Università di Trieste
Corso di Laurea in Geologia

Anno accademico 2021 - 2022

Geologia Marina

Parte IV

Modulo 4.2 Indicatori di movimento di fluidi: Vulcani di Fango, 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

Mud volcanoes

Surface expressions of focused fluid flow inside hydrocarbon-bearing sedimentary basins. They can:

- indicate subsurface petroleum accumulations
- may react to or reveal precursor signals of earthquakes
- induce hazards for people and industrial facilities
- release large amounts of methane into the atmosphere.

Mazzini and Etiope, 2017, ESR

Definition of Mud Volcano
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.

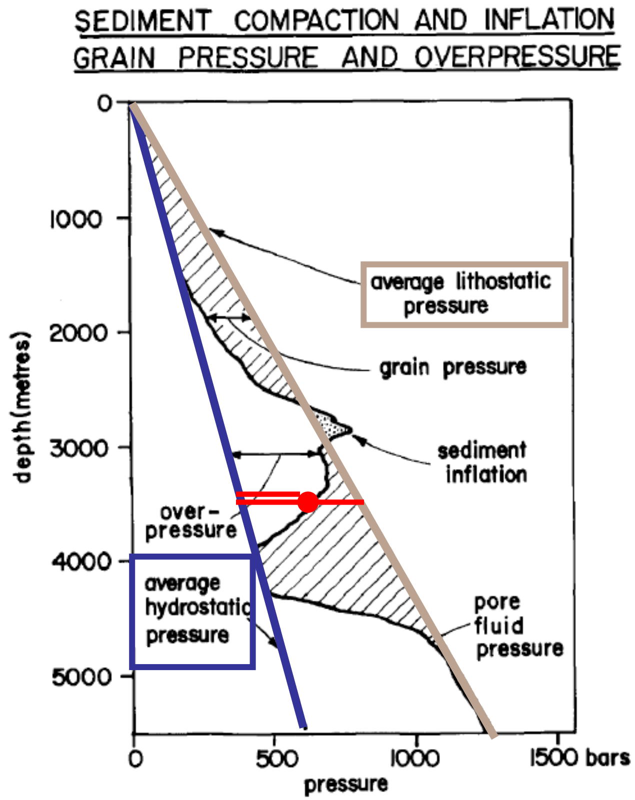
Olistostromes, or **sedimentary mèlanges:** uplifted and at times deformed **chaotic** sedimentary bodies (Cretaceous to Pliocene) originated by subacqueous mass gravitational processes, such as debris-flows, and submarine slides and/or mud volcanoes/diapirs.

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.

Degree of Overpressure

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

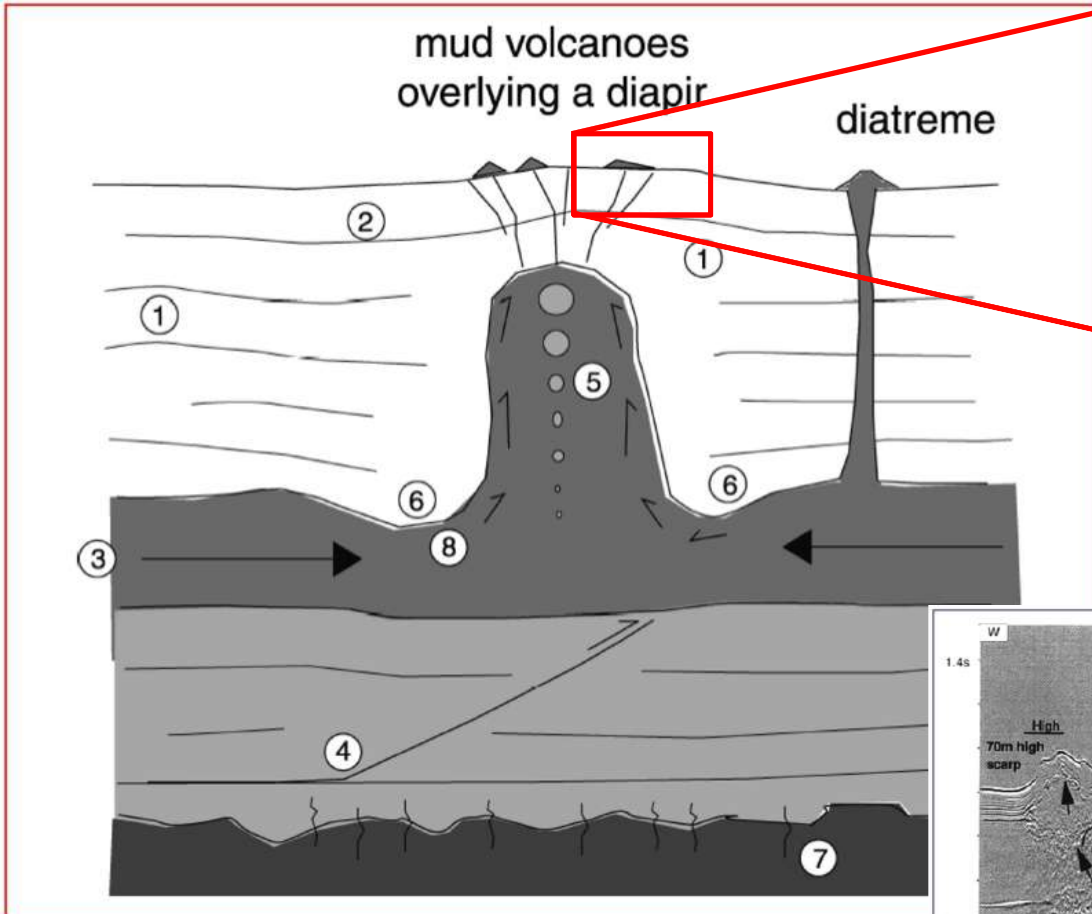
P_f = Pore pressure
P_{hy} = Hydrostatic Pressure
P_d = Total Stress

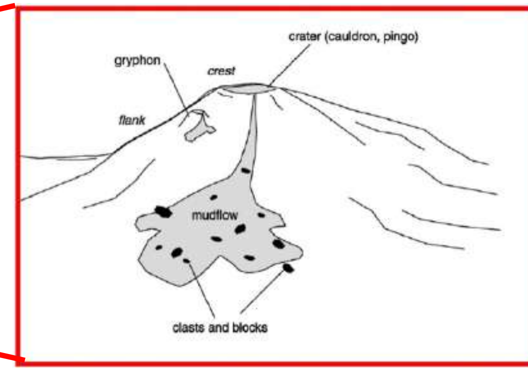


$\lambda = 0$ if $P_f = P_{hy}$
$\lambda = 1$ if $P_f = P_d$ = fluid movement (liquid mud)

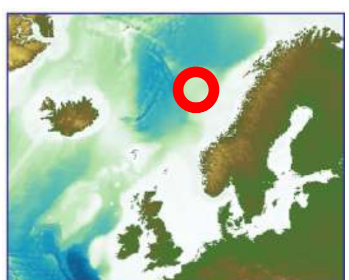
Mud diapirs move when $0<\lambda<1$

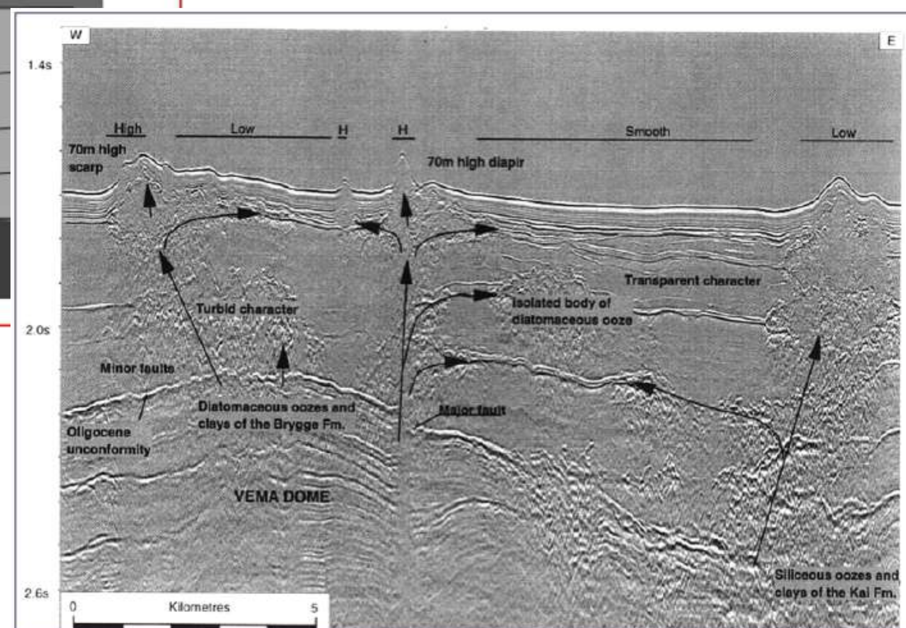
Brown, 1990



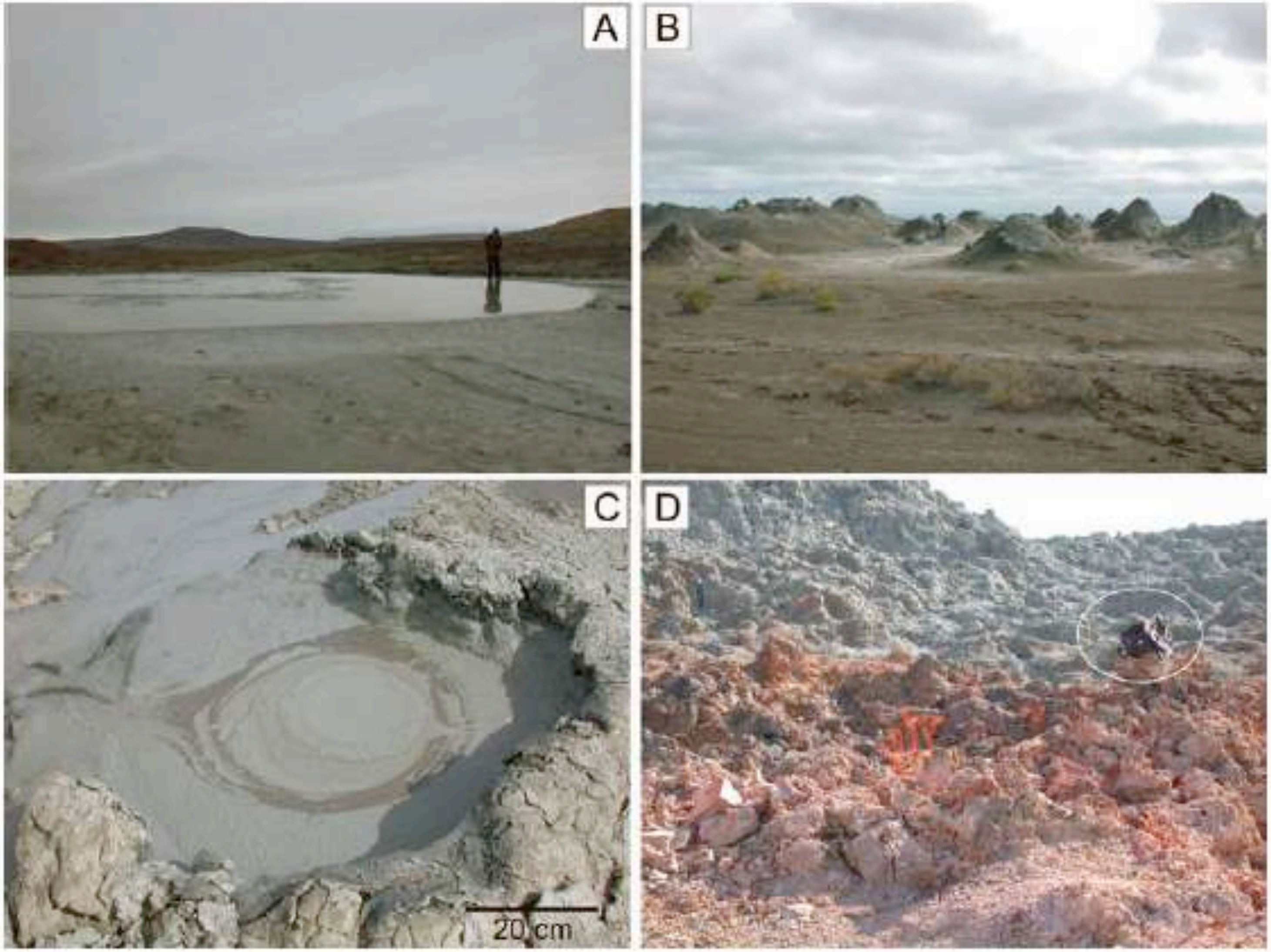


Kopf (2002)



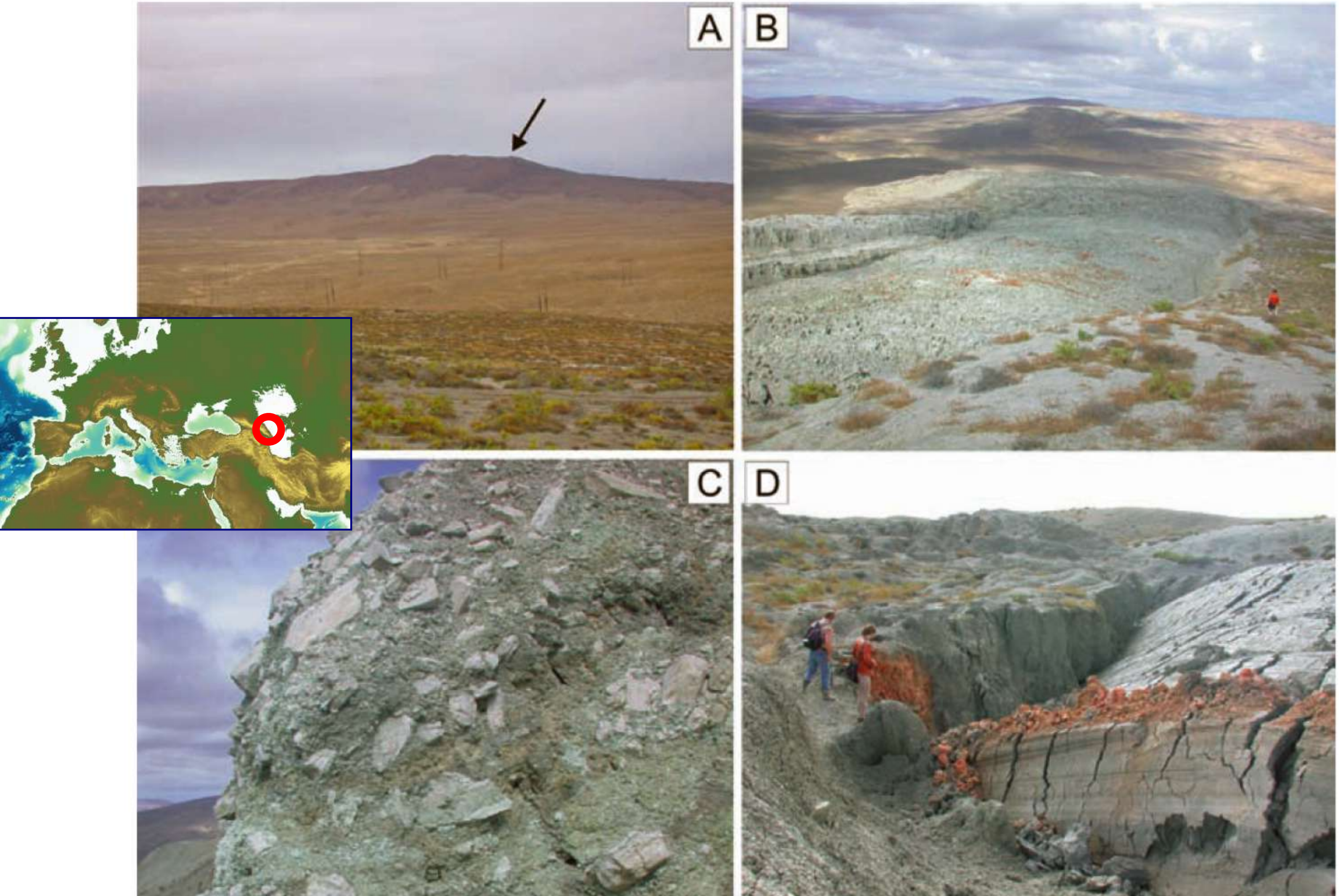


Hovland et al. (1998)



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)

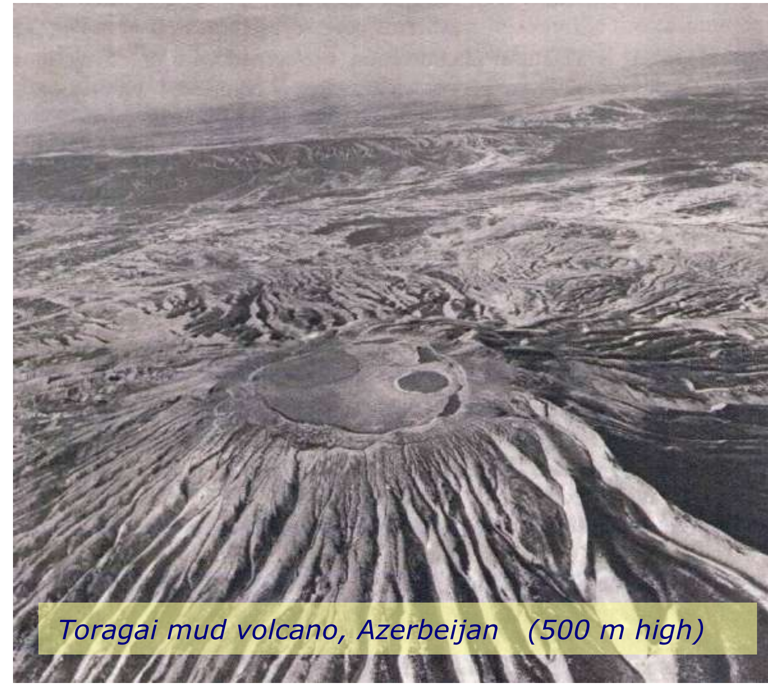
NATURAL FIRES OF AZERBEIJAN

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)

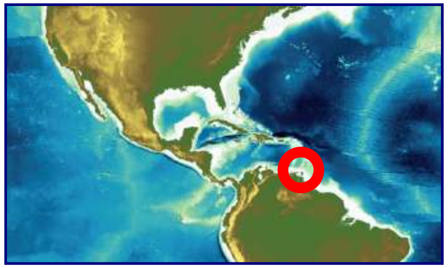


Toragai mud volcano, Azerbeijan (500 m high)

Lokbatan Mud Volcano, Azerbeijan, 25 October 2001

https://www.youtube.com/watch?v=0xCPXg5IJeg

Eruption Piparo, 22/2/1987



Piparo, Trinidad
22 Febbruary 1987

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

CHECKING IT OUT: BENDING down, Opposition Leader Patrick Manning, a trained geologist, and ... closely examine the mud which was spewed from the Piparo mud volcano last Saturday ...

Sunday Guardian

• 25519 SUNDAY, FEBRUARY 23, 1997 $3

Taekwondo champion Cheryl-Ann Sankar is flying high — PAGE 13

SUNSHINE's Danella Callender cuddles up with teddy bear

Courtney Walsh is Windies captain against India — PAGE 6

Jeanille Bontemps is a shining star in ZONE

Volcano erupts

Mountain of mud leaves 31 Piparo families homeless

By LOUIS B HOMER

A MUD volcano erupted in Piparo at 5.30 am yesterday leaving 31 families homeless and 12 houses and 20 cars buried under a 100-foot high mountain of mud.

Trinidad Guardian

• 25520 MONDAY, FEBRUARY 24, 1997 $1.25

Volcano takes first life

Piparo resident dies after helping villagers

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

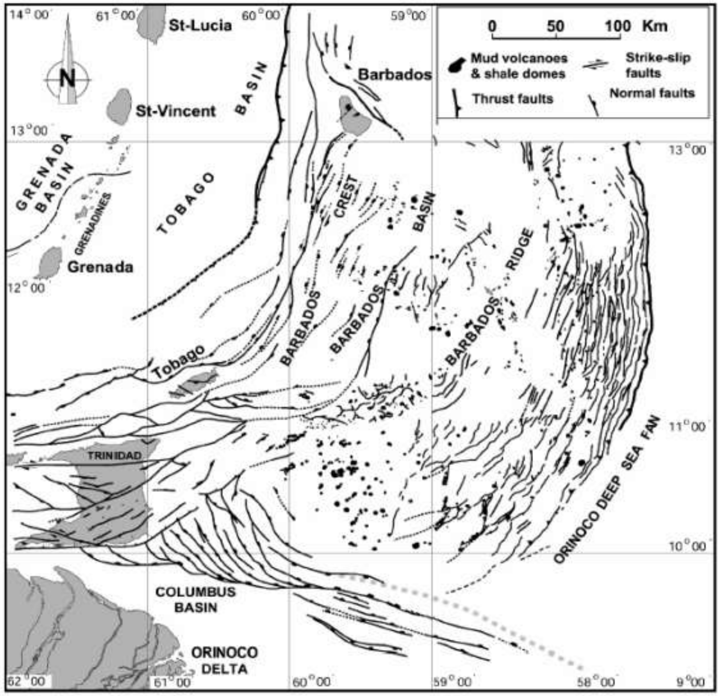
By LOUIS B HOMER

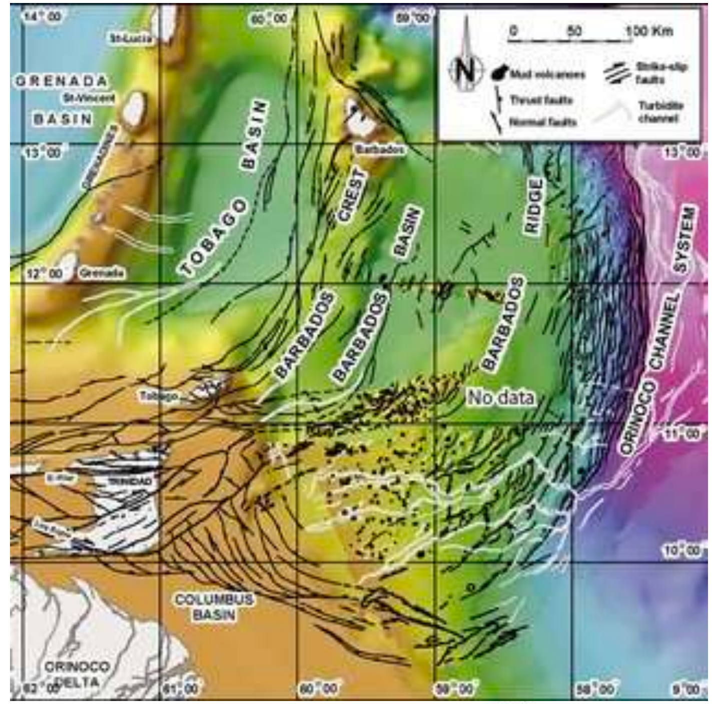
VICTIMS of the volcano eruption at Piparo are expected to be relocated either at Buen Intento, Stone Road Piparo, or a site on Ho... Mosque, Prime Minister Basdeo Panday, who travelled by helicopter to the area, said the volcano eruption could be seen as another opportunity "to unite our people as one." 25 miles of roadway. Those listed for immediate attention are Piparo R... Guaracara Tabaquite Rd, Sisters Rd... cho Road, Hosein Road, and Na... Mayaro Road.

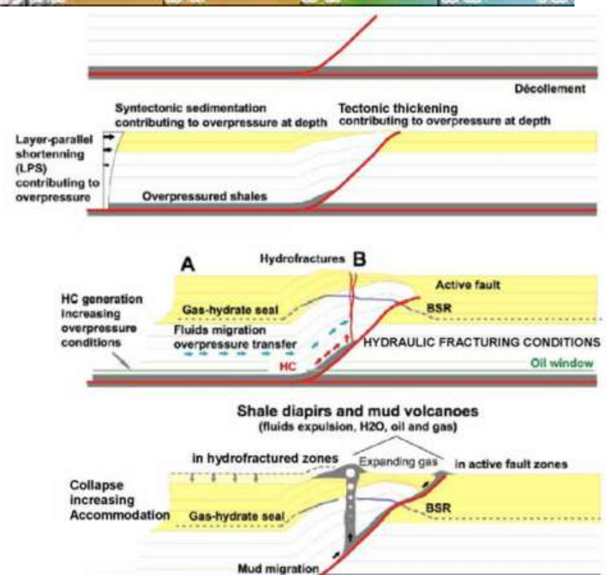
Mud mass

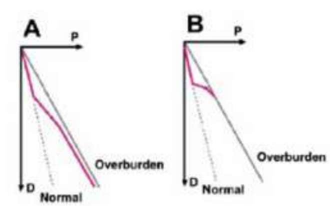
Piparo volcano erupts Page 3

BELOW: A HOUSE is left in ruins in the aftermath of the eruption of a mud volcano in Piparo early yesterday morning. This house was pushed over by the wall of mud on the left. RIGHT: MEMBERS of a Piparo family salvage what is left of their belongings from this wooden house which was pushed over and partially covered by mud following the early morning eruption. Photos: STEPHEN AZIZ



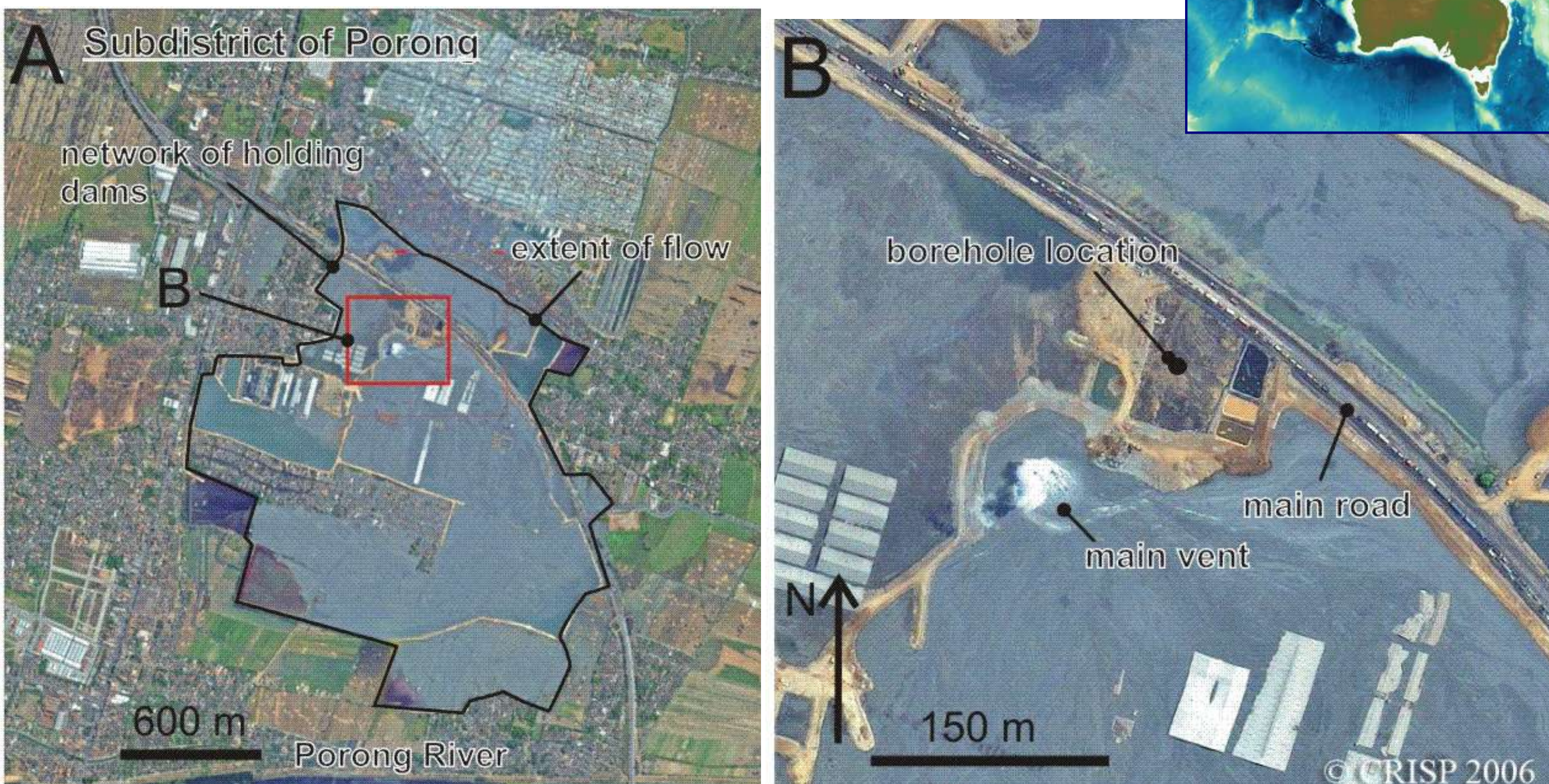






Deville et al.,
https://www.researchgate.net/publication/352001194

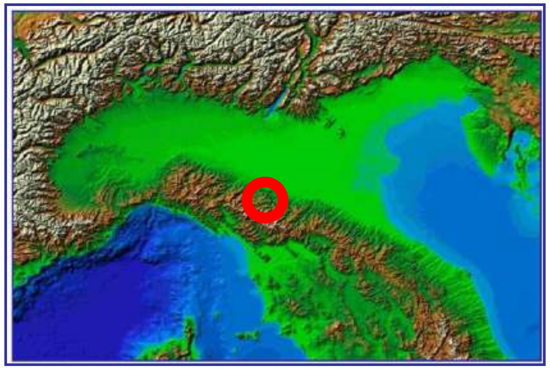
THE ENVIRONAMENTAL DISASTER OF THE MUD VOLCANOE TRIGGERED BY DRILLING FOR OIL IN JAVA: ISOLA DI GIAVA, MAY 29 2006



Davies, 2007, GSA-Today

SPIEGEL ONLINE International, Reuter

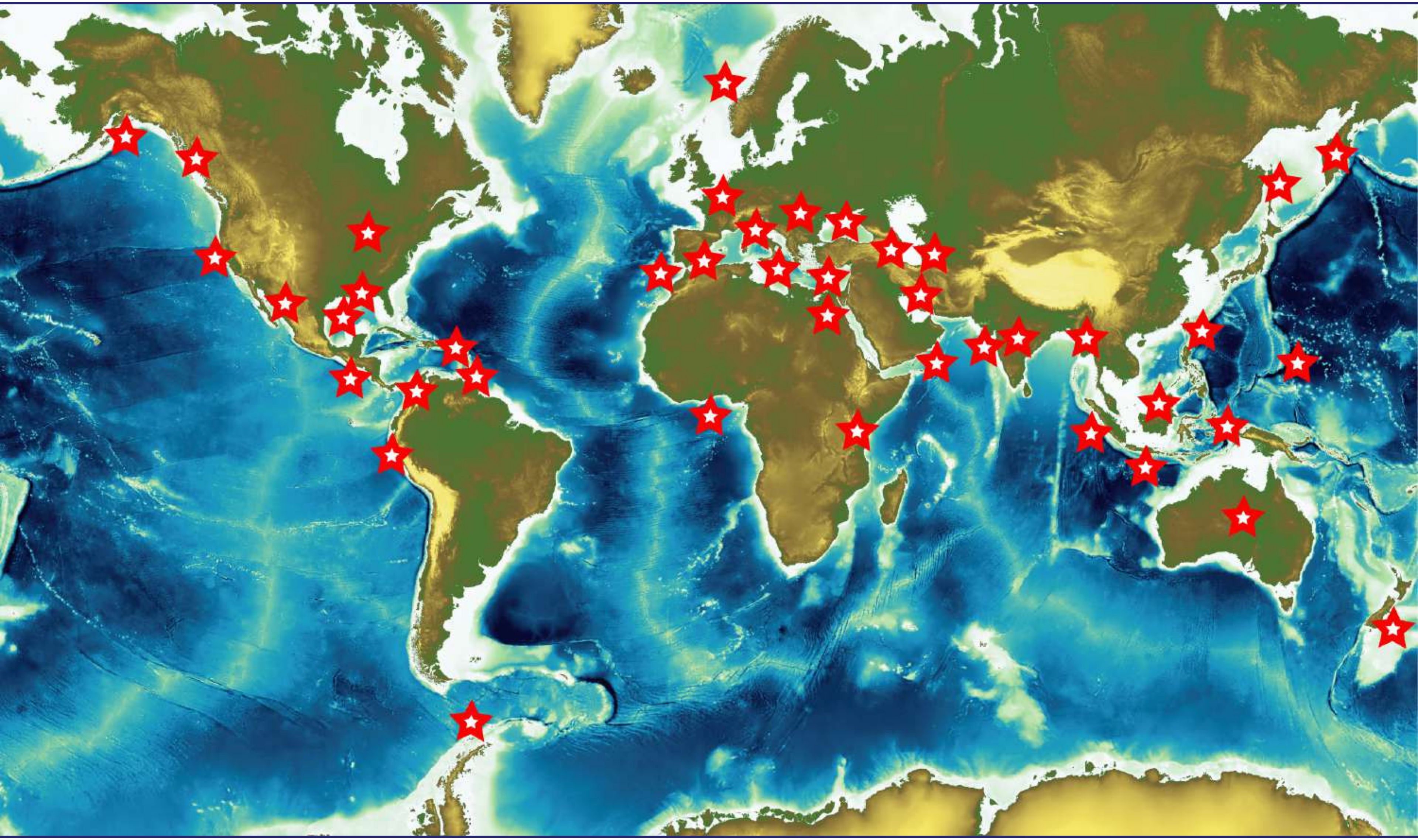
MUD VOLCANOES **SALSE DI NIRANO**, ITALY

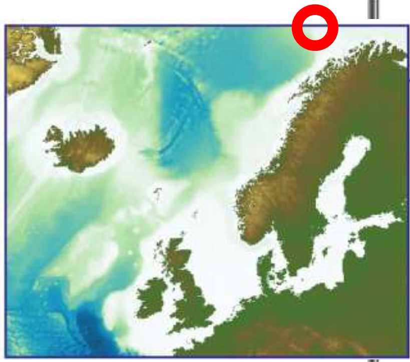


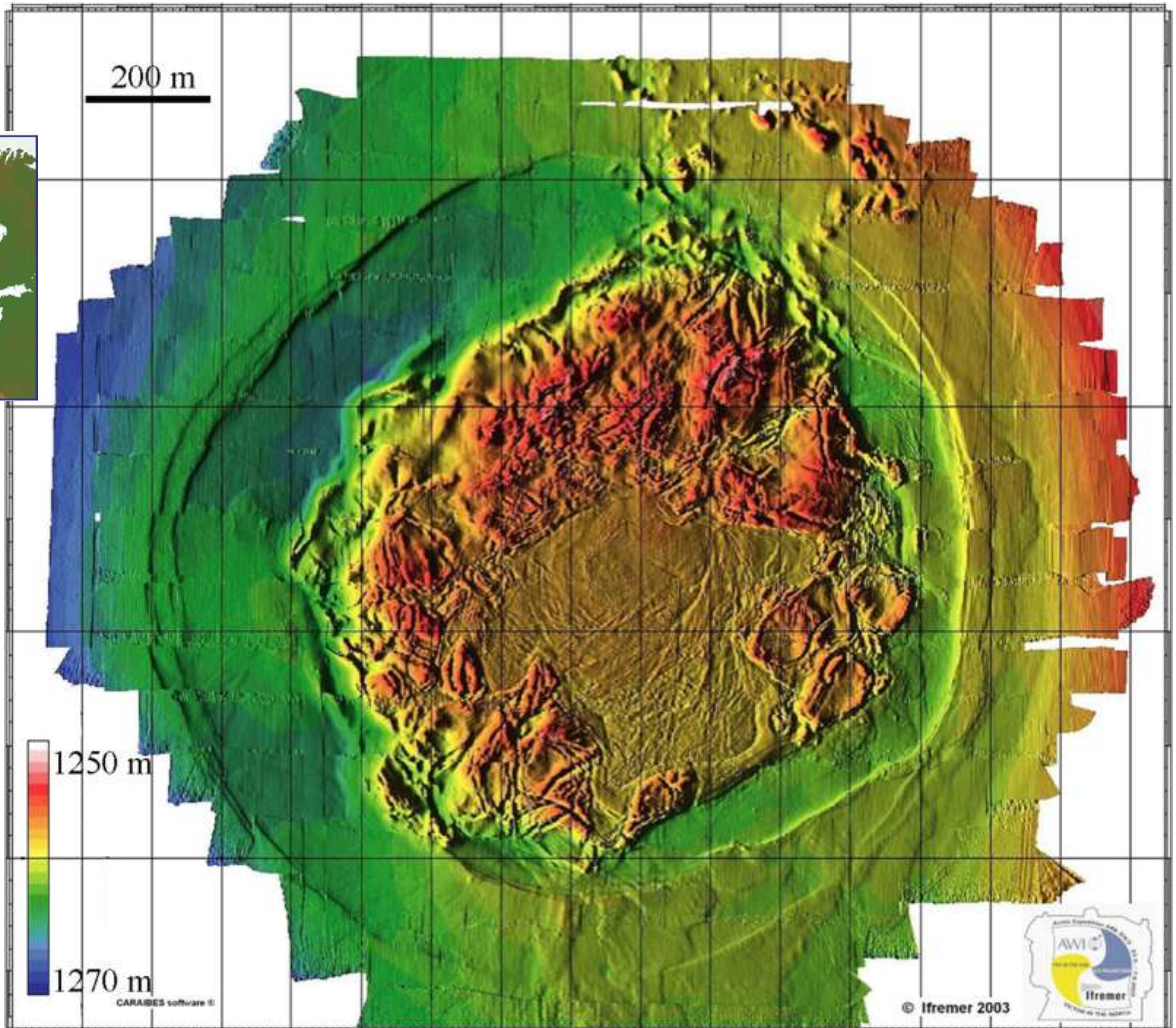
Onland mud volcanoes until now. They are more common in the marine environment

How to recognize submarine mud volcanoes
1. Strong backscatter on side-scan sonar records representing topographic features (craters, cones, mud flows, etc.).
2. Core samples showing 'mud breccia' containing sediments with a range of different ages, compositions and structures.
3. Evidence of gas seepage and associated features (bacterial mats, cold-seep communities or methane derived authigenic carbonate – MDAC.
5. Seismic evidence of feeder channels and/or mud diapirs.

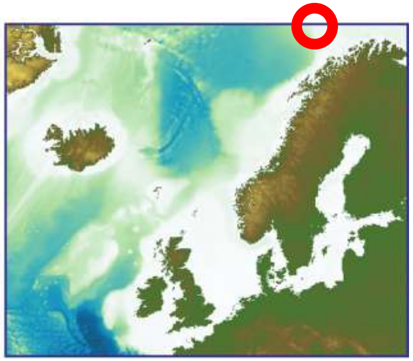
MUD VOLCANOES IN THE WORLD

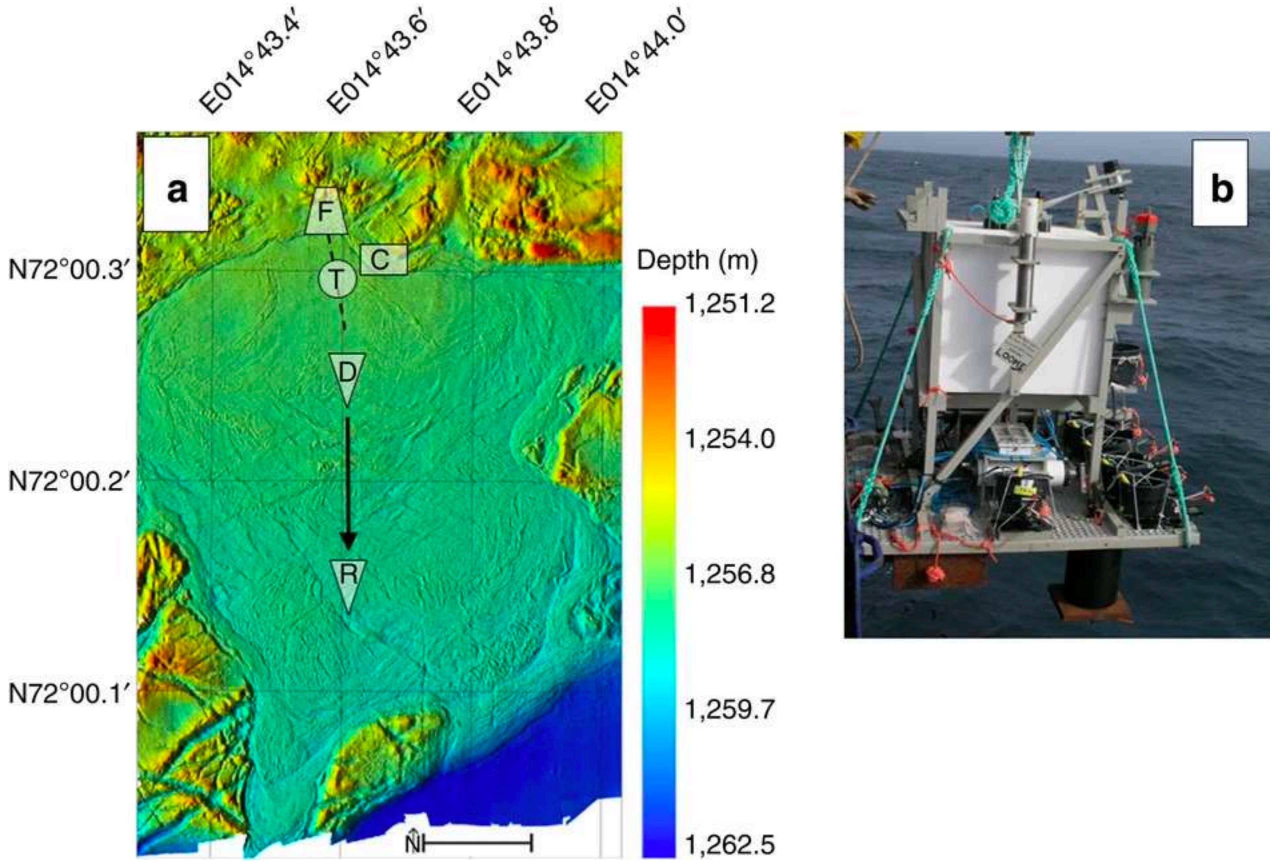




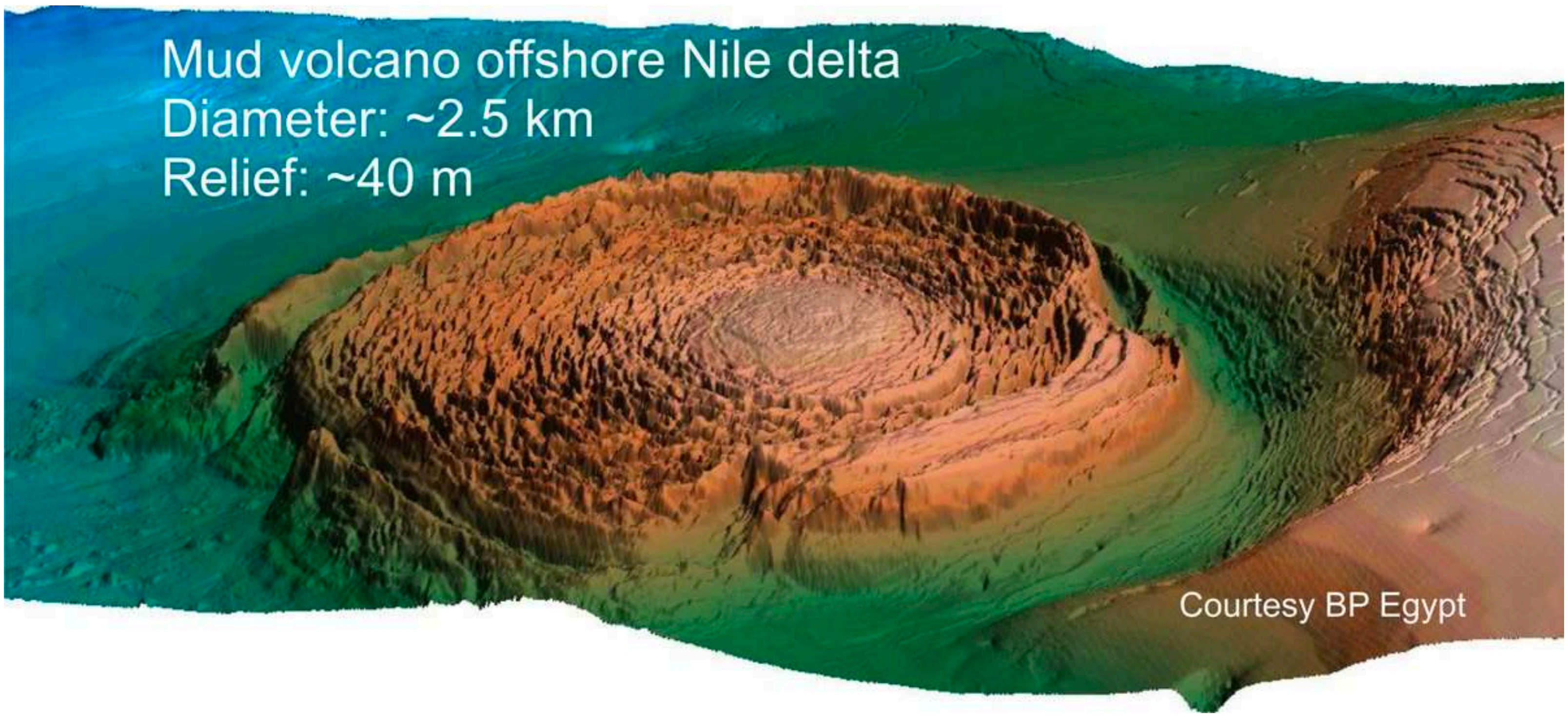


Multibeam bathymetry
From ROV.

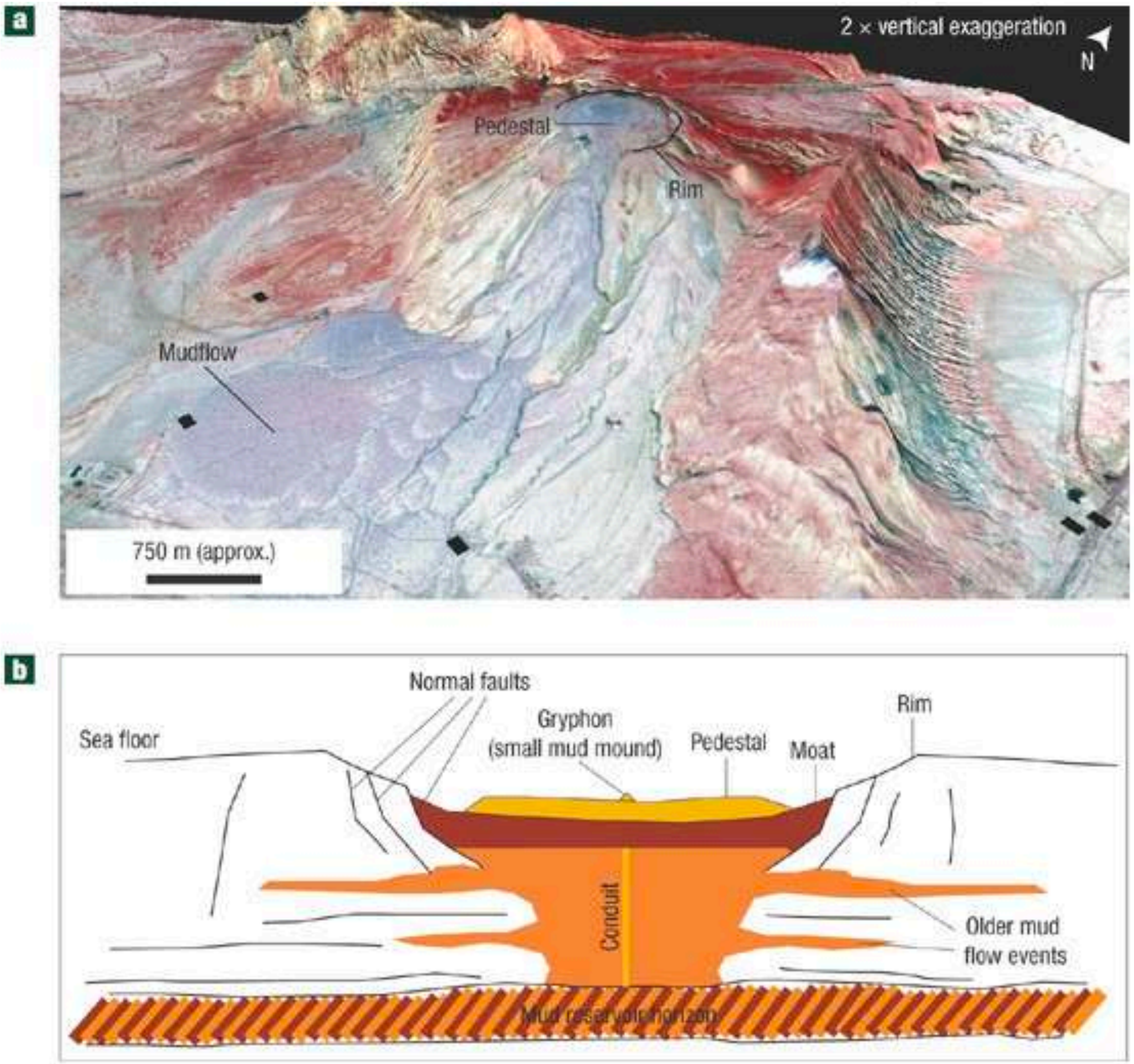




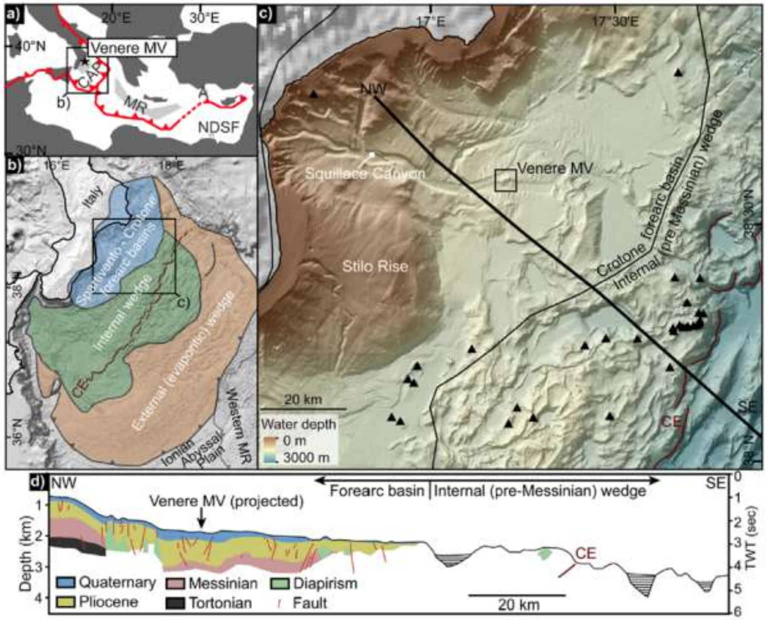
Tomas Feseker, Antje Boetius, Frank Wenzhöfer, Jerome Blandin, Karine Olu, Dana R. Yoerger, Richard Camilli, Christopher R. German & Dirk de Beer, 2014. Eruption of a deep-sea mud volcano triggers rapid sediment movement. Nature Communications volume 5, Article number: 5385 (2014)

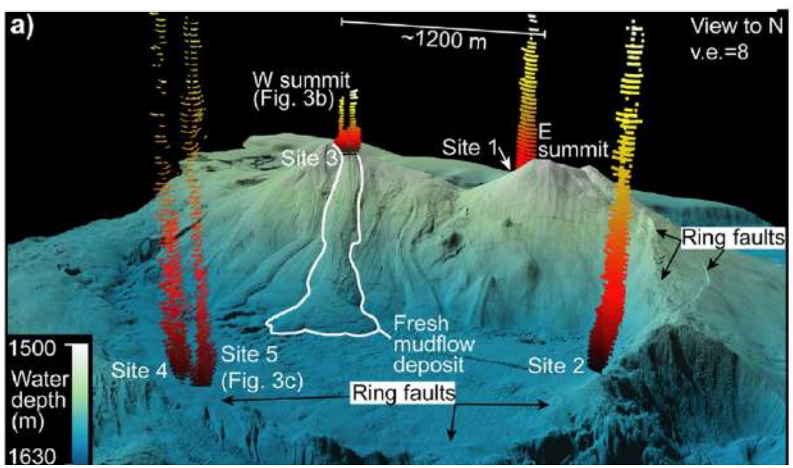


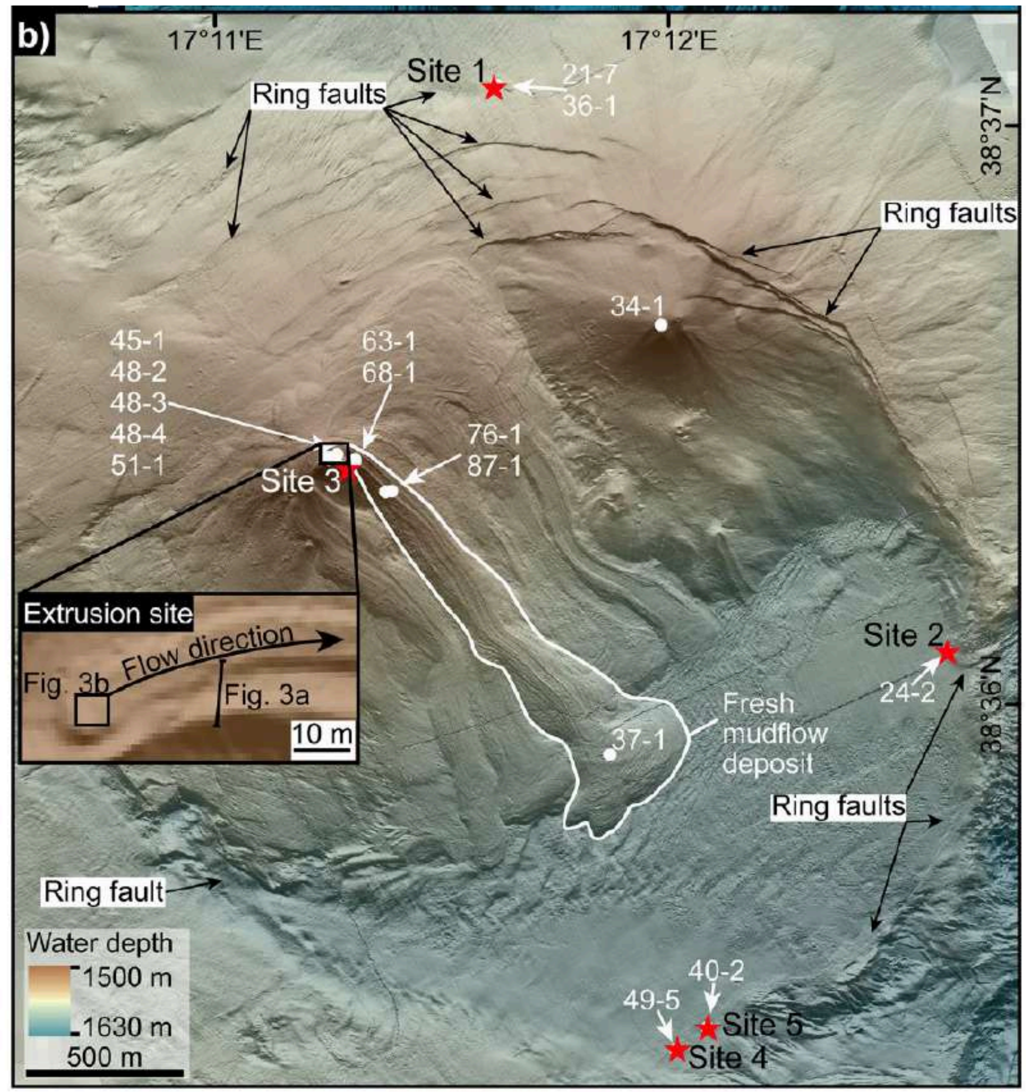
https://twitter.com/criticalstress_/status/1008632107306897409?lang=de



Kopf, A. Making calderas from mud. Nature Geosci 1, 500–501 (2008). https://doi.org/10.1038/ngeo256

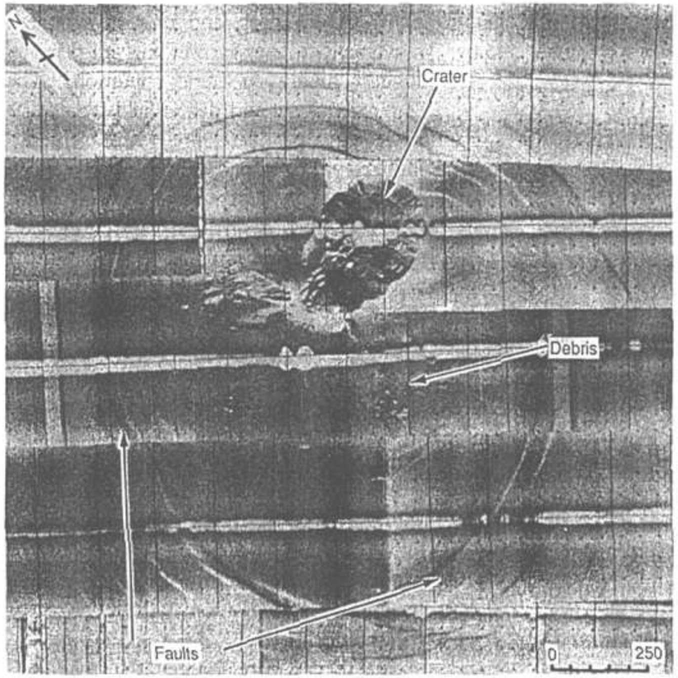


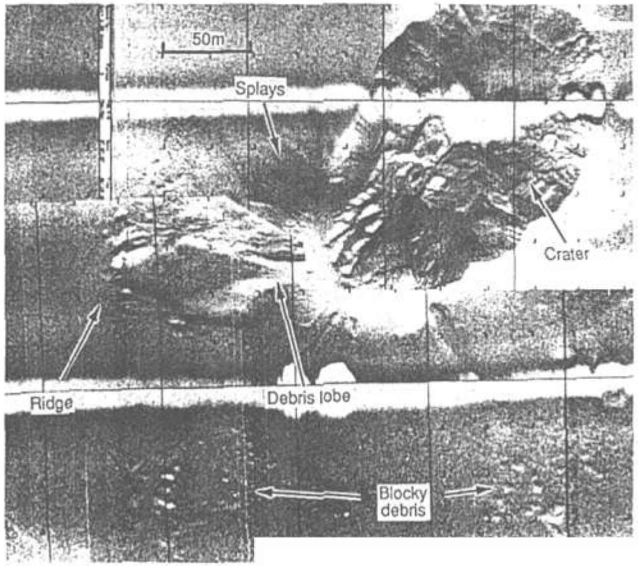


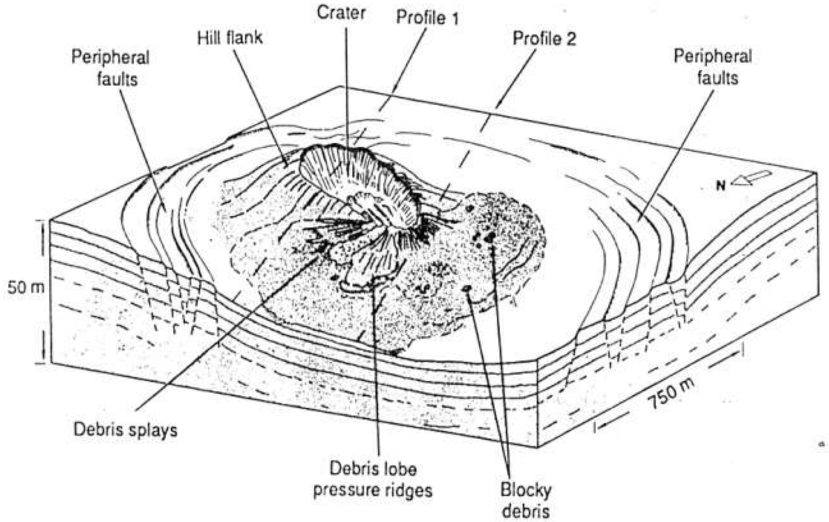


Loher & al., 2018 Scientific Reports

Mud volcanoes in the Gulf of Mexico. One of the first cases studied

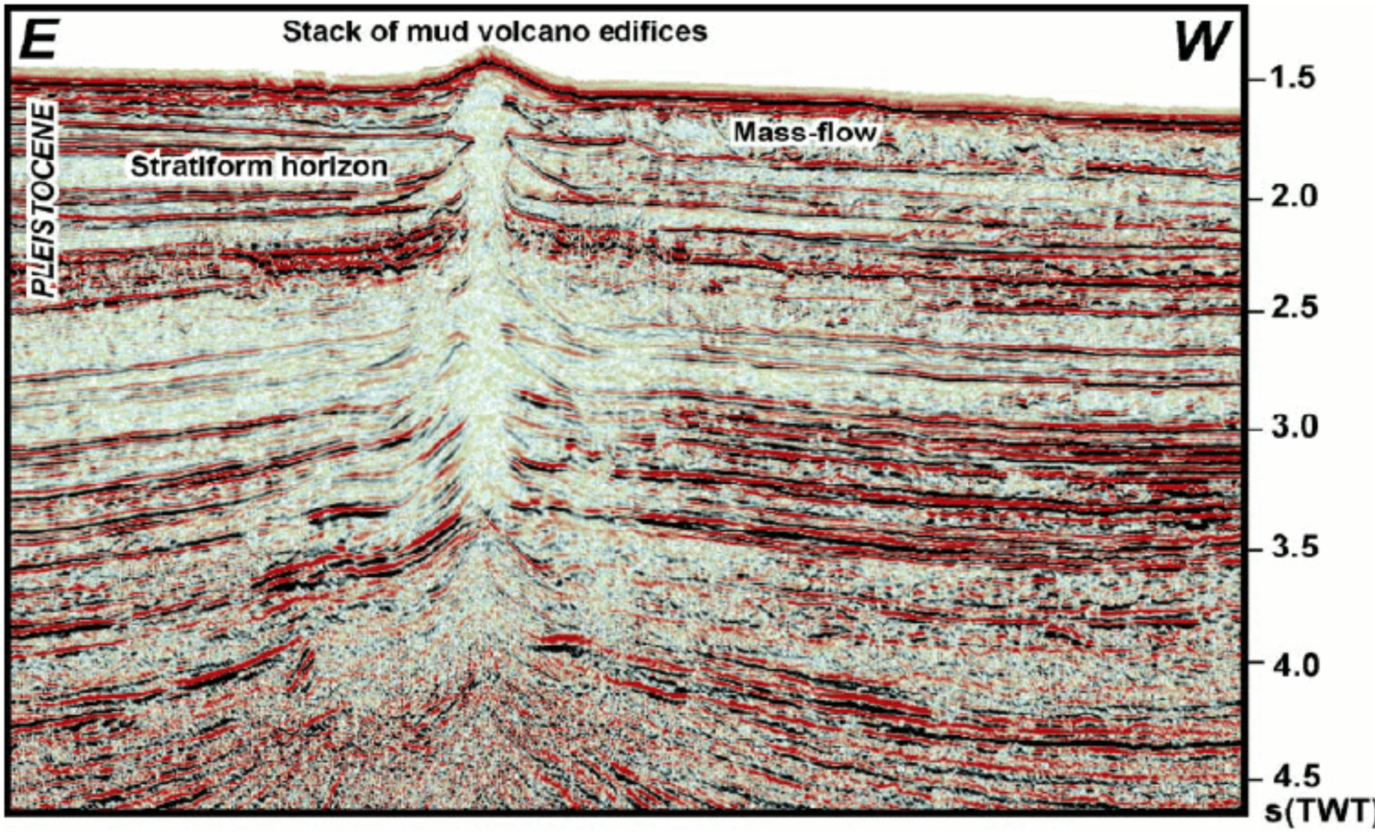






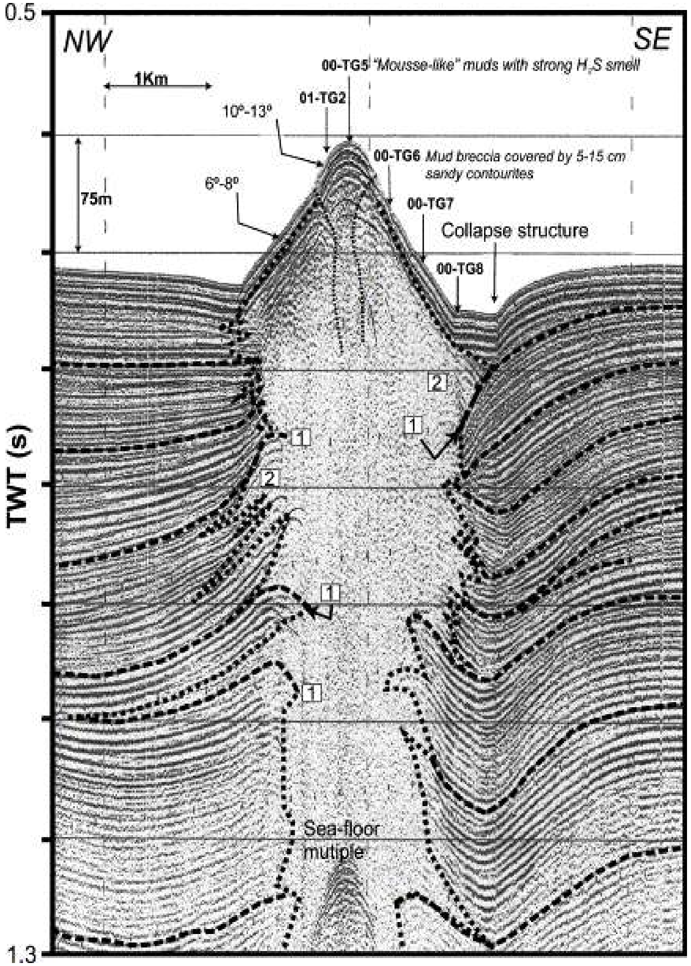
Prior et alii, Science 243 (1989), 517-519

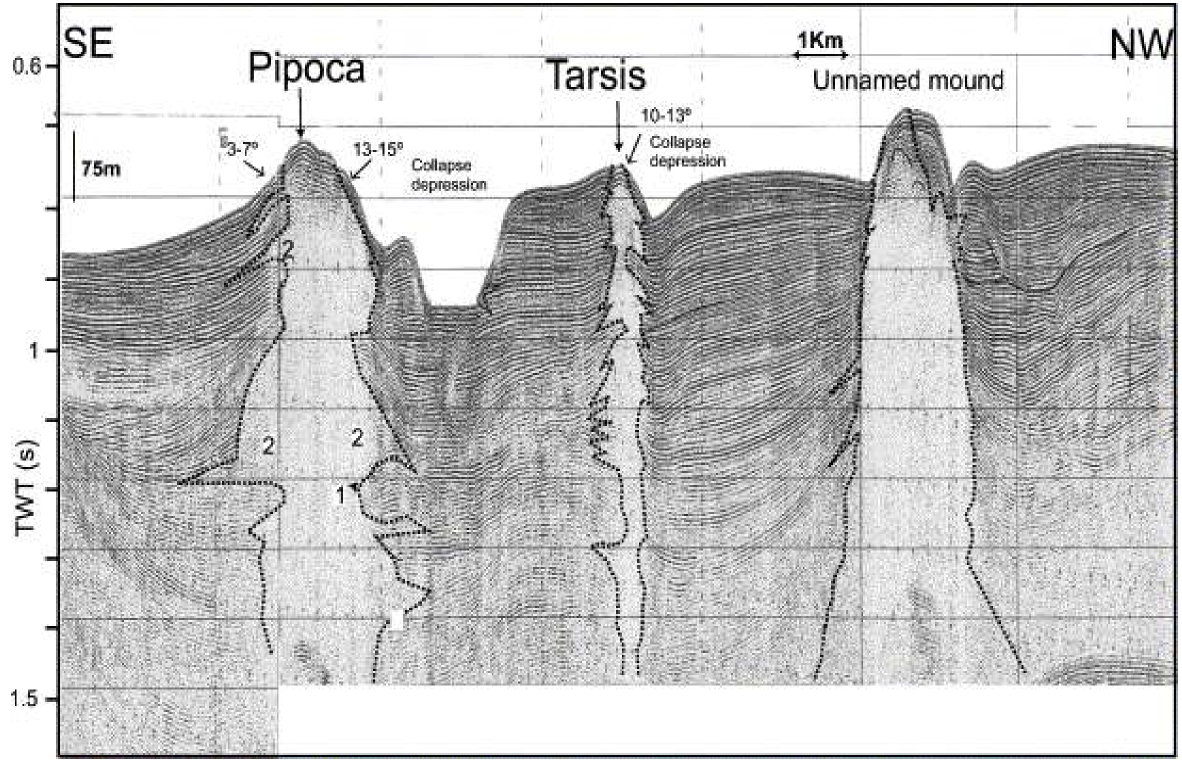
Mud volcanoes in seismic reflection data



https://www.researchgate.net/figure/An-example-of-seismic-profile-across-a-mud-volcano-in-the-eastern-offshore-of-Trinidad_fig12_286291175

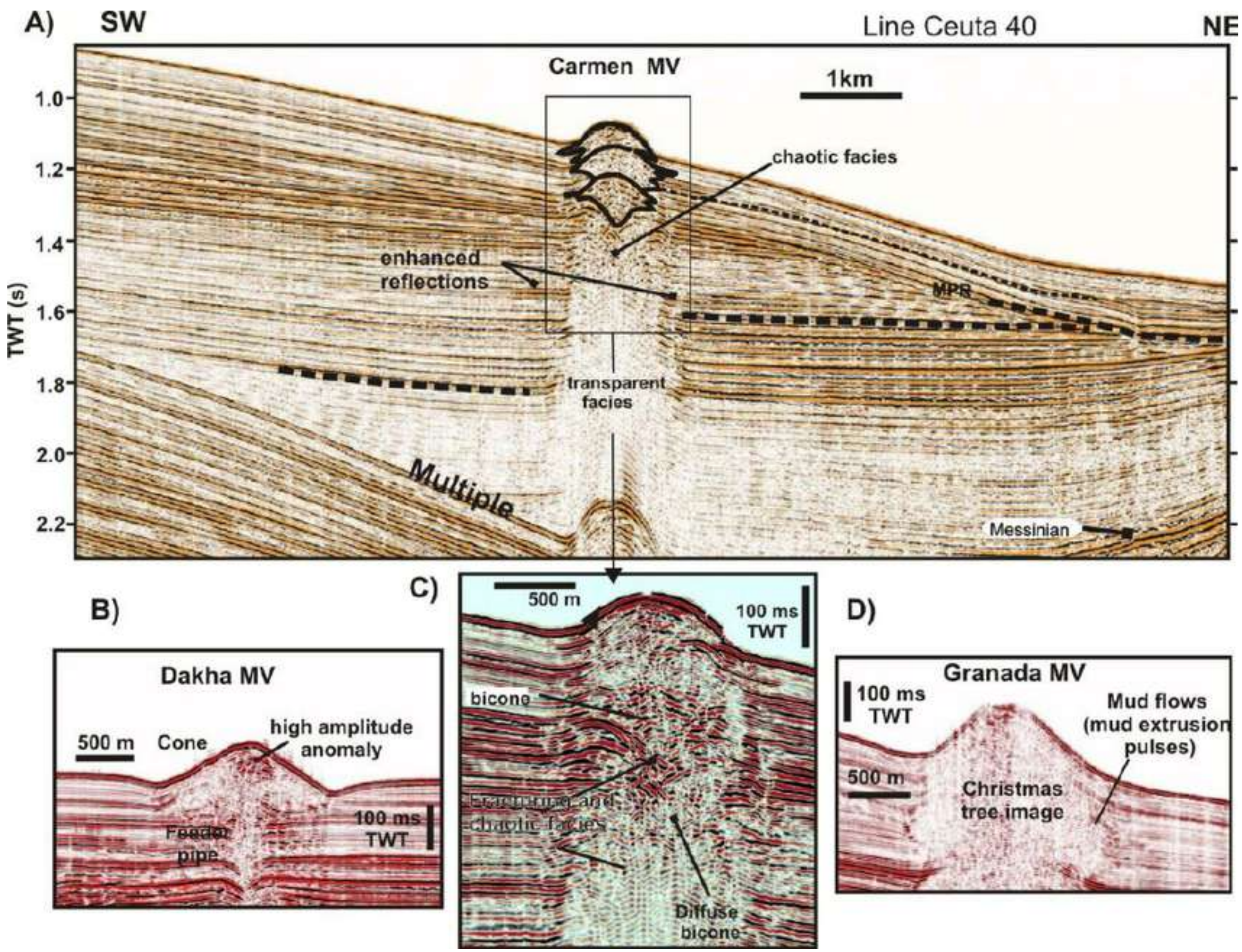
Mud volcanoes in seismic reflection data





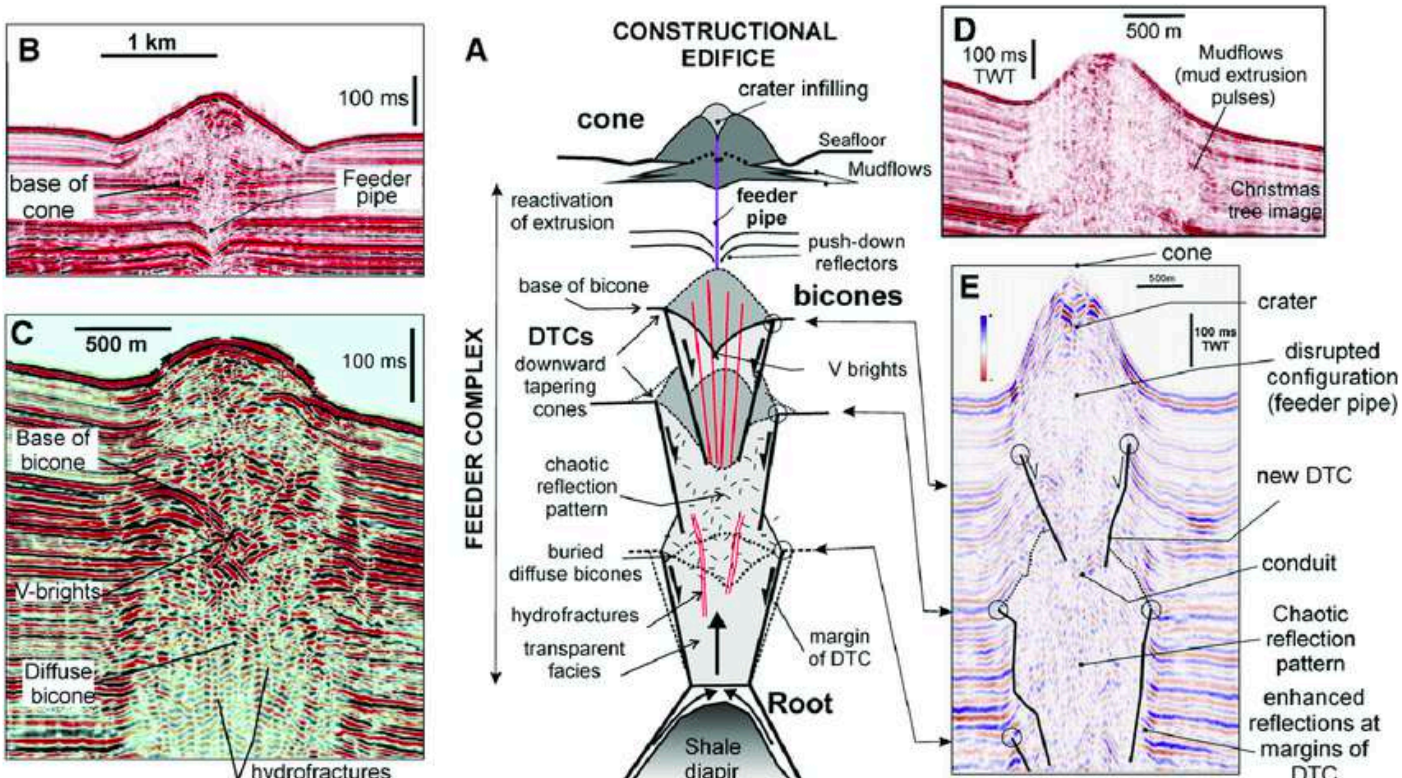
Somoza et al., Marine Geology 195, 1-4, 153-176

Mud volcanoes in seismic reflection data



[Medialdea et al., 2012. Seismic architecture of mud volcano systems in the Ceuta Contourite Depositional System (Western Alboran Sea)]()

Mud volcanoes in seismic reflection data



Somoza et al., 2012 Marine Geology 332-334:4-26 DOI:10.1016/j.margeo.2012.06.002

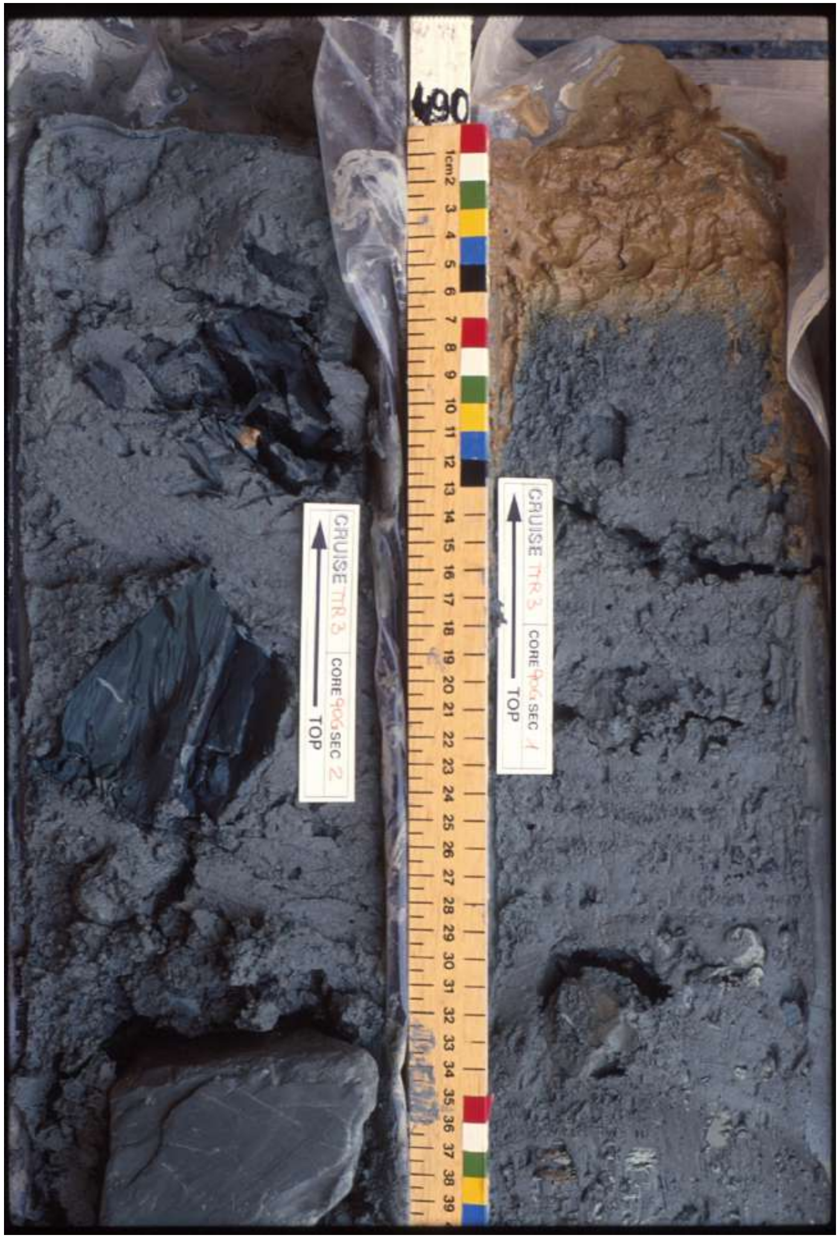
Classification of mud breccia from Mediterranea Sea mud volcanoes according to sedimentary facies

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



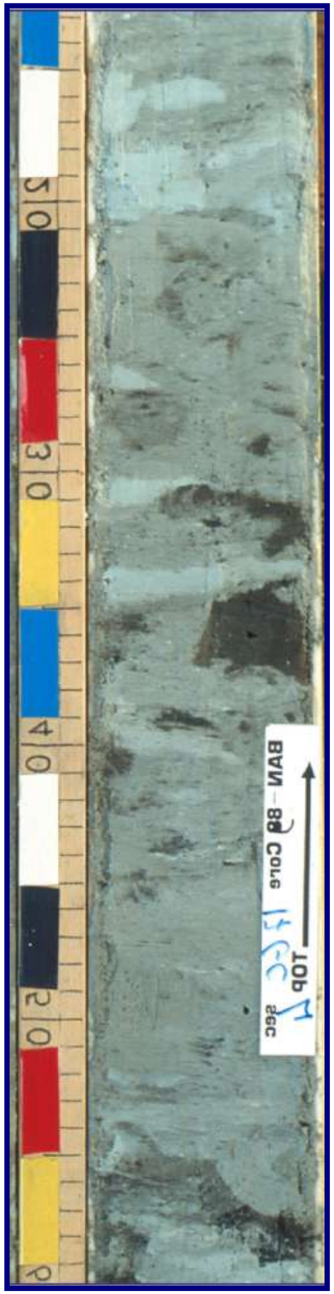
Clasts

Courtesy Renata G. Lucchi

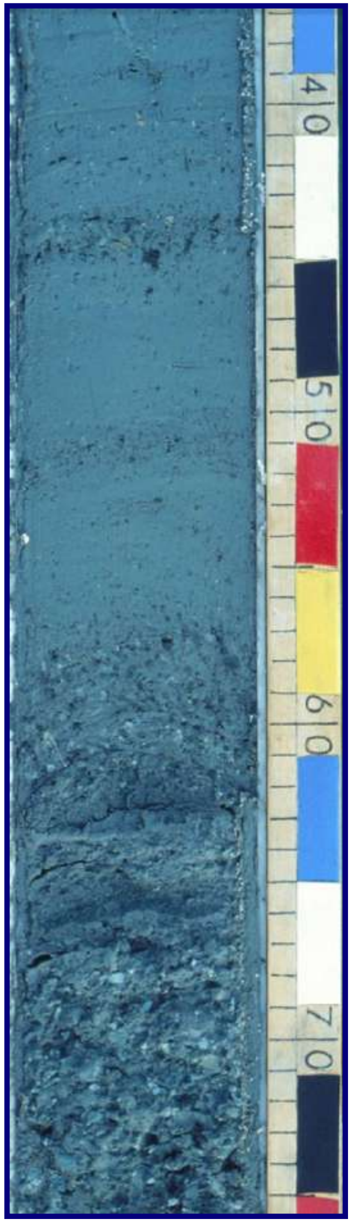
slumps

Photos by Renata G. Lucchi

Mud-breccia oxidized

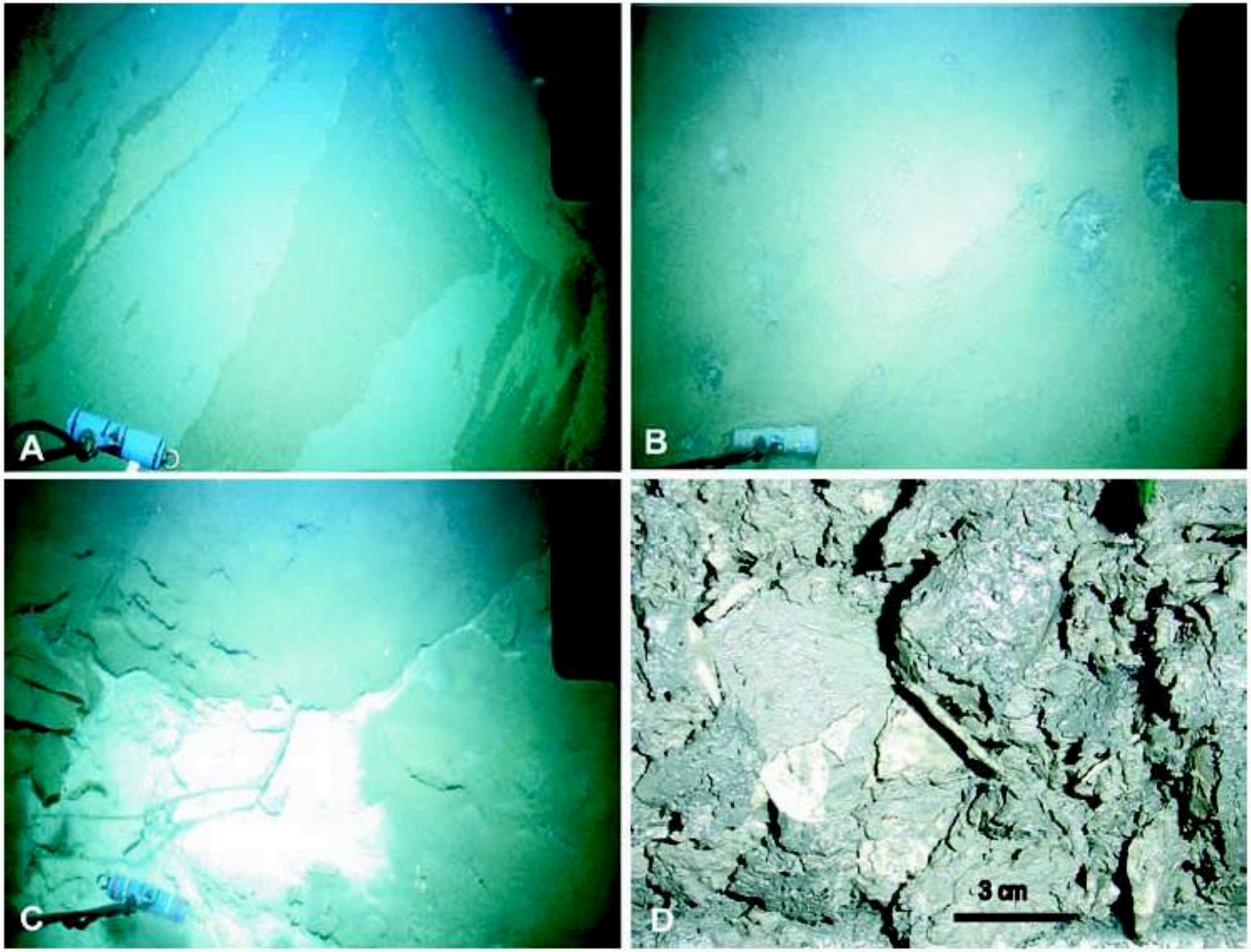


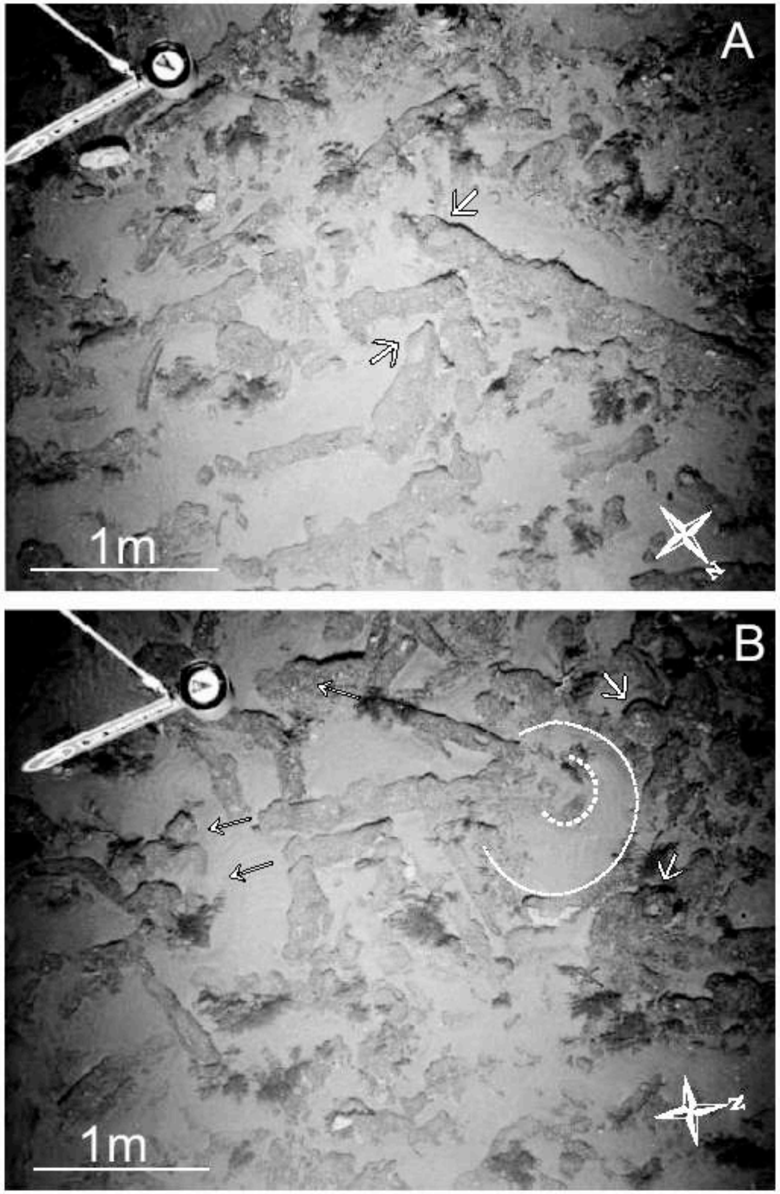
Mousse facies



Organized facies

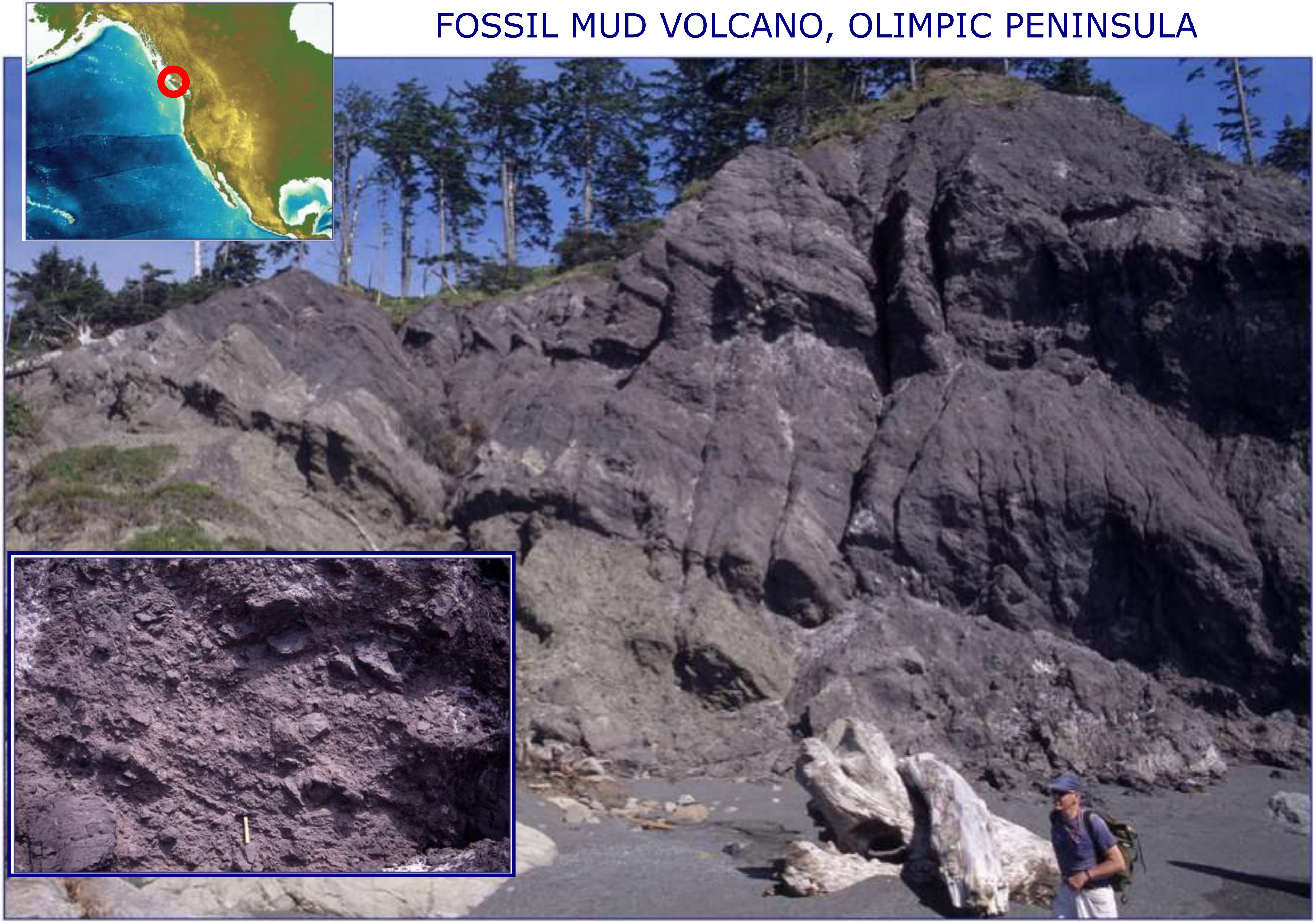
Fig. 4 Seafloor and sediment images from DMV (4A-C): **A** recent mud flow sheets from a seafloor fissure; **B** small vent sites from an area of seepage on DMV; **C** white bacterial mat in a seafloor crack on DMV; **D** fractured gas hydrate slabs in sediments from Odessa mudflow core M52/1-18



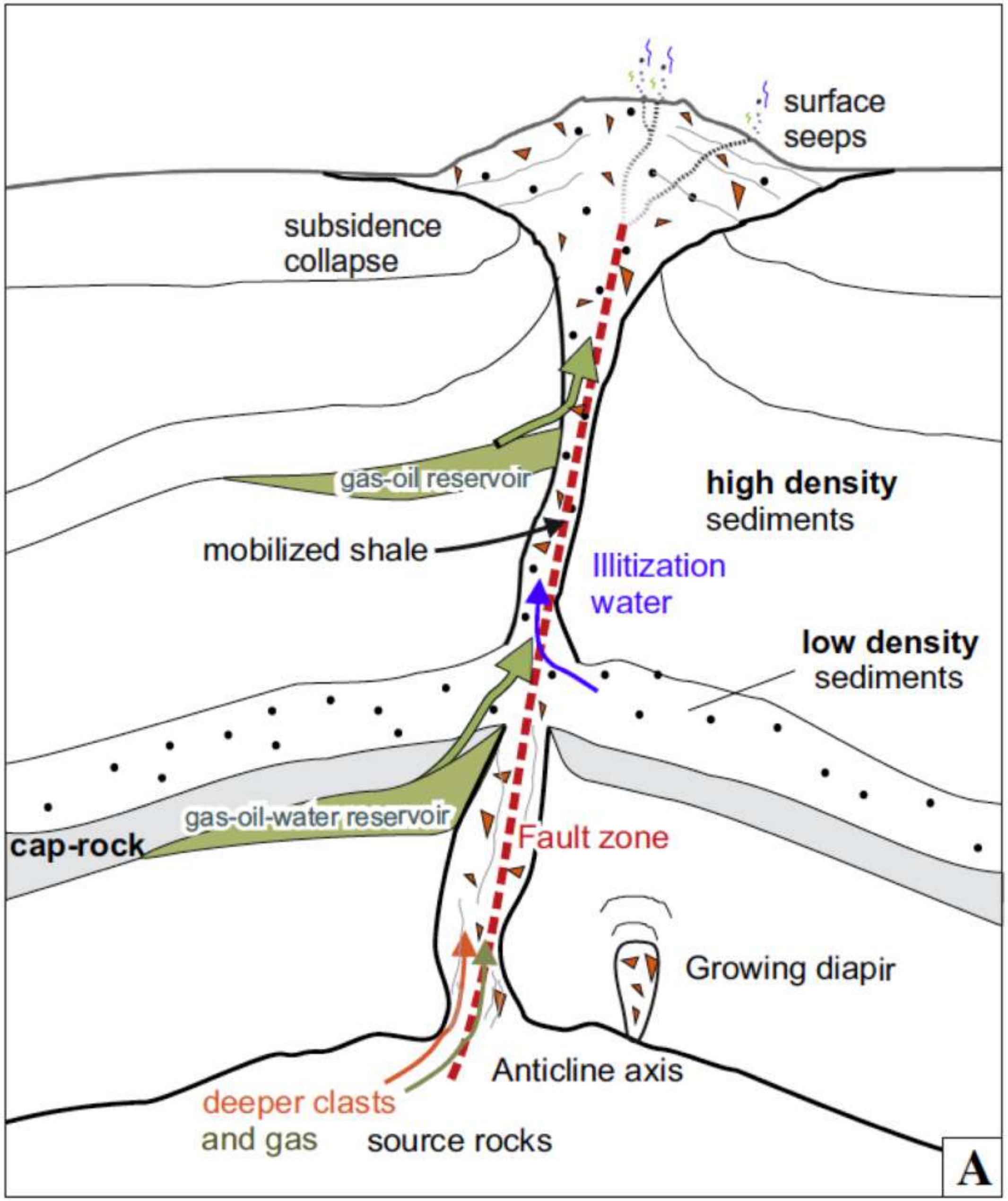


Diaz del Rio al., Marine Geology 195 (2003) 177-200

FOSSIL MUD VOLCANO, OLIMPIC PENINSULA

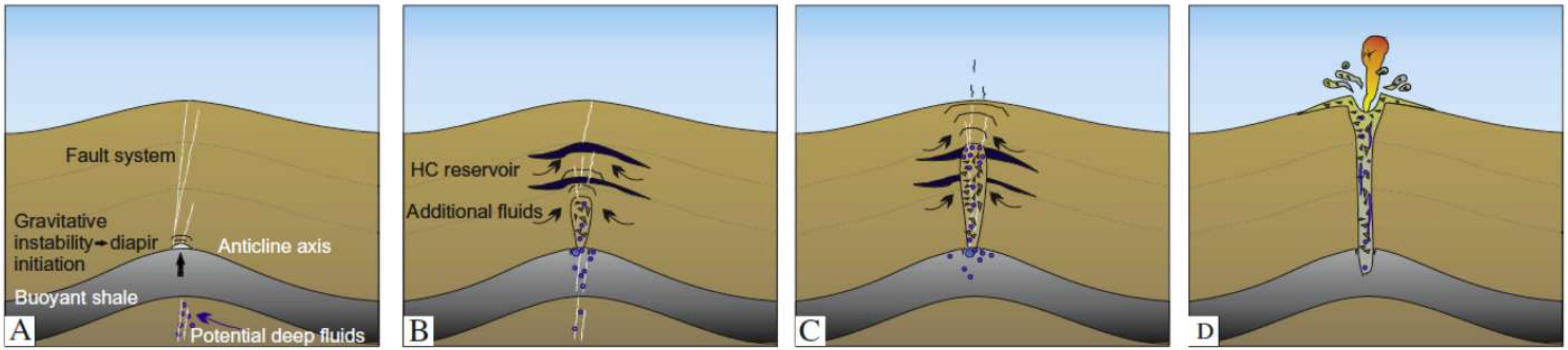


Mechanisms of emplacement



Mazzini and Etiope, 2017, ESR

Mechanisms of emplacement



Diapir initiation in buoyant shales with potential deep fluids migration along structural highs (e.g. anticline axes) or fault networks

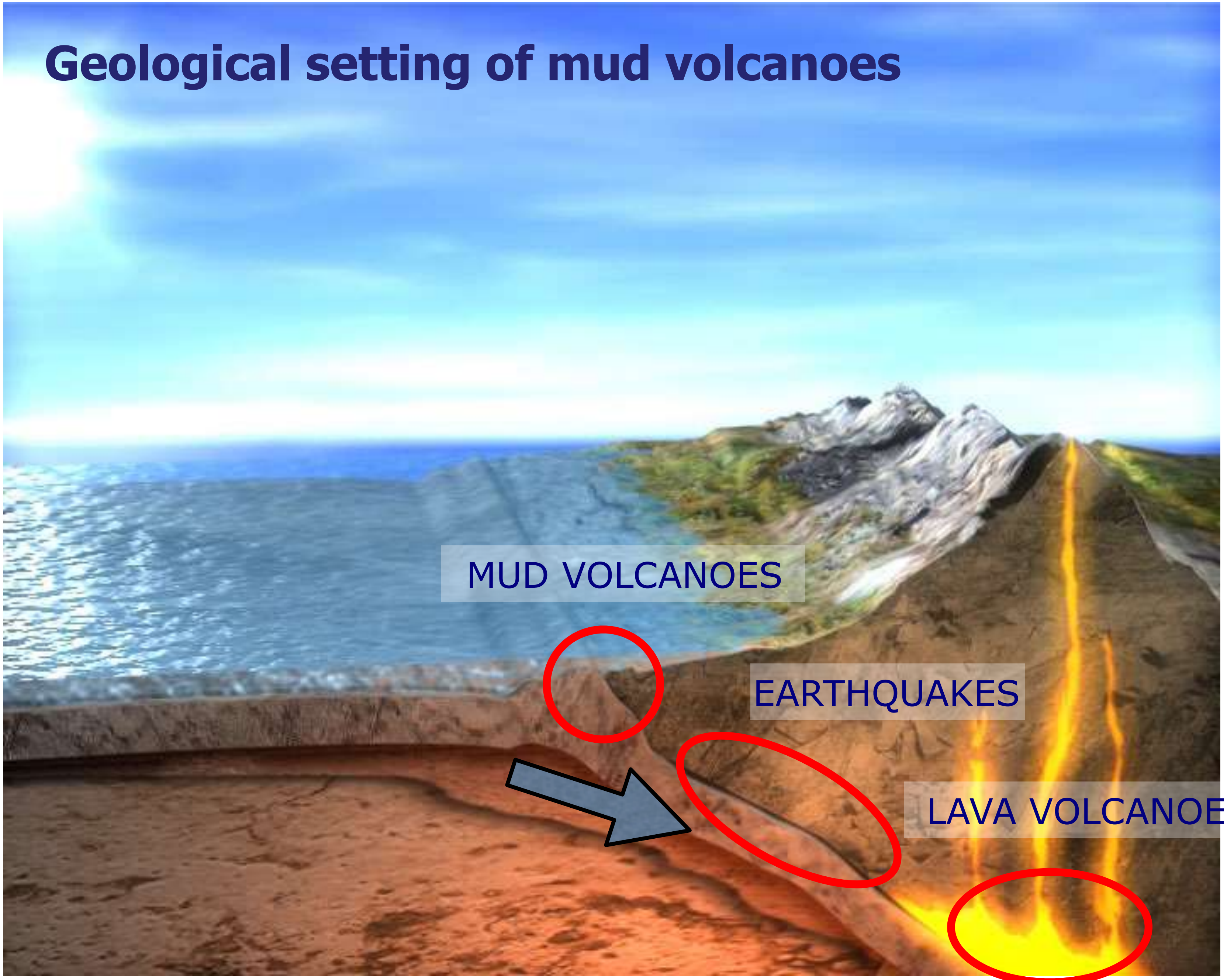
Fluids migration from different units and overpressure increase, diapiric structure development and brecciation during its growth

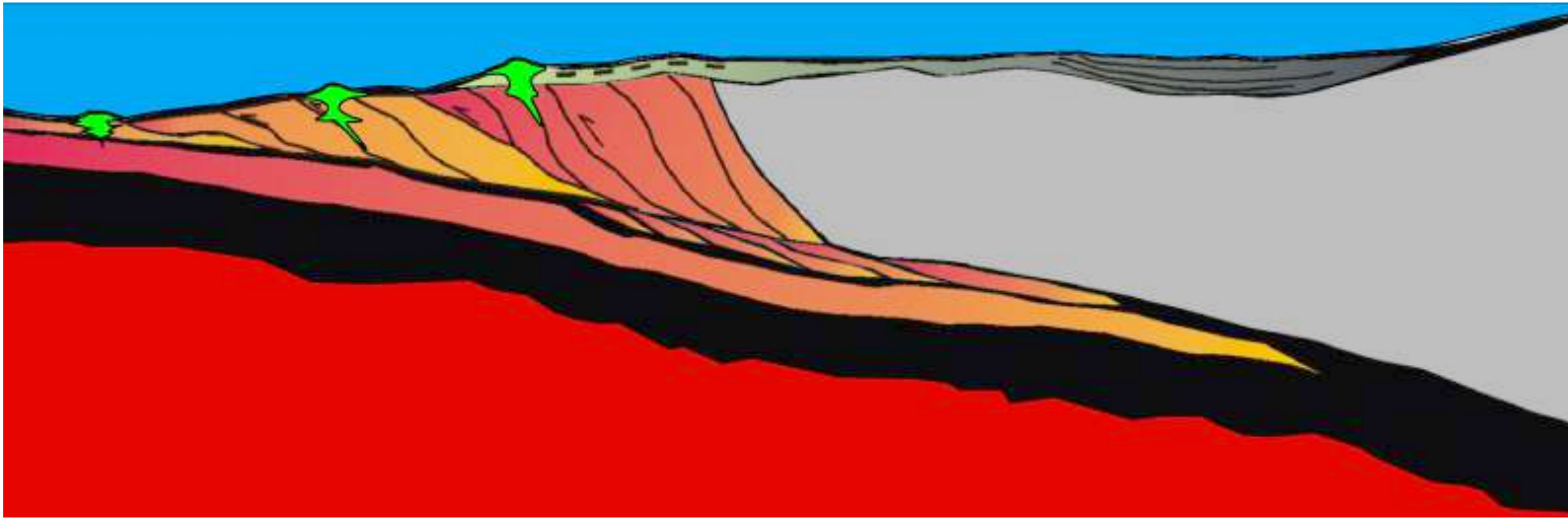
Overpressured diapir reaches critical depth. Overburden cannot contain fluids rich diapir. System in unstable conditions ready for triggering

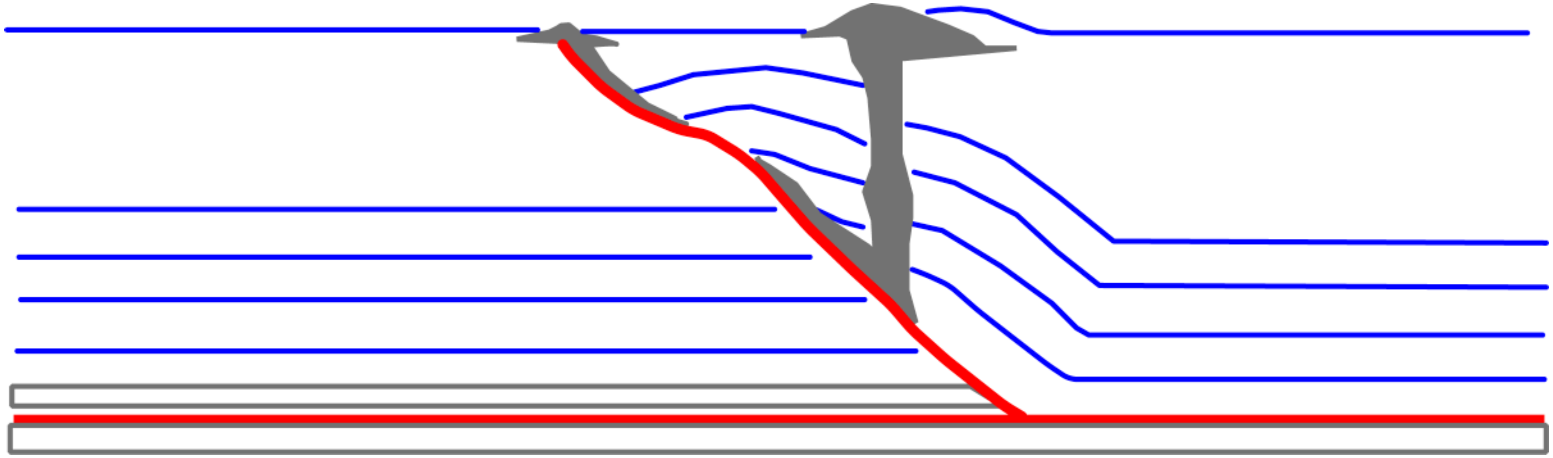
Blast of gas. The sudden pressure release allows large amount of fluidized and gas saturated sediments to reach the surface

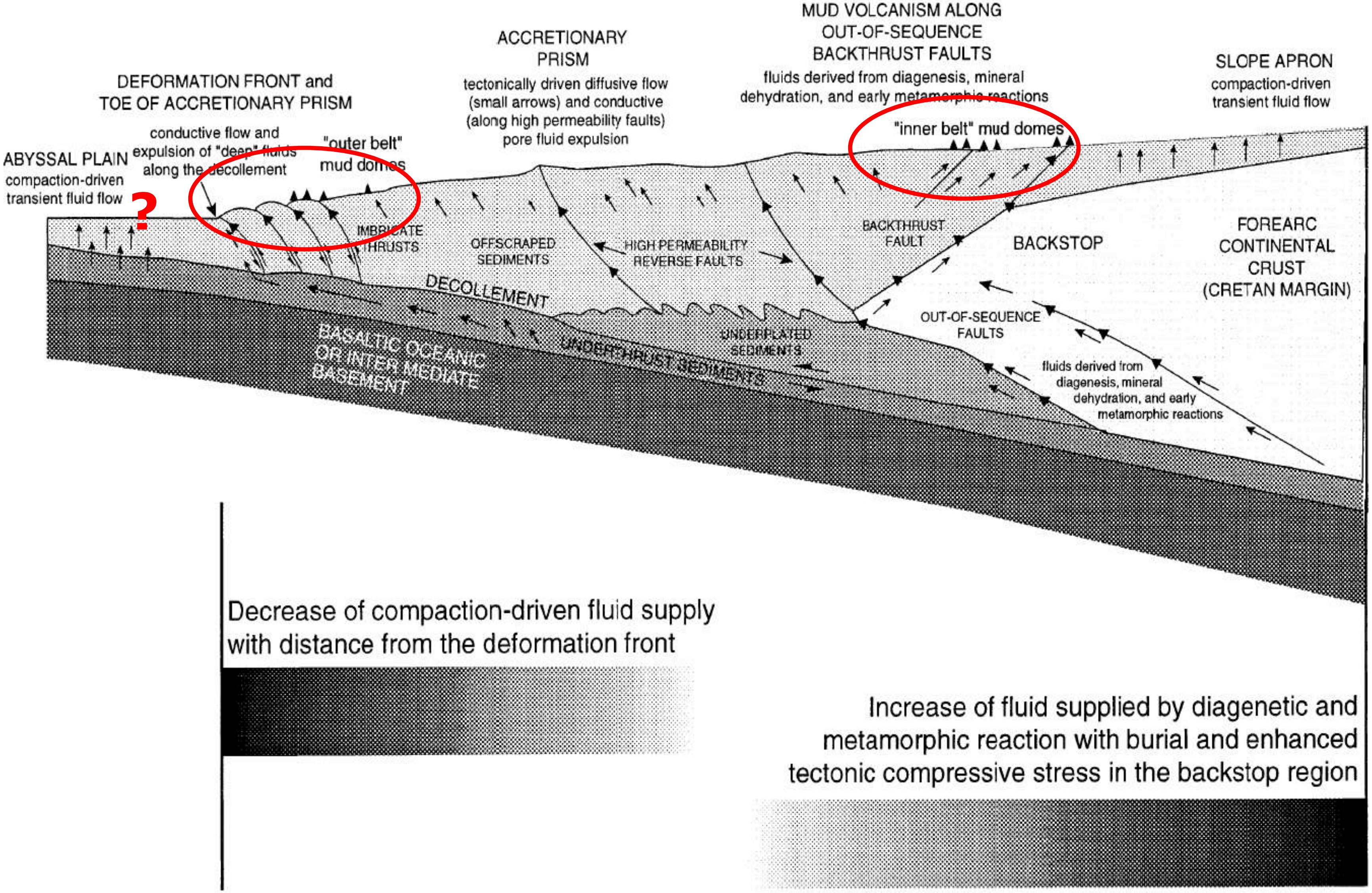
Mazzini and Etiope, 2017, ESR

Geological setting of mud volcanoes



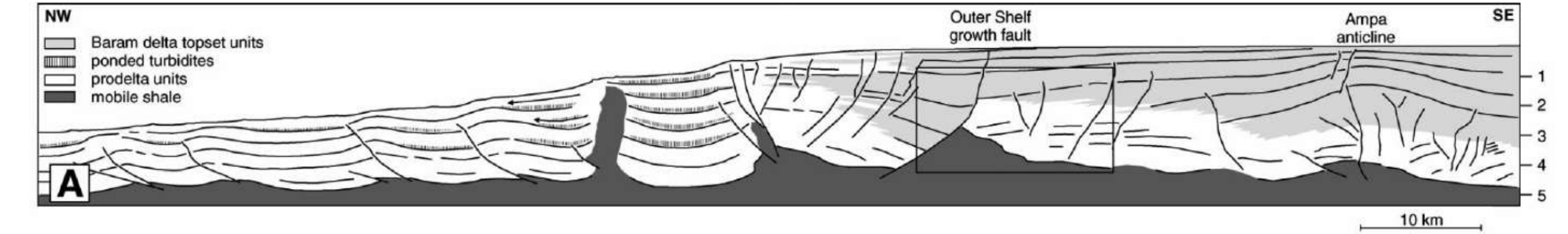


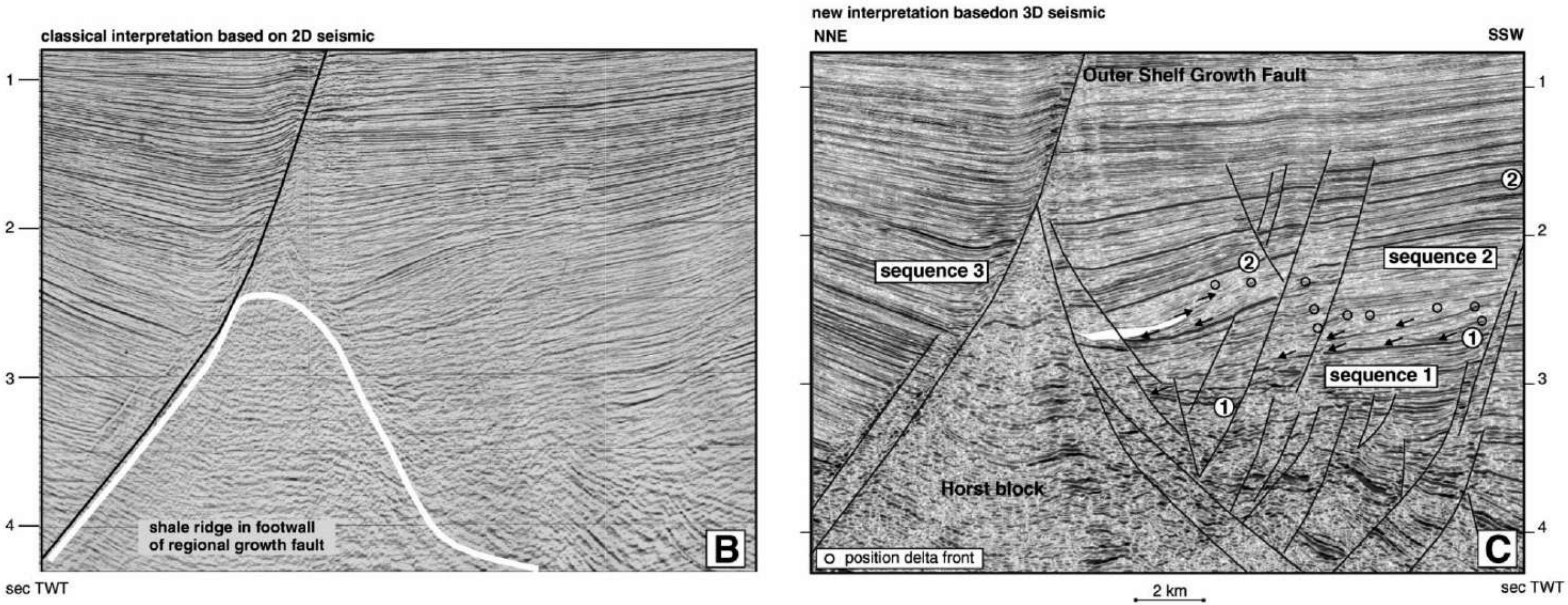




Kopf et al., EPSL, 189 (2001) 295-313

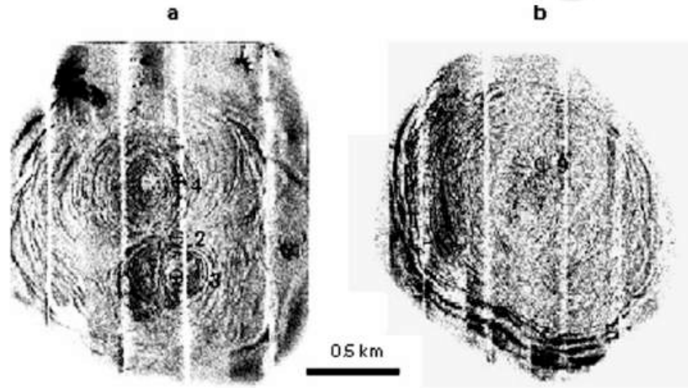
Shale tectonics, Offshore Brunei

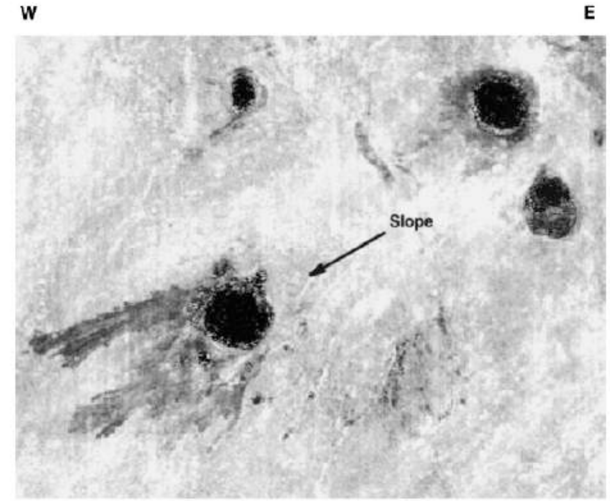


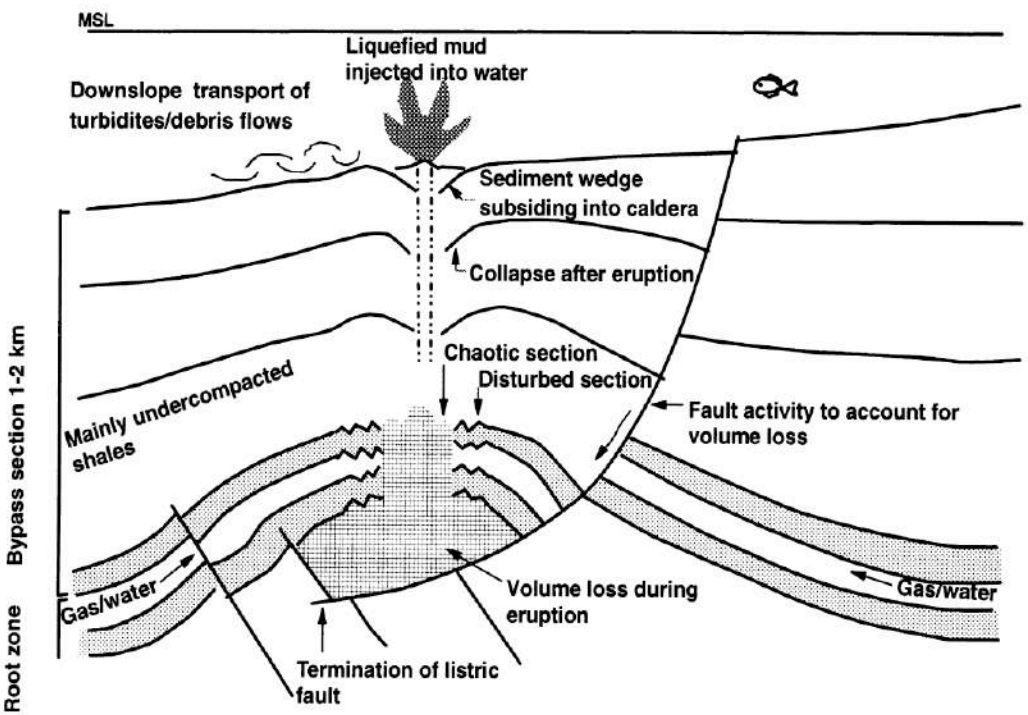


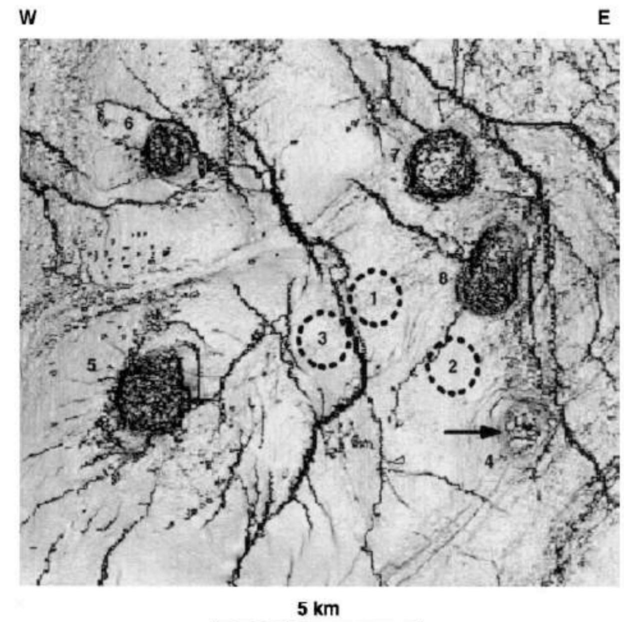
Van Rensbergen and Morley, 2000

Mud volcanoes offshore Nigeria

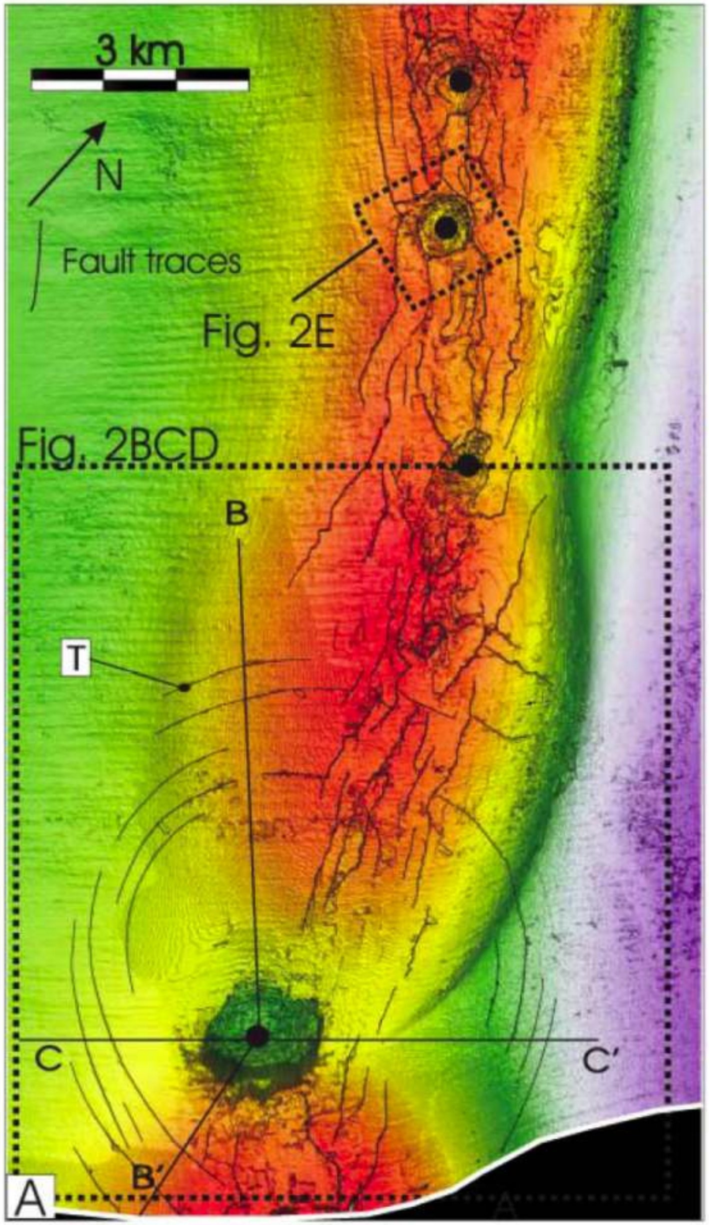


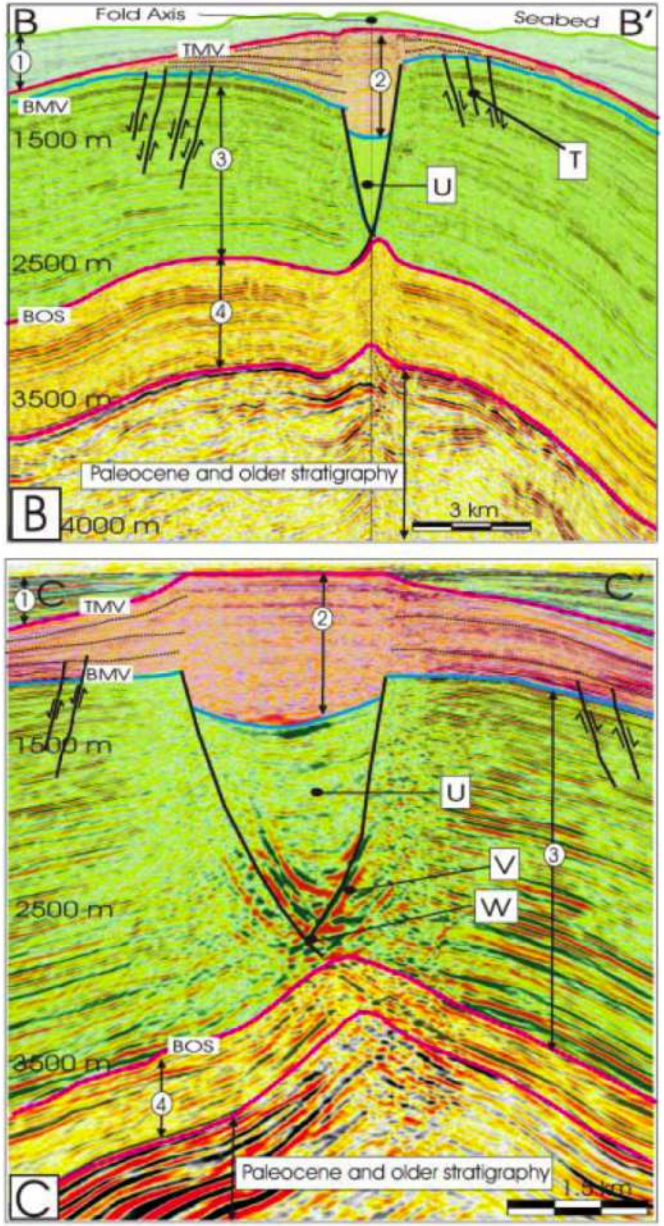






Graue, Marine and Petroleum Geology 17 (2000) 959–974





Davies and Stewart, 2005, J. Geol. Soc. London

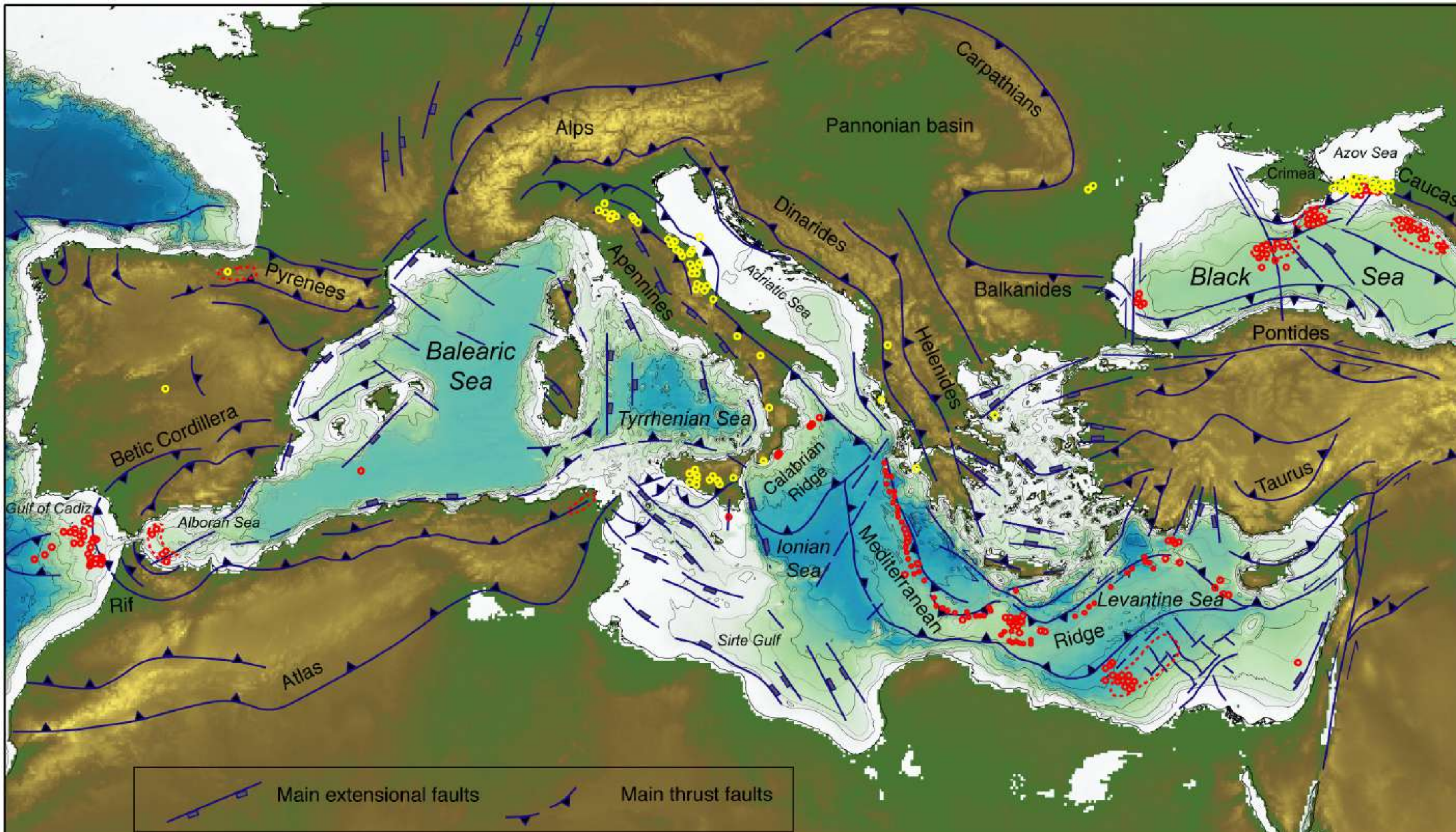
THE DISCOVERY OF SUBMARINE MUD VOLCANOES IN THE MEDITERRANEAN SEA

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

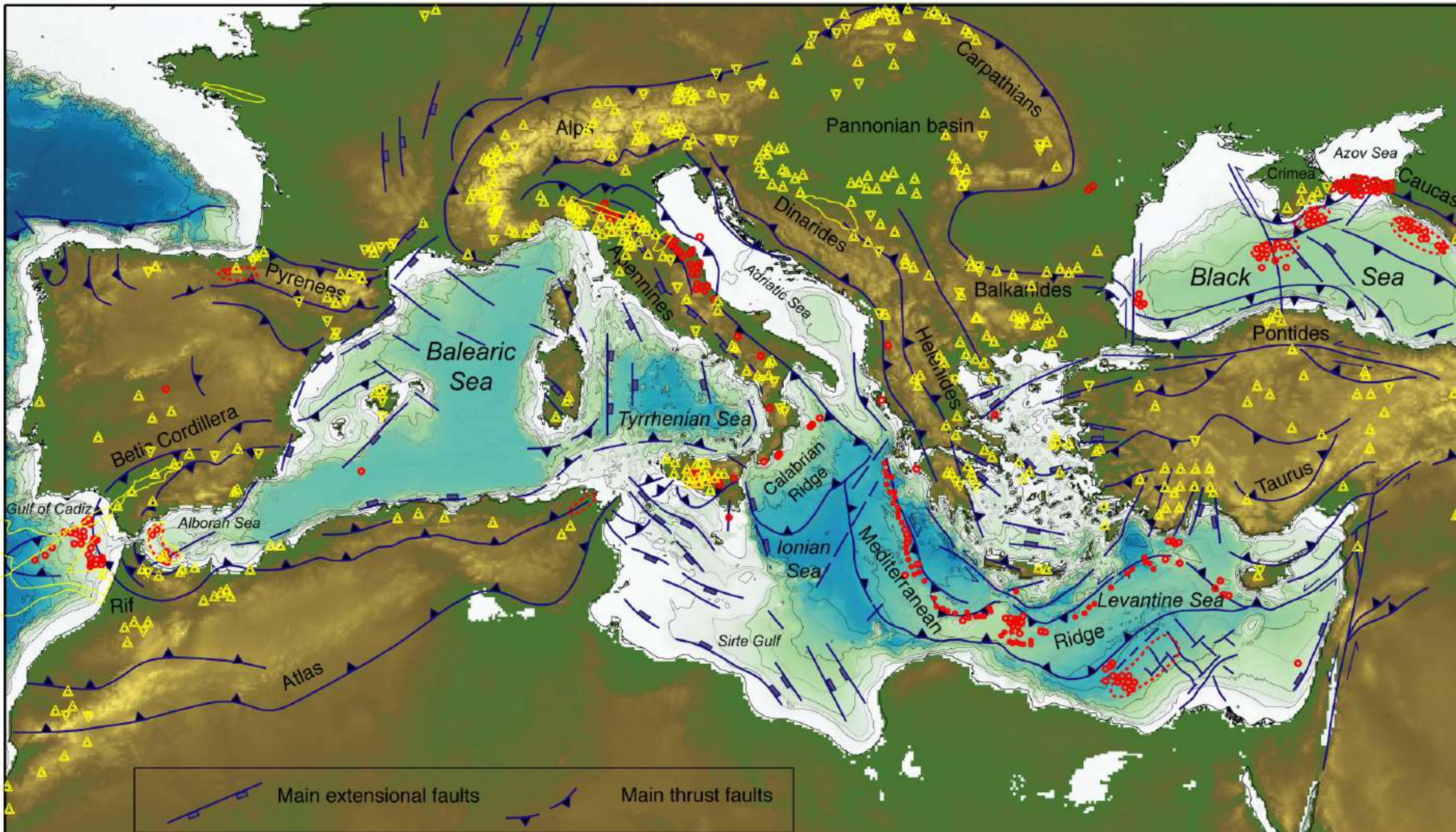
The Prometheus dome was identified according to:

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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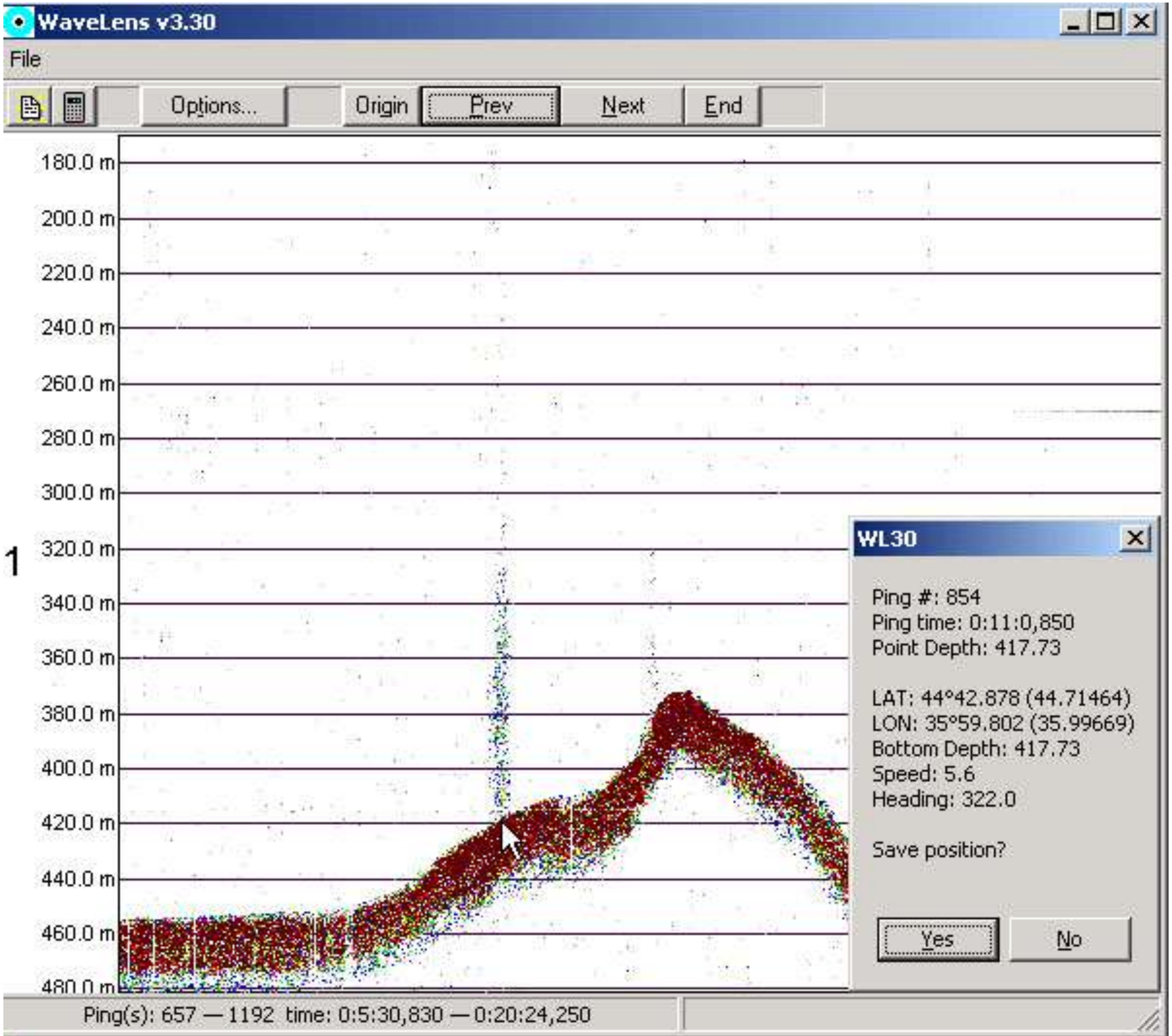
Outline

Review of main mechanisms of fluid flow:

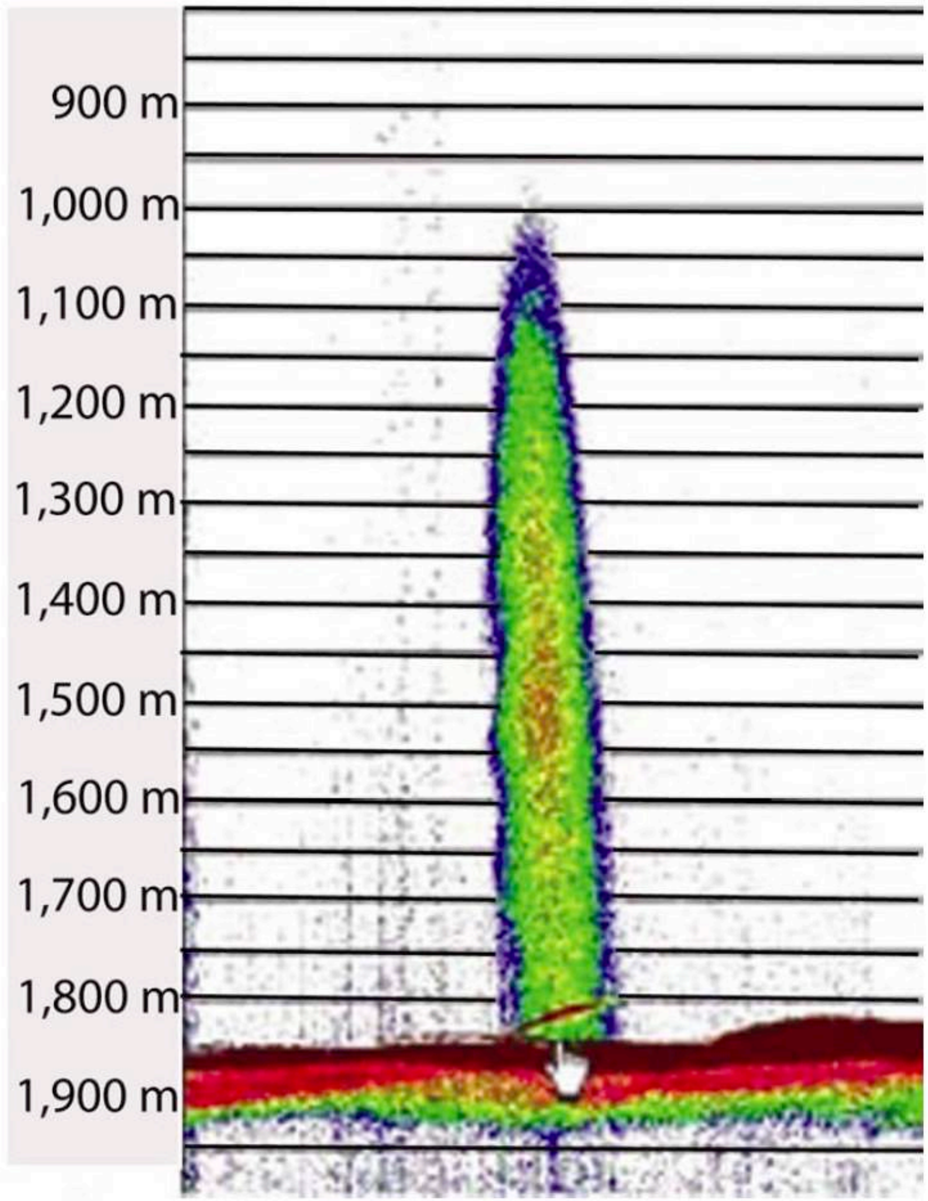
- Mud diapirs and mud volcanoes
- **Gas chimneys**
- **Pockmarks**
- **Seafloor vents in general**
- **Polygonal fault systems**
- **Diagenetic fronts**
- Gas hydrates

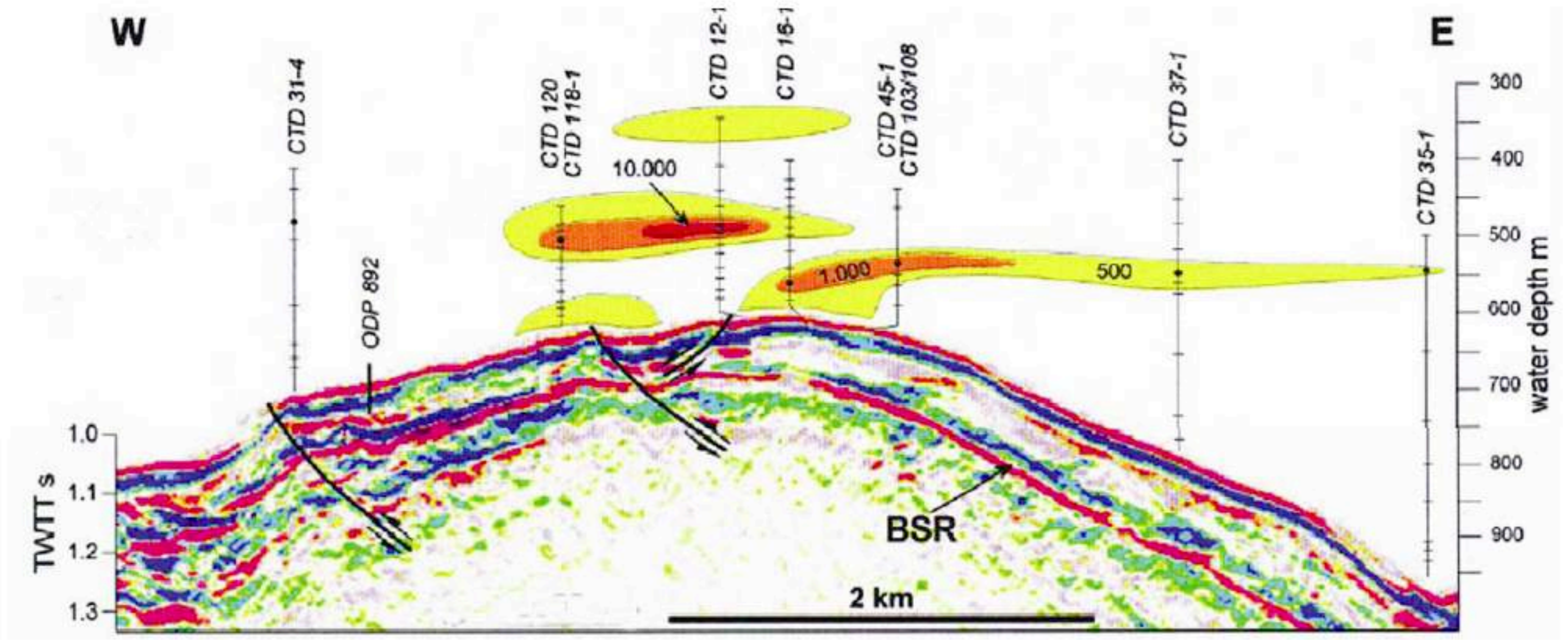


G. Bohrmann, Initial results from M52/1 **MARGASCH**

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

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