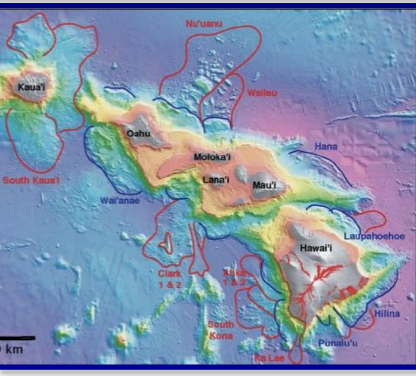
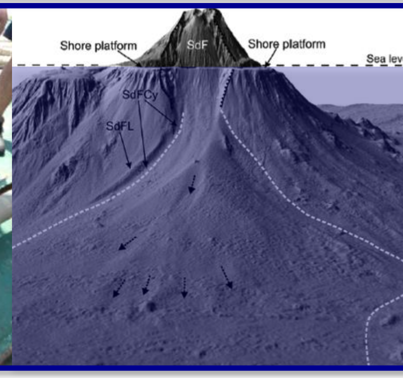
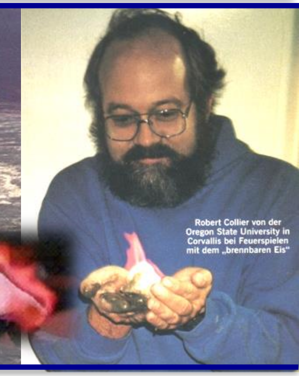


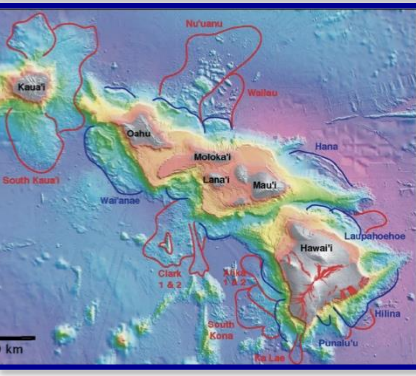



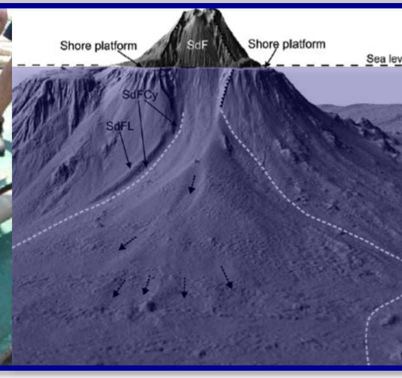
SUBMARINE GEOHAZARDS

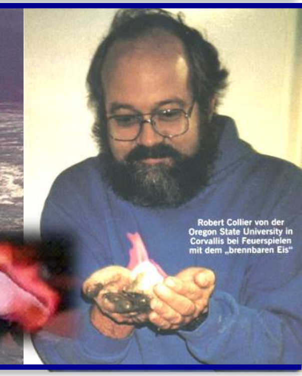
Angelo Camerlenghi

OGS - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italy

SUBMARINE GEOHAZARDS



OUTLINE

- DEFINITIONS
- DISTRIBUTION
- CASE STUDIES
- CAUSES (Triggers VS pre-conditioning factors)
- COMPLEXITY (Phenomena depend, often, one to another)

BASIC CONCEPTS

HAZARD: Is an **event** posing a threat to life, health, property or environment. Hazard assessment is the evaluation of the the **probability** of occurrence of a potentially damaging event, (where, when, how frequently, magnitude)

VULNERABILITY: is the **probability** that a community can be affected by the impact of a hazard.

RISK: is the **probability** that a specific hazard will cause harm.

Risk = Hazard x Vulnerability

Japanese Earthquake Highway Repair

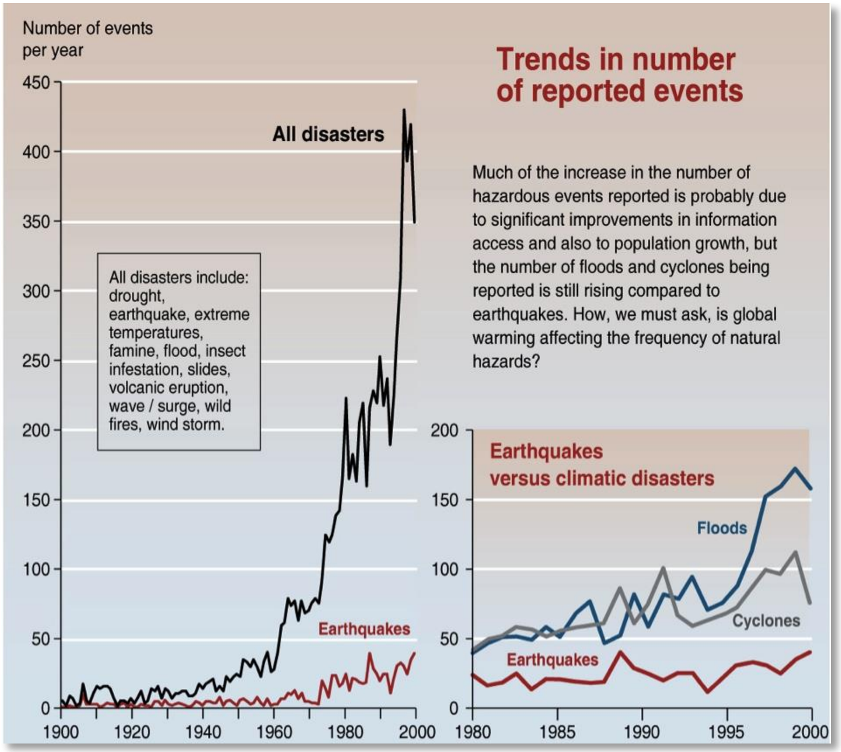
- **Earthquake: March 11 2011**
- **Repair begun: March 17 2011**
- **Road ready: March 22 2011 (six days later)**

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

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

Risk = (Hazard x Vulnerability) - Resilience

Concern for Society

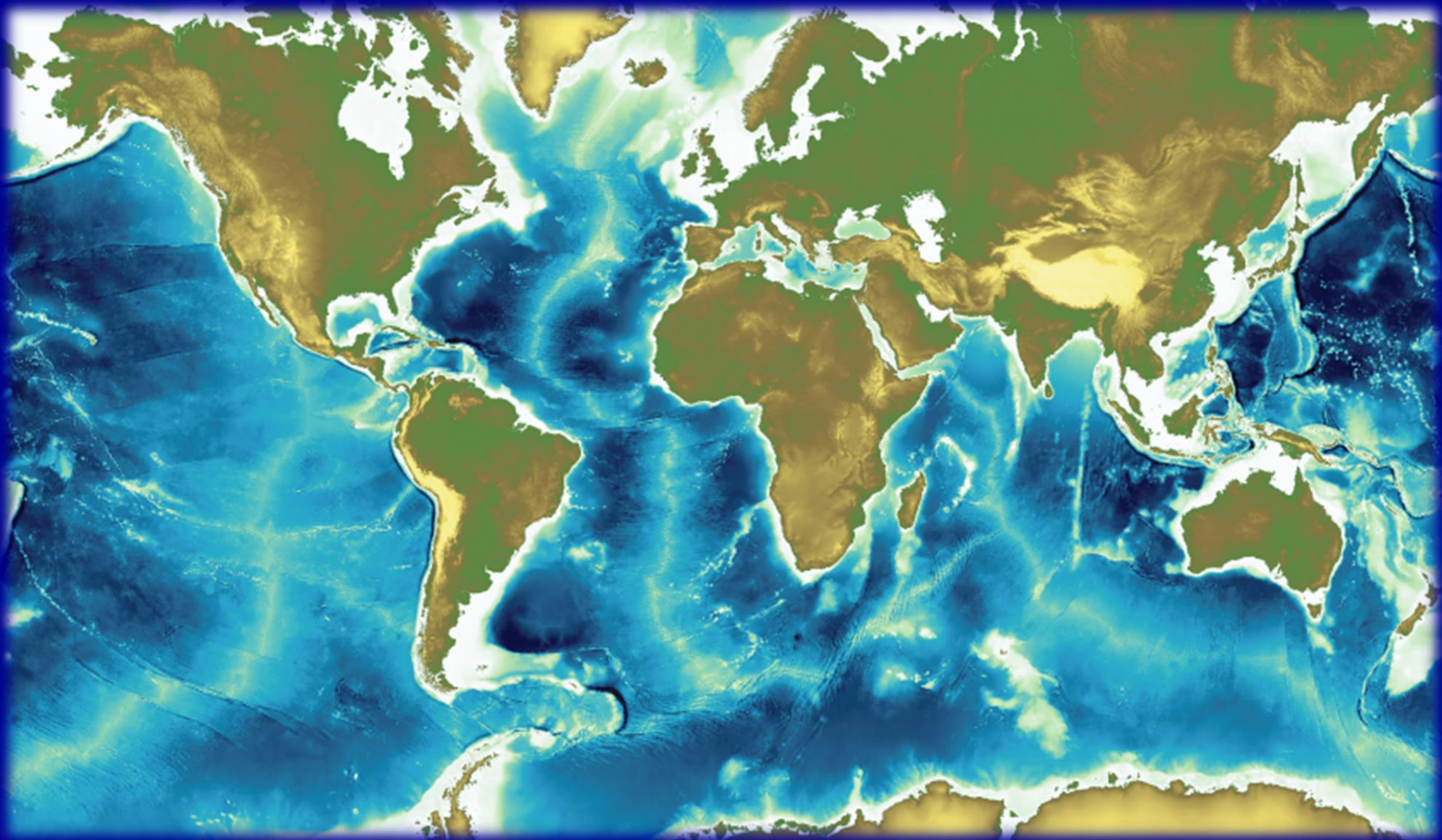


Source: UNEP GRID Arendal
http://maps.grida.no/go/graphic/trends-in-natural-disasters

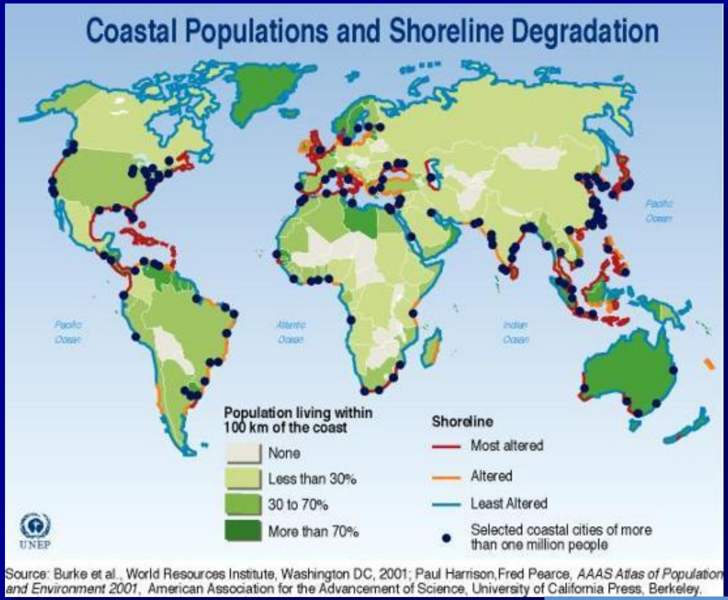
Global warming?	Anthropization Poor planning	Preparedness of modern society

Risk = (Hazard x Vulnerability) - Resilience

The World is Blue....



The overwhelming bulk of humanity is concentrated along or near coasts on just 10% of the earth's land surface



Coastal areas with high population densities are those with the most shoreline degradation or alteration. Densely populated areas close to seas are also the most attractive for a lot of **economic activity**.

Top Ten World Largest Cities:

- Tokyo, Japan (coastal)
- Mexico Cisty, Mexico
- Mumbai, India (coastal)
- Sáo Paulo, Brazil
- New York City, USA (coastal)
- Shanghai, China (coastal)
- Lagos, Nigeria (coastal)
- Los Angeles, USA (coastal)
- Calcutta, India (coastal)
- Buenos Aires, Argentina (coastal)

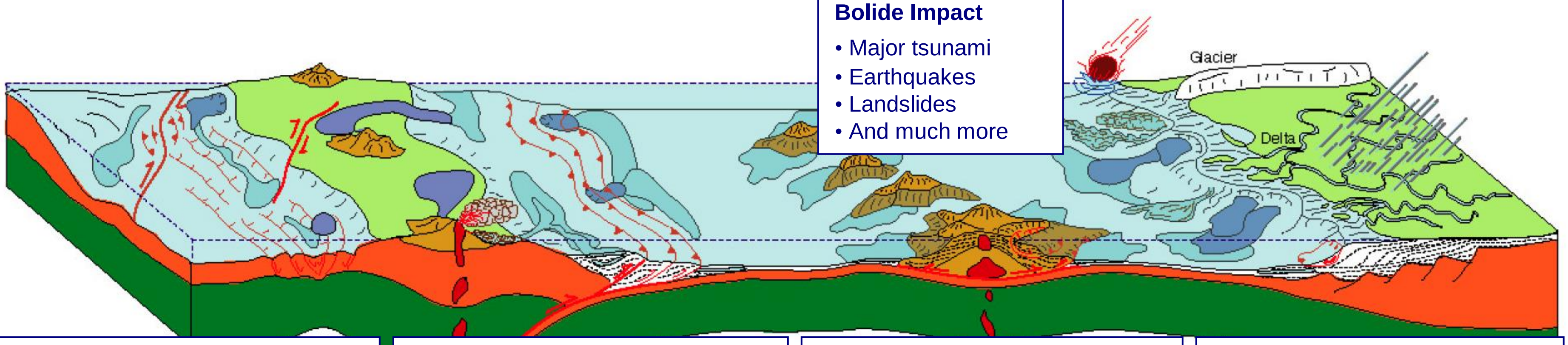
….we must understand submarine hazards

SUBMARINE GEOHAZARDS

- **EARTHQUAKES** originated below the sea floor
- **VOLCANIC ISLAND ERUPTIONS** and **FLANK COLLAPSE**
- **SUBMARINE LANDSLIDES** and sediment mass movements (turbidity currents, debris flows, slumps)
- **TSUNAMIS** (originated by the above)
- **METHANE EMISSIONS**
- **METEORITE IMPACTS in the OCEANS**

SUBMARINE GEOHAZARDS OCCUR IN ALL OCEANIC ENVIRONMENTS but THEY CONCENTRATE ON CONTINENTAL MARGINS

Bolide Impact
- Major tsunami
- Earthquakes
- Landslides
- And much more



Rift & Transform Margins
- Moderate earthquakes
- Submarine/subaerial landslides
- Debris flows, turbidity currents
- Tsunamis
- Methane emissions

Subduction Margins
- Large earthquakes
- Submarine/subaereal landslides
- Explosive eruptions, lahrs
- Debris flows, turbidity currents
- Tsunamis
- Methane emissions

Oceanic Volcanoes
- Submarine/subaerial landslides
- Debris flows, turbidity currents
- Volcanic eruptions
- Earthquakes
- Tsunamis
- Methane emissions

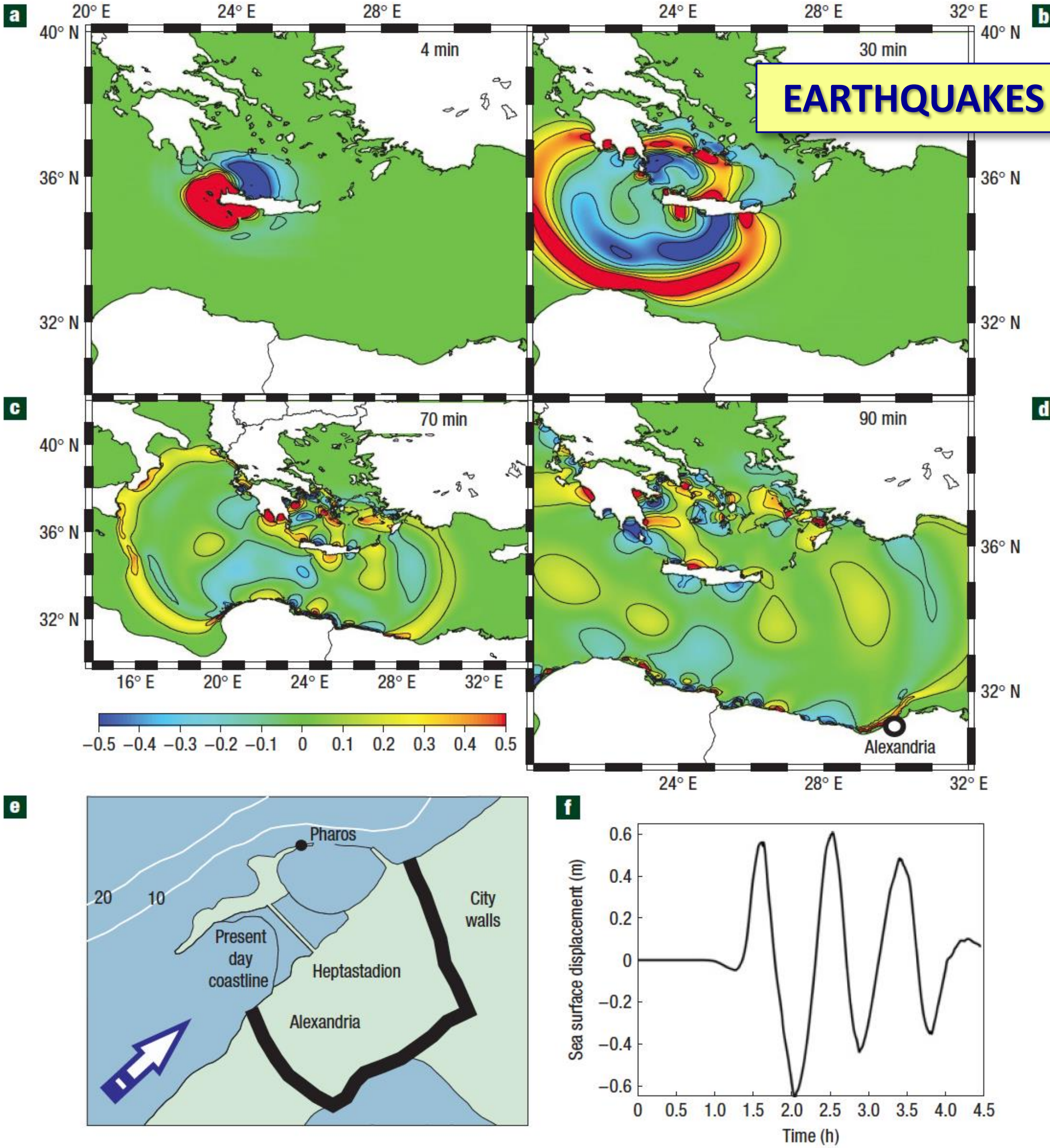
Passive Margins
- Submarine landslides
- Debris flows, turbidity currents
- Modest earthquakes
- Tsunamis
- Methane emissions

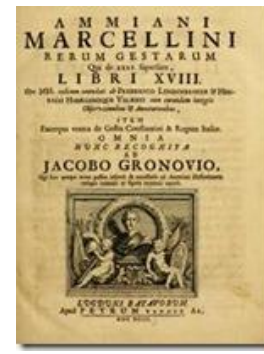
Adapted from Morgan et al., 2009. *Scientific Drilling*, available at: http://www.iodp.org/geohazards/

EARTHQUAKES originated below the sea floor

Eastern Mediterranean tectonics and tsunami inferred from the AD 365 earthquake

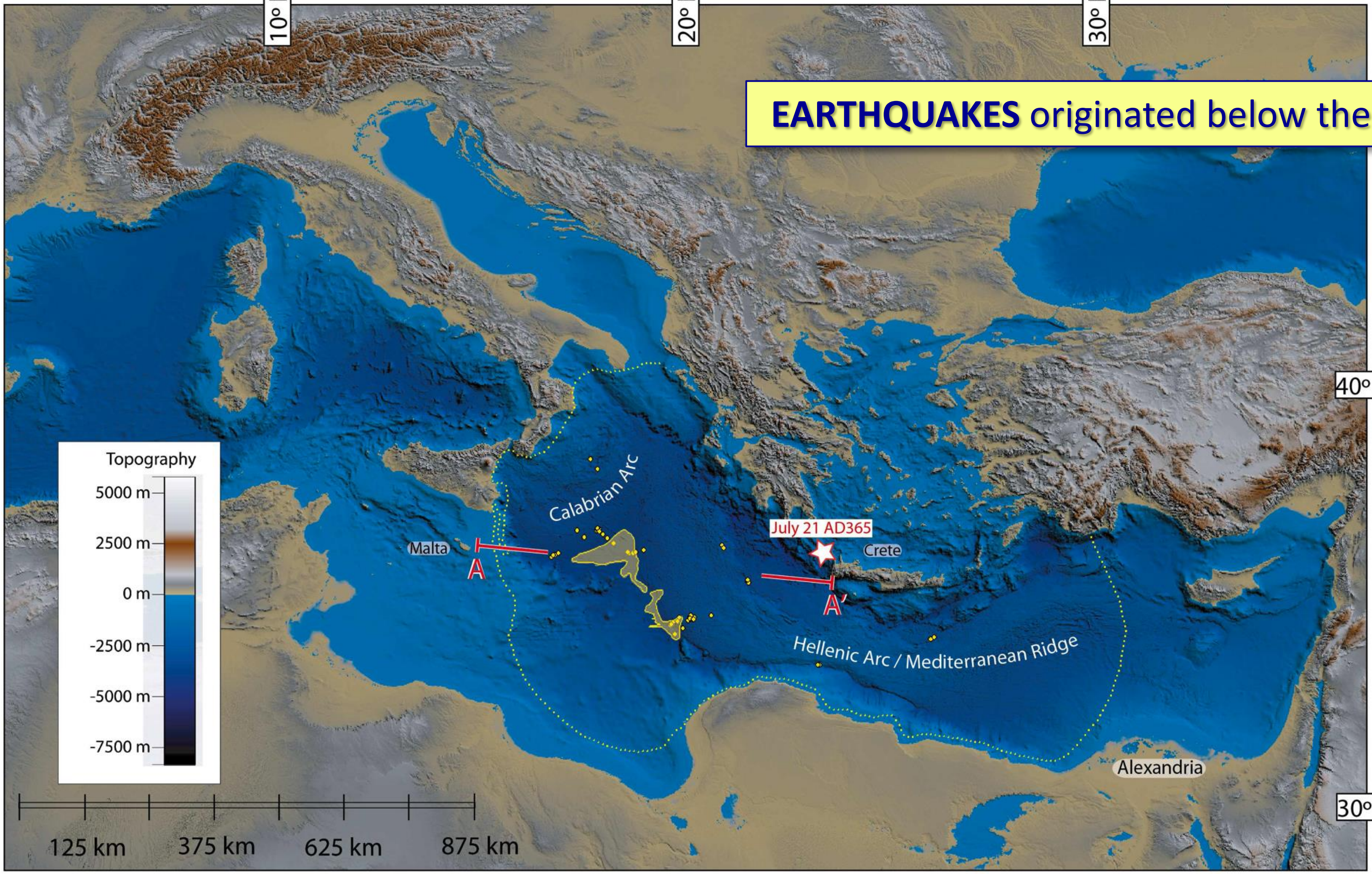
Shaw et al., 2008. Nature

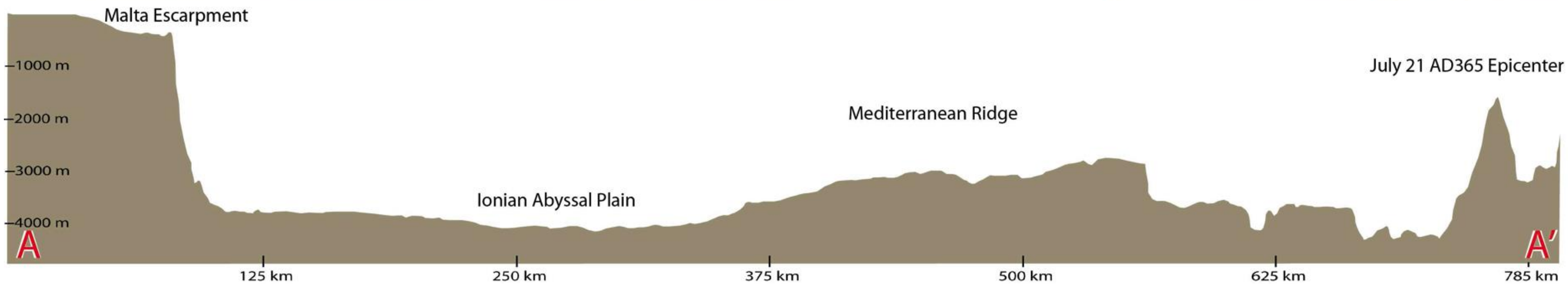




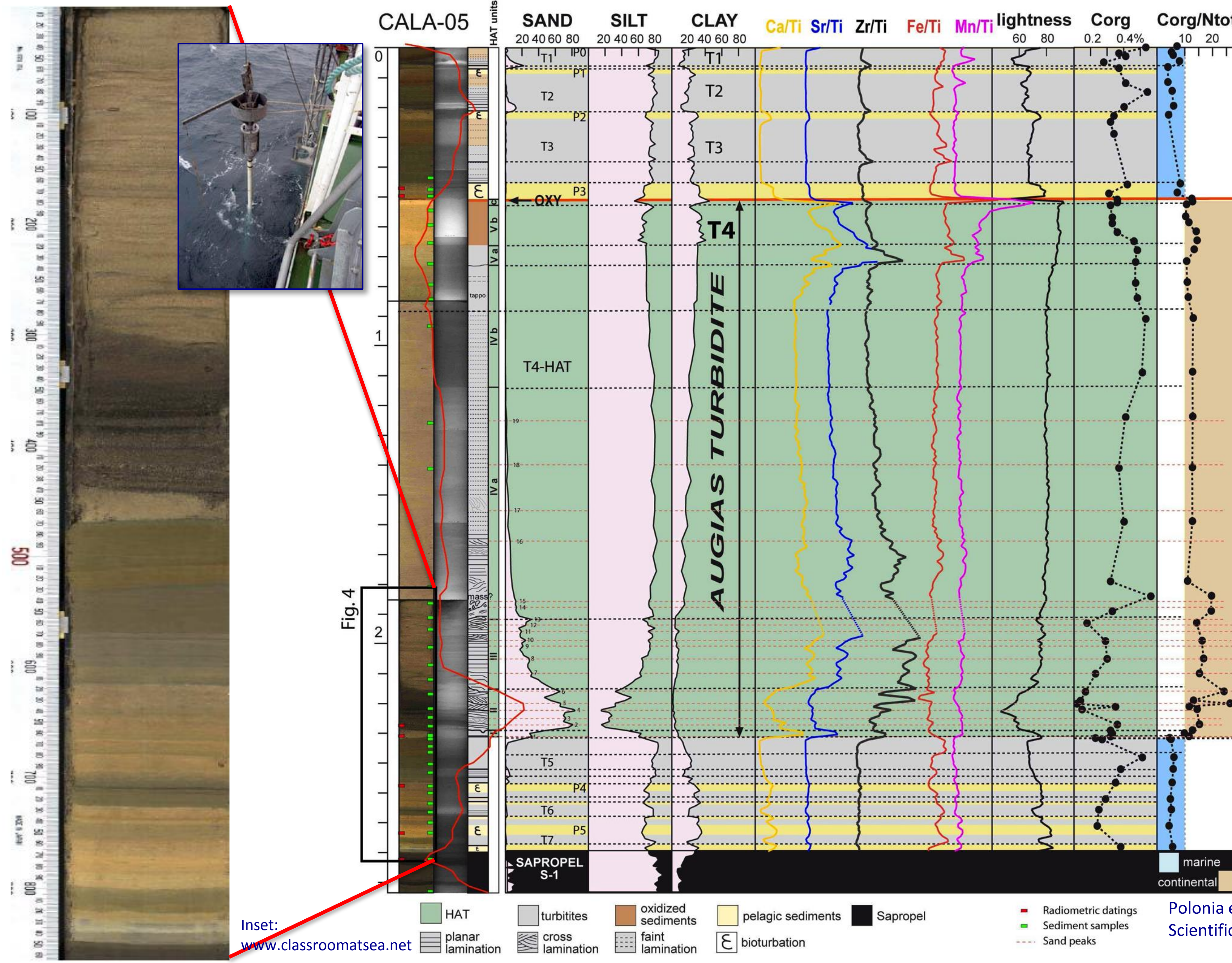
Marcellinus, A. (390)
Res Gestae, Vol. II,
(26) 15-19.

EARTHQUAKES originated below the sea floor





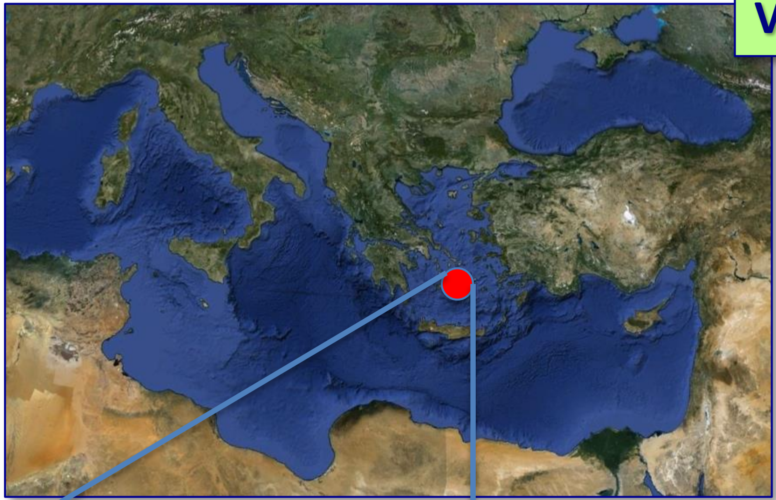
Polonia et al., 2013
Scientific Reports

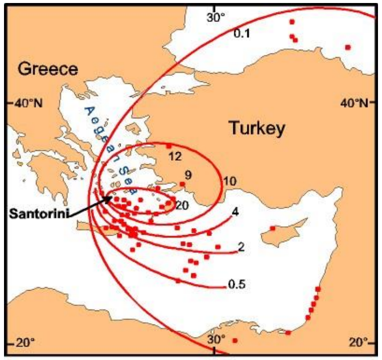


Inset:
www.classroomatsea.net

Polonia et al., 2013
Scientific Reports

VOLCANIC ISLAND ERUPTIONS and **FLANK COLLAPSE**



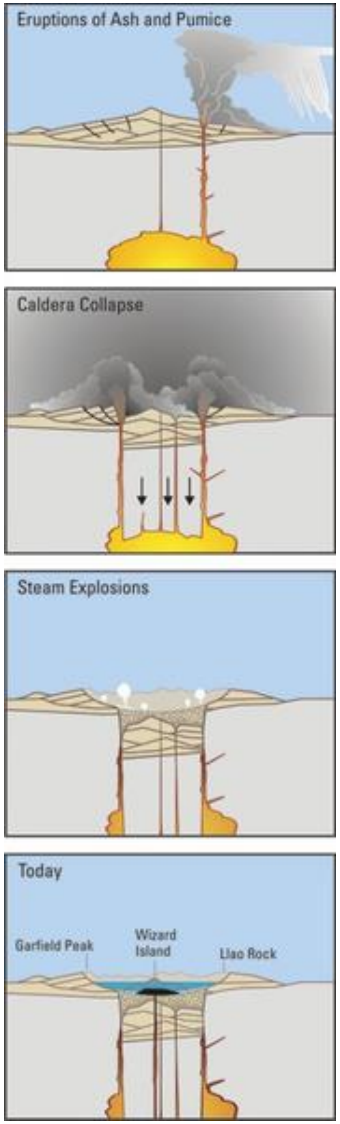


Ash from the Minoan eruption (in cm)

Friedrich (1994)

The Minoan eruption of Santorini happened around 1645 BC in the Late Bronze Age.

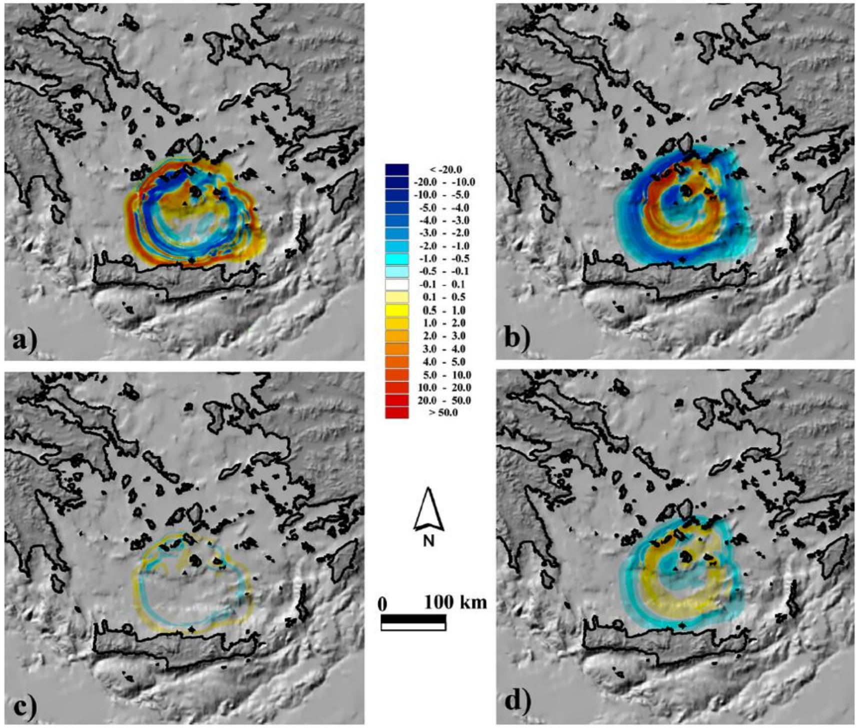
Akrotiri remains

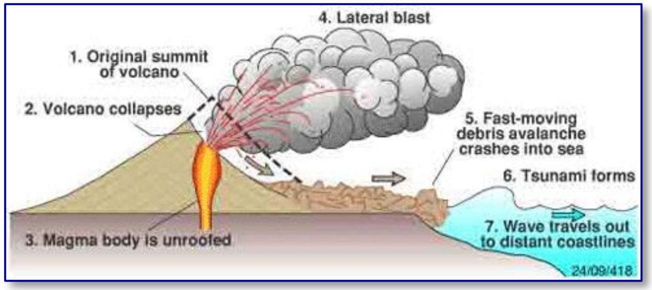


http://pubs.usgs.gov/fs/2002/fs092-02/

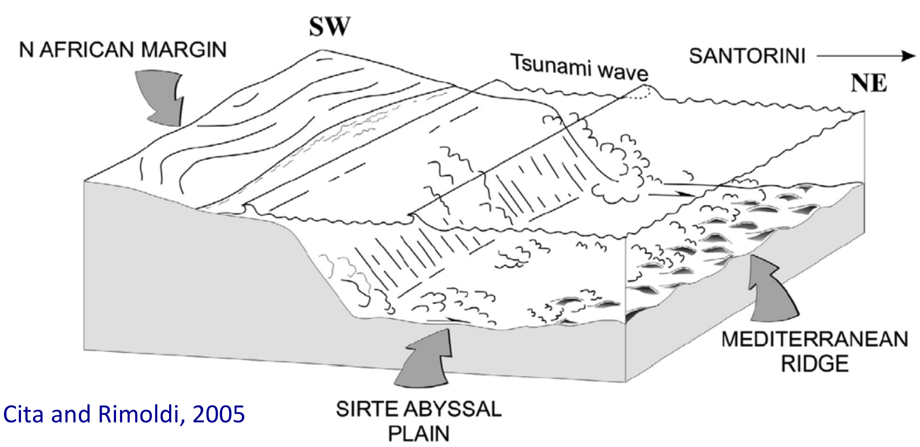
Santorini Caldera Collapse: Modeled tsunami

Pareschi et al., 2006



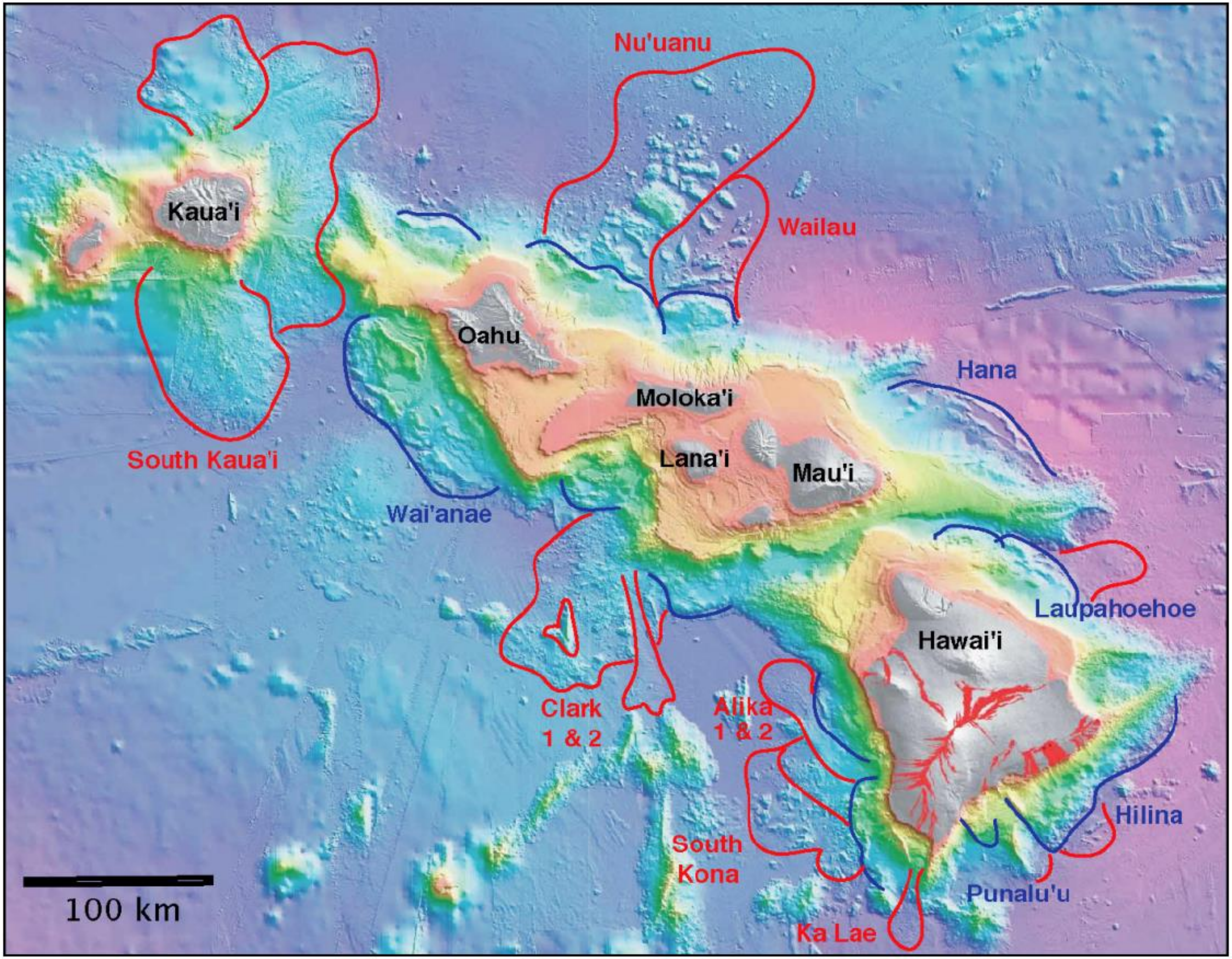


http://academic.evergreen.edu/g/grossmaz/springle/volcano3.gif



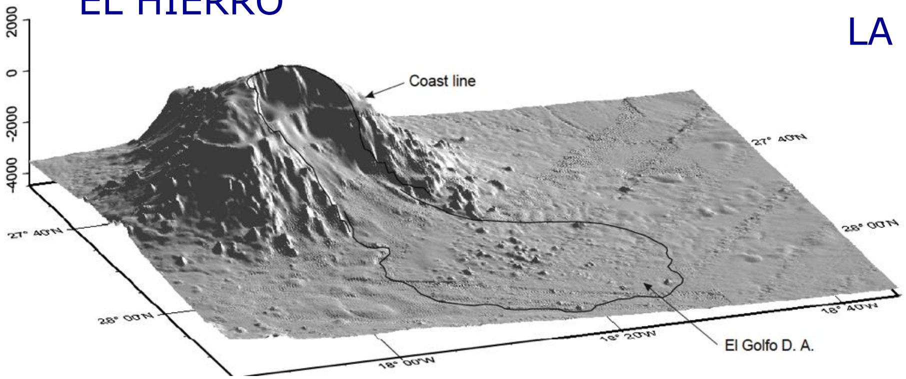
Cita and Rimoldi, 2005

Modified from Polonia et al., 2013 Scientific Reports

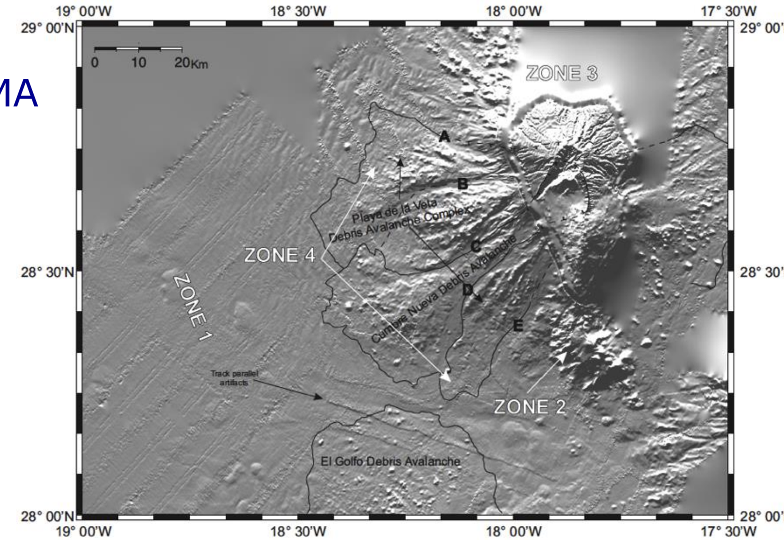


Morgan et al., 2009. Scientific Drilling

EL HIERRO

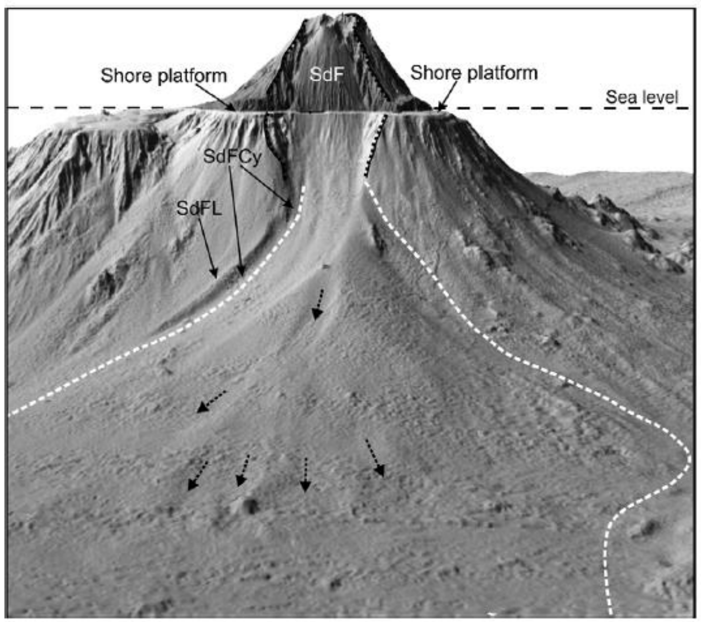


LA PALMA



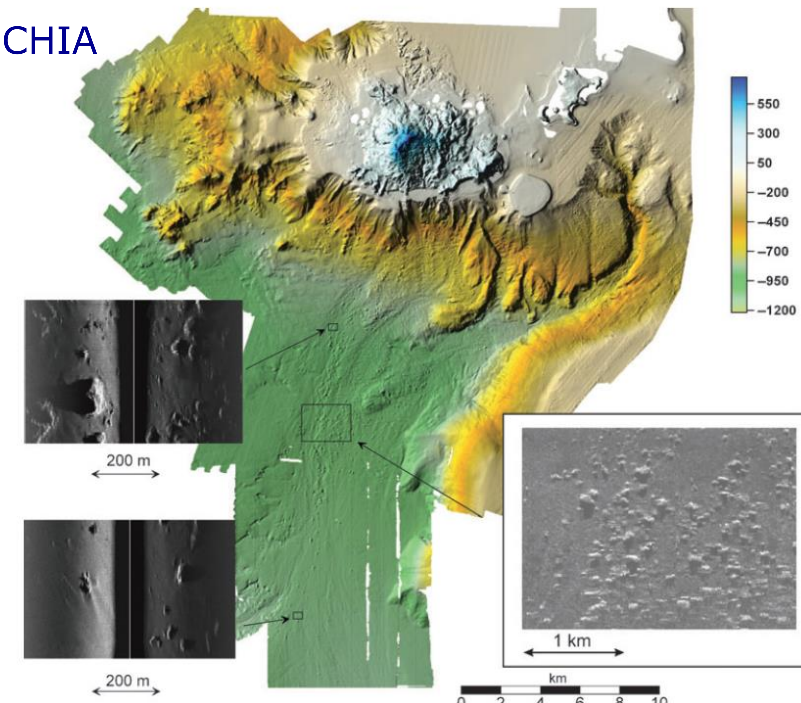
Urgeles et al., 1999. JGR

STROMBOLI



Romagnoli et al., 2009. Marine Geology

ISCHIA



Chiocci & DeAlteris, 2006. Terra Nova

SUBMARINE LANDSLIDES and sediment mass movements (turbidity currents, debris flows, slumps)

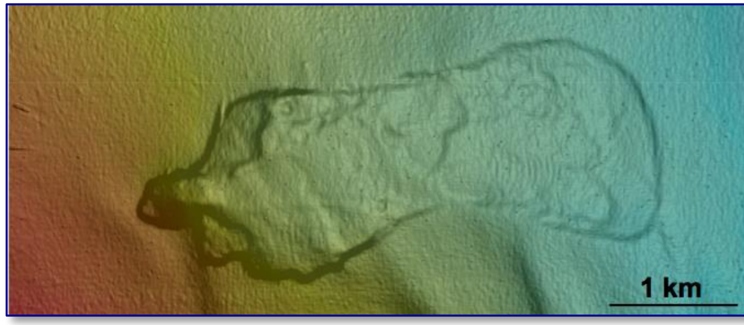
DEFINITIONS

- **Submarine landslides** are one of the main agents through which sediments are transferred across the continental slope to the deep ocean.

- They are **ubiquitous** features of submarine slopes in all geological settings and at all water depths.

- **Hazards** related to such landslides range from destruction of offshore facilities to collapse of coastal facilities and the generation of tsunamis.

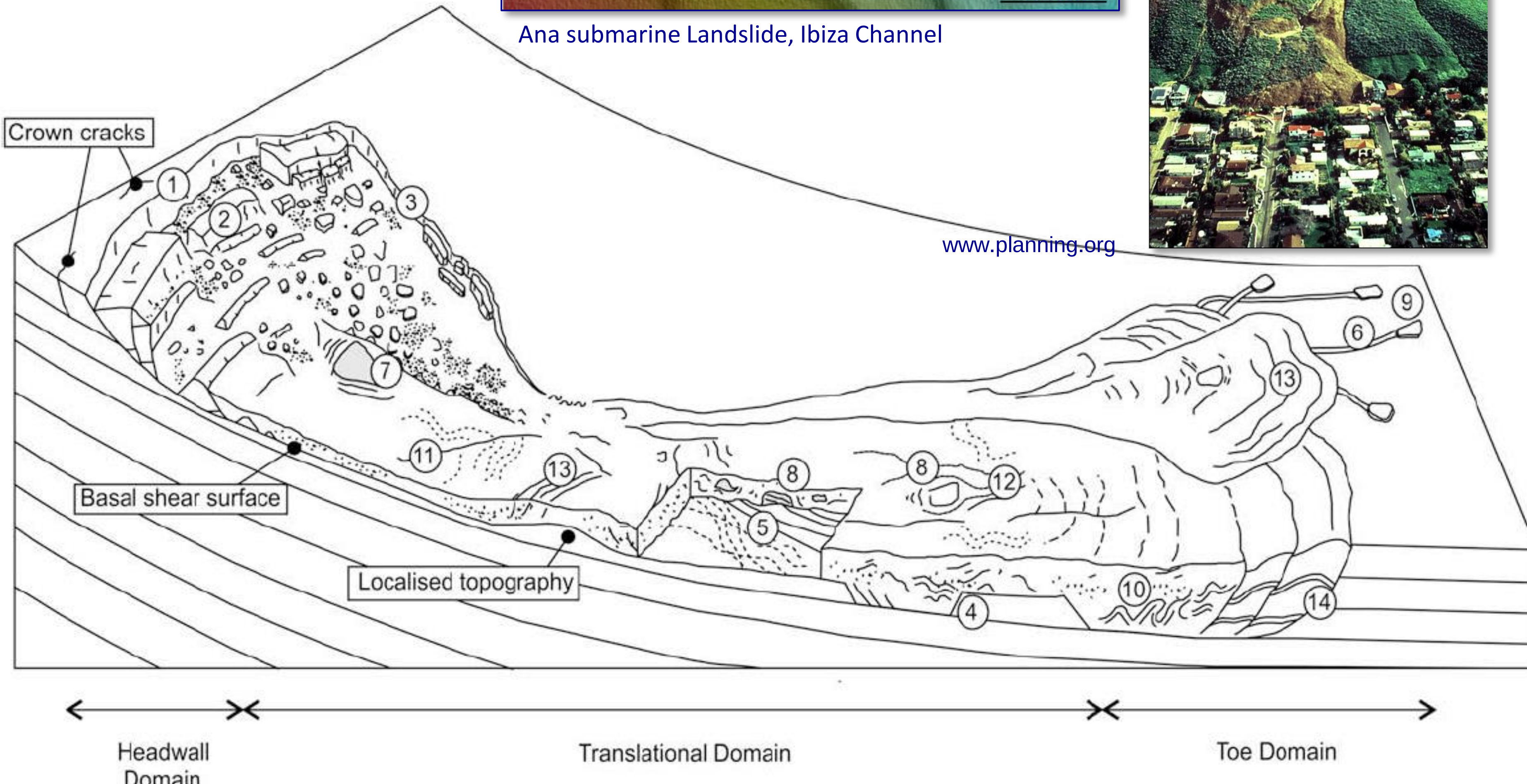
OFFSHORE



Ana submarine Landslide, Ibiza Channel

ON LAND

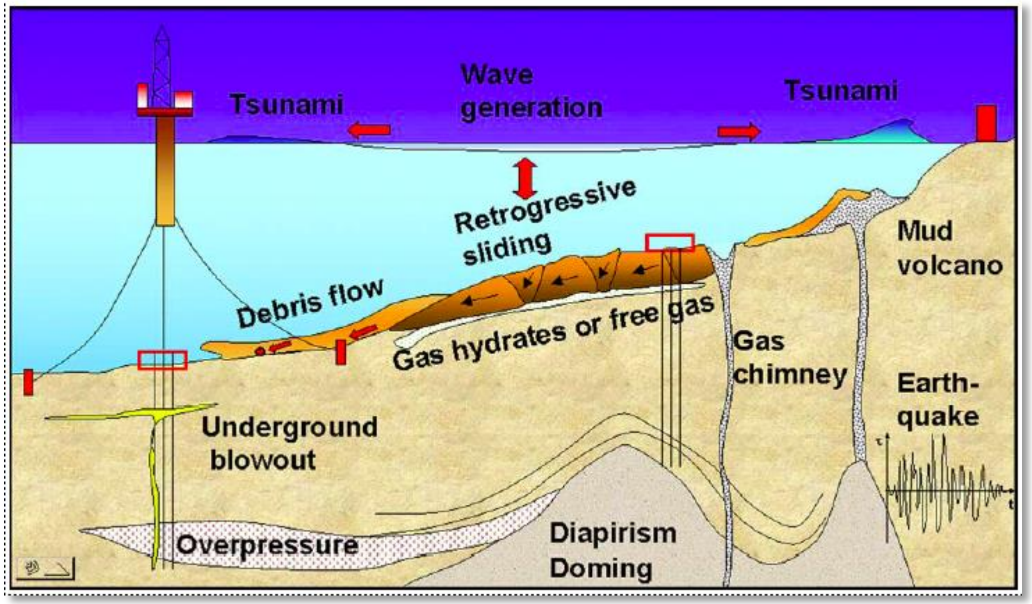
www.planning.org



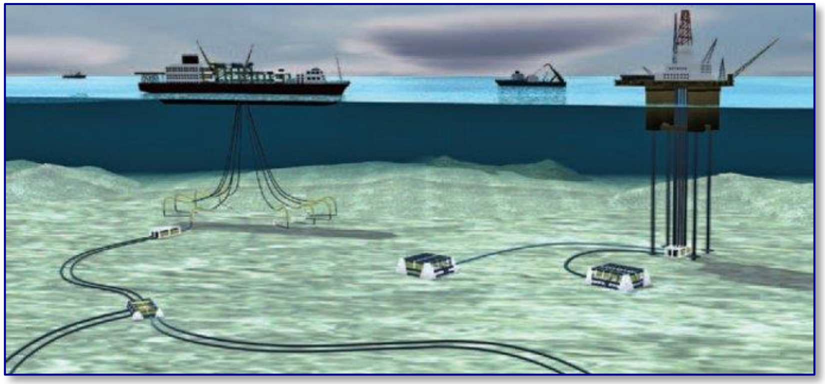
Modified after Prior et al. (1984)

Bull et al., 2009. Marine and Petroleum Geology

Concern for safety of economic activity (energy, communications, possibly mineral resources)



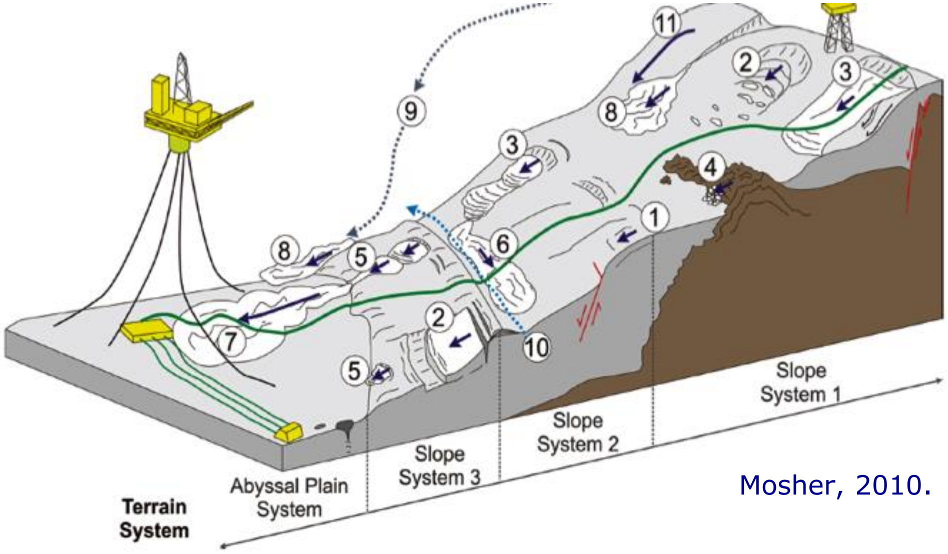
Courtesy NGI, Oslo.
After Camerlenghi et al., 2007, *Scientific Drilling*



ISOVER Subsea Products SeaLine

Increasing use of the seafloor, also in the deep sea

R. Craig Shipp, Shell International E&P Inc. IODP Geohazard Workshop, Portland 2008



Mosher, 2010.

Approaches to the study of submarine landslides

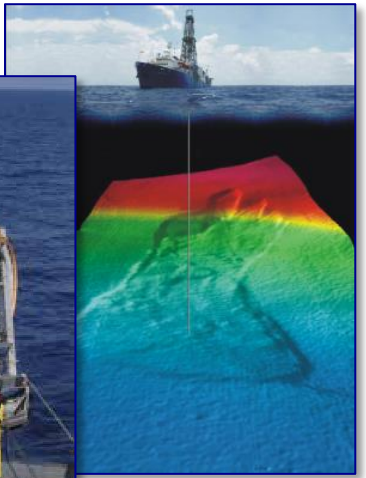
• **CHARACTERIZATION**
(morphology, geometry, structure)

• **PRECONDITIONING FACTORS**
(sedimentology, fluid flow regime, tectonic history…)

• **TRIGGERS**
(external stimulus that initiates the process)

• **TRANSPORT MECHANISMS**
(flow mechanics)

• **FREQUENCY**
(Stratigraphic analysis and ^{14}C dating)

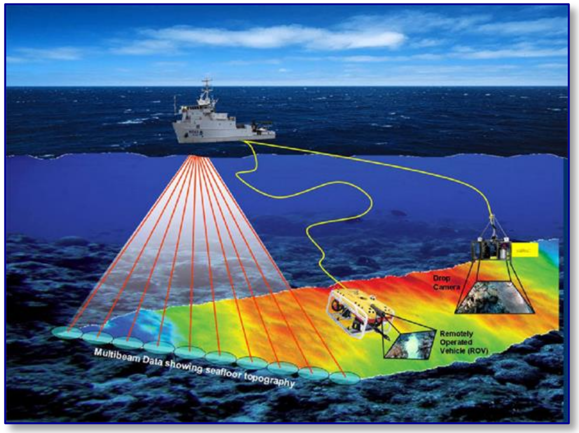


Drilling

In Situ geotechnical merasurements (IFREMER Penfeld Penetrometer)

Mid-term temperature/pore pressure lance (SAPPI)

Autosub6000, a new AUV, NOCS

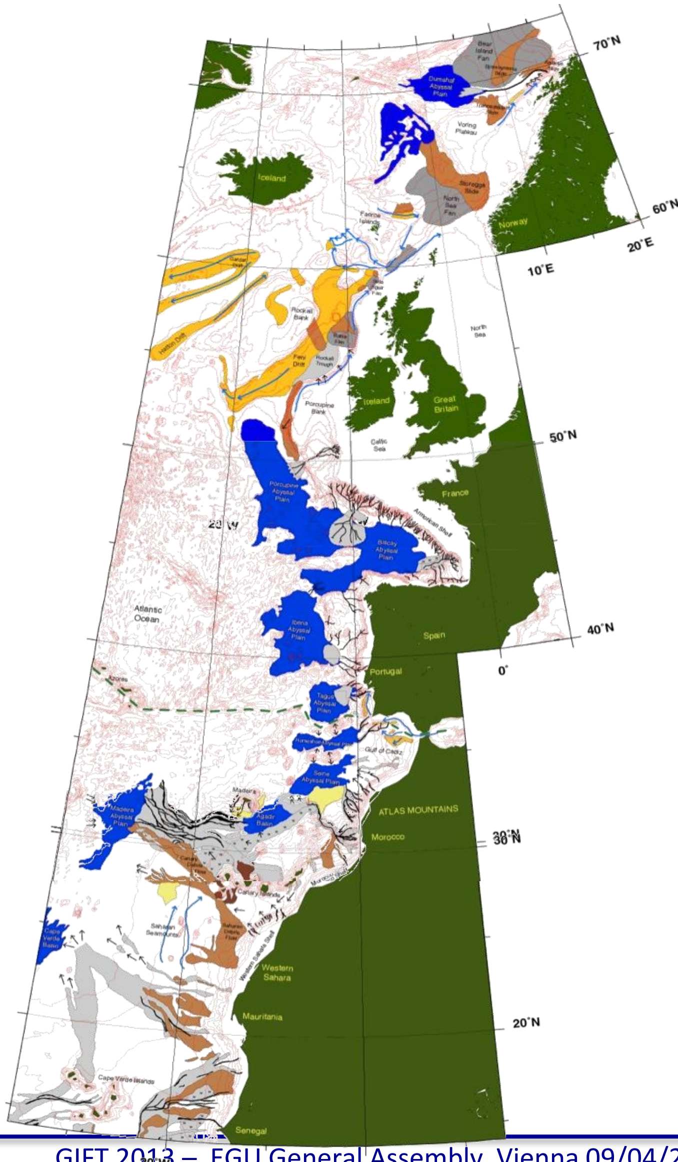


NOOA Grey Reef Expedition

Seismic surveys

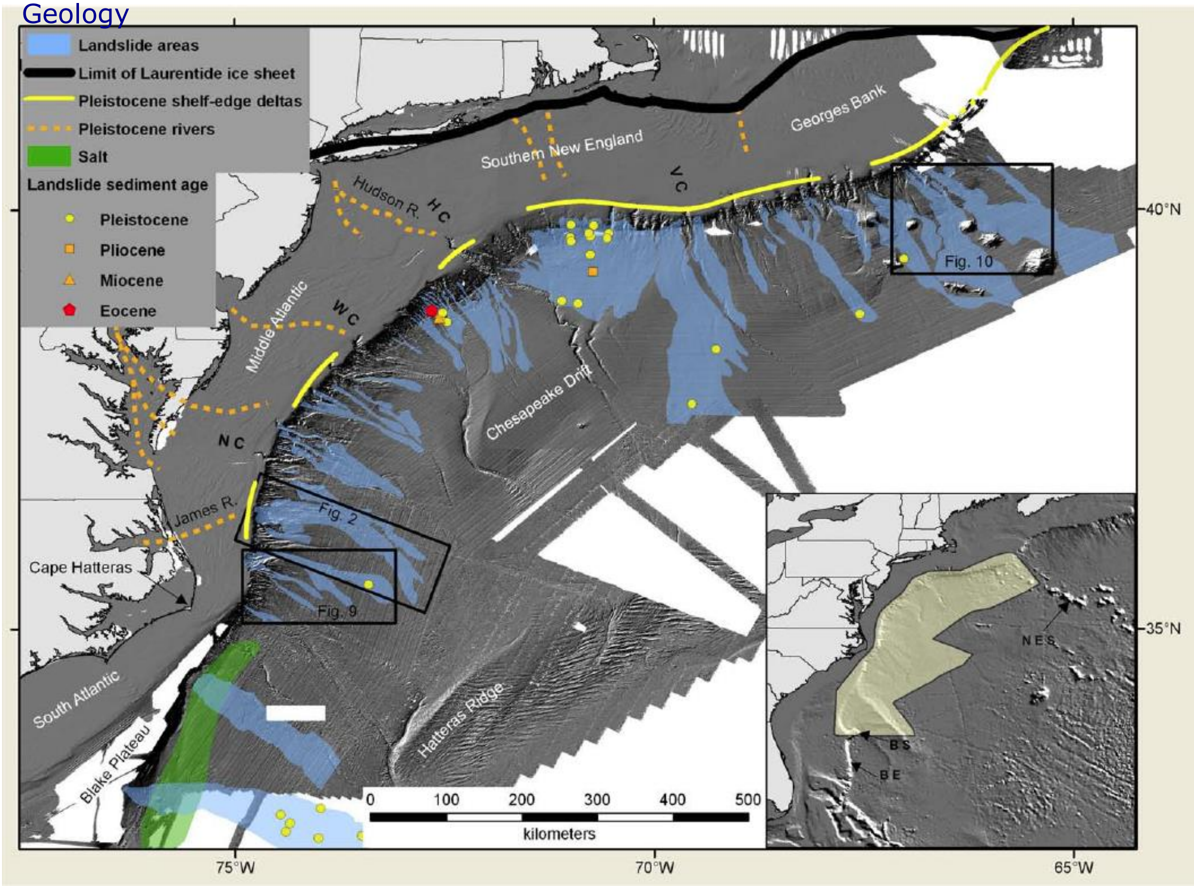
West European and African Margin

Weaver et al., 2000. Sedimentology

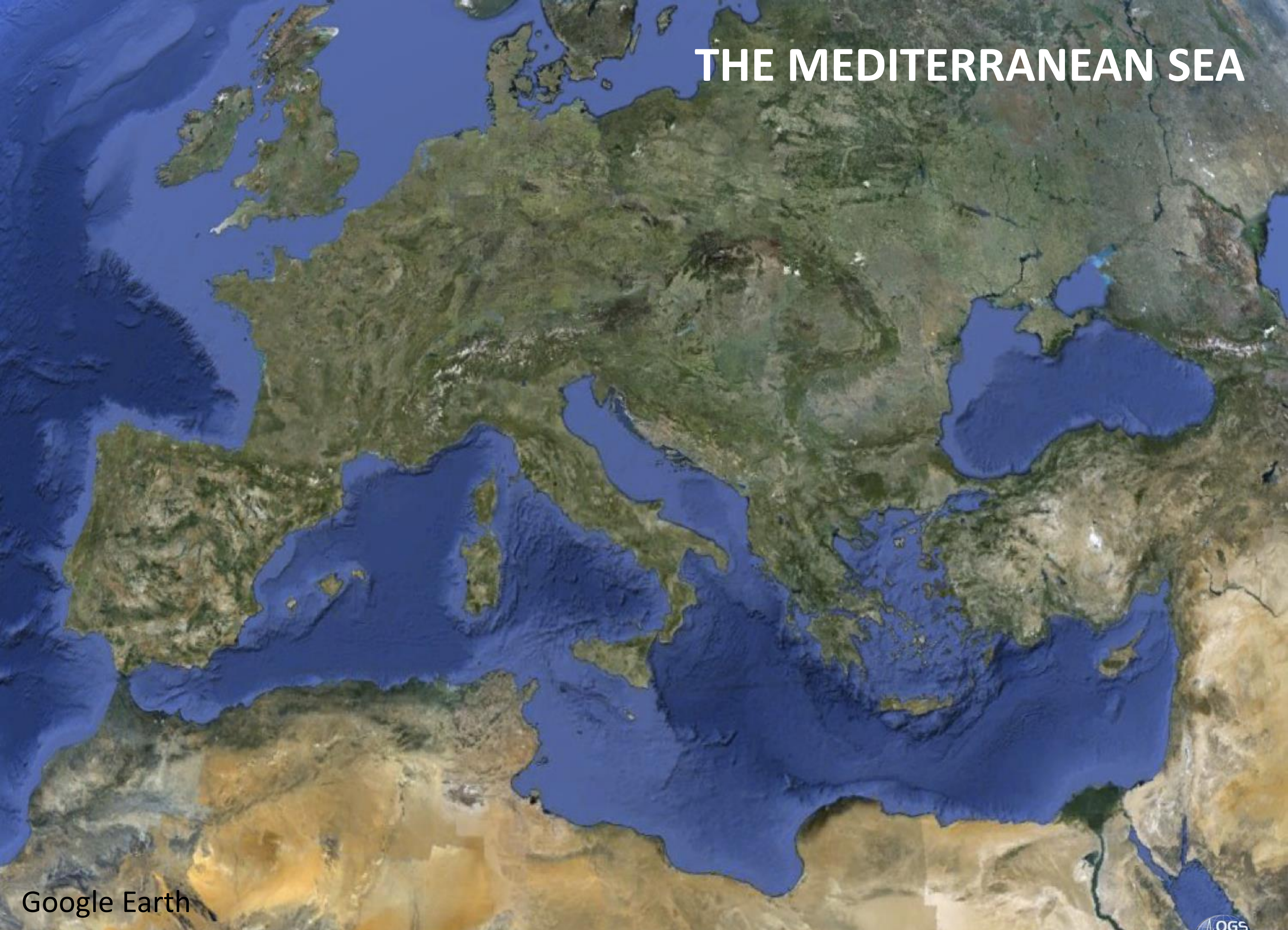


USA Atlantic Coast

Twichell et al., 2009. Marine Geology



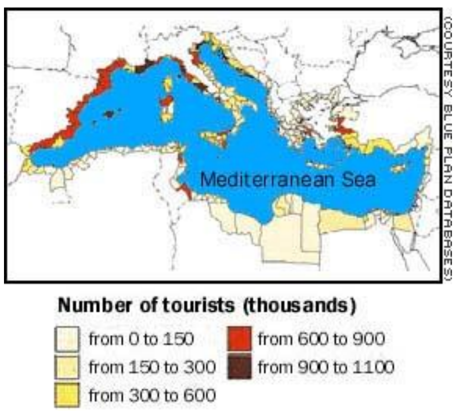
THE MEDITERRANEAN SEA



Google Earth

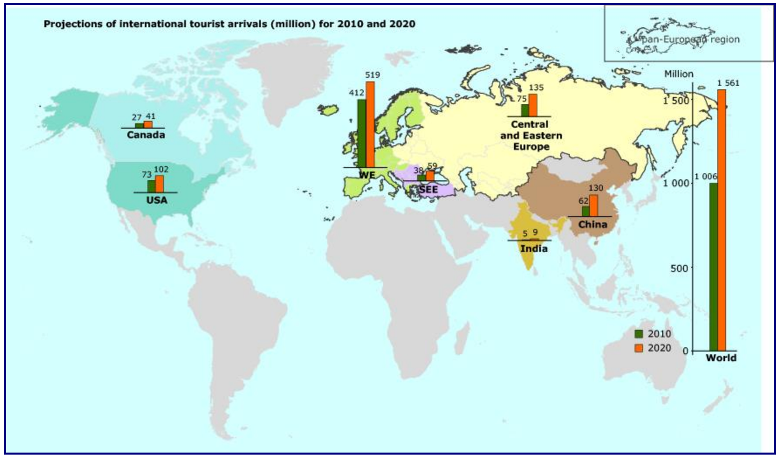
VULNERABILITY

- 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).



"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

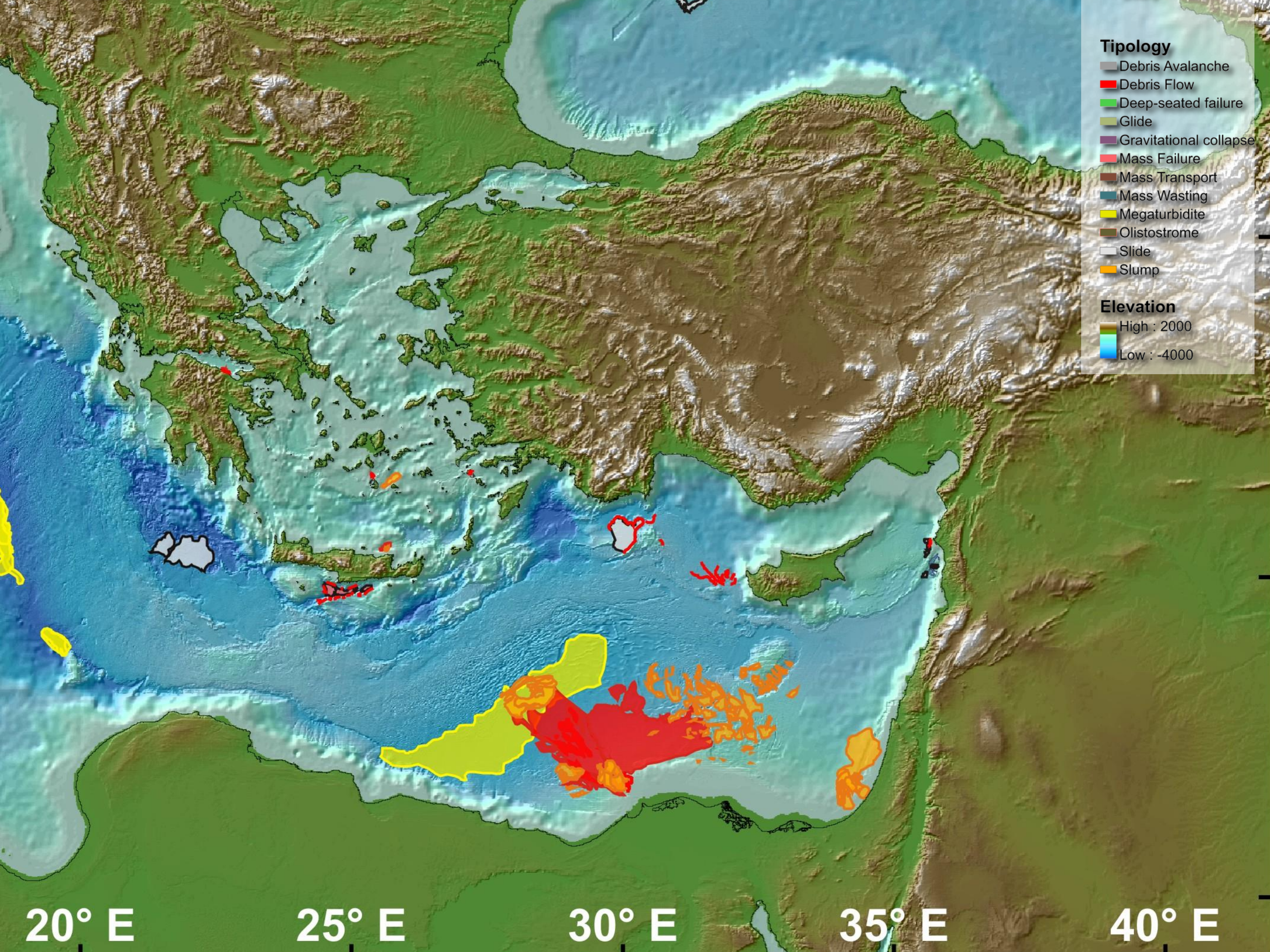
Very high density of seafloor structures / increasing use of the seafloor:

- ✓ Infrastructures (oil, windmills, telecommunications, pipelines, ...)
- ✓ Fisheries
- ✓ Environment
- ✓ Exploitation of mineral and energy resources
- ✓ Waste disposal

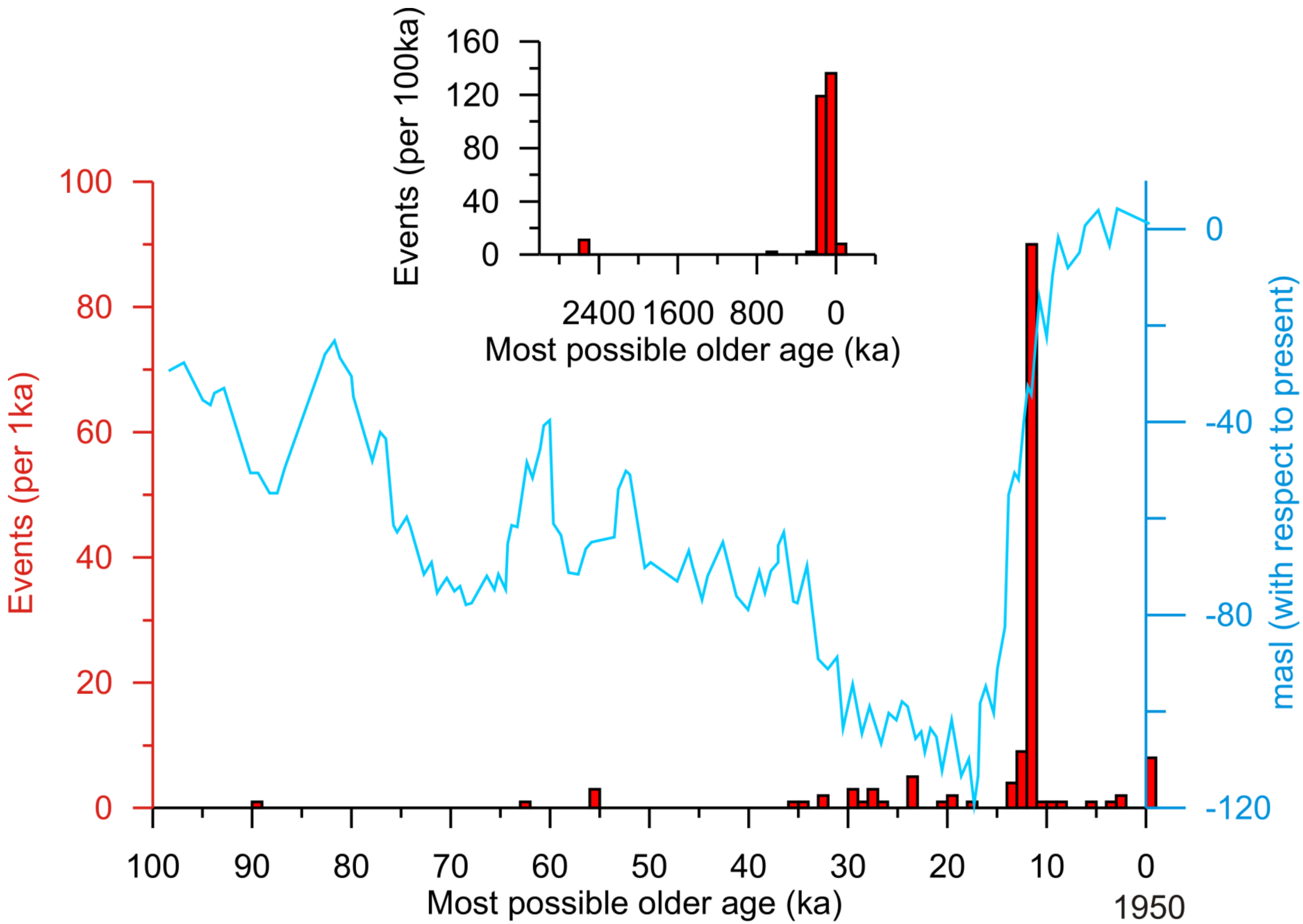
Casablanca Platform, off Spain

A study on behalf of the Submarine Cable Improvement Group shows 25% of all faults are caused by **natural hazards such submarine earthquakes, density currents and extreme weather.**

Mediterranean Fibre Cable Cut - a RIPE NCC Analysis http://www.ripe.net/ Analysis by the RIPE NCC Science Group with contributions from Roma Tre University.Editors: Rene Wilhelm, Chris Buckridge


Tipology
Debris Avalanche
Debris Flow
Deep-seated failure
Glide
Gravitational collapse
Mass Failure
Mass Transport
Mass Wasting
Megaturbidite
Olistostrome
Slide
Slump
Elevation
High : 2000
Low : -4000
20° E
25° E
30° E
35° E
40° E

Timing of failure

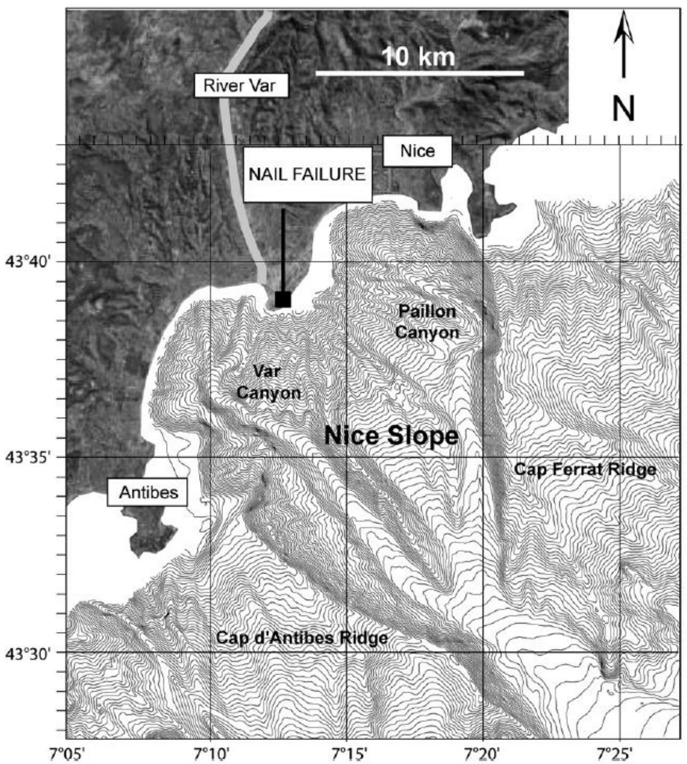


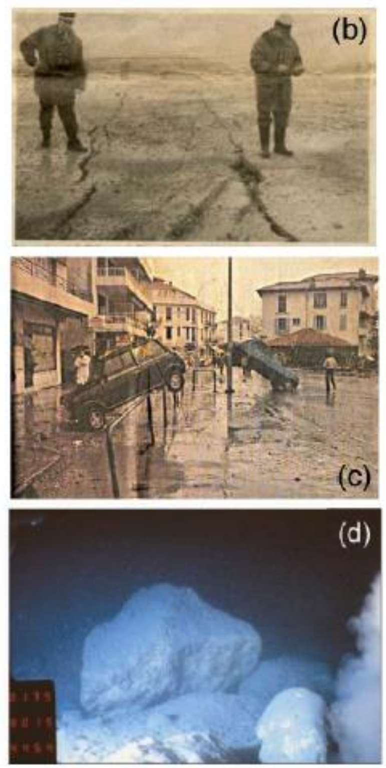
Landslide emplacement during the last de-glaciation

Camerlenghi et al., 2009

1979 October 16
Nice international airport submarine landslide

Hydrogeology and its effect on slope stability along the coastal aquifer





Seed et al., 1988

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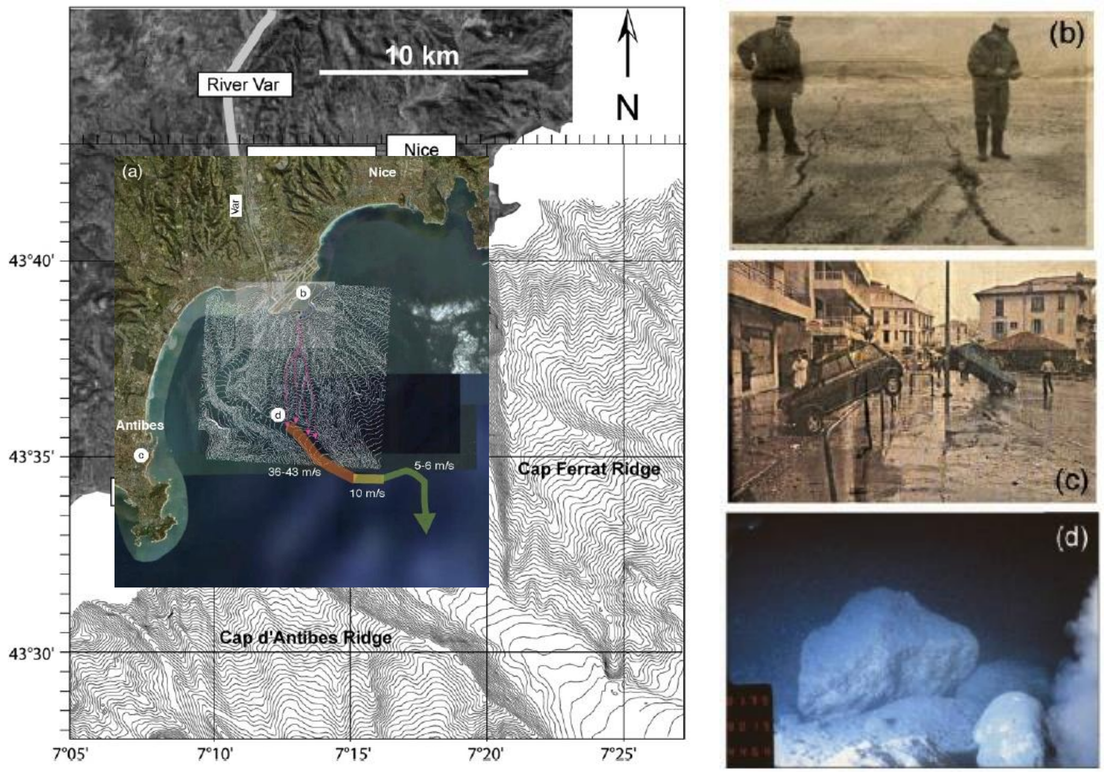
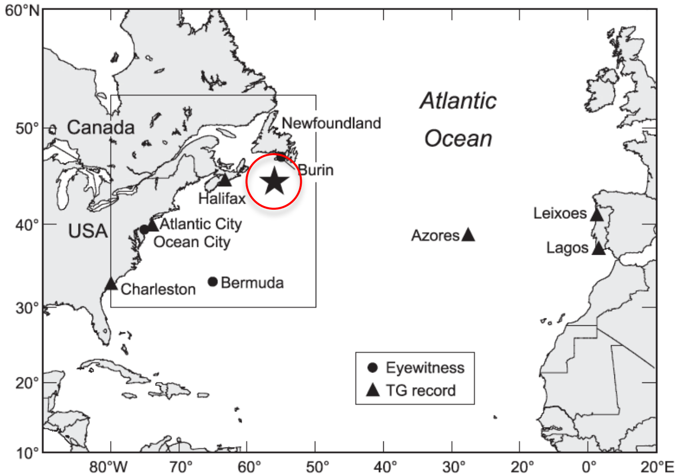
Hydrogeology and its effect on slope stability along the coastal aquifer



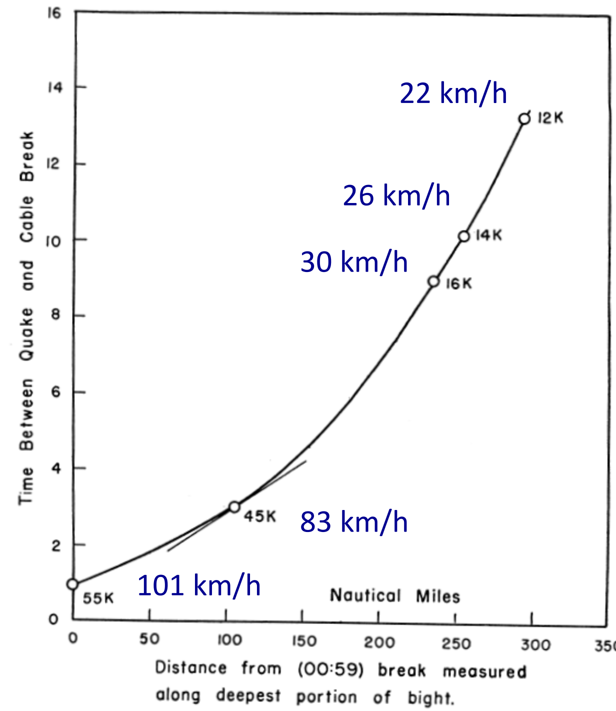
Seed et al., 1988

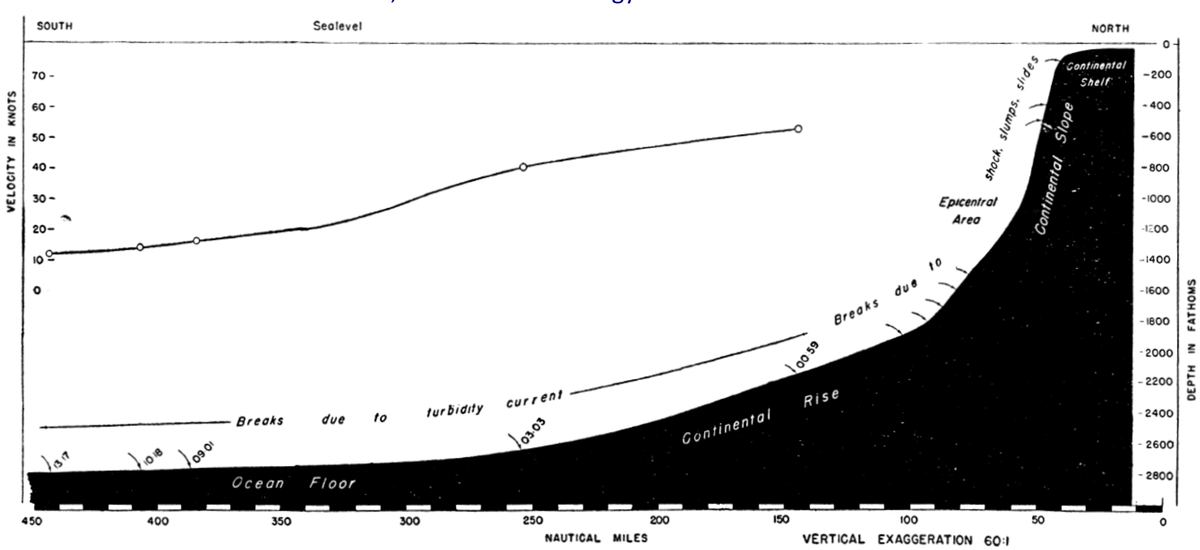
The discovery of submarine Turbidity Currents: The Newfoundland Tsunami of November 18, 1929

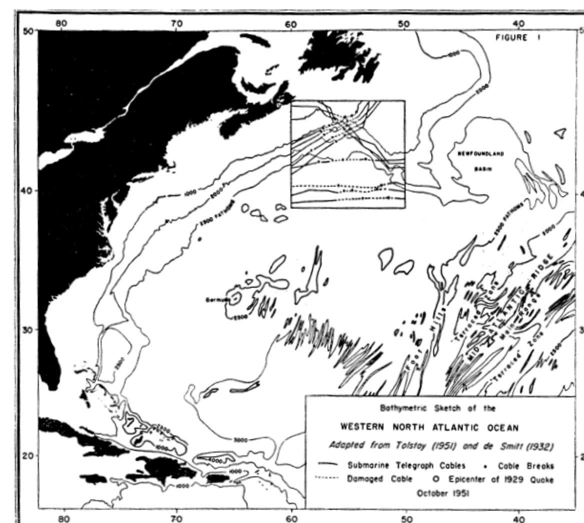


Fine et al., 2005 Marine Geology

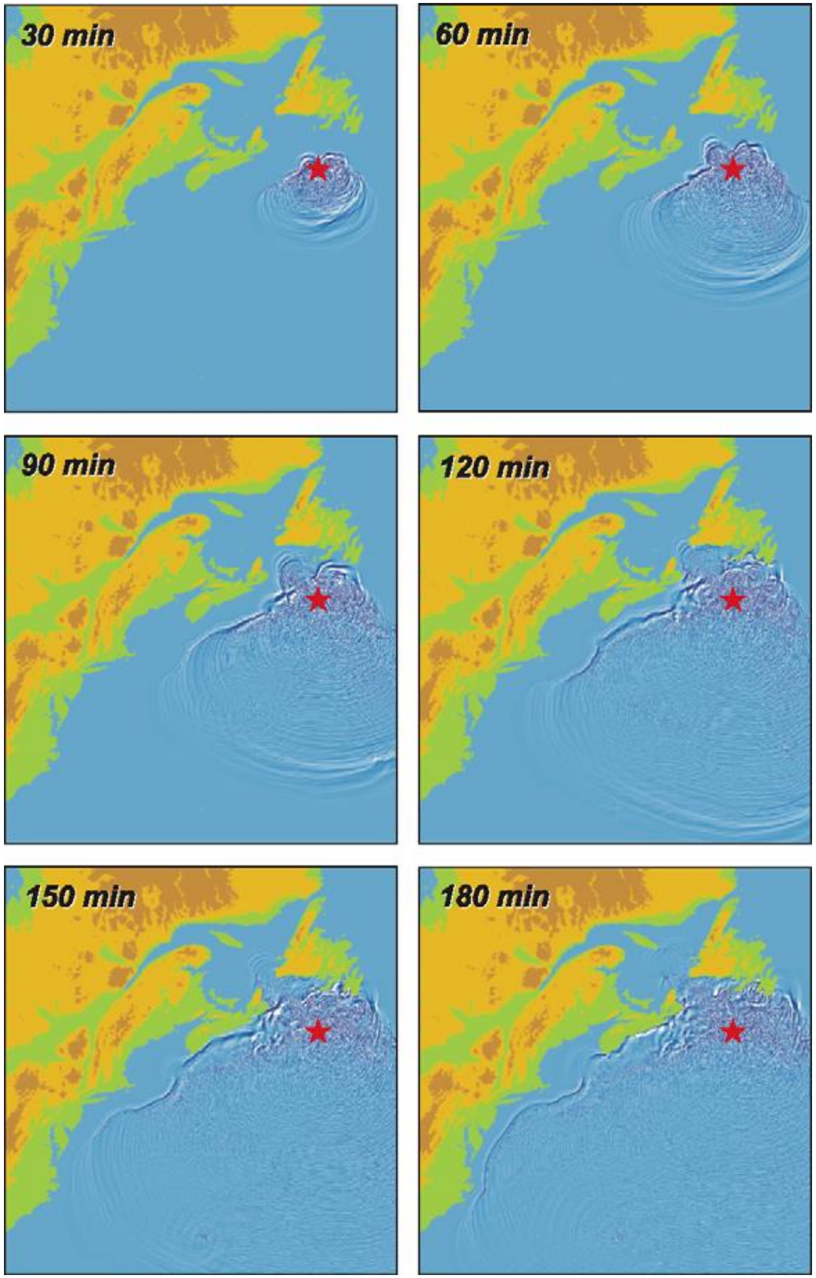
- EARTHQUAKE
- LANDSLIDE
- TSUNAMI



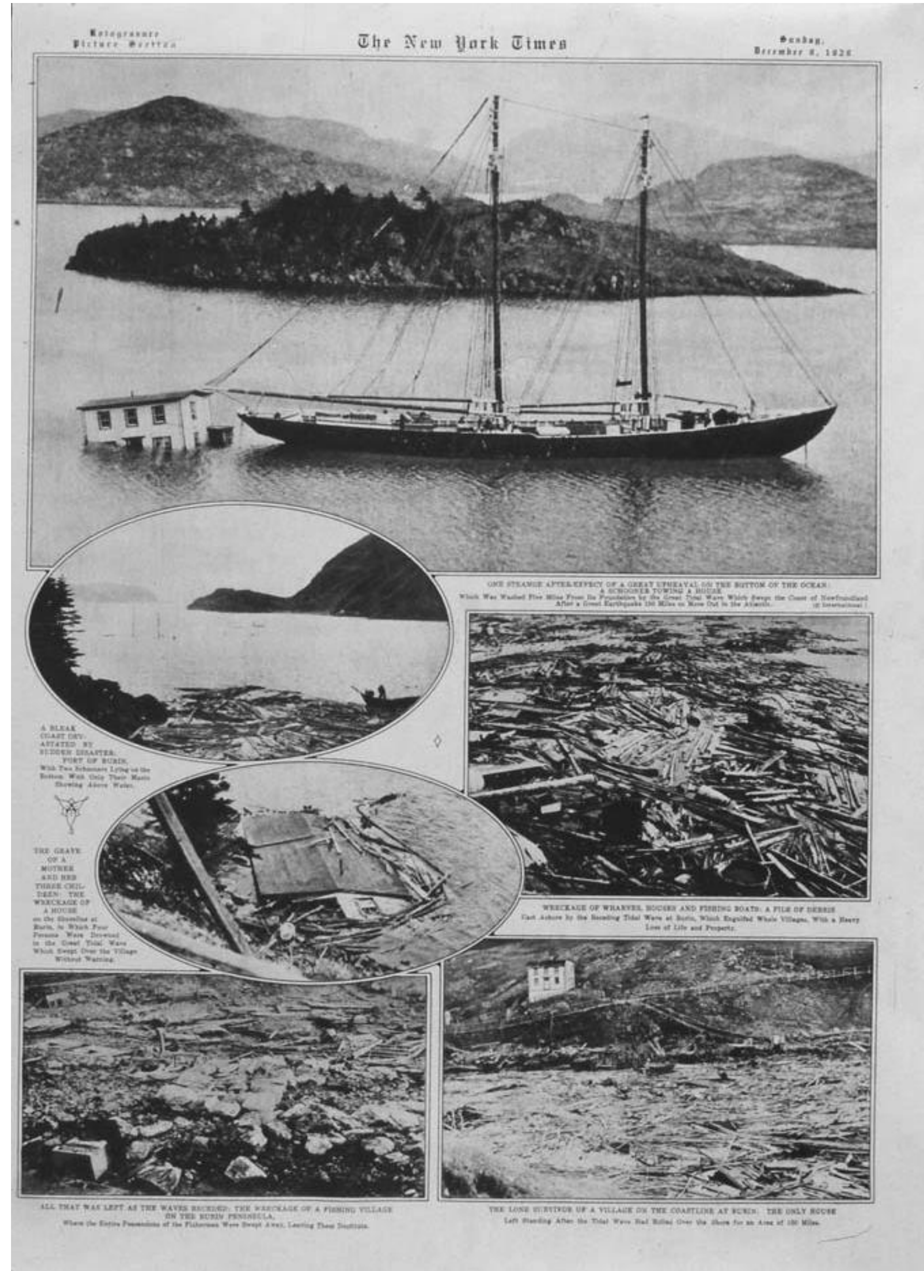




Ewing and Heezen, 1952



Fine et al., 2005 Marine Geology



The New York Times

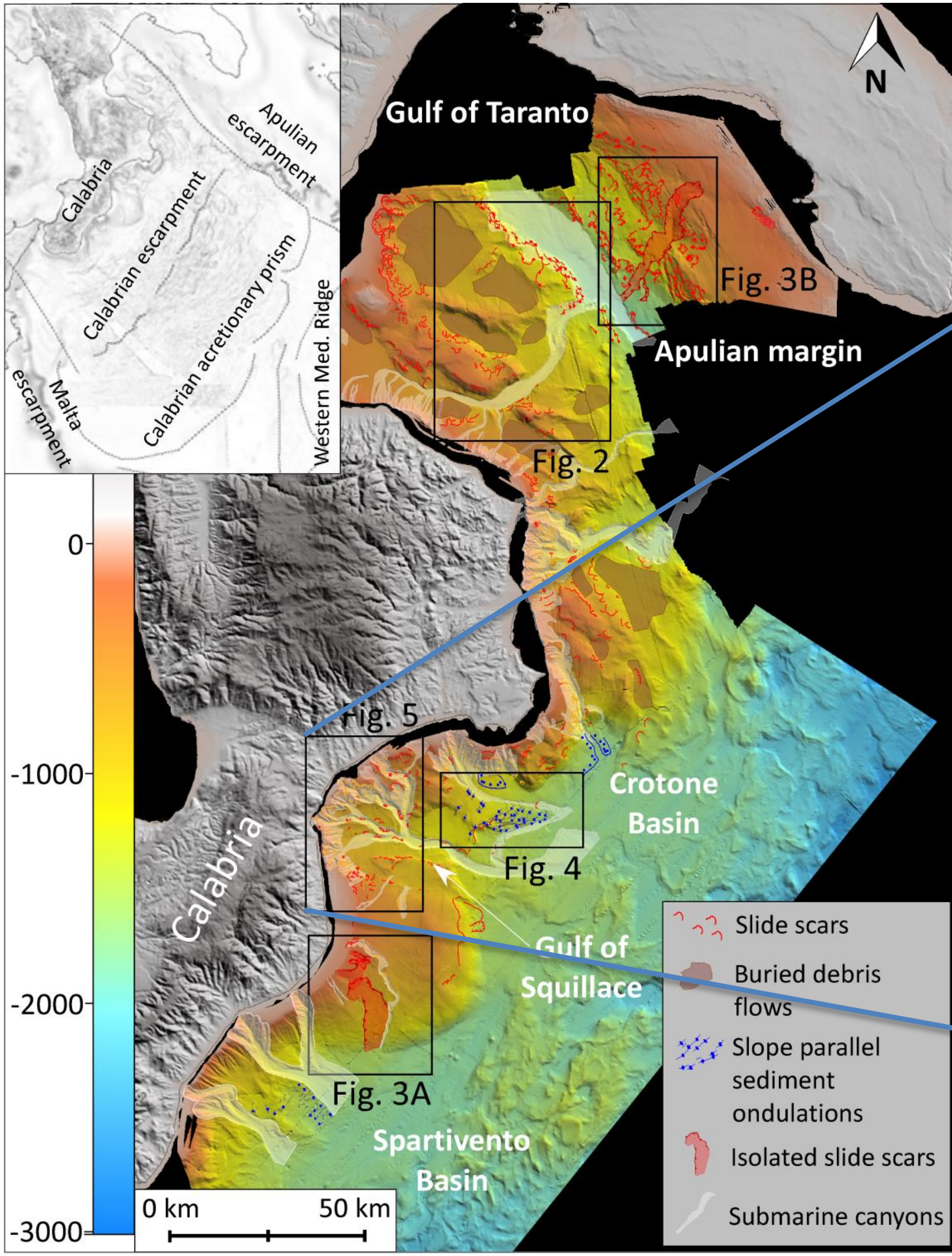
ONE STRANGE AFTER-EFFECT OF A GREAT UPHEAVAL ON THE BOTTOM OF THE OCEAN:
A SCHOONER TOWING A HOUSE

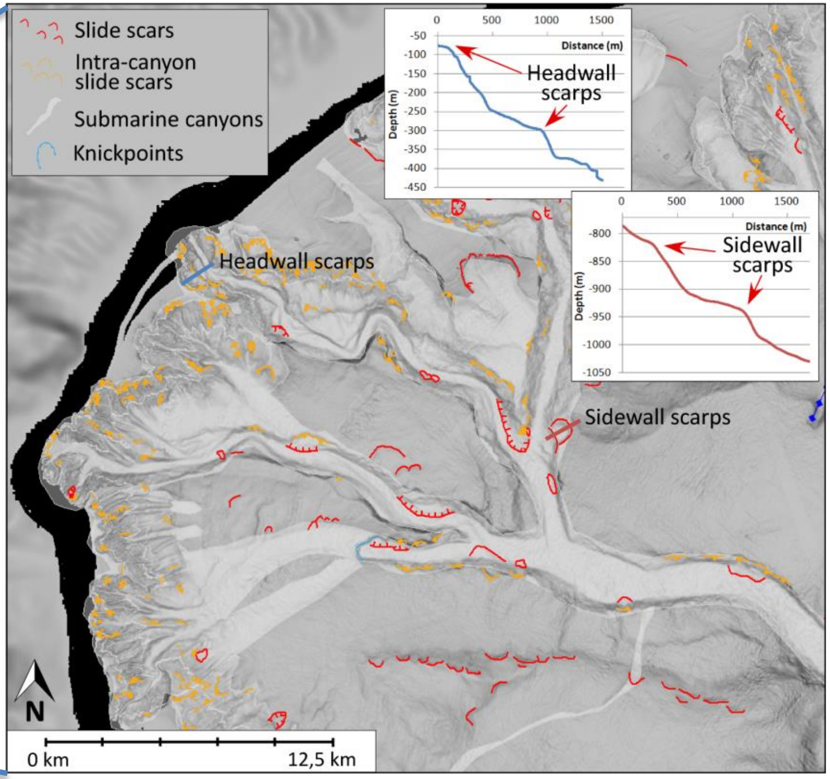
ALL THAT WAS LEFT AS THE WAVES RECEDED: THE WRECKAGE OF A FISHING VILLAGE ON THE BURIN PENINSULA,

THE LONE SURVIVOR OF A VILLAGE ON THE COASTLINE AT BURIN: THE ONLY HOUSE

Ruffman and Hann, 2006

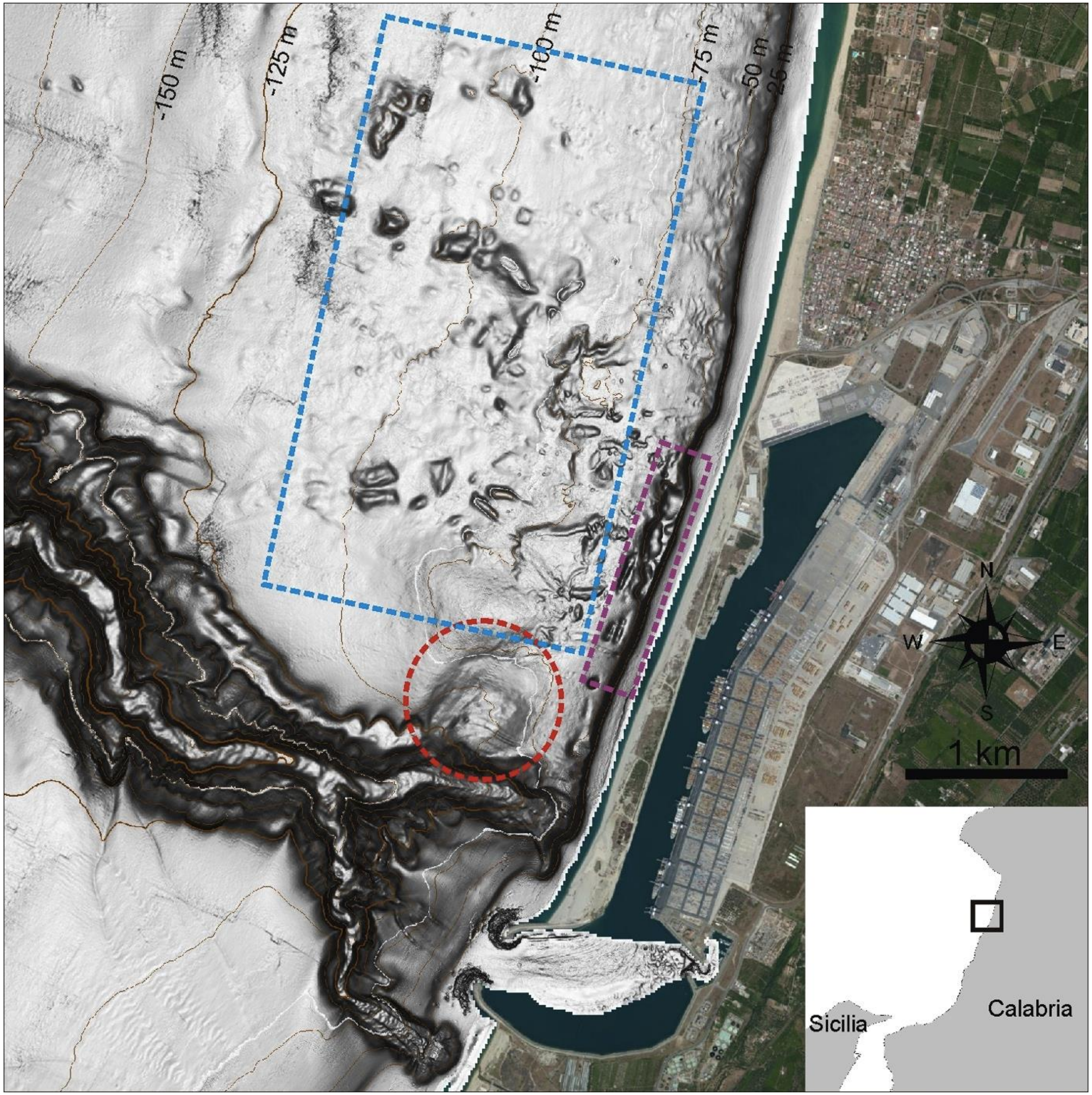
Seafloor mapping for hazard assessment: Submarine landslides and pathways of turbidity currents





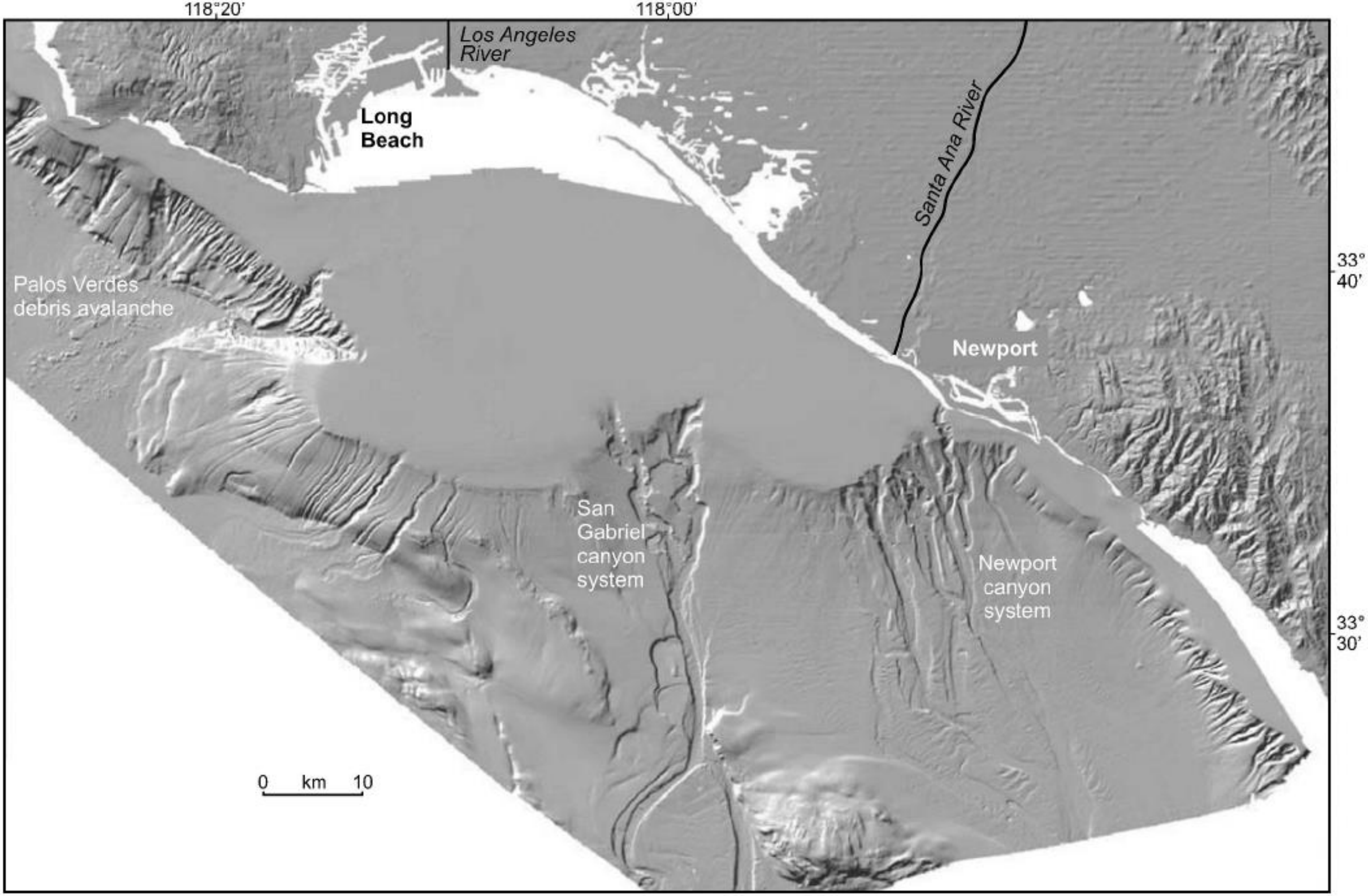
Ceramicola et al. in press

Turbidity-current erosion: Gioia Tauro seaport, Calabria, Italy



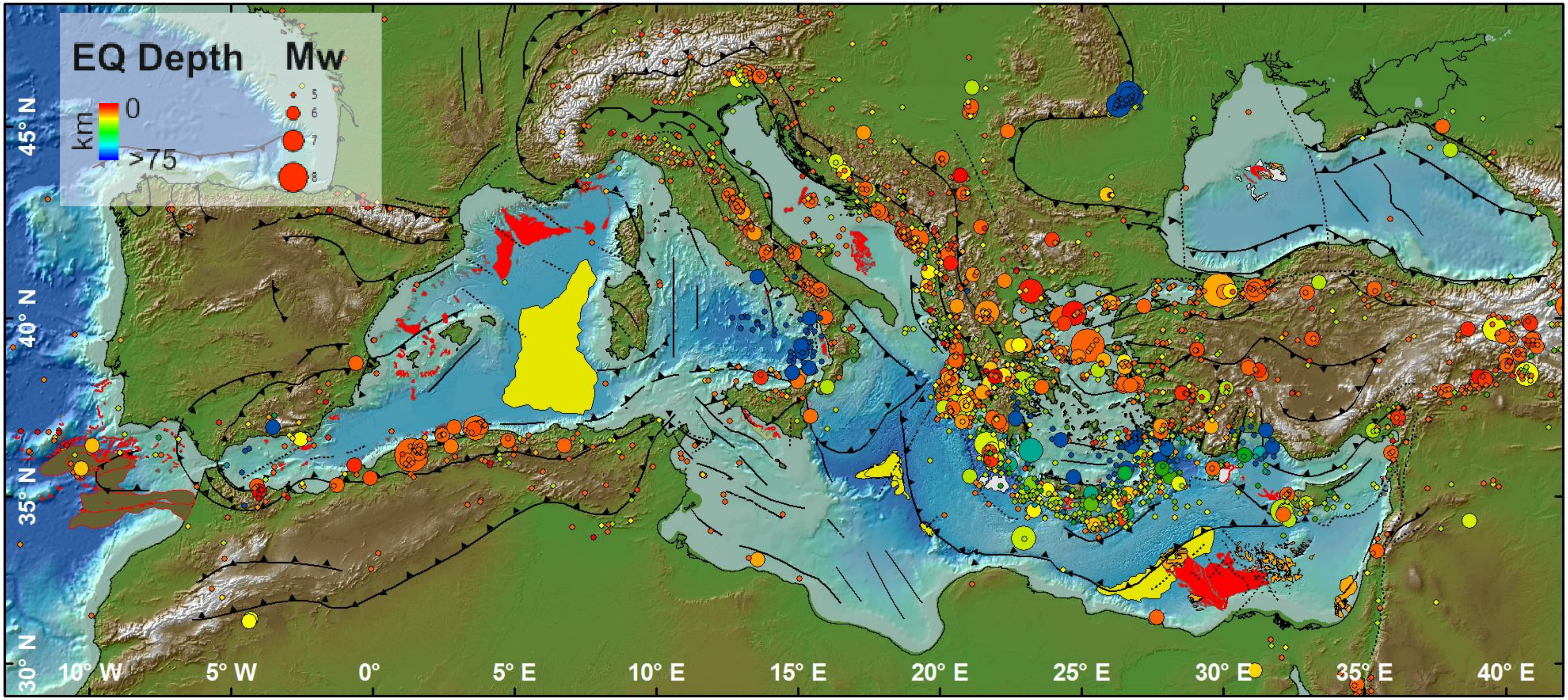
F. Chiocci, personal Communication

Turbidity-current erosion: California continental borderland south of Los Angeles



Piper and Normark, 2009 Journal of Sedimentary Research

WHAT TRIGGERS SUBMARINE LANDSLIDES



Earthquakes 1973-2011 USGS/NEIC (PDE) catalog

The paradigma of earthquakes as triggers of modern submarine landslides

Marine sediment behaviour in response to a cyclic loading (earthquake)
Decreasing sediment strength

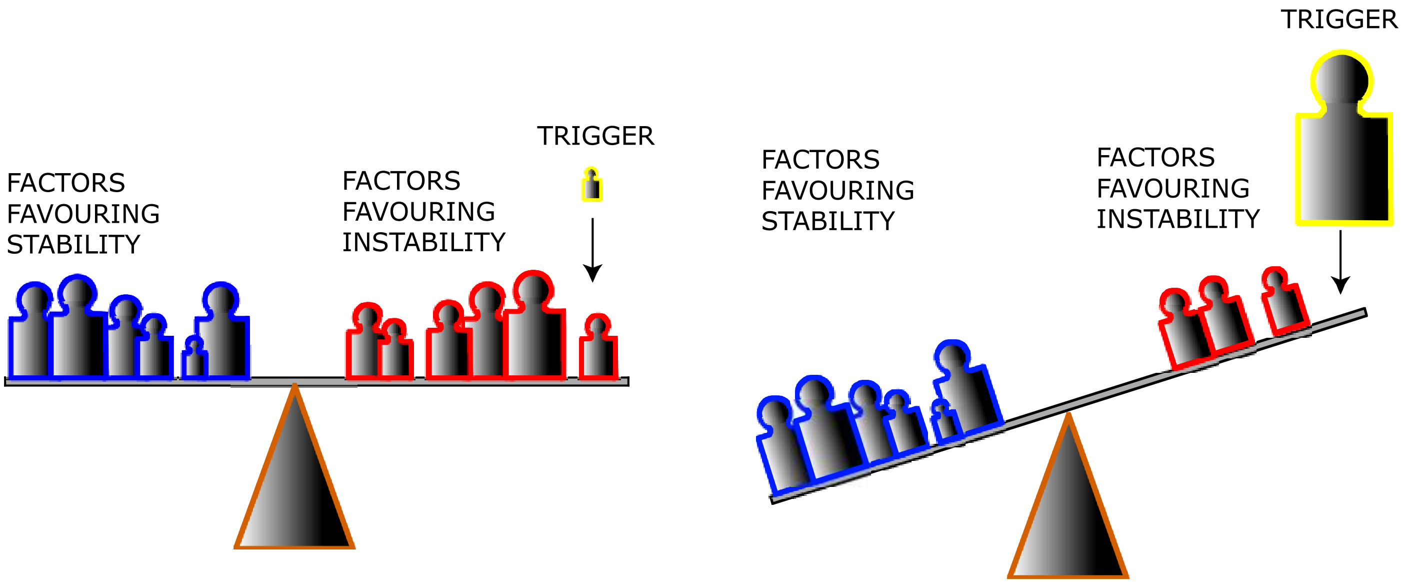
The paradox of the distribution of submarine landslides on present-day continental margins

↓

Geological control on the distribution of submarine landslides

importance of

short-term TRIGGERS against **pre-conditioning FACTORS**:

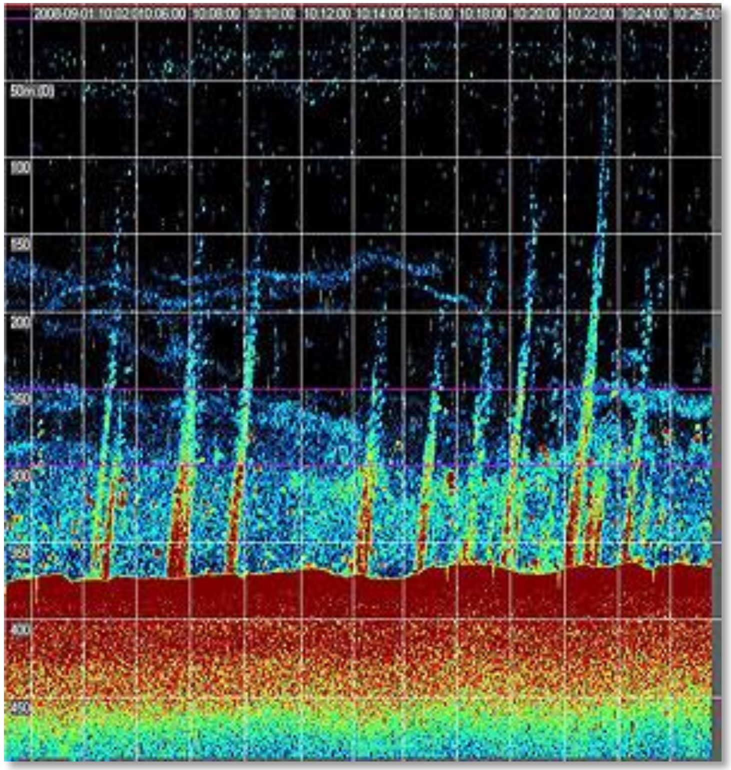


F ≈ 1

F >> 1

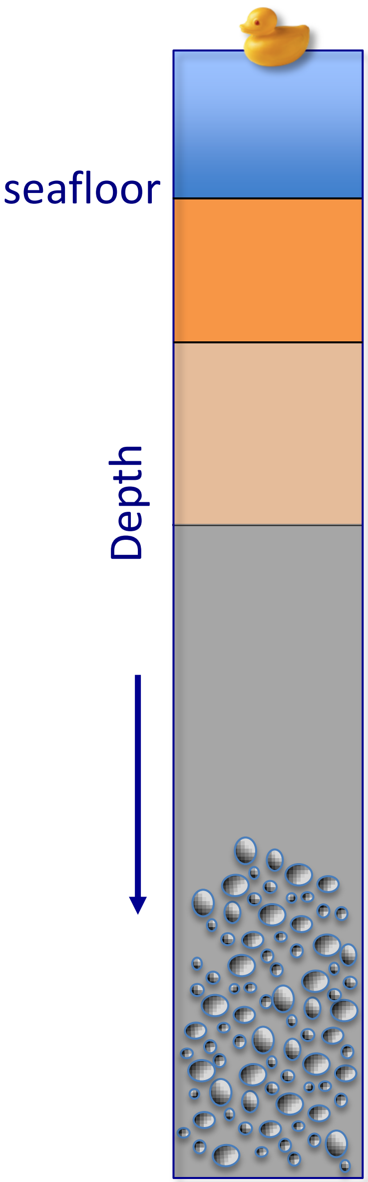
METHANE EMISSIONS

Rig: Smedvig West Vanguard Semi-Sub
Date: 06 October 1985
Location: Haltenbanken, Norwegian Continental Shelf
Operator: Statoil



Westbrook et al., 2009, GRL http://www.see.ed.ac.uk

Methane Generation: biogenic



Photic zone

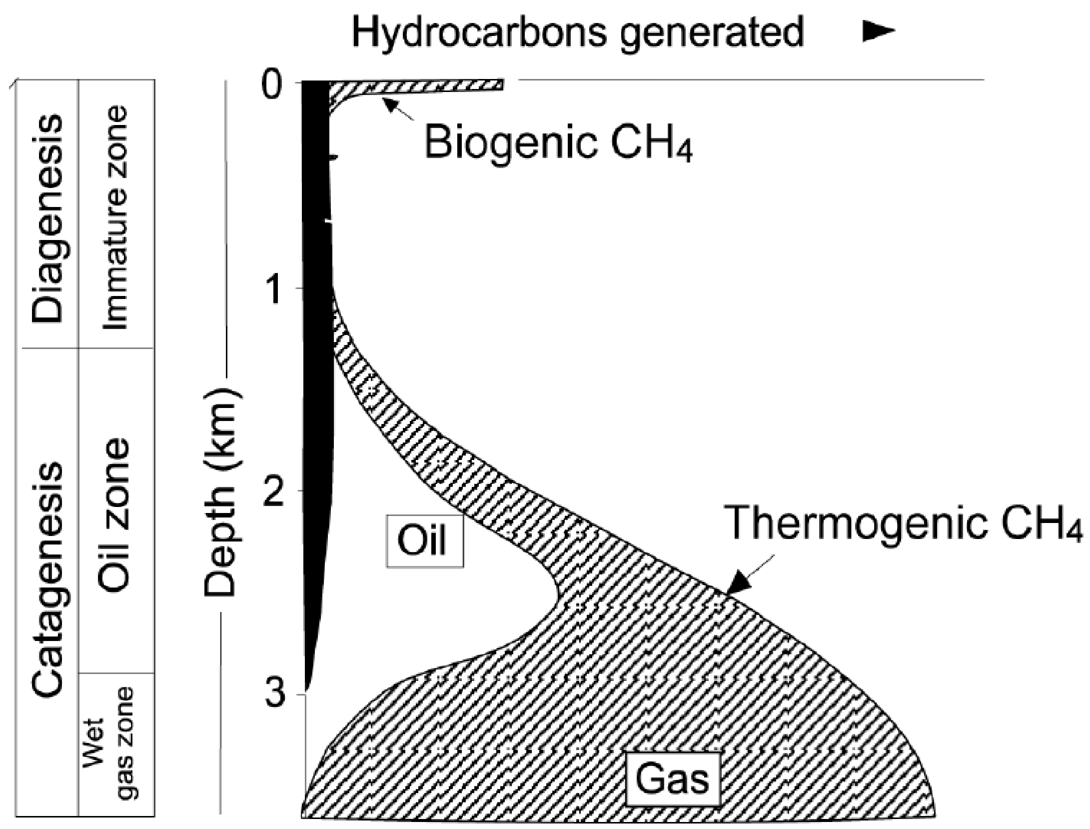
1. Aerobic (respiration):
$CH_2O + O_2 = CO_2 + H_20$

2. Sub-oxic zone

3. Anoxic (sulfate reducing) zone:
$CH_2O + SO_4 = CO_2 + H_2S$

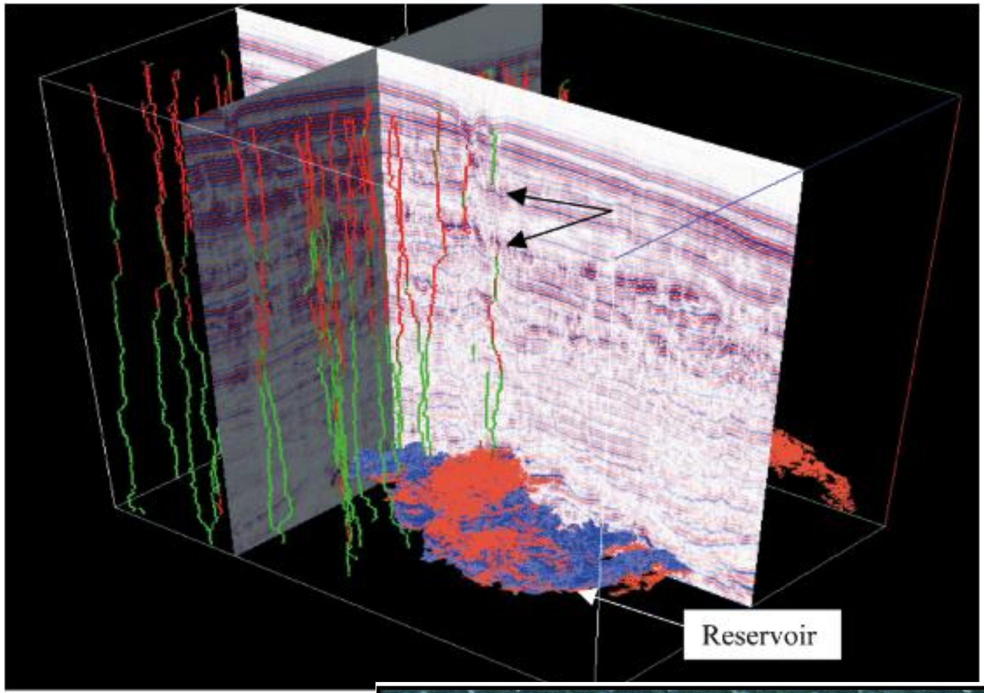
4. Methanogenesis:
$CH_2O = CO_2 + CH_4$

Methane Generation: thermogenic

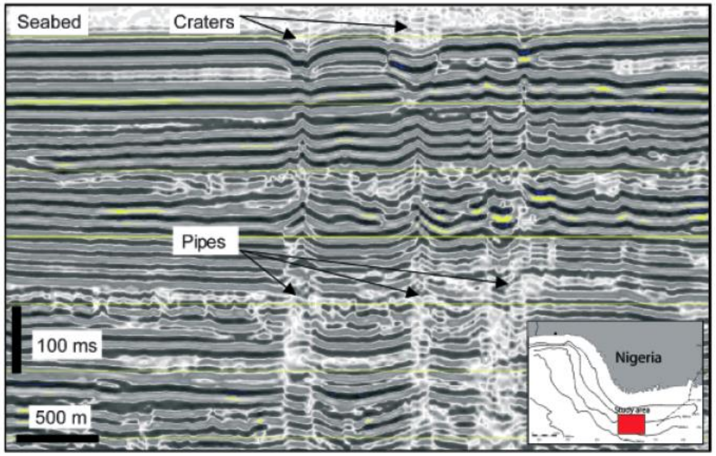


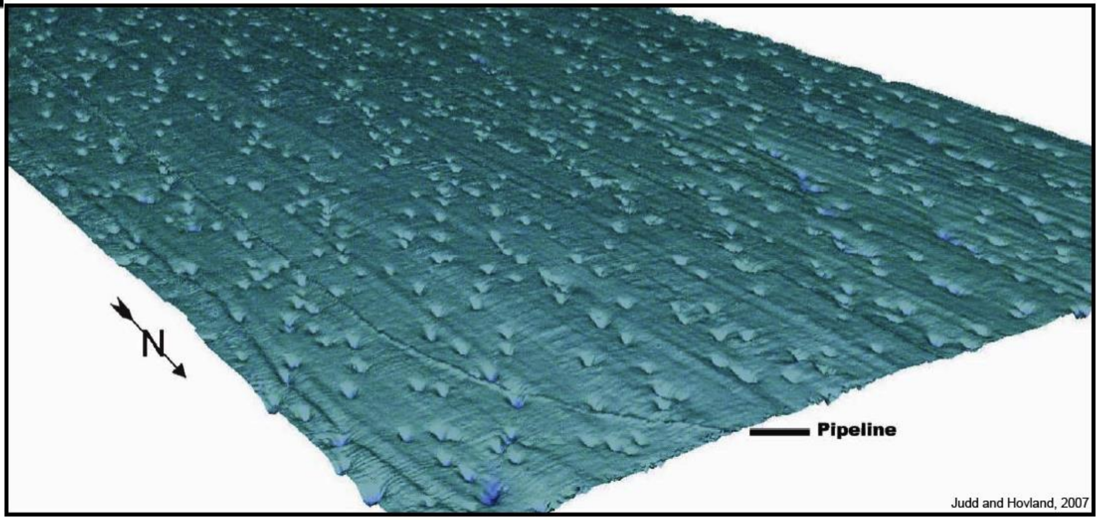
Tissot and Welte, Petroleum Formation and Occurrence, Springer-Verlag, 1992.

Methane migration and escape to the seafloor

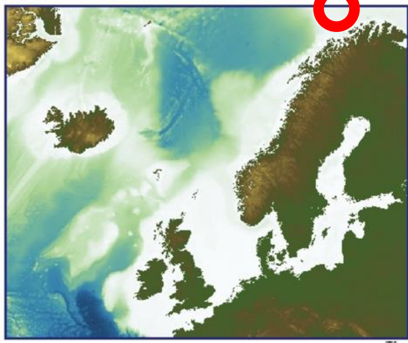


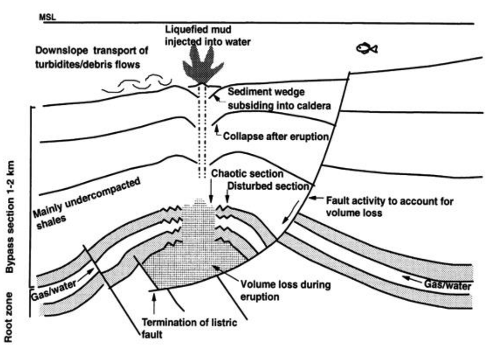
Lseth et al., 2001



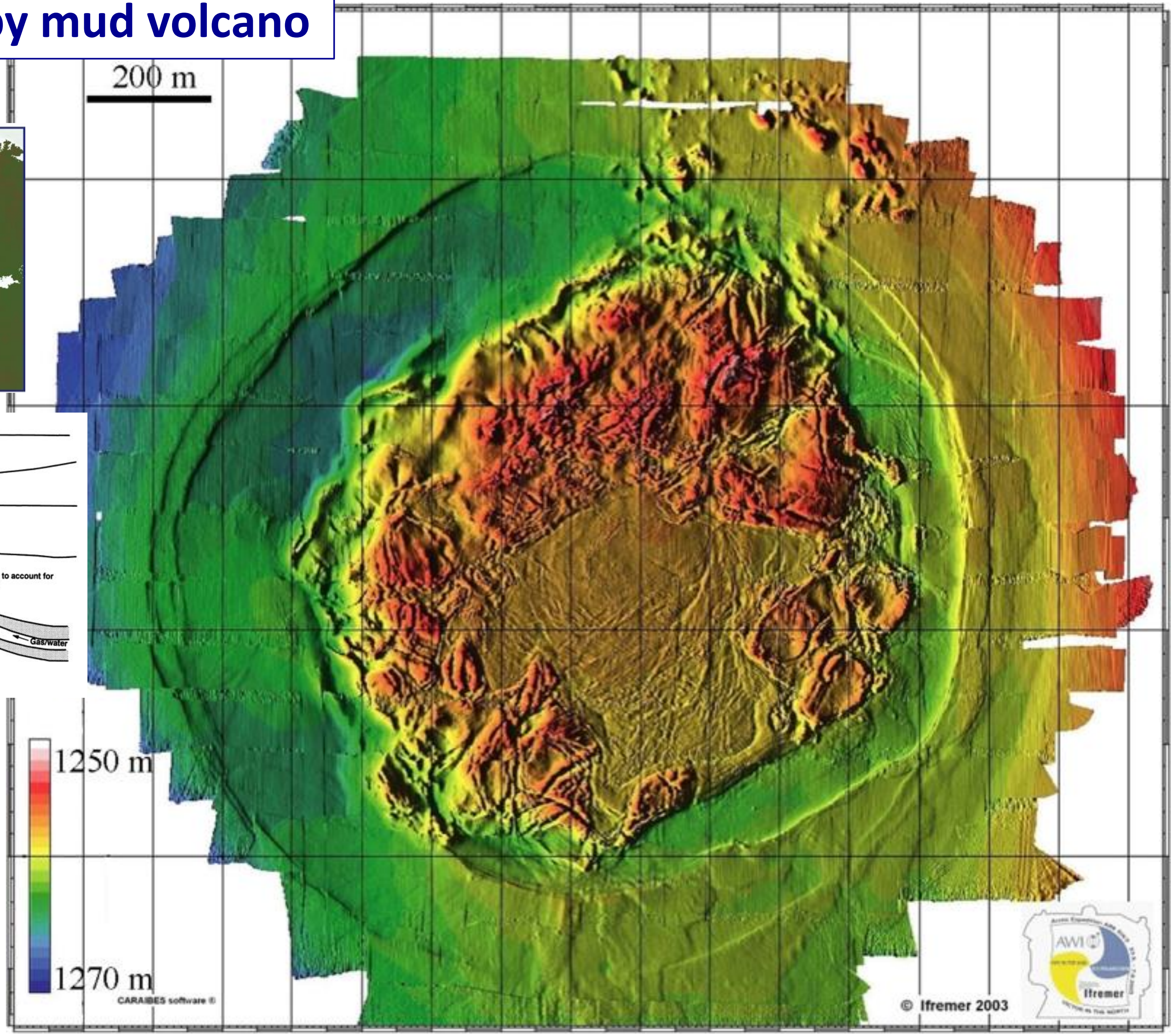


Haakon Mosby mud volcano





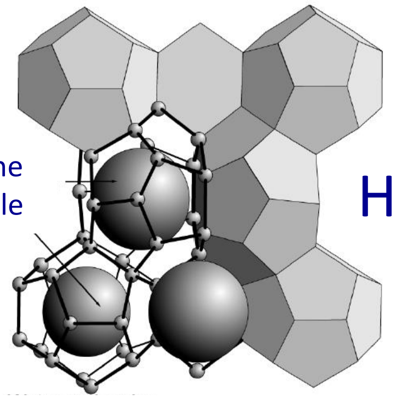
Niger Delta
Graue, Marine and
Petroleum Geology 17
(2000) 959–974



Niemann et al., 2006. Nature

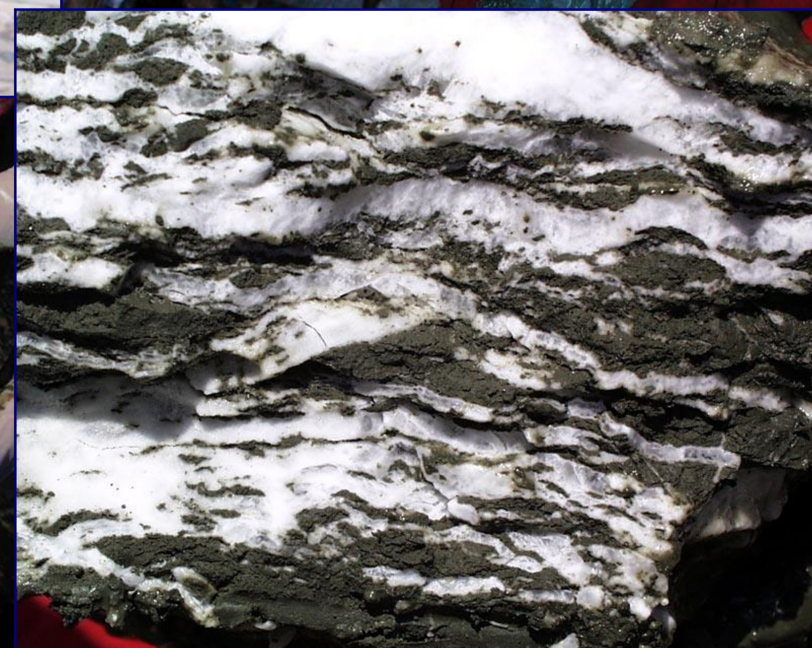
HYDRATES OF NATURAL GAS *(discovered in 1810)*

- Gas hydrates are a **solid phase** composed of **water** and low-molecular weight **gases** (predominantly methane)
- Water molecules form an ordered crystalline solid matrix which includes gas molecules with weak electro-static bounds
- The state of **saturation of hydrates is a function of pressure and temperature**. They form under conditions of low temperature, high pressure, and adeguate gas concentration



Bohrmann and Torres, 2006, in Schulz, Horst D.; Zabel, Matthias (Eds.) Marine Geochemistry

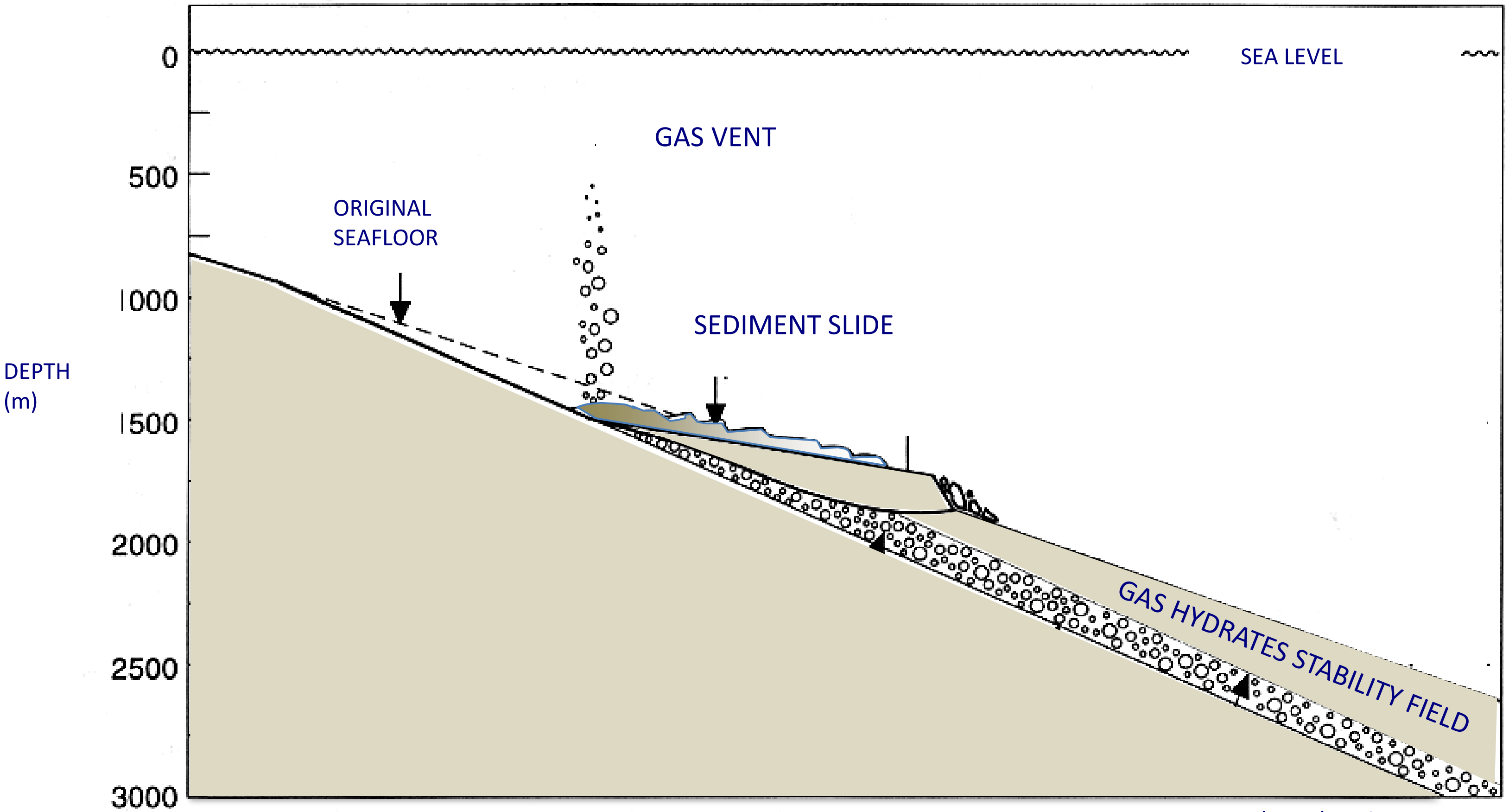
Gas hydrate laboratory
University of Rome La Sapienza



http://www.rcom.marum.de

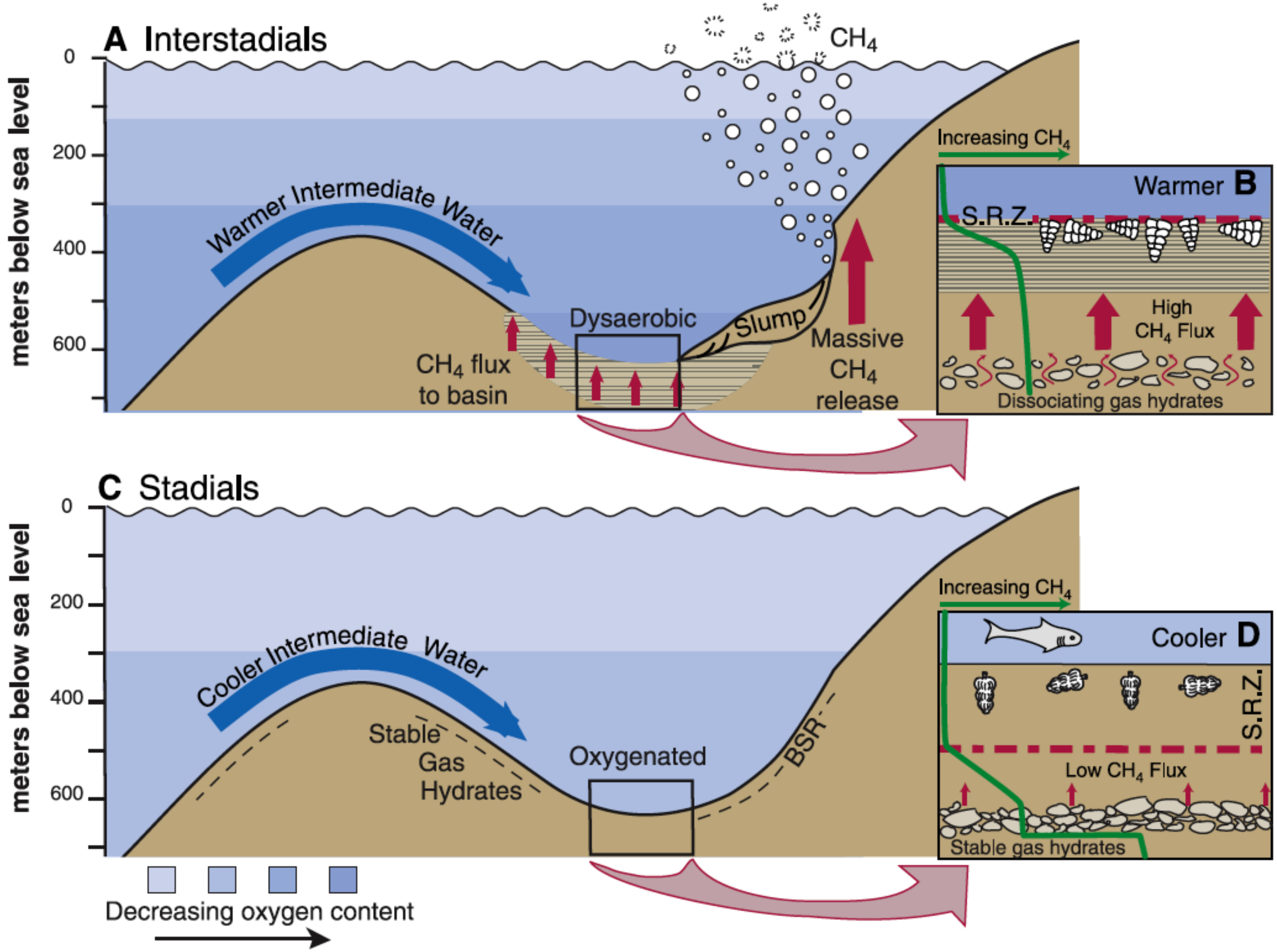
Gas hydrates and submarine landslides
A conceptual model

In response to global warming....



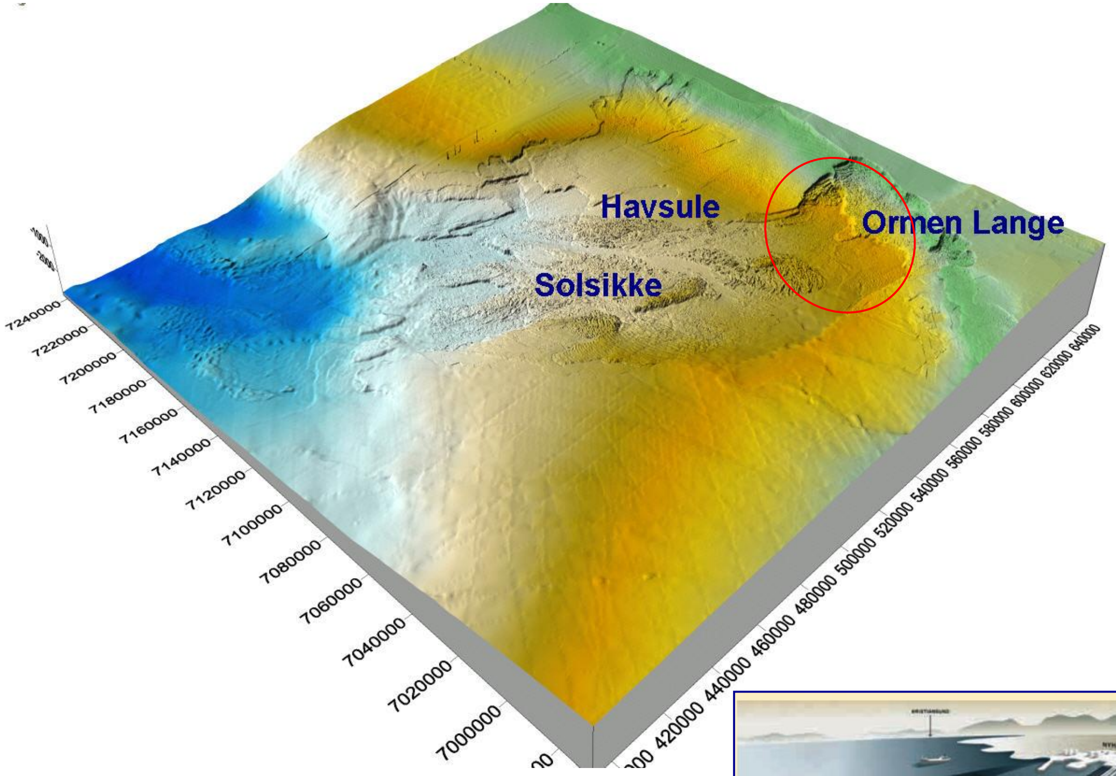
Adapted, various sources

The Clathrate Gun Hypothesis



Kennett *et alii*, Science, 2000

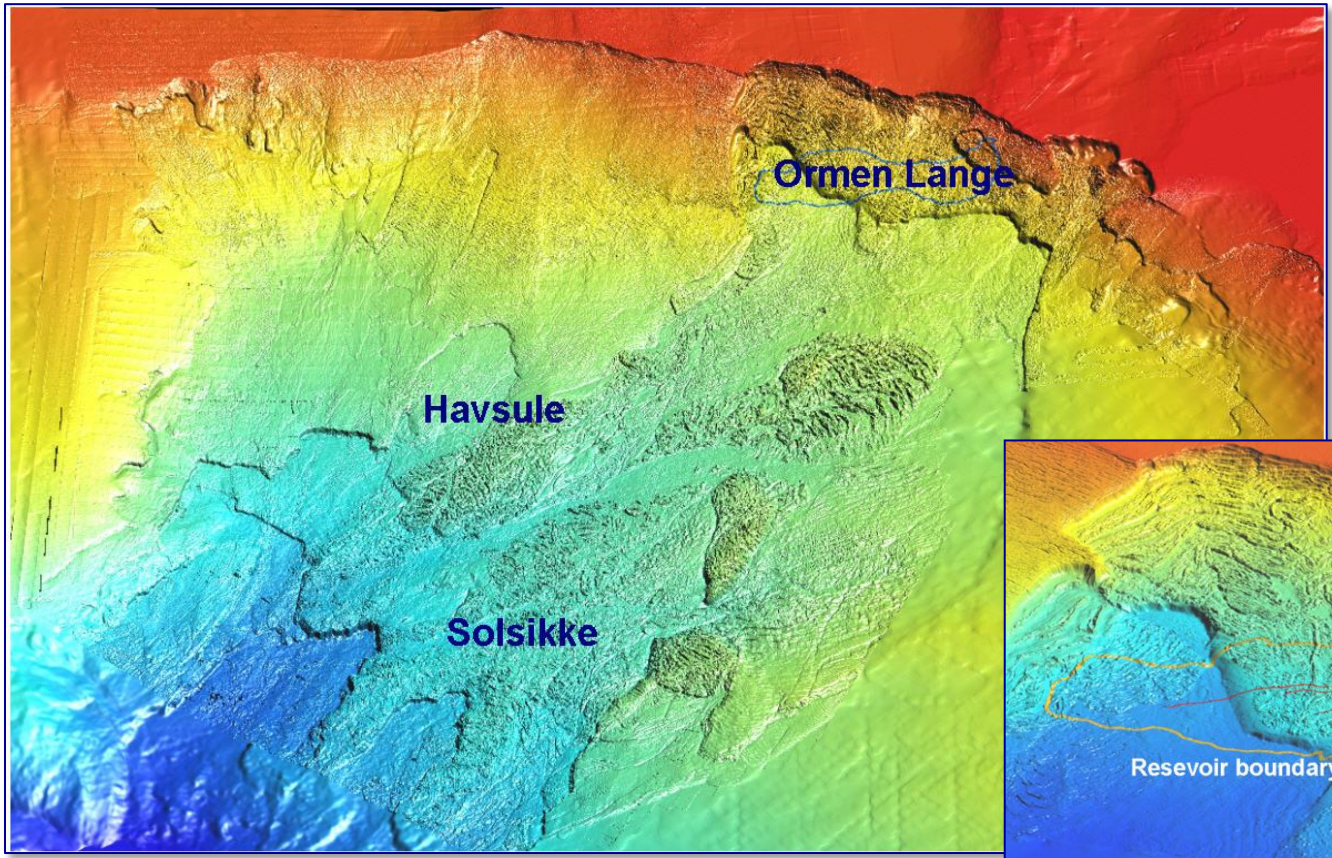
The Storegga submarine landslide on the Norwegian Continental margin (about 7000 years ago)

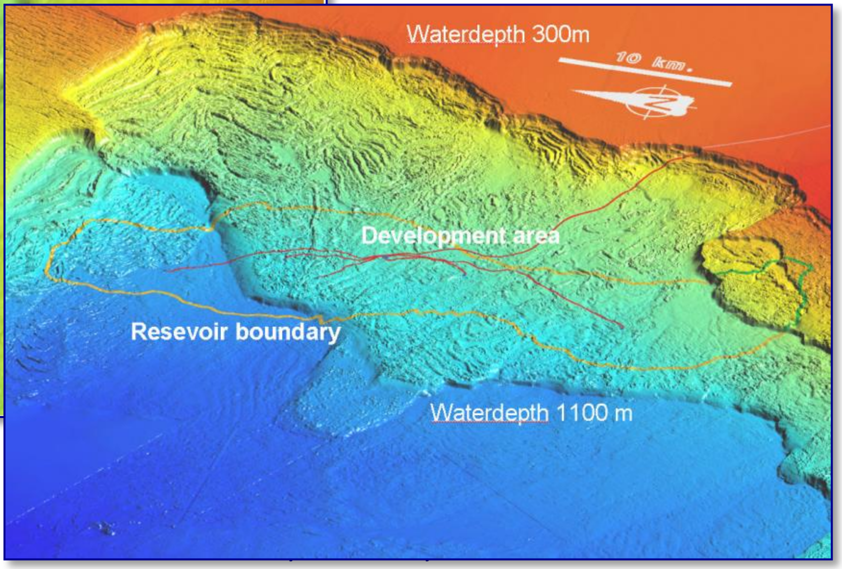


Courtesy Petter Bryn

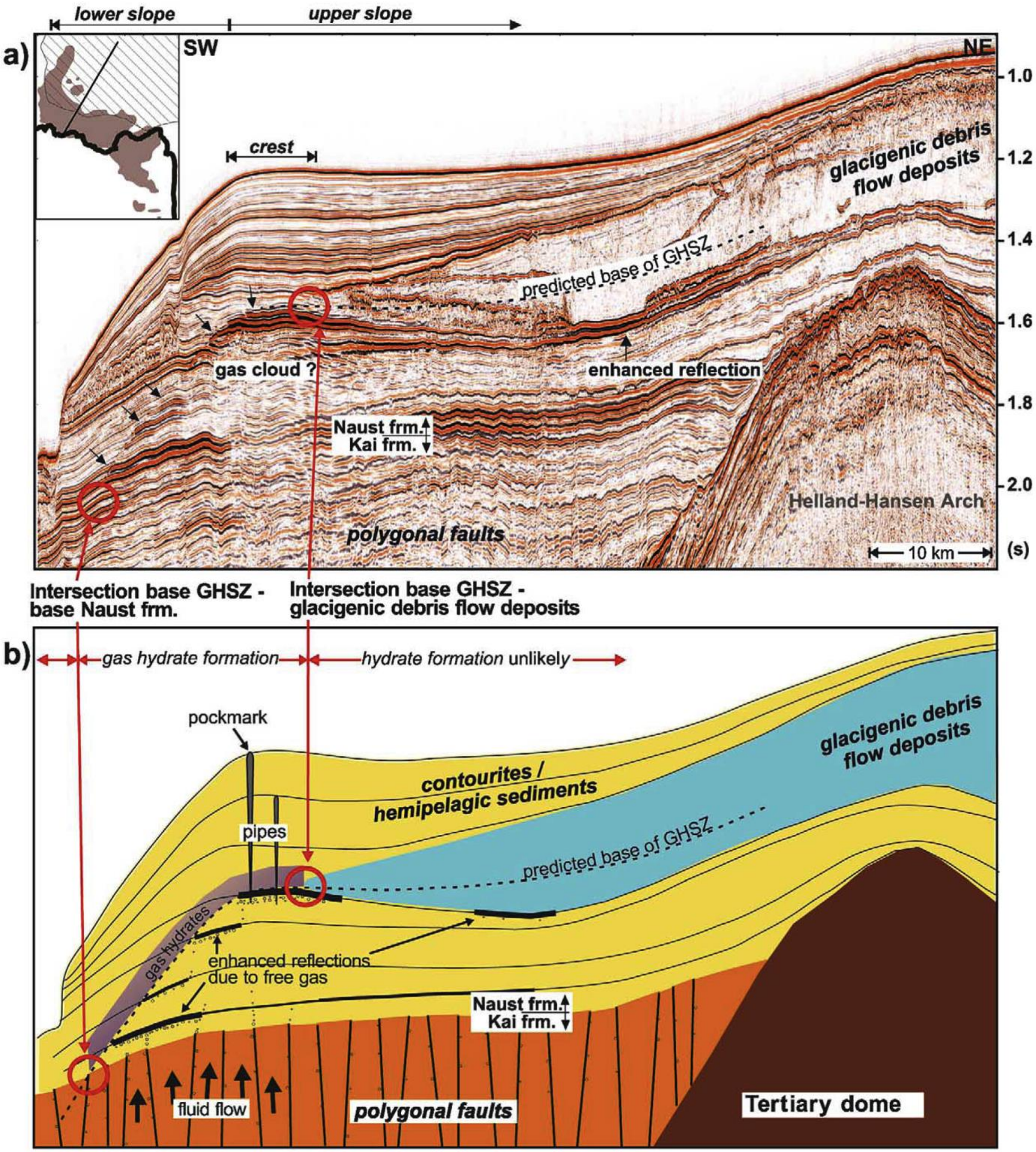
Norsk Hydro
E&D Norway
Geophysical Operations

The Storegga submarine landslide on the Norwegian Continental margin (about 7000 years ago)

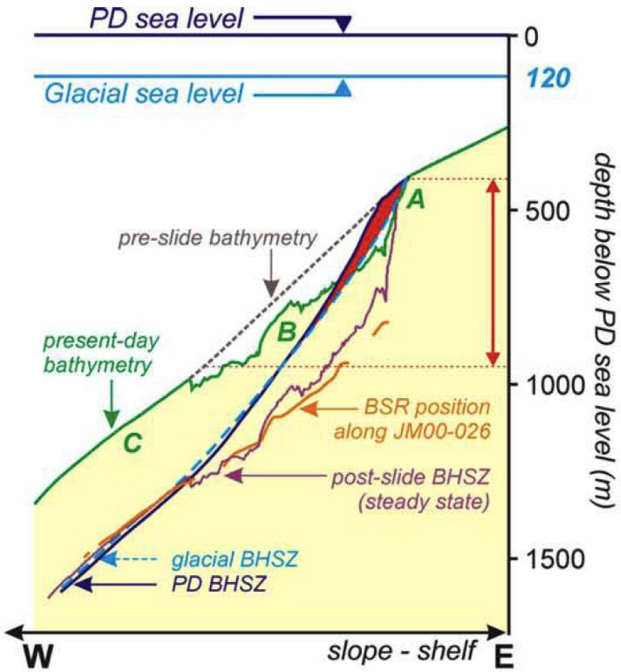




GAS HYDRATES BELOW THE STOREGGA SUBMARINE LANDSLIDE



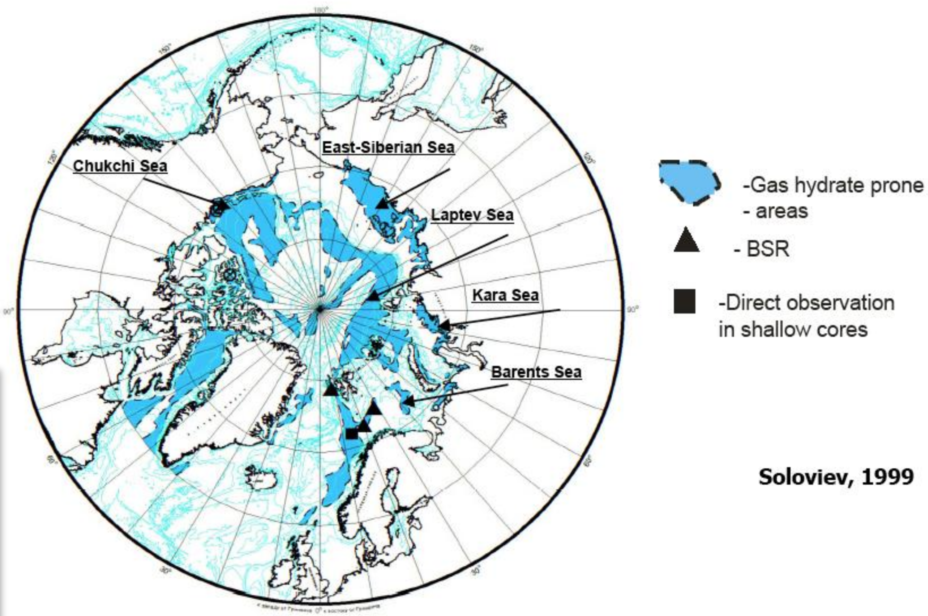
Buenz et al., 2003



Mienert et al., 2005

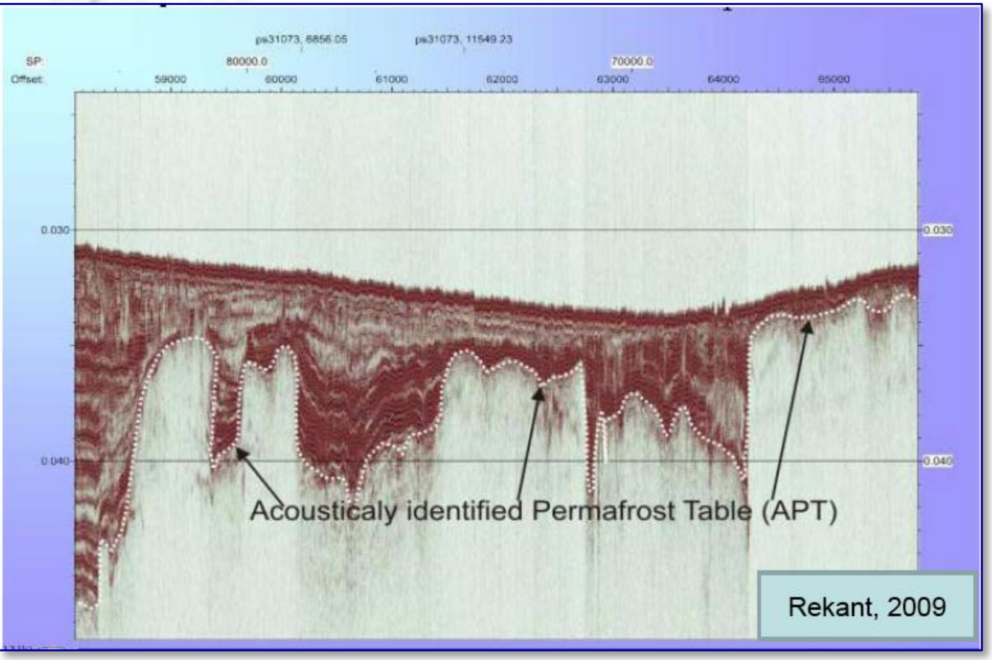
It is speculated that "relic" permafrost and gas hydrate may exist on the continental shelf of the Arctic Ocean to present water depths of 120 m.

Potential hydrate basins in the Arctic



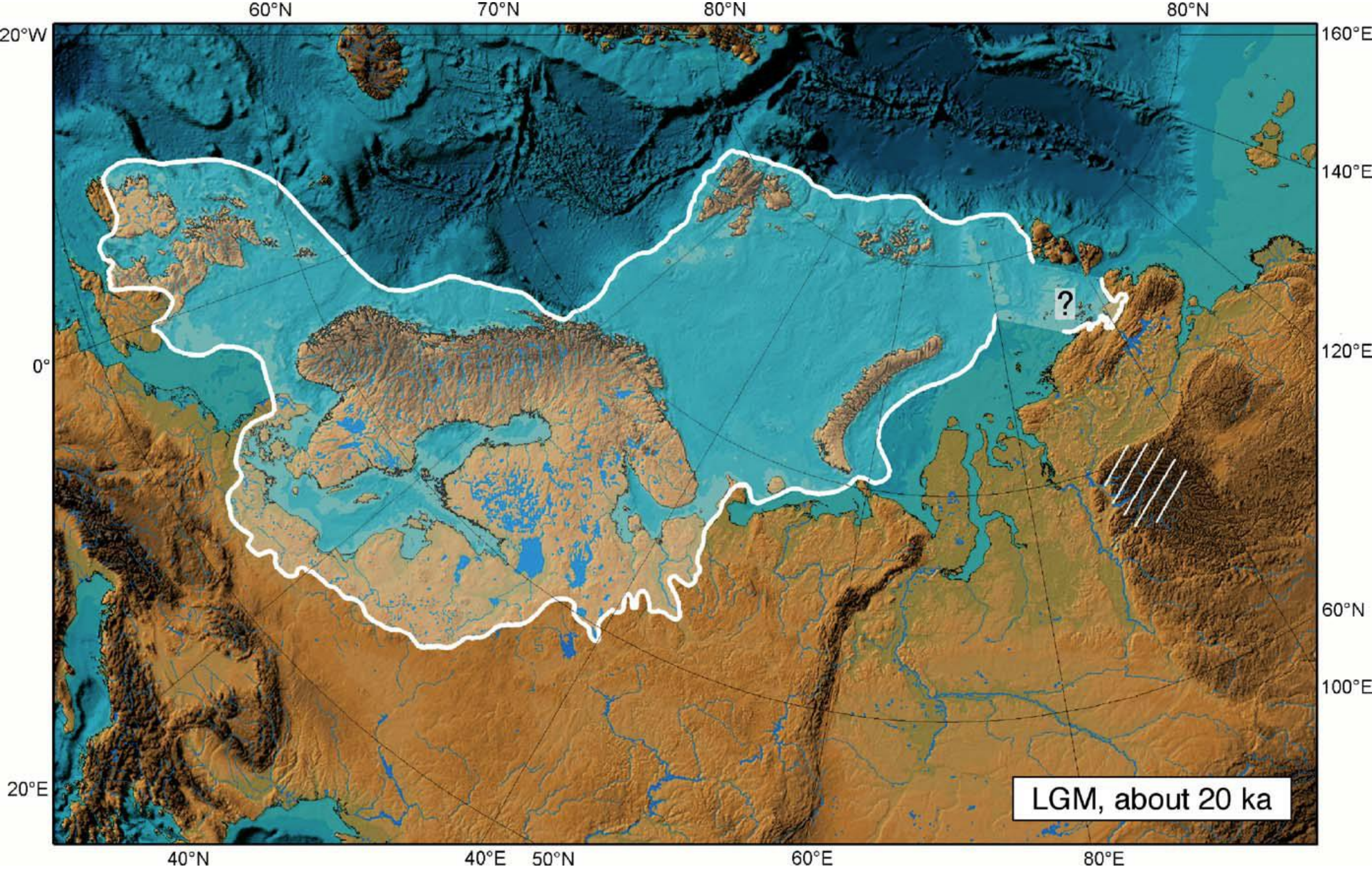
Soloviev, 1999

Laptev Sea



Rekant, 2009

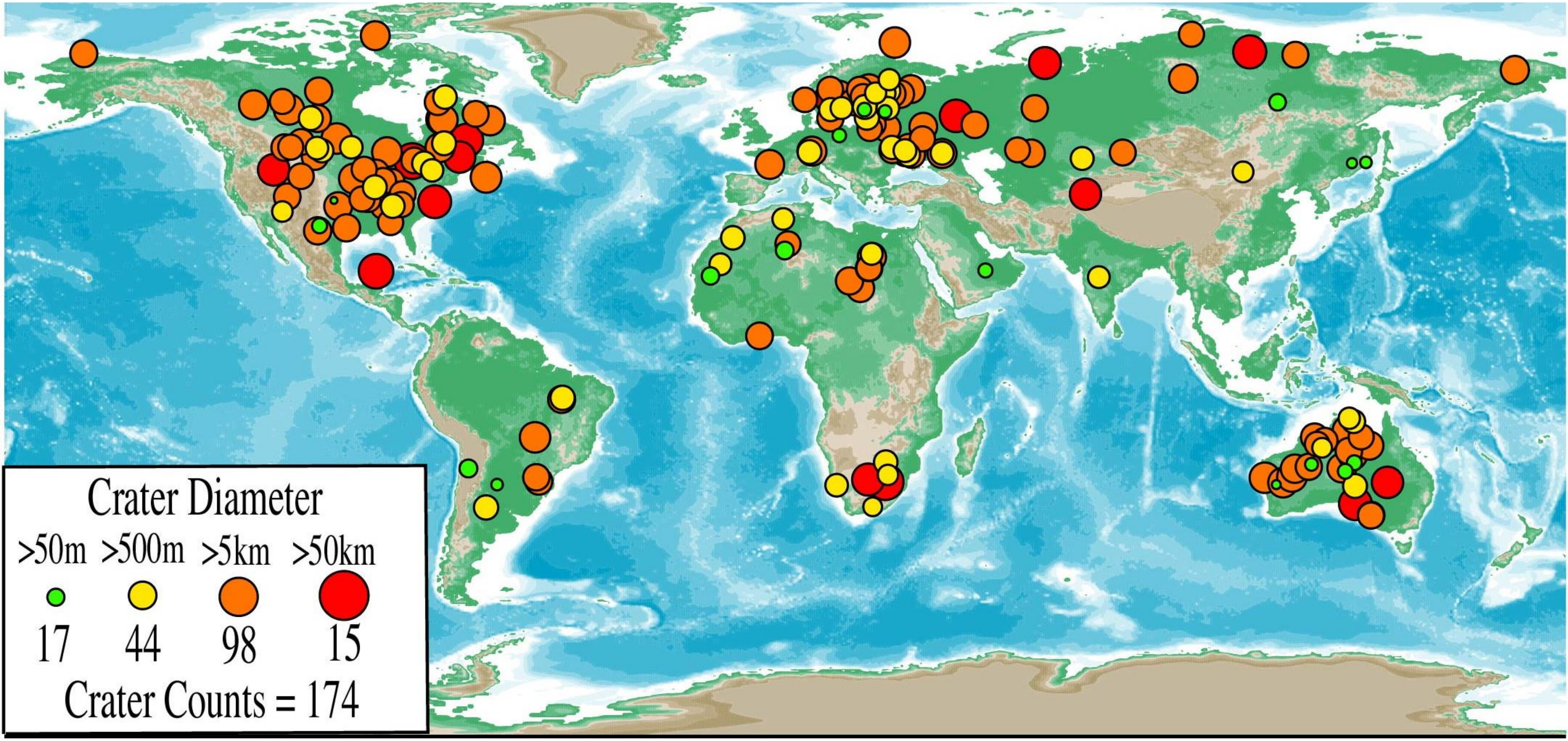
How much methane from the seabed goes to the water column and how much leaves the ocean to atmosphere?



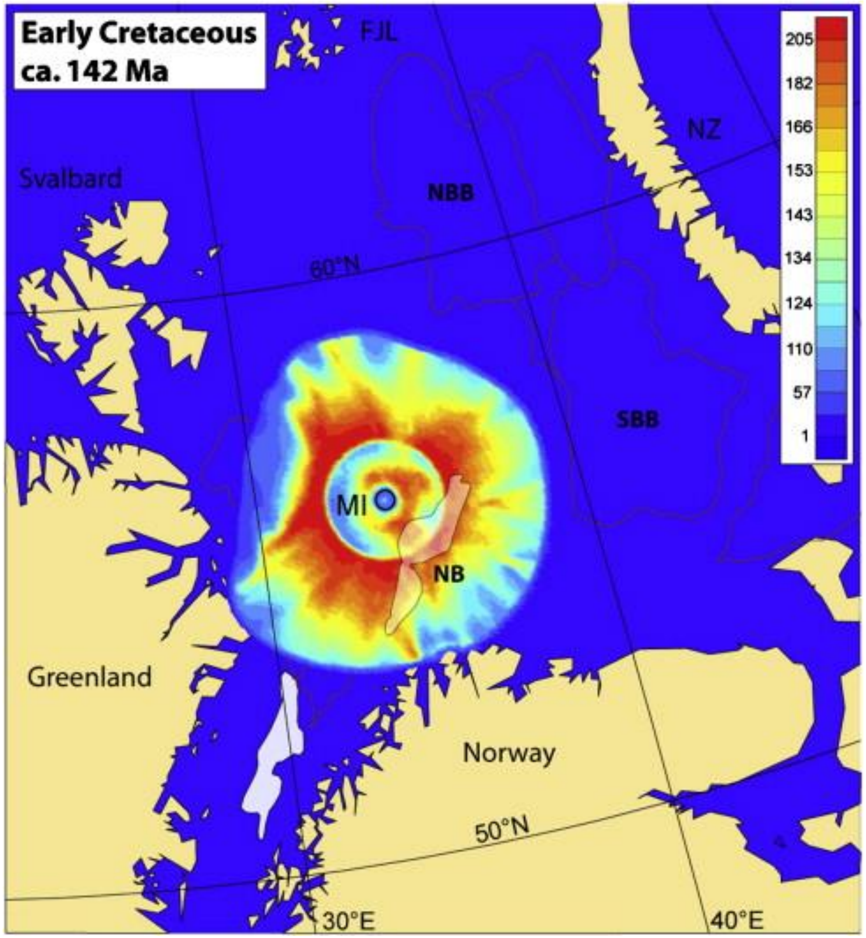
Svendsen et al., 2004

METEORITE IMPACTS in the OCEANS

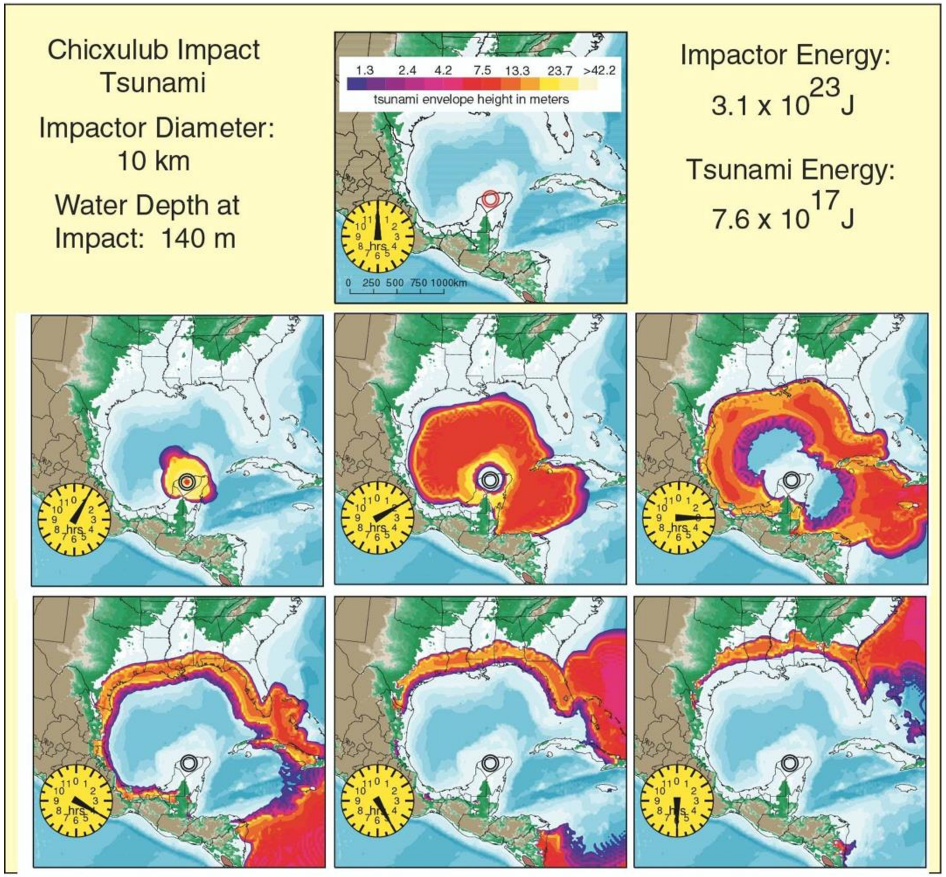
http://es.ucsc.edu/~ward/



METEORITE IMPACTS in the OCEANS



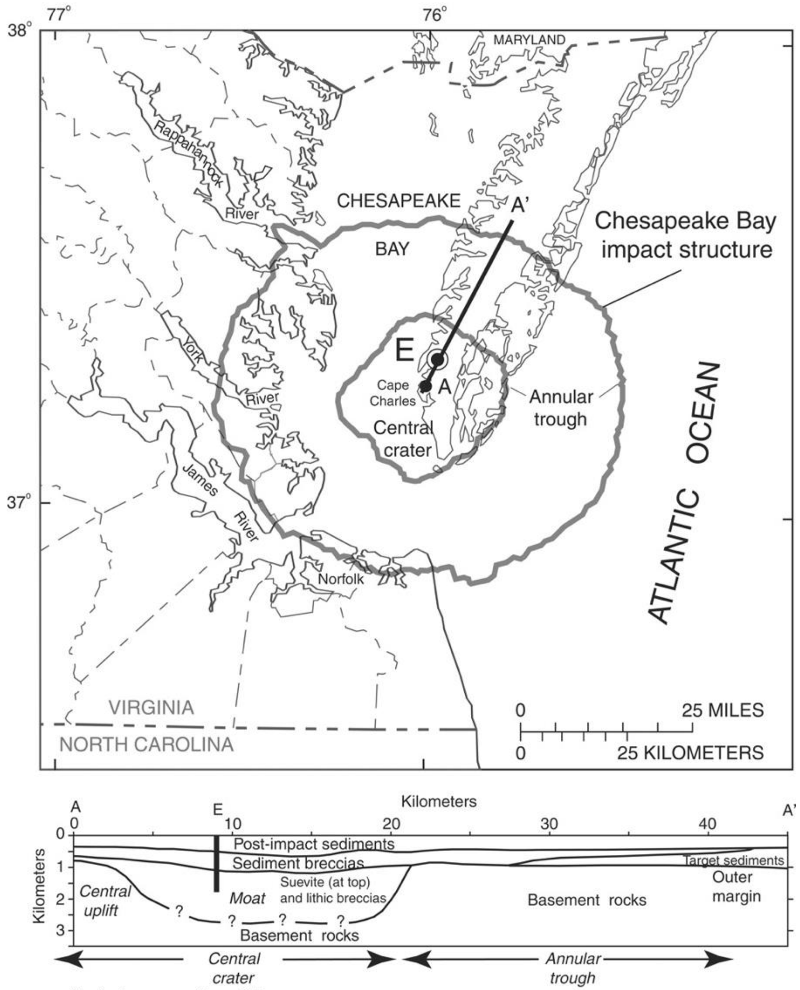
Werner and Torsvik, 2010



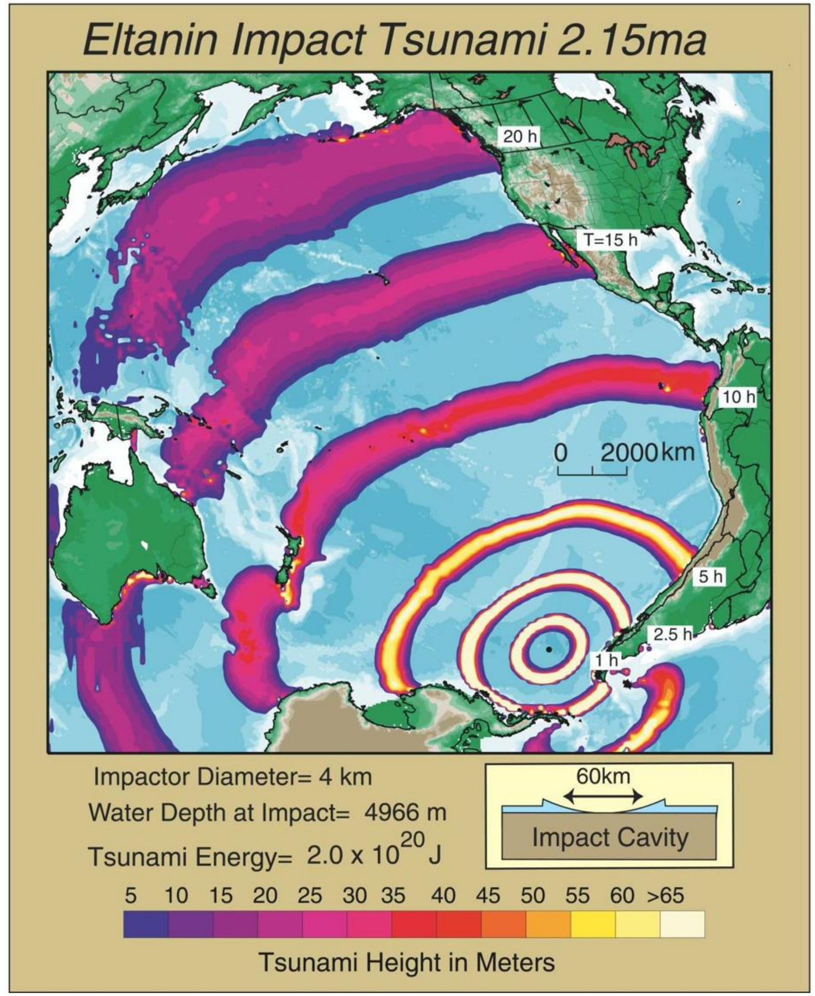
http://es.ucsc.edu/~ward/

METEORITE IMPACTS in the OCEANS

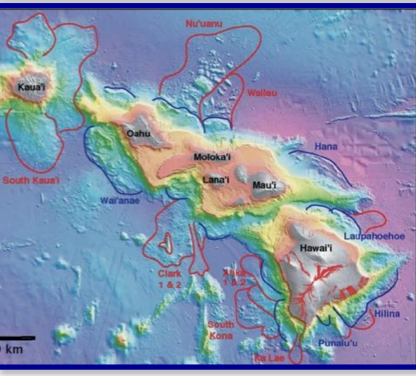
late Eocene Chesapeak Bay Impact

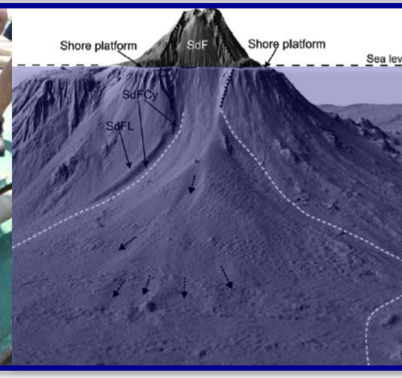


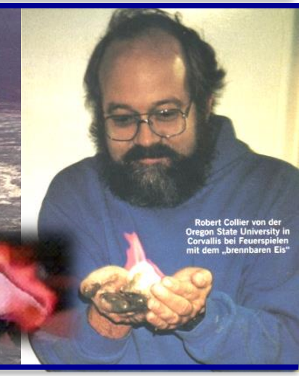
Gohn et al., 2008. Science



http://es.ucsc.edu/~ward/



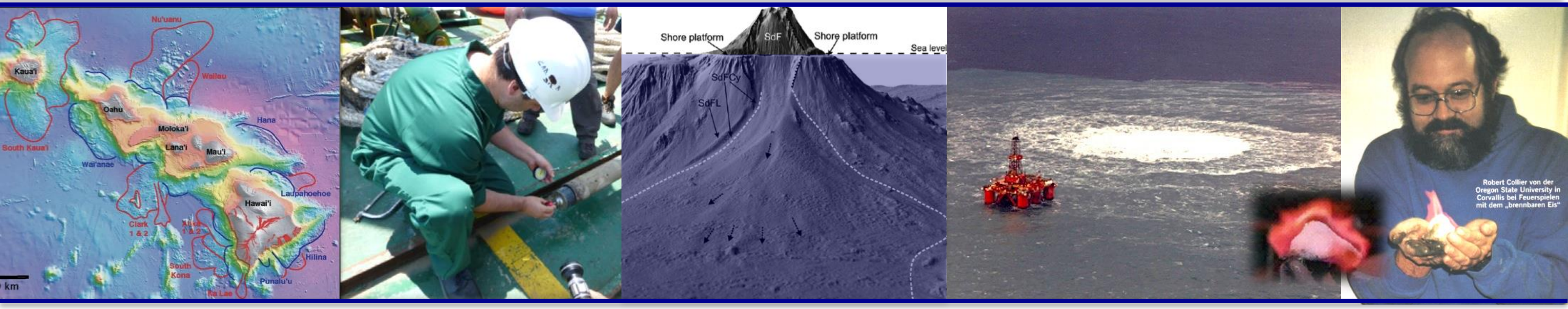




CONCLUDING REMARKS

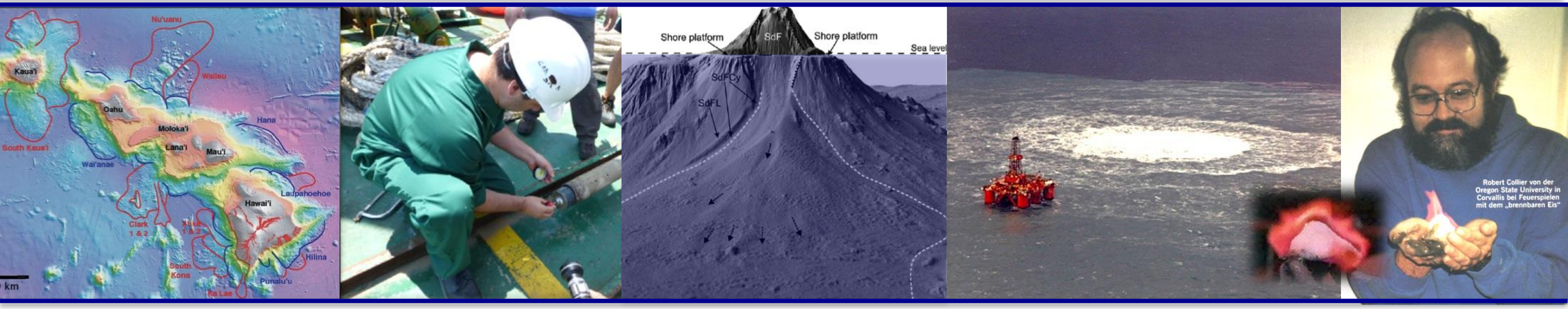
- THERE ARE THINGS MOVING DOWN THERE
- TECHNOLOGY HAS PERMITTED TO IDENTIFY GEOLOGICAL PROCESS ON THE SEAFLOOR THAT CAN BE DEFINED AS HAZARDS
- VULNERABILITY IS INCREASED DUE TO INCREASED USE OF THE SEAFLOOR

SUBMARINE GEOHAZARDS



CONCLUDING REMARKS

- CLIMATE CHANGE CAN INCREASE THE FREQUENCY AND MAGNITUDE OF CERAIN SUBMARINE GEOHAZARDS (GAS EMISSIONS AND SUBMARINE LANDSLIDES)
- UNDERSTANDING OF MECHANISMS IS STILL POOR
- THERE ARE UNCERTAINTIES ON RECURRENCE TIMES
- MAGNITUDE OF EVENTS IS EXTREMELY VARIABLE



CONCLUDING REMARKS

THERE IS A NEED FOR IMPROVED KNOWLEDGE!

Which means bright students in oceanography earth science, geophysics, engineering, biology, chemistry

For any question also after the GIFT Workshop: acamerlenghi@ogs.trieste.it