

Università di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE SM62

Percorso Esplorazione Geologica

Anno accademico 2022 - 2023

Geologia Marina 953SM

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 mélanges.

Olistostromes, or **sedimentary m \grave{e} langes**: uplifted and at times deformed **chaotic** sedimentary bodies (Cretaceous to Pliocene) originated by subaqueous 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

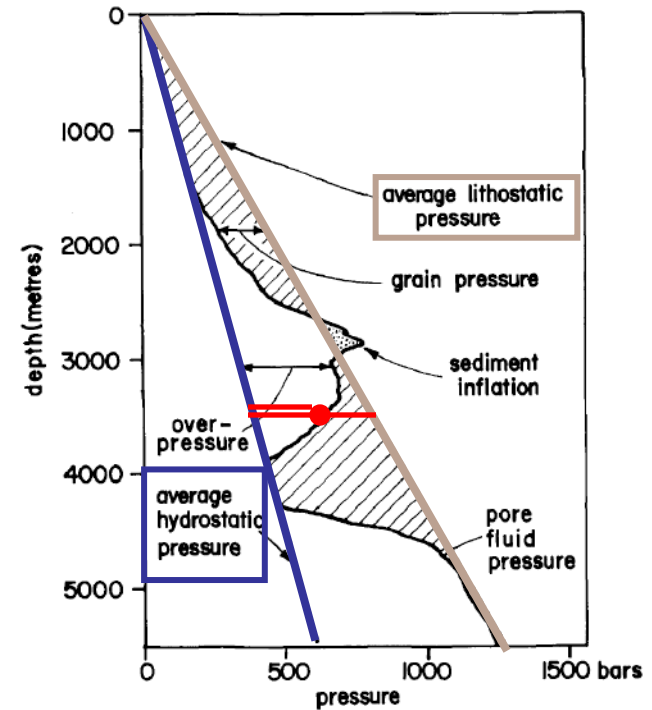
P_d = Total Stress

$\lambda = 0$ if $P_f = P_{hy}$

$\lambda = 1$ if $P_f = P_d$ = fluid movement (liquid mud)

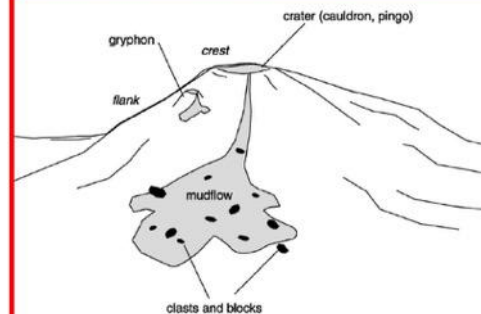
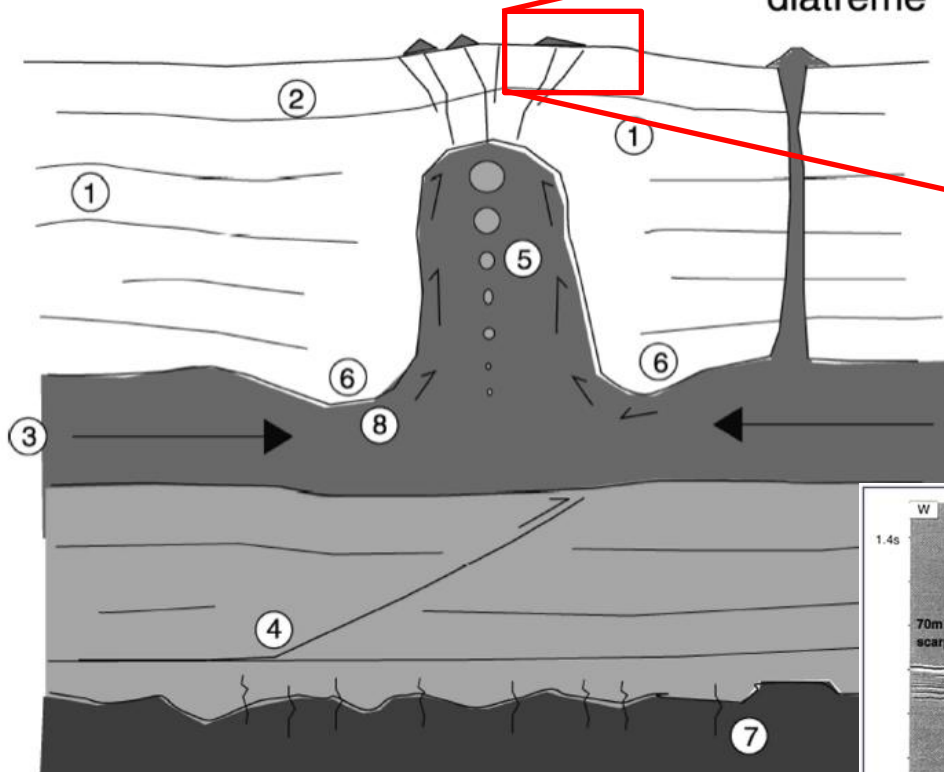
Mud diapirs move when $0 < \lambda < 1$

SEDIMENT COMPACTION AND INFLATION GRAIN PRESSURE AND OVERPRESSURE

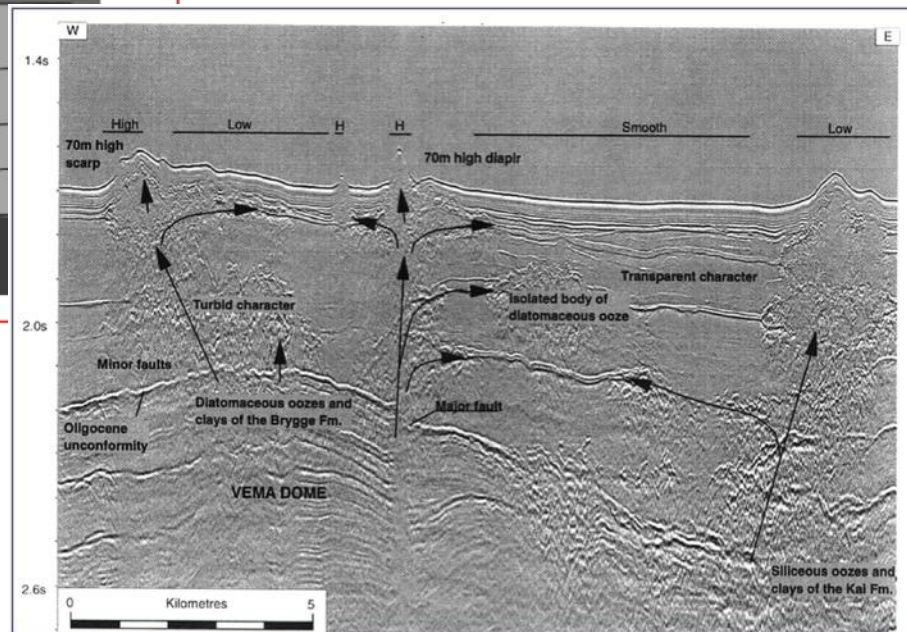


mud volcanoes
overlying a diapir

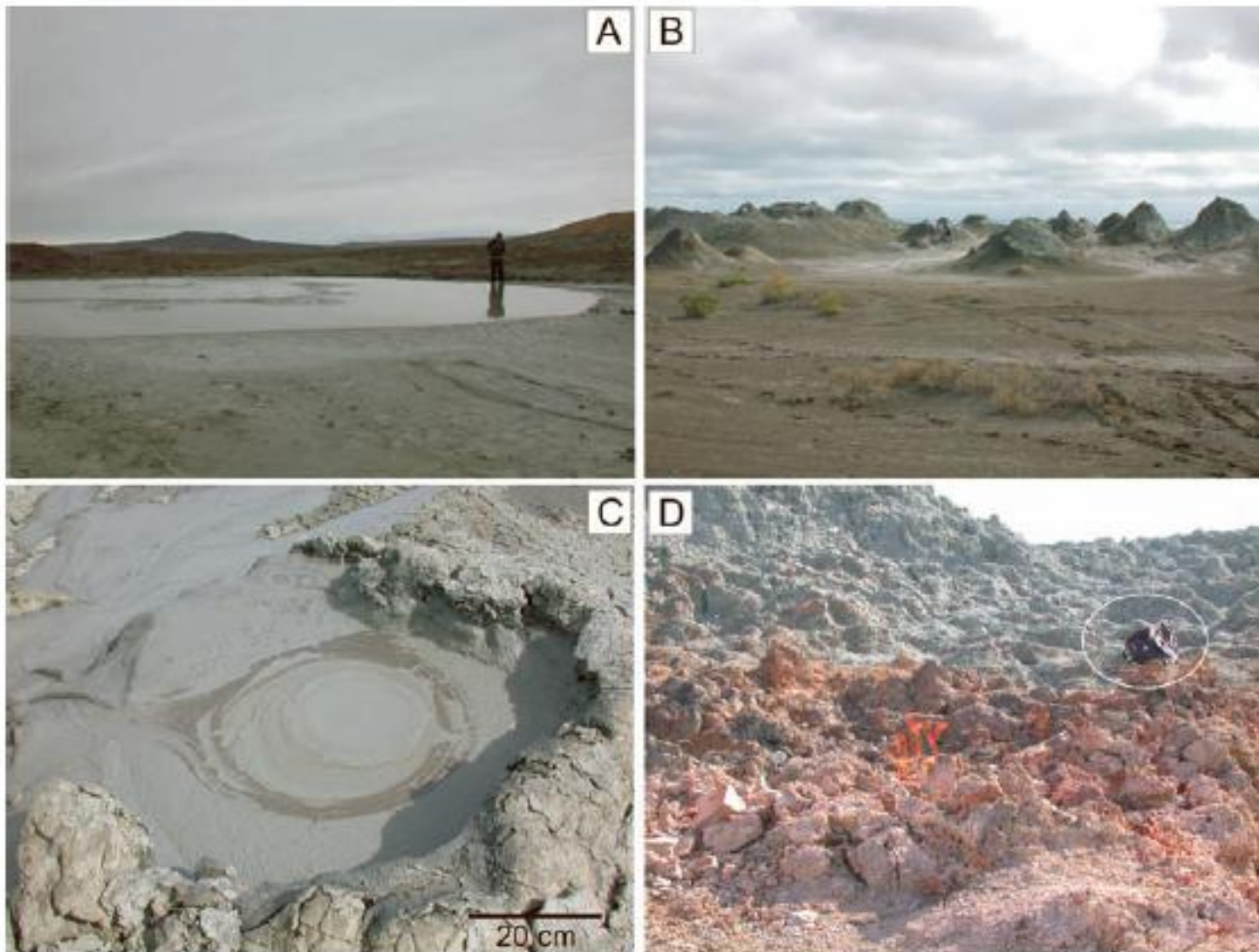
diatreme



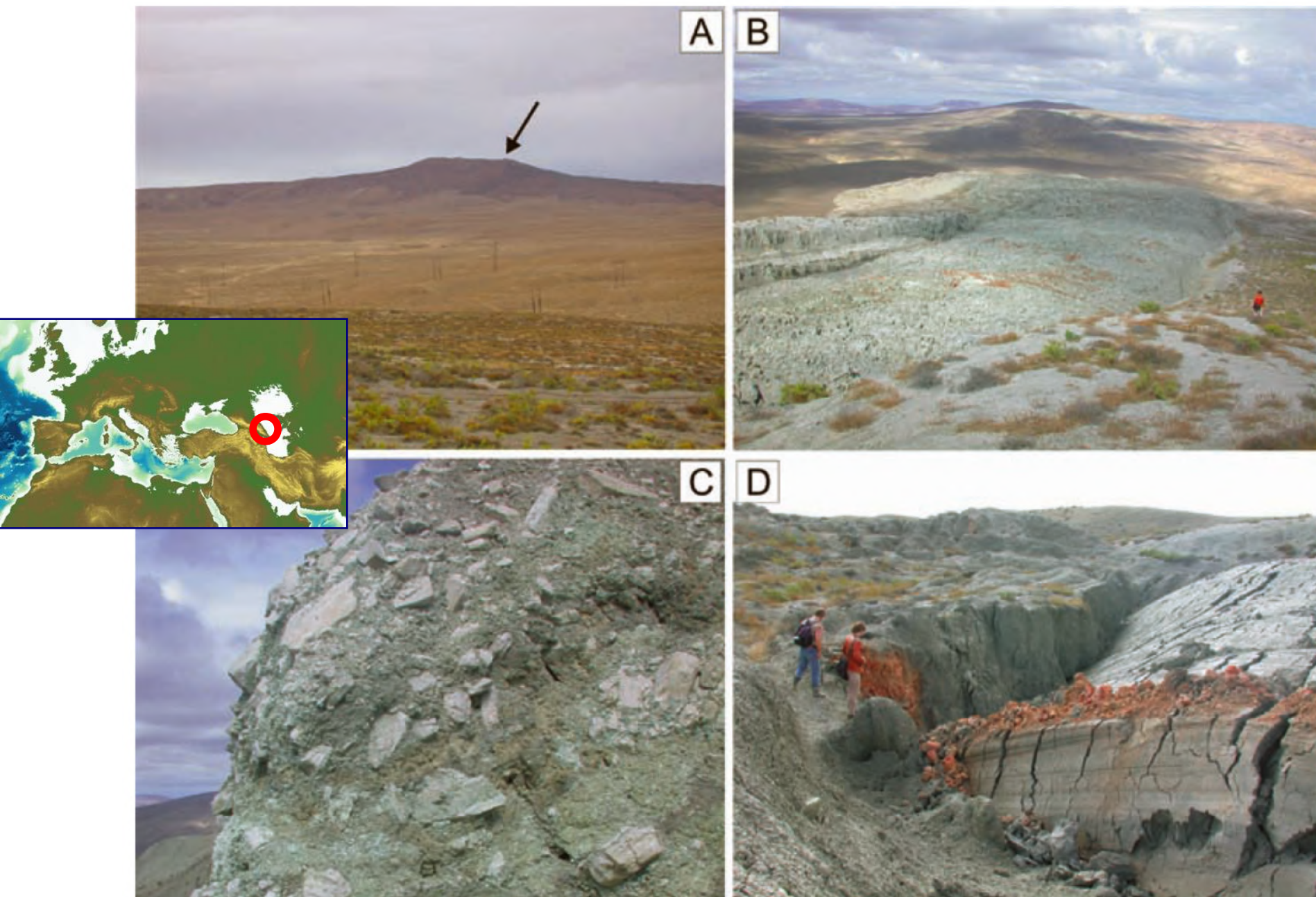
Kopf (2002)



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)



NATURAL FIRES OF AZERBEIJAN

Marco Polo(?)



Images courtesy of Luis Piñero

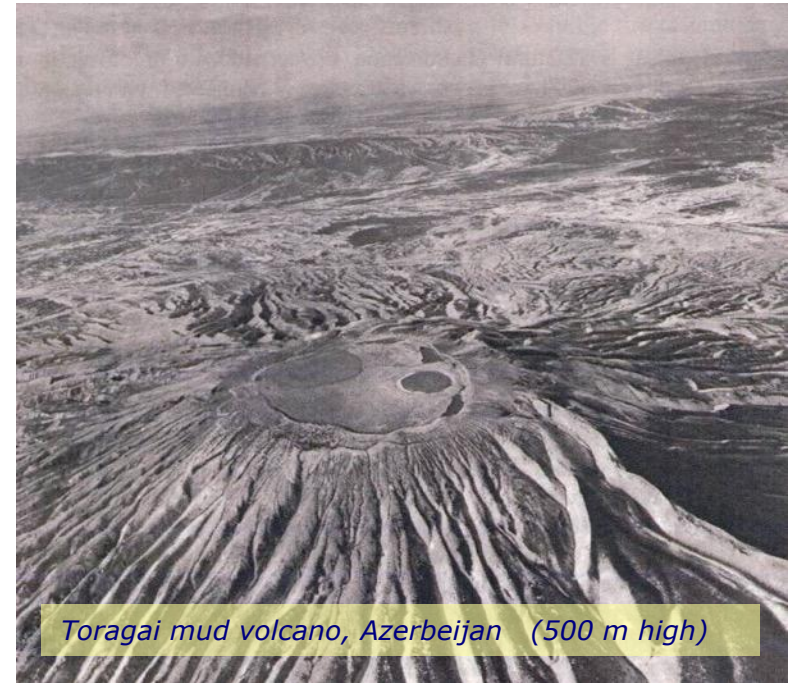


“The appearance of Zoroastrans in Azerbaijan and their cult of the eternal flame in the Temple of Fire of the Magi might be related to the fires from the mud volcanoes”



Planke et al. (2003)

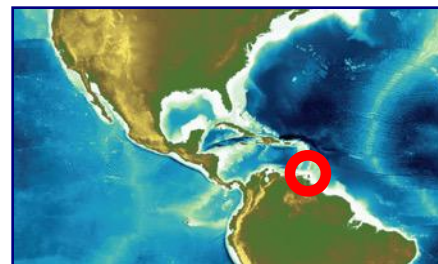
Lokbatan Mud Volcano, Azerbaijan, 25 October 2001



<https://www.youtube.com/watch?v=0xCPXg5Ijeg>



Eruption Piparo, 22/2/1987



Piparo, Trinidad 22 February 1987





CHECKING IT OUT: BEHIND: down, Opposition leader Patrick Manning, a trained geologist, and Prime Minister Basdeo Pandey, closely examine the mud which has covered the Piparo mud volcano last Saturday.

Sunday Guardian

• 25519 • Edition: September 5, 1917 • SUNDAY, FEBRUARY 23, 1997 • Contents Continued ON THE TRIESTE PAGES ON P. 10 • \$3

Teekwondo champion Cheryl-Ann Sankar in flying high — PAGE 19

SUNSHINE's Daniela Callender cuddles up with teddy bear

Courtney Walsh is Windies captain against Indians — PAGE 6

Jeanille Bonterra 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 13 houses and 20 cars buried under a 100-foot high mountain of mud.

Villagers, who live on the edge of the newly formed crater, were yesterday basically mourning household items as well as farm animals and even parts of houses.

The officials who visited the area have issued a warning for people to stay away from the village since the volcano is still smouldering.

A normally quiet area, Lightfoot Town, the scene of disaster, was a hub of activity with hundreds of tourists people coming to see the volcano and listen to the villagers tell of the horror of the eruption.

Alan Khan, one of the Piparo villagers who lost his house to the volcano, was lucky to be awake when the eruption started.

"It was about midnight after five o'clock when I heard the electricity wires crackling, then it started to rain. The earth started to move, then I heard a rattle and then an explosion."

"When I looked outside I saw a set of mud going up in the air for about 100 feet high. This lasted for about 15 minutes, then it quieted down and started again and lasted for over one hour." He took his family to stay with relatives who live further away from the volcano in Pigeon.

Another villager, Hulsan Sarcote, followed a storm was coming on. Going outside to check, he saw mud pouring from the sky like fallows of smoke from a chimney.

"The mud was about 60 feet in diameter. I had to run like hell because the mud from the volcano was so hot."

The

Trinidad Guardian

• 25520 • Edition: September 5, 1917 • MONDAY, FEBRUARY 24, 1997 • Contents Continued ON THE TRIESTE PAGES ON P. 10 • \$1.25

Volcano takes first life

Piparo resident dies after helping villagers

By LOUIS B HOMER

In July villagers in killing fields and other significant to victims during the eruption which has claimed the lives of one 100 people in Piparo, South Trinidad, on Saturday.

Forty-eight-year-old Archibald Spencer, who lived about 200 feet from the mud volcano, died yesterday after he was found by mud in his house in Piparo.

Spencer was helping villagers to escape the volcano when he was killed.

Minister of Government, justice, energy, fire, Police, Emergency Management Agency (ONEMA) and Ministry of Health, Dr. Nicholas, his wife and their three children, Marlon, 10, Shyla, 11 and Lavonia, 5, spent the night at the center's home in the village.

Spencer was the only one who was killed during the eruption.

His wife and three children were found in their house which was buried in mud.

Spencer was found in his house which was buried in mud.

Spencer was found in his house which was buried in mud.



Mud mass

Piparo volcano erupts Page 3

RIGHT MEMBERS of a Piparo family salvage what is left of their belongings from this second house which was partially covered by mud following the early morning eruption.

PHOTO: STEPHEN AZIZ



TESTING THE MUD: Slipping lightly, Prime Minister Basdeo Pandey 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.

Piparo villagers to be relocated

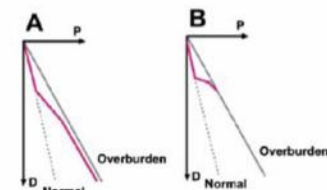
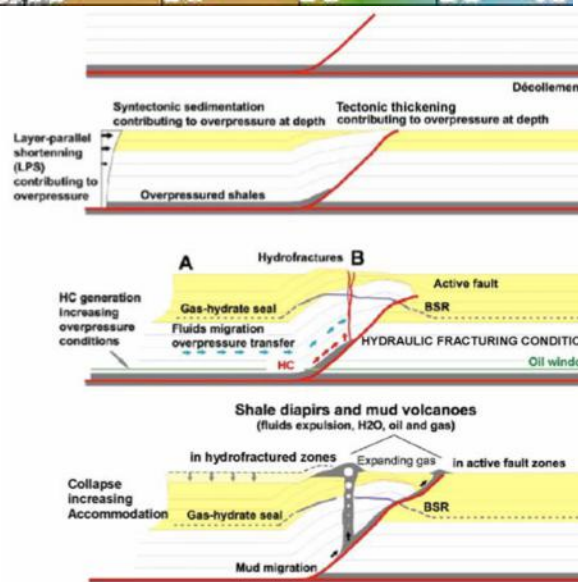
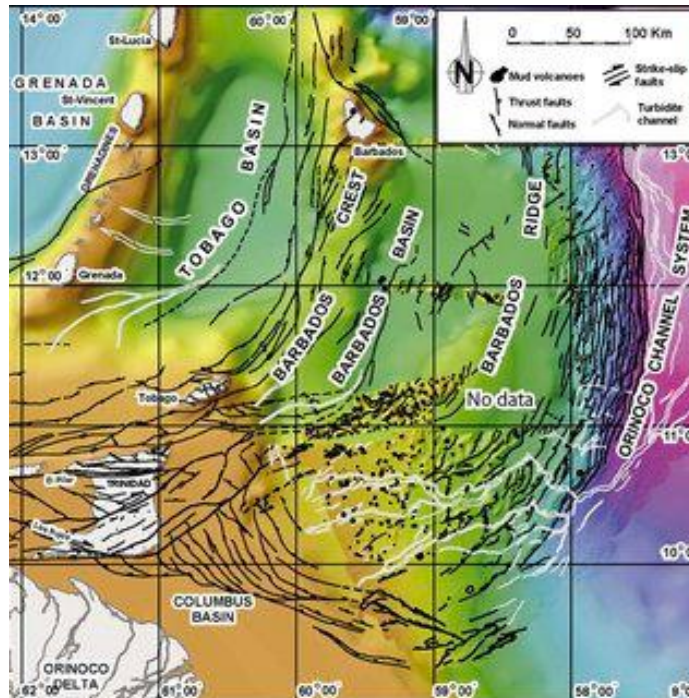
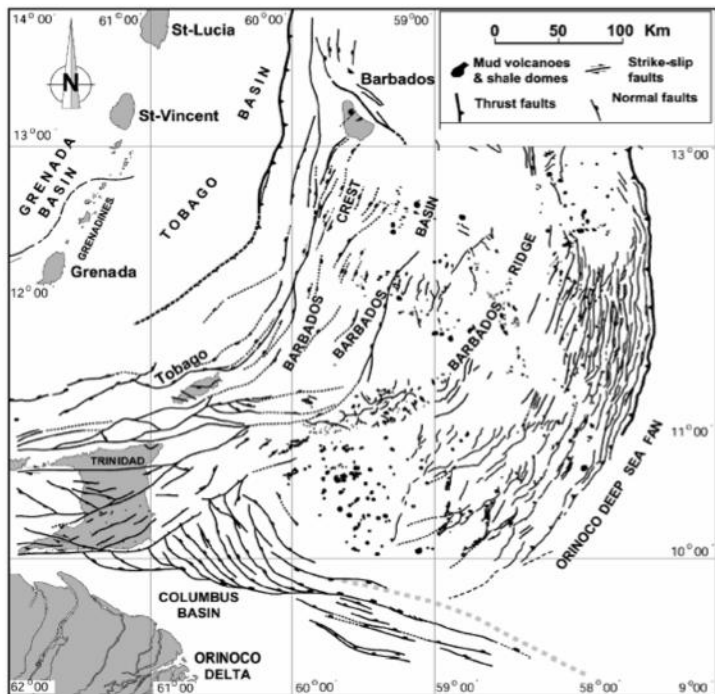
By LOUIS B HOMER

Mosque, Prime Minister Basdeo Pandey, 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 Road, Guarscara Tabasquito Rd, Sisters Rd, cho Road, Hoesineer Road, and Nap Mayaro Road.



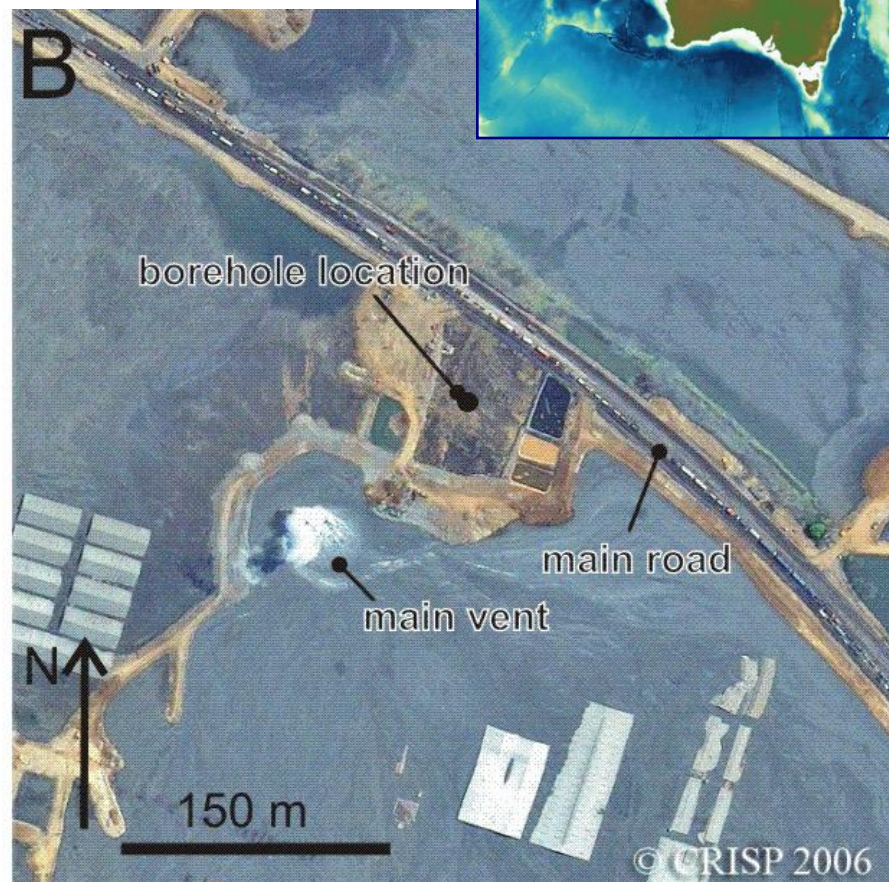
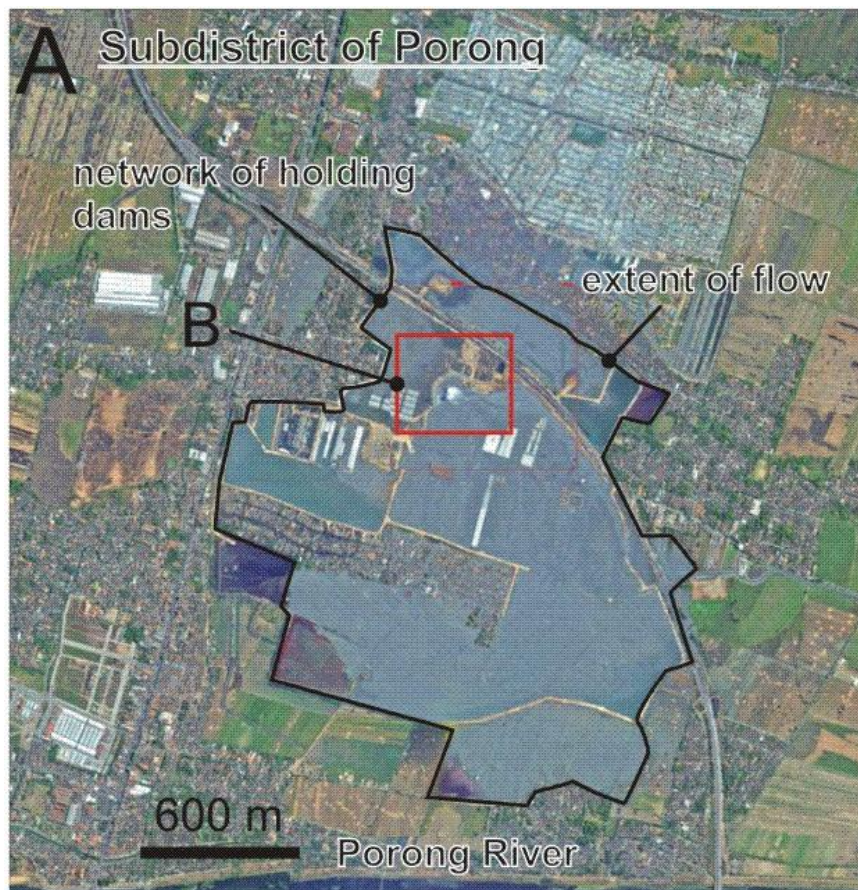
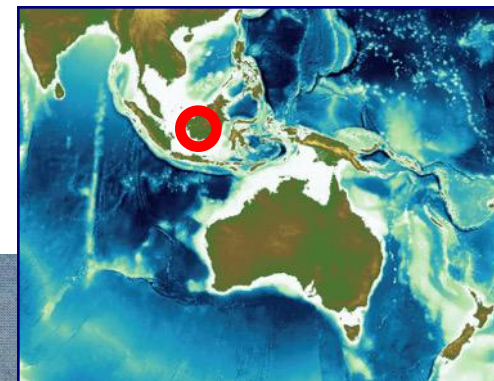
BELOW: A HOUSE is left in ruins in the aftermath of the eruption of a mud volcano in Piparo early yesterday morning. This house was pushed over by the wall of mud on the left.



Deville et al.,

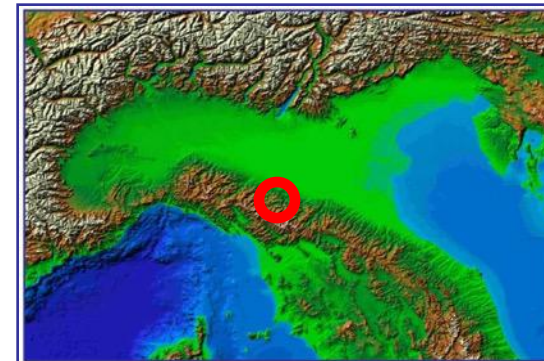
<https://www.researchgate.net/publication/352001194>

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





MUD VOLCANOES **SALSE DI NIRANO, ITALY**

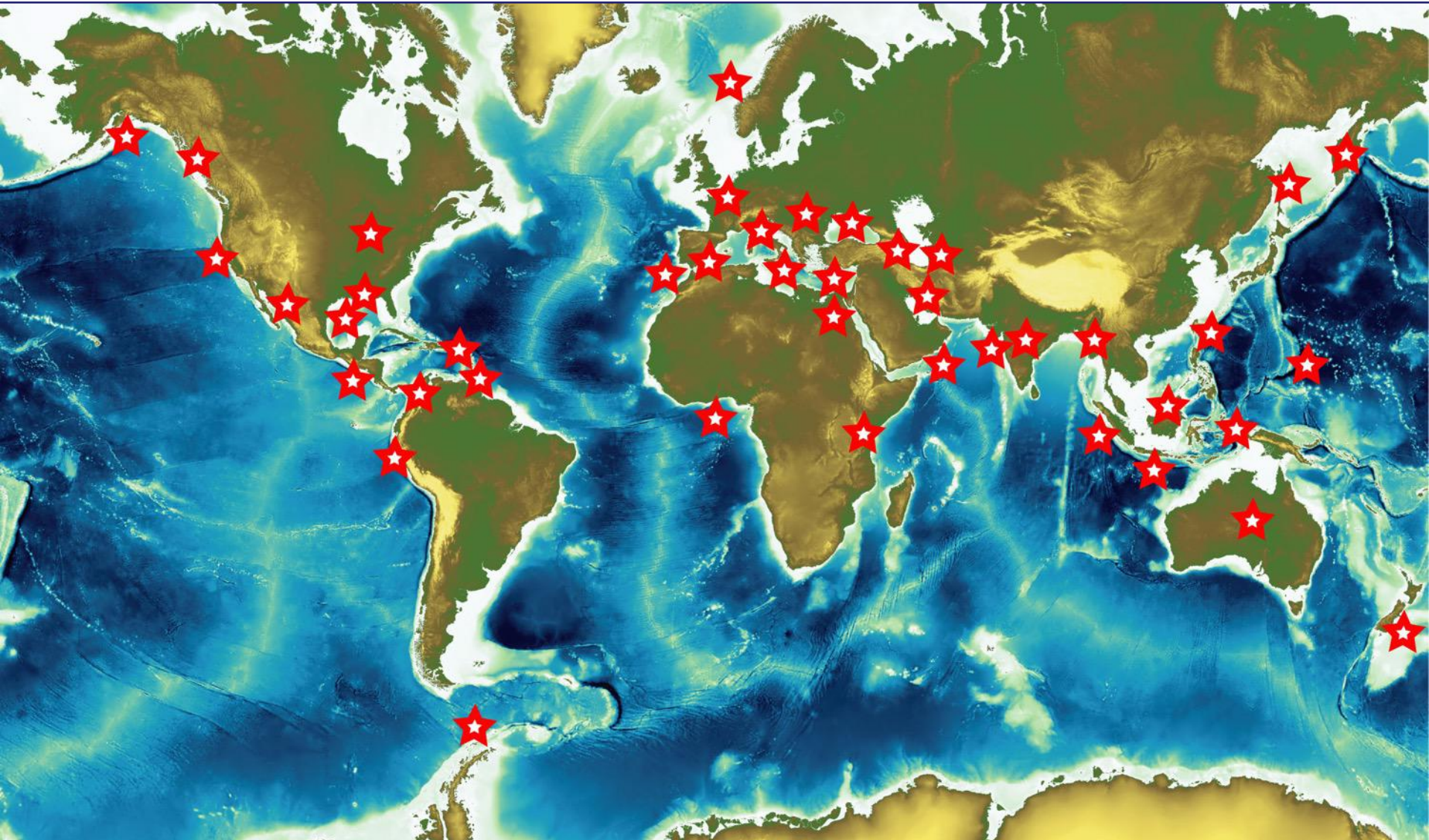


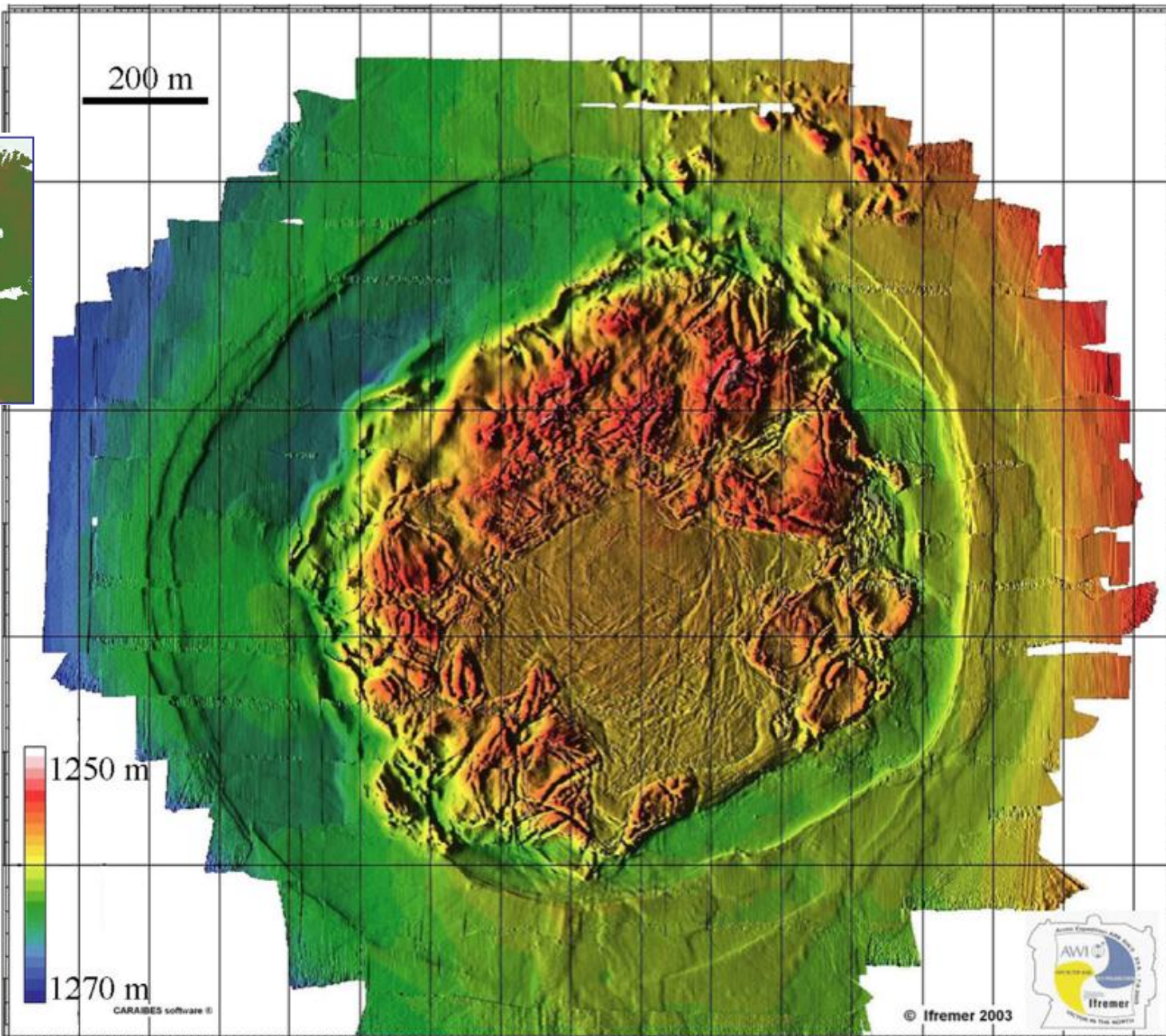
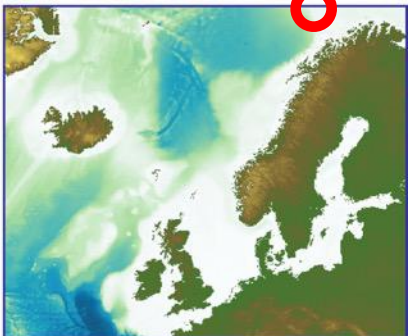
Onland mud volcanoes until now. They are more common in the marine environment

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.

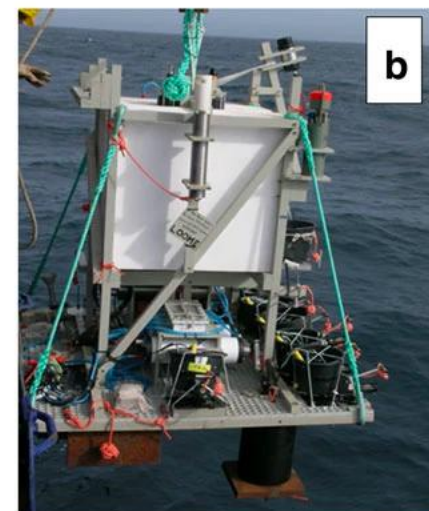
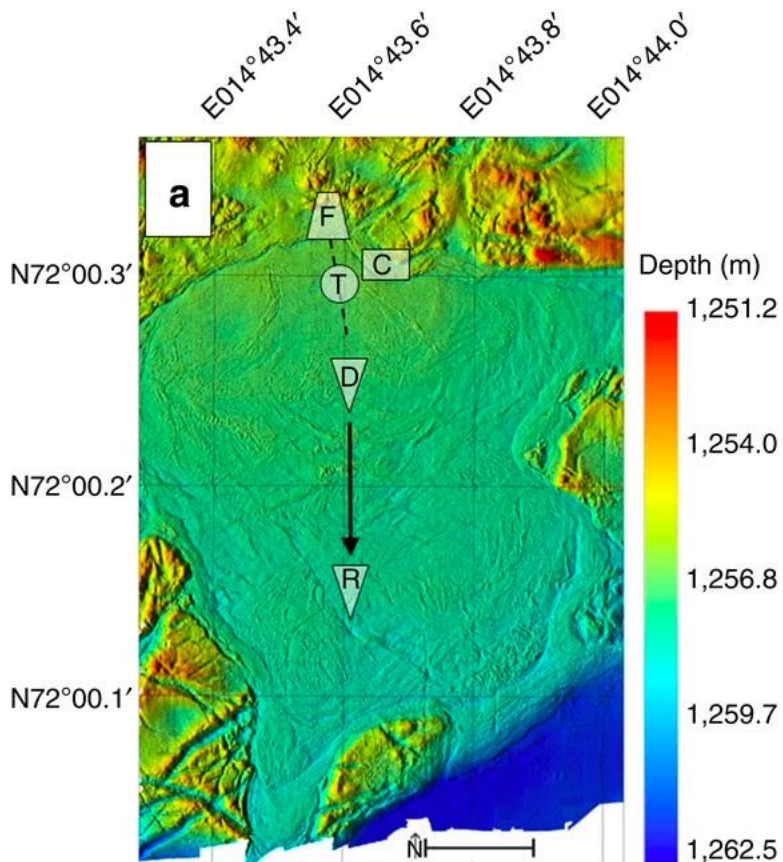
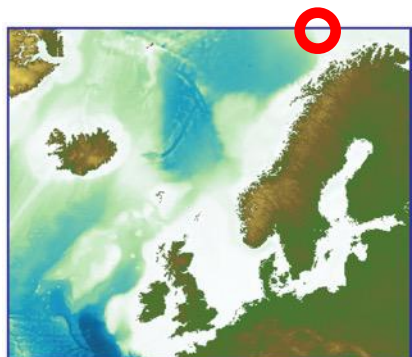
MUD VOLCANOES IN THE WORLD



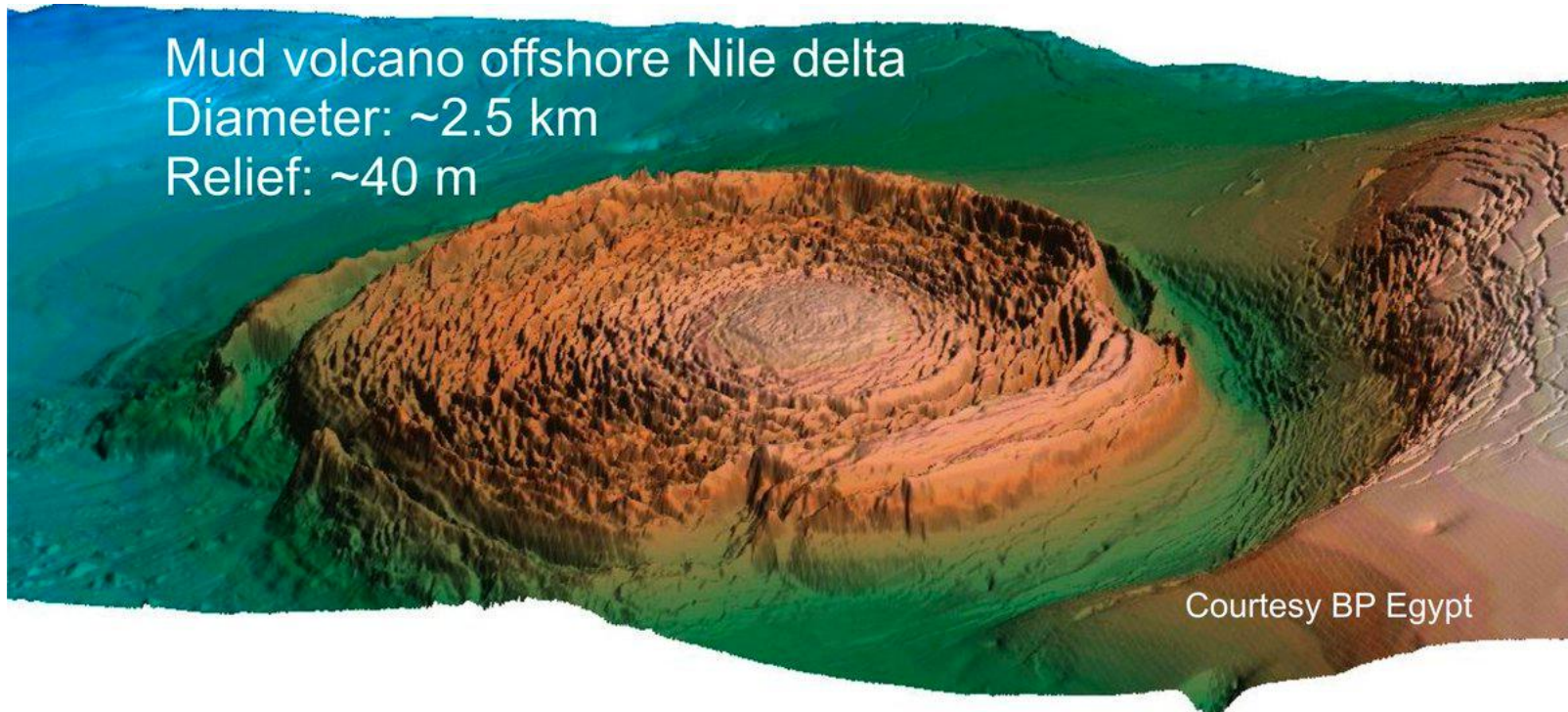


Multibeam bathymetry
From ROV.

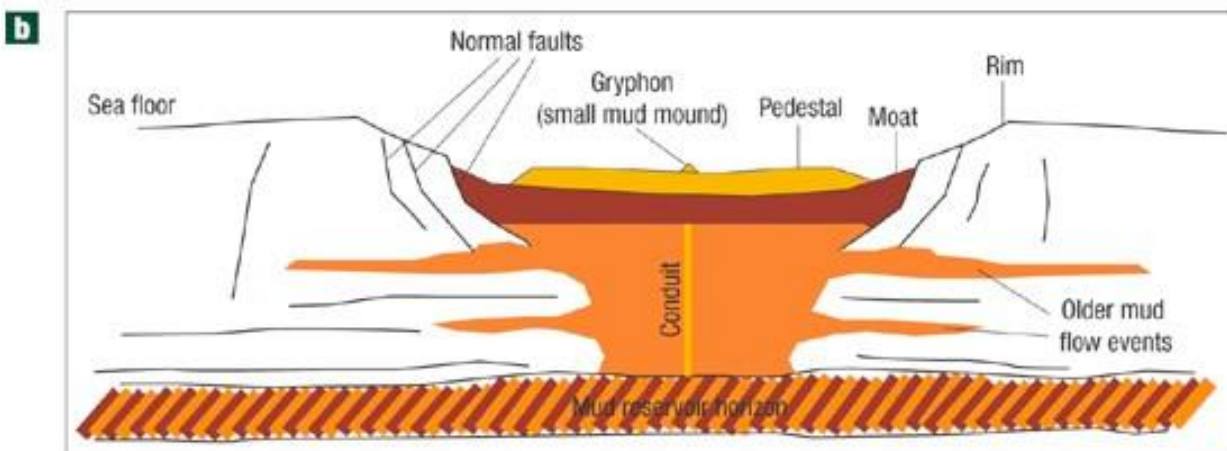
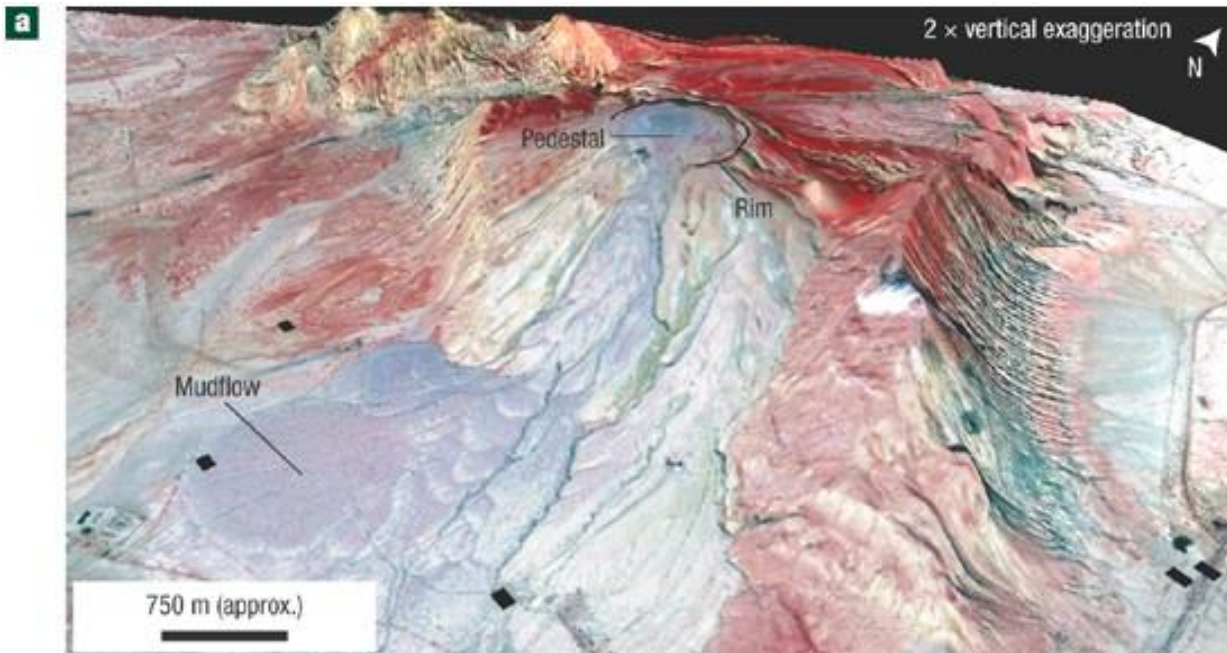


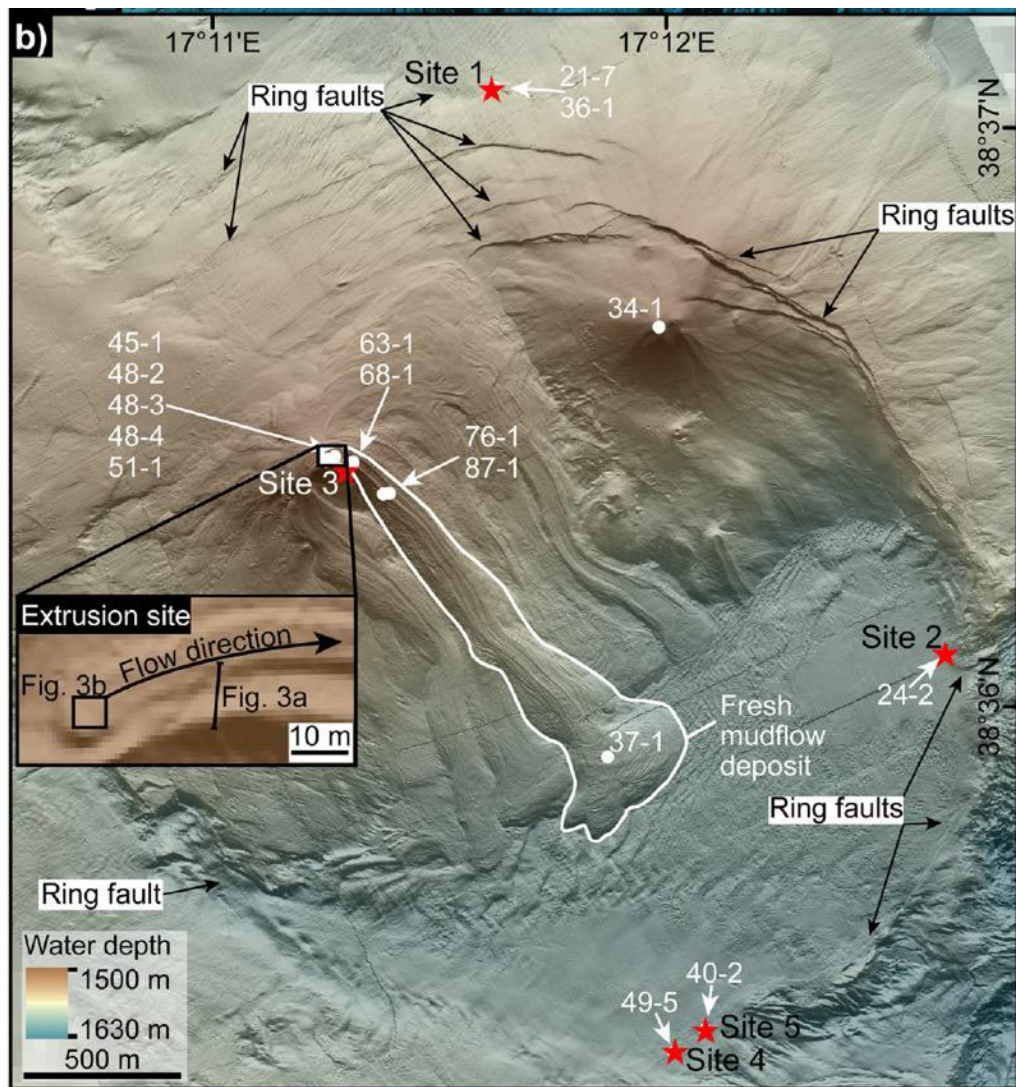
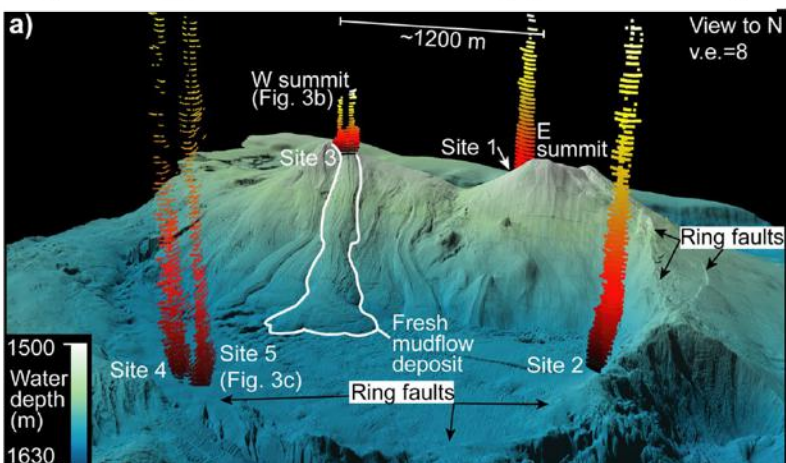
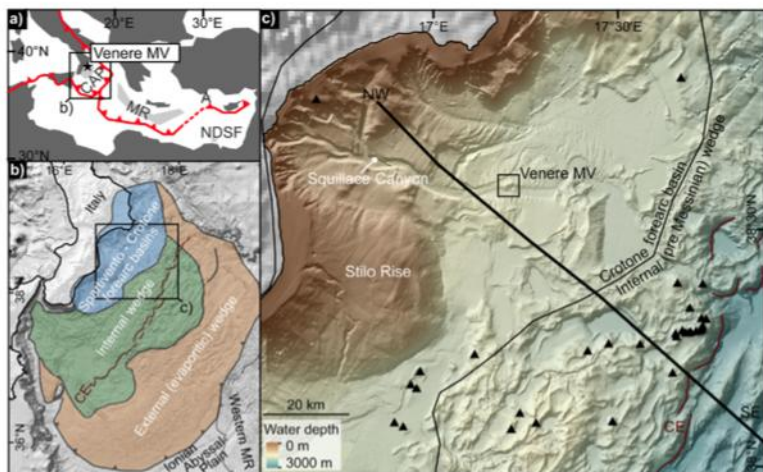


Tomas Feseker, Antje Boetius, Frank Wenzhöfer, Jerome Blandin, Karine Olu, Dana R. Yoerger, Richard Camilli, Christopher R. German & Dirk de Beer, 2014. Eruption of a deep-sea mud volcano triggers rapid sediment movement. Nature Communications volume 5, Article number: 5385 (2014)

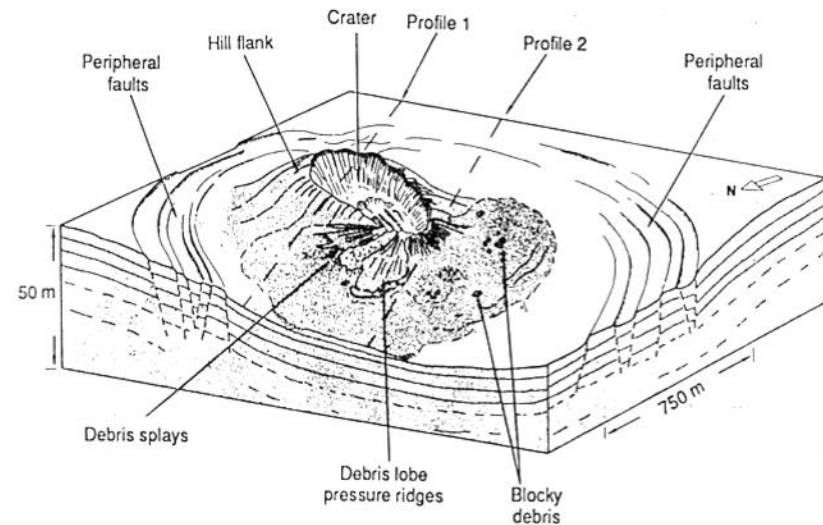
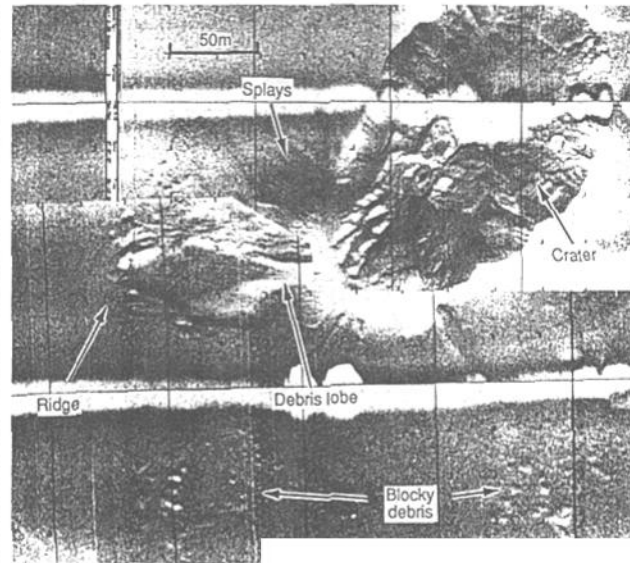
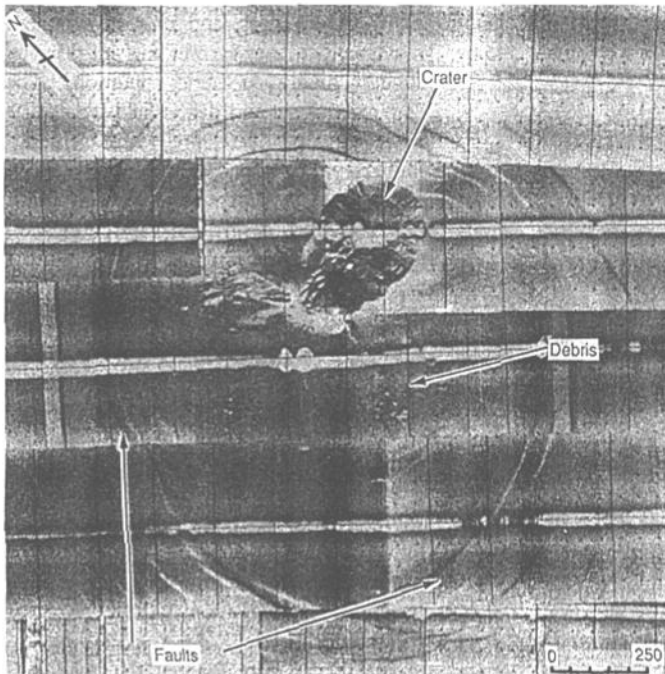


https://twitter.com/criticalstress_/status/1008632107306897409?lang=de

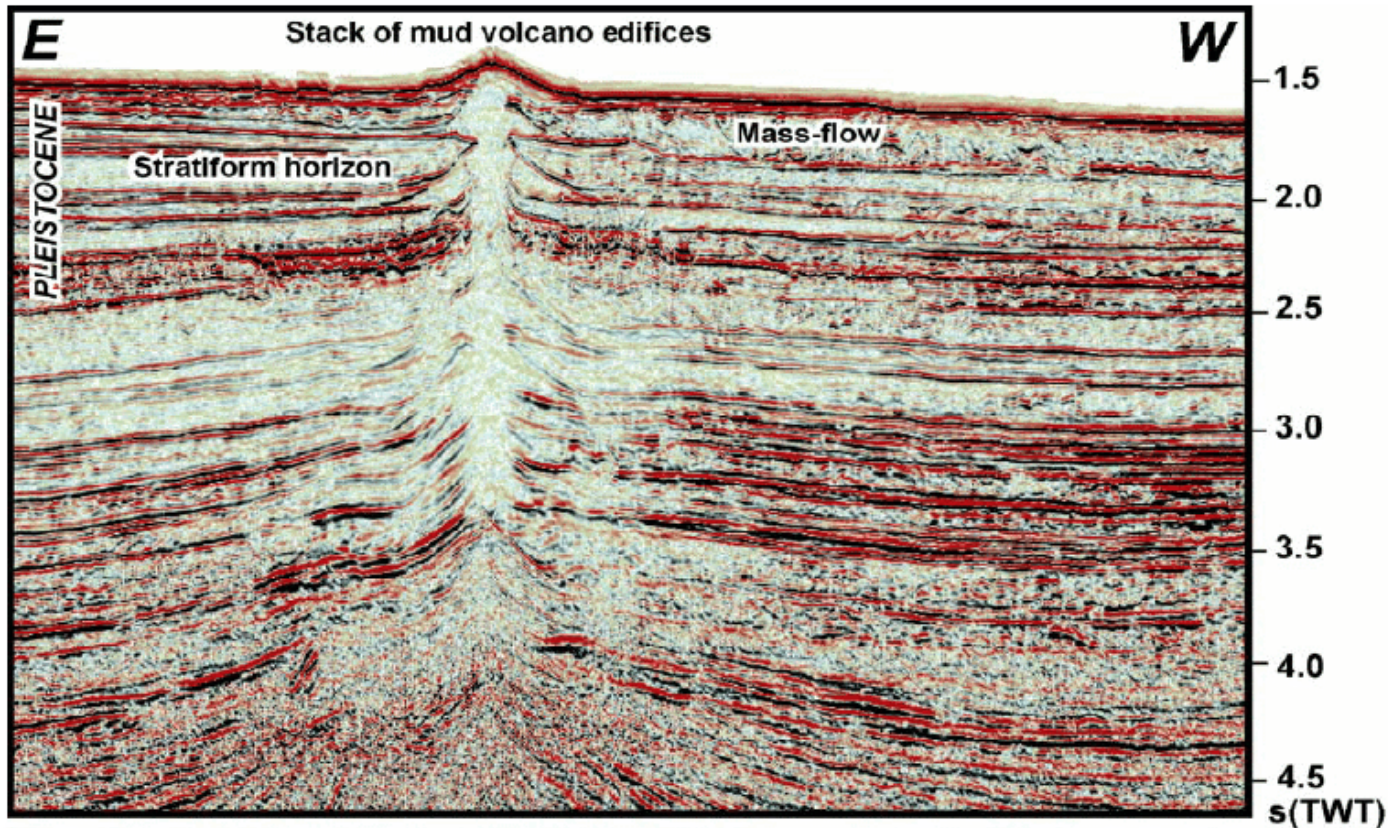




Mud volcanoes in the Gulf of Mexico. One of the first cases studied

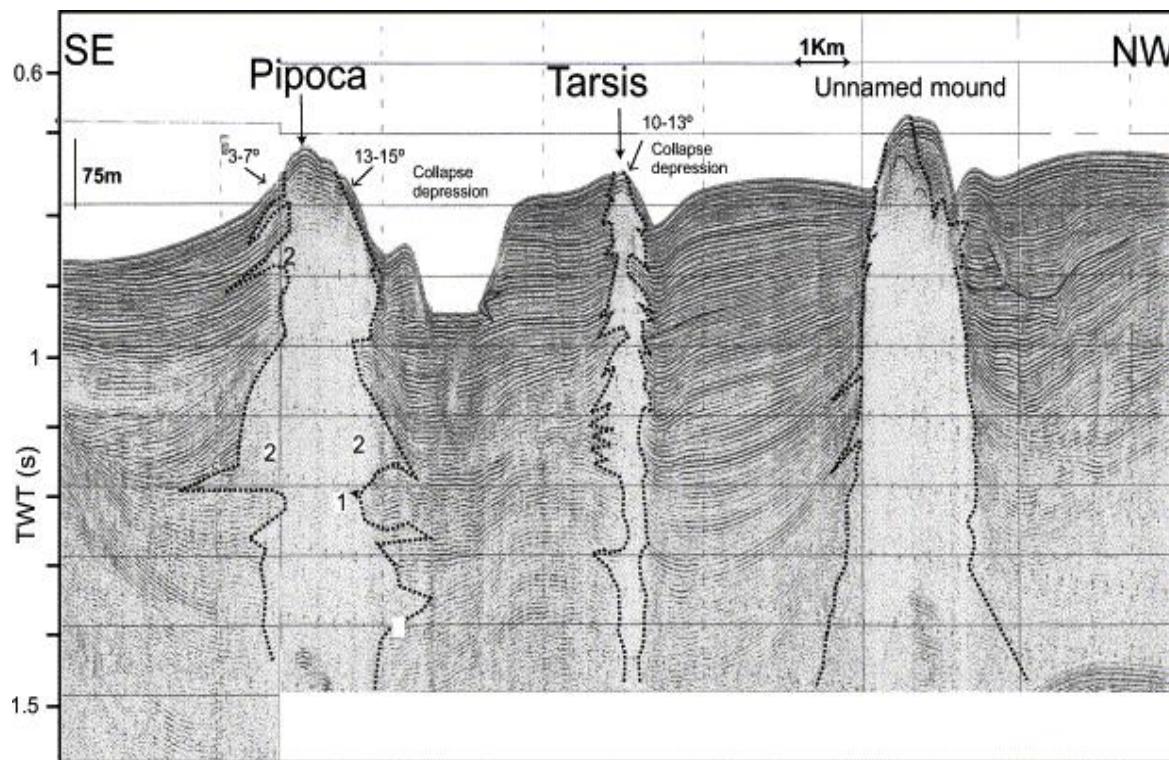
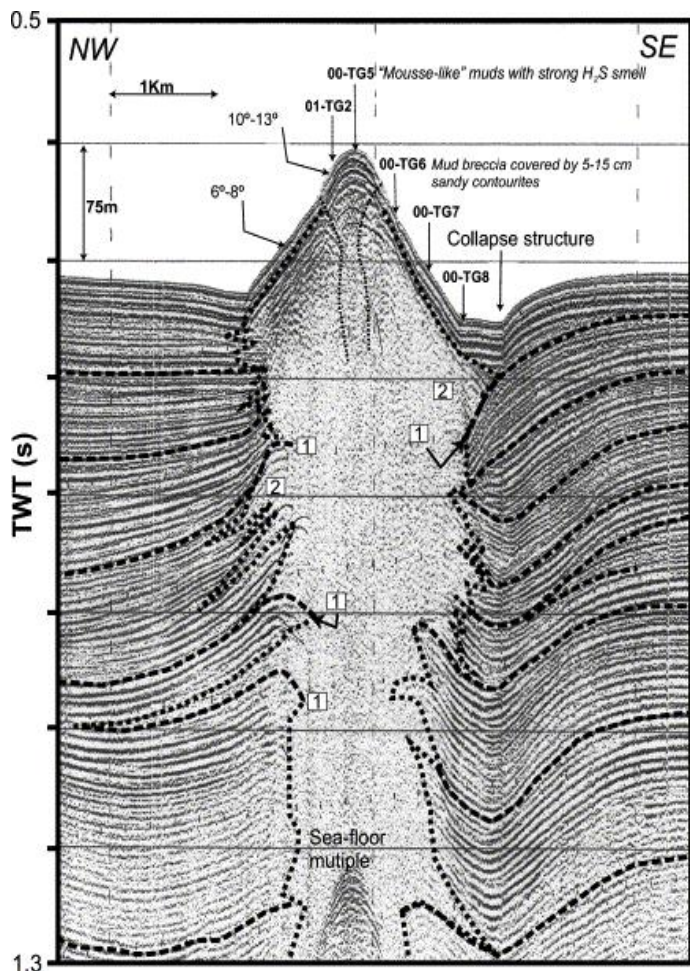


Mud volcanoes in seismic reflection data

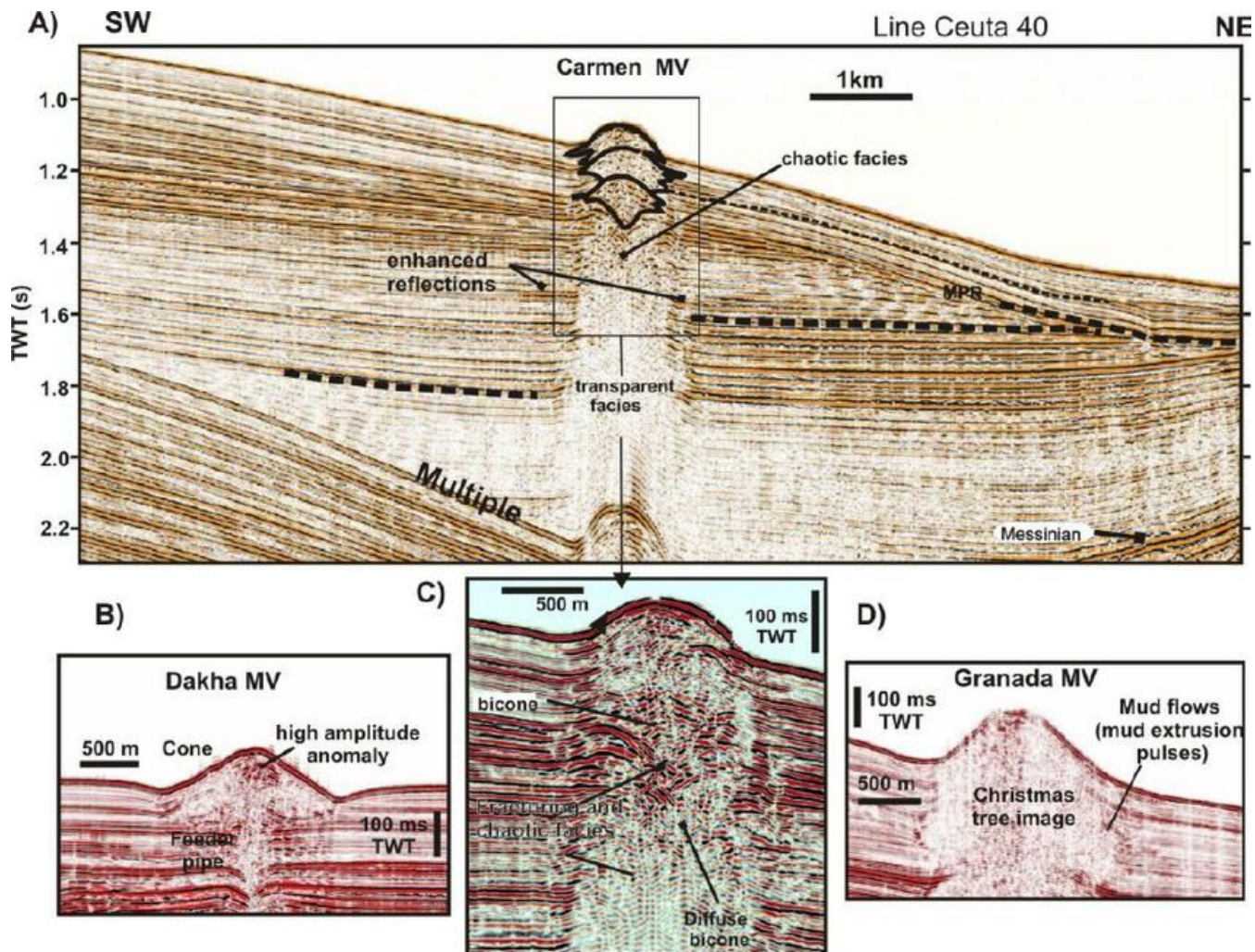


https://www.researchgate.net/figure/An-example-of-seismic-profile-across-a-mud-volcano-in-the-eastern-offshore-of-Trinidad_fig12_286291175

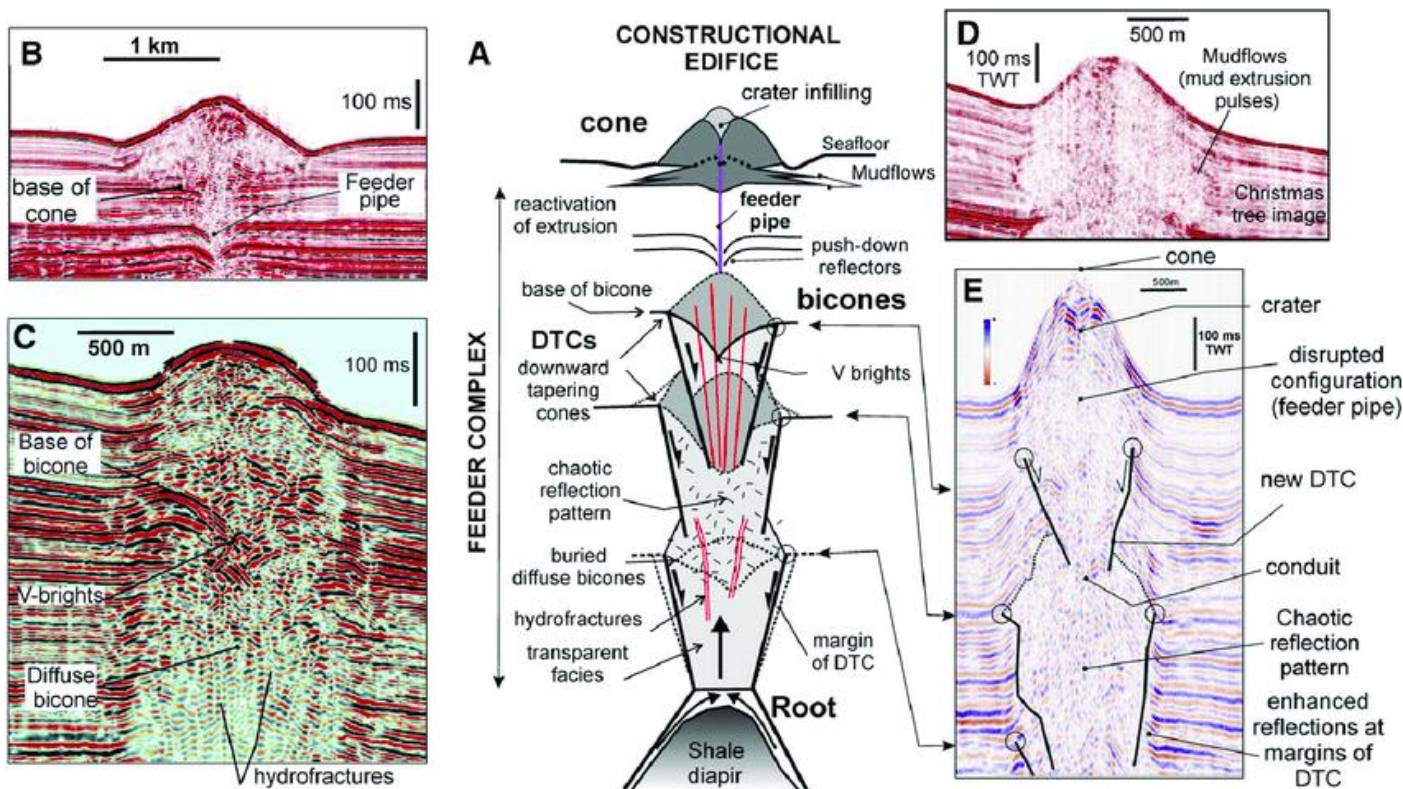
Mud volcanoes in seismic reflection data



Mud volcanoes in seismic reflection data



Mud volcanoes in seismic reflection data



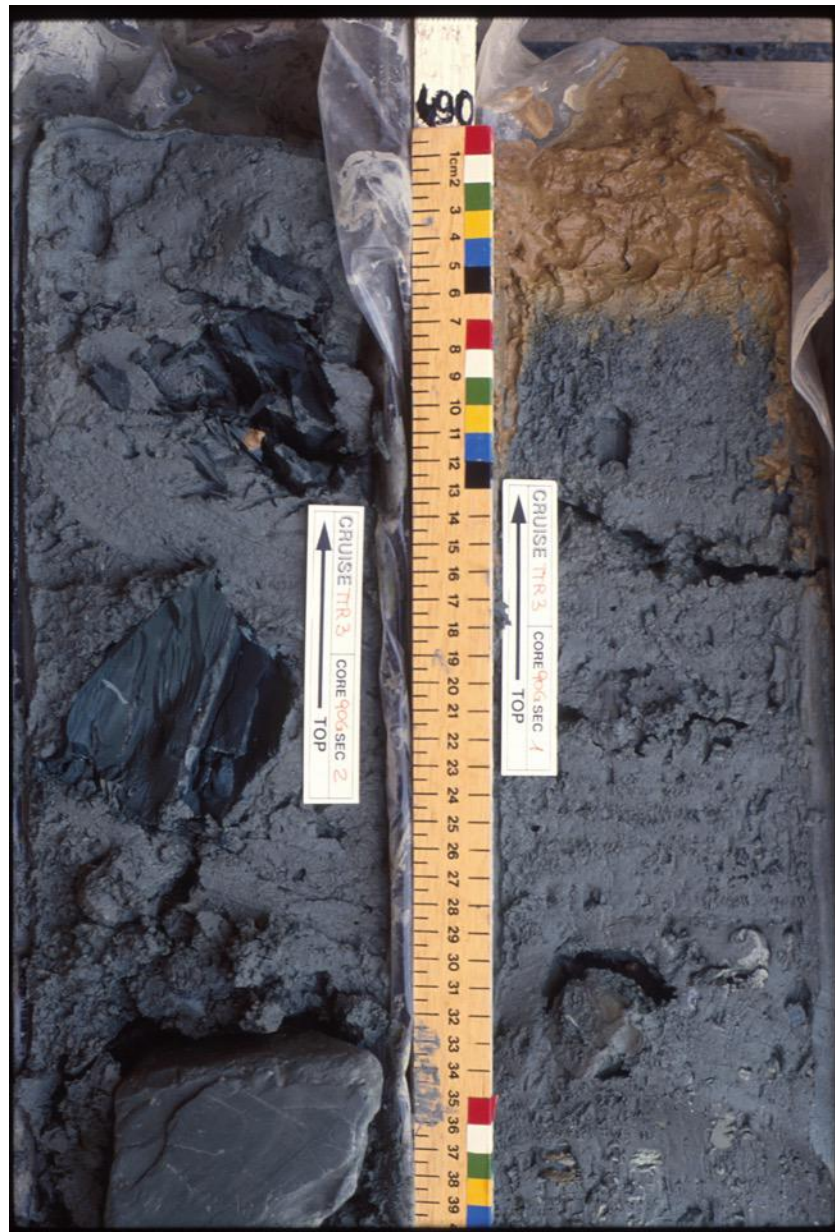
Classification of mud breccia from Mediterranean Sea mud volcanoes according to sedimentary facies

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-vesicles
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 embriicate 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



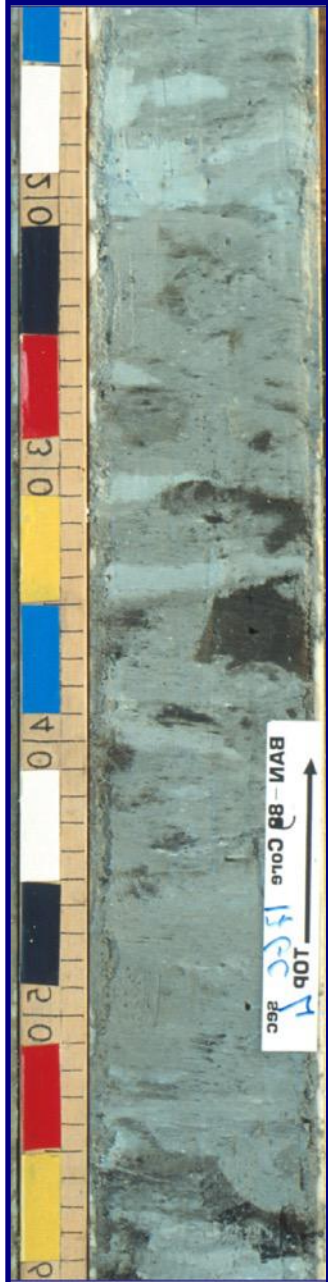
Clasts



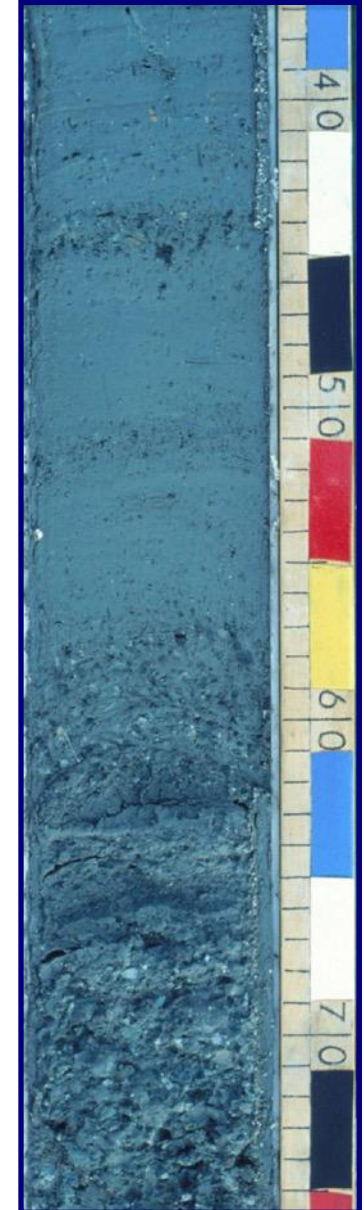
slumps



Mud-breccia oxidized

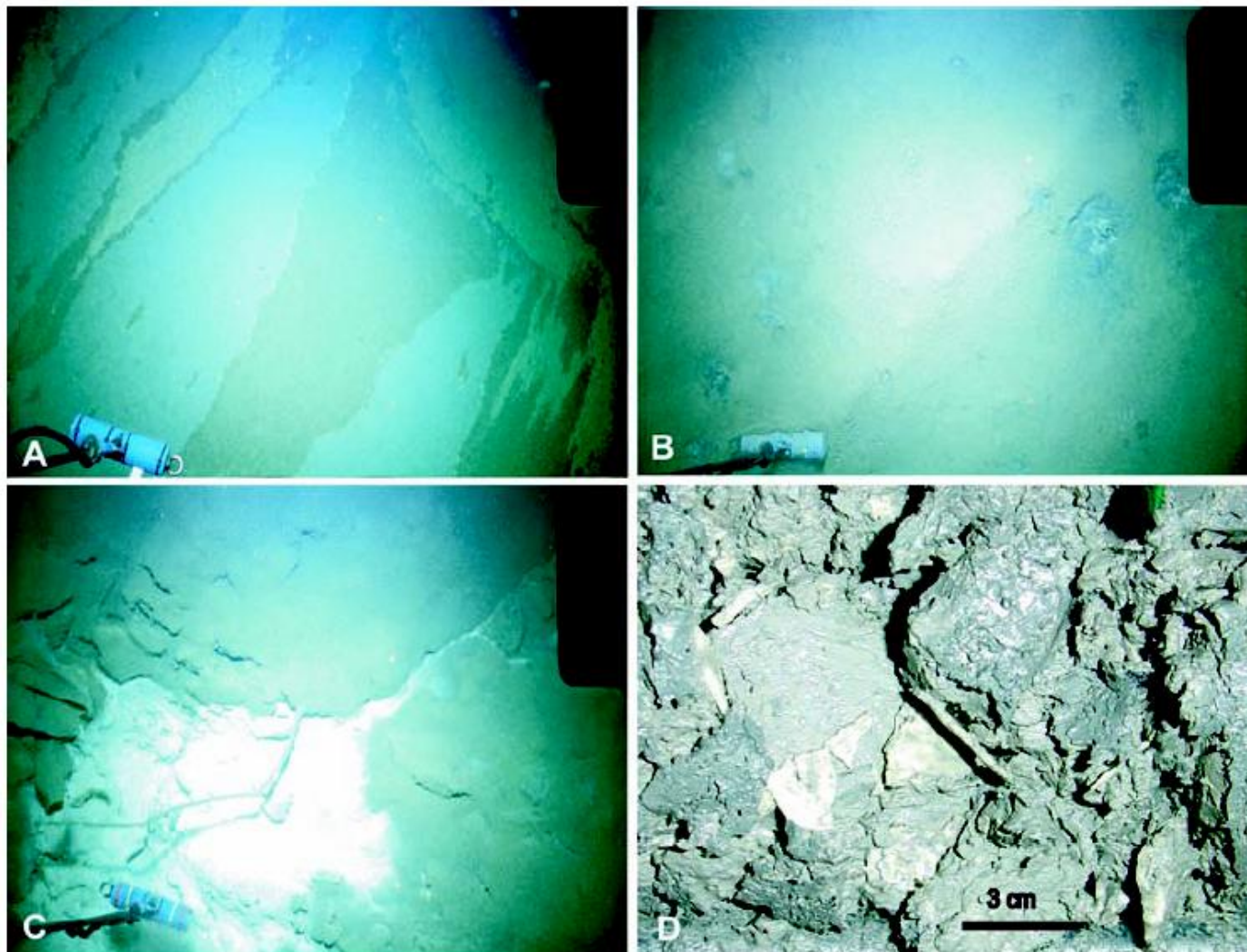


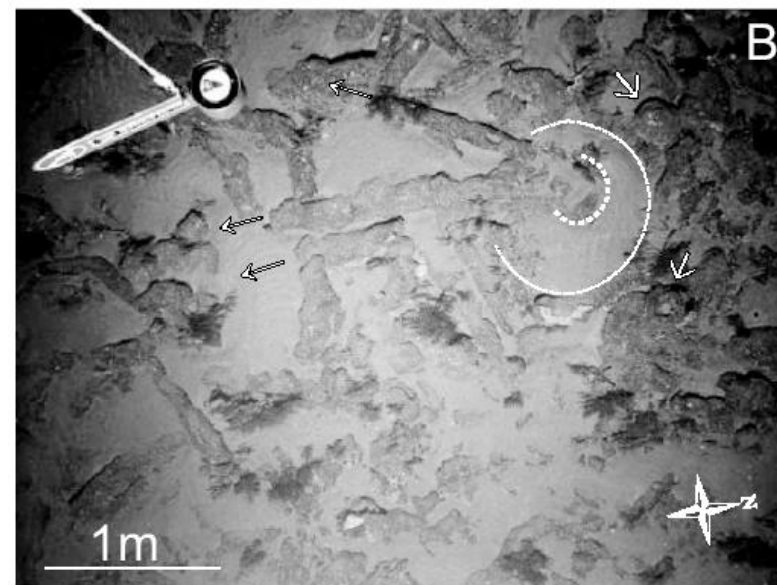
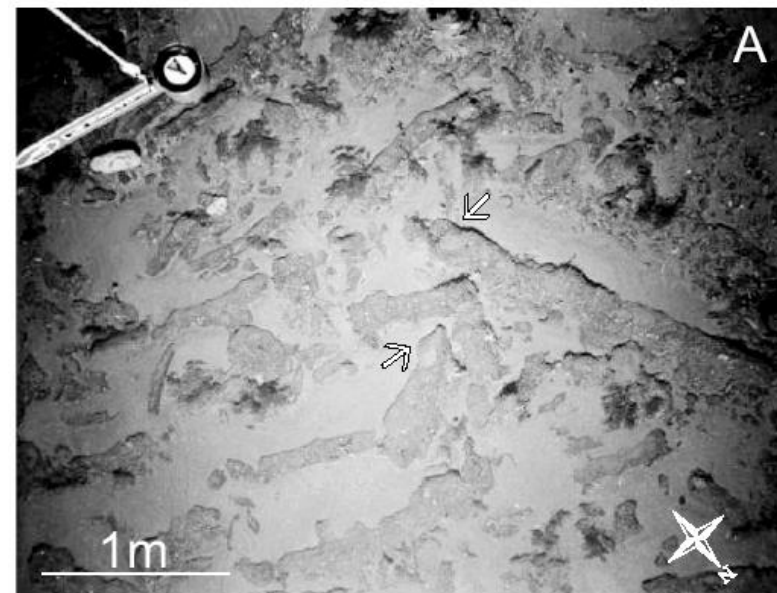
Mousse facies



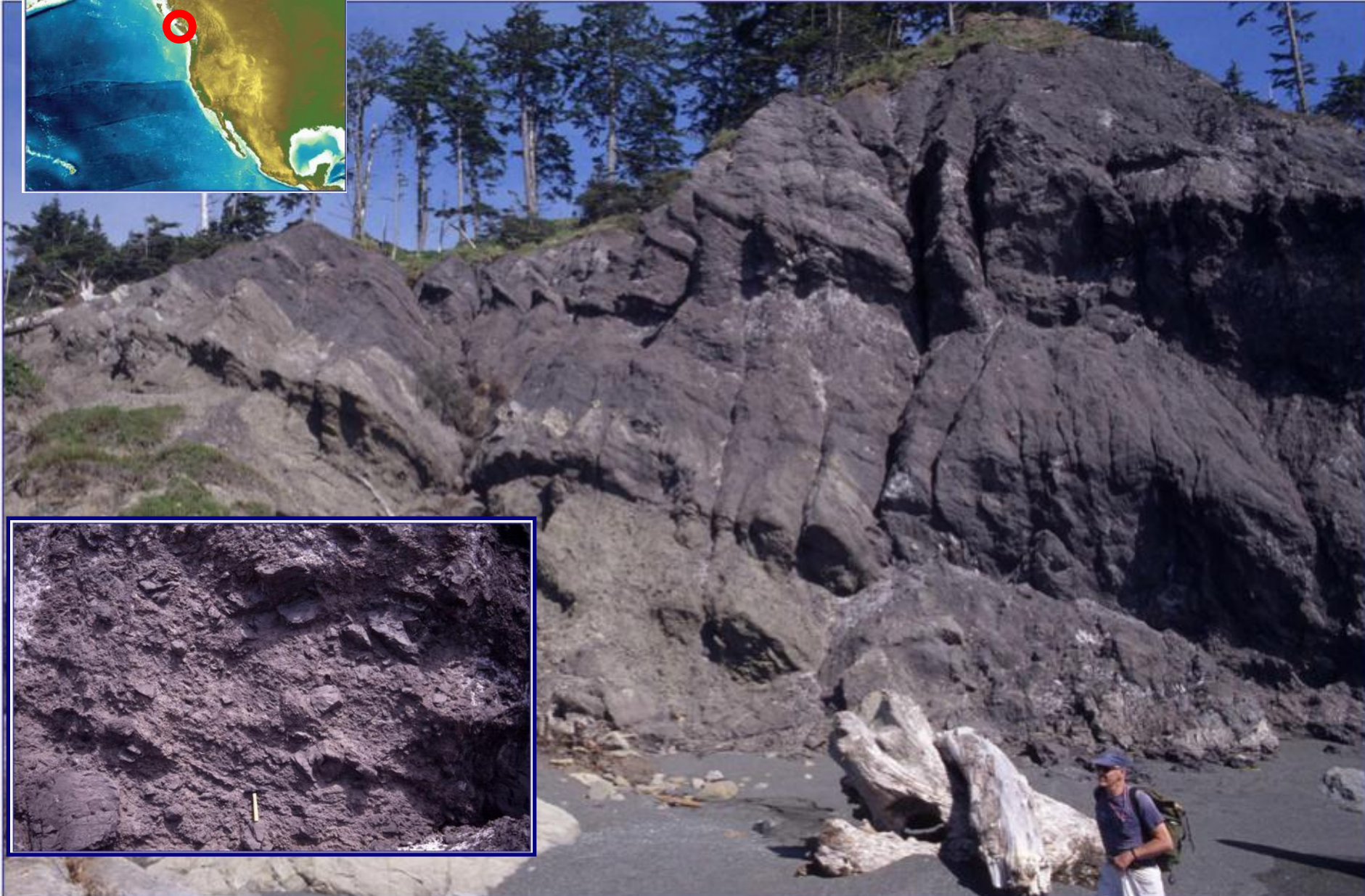
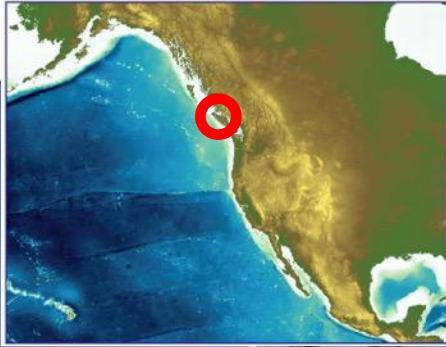
Organized facies

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

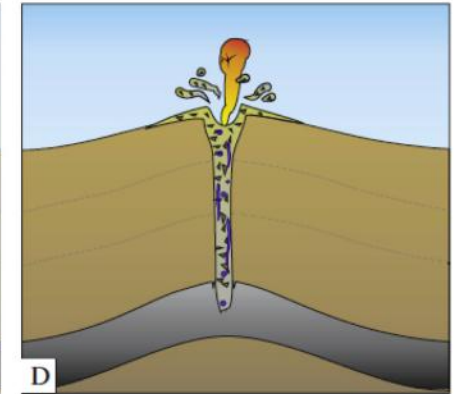
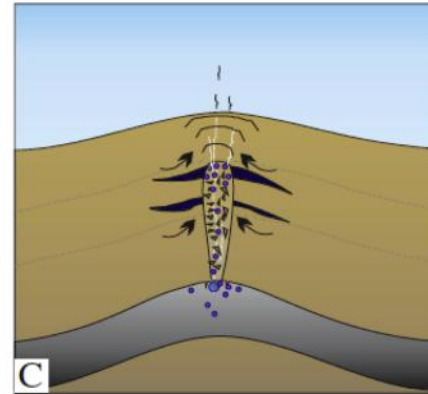
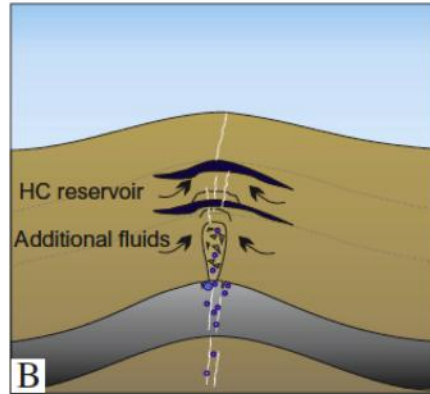
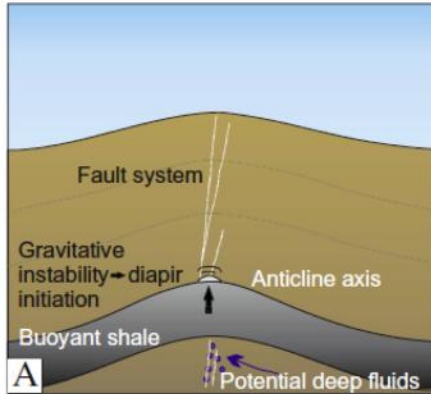




FOSSIL MUD VOLCANO, OLIMPIC PENINSULA



Mechanisms of emplacement



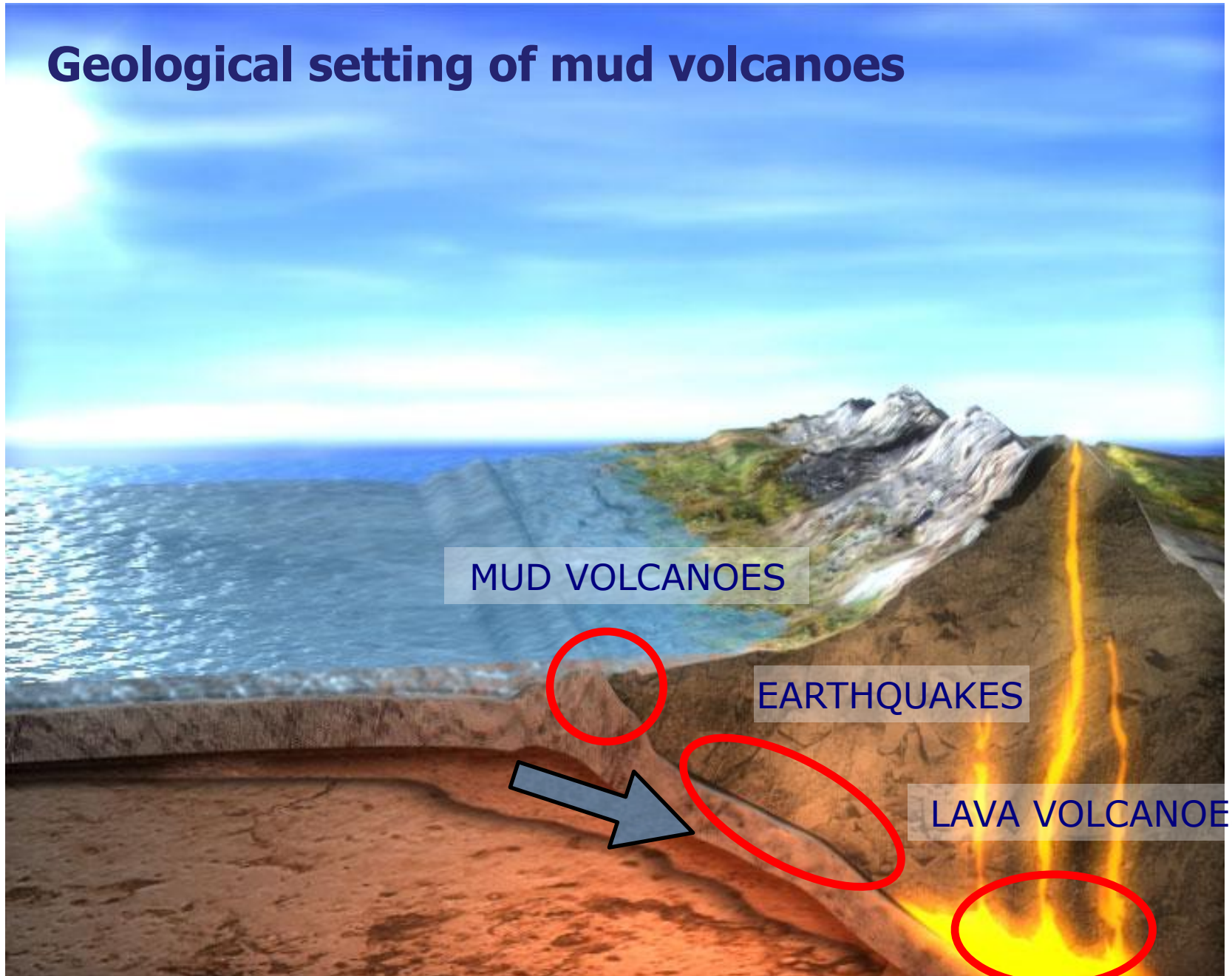
Diapir initiation in buoyant shales with potential deep fluids migration along structural highs (e.g. anticline axes) or fault networks

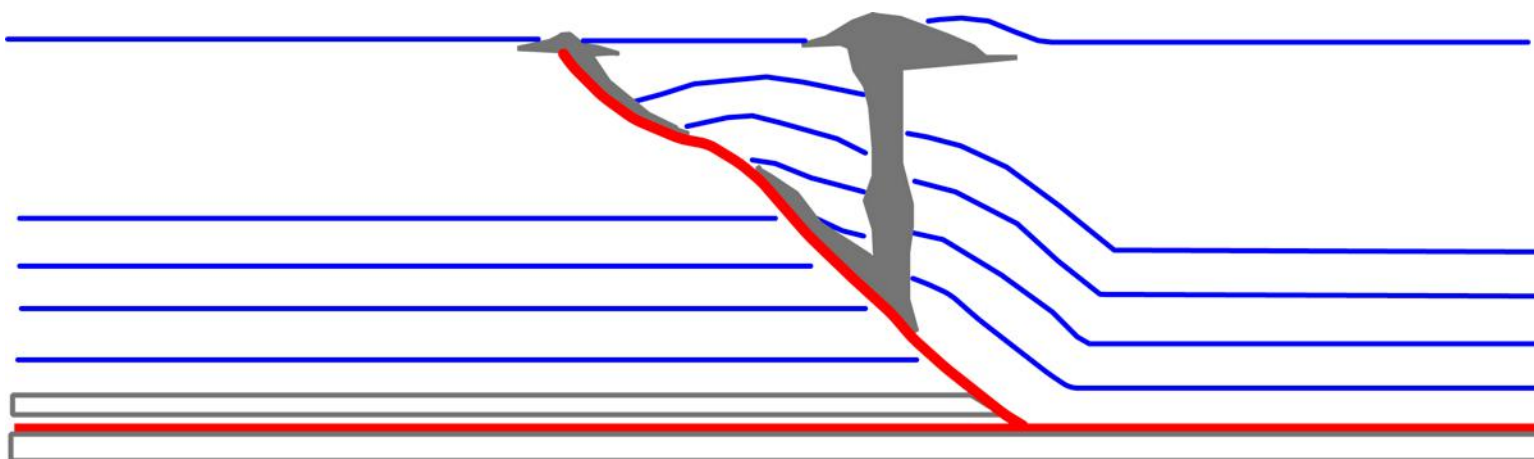
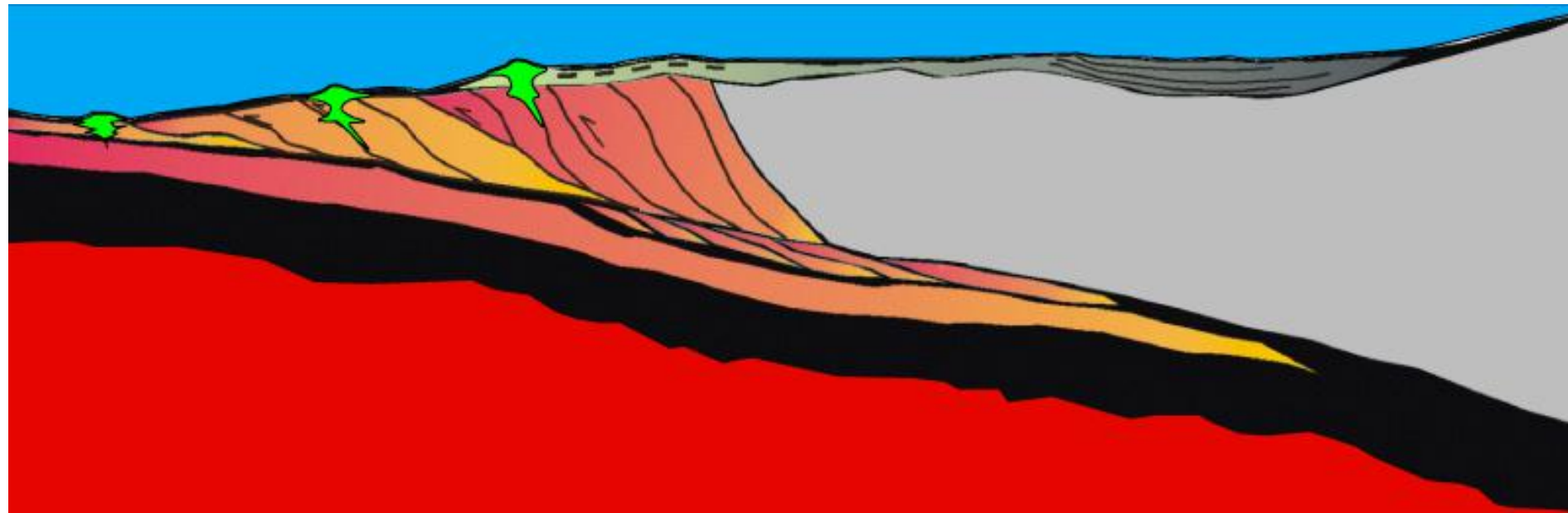
Fluids migration from different units and overpressure increase, diapiric structure development and brecciation during its growth

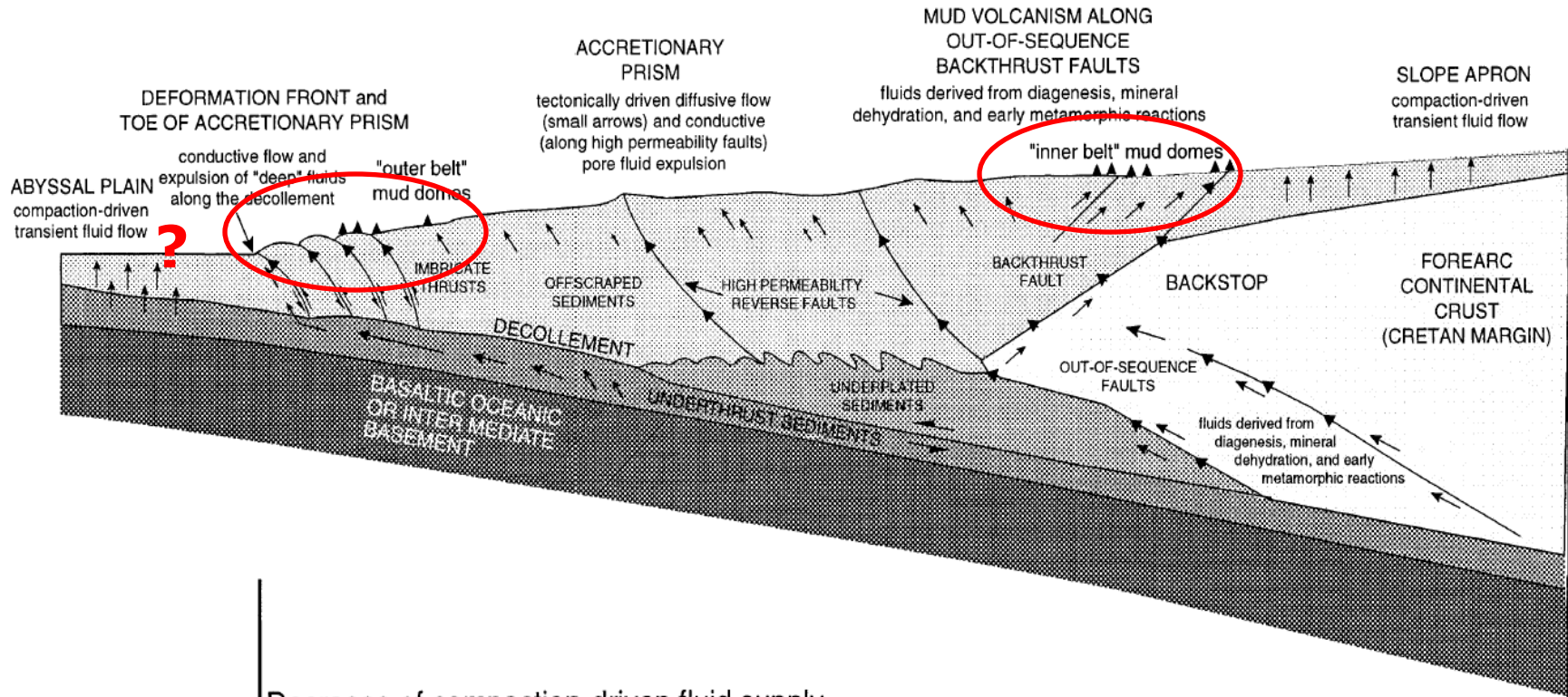
Overpressured diapir reaches critical depth. Overburden cannot contain fluids rich diapir. System in unstable conditions ready for triggering

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

Geological setting of mud volcanoes



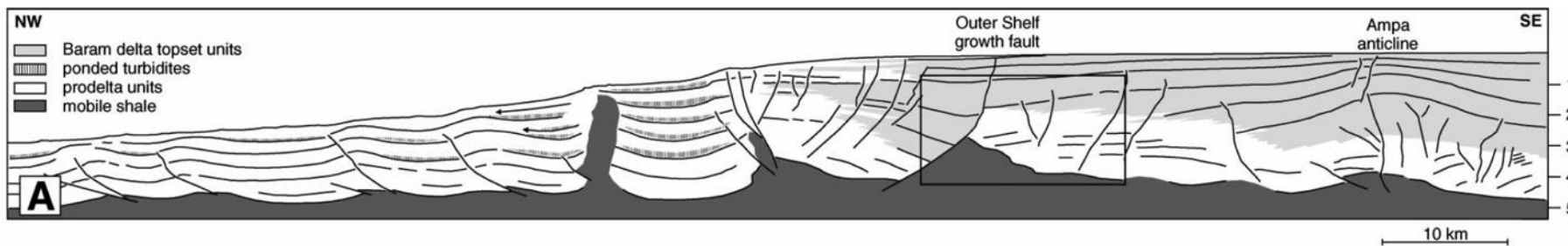




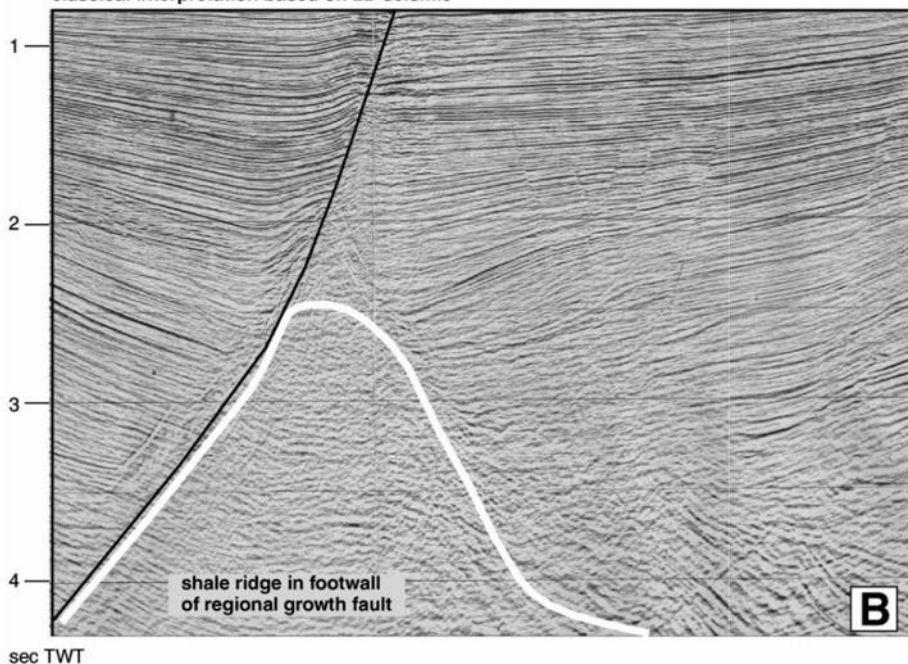
Decrease of compaction-driven fluid supply with distance from the deformation front

Increase of fluid supplied by diagenetic and metamorphic reaction with burial and enhanced tectonic compressive stress in the backstop region

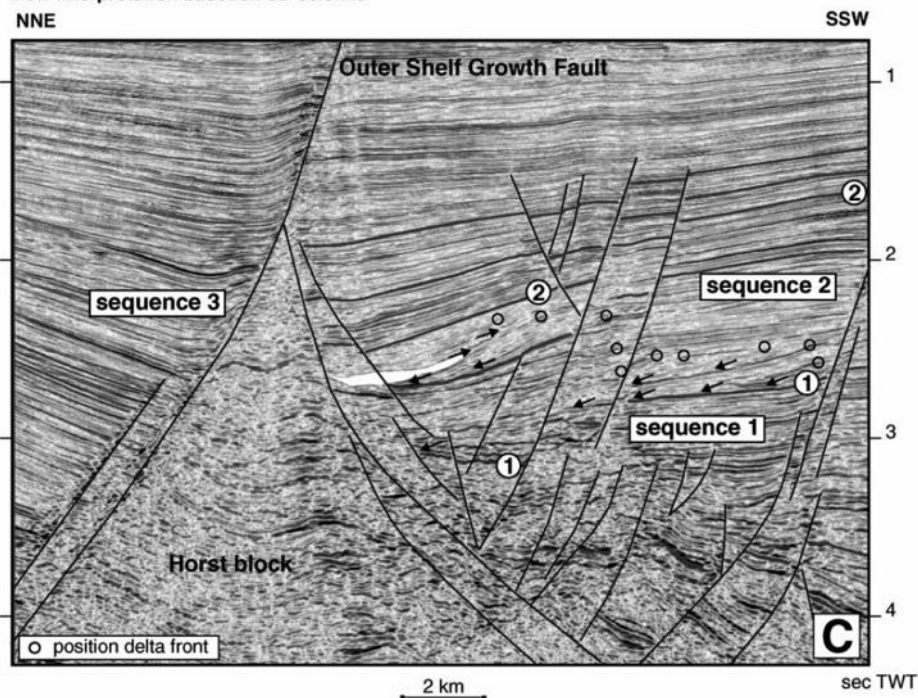
Shale tectonics, Offshore Brunei



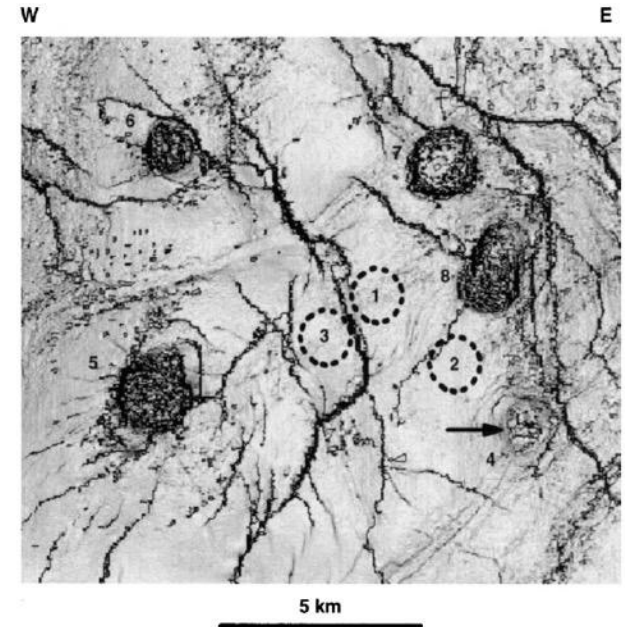
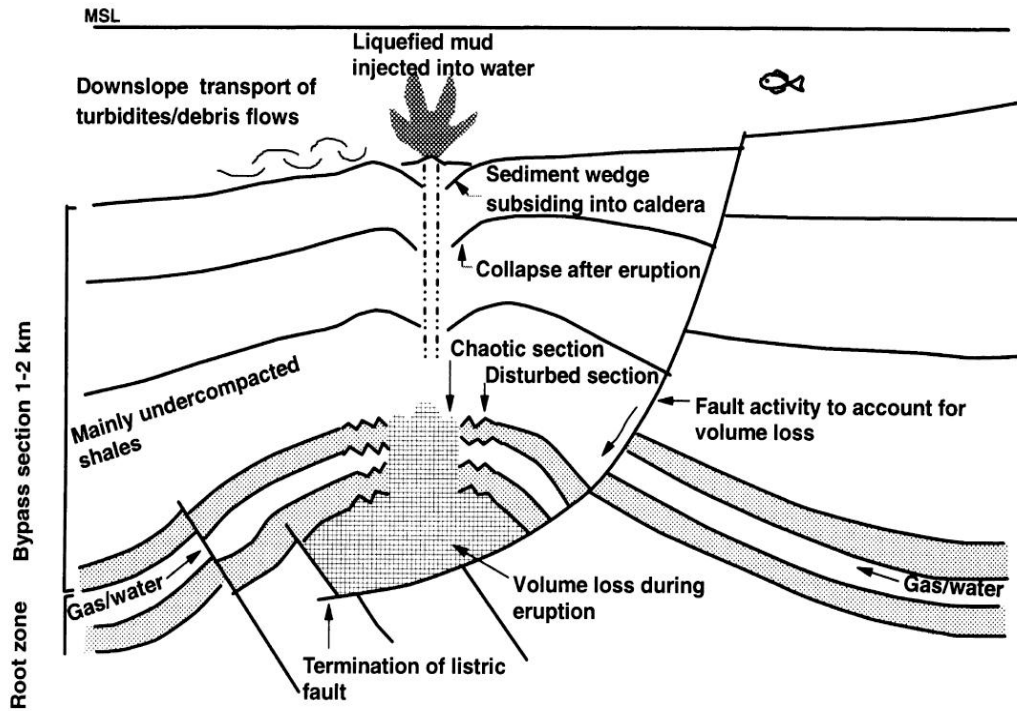
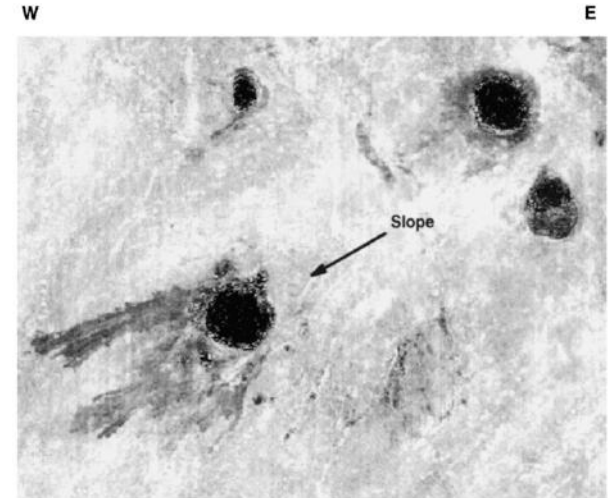
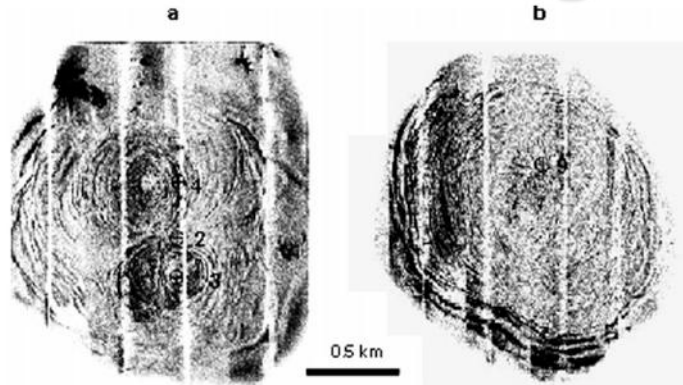
classical interpretation based on 2D seismic

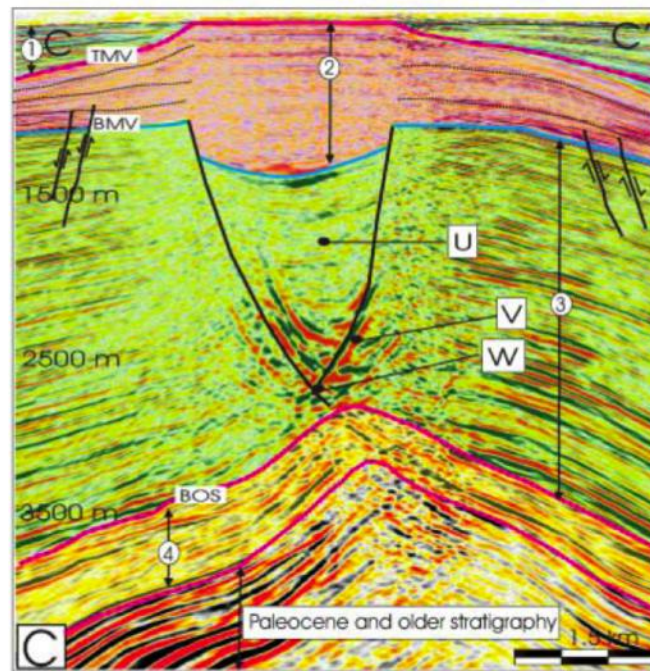
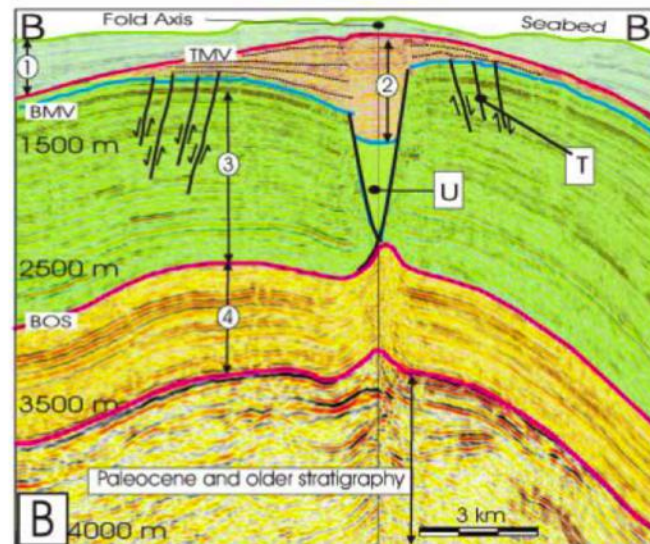
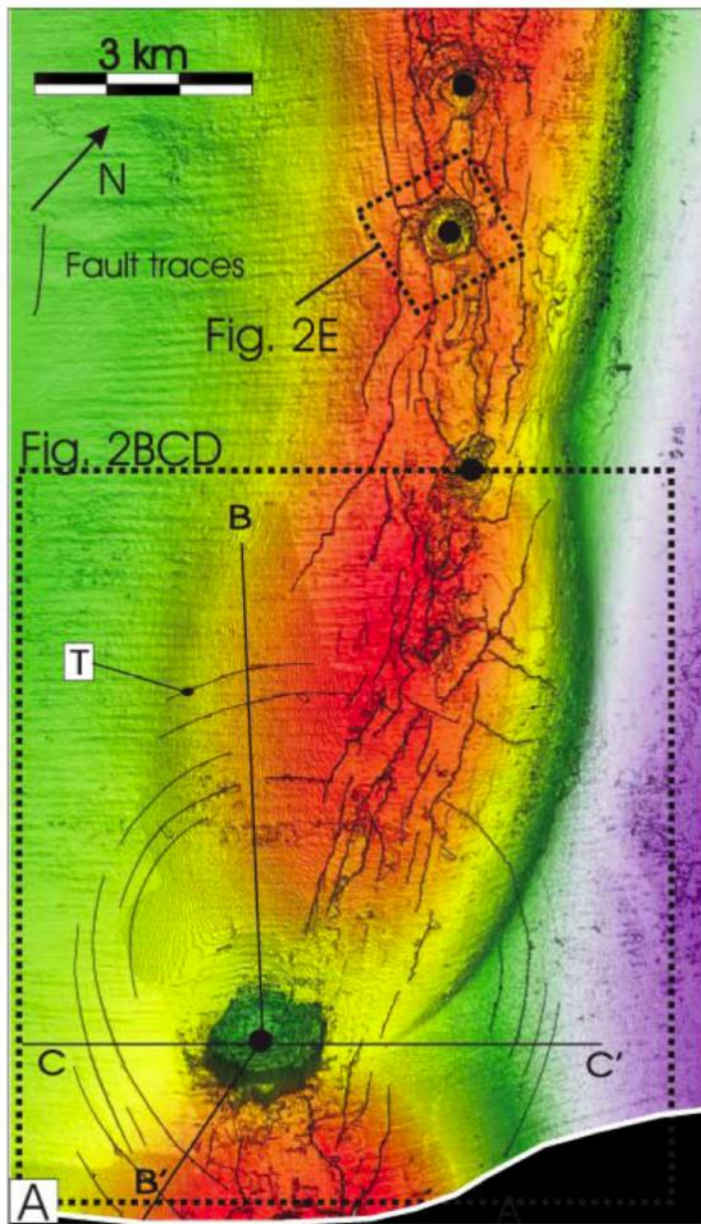


new interpretation based on 3D seismic



Mud volcanoes offshore Nigeria





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.



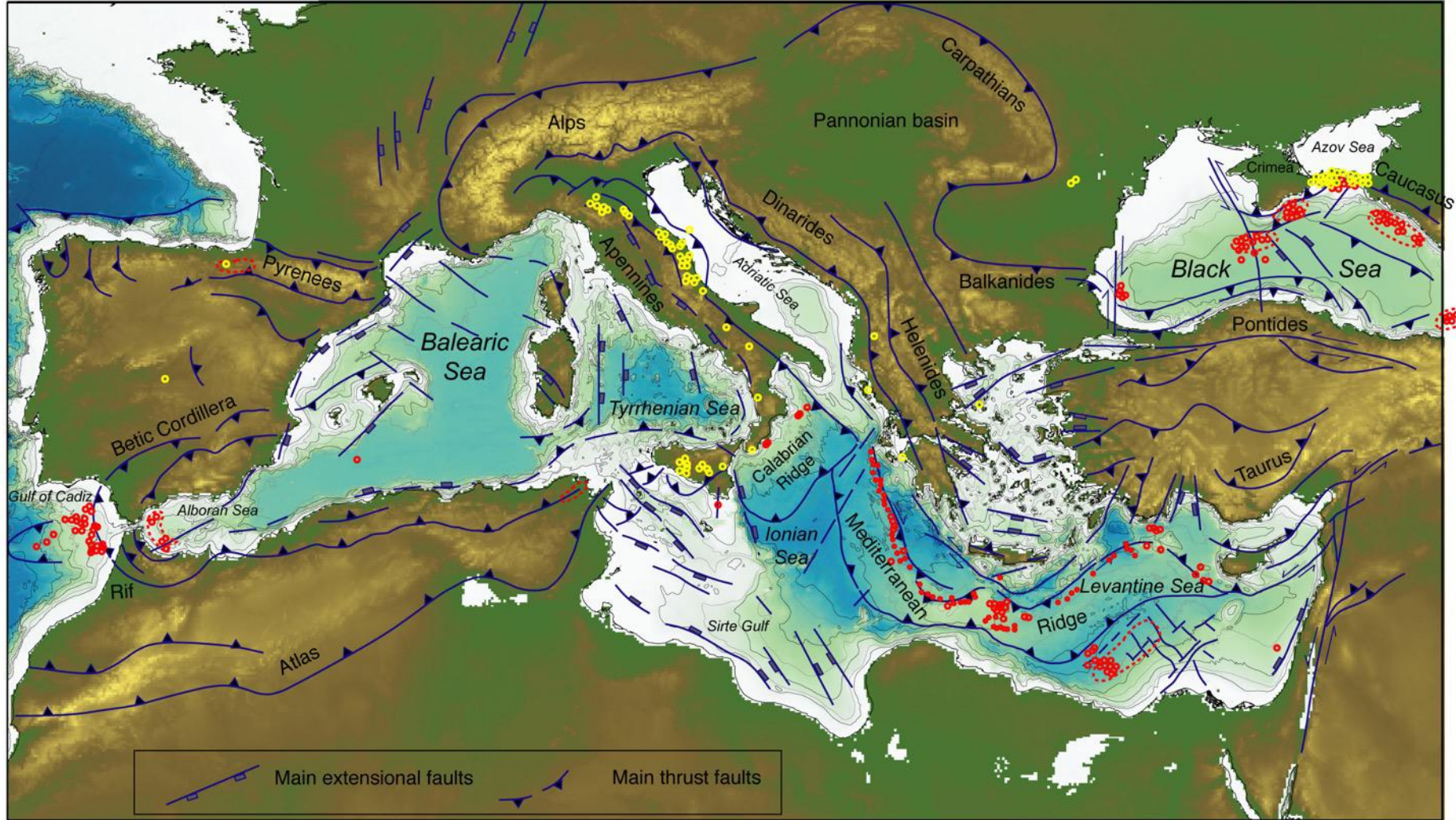
The Prometheus dome was identified according to:

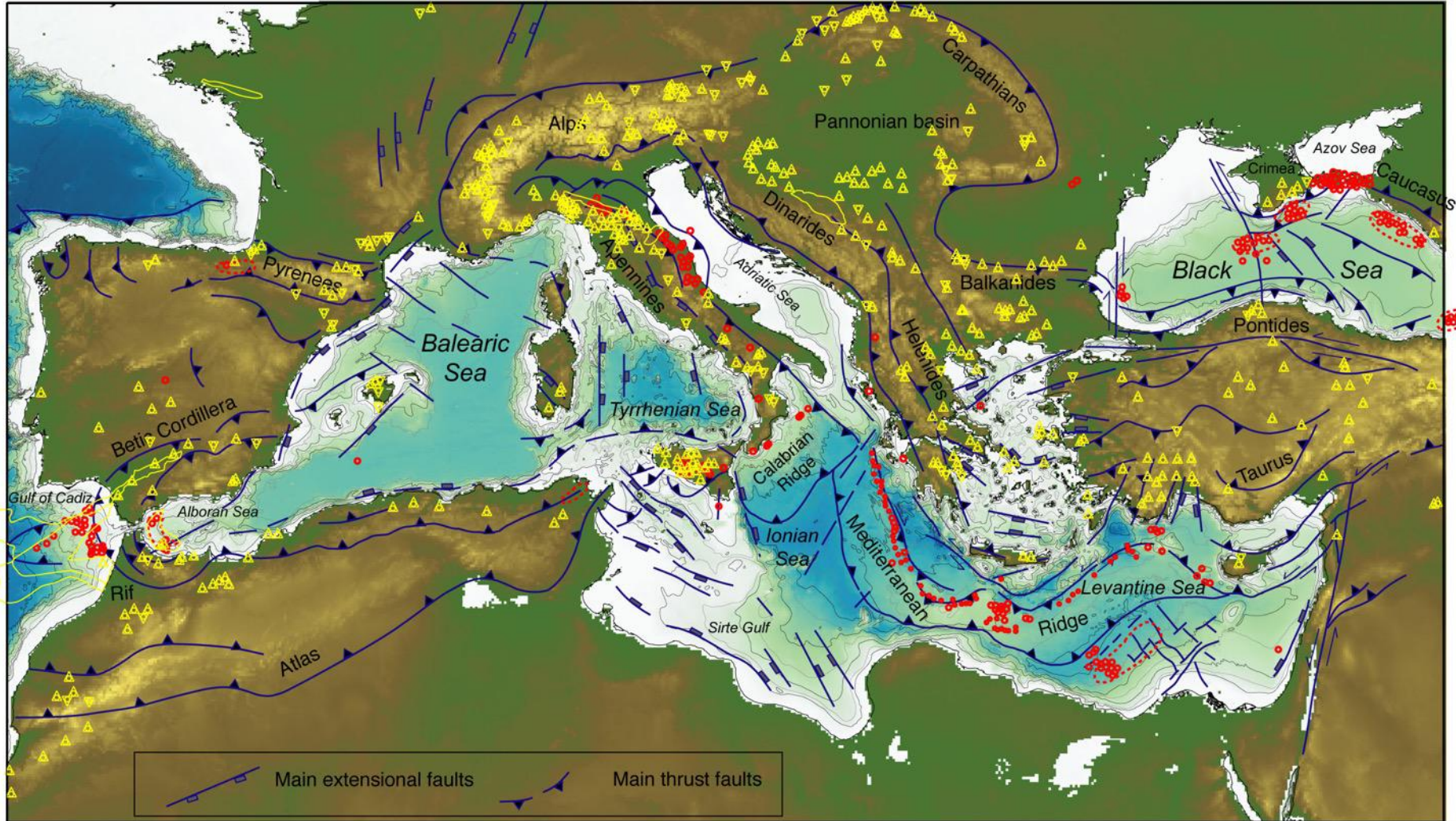
Morphology: wrinkled surface of small concentric ridges;

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.





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