# Geology of the

# Mediterranean Basins

# *TALK OUTLINE*

## Brief introduction of the Mediterranean geological provinces

Pre-Mesozoic and Meso-Cenozoic Tectonic evolution

– Continental vs. oceanic crust

– Subduction

– Collision

## Development of the Mediterranean basins

Western basins

Eastern Basins

## The seas  surrounding the Italian Peninsula

Tyrrhenian Sea

Ionian Sea

Sicilian Channel

Adriatic Sea

## Gulf of Trieste

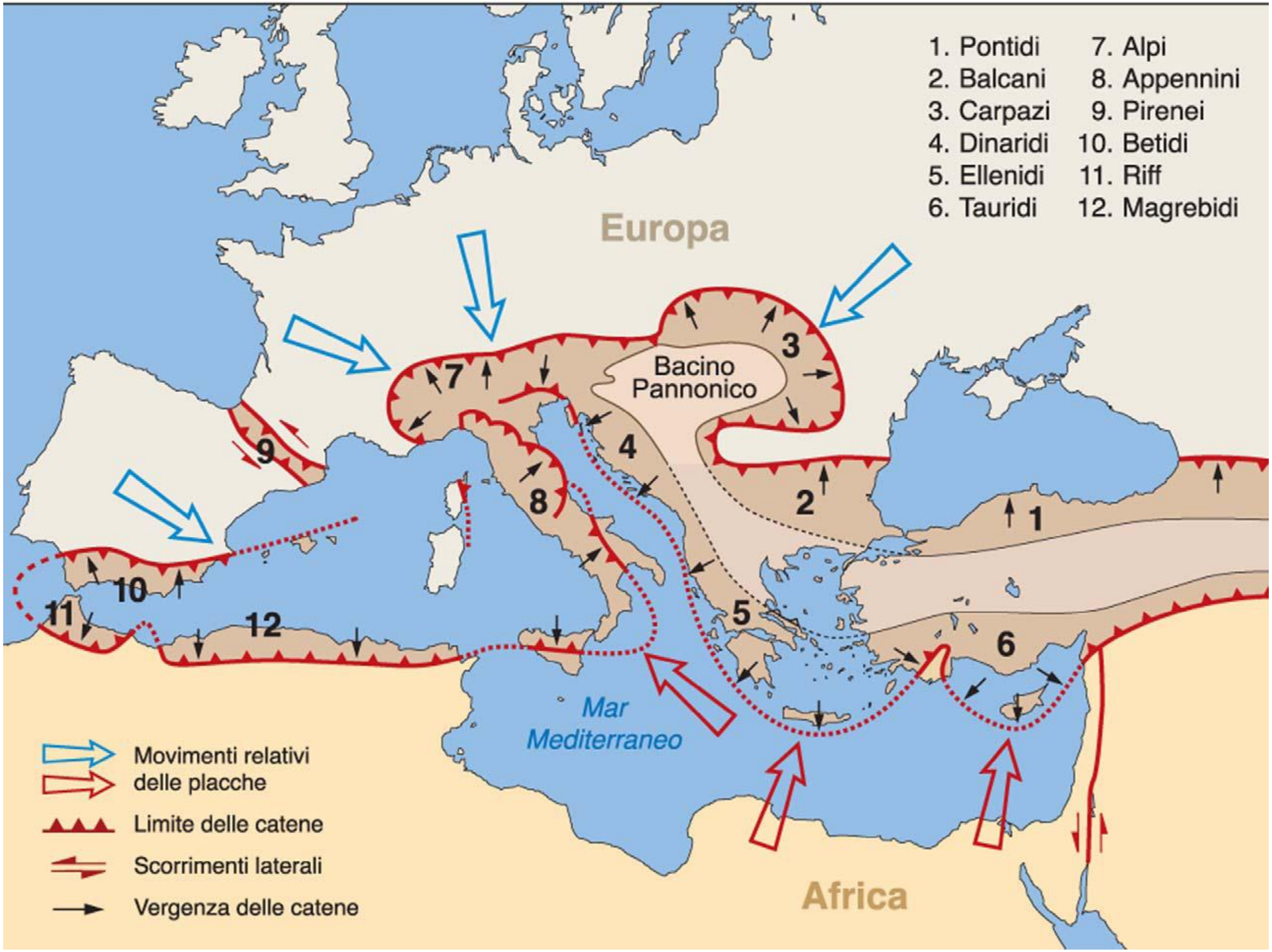
## Two main palaeo-geographic episodes

- Messinian salinity crisis
- Post-LGM sea-level rise

## Some considerations about climate change

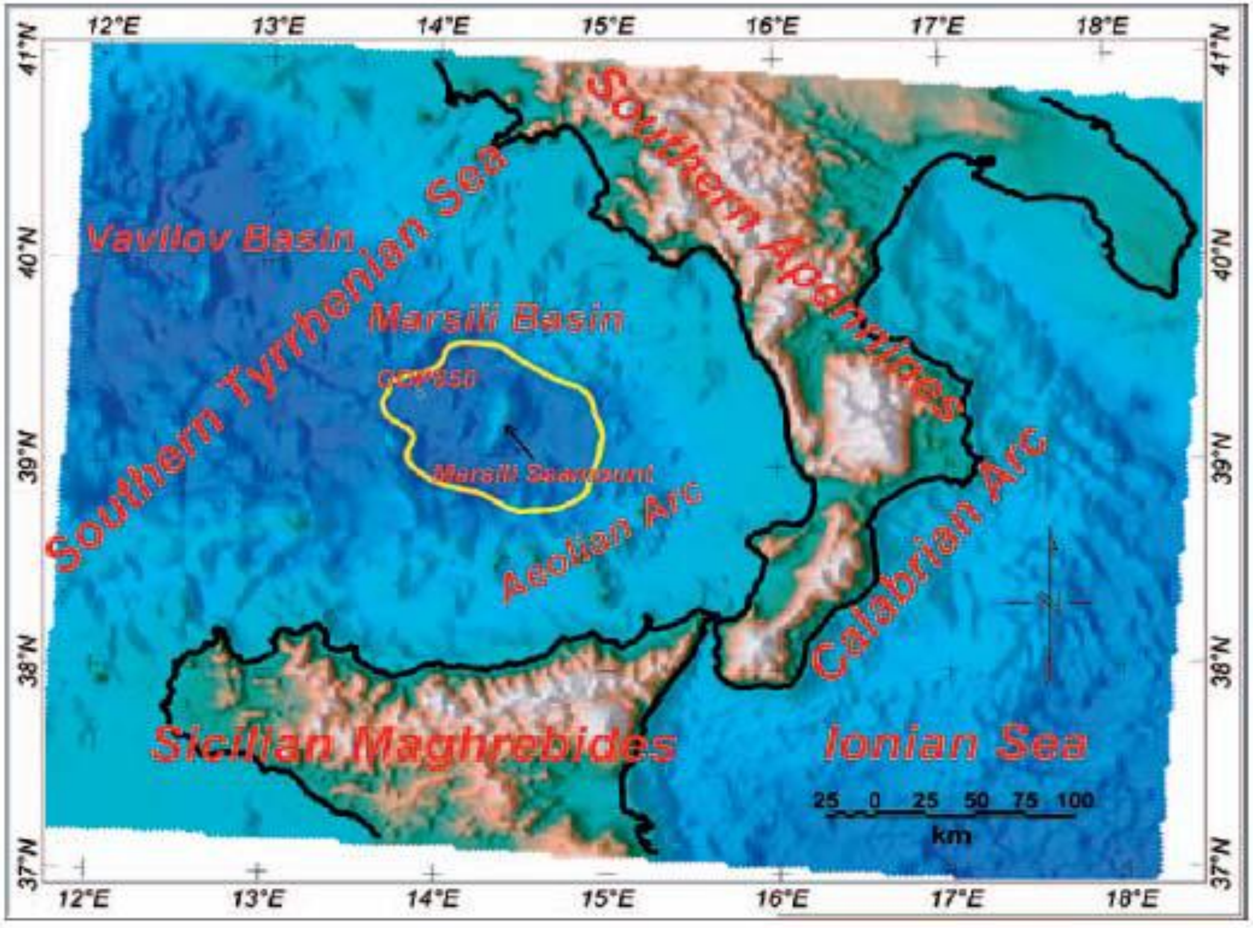
# CIRCUM-MEDITERRANEAN OROGENIC CHAINS

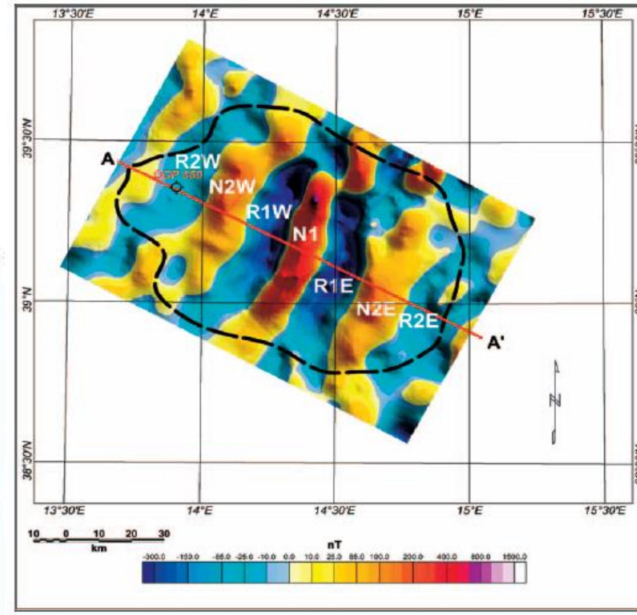
## Alpine – Himalayan collisional system (Mesozoic-Present)



# Rifting (Corinth, Sicilian Channel)

# Back-arc opening (Tyrrhenian Sea)



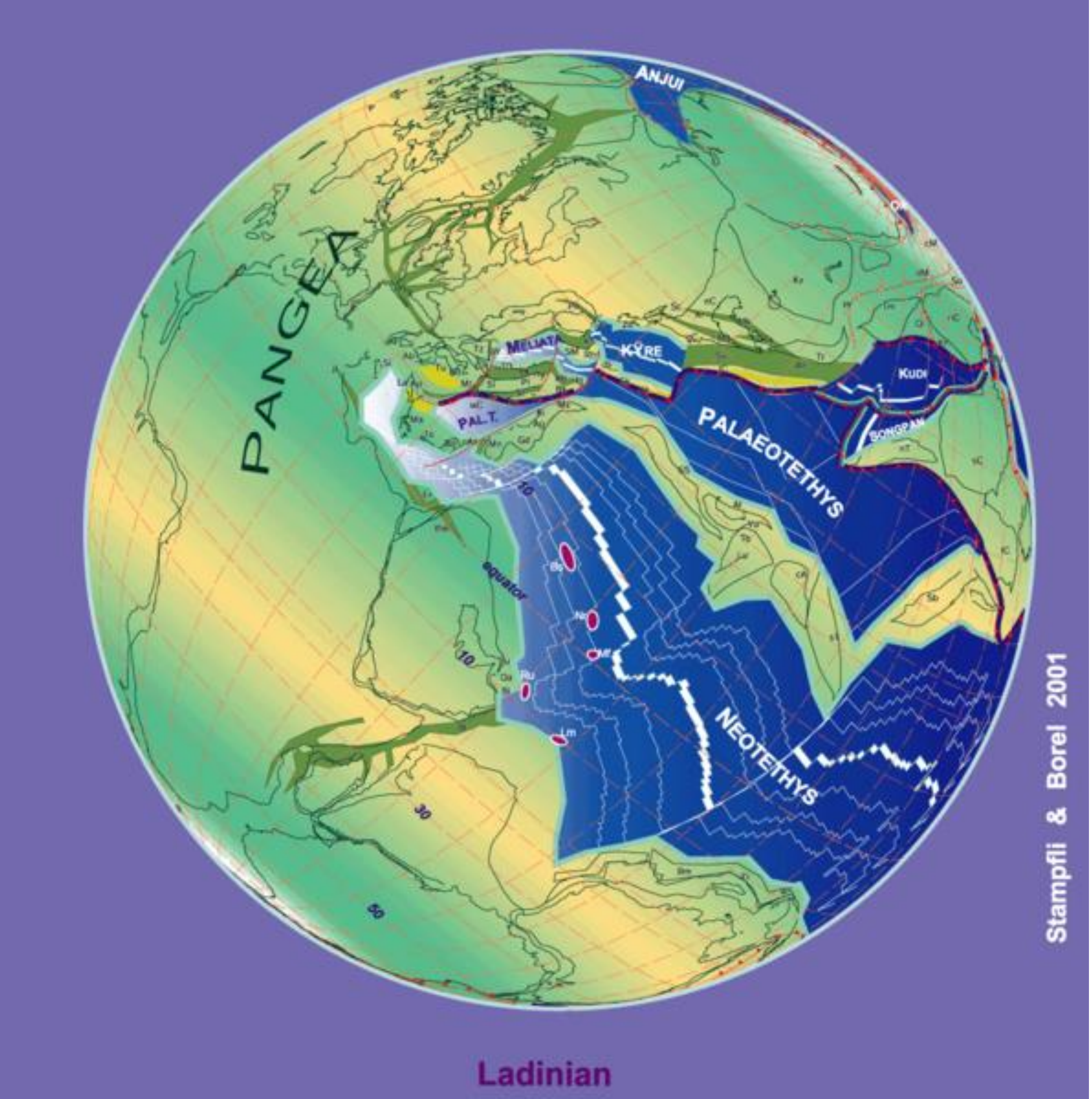



# Subduction (Calabrian Arc, Aegean Sea)

# Continent-continent collision (Alps)

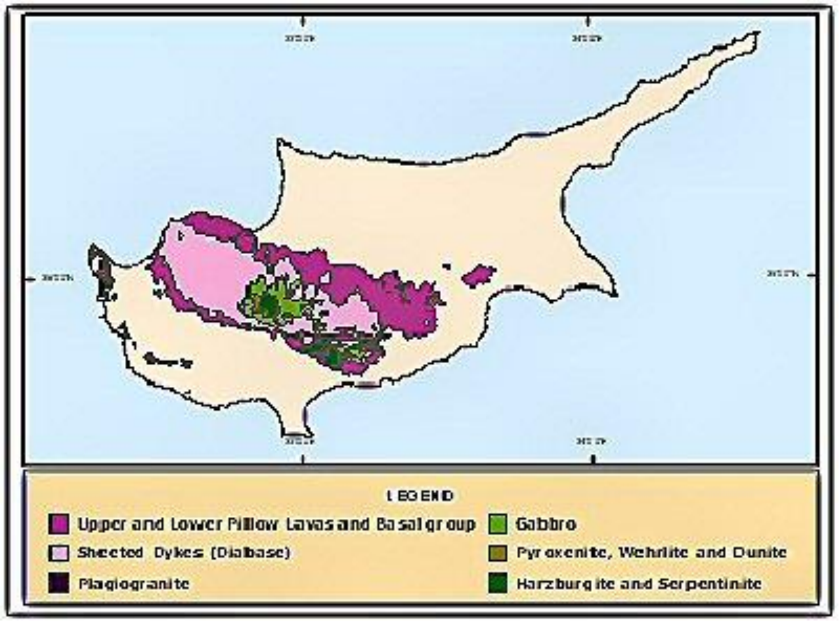
# MEDITERRANEAN SEISMICITY AND PLATE BOUNDARIES

The **Tethys Ocean** (also called **Neotethys**), was an ocean during much of the Mesozoic, located between the ancient continents of Gondwana and Laurasia, before the opening of the Indian and Atlantic oceans during the Cretaceous.




**Neotethys ~220 Ma**

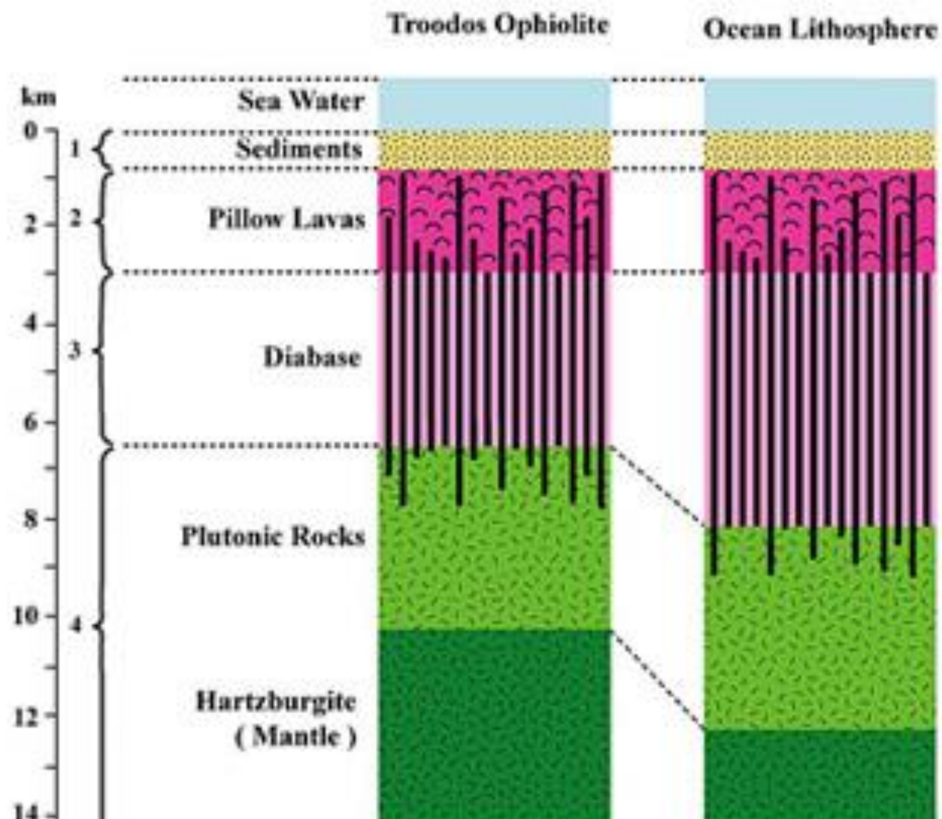
Evidence from Sicily to the eastern Mediterranean (followed the Variscan orogeny, resulting from the collision of Laurasia with Gondwana to form Pangea supercontinent)

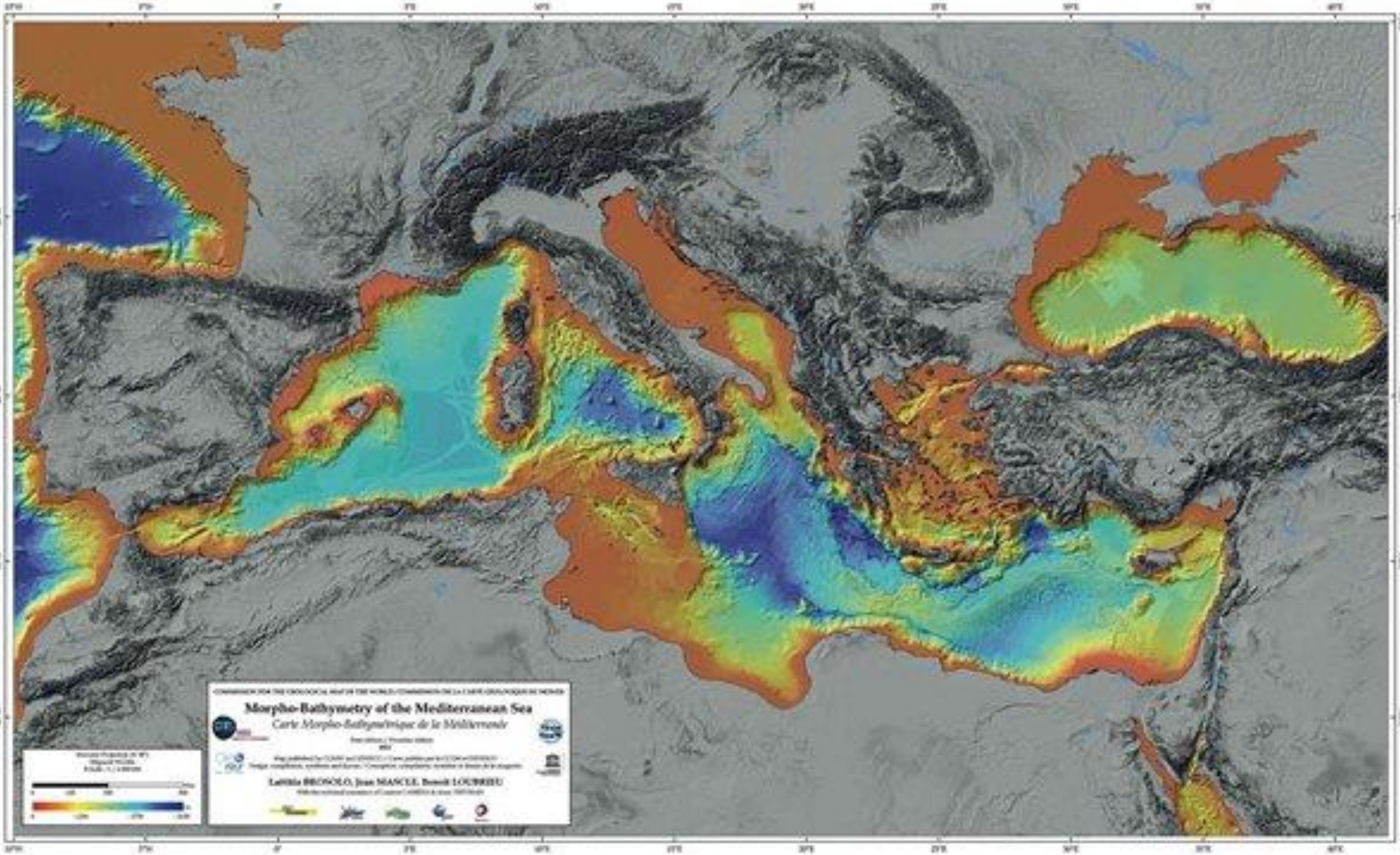



The Troodos Ophiolite complex dominates the central part of the island. It was formed in the Upper Cretaceous (90 Ma) on the Tethys sea floor, which then extended from the Pyrenees through the Alps to the Himalayas. It is regarded as the most complete, intact and studied ophiolite in the world. It is a fragment of a fully developed oceanic crust, consisting of plutonic, intrusive and volcanic rocks and chemical sediments. It was created during the complex process of sea-floor spreading and formation of oceanic crust and was emerged and placed in its present position through tectonic processes related to the collision of the Eurasian plate to the north and the African plate to the south. The stratigraphy of the ophiolite shows a topographic inversion, with the stratigraphically lower suites of rocks outcropping in the highest points of the range, while the higher units appear on the periphery of the ophiolite. The uplift of the island took place during episodes of abrupt uplift up to the Pleistocene (2 Ma).

# Troodos Ophiolite Complex (Cyprus)

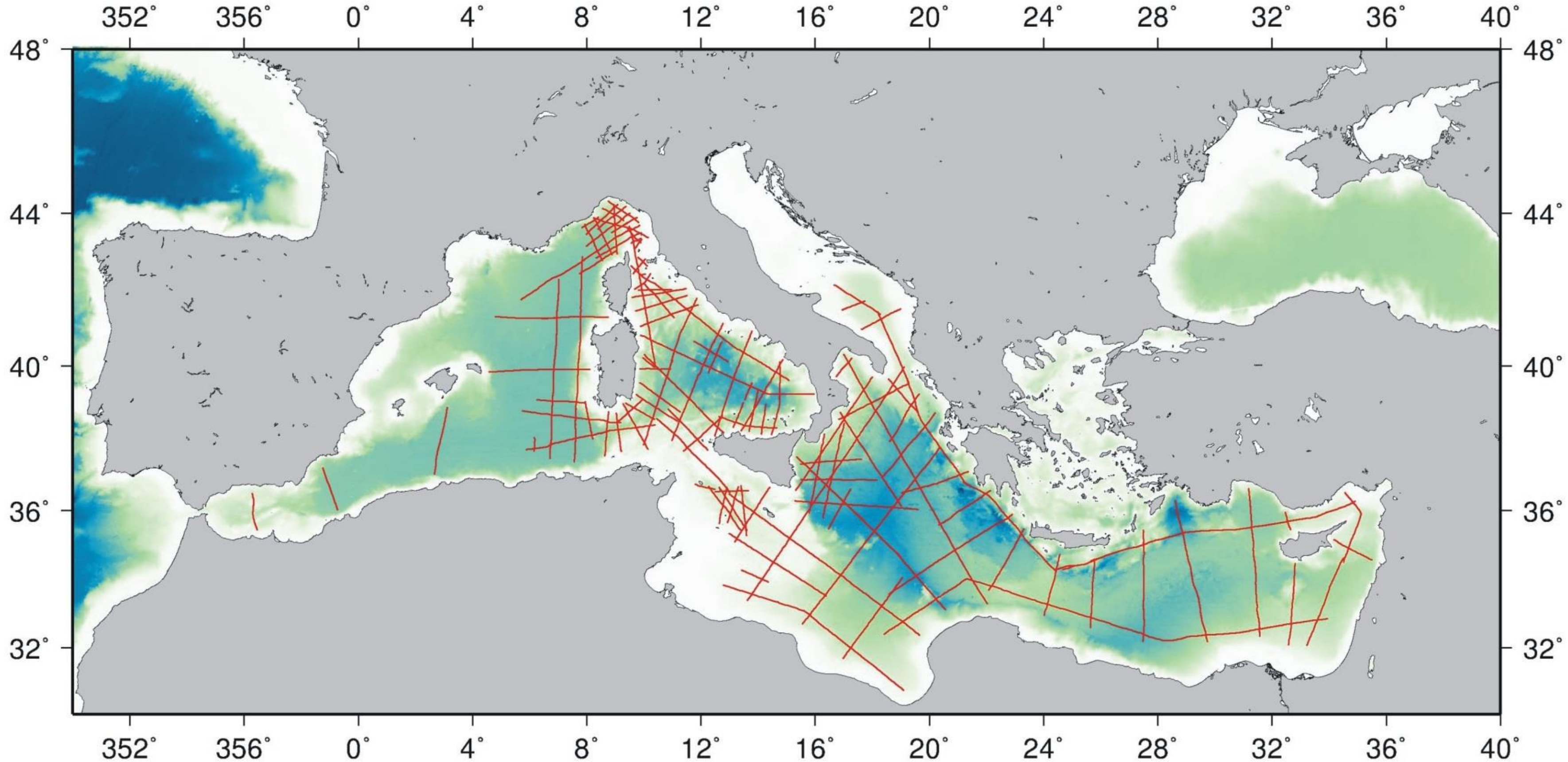
The Troodos Ophiolite consists of the following stratigraphic units, in ascending order: Plutonics (mantle sequence and cumulates), Intrusives, Volcanics and sediments.



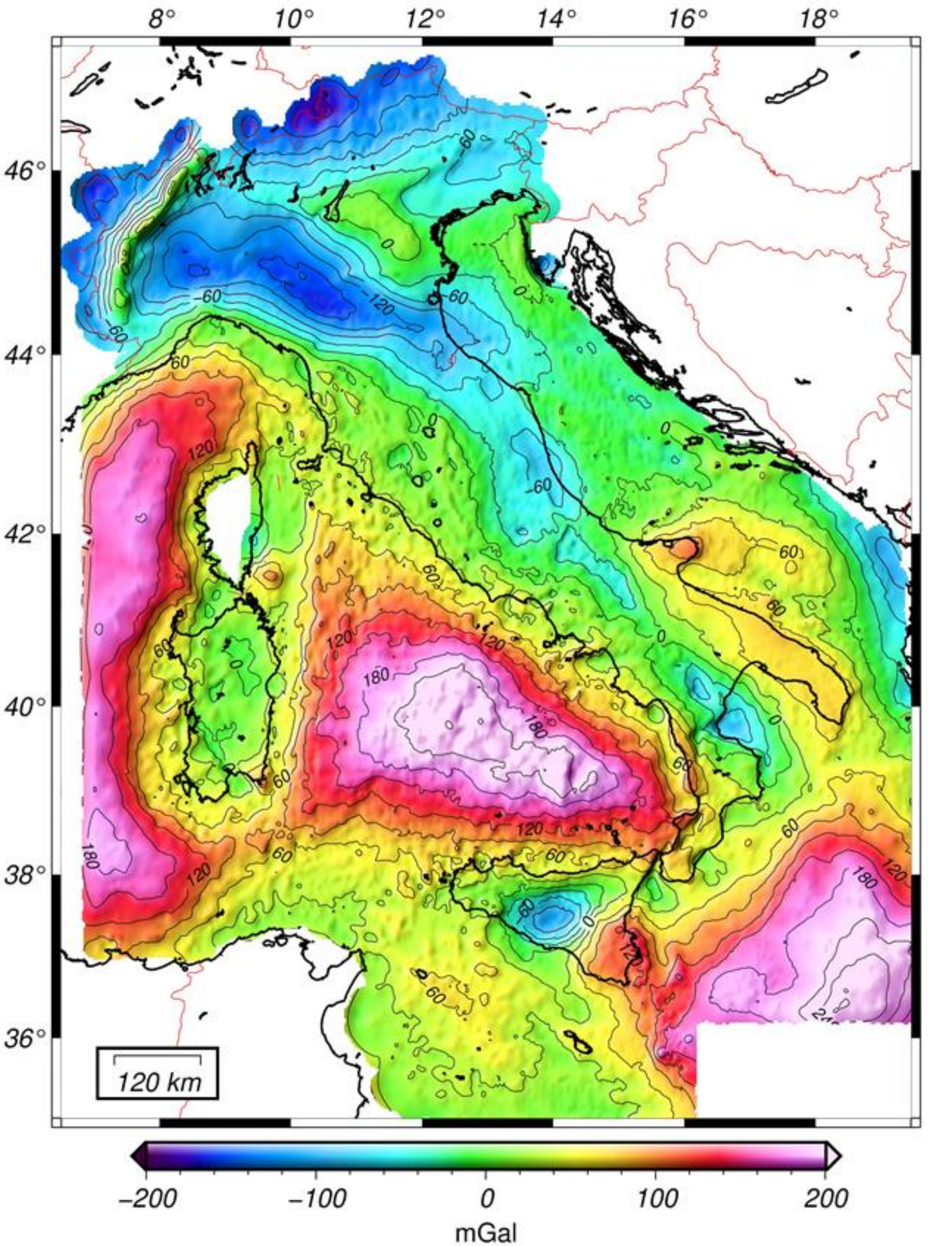

Morpho-Bathymetry of the Mediterranean Sea
Carte Morpho-Bathymétrique de la Méditerranée

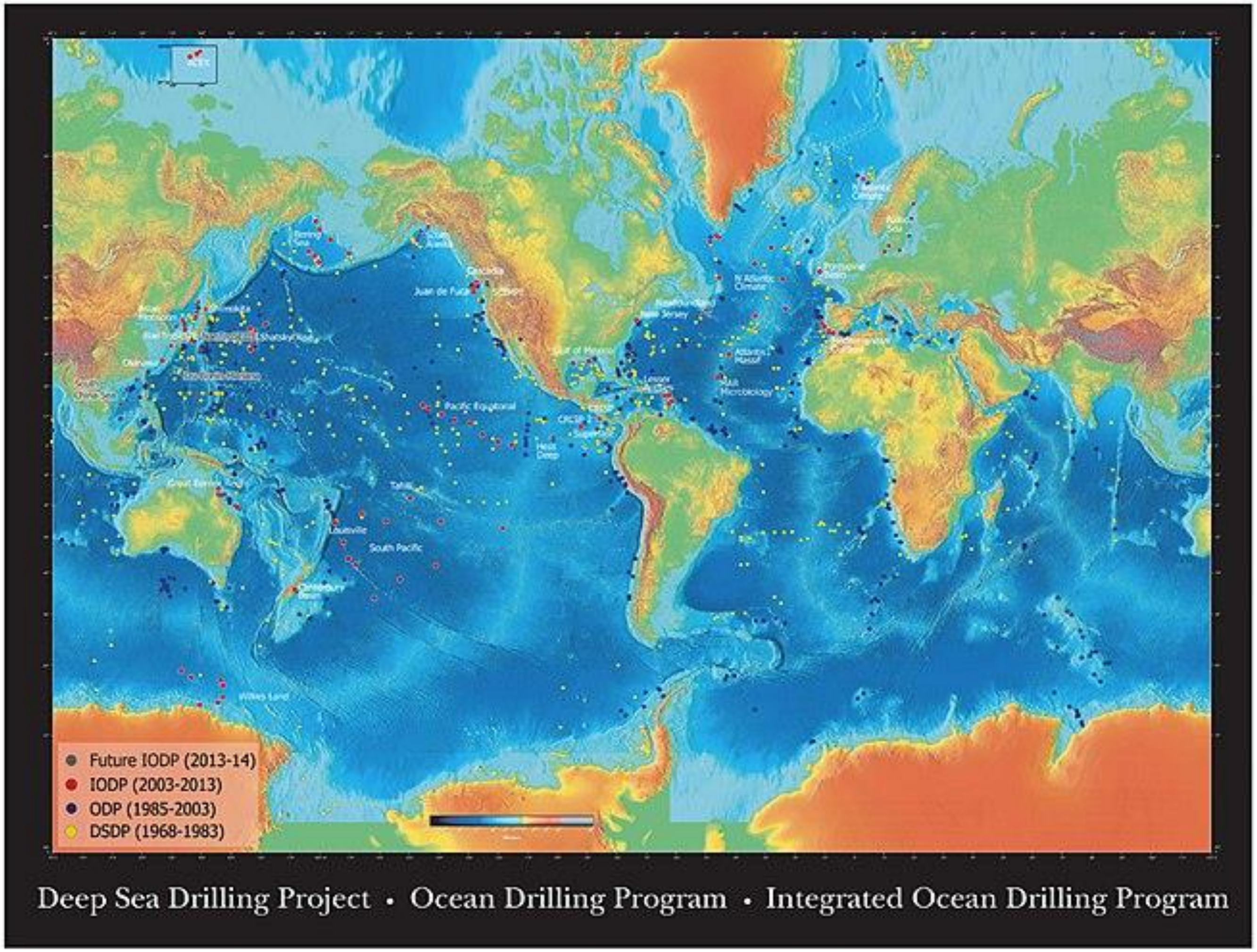
# MS map

(seismic profiles collected from 1968 to 1982)



# Bouguer gravity anomaly map of the Central Mediterranean






# HISTORY

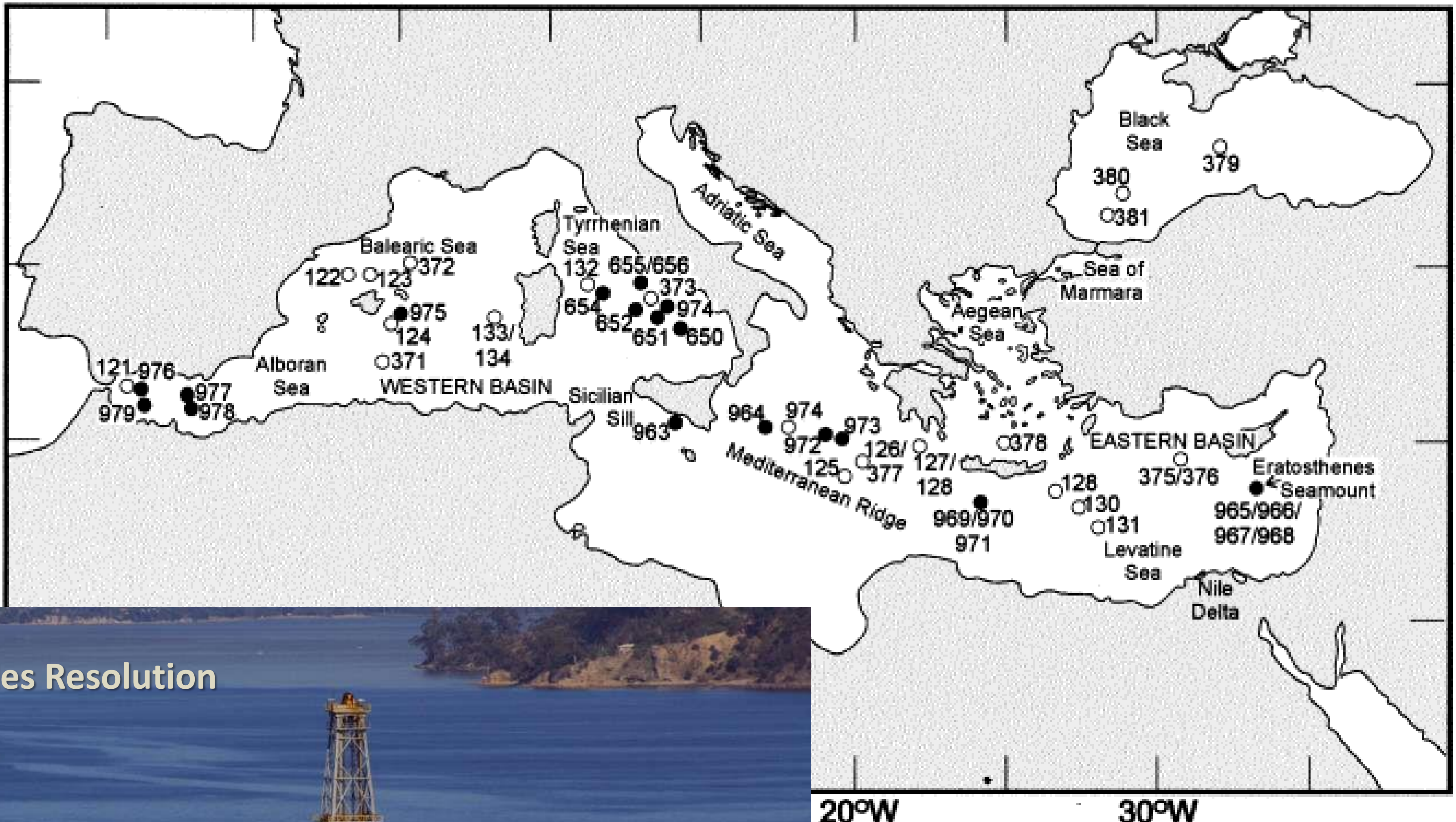
**1961: Project MoHole**

**1966-1983: Deep Sea Drilling Project (DSDP)**
Drilling Vessel *Glomar Challenger*

**1983-2003: Ocean Drilling Program (ODP)**
*JOIDES Resolution* replaced the *Glomar Challenger*

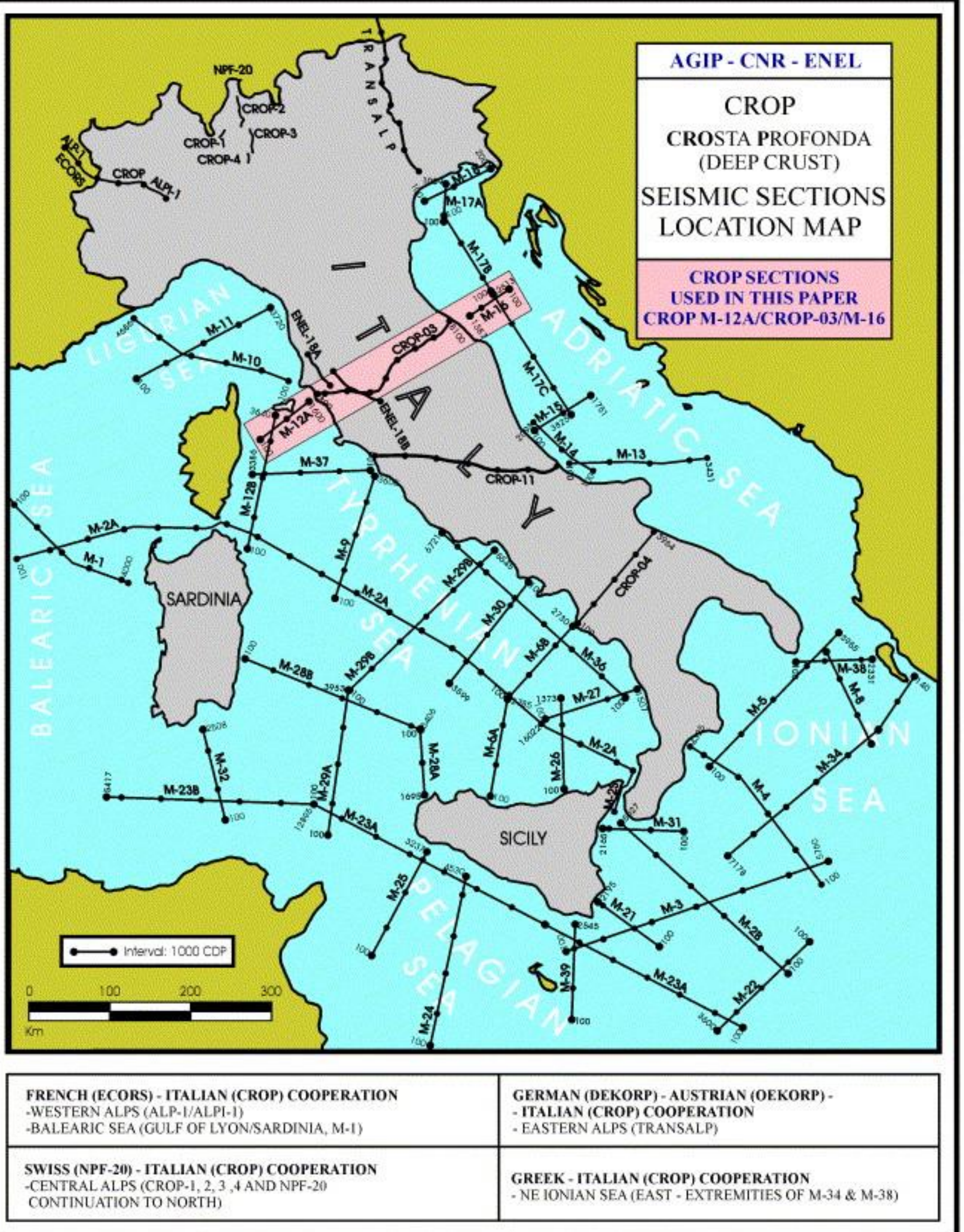
**2003-2013: Integrated Ocean Drilling Program (IODP)**
*JOIDES Resolution*, the new marine-riser equipped Japanese
Vessel *Chikyu*, and specialized Mission-Specific-Platforms

**2013-Present: International Ocean Discovery Program (IODP)**



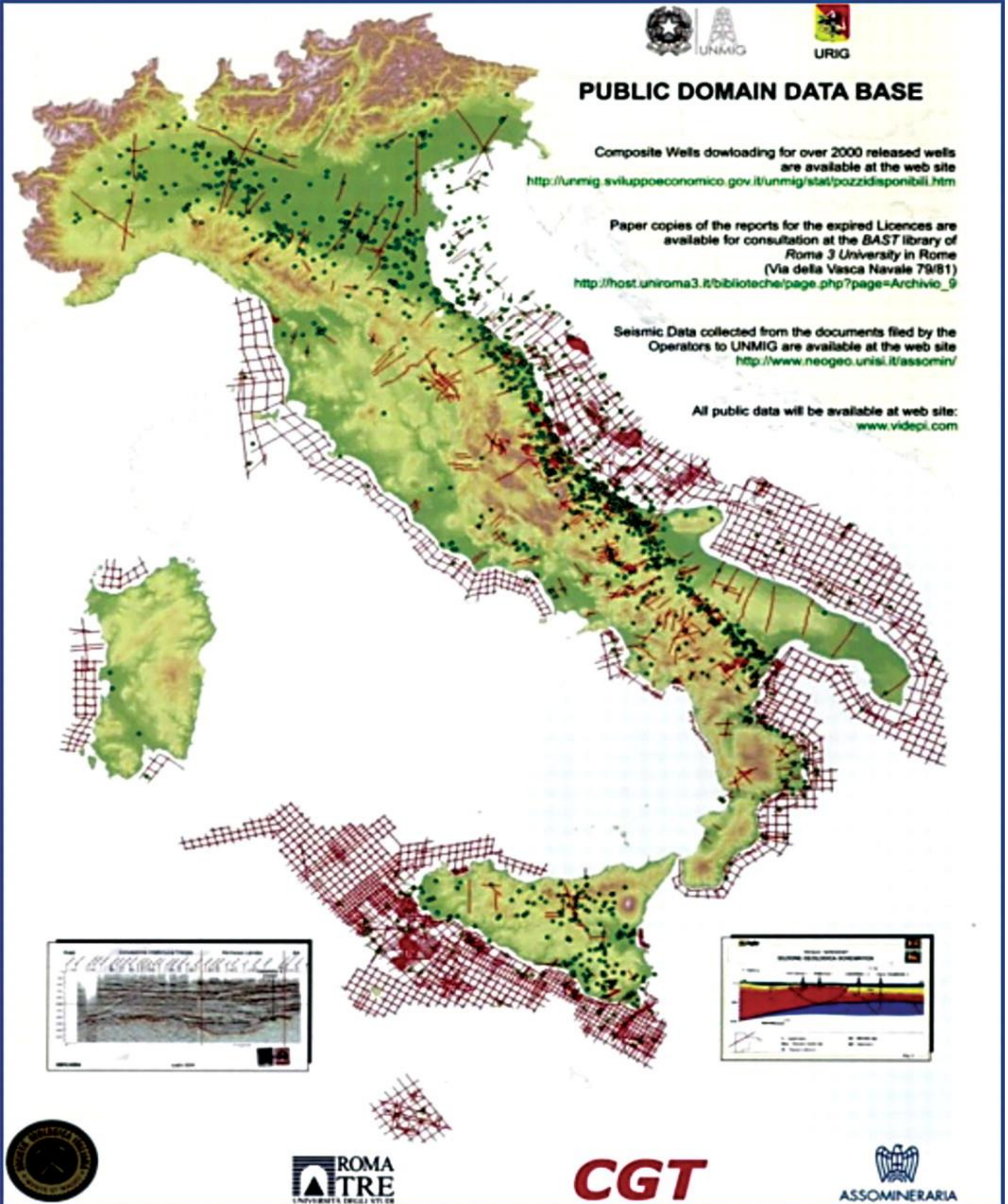


# DSDP and IODP program




# CROP map

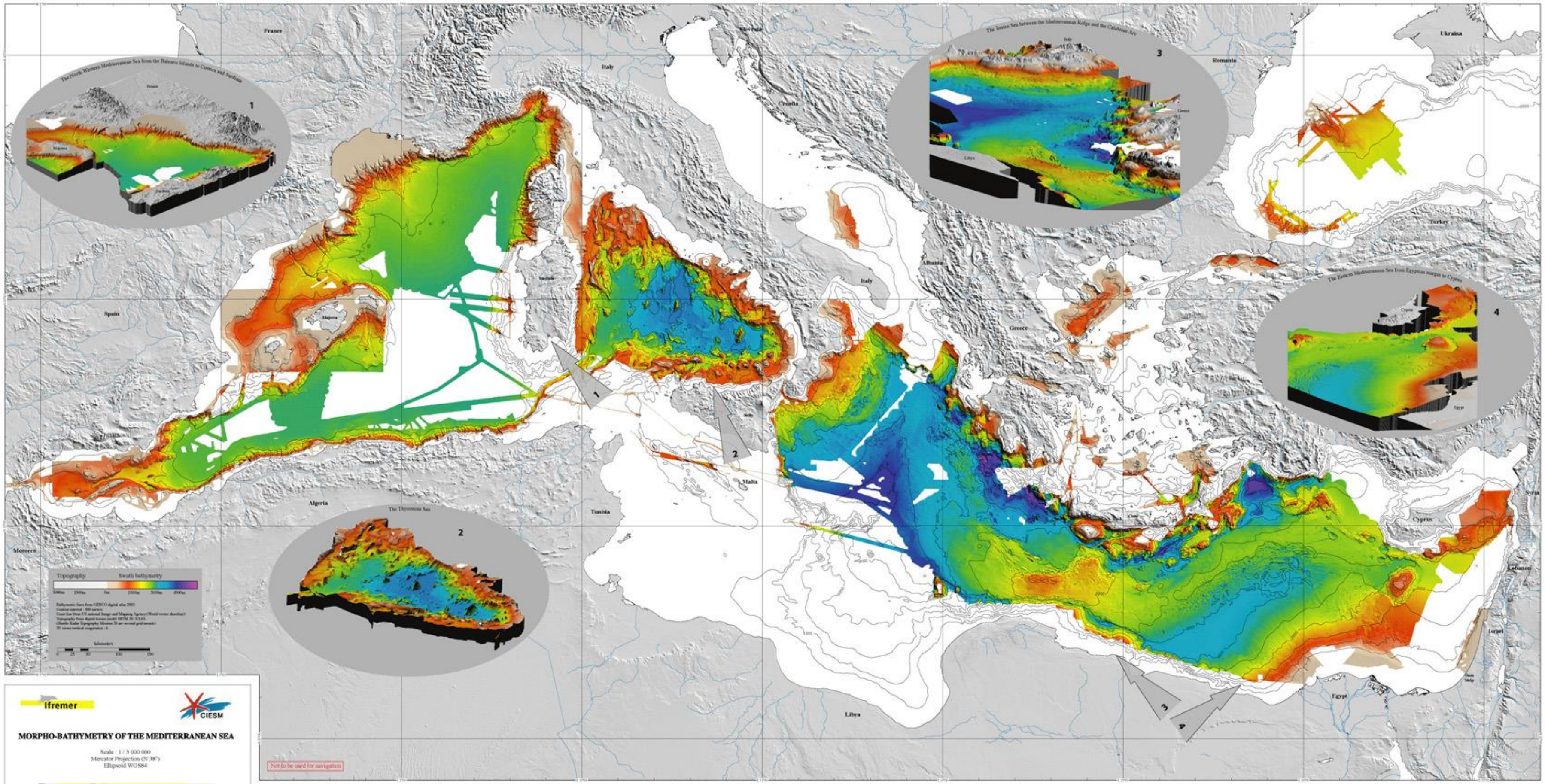
**(Seismic profiles collected both onshore and offshore)**




# ViDEPI

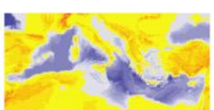
Visibilità dei dati afferenti all'attività di esplorazione petrolifera in Italia
http://unmig.sviluppoeconomico.gov.it/videpi/

# MORPHO-BATHYMETRY OF THE MEDITERRANEAN SEA




## MORPHO-BATHYMETRY OF THE MEDITERRANEAN SEA

Scale : 1 / 3 000 000
Mercator Projection (N 38°)
Ellipsoid WGS84



Medimap Group, 2007. Morpho-bathymetry of the Mediterranean Sea, CIESM / Ifremer special publication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**Cartographers**
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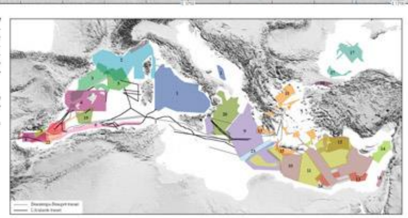
Swath mapping of most of the Mediterranean Sea is being progressively completed in the frame of cooperation between several national Research Oceanographic and Hydrographic Institutions. Since 2001, the CIESM Marine Geosciences Committee and Ifremer mapping office have jointly promoted compilations and publications of synthesis maps of the Eastern and Western Mediterranean basins. The maps reveal many active geological (tectonic, volcanic, sedimentary, geochemical) characteristics imprinted on the seafloor. They illustrate the startling changes brought to the knowledge and understanding of deep basins and geological processes by mapping using modern swath systems.

Institutions and laboratories have provided Digital Terrain Models at a 500m grid spacing extracted from their own swath bathymetry data sets allowing Ifremer mapping office to produce this synthesis map.
The Digital Terrain Model, sampled at a 1km grid spacing is available at the web site : http://www.ifremer.fr/drogm_uk/Realisation/carto/Mediterranee/index.html



**Data sources**

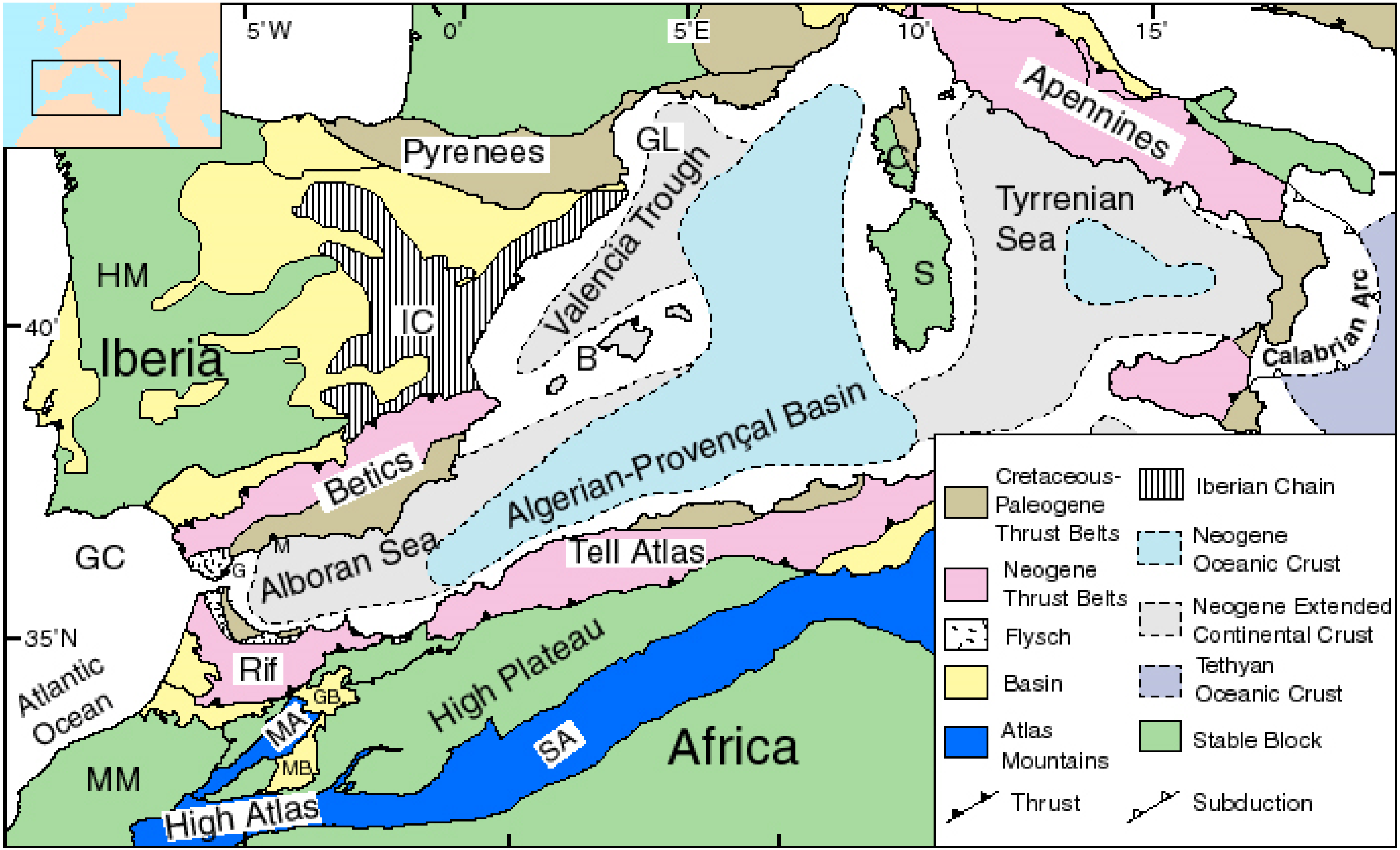
- **The present-day geological configuration of the Mediterranean region is the result of the creation and ensuing consumption of two major oceanic basins—the Paleotethys and the Neotethys.**

- **The overall tectonic regime was (and it is) the regime of prolonged interaction between the Eurasian and the African-Arabian plates (average convergence rate of 1 cm/yr).**

- **The Mediterranean domain provides a present-day geodynamic analog for the final stages of a continent-continent collisional orogeny. Over this area, the oceanic lithospheric domains originally present between the Eurasian and African-Arabian plates have been subducted and partially obducted (ophiolitic terranes), except for the Ionian basin and the south-eastern Mediterranean.**

- **The modern marine basins of the Mediterranean Sea are variably floored by: (i) remnants of the Tethyan oceanic domains (Ionian, E Mediterranean); (ii) Neogene oceanic crust (Algero-Provençal basin and Tyrrhenian Sea); (iii) extended continental lithosphere (Alboran Sea, Valencia Trough, Aegean Sea), and (iv) thick continental lithosphere (Adriatic Sea).**

# WESTERN MEDITERRANEAN BASINS



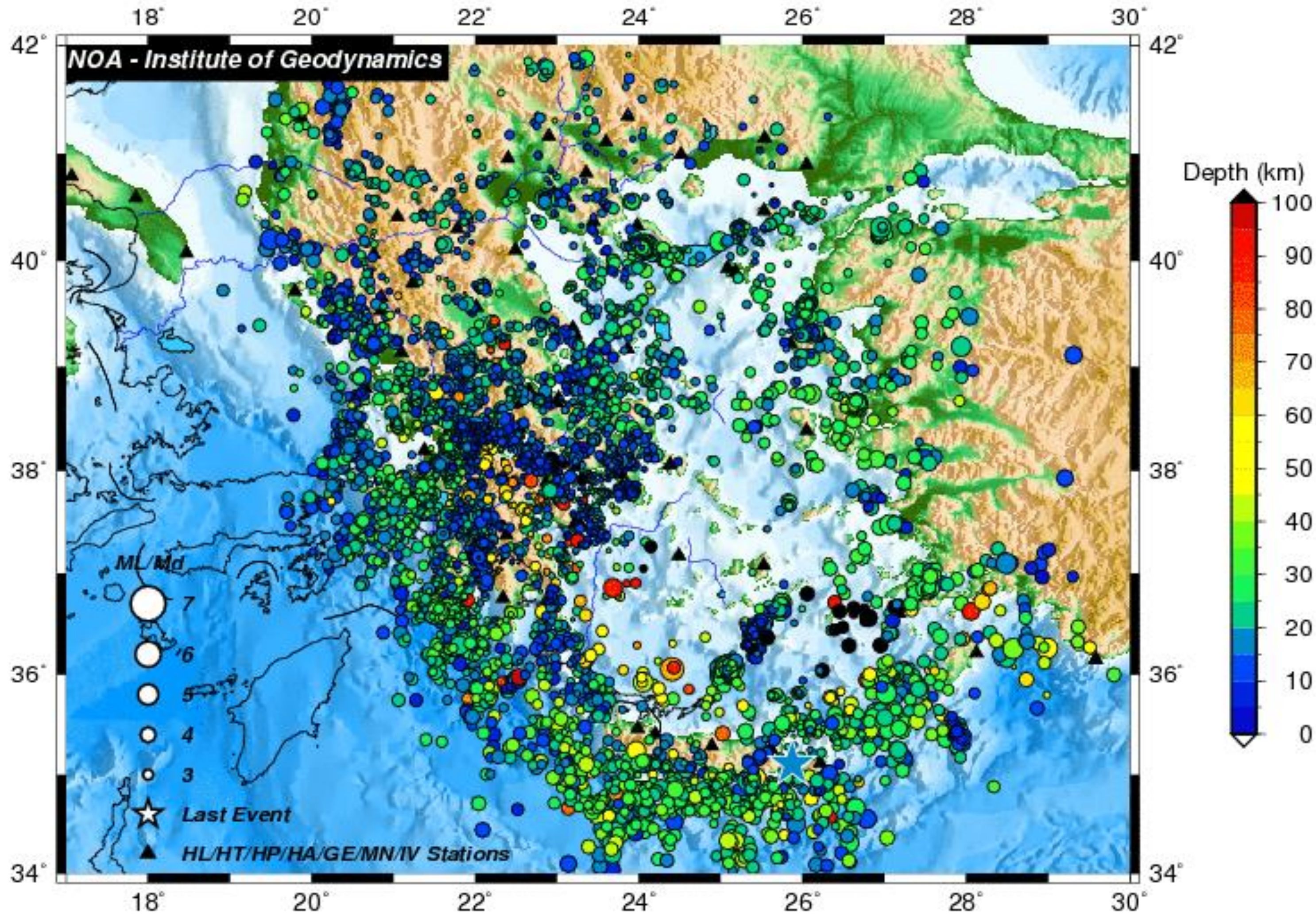
- **The western Mediterranean is the younger part of the Mediterranean (late Oligocene to present). It consists of a series of sub-basins: Alboran, Valencia, Provençal, Algerian and Tyrrhenian seas. These generally rejuvenate moving from west to east. They are partly floored by oceanic crust (Provençal and Algerian basins, and two smaller areas in the Tyrrhenian Sea). The remaining submarine part of the western Mediterranean basin is made of extensional and transtensional passive continental margins.**

- **The Algerian Basin is a deep basin (around 3000 m) located between the Balearic Promontory and the North Africa margin. The crust in the Algerian Basin seems to have an oceanic character. In most of the basin the Moho depth is less then 14 km and the crust is 4 to 6 km thick.**

- **The Liguro-Provençal Basin comprises the Ligurian Sea, the Gulf of Lions as well as the portion of the Mediterranean Sea located West of Corsica and Sardinia, and East of Menorca. It is the oldest Western Mediterranean basin and has a maximum water depth of 2800 m. The lithosphere beneath the Liguro-Provençal basin is thin (less than 30 km) the crust decreases in thickness to about 5 km beneath the central part of the basin where it is oceanic, dated as late Aquitanian to late Burdigalian-early Serravallian. Rifting in the Provençal-Ligurian basin started during latest Eocene-Early Oligocene (34-28 Ma) and ended in the middle Aquitanian. Subsequently, the central oceanic portion of the basin was generated between the late Aquitanian and late Burdigalian (21-16 Ma) associated with the counter clockwise rotation of the Corsica-Sardinia Block. Before drifting, this block of the Iberian plate was located close to the Provençal coast and the present-day Gulf of Lions. The Liguro-Provençal Basin is considered to be a back-arc basin generated from the south-eastward roll-back of the Apennines-Maghrebides subduction.**

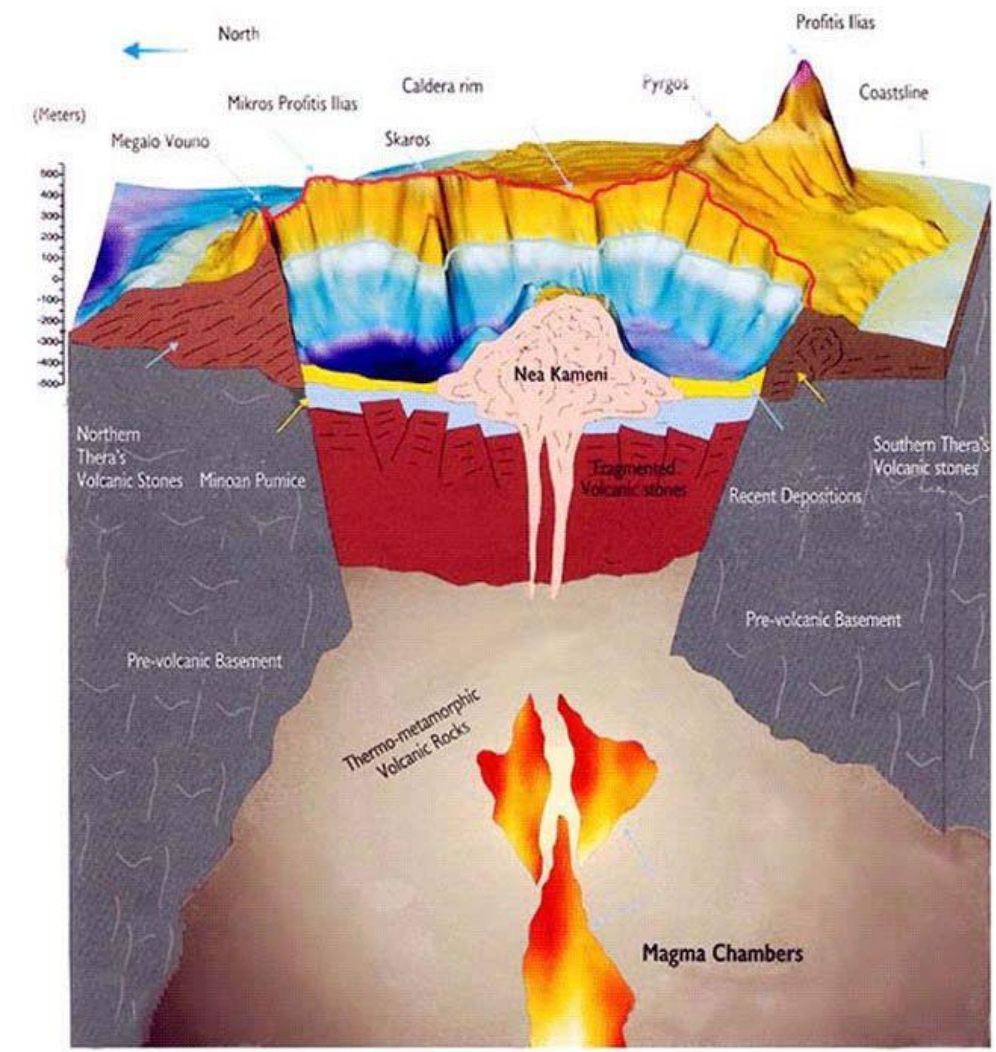
# Aegean region

# Aegean Sea seismicity



The volcanic complex of Santorini is the most active part of the South Aegean Volcanic Arc. It is about 500 km long and 20 to 40 km wide and characterized by earthquakes at depths of 150-170 km that mark the subduction of the African underneath the Eurasian plate, at a rate of up to 5 cm/year in a NE direction.

Schematic geological section of Santorini




Santorini is what remains after an enormous volcanic eruption that destroyed the earliest settlements on a formerly single island, and created the current geological caldera. The island is the site of one of the largest volcanic eruptions in recorded history: the Minoan eruption, occurred some 3600 years ago at the height of the Minoan civilization.

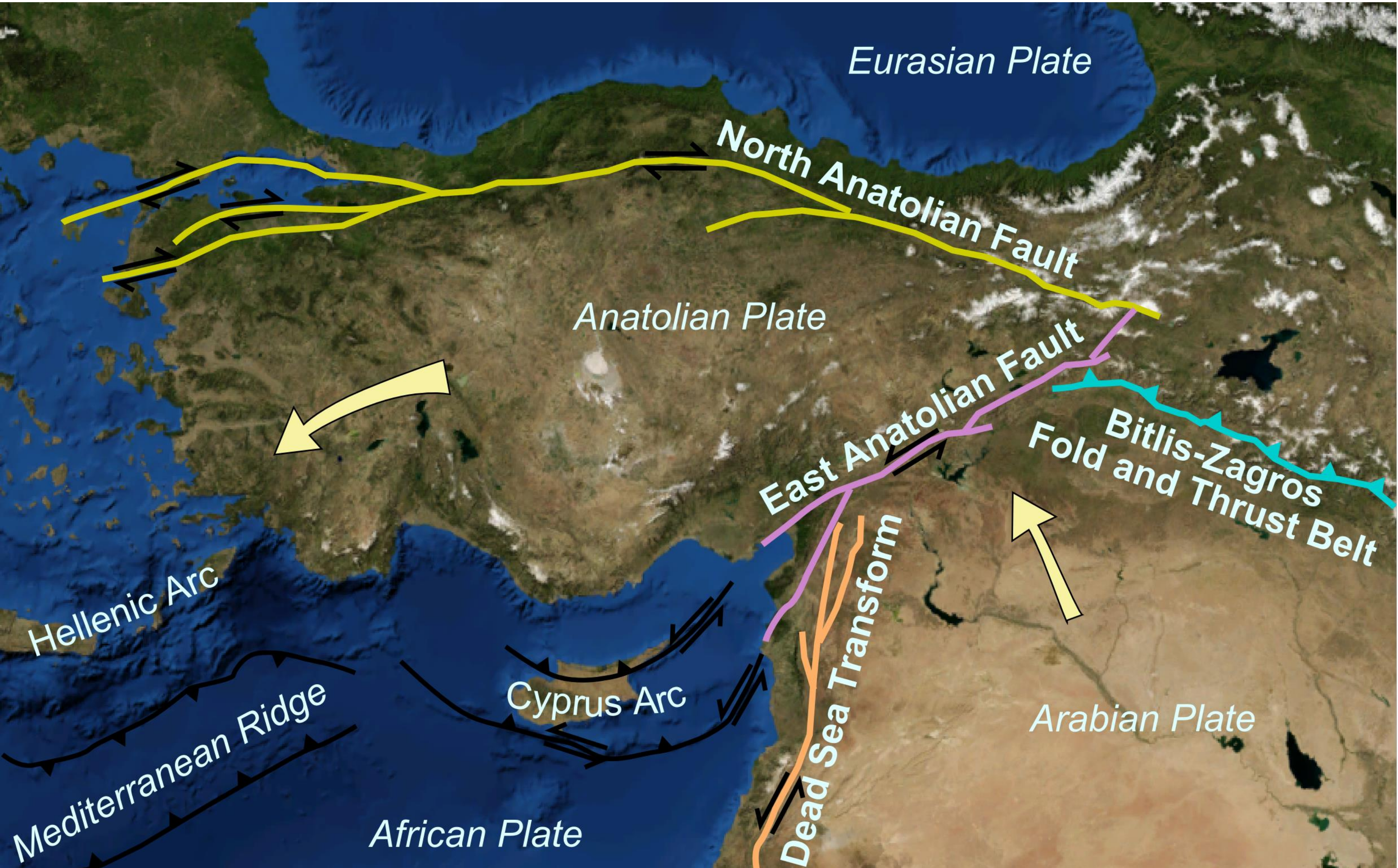
# Santorini Is.

- **The Aegean is characterized by a relatively thicker crust (25-30 km) than a typical oceanic crust, which might be interpreted as a thinned continental crust**

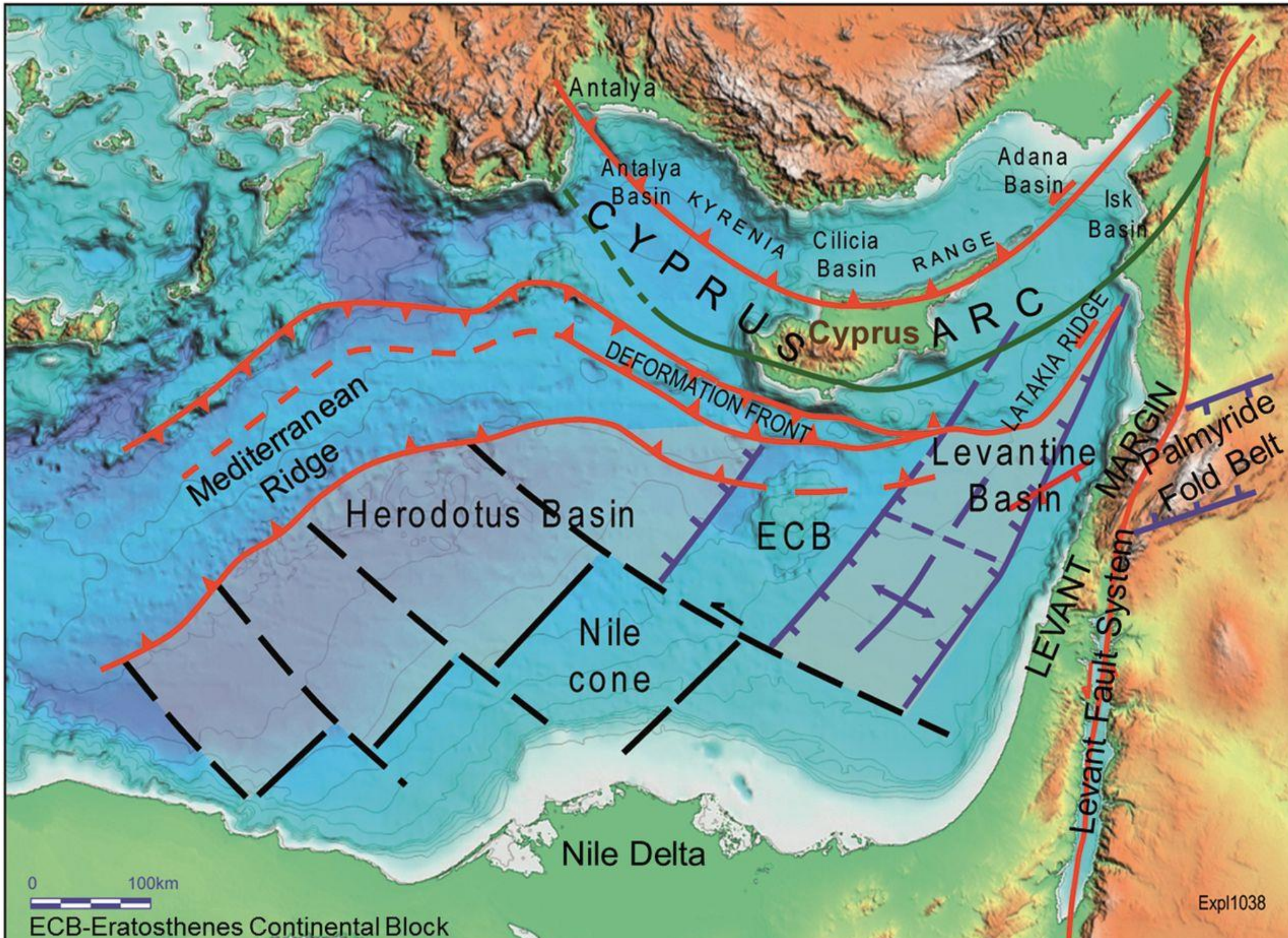
- **The existence of a calc-alkaline inner volcanic arc, the spatial distribution of earthquakes and detailed tomographic studies indicate the existence of a northward-dipping subducted slab beneath this region (African plate beneath Eurasian plate).**

- **The Arabian plate is moving in a north-northwest direction relative to Eurasia at a rate of about 18 mm/yr, averaged over about 3 Myr. These models also indicate that the African plate is moving in a northly direction relative to Eurasia at a rate of about 6 mm/yr.**

# Middle East tectonic setting

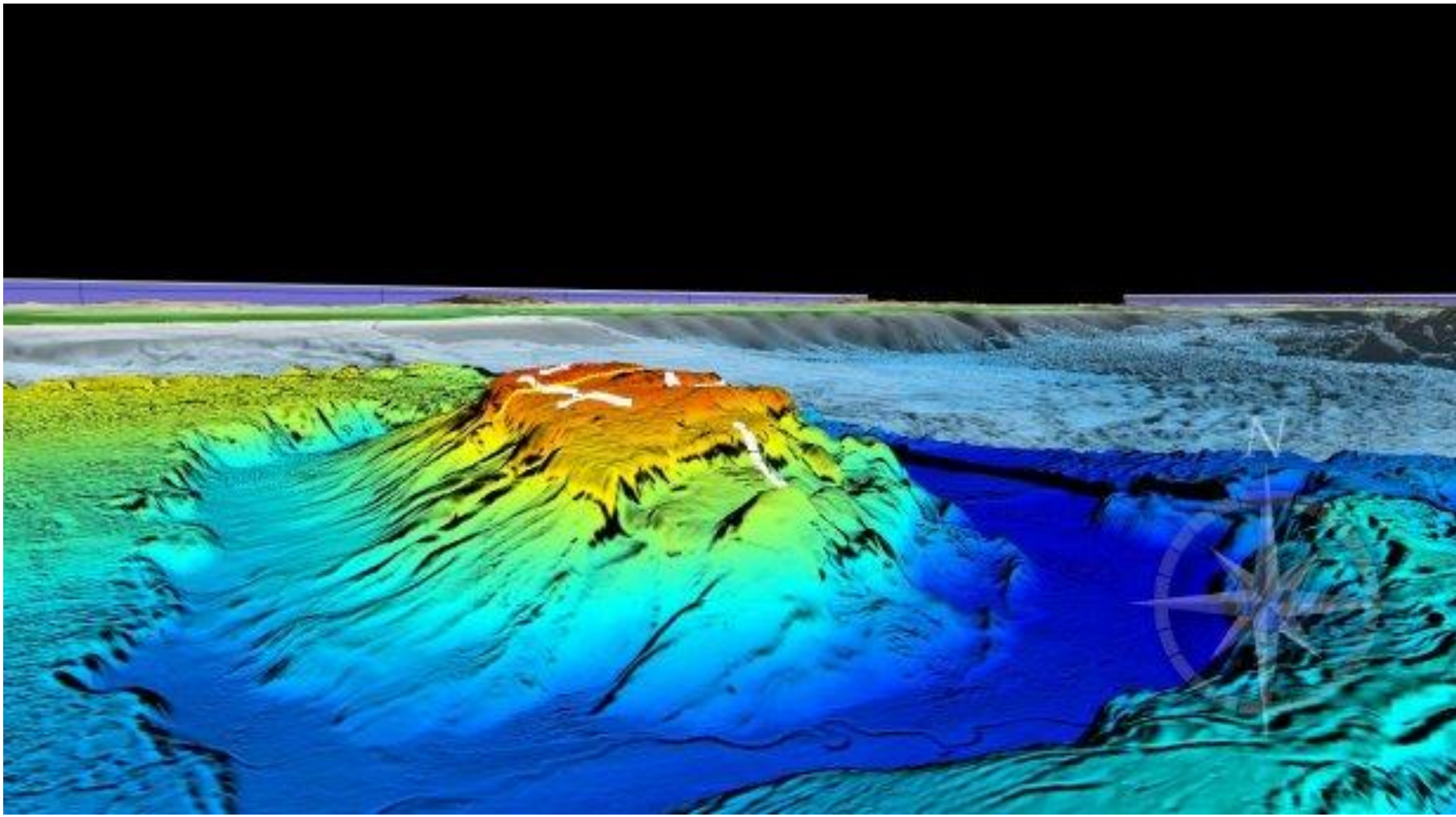


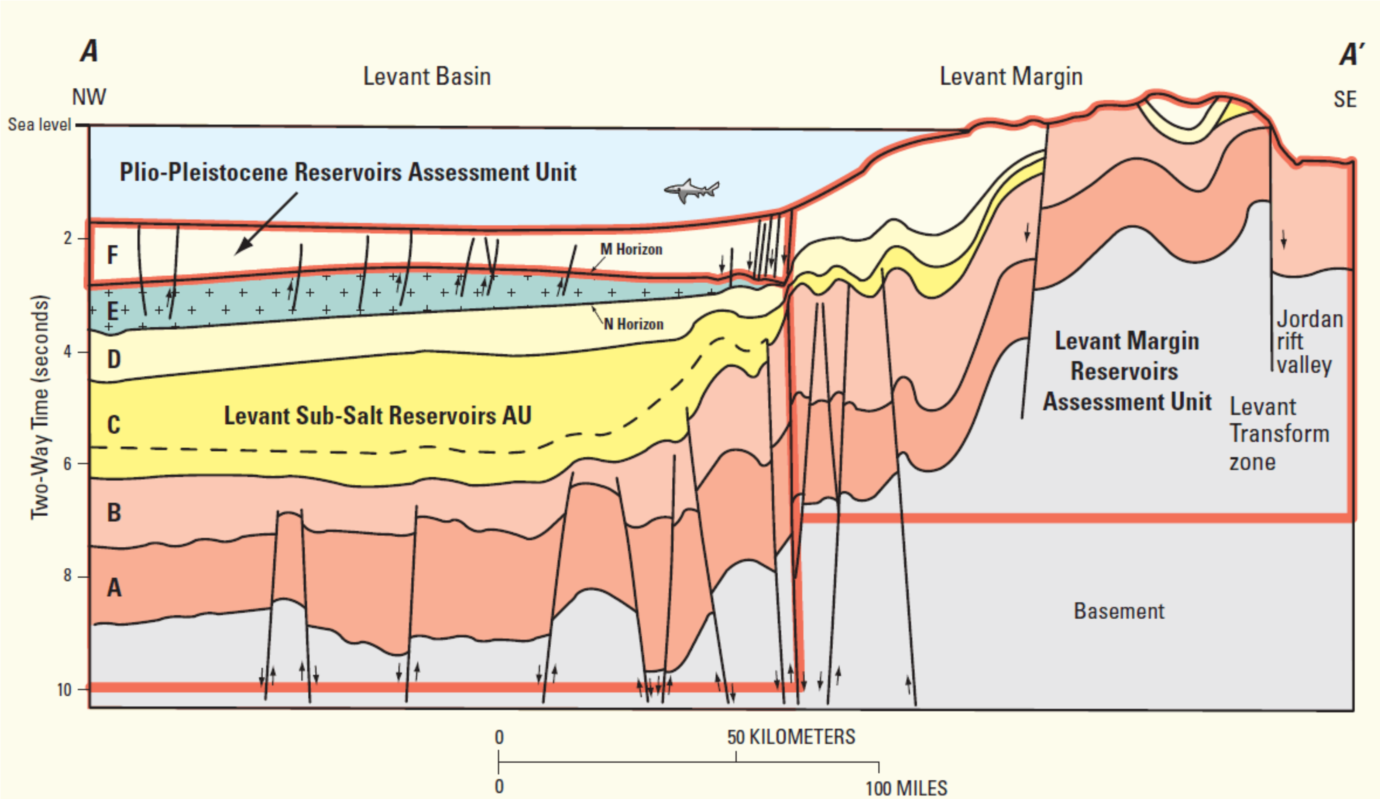
# Levant Basin



# Heratostene Seamount

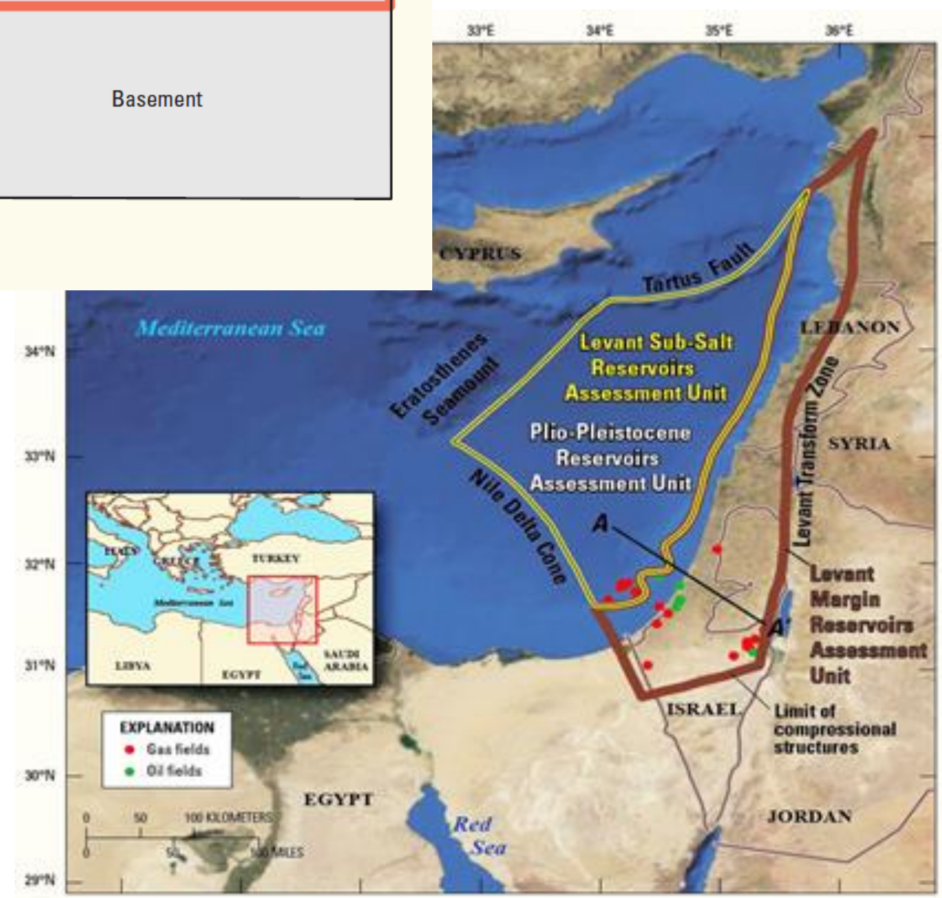
**It is located about 100 km south of western Cyprus. It is a large, submerged massif, about 120 km long and 80 km wide. Its peak lies at the depth of 690 m and it rises 2000 m above the surrounding seafloor, which is located at the depth of up to 2,700.**
**It is capped by a carbonatic layer**



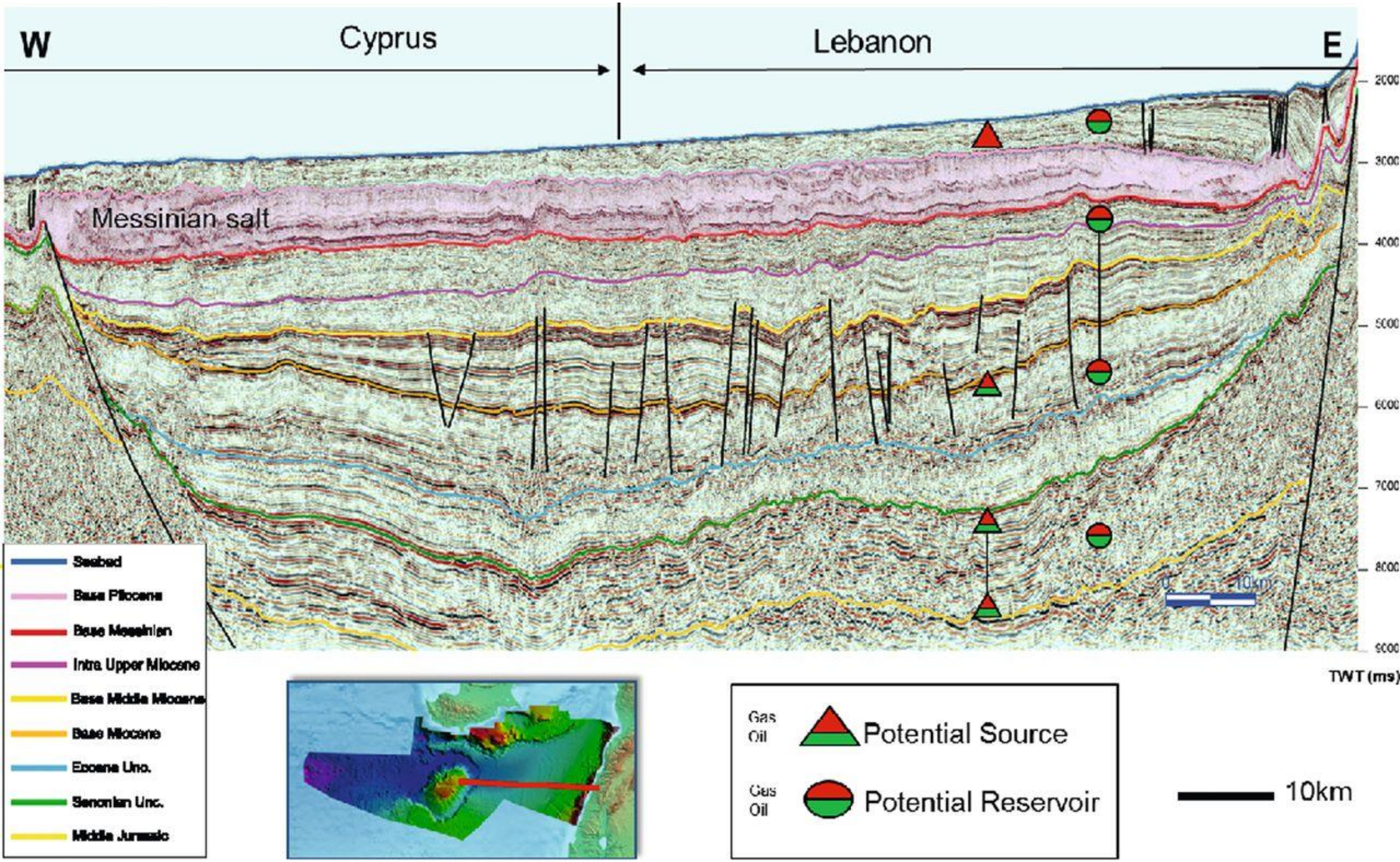



# Oil and gas reservoir In the Levant Basin

**Estimated total of 3.5 trillion ($10^{12}$) cubic meters of gas and 1.7 billion ($10^{9}$) barrels of oil**



# SEISMIC PROFILE ACROSS THE LEVANT BASIN



- **The formation of the Levant Basin was associated with the evolution of the Neo-Tethys ocean and its margins**

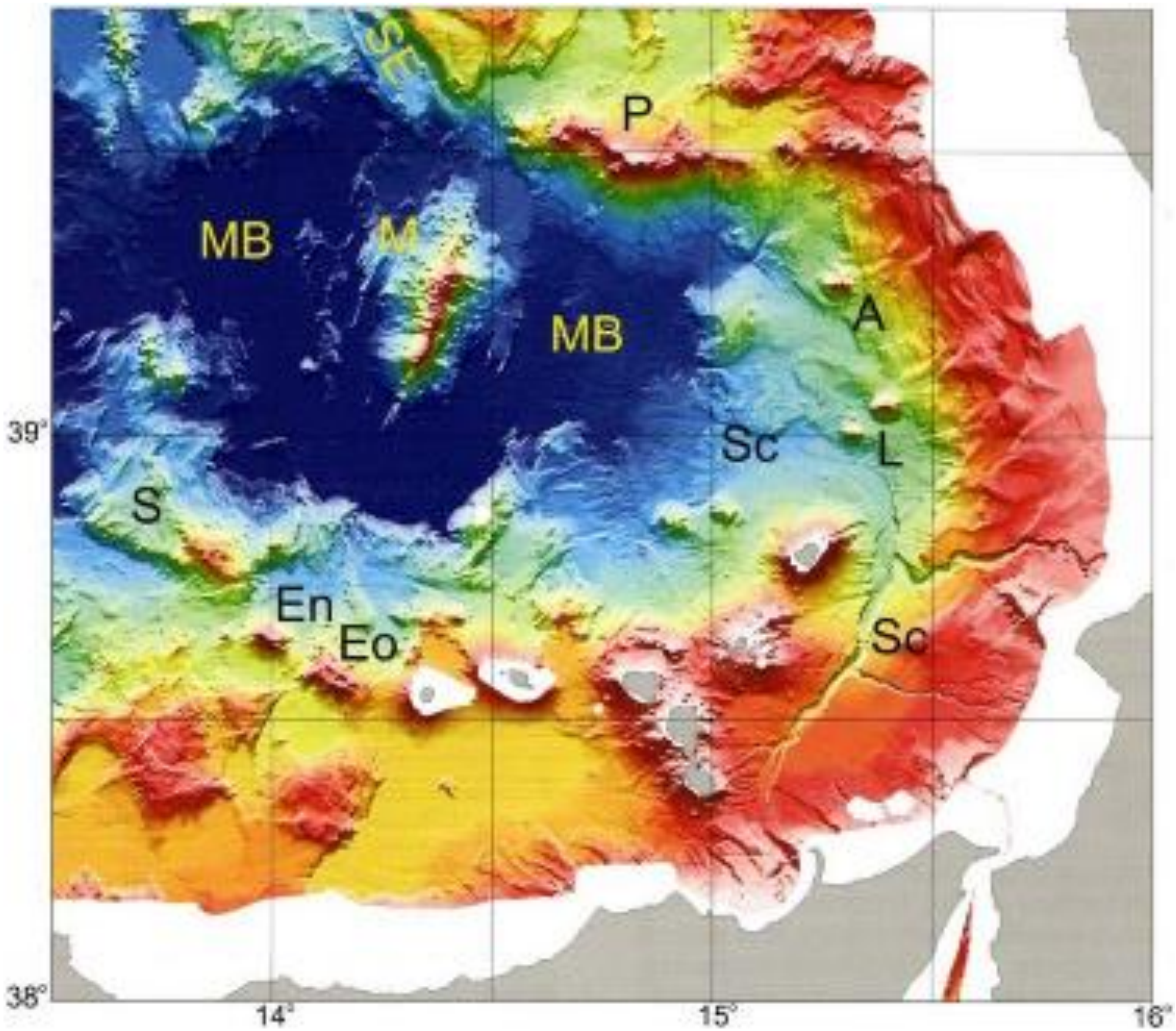
- **The tectonic framework of the eastern Mediterranean is dominated by the collision of the Arabian and African plates with Eurasia**

- **The sedimentary sequence reaches (in some places) a thickness of 12–14 km**

- **Data suggest the existence of oceanic crust under parts of the Levant Basin and continental crust under the Eratosthene Seamount**

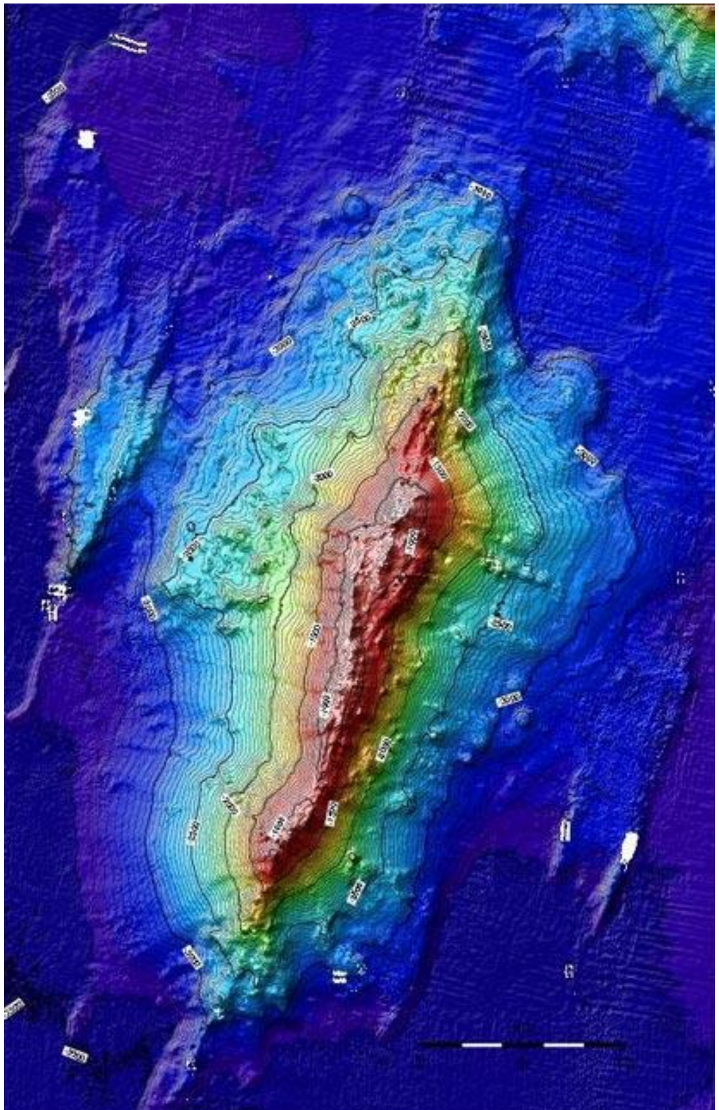
# Tyrrhenian Sea

# Tyrrhenian Sea bathymetry

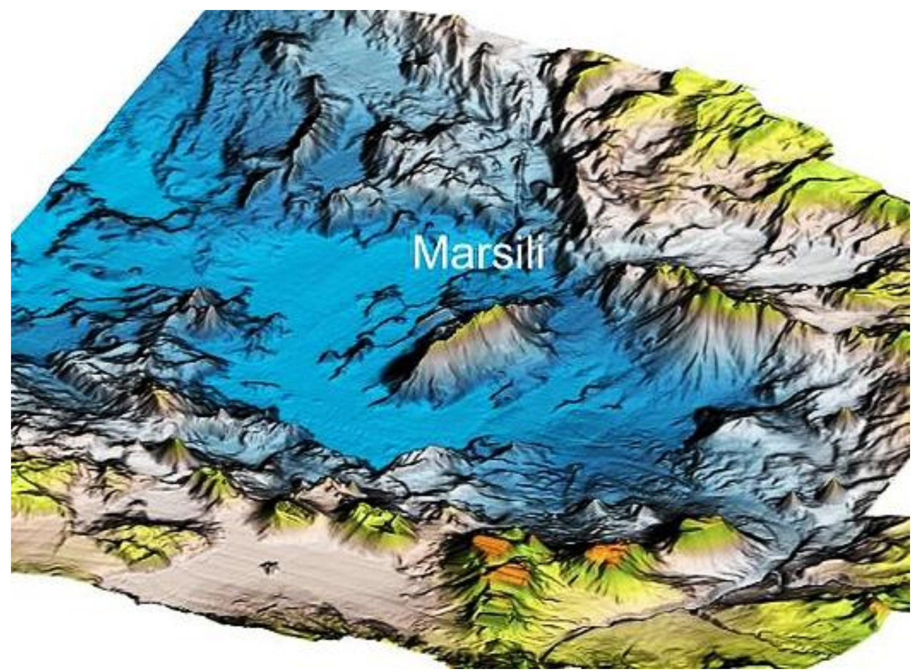


# Marsili volcano

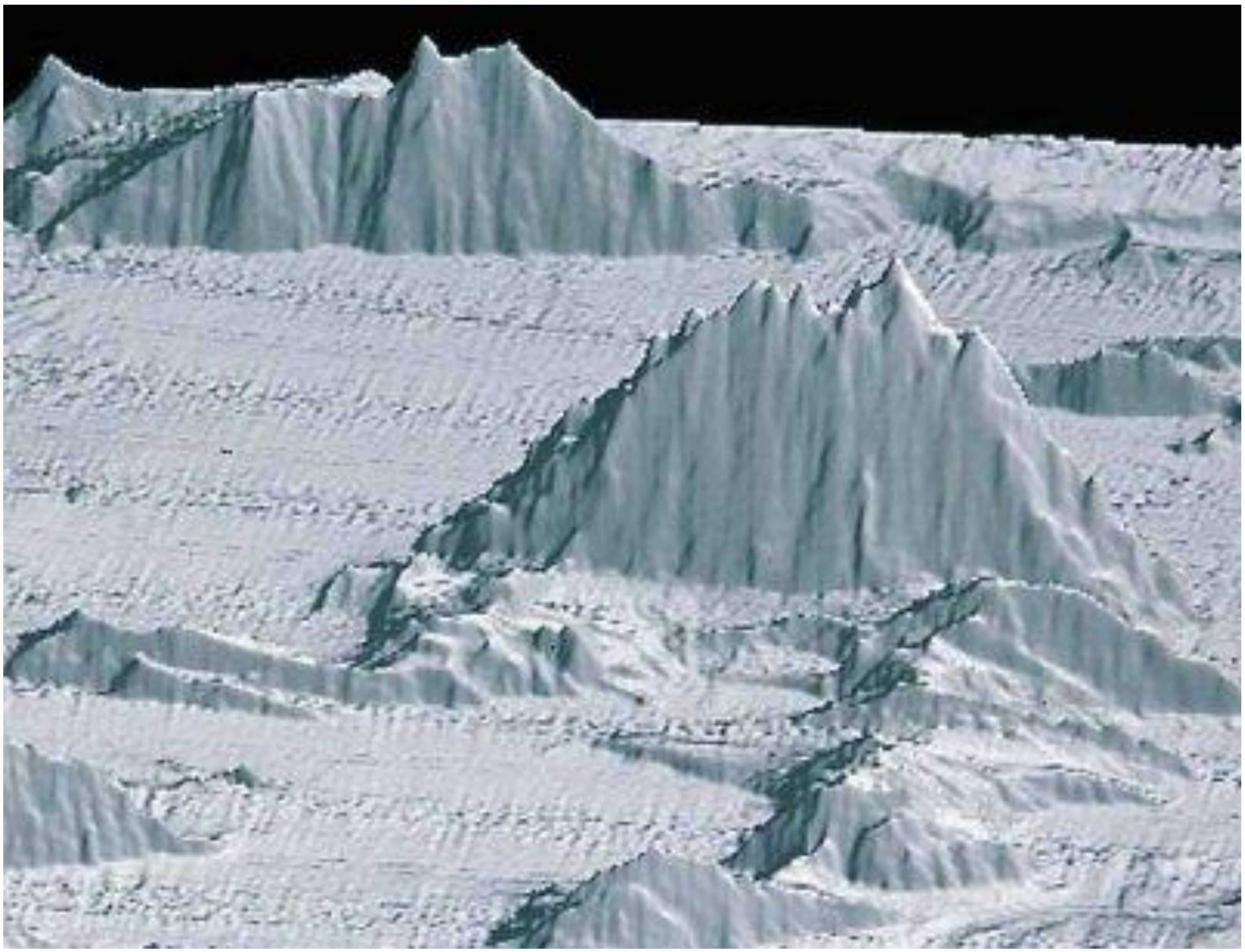
**The Marsili volcano is 70 km long and 30 km wide, one of the largest in Europe. Rises to about 3000 meters from the seabed, with the top reaching the altitude of about 450 m below the surface of the Tyrrhenian Sea**



K/Ar ages from the Marsili seamount suggest that the Marsili Basin opened at the remarkable full-spreading rate of ~19 cm/yr between ca. 1.6 and 2.1 Ma. This is the highest spreading rate ever documented, including that observed at the Cocos-Pacific plate boundary. Renewed but slow spreading during the Brunhes chron (after 0.78 Ma), coupled with huge magmatic inflation, gave rise to the Marsili volcano.



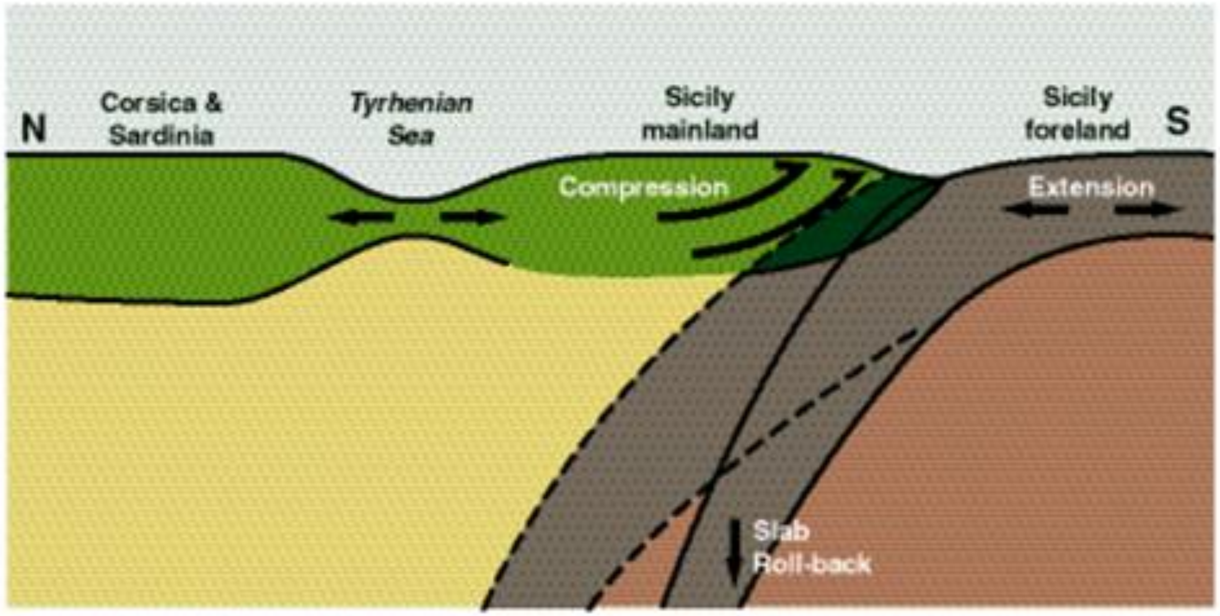
**It is an extinct volcano (33 km in length and 17 km in width), which rises to about 2700 m from the sea bed reaching a total of about 800 meters below the surface of the Tyrrhenian Sea. The base of the Vavilov is at depths ranging from 3500 m to 3200 m. A distinctive feature of the volcano is a strong asymmetry between the two sides, with a steep slope on the western side and a slight incline on the eastern side. Its origin is dated from 7.6 to 2 Ma**



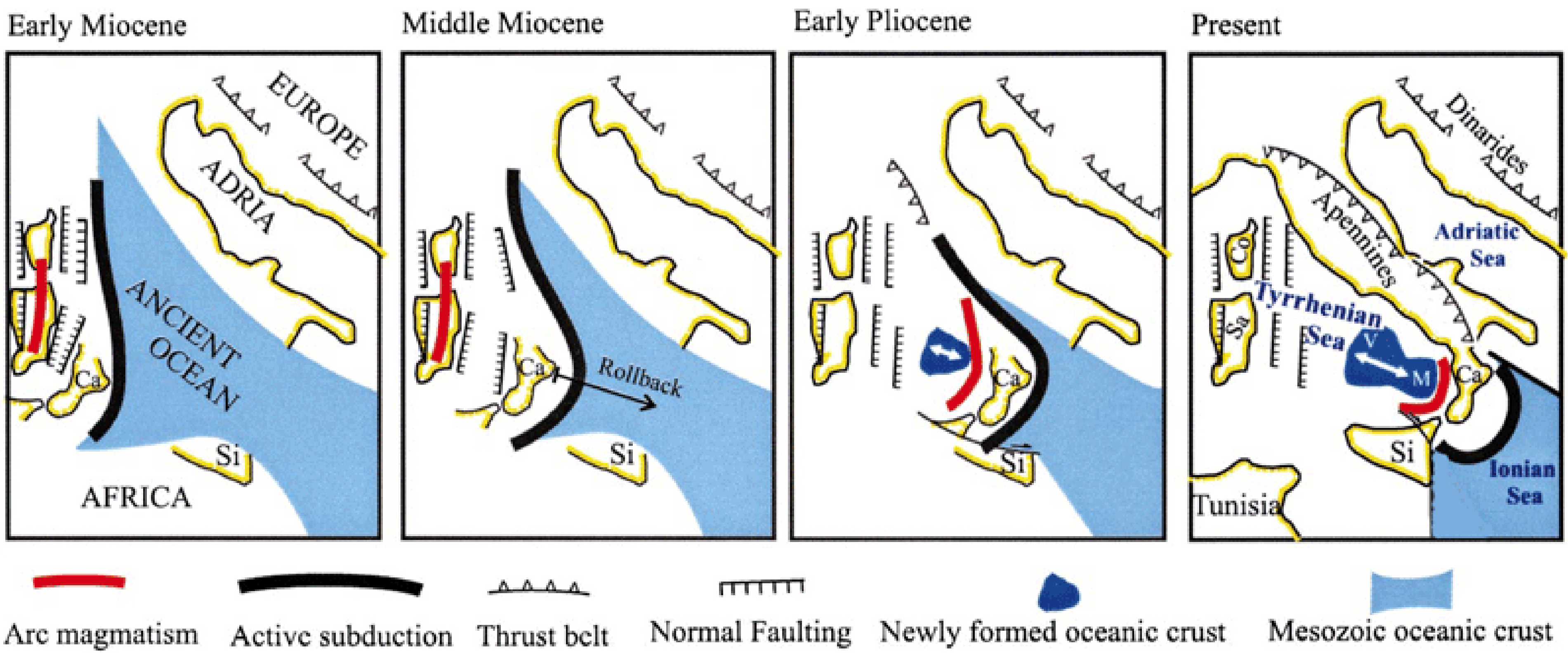
# Vavilov volcano

# Mechanisms for the Tyrrhenian opening

- Extension in the Tyrrhenian has been explained by a SE rollback of the subduction hinge. If the subduction hinge migrates, or "rolls back" faster than the plates converge, extension will take place in the overriding plate.
- Another mechanism proposed for the Tyrrhenian extension invokes the extensional collapse of a pre-existing orogenic belt.
- Rollback and orogenic collapse are often presented as alternatives, but in the Tyrrhenian region they acted together.

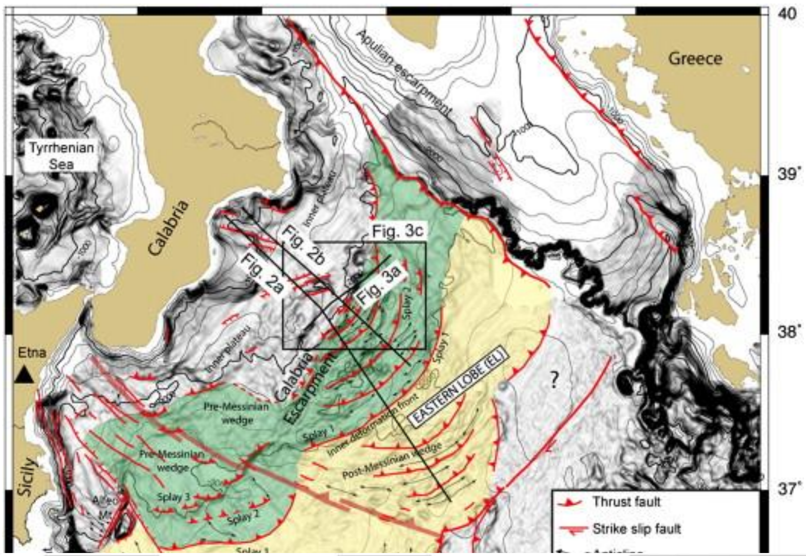


# Evolutionary tectonic model showing the opening of the Tyrrhenian Sea and the formation of the Calabrian Arc at four different stages

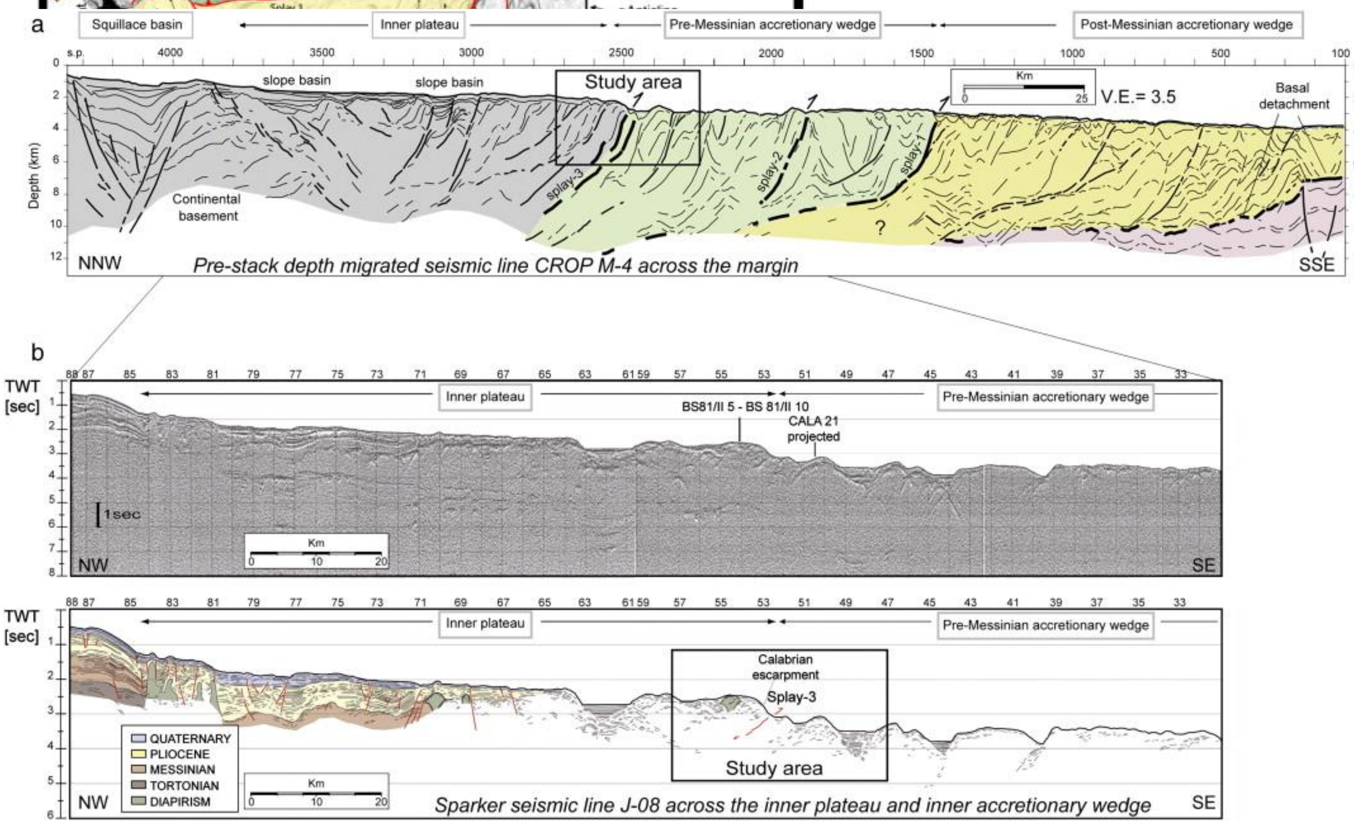



Sa - Sardinia; Si - Sicily; Ca - Calabria; Co - Corsica; V - Vavilov Basin; M - Marsili Basin

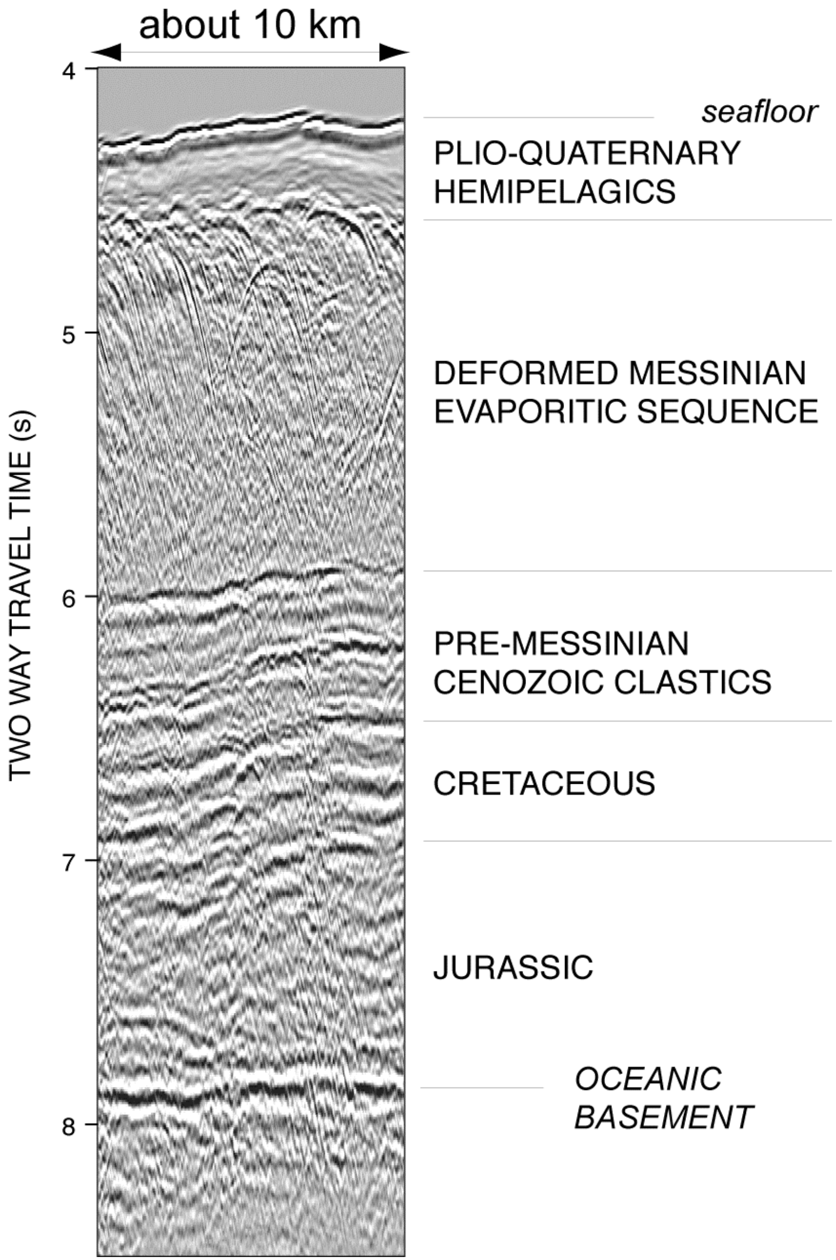
# Calabrian Arc




**Deformation is related to an imbricate fan within the post-Messinian salt-bearing accretionary wedge (yellow domain), out-of-sequence thrust faults in the pre-Messinian wedge (green domain) and normal faults in the Inner plateau (gray domain).**



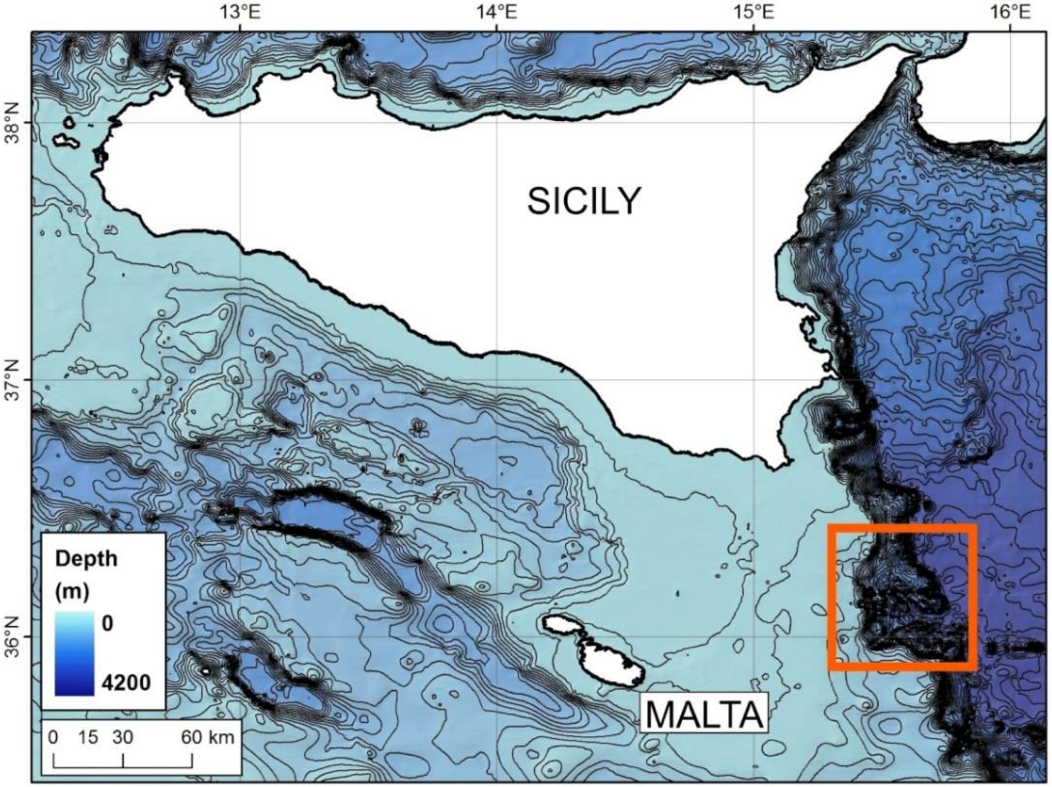
- The Tyrrhenian Sea is an extensional basin that formed in the last 10 Ma in the broad suture between the African and European plates. The convergent plate boundary is evident in the SE corner of the Tyrrhenian Sea, which contains a Benioff zone, a subducting slab imaged by seismic tomography, and the Aeolian islands Quaternary calc-alkaline volcanic arc.
- Backarc spreading of the Tyrrhenian Sea was episodic, with sudden rapid pulses punctuating relatively long periods of tectonic quiescence.
- Extension in the Tyrrhenian Sea took place at the same time as shortening in the arcuate Apenninic-Maghrebian thrust belt that surrounds the basin to the E and S. The maximum amount of extension is more than 300 km in a WNW-ESE direction between Sardinia and Calabria, and is matched by a similar amount of shortening in the Southern Apennines.
- Africa and Europe converged by only about 80 km in a NW-SE direction in the last 10 Ma.
- During the Tyrrhenian opening, the Apenninic deformation front migrated to the E and S and the sedimentary covers of the Adria and African margin were progressively incorporated in the orogenic wedge to form the southern Apennines and the Sicilian Maghrebides. Most of the shortening in the southern Apennines took place after 10 Ma, at the same time as extension in the Tyrrhenian basin. The deformation front moved the farthest to the southeast toward the subducting Ionian oceanic seaway. Sediments accreted or underplated from the Ionian basin formed a large accretionary wedge to the SE of Calabria.
- Extension rates averaged over the last 10 Ma are 40-50 km/Ma. If the Tyrrhenian started forming 10 Ma, this gives an average extension rate of 37 km/Ma, which matches the averages estimated by other authors.
- GPS data show that Calabria is not presently moving to the SE with respect to Sardinia, suggesting that extension in the Tyrrhenian domain is not active at present.

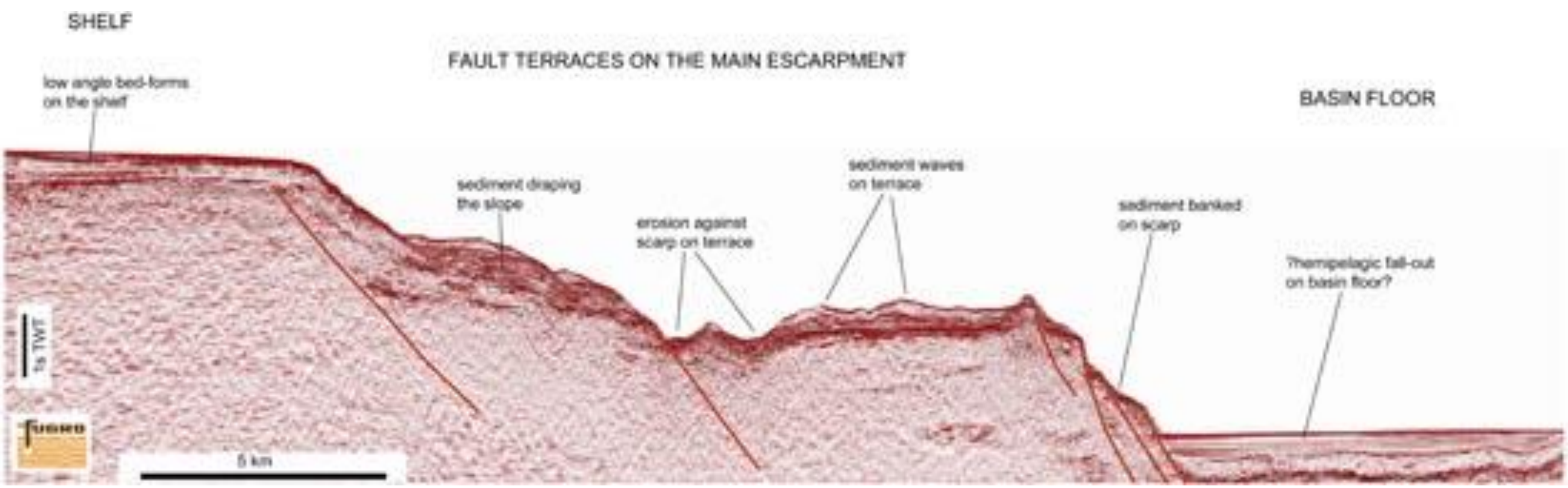



# Ionian Sea

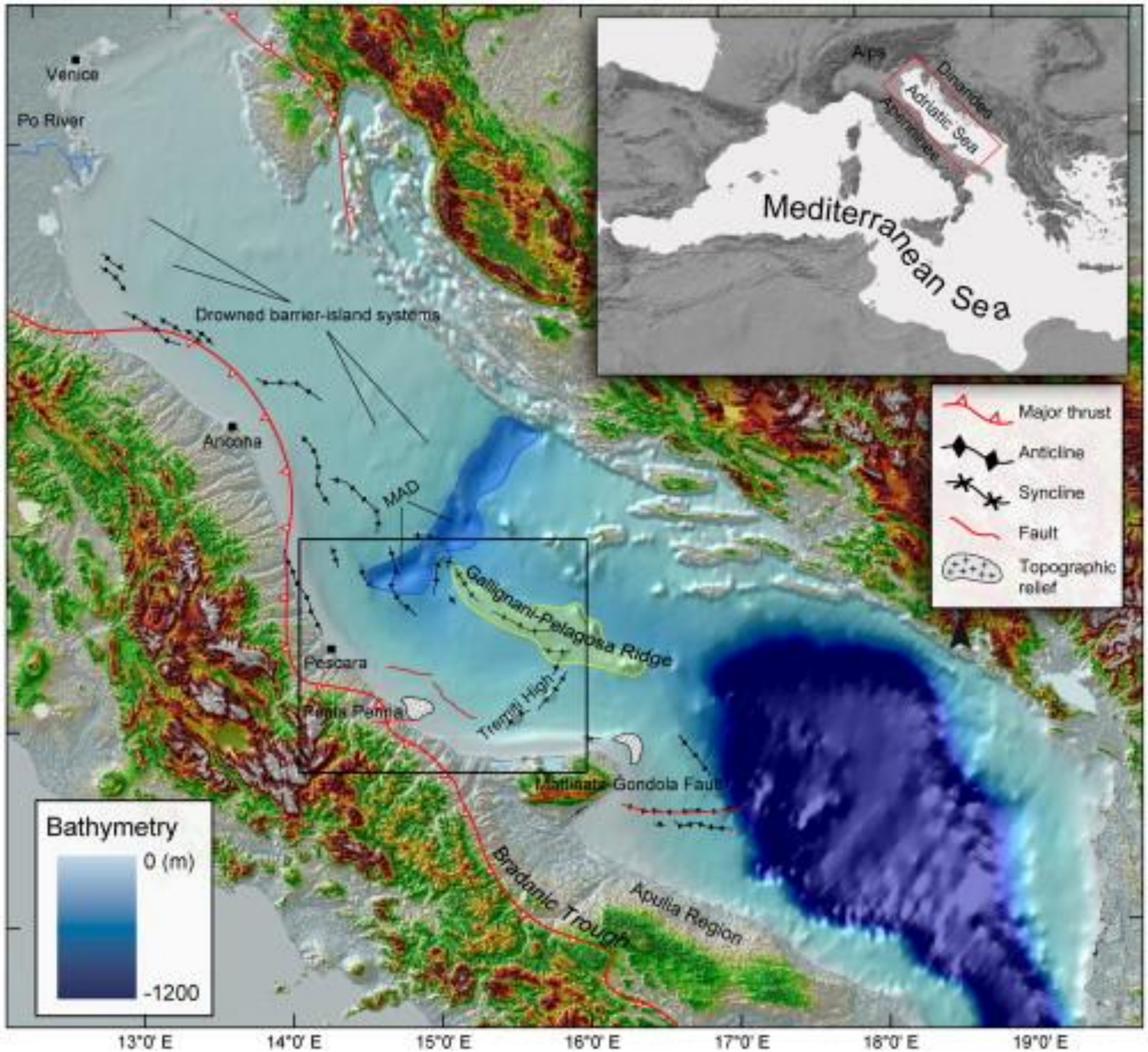
- **As the last non-subducted sector of the Neo-Tethys ocean, the Ionian Sea turns out to be the oldest *in situ* ocean fragment of the world.**
- **It has been saved from subduction since locked within irregular S shaped continental margins of Africa and Eurasia.**
- **It is a 350 km wide x 600 km long abyssal plain lying at 3–4 km depth, locked between the continental platforms of northern Africa, Malta-Hyblean plateau, and Apulia, and active orogens of Calabria Arc and Hellenides.**
- **A thick package (5–7 km) of sediments overlying an extremely thin (8–11 km) crystalline crust.**

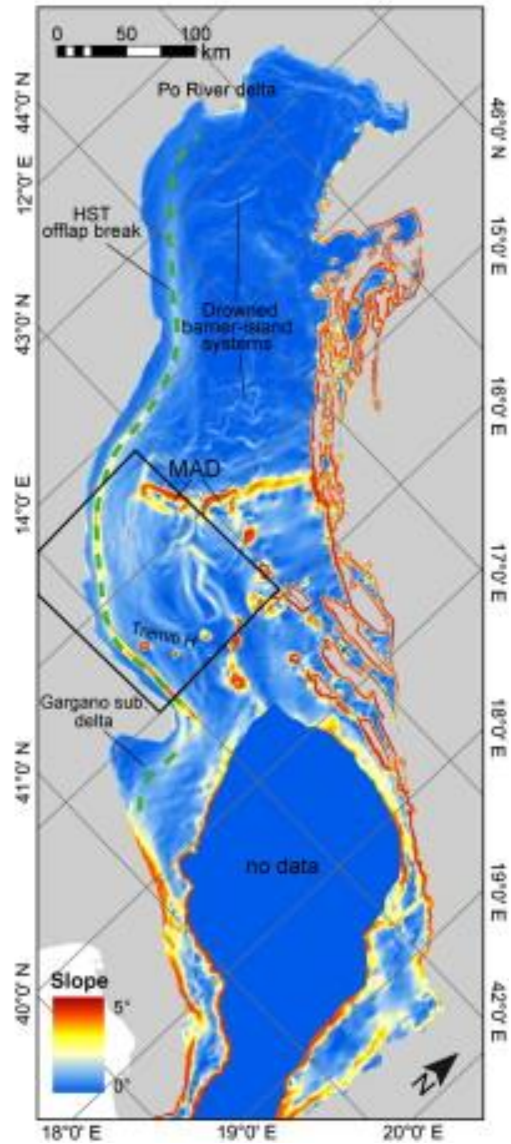
# Malta Escarpment



# Adriatic Sea



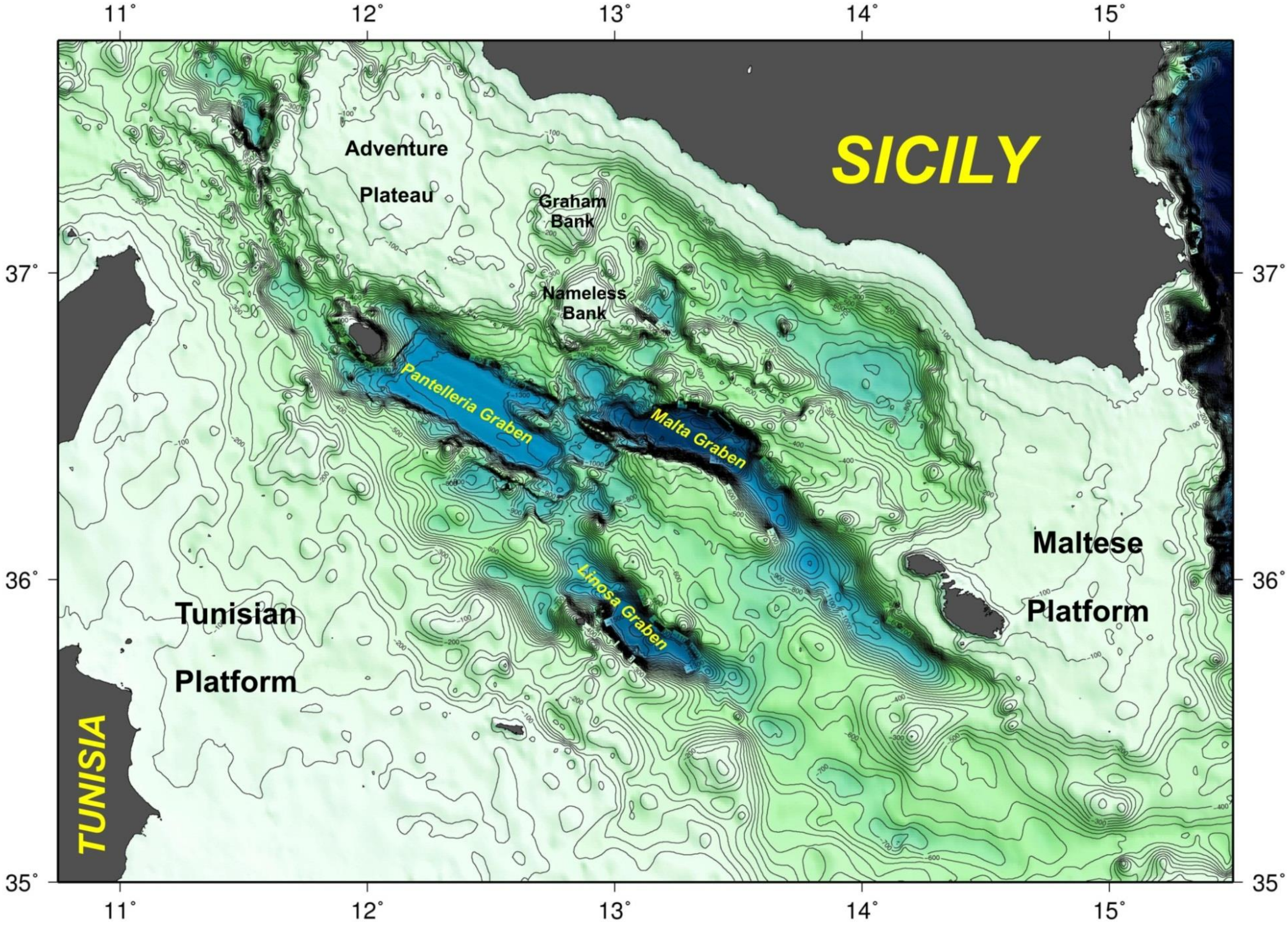



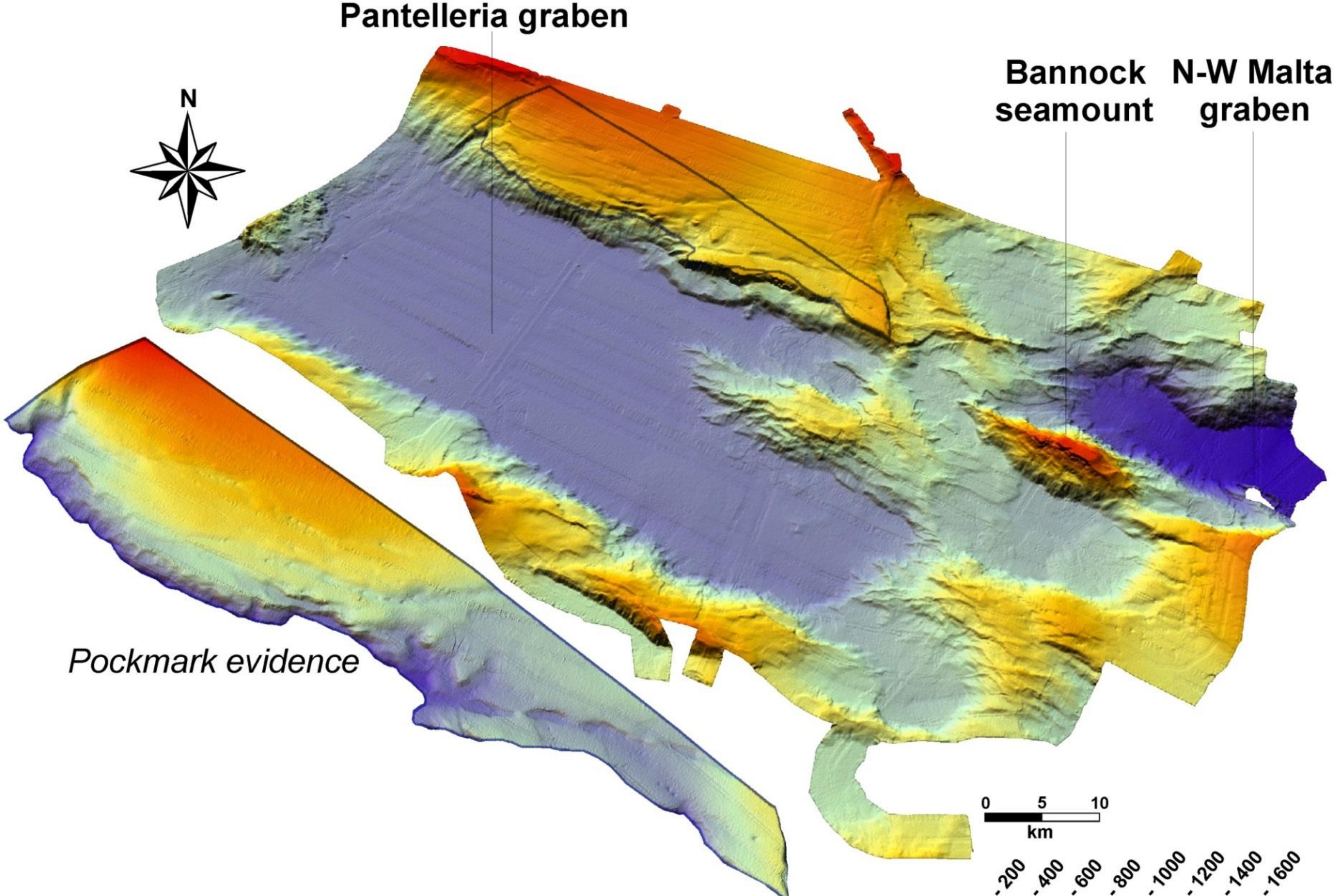
- **The Adriatic Sea and the Po Valley are associated with a tectonic microplate - Apulian or Adriatic Plate - that separated from the African Plate during the Mesozoic. This separation began in the Middle and Late Triassic, when limestone began to be deposited in the area. Between the Norian and Late Cretaceous, the Adriatic and Apulia Carbonate Platforms formed as a thick series of carbonate sediments (dolomites and limestones), up to 8 km thick. In the Eocene and early Oligocene, the plate moved north and north-east, contributing to the Alpine orogeny (along with the African and Eurasian Plates' movements) via the tectonic uplift of the Dinarides and Alps. In the Late Oligocene, the motion was reversed and the Apennine Mountains' orogeny took place.**

- **The Adriatic Basin was formed by the subsidence of the pre-existing foreland region into a basin (present since Pliocene time) and the subsequent eastward-thrusting movements of the Apennine mountain chain toward and into the western part of this Adriatic Pliocene basin.**

- **The most important structural elements are the Apennine overthrust chain in the west, the Dinarides overthrust chain in the east. The Adriatic Sea which is in the middle is being squeezed on both sides by both overthrust areas. The Adriatic comprises the folded foredeep region just to the east of the Apennines which have significantly folded and compressed the section and the central foreland or carbonate high region which runs roughly down the center of the Adriatic Sea from the east in the northern region offshore Croatia, to the west of the Adriatic in the south near the heel of Italy. This foreland region effectively splits the Adriatic basins into two main areas.**

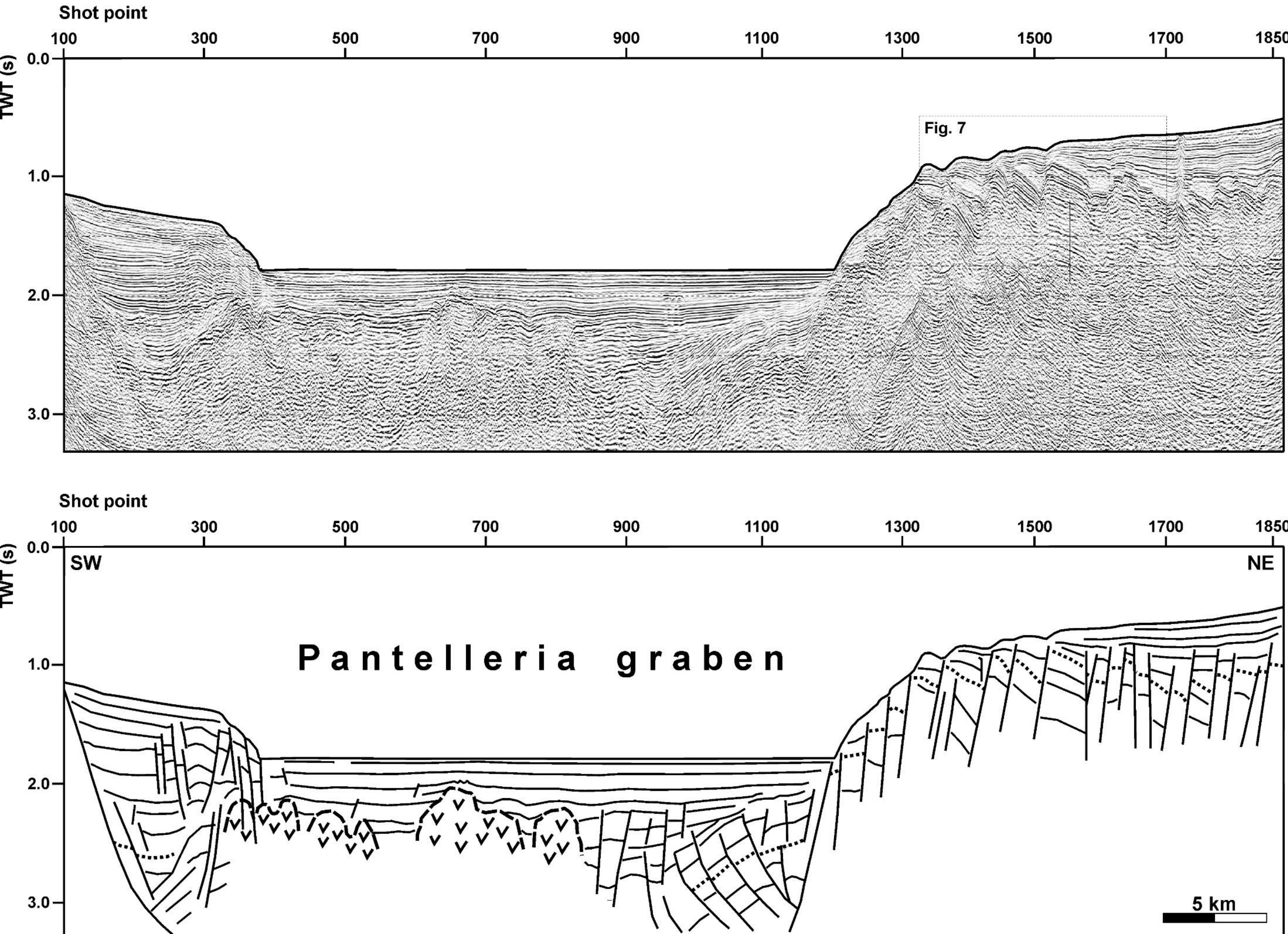
# SICILIAN CHANNEL





Pantelleria graben
N
Bannock
seamount
N-W Malta
graben
Pockmark evidence
0
5
10
km
-200
-400
-600
-800
-1000
-1200
-1400
-1600
Depth (m)

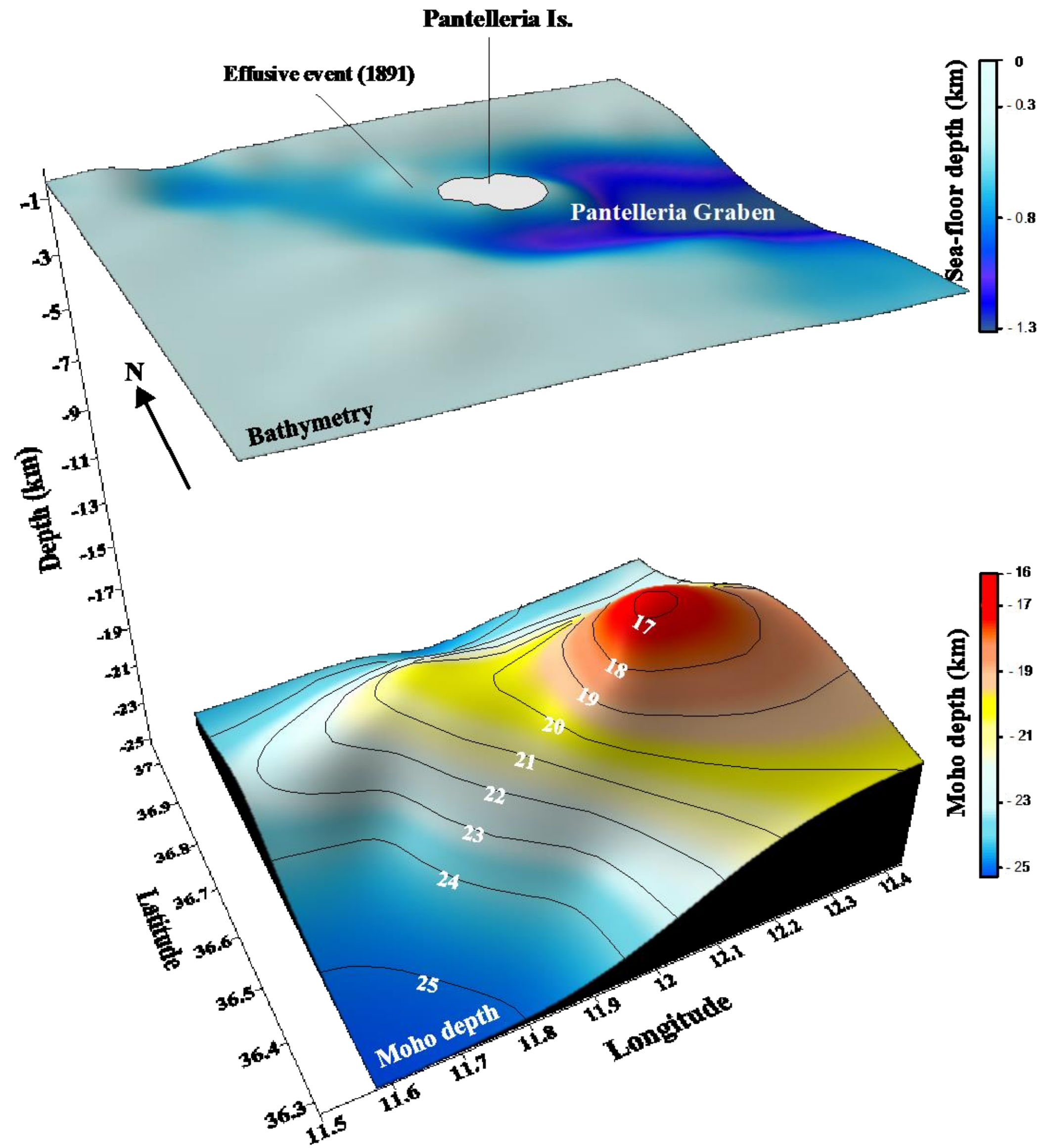
PANT - 3


Shot point
100
300
500
700
900
1100
1300
1500
1700
1850
TWT (s)
0.0
1.0
2.0
3.0
Fig. 7
Shot point
100
300
500
700
900
1100
1300
1500
1700
1850
TWT (s)
0.0
1.0
2.0
3.0
SW
NE
Pantelleria graben
5 km

# Montagna Grande


# Lago di Venere

# 3-D Moho depth geometry beneath the Pantelleria Island



# Ferdinandea Is.

Emersion: July, 1831
(4 sqkm, 65 m high)
Disappeared: December, 1831

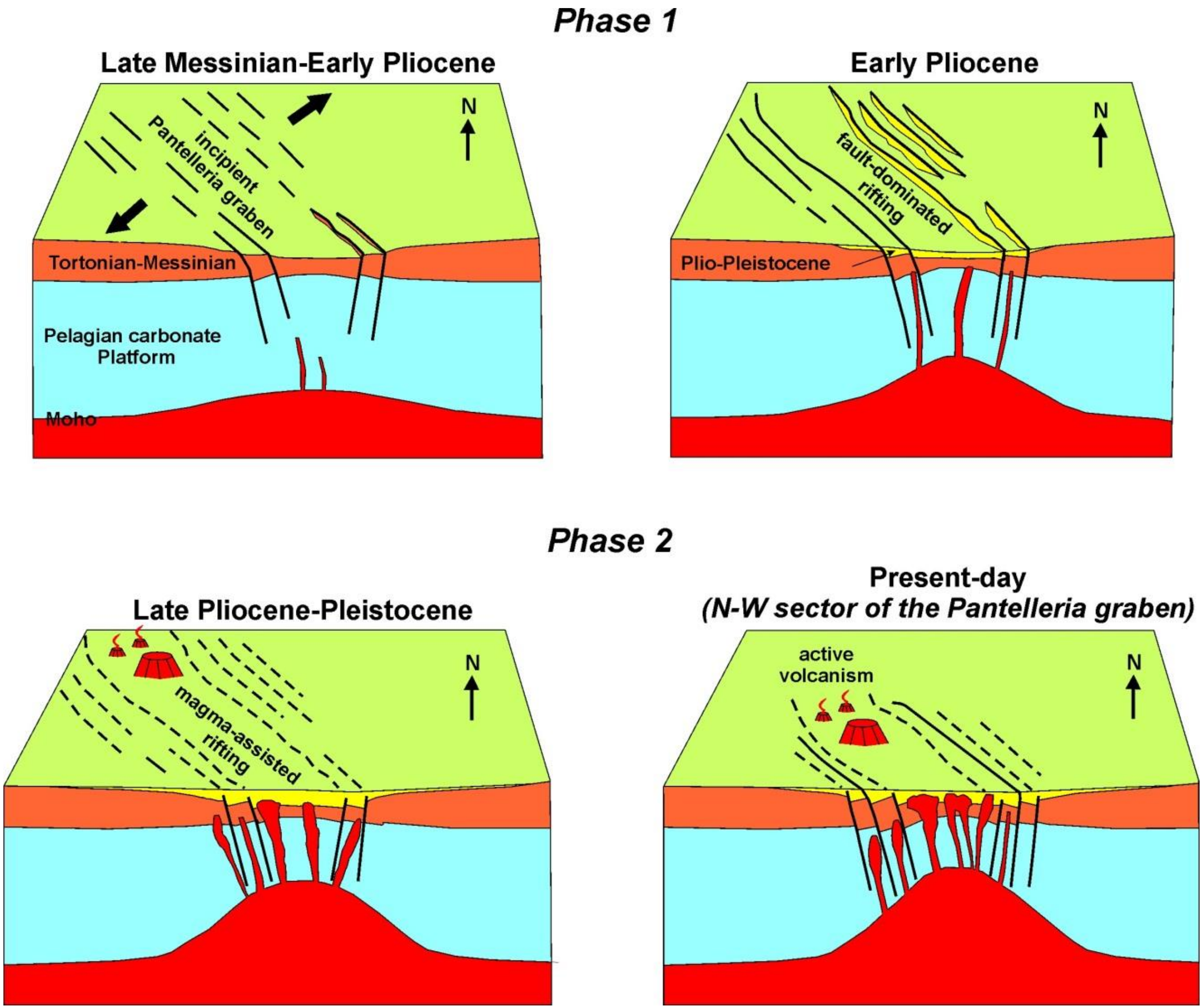


**Claimed by:**
**UK, FRANCE, REGNO DUE SICILIE**

# Surtsey Island

**(emerged on 1963)**

# Pantelleria Graben development

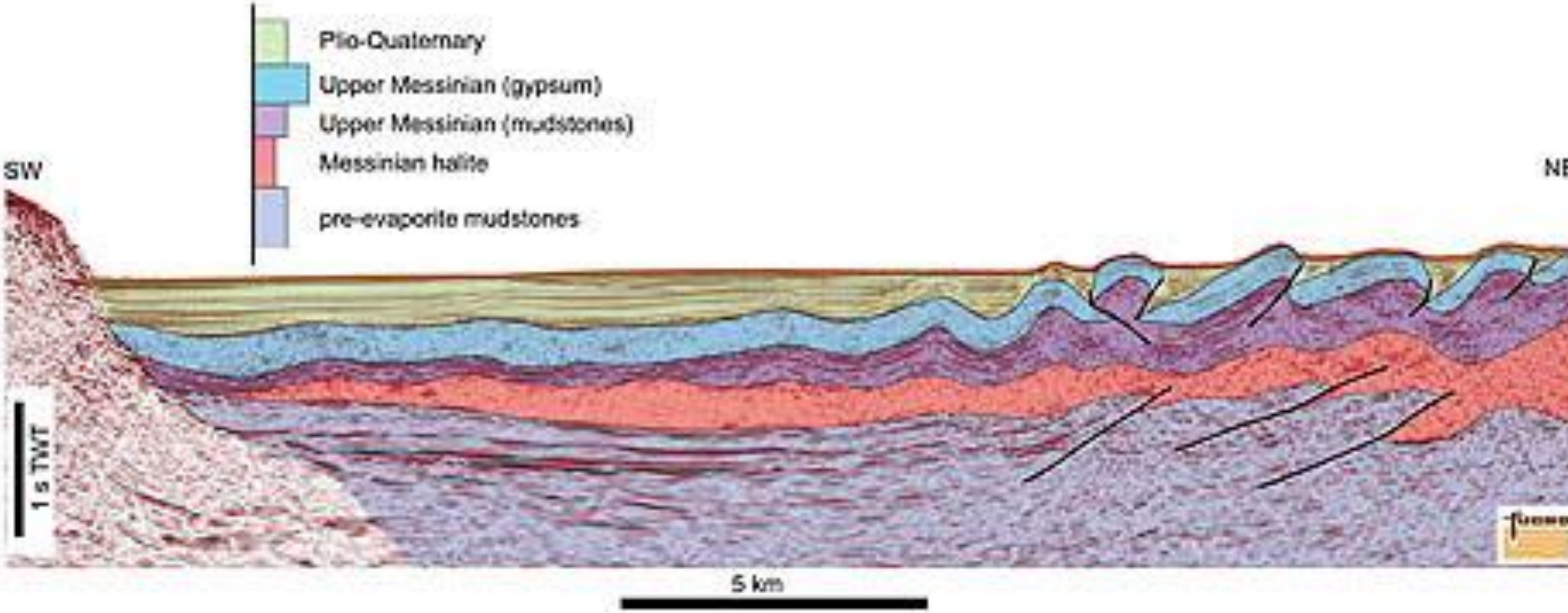


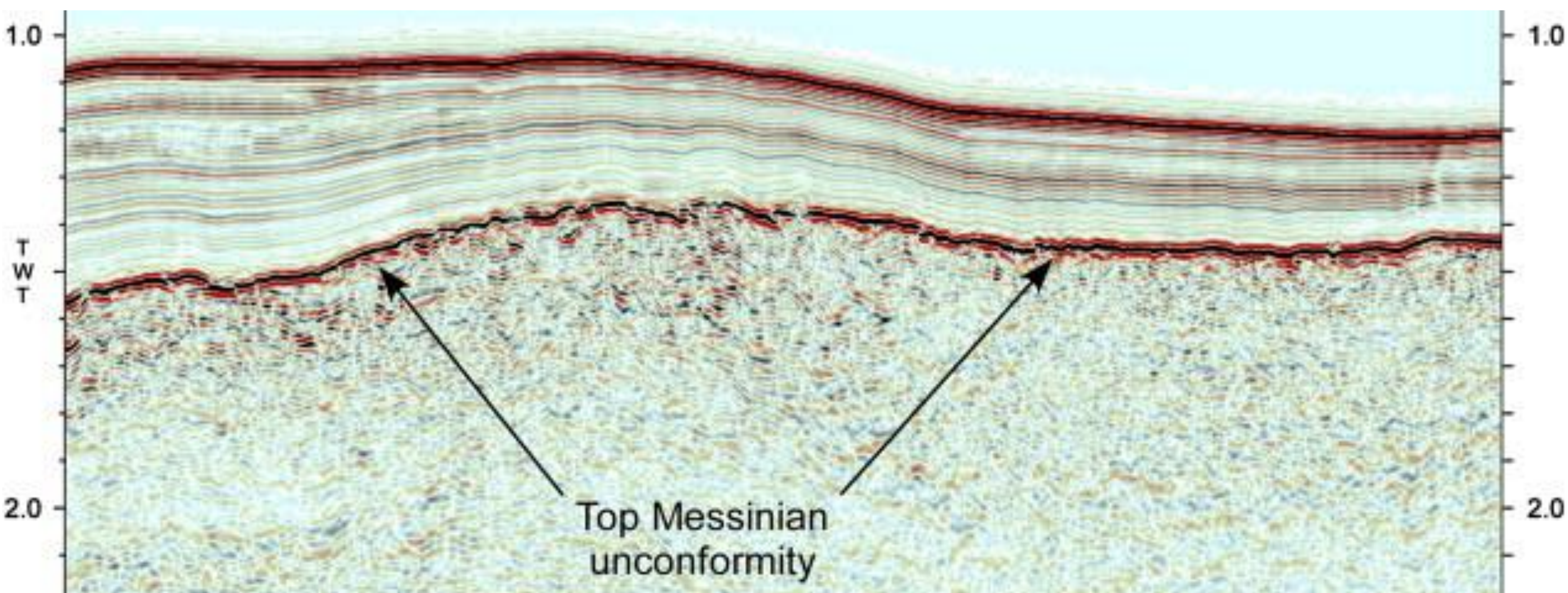
- **The Sicily Channel is a shallow-water platform located in the northern part of the African continental plate. It consists of a 6-7 km thick Meso-Cenozoic, shallow-water to deep-water carbonate succession, with intercalated volcanic rocks, and covered by Upper Tortonian-Lower Messinian silicilastic deposits.**

- **The Sicily Channel is cut through by three main, NW-trending, elongated depressions (Pantelleria, Malta and Linosa graben) formed by continental rift-related processes initiated since Late Miocene-Early Pliocene. Continental rifting is controlled by sub-vertical normal faults. These troughs, where water depths range from 1300 to more than 1700 m, are filled by Lower Pliocene-Pleistocene turbidites.**

- **Widespread volcanic activity accompanied the rifting process in the Sicily Channel. Volcanism is mainly concentrated on the islands of Pantelleria and Linosa, but a series of submarine magmatic manifestations have been identified in the Adventure Plateau, Graham and Nameless banks. The volcanic products consist mainly of alkali basalts and hawaiites, similar to that found in continental rift areas. The volcanism took place substantially during the Plio-Pleistocene, although some manifestations have occurred up to historical time, with the ephemeral emergence of the Ferdinandea Island in the Graham Bank (A.D. 1831), and the submarine eruption (Foerstner 'volcano') occurred about 5 km N-W of Pantelleria (A.D. 1891).**

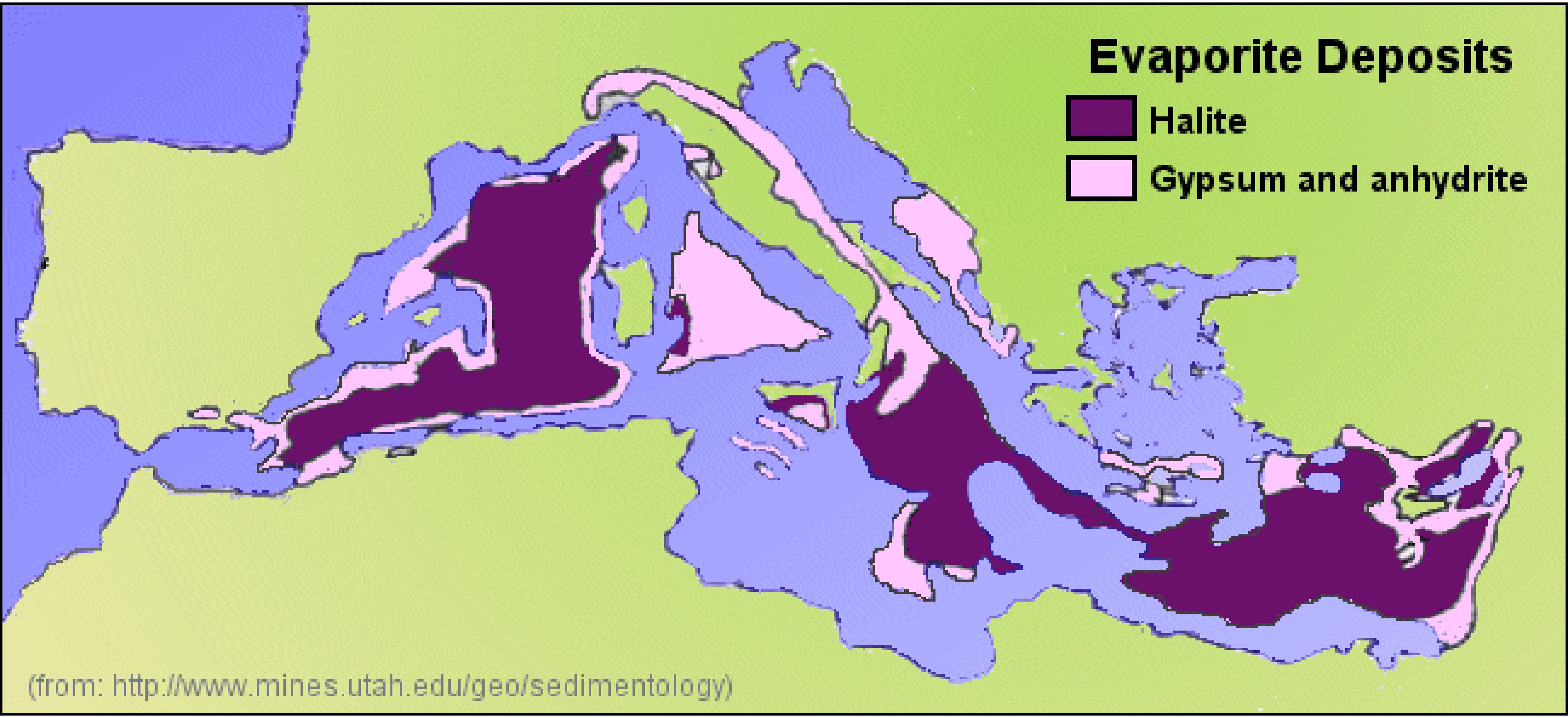

DSDP Leg 13
August-October, 1970


Plio-Quaternary
Upper Messinian (gypsum)
Upper Messinian (mudstones)
Messinian halite
pre-evaporite mudstones
SW
NE
1 s TWT
5 km

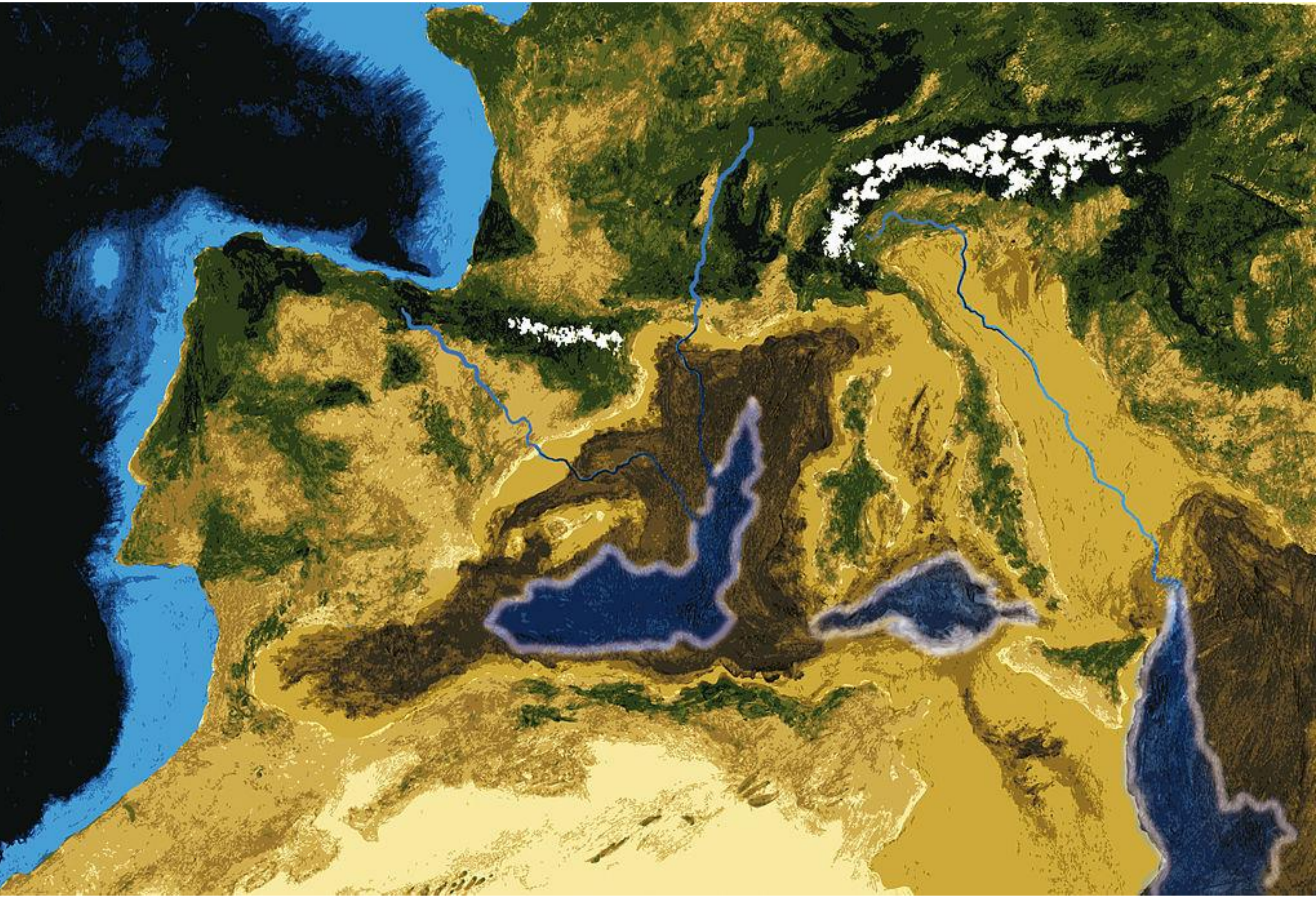

1.0
1.0
T
W
T
2.0
2.0
Top Messinian
unconformity

# MIOCENE SALINITY CRISIS

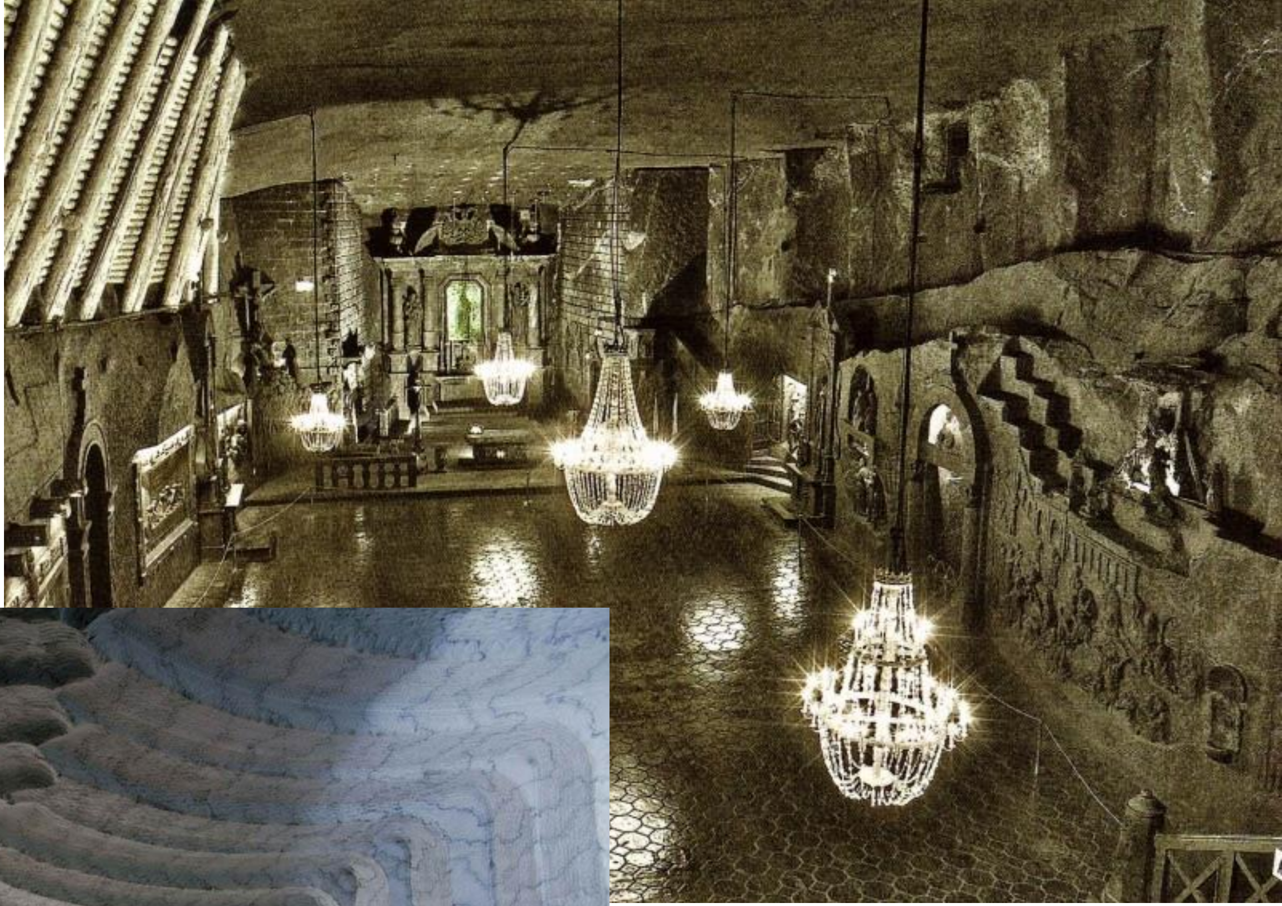
## Miocene Sup. (5.9 - 5.3 Ma)



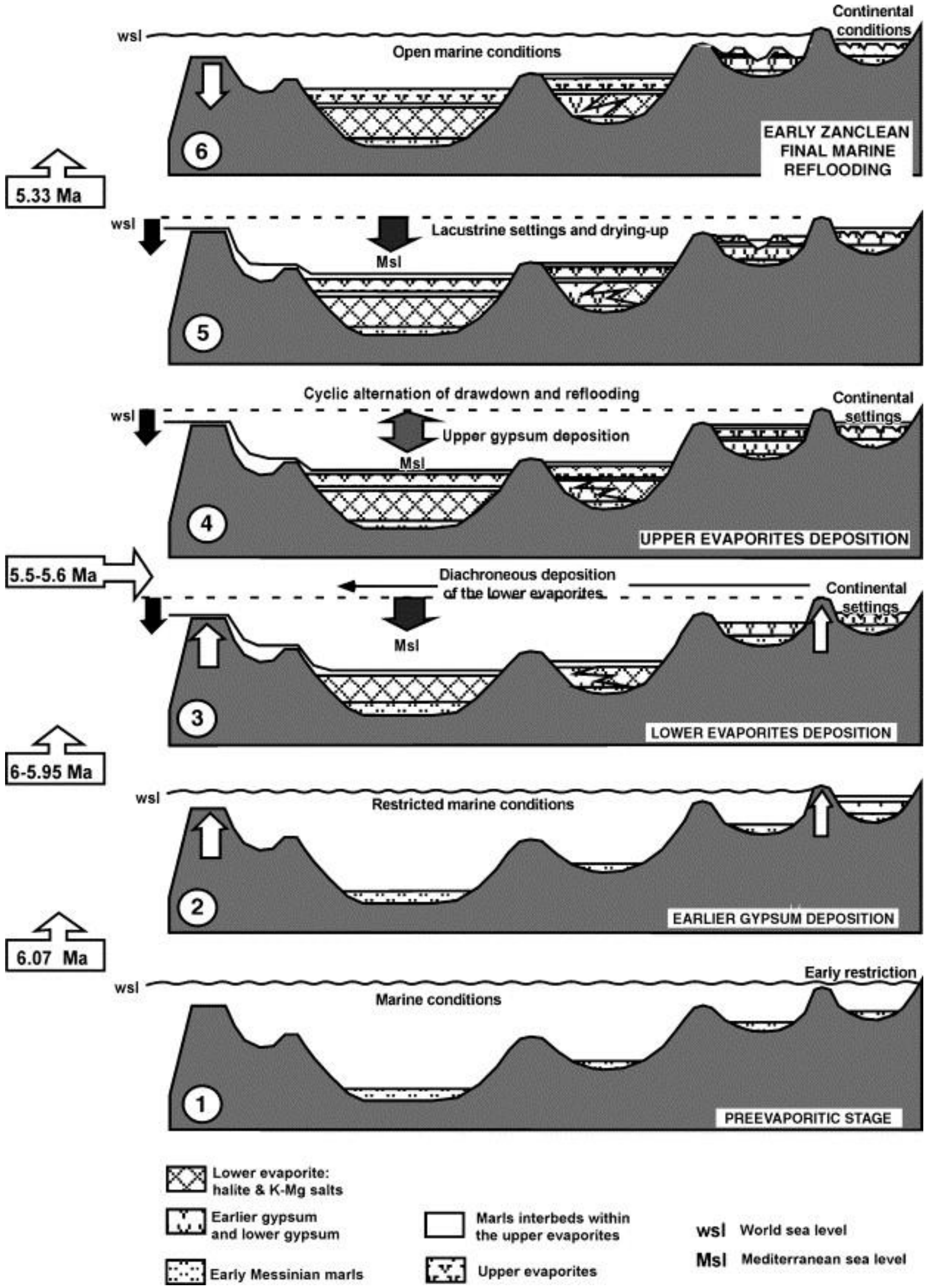
# Messinian paleogeography

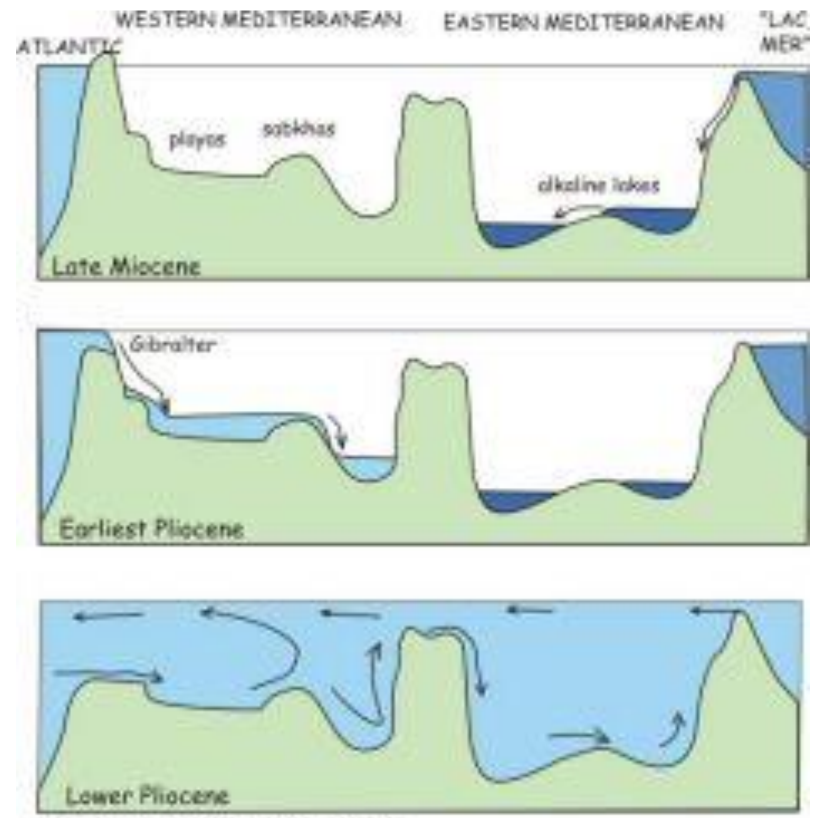


# Salt mines in Sicily



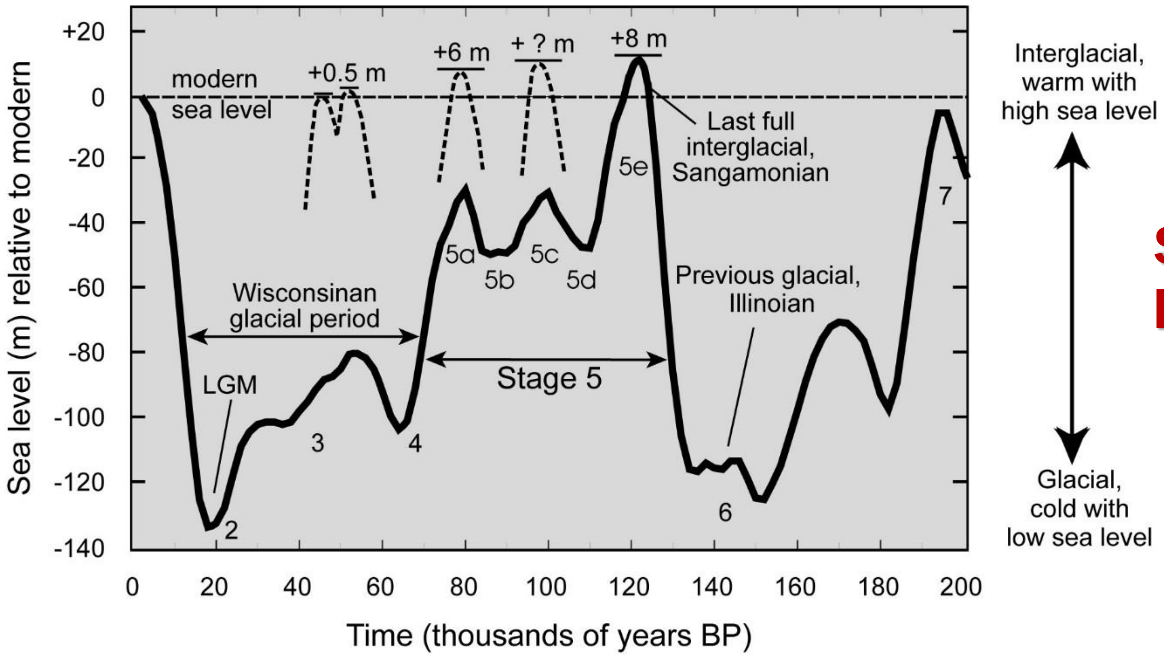
# Summary of the sedimentary and hydrological changes that occurred in the Mediterranean during the Messinian



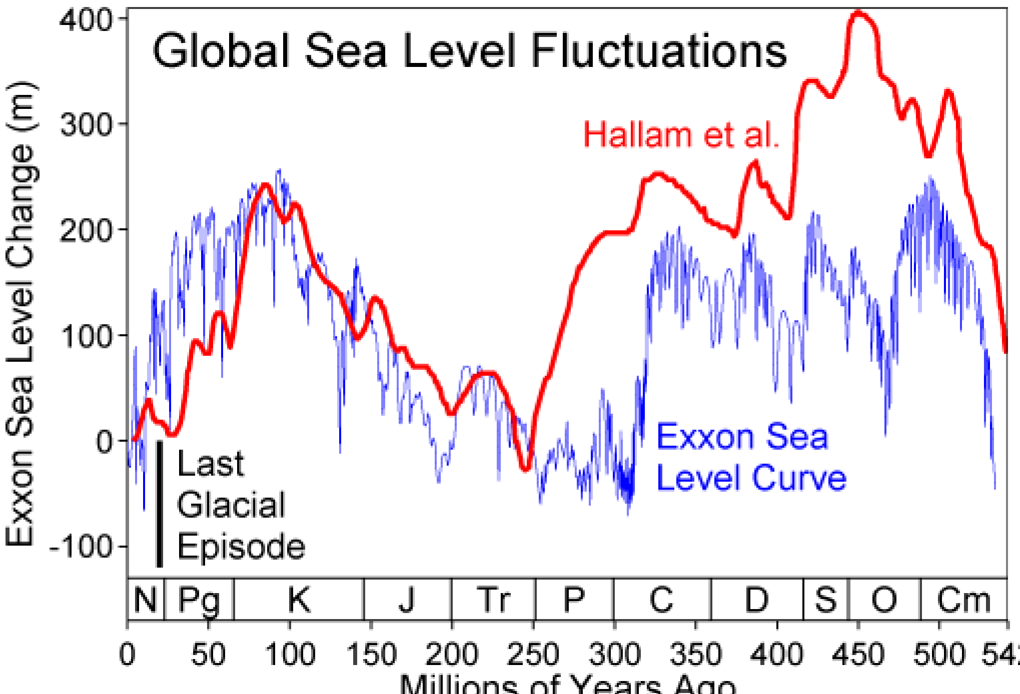

Hsu, Cita and others: late 1970s

## Artistic interpretation of the flood theorized to have refilled the Mediterranean Sea 5.33 million years ago (Zanclean flood) through the present-day Gibraltar Strait (discharge of about 1000 times the modern Amazon River)



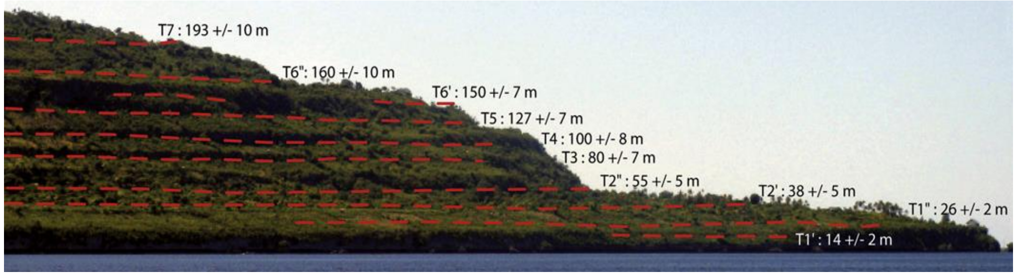

**Sea-level change in the last 200,000 yr**

**Sea-level change in the last 500 million years**

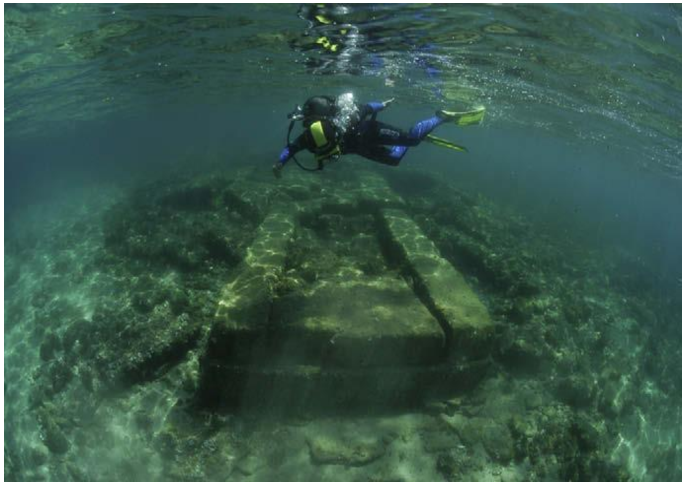


# PAST SEA-LEVEL RECONSTRUCTIONS

## Emerged and near-the-coast areas




- Marine terraces
- Tidal and submerged notches
- Coral reef terraces
- Submerged speleothems
- Core analyses
- Archaeological remains
- ecc…

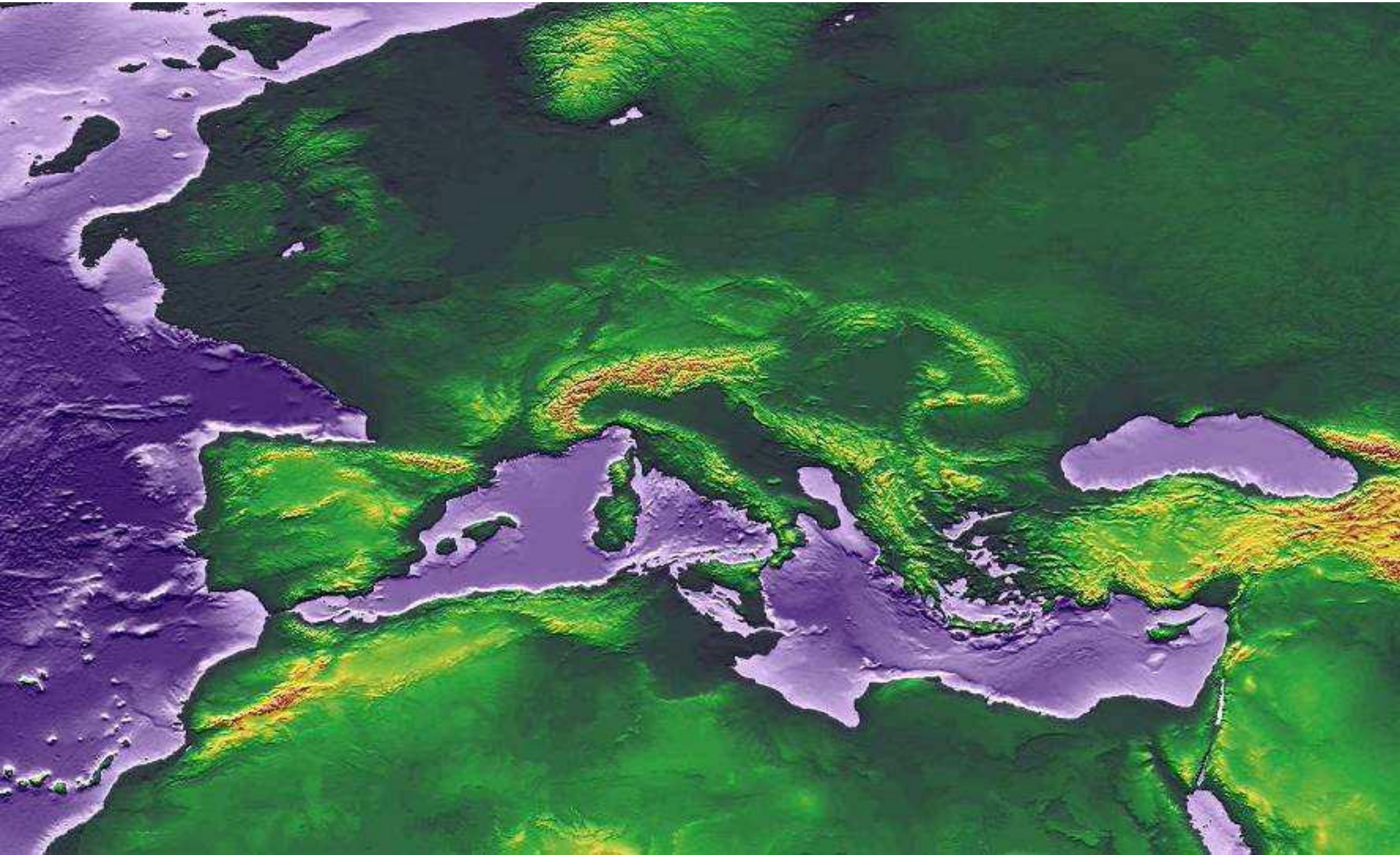


## Submerged landscape areas (prehistoric sites)

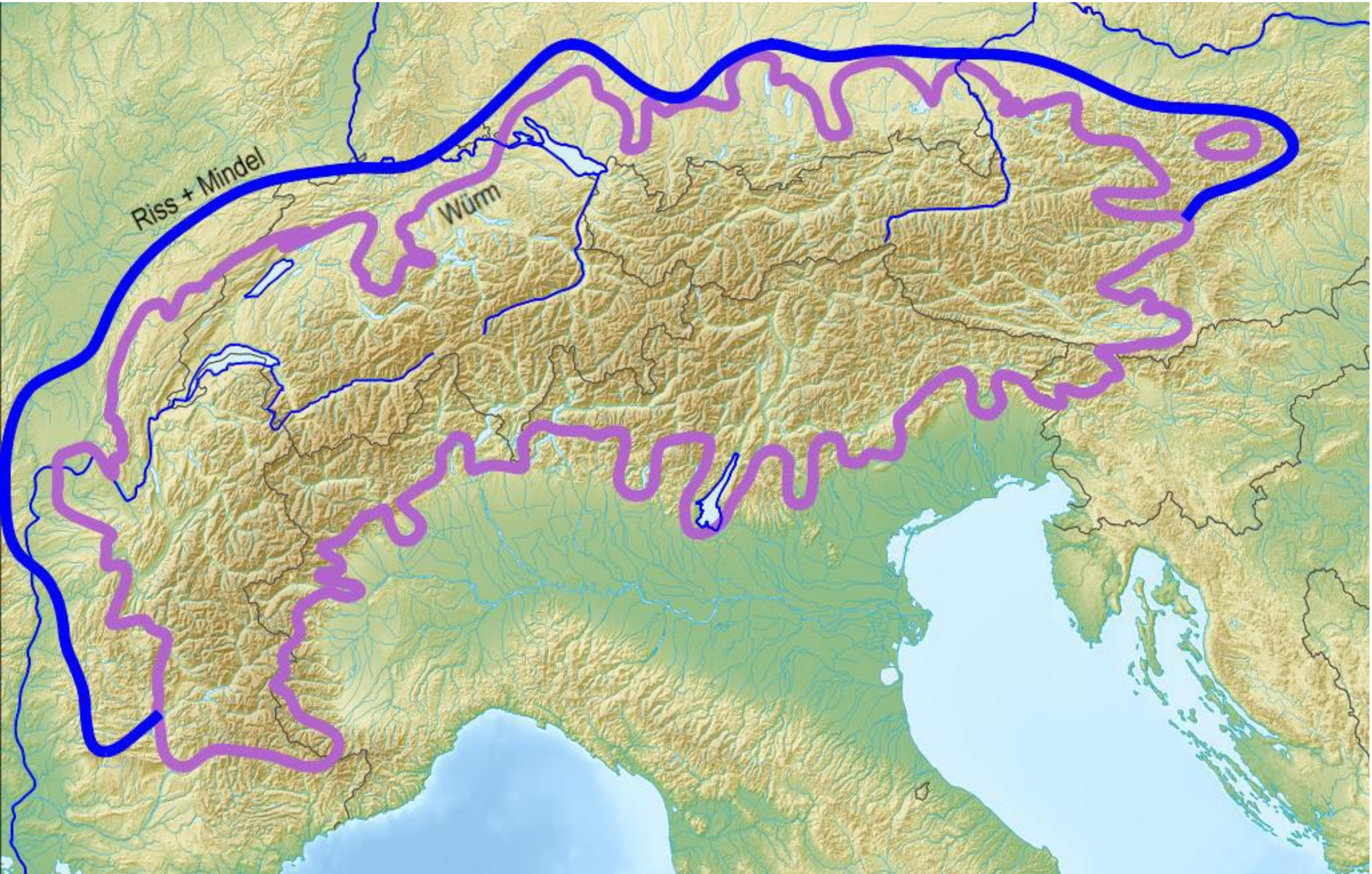
In shelf areas (shallower than 100 m) far from the coast, the reconstructions of ancient sea-level are much more difficult, because the geomorphological markers are often covered by a more or less thick sedimentary layer, and adequate geophysical data are scarce

# The Northern Hemisphere at LGM

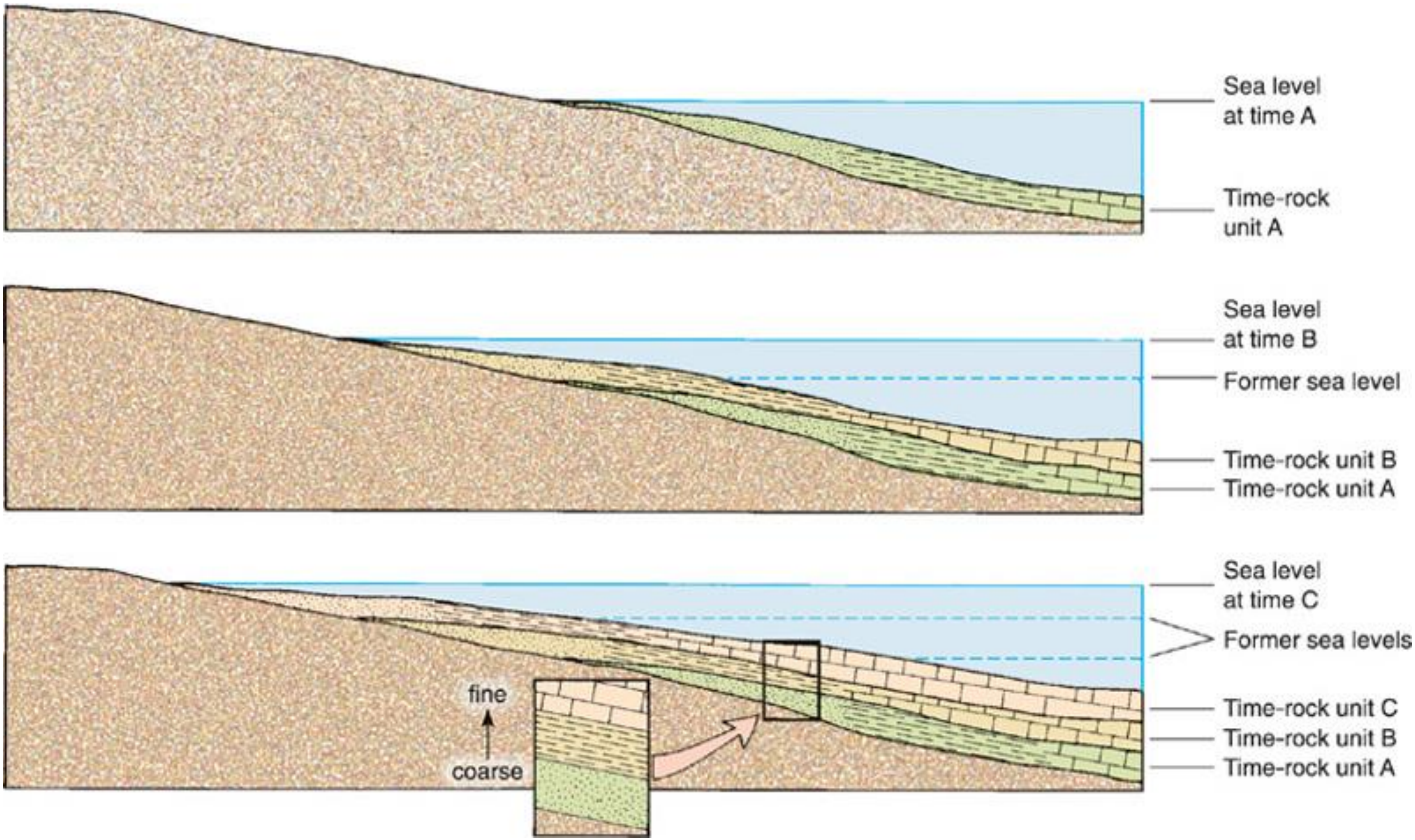
# European and Mediterranean coastlines at about 18,000 yr BP (LGM)



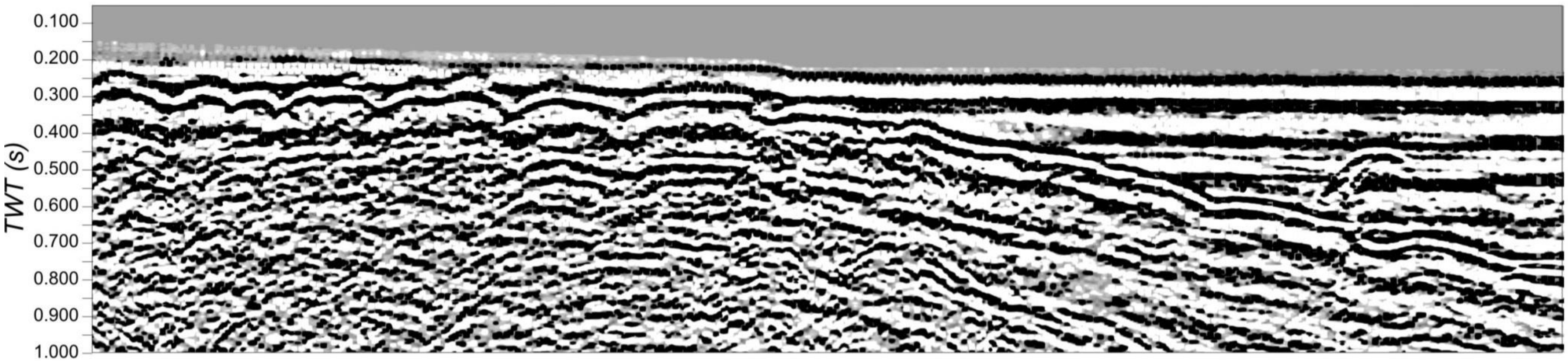
# Maximum ice extent in the Alps during the LGM

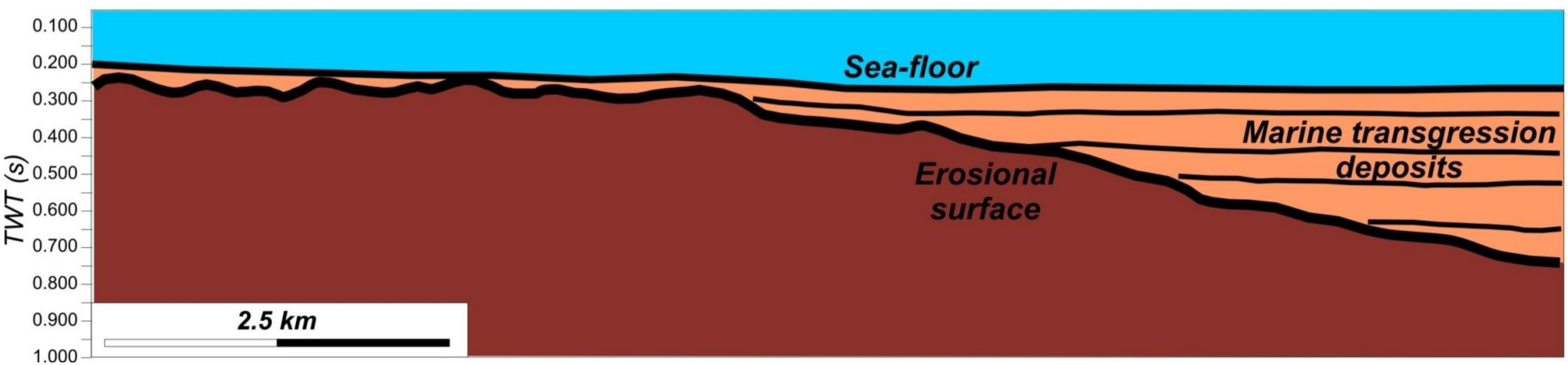


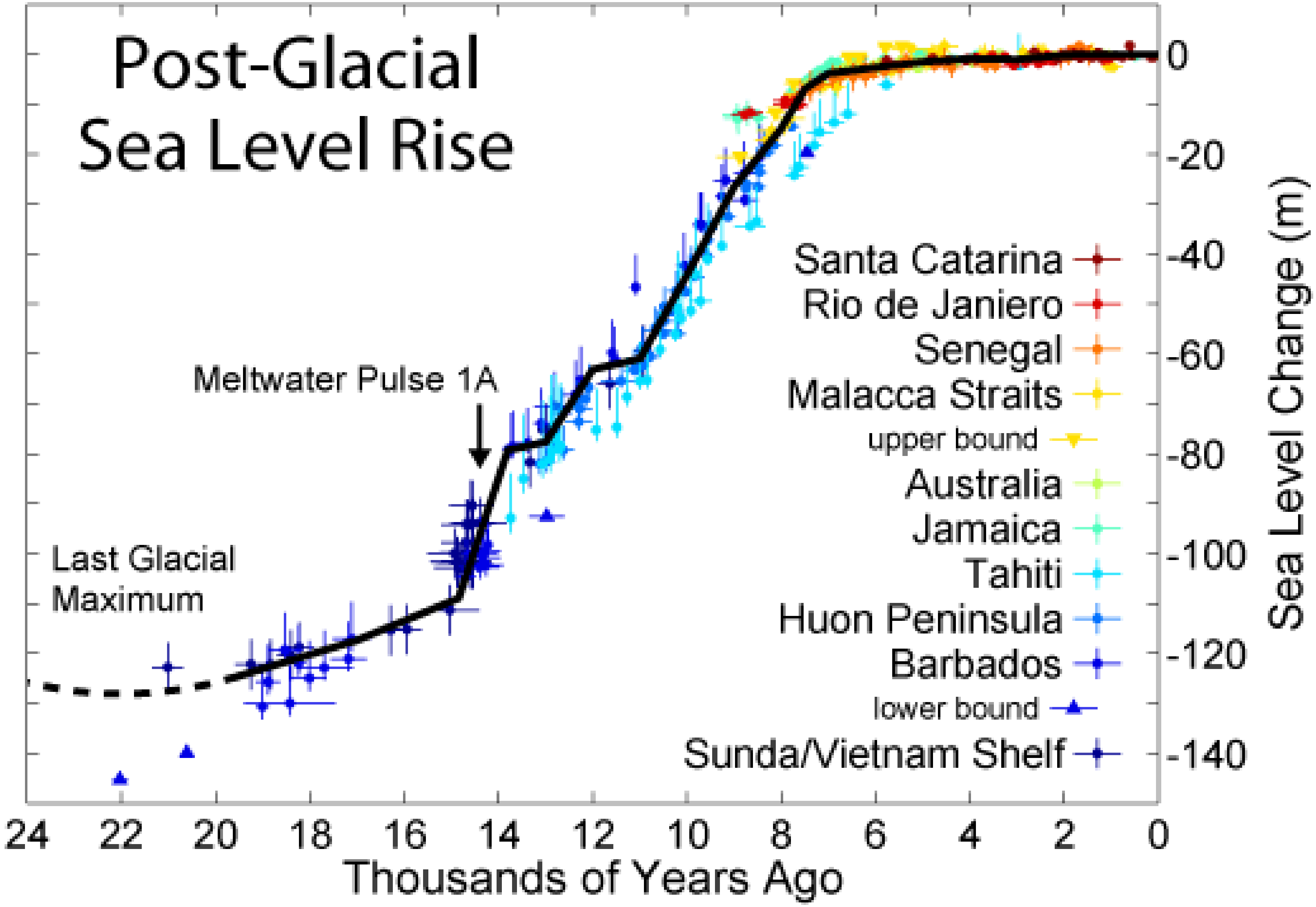
# MODEL OF MARINE TRANSGRESSION



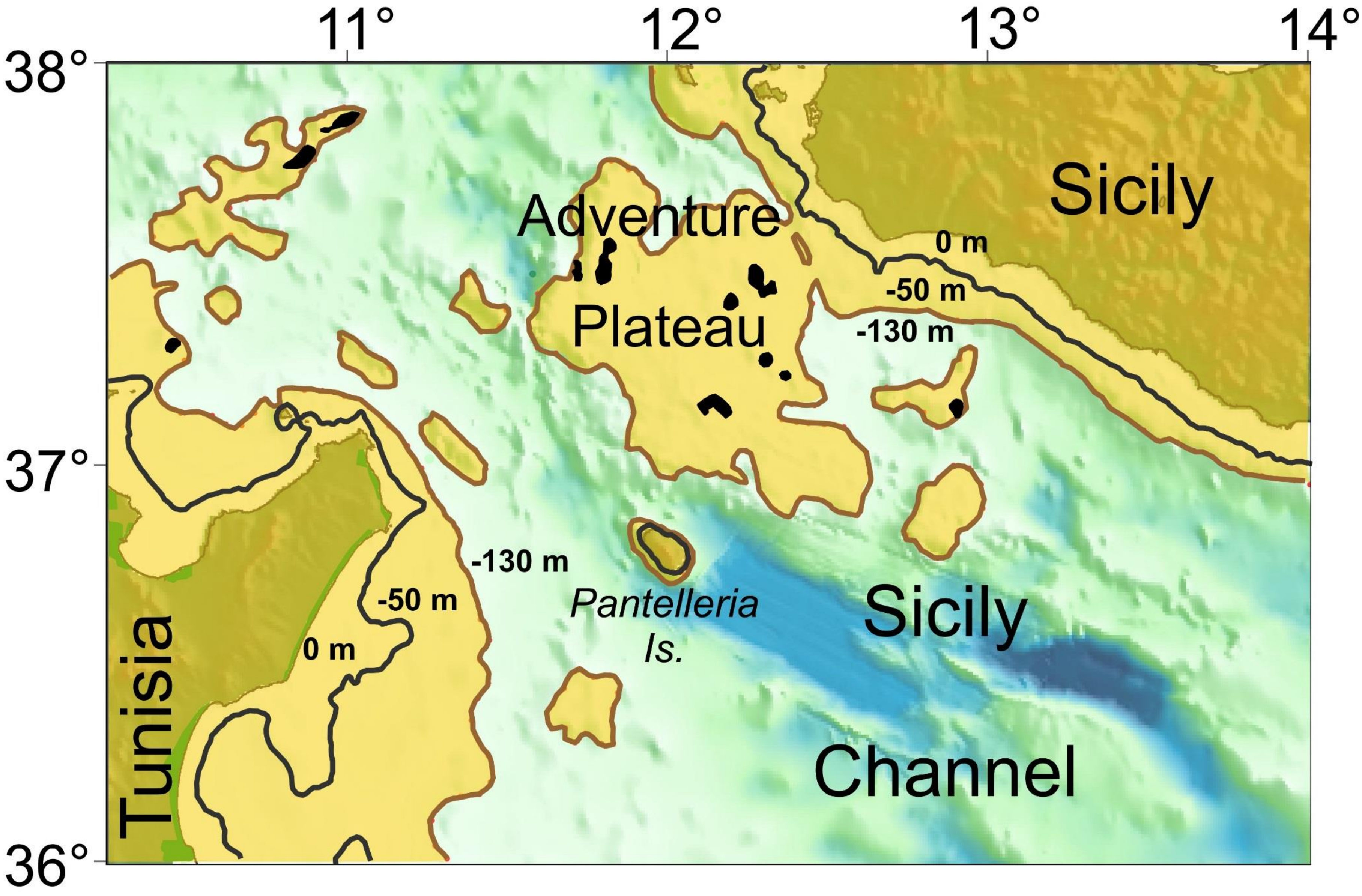
# SEISMIC EXAMPLE OF MARINE TRANSGRESSION

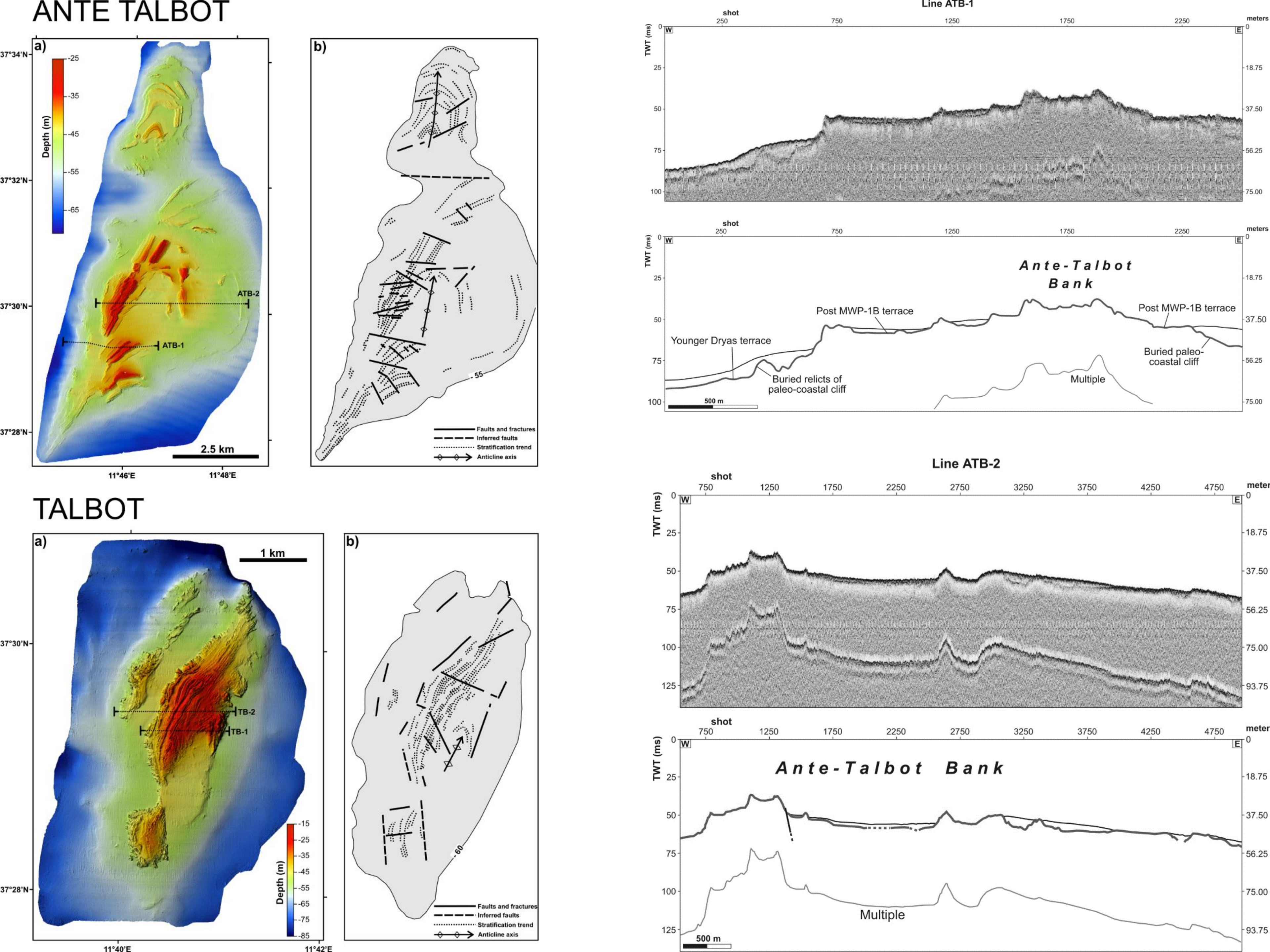


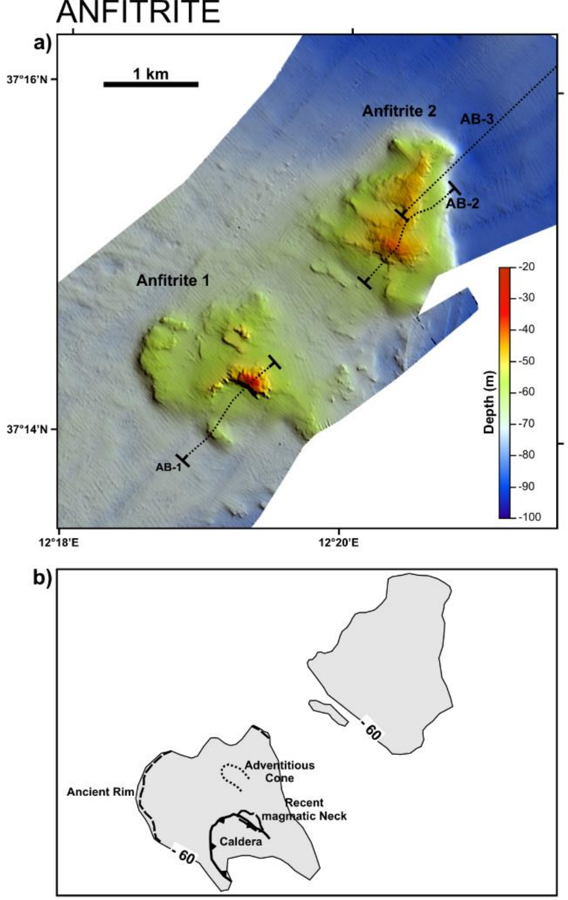

Post-Glacial
Sea Level Rise
Meltwater Pulse 1A
Last Glacial
Maximum
Santa Catarina
Rio de Janiero
Senegal
Malacca Straits
upper bound
Australia
Jamaica
Tahiti
Huon Peninsula
Barbados
lower bound
Sunda/Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Sea Level Change (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago

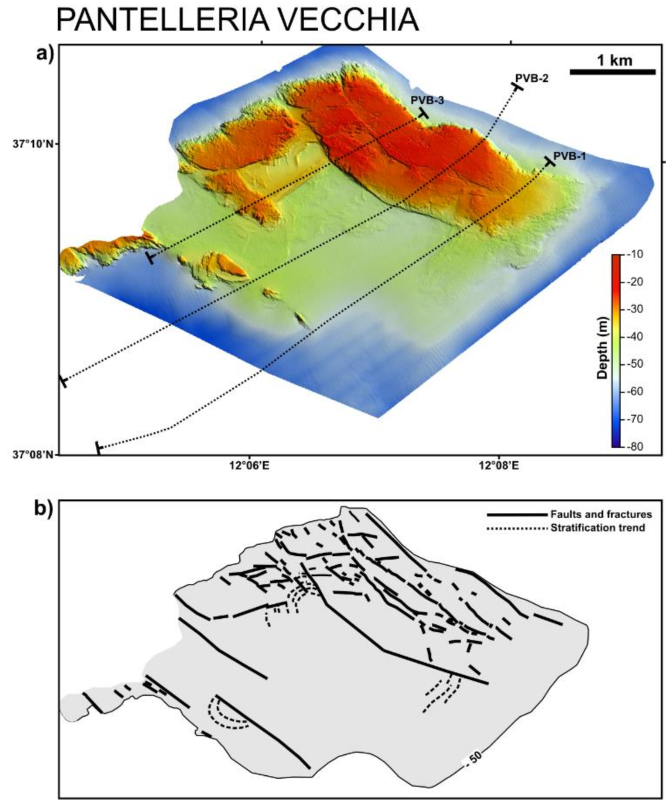
# The Sicilian Channel at LGM

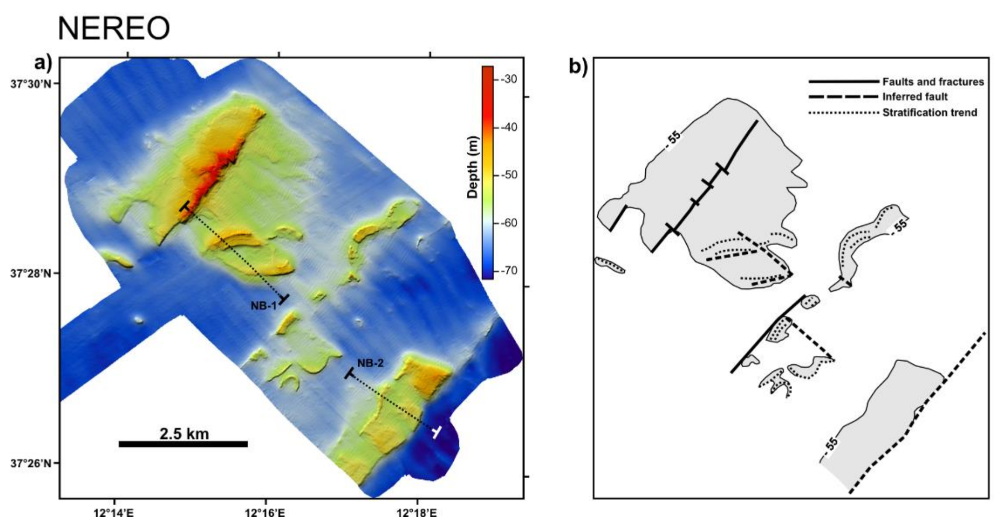


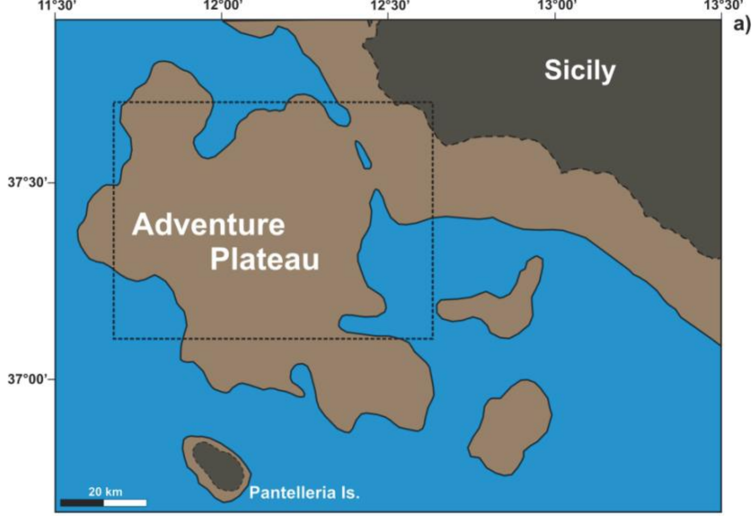


ANTE TALBOT
a)
b)
Depth (m)
-25
-35
-45
-55
-65
37°34'N
37°32'N
37°30'N
37°28'N
11°46'E
11°48'E
ATB-2
ATB-1
2.5 km
55
Faults and fractures
Inferred faults
Stratification trend
Anticline axis
TALBOT
a)
b)
1 km
37°30'N
37°28'N
11°40'E
11°42'E
TB-2
TB-1
Depth (m)
-15
-25
-35
-45
-55
-65
-75
-85
60
Faults and fractures
Inferred faults
Stratification trend
Anticline axis
Line ATB-1
shot
250
750
1250
1750
2250
meters
TWT (ms)
W
E
Ante-Talbot Bank
Post MWP-1B terrace
Post MWP-1B terrace
Younger Dryas terrace
Buried relicts of paleo-coastal cliff
Buried paleo-coastal cliff
Multiple
500 m
Line ATB-2
shot
750
1250
1750
2250
2750
3250
3750
4250
4750
meters
TWT (ms)
W
E
Ante-Talbot Bank
Multiple
500 m

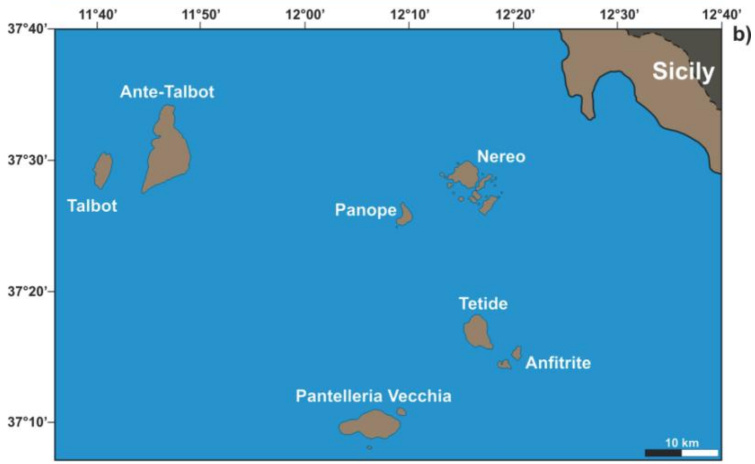

ANFITRITE
a)
1 km
37°16'N
Anfitrite 2
AB-3
AB-2
Anfitrite 1
AB-1
37°14'N
Depth (m)
-20
-30
-40
-50
-60
-70
-80
-90
-100
12°18'E
12°20'E
b)
60
Adventitious Cone
Ancient Rim
Recent magmatic Neck
Caldera
60


PANTELLERIA VECCHIA
a)
1 km
PVB-2
PVB-3
37°10'N
PVB-1
Depth (m)
-10
-20
-30
-40
-50
-60
-70
-80
37°08'N
12°06'E
12°08'E
b)
Faults and fractures
Stratification trend
50


NEREO
a)
37°30'N
37°28'N
37°26'N
NB-1
NB-2
2.5 km
Depth (m)
-30
-40
-50
-60
-70
12°14'E
12°16'E
12°18'E
b)
Faults and fractures
Inferred fault
Stratification trend
55
55
55



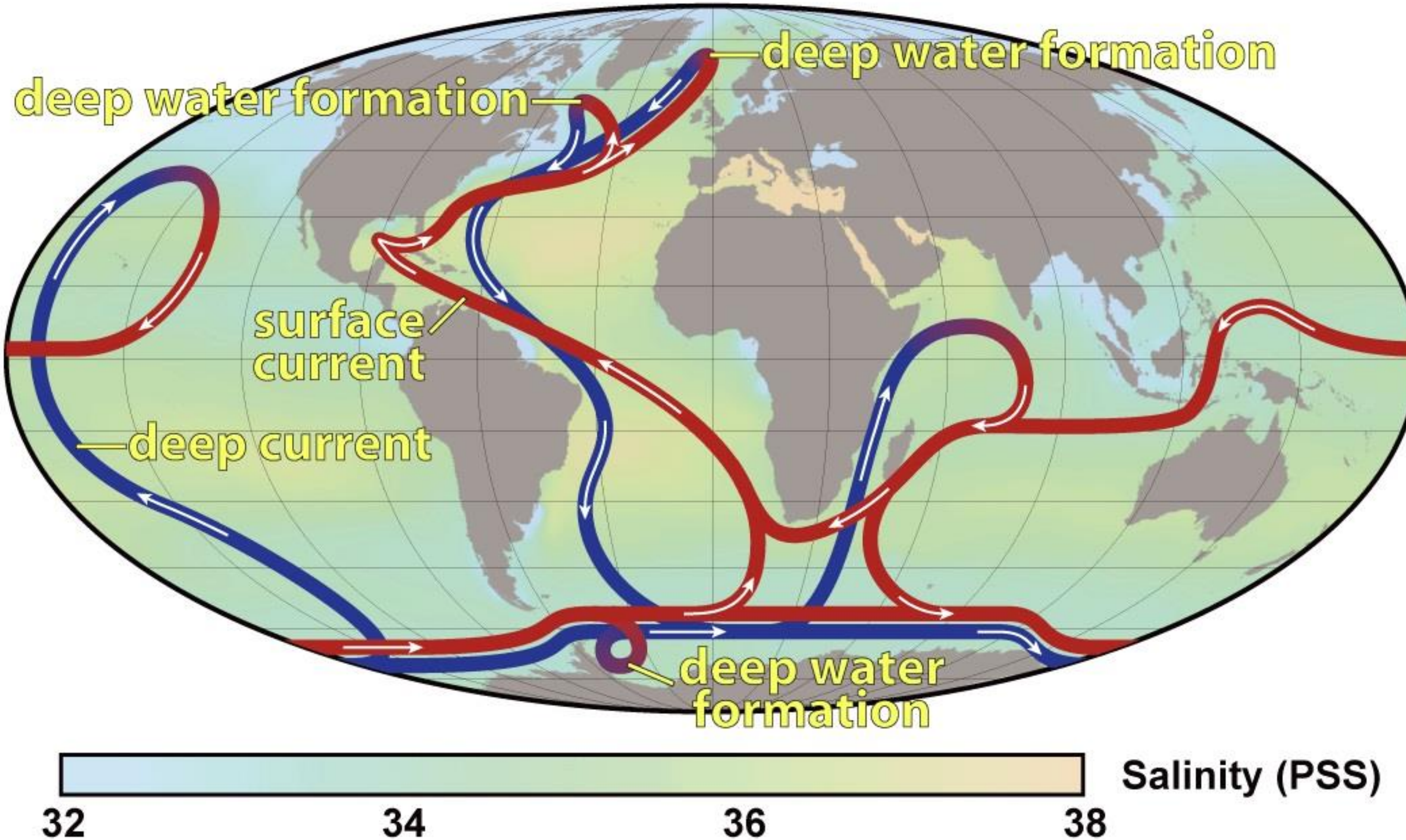

# The Adventure Plateau at the LGM (~18000 yr B.P.)




# Adventure Archipelago at about 11,700 yr B.P.
# Former sea level -60 m

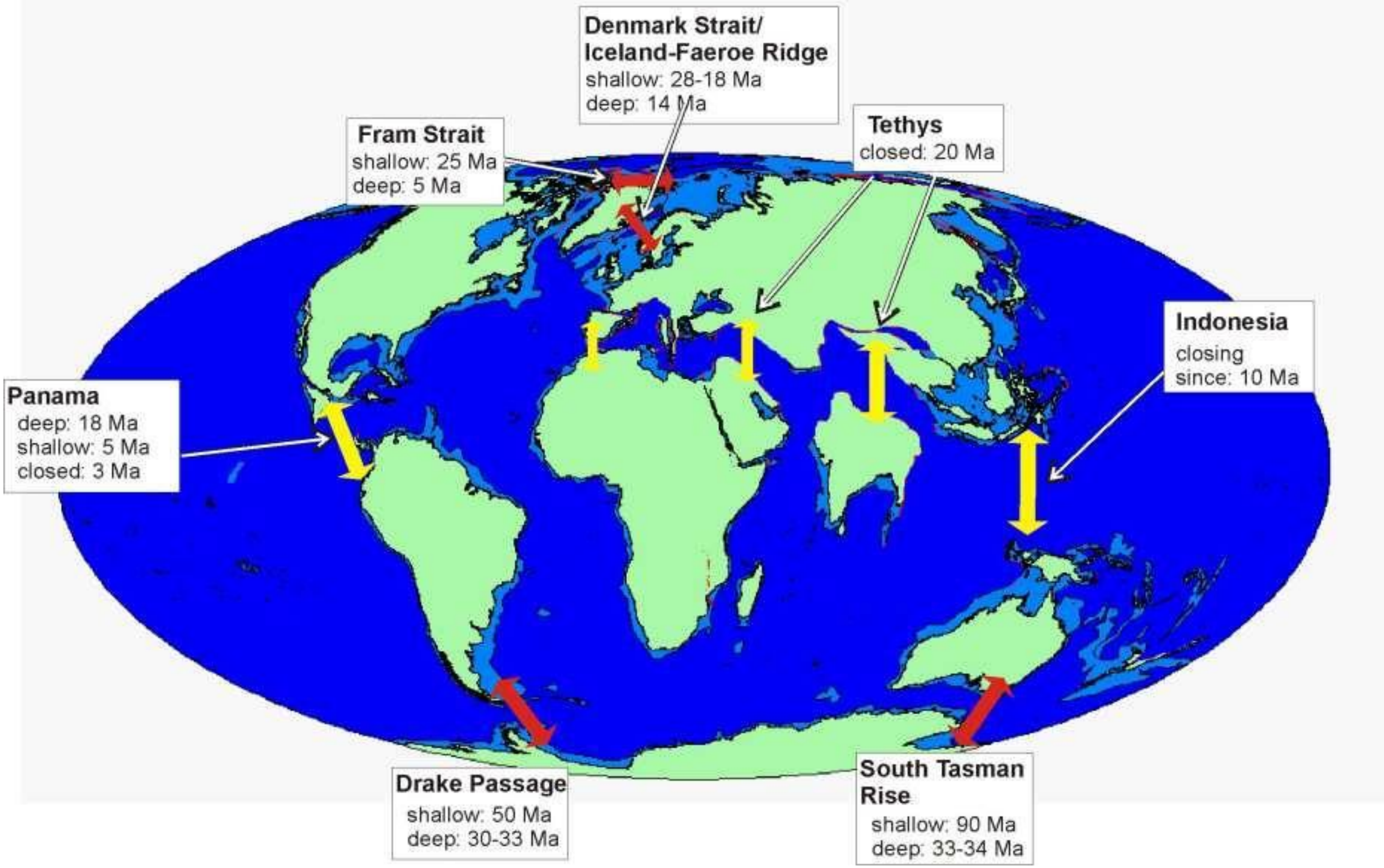

# Adventure Archipelago at about 11,200 yr B.P.
# Former sea level -42 m

# Thermohaline Circulation




**The major ocean currents of the world act as the heating and cooling ducts of the Earth, transporting heat from the equator and taking it to the poles. All of these currents are cumulatively called “Ocean Conveyor Belt”.**

## Ocean Gateways




**The position of the continents determines the geometry of the oceans and therefore influences patterns of ocean circulation. Plate tectonics relative motions over the course of millions of years has affected both global and local patterns of climate and atmosphere-ocean circulation.**

**The locations of the seas are important in controlling the transfer of heat and moisture across the globe, and therefore, in determining global climate.**

# Anthropocene

The “Anthropocene” Epoch is an unofficial unit of geologic time, used to describe the most recent period in Earth’s history when human activity started to have a significant impact on the planet’s climate and ecosystems.

# Key data about global warming

At the Paris meeting in 2015, 195 nations pledged to eventually reduce their emissions enough to hold global warming to well below 2 °C by 2100. Restricting global warming further, to just 1.5 °C, would forestall many more devastating consequences of climate change.

Current pledges to reduce greenhouse gas emissions still put the world on track to warm by 2.7 °C above pre-industrial levels by 2100.

At the current emissions trend, the year that global temperatures will reach 1.5 °C is now only 10 years away.

The global mean temperature from January to September 2021 was already about 1.09 °C above the pre-industrial average.

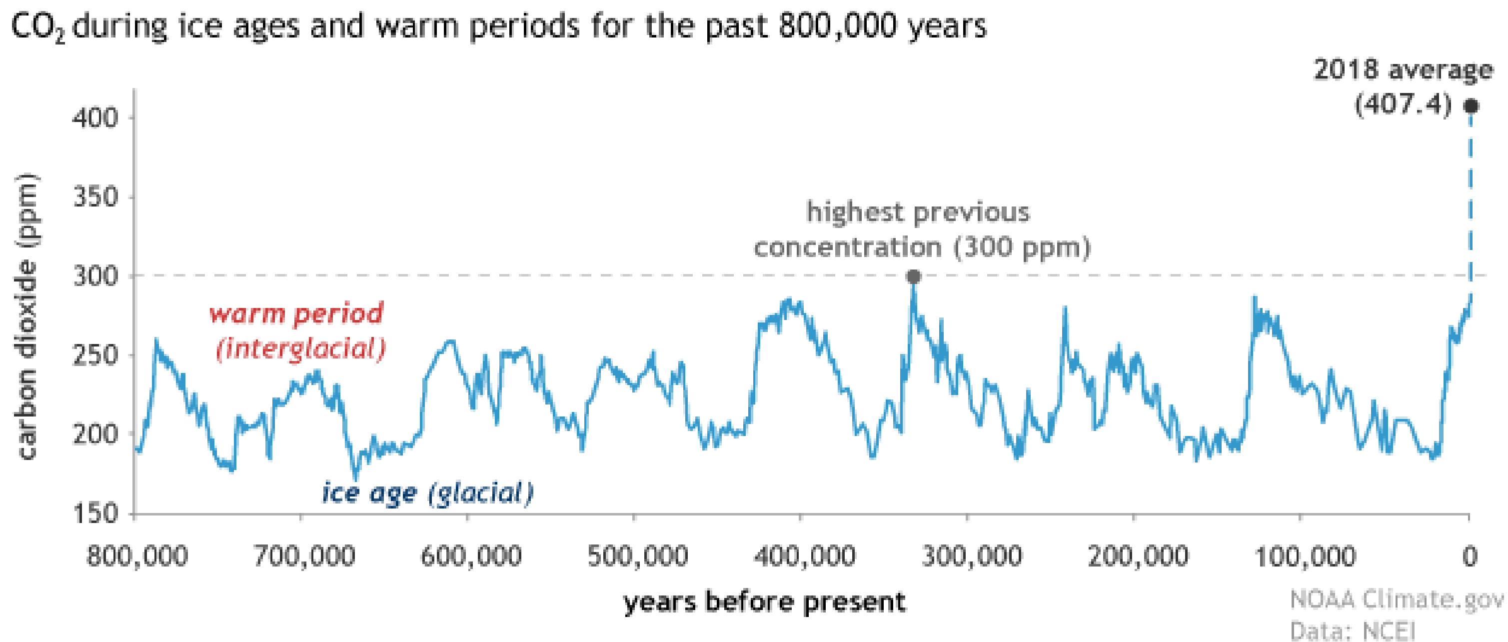
As started in the last (August 2021) Intergovernmental Panel on Climate Change (IPCC) report, extreme weather events, exacerbated by human-caused climate change, now occur in every part of the planet — and warned that the window to reverse some of these effects is closing.

In the past nine months, the world has experienced numerous wildfires, several extreme heat waves, cyclones, hurricanes, droughts, and some severely cold weather events.

Aiming for “net-zero emissions” by midcentury — a goal recently announced by China, the United States and other countries — could reduce that warming to 2.2 °C.

Unless emissions are reduced rapidly and dramatically, global warming will reach a level that has not been seen for millions of years.

UN's World Meteorological Organization (WMO) recently calculated the last seven years have been the warmest on record.

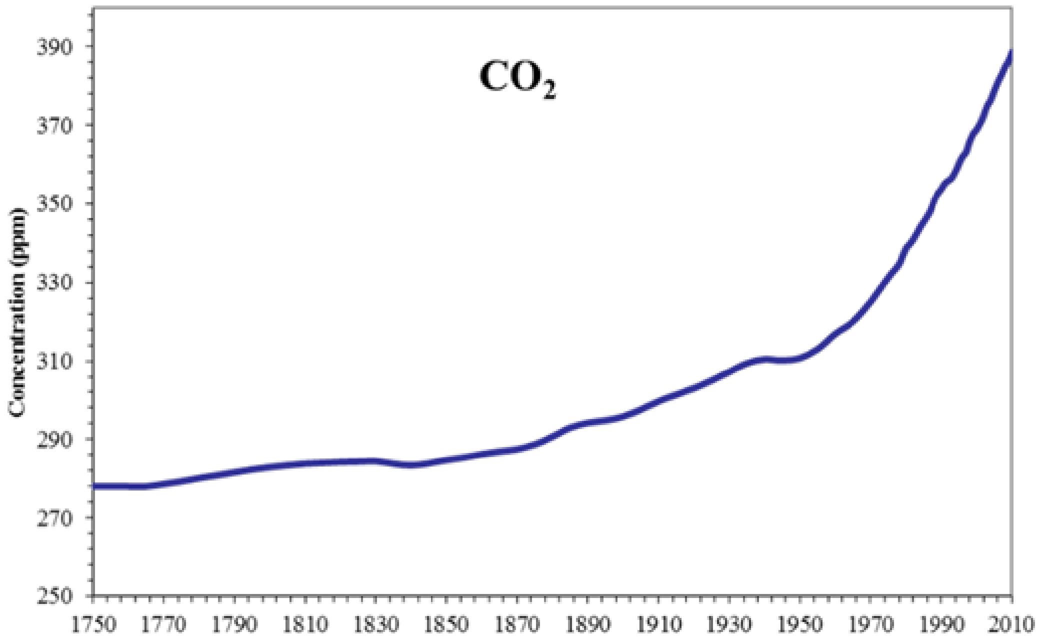

**EPICA ice-core records 100,000-yr cycle**

# Measurement of past climate changes

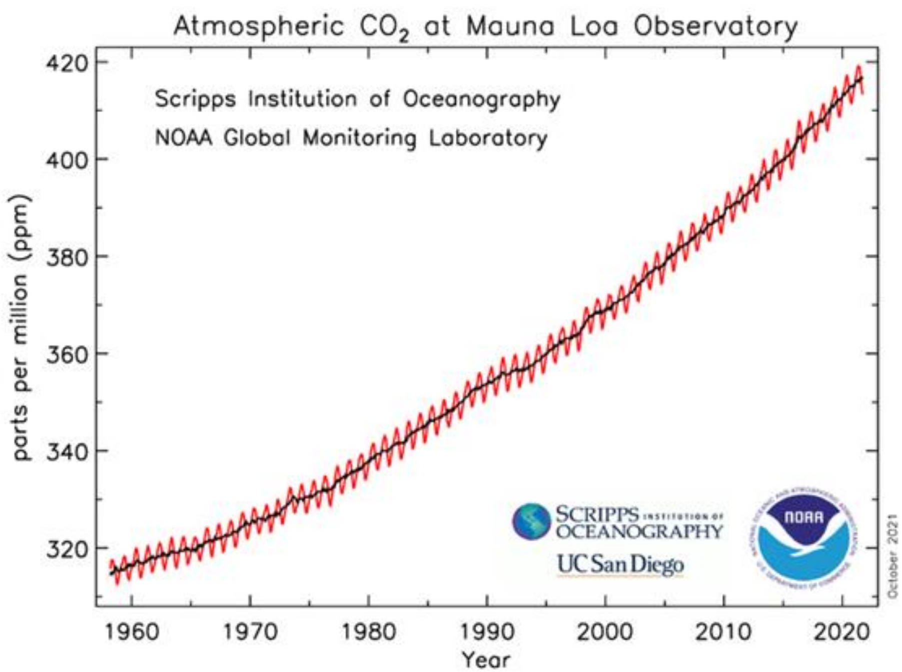
Knowing what happened in the past is the key to predicting the near future.

Past climate changes are recorded in rocky outcrops, sediments from the ocean floor and lakes, in polar ice sheets, and in other shorter-term archives such as tree rings and corals. Overall, past climates show us that recent changes across all aspects of the Earth system are unprecedented in at least thousands of years.

- Global temperature (currently 1.1 °C above a pre-industrial baseline) is higher than at any time in at least the past 120,000 or so years. That's because the last warm period between ice ages peaked about 125,000 years ago – in contrast to today, warmth at that time was driven not by $CO_2$, but by changes in Earth's orbit and spin axis.
- The current atmospheric $CO_2$ concentration of around 415 parts per million (compared to 280 ppm prior to industrialization in the early 1800s), is greater than at any time in at least the past 2 million years.
- Greenhouse gases - methane and nitrous oxide - are now greater than at any time in at least 800,000 years.
- Late summer Arctic sea ice area is smaller than at any time in at least the past 1,000 years.
- Glacier retreat is unprecedented in at least 2,000 years.
- Sea level is rising faster than at any point in at least 3,000 years.
- Ocean waters are unusually acidic compared to the past 2 million years.




**Concentration of carbon dioxide (ppm) since the Industrial Revolution (*ca.* 1760)**



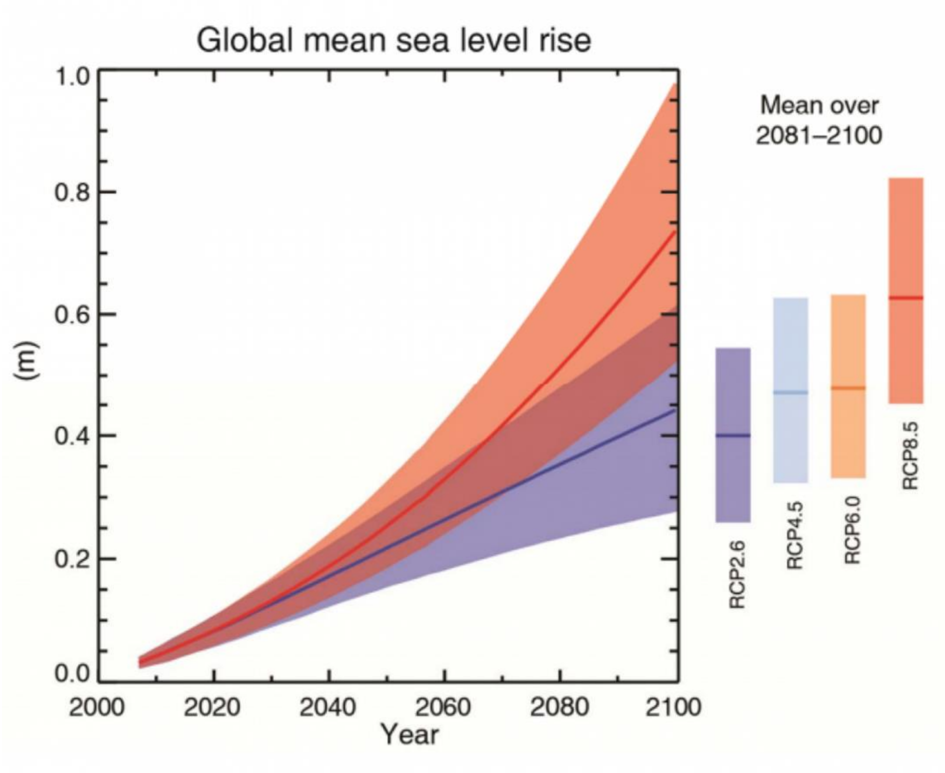

**Concentration of carbon dioxide (ppm) since 1960**

# Predictions from climate models

An intermediate amount of emissions will likely lead to global warming of between 2.3°C and 4.6°C by the year 2300, which is similar to the mid-Pliocene warm period of about 3.2 million years ago.

Extremely high emissions would lead to warming of somewhere between 6.6°C and 14.1°C, which just overlaps with the warmest period since the "Paleocene-Eocene Thermal Maximum" kicked off by massive volcanic eruptions about 55 million years ago.

As such, humanity is currently on the path to compressing millions of years of temperature change into just a couple of centuries.



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**Mediterranean palaeo-geography and the Messinian salinity crisis**

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