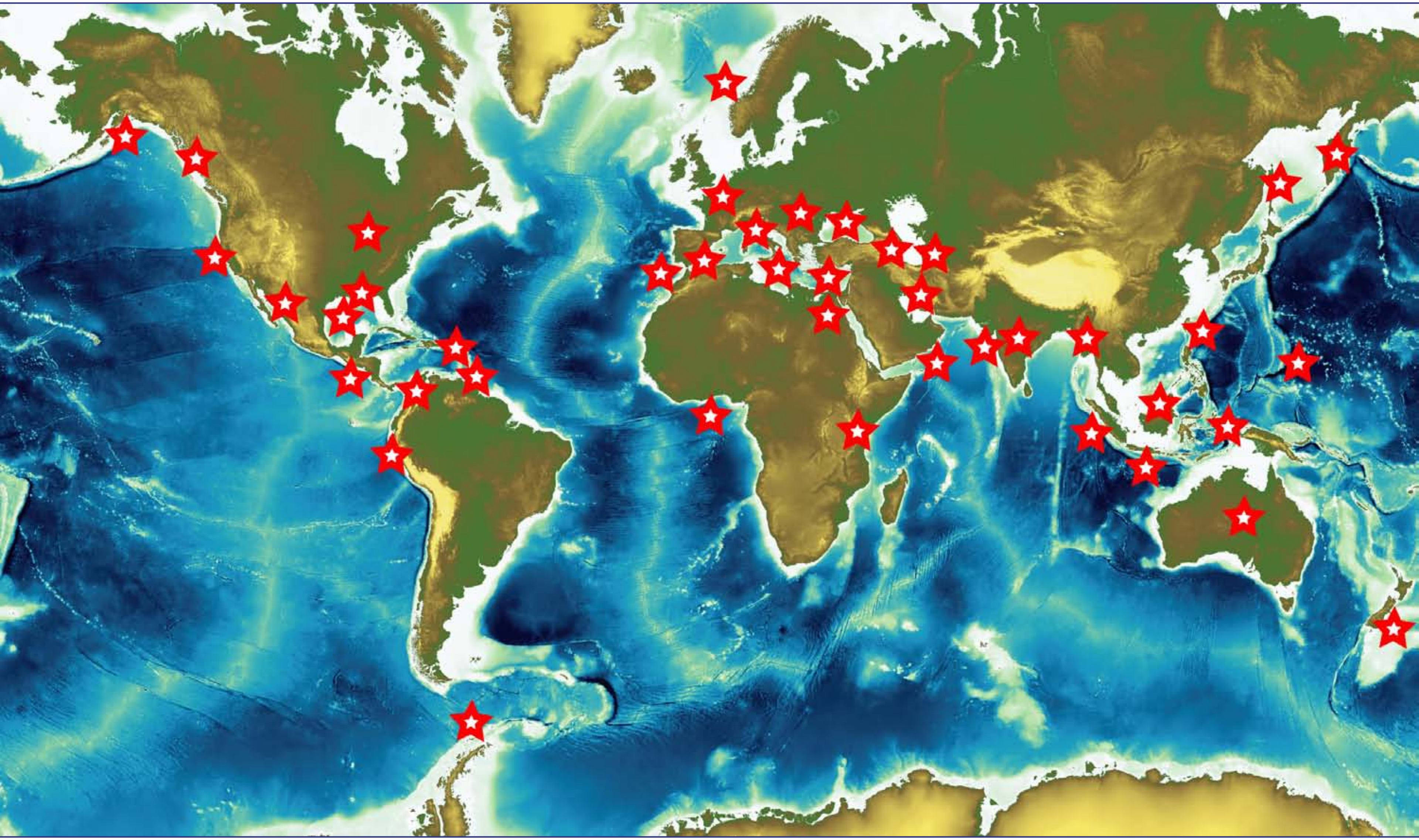


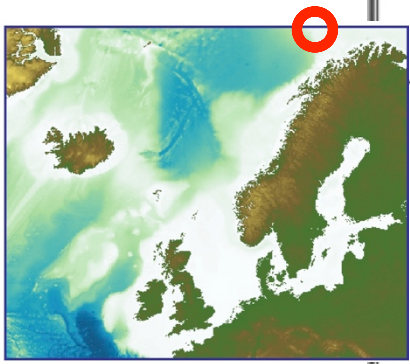
$$\lambda = 0 \text{ if } P_f = P_{hy}$$
$$\lambda = 1 \text{ if } P_f = P_d = \text{fluid movement (liquid mud)}$$

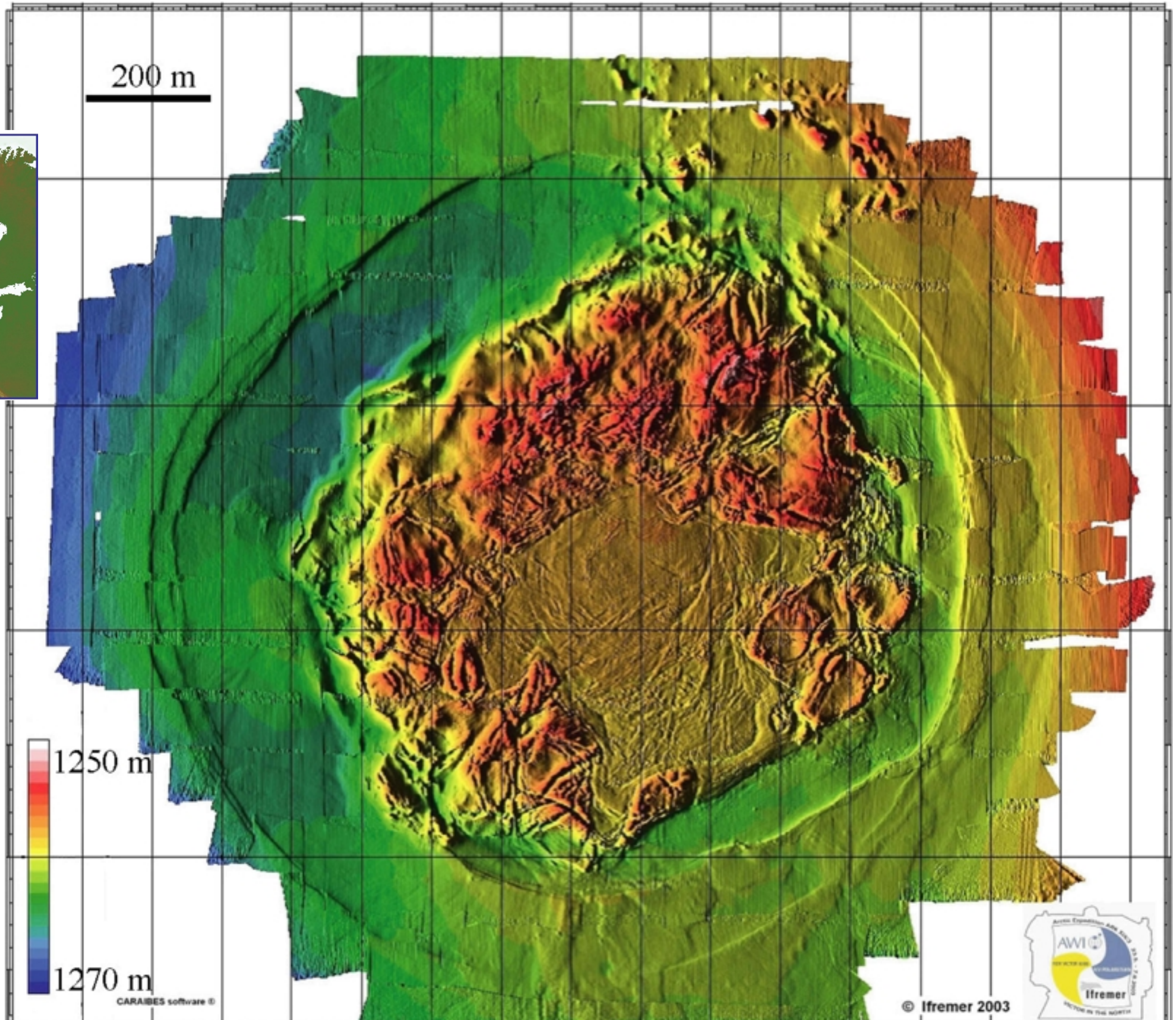
Mud diapirs move when $0<\lambda<1$

Brown, 1990

MUD VOLCANOES IN THE WORLD






200 m
1250 m
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CARAIBES software ©
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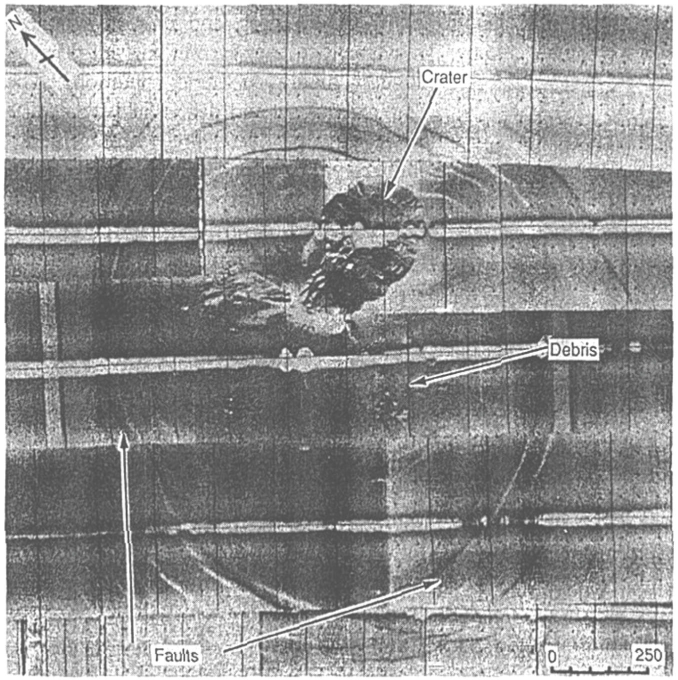
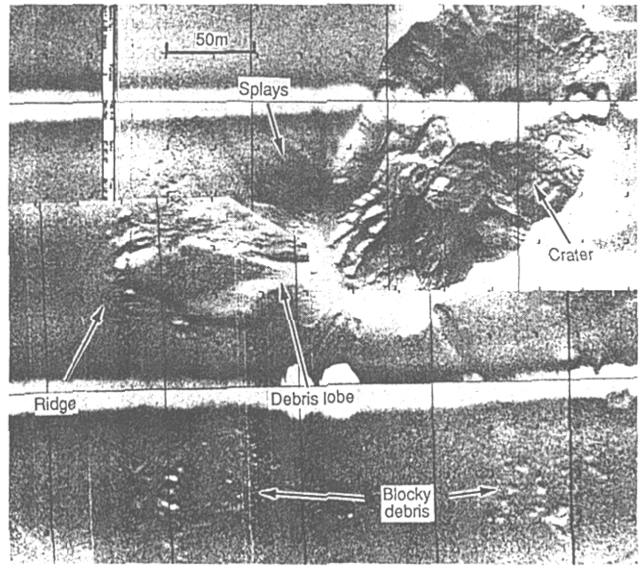
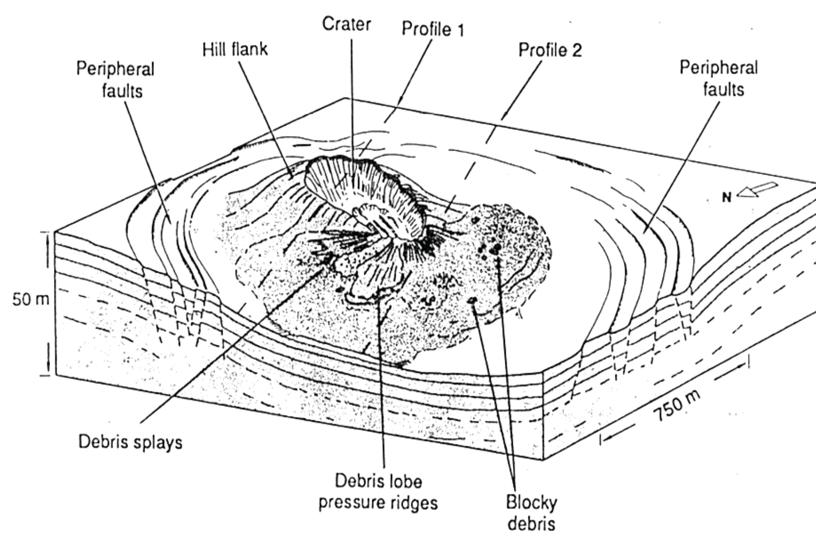
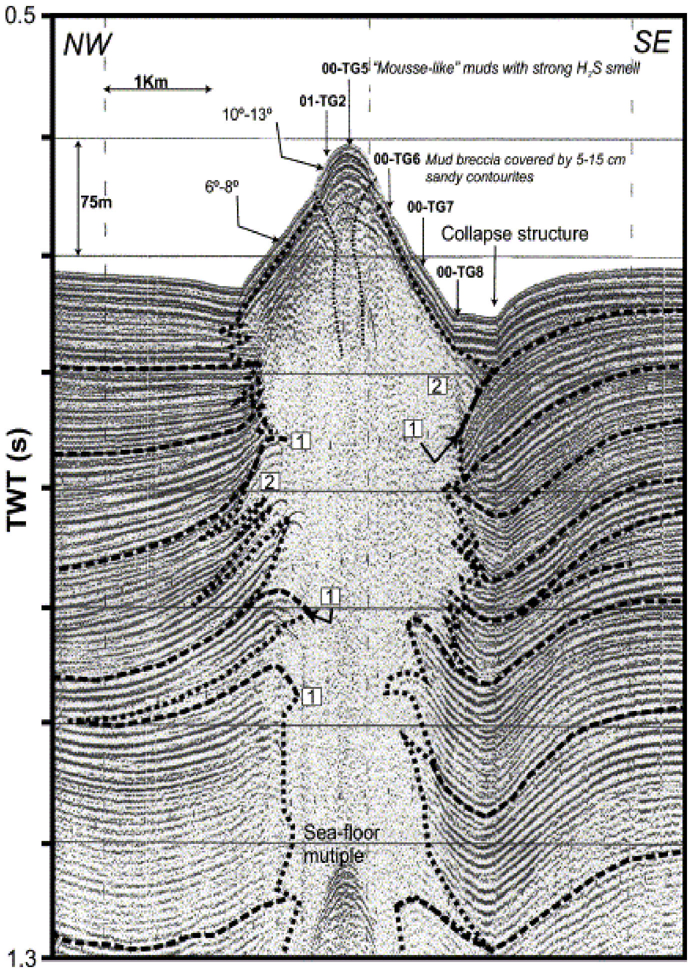
Mud volcanoes in the Gulf of Mexico

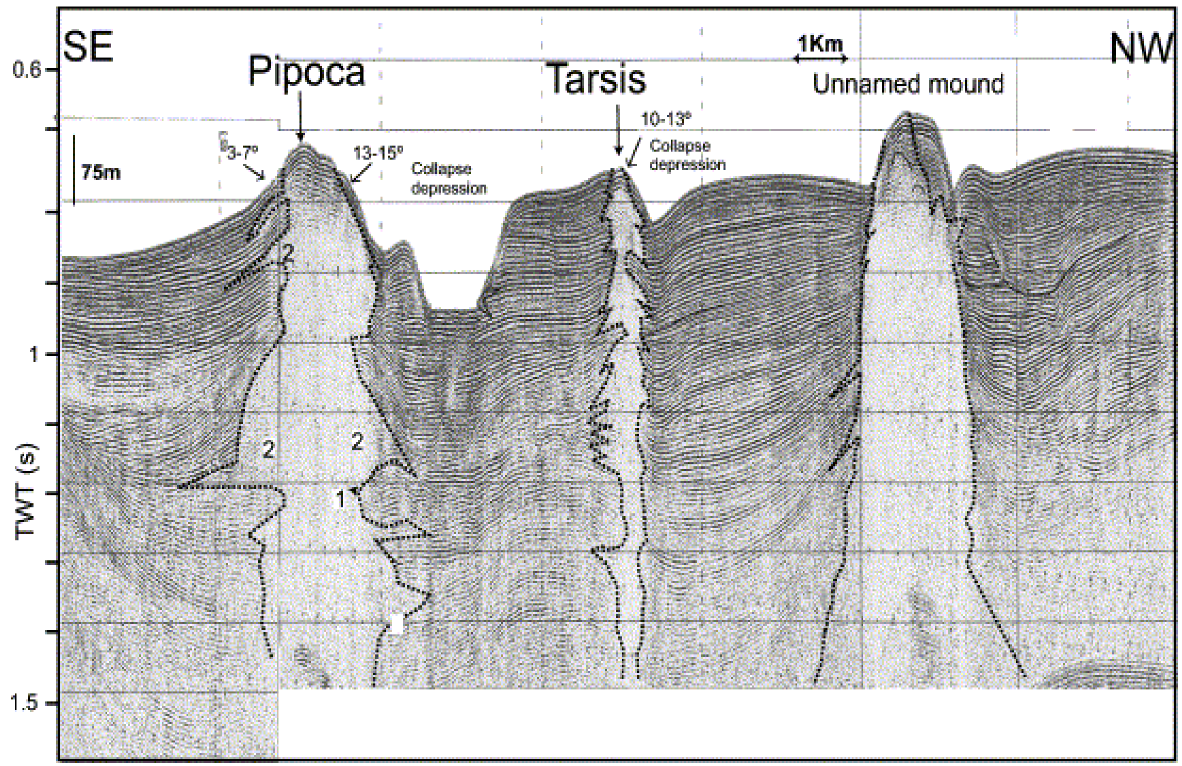






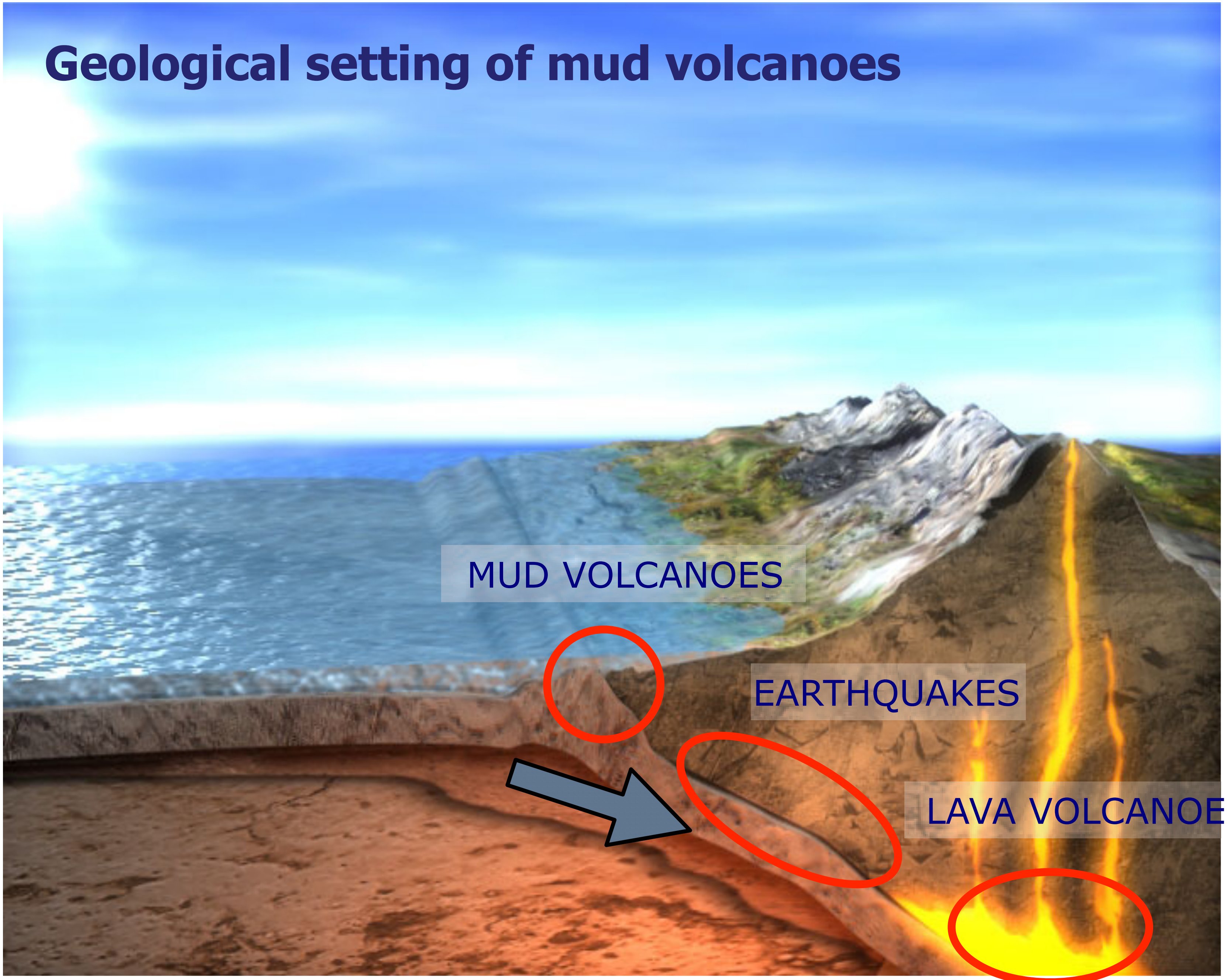
Prior et alii, Science 243 (1989), 517-519

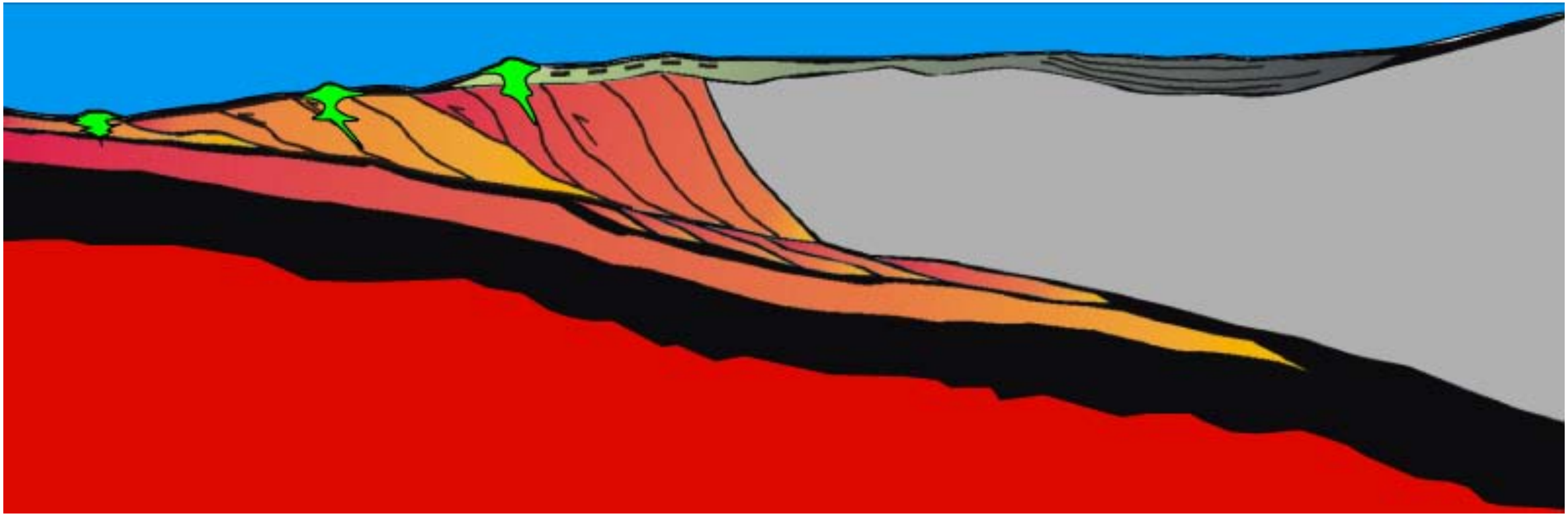


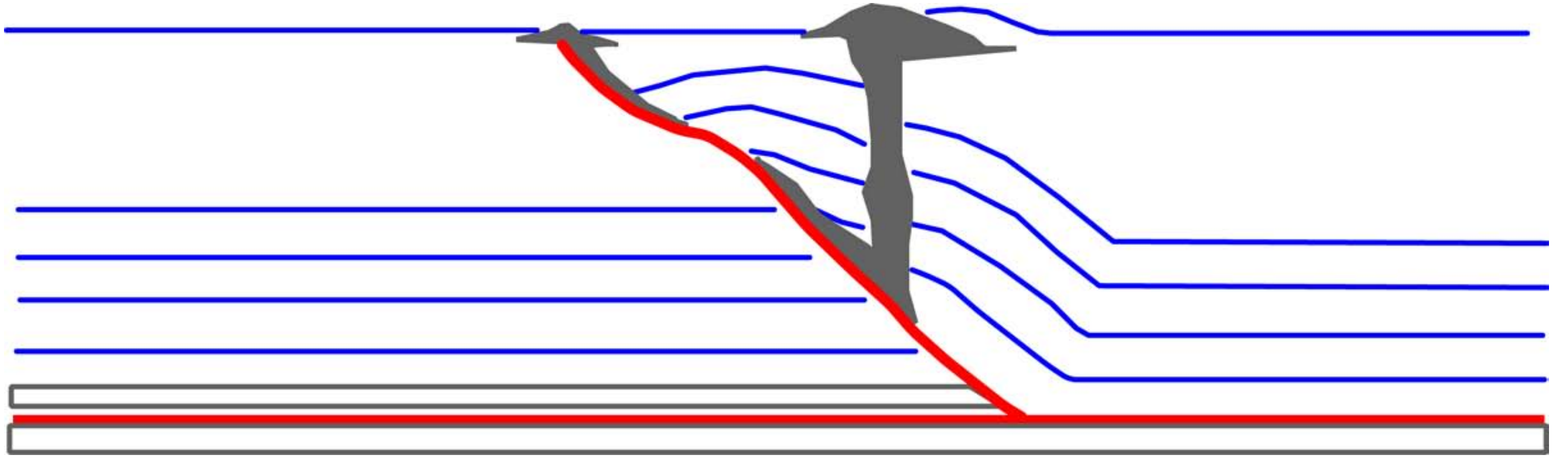


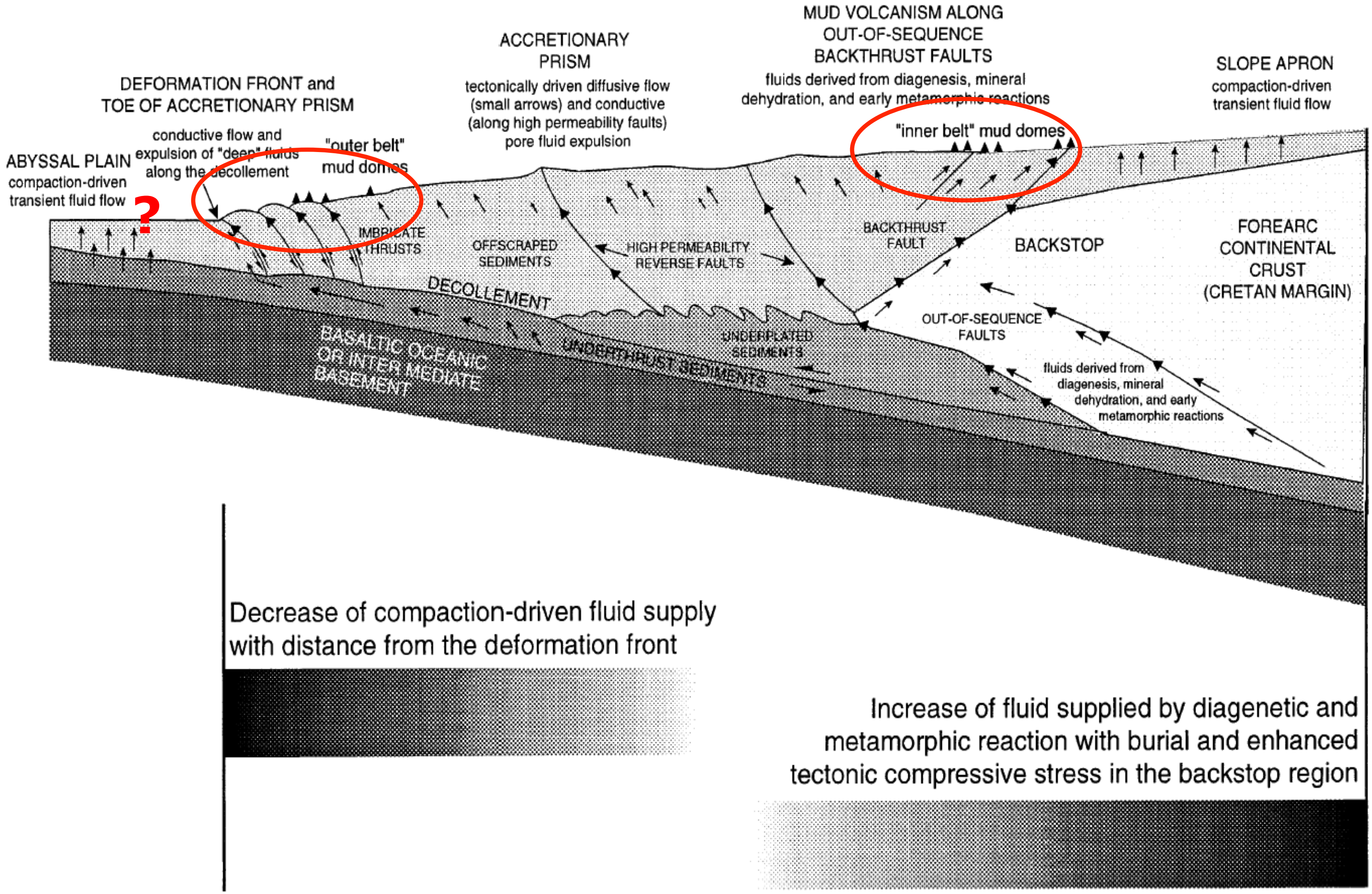
Somoza et al., Marine Geology 195, 1-4, 153-176

Geological setting of mud volcanoes

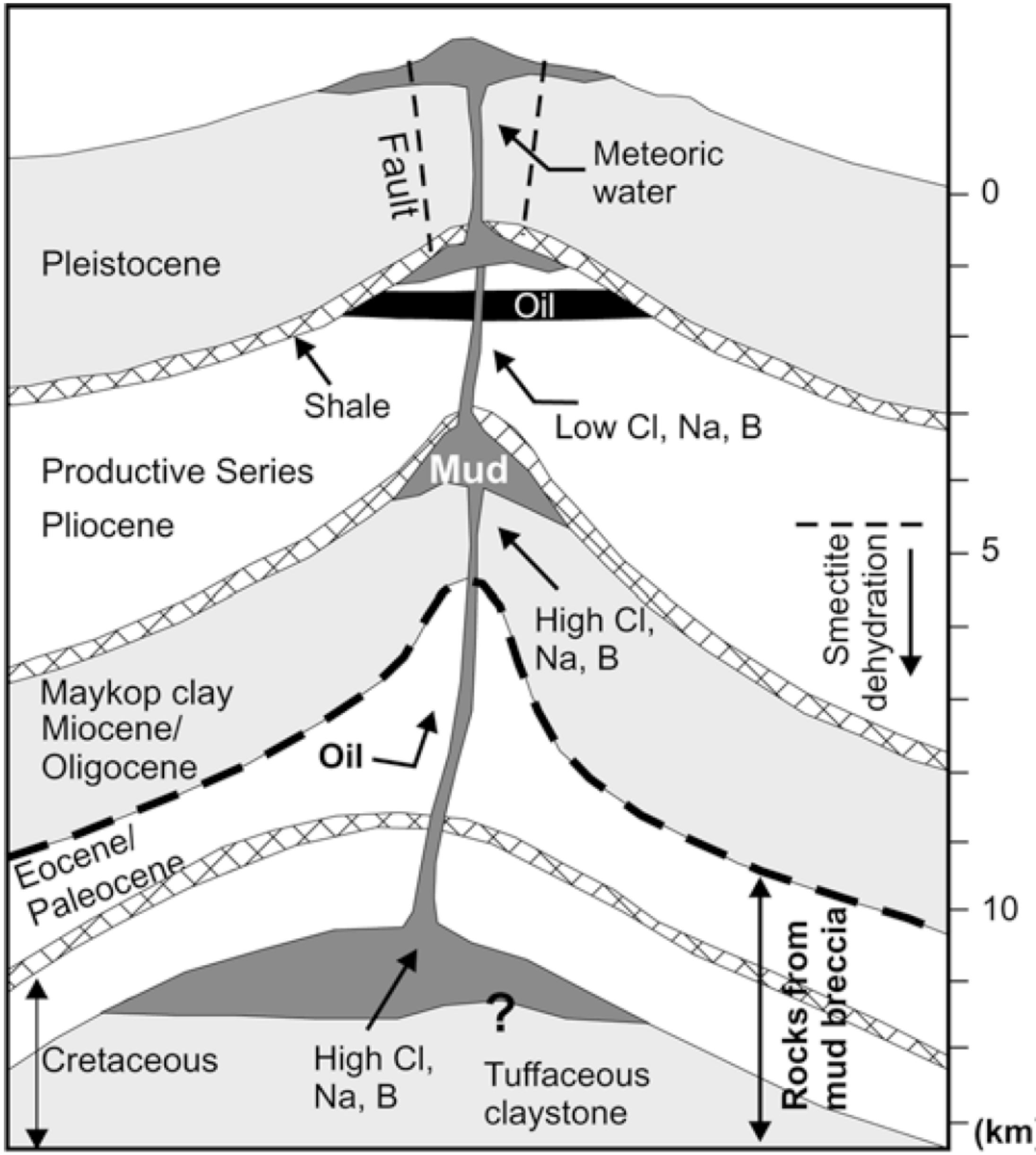






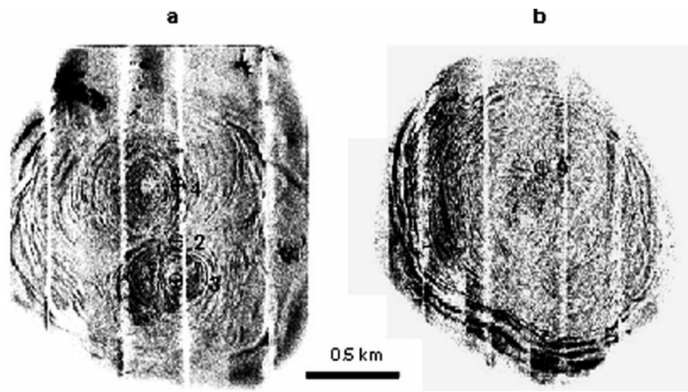


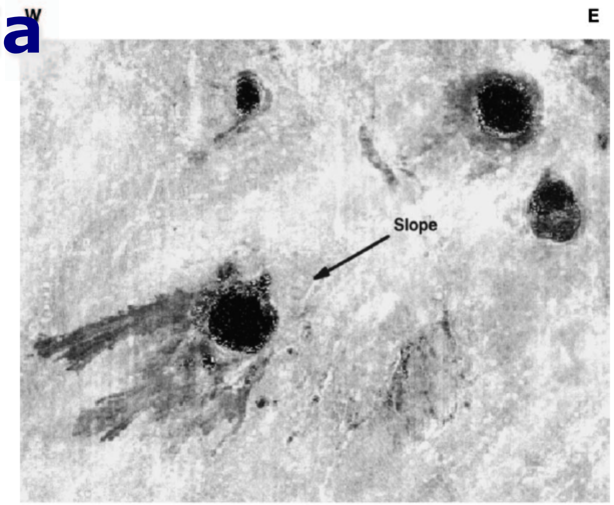
Kopf et al., EPSL, 189 (2001) 295-313

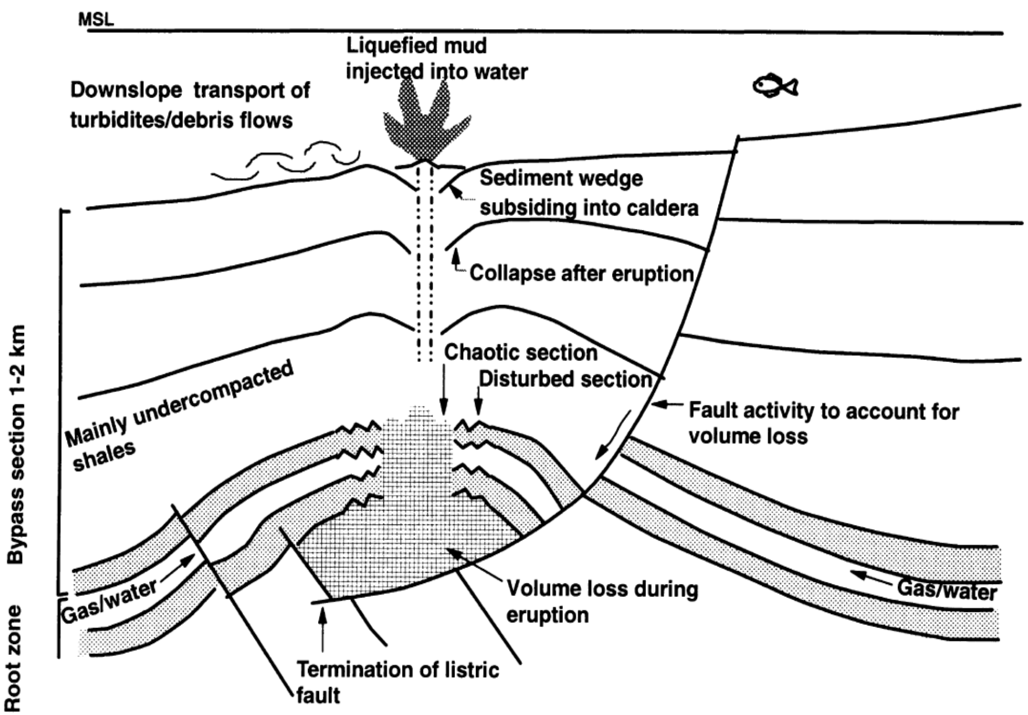


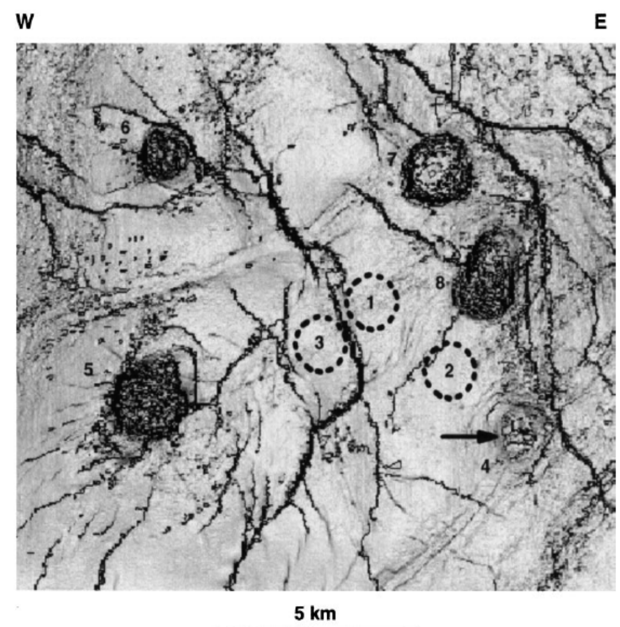
Planke et al. (2003)

Mud volcanoes offshore Nigeria









Graue, Marine and Petroleum Geology 17 (2000) 959–974

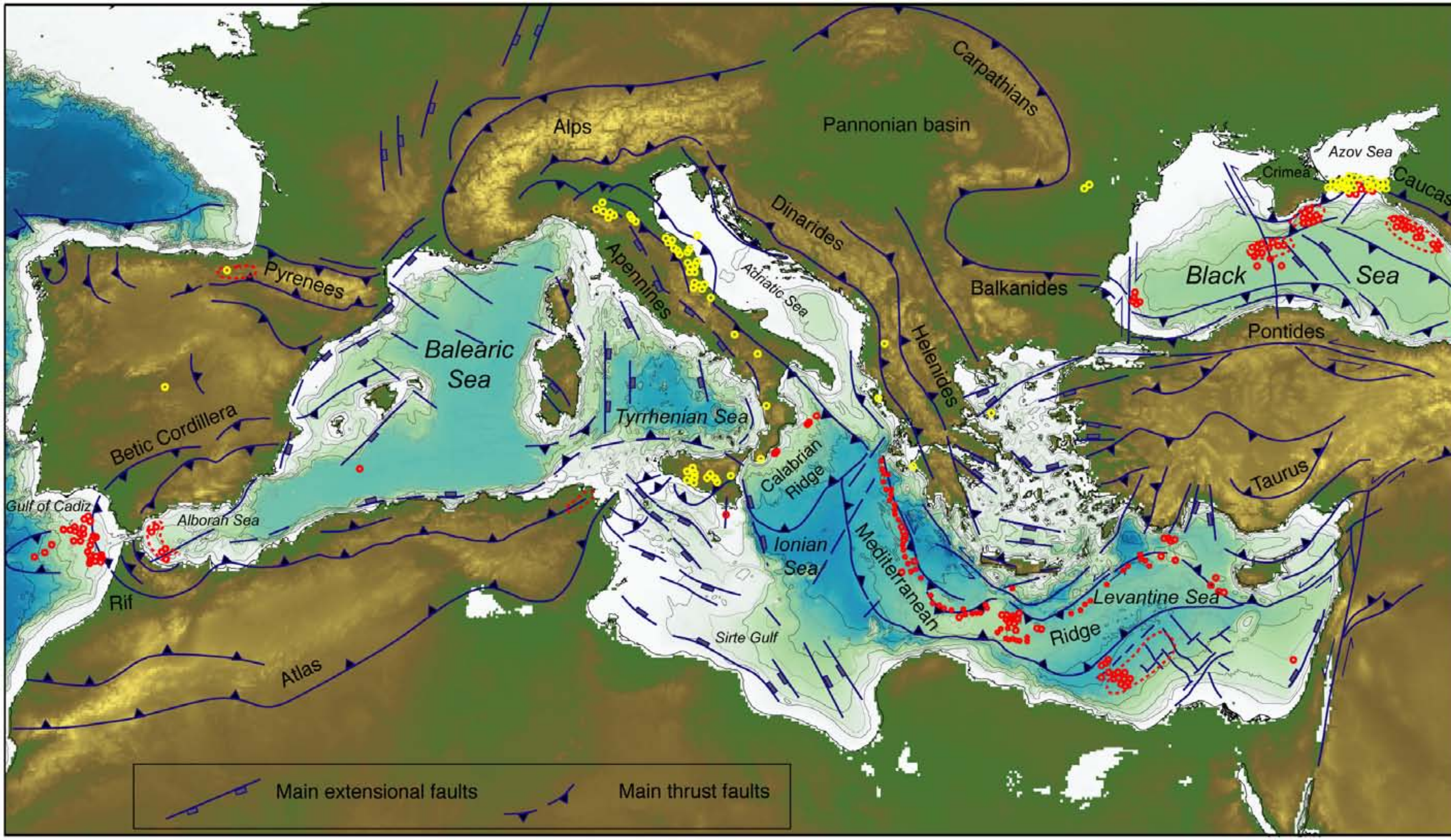
THE DISCOVERY OF SUBMARINE MUD VOLCANOES IN THE MEDITERRANEAN SEA

- **1981** Mud volcanoes were first reported in the Eastern Mediterranean by M.B. Cita, W.B. Ryan and L. Paggi.

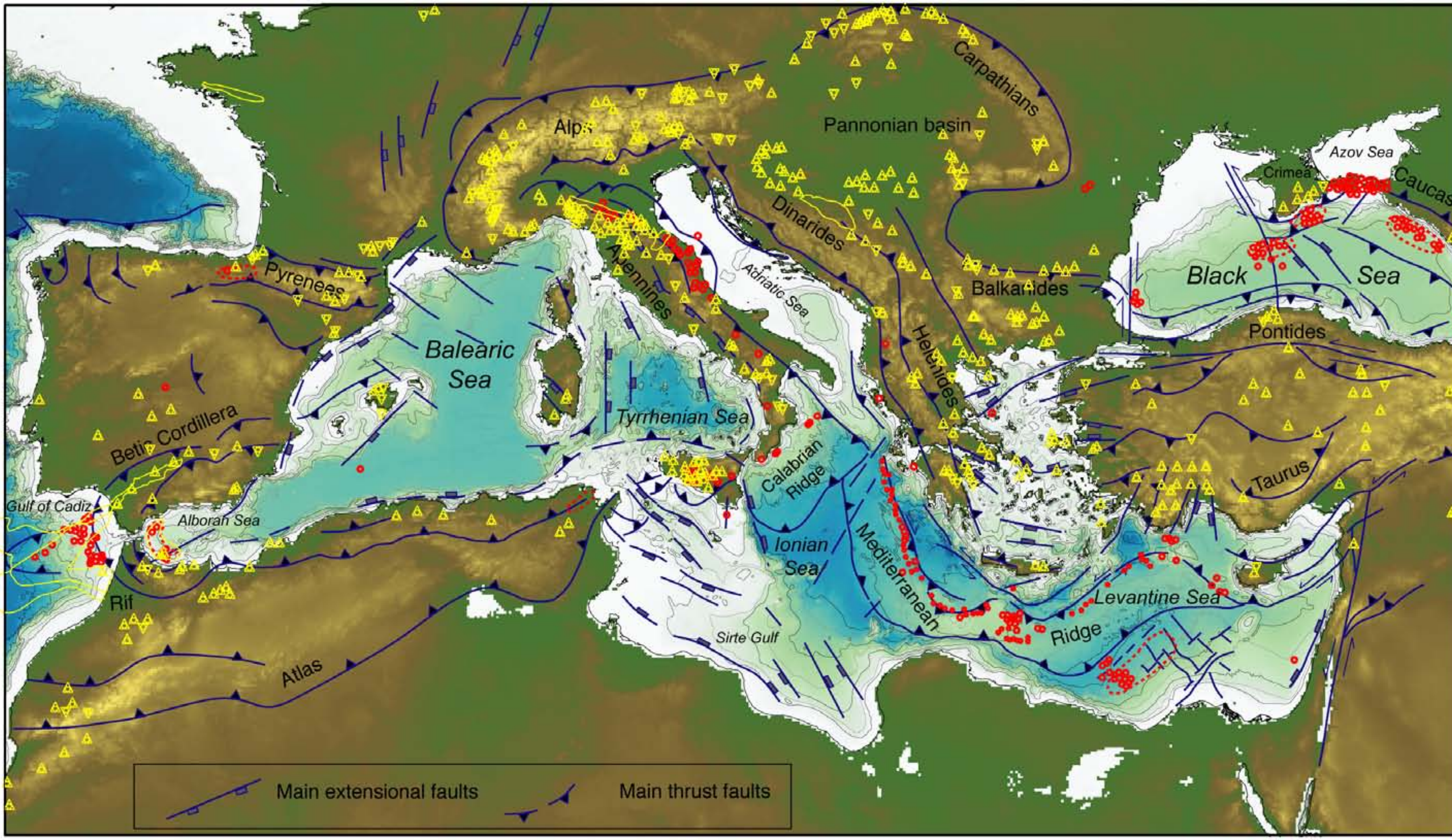
The Prometheus dome was identified according to:

Morphology: wrinkled surface of small concentric ridges;
Acoustic character: no penetration, no coherent reflections
Lithologic composition : **MUD BRECCIA**, structureless pebbly mud with dominantly angular semi-indurated clasts of various, non carbonatic composition. The matrix contains foraminiferal species dating to the Aptian-Cenomanian.

It was interpreted as a SHALE DIAPIR, and a comparison between the chaotic sedimentary facies of the Prometheus dome and the Argille Scagliose was immediately presented to the public.



Camerlenghi and Pini, 2009



Camerlenghi and Pini, 2009

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B2 - 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

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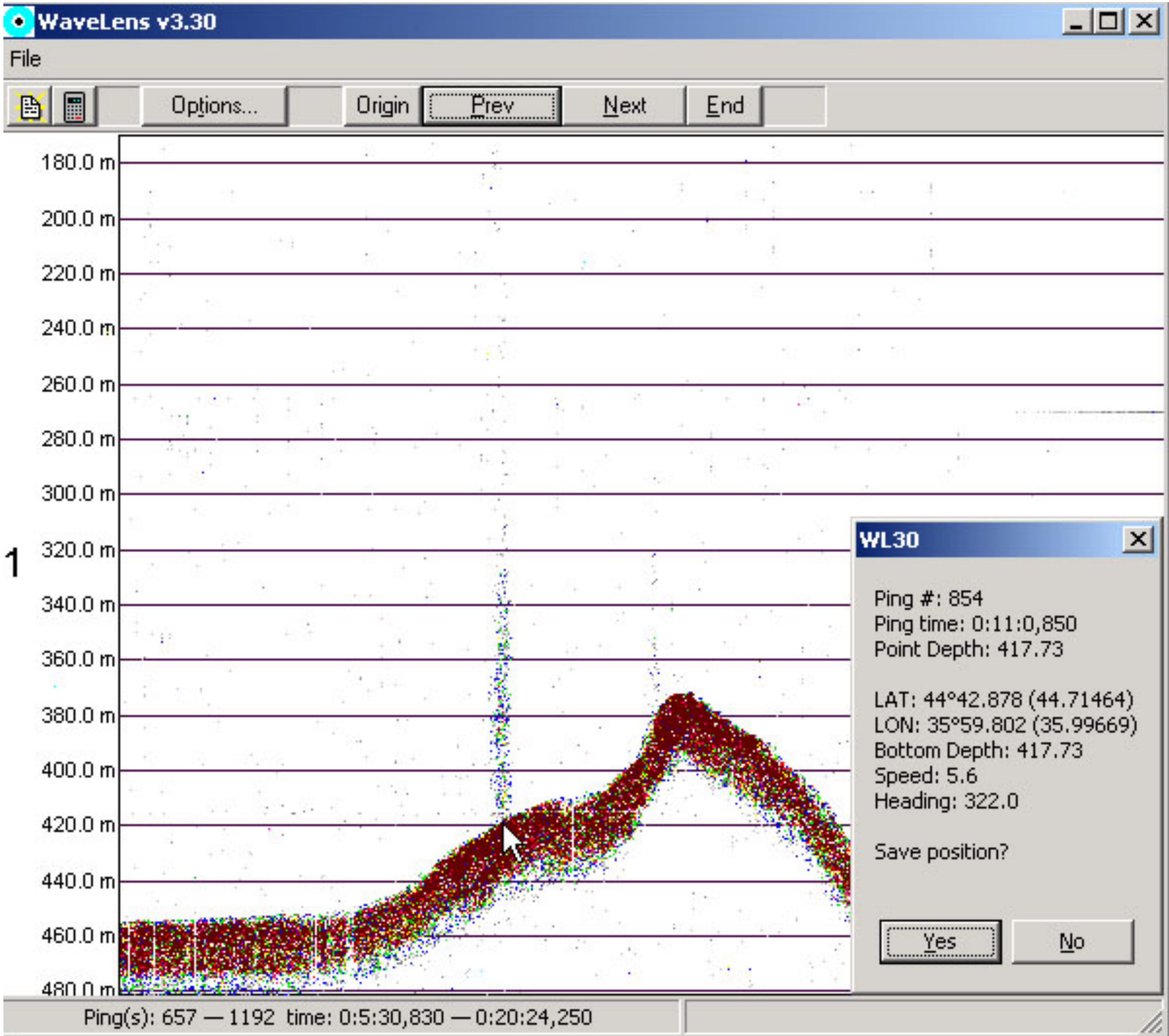
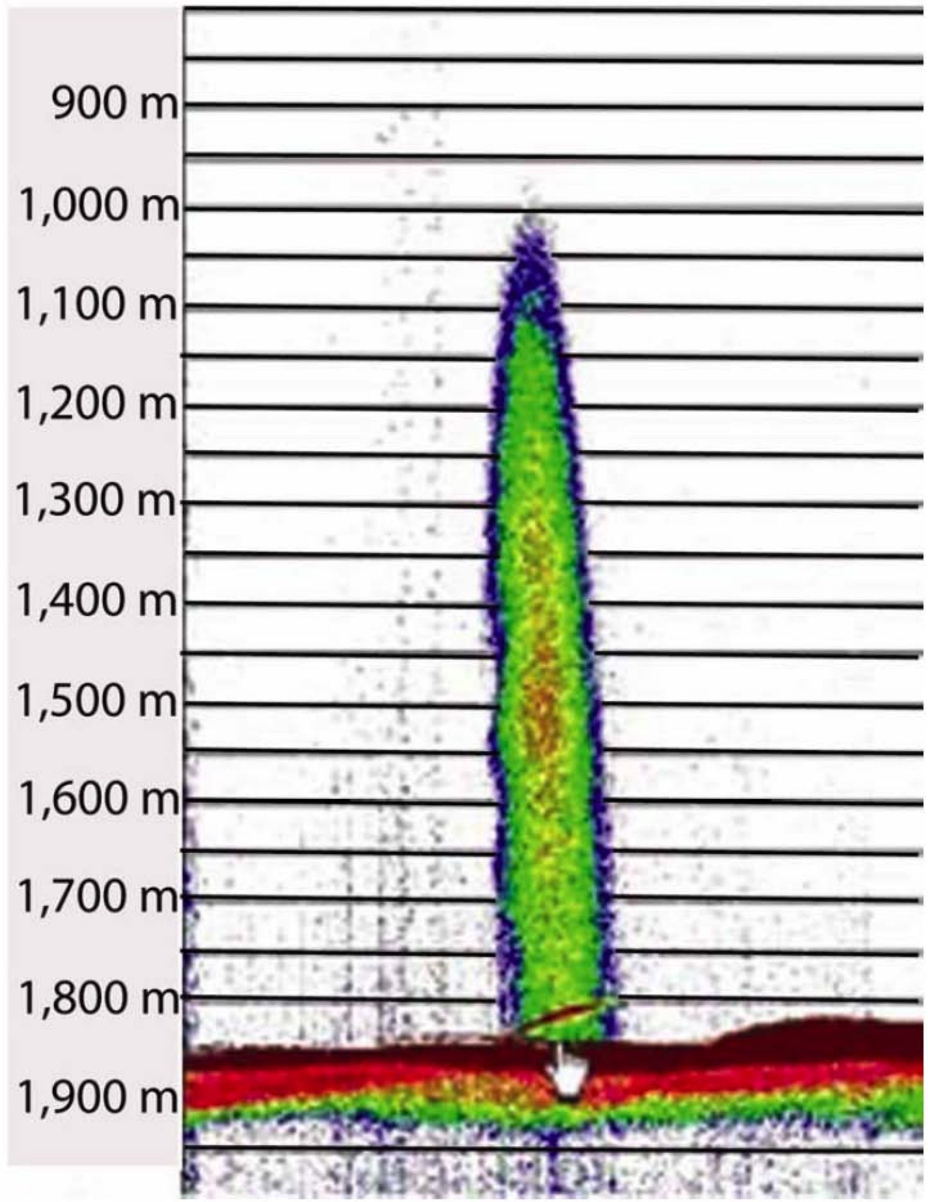
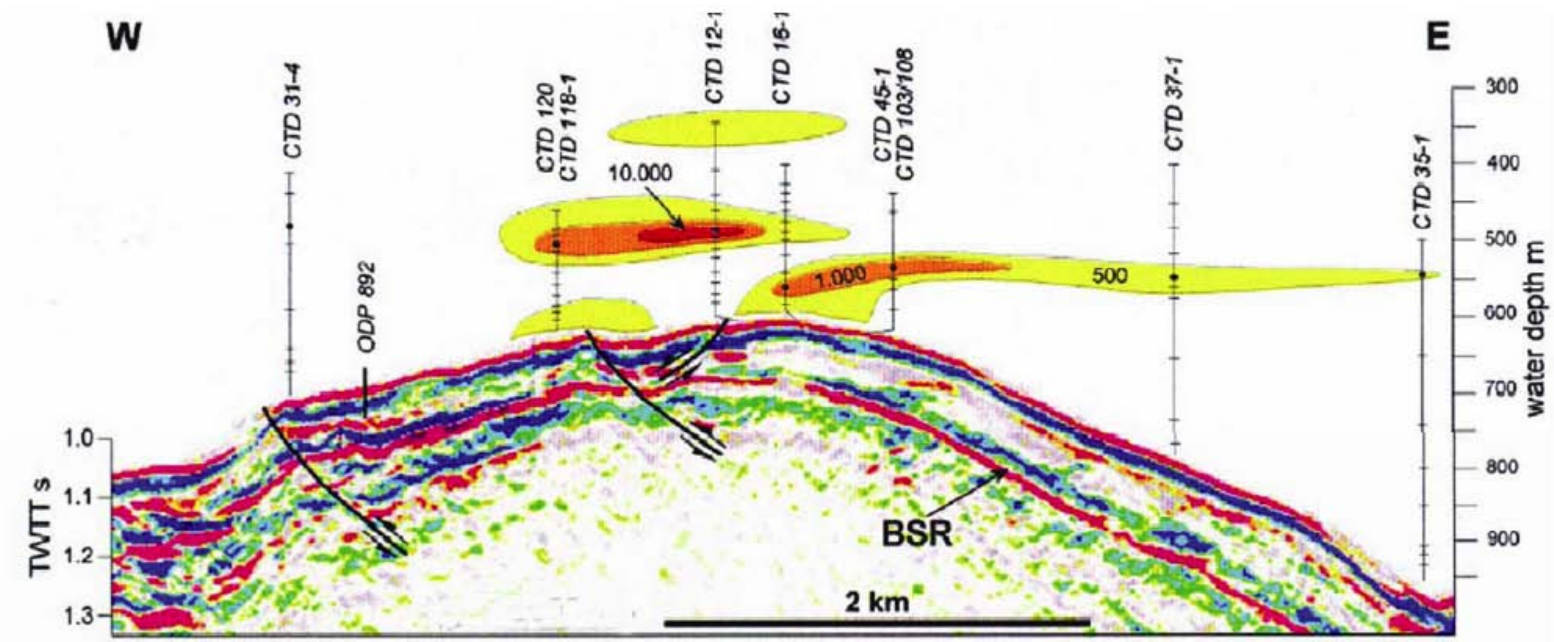


G. Bohrmann, Initial results from M52/1 **MARGASCH**

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

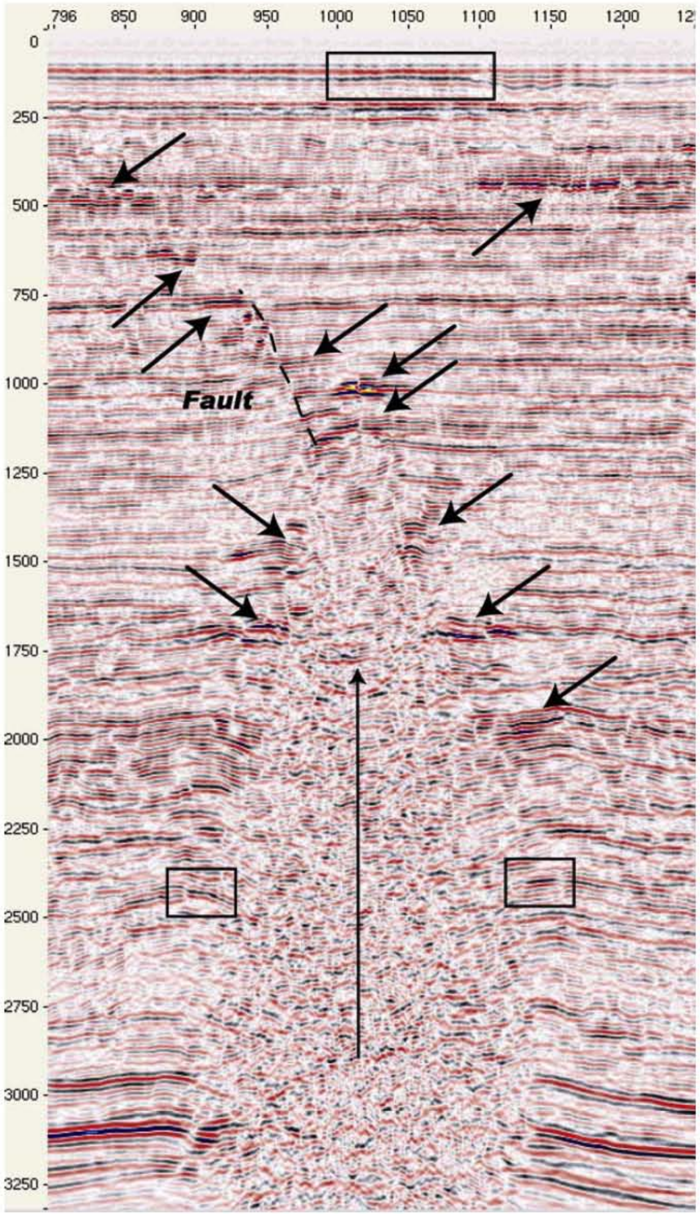
Gas chimneys are vertical zones in some way or other have been 'disturbed' by previous or on-going gas migration.

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.

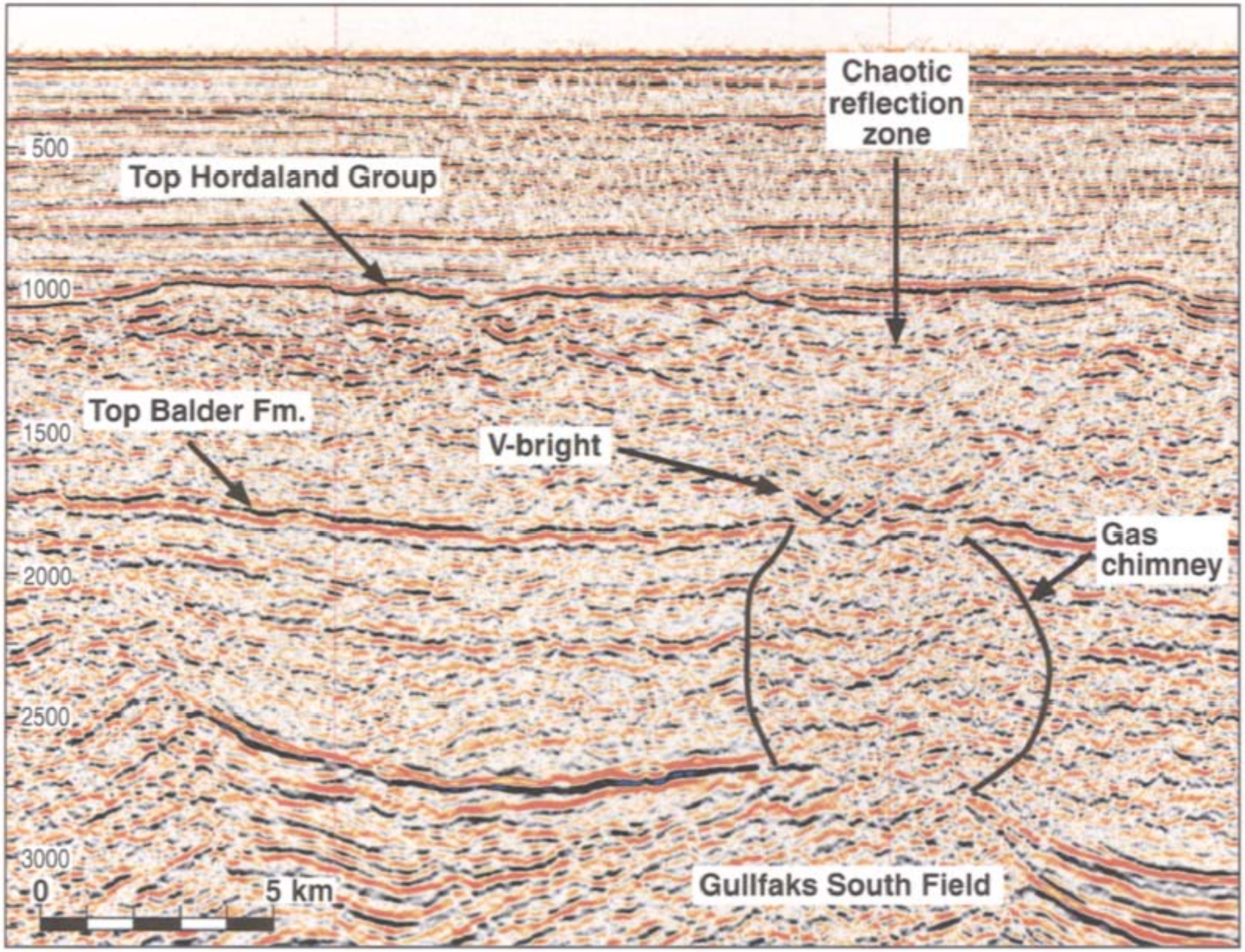
- **Enhanced seismic reflections**
- **Bright spots**
- **Flat spots**
- **Acoustic blanking**
- **Columnar disturbances, gas chimneys, pipes**
- **BSR (in case of gas hydrates)**

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

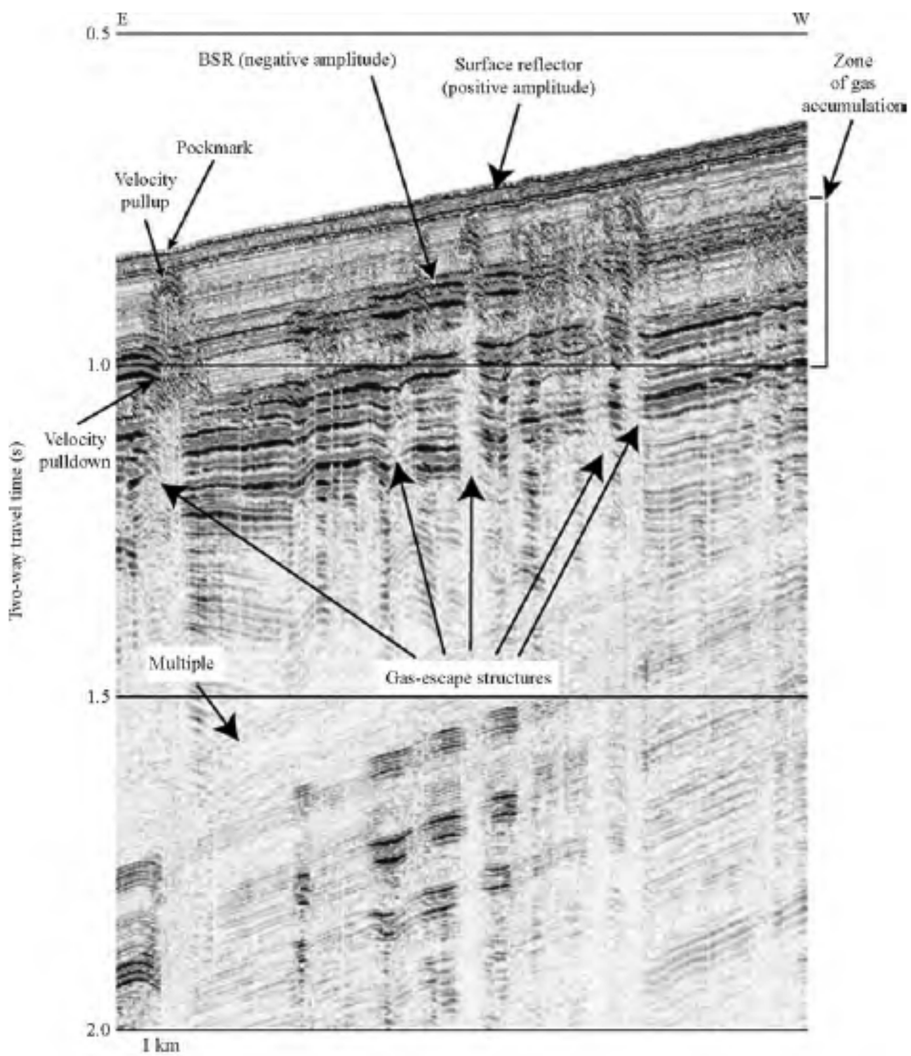


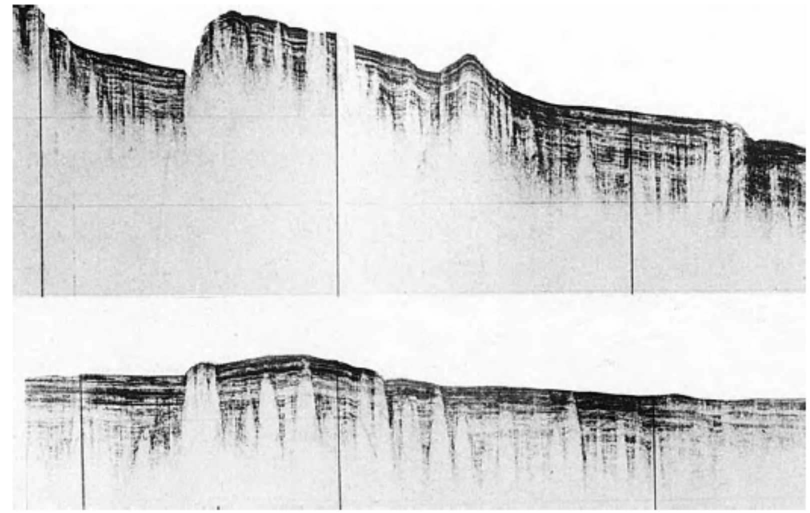
Seismic section across the Tommeliten Delta structure, a saltpiercement diapir. The noisy zone is interpreted as a gas chimney through whichgas rises vertically (as indicated by the large arrow). Some gas escapes laterally toproduce brightening of adjacent reflectors, and reducing the acoustic velocity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

Judd & Hovland 2007

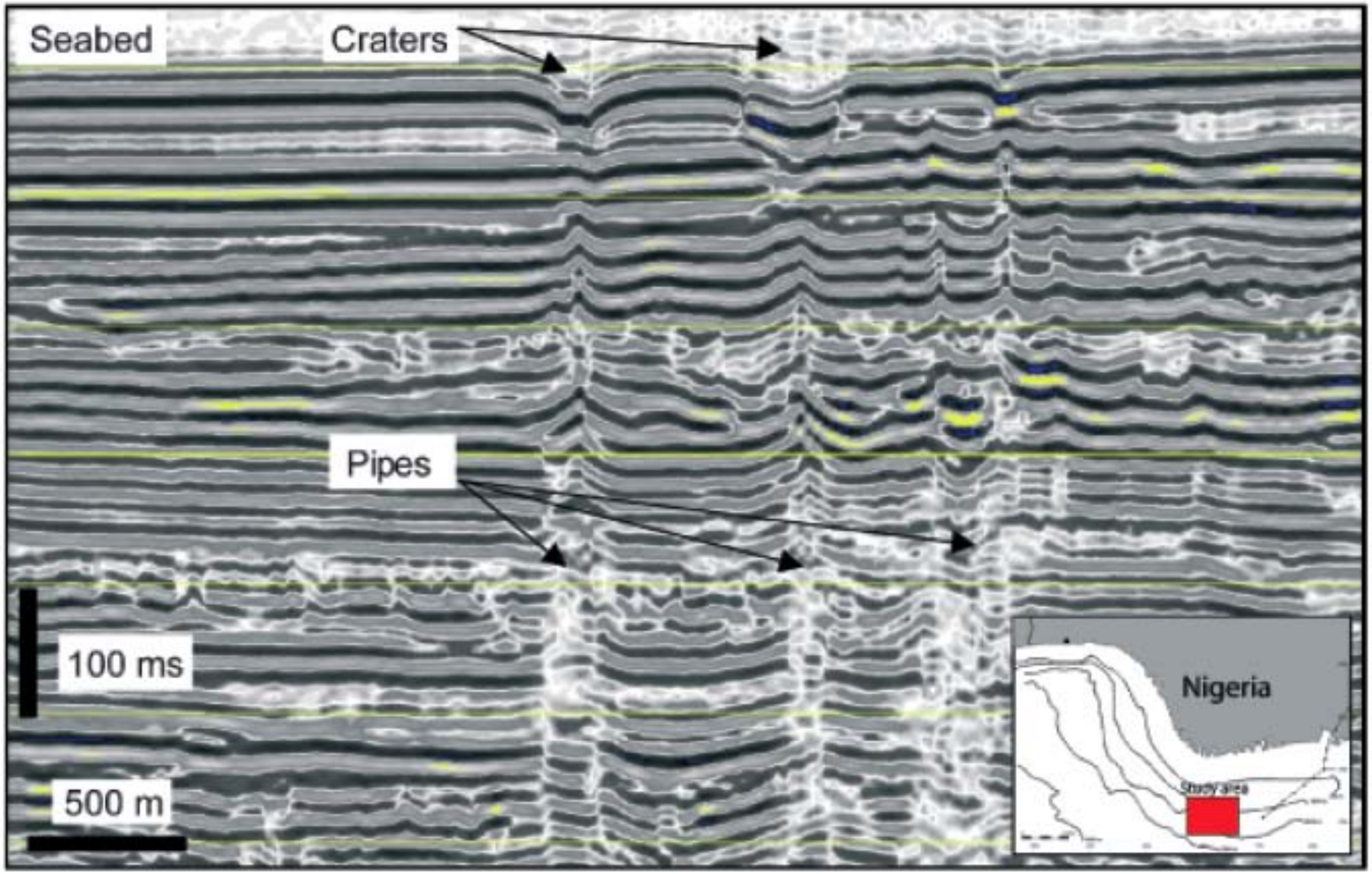


Løseth et al., 2003

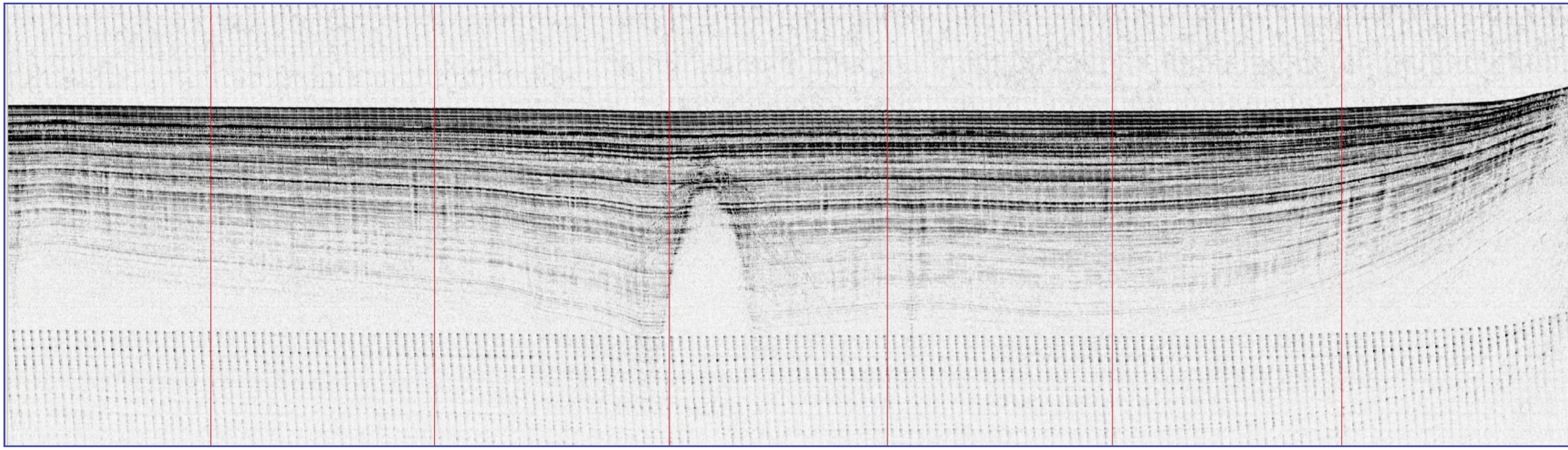


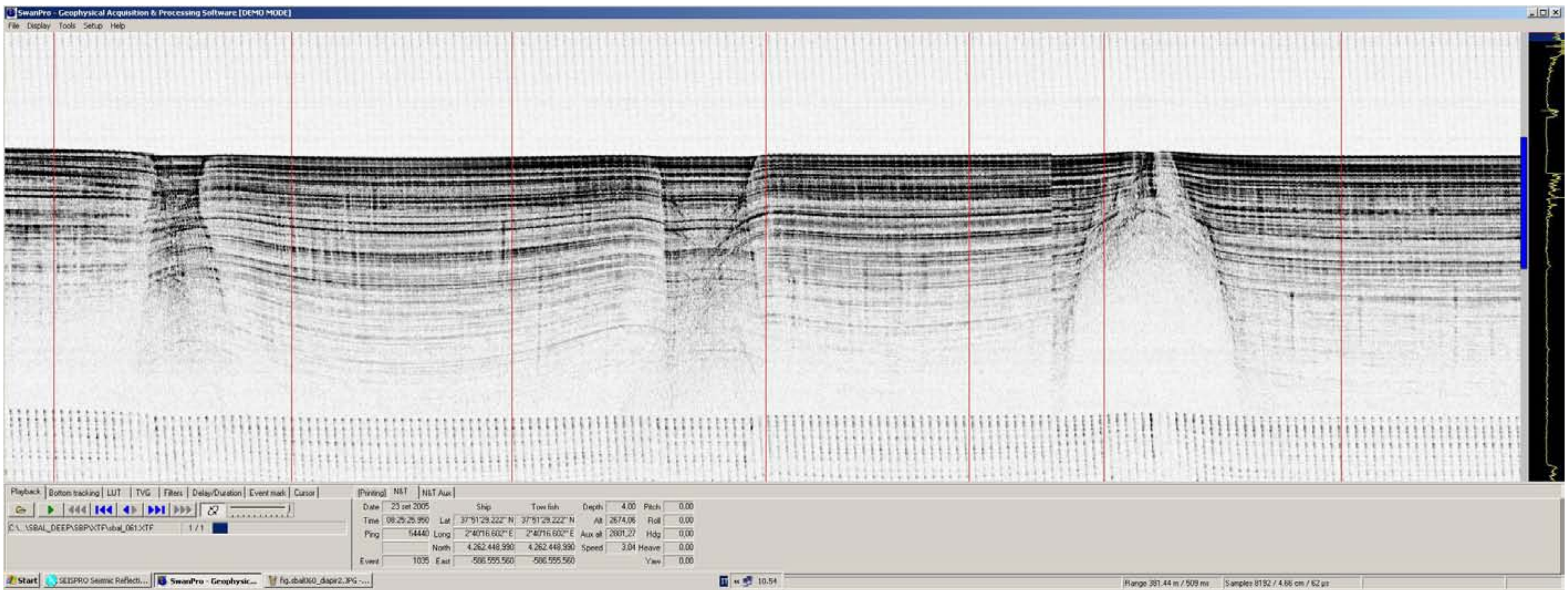


Judd & Hovland 2007



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.***

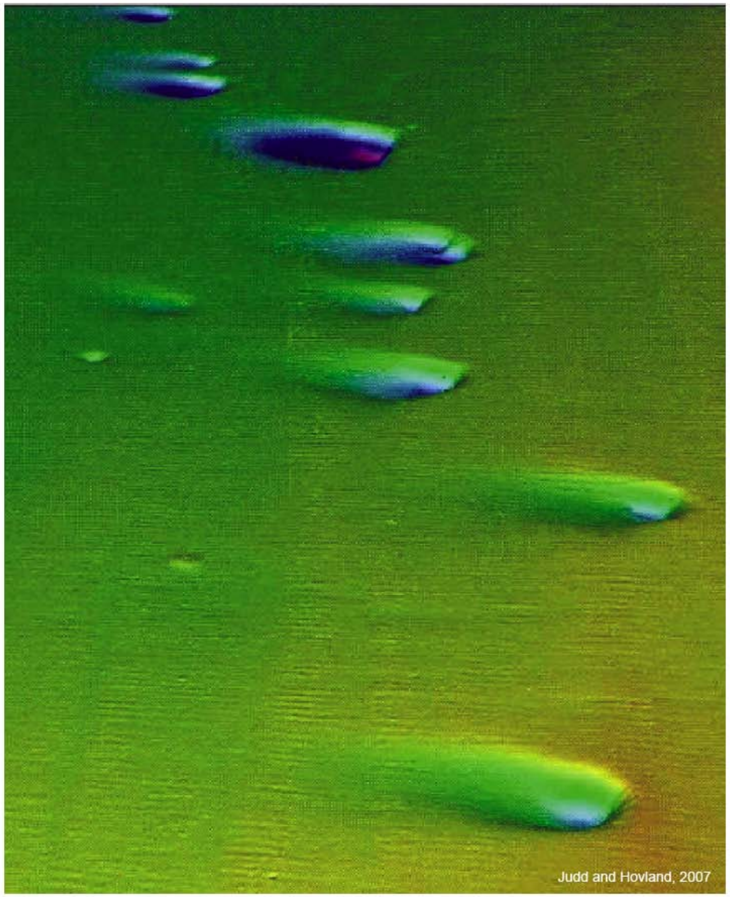


Figure 2.6: Assymetric pockmarks, Witch Ground Basin, UK North Sea. Multi-beam echo sounder image [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]

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.*

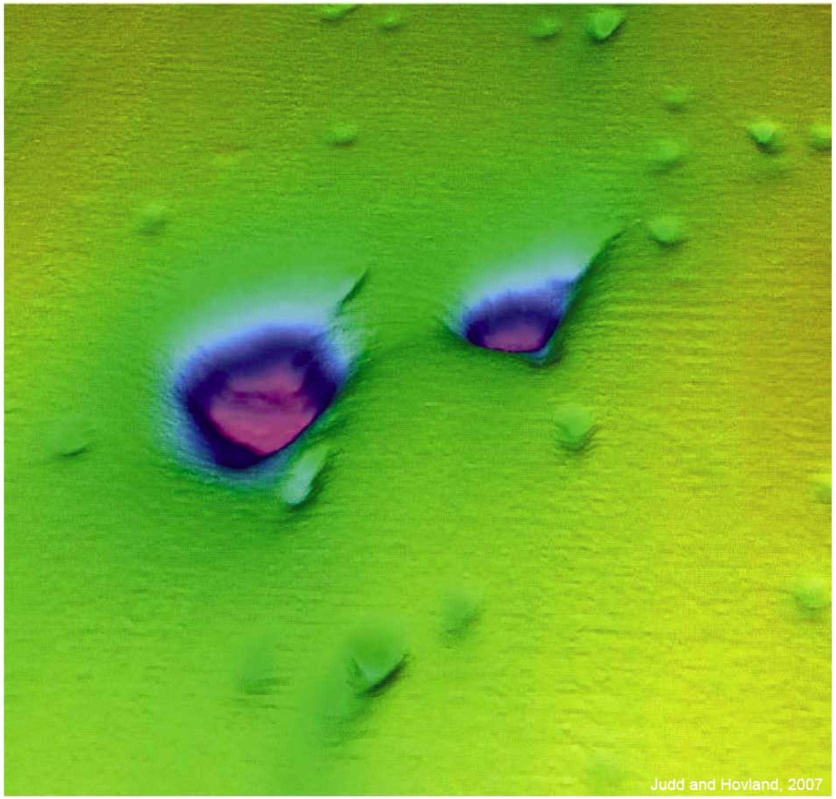


Figure 2.40: MBES image of the *Scanner* pockmark, Block UK15/25, North Sea. [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]

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

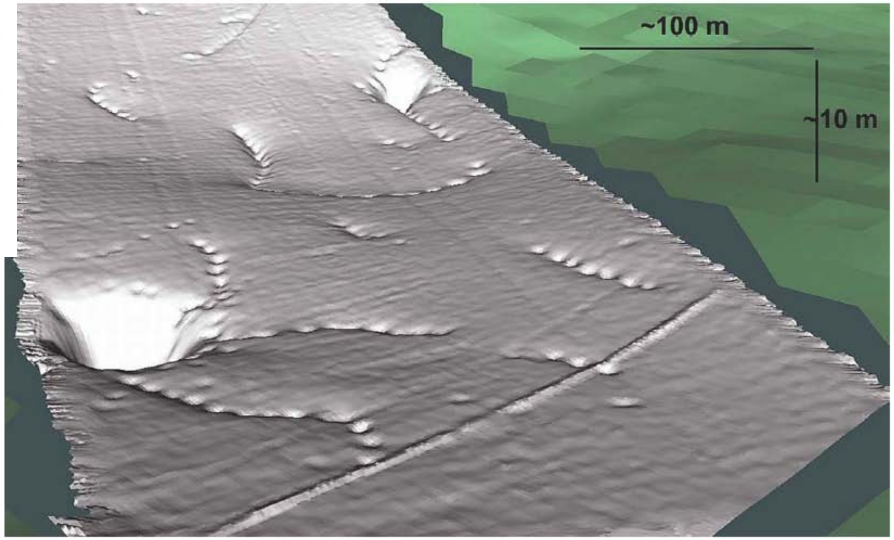


Figure 2.8: MBES image of pockmark strings in the Norwegian Sea. These strings have no preferred orientation, and some lead to (or from) large standard pockmarks. The 26 inch Haltenpipe pipeline is visible on the lower part of the image.

Judd & Hovland 2007

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

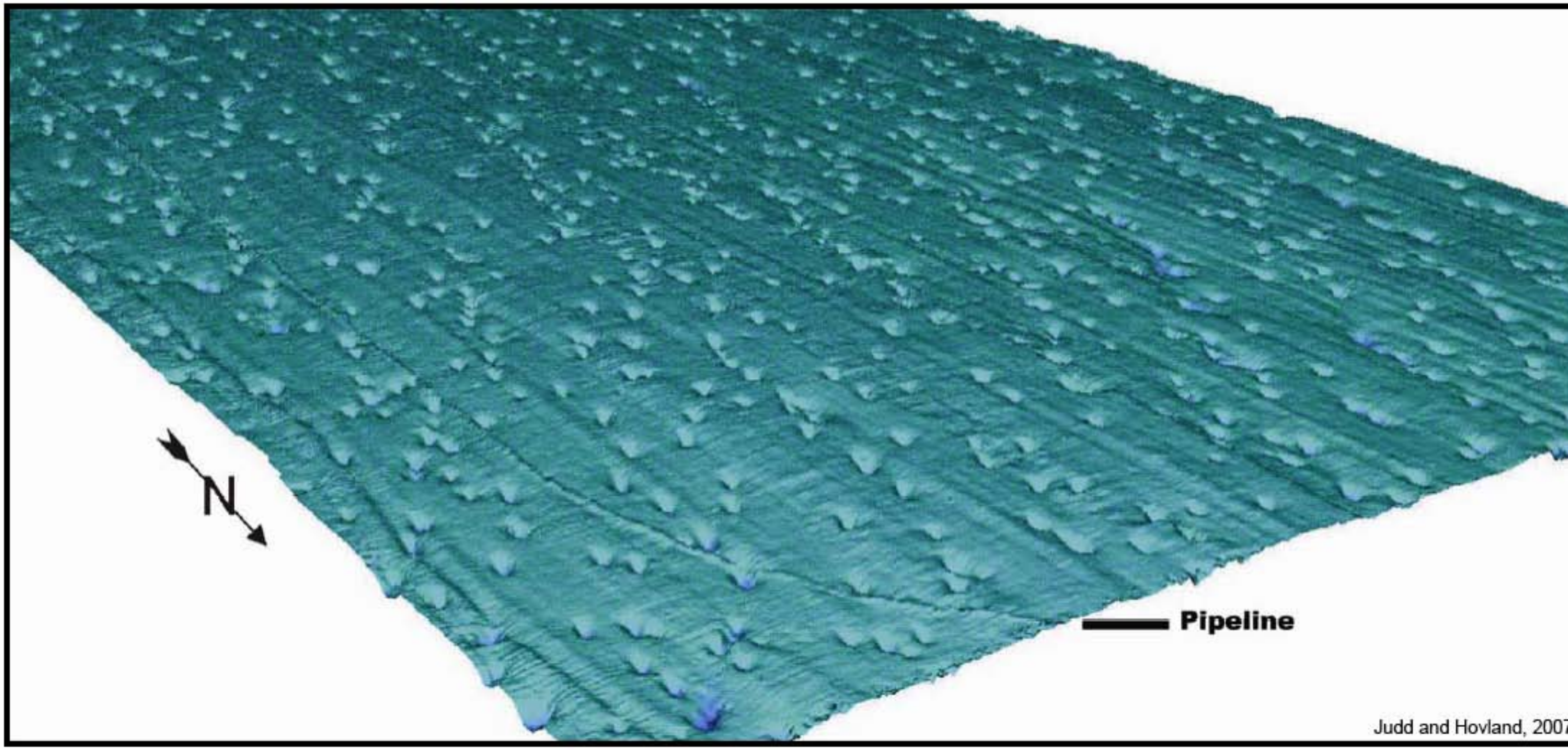


Figure 2.16: Pockmarks in the northern part of the South Fladen Pockmark Study Area; MBES survey, 2001. The pipeline (Scott-Forties Unity pipeline; 24 inch, 61 cm, diameter) gives an idea of the scale. [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental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

Judd & Hovland 2007

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

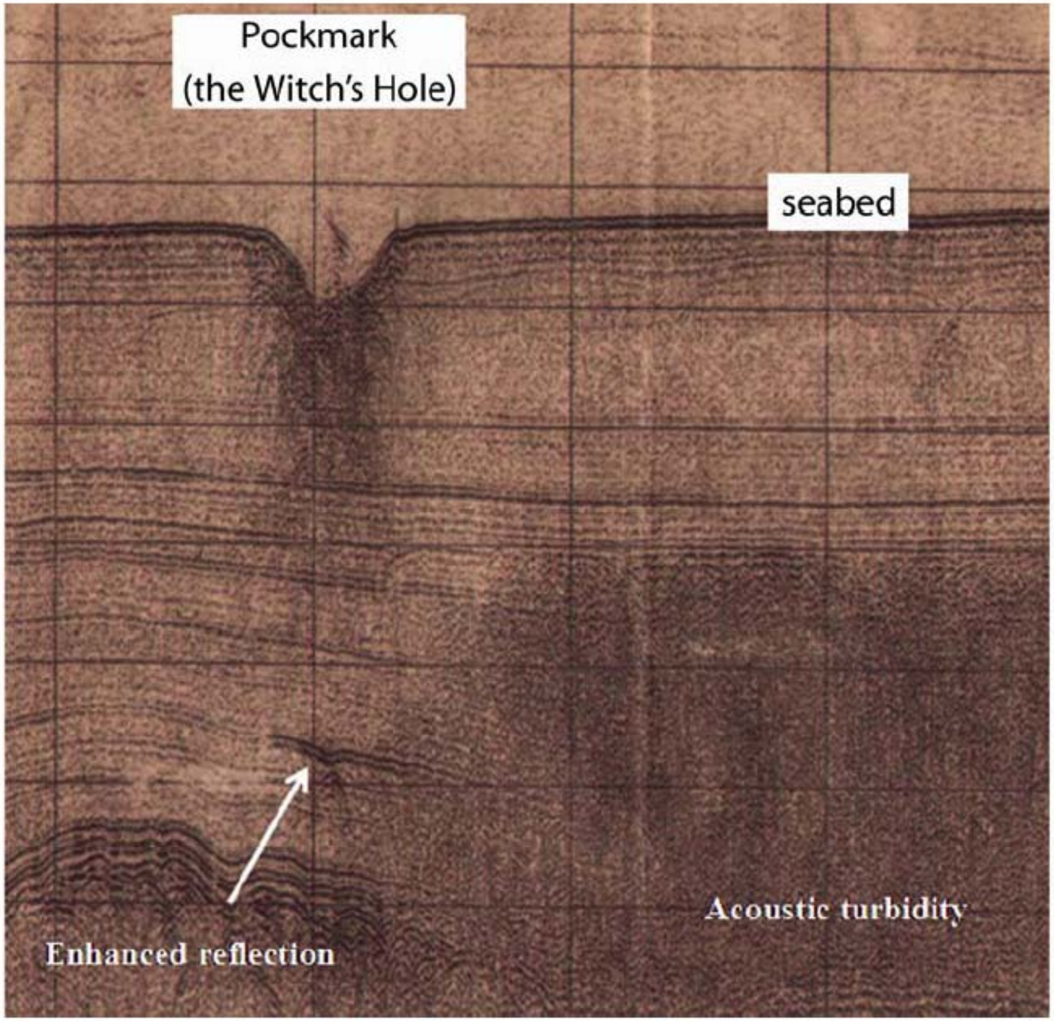


Figure 2.19: Boomer profile across the Witch's Hole, an unusual pockmark in the South Fladen area. [Reproduced by permission of the British Geological Survey. © NERC. All rights reserved. IPR/67-34C.]

Judd & Hovland 2007

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

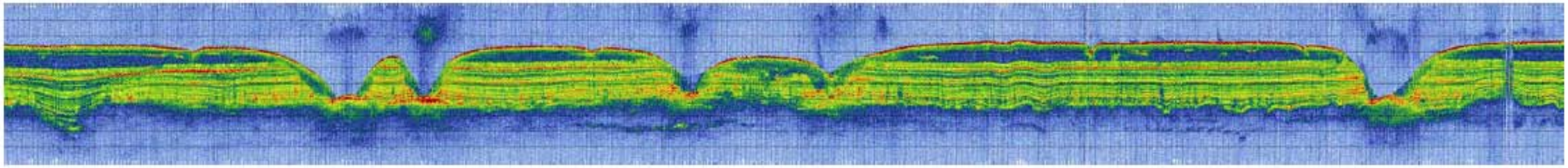
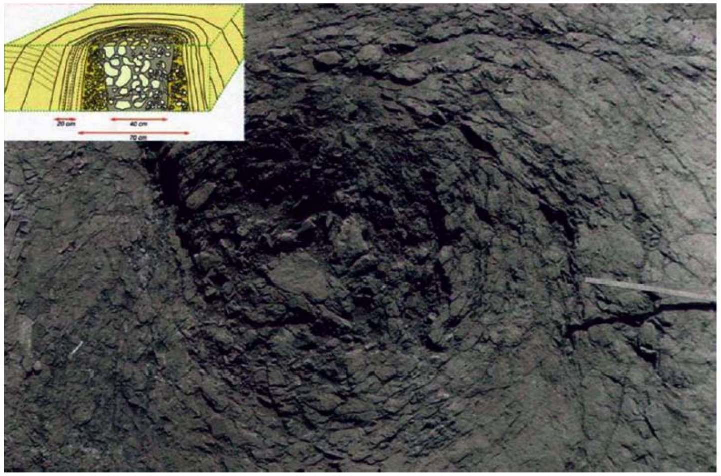


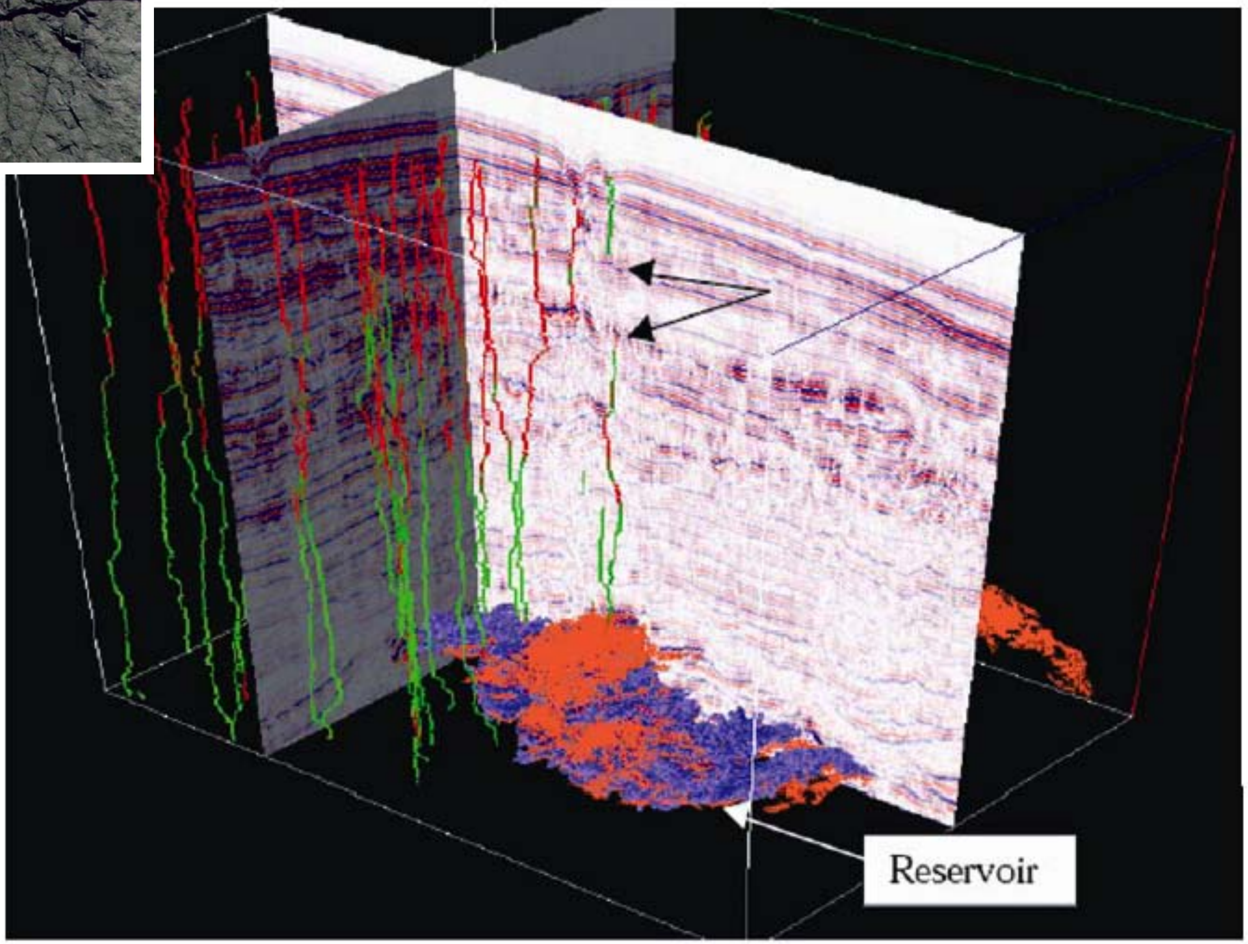
Figure 2.44: Seep plumes from the Scanner (left), Scotia (centre), and Challenger (right) pockmarks, Block UK15/25, North Sea acquired during the Heincke 180 cruise, October 2002 (Alfred Wegener Institute) using the parametric sediment echo sounder system (SES-2000DS) developed at Rostock University,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

Judd & Hovland 2007

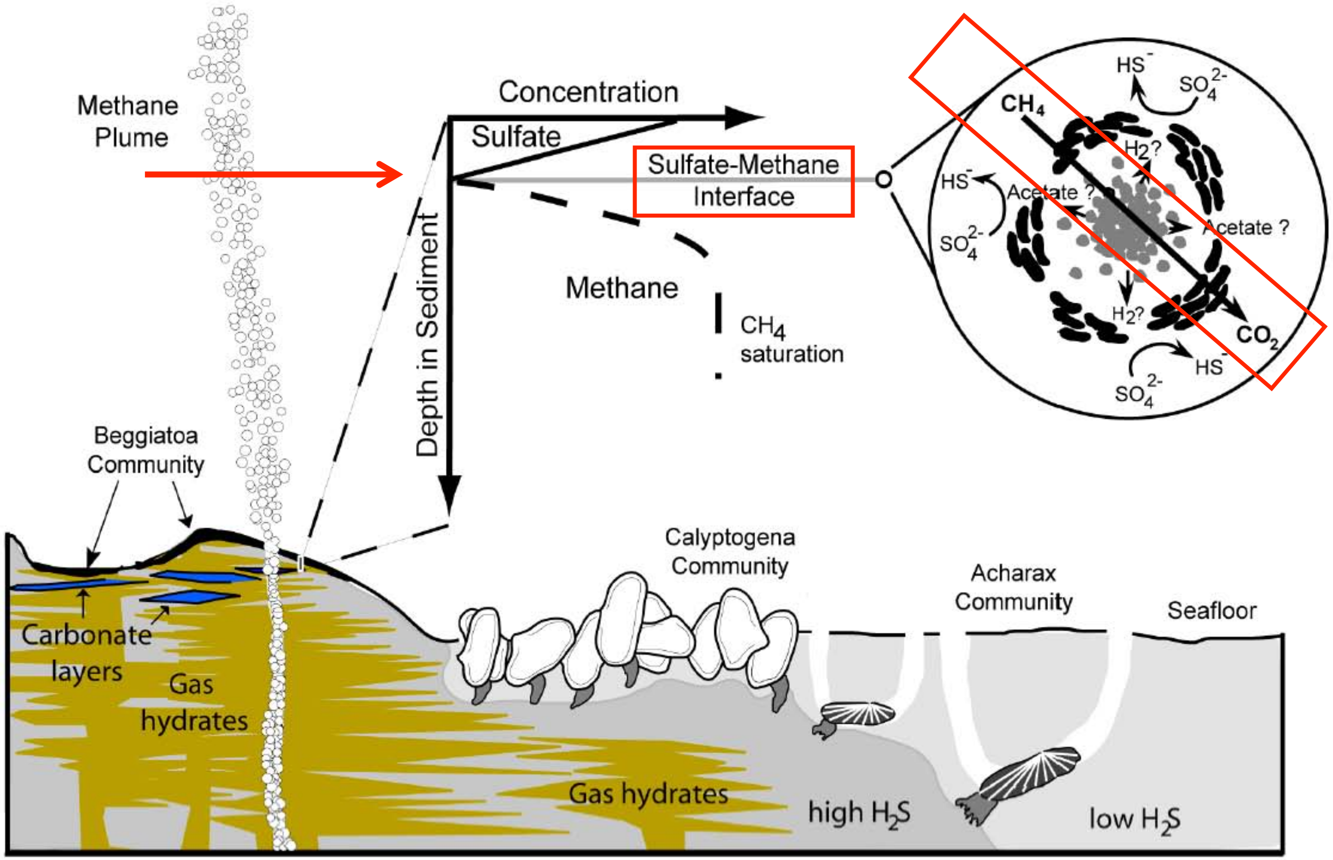
Judd and Hovland, 2007. *Seabed Fluid Flow.*

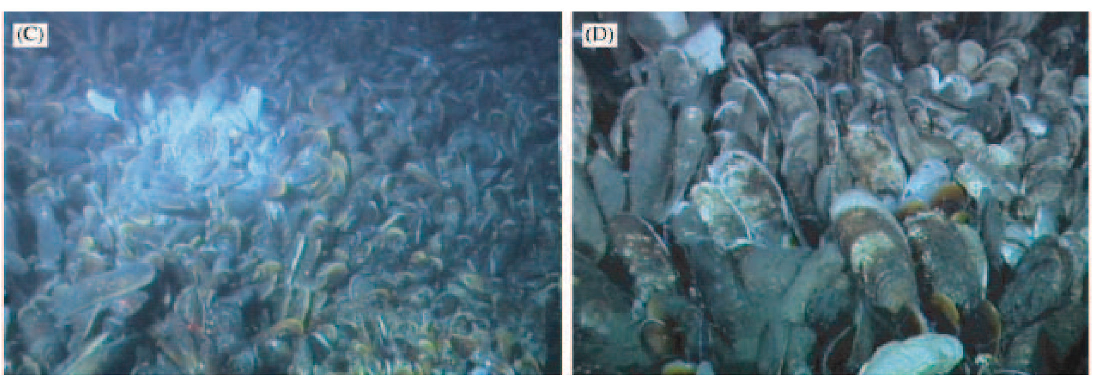


Judd and Hovland, 2007. *Seabed Fluid Flow.*



Judd & Hovland 2007





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.

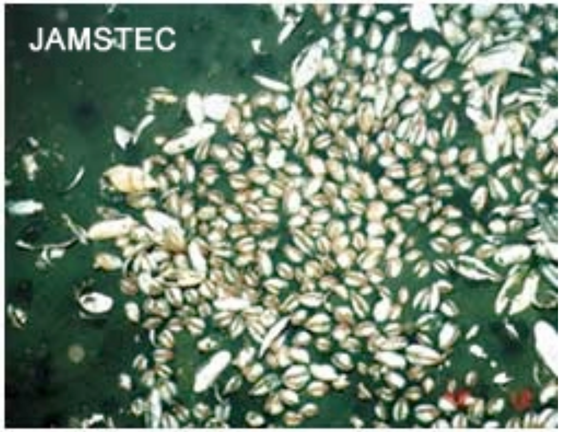
Van Dover et al. (2003). *Deep Sea Research*

Chemosynthetic organisms at cold seeps

Free-living filamentous sulfur bacteria: *Beggiatoa*

tube worms: *Lamellibrachia*

clams: *Calyptogena*

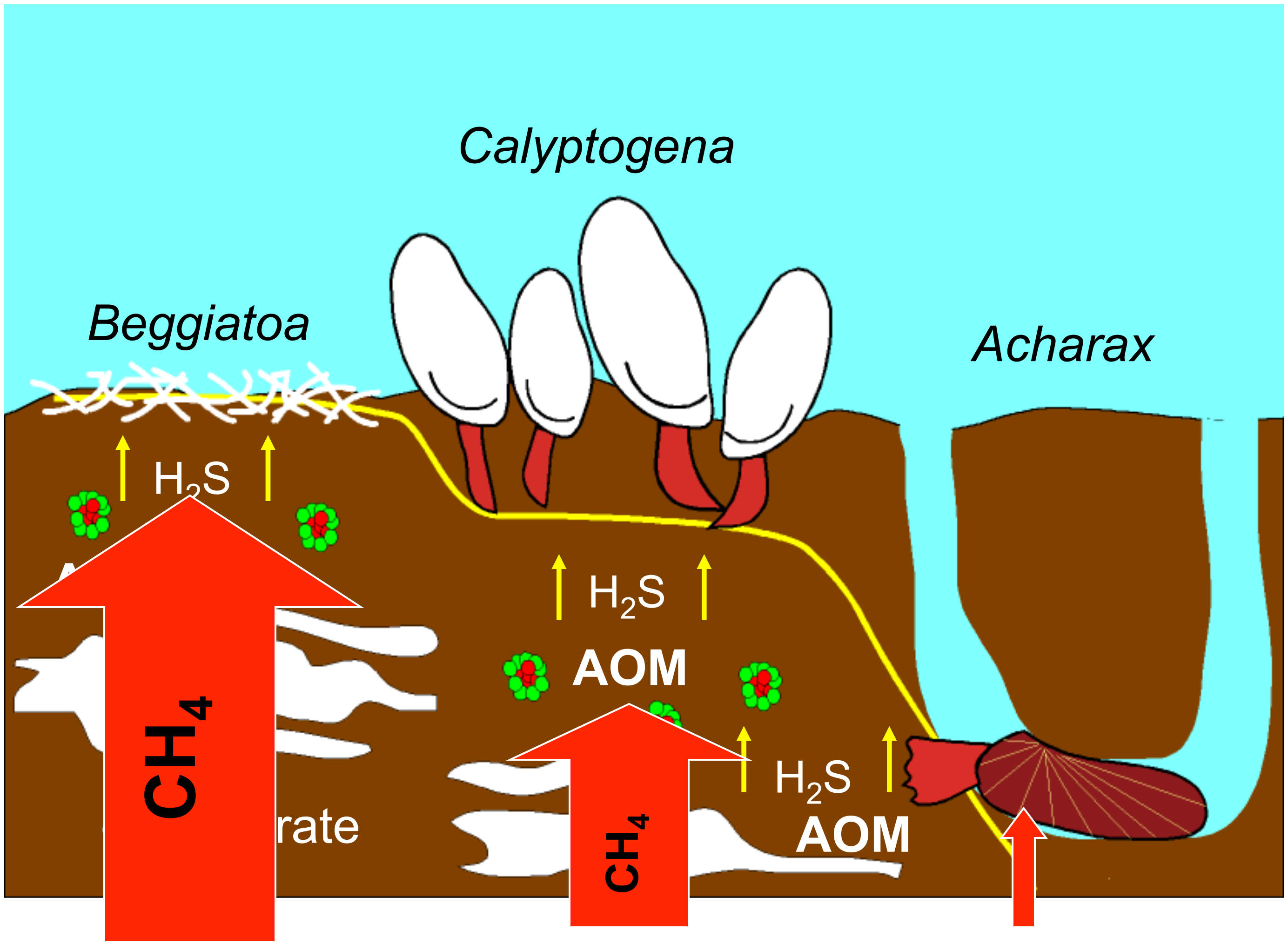


mussels: *Bathimodiolus*

mussels: *Acharax / Solemya*

Thanks to Tine Treude, Max Plank Institute, Bremen Germany

Gradient of chemosynthetic communities



Thanks to Tine Treude, Max Plank Institute, Bremen Germany

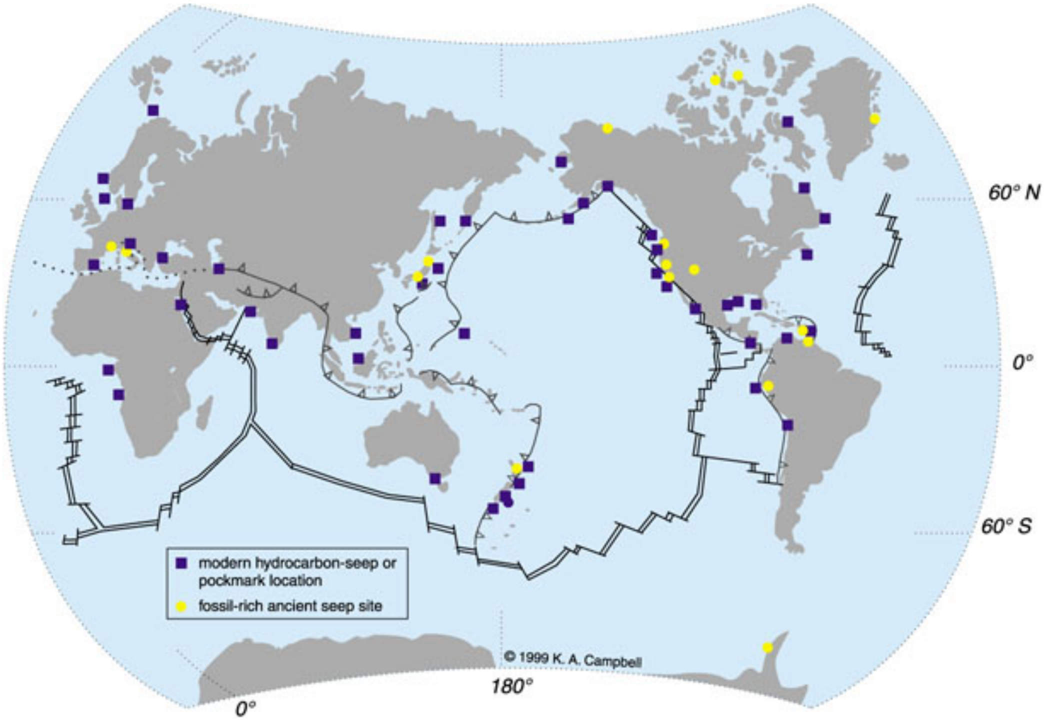
Dissolved Inorganic Carbon (DIC) of the water

Normal marine environment: $\delta^{13}C_{DIC} \cong 0‰$

(Peterson e Fry, 1987)

Methane seeps environment: $\delta^{13}C_{DIC} \cong -30/-60‰$

(Aharon *et al*., 1992)



Authigenic Carbonates:

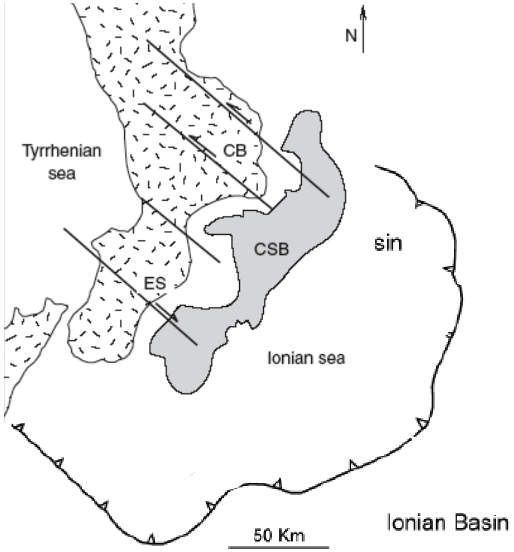
Isotopically light

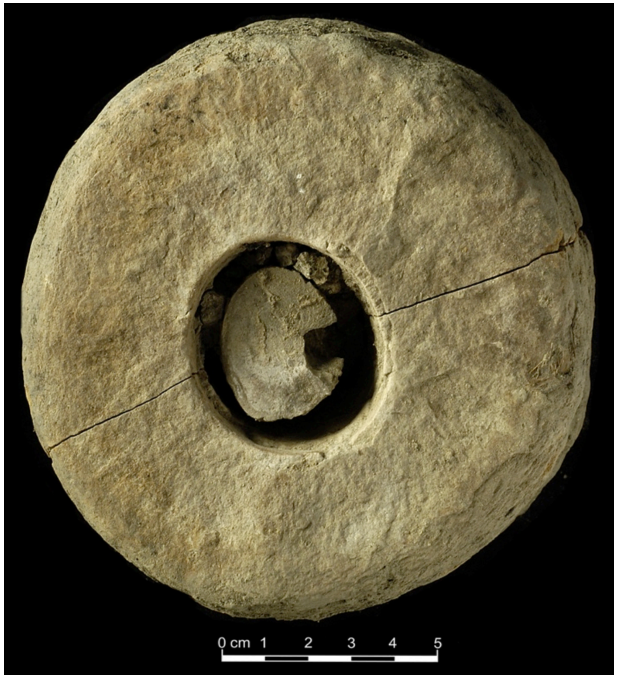
Organic markers indicate presence of methane oxidizers

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

Jensen *et al*., 1992

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





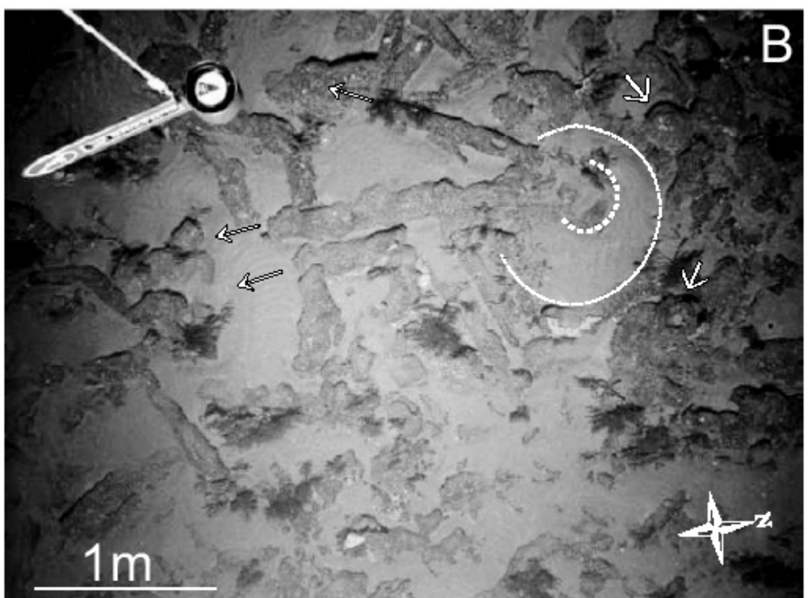
Courtesy, Domenico Rio, University of Parma

FOSSIL DEWATERING CHIMNEYS IN PLIOCENE MARLS, CROTONE BASIN

Pipe-like chimneys in Gulf of Cadiz Mud Volcanoes

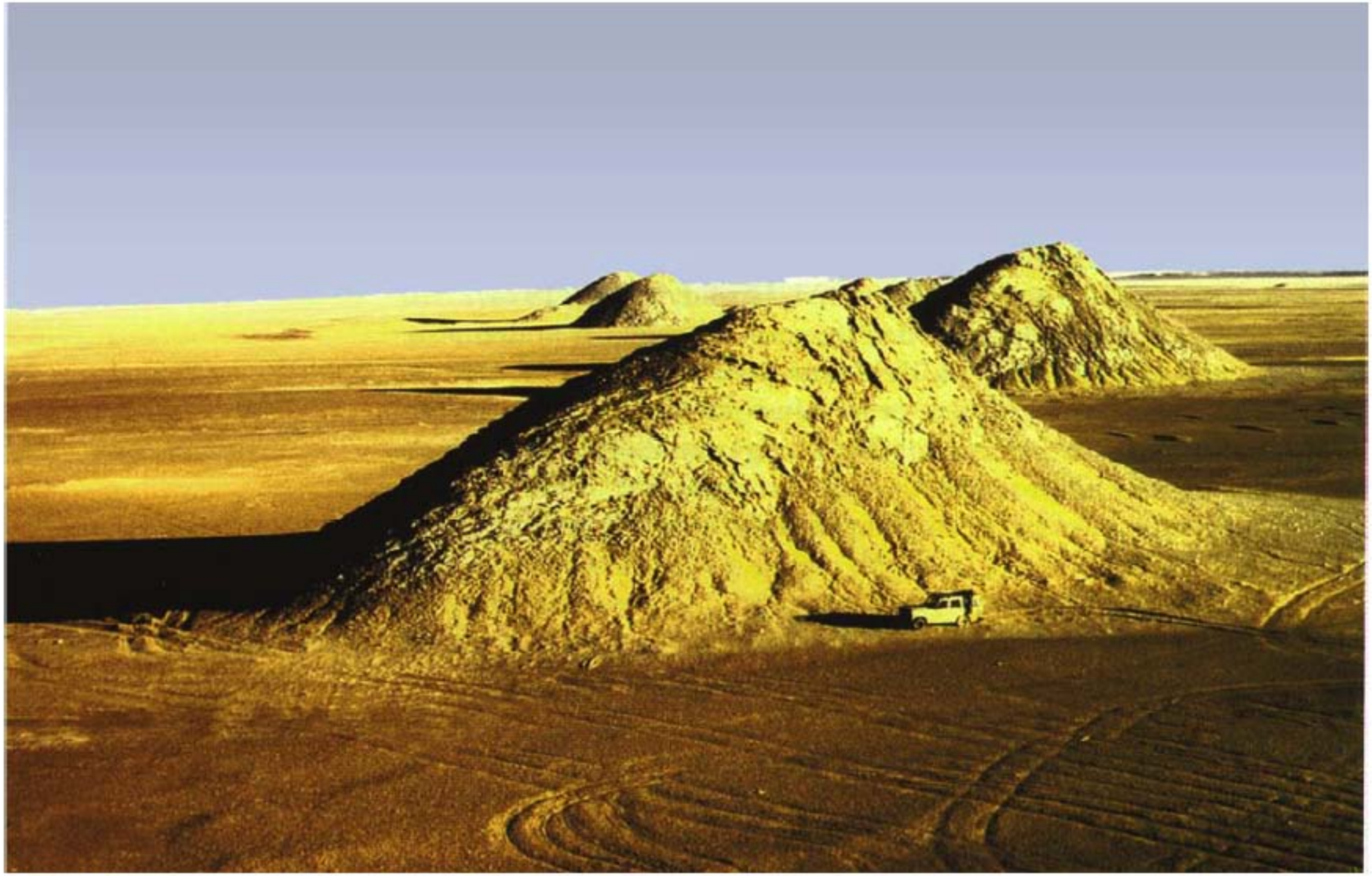
Composed of authigenic carbonates with iron oxides.

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



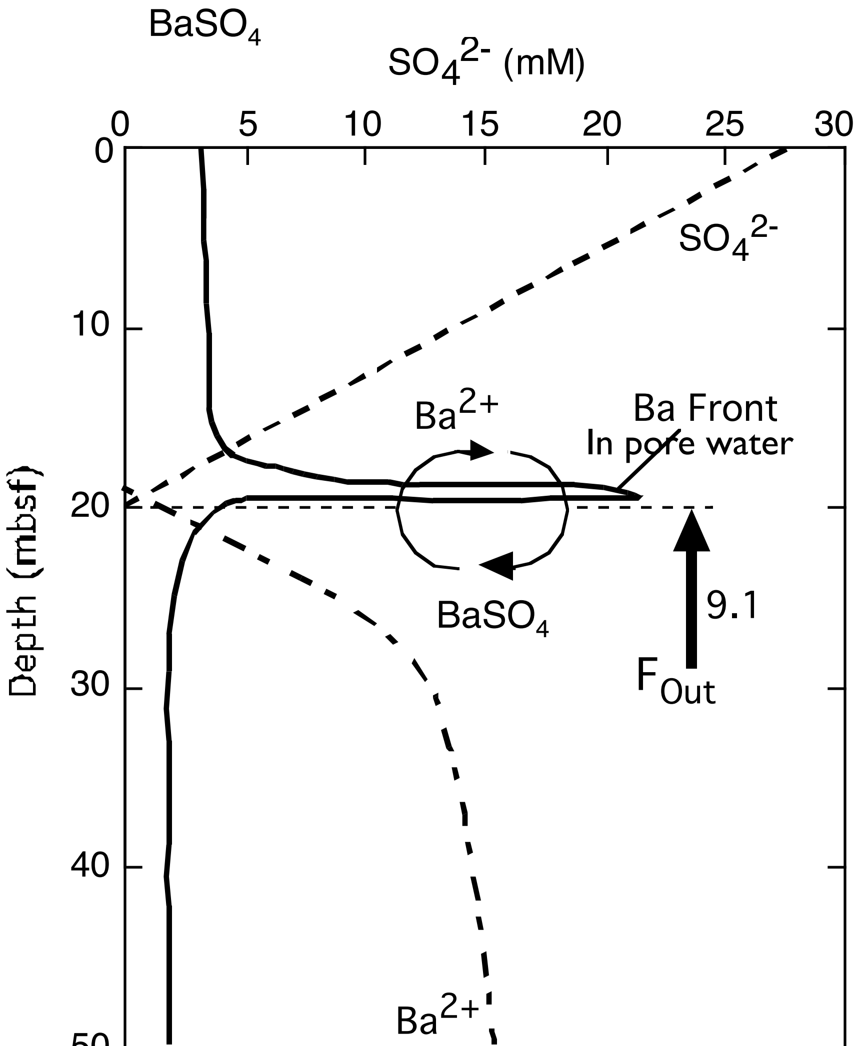
Diaz del Rio al., Marine Geology 195 (2003) 177-200

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



Judd & Hovland, 2007

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



Coupled Sulfate / Barium Profiles

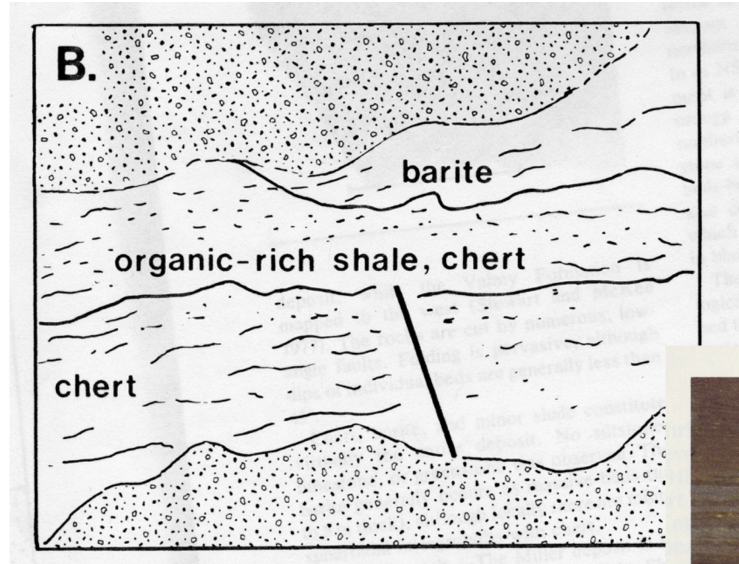
1. High concentrations of barite in pelagic sediments underlying high productivity waters are thought to result from **biologically mediated precipitation of barium sulfate within the water column.**

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



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

***Cold seep barites* along continental margins are associated with:**

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

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.

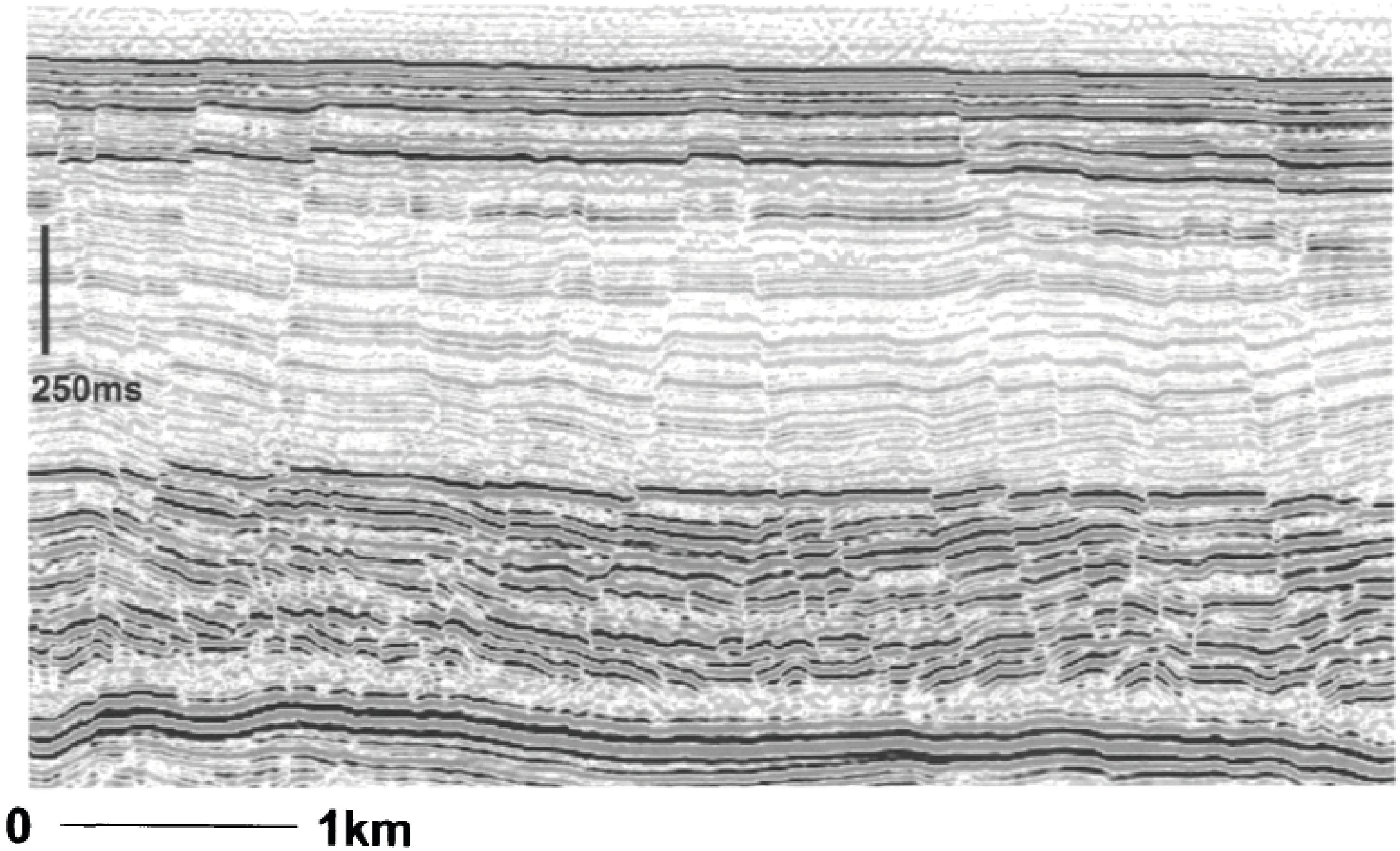
- They range in fault trace length from 100 m to several kilometres and extend vertically across discrete layers from a few tens of metres to over one kilometre in thickness.

- Polygonal faults can be planar or listric

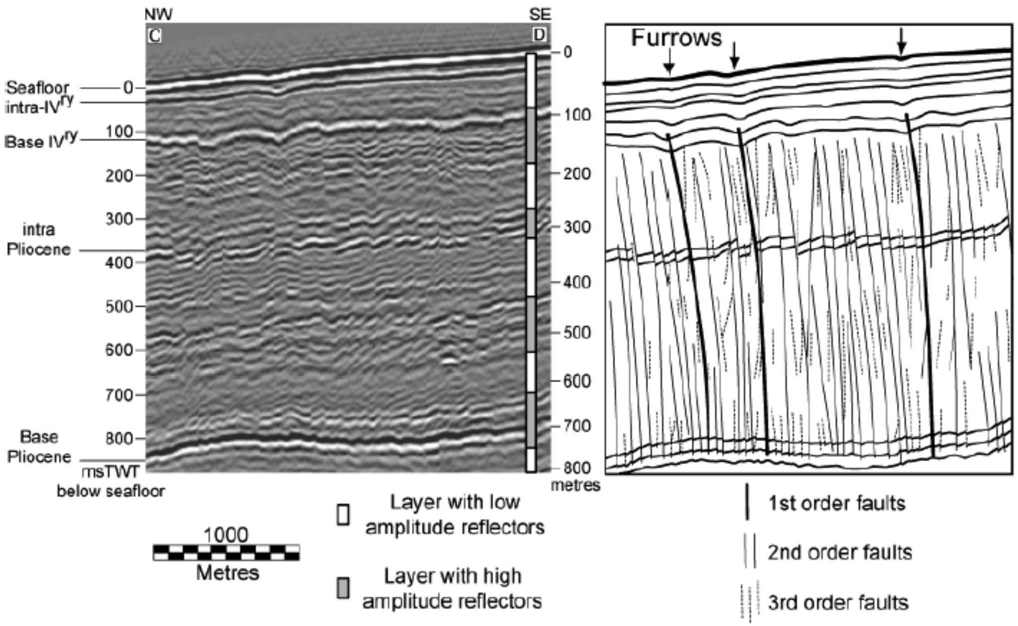
- Faults are characterized by a large range of fault strikes. Where strikes are almost randomly oriented, a classical polygonal plan form geometry results. *Variations in the basic polygonal plan form can arise from regional slope, tectonic context, or basement topography, or from intrinsic variation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

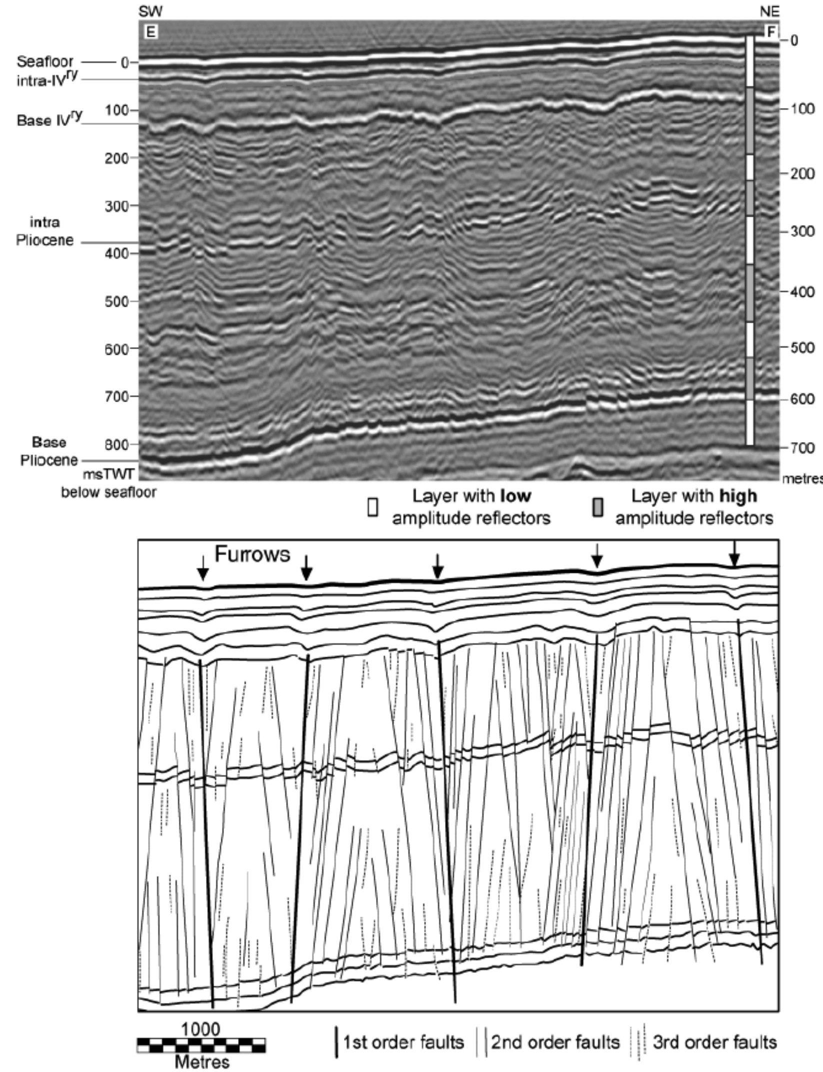
- Three-dimensional geometry of polygonal fault systems is invariably complex and difficult to appreciate from simple 2D cross-sections.

Cartwright et al., 2003.

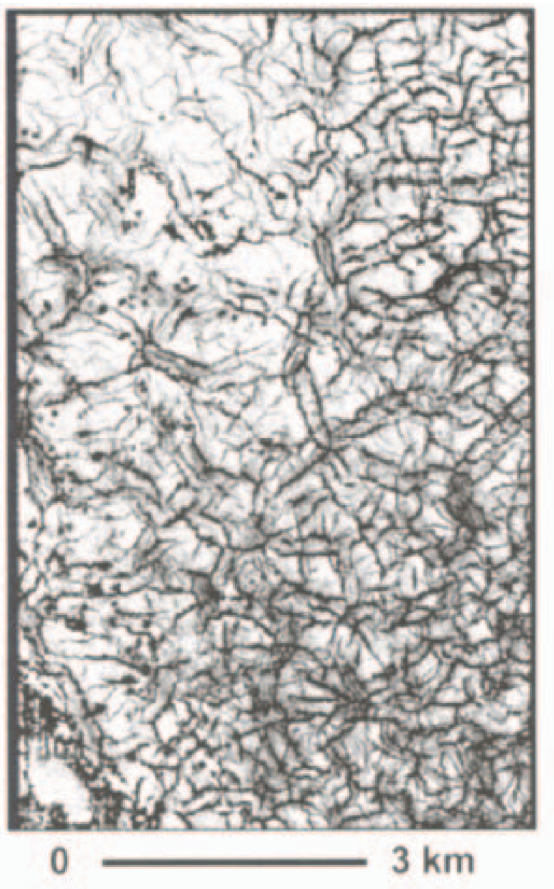


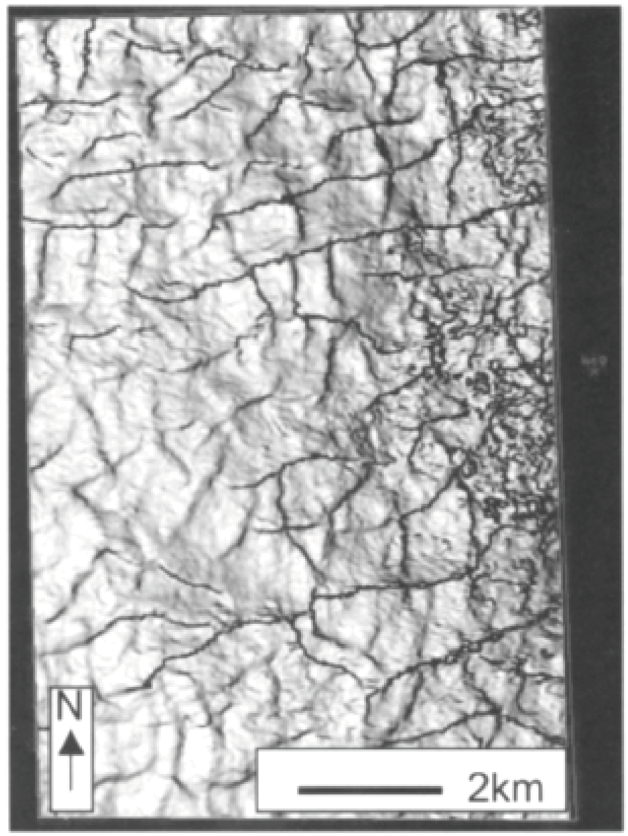
Cartwright et al., 2003.

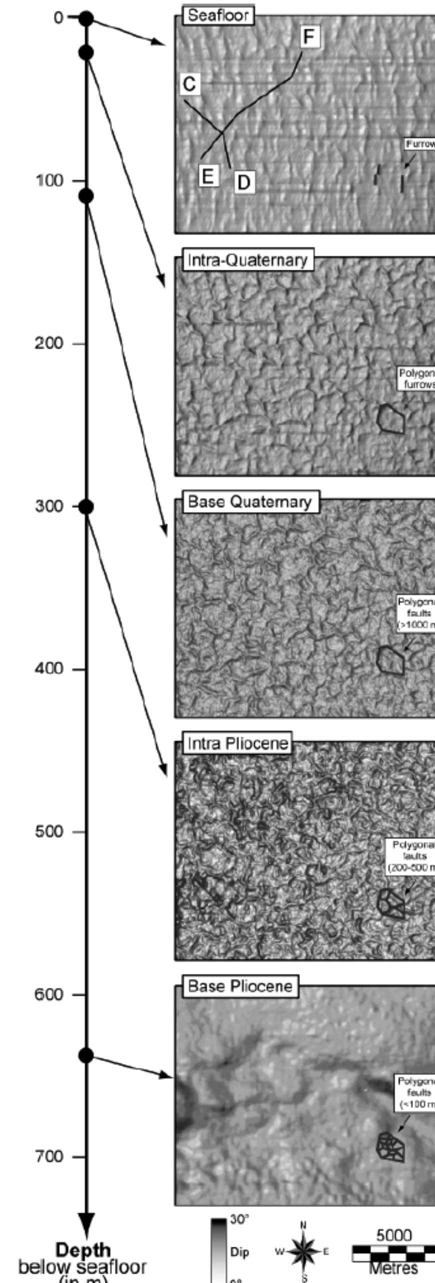




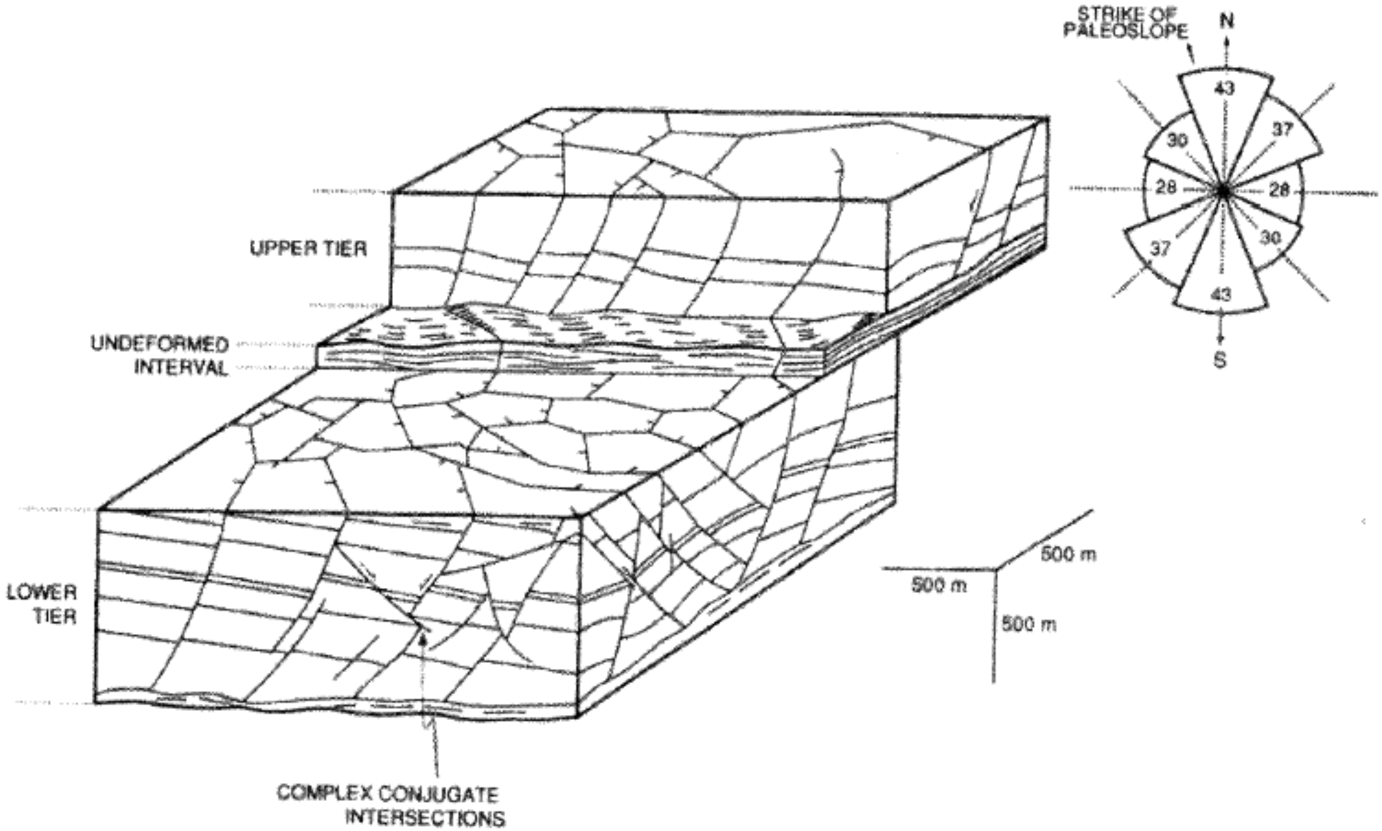
Gay et al., Basin Research (2004) 16, 101-116







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)

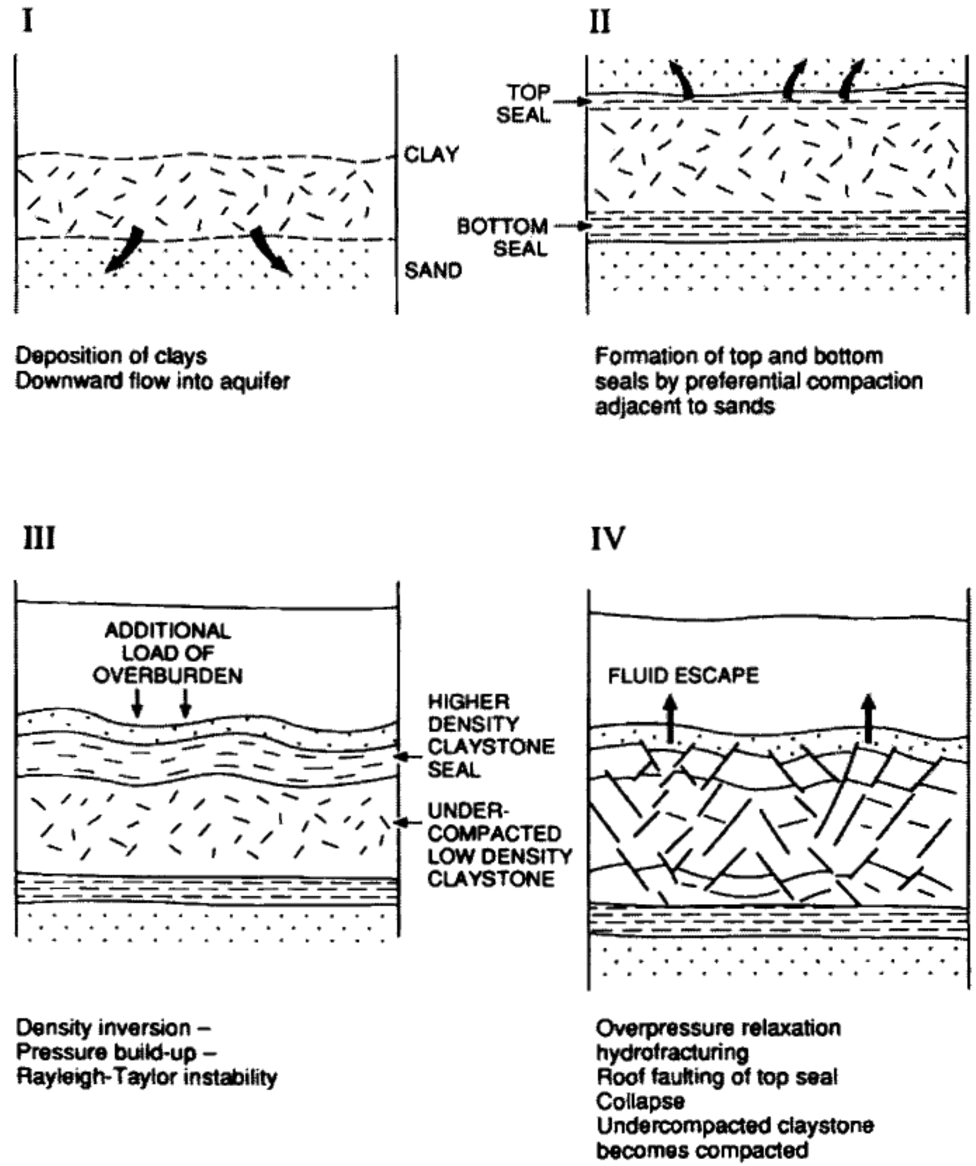
Density inversion should produce folding (like in salt diapirs), whicha are not always observed.

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

References:

Cartwright, J.A., 1994a. Episodic basin-wide hydrofracturingof overpressured Early Cenozoic mudrocksequences in the North Sea Basin. *Marine andPetroleum Geology,* 11,587-607.
Cartwright, J.A. 1994b. Episodic collapse of geopressuredshale sequences in the North Sea Basin.*Geology,* 22, 447-450.
Cartwright, J.A. 1996. Polygonal Fault Systems: a newtype of geological structure revealed by 3D seismicdata. *In:* WEIMER, P. (ed.) *Application of 3-D seismicData to Exploration and Production, AmericanAssociation of Petroleum Geologists, Studies in Geology,* 42, 225-231.
Cartwright, J.A. 1997. Polygonal Fault Systems in thickshale sequences. *In:* Yardley, B, & Jamtveit, B. (Eds) *Fluid Flow Processes in the Continental Crust.*Chapman & Hall, London, 81-104.
Cartwright, J.A. and DeWhurst, D. 1998. Layer-boundcompaction faults in fine-grained Sediments. *Bulletinof the Geological Society of America,* 110,1242-1257.
Cartwright, J.A. and Lonergan, L. 1996. Volumetriccontraction during the compaction of mudrocks: amechanism for the development of regional-scalepolygonal fault systems. *Basin Research,* 8, 183-193.
Cartwright, J. and Lonergan, L. 1997. Polygonal faultSystems in the Eromanga and North Sea Basins: acomparison. *Exploration Geophysics,* 28, 323-331.
Davies, R. Cartwright, J.A. & Rana, J. 1999. Polygonaldensity inversion structures from the FaerOe-ShetlandTrough. *Geology,* 27, 798-802.
DeWhurst, D., Cartwright, J.A. & Lonergan, L. 1999a.The development of polygonal fault systems by thesyneresis of fine-grained sediments. *Marine andPetroleum Geology,* 16, 793-810.
DeWhurst, D., Cartwright, J.A. & Lonergan, L. 1999b.Three-dimensional consolidation of clay-rich sediments.*Canadian Geotechnical Journal,* 36, 355-362.
Goulty, N.R. 2001. Polygonal fault networks in finegrainedsediments - an alternative to the syneresismechanism. *First Break,* 19, 69-73.
Henriet, J.P., De batist, M., Van vaerenbergh, W. & Verschuren, M. 1989. Seismic facies and clay tectonic features in the southern North Sea. *Bulletin of the Belgian Geological Society*, 97, 457-472.

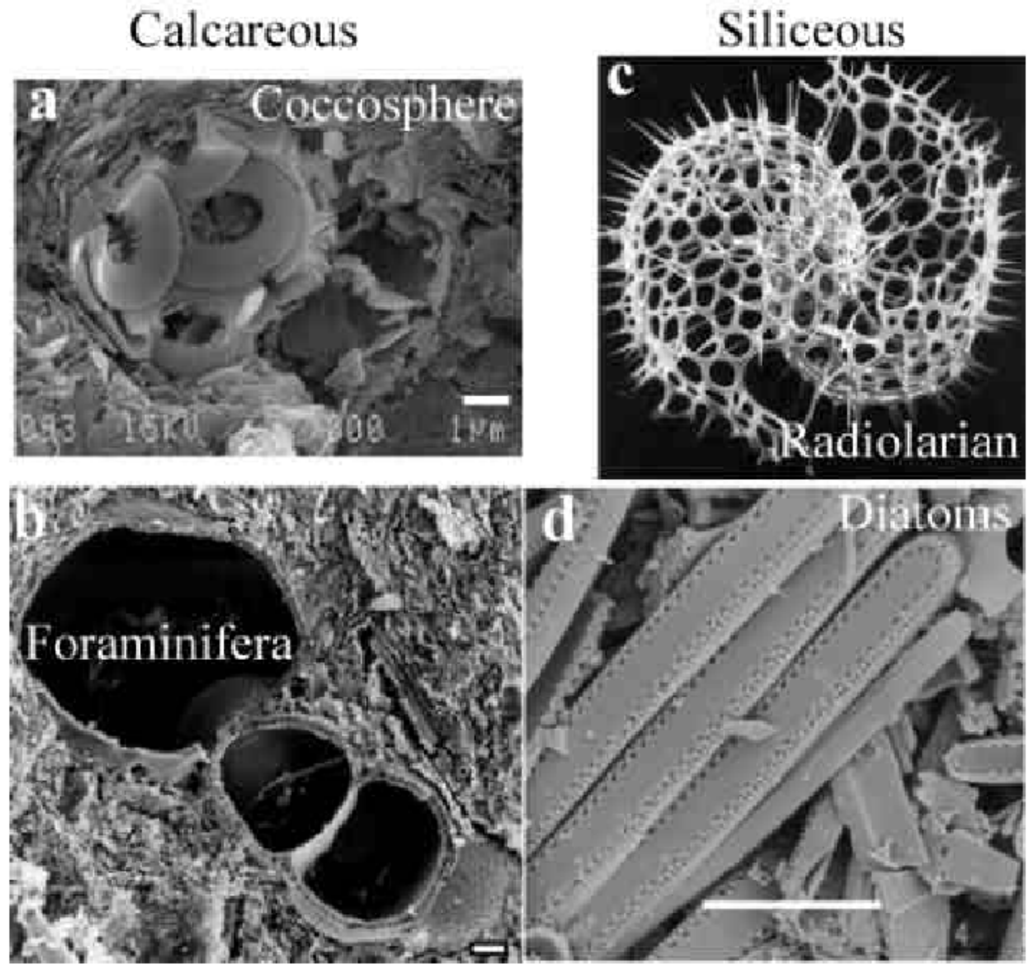
FOSSILIFEROUS SOILS

-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.

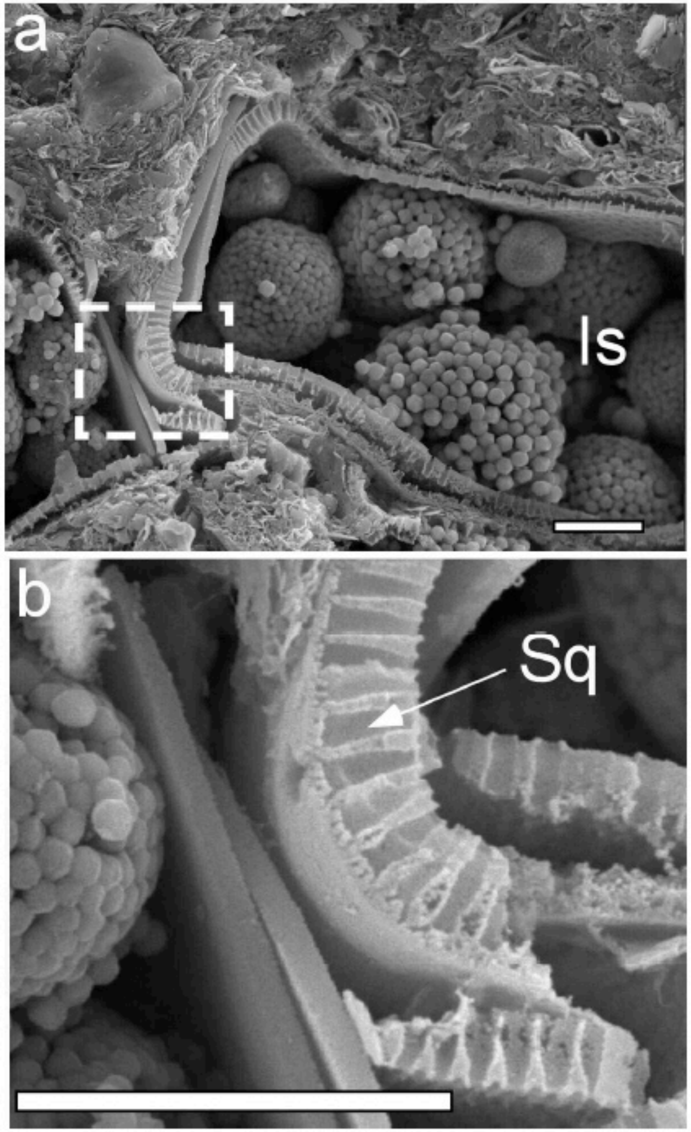
-They can provide delayed compressibility or a sudden increase in compressibility once the yield strength of the microfossil is exceeded.

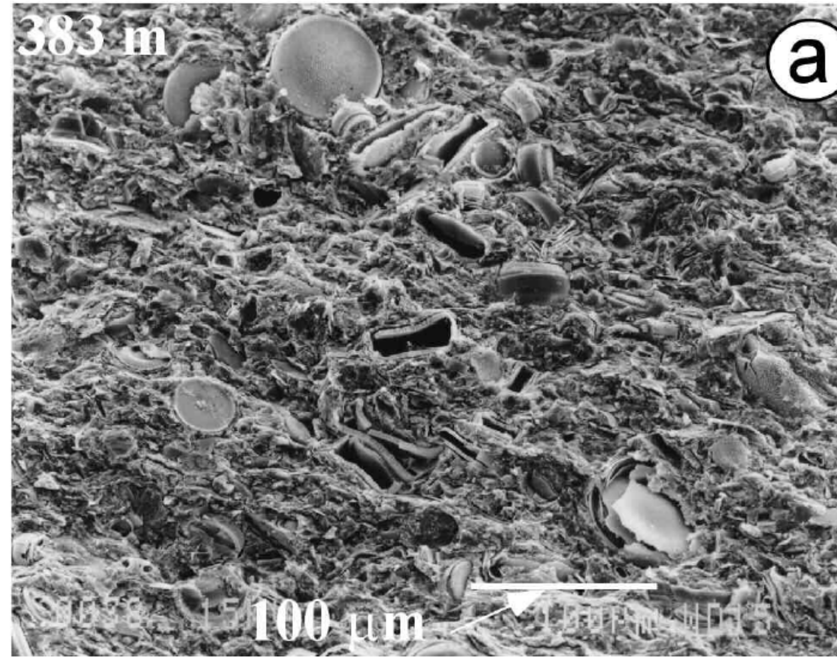
- They influence the frictional behavior of soils by their size and shape.

Locat & Tanaka, 2001; Tanaka & Locat, 1999



Locat & Tanaka, 2001; Tanaka & Locat, 1999

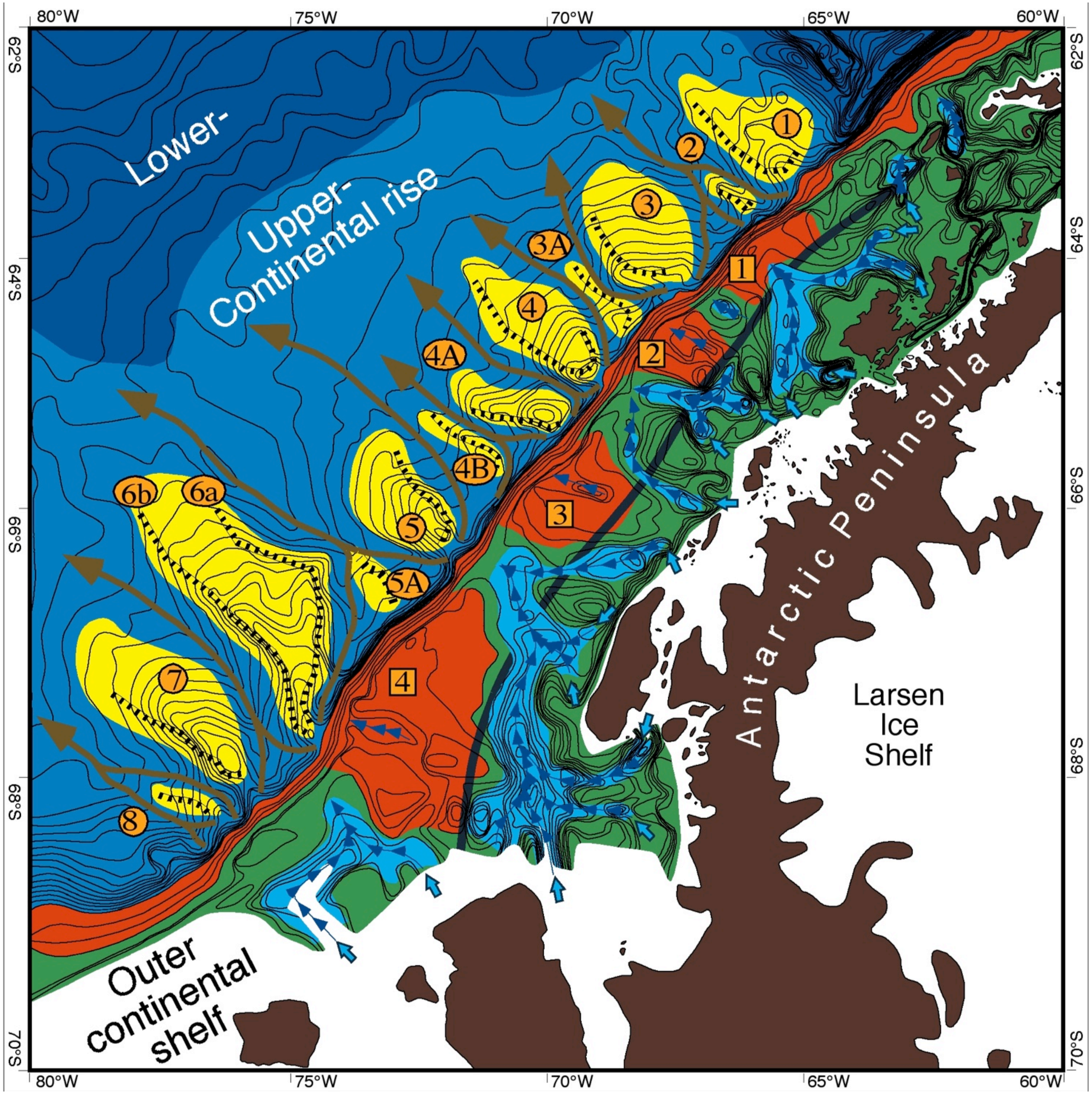




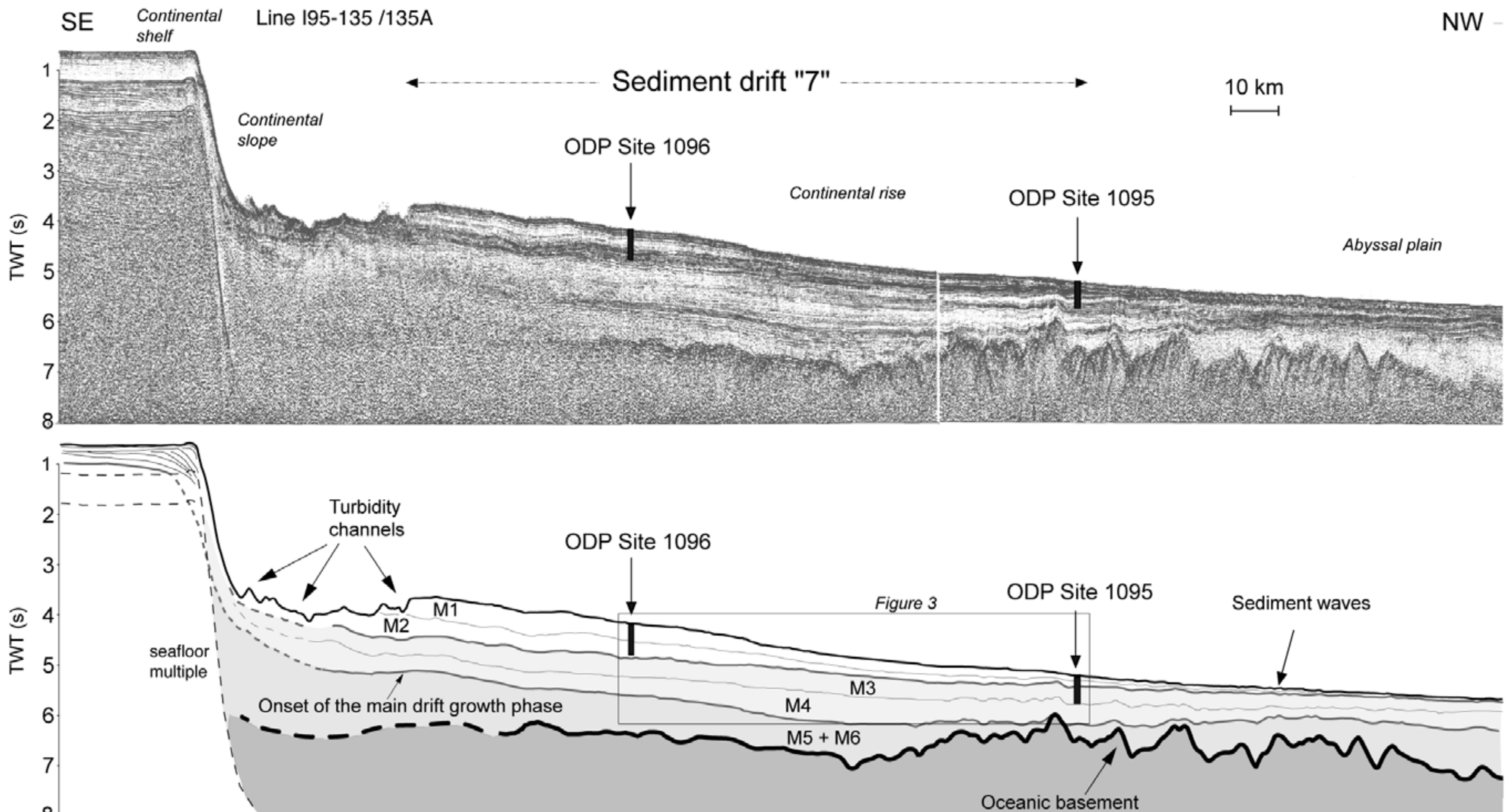
Distribution of diatoms in a consolidated sediment taken at a depth of 383 m at the site of Kansai airport.

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

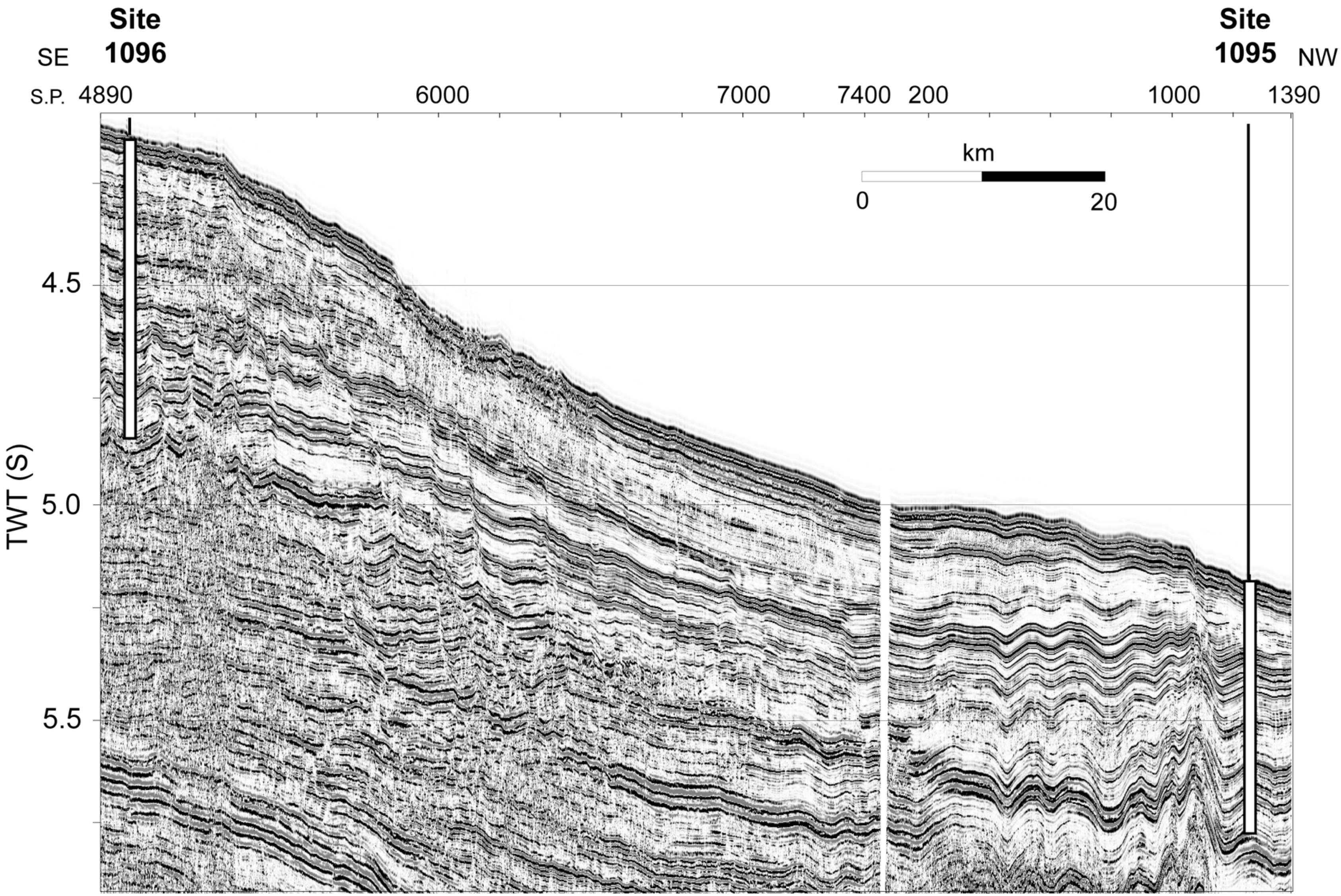
Locat & Tanaka, 2001; Tanaka & Locat, 1999



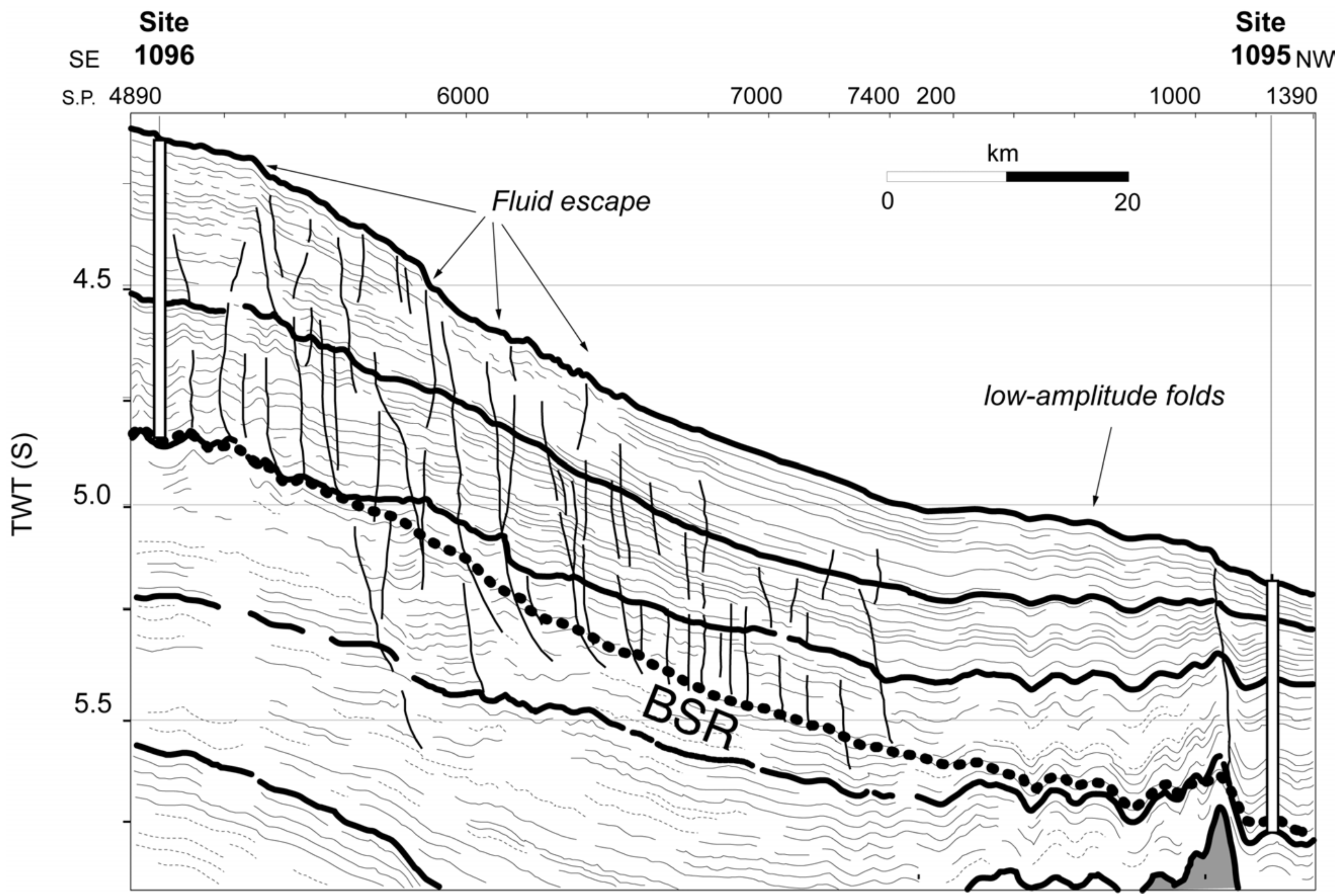
Rebesco et al. (1998), Terra Antartica, 5(4), 715-725



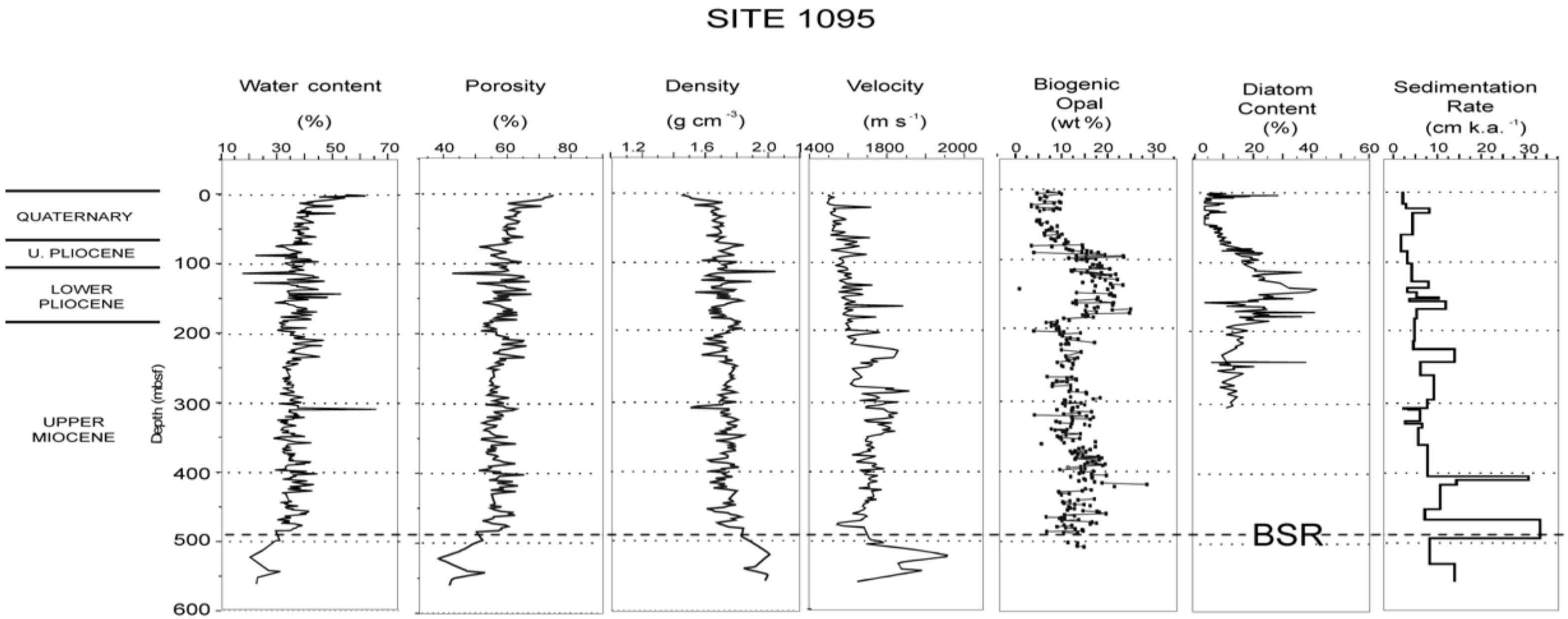
Volpi et al., 2003

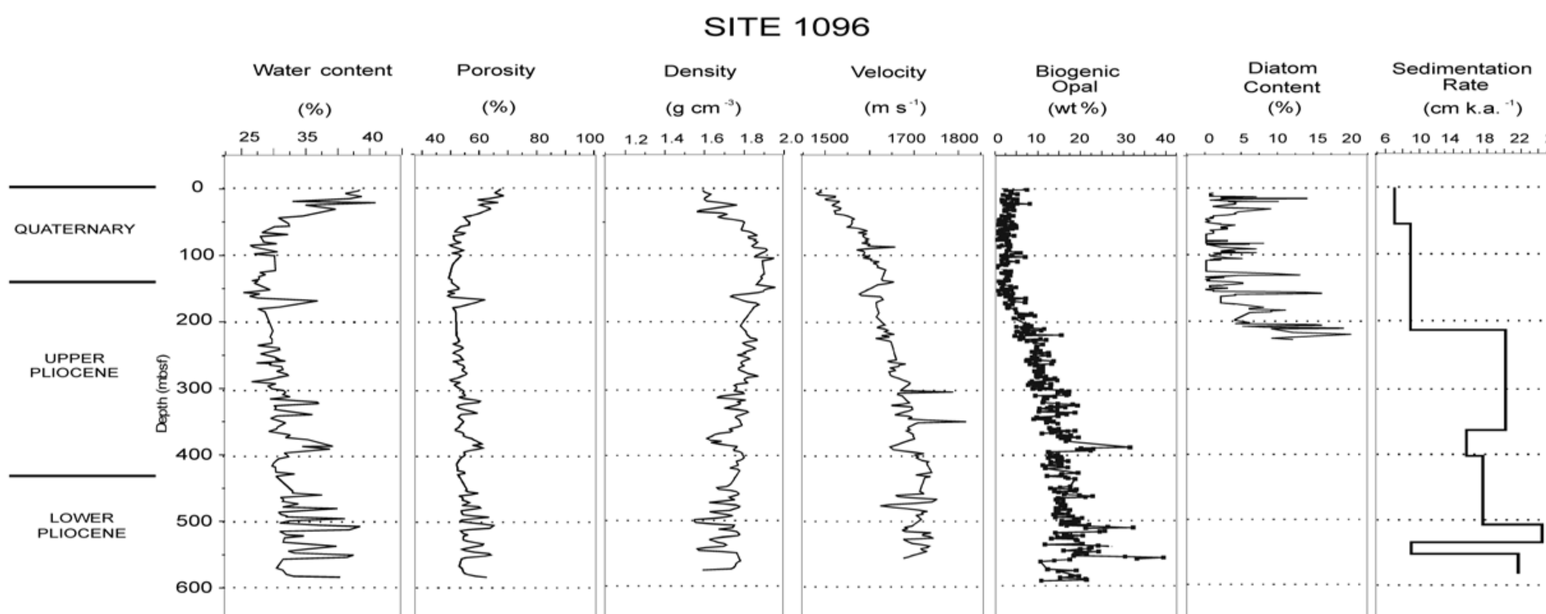


Volpi et al., 2003

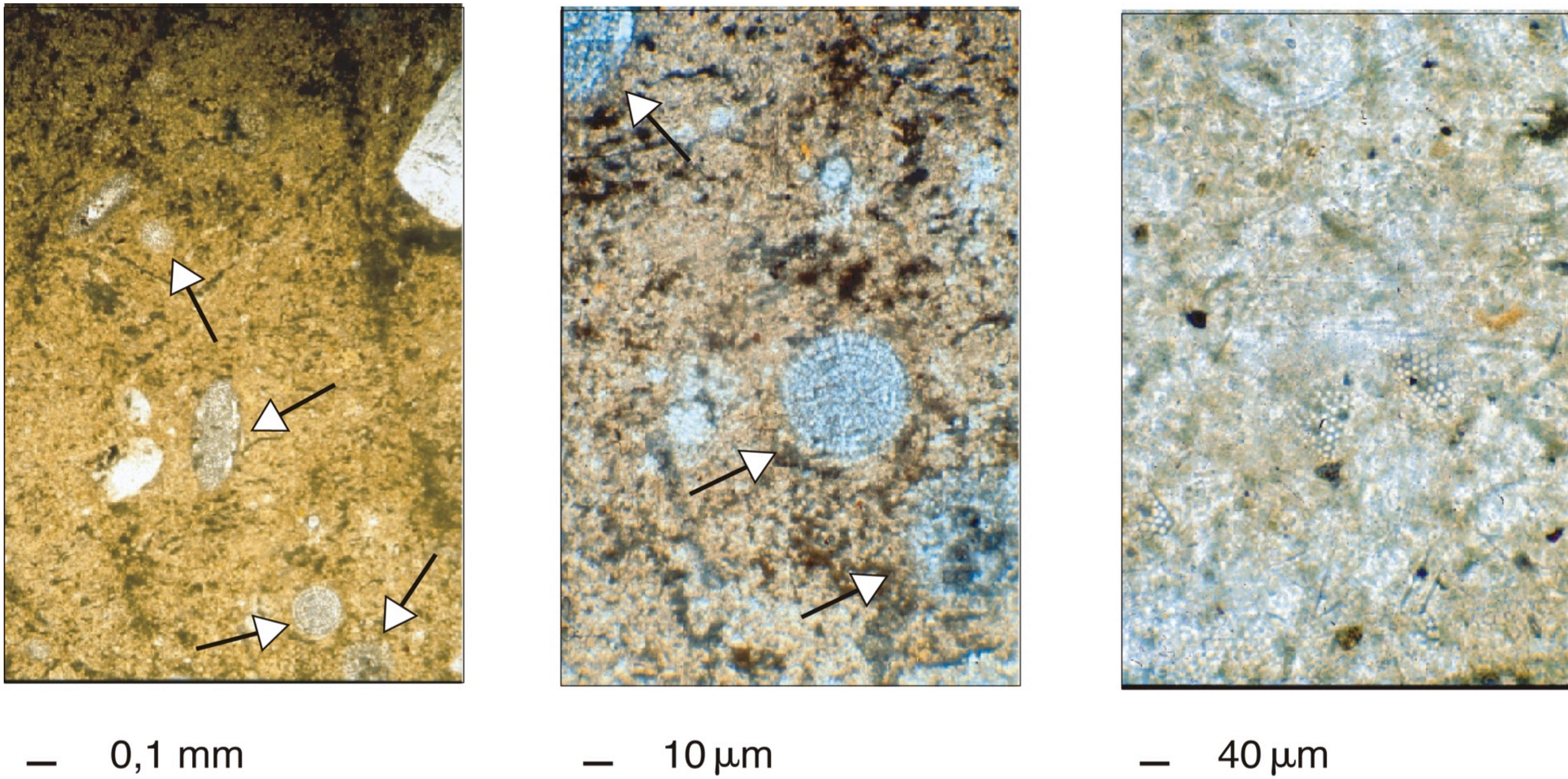


Volpi et al., 2003

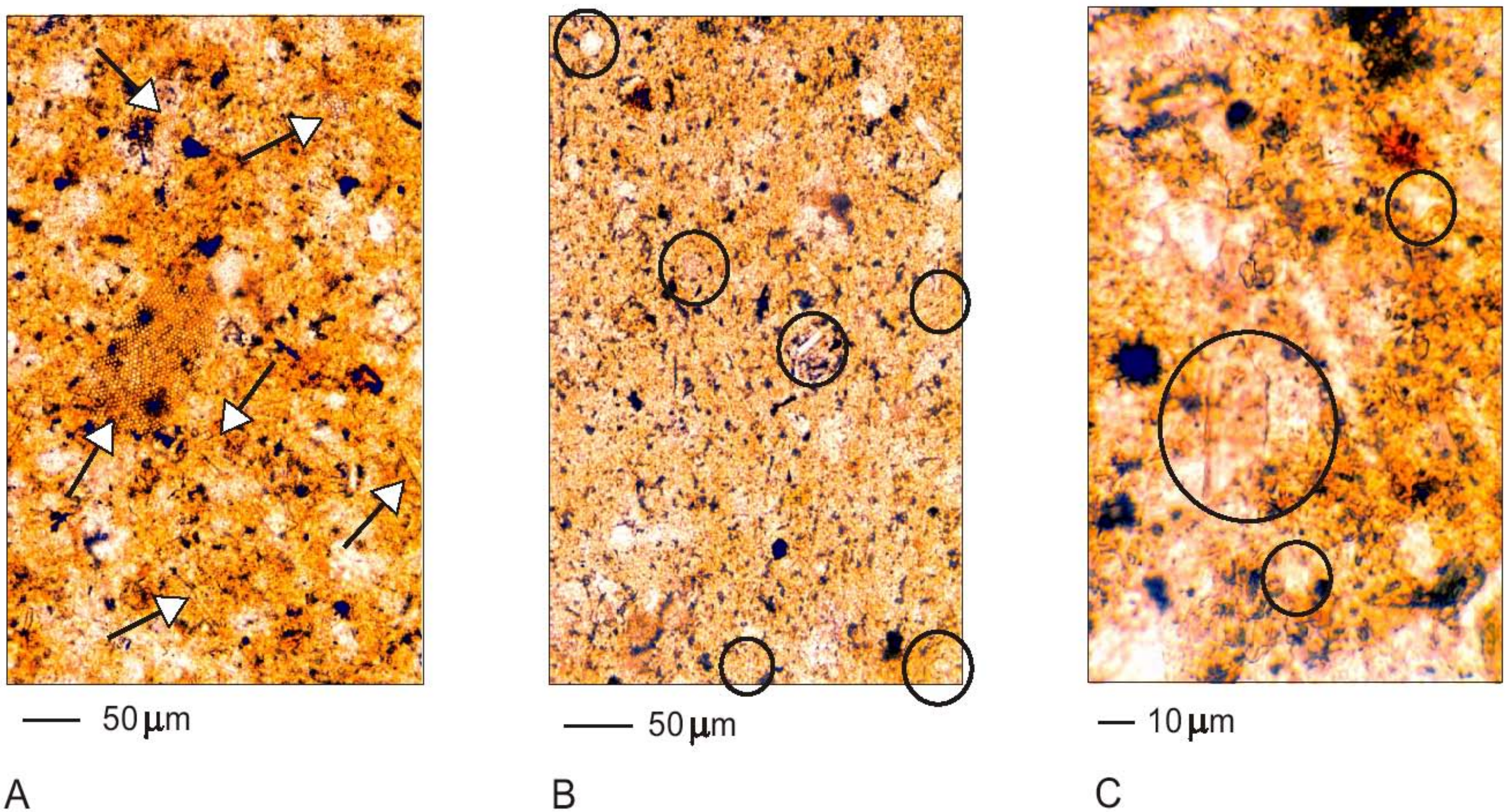




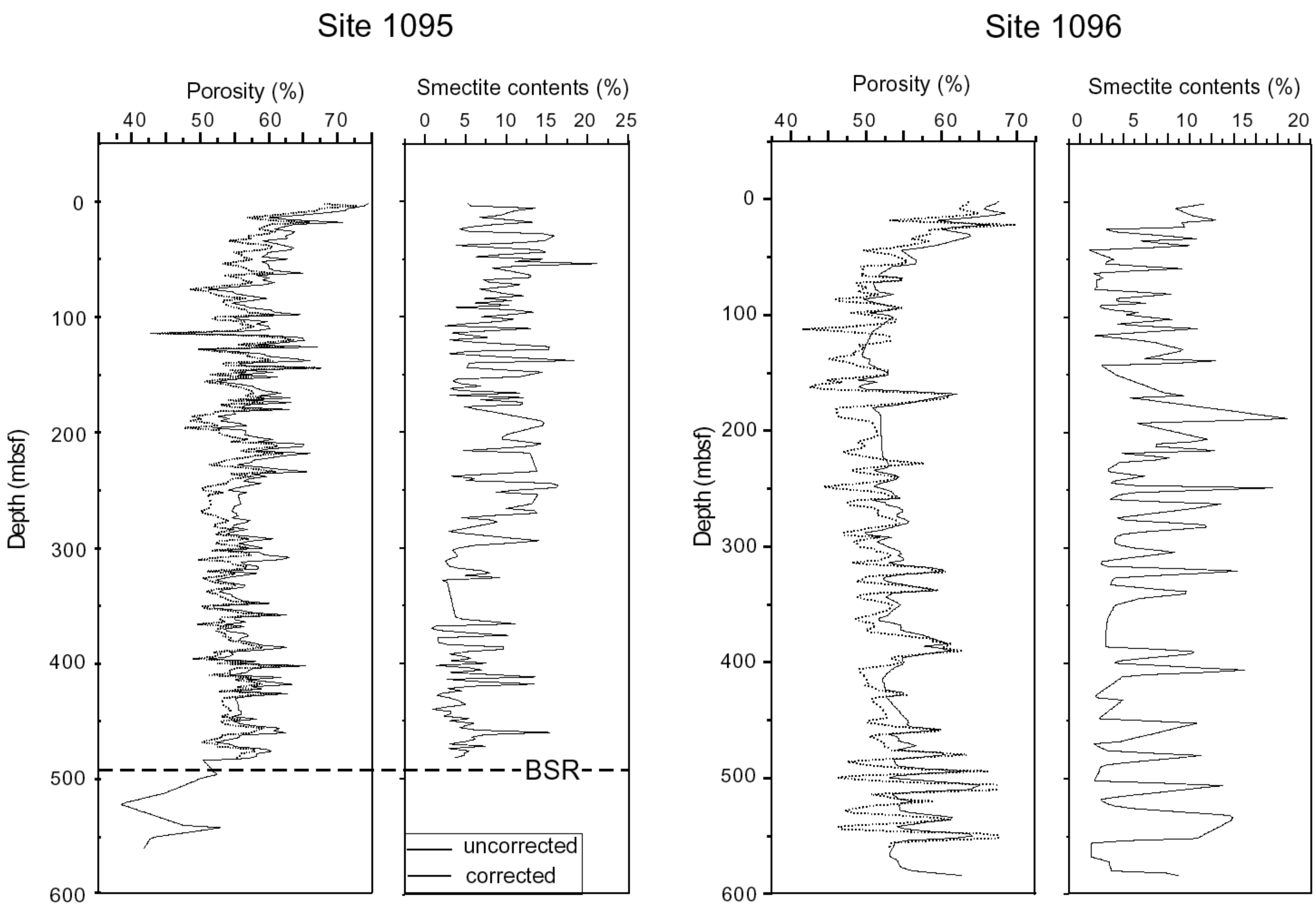
Volpi et al., 2003



Volpi et al., 2003



Volpi et al., 2003



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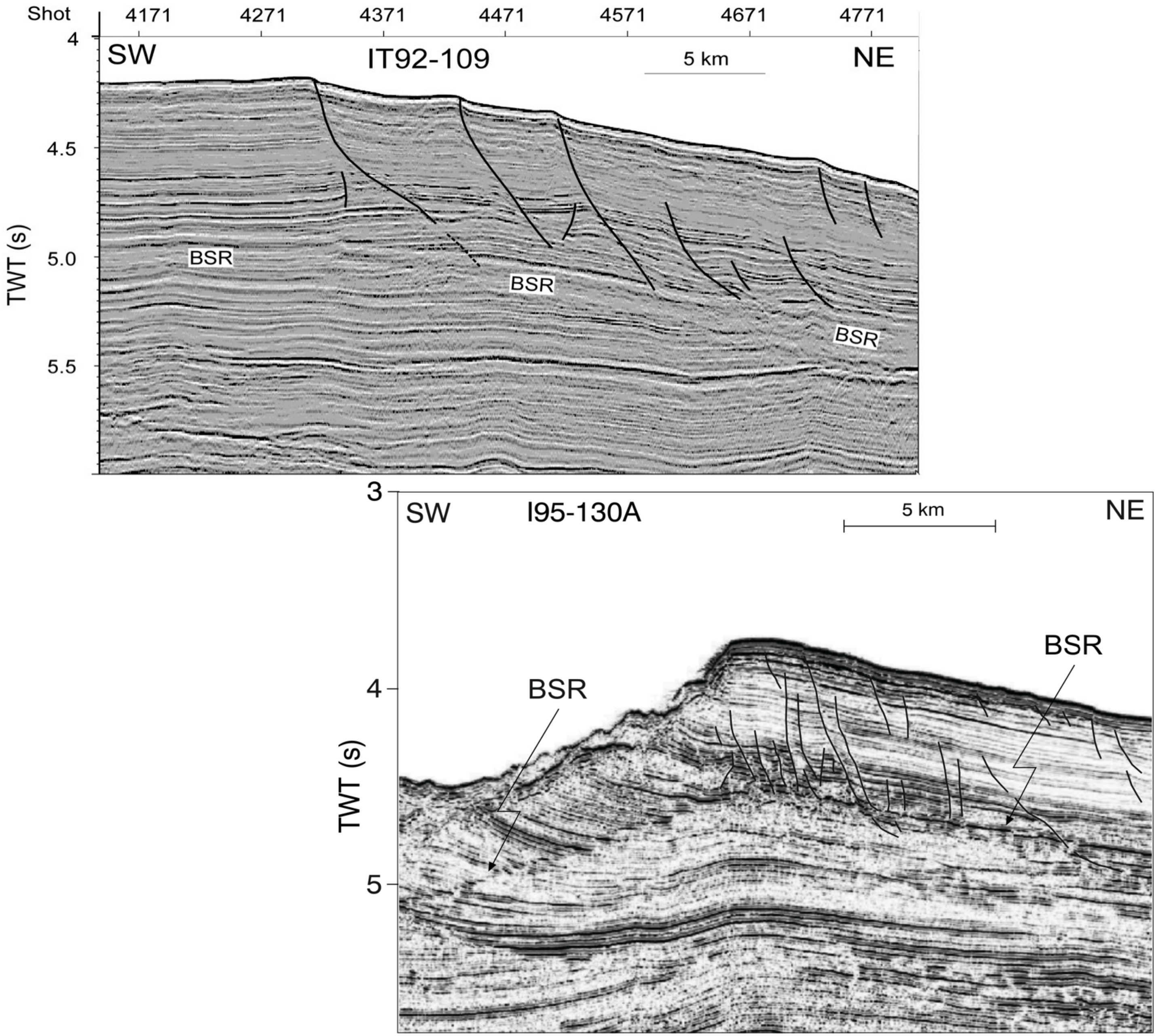

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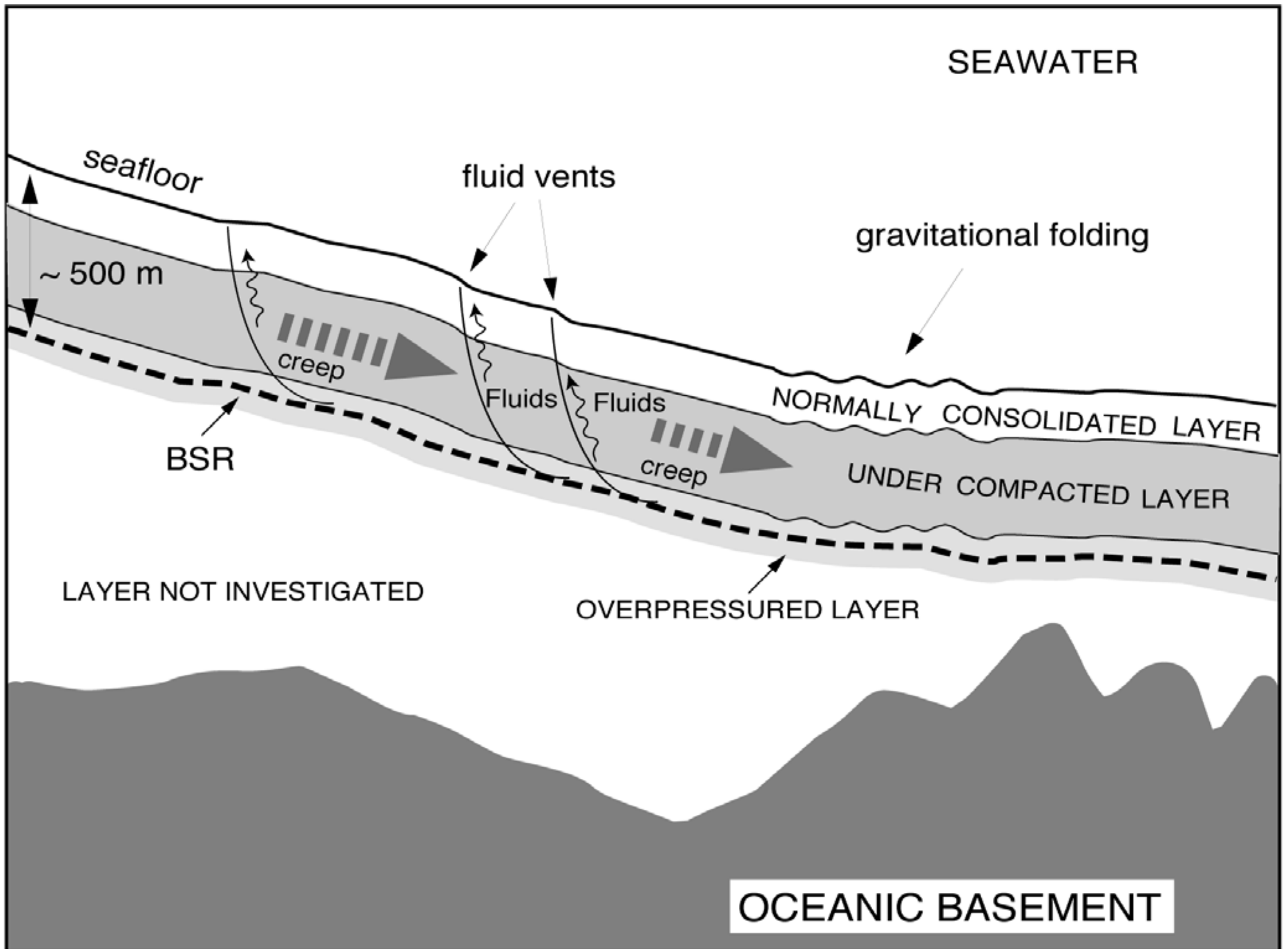

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Conclusions:

- 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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