

**Università di Trieste**  
**LAUREA MAGISTRALE IN GEOSCIENZE**  
**Curriculum Geofisico**  
**Curriculum Geologico Ambientale**

**Anno accademico 2019 – 2020**

# **Geologia Marina**

2019-20

**Modulo 6.2      Pericolosità dei fondali sottomarini**

**Docente**  
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## OUTLINE

- Concepts of hazard, vulnerability, risk, mitigation, resilience
- Natural marine geohazards
- The use of integrated acoustic methods ....
- ...and examples of geohazard assessment in the Ionian sea

**HAZARD**  
**VULNERABILITY**  
**RISK**  
**MITIGATION**  
**RESILIENCE**

**HAZARD:** Is an **event** posing a threat to life, health, property or environment. Hazard assessment is the evaluation of the occurrence of a potentially damaging event, (where, when, how frequently, magnitude). The **identification of hazards** is the first step in performing **hazard assessment**

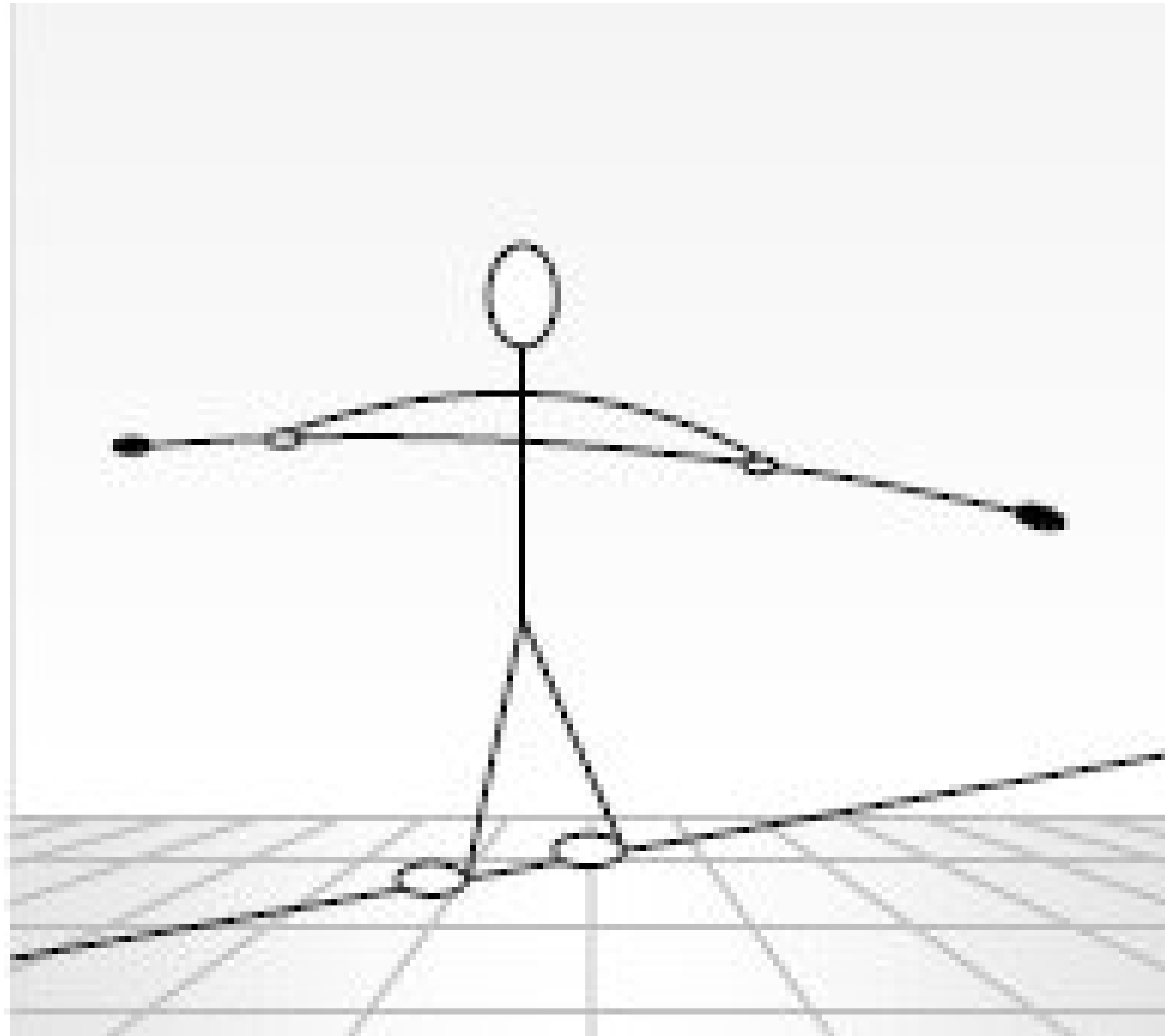
**VULNERABILITY:** is the **probability of being damaged** by a specific event (hazard)

**RISK:** is the **probability that exposure to a specific hazard will cause harm**. Thus, a hazard poses no risk if there is not exposure to that hazard

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$



# Risk and Mitigation



The **concept of risk** is illustrated by the tightrope walker. In this example, the risk to the tightrope walker is falling off and getting killed—a high-risk activity!

If the highwire is only one meter above the ground the falling hazard still exists and the **chance of falling remains constant**, but the risk is considerably different than if the person were 100 metres above the ground.

Perhaps there is a crowd below the tightrope walker vulnerable to injury. The severity of impact to the tightrope walker and the crowd can be **mitigated** by a safety net, the chance of falling can be reduced by special training and the extent of injury can be mitigated by emergency medical response capability.

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$



### Japanese Earthquake Highway Repair

- Earthquake: March 11 2011
- Repair begun: March 17 2011
- Road ready: March 22 2011 (six days later)



By Mail Foreign Service, 02:01 GMT, 24 March 2011

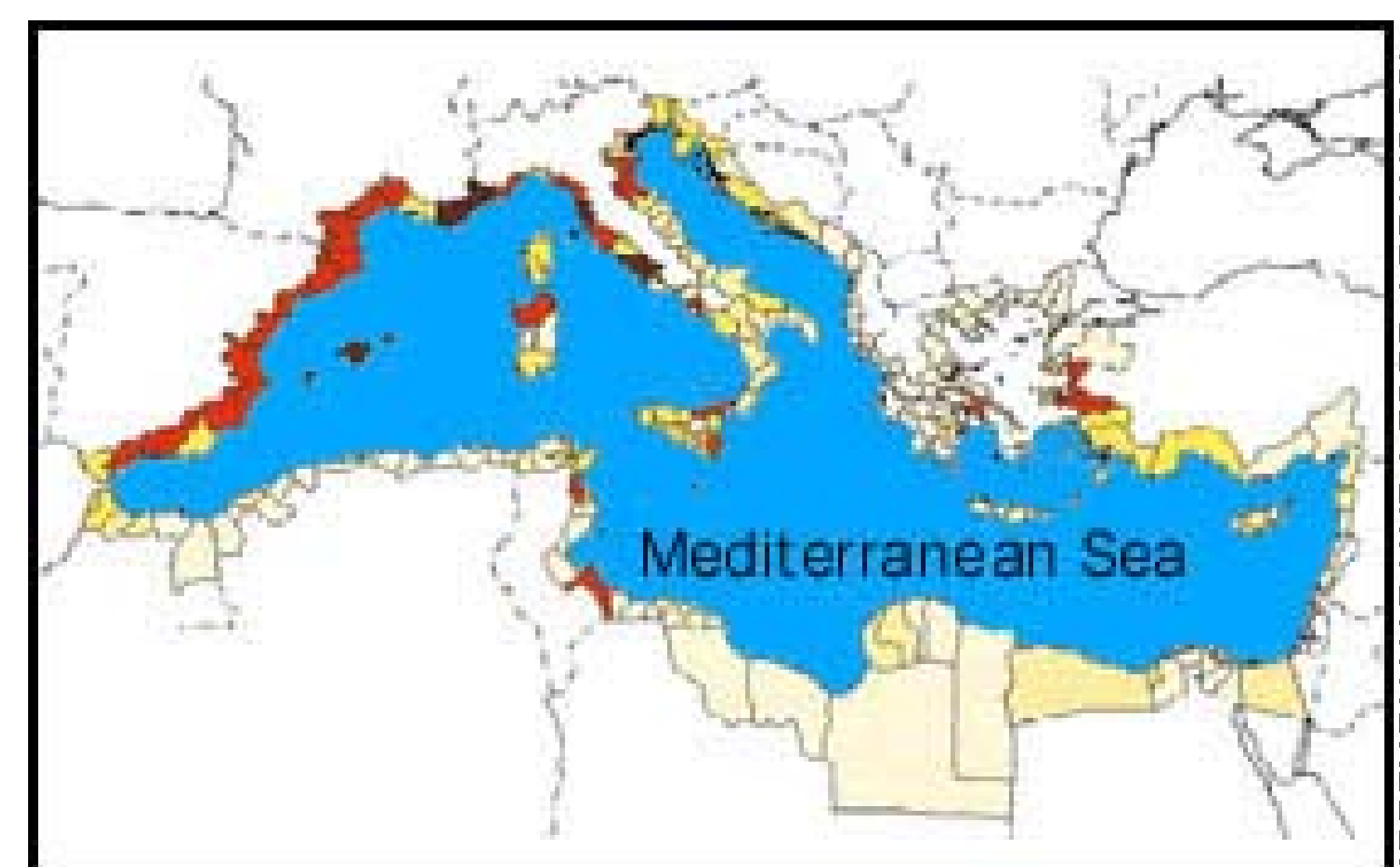
**RESILIENCE:** community's capacity to cope with and recover from impacts of natural hazards.

$$\text{Risk} = (\text{Hazard} \times \text{Vulnerability}) - \text{Resilience}$$



# VULNERABILITY OF COASTAL AREAS

- **Very densely-populated coastline:** 160 million inhabitants sharing 46,000 km of coastline (**3.5 inhabitants per m of coastline**).
- **World's leading holiday destination**, receiving up 30% of global tourism and an average of 135 million visitors annually; this is predicted to increase to 235-350 million tourists by year 2025 (European Environmental Agency - EEA).

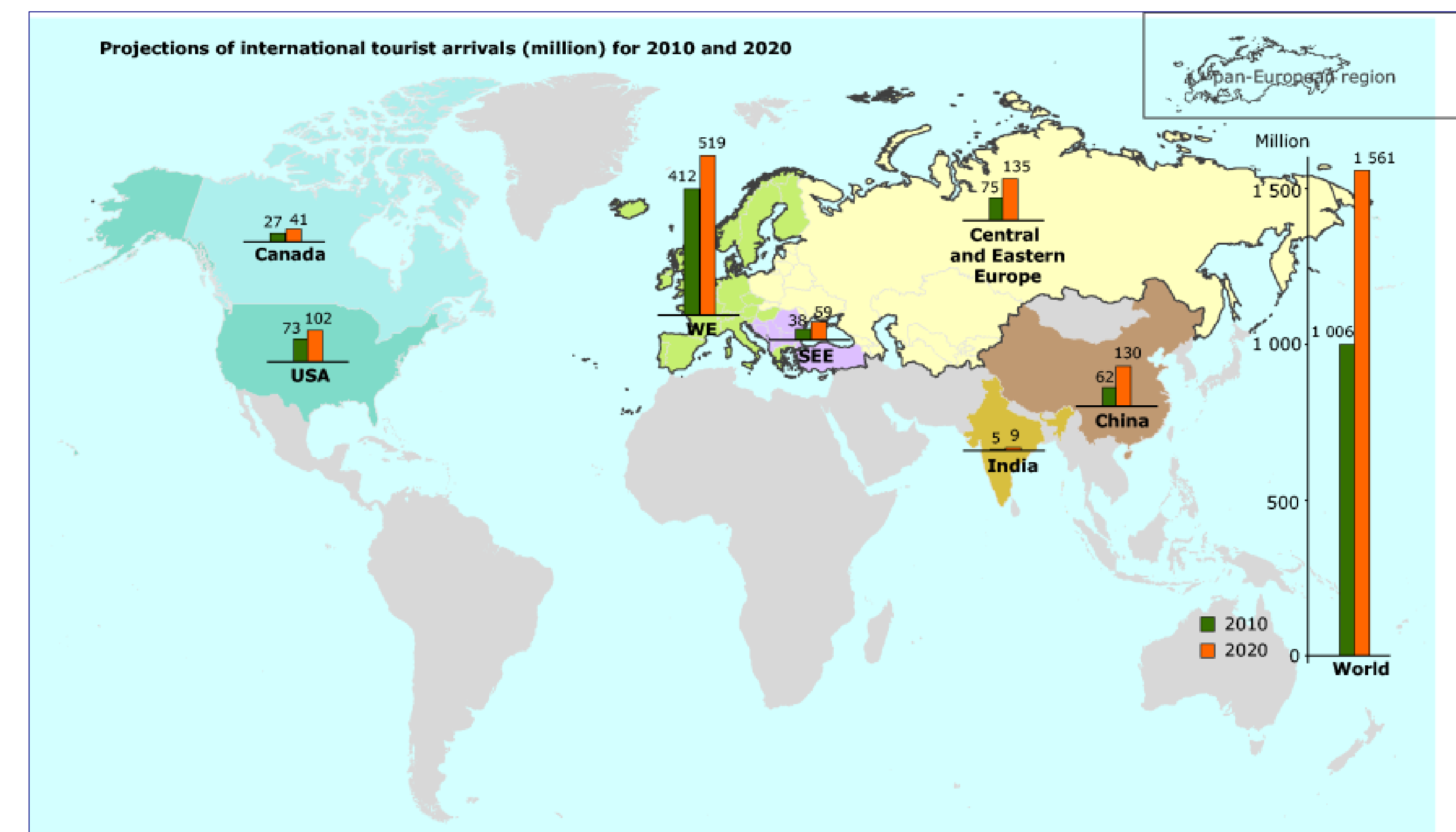


Number of tourists (thousands)



“By 2025, the annual crowd will soar to anywhere from 235 to 350 million tourists, according to the EEA.”

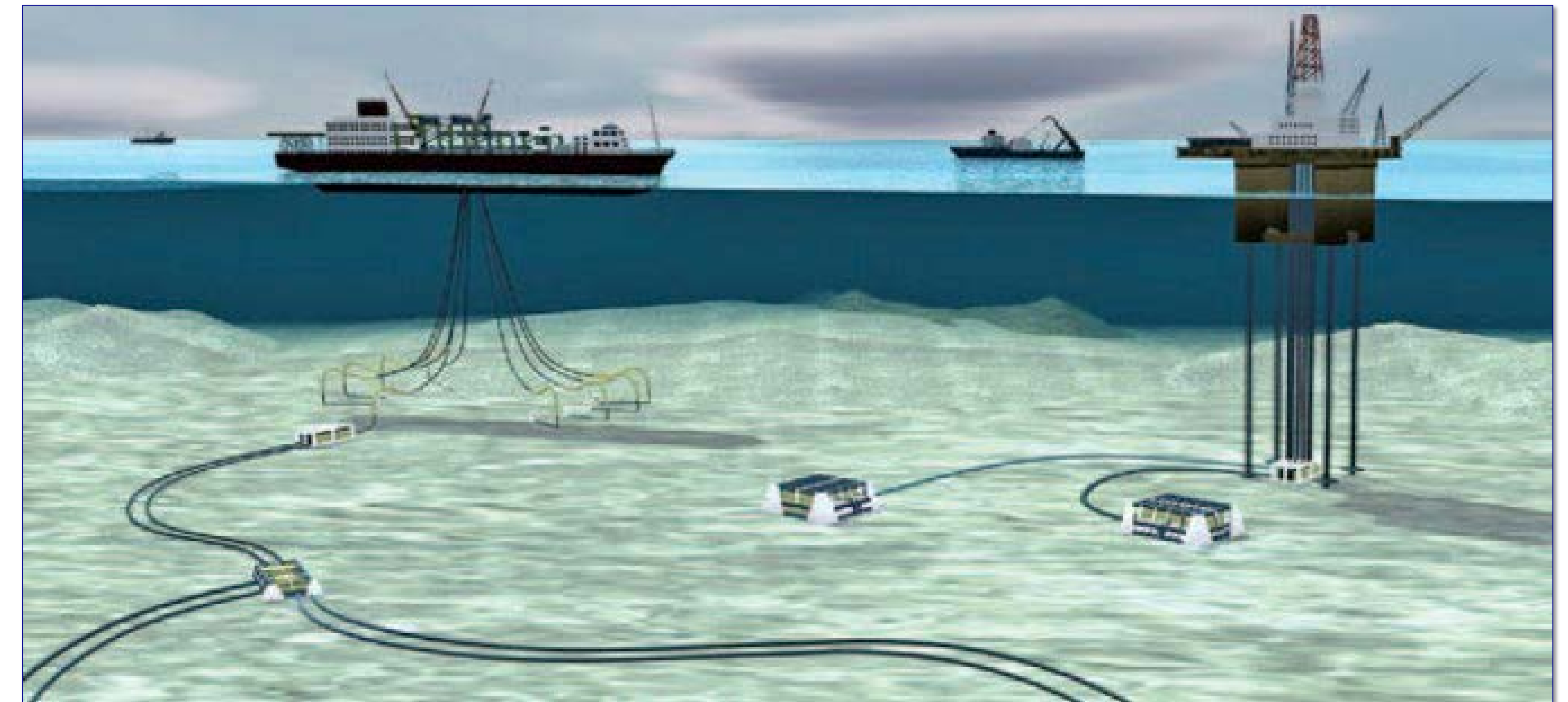
Mediterranean tourism takes its toll. By Environmental News Network (ENN) March 14, 2000;  
<http://archives.cnn.com/2000/NATURE/03/14/mediterranean.enn/index.html>



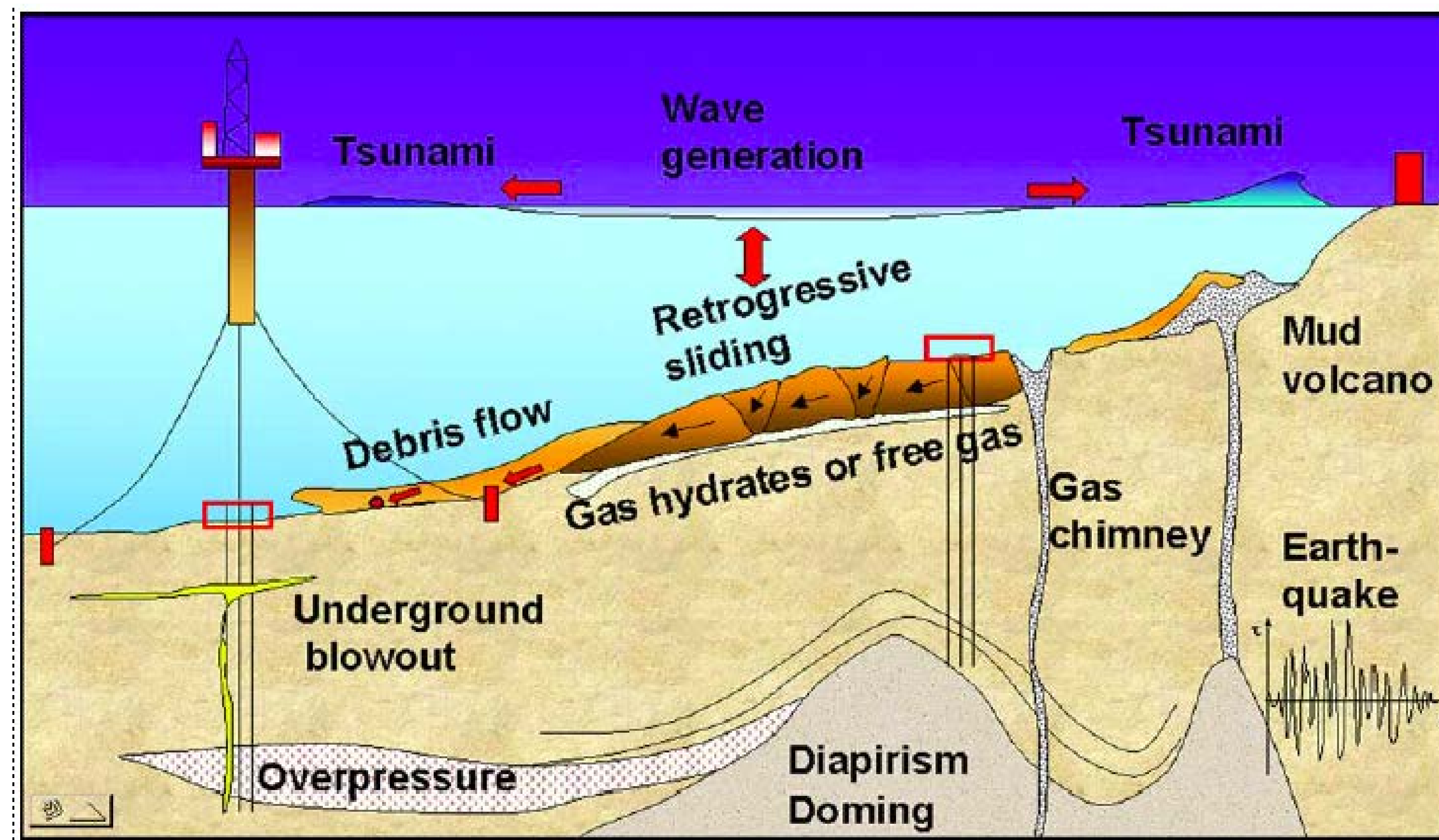
EEA web site <http://www.eea.europa.eu>  
 Copyright EEA, Copenhagen.



# VULNERABILITY OF OFFSHORE



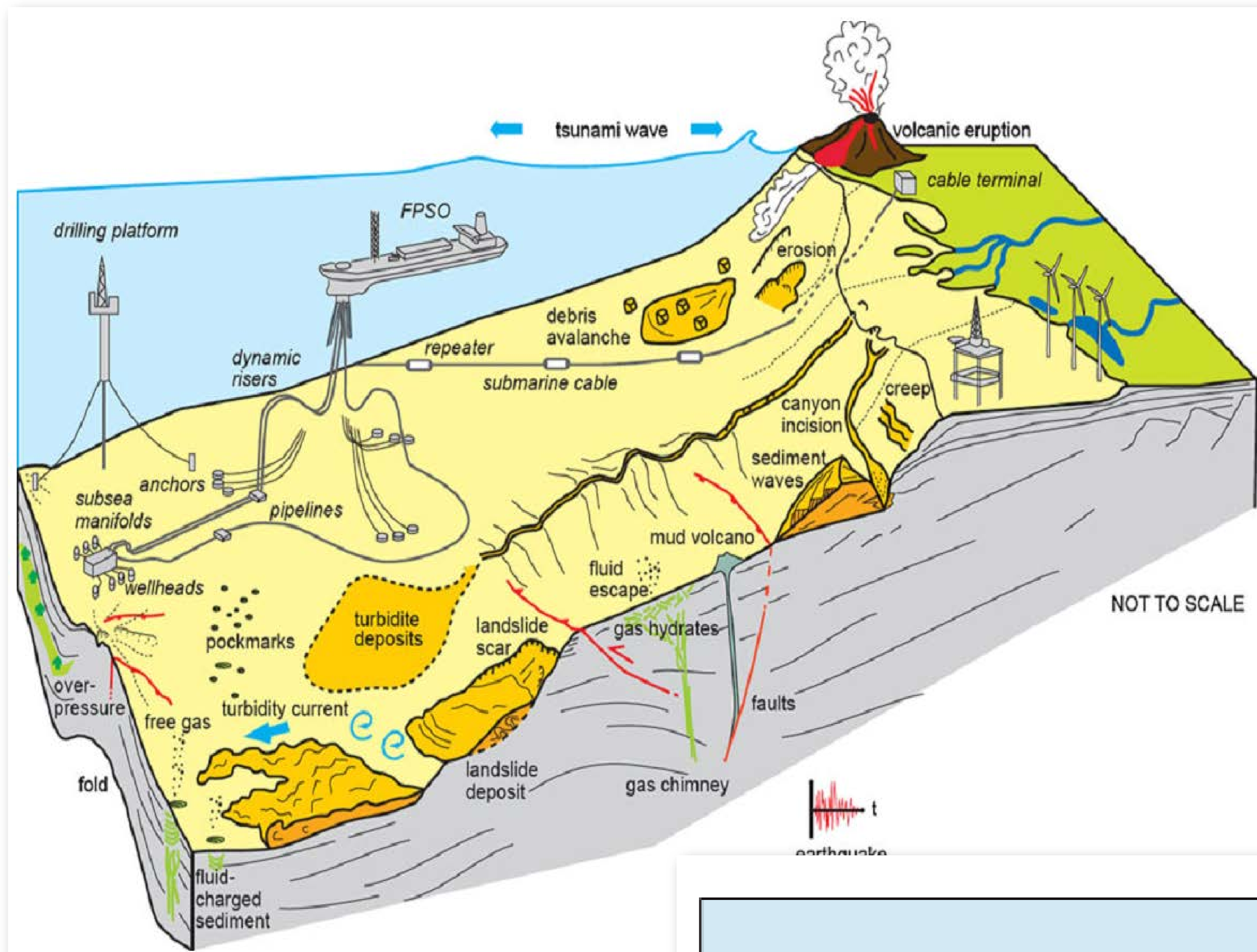
ISOVER Subsea Products SeaLine



Increasing  
economic use of  
the seafloor for  
energy,  
communications  
and mineral  
resources)

Courtesy NGI, Oslo. After Camerlenghi et al., 2007, *Scientific Drilling*



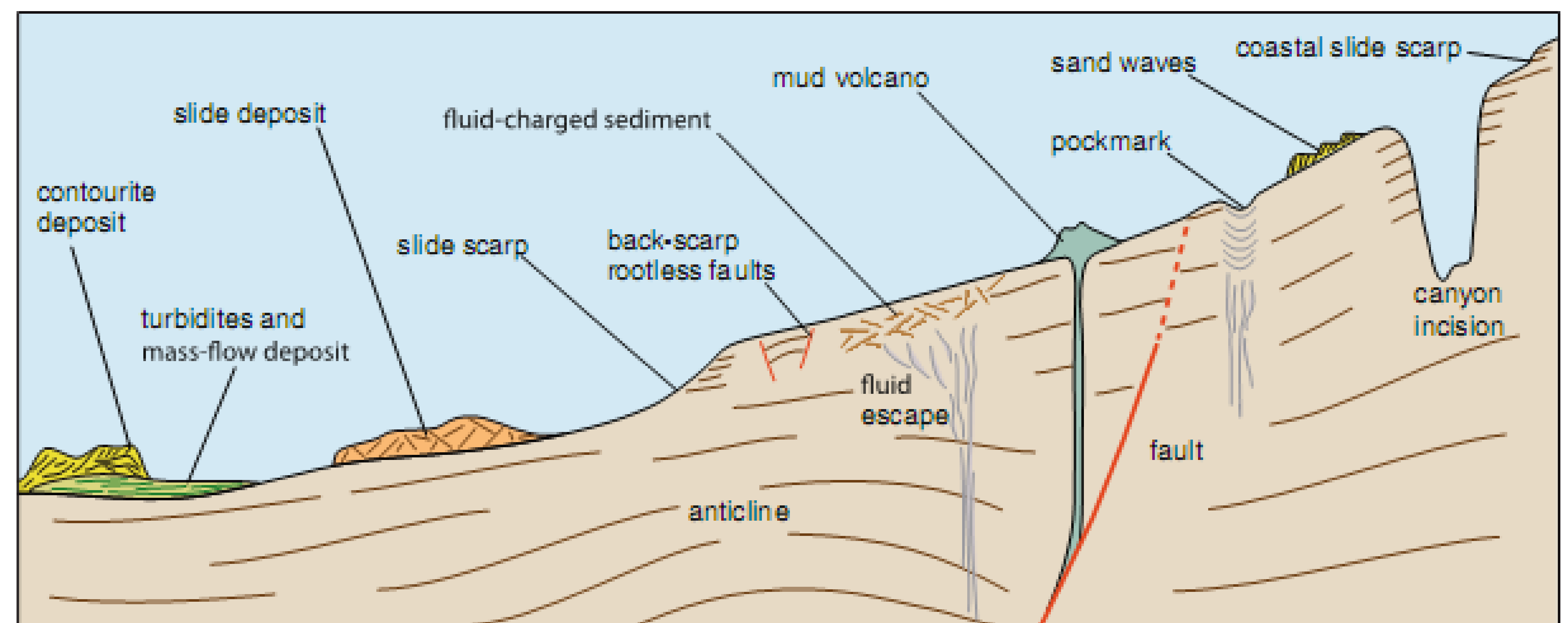


Chiocci et al. 2011

Everything that's active  
at sea bottom and below  
can create an hazard....

## Geomorphic features as geohazard indicators:

scars and deposits, canyon  
headscarps and steep  
erosional flanks, fault-related  
seafloor unevenness, mud  
volcanoes, pock-marks, gravity  
flow deposits, erosional scours  
and bed-forms indicating  
sediment mobility at diverse  
temporal/spatial scale....

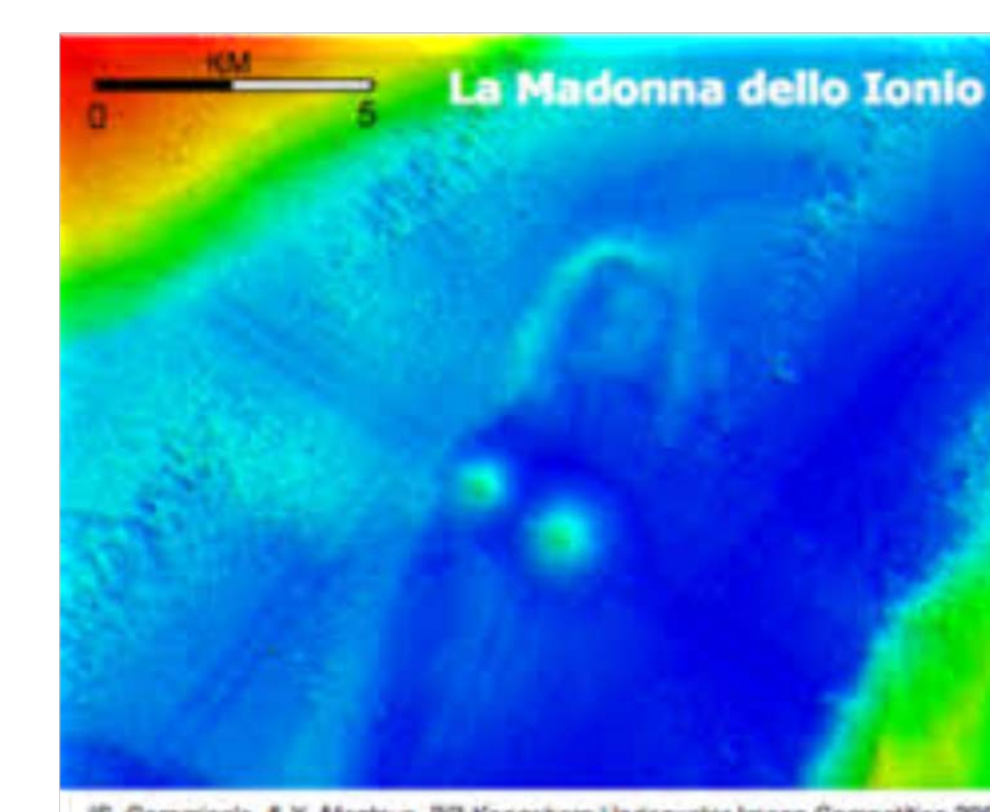
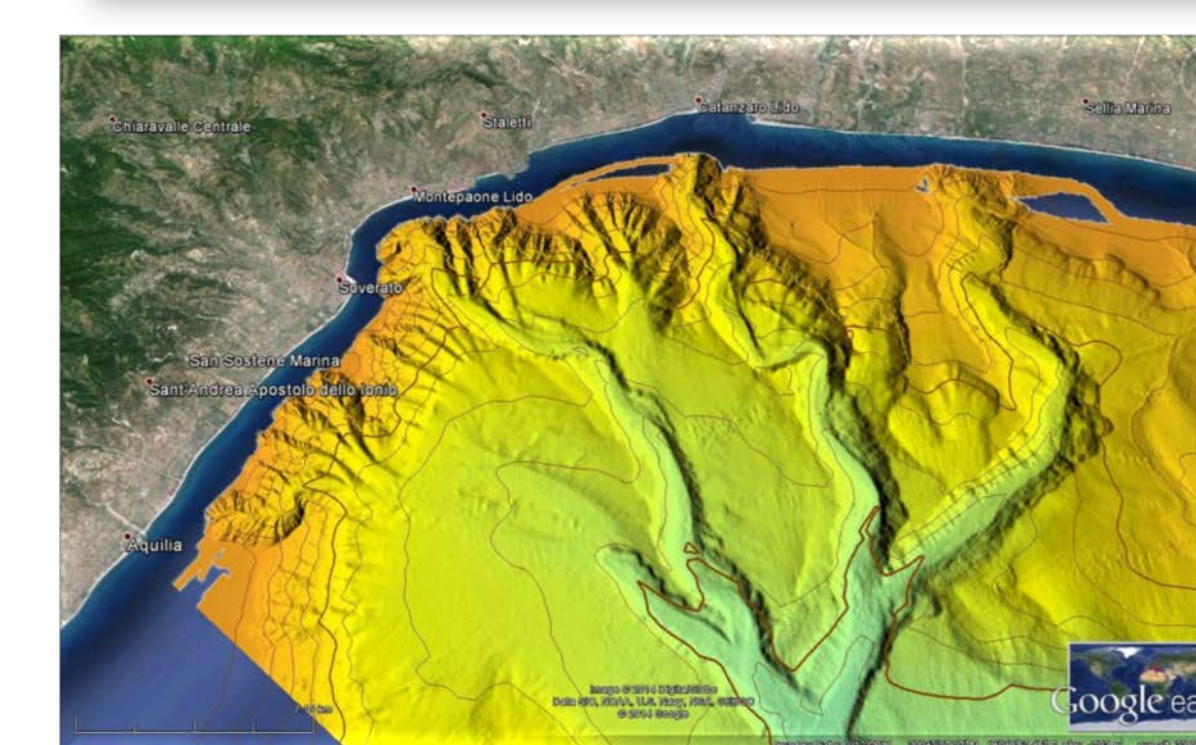
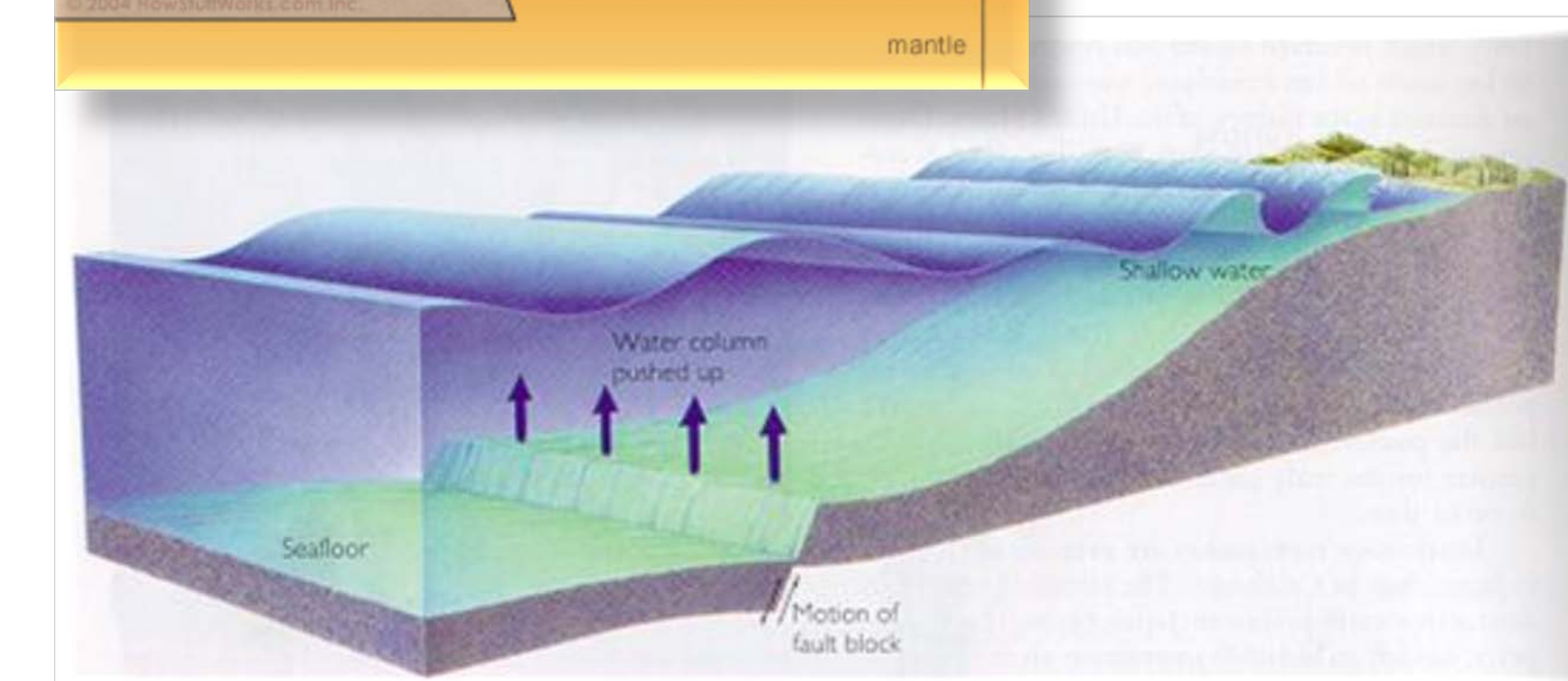
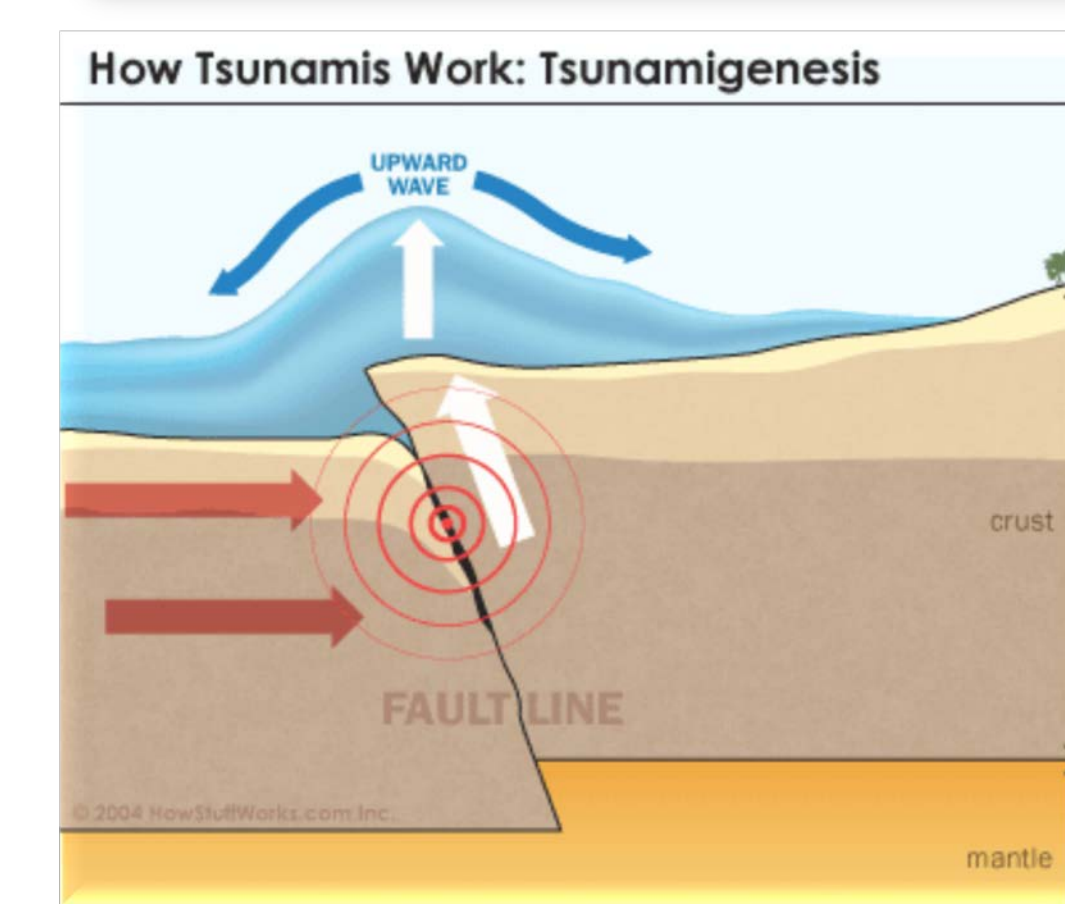
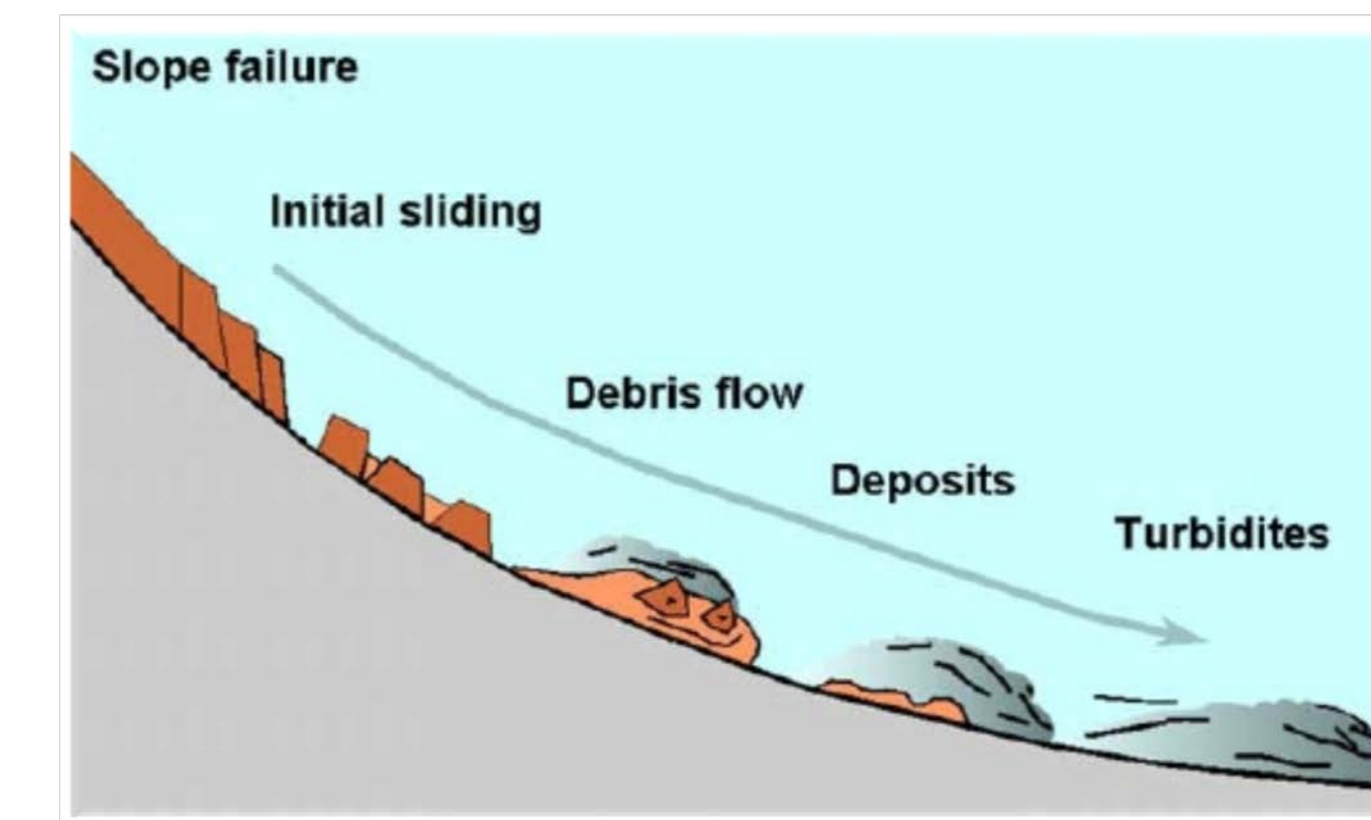


Chiocci and Ridente 2011



# NATURAL MARINE GEOHAZARDS

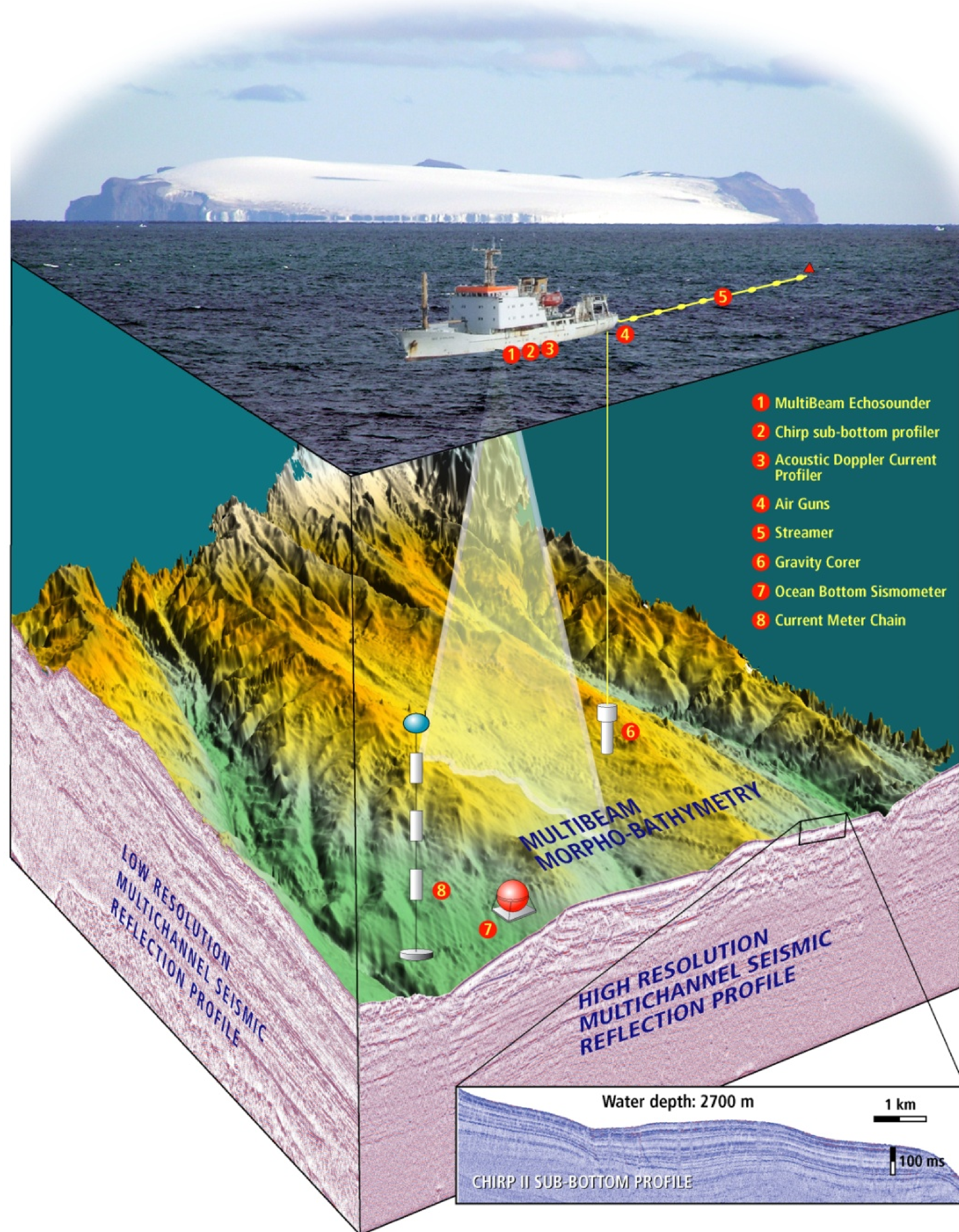
1. **SUBMARINE LANDSLIDES** including **VOLCANIC ISLAND ERUPTIONS** and **FLANK COLLAPSE**: sediment mass movements (turbidity currents, debris flows, slumps, retrogressive canyon headwalls)
2. **SEISMOGENIC FAULTS** (earthquakes originated below the sea floor)
3. **TSUNAMIS** (originated by earthquakes and/or landslides)
4. **SUBMARINE CANYONS** (coastal erosion)
5. **FLUID EMISSIONS** ( $\text{CH}_4$ ,  $\text{CO}_2$  mainly)
6. **METEORITE IMPACTS** in the oceans





# INTEGRATED ACOUSTIC METHODS

R/V OGS Explora

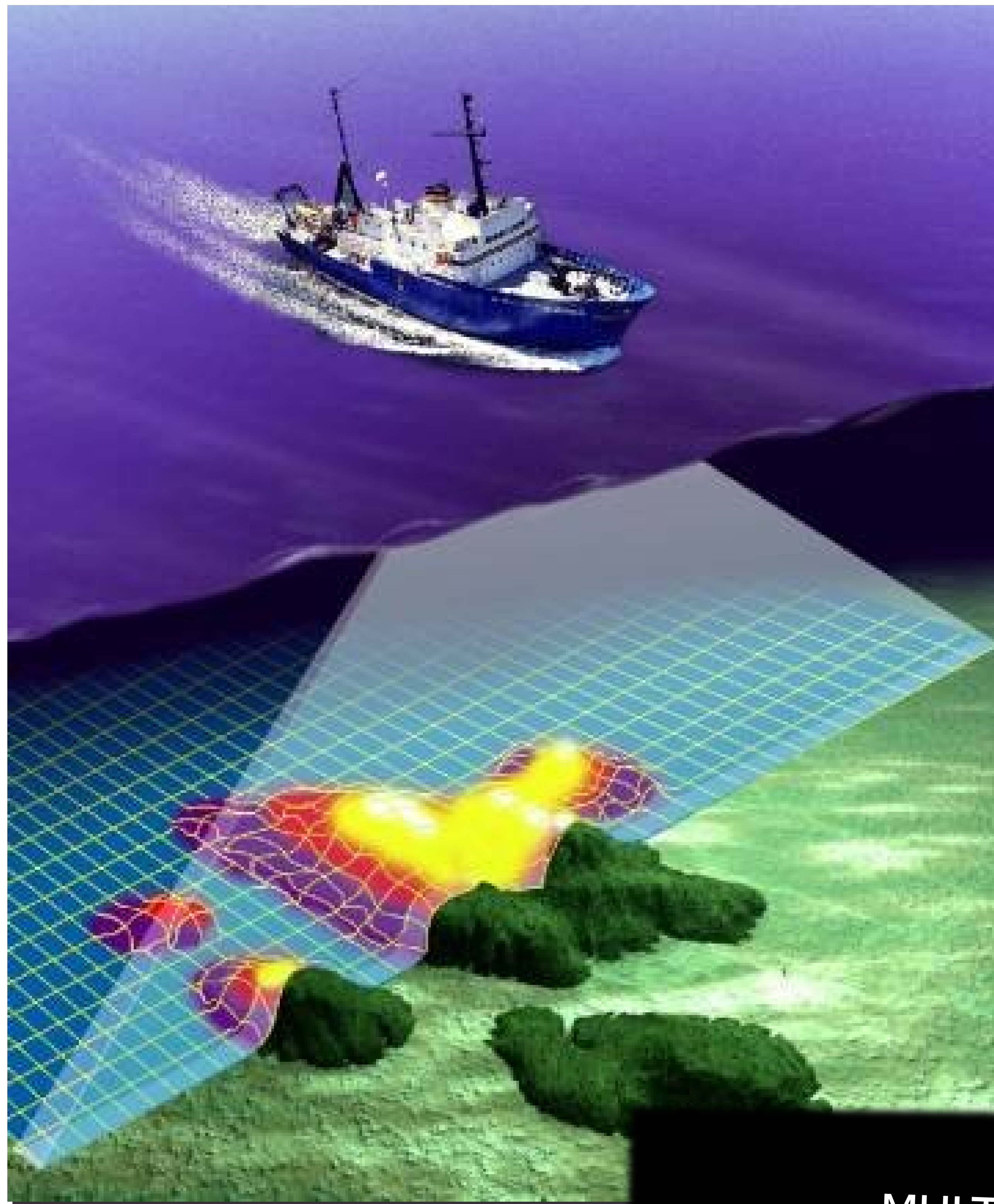


Integrating geophysical data at **different resolution** enable to investigate the **geological features** present on the seafloor and to depths of kilometers.

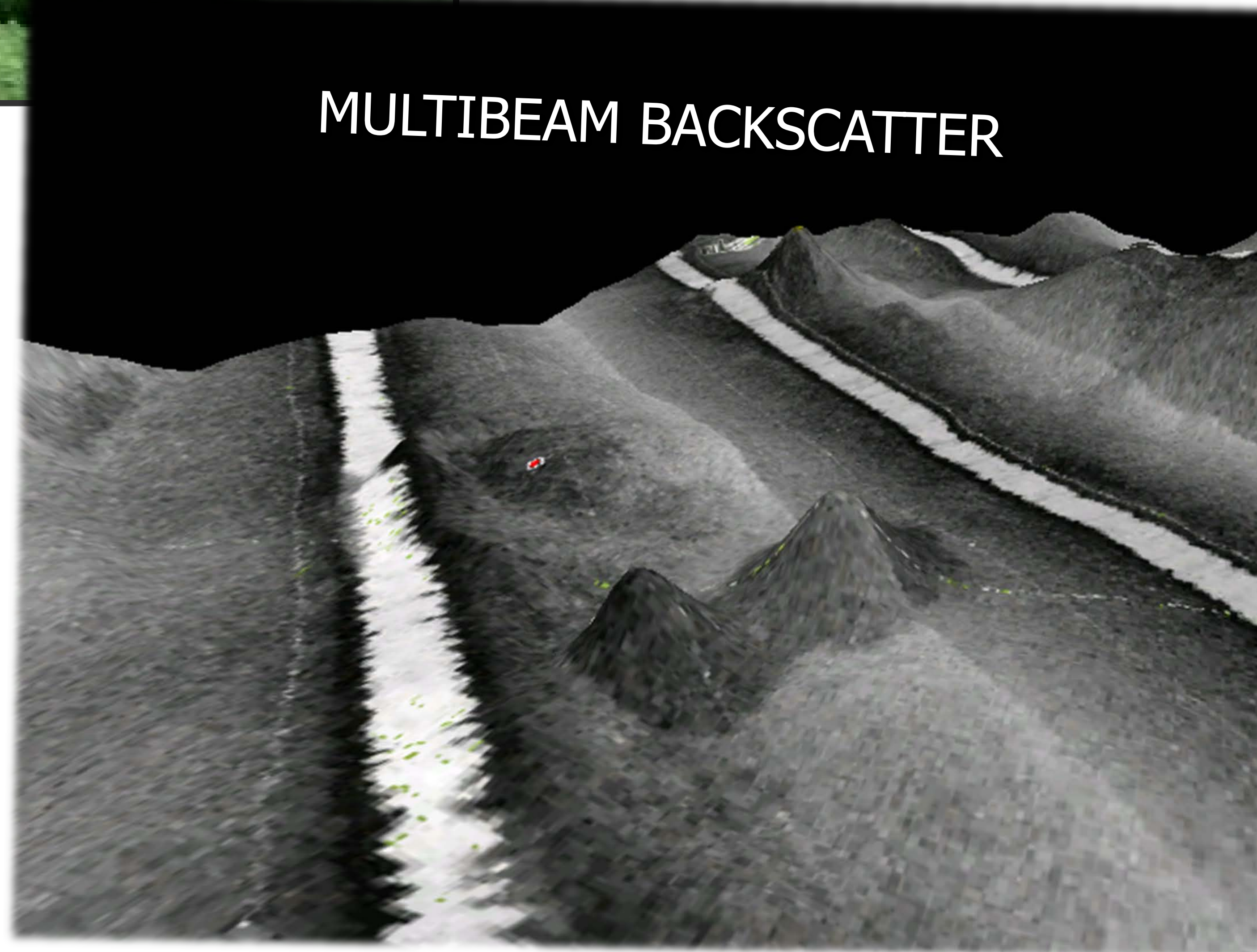
This allows to gain a **good understanding of the geological processes that are active** on the seafloor and beneath



# SEAFLOOR MAPPING



MULTIBEAM BACKSCATTER



Seafloor mapping is the first step in making a census of the **geohazard-bearing features** present in a given offshore area. It often provides the only tool for a comprehensive **seafloor geohazard assessment over large areas** that are scarcely groundtruthed by acoustic prospection and seafloor sampling.

by Chiocci et al 2011



# REMOTE AND AUTONOMOUS VEHICLES

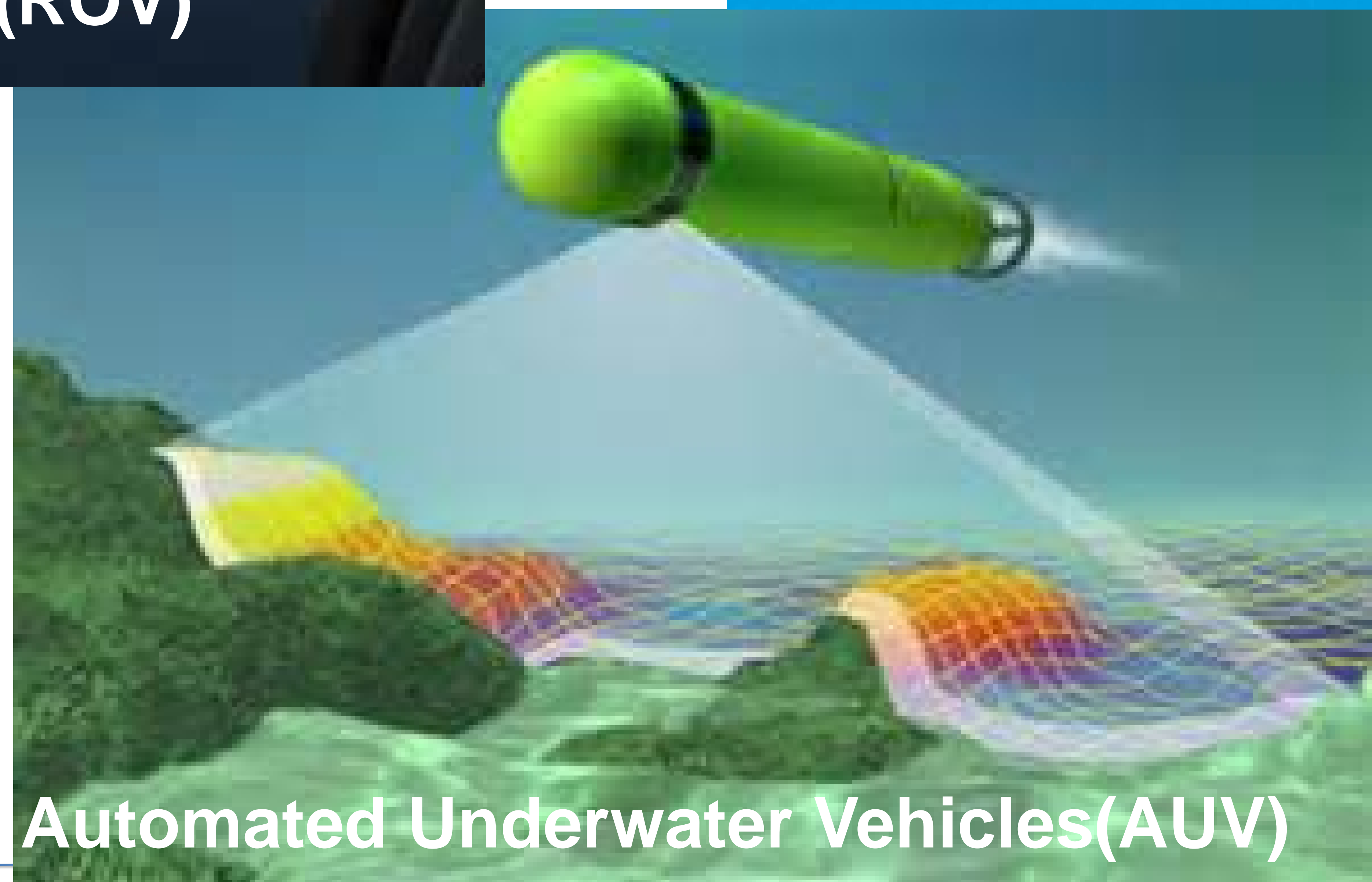


Remote Operated Vehicles (ROV)



(ROV)

- 1) obtain **very high-resolution** imaging of the seafloor (up to cm)
- 2) **access remote** settings (i.e. canyons)



Automated Underwater Vehicles(AUV)



# THE IONIAN MARGIN A NATURAL LABORATORY FOR MARINE GEOHAZARDS

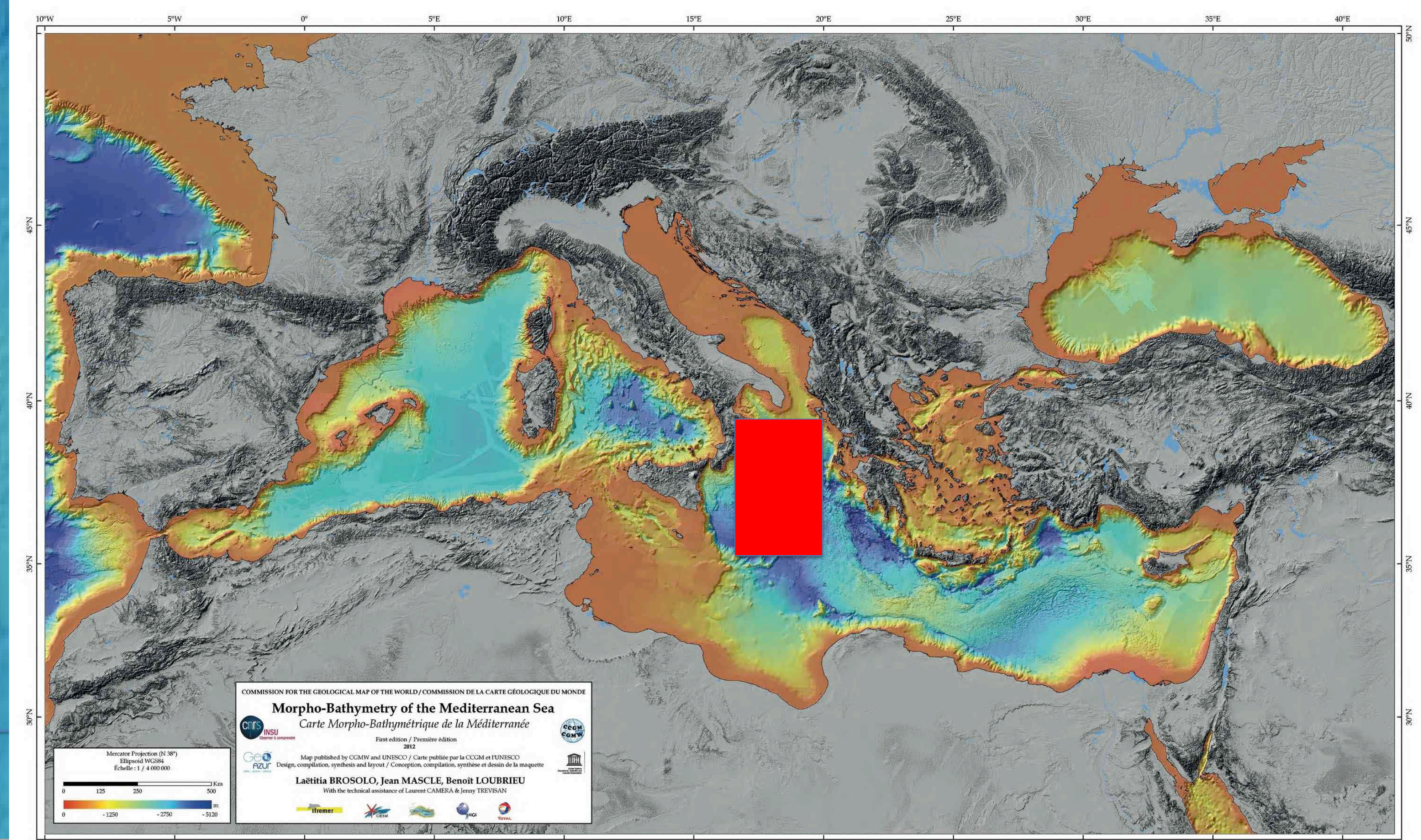
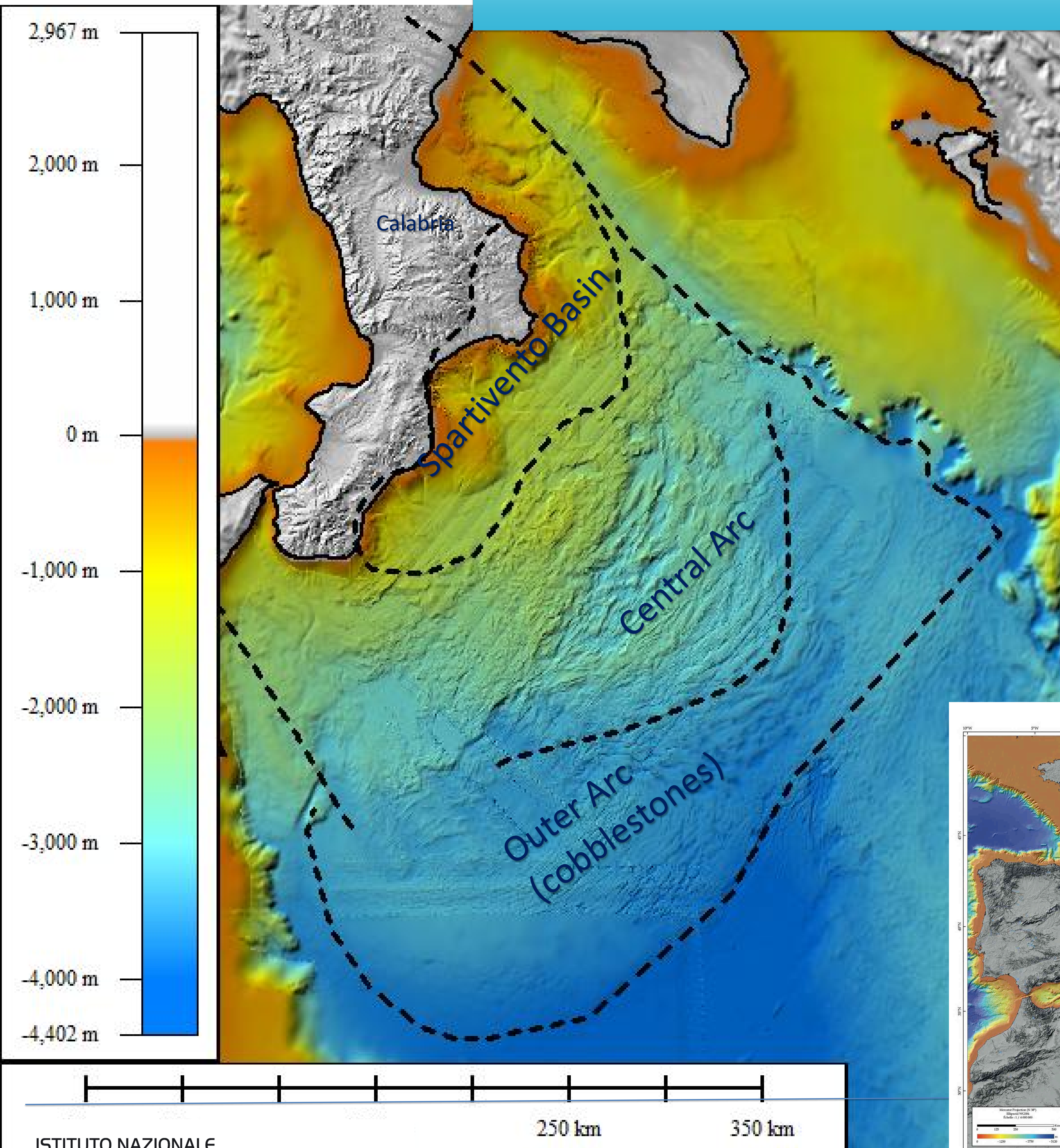
## TECTONIC FRAMEWORK

**Active** continental margin  
(convergent) → **Subduction**

2 main processes related:

→ Frontal **compression** and  
forearc **extension** during the SE  
advance of the Calabrian  
accretionary prism since late  
Miocene (15 Ma);

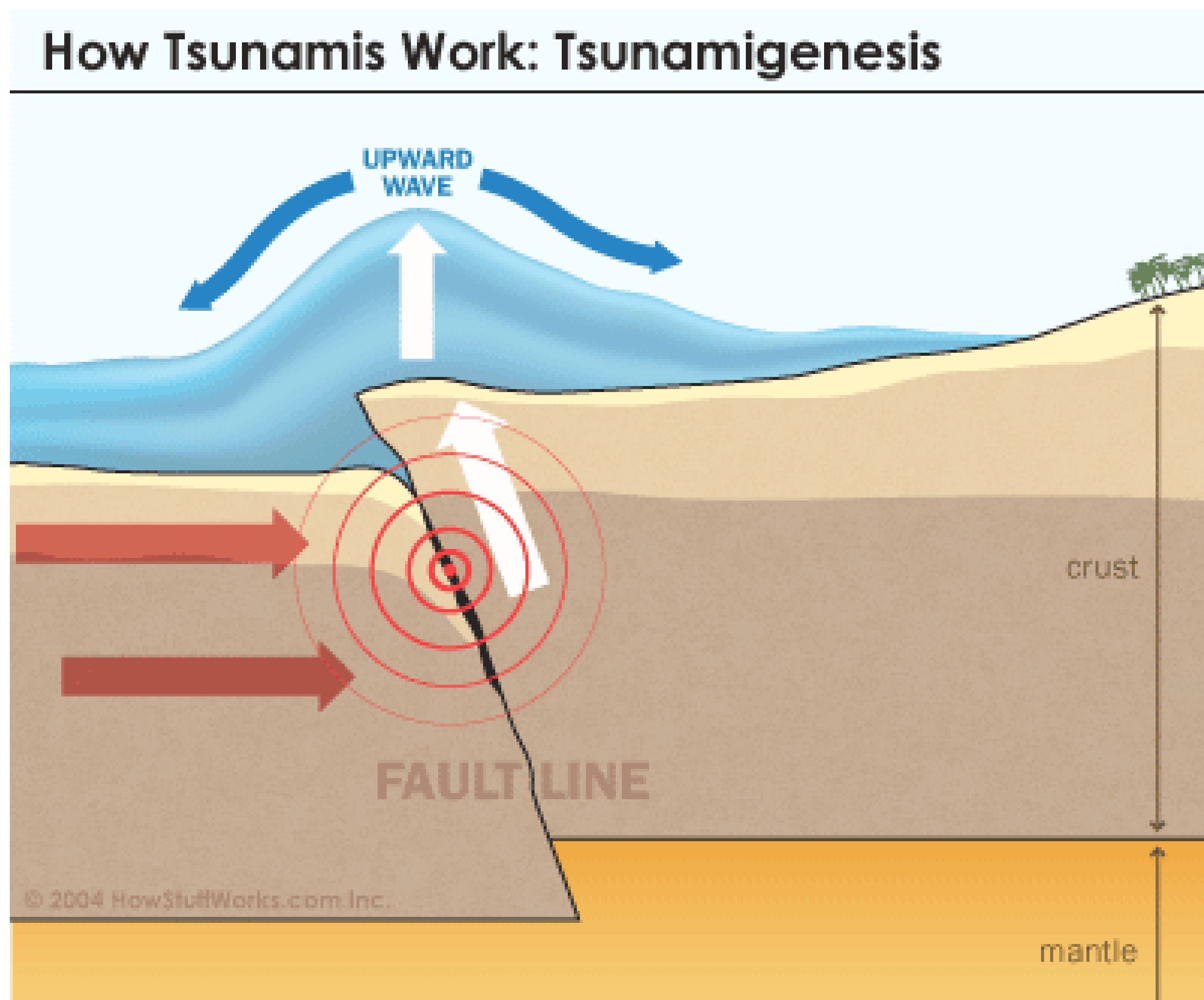
→ A **rapid uplift** (up to 1 mm/yr) of  
onshore and shallow shelf areas  
since mid-Pleistocene (0,5Ma)







# 1) Faults and Earthquakes



**active Fault:** is a fault which had displacement (or generated earthquakes) during the geologically recent period (20ka)

**capable Fault :** an active fault able to generate superficial displacement of the seabottom in recent period (20ka)

**seismogenic Fault :** an active fault capable of generating earthquakes in the upper lithosphere

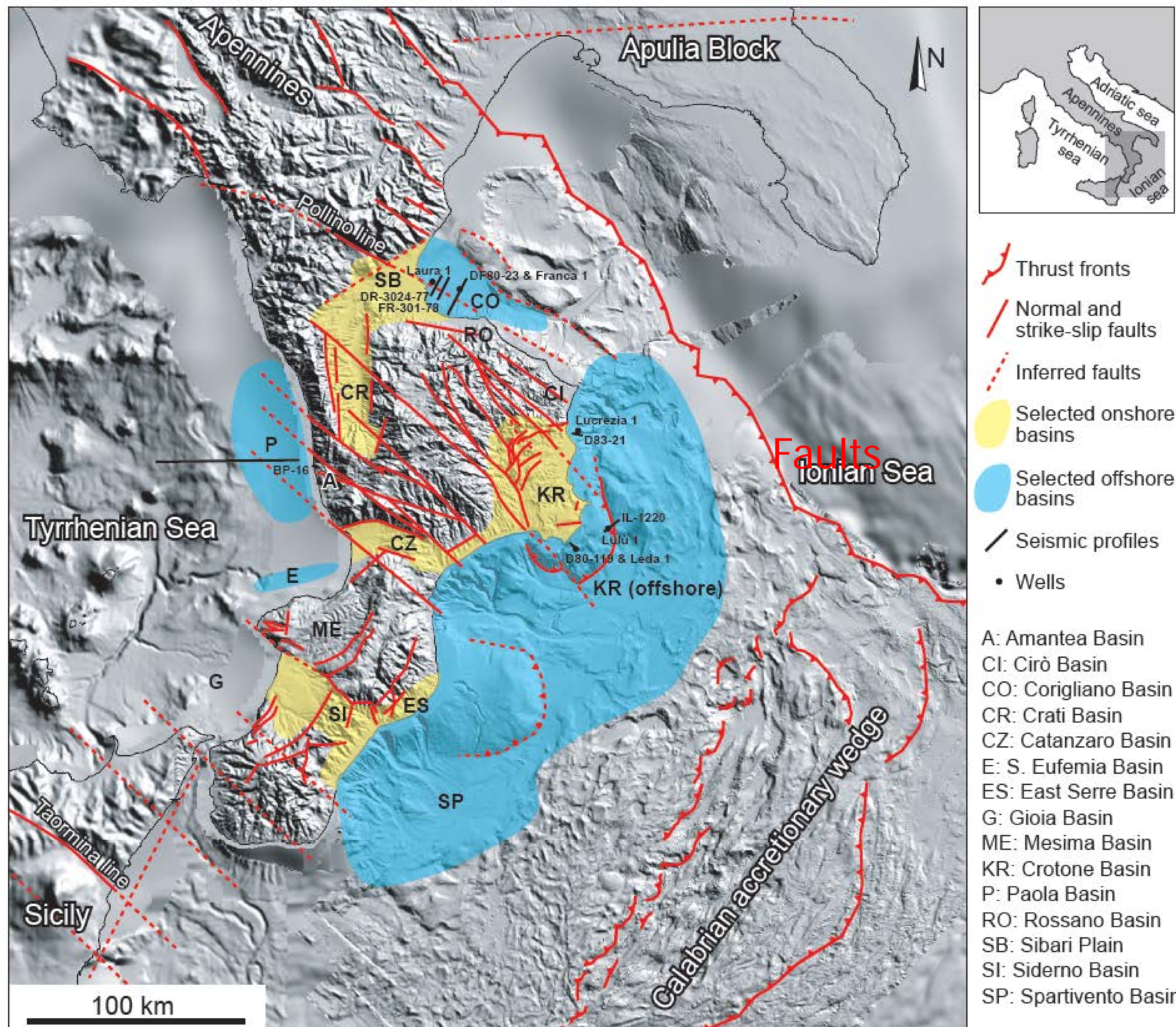
**aseismic Fault :** faglia non attiva in tempi recenti con comportamento lento e continuo (crosta inferiore)

**blind Fault:** some faults do not break through to the sea bottom anywhere along their length (

It is possible to **identify** the faults that have displaced the seabottom (using acoustic methods), to **map** them and thus **assess their hazard** but it is NOT possible predict if and when they will be active again → **earthquakes are not predictable!**



# 'Faults' in the Calabrian margins



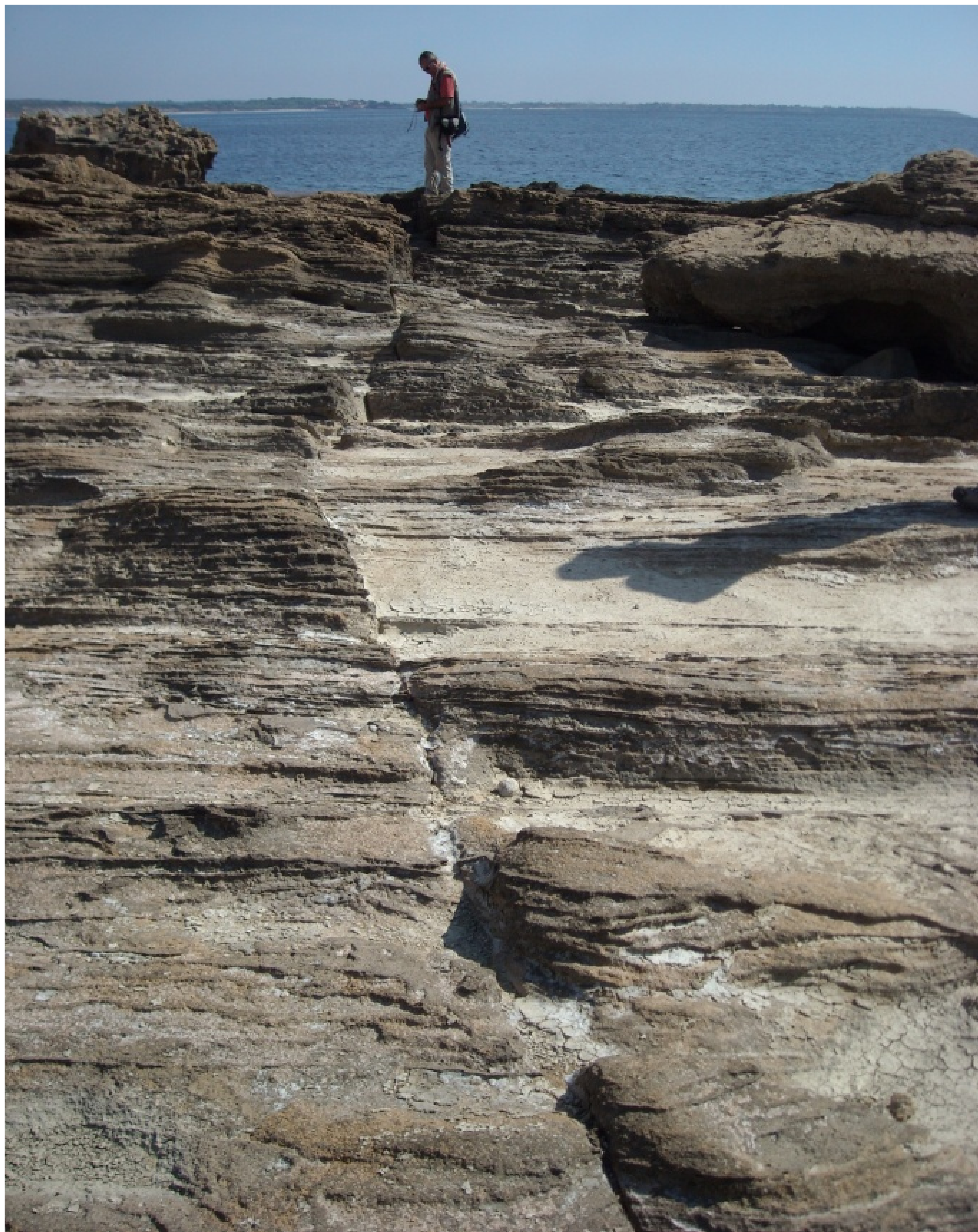
1) Fault systems do not stop at the coastline!!

2) Mapping fault systems allows to assess their distribution and characterise their occurrence (lengths, type, displacement....)

Zecchin et al. 2015



# Onshore....



Examples of joints oriented N100-120° and dissecting the deposits of the Le Castella marine terrace (Calabria, Italy)





# Offshore.....

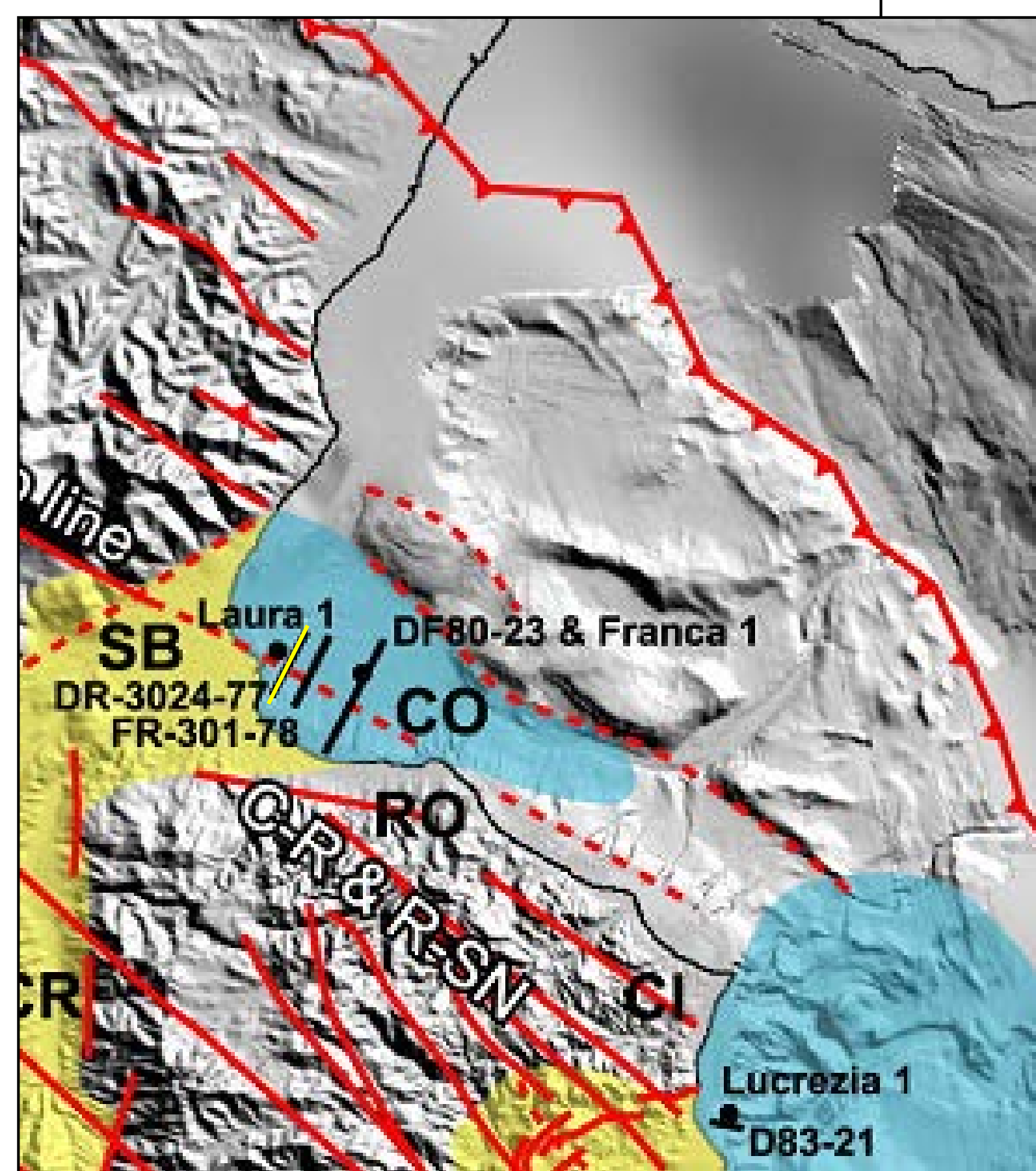
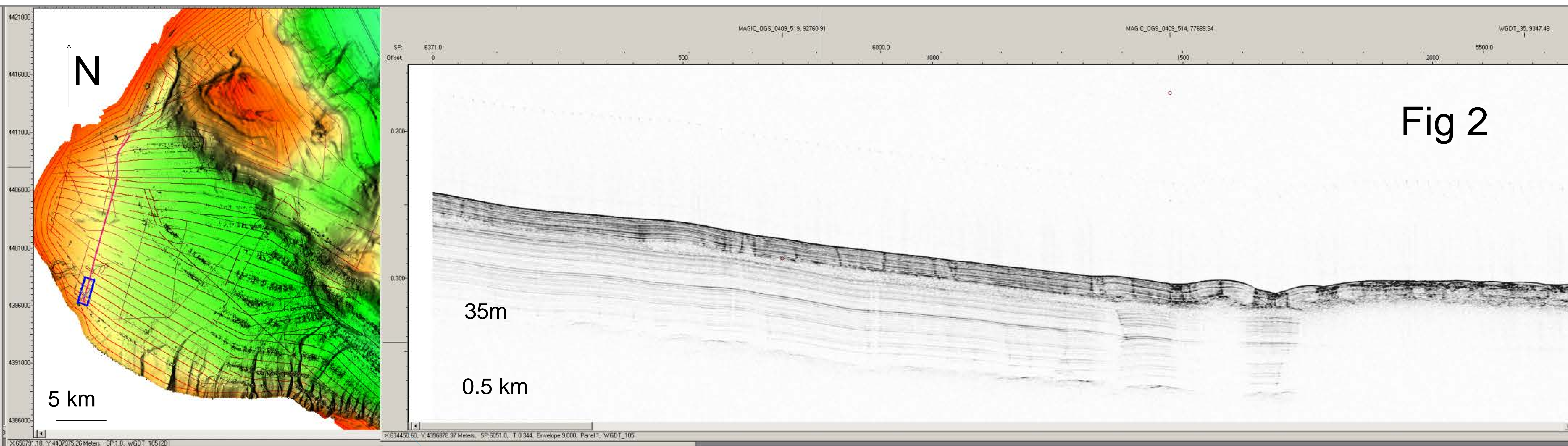
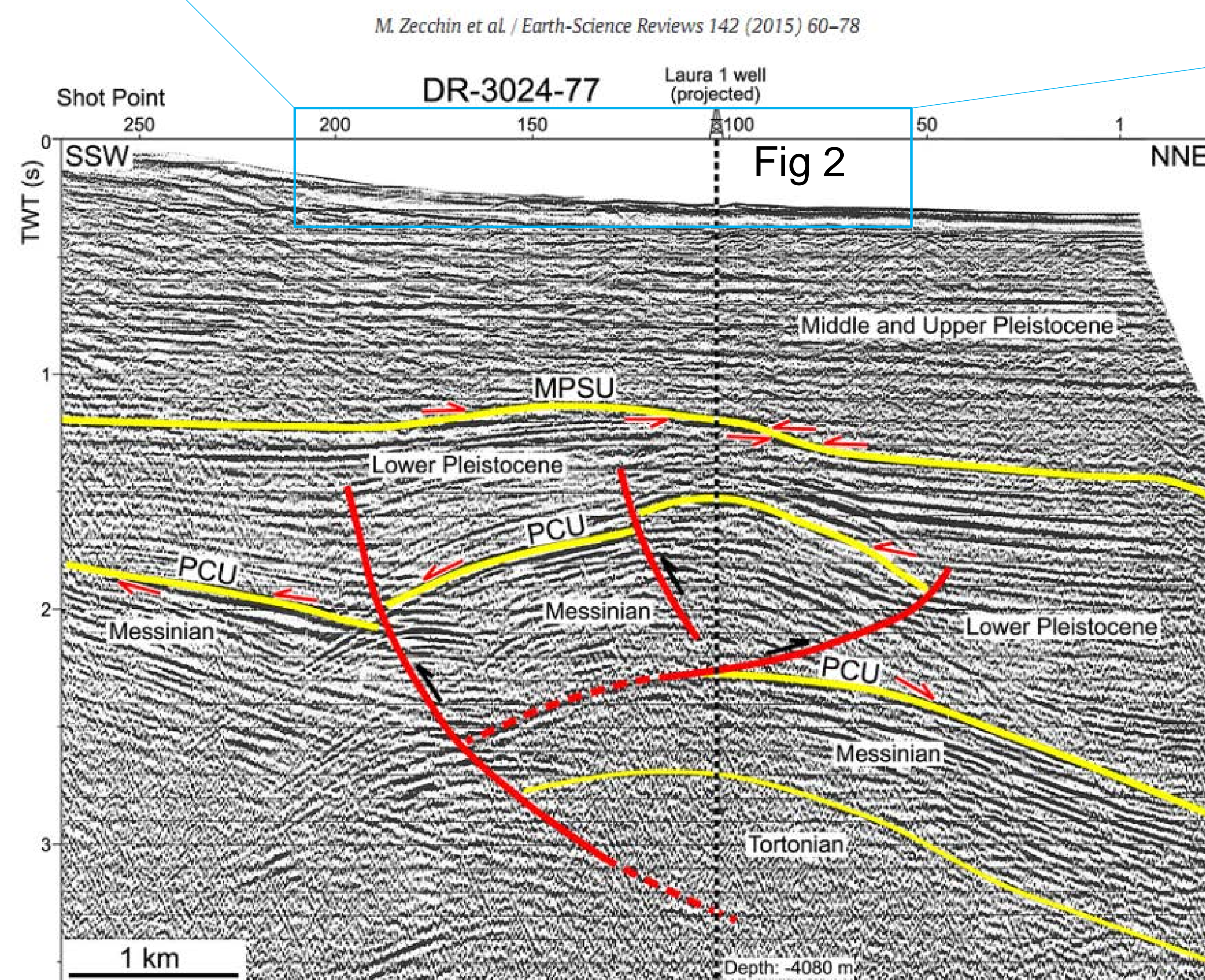


Fig 1



...things are more complicated!

possible problems:

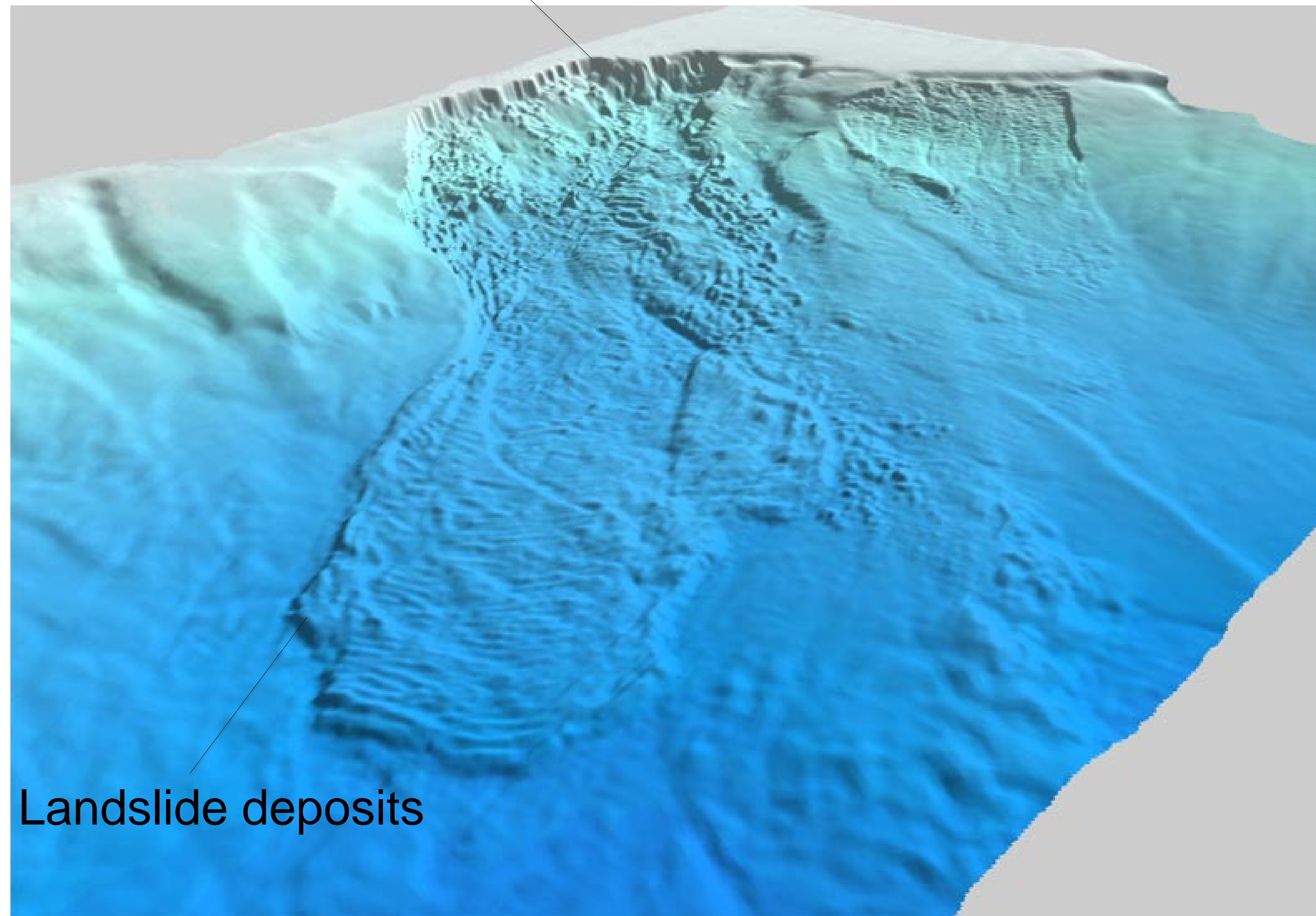
- 1) Do we have the good **data resolution**?
- 2) Are we investigating **the right portion of seabed**?





## 2) Submarine landslides

Landslide scars



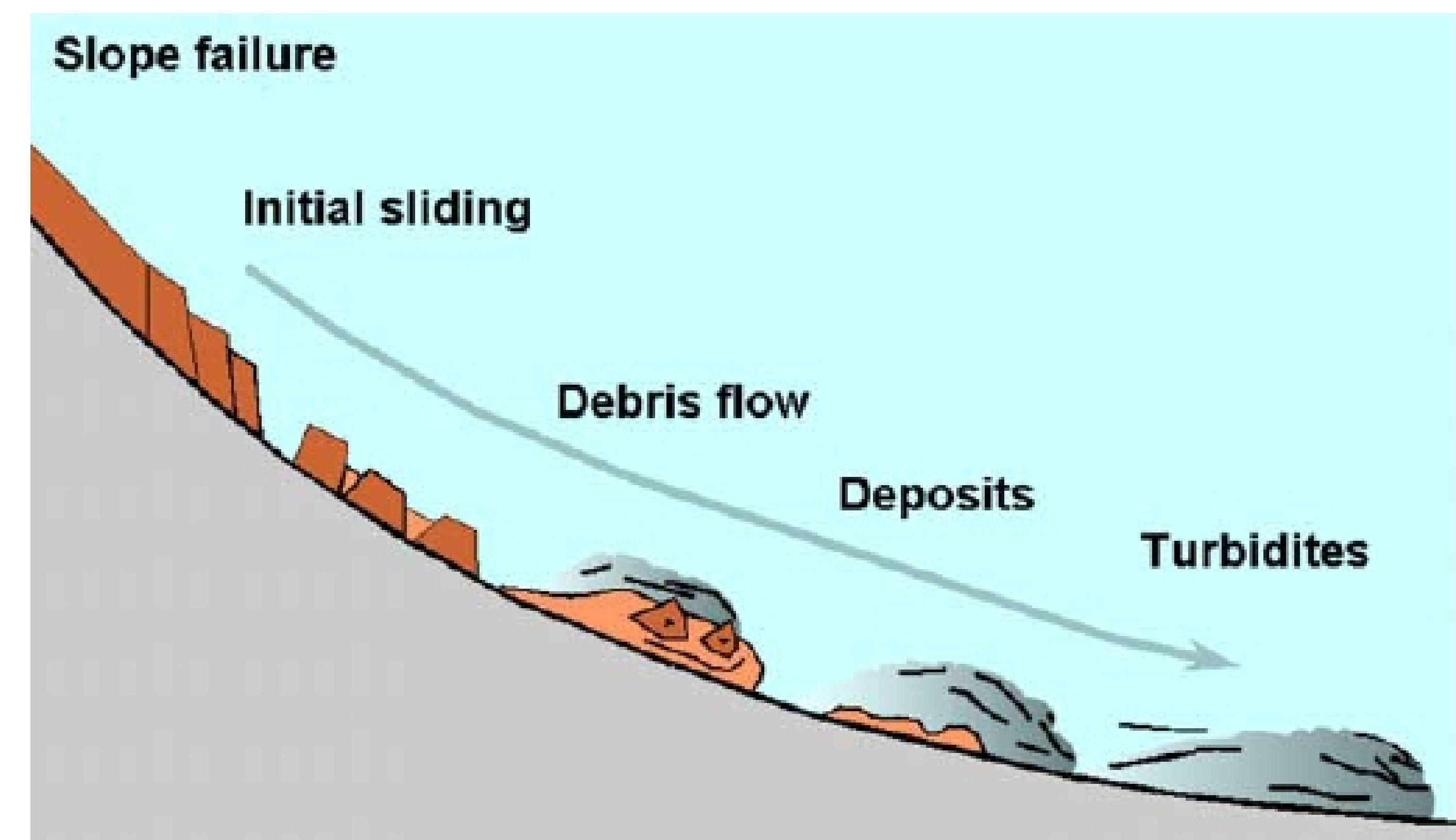
Landslide deposits

are able to **transport sediments** across the continental shelf and into the deep ocean.

A submarine landslide can be initiated by different **trigger mechanisms** such as:

- i) presence of weak geological layers,
- ii) overpressure due to rapid accumulation of sedimentary deposits,
- iii) earthquakes,
- iv) storm wave loading and hurricanes,
- v) gas hydrates dissociation,
- vi) groundwater seepage and high pore water pressure,
- vii) glacial loading,
- viii) volcanic island growth,
- ix) oversteepening.

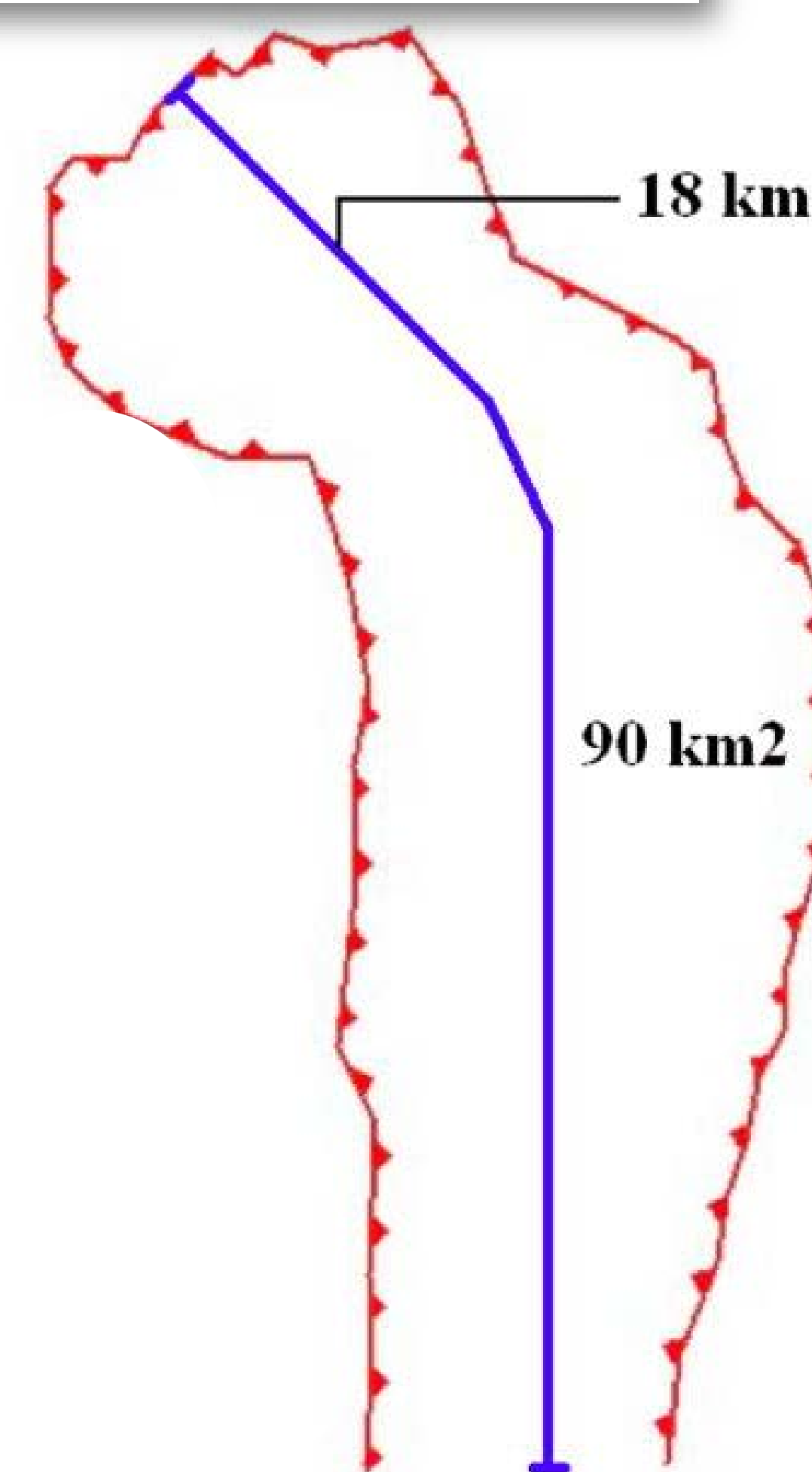
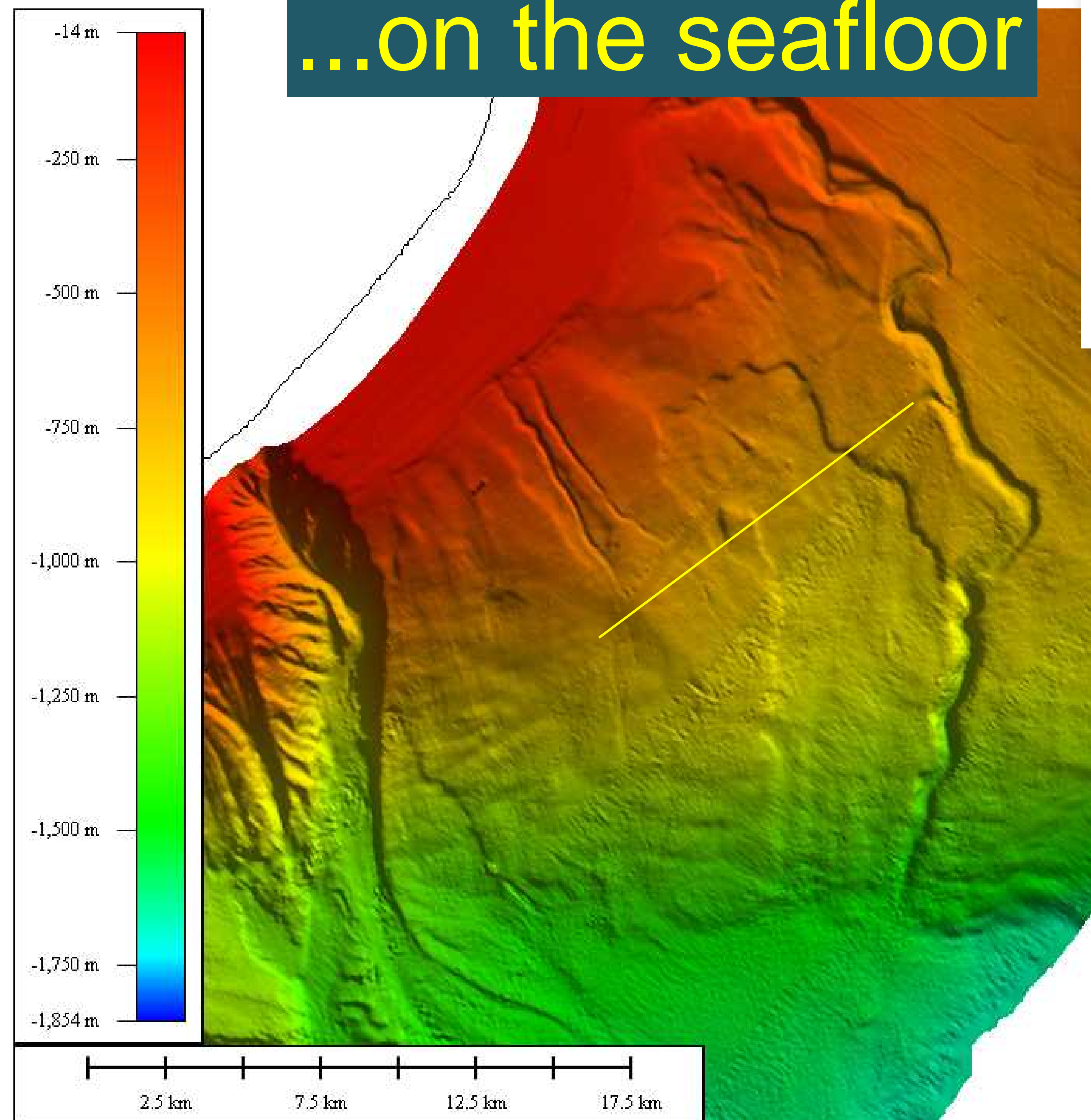
Huge landslides, mobilizing **hundreds to thousands of km<sup>3</sup>** of sediment and rock, they take place in a variety of different geological settings including planes as low as 1° and can **cause significant damage** to life (human and/or marine ecosystems) as well as coastal and deep sea infrastructures



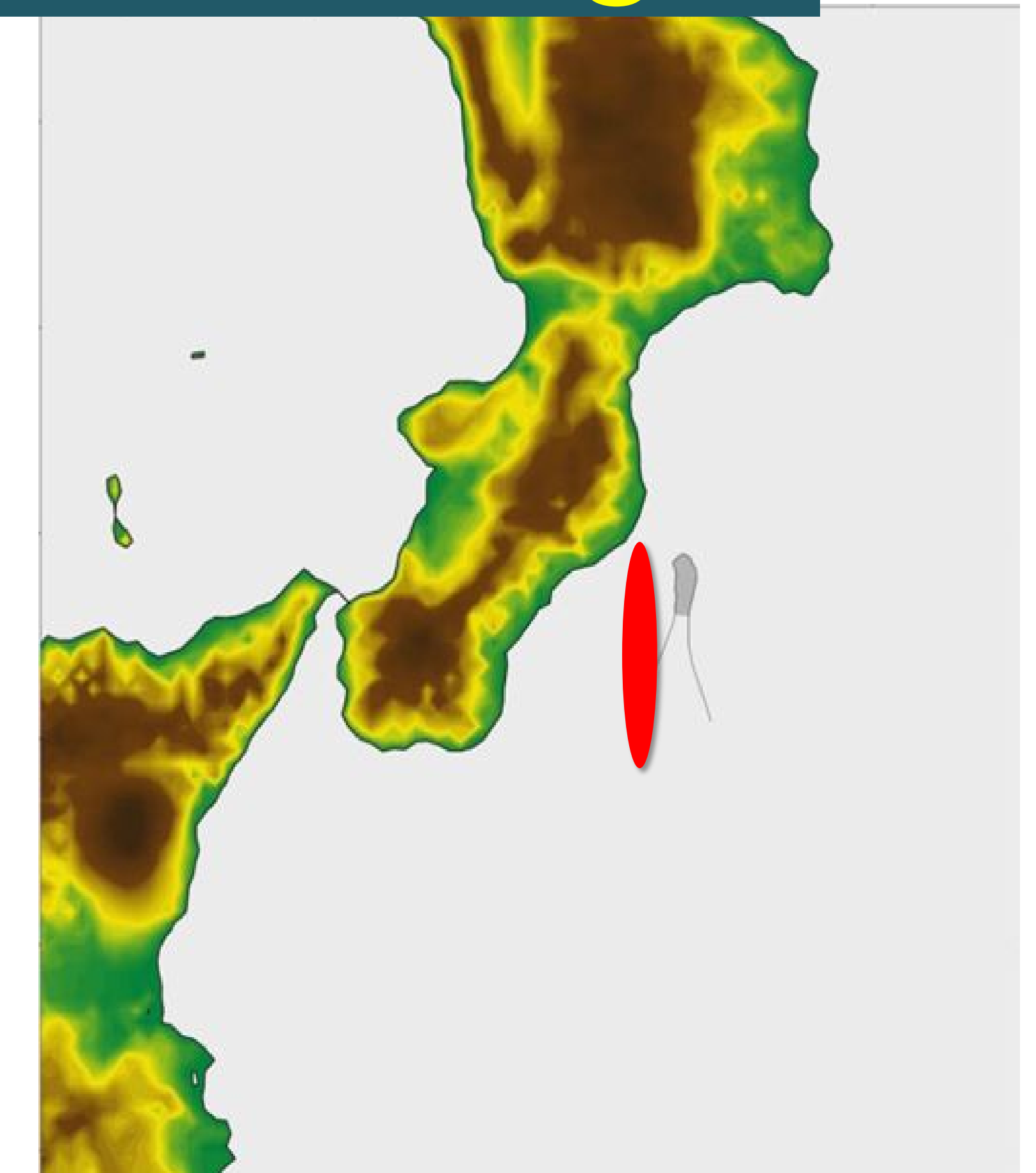


# The Assi Failure

...on the seafloor



...the Calabrian margin

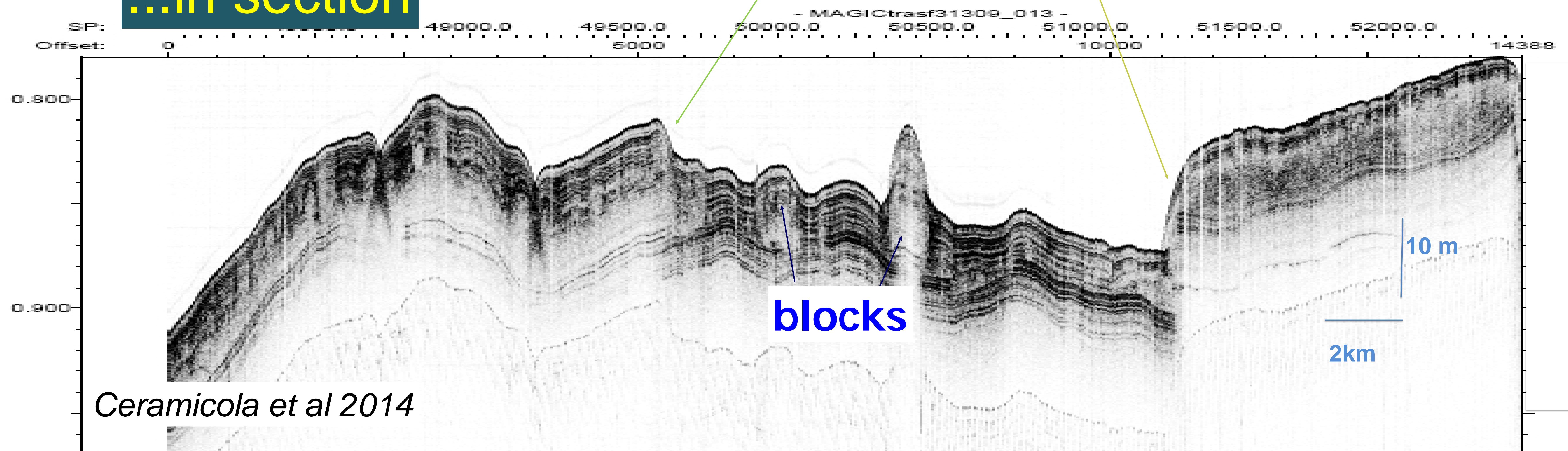


Volume of sediments of the failure is about 2km<sup>3</sup>

sidescars

E

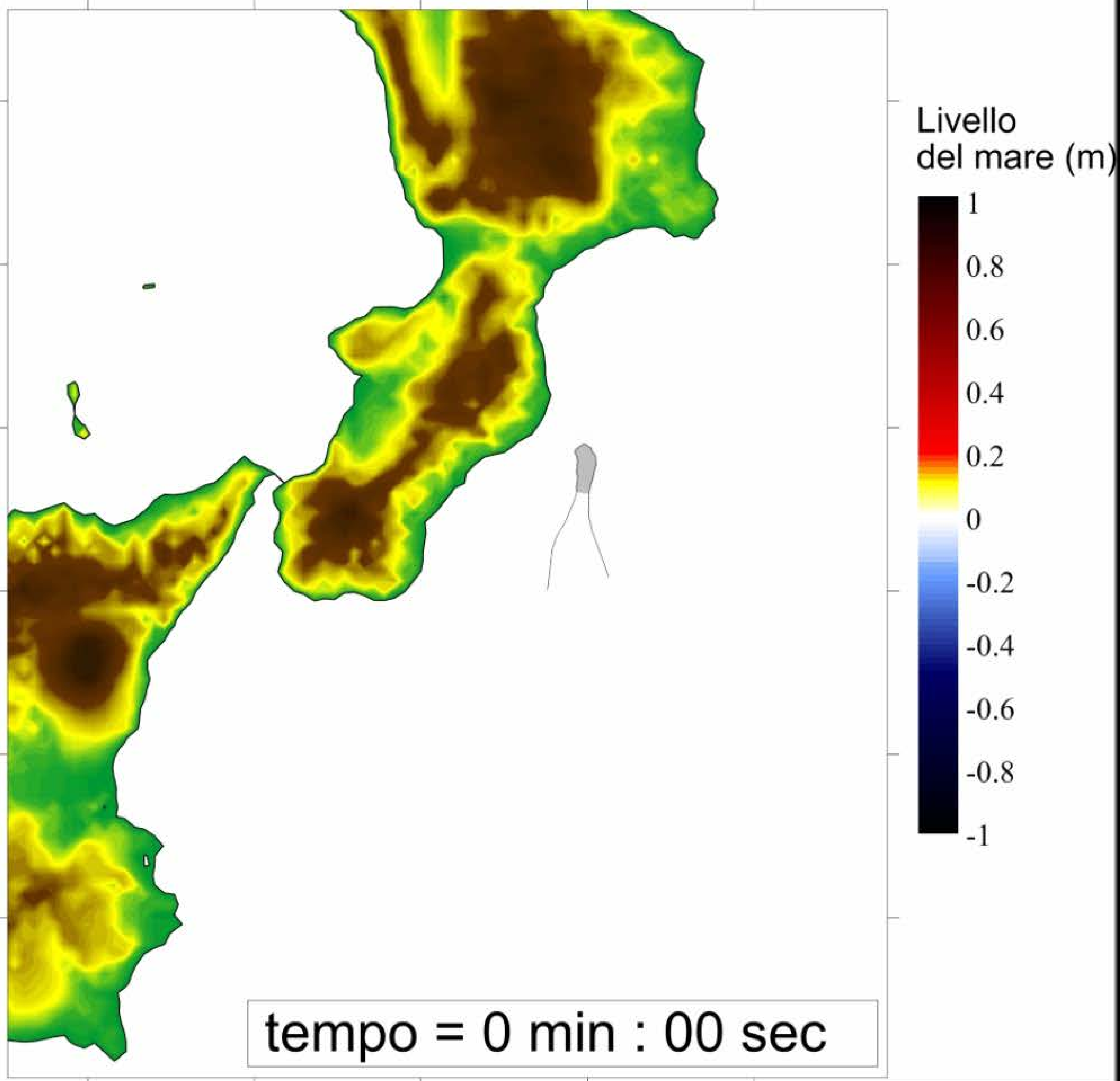
...in section





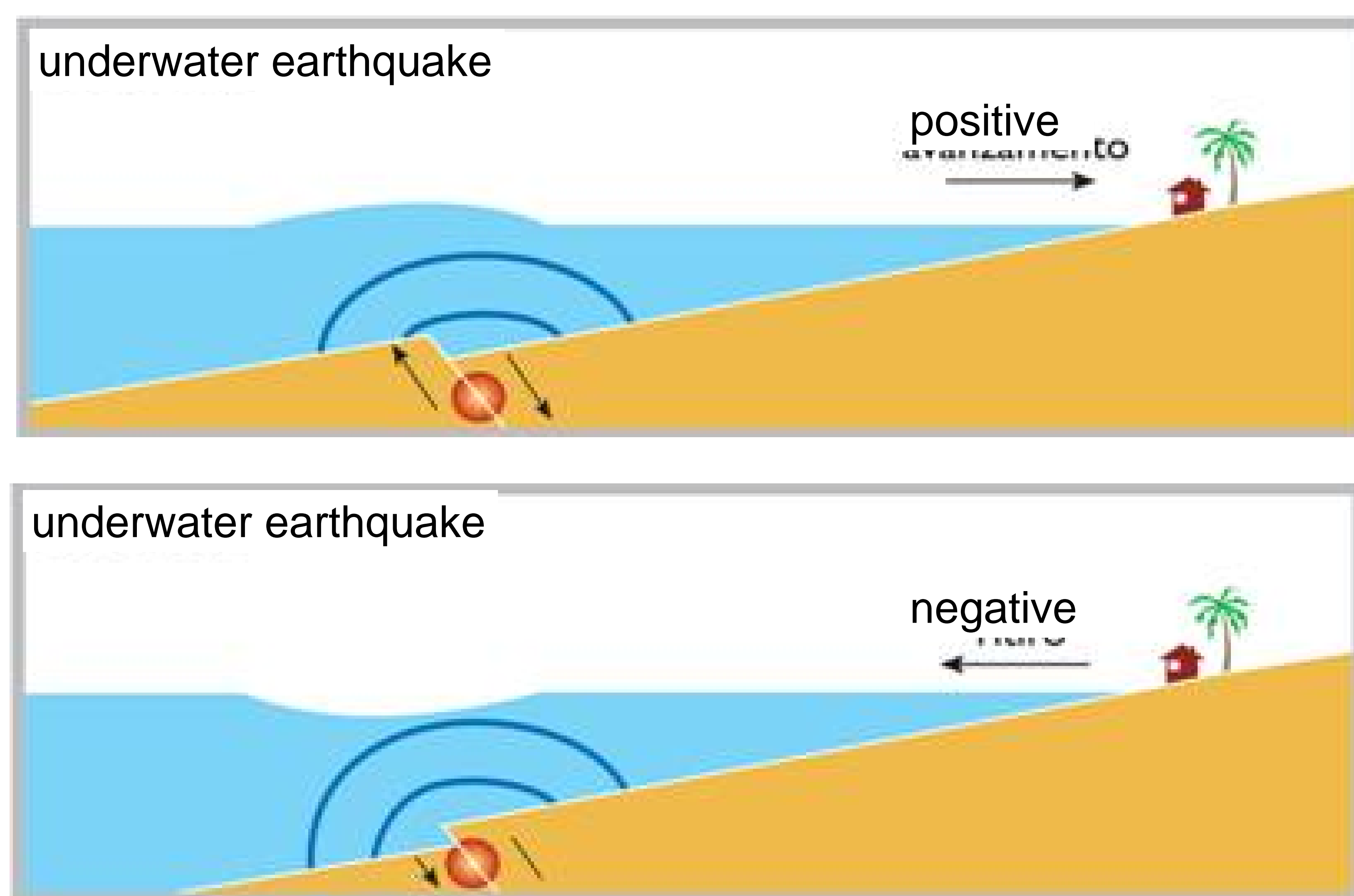
# Maremoto dalla frana di Assi

Gruppo di Ricerca Maremoti - Università di Bologna



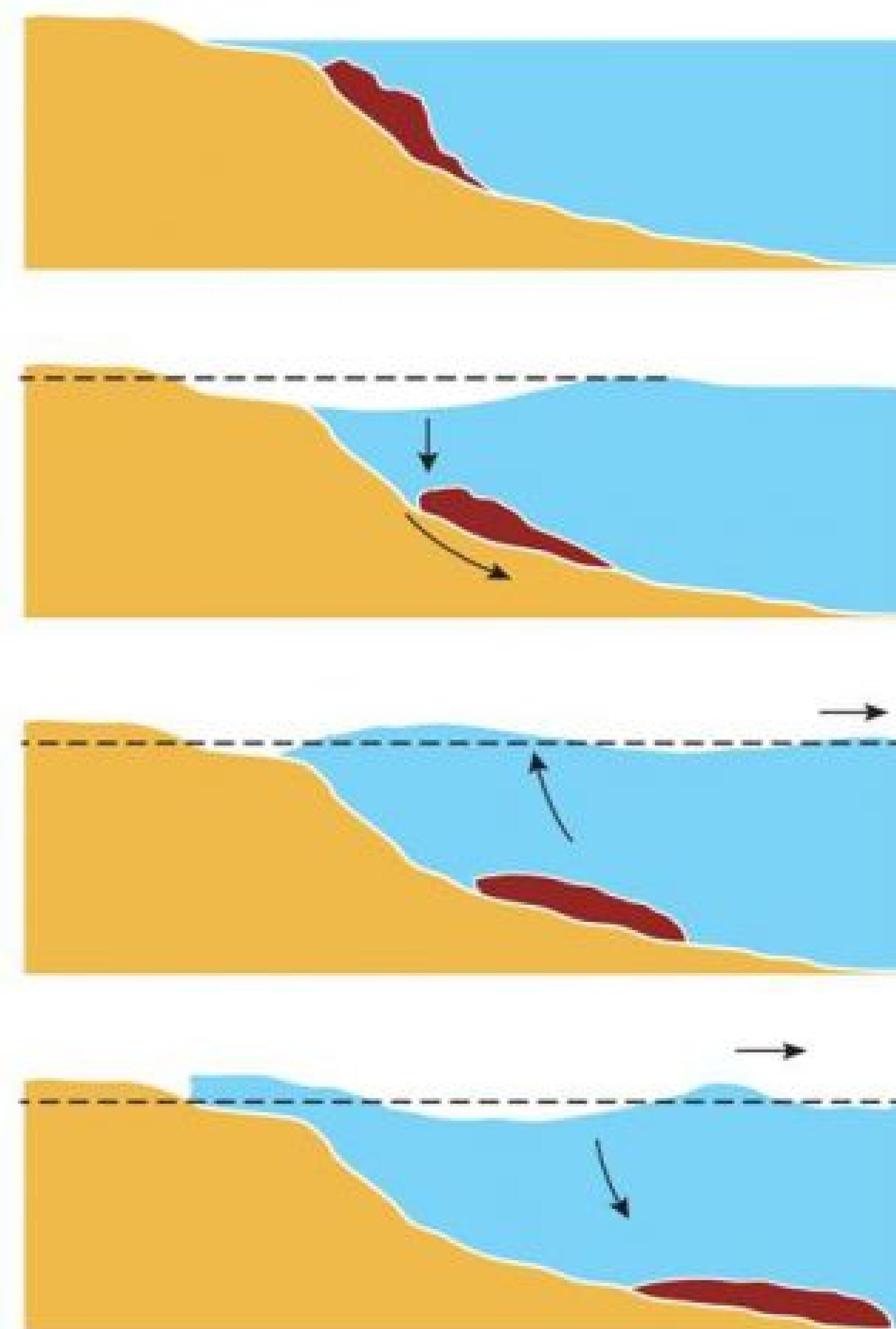


# 3) Tsunamis



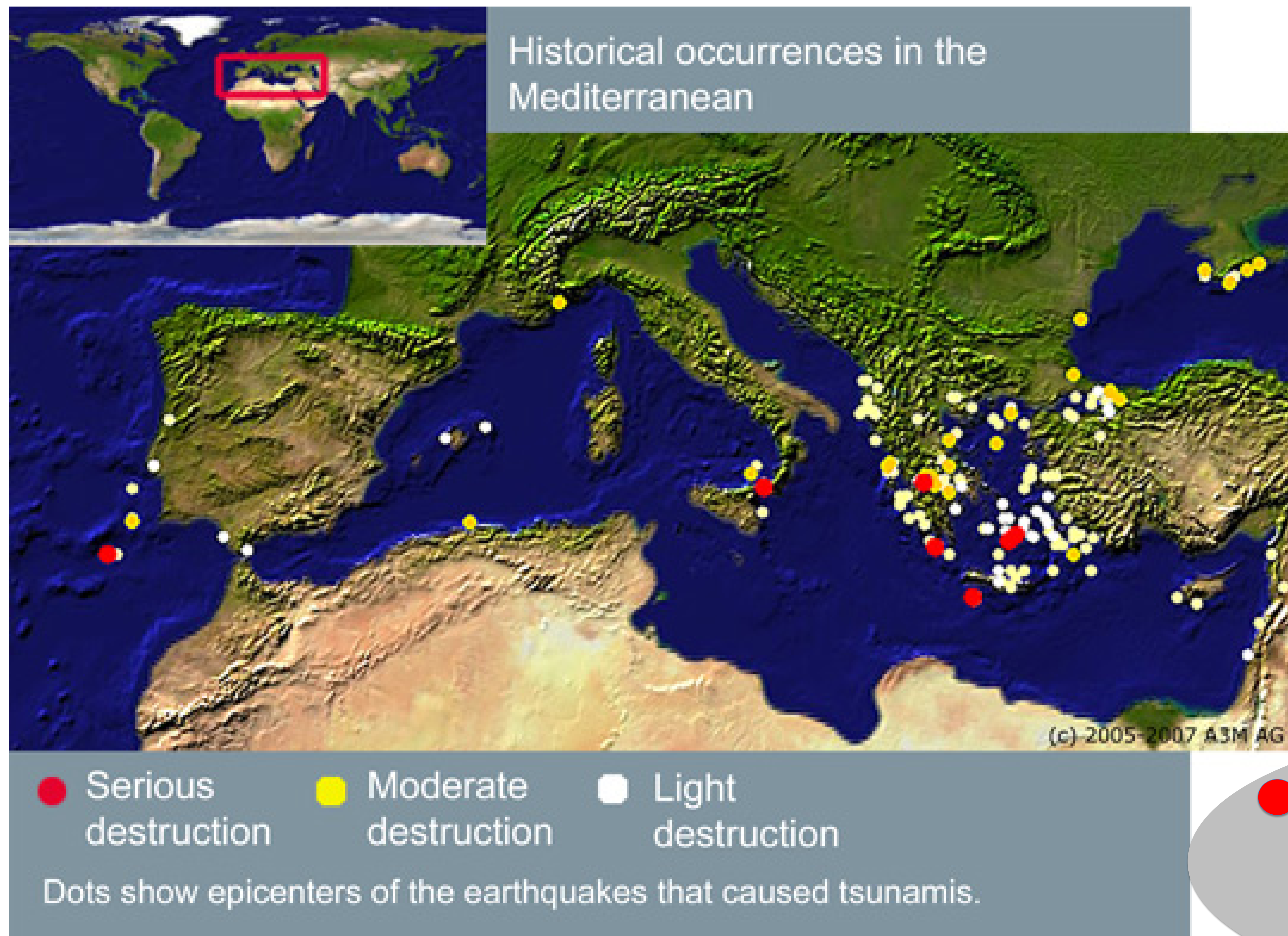
A tsunami is a series of **ocean waves** that send **surges of water**, sometimes reaching heights of over 30 meters, onto land. They are different from waves generated by storms as they involve the entire water column. These walls of water **can cause widespread destruction** when they crash ashore.

submarine landslide





# Tsunamis in the Med



Tsunamis threaten the coasts and beaches **all over the world**.

They occur in all oceans and **seas**, including the Mediterranean, the Atlantic, the Indian, the Pacific and in **large lakes**.

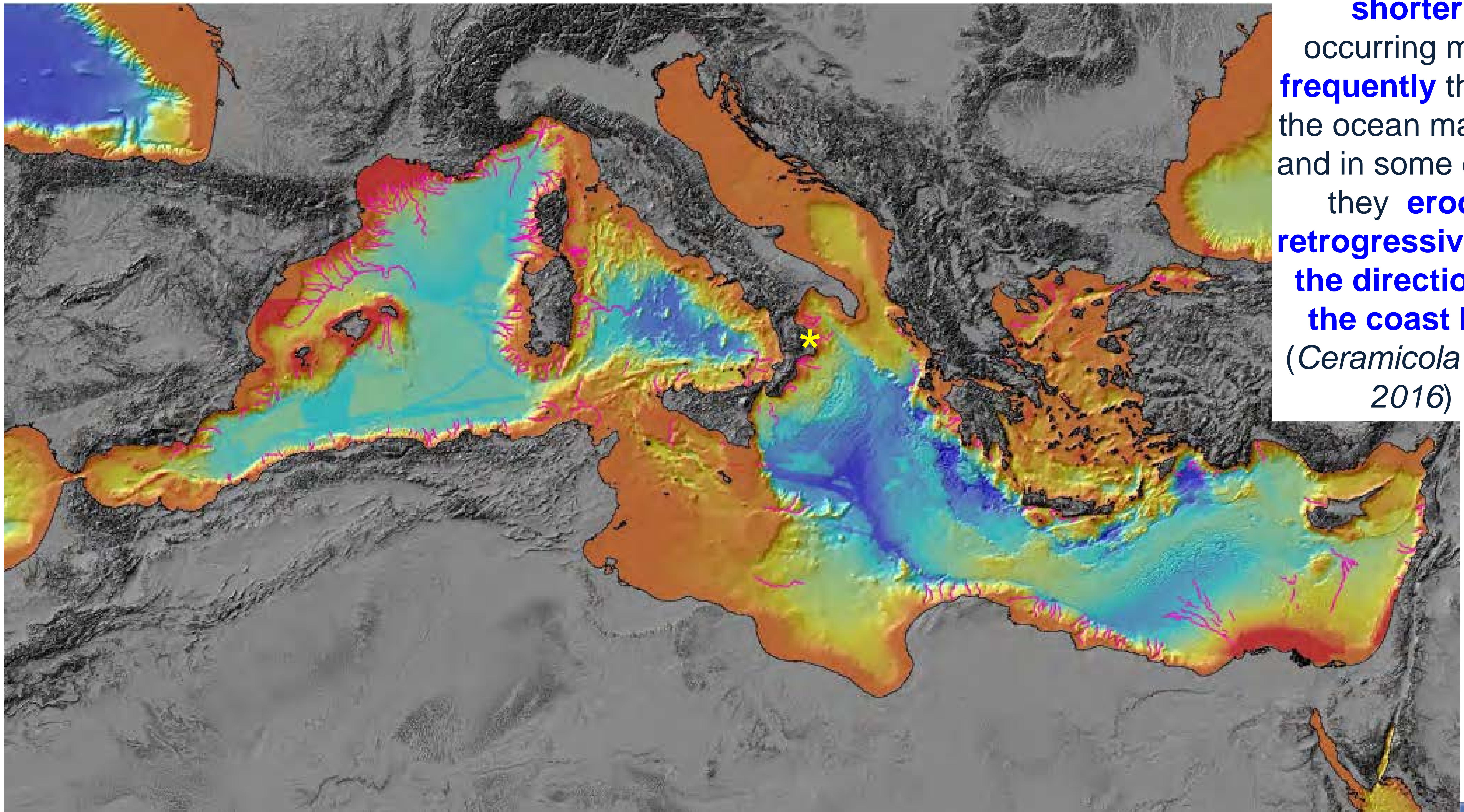
About **10%** of all tsunamis reach the beaches of the **Mediterranean Sea**.

● **28 December 1908:** Due to an earthquake and the ensuing tsunami, the city of Messina in Italy was almost completely destroyed. More than 75 000 people were killed.

Tsunamis in the Med travel quickly from coast to coast (in hours) and so it is difficult to settle an efficient **warning system!**



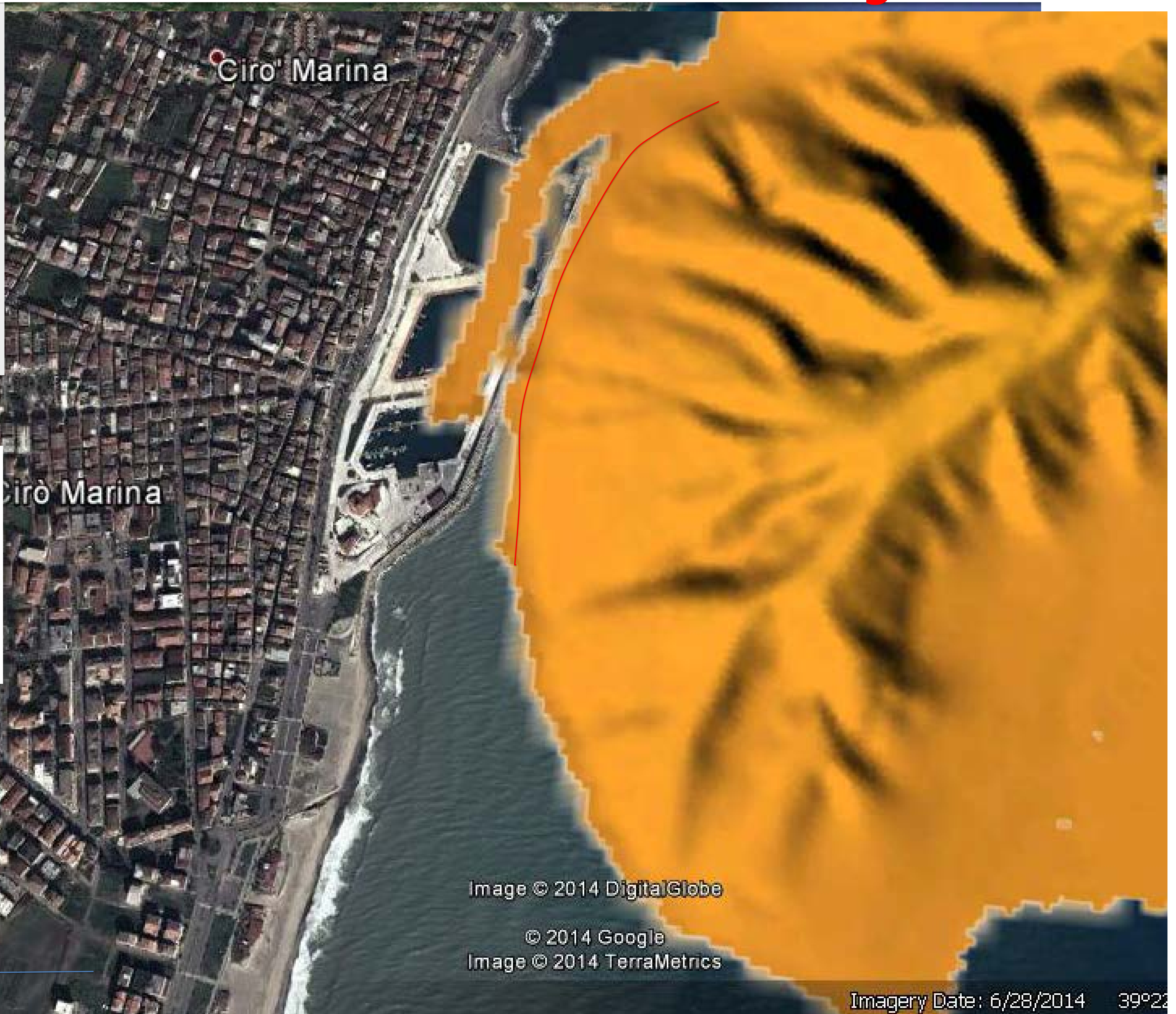
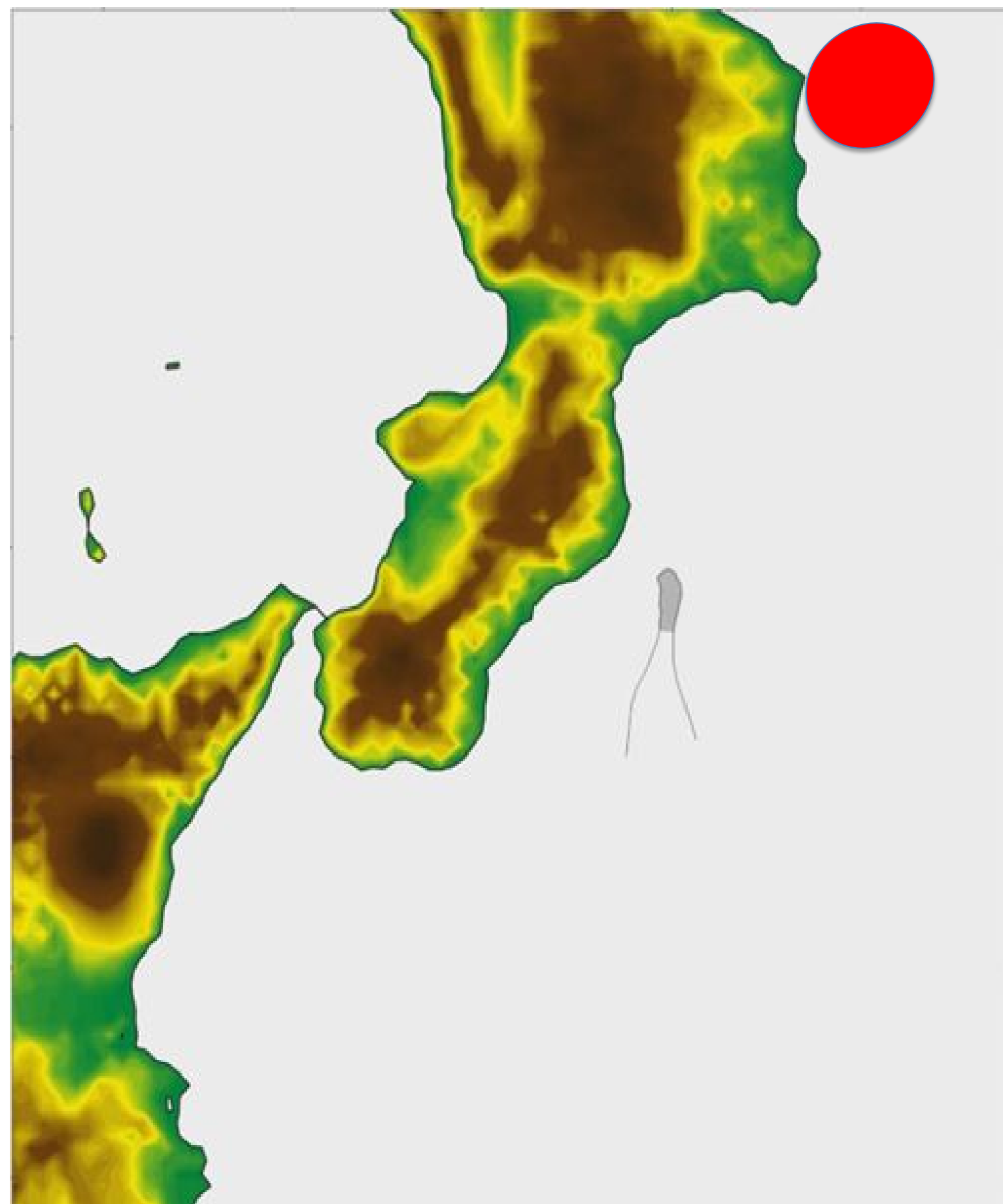
# 4) Submarine canyons in the Med



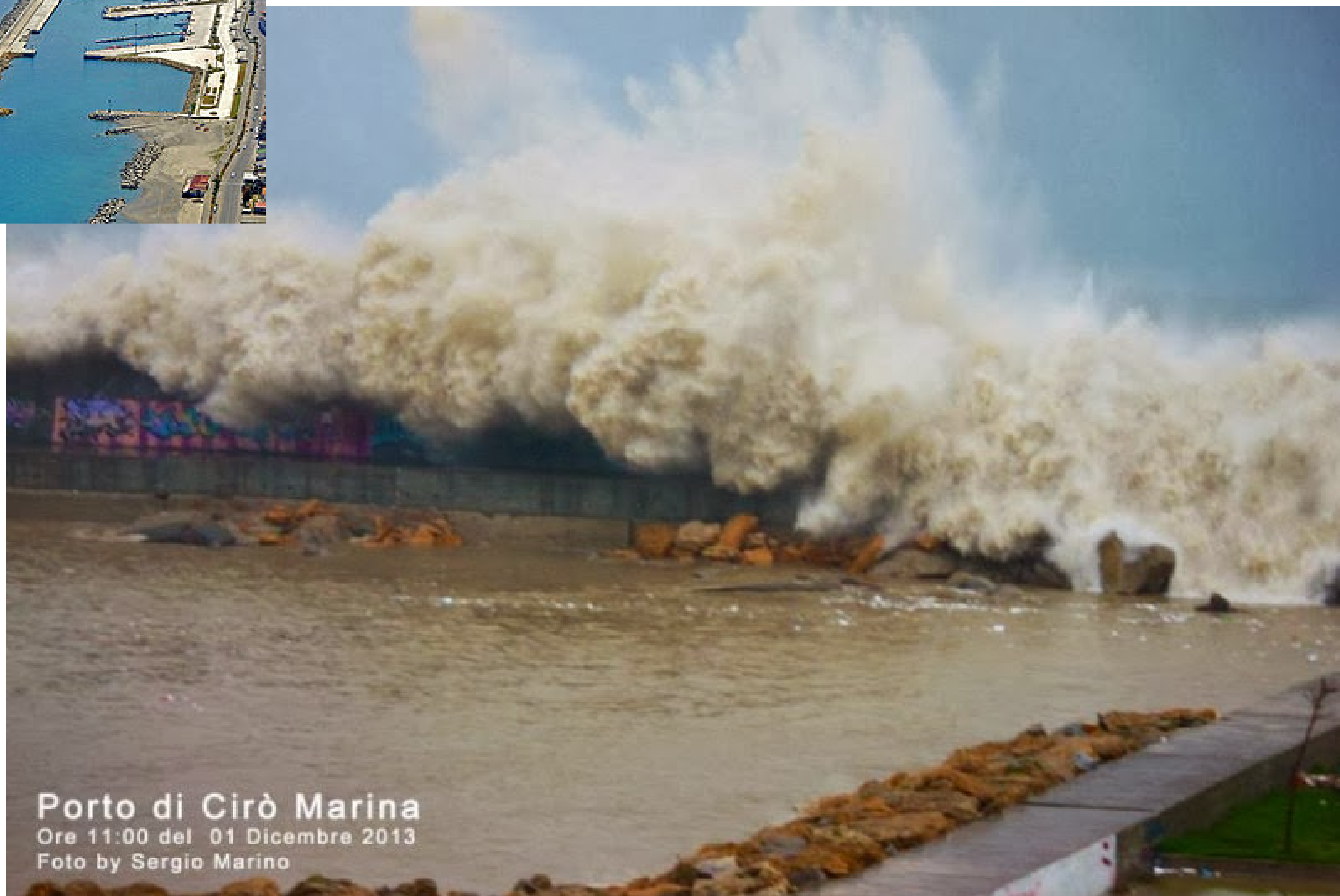
...they are **shorter**, occurring more **frequently** than in the ocean margins and in some cases they **erode retrogressively in the direction of the coast line** (Ceramicola et al. 2016)



# The Ciro' submarine canyon



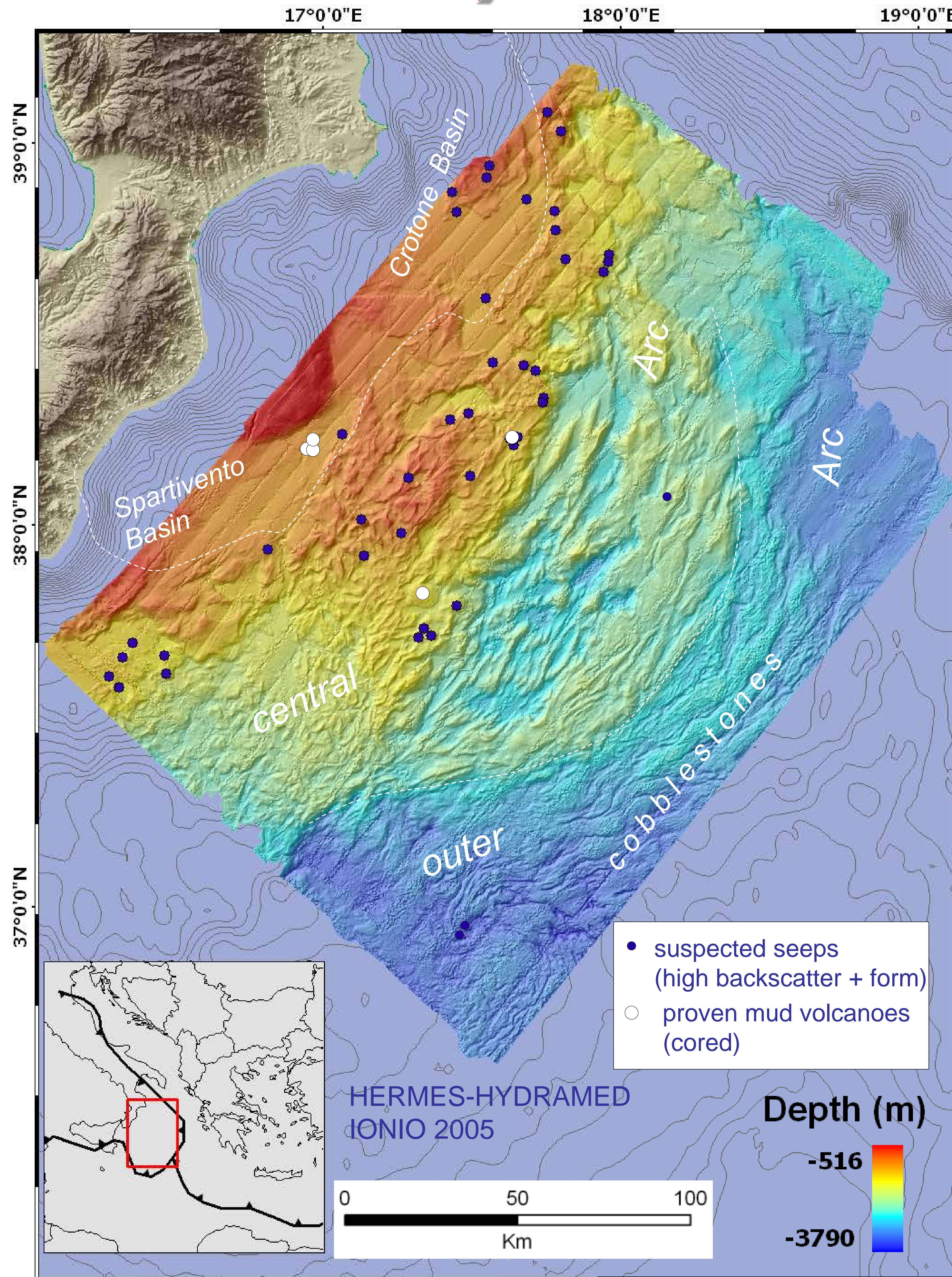




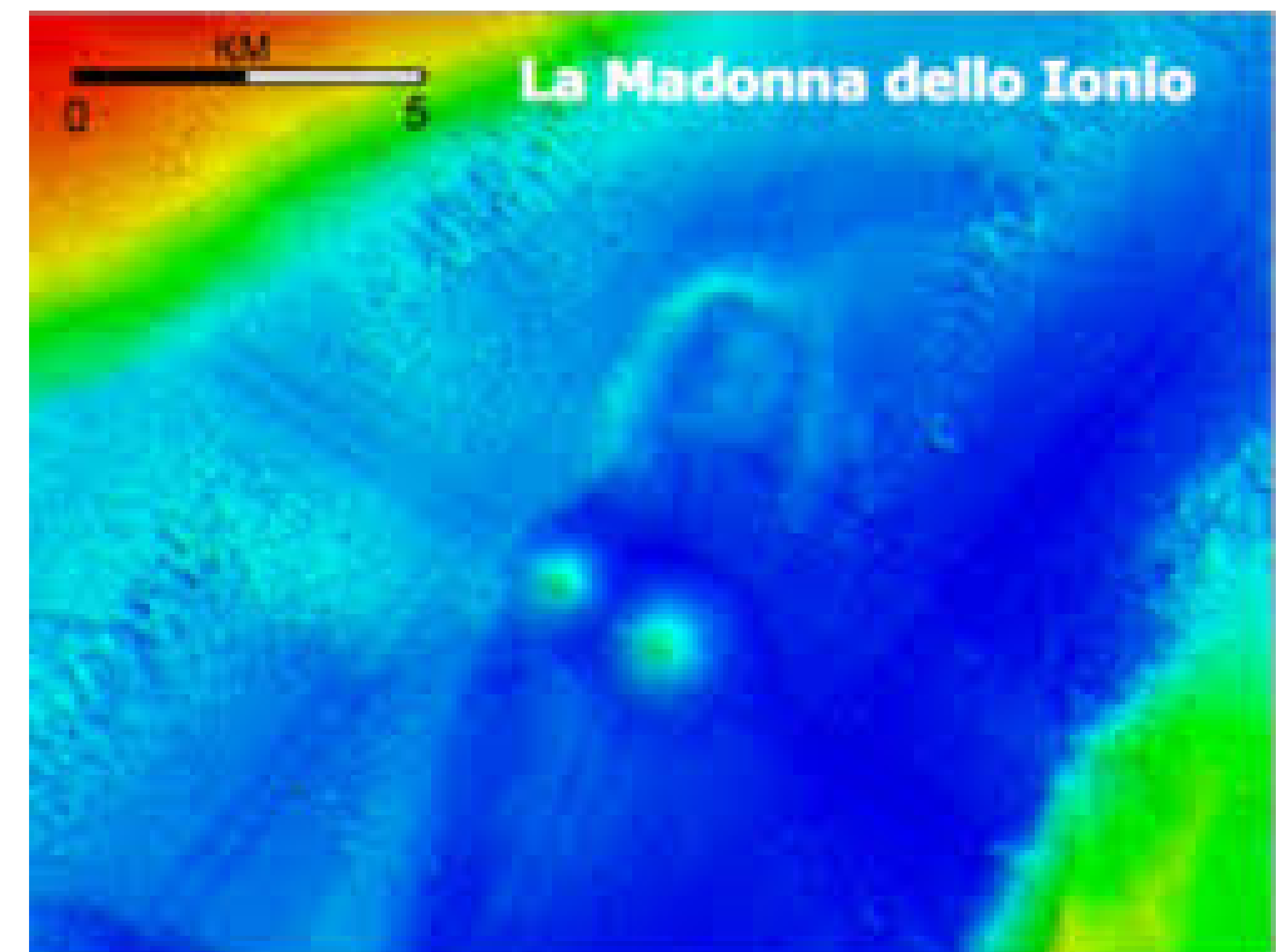
Porto di Cirò Marina  
Ore 11:00 del 01 Dicembre 2013  
Foto by Sergio Marino



# 5) Fluid emissions



Using different geophysical and geological methods we have been able to **identify 54 mud volcanoes**, map their distribution, characterise their activity and assess possible geohazards

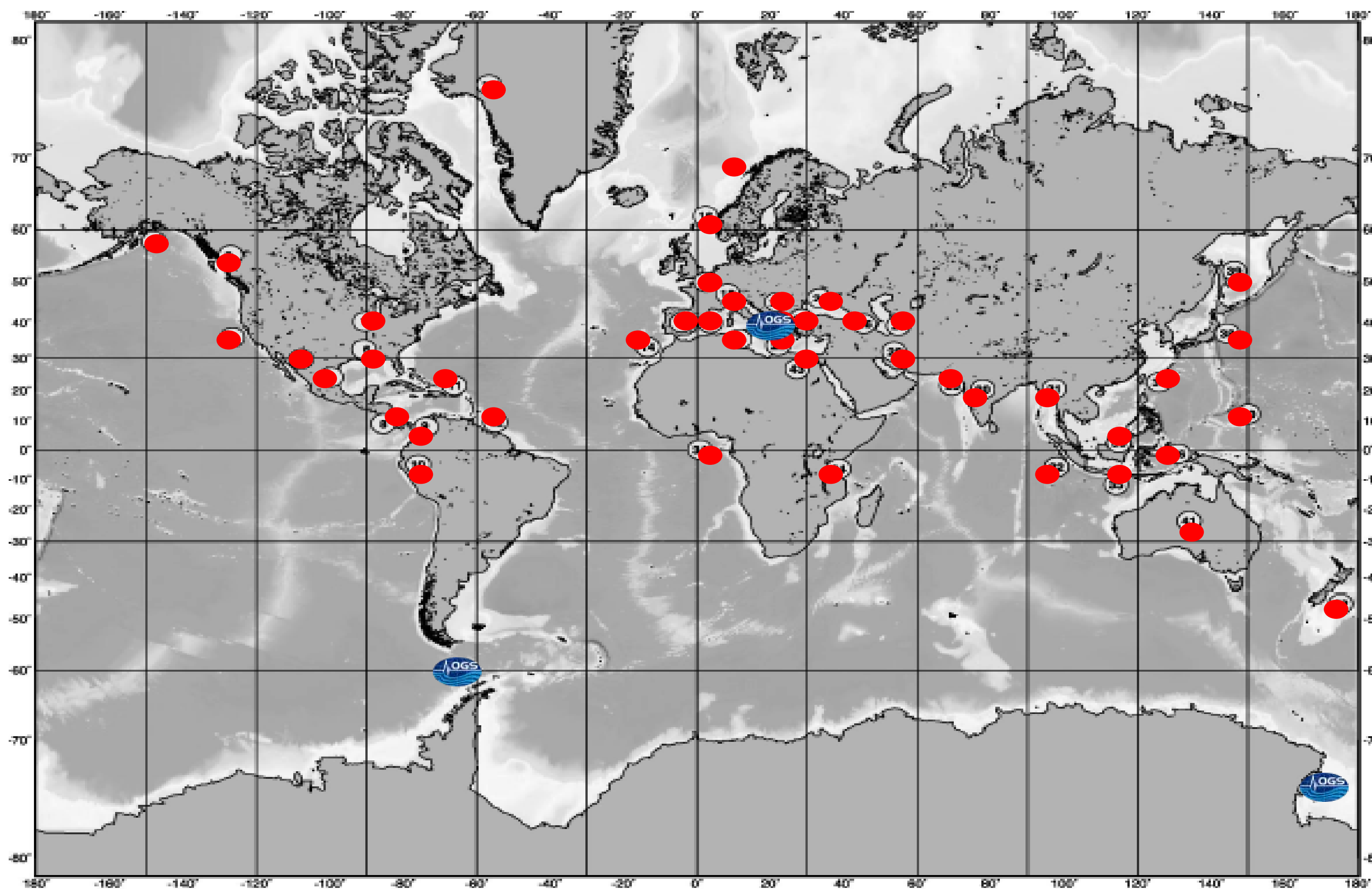


discovered by OGS in 2015

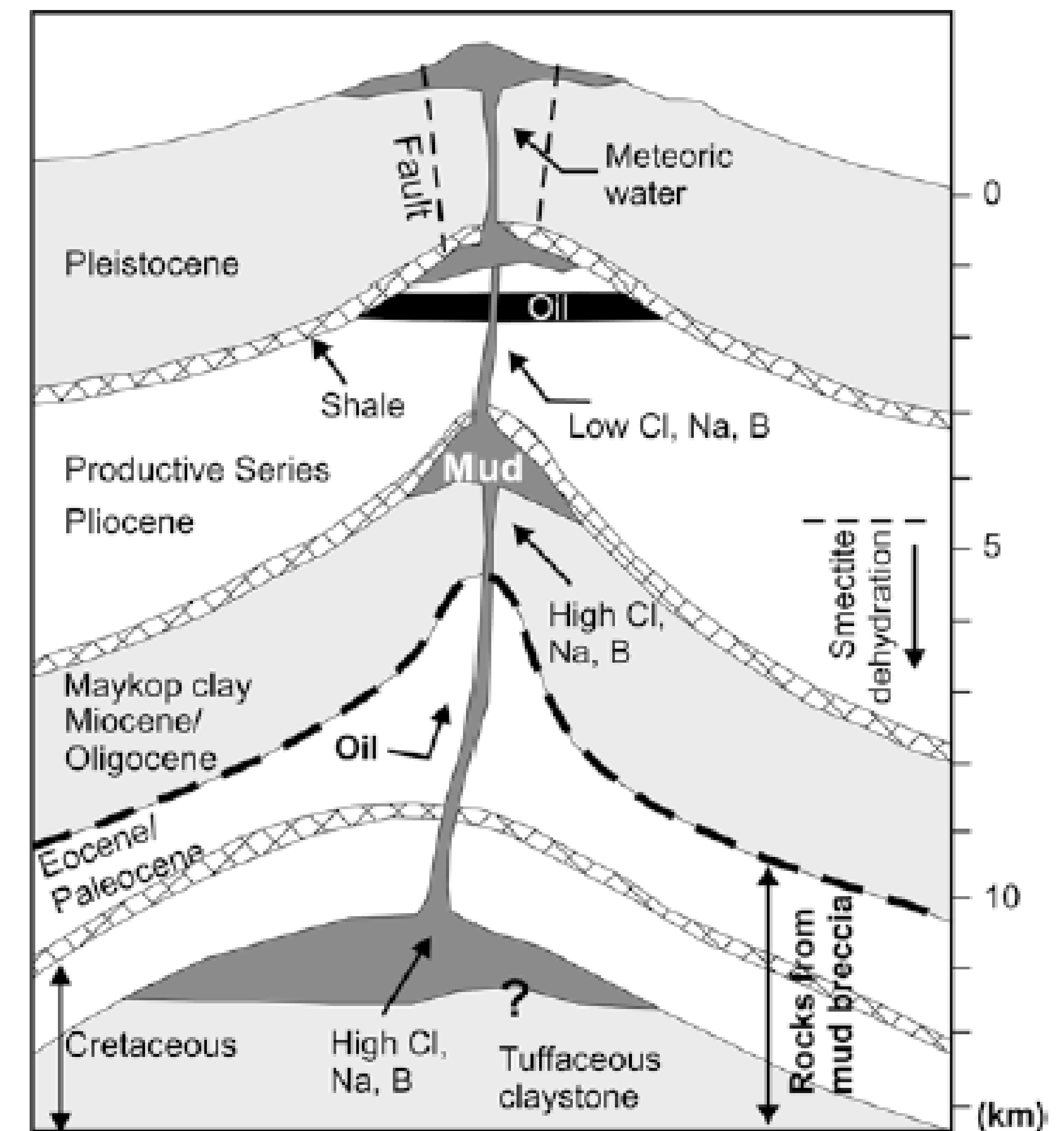
*Ceramicola et al. 2014*



# Fluid emissions



Mud volcanoes occurrence on continental margins worldwide (*Kopf 2002*)



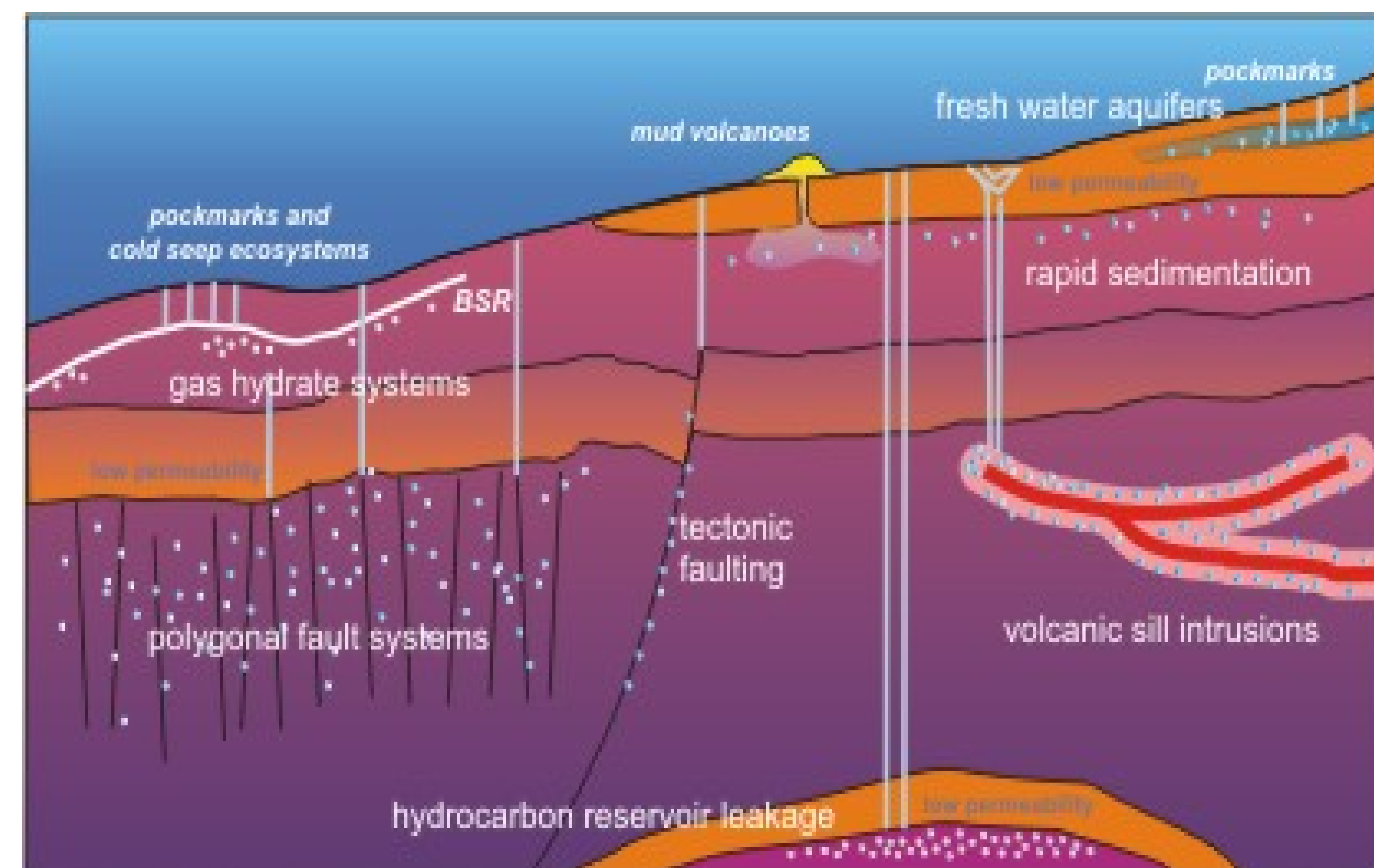
Conceptual model of functioning of Azeri mud volcanism – deep rooting (12 km), multiple mud chambers (*Planke et al. 2003*)



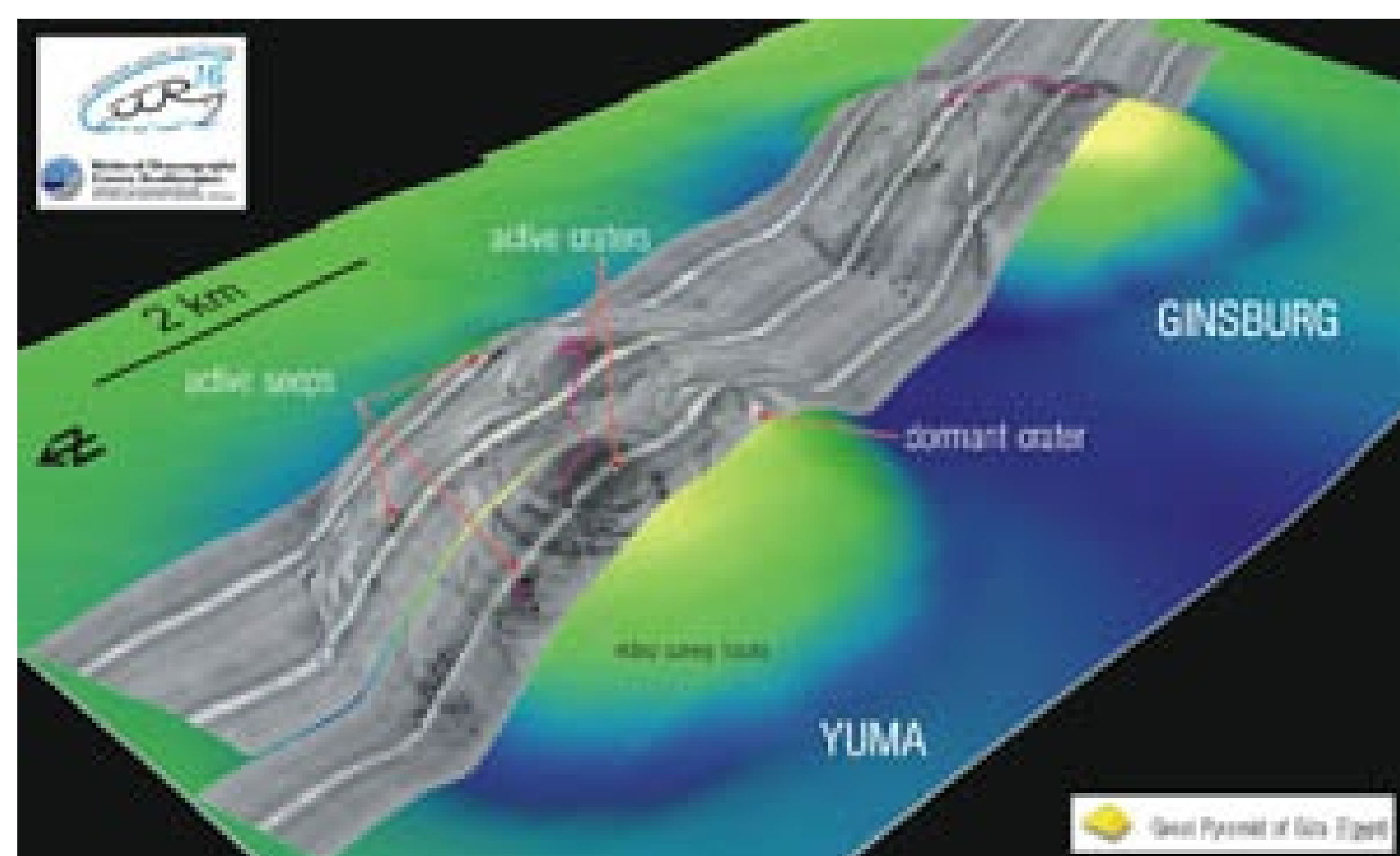
# COLD SEEPS EXAMPLES

## COLD SEEPS

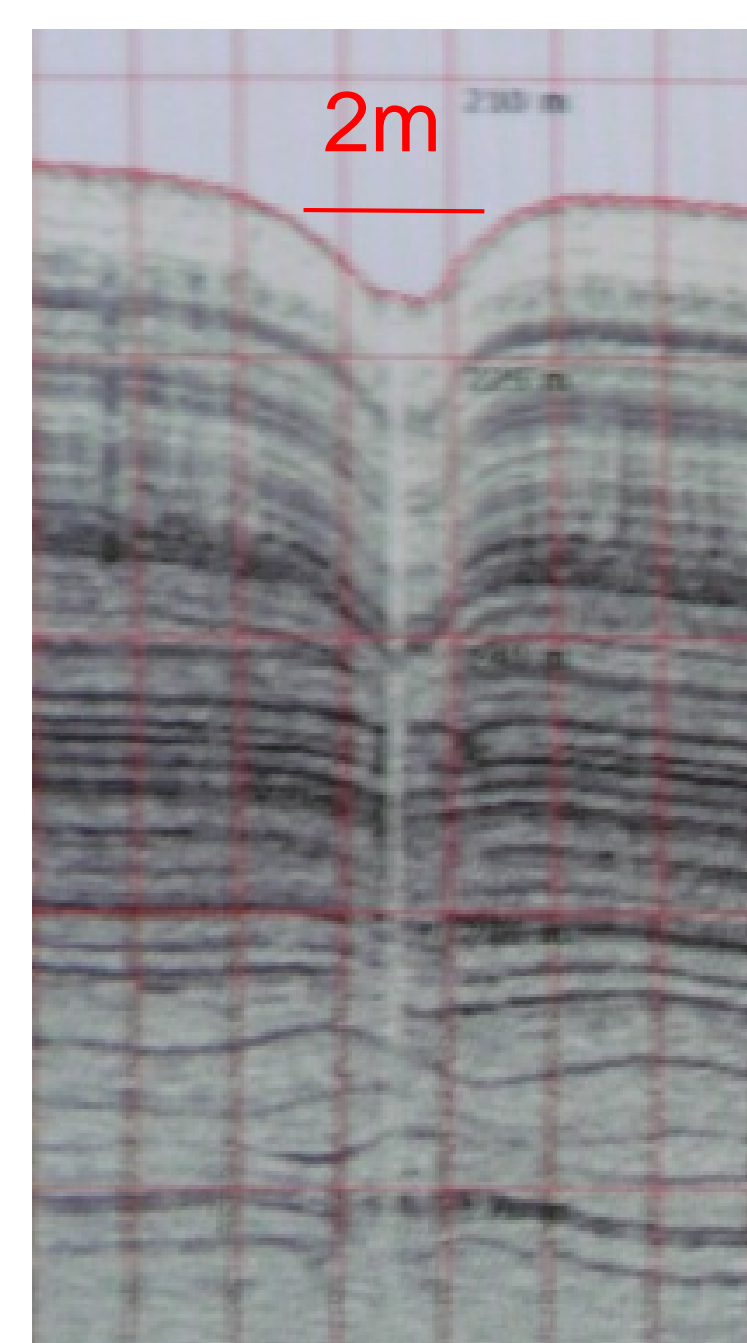
- MUD VOLCANOES (CONIC PIES)
- POCKMARKS
- CARBONATIC CRUSTS
- BRINE POOLS
- GAS HYDRATES



Schema della circolazione dei fluidi nei sedimenti, Berndt (2005)



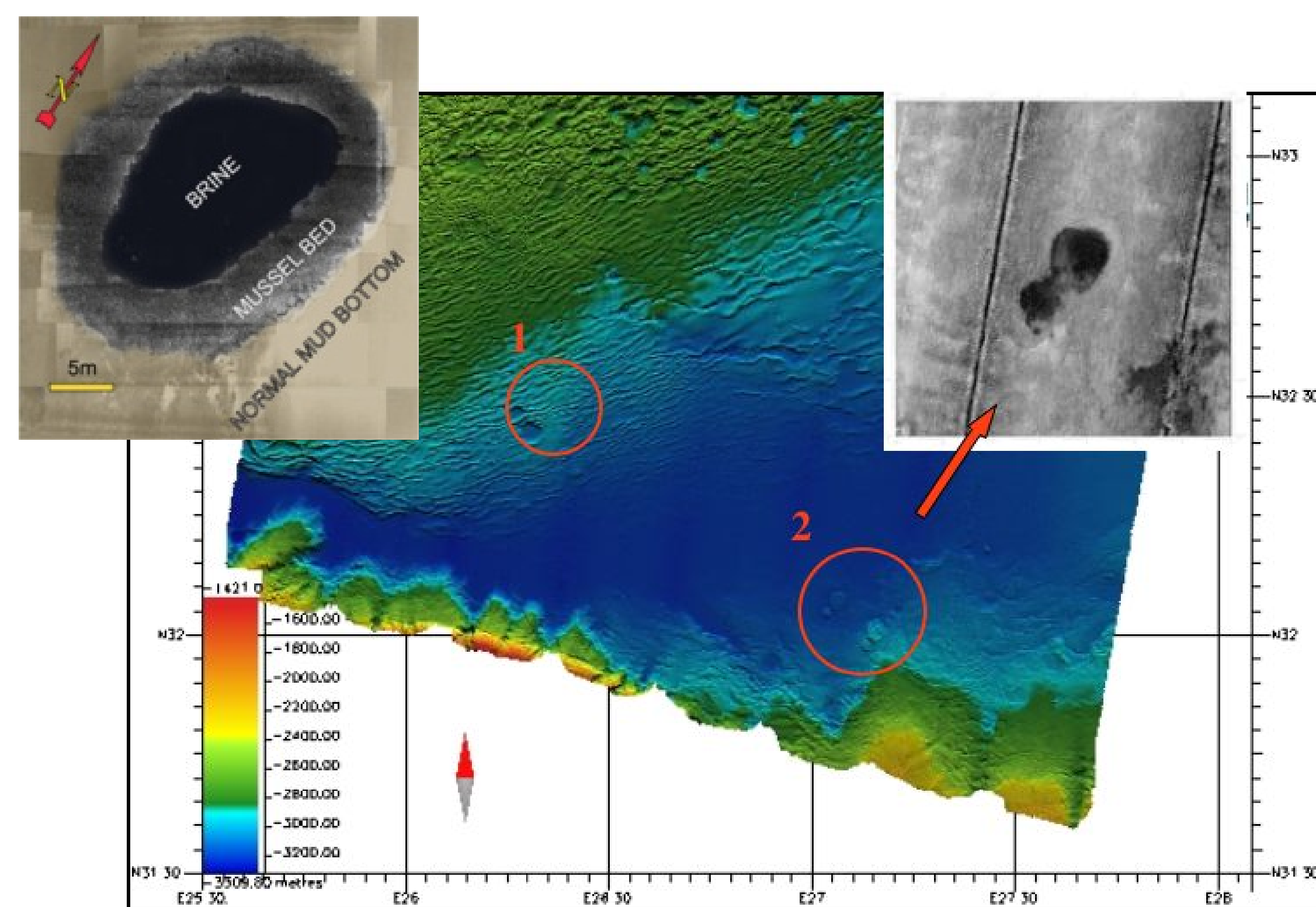
Vulcani di fango (Golfo di Cadice)



Pockmarks - Mar Adriatico



Fuoriuscite di metano  
Hakon Mosby Mud Volcano



Brine salmastre (Delta del Nilo)



Croste carbonatiche - Vulcano di Fango Amon (Delta del Nilo)

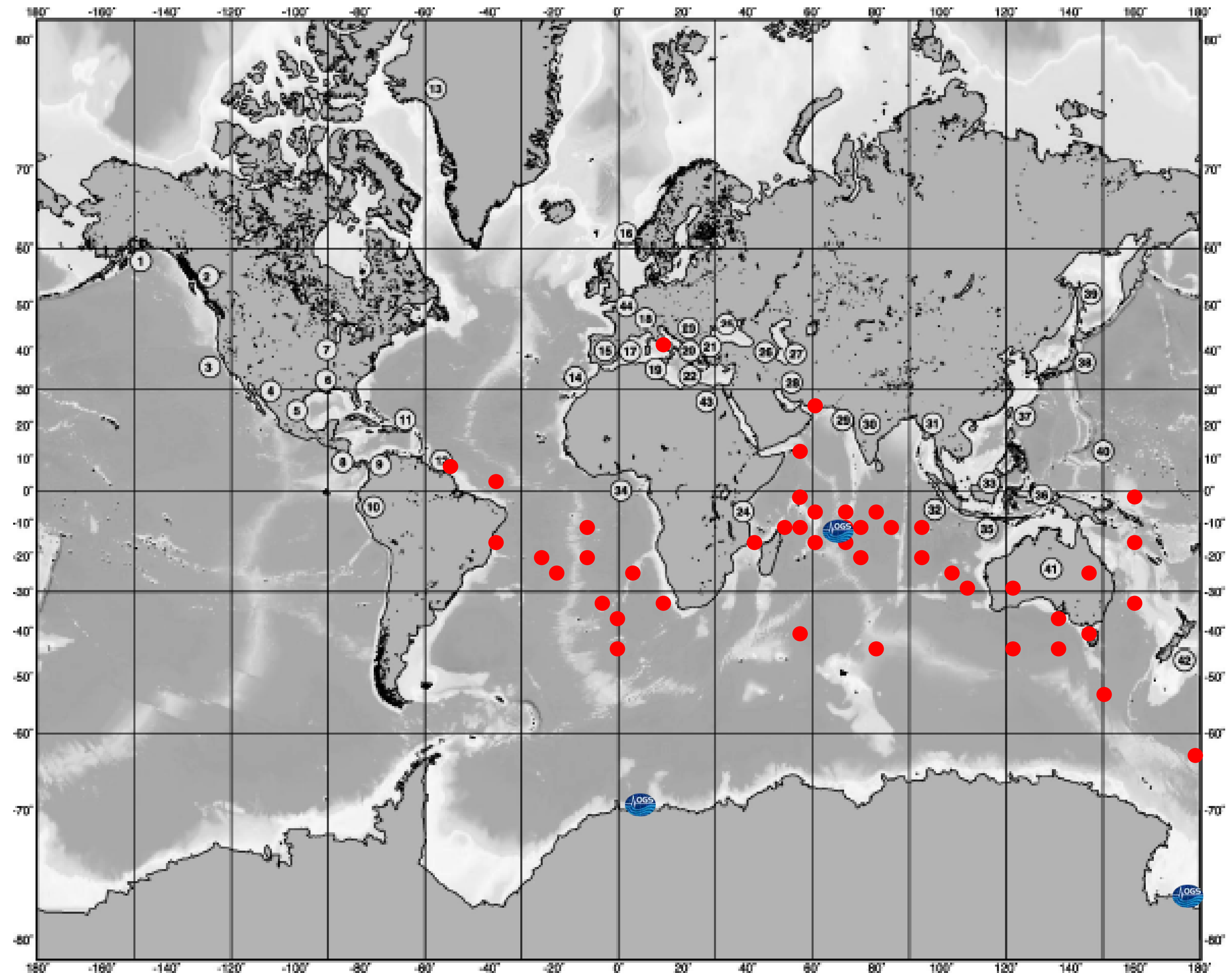


Le salse di Nirano (Modena)



# Why do we study COLD SEEPS?

- because we do not know their functioning through time
- geosphere biosphere interaction
- impact of gas emission (greenhouse) in the atmosphere
- responsible for slope instability in association with gas hydrates (geohazards)
- gas hydrates represent a potential economic resource



Distribuzione dei vulcani di fango nel mondo, Kopf (2002)





Volcano di fango Lusi, Java orientale, Indonesia  
(dal 2006)

Lusi Mud Volcano, W-Java, Indonesia (erupting since 2006)

It began erupting mud more than a decade ago and hasn't stopped since.

At its peak 180,000 cubic metres of mud a day spewed to the surface.



1 KM

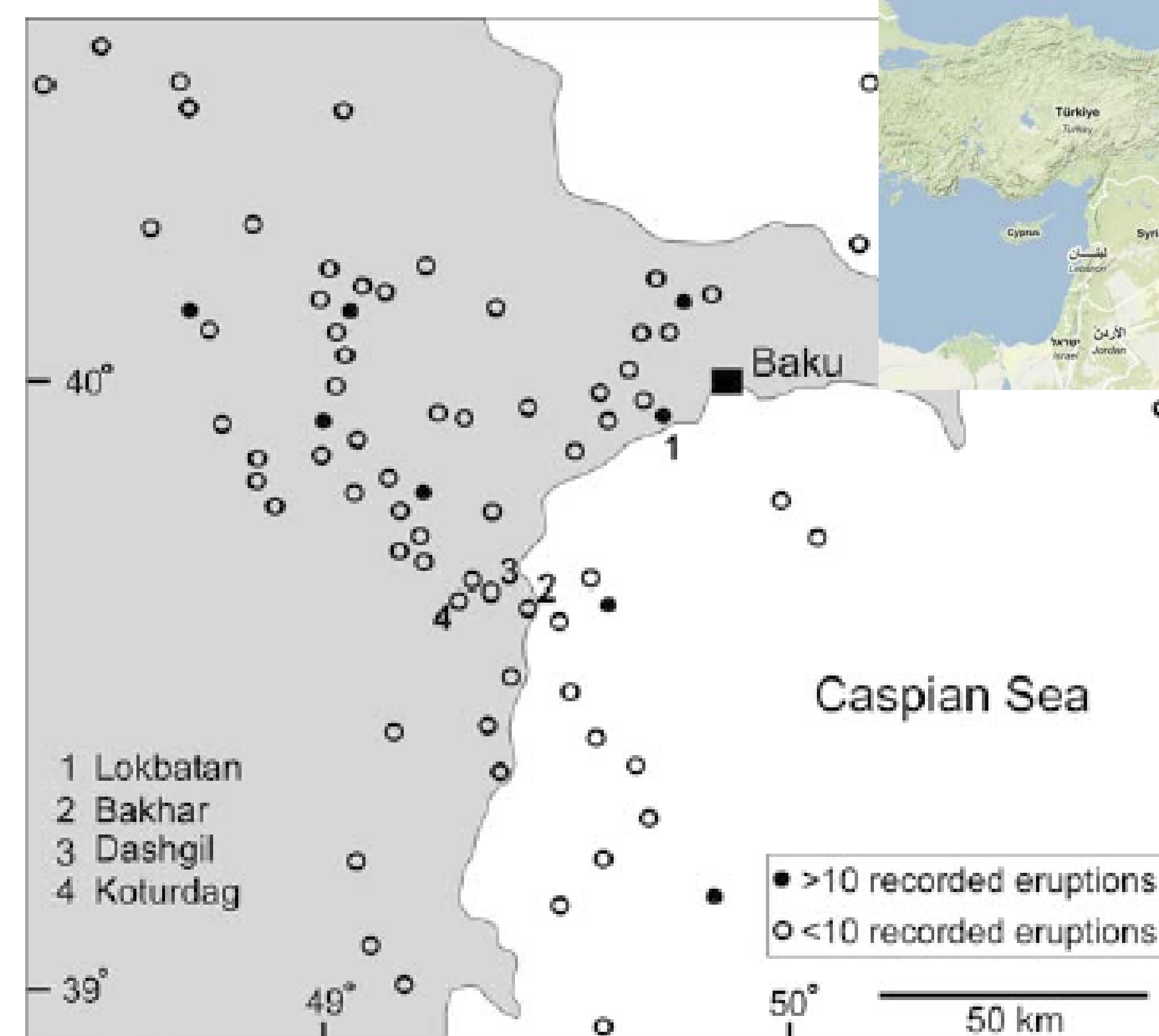
Ikonos Satellite images (CRISP)



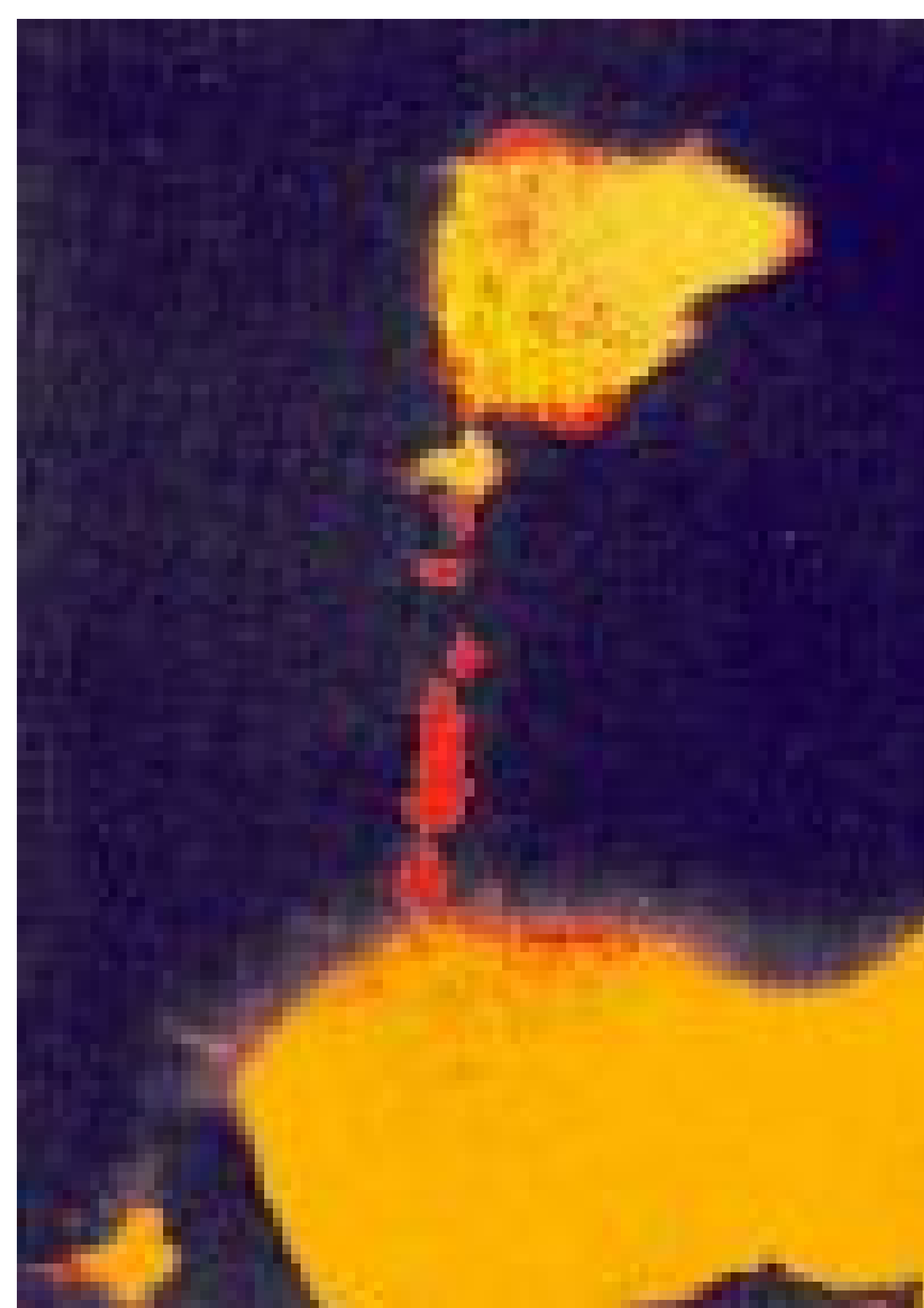
# Azerbaijan mud volcanoes (among world's largest)



Lokbatan MV (B. Asbrink 2003 - Azerbaijan International)

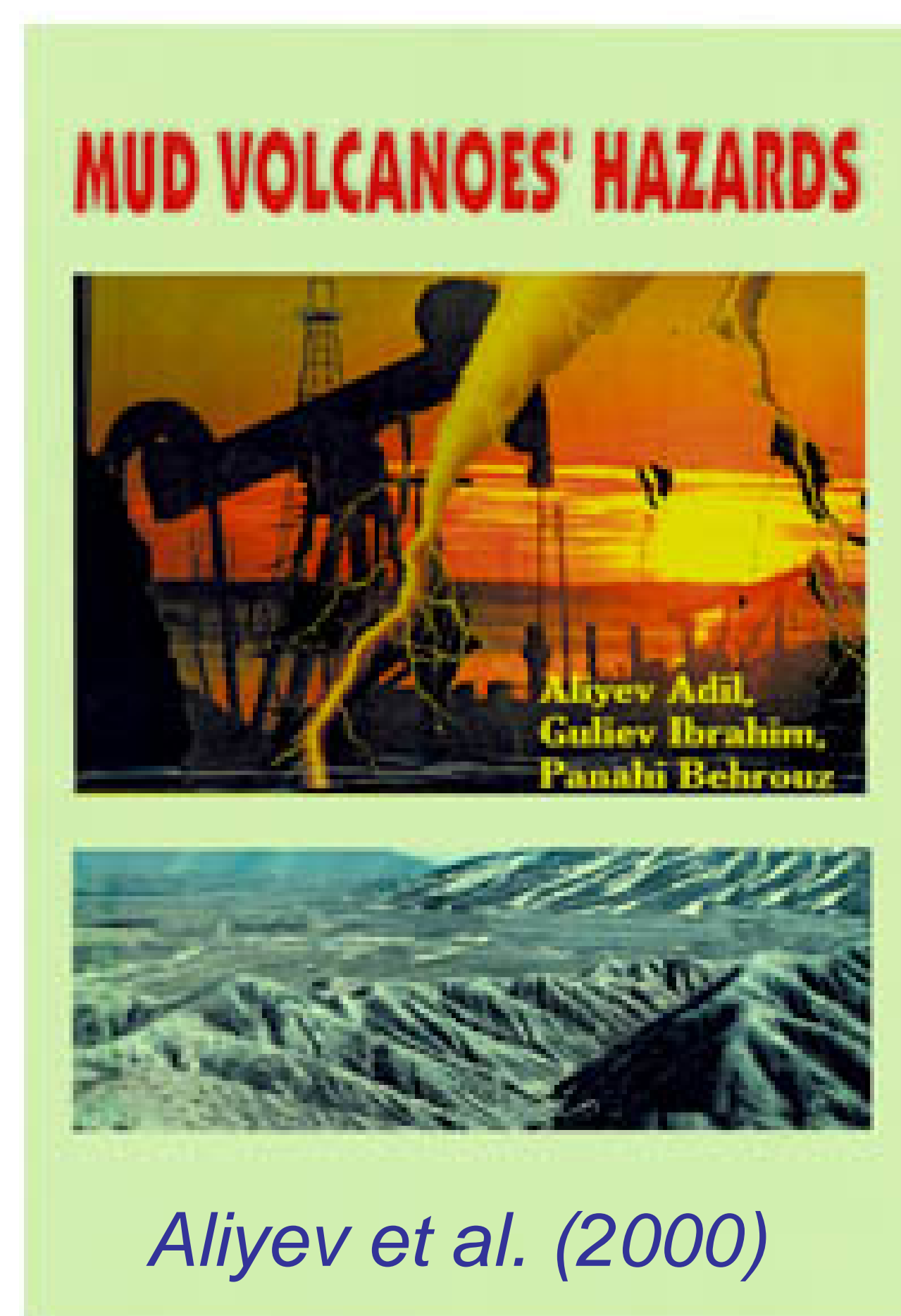


Mud volcanoes in Azerbaijan (Planke et al. 2003)



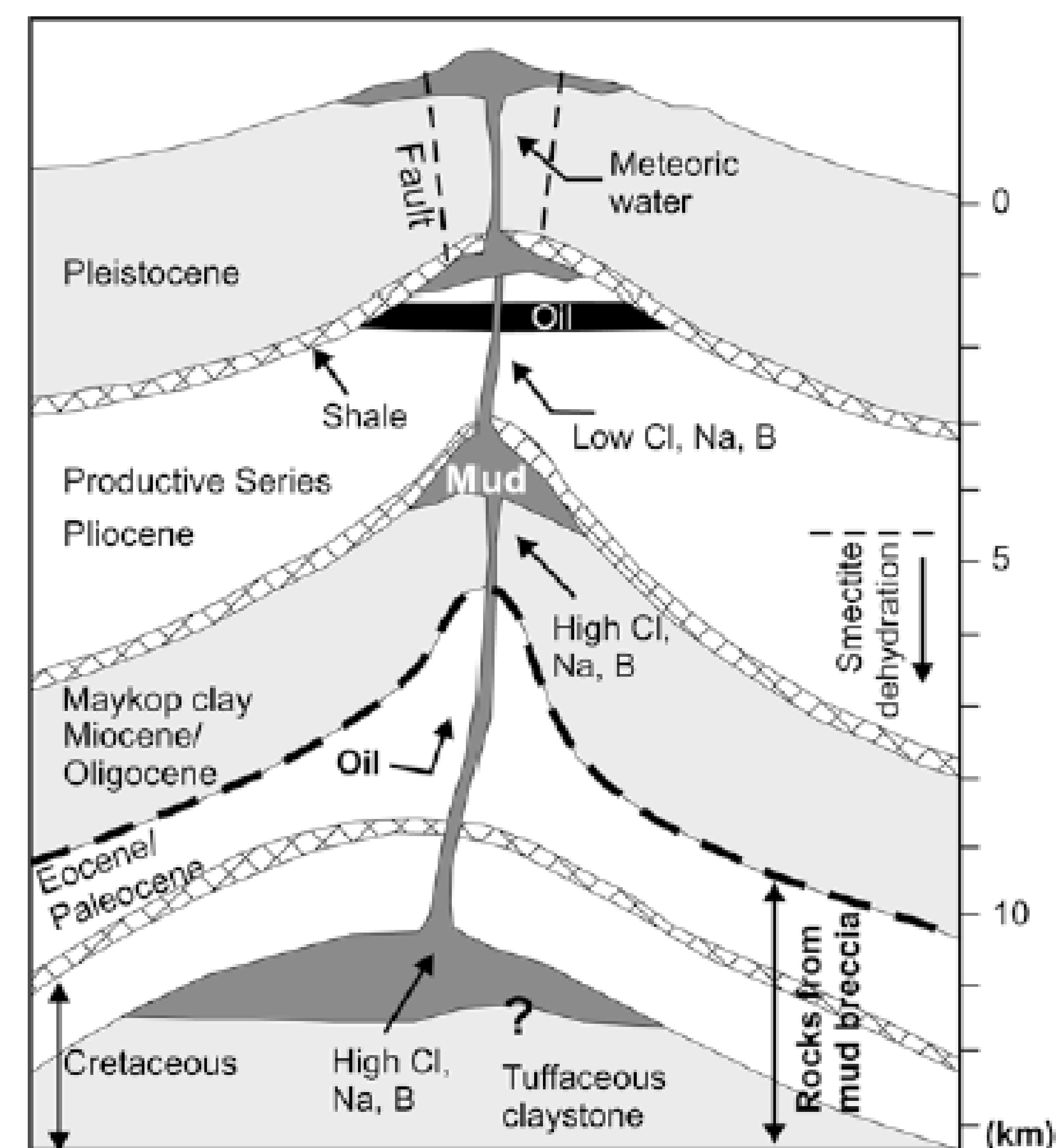
[www.martinhovland.com](http://www.martinhovland.com)

Self-igniting supersonic gas blowout - height 750 m, distance 20 km from Baku (1958)



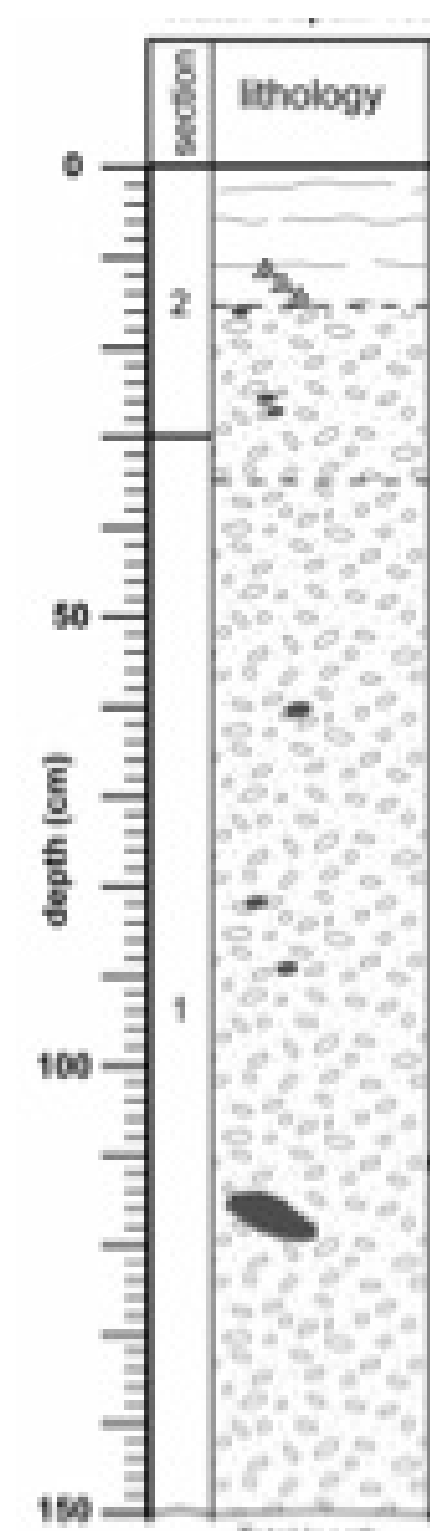
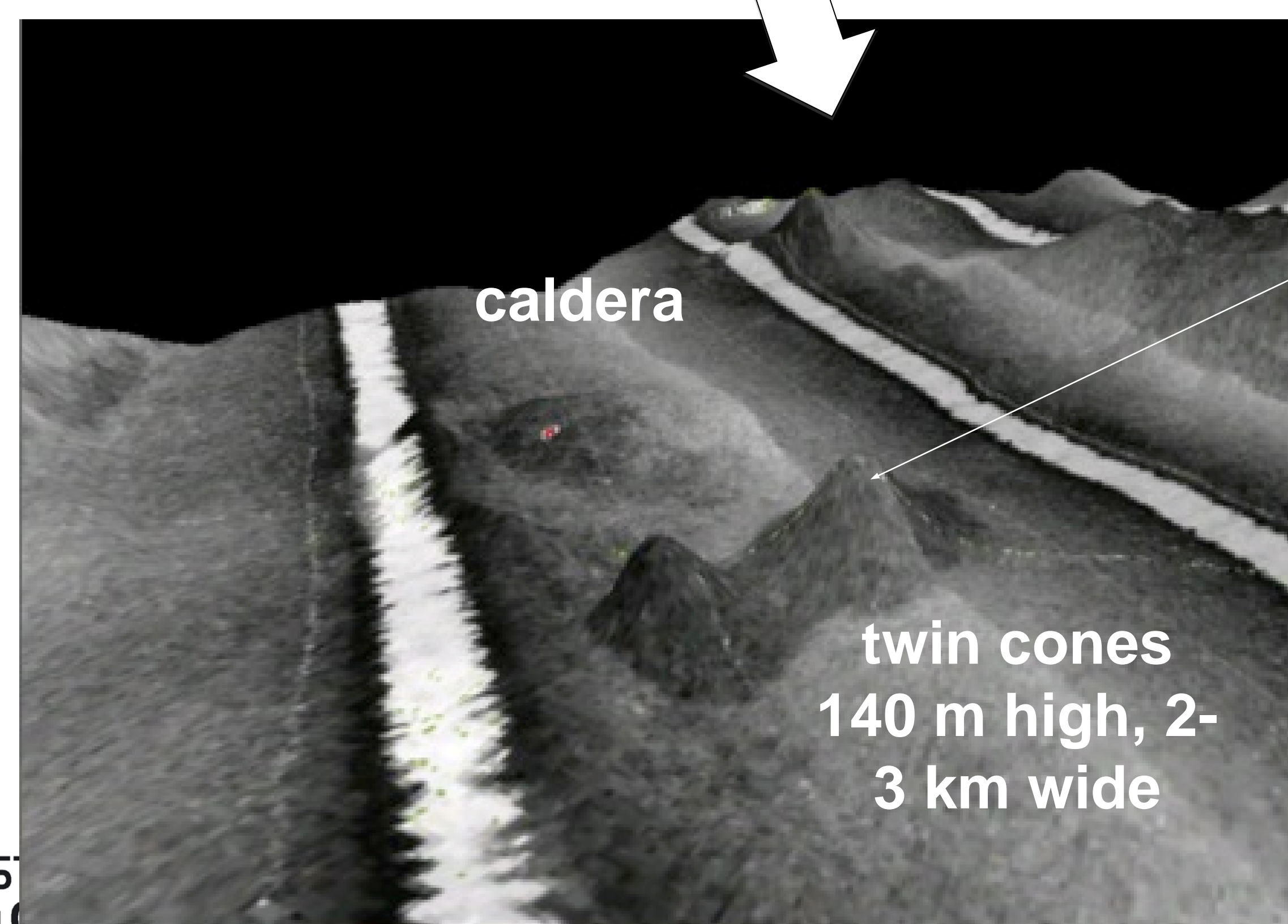
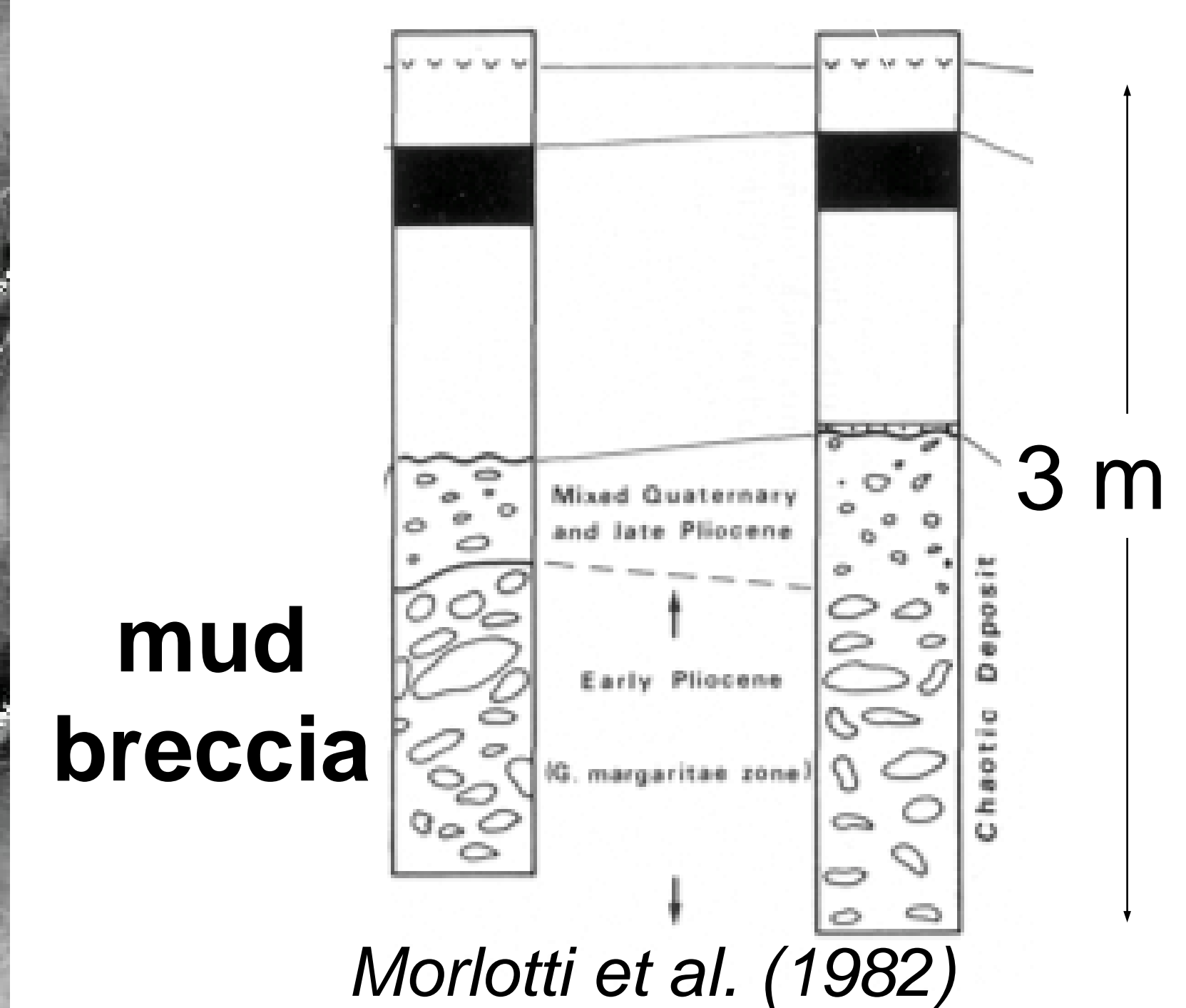
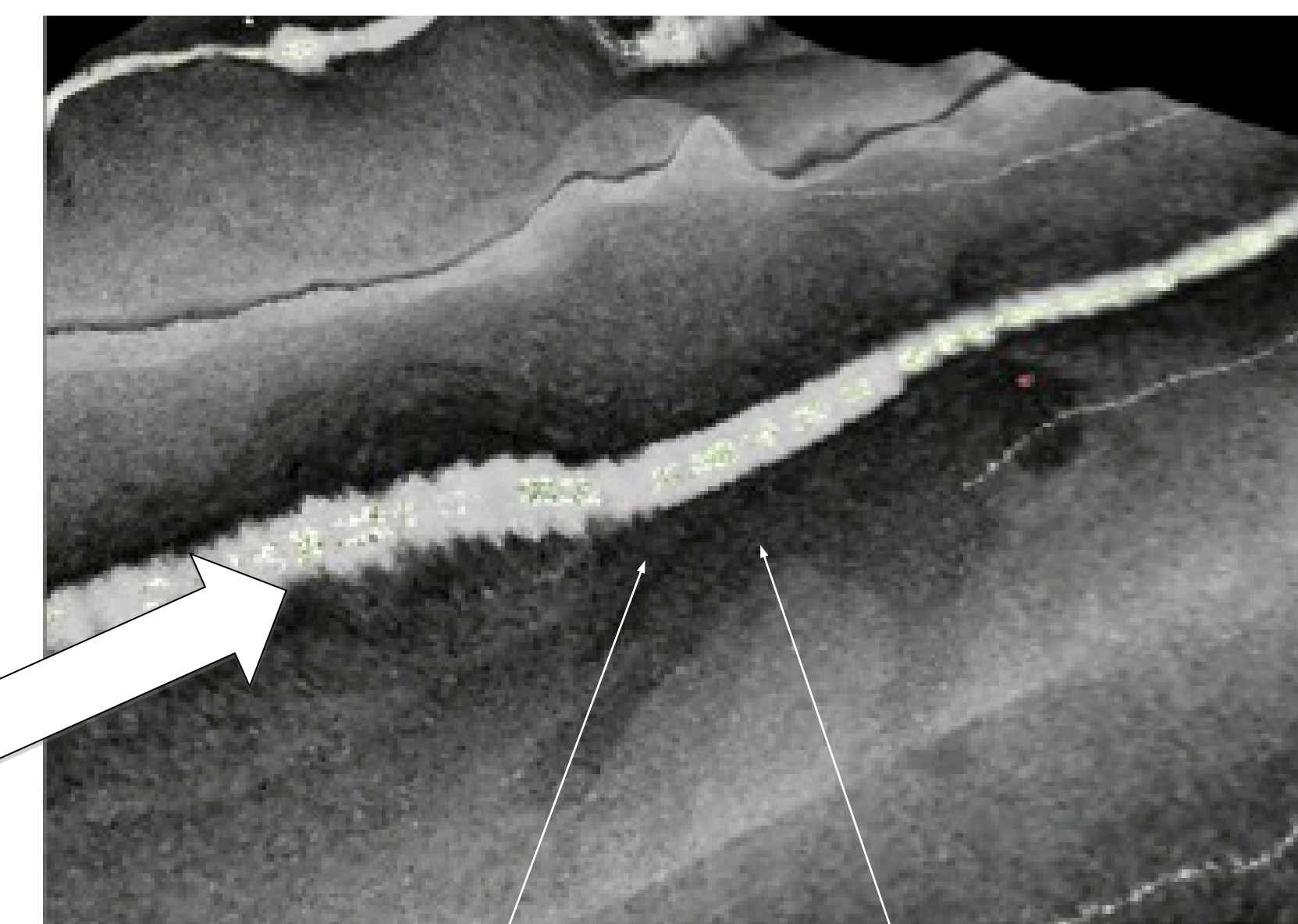
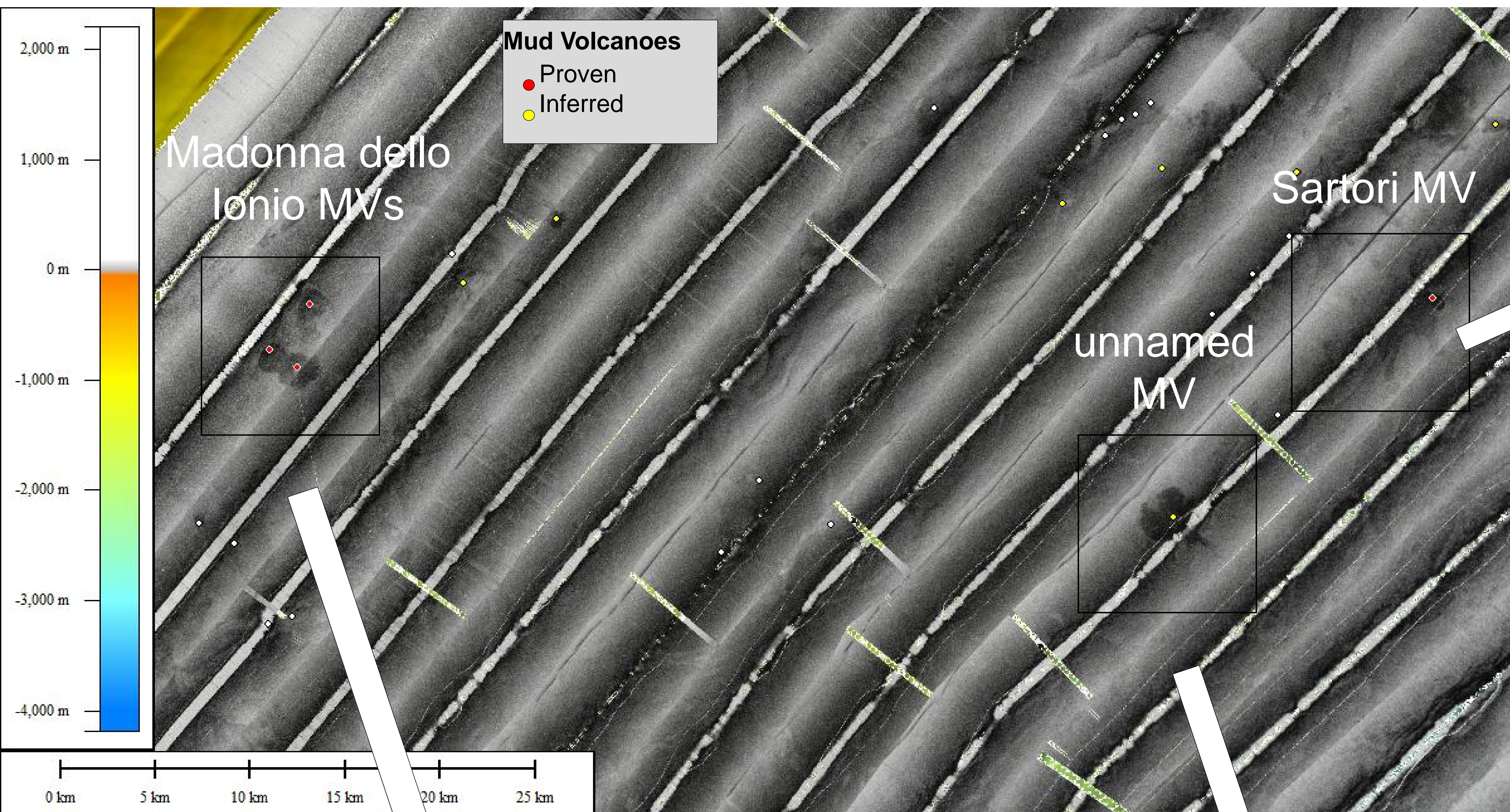
Aliyev et al. (2000)

Conceptual model of Azeri mud volcanism - deep roots (12 km), multiple mud chambers (Planke et al. 2003)

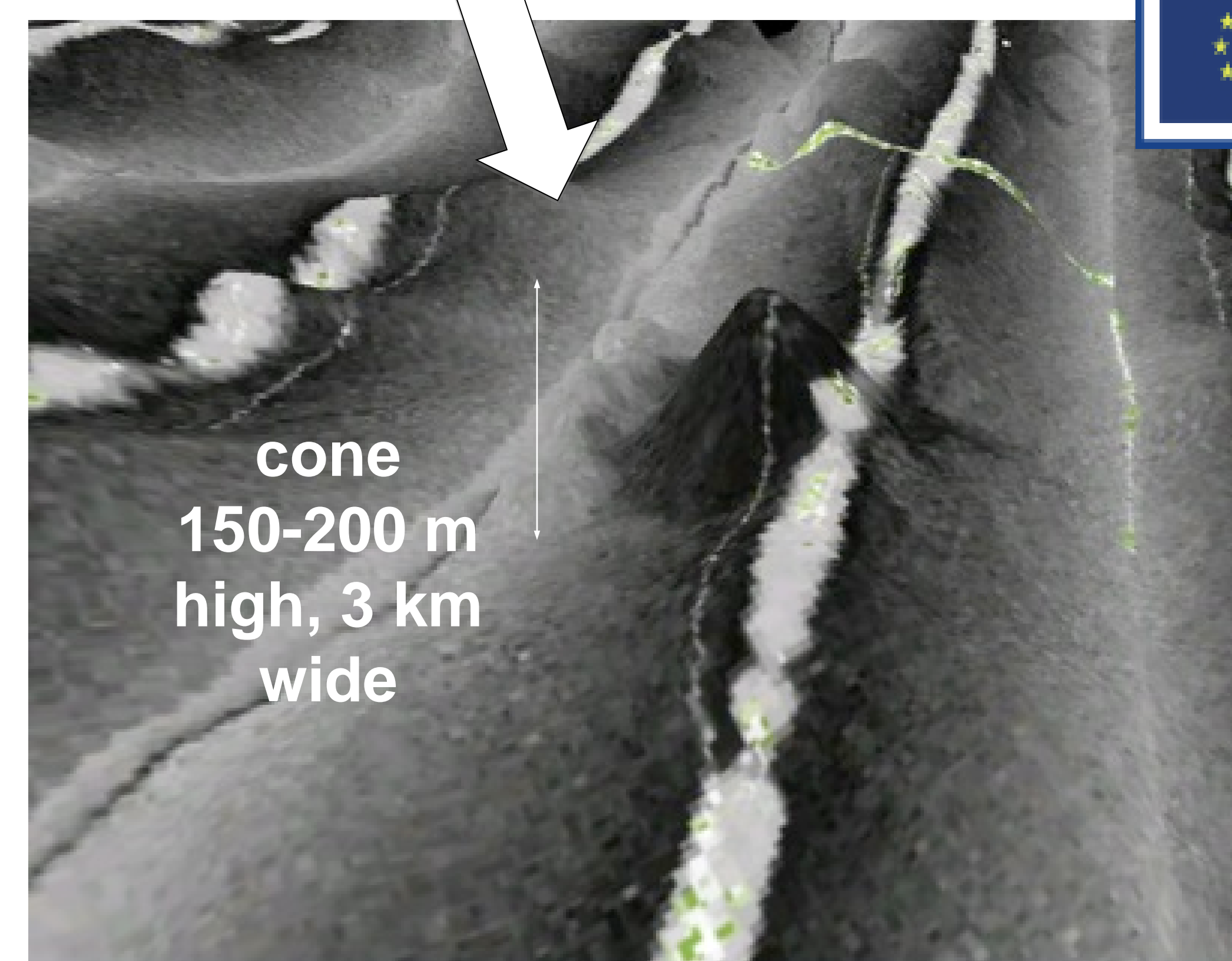




# Use of multibeam morpho-bathymetry + backscatter data to map mud volcanoes (Calabrian Arc)

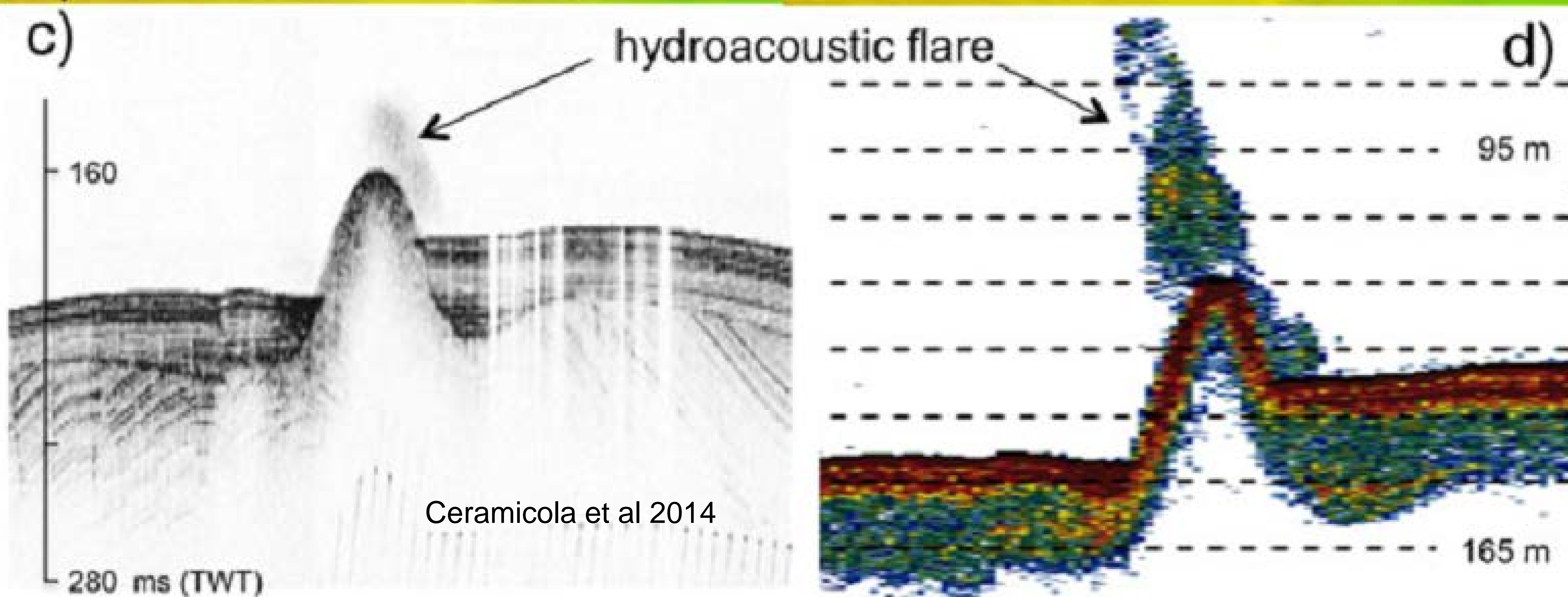
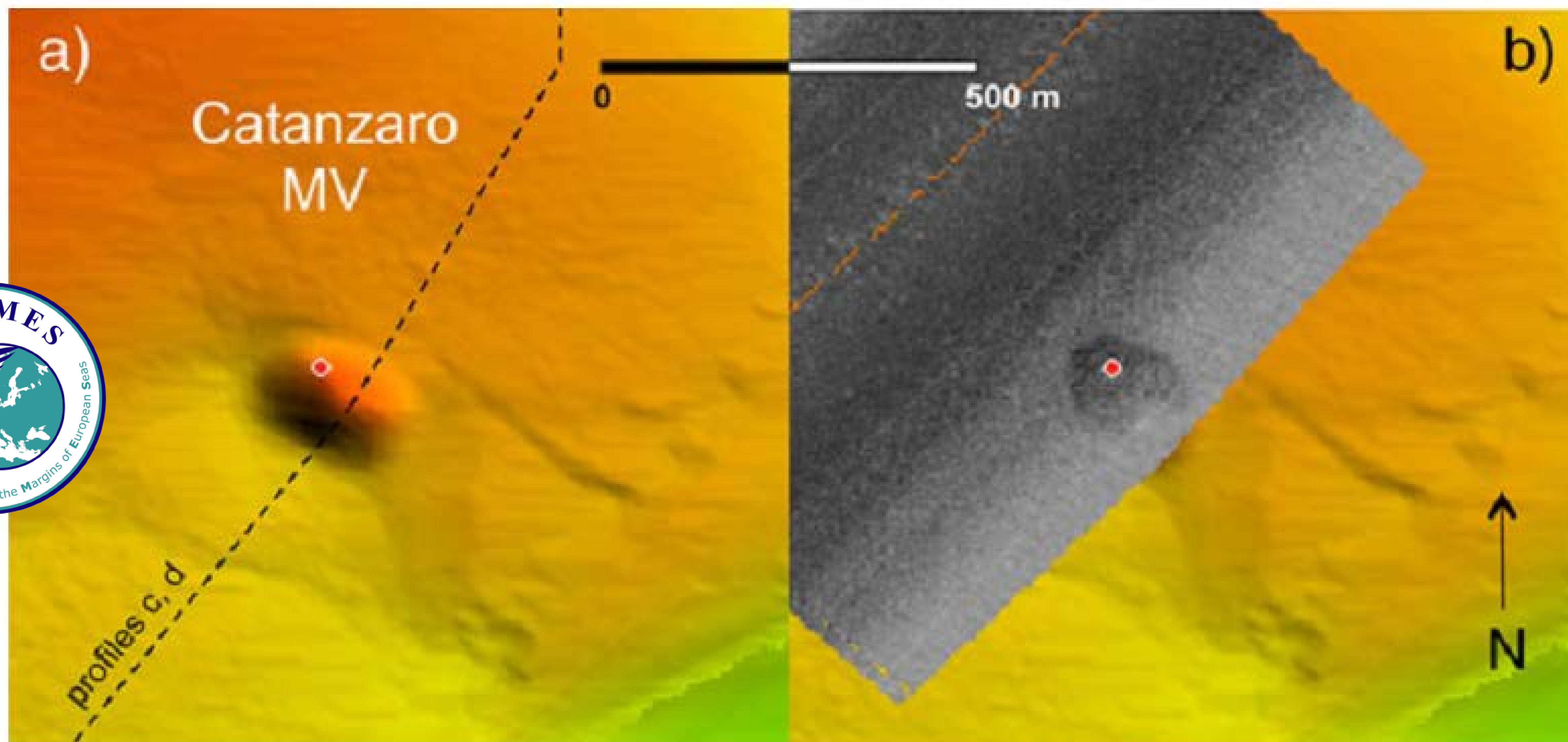


mud breccia



Ceramicola et al. (2014)



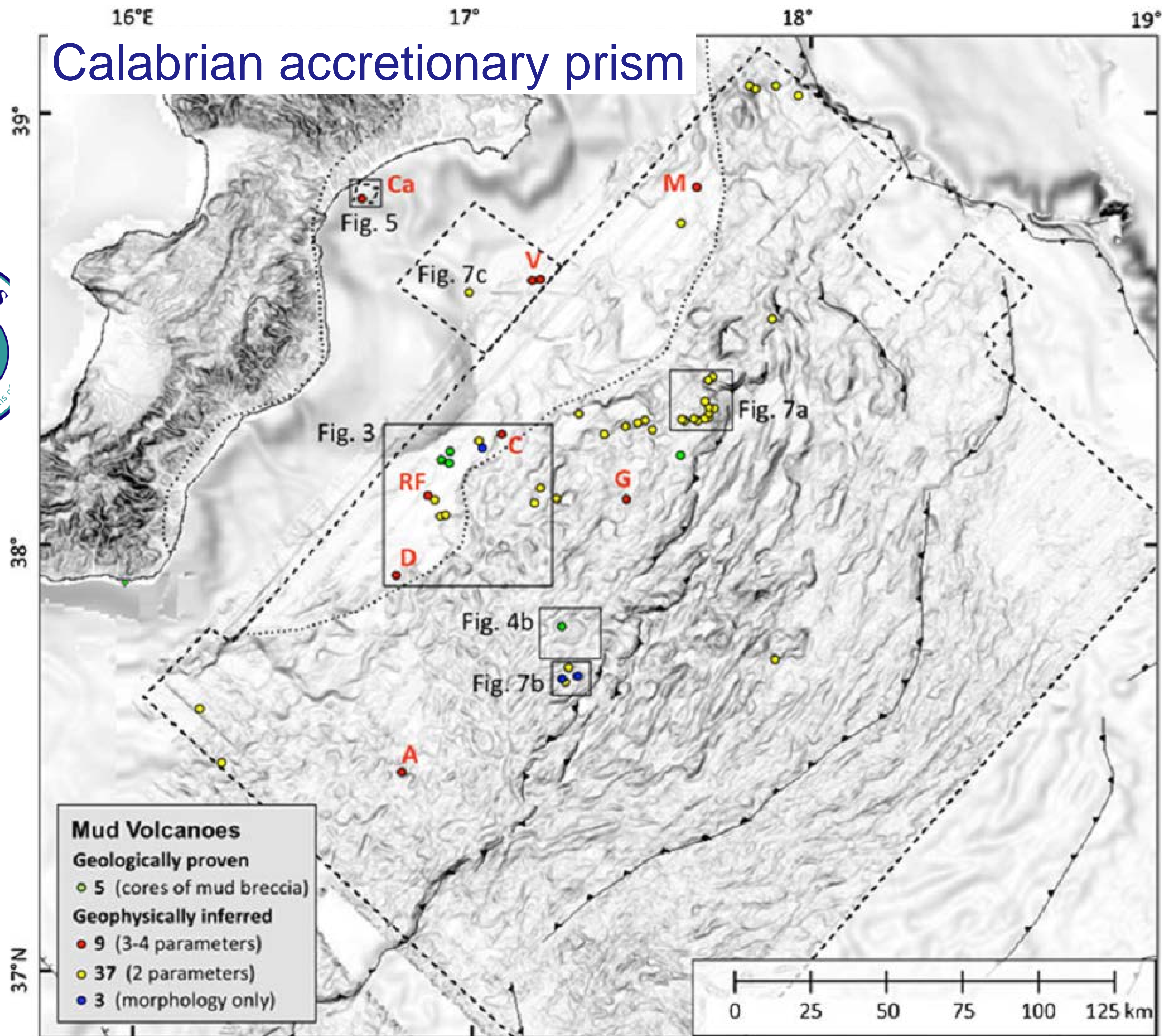


Ceramicola et al 2014





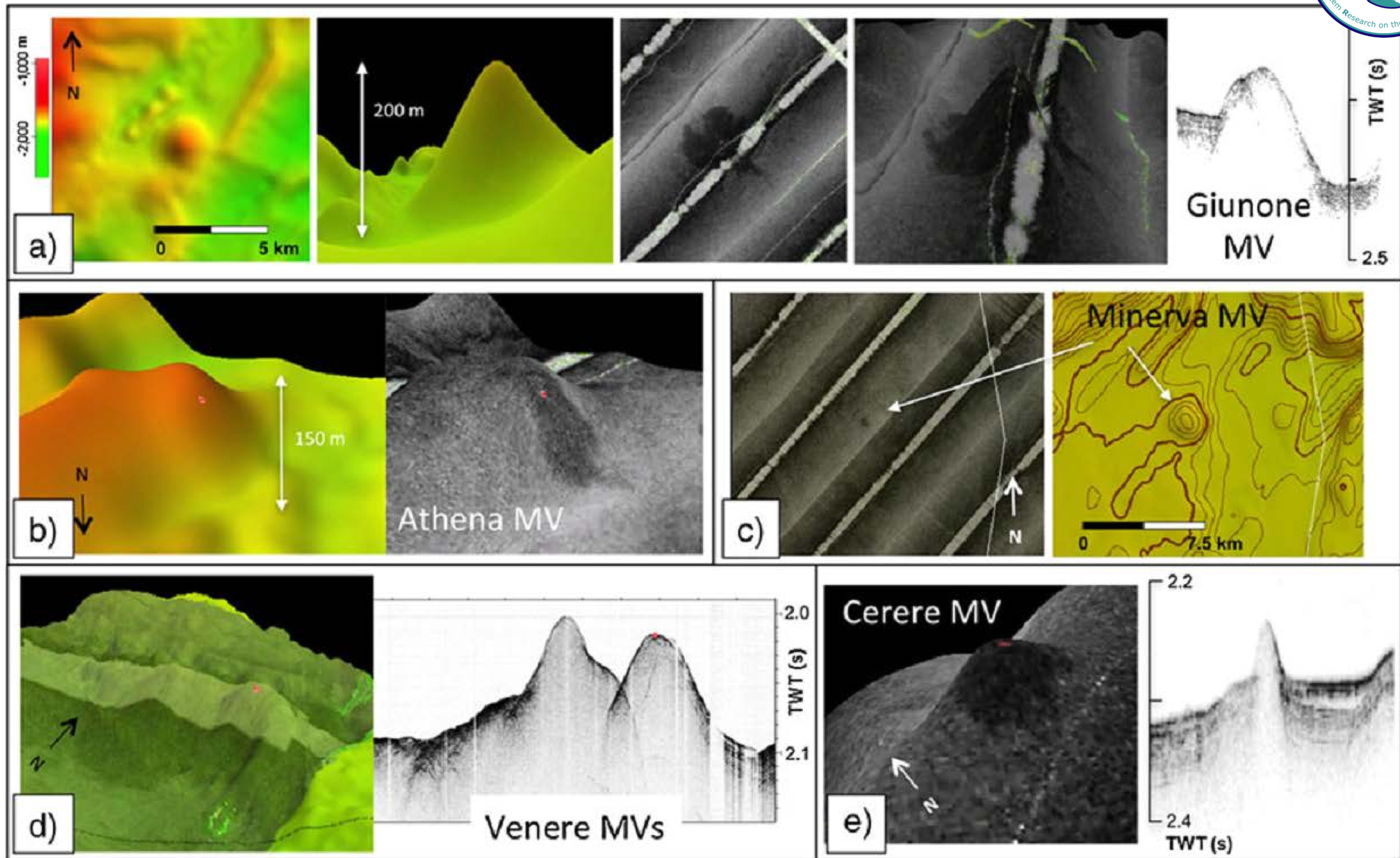
# Calabrian accretionary prism



Ceramicola et al 2014

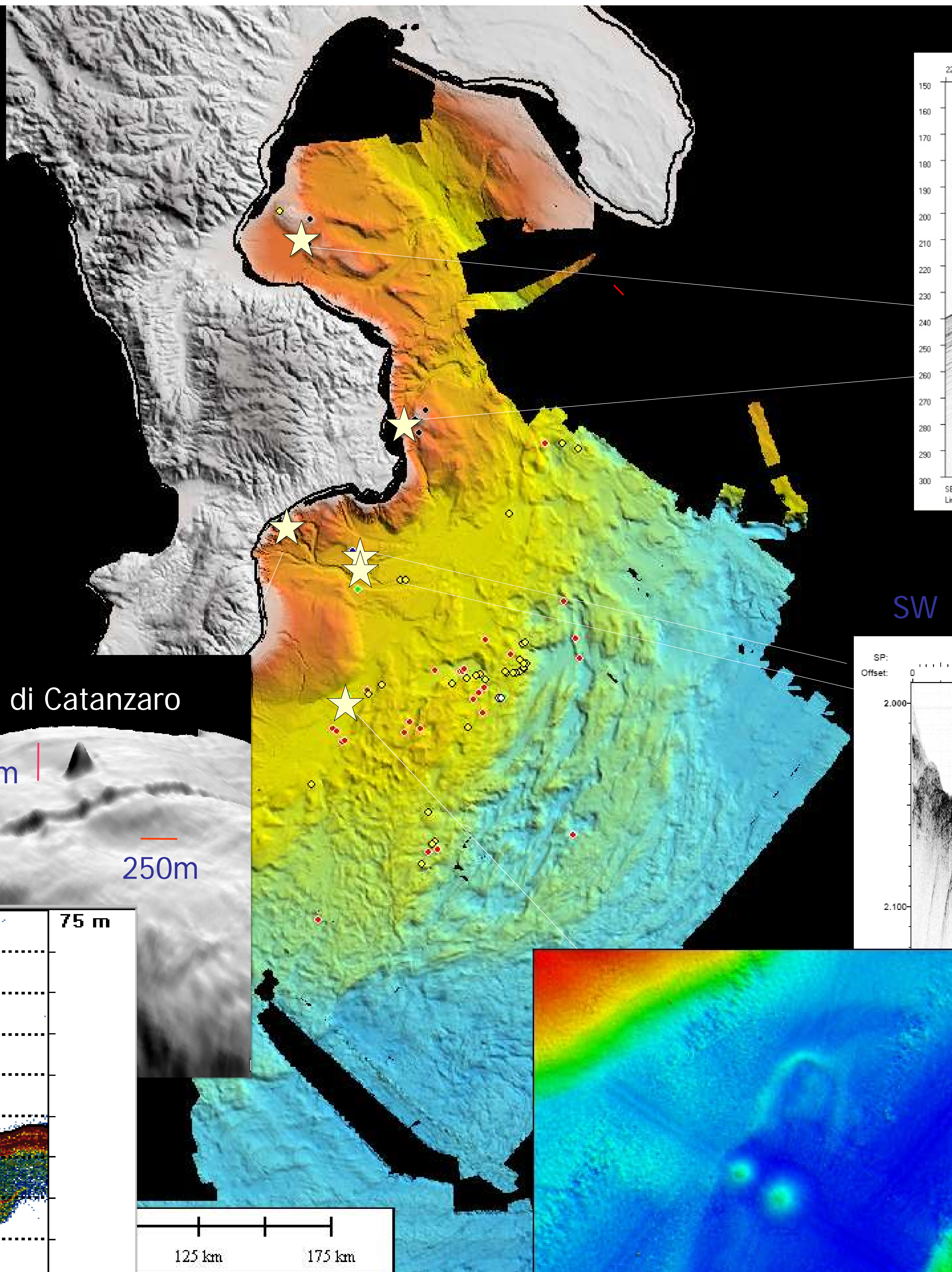
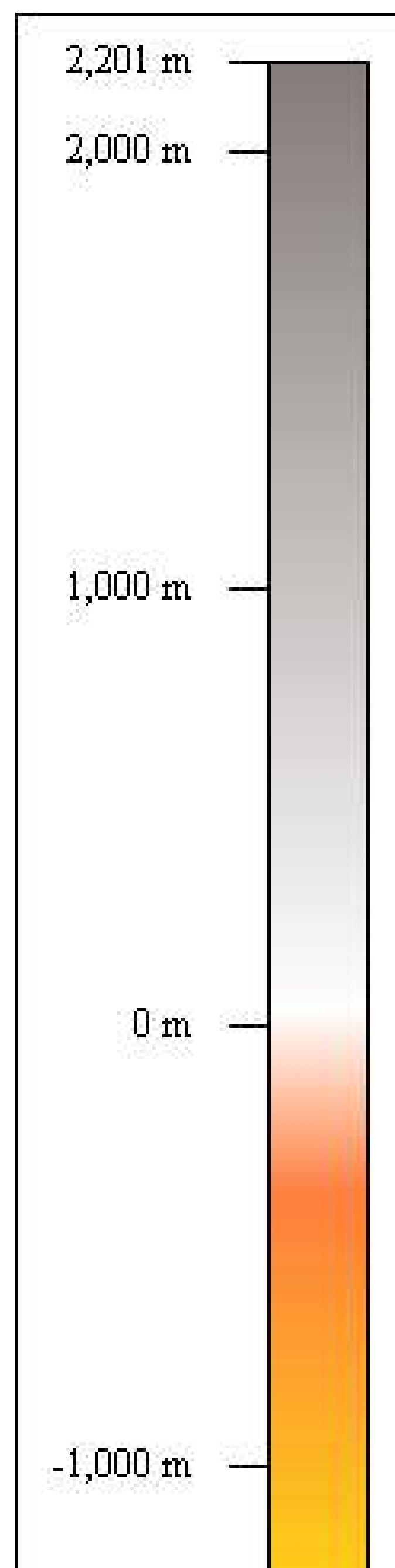




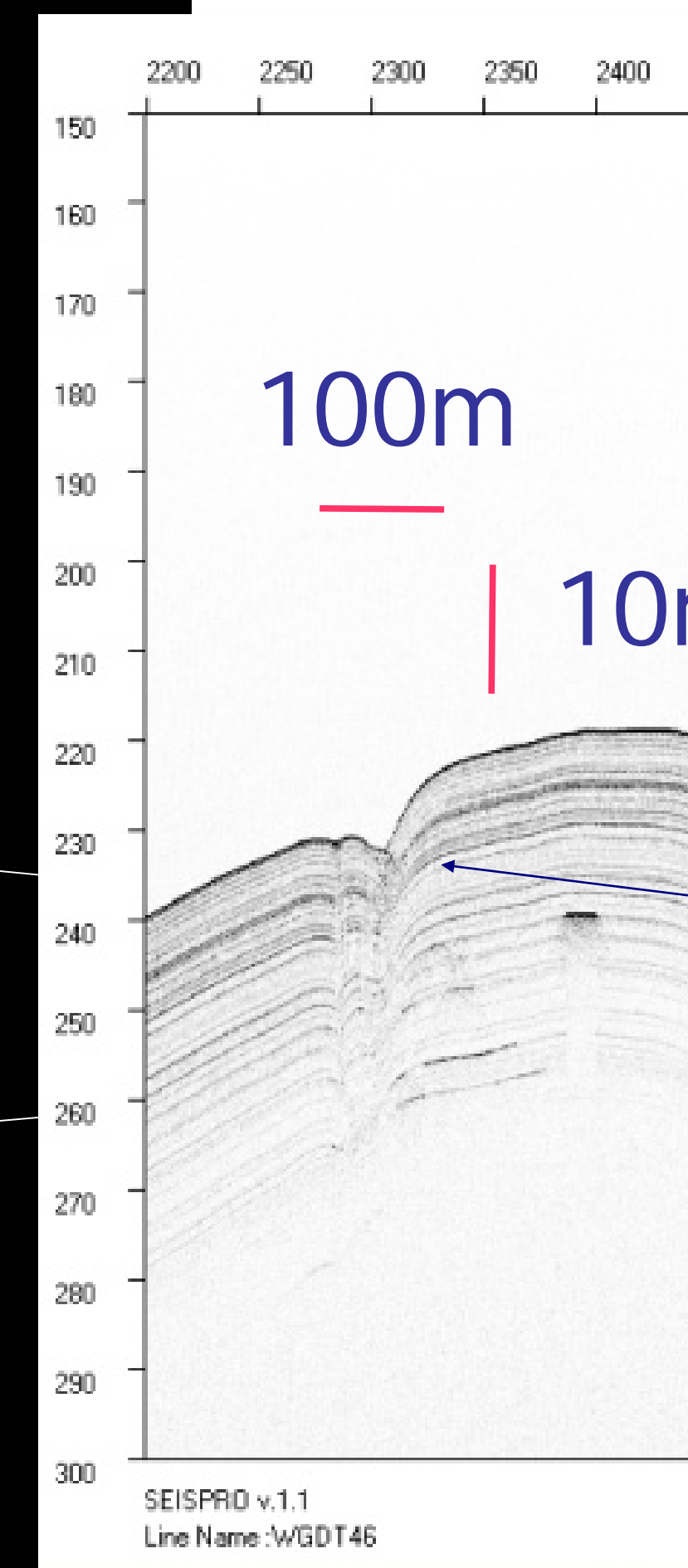


Ceramicola et al 2014



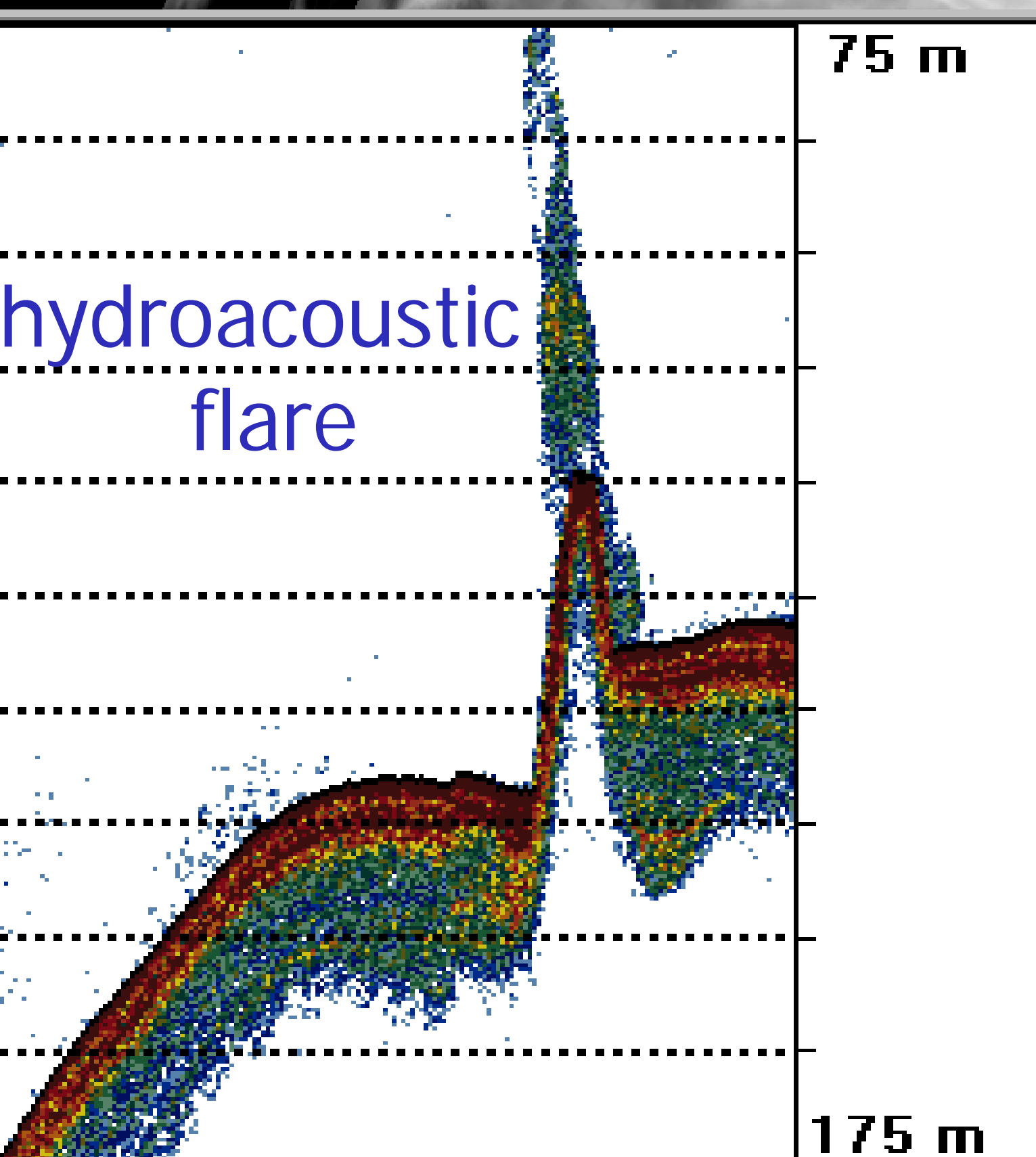
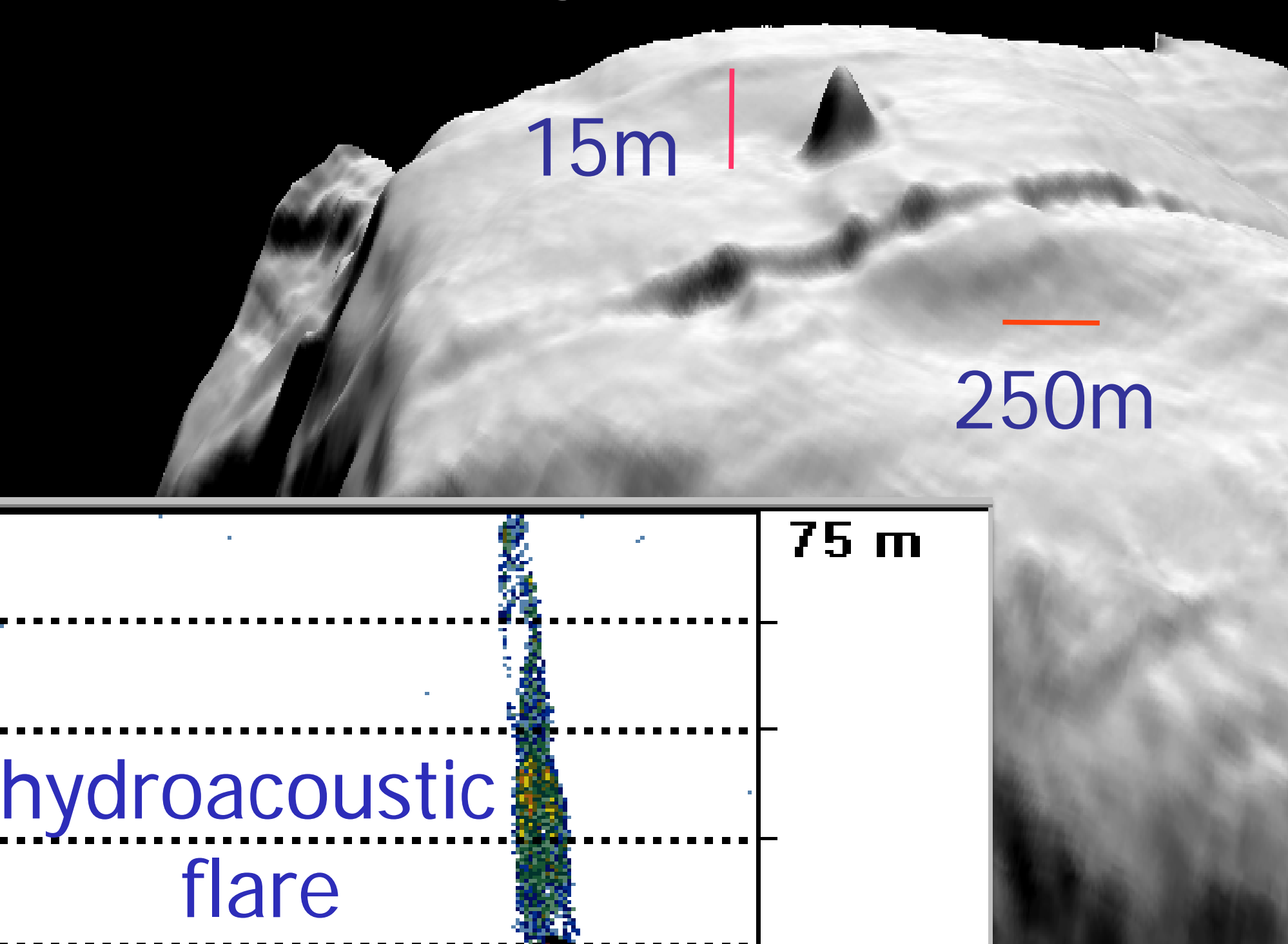


# SEABED SEEPAGE MAPPING

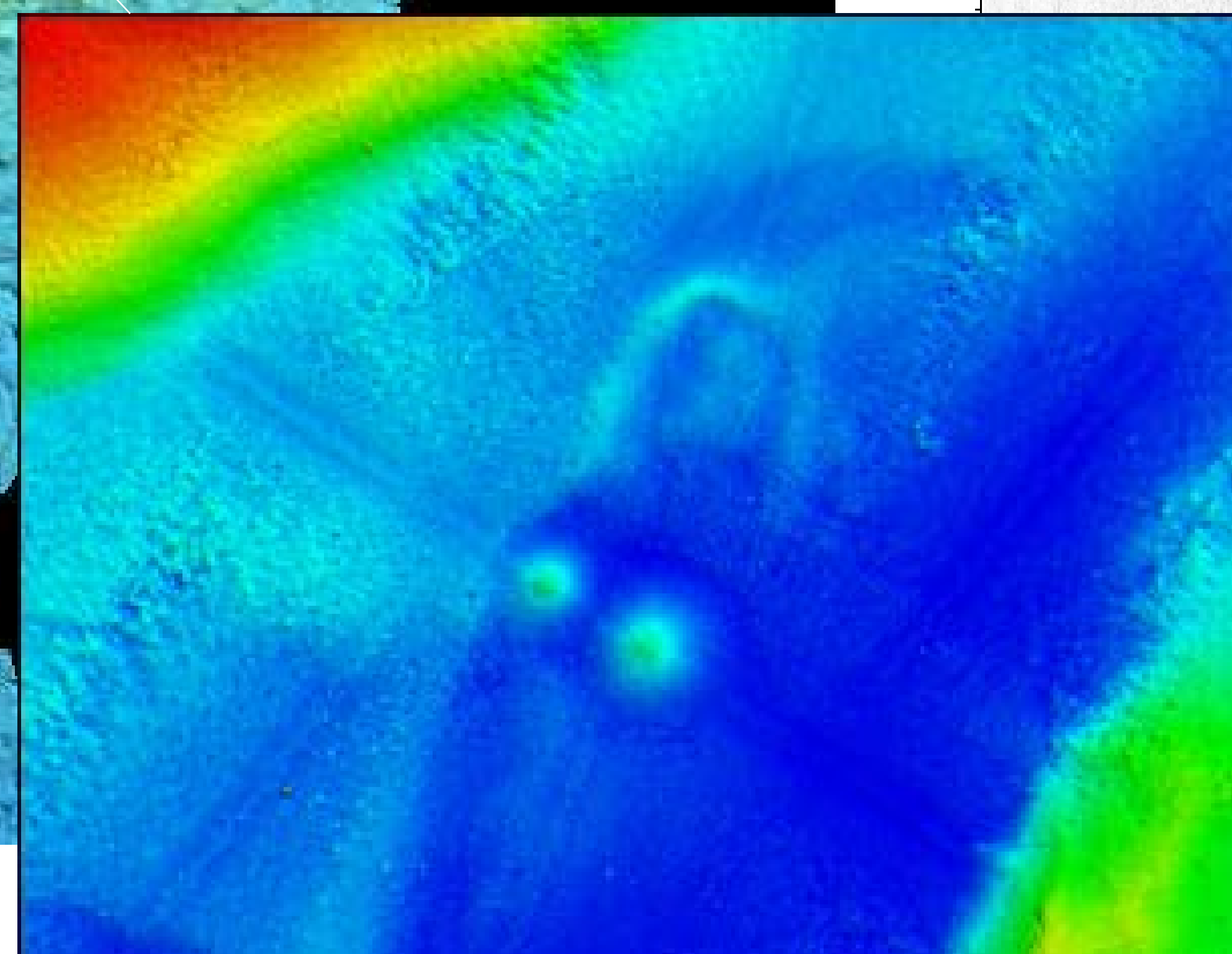
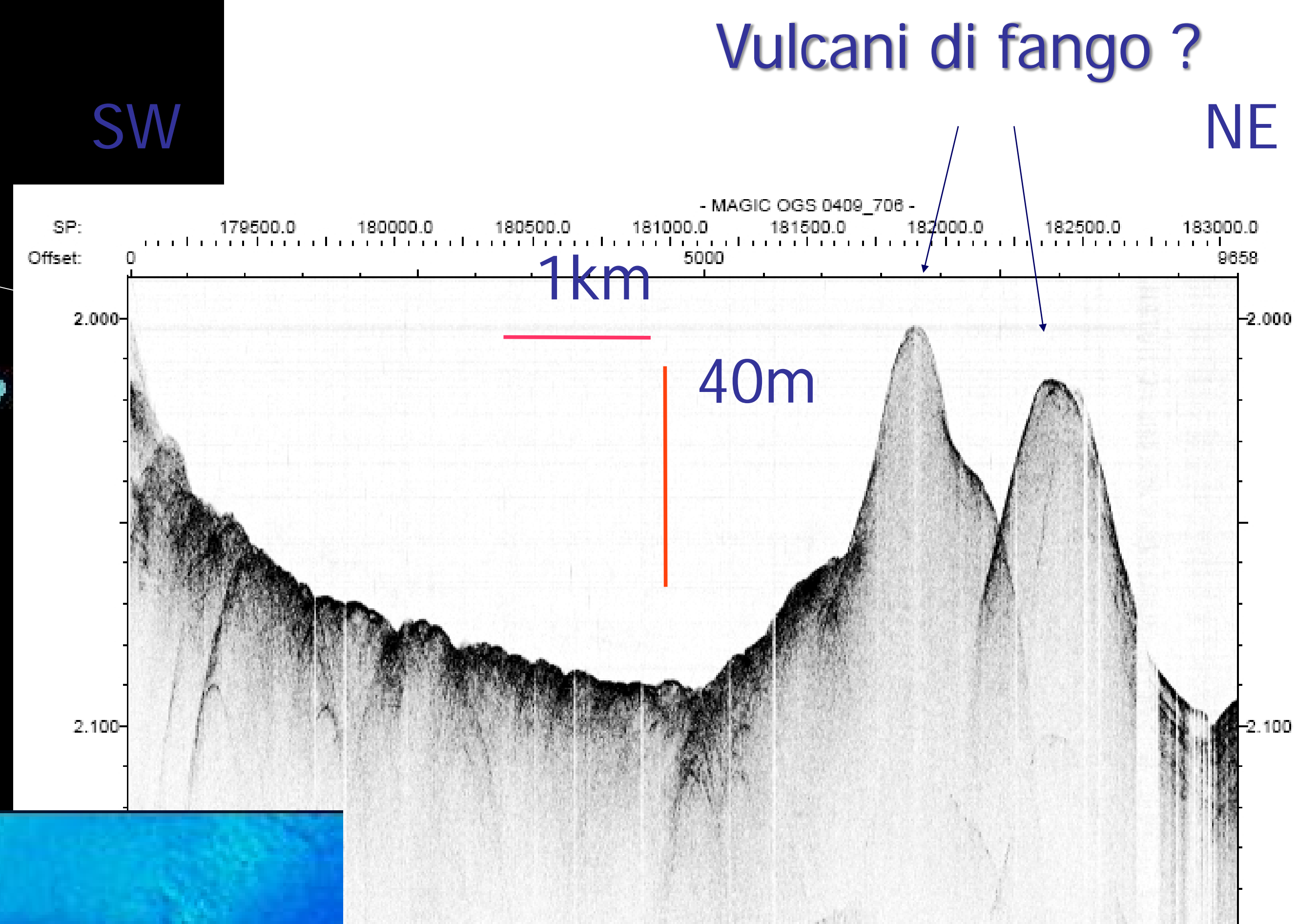


Pockmarks

Vulcano di fango di Catanzaro



ISTITUTO NAZIONALE DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE



...siti individuati nel  
...argine calabro ionico sottocosta,  
...olti di piu' sul prisma di accrezione

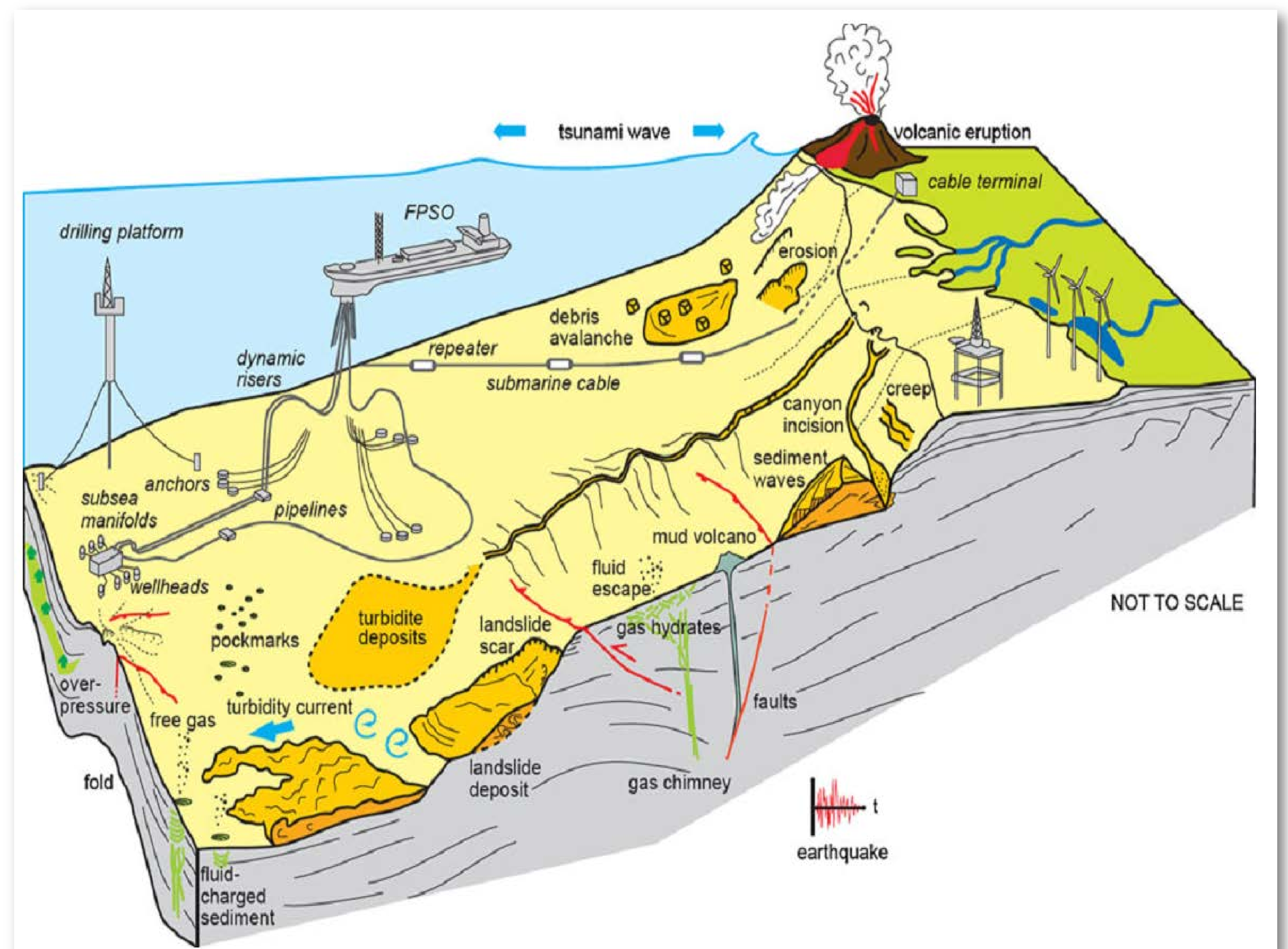


presenter: Silvia CERAMICOLA – OGS Trieste, Italy



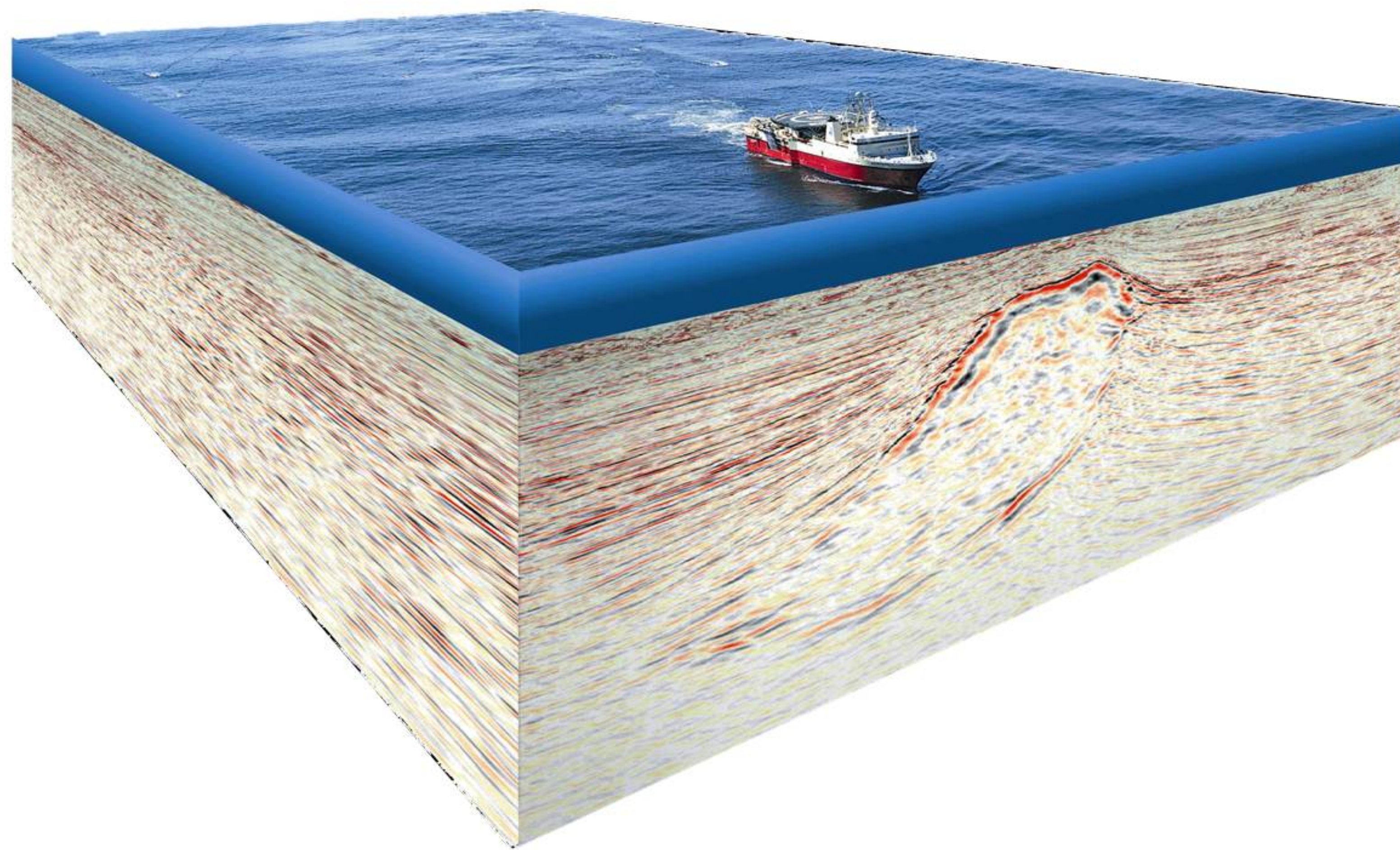
# Concluding.....

- 1) The submarine portion of continental margins can be 'disturbed' by **natural geohazards: faults, landslides, retrogressive erosional canyons and fluid emissions...** Their activity at seafloor can damage humans and (costal and deep sea) infrastructures.





# Concluding.....

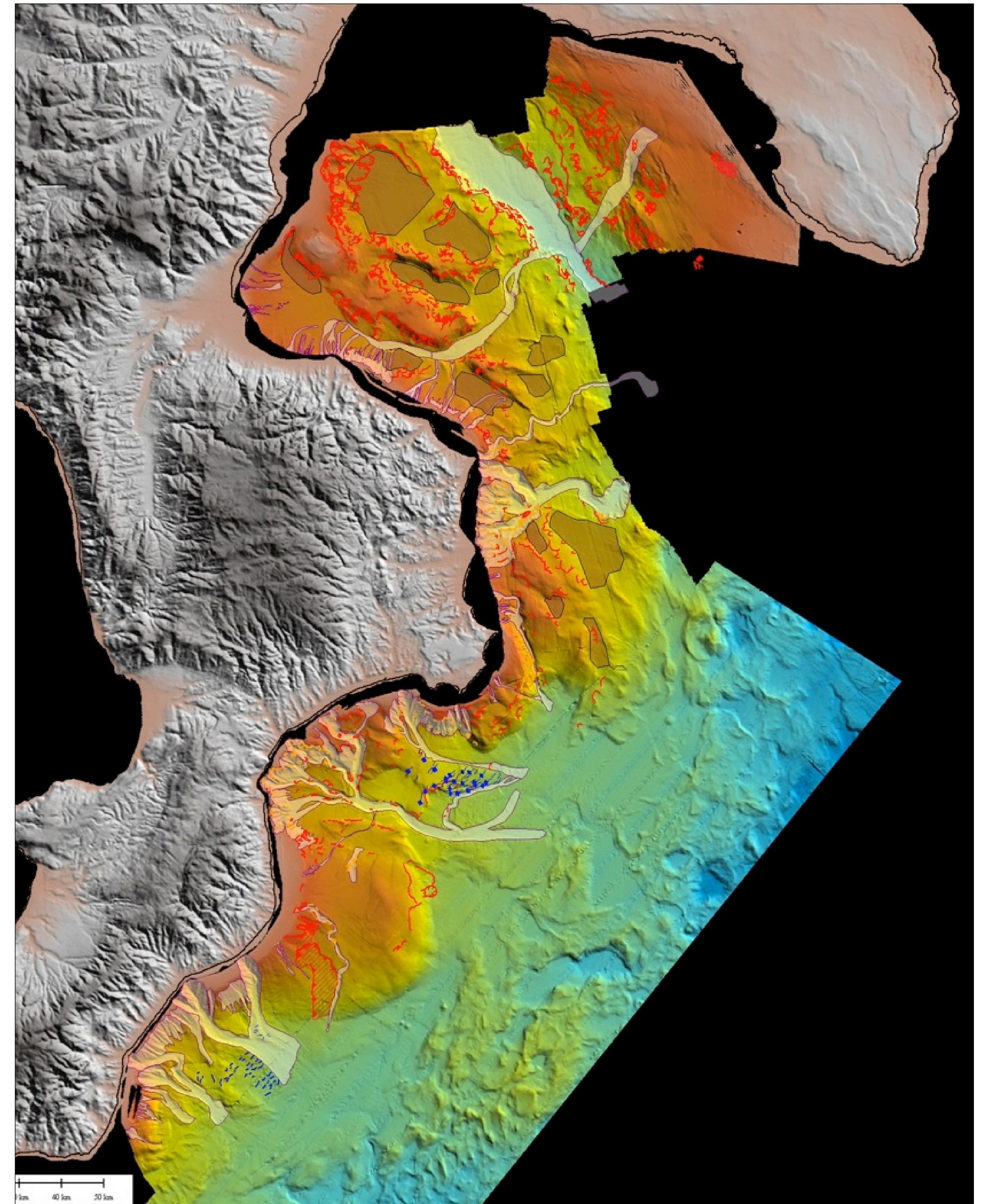


2) Integrated **marine geophysical methods (including robotics)** at different resolutions (up to cm) enable researchers to reach remote areas of our oceans and **identify marine geohazards**



# Concluding.....

- 3) **Marine geohazards assessment** is about identifying, mapping, and characterizing geohazards occurrence (their parameters and the processes that regulate their occurrence),
- 4) **Marine geohazard assessment** is a prerequisite to undertake successful risk management and risk mitigation of coastal and deep sea areas





# Further reflections

- Assessment of submarine geohazards is of broad scientific and social importance notably in the densely populated Mediterranean region
- Seimogenic faults, failure, gas seepage, tsunami and their interaction (cascading effects)
- Understanding (mechanisms and locations) of the geohazards of our seabed: maps of geohazards of all European seas, eventually Mediterranean Sea
- developing research/industry collaborative actions by means of the research vessels for sensitive infrastructures (nuclear power plant- submarine cable/pipelines)



# Critical questions

- 1) What's the difference between hazard and risk?*
- 2) Which are the most harmful marine geohazards in the Med in your opinion and why?*
- 3) Why in the Med an alerting system could be not as efficient as in the Pacific ocean?*
- 4) Why seabed mapping is important to assess marine geohazards?*



# Bibliography

## Some books and papers on marine geohazards

- Submarine geomorphology. Ed. Springer, Editors: A. Micallef, S. Krastel A. Savini Ed. Springer
- Submarine mass movements and their consequences: international symposium (1<sup>st</sup> to 7<sup>th</sup> volume) . Springer Ed.
- Regional-scale seafloor mapping and geohazard assessment. The experience from the Italian project MaGIC (Marine Geohazards along the Italian Coasts)PrFL Chiocci, D Ridente - Marine Geophysical Research, 2011 – Springer-
- Submarine mass-movements in the Ionian Calabrian margin and their consequences for marine geohazards: S. Ceramicola, S., Praeg, D. Coste, M., Forlin, E. Colizza, F. Critelli, S. (2014).. In Submarine Mass Movements and Their Consequences, 6th International Symposium, Advances in Natural and Technological Hazards Research (Krastel et al., Eds); Springer Science + Business Media B.V. Ch. 26, pp. 295-306, doi:10.1007/978-3-319-00972-8\_26.

## International projects on marine geohazards

SLATE: Project <http://itn-slate.eu/project/>

IGCP 640 S4Slide <http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/international-geoscience-programme/igcp-projects/geohazards/project-640-new-2015/>



# On the WEB

## Preparedness and Disaster

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

**Meet "Disaster" and "Preparedness" -- two characters who will help you understand why you need to take personal responsibility to prepare yourself and your family for potential emergencies. Produced by the Metropolitan Emergency Managers Committee with funding support from the Kansas City Regional Homeland Security Coordinating Committee's Urban Area Security Initiative grant.**



# Media and outreach

## TWIST

### TIDAL WAVE IN SOUTHERN

Salerno – 25 maggio 2013

Emergency exercise simulating a tsunami wave against the coast of Salerno, following a submarine failure along the volcano Palinuro

24 -25 -26 -27 October 2013

Croatia, France, Greece, Italy  
Malta, Portugal, Spain

**IO NON RISCHIO maremoto**

### Que faut-il savoir et faire AVANT le raz-de-marée

**Que dois-tu savoir ?**  
Si tu vis, travailles ou vas en vacances dans une aire côtière, apprends à reconnaître les phénomènes qui peuvent signaler l'arrivée d'un raz-de-marée :

- Un fort tremblement de terre que tu as ressenti directement ou dont tu as été informé
- Un bruit sourd et croissant qui provient de la mer, comme celui d'un train ou d'un avion volant en rase-motte
- Un retrait de la mer soudain et insolite, un soulèvement rapide du niveau de la mer ou une grande vague étendue sur tout l'horizon

Rappelle-toi que les maisons et les bâtiments proches de la côte ne sont pas toujours sûrs.

- La sûreté d'un édifice dépend de plusieurs facteurs, par exemple la typologie et la qualité des matériaux employés dans la construction, l'altitude où il se trouve, la distance du rivage, le nombre d'étages, l'exposition plus ou moins directe à l'impact de l'onde
- Généralement les étages hauts d'un édifice en béton, si l'édifice est bien construit, peuvent offrir une protection convenable

**Que dois-tu faire ?**  
Connaître le milieu où tu vis, tu travailles ou séjournes, est important pour mieux réagir en cas d'urgence :

- Renseigne-toi auprès des responsables locaux de la Protection Civile au sujet du plan d'urgence de la commune, des zones dangereuses, des voies et des temps d'évacuation, de la signalisation à suivre et des aires d'attente à rejoindre en cas d'urgence
- Renseigne-toi sur la sécurité de ta maison et des endroits qui l'entourent
- Assure-toi que ton école et ton lieu de travail ont un plan d'évacuation et que des exercices d'entraînement sont faits périodiquement
- Prépare-toi à l'urgence avec ta famille et fais un plan sur la façon de rejoindre les voies de fuite et les aires d'attente
- Garde chez toi un coffret pharmacie prêt à l'usage et des réserves d'eau et nourriture

**APPRENDRE À PRÉVENIR ET RÉDUIRE LES EFFETS DU RAZ-DE-MARÉE EST UNE TÂCHE QUI NOUS REGARDE**

Partage ce que tu sais en famille, à l'école, avec les amis et collègues : la diffusion d'informations sur le risque du raz-de-marée est une responsabilité collective, à laquelle nous devons tous contribuer.

La campagne **IO NON RISCHIO maremoto** (Je ne risquais pas le raz-de-marée) est réalisée par :

PROTEZIONE CIVILE, INGV, ANPAS, reluis

En collaboration avec : ISPRA, OGS

**IO NON RISCHIO** est une campagne d'information nationale sur les risques naturels et anthropiques qui intéressent notre pays. Elle s'adresse aux citoyens avec l'objectif de promouvoir un rôle actif dans le domaine de la prévention. Les protagonistes de cette initiative sont d'autres citoyens organisés, formés et préparés : les volontaires de la protection civile. Des hommes et des femmes qui contribuent quotidiennement à la réduction du risque en s'engageant personnellement.

**IO NON RISCHIO maremoto**  
BUONE PRATICHE DI PROTEZIONE CIVILE

www.iononrischio.it  
facebook.com/iononrischio  
@iononrischio

**IO NON RISCHIO maremoto**

### Cosa fare DURANTE il maremoto

Se sei in spiaggia o in una zona costiera e riconosci almeno uno di questi fenomeni:

- Forti terremoto che hai percepito direttamente o di cui hai avuto notizia
- Improvviso e insolito ritiro del mare, rapido innalzamento del livello del mare o grande onda estesa su tutto l'orizzonte
- Rumore cupo e crescente che proviene dal mare, come quello di un treno o di un aereo a bassa quota

Alontanati e raggiungi rapidamente l'area vicina più elevata (per esempio una collina o i piani alti di un edificio).

Avverti le persone intorno a te del pericolo imminente.

Corri a piedi seguendo la via di fuga più rapida. Non usare l'automobile, potrebbe diventare una trappola.

Se sei in mare potresti non accorgerti dei fenomeni che accompagnano l'arrivo di un maremoto, per questo è importante ascoltare sempre i comunicati radio:

se sei in barca e hai avuto notizia di un terremoto sulla costa o in mare, portati al largo, se sei in porto abbandona la barca e mettili al sicuro in un posto elevato.

**Cosa fare DOPO il maremoto**

Rimani nell'area che hai raggiunto e soccorri chi vuole tornare verso la costa: alla prima onda potrebbero seguirne altre più pericolose.

Assicurati delle condizioni di salute delle persone intorno a te e, se possibile, presta i primi soccorsi.

Rivolgiti alle autorità per capire quando lasciare il luogo in cui ti trovi e cosa fare.

Usa il telefono solo per reale necessità.

Se la tua abitazione è stata interessata dal maremoto, non rientrare prima di essere autorizzato.

Non mangiare cibi che siano venuti a contatto con l'acqua e con i materiali trasportati dal maremoto: potrebbero essere contaminati. Non bere acqua del rubinetto.

Il maremoto può essere generato da un sisma o da attività vulcanica: informati, quindi, anche su cosa fare in caso di terremoto o eruzione.

www.protezionecivile.gov.it  
www.anpas.org  
www.ingv.it  
www.reluis.it  
www.isprambiente.gov.it  
www.ogs.trieste.it



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