Università di Trieste
Corso di Laurea Magistrale in Esplorazione Geologica

Anno accademico 2021 - 2022

Geologia Marina

Modulo 6.2 Pericolosità dei fondali marini 1

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OUTLINE

- The Seabed: Continental Margins and Physiographic Domains
- Geological Processes shaping the Seabed
- The role of Seabed mapping: Bathymetry and Geomorphology
- Concepts of Hazard, Vulnerability, Risk, Mitigation, Resilience
- Active Seabed: Natural Marine Geohazards
- Examples of Geohazard Assessment along the Ionian Seabed
- Natural Hazard Management of the Seabed

OUTLINE

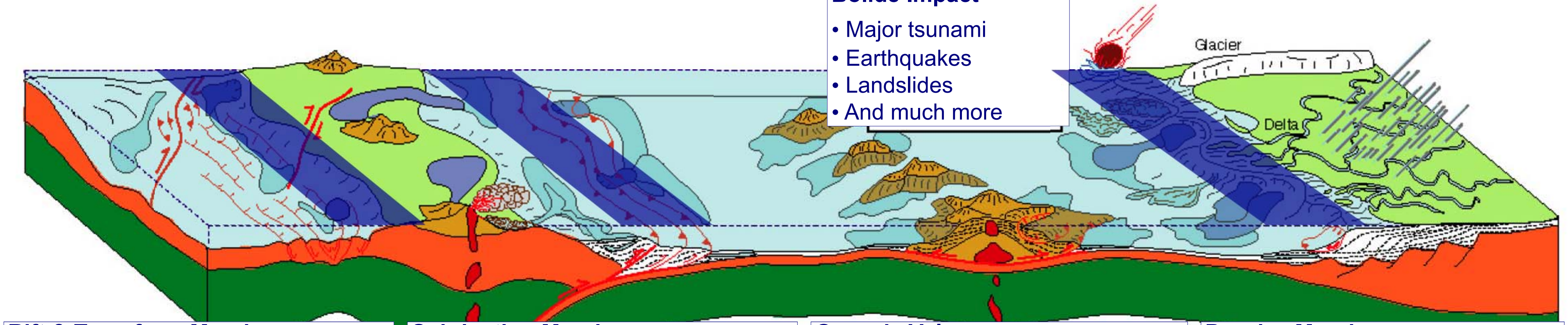
- Concepts of hazard, vulnerability, risk, mitigation, resilience
- Natural marine geohazards
- The use of integrated acoustic methods ….
- …and examples of geohazard assessment in the Ionian sea

CONTINENTAL MARGINS

Plate tectonics is a scientific theory describing the large-scale motion of the plates making up the Earth's lithosphere since tectonic processes began on Earth between 3.3 and 3.5 billion years ago.

Earth's ***lithosphere*** includes the crust and the uppermost mantle, which constitutes the hard and rigid outer layer of the Earth

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

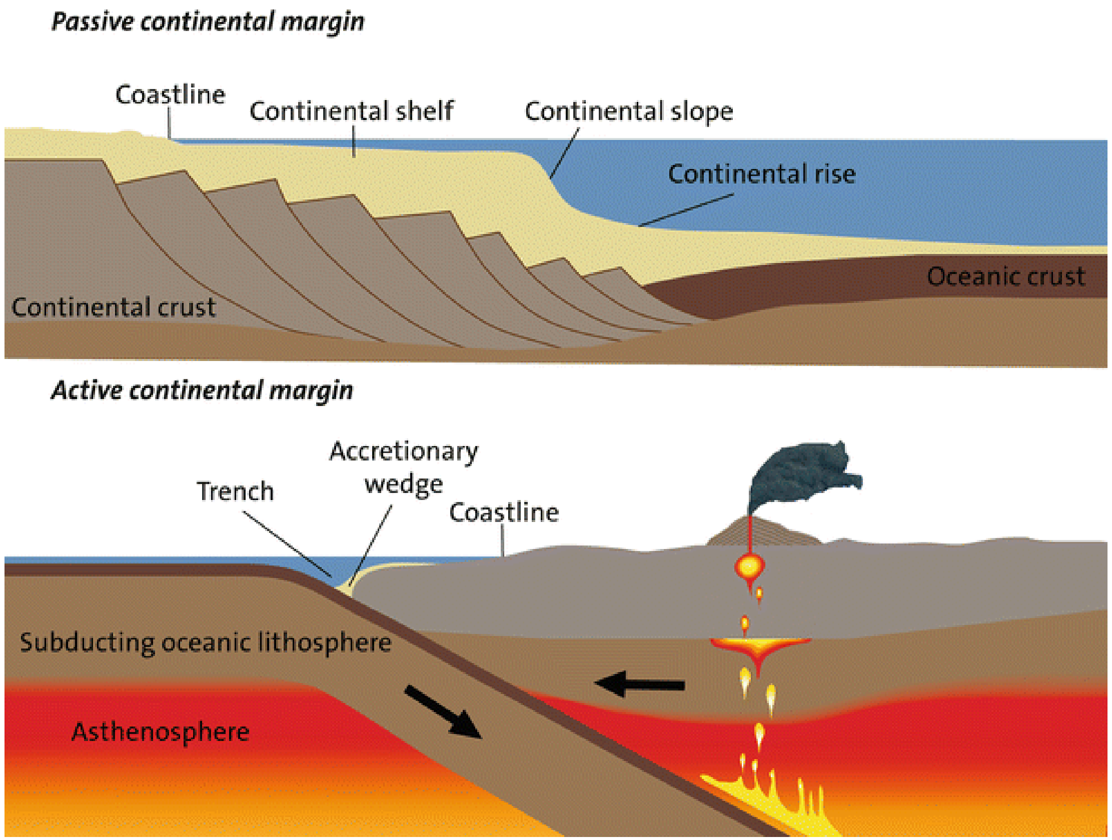
Geologically
They mark the transition between the oceans and the continents. They extend from the coastal zone to the abyssal plains and basins. Continental margins are the regions on Earth where most of the sediments are deposited (as much as 90% of the sediment generated by erosion on land) (McCave, 2002).

Continental margins are very significant economically.
Most of the major fisheries of the world are located on them. Tourist industries are becoming increasingly important to the economies of developed nations. Paradoxically, continental margins also are one of the world's biggest dump sites. All kinds of wastes are disposed along the margins, and the effects of pollution have become a major global concern .Continental margins are the only parts of the world's oceans to be effectively exploited for mineral resources. By far the largest mineral resources to be exploited from continental margins are oil and natural gas.

Physiographic domains

Bathymetry

The term bathymetry is used to describe underwater relief.



A ***continental shelf*** is a portion of a continent that is submerged under an area of relatively shallow water known as a shelf sea

Continental slopes are regions of steeply sloping seafloor that lie between continental shelves and the deep ocean basins

Ocean basin, any of several vast submarine regions that collectively cover nearly three-quarters of Earth's surface Ocean basins are depocenters for sediment derived from the continents as well as from intrabasinal sources. The rate of aggradation of sediment can be very high,

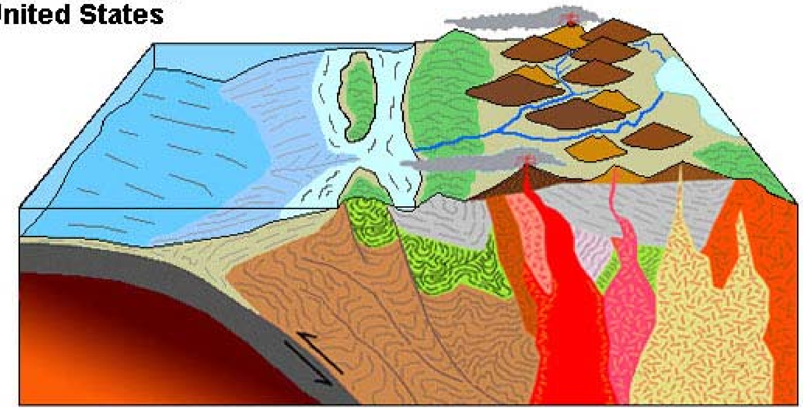
Geomorphology is the discipline that study the origin and evolution of topographic and bathymetric features created by physical, chemical or biological processes

Why we have high relieves and deep basins?

the role of plate tectonics in driving topography and morphologies

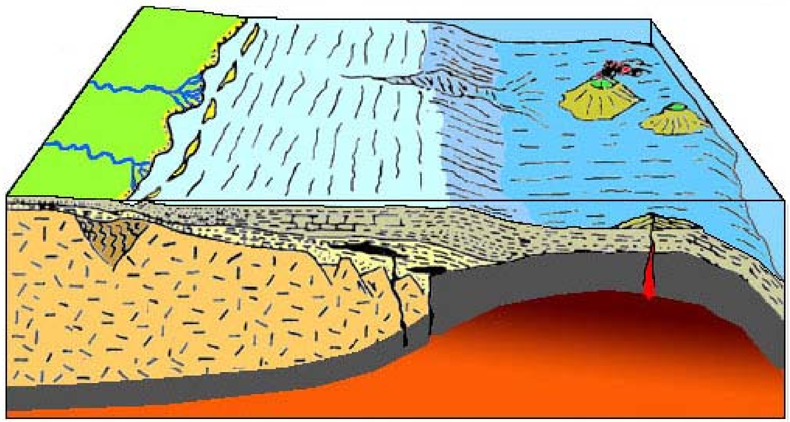
Active Continental Margin
example: West Coast of United States

tectonically active
-- earthquakes common
-- many volcanoes
high relief



Passive Continental Margin
example: East and Gulf Coasts of United States

tectonically stable
-- few earthquakes
-- no volcanoes
sedimentary deposits covers older rocks
low relief

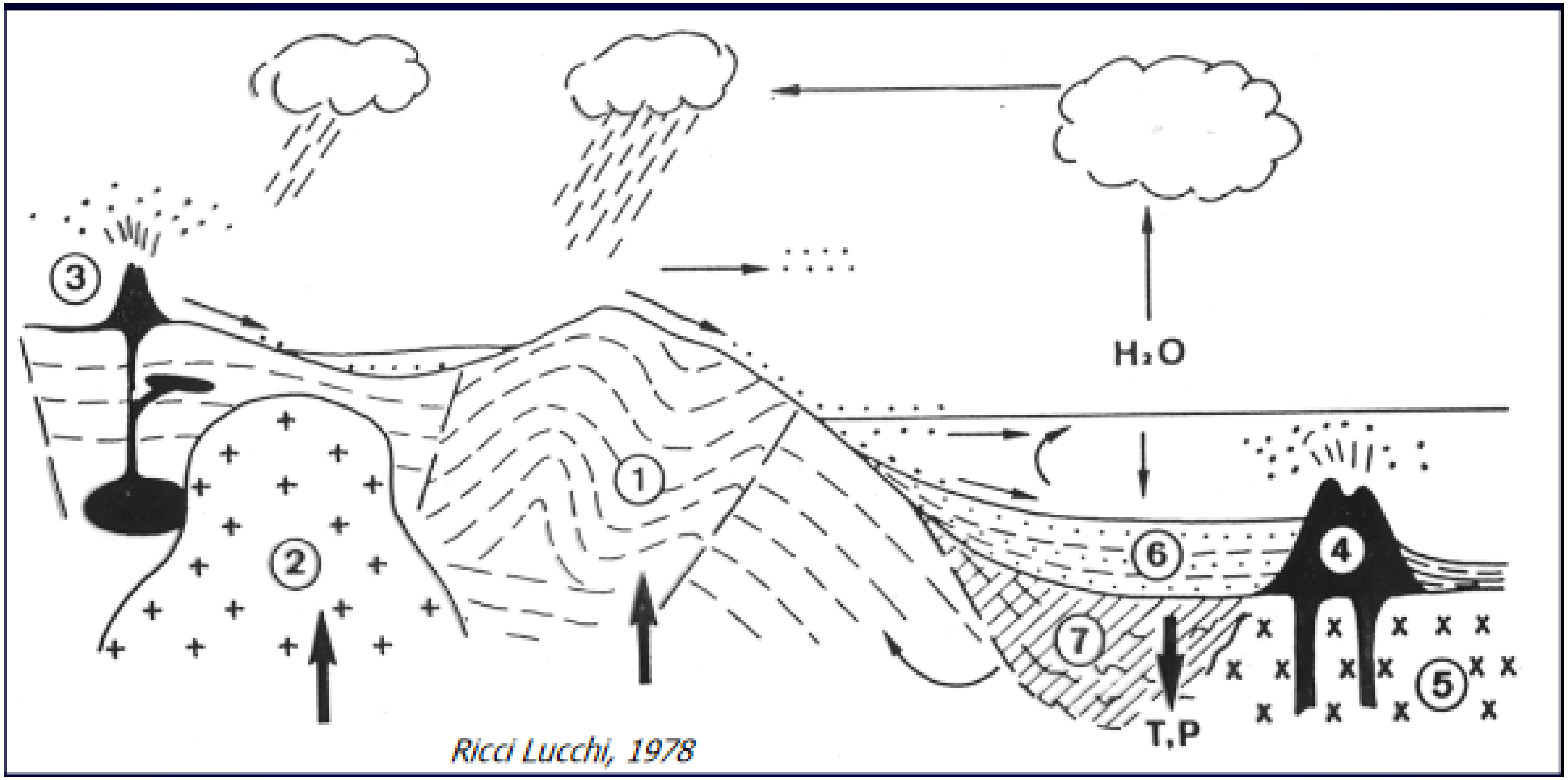


Endogenic processes are processes formed or occurring beneath the surface of the Earth: the main endogenic processes are:

- Tectonics (fold, fault & earthquakes,) the process of deformation that produces in the earth's crust its continents and ocean basins, plateaux and mountains, folds of strata,
- Volcanism is the phenomenon of eruption of molten rock (magma) onto the surface of the Earth
- Metamorphism is a process that changes preexisting rocks into new forms because of increases in temperature, pressure, and chemically active fluids

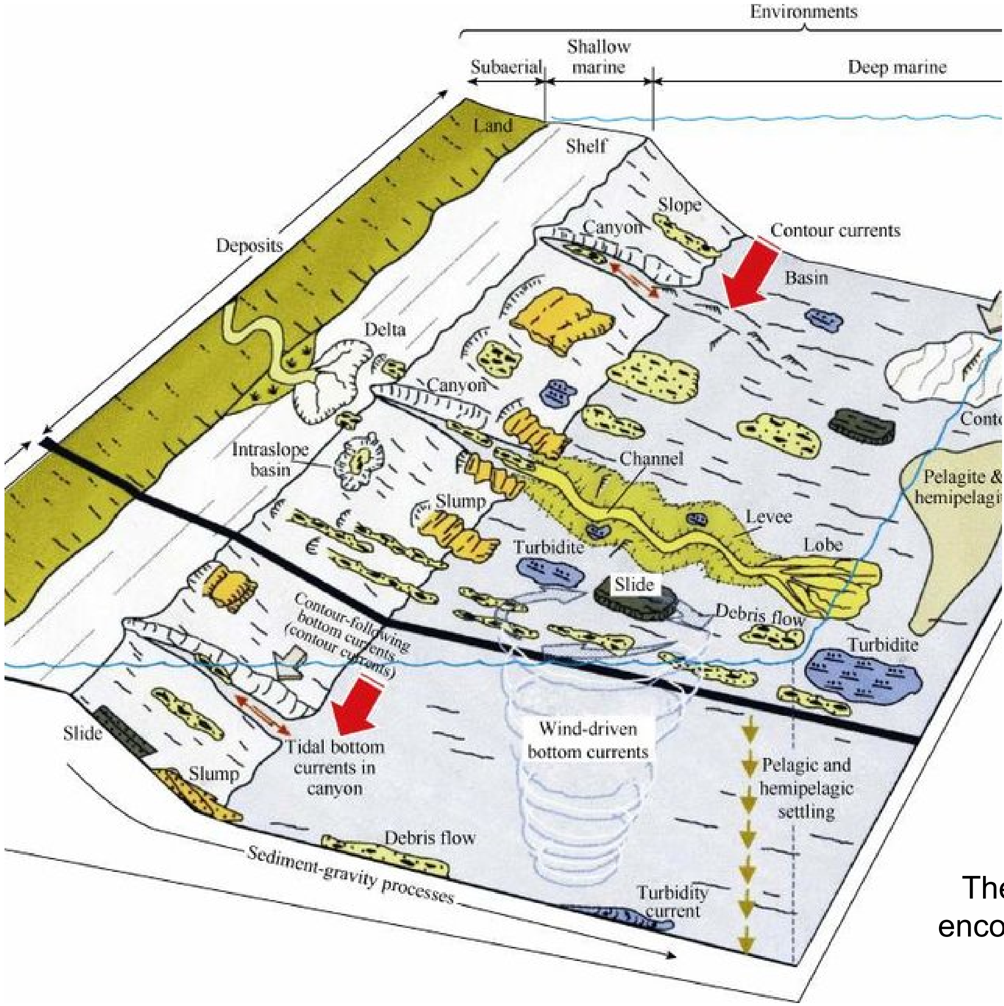
Endogenic process form the major seascape features.
Endogenic processes have been responsible for shaping the earth's geologic structures and for the formation of many of the most important mineral resources.

Where the sediments come from? The sediment cycle



Sedimentary rocks are formed by consumption of previous rocks due to processes of erosion, transport deposition a diagenesis

Schematic diagram showing complex deep-marine sedimentary environments (natural processes)



Exogenic processes All those processes which operate on or close to the surface of the Earth or Sea and which involve weathering, mass movement, fluvial, aeolian, glacial, periglacial, and coastal processes. The term is normally used in contrast to the endogenetic processes, whose origin is within the Earth.

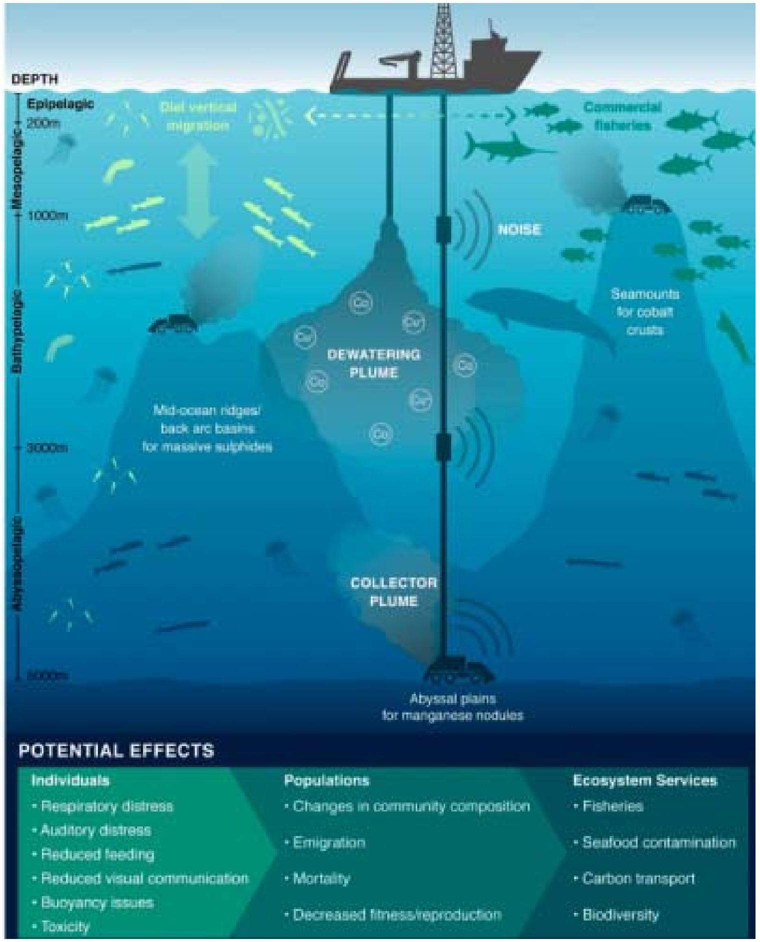
The deep ocean is the world's largest depositional environment, encompassing all of the ocean floor below the continental shelf and slope environments.

For the most part, deep marine environments are very still and experience little to no flow. Turbidity currents may reach deep ocean, depending on the size and density of the load, but generally do not extend more than a few thousand kilometers away from continental margins.

The majority of sediments are deposited through settling of suspended material. Deposition by settling occurs very, very slowly and is usually measured in mm/ka.

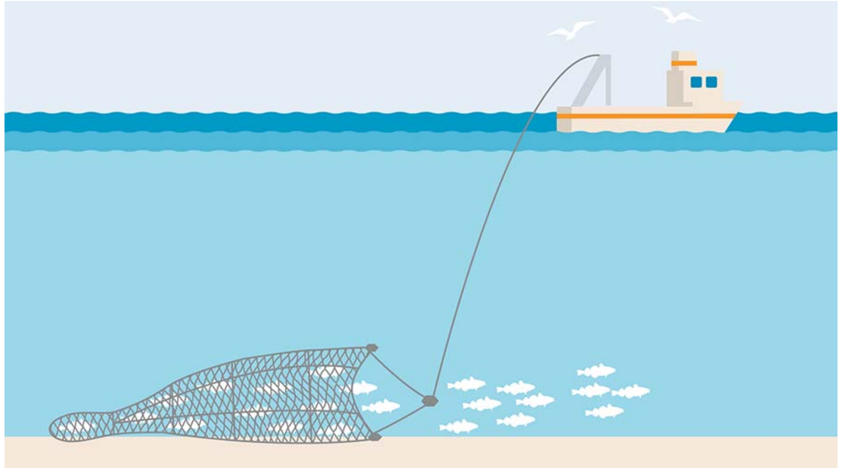
Anthropic driven processes at seabed: anthropic hazards

Processes driven by the needs of humans of having infinite resources available.
Instead, Our Planet is a close system!!
We should think toward a sustainable use of planet resources….



Deep-sea mining activities search for copper, cobalt, zinc, manganese and other valuable metals as interest has grown substantially in the last decade. **Most research assessing the impacts of mining has focused on the seafloor**.

Fish trawling



Although trawling today is heavily regulated in some nations, it remains the target of many protests by environmentalists. Environmental concerns related to trawling refer to two topics: the lack of selectivity and the physical damage which the trawl does to the seabed

Marine pollution & plastic

Marine pollution is a combination of chemicals and trash, most of which comes from land sources and is washed or blown into the ocean.

HAZARD

VULNERABILITY

RISK

MITIGATION

RESILIENCE

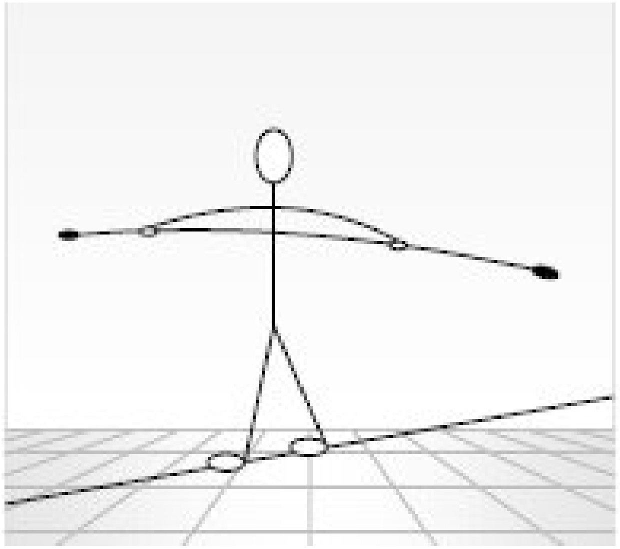
HAZARD: Is an **event** posing a threat to life, health, property or environment. Hazard assessment is the evaluation of the occurrence of a potentially damaging event, (where, when, how frequently, magnitude). The **identification of hazards** is the first step in performing **hazard assessment**

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

Risk = Hazard x 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.*

Risk = Hazard x Vulnerability

HAZARD vs RISK

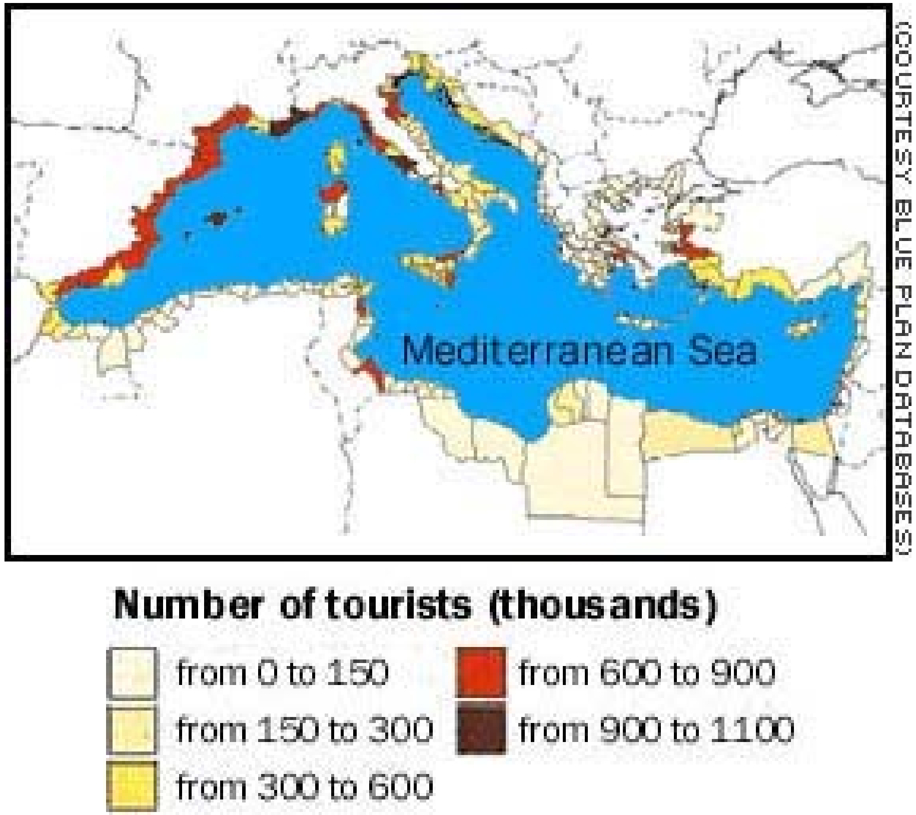
A HAZARD is something that has the potential to harm you

RISK is the likelihood of a hazard causing harm

Risk = Hazard x Vulnerability

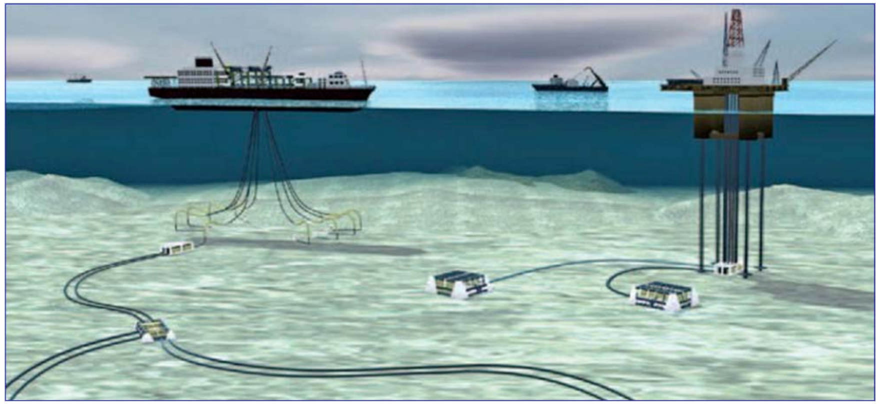
- **Mediterranean Basin is one of the most geological active areas in the world.**

- **Very densely-populated coastline**: 160 million inhabitants sharing 46,000 km of coastline (**3.5 inhabitants per m of coastline**).

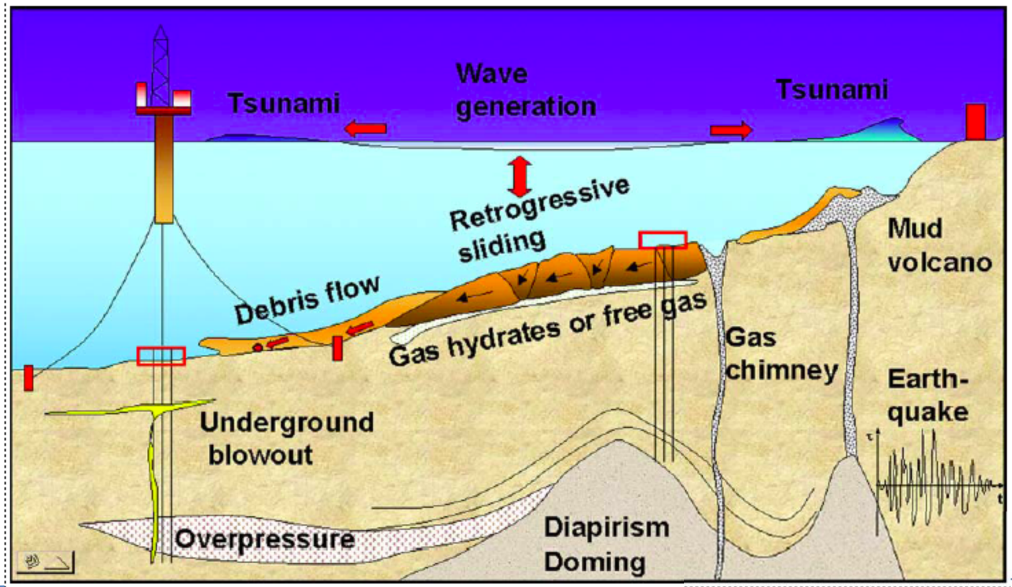


- **World's leading holiday destination**, receiving up 30% of global tourism and an average of 135 million visitors annually; this is predicted to increase to 235-350 million tourists by year 2025 (European Environmental Agency - EEA).

VULNERABILITY OF OFFSHORE



ISOVER Subsea Products SeaLine



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

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

Resilience

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

Risk = Hazard x V x Exposure

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(as far as we kno

Risk =

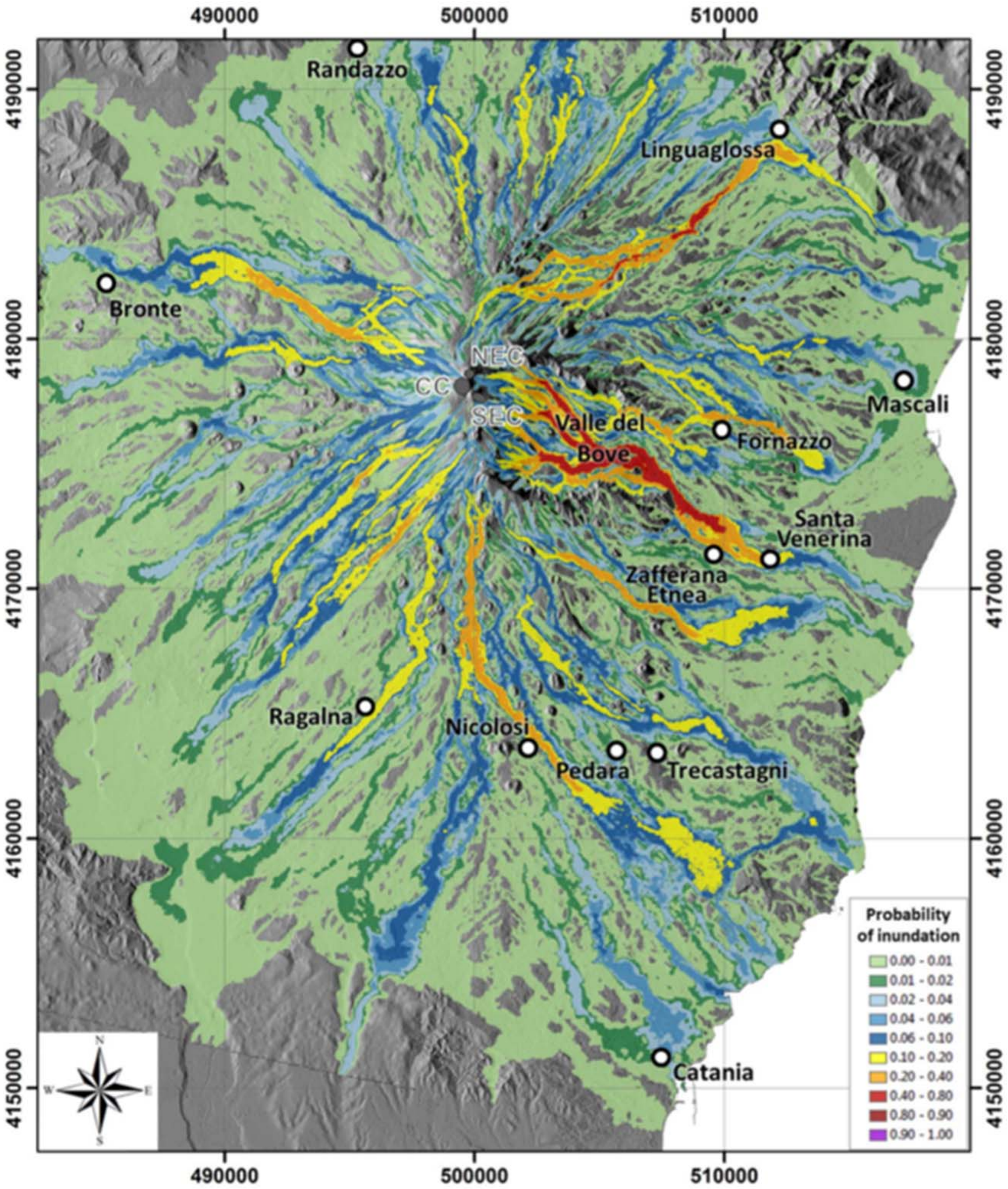

Figure 3 | Hazard map by lava flow inundation at Mt. Etna, based on 28,908 simulations of lava flow paths starting from 4,818 different potential vents. Colors represent different hazard levels indicating a range of probability of inundation by a lava flow from a flank eruption in the next 50 years. Summit craters are masked because their activity is investigated separately. This figure was generated using the free and open source GRASS GIS software. The topography is based on a DEM owned by INGV.

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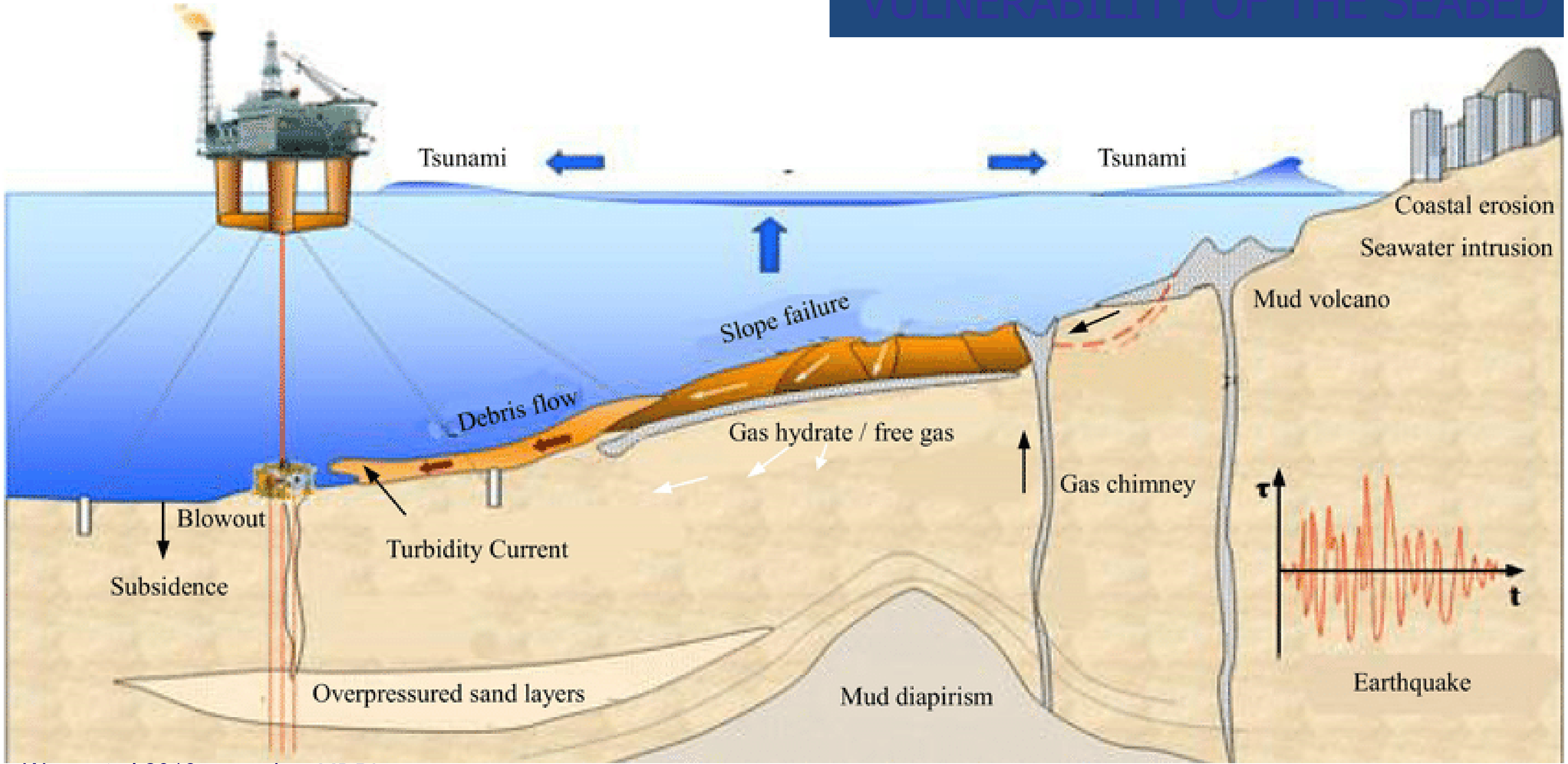
nhab./km²

VULNERABILITY OF THE SEABED



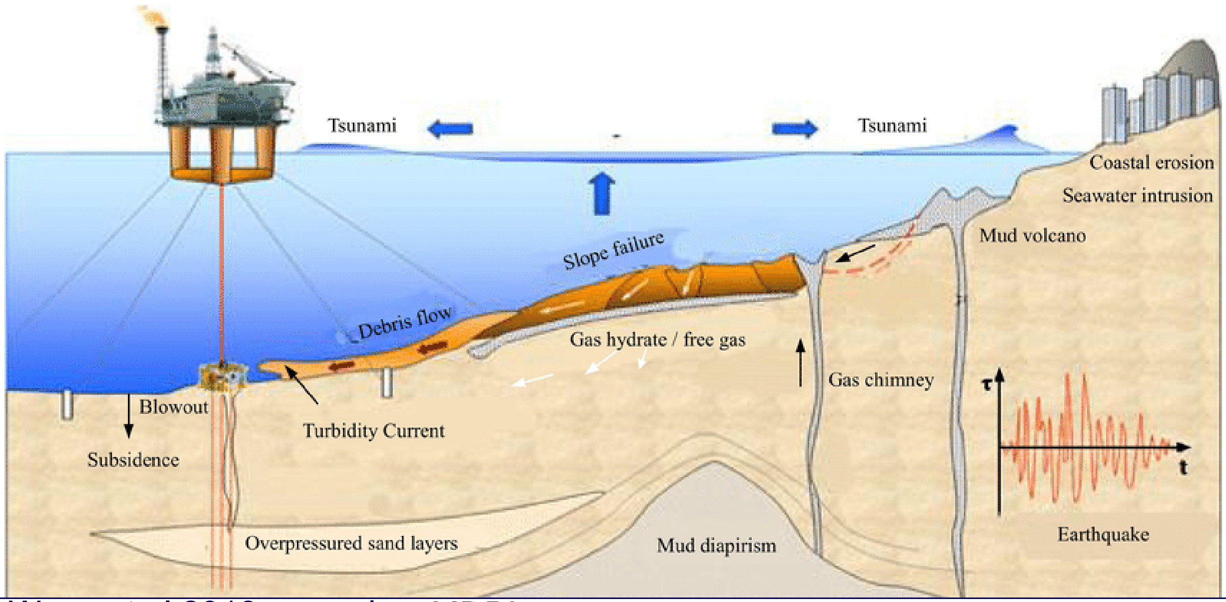
Wang et al 2018, *energies, MDPI*

- Very densely-populated coastlines of certain European regions
- Increasing economic use of the seabed for energy, communications and mineral resources.

Marine geohazards are natural, real and complex and their occurrence can arm people and infrastructures

Marine geohazards

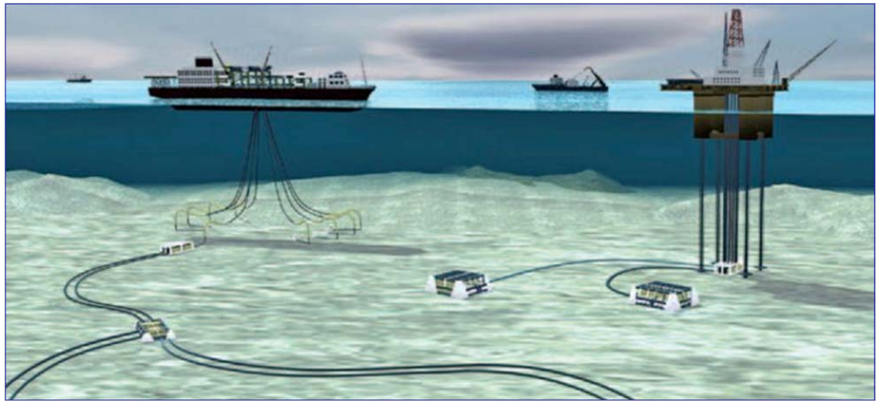
Geohazard Feature	Causative event	Effects	Consequences	Recent historical examples
Landslide scar and deposit	Sediment failure	Gravity flow	Cable break	Algeria 2003[7]
		Tsunami	Coastal inundation	Stromboli 2002[8]
Canyon head	Seafloor erosion and sediment failure	Retrogressive erosion	Coastal landslide	Finneidfjord 1996[9]
				Punta Alice 2006[10]
		Tsunami	Coastal inundation	Nice 1979[11]
		Gravity flow	Cable break	Gioia Tauro 1977[12]
Mud volcano, pockmark	Fluid escaping the seafloor	Fluidification of sediment	Weakening of soil	Patras Gulf 1993[13]
		Gas eruption	Navigation problems	Scoglio d'Affrica 2017[14]
Active faults	Earthquake	Submarine landslide	Cable break	Pingtung 2006[15]
		Land shaking	Structure collapse	Messina 1908[16]
		Tsunami	Coastal inundation	
Submarine and insular volcanoes	Eruption	Emissions in oceans and atmosphere	Navigation problems	Hierro 2011-'12[17]
	Caldera or sector collapse	Tsunami	Coastal inundation	Anak Krakatoa 2018[18]



Wang et al 2018, *energies, MDPI*

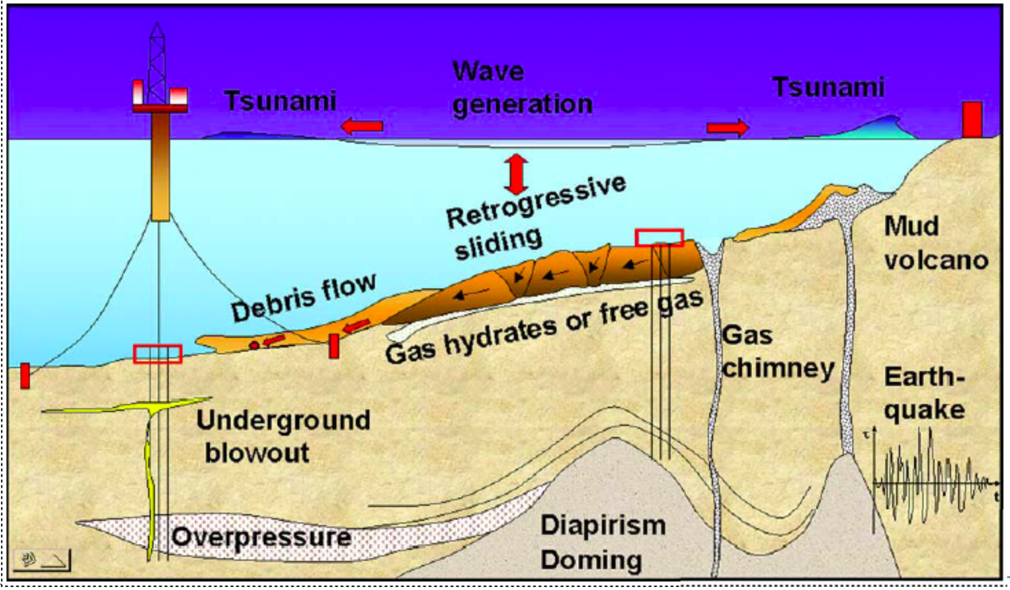
Marine geohazards are natural, real and complex and their occurrence can arm people and infrastructures

- ✓ Increasing economic use of the seabed for energy, communications and mineral resources.
- ✓ Very densely-populated coastlines of certain European regions



ISOVER Subsea Products SeaLine

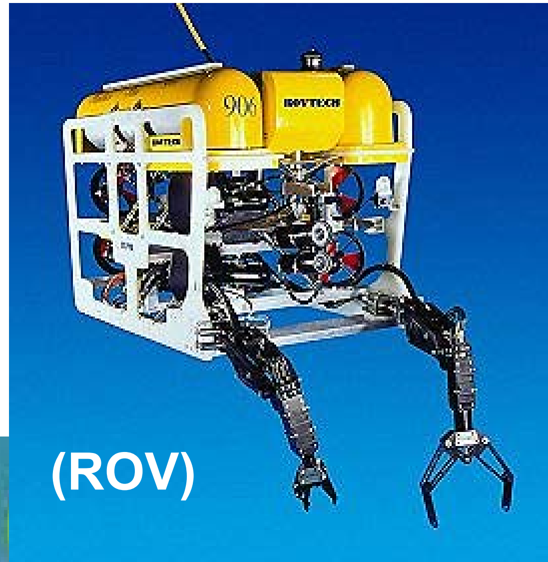
Increasing economic use of the seafloor for energy, communications and mineral resources)

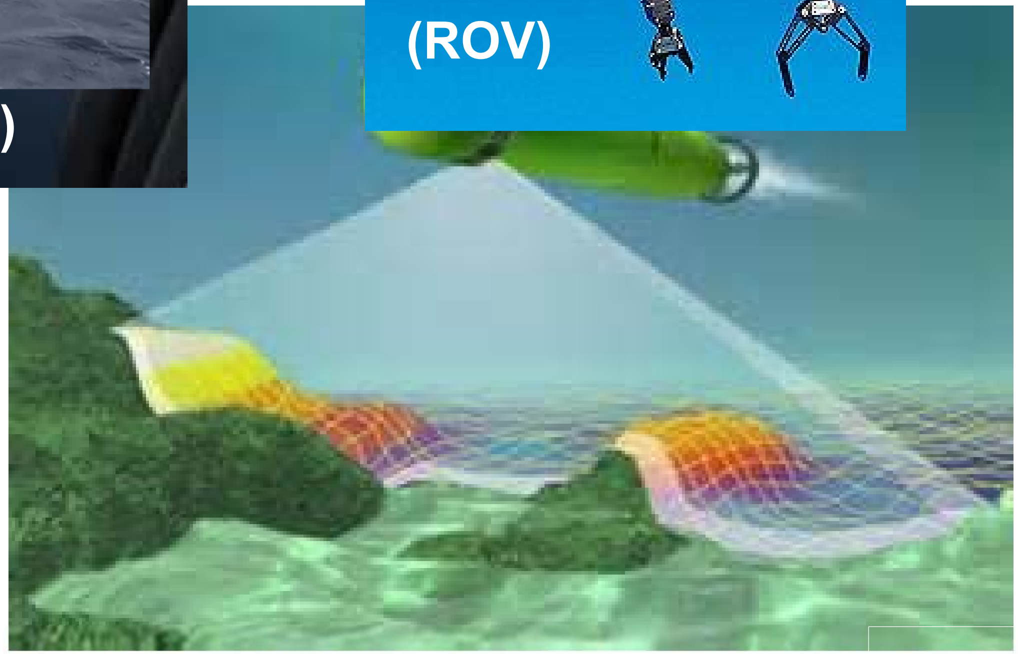


Courtesy NGI, Oslo. After Camerlenghi et al., 2007, *Scientific Drilling*

ROBOTICS - DRONES

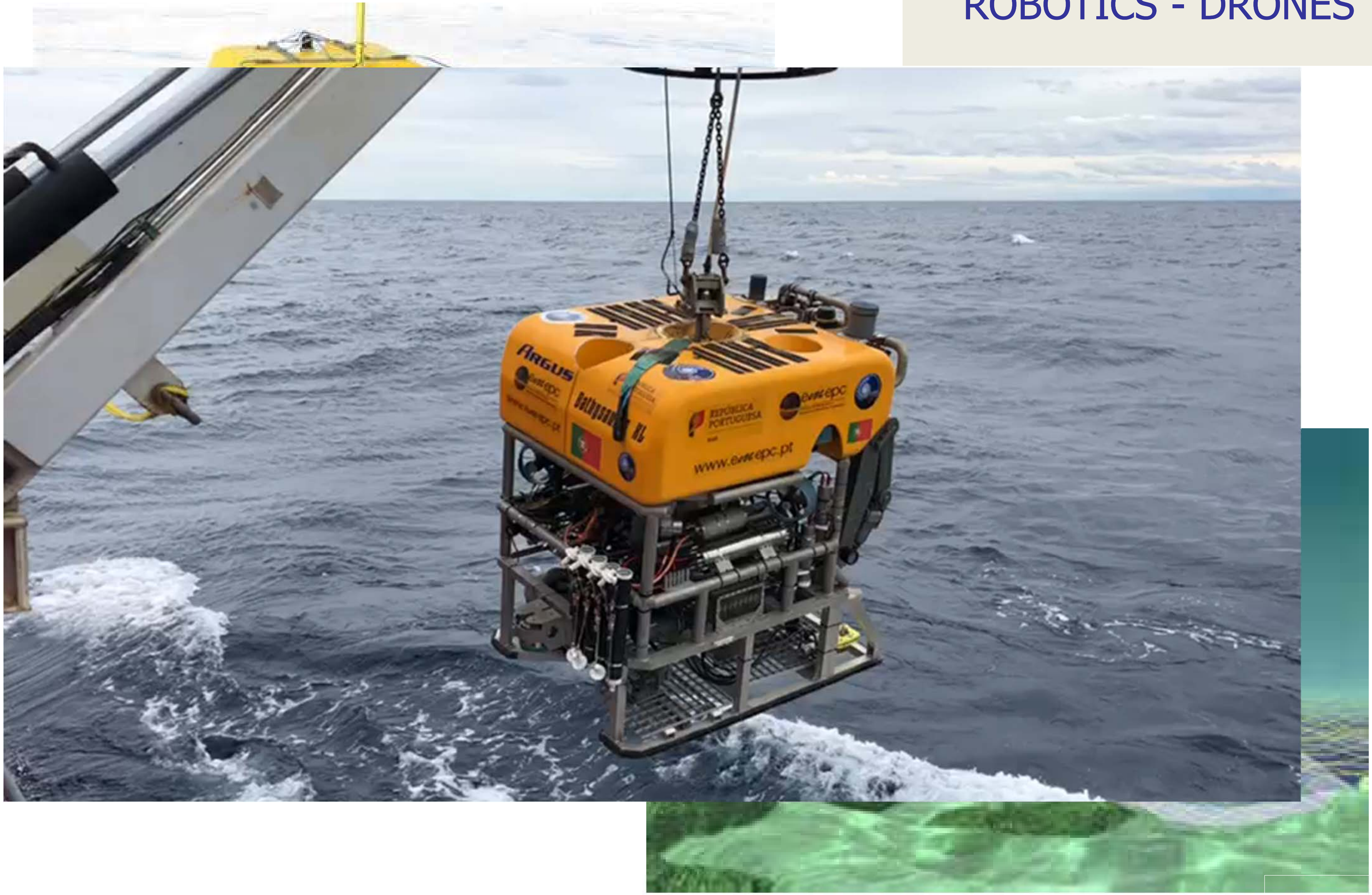
Remotely Operated Vehicles (ROV)





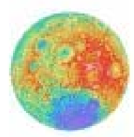
1) obtain **very high-resolution** imaging of the seafloor (up to cm)

2) **access remote** settings (i.e. canyons)

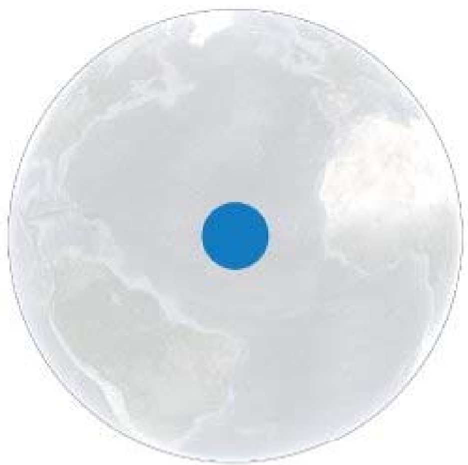

ARGUS
www.emepc.pt

It’s easy to ignore what we cannot see.

While some **satellite-based technology** that we use to map the land surface can be used in shallow water, **these technologies do not work once for the deeper parts of the ocean, because the water stops the signals from reaching the seafloor**

Moon  100% mapped

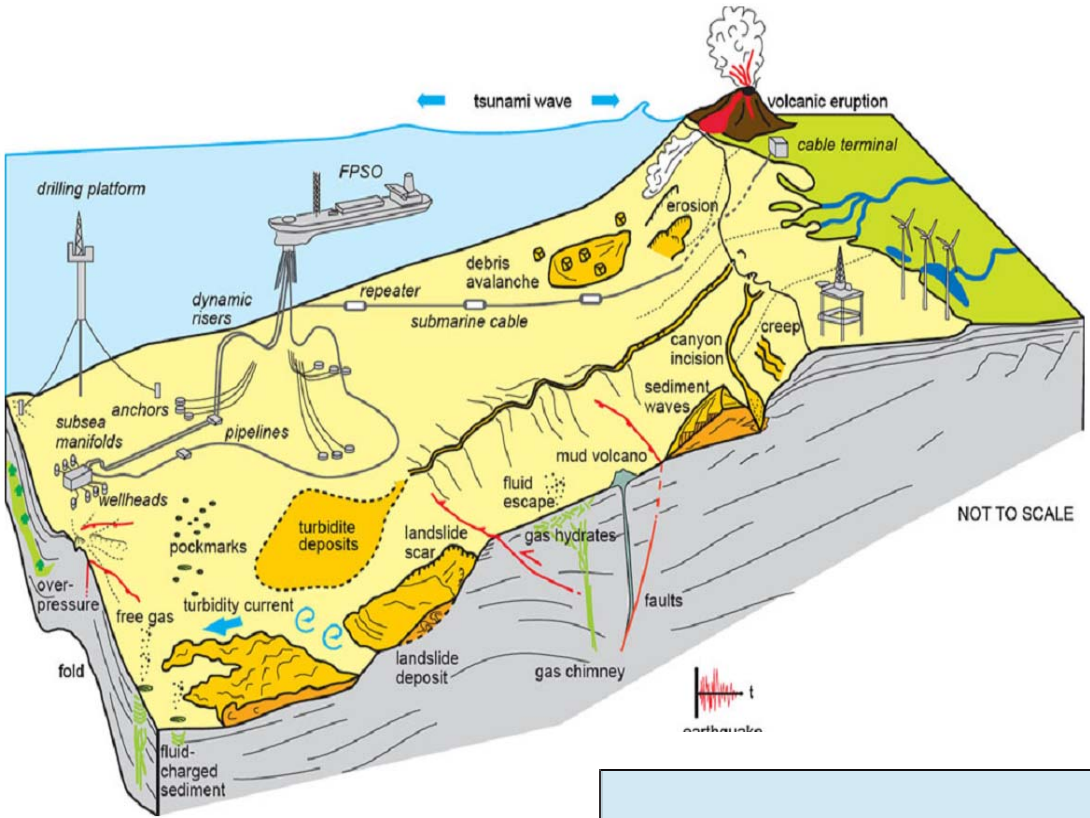
Mars  100% mapped

Earth’s ocean  5% mapped

STUDIO/
GANG
/ARCHITECTS

NATIONAL AQUARIUM.

NATURAL MARINE GEOHAZARDS

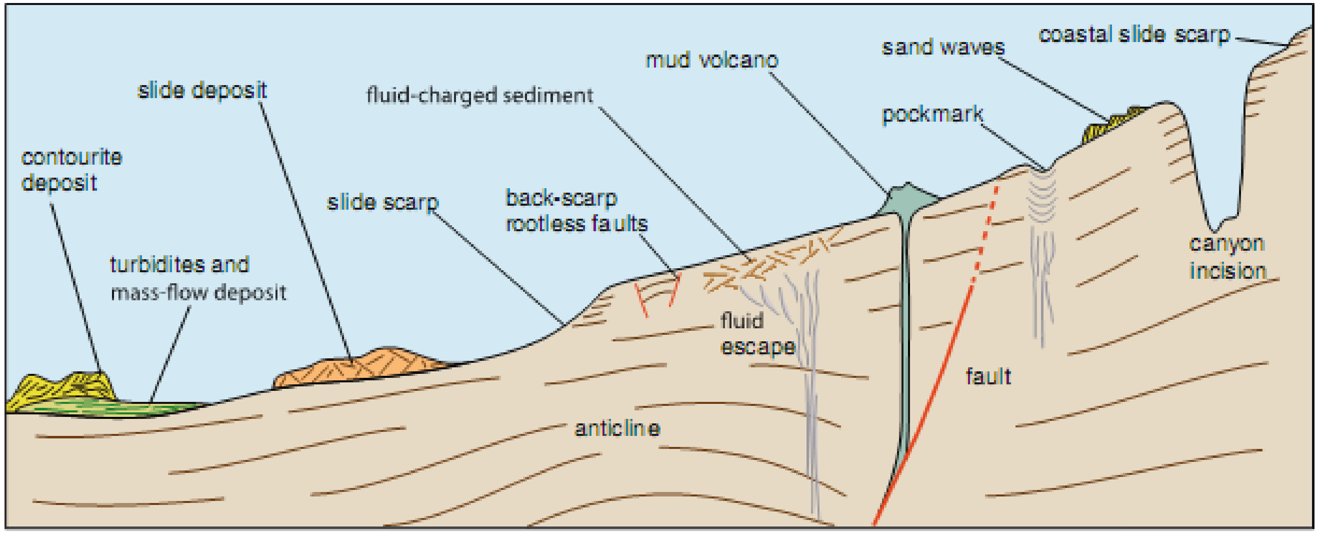


Chiocci et al. 2011

Geomorphic features as geohazard indicators:

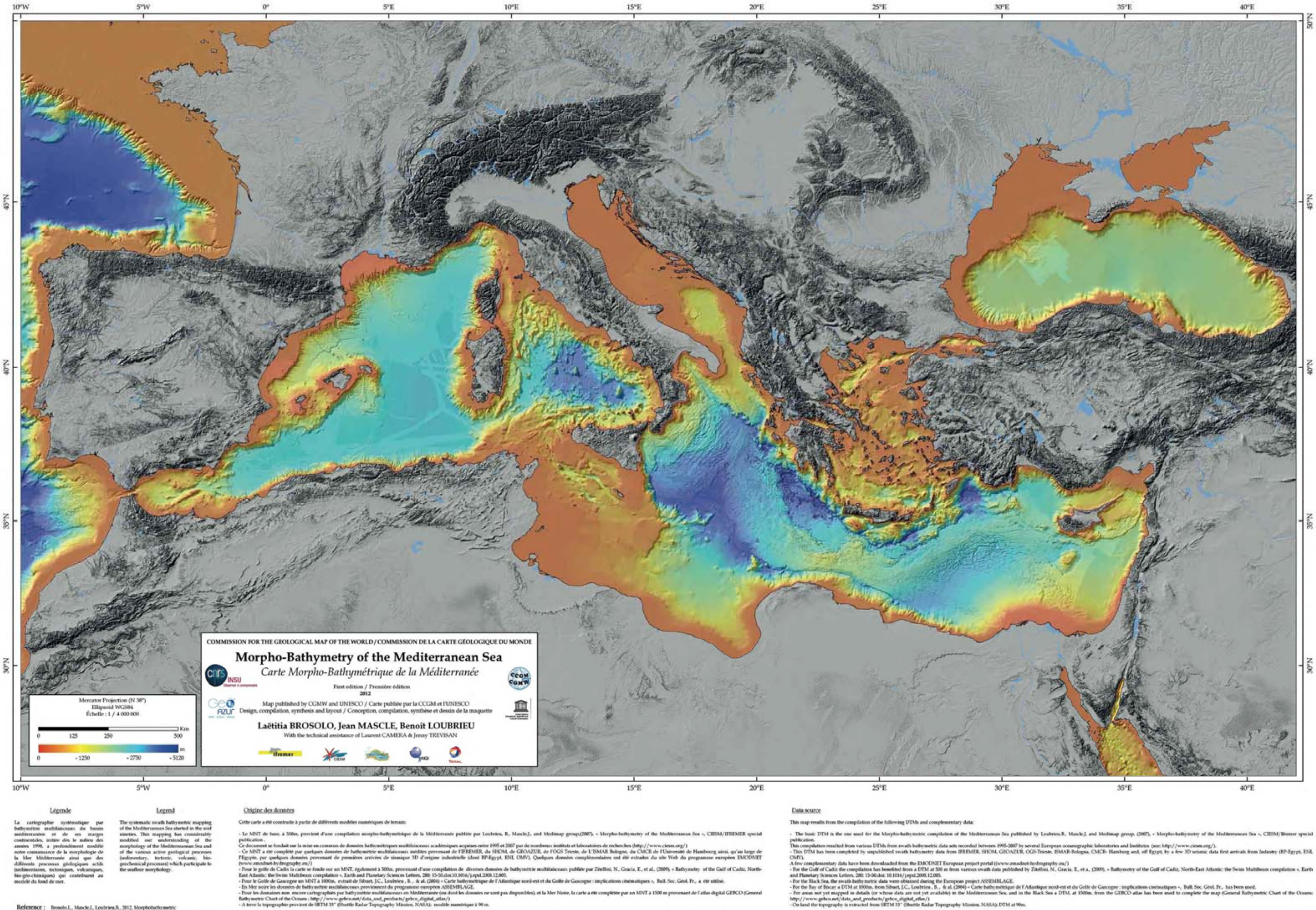
scars and deposits, canyon headscarps and steep erosional flanks, fault-related seafloor unevenness, mud volcanoes, pock-marks, gravity flow deposits, erosional scours and bed-forms indicating sediment mobility at diverse temporal/spatial scale….

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

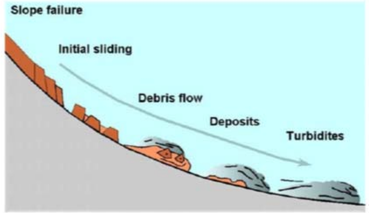


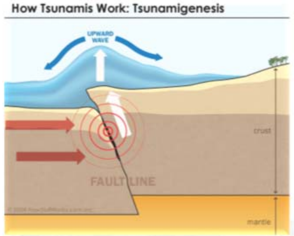
Chiocci and Ridente 2011

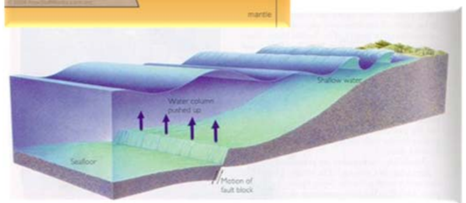
CCGM Morpho-Bathymetry of the Mediterranean sea

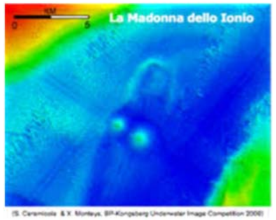


1. **SUBMARINE LANDSLIDES** including **VOLCANIC ISLAND ERUPTIONS** and **FLANK COLLAPSE**: sediment mass movements (turbidity currents, debris flows, slumps, retrogressive canyon headwalls)
2. **SEISMOGENIC FAULTS** (earthquakes originated below the sea floor)
3. **TSUNAMIS** (originated by earthquakes and/or landslides)
4. **SUBMARINE CANYONS** (coastal erosion)
5. **FLUID EMISSIONS** (CH_4, CO_2 mainly)
6. **METEORITE IMPACTS** in the oceans

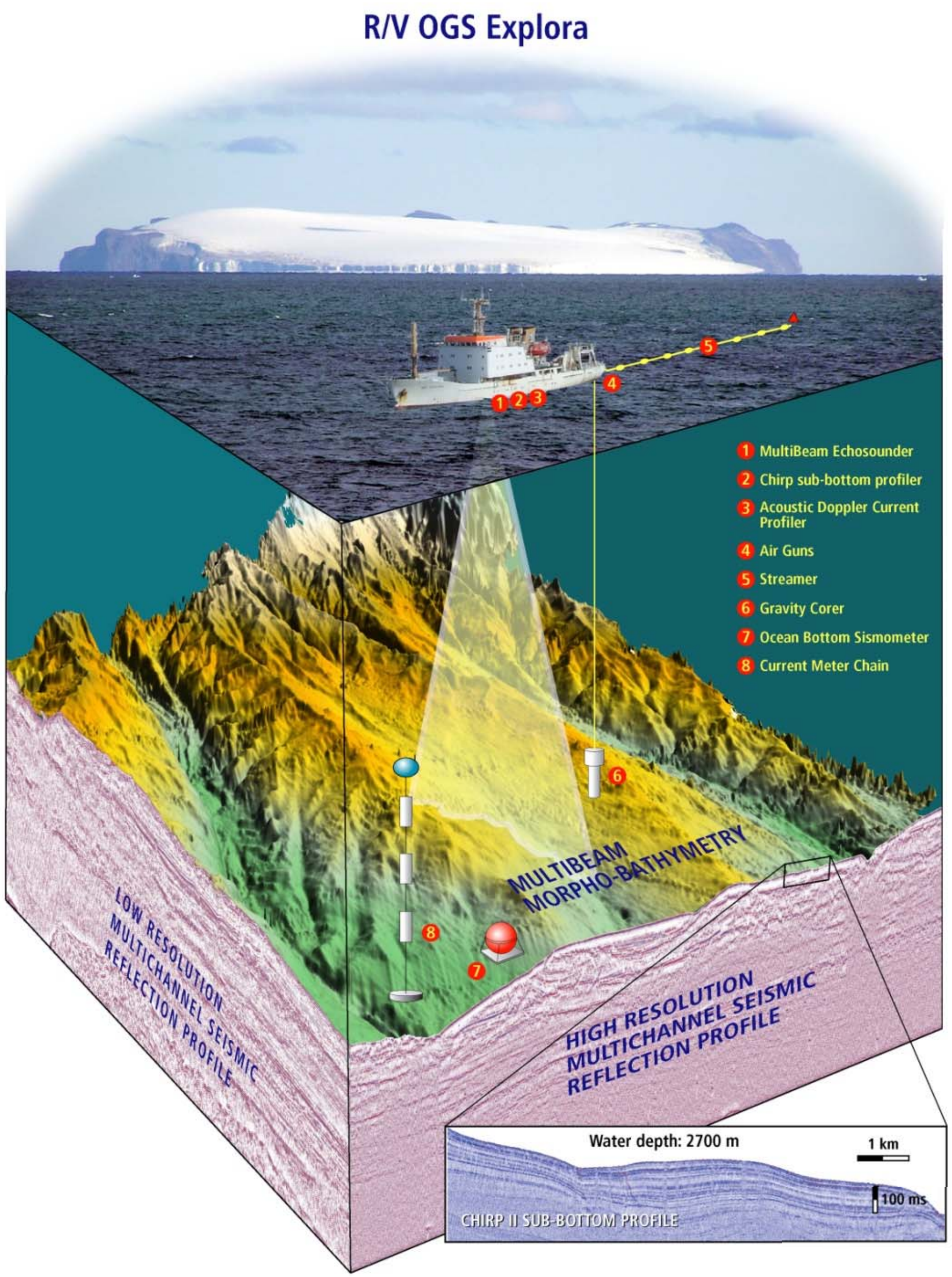








INTEGRATED ACOUSTIC METHODS

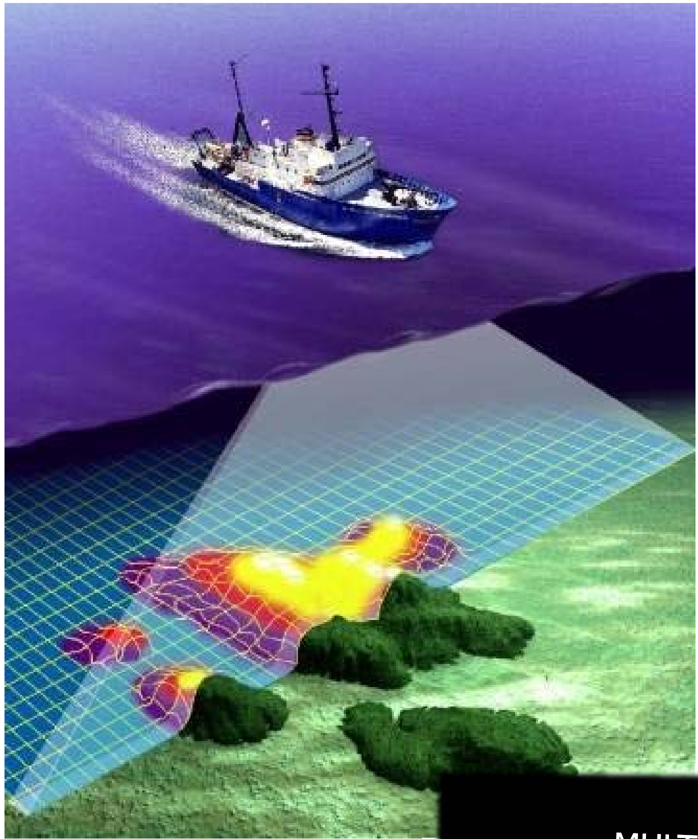


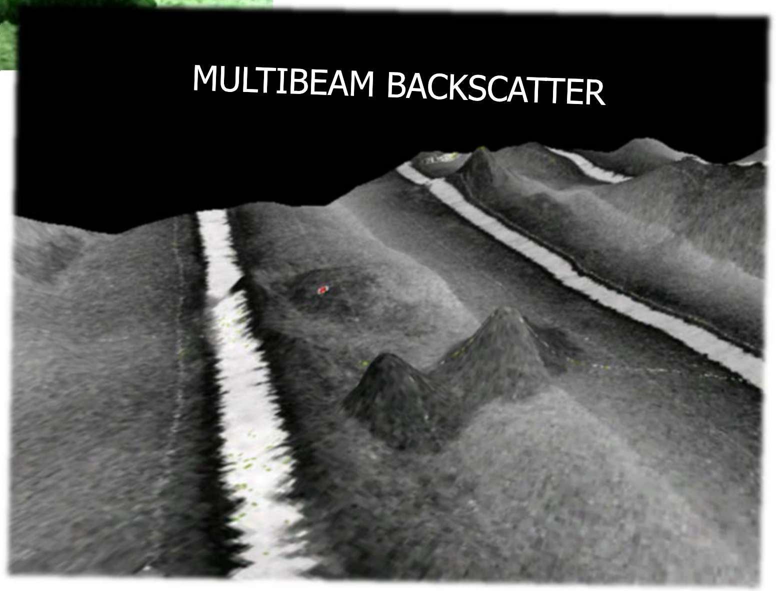
The **characterization of geohazard features on a morphological basis alone is limited**, and more detailed investigations are needed **to define the character and state of activity of potentially hazardous features.**

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

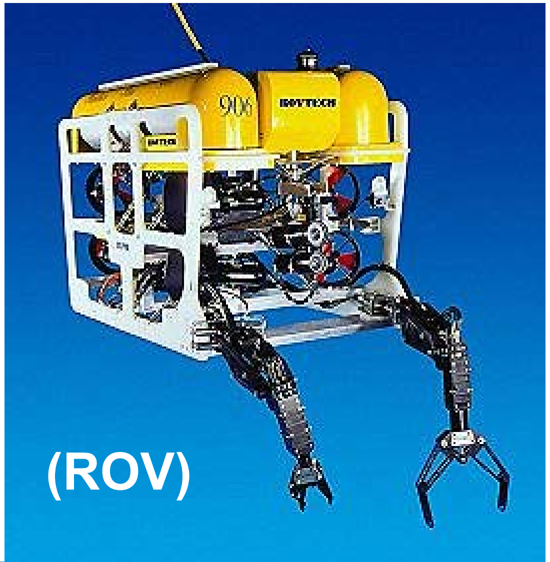




Seafloor mapping is the first step in making a census of the **geohazard-bearing features** present in a given offshore area. It often provides
the only tool for a comprehensive **seafloor geohazard assessment over large areas** that are scarcely groundtruthed by acoustic prospection and seafloor sampling.

by Chiocci et al 2011

REMOTE AND AUTONOMOUS VEHICLES



1) obtain **very high-resolution** imaging of the seafloor (up to cm)

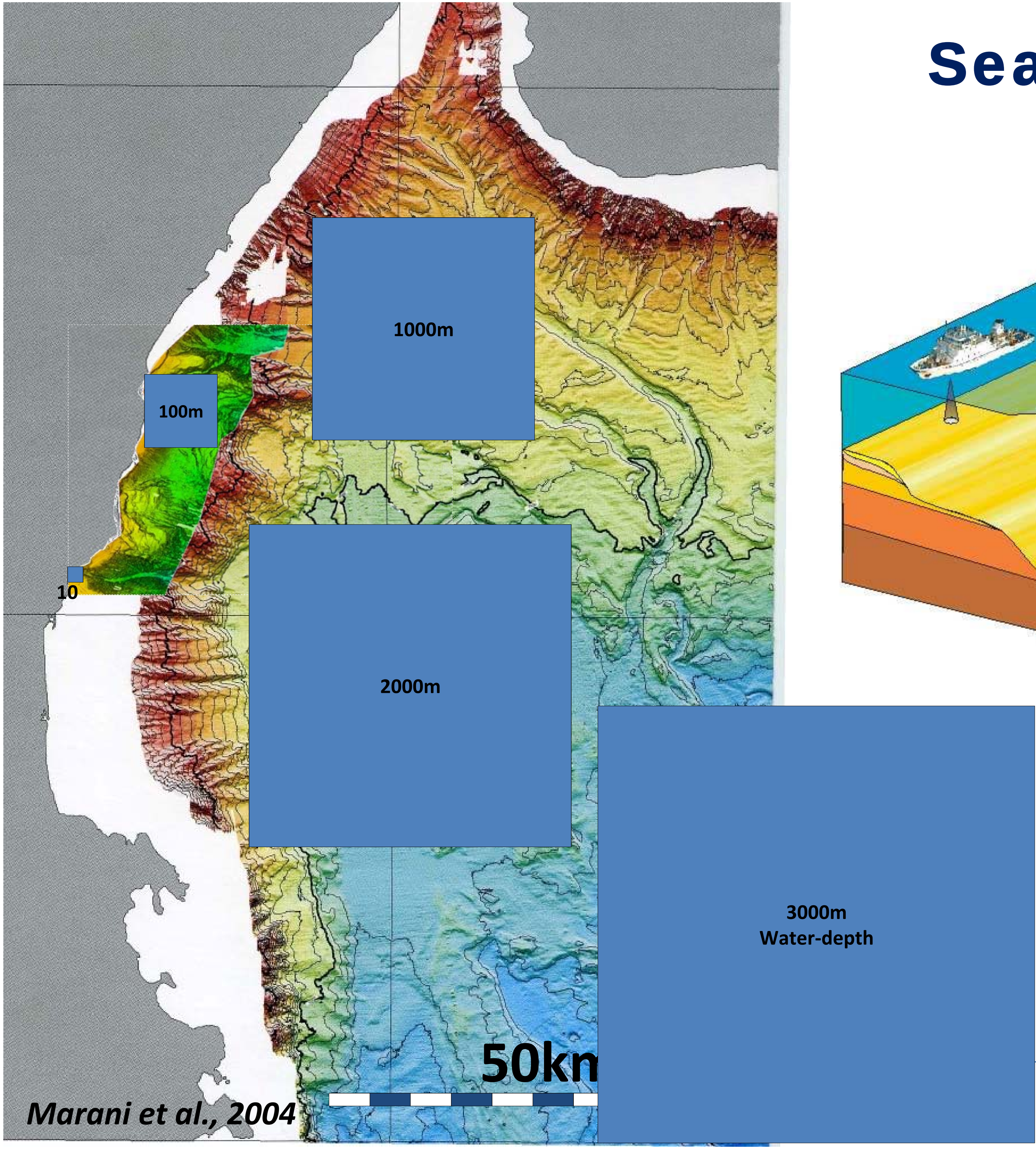
2) access remote settings (i.e. canyons)

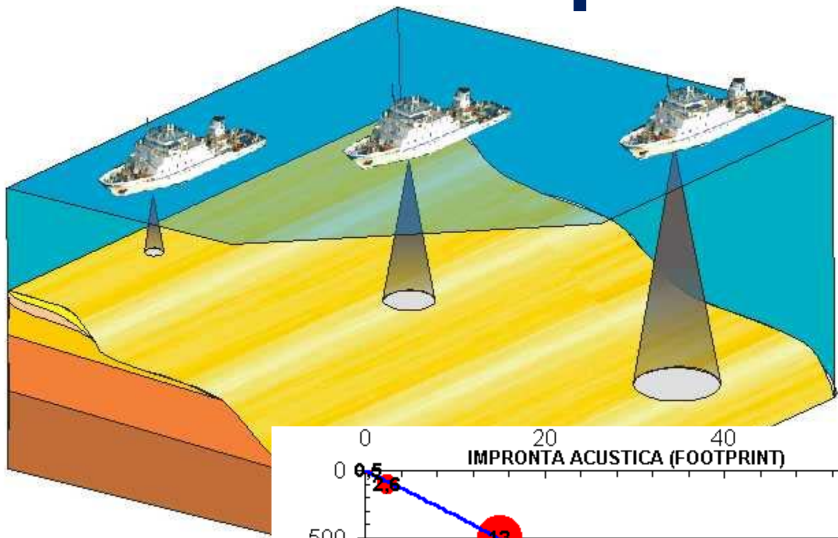
The *ex-*Italian Mediterranean research fleet

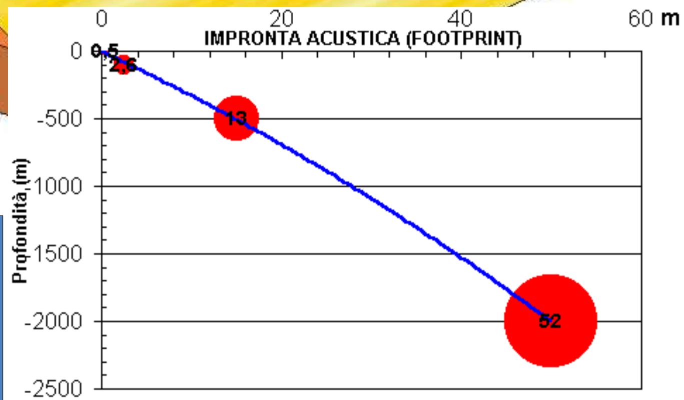
The whole Italian marine geological community and infrastructures were involved in the project:

Istituto di Geologia Ambientale e Geoingegneria (IGAG- CNR), Roma
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Trieste
Istituto di Scienza del Mare (ISMAR – CNR), Bologna
Istituto per l'Ambiente Marino e Costiero (IAMC- CNR), Napoli
Sette Università del Consorzio Nazionale Interuniversitario per le scienze del Mare (Conisma)

Seafloor coverage is water-depth dependent

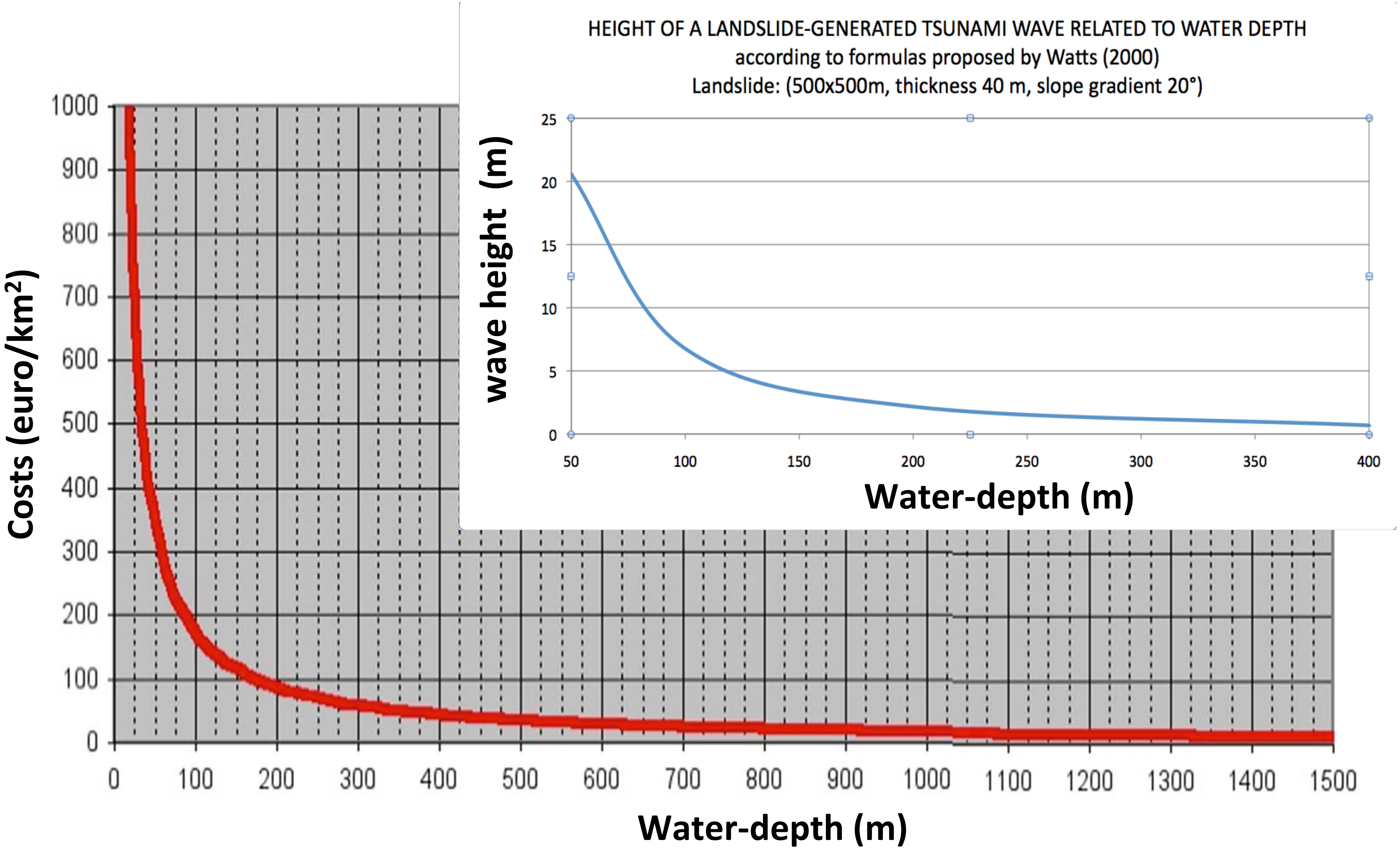




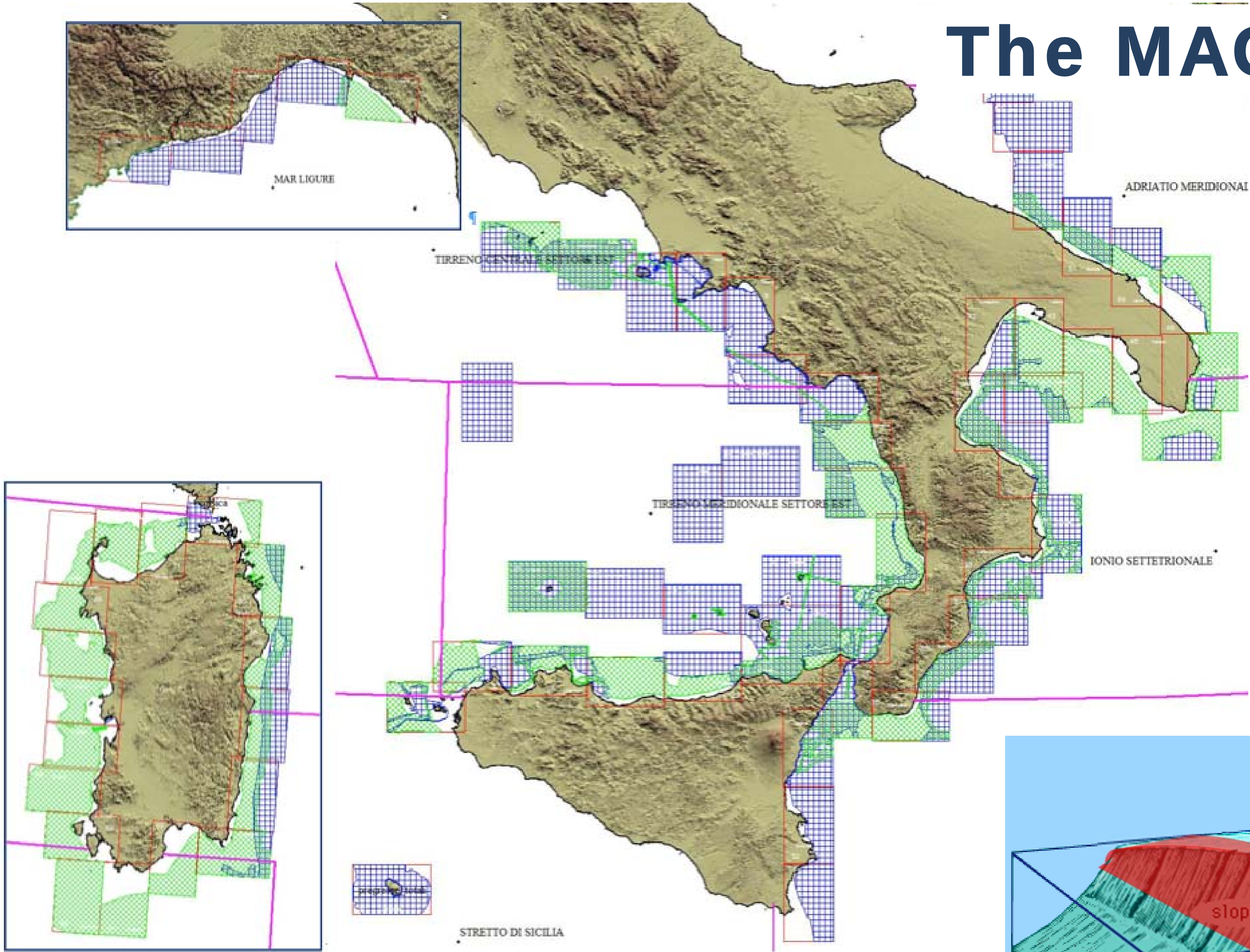


MBES coverage of a 24h survey at different water-depths

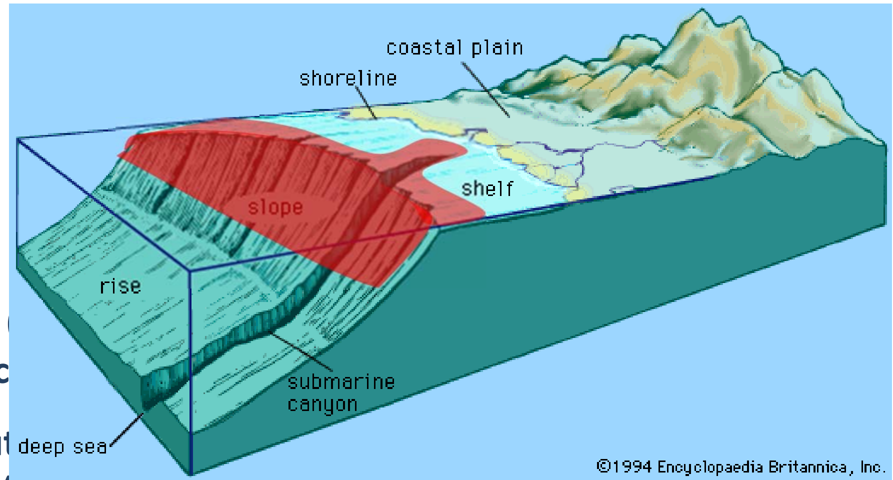
Hazards are water-depth dependent



The MAGIC strategy



Therefore MaGIC project planned to acquire data along the continental margins with a reference depth range 50-500.



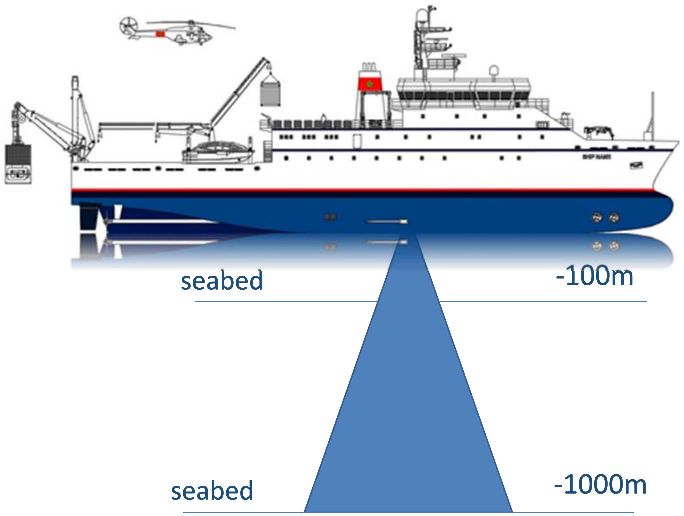
It can be extended in shallow waters (
and to deeper water if time allows on c

It can be reduced in the out
if relevant features are not present (e.g. Adriatic sea)

…on Earth we have ca. **360 million km²** of seabed…

…TIME CONSUMING AND HIGHLY COSTING ACTIVITIES

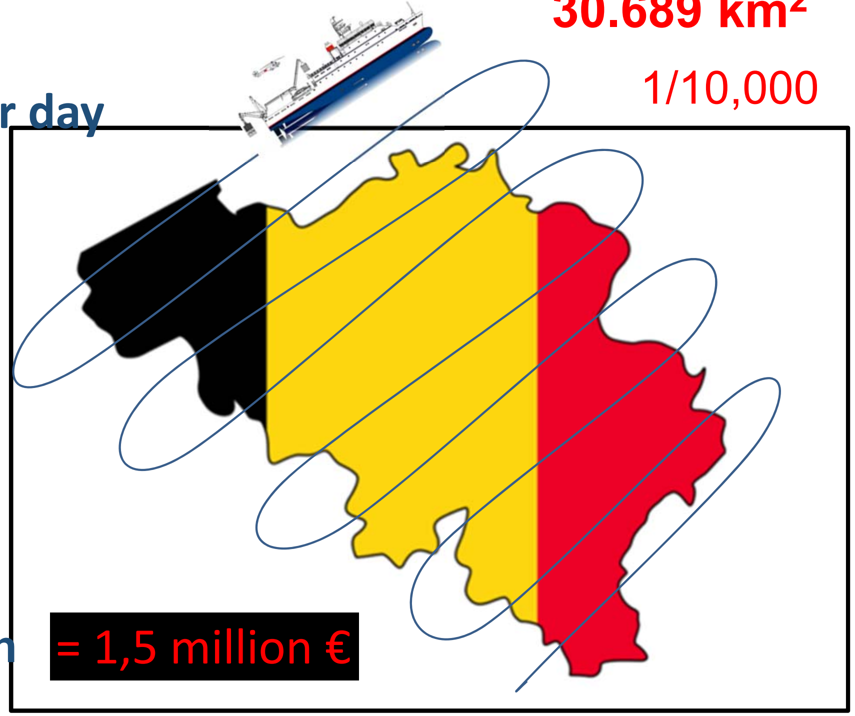
Acquiring a HR- DEM of a portion of seabed of the extension of Belgium:

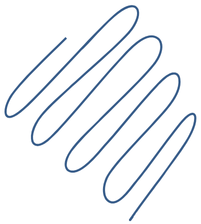


= **50,000€ per day**

30.689 km²

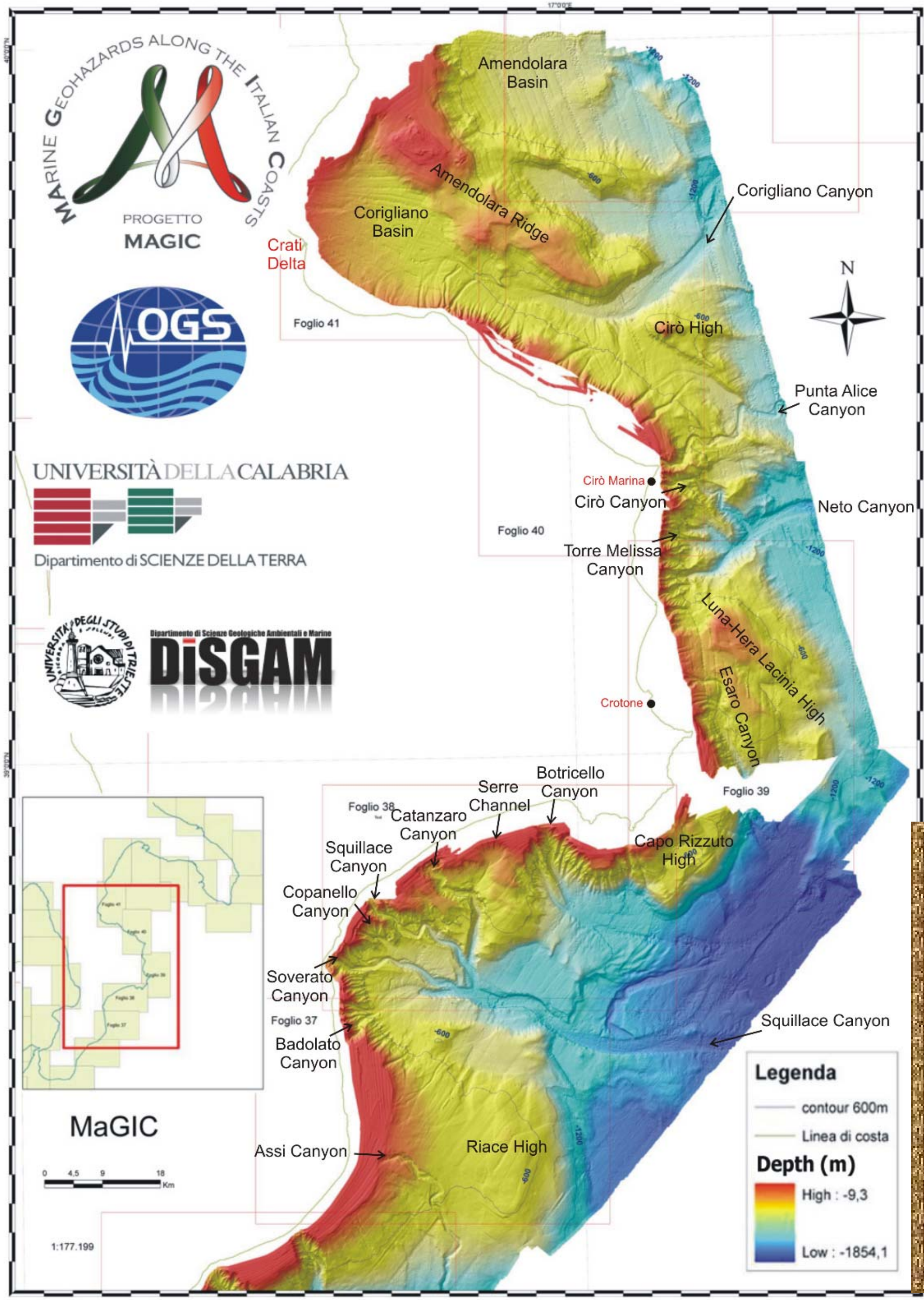
1/10,000





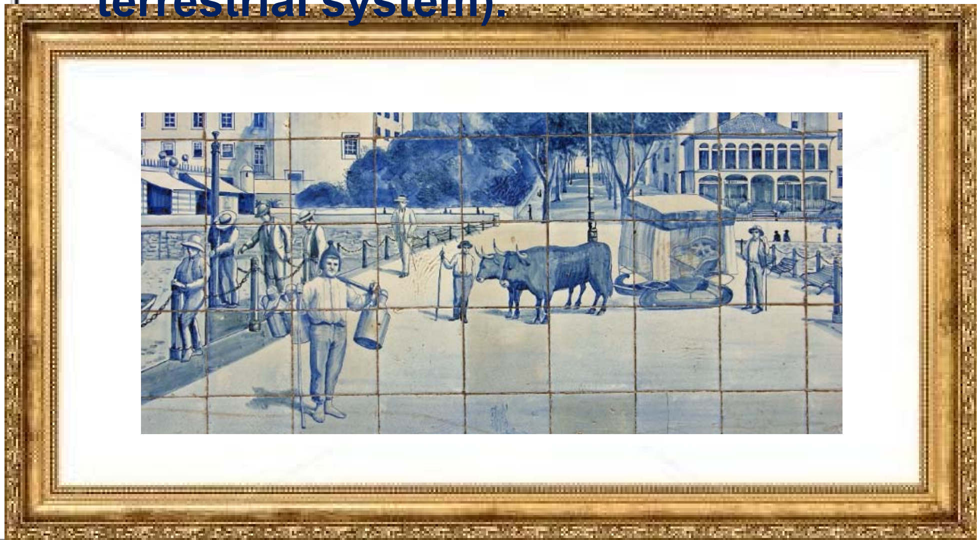
at **-1000 m** (deep sea) → ca.**1 month** = 1,5 million €

at **-100 m** (coastal area) → ca. **1 year** over 15 millions €

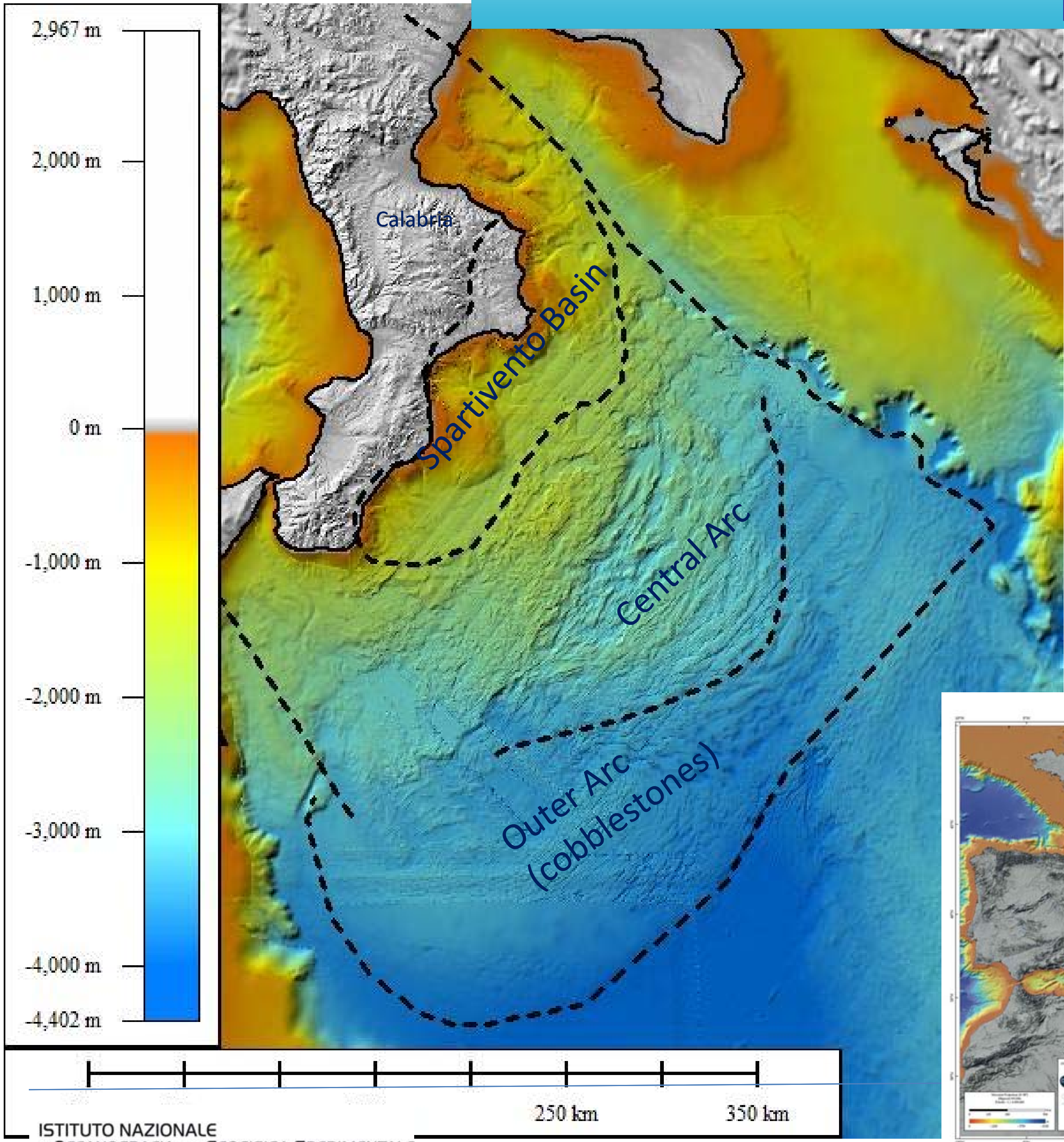


The "white frame" problem

Most of the time geohazard indicators (such as 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) are located (or terminate) very close to the coastlines and provide important information on their hazard/risk (and the gap with the terrestrial system).



THE IONIAN MARGIN A NATURAL LABORATORY FOR MARINE GEOHAZARDS



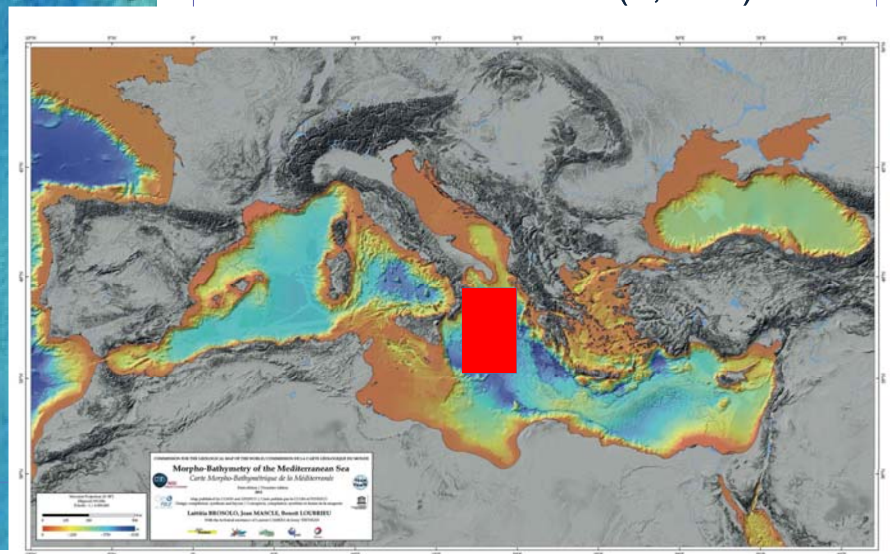
TECTONIC FRAMEWORK

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)

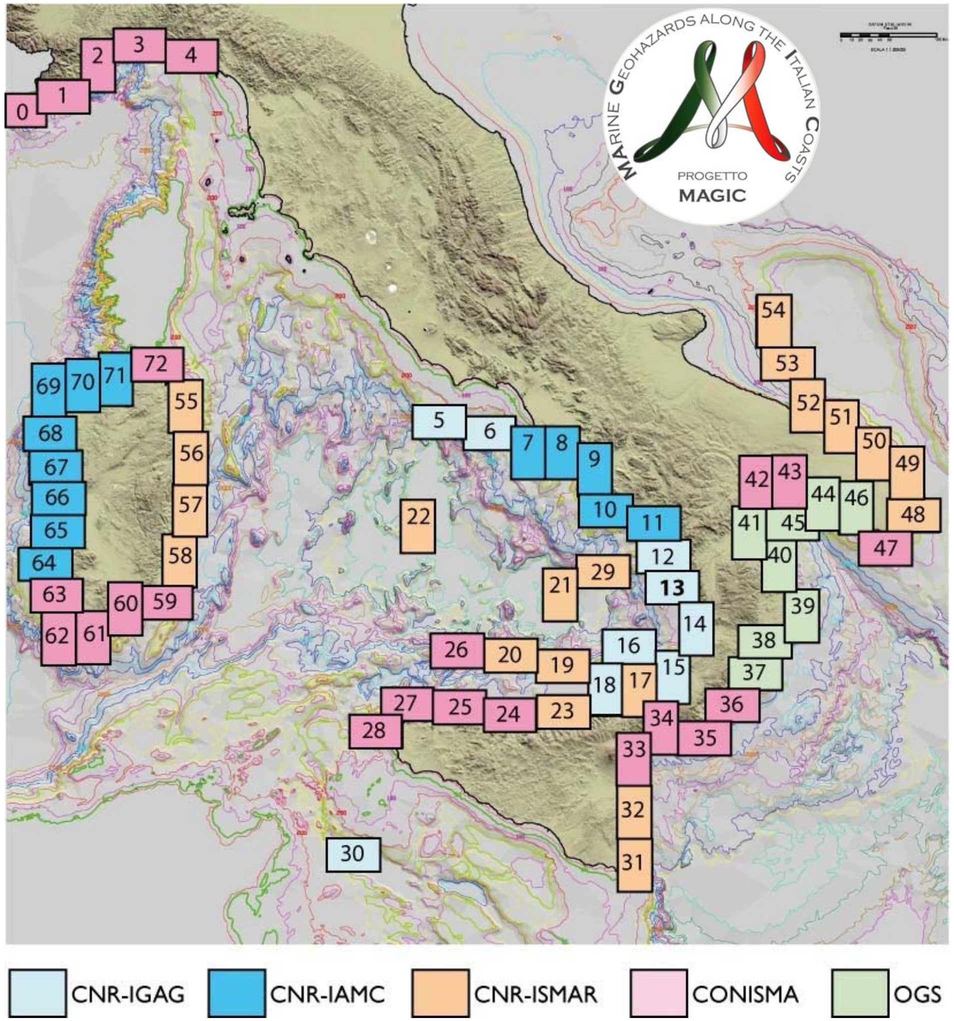


ISTITUTO NAZIONALE
DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE

MAGIC project: *MA*rine *G*eohazards along the *I*talian Coas

Aim of the Project:
Provide (for the first time) the Italian DPC with a basic tool for monitoring and managing marine geohazards (and risks) at national level.

Timeframe:
From December 2007- to June 2013
(5½-year period)

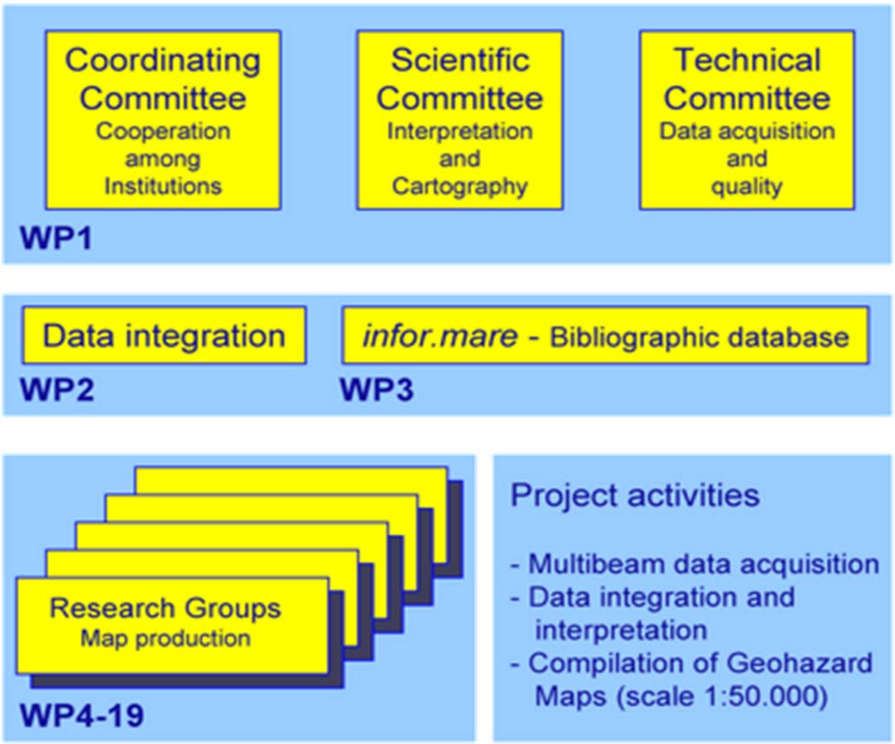


Funded by:
Italian Civil Protection Department (DPC)

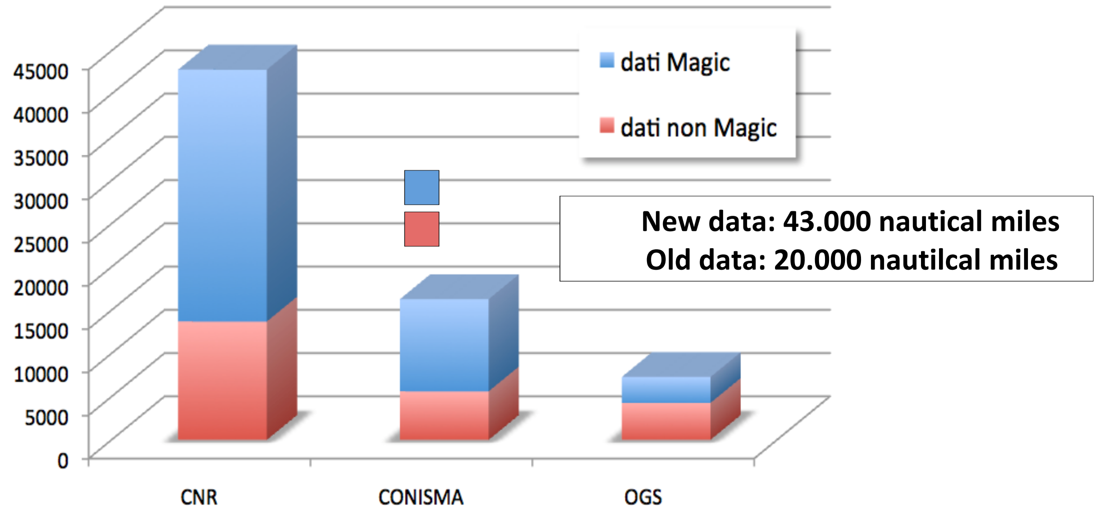
5.25 M€ direct funding +
2 M€ ship-time CNR/OGS co-funding

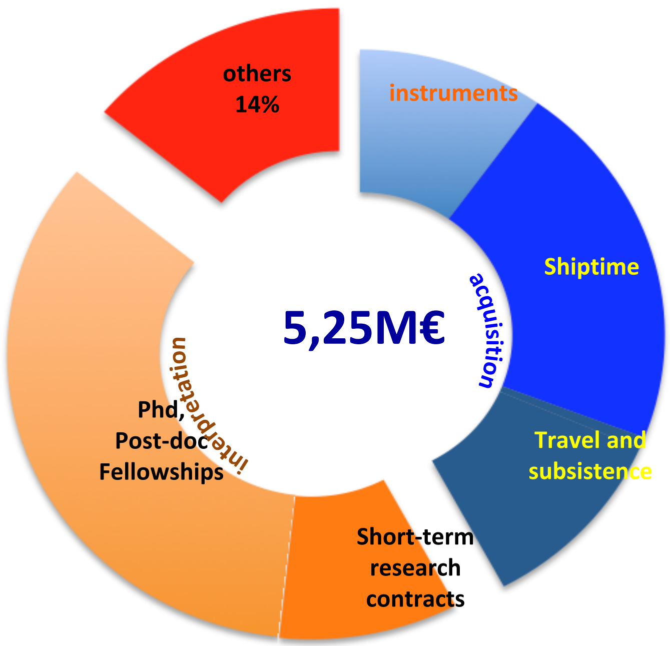
Seafloor mapping with Multibeam Echosounder (MBES) of the most vulnerable Italian margins in the depth range between 50-500m to produce 73 sheets 1:50.000

Structure of the project



- ✓ Coordination at the CNR-IGAG Rome (Prof. F. L. Chiocci)
- ✓ Each sheet was under responsibility of one of the 15 research groups, whose leaders form the Scientific and Technical Committee.
- ✓ The first year of the project was devoted to retrieve and re-process 'old' data acquired before the project.
- ✓ Funding has been mainly devoted to ship time and to fellowships or contract for young researchers .





Criteria of representation of geohazard features

How do we define criteria of objective interpretation and homogenous representation independent from context an interpreter experience?

How do we identify geohazards from only multibeam morphology (i.e. possibly ignoring the real genesis of some/most of the features)?

1 - show all the available information, maintaining a good readability of the map

2 - set up criteria to define, identify and map geohazard features homogeneously

3 - establish a hierarchy among the information, trough different mapping levels

The solution adopted was to map ALL and ONLY features having morphobathymetric expression

The Magic legend

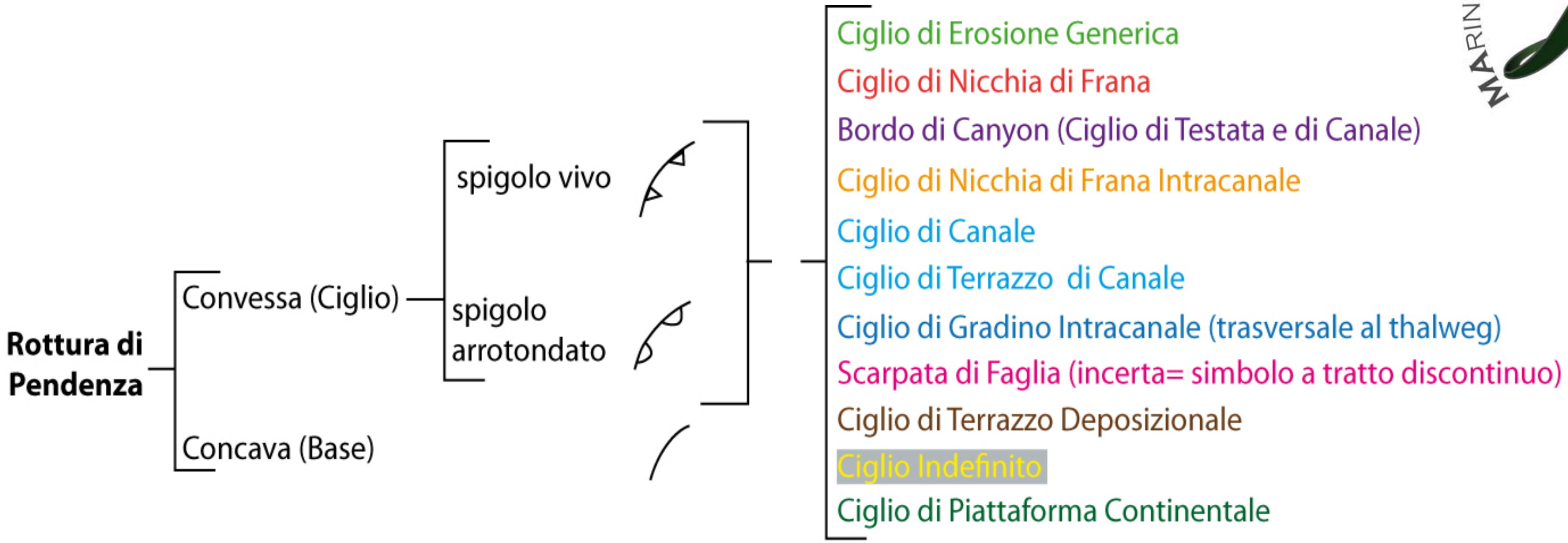
LEGENDA

1.1 Ciglio di Erosione Generica
1.2 Ciglio di Nicchia di Frana Semplice
1.3 Area di Traslazione
1.4 Ciglio di Nicchia di Frana Complessa
1.5 Ciglio di Nicchia di Frana Intracanale
1.6 Bordo di Canyon
1.7 Bordo di Area a Erosione Diffusa
1.8 Ciglio di Canale Secondario o Semplice
1.9 Ciglio di Canale con Argine
1.10 Ciglio di Terrazzamento Intracanale
1.11 Ciglio di Gradino Intracanale
1.12 Ciglio di Terrazzo deposizionale
1.13 Ciglio di Scarpata di Faglia
1.14 Ciglio Indefinito
1.15 Ciglio di Piattaforma Continentale
1.16 Base di Scarpata

1.17 Bordo di Thalweg di Canale Secondario o Semplice
1.18 Bordo di Thalweg di Canyon
1.19 Letto di Canale a Profilo Arrotondato
1.20 Letto di Canale Con Profilo a V
2.1 Solco Erosivo
2.2 Area a Depressioni Erosive
2.3 Duna (Cresta/Area a)
2.4 Area a Megaripple
2.5 Onda di Sedimento (Cresta/Area a)
2.6 Impronte da Ostacolo
3.1 Deposito Intracanale
3.2 Deposito da Flusso Gravitativo non Canalizzato
3.3 Corpo di Frana a superficie regolare
3.4 Corpo di Frana a Hummocky/Area a
3.5 Corpo di Frana a Blocchi/Area a
3.6 Colata Lavica

4.1 Rilievo di Origine Incerta
4.2 Depressione di Origine Incerta
4.3 Pockmark/Area a
4.4 Area ad Espulsione di fluidi
4.5 Vulcano di fango/Area a
4.6 Diapiro di fango/Area a
4.7 Area con Fessure di Trazione
4.8 Cresta di Pieghe di Compressione/Area a
4.9 Area con Deformazioni da Creep
4.10 Cresta (lama, arrotondata)
4.11 Substrato Litoide Affiorante
4.12 Substrato Vulcanico Affiorante
4.13 Biocostruzione
4.14 Centro Eruttivo (certo/incerto)

The Magic 'Global Mapper'



3rd Morphologic features (1:50.000 vectors)

Marble Geographics


LEGENDA

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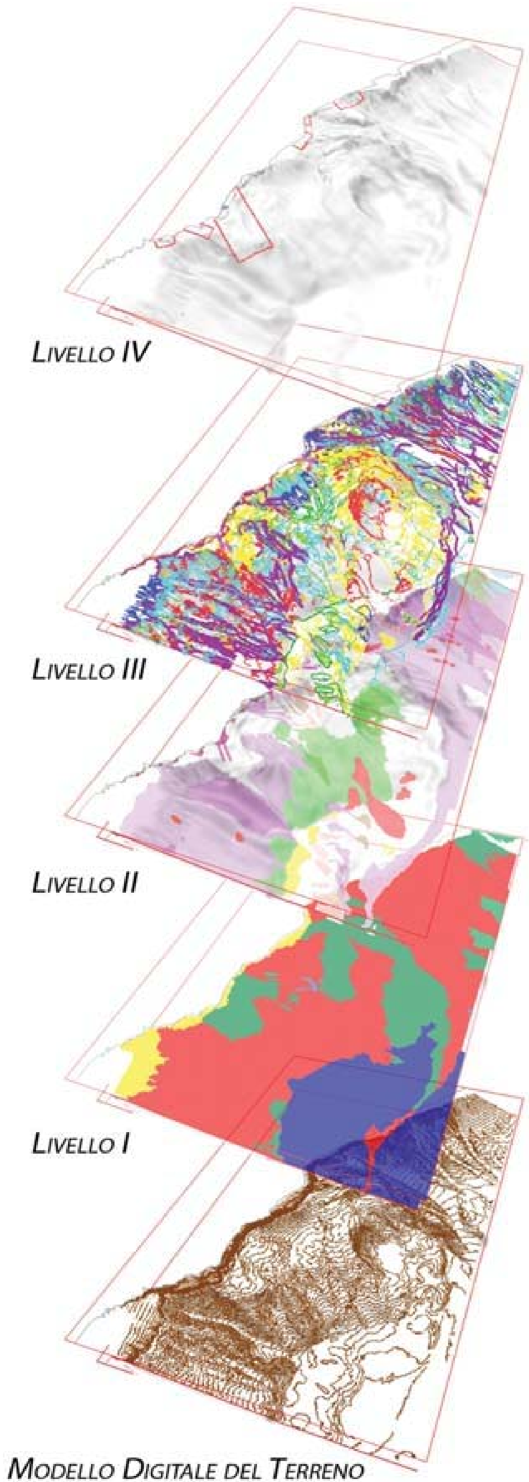
The Magic concept



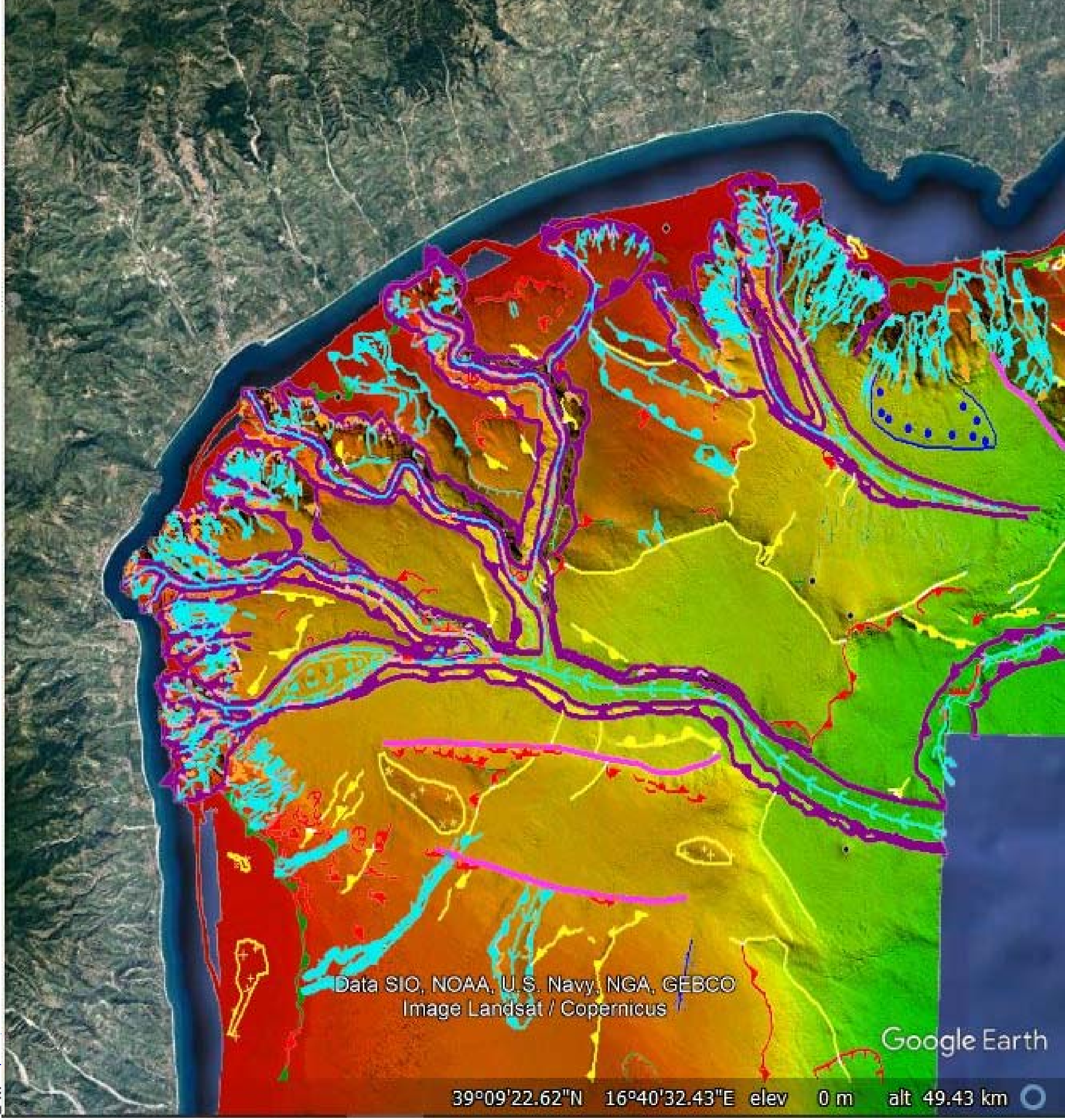
Four level representation model

1st Physiographic domains (1:250.000 areas)

2nd Morphostructural units (1:50.000 areas + database)

3rd Morphologic features (1:50.000 vectors)

4th Critical points (detailed scale - variable highlights)


Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Google Earth
39°09'22.62"N 16°40'32.43"E elev 0 m alt 49.43 km

Thank you for your attention…