Università di Trieste
Corso di Laurea in Geologia

Anno accademico 2016 - 2017

Geologia Marina

Parte I

Modulo 1.2 Oceani. Morfologia, struttura ed evoluzione

Docente
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The oceans

1. Oceans and seas of the world
2. Morphology of the ocean and sea floor
3. Structure of the ocean
4. Classification of the ocean and sea environments
5. Ancient oceans

1. Etymology

The term Ocean derives from Ὠκεανὸς (OKEANOS), greek river-god that was believed to surround the world, the external sea (not the Mediterranean).
But the rooth of word are from sanscrit ACAYANA, in the sense of “containing the waters.

Okeanos is one of the Titans,
son of Uran (sky) and Gea (earth),
husband of **Teti**,
and father of all the fluvial divinities.

The oceans and the seas are important because they :

The Blue Planet

- cover 71-72% of the Earth surface
- contain the 97% of the water of the Earth
- but less than 5-10% have been explored

The present Oceans of the world

International Hydrographic Organization

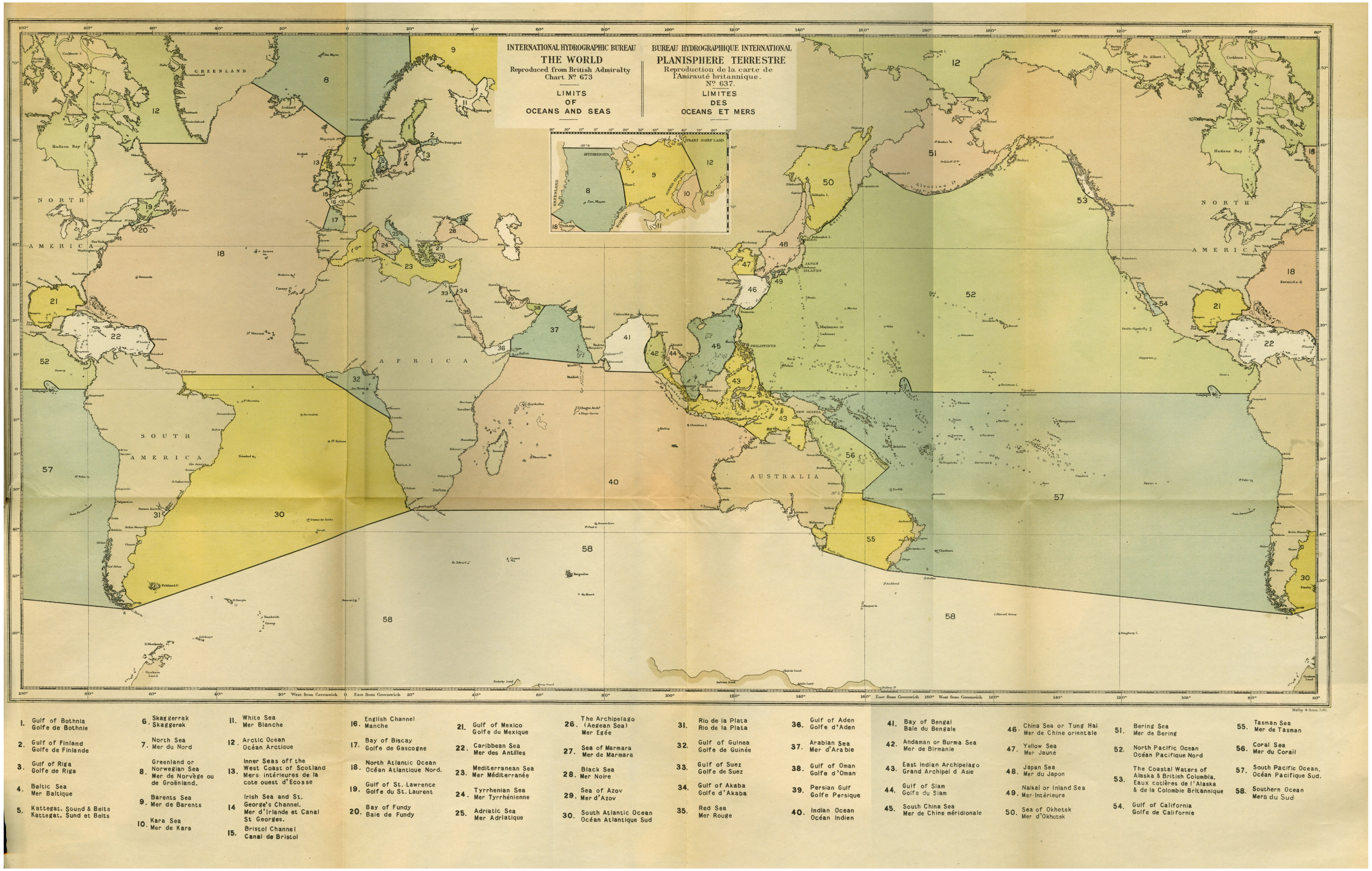
It is the inter-governmental organisation representing the hydrographic community. It enjoys observer status at the UN where it is the recognised competent authority on hydrographic surveying and nautical charting.

A principal Aim of the IHO is to ensure that all the world's seas, oceans and navigable waters are surveyed and charted.

The **Mission** of the IHO is to create a global environment in which States provide adequate and timely hydrographic data, products and services and ensure their widest possible use.

The **Vision** of the IHO is to be the authoritative worldwide hydrographic body which actively engages all coastal and interested States to advance maritime safety and efficiency and which supports the protection and sustainable use of the marine environment.

The limits of the oceans and seas
1st edition in 1928 by the IHO



The oceans of the world

The limit of the oceans formally defined by the IHO
(black line – excluding marginal waterbodies)

Pacific Ocean

Atlantic Ocean

Indian Ocean

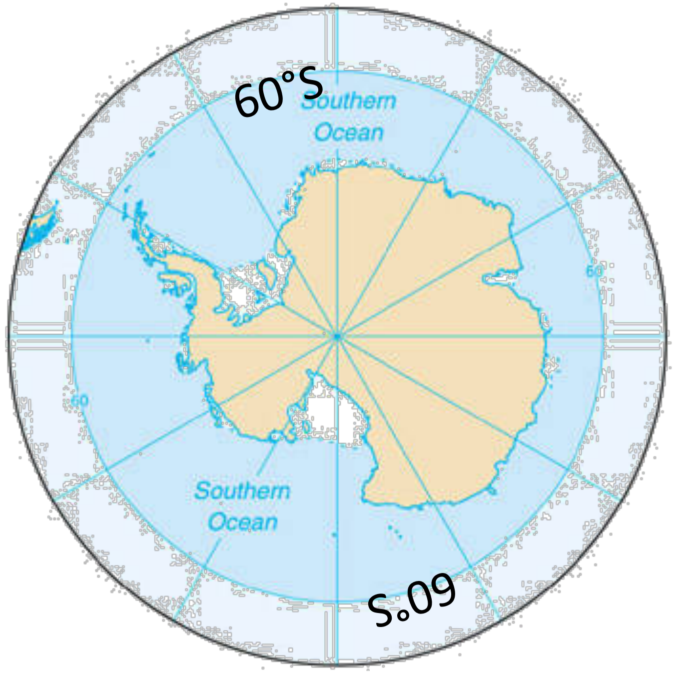
The oceans of the world

Artic Ocean

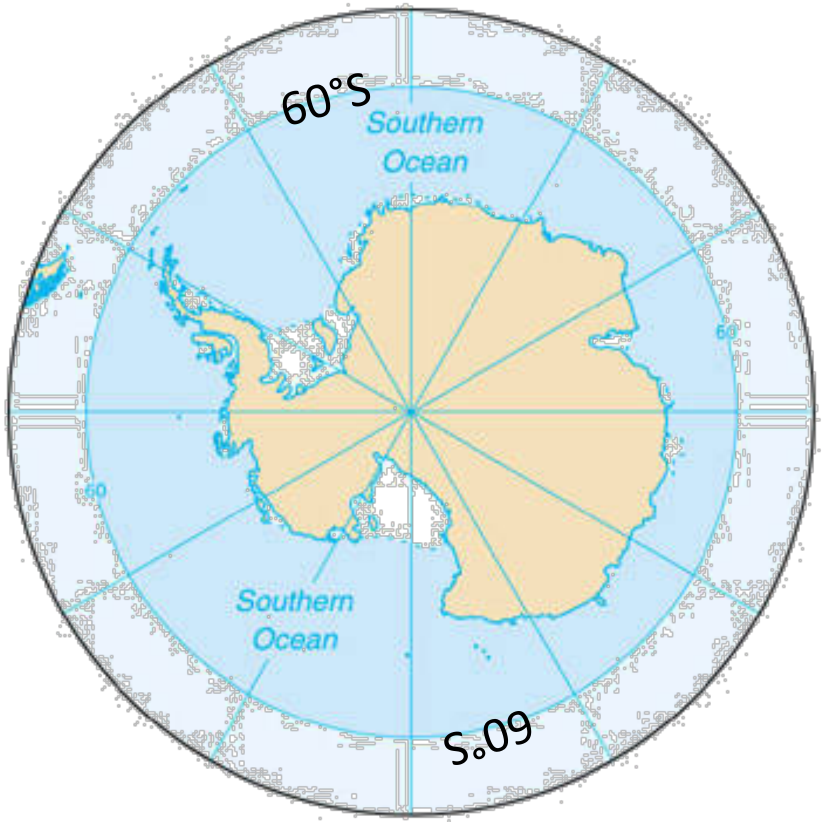
The limit of the oceans formally defined by the IHO (black line – excluding marginal waterbodies)

Southern Ocean

In 2000, the IHO published a draft definition of the Southern Ocean, surrounding Antarctica and extending to 60° S.
Up to now, the **Southern Ocean is not formally defined by the IHO**.



Southern Ocean



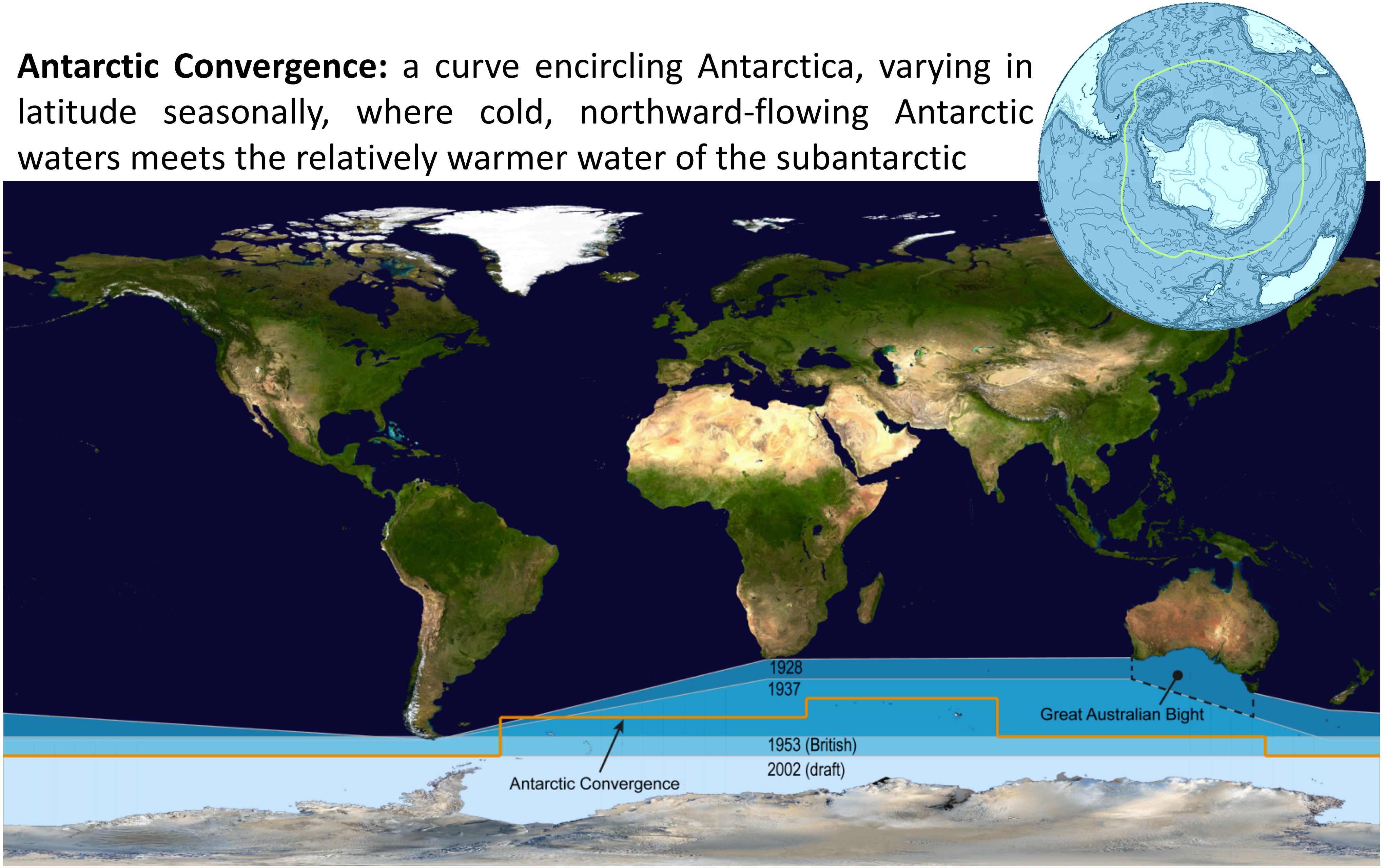
In 2000, the International Hydrographic Organization (IHO), published a draft definition of a new ocean:

the Southern Ocean

surrounding Antarctica and extending to 60° S.
Up to now, the Southern Ocean is not formally defined by the IHO.

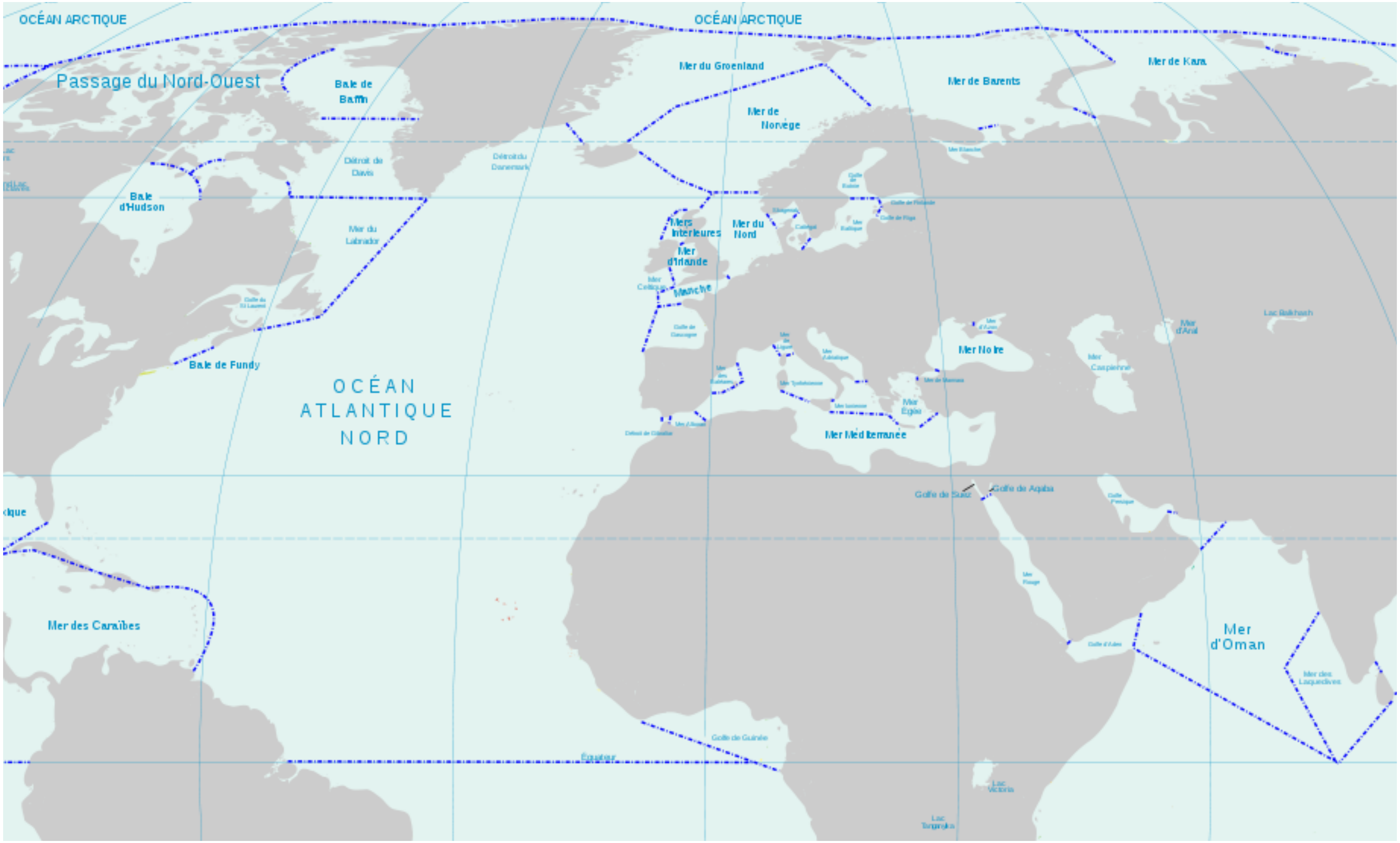
IH0's delineation of the Southern Ocean

Antarctic Convergence: a curve encircling Antarctica, varying in latitude seasonally, where cold, northward-flowing Antarctic waters meets the relatively warmer water of the subantarctic

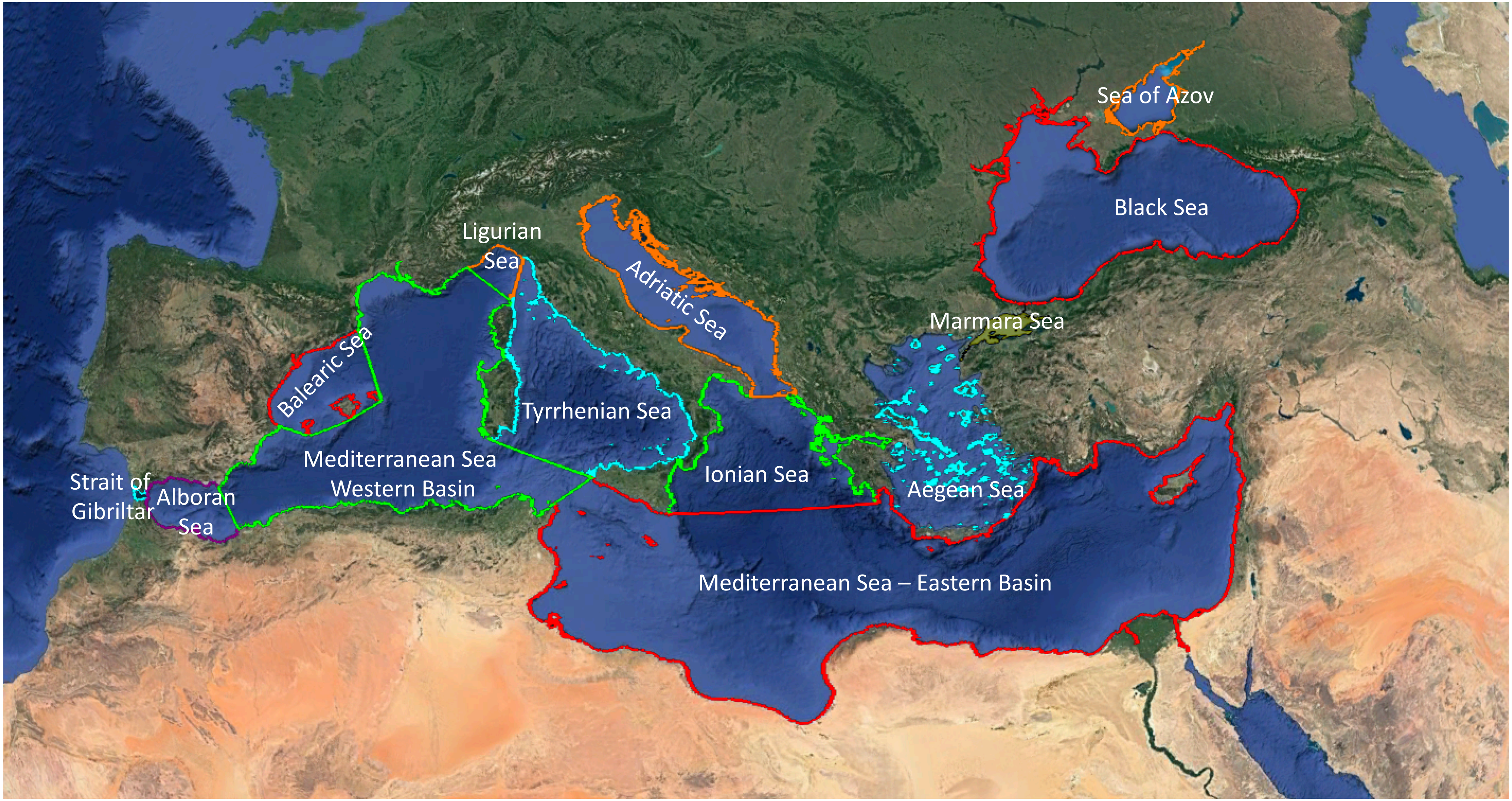


Ocean	Area	Average Depth (m)	Deepest depth (m)
Pacific Ocean	165,250,000 km^2	4,028 m	Mariana Trench 11,033 m
Atlantic Ocean	106,400,000 km^2	3,926 m	Puerto Rico Trench 8,604 m
Indian Ocean	73,560,000 km^2	3,963 m	Java Trench, 7,725 m
Southern Ocean	20,330,000 km^2	4,000 to 5,000 m	the southern end of the South Sandwich 7,236 m
Arctic Ocean	13,990,000 km^2	1,205 m	Eurasia Basin, 5,540 m

The seas of the world



The seas of the Mediterranean formally defined by the IHO

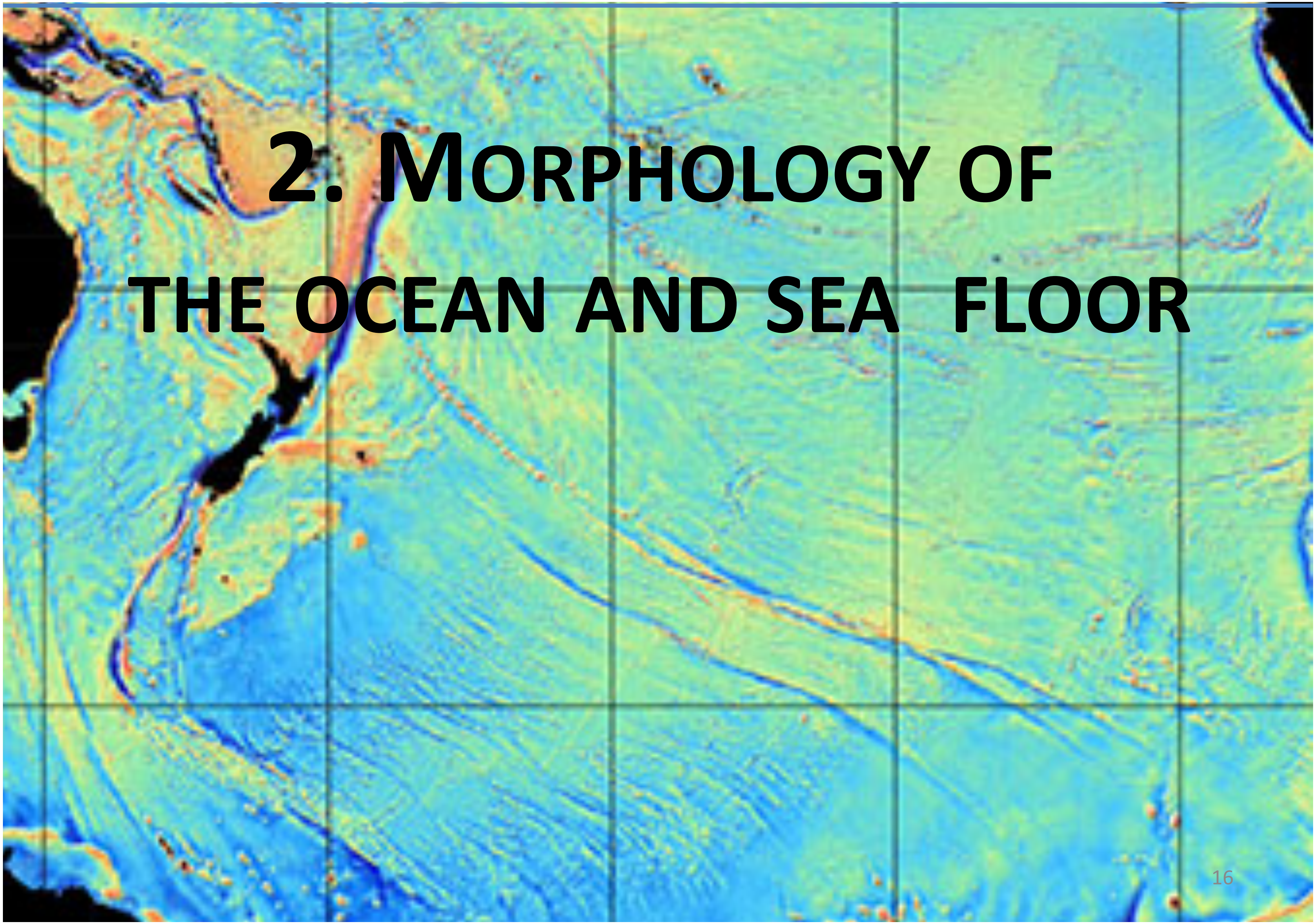


The seas of the Mediterranean

from latin "Mediterraneus": medi > between terraneous > land

Not all the seas present in the map are formally defined!!

2. MORPHOLOGY OF THE OCEAN AND SEA FLOOR



OCEAN AND SEA FLOOR MORPHOLOGY

less than 5-10% of the ocean have been explored

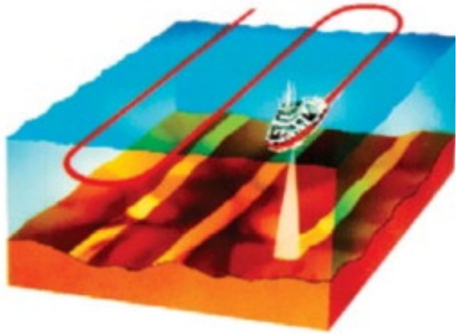
To investigate the oceans and seas we need appropriate instruments and techonologies:

5-10%

1) First instrument: the SONAR, constructed at the beginning of the 1900

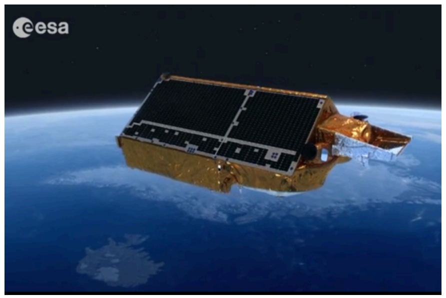
2) Multibeam technologies, developped in the last decades of the 1900

3) Satellite derived bathymetry and and sea floor morphology developped in the last decades of the 1900



(a) Single-Beam

(b) Multi-Beam

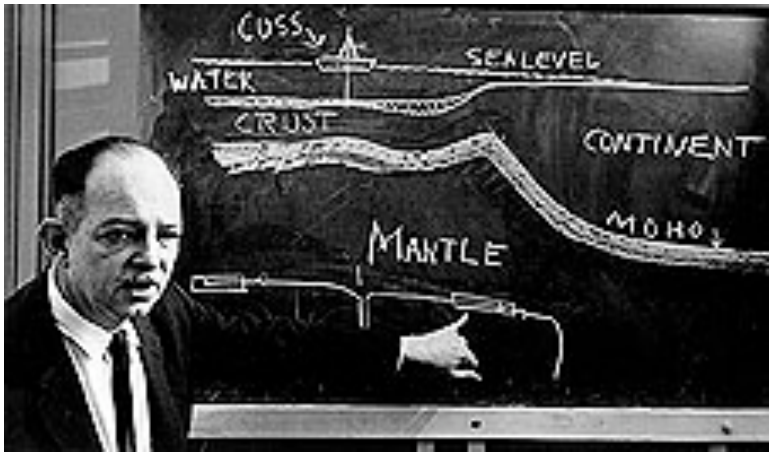


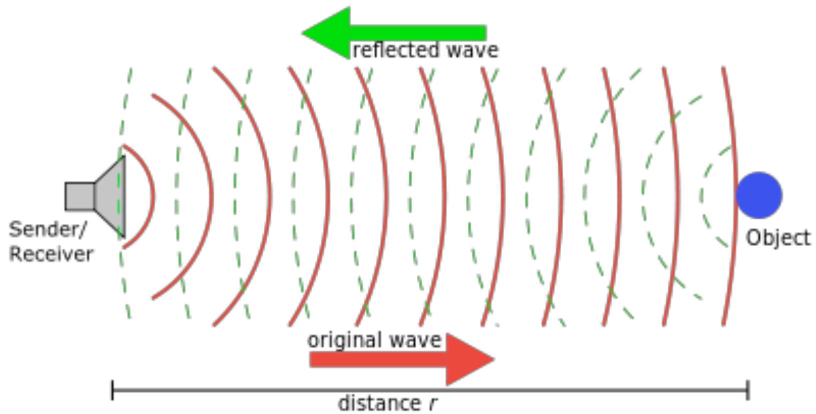
Harry Hess (1906 – 1969)

Professor of geology at Princeton University

During the Second World War, Hess was the captain of a ship equipped with a SONAR (SOund NAvigation and Ranging, invented in 1917 by Paul Langevin).

Hess discovered the Mid-oceanic ridges and the guyots, and in the ’62 he published the Sea floor Spreading theory, fundamental for the Plate Tectonic theory.



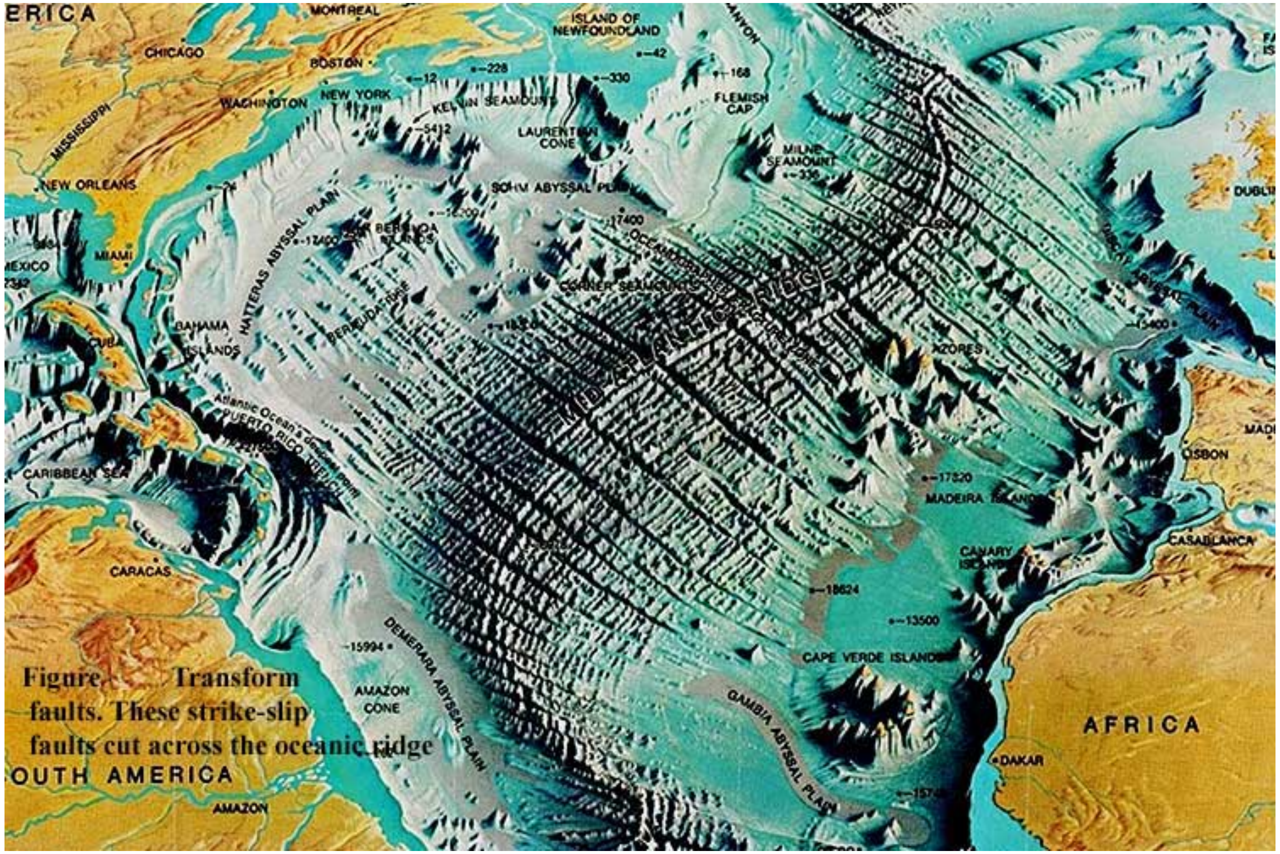


The SONAR principle

SEA FLOOR MORPHOLOGY 1977

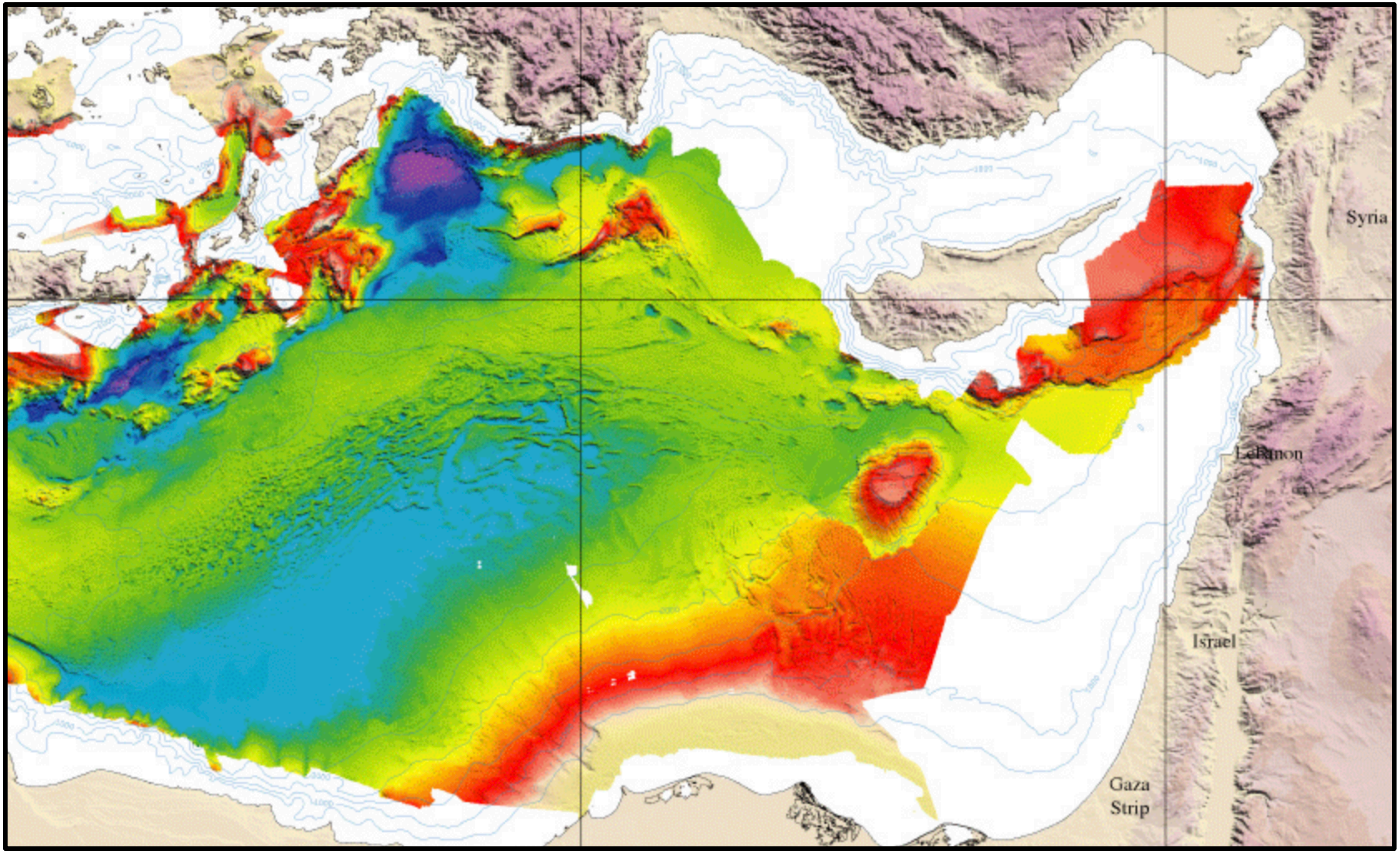
Marie Tharp and Bruce Heezen, oceanographers of the Columbia University's Lamont Geological Observatory. They discovered the 60.000 km of underwater ridges The map was painted by Heinrich C. Berann.

Mid-Ocean Ridges

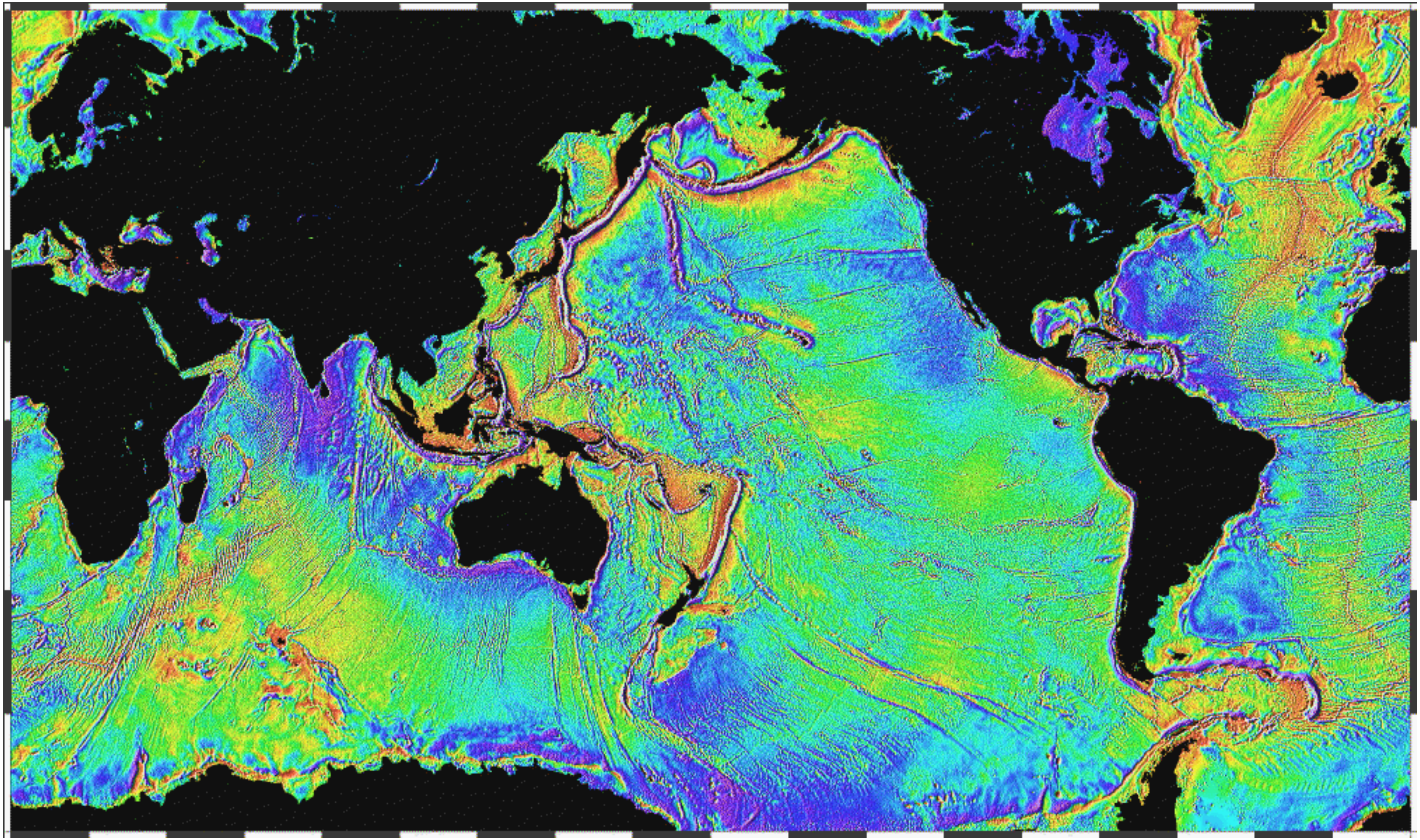


- The largest feature of the ocean floor.
- Linear belt of submarine mountains and active volcanoes about 60.000 km long.
- Plate boundaries: new magma forces its way up between two plates and pushes them apart.

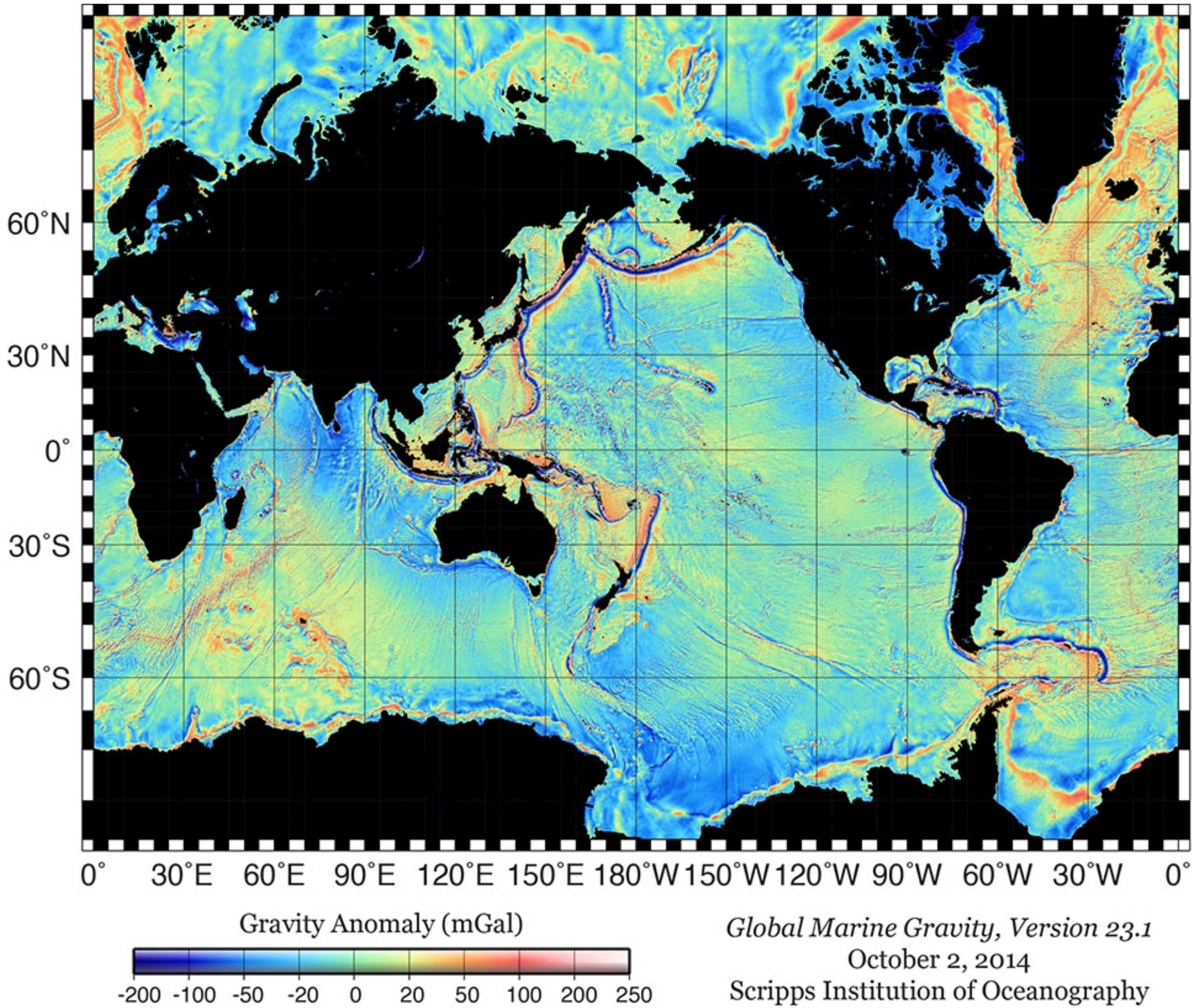
Sea floor mapping from multibeam data



Global gravity map of the oceans - from GEOSAT and ERS-1

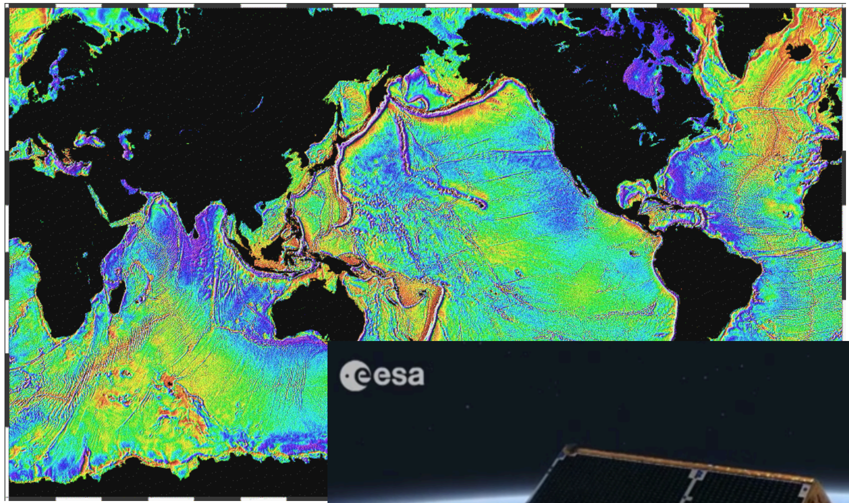


SMITH AND SANDWELL, 1996

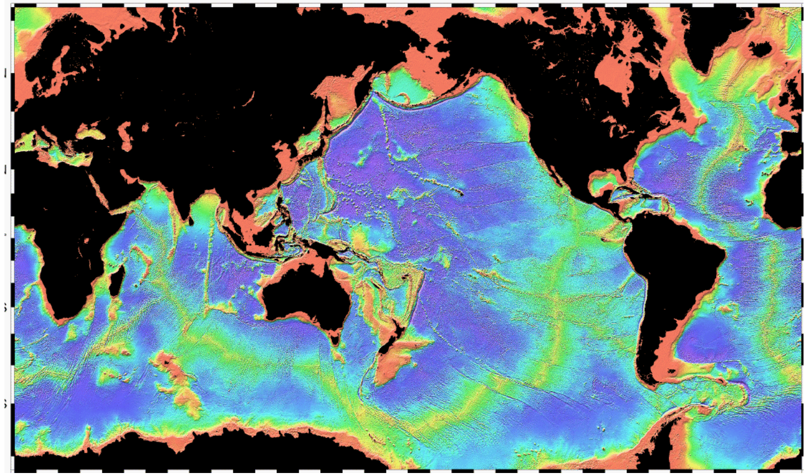


Sandwell et alii, Science 2014

Global gravity map of the oceans
from GEOSAT and ERS-1



Global sea floor topography
from gravity data and shipboard depth soundings



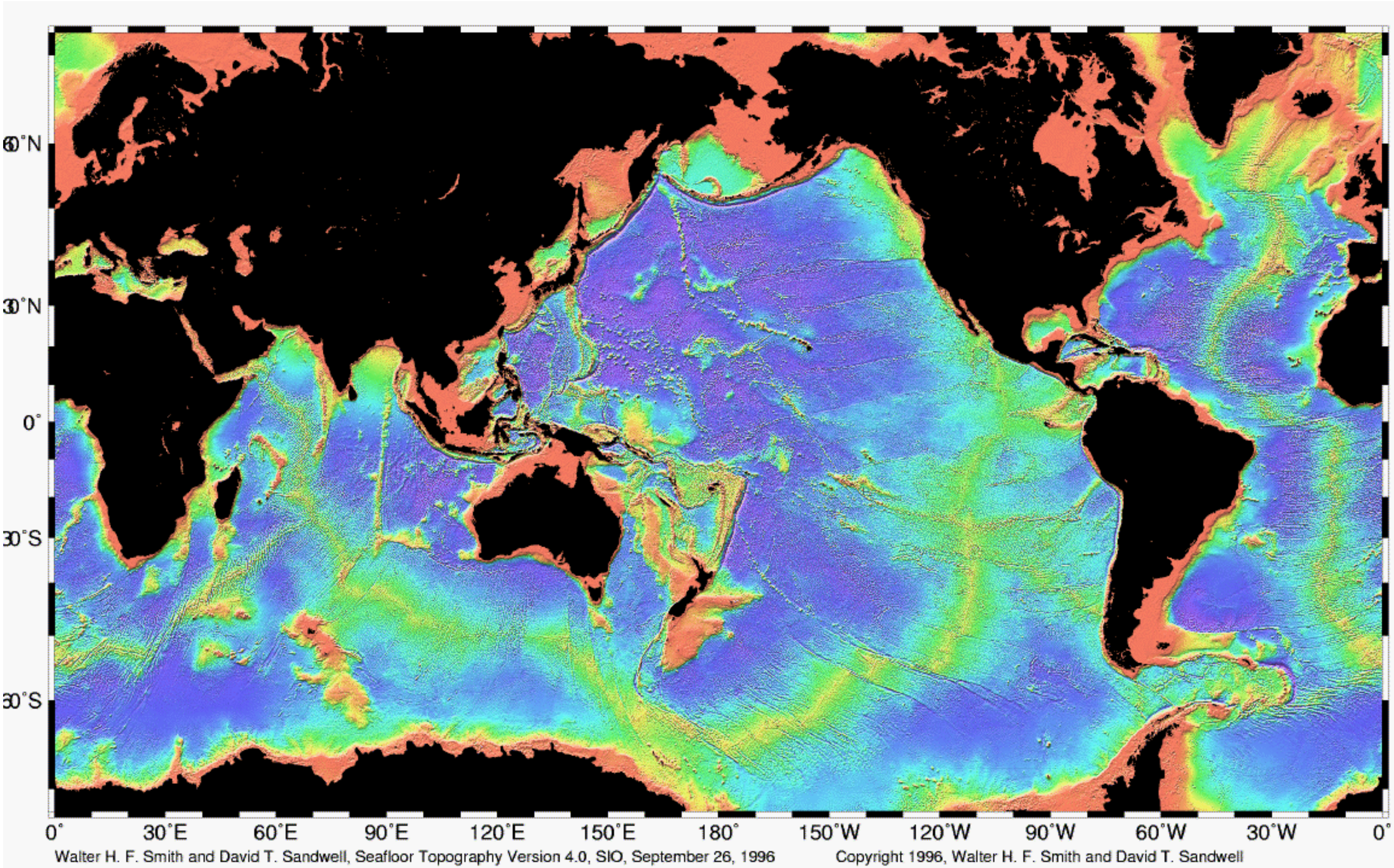
SMITH AND SANDWELL, 1996

Dixon *et al., JGR, (*1983) have summarized the basic theory for estimating sea floor topography from gravity anomalies.

Models of the isostatic compensation of sea floor topography furnish a spectral transfer function that predicts the gravity anomaly expected from sea floor topography.

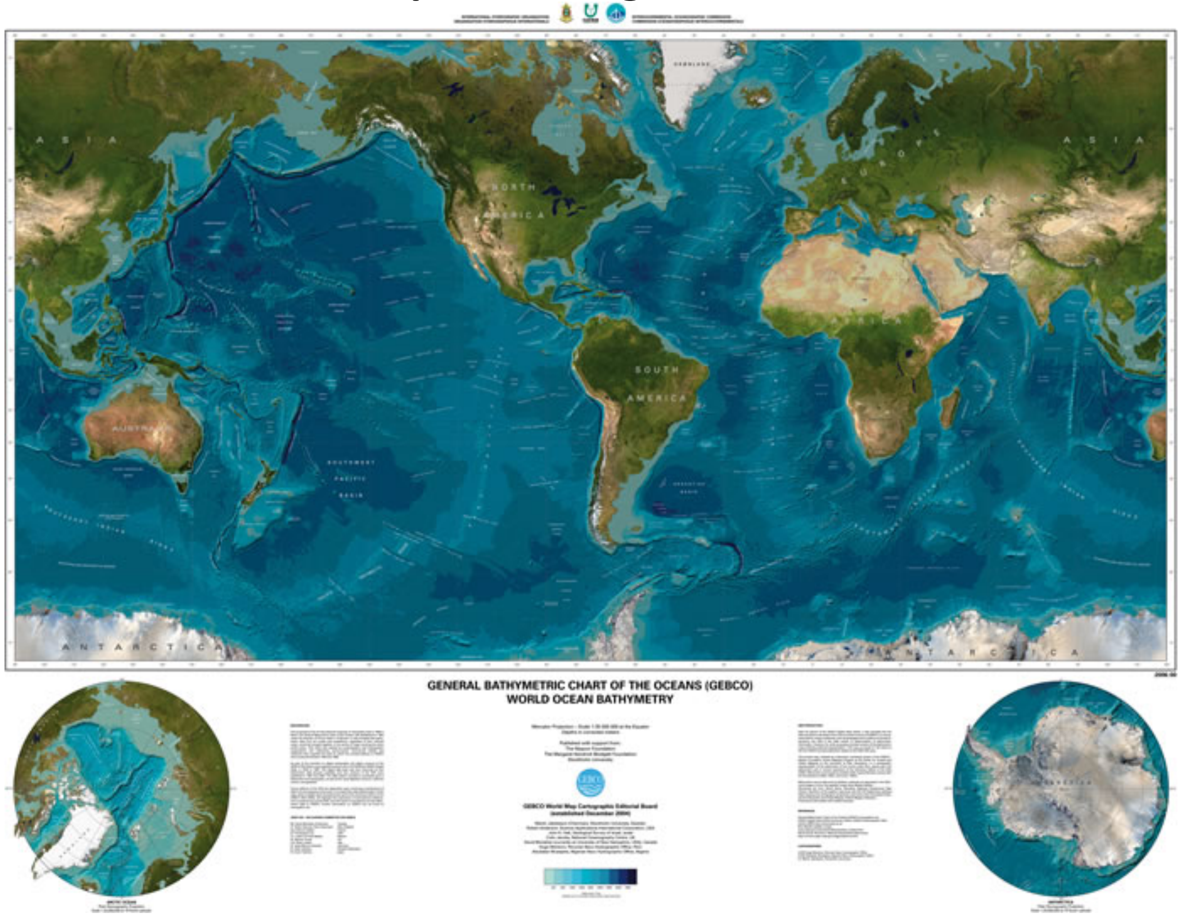
This transfer function depends on: mean depth, crustal density and thickness, and elastic lithosphere thickness.

Global sea floor topography from gravity data derived from satellite altimetry and shipboard depth soundings



SMITH AND SANDWELL, 1996

General Bathymetric Chart of the Oceans - GEBCO
http://www.gebco.net



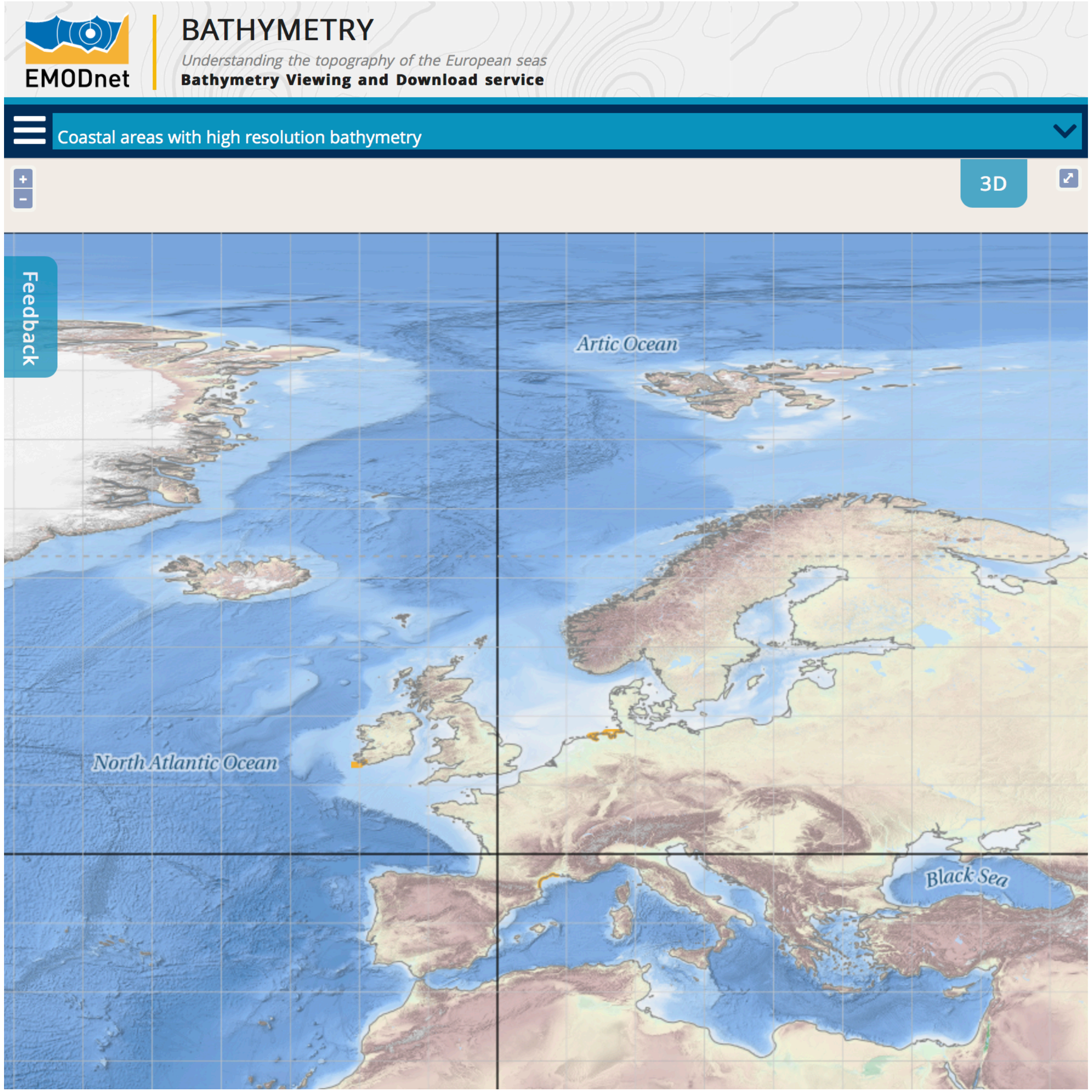
Gridded bathymetry data

GEBCO's gridded bathymetric data sets are global terrain models for ocean and land and include the

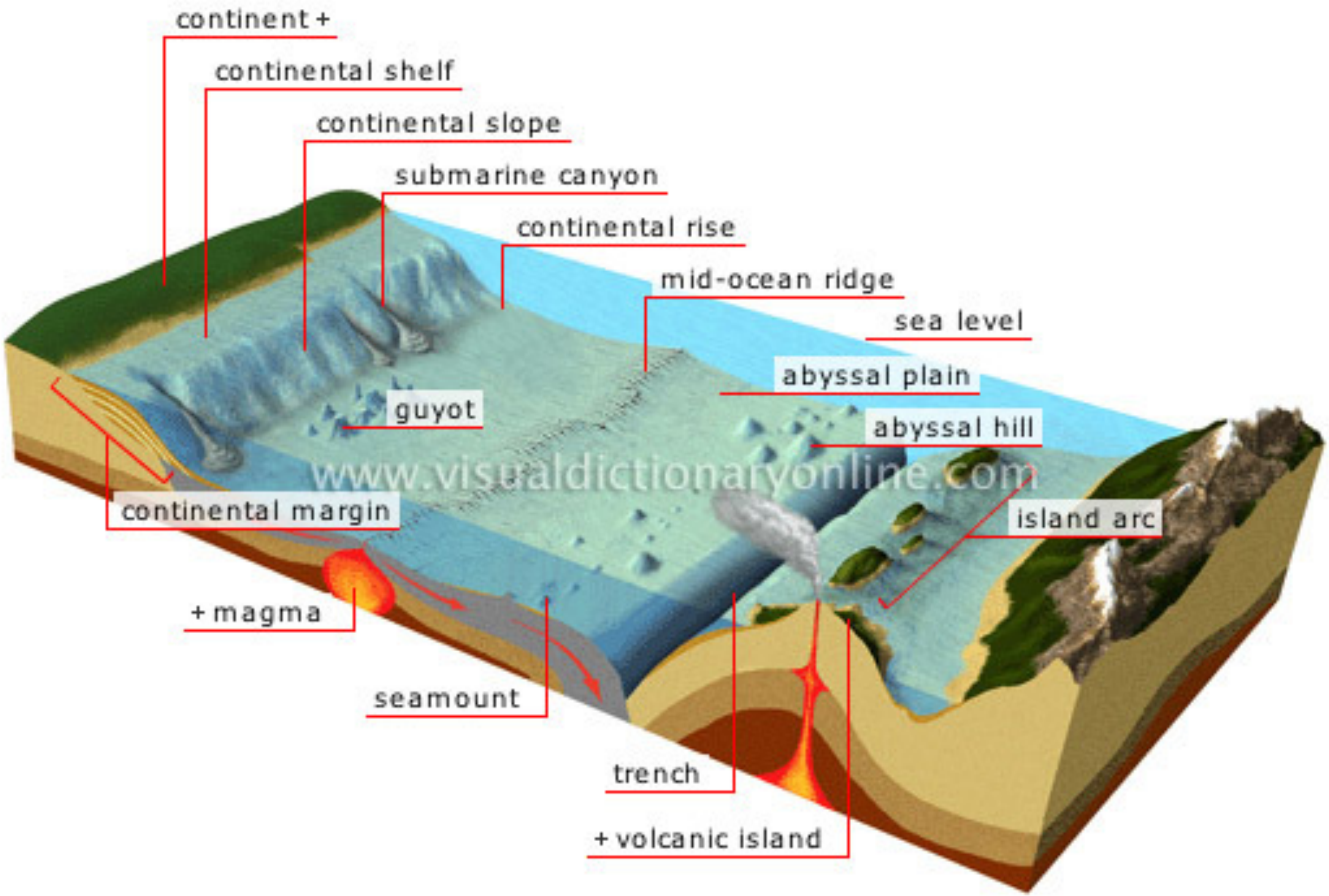
- GEBCO_2014 Grid — a global 30 arc-second interval grid
- GEBCO One Minute Grid — a one arc-minute interval grid. Last updated in 2008. Please note that there are no plans for further development of this data set.

The GEBCO_2014 Grid is **available to download** for user-defined areas in netCDF, Esri ASCII raster or INT16 GeoTiff formats. The GEBCO One Minute Grid is available in netCDF only.

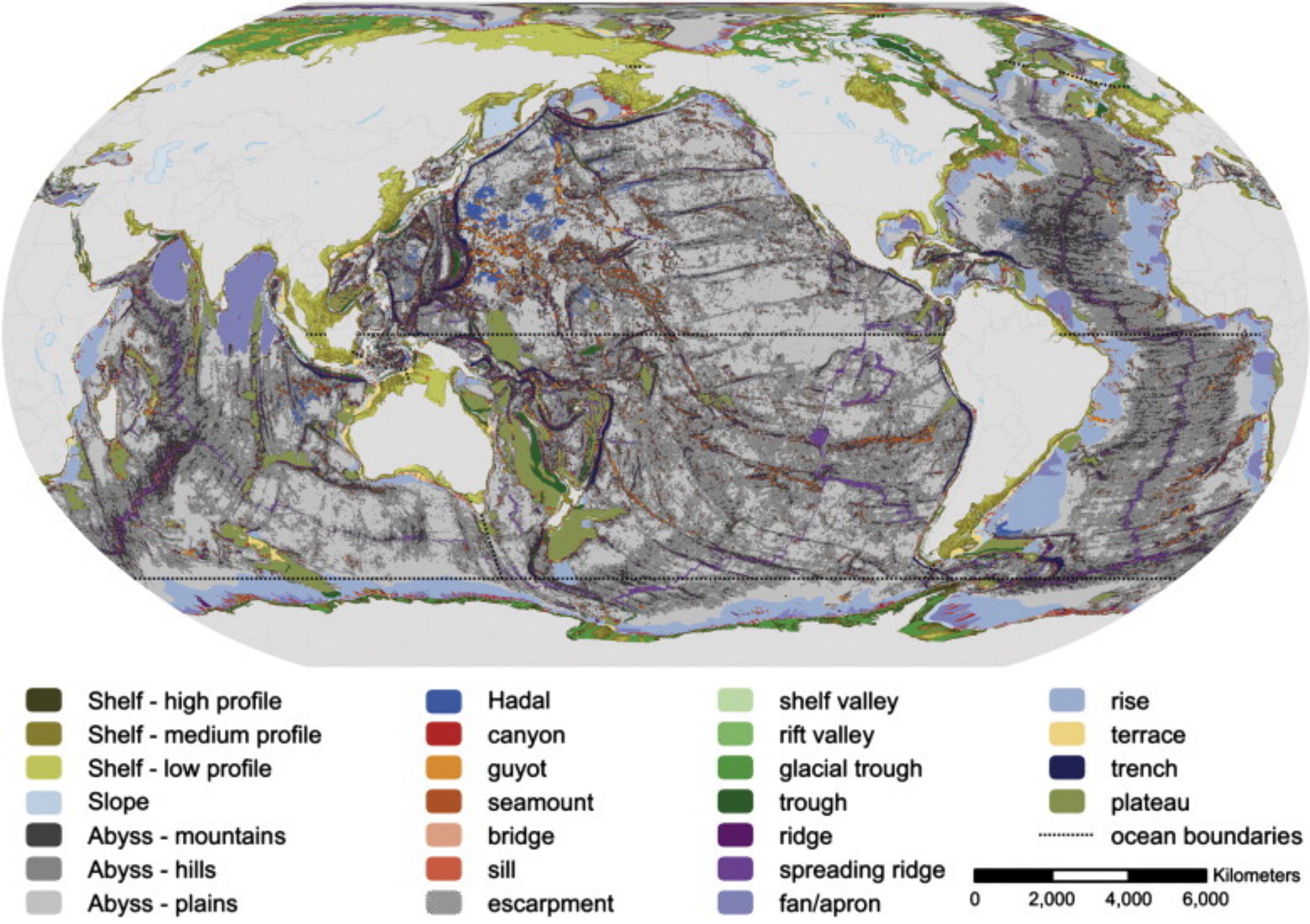
EMODNET
http://www.emodnet.eu



SEA FLOOR MORPHOLOGY

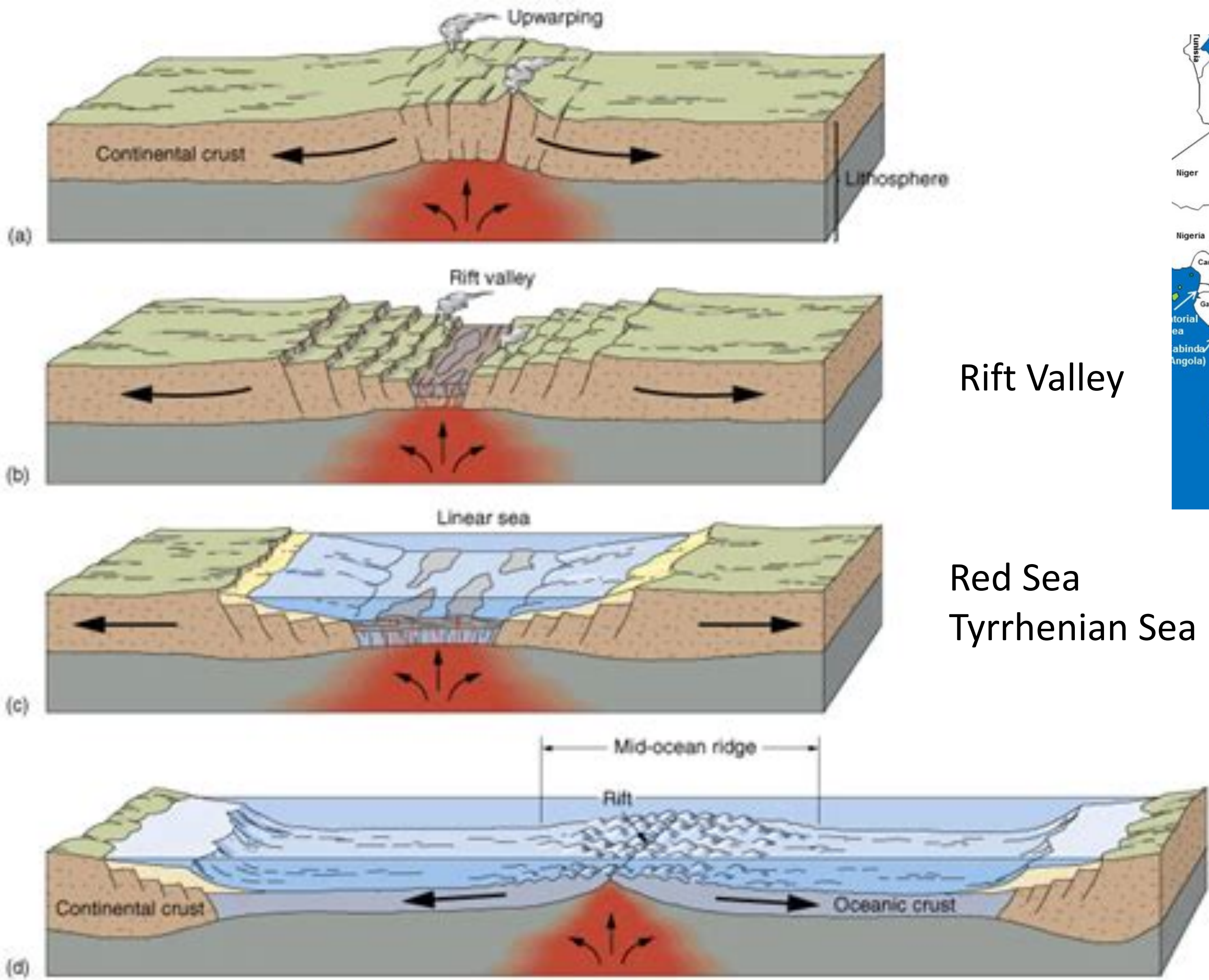


Geomorphic features map of the world's oceans.



Harris, Macmillan-Lawler, Rupp, Baker, 2014. **Geomorphology of the oceans.** Marine Geology, 352, 2014, 4–24. http://dx.doi.org/10.1016/j.margeo.2014.01.011

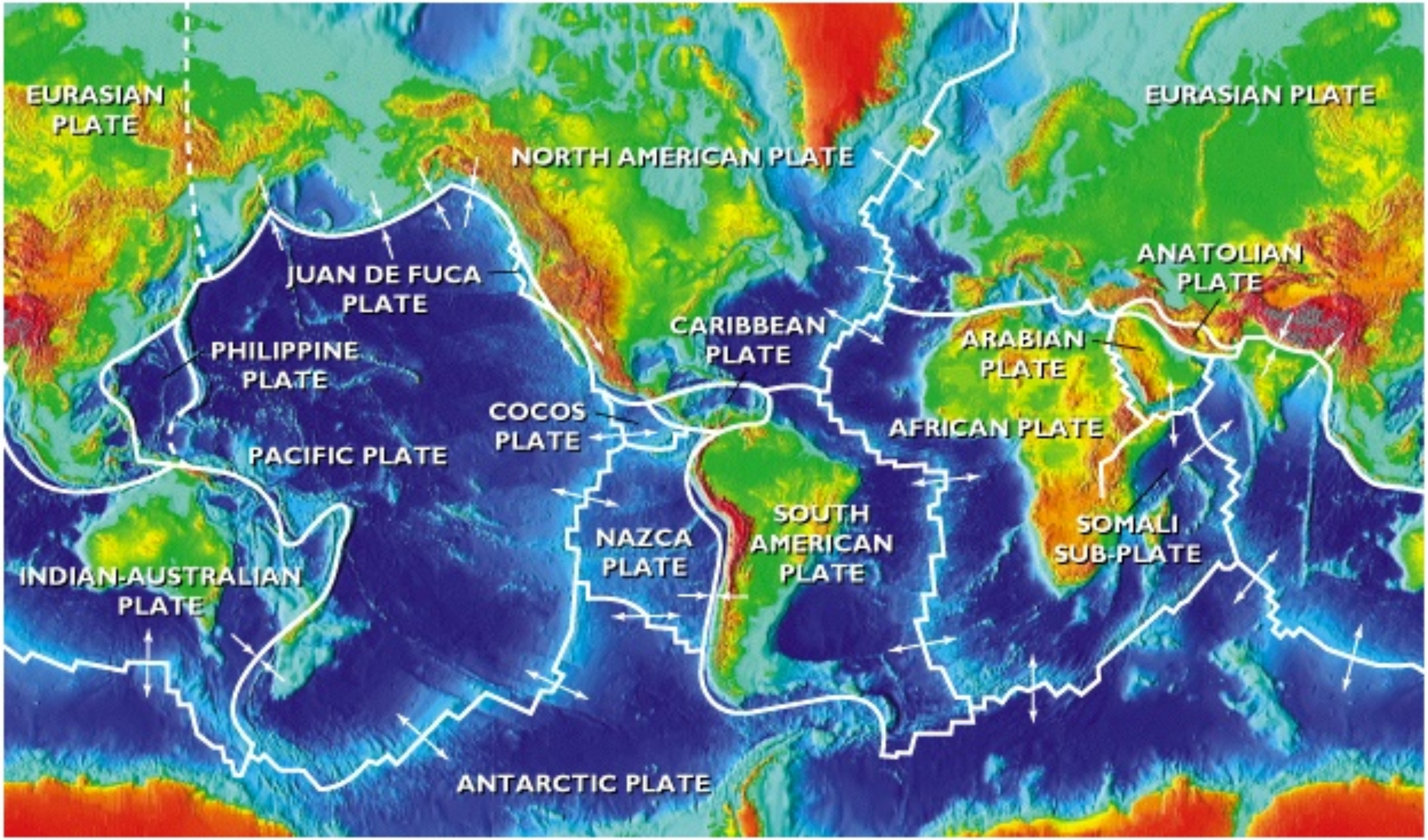
3. The structure of the ocean



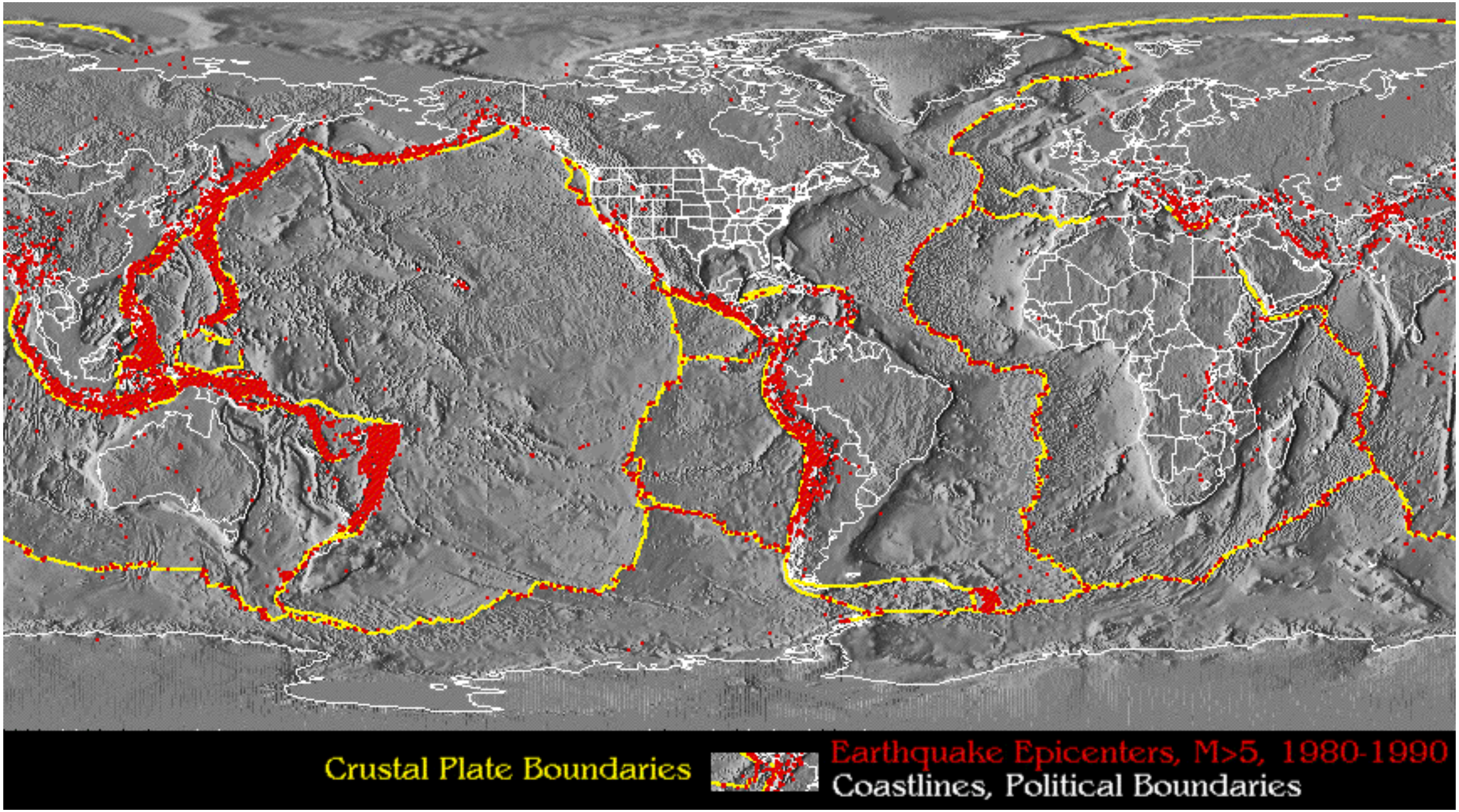
Rift Valley

Red Sea
Tyrrhenian Sea

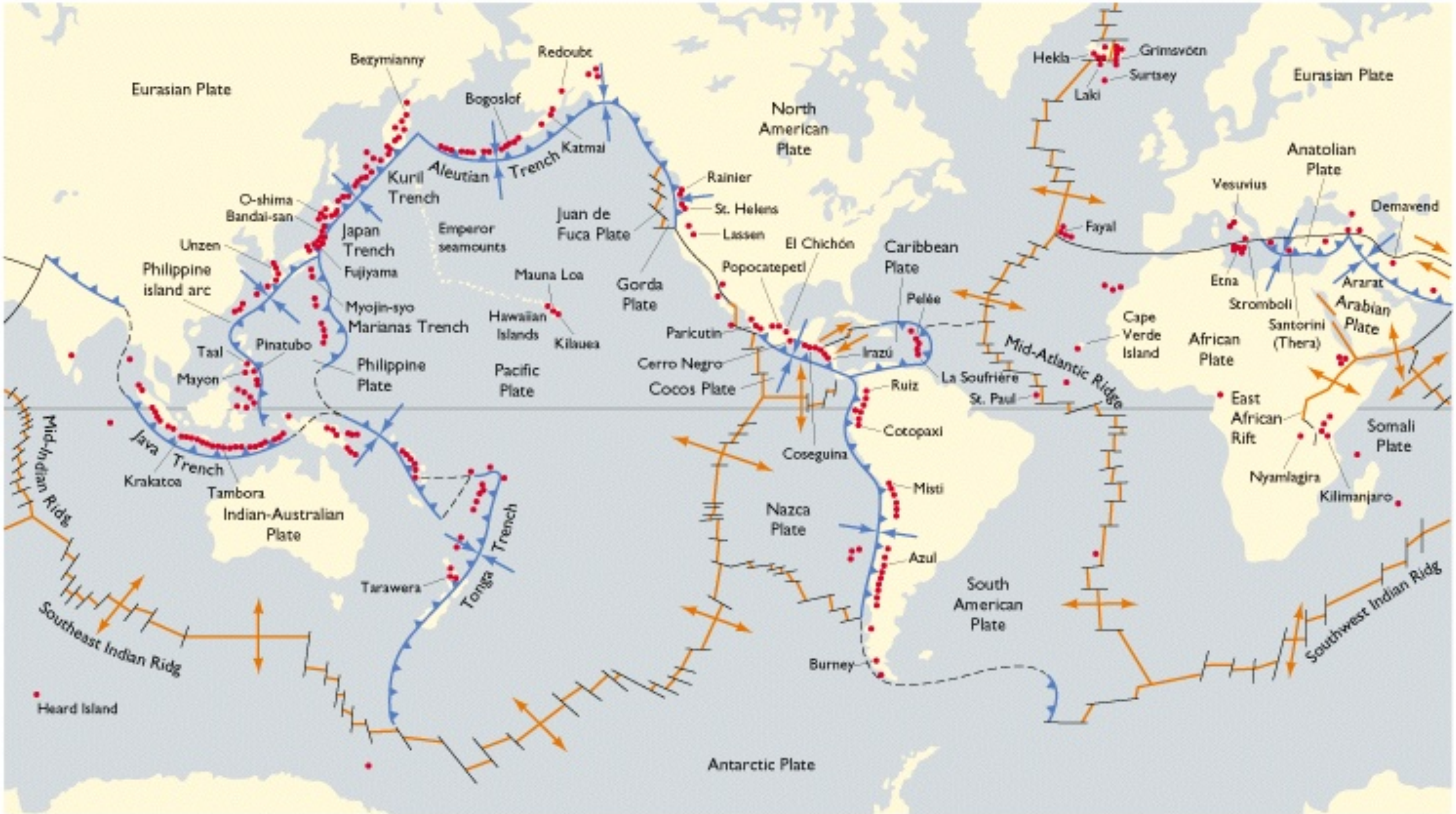
PLATES OF THE WORLD

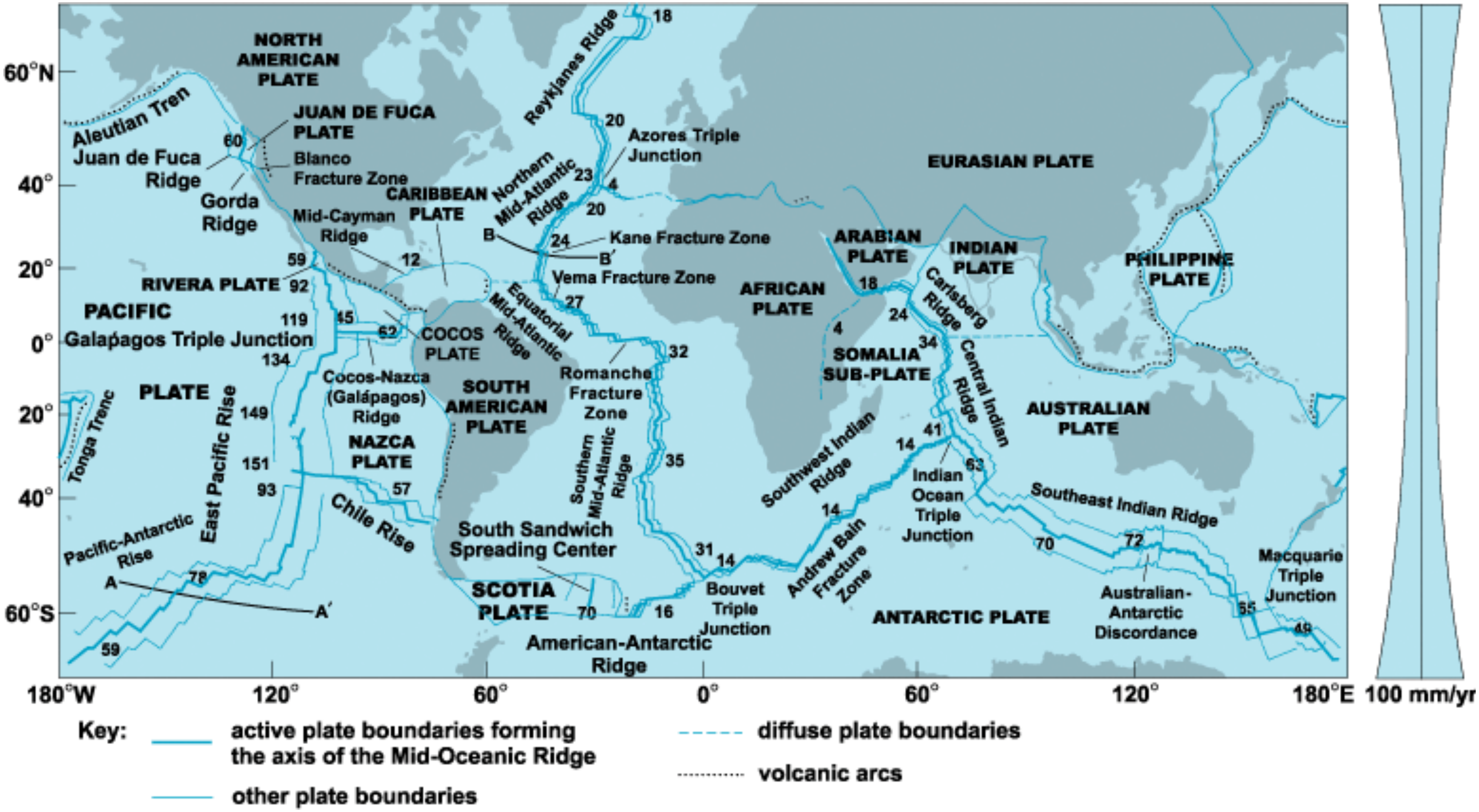


Mid-oceanic ridge system is 60,000 km long, 2000 km wide, 3000 m high



Shallow earthquakes at the Ocean Ridges

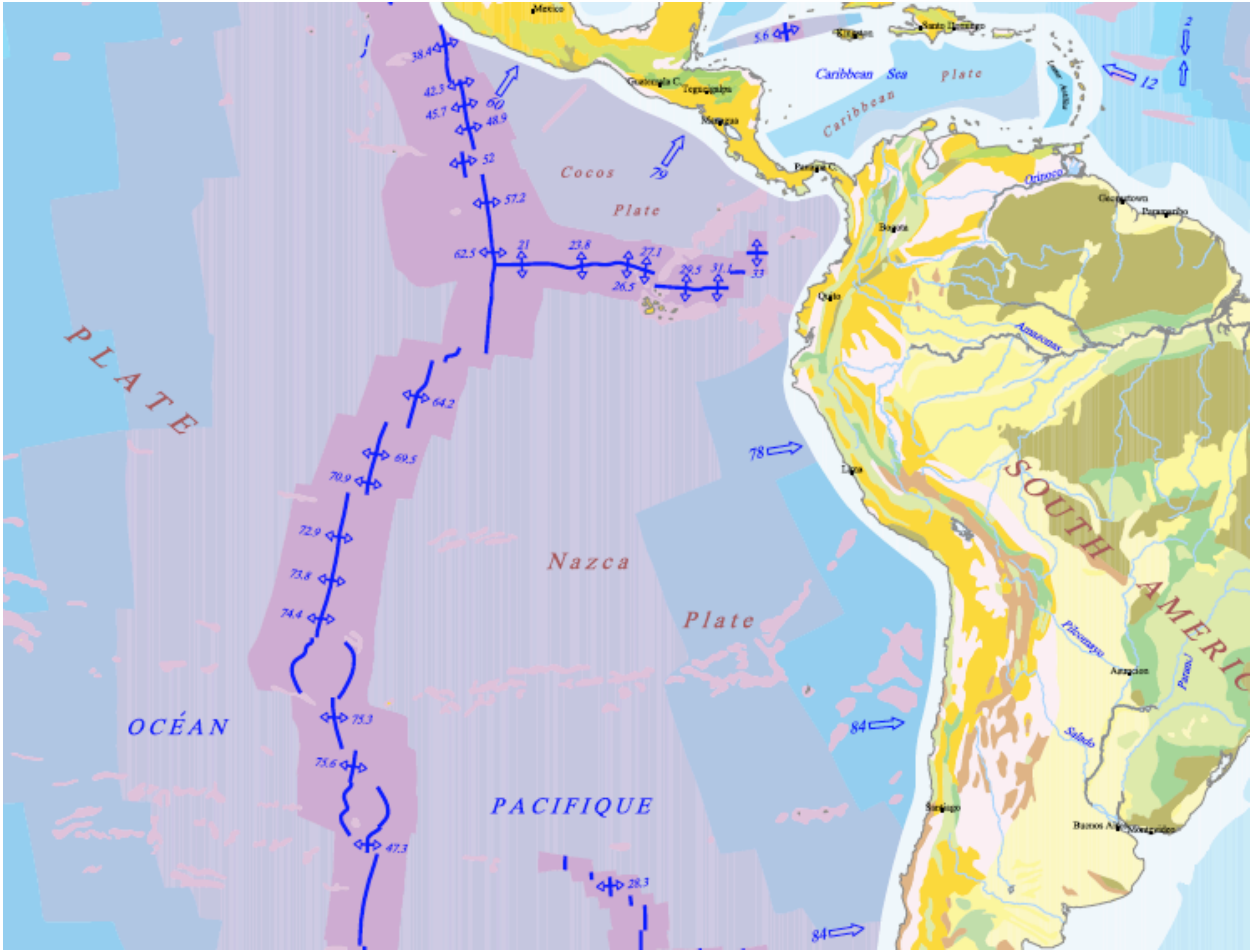

Eurasian Plate
Bezymianny
Redoubt
Bogoslof
Katmai
Aleutian Trench
Kuril Trench
O-shima
Bandai-san
Japan Trench
Unzen
Fujiyama
Emperor seamounts
Philippine island arc
Myojin-syo
Marianas Trench
Pinatubo
Taal
Mayon
Philippine Plate
Mauna Loa
Hawaiian Islands
Kilauea
Pacific Plate
Juan de Fuca Plate
Gorda Plate
Rainier
St. Helens
Lassen
North American Plate
El Chichón
Popocatepetl
Paricutin
Cerro Negro
Cocos Plate
Irazú
Caribbean Plate
Pelée
La Soufrière
St. Paul
Ruiz
Cotopaxi
Coseguina
Nazca Plate
Misti
Azul
Burney
South American Plate
Mid-Atlantic Ridge
Hekla
Grimsvötn
Surtsey
Laki
Fayal
Cape Verde Island
African Plate
Eurasian Plate
Anatolian Plate
Vesuvius
Demavend
Etna
Stromboli
Santorini (Thera)
Ararat
Arabian Plate
East African Rift
Nyamlagira
Kilimanjaro
Somali Plate
Southwest Indian Ridge
Mid-Indian Ridge
Java Trench
Krakatoa
Tambora
Indian-Australian Plate
Tarawera
Tonga Trench
Southeast Indian Ridge
Heard Island
Antarctic Plate



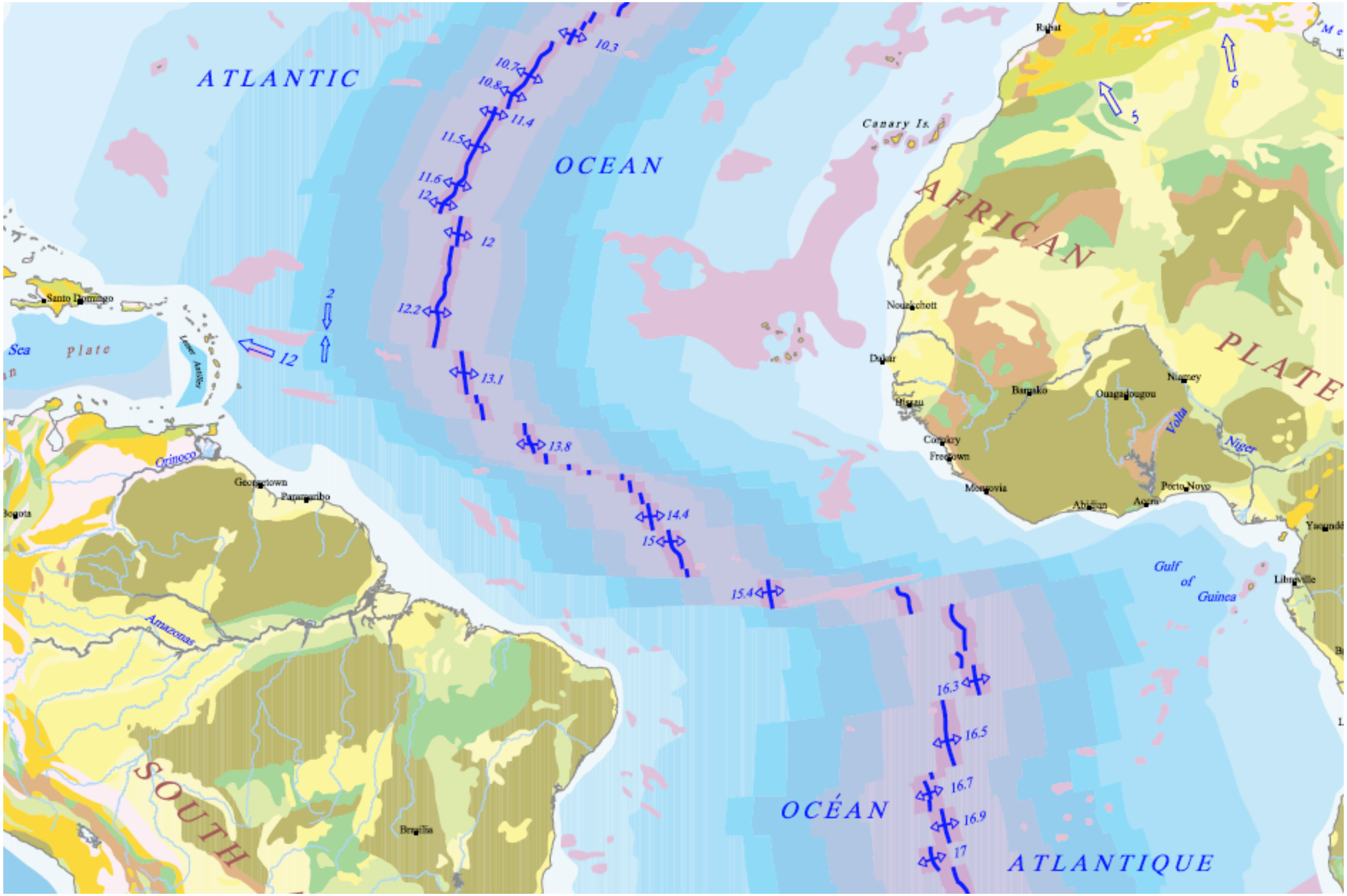
Mid-Oceanic Ridge system

Paired lines on either side of the axis show the amount of crust generated in the last 10 million years at the current opening rates.

Dotted lines show the volcanic arcs, which are lines of volcanoes and volcanic islands formed from magma rising from the subducted plate. The distortion caused by plotting these lines on a Mercator projection is indicated by the hourglass-shaped graph on the right, which gives the amount of crust generated at a 100 mm/yr opening rate (1 mm = 0.04 in.).



half spreading rate in mm/year



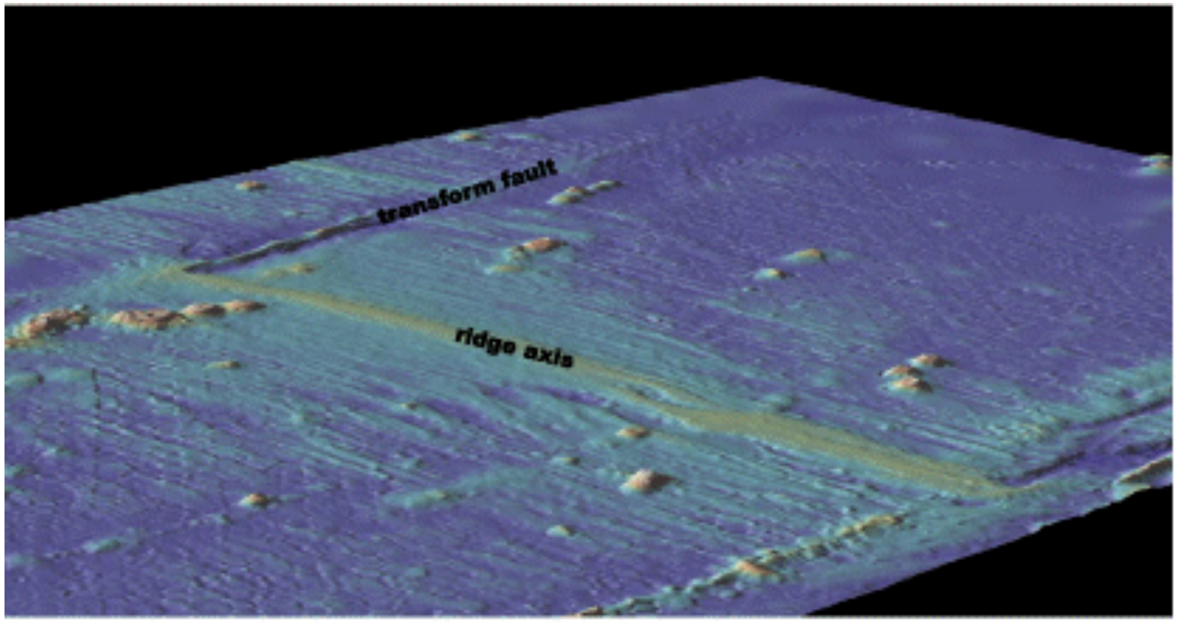
half spreading rate in mm/year

Pacific-Antarctic Ridge: fast-spreading, broad and smooth

Mid-Atlantic Ridge: slow-spreading, narrow and rough

In places where spreading is fastest (more than 80 millimeters per year), the ridge has relatively gentle topography and is roughly dome-shaped in cross-section as a result of the many layers of lava that build up over time.
At slow- and ultra-slow spreading centers, the ridge is much more rugged, and spreading is dominated more by tectonic processes rather than volcanism.

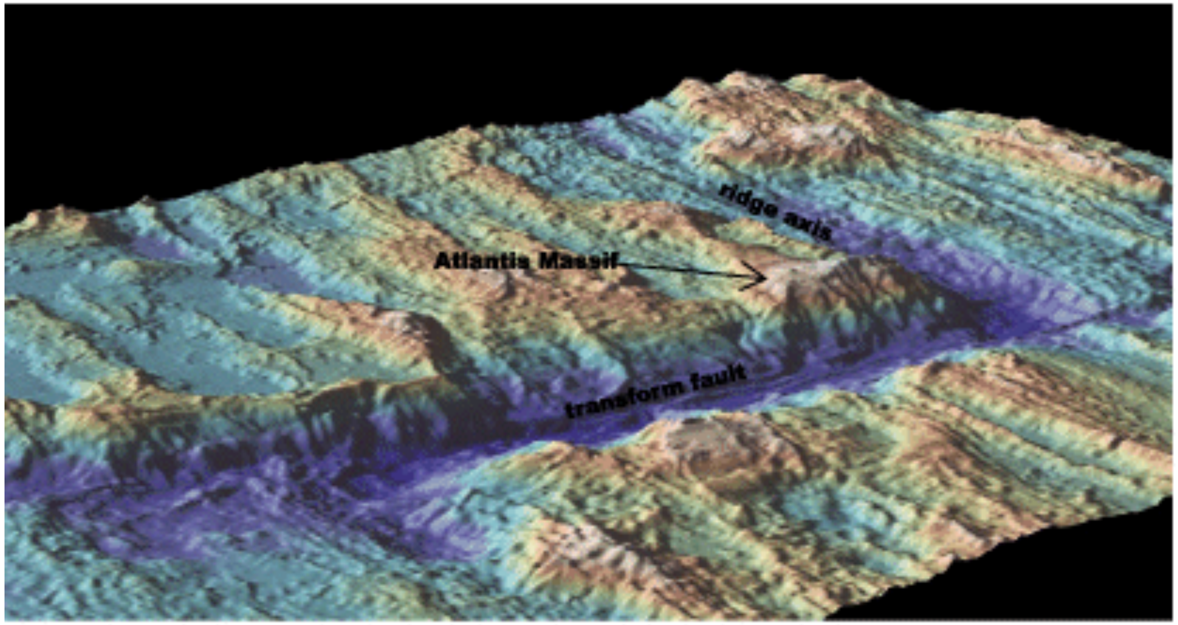
The more prominent ridges and valleys on the flanks are fracture zones (transform fault zones) that were crossed at an oblique angle.
(After B. C. Heezen, The deep-sea floor, in S. K. Runcorn, ed., Continental Drift, Academic Press, 1962)



(a)

Oblique view of fast- and slow-spreading mid-ocean ridges, showing differences in morphology along the ridge.

a) *Fast-spreading East Pacific Rise at 19°S, viewed toward the north.*

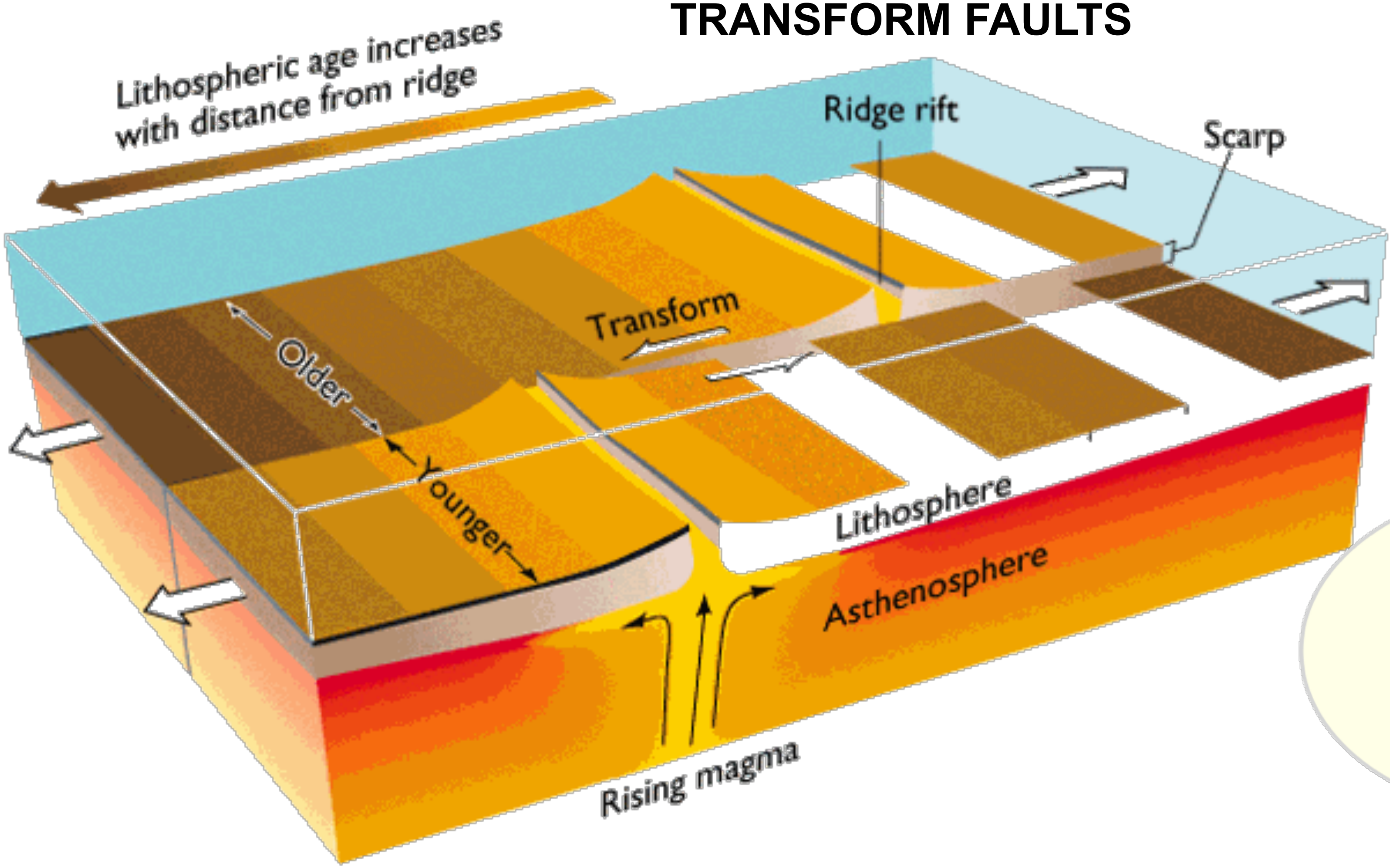


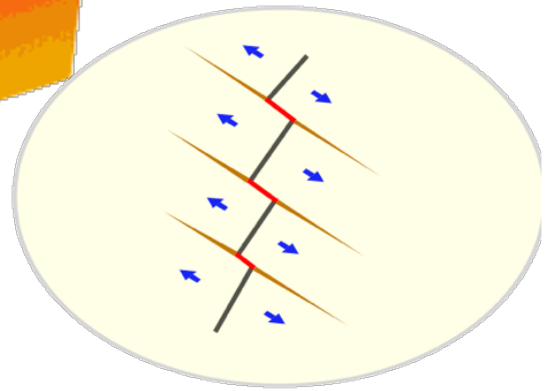
(b)

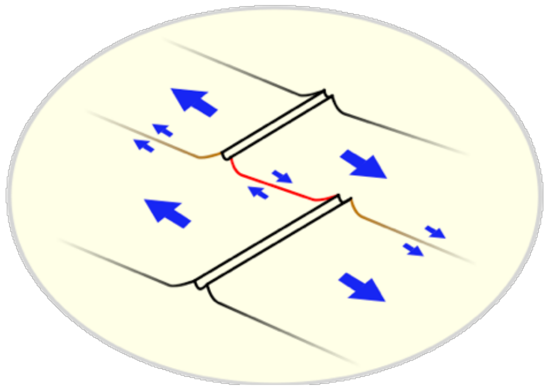
b) *Slow-spreading Mid-Atlantic Ridge at 30°N and the Atlantis transform view toward the northeast.*

Images made with GeoMapApp software with multibeam sonar data (each with 2× vertical exaggeration).
(W. Haxby 2006, GeoMapApp; Marine Geosciences Data Management System, http://www.GeoMapApp.org/)

TRANSFORM FAULTS







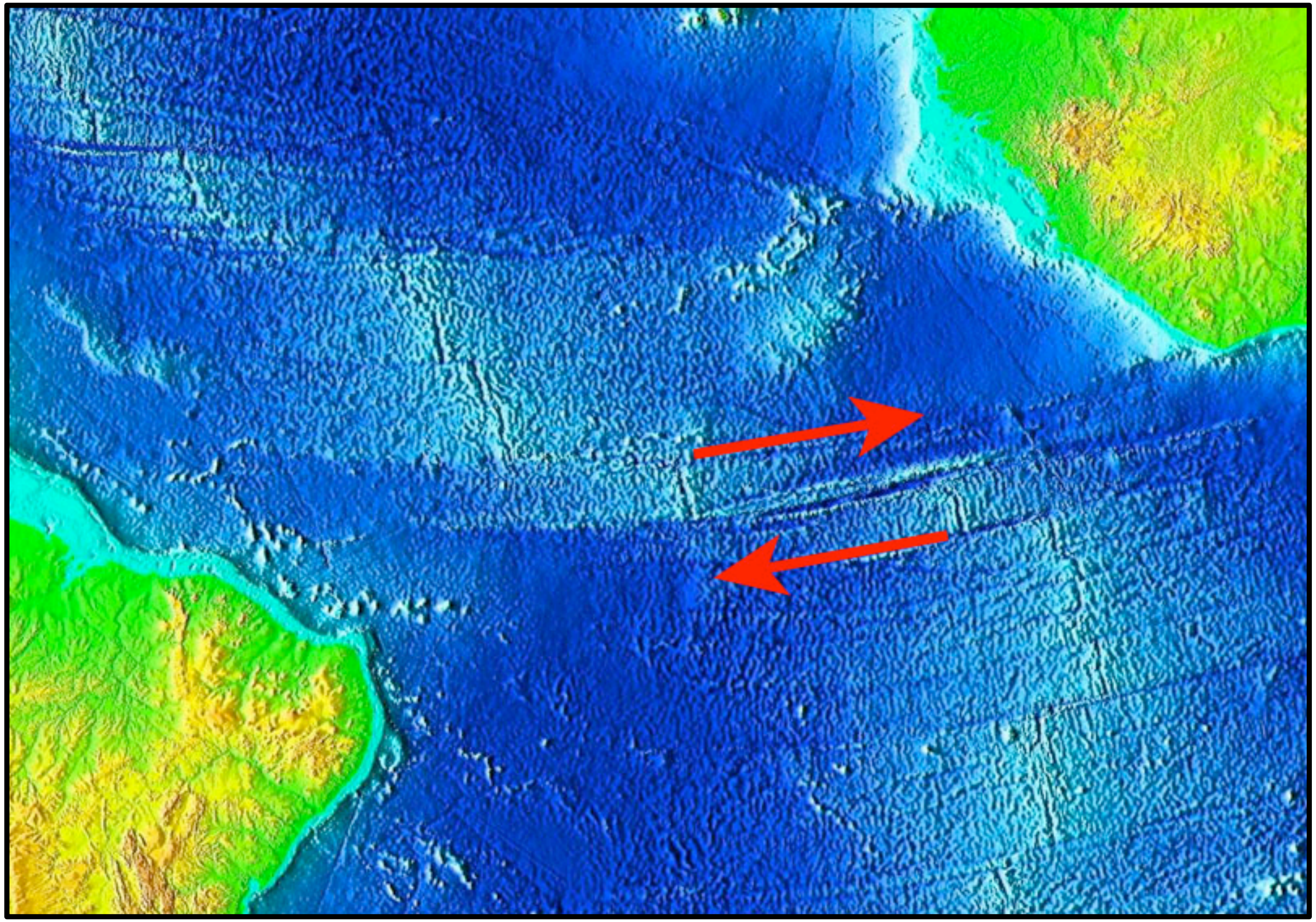
A transform fault or transform boundary, also known as conservative plate boundary since these faults neither create nor destroy lithosphere, is a type of fault whose relative motion is predominantly horizontal in either sinistral or dextral direction.

TRANSFORM FAULTS

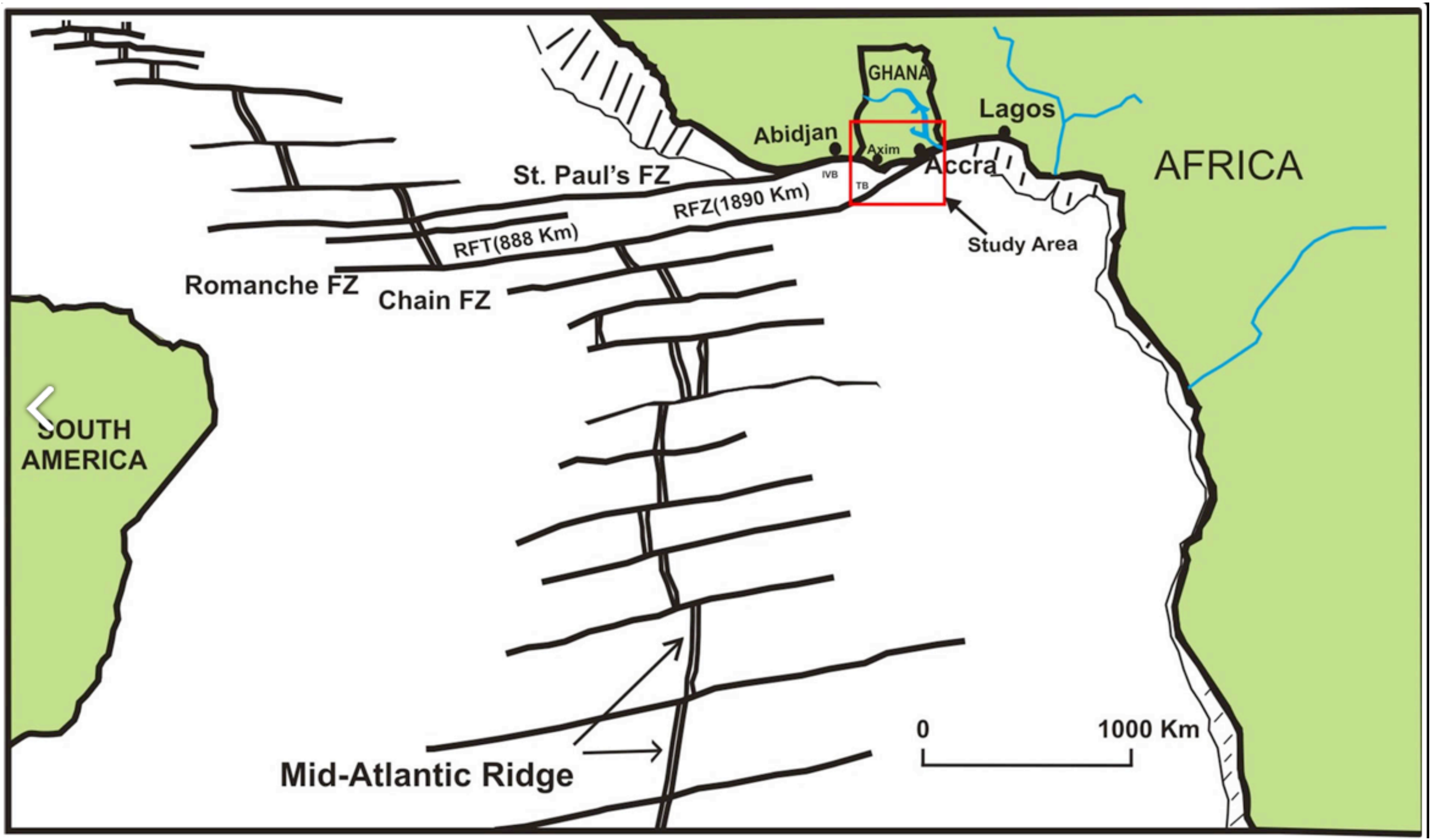
First discovered in the Pacific Ocean by Vacquier (1965): left-lateral offset along the Mendocino and Pioneer faults amount of 1450 km, while the right-lateral offset across the Murray fault is 600 km in the west and only 150 km in the east.

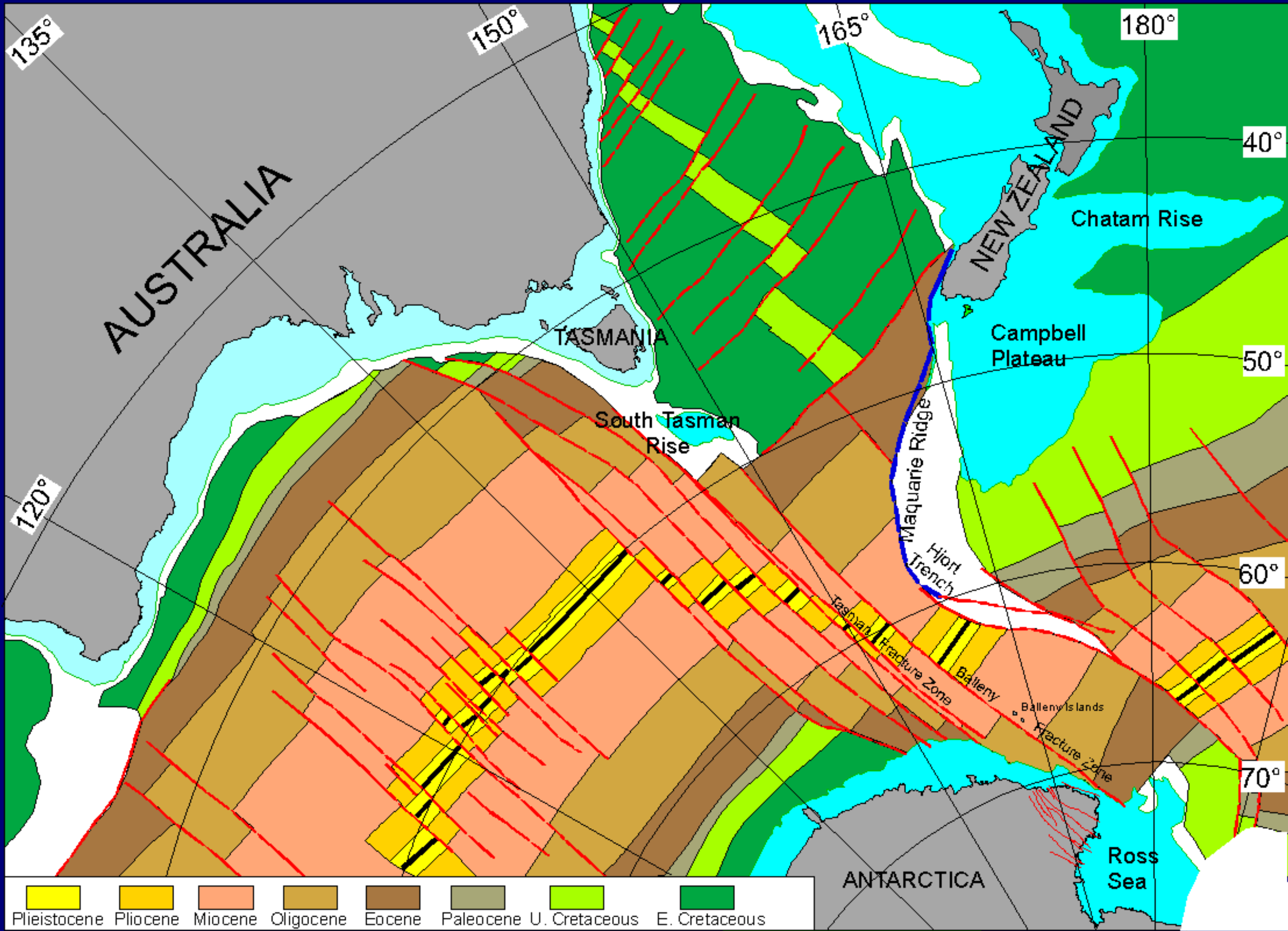
Wilson (1965) termed the faults “Transform” as:
the lateral displacement across the fault is taken up by transforming it into either the formation of new lithosphere at a terminated ocean ridge segment or lithosphere subduction at a trench.

The transtorm faults can form a tectonic plate boundary

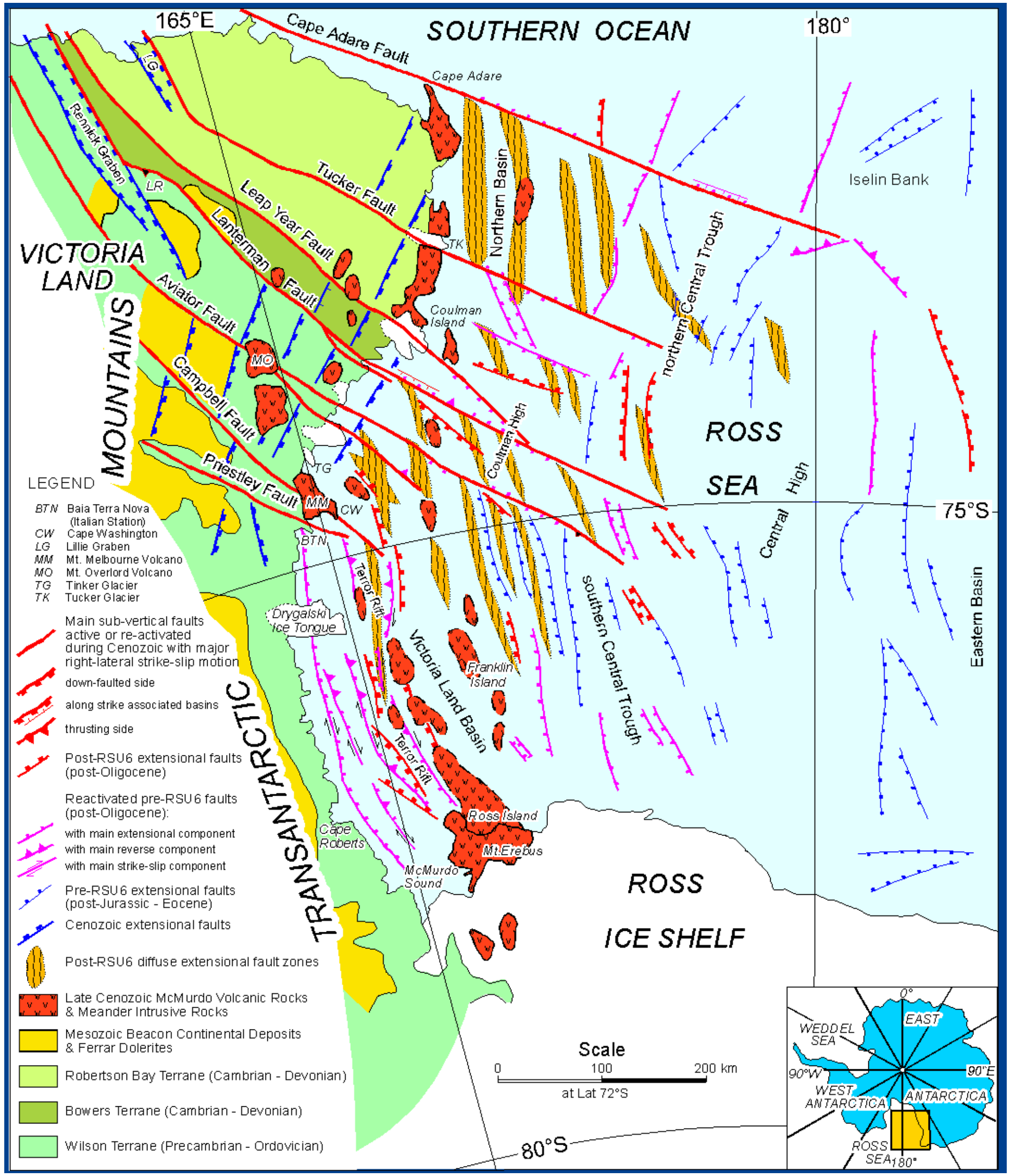


The Romanche Trench bisects the Mid-Atlantic Ridge just north of the equator at the narrowest part of the Atlantic between Brazil and West Africa.


GHANA
Lagos
Abidjan
Axim
Accra
AFRICA
St. Paul's FZ
IVB
TB
RFZ(1890 Km)
RFT(888 Km)
Study Area
Romanche FZ
Chain FZ
SOUTH
AMERICA
0
1000 Km
Mid-Atlantic Ridge



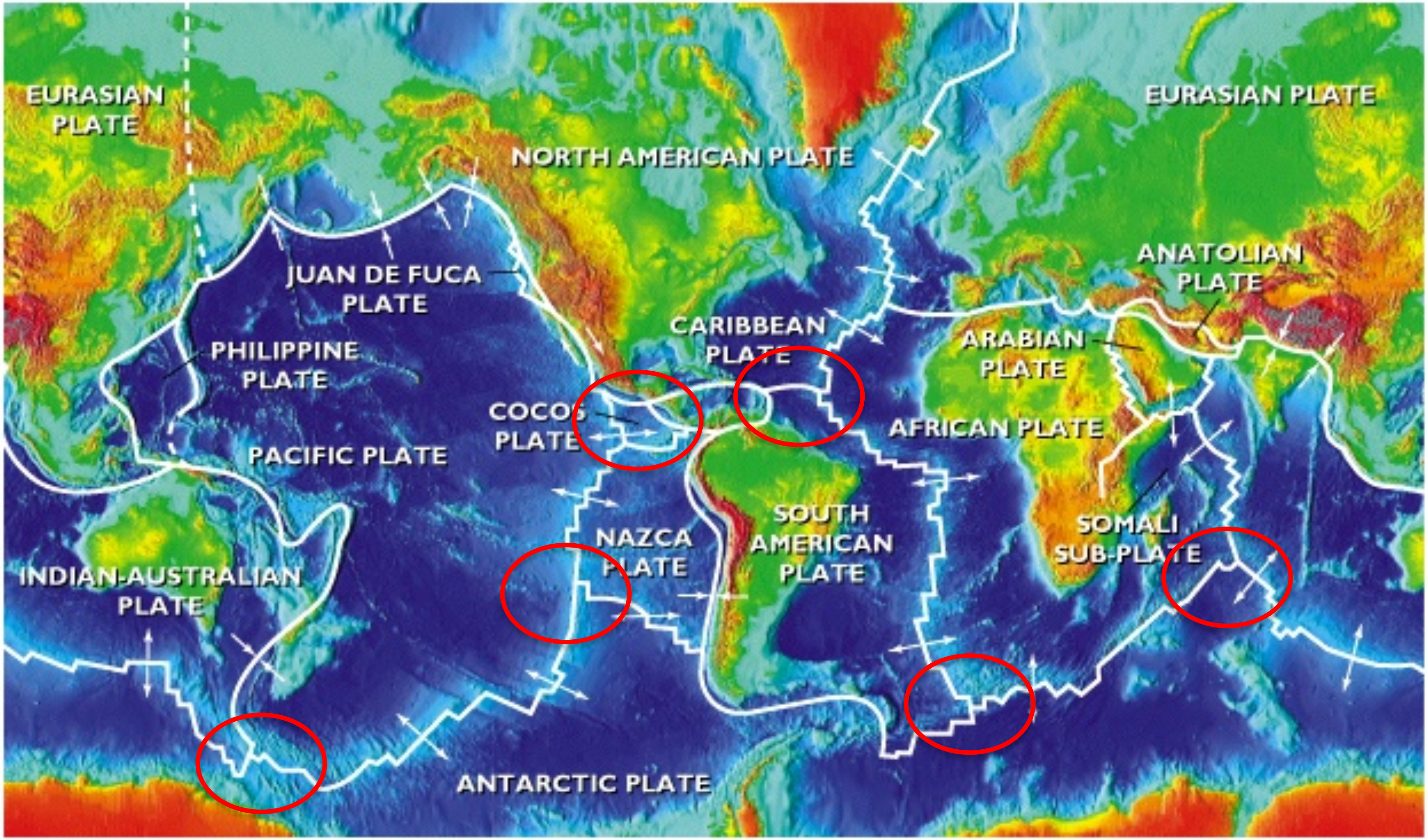
Modified from Hayes, 1991

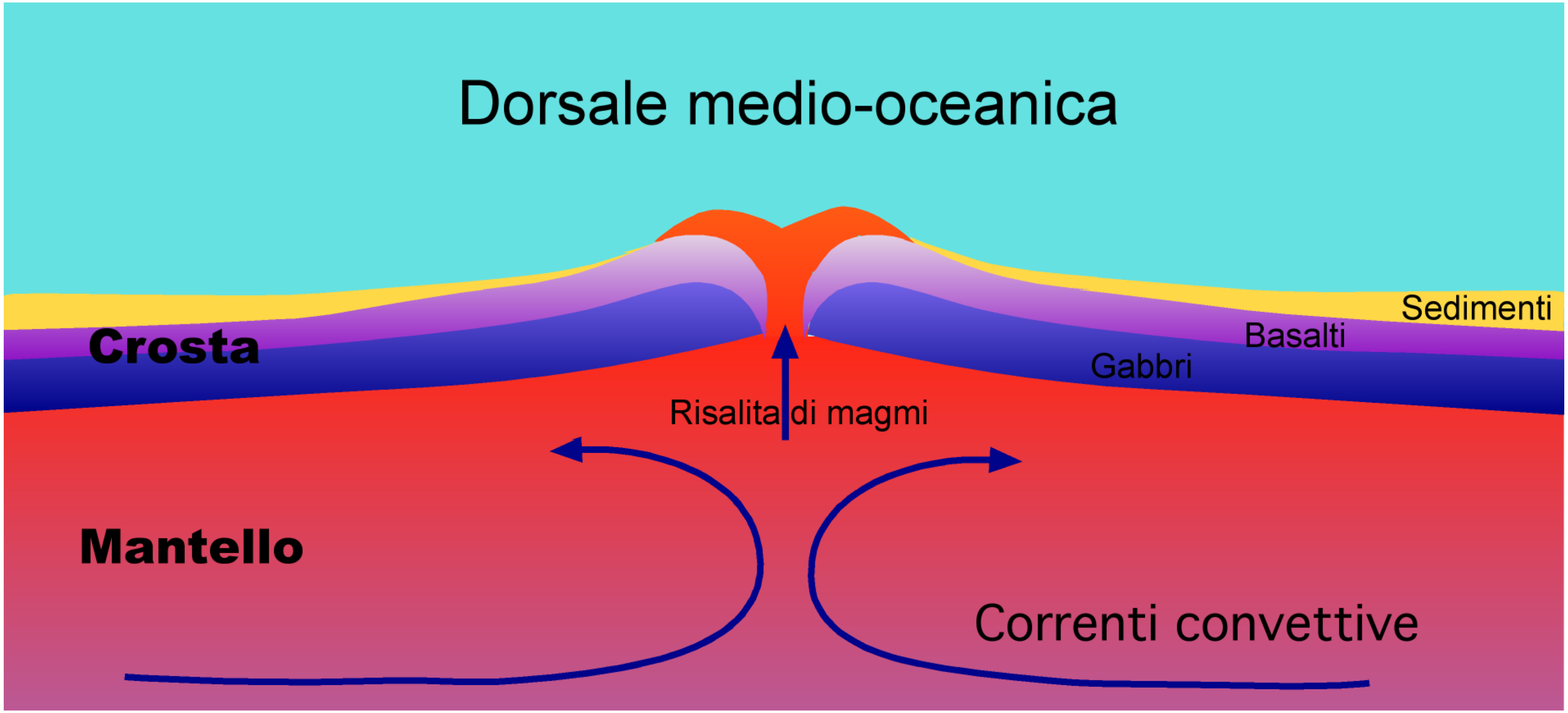


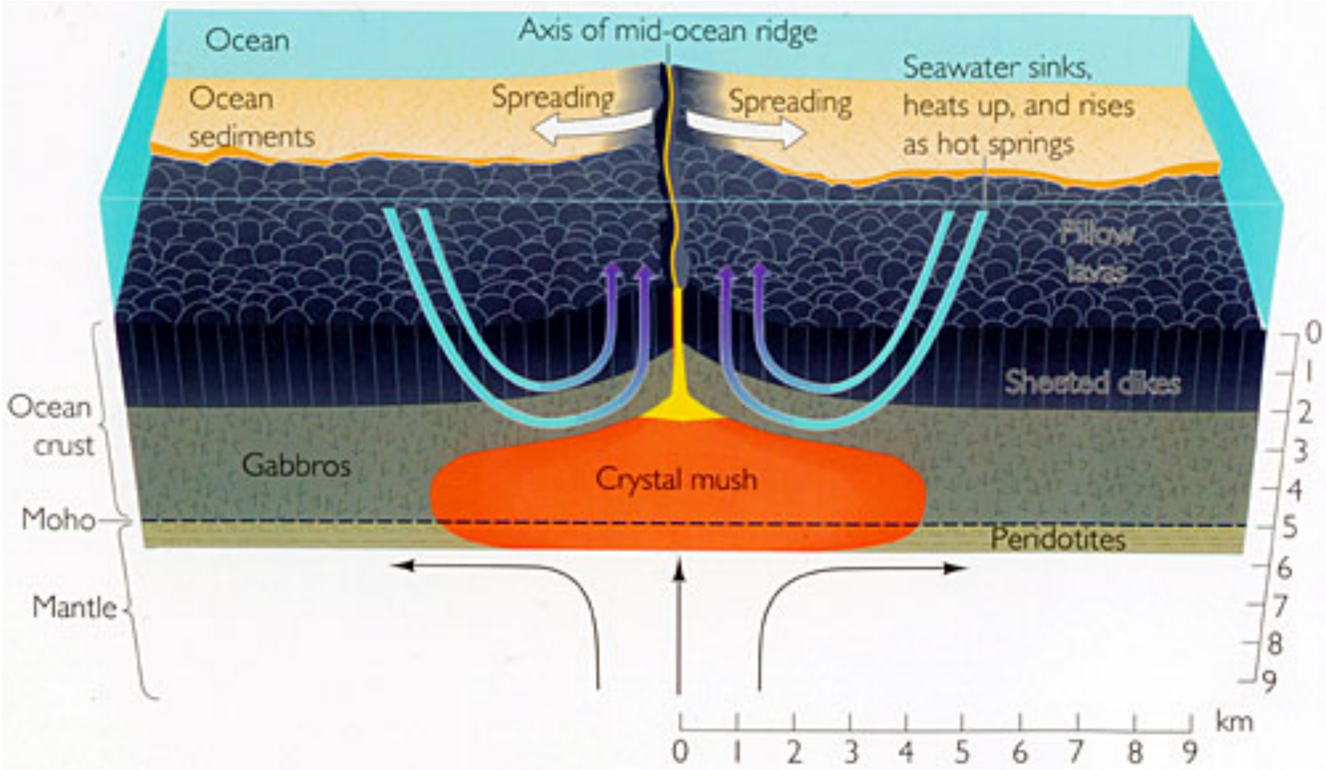
Salvini et al., 1997, Journal of Geophysical Research

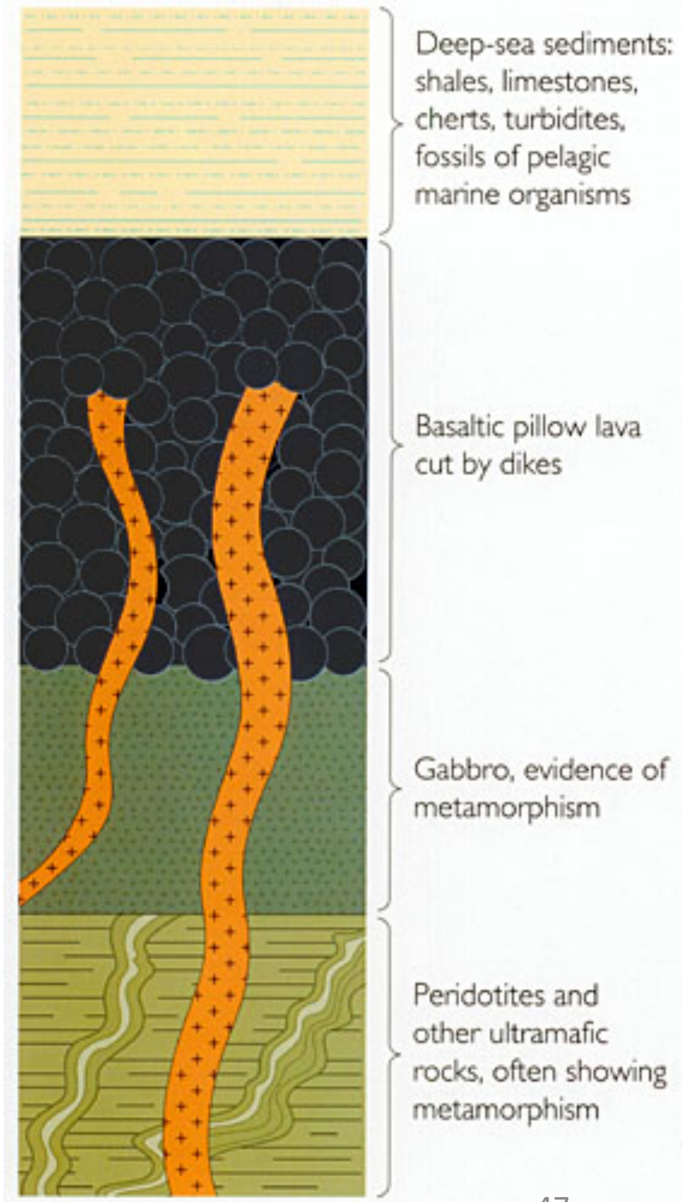
La faglie principali nella Terra Vittoria Settentrionale e nel Mare di Ross.

Triple junction




Dorsale medio-oceanica
Crosta
Sedimenti
Basalti
Gabbri
Risalita di magmi
Mantello
Correnti convettive





Oceanic plates thin crust (MOHO at about 6 km)
Oceanic plates thicken as they cool (boundary between convecting and non-convecting mantle deepens)
Colder (older) plates sink (subduction)
Examples: Pacific, Nazca, Cocos, Phillipine
On-land examples of ocean crust: ophiolites

- Oceanic crust emplaced upon continents
- Thickness of 8-10 km
- Ophiolite stratigraphy same worldwide => same processes operate worldwide

The compositions of materials erupted at the mid-ocean ridges are tholeiitic basalts called **m**id-**o**cean **r**idge **b**asalts (MORB).

Magnetic Susceptibility

$$K = \frac{M}{H}$$

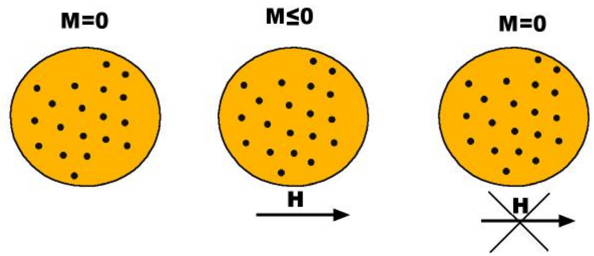
K = magnetic susceptibility
M = induced magnetization in the material
H = applied magnetic field

K < 0

DIAMAGNETIC

weak negative susceptibility

(water, organic matter, quartz, feldspars, calcium carbonate)



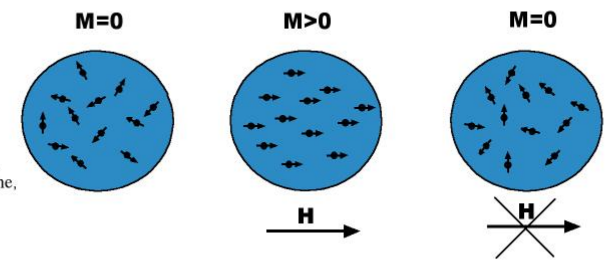
Quarzo, calcite e dolomite

K > 0

PARAMAGNETIC

weak positive susceptibility

(many Fe-containg minerals and salts, eg. biotite, muscovite, pyroxene, olivine, ferrous sulfate)

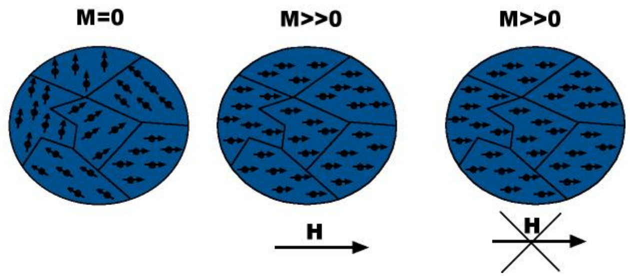


K >> 0

FERROMAGNETIC

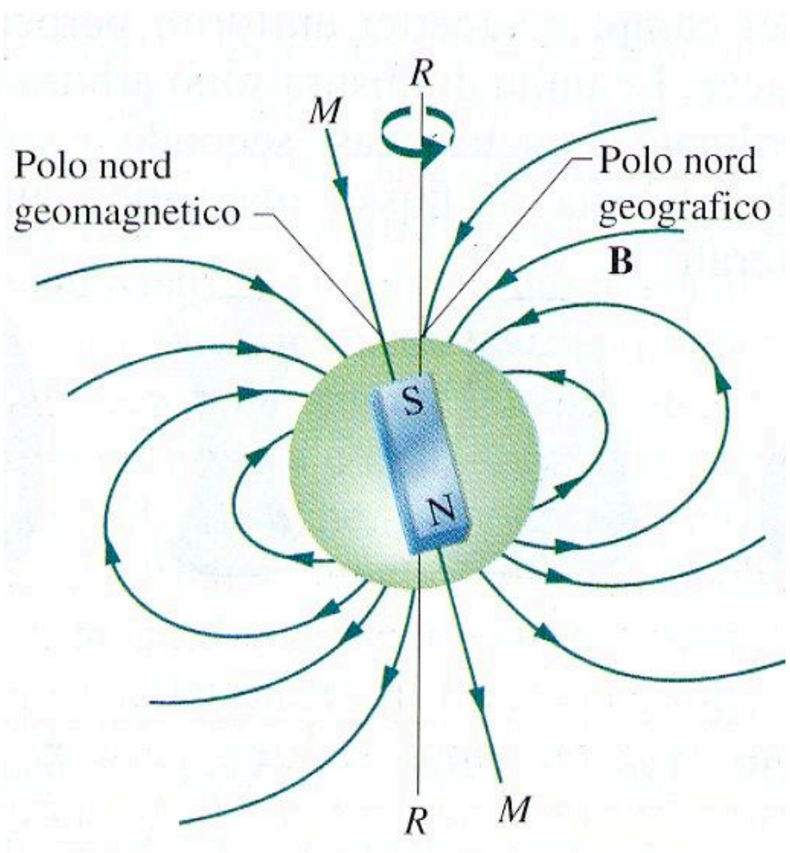
strong positive susceptibility

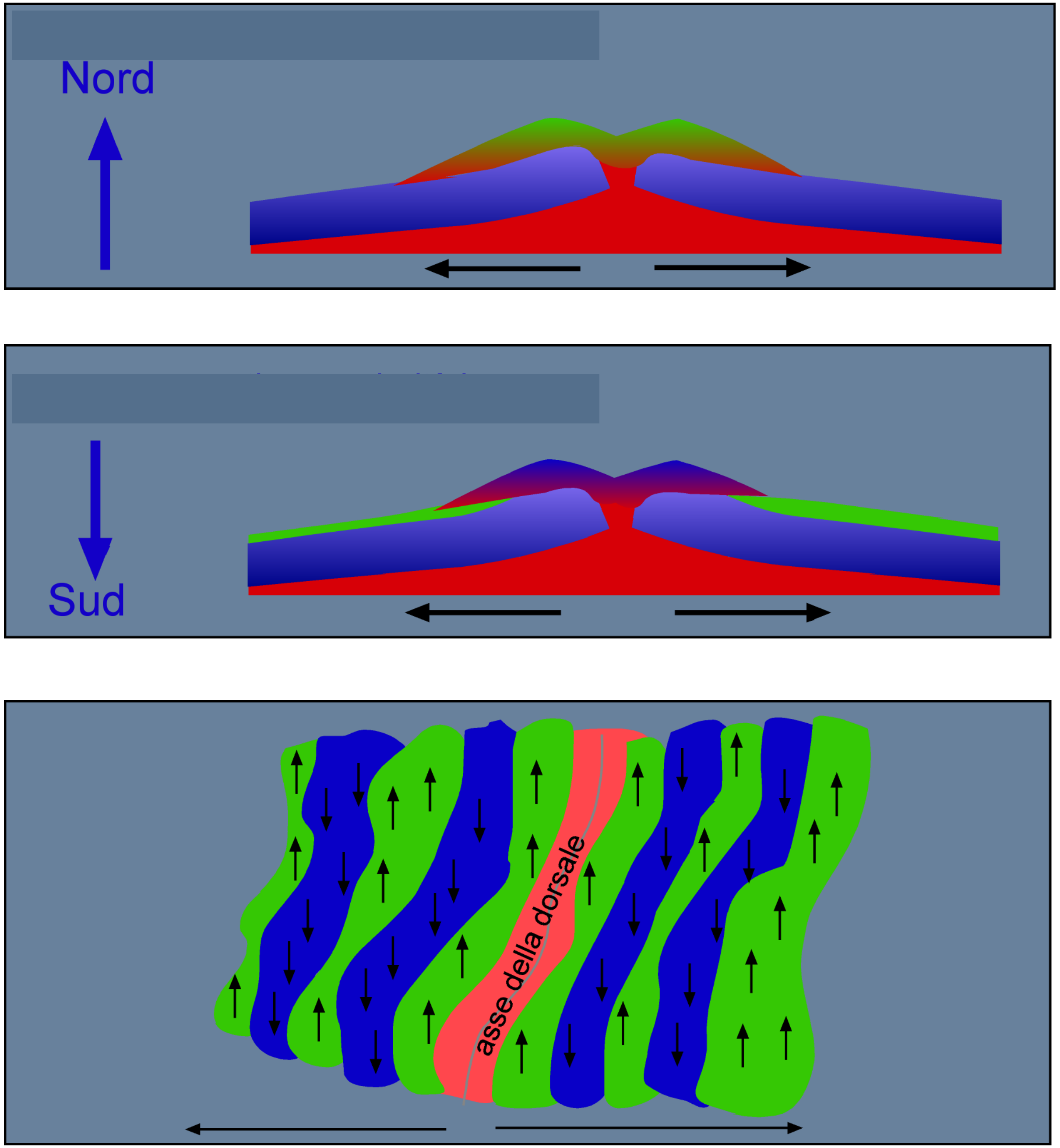
(pure iron like magnetite and ematite, nickel, chromium)



Ossidi di ferro (magnetite Fe_3O_4, ematite α-Fe_2O_3, ilmenite $FeTiO_3$, magnemite γ-Fe_2O_3 e ulvospinello Fe_2TiO_4), idrossidi (es. la goethite (α-$FeO \cdot OH$), solfuri (es. pirite FeS_2).

Present magnetic filed



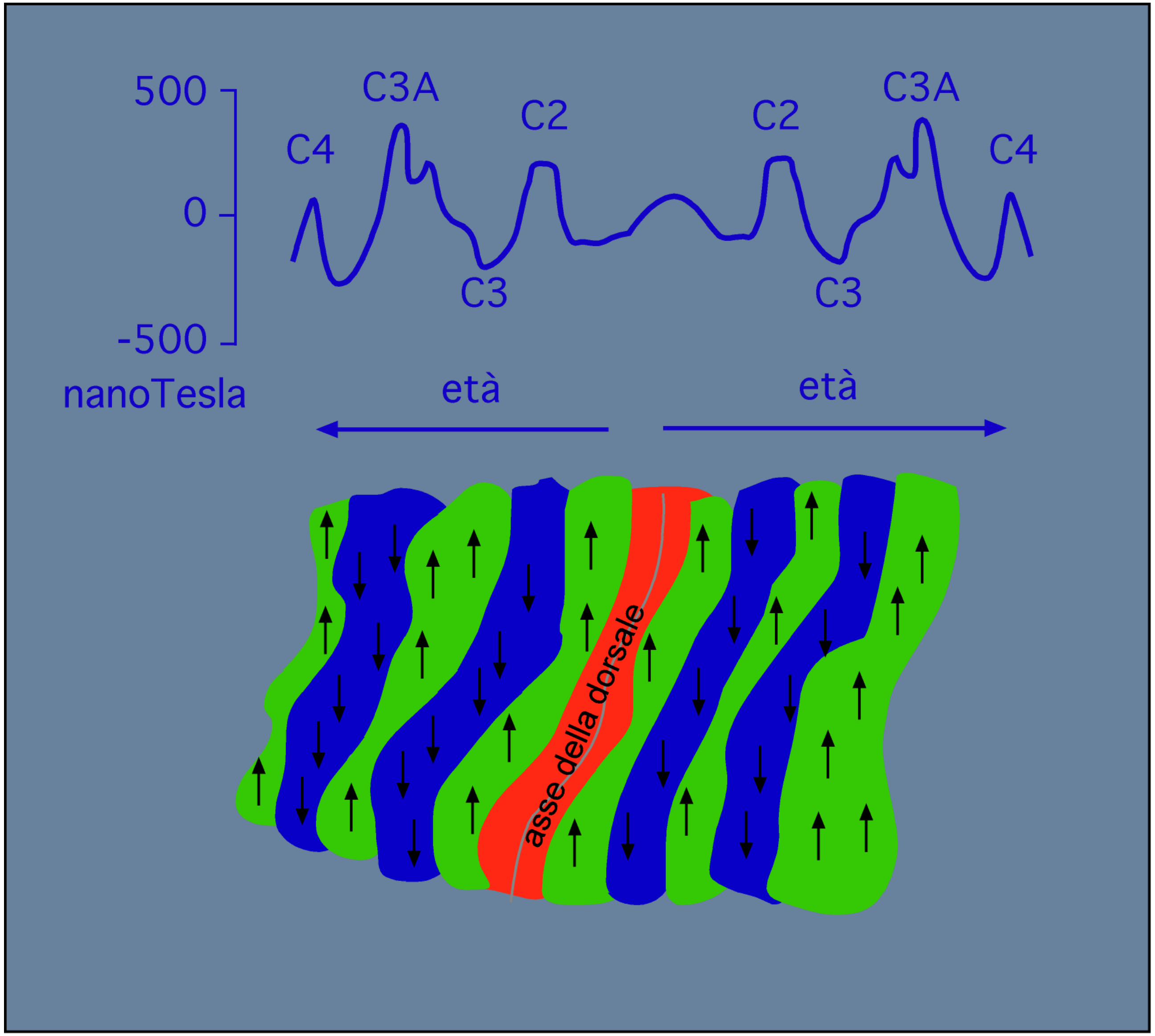



Mare di Ross (Antartide) 2002 – M/N Italica

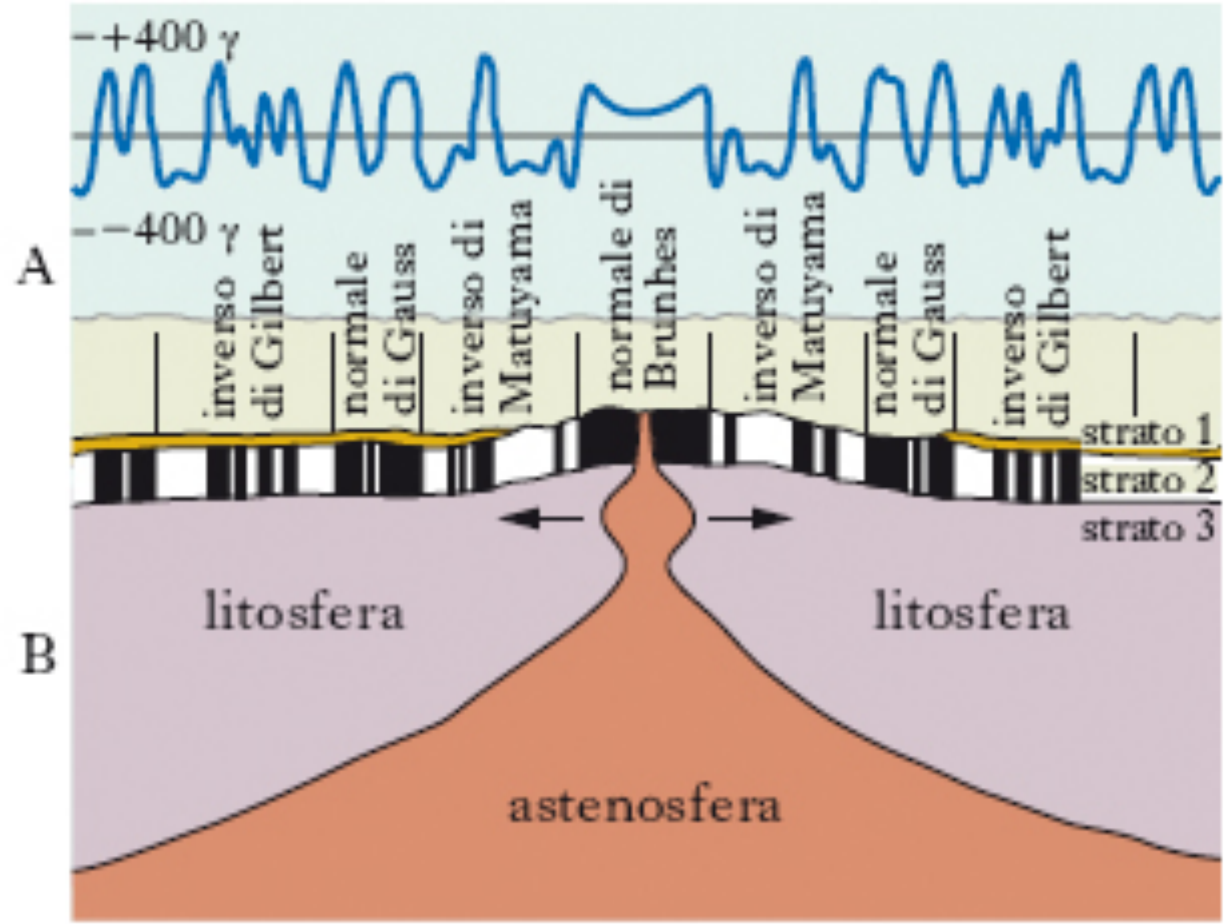
Instruments to measured the earth magnetic field in the ocean:

- magnetometer

- gradiometer composed by two magnetometers to filter time variation in the magnetic field

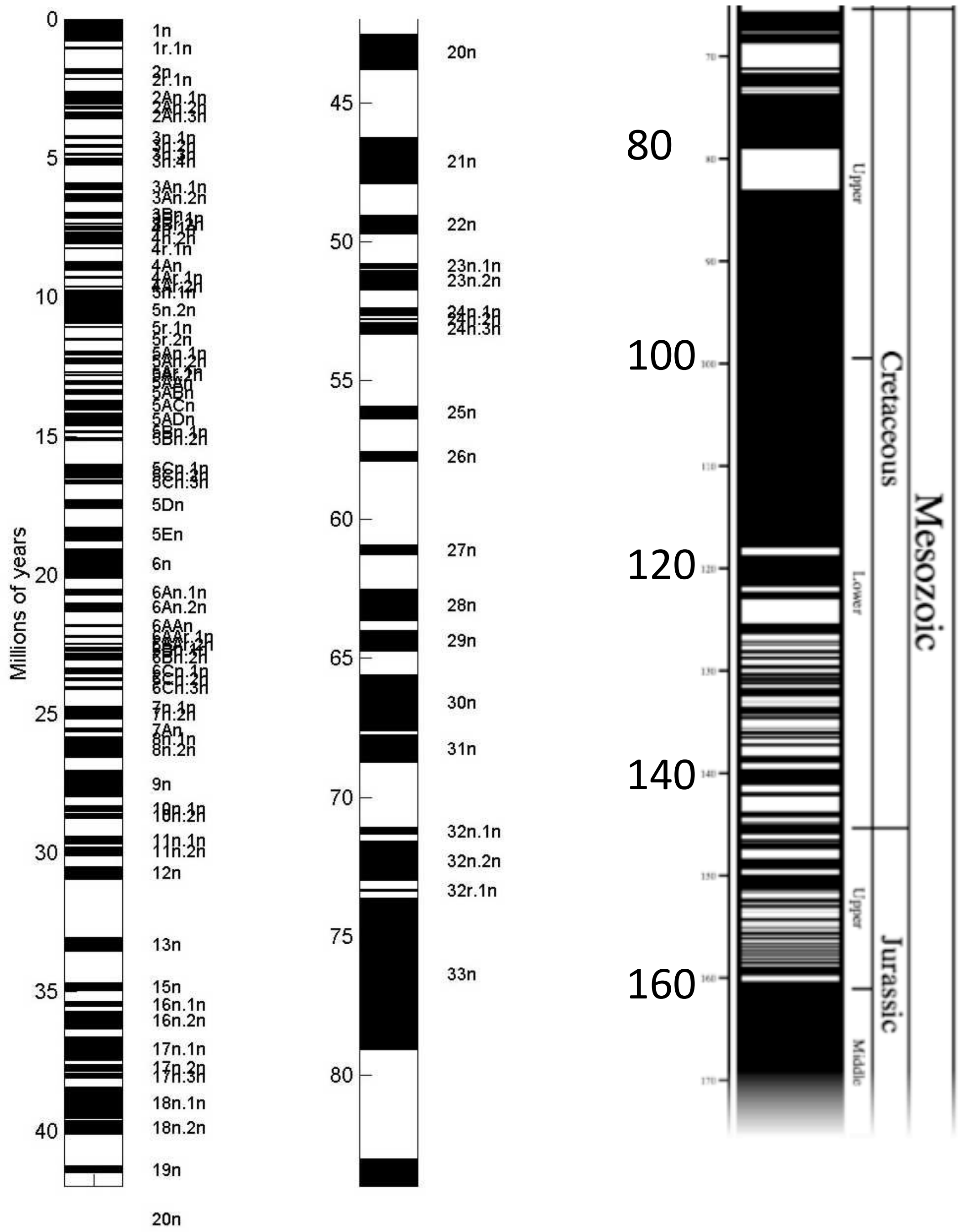


The magnetic anomalies are numbered as C*n* (Chrone *n*) or A*n (*Anomaly *n)*
(C1 or A1 is the youngest and C23 or A23 is older).

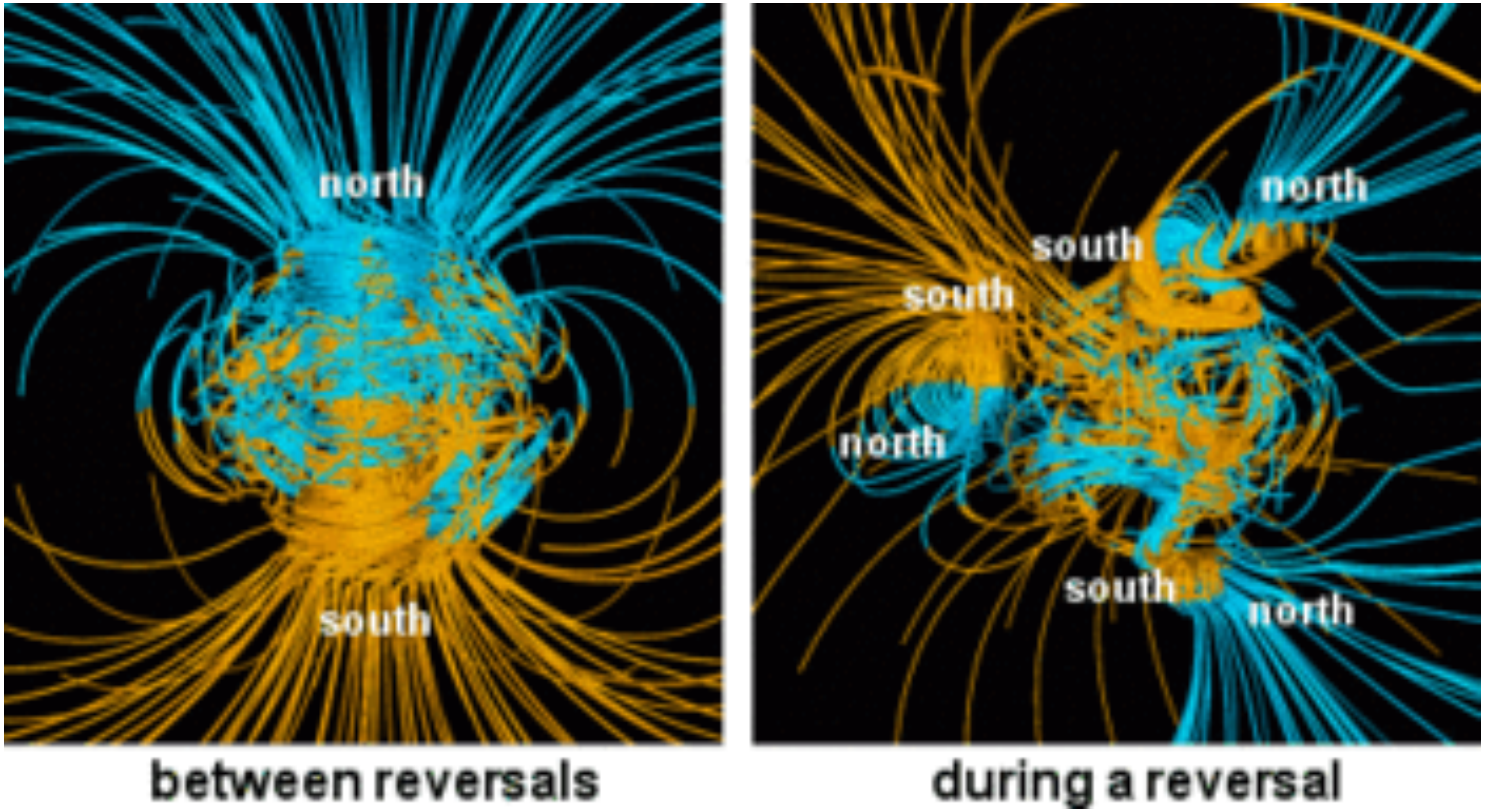


1 - sedimenti non magnetici
2 - colate e strato di basalto a cuscini (altamente magnetico: in nero, polarita normale; in bianco, polarita inversa)
3 - crosta oceanica a gabbri (debolmente magnetica)

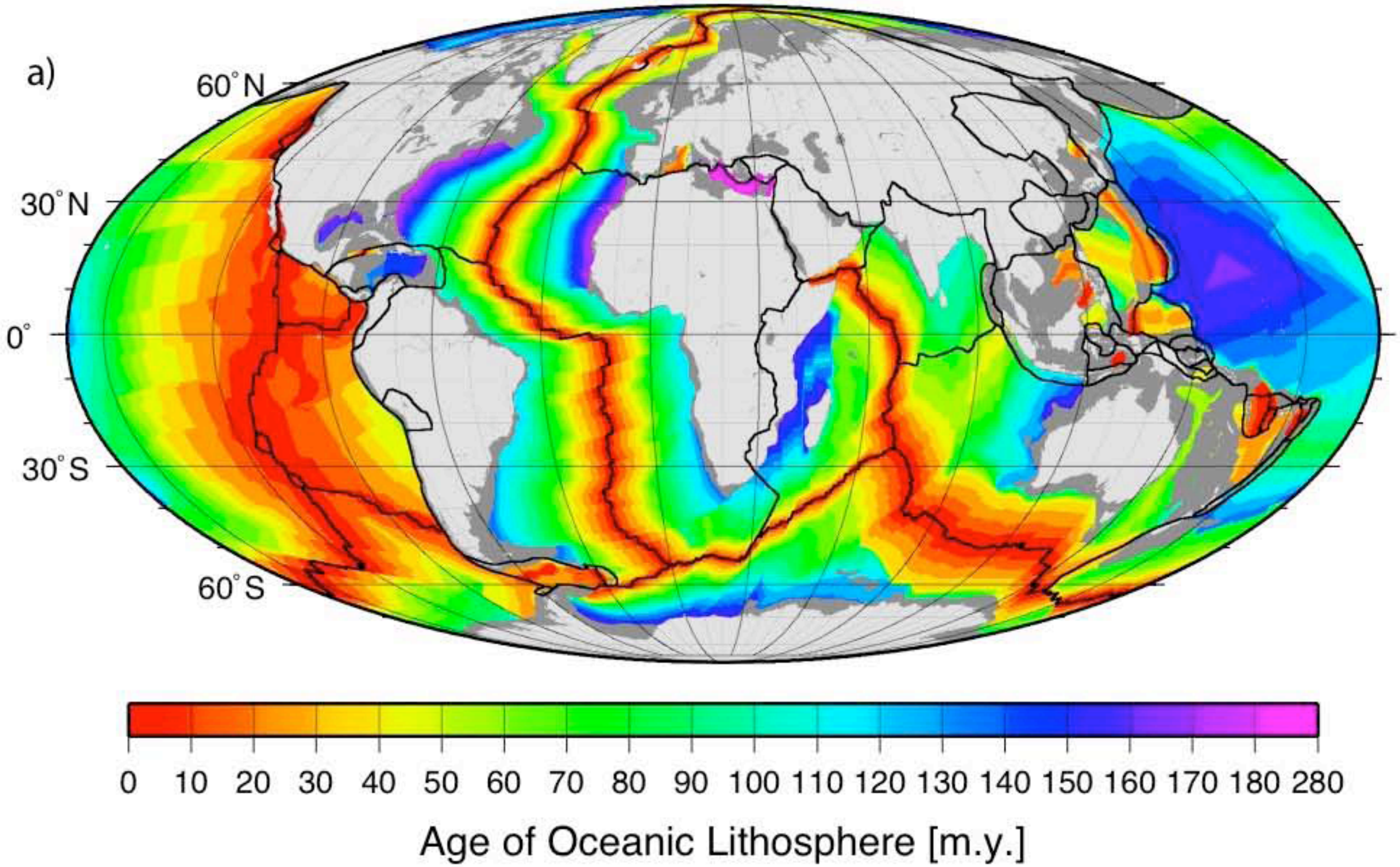
Geomagnetic Polarity Time Scale (GPTS)



Cande & Kent 1995

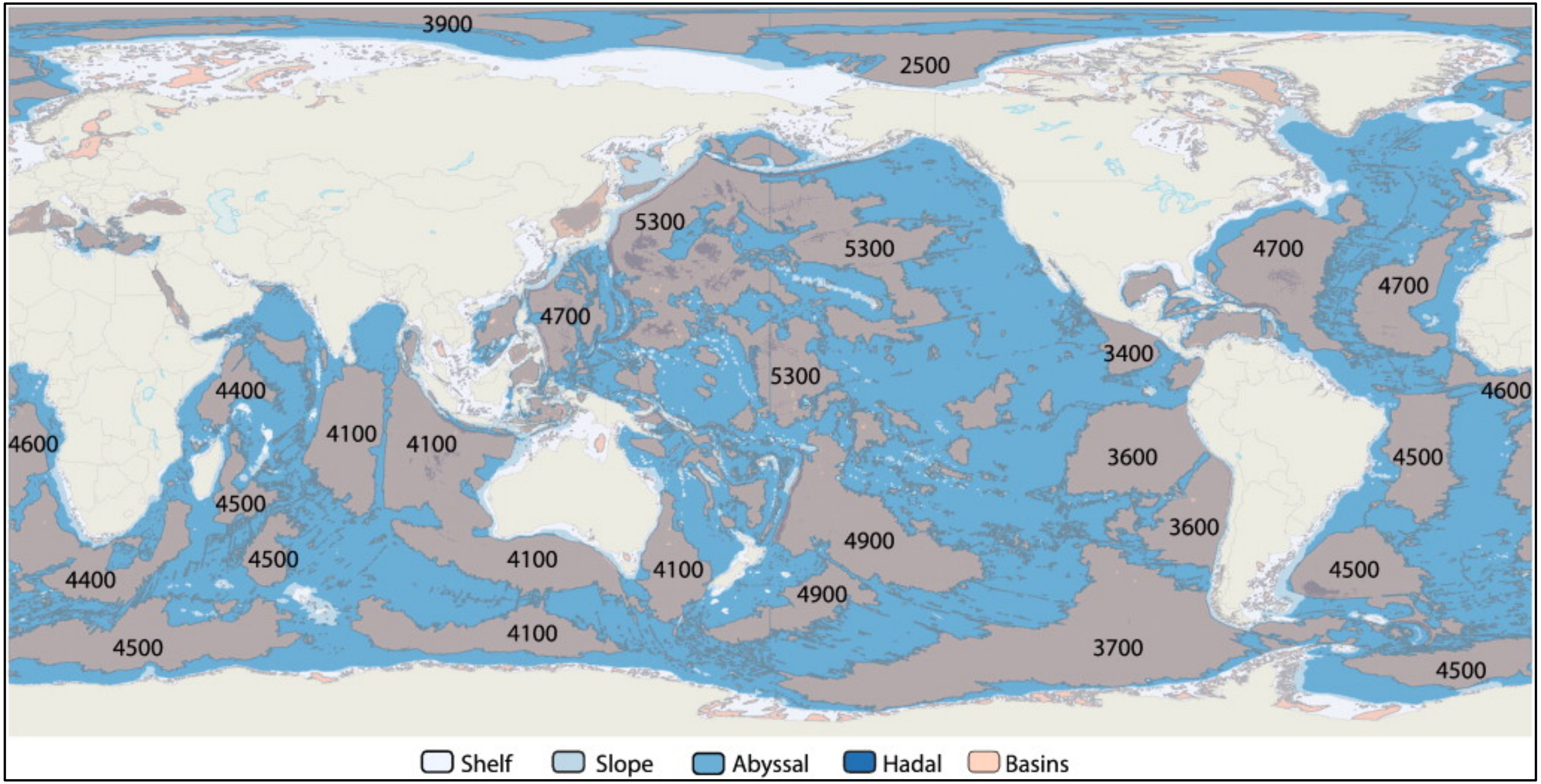


NASA computer simulation using the model of Glatzmaier and Roberts. The tubes represent magnetic field lines blue when the field points towards the center and yellow when away. The rotation axis of the Earth is centered and vertical. The dense clusters of lines are within the Earth's core.



From Muller et al., 2008

Basins in the oceans



The numbers indicate contour depths of major ocean basins based on the most shallow, closed, bathymetric contour that defines the basin outline, illustrating that the deepest basins are located in the northwest Pacific.

Harris, Macmillan-Lawler, Rupp, Baker, 2014. **Geomorphology of the oceans.** Marine Geology, 352, 2014, 4–24.
http://dx.doi.org/10.1016/j.margeo.2014.01.011

Stato termico dei ridge e piane abissali

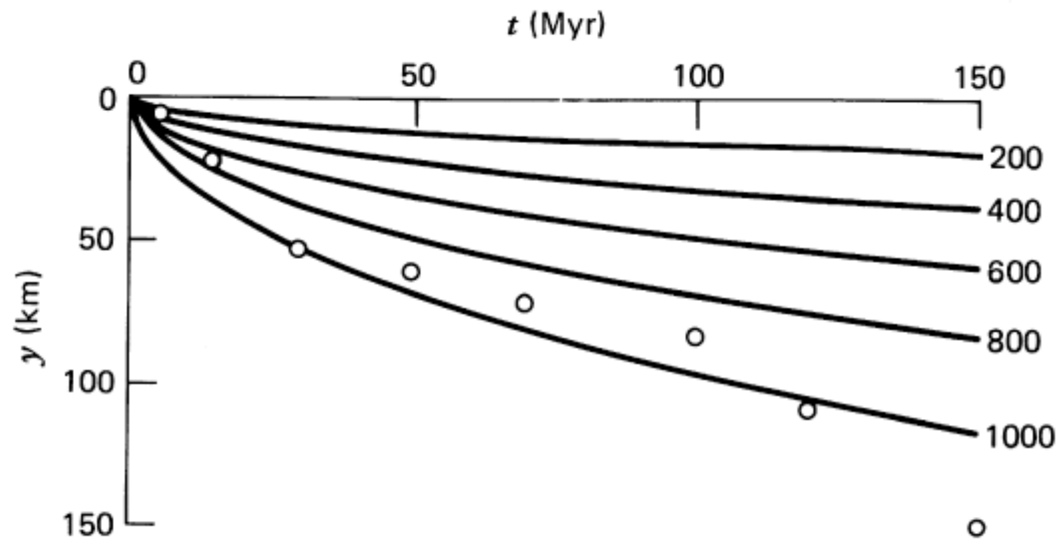
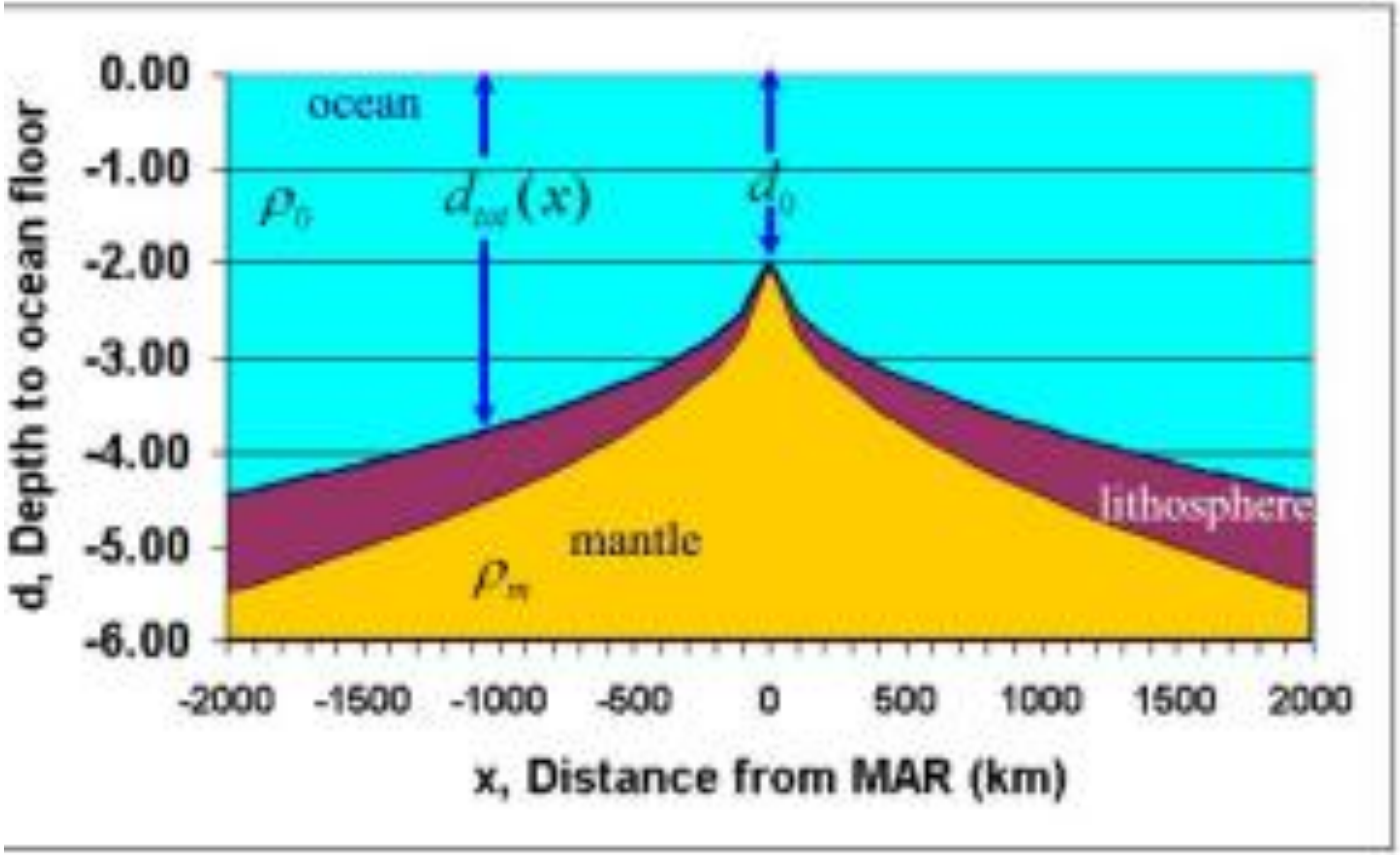
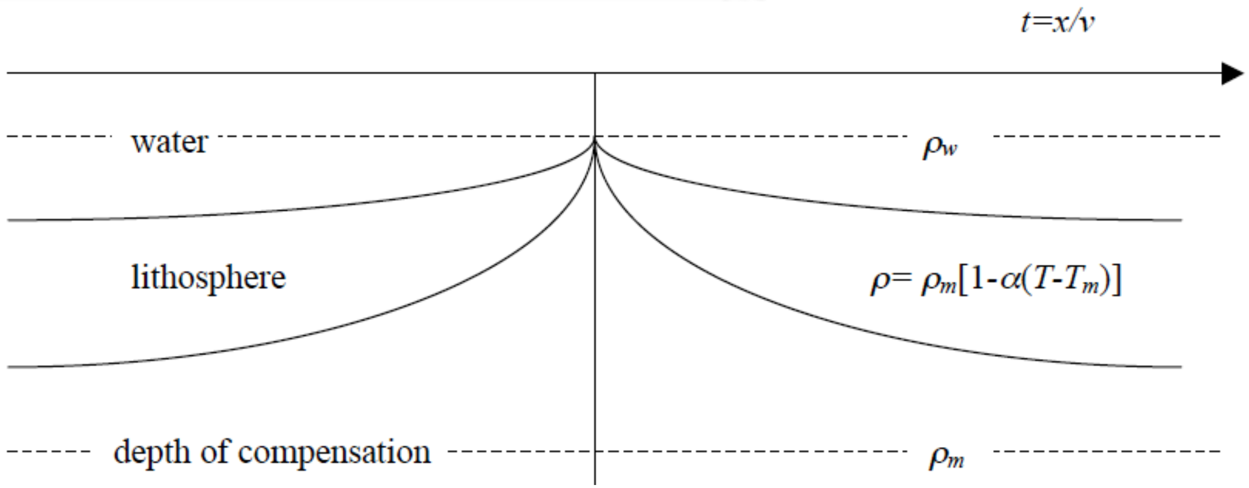


Figure 4-24 The solid lines are isotherms, $T - T_s$ (°K), in the oceanic lithosphere from Equation (4-125). The data points are the thicknesses of the oceanic lithosphere in the Pacific determined from studies of Rayleigh wave dispersion data. (From A. R. Leeds, L. Knopoff, and E. G. Kausel, Variations of upper mantle structure under the Pacific Ocean, *Science*, **186**, 141–143, 1974.)



Cooling of oceanic crust

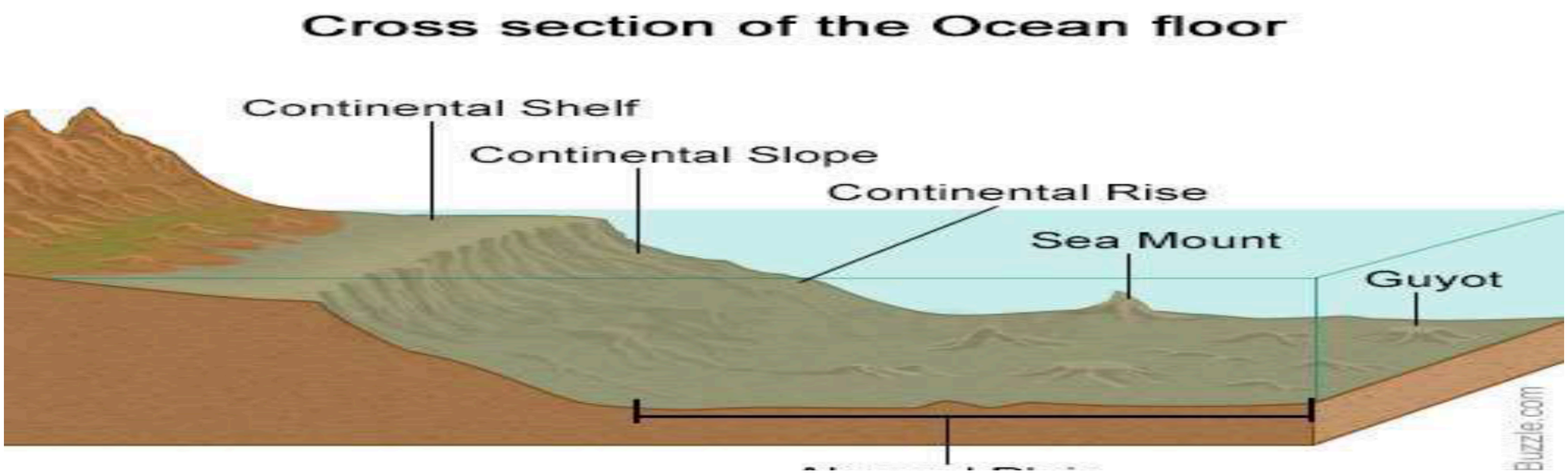


Abyssal floor

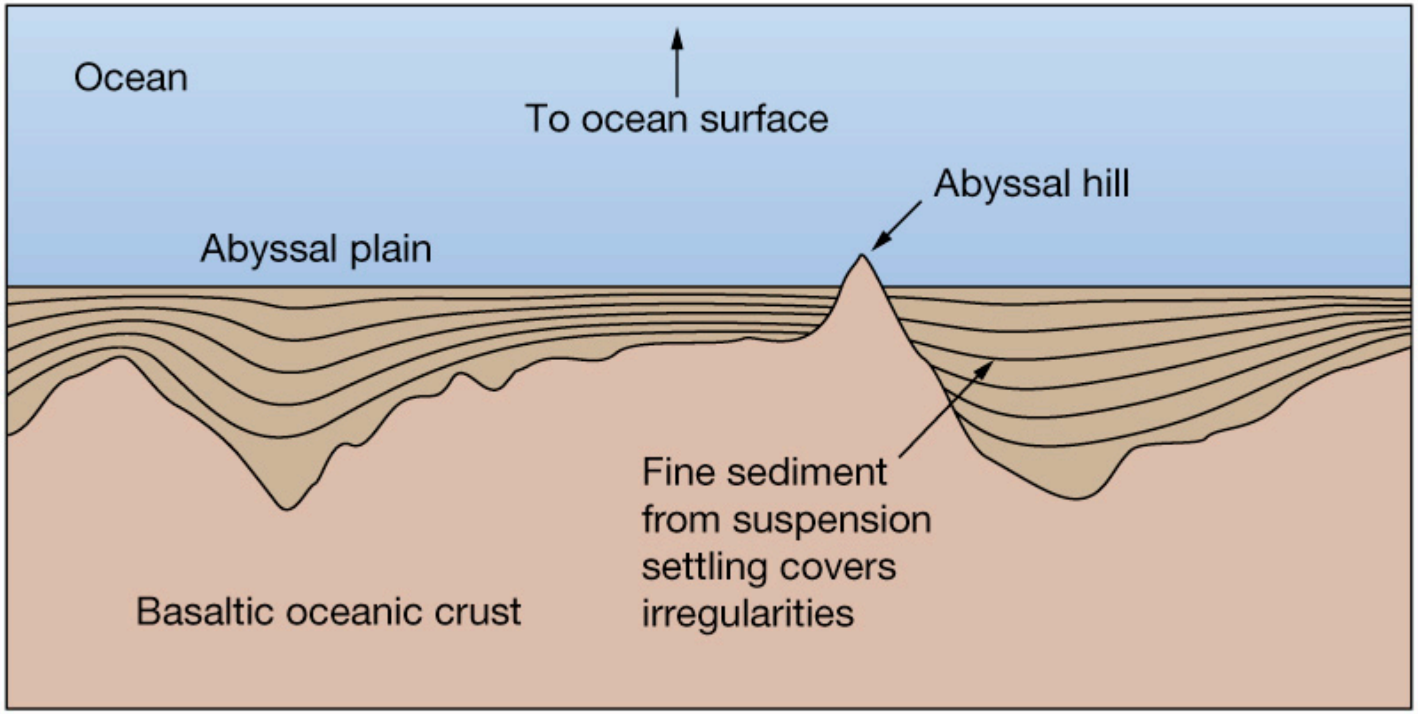
Abyssal floor are broad, relatevely smooth surfaces and consists of:

- **Abyssal plains**: the flattest of all Earth’s surface area. The are composed of sediments, most of which came formcontinten and can be more than one km thick

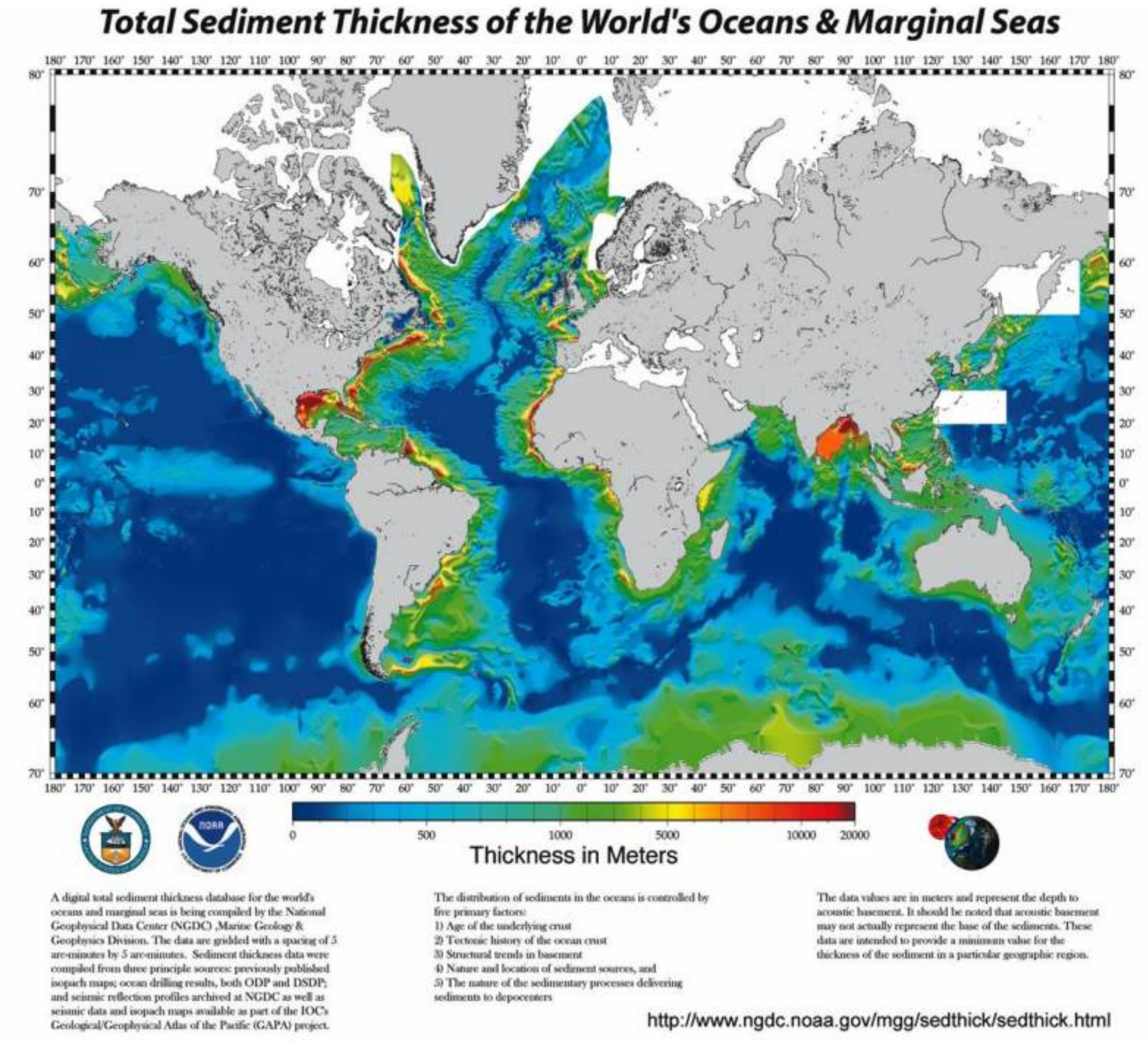
- **Abyssal hills**: small, rolling hills ogete occurrinfg in groups near ocean ridges system



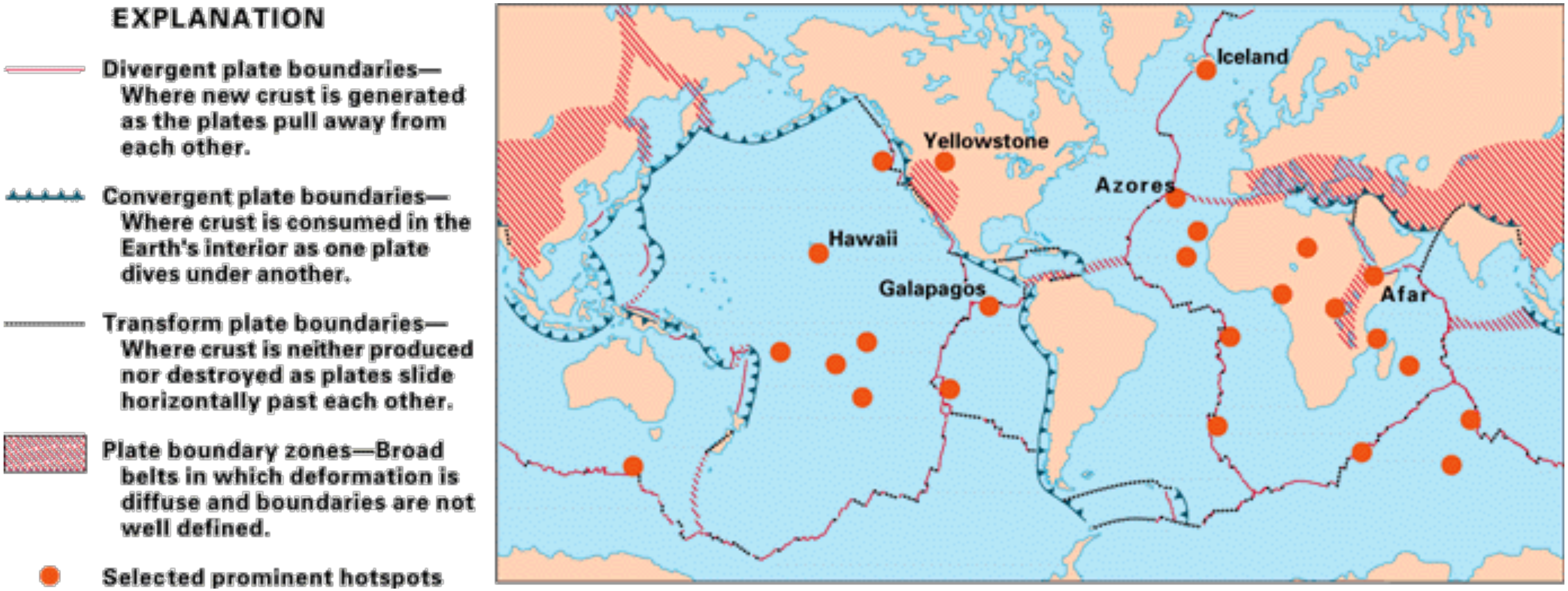
Abyssal Plain



Result from the blanketing of the oceanic crust by fine-grained sediments, mainly clay and silt from turbidity currents and from pelagic sediments.
Metallic nodules are common in some areas of the plains, with varying concentrations of metals, including manganese, iron, nickel, cobalt, and copper.


Total Sediment Thickness of the World's Oceans & Marginal Seas
0
500
1000
5000
10000
20000
Thickness in Meters
A digital total sediment thickness database for the world's oceans and marginal seas is being compiled by the National Geophysical Data Center (NGDC) ,Marine Geology & Geophysics Division. The data are gridded with a spacing of 5 arc-minutes by 5 arc-minutes. Sediment thickness data were compiled from three principle sources: previously published isopach maps; ocean drilling results, both ODP and DSDP; and seismic reflection profiles archived at NGDC as well as seismic data and isopach maps available as part of the IOC's Geological/Geophysical Atlas of the Pacific (GAPA) project.
The distribution of sediments in the oceans is controlled by five primary factors:
1) Age of the underlying crust
2) Tectonic history of the ocean crust
3) Structural trends in basement
4) Nature and location of sediment sources, and
5) The nature of the sedimentary processes delivering sediments to depocenters
The data values are in meters and represent the depth to acoustic basement. It should be noted that acoustic basement may not actually represent the base of the sediments. These data are intended to provide a minimum value for the thickness of the sediment in a particular geographic region.
http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html

HOT SPOT



Hotspots are places where molten rock from the earth's mantle is erupting at the surface. They are in the middle of the plate.

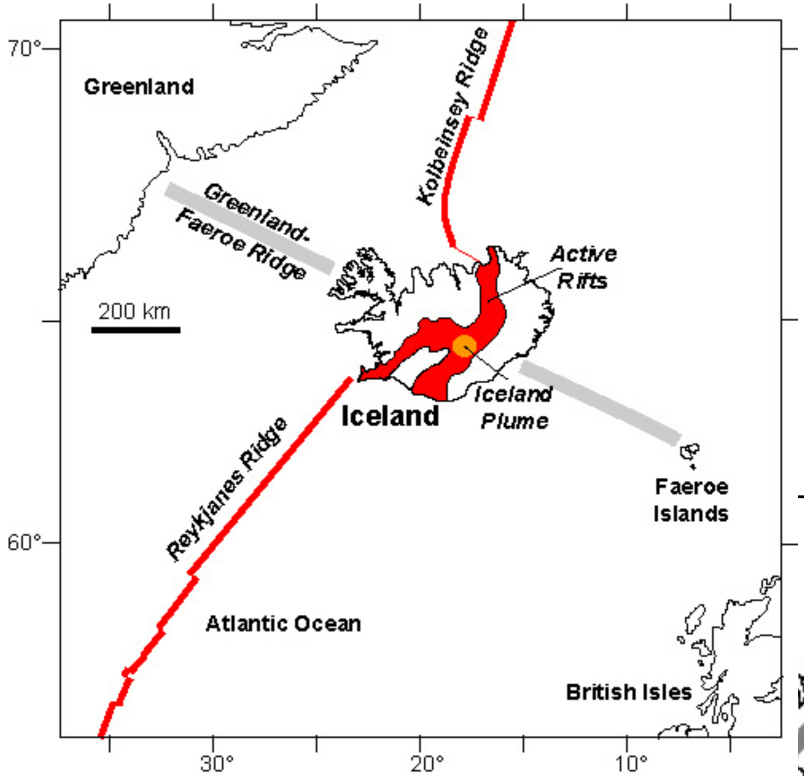
Two hypothesis:

a) the hotspots move relative to the earth;

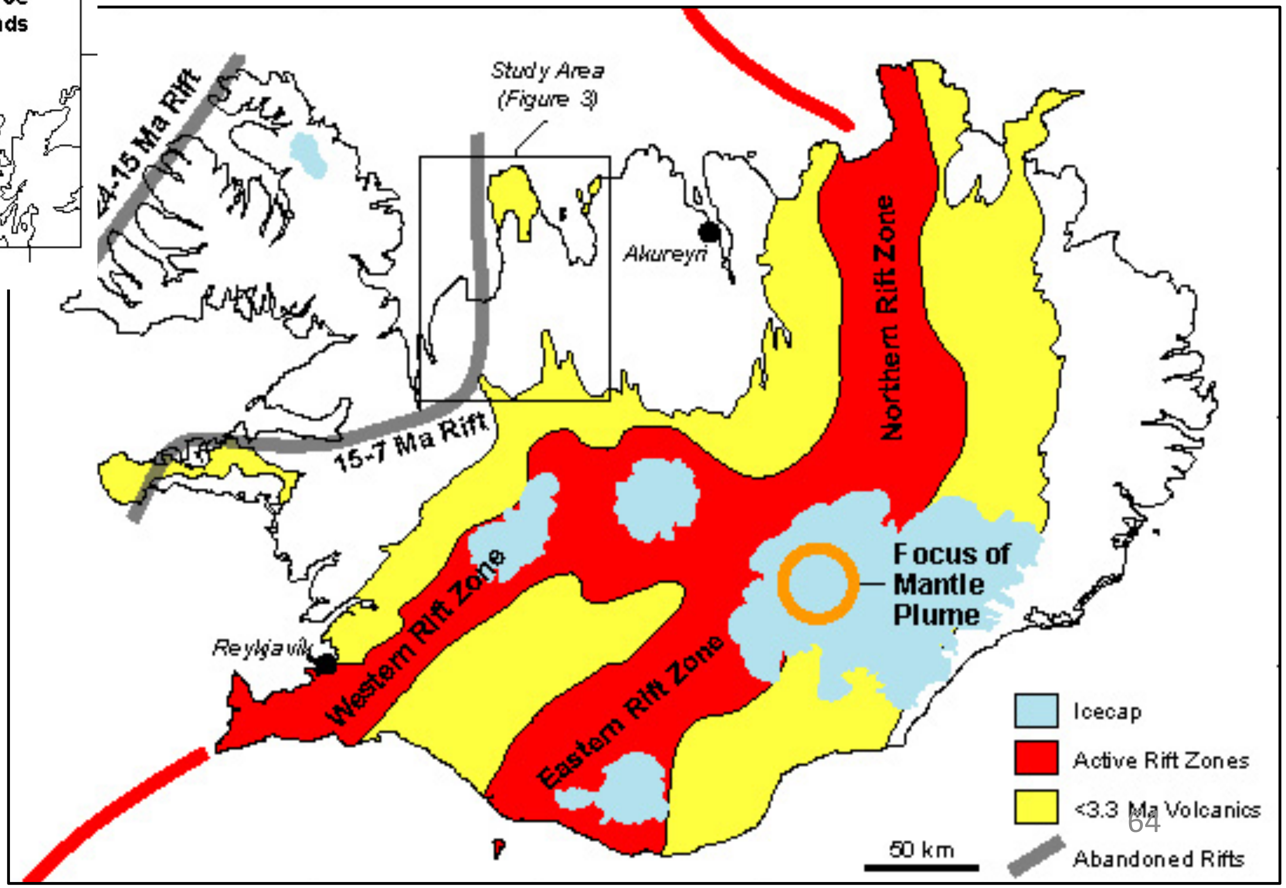
b) the hotspots are fixed to the earth.

ICELAND HOT SPOT

- mid oceanic ridge rises above sea level
- 20 million years old
- some of the most active volcanoes in the world are located in Iceland
- is situated on a hotspot

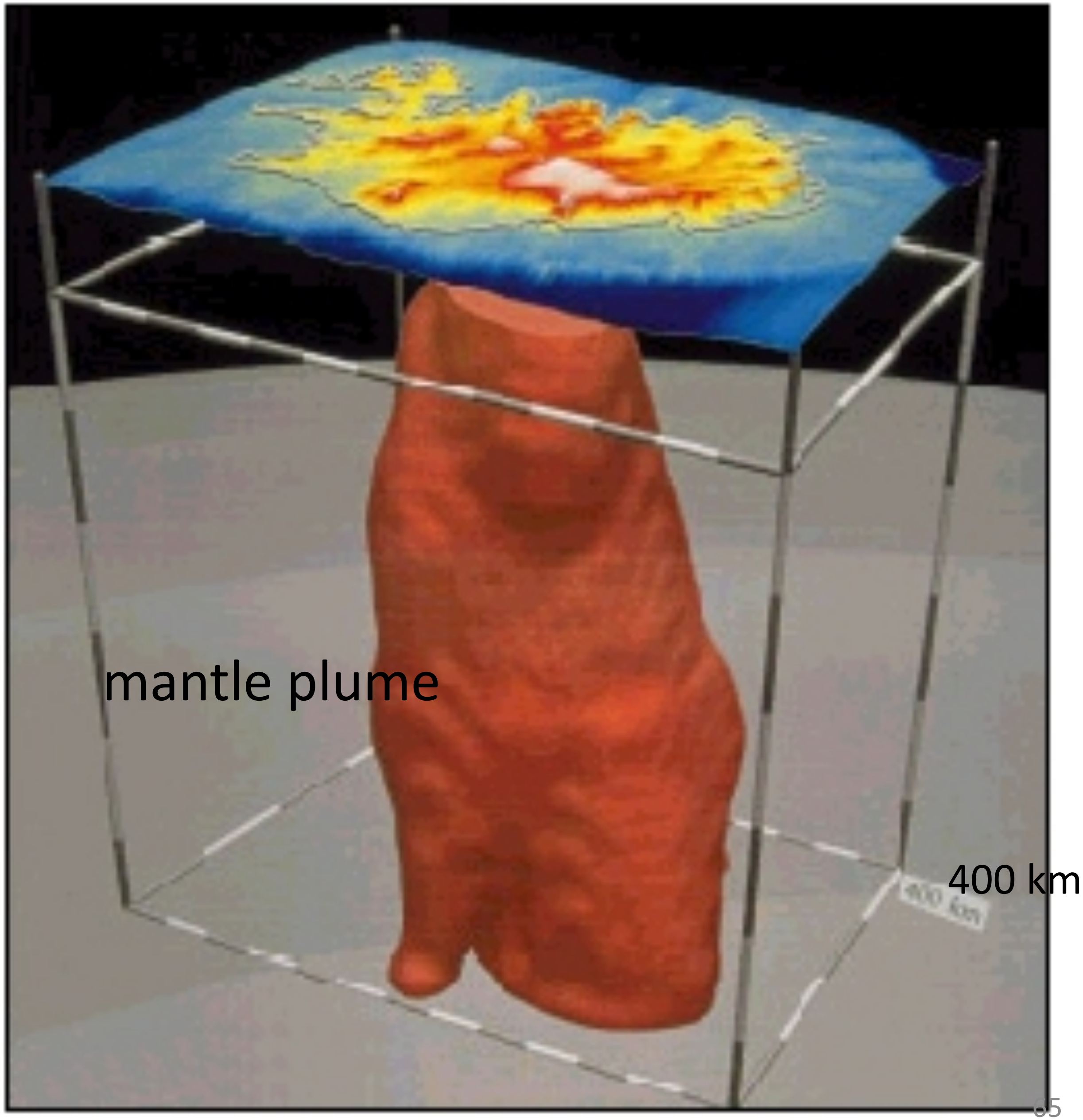


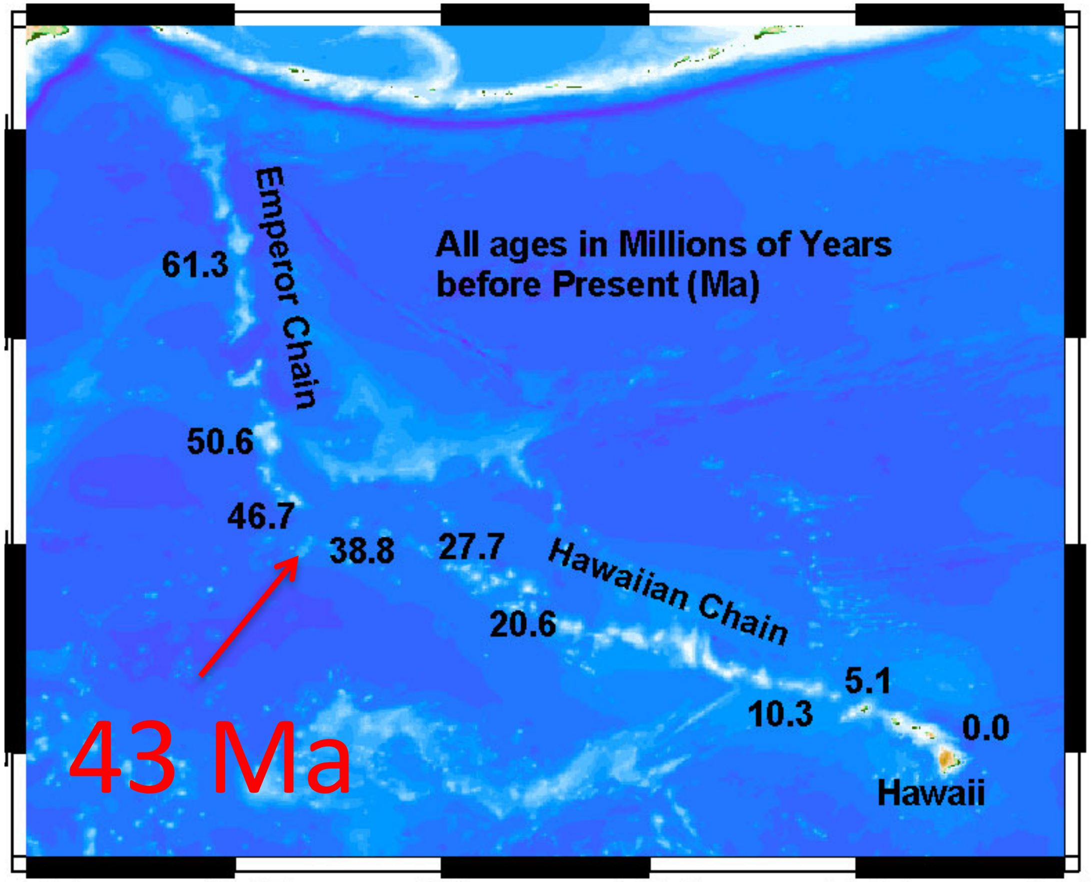
A detailed map of Iceland lying in the middle of the Atlantic Ocean. It shows the mid Atlantic ridge cutting through Iceland along with the location of its hotspot.
Image taken from [Iceland Keck]



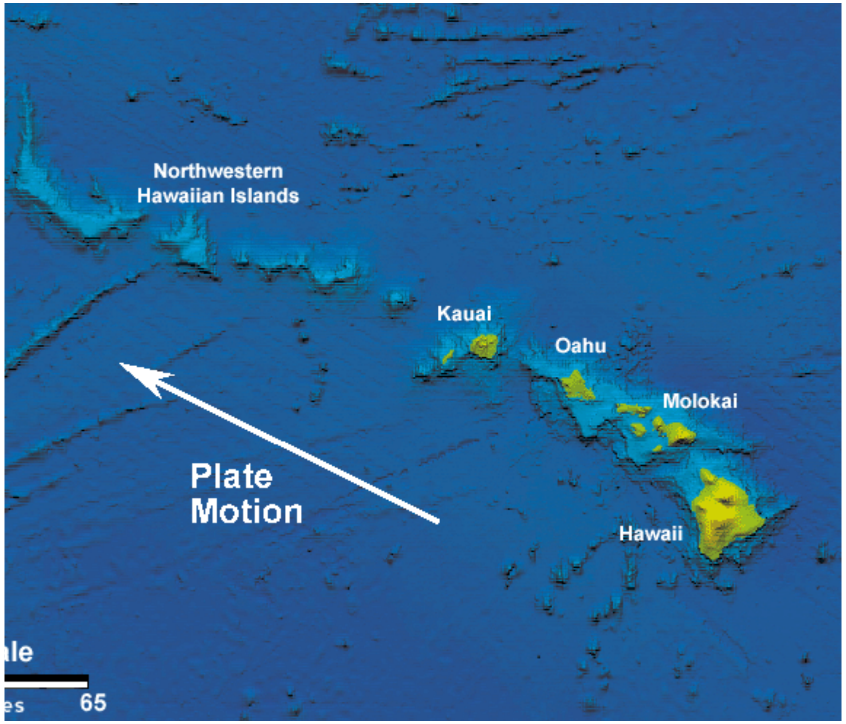
ICELAND HOT SPOT (or mantle plume)

The starting plume head, **hundreds of degrees hotter than normal mantle**, spreads sideways, incorporates surrounding mantle, and buoyantly uplifts a region roughly 1000 km in diameter to produce a **topographic bulge about 1 km high**.
(Image by D. Müller, University of Sydney).





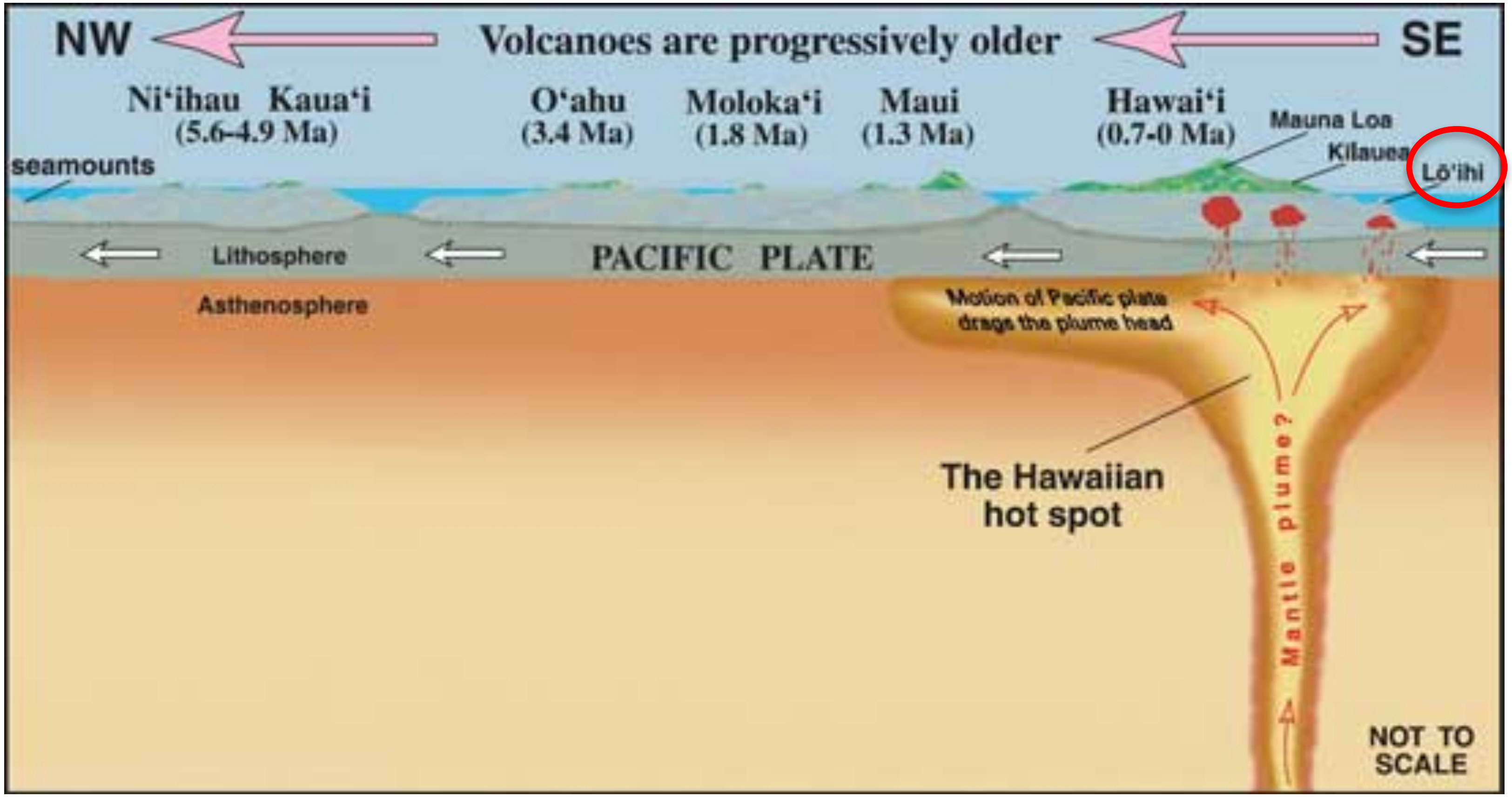
HAWAII HOT SPOT



The Hawaiian Ridge-Emperor Seamounts chain:

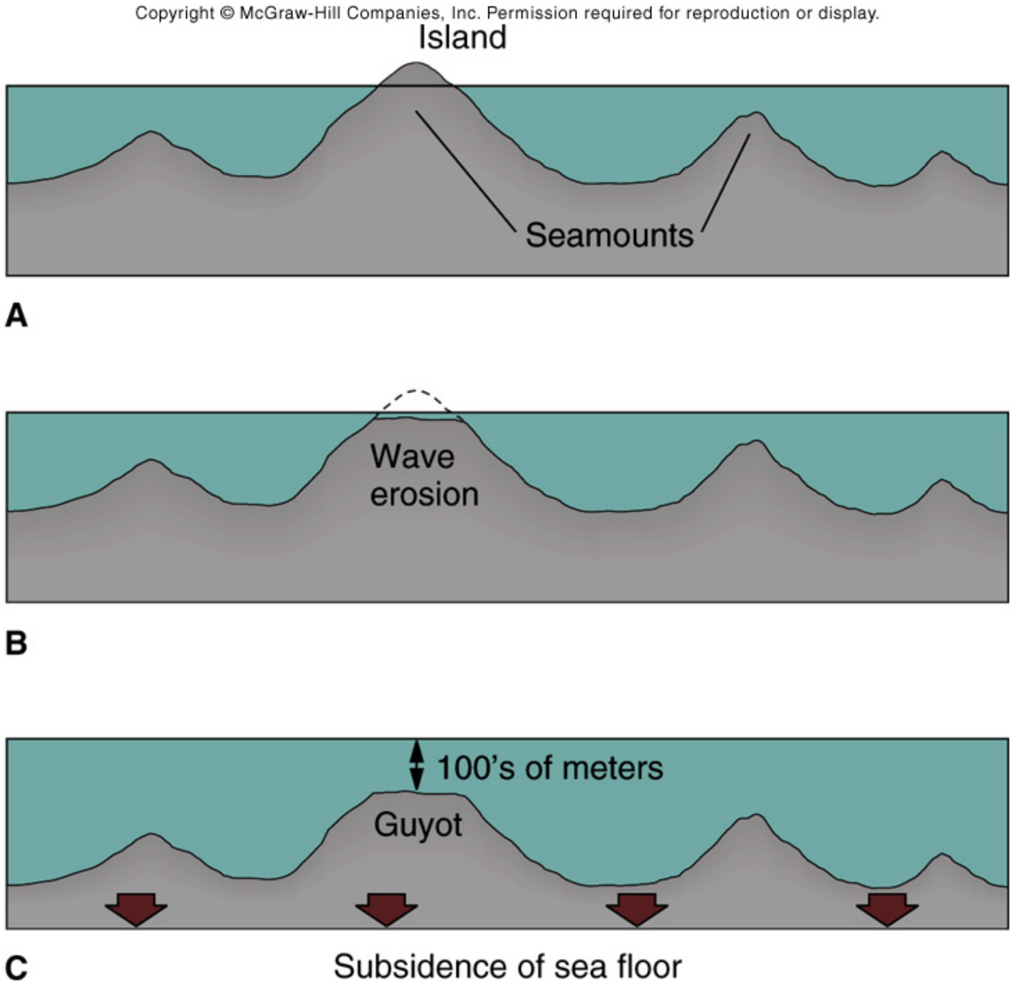
- extends some 6,000 km,
- composed by 80 volcanoes
- started 70 Ma ago, and sharp bend indicates change of motion at 43 Ma, possibly due to India-Asia collision
- is stationary

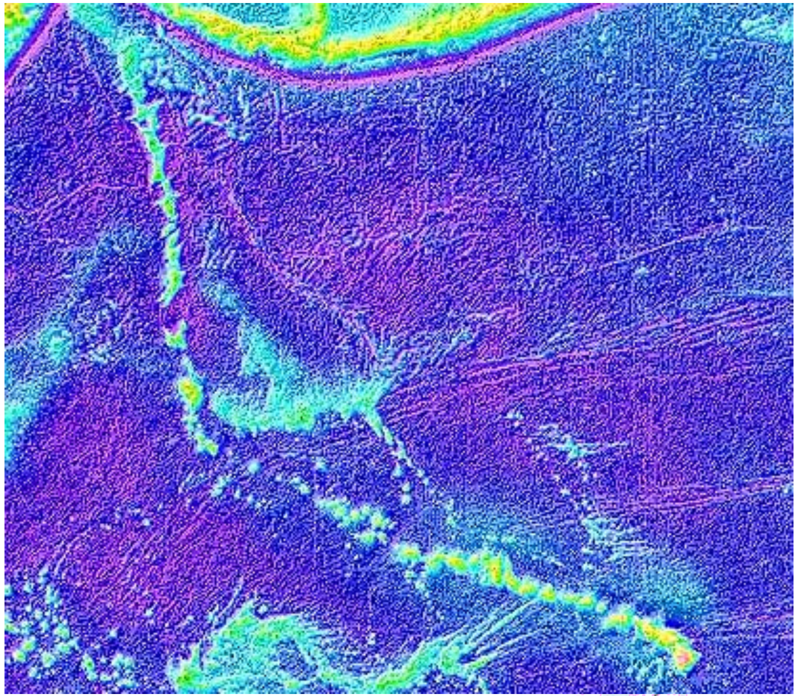
HAWAII HOT SPOT

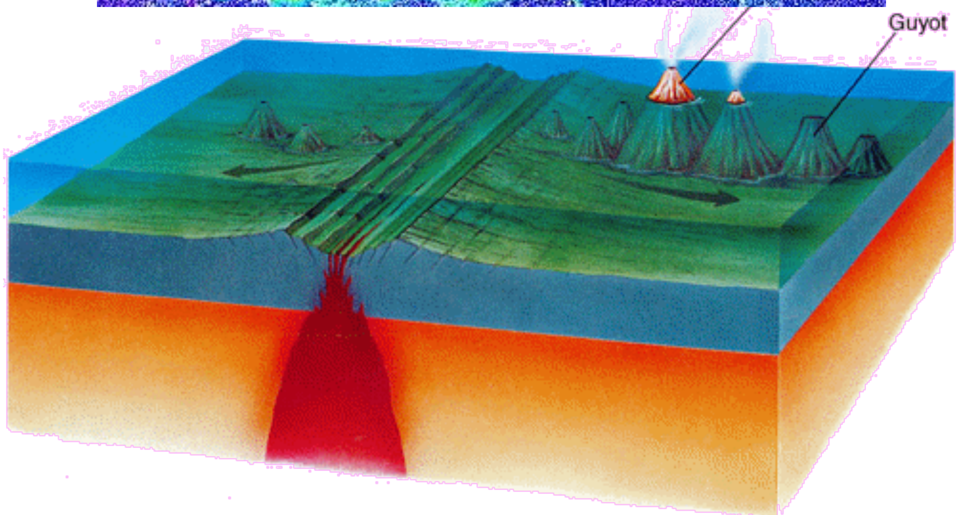


As the Pacific Plate continues to move west-northwest, the Island of Hawaii will be carried beyond the hotspot by plate motion, setting the stage for the formation of a new volcanic island in its place. In fact, this process may be under way. **Loihi Seamount**, an active submarine volcano, **is forming about 35 km off the southern coast of Hawaii**. Loihi already has risen about 3 km above the ocean floor to within 1 km of the ocean surface. According to the hotspot theory, assuming Loihi continues to grow, it will become the next island in the Hawaiian chain. In the geologic future, Loihi may eventually become fused with the Island of Hawaii, which itself is composed of five volcanoes knitted together-Kohala, Mauna Kea, Hualalai, Mauna Loa, and Kilauea.

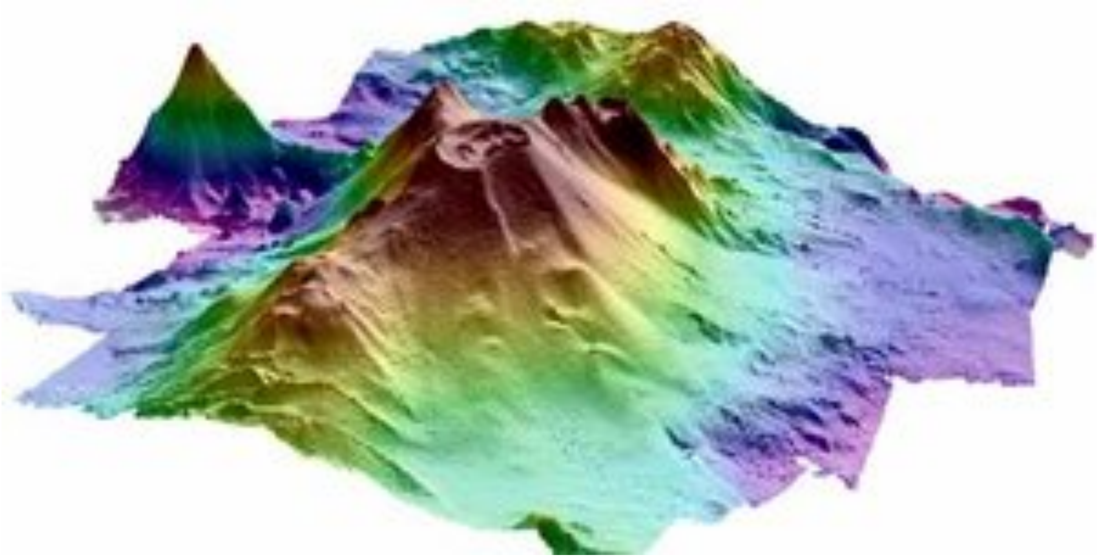
Morphological Features
Seamounts, volcanic island and guyots



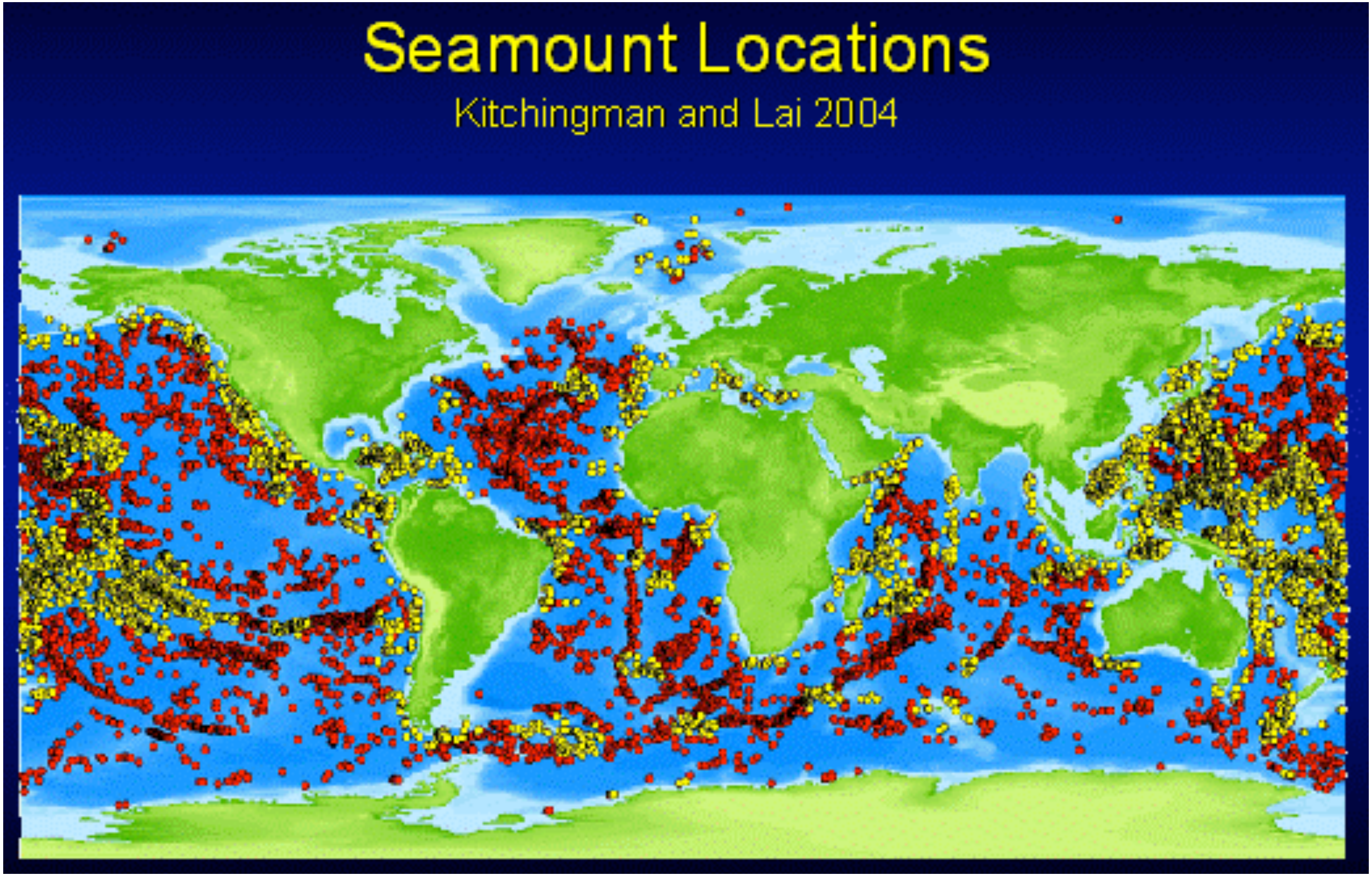




SEAMOUNT

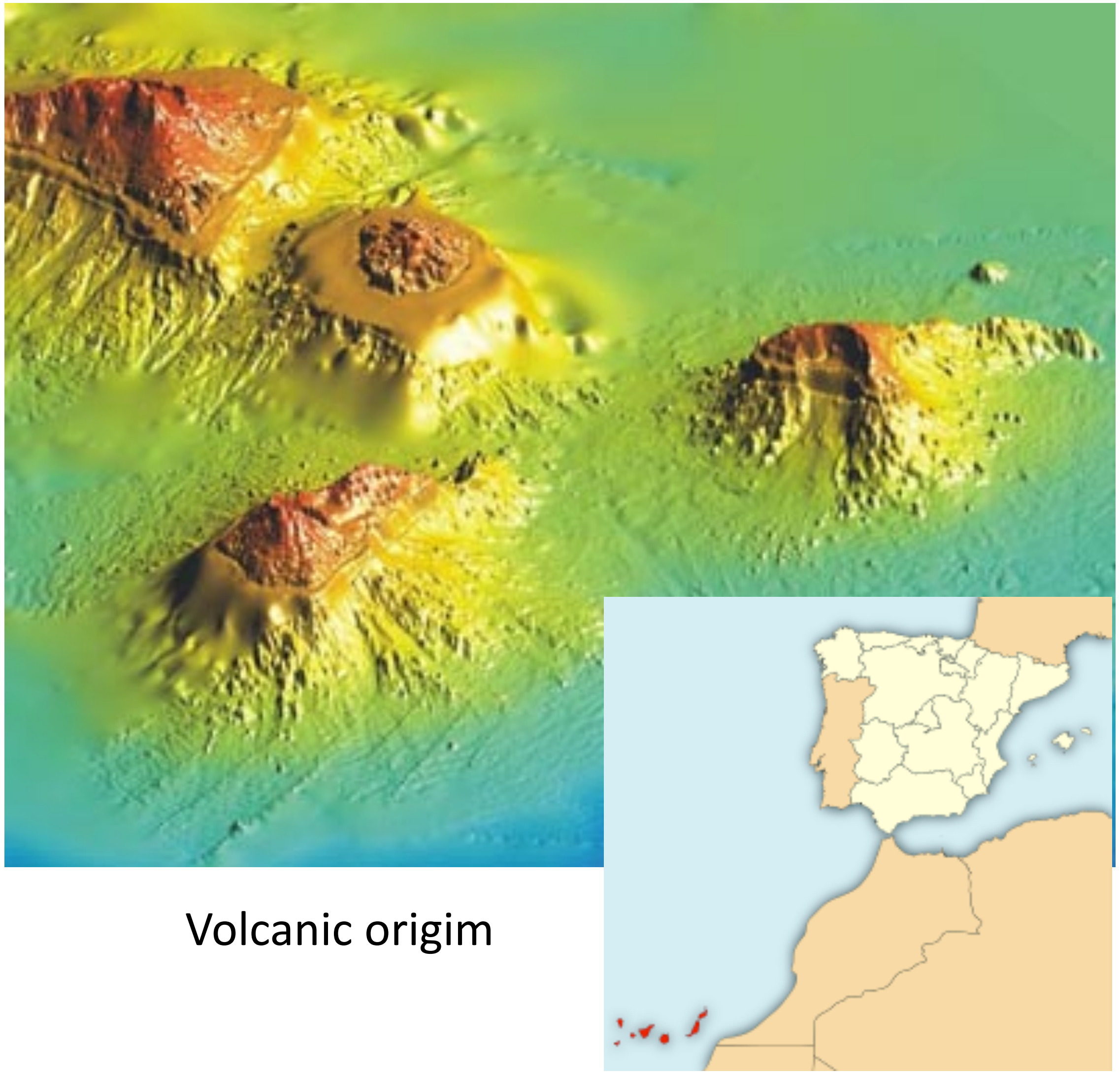


Seamounts: undersea mountains rising from the bottom of the sea with a minimum elevation of 1,000 meters, that do not break the water's surface.
Seamounts are usually isolated and cone-shaped, are mostly volcanic and therefore found on oceanic crust, formed near mid-oceanic ridges, hotspot and island-arc convergent settings.
A seamount tall enough to break the sea surface is called an oceanic island, e.g., the islands of Hawaii, the Azores and Bermuda.



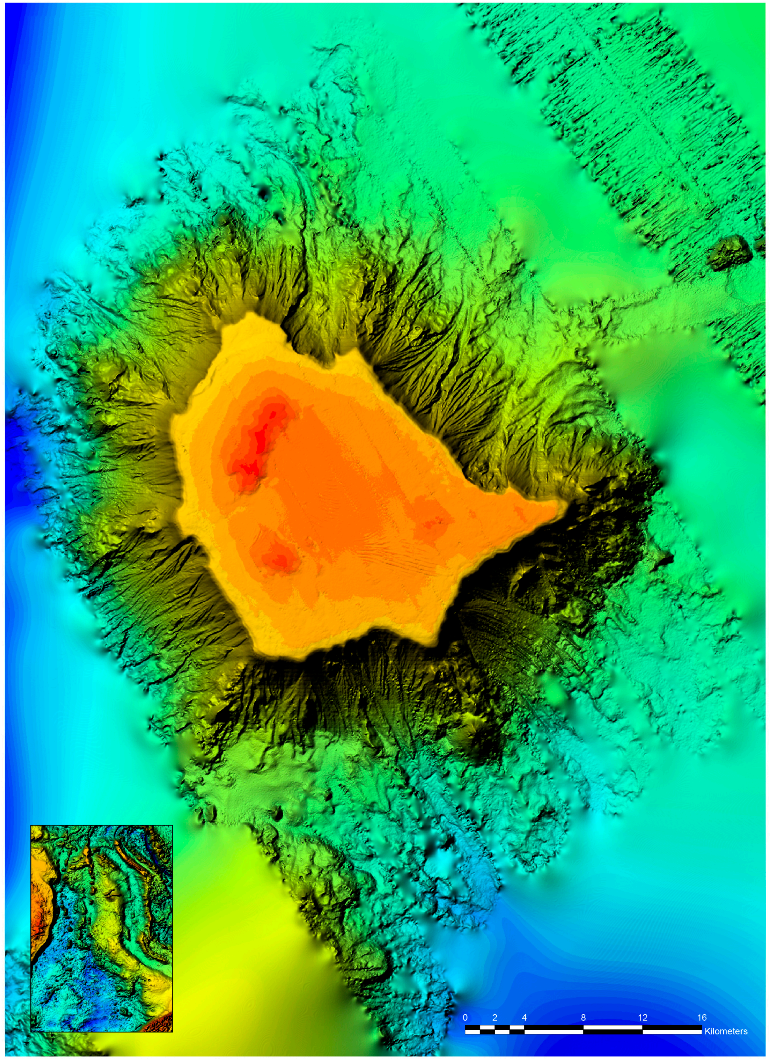
about 60.000 seamounts

Canary Islands (Atlantic Ocean)

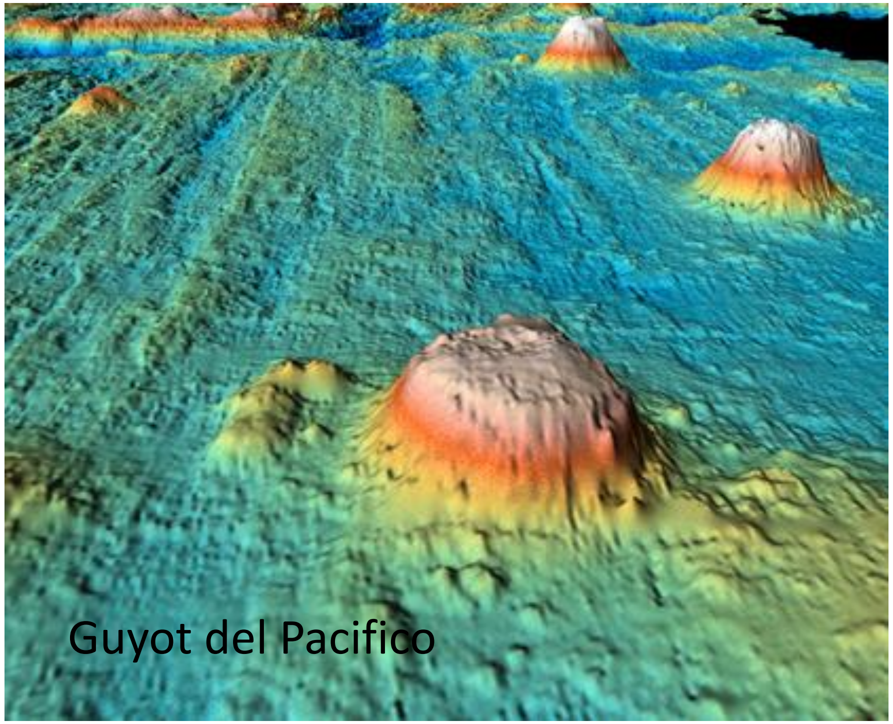


Volcanic origim

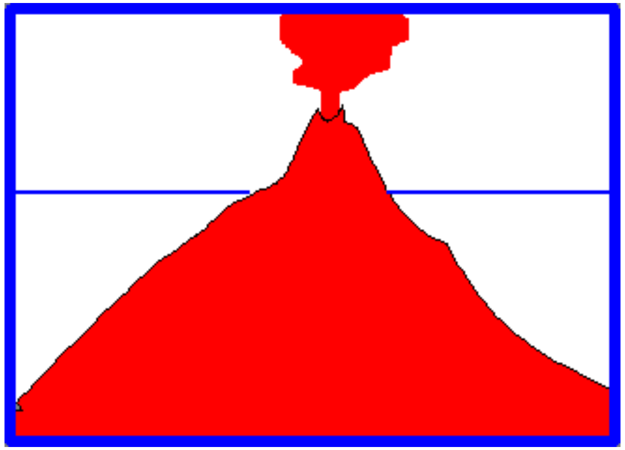
Gifford Guyot (Tasman Sea)



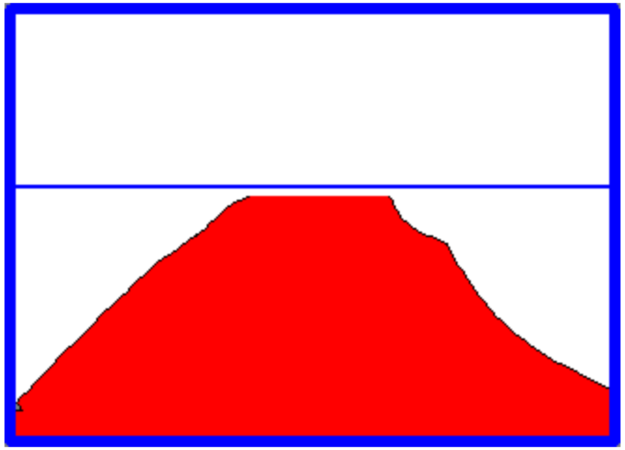
GUYOT



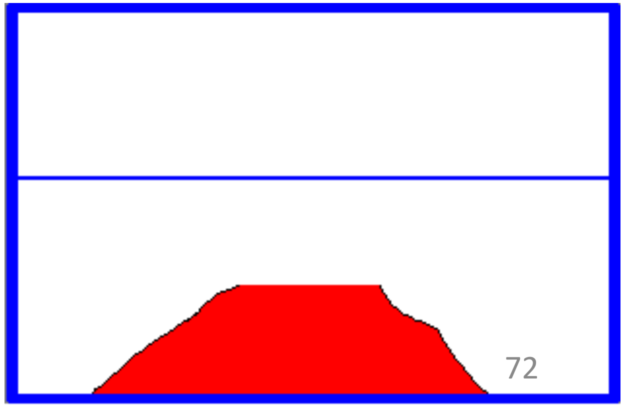
1. Volcanic Island



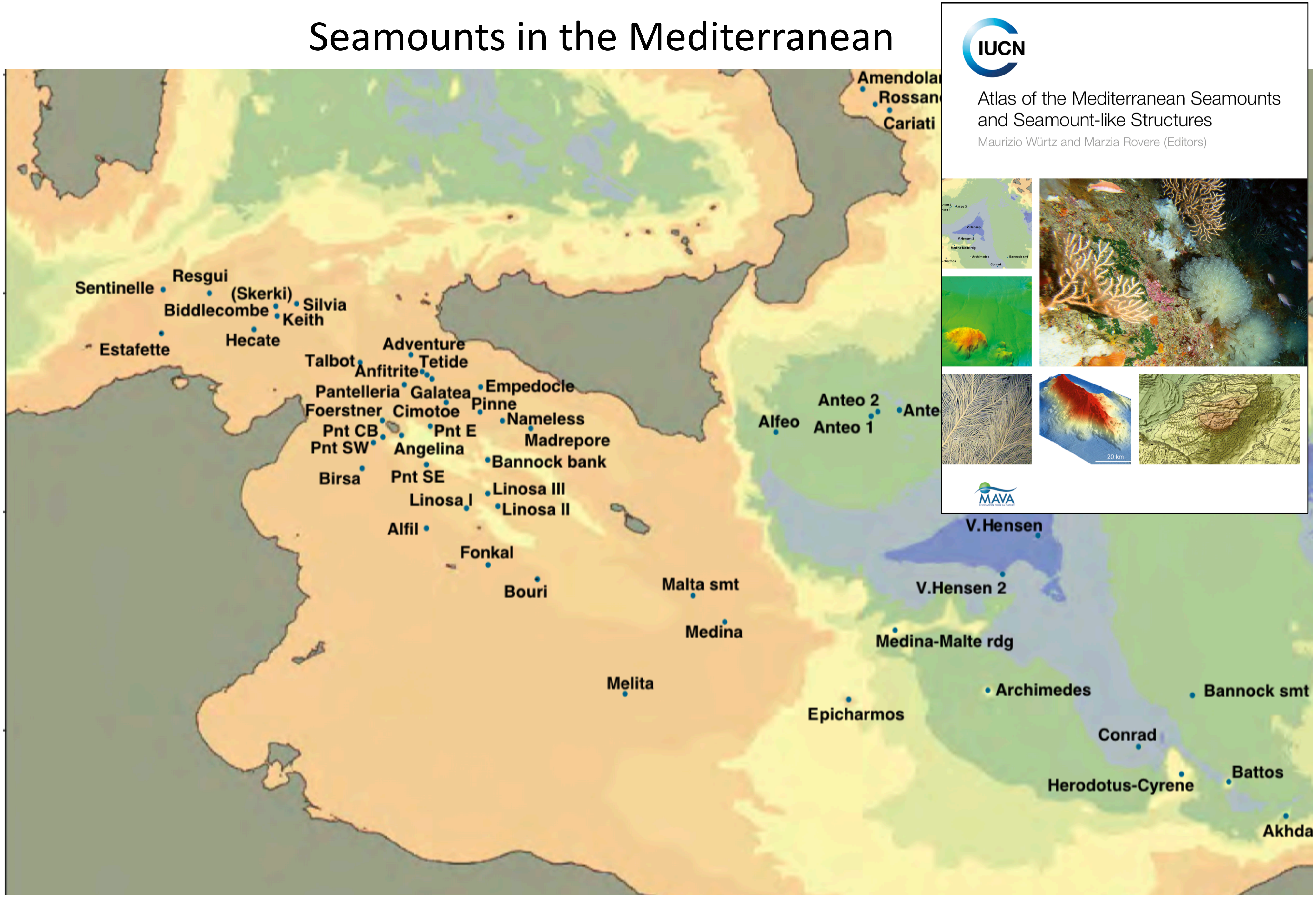
2. Wave erosion



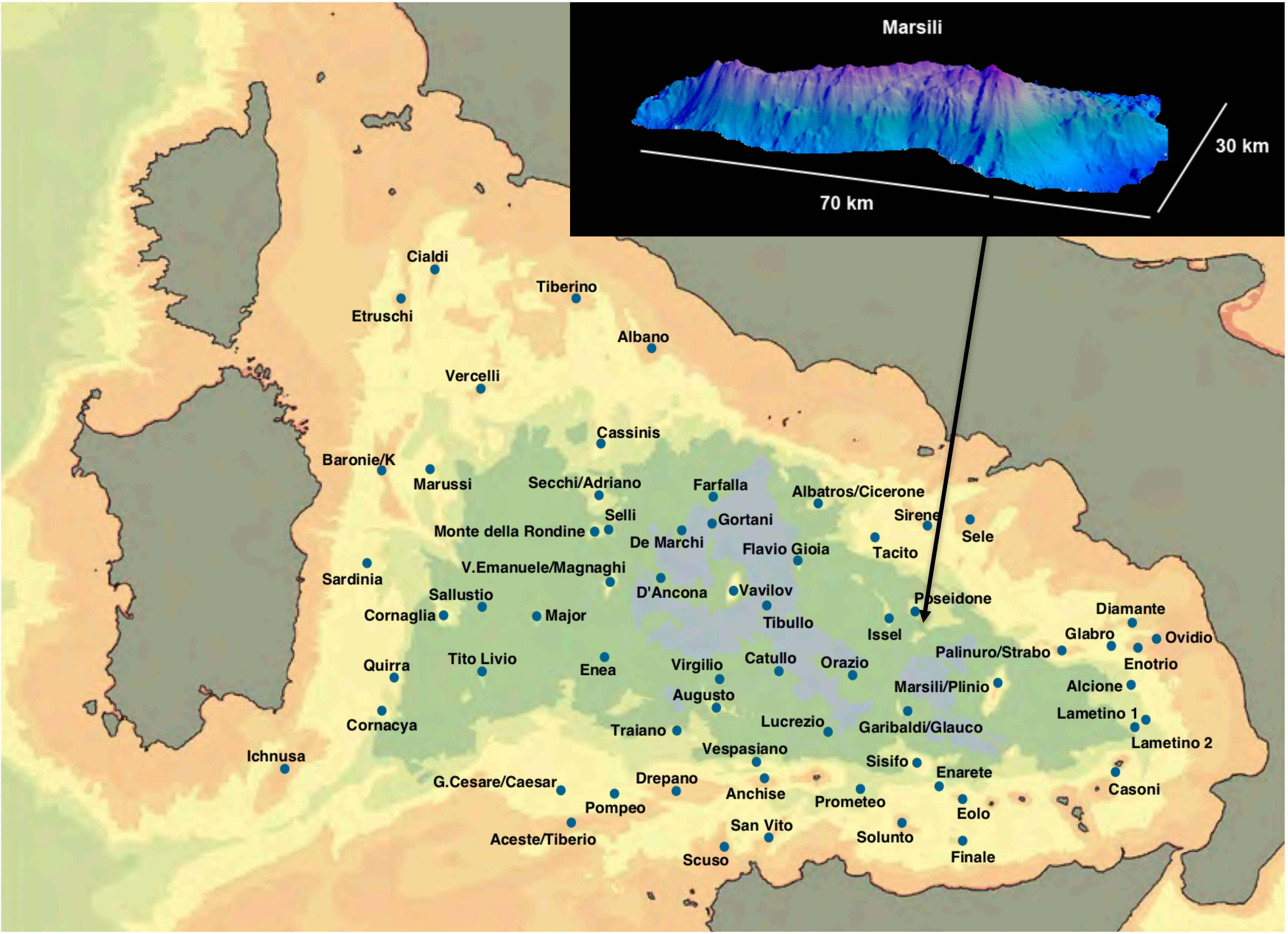
3. Guyot



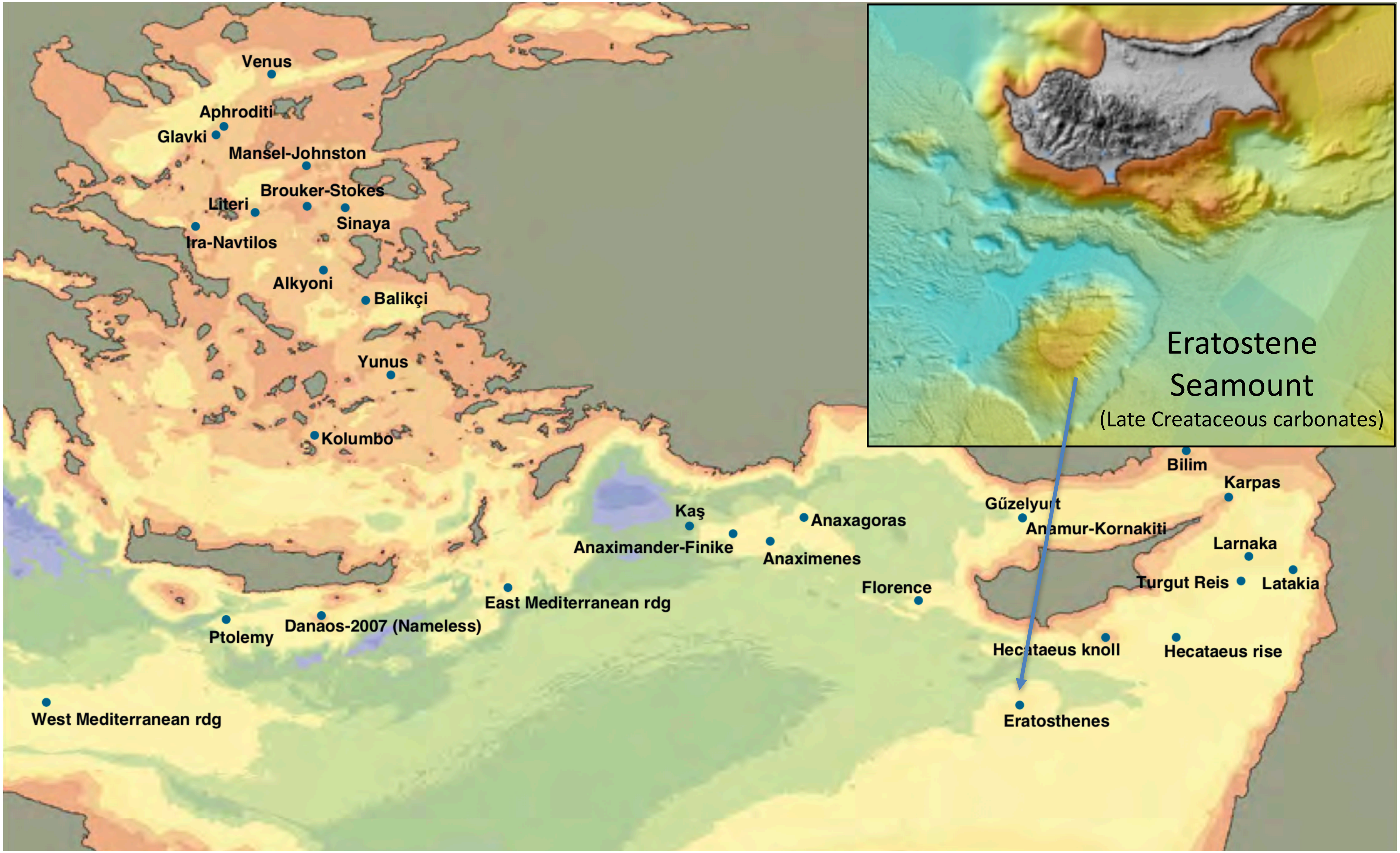
Seamounts in the Mediterranean



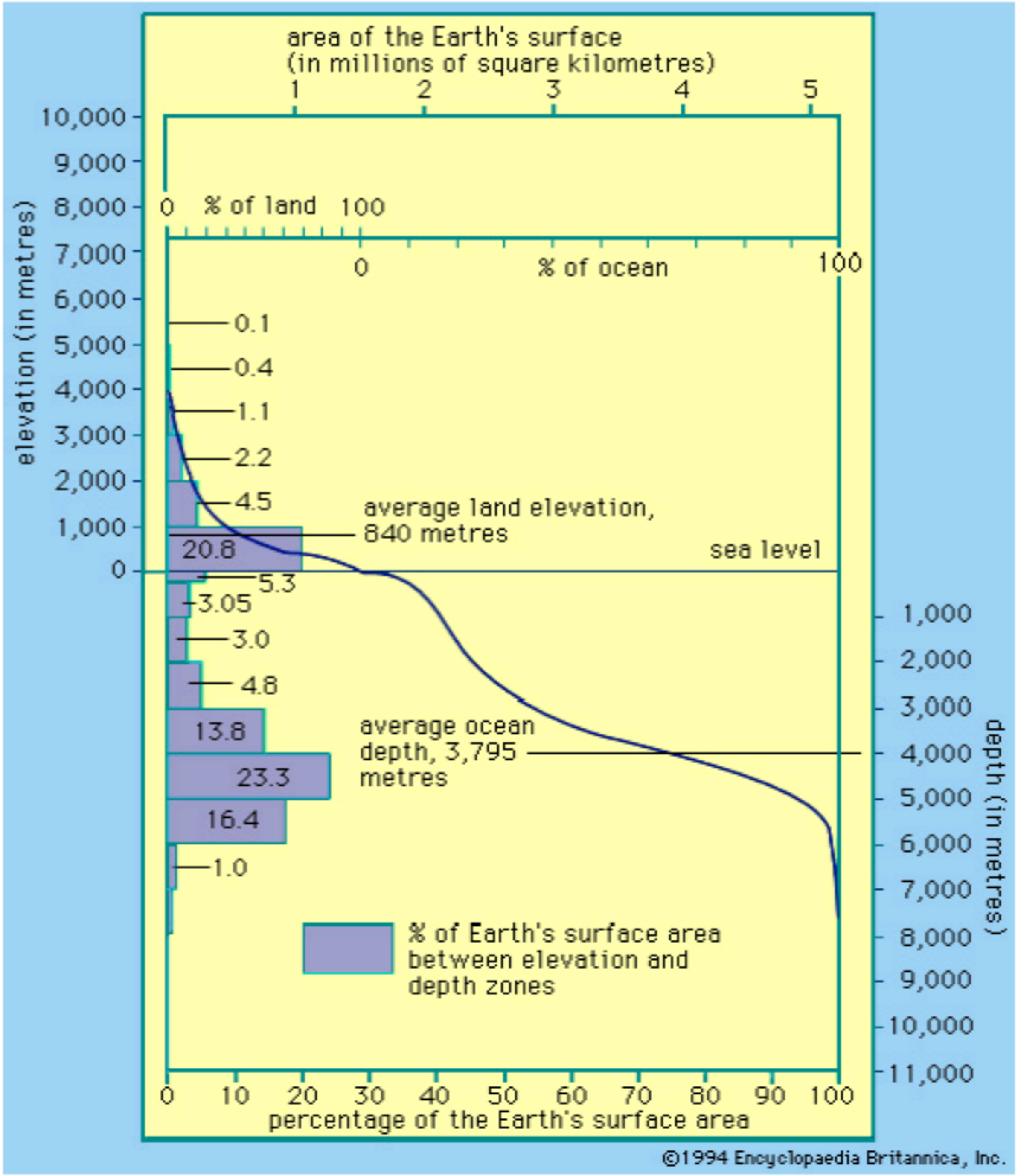
Seamounts in the Mediterranean



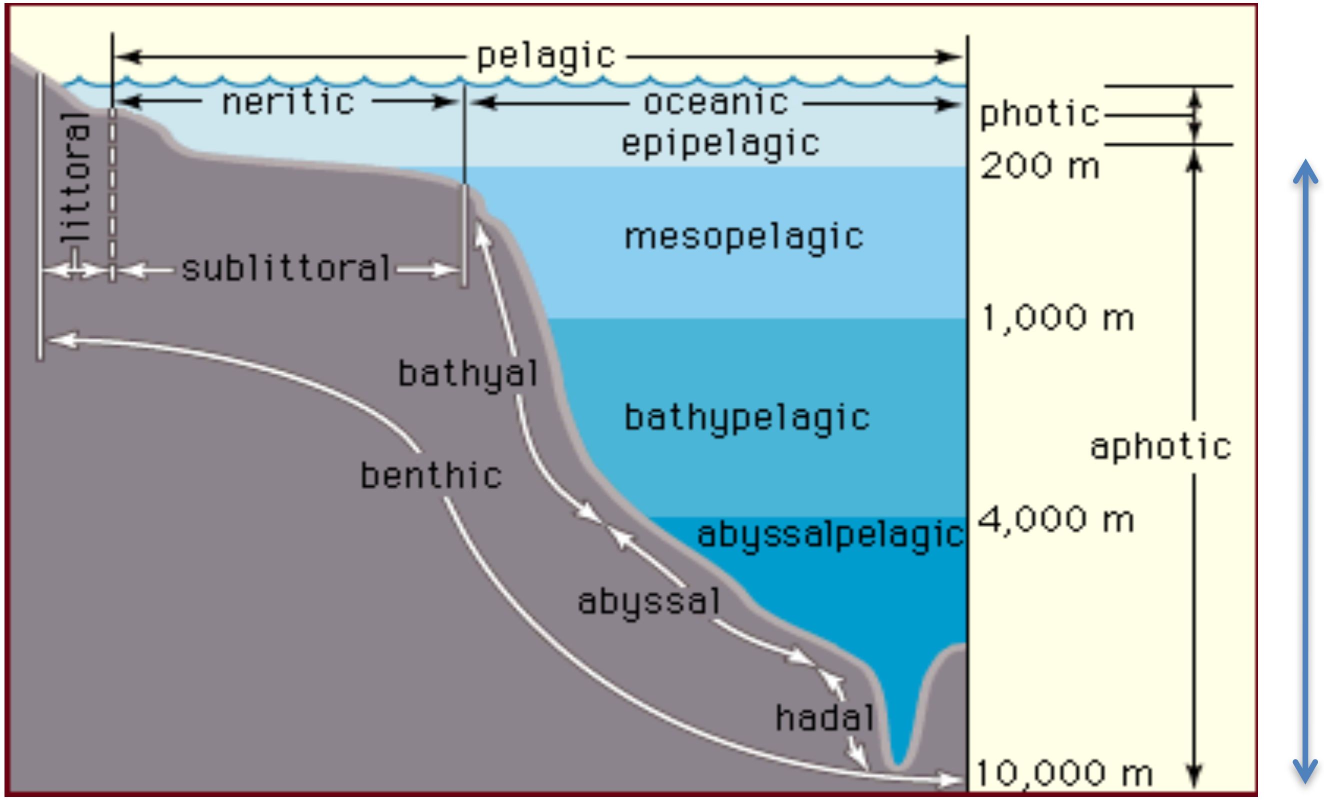
Seamounts in the Mediterranean Sea



4. The classifications of marine enviroments


area of the Earth's surface
(in millions of square kilometres)
1 2 3 4 5
elevation (in metres)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0 % of land 100
0 % of ocean 100
0.1
0.4
1.1
2.2
4.5
20.8
5.3
3.05
3.0
4.8
13.8
23.3
16.4
1.0
average land elevation,
840 metres
sea level
average ocean
depth, 3,795
metres
% of Earth's surface area
between elevation and
depth zones
depth (in metres)
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
0 10 20 30 40 50 60 70 80 90 100
percentage of the Earth's surface area
©1994 Encyclopaedia Britannica, Inc.

Classification of the Marine Zones



Temperature

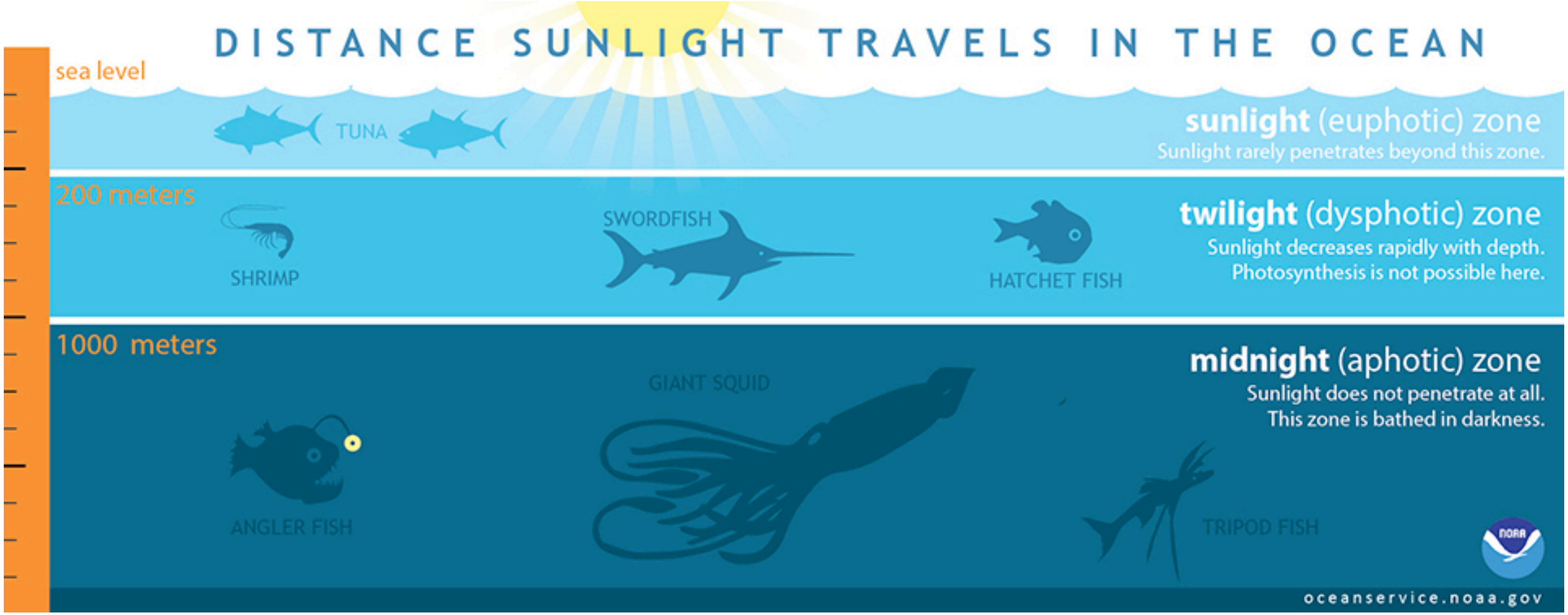
T= 12° C
at about 700-1000 m depth
in the tropic

T= 4° C
at about 4000 m depth
in the tropic

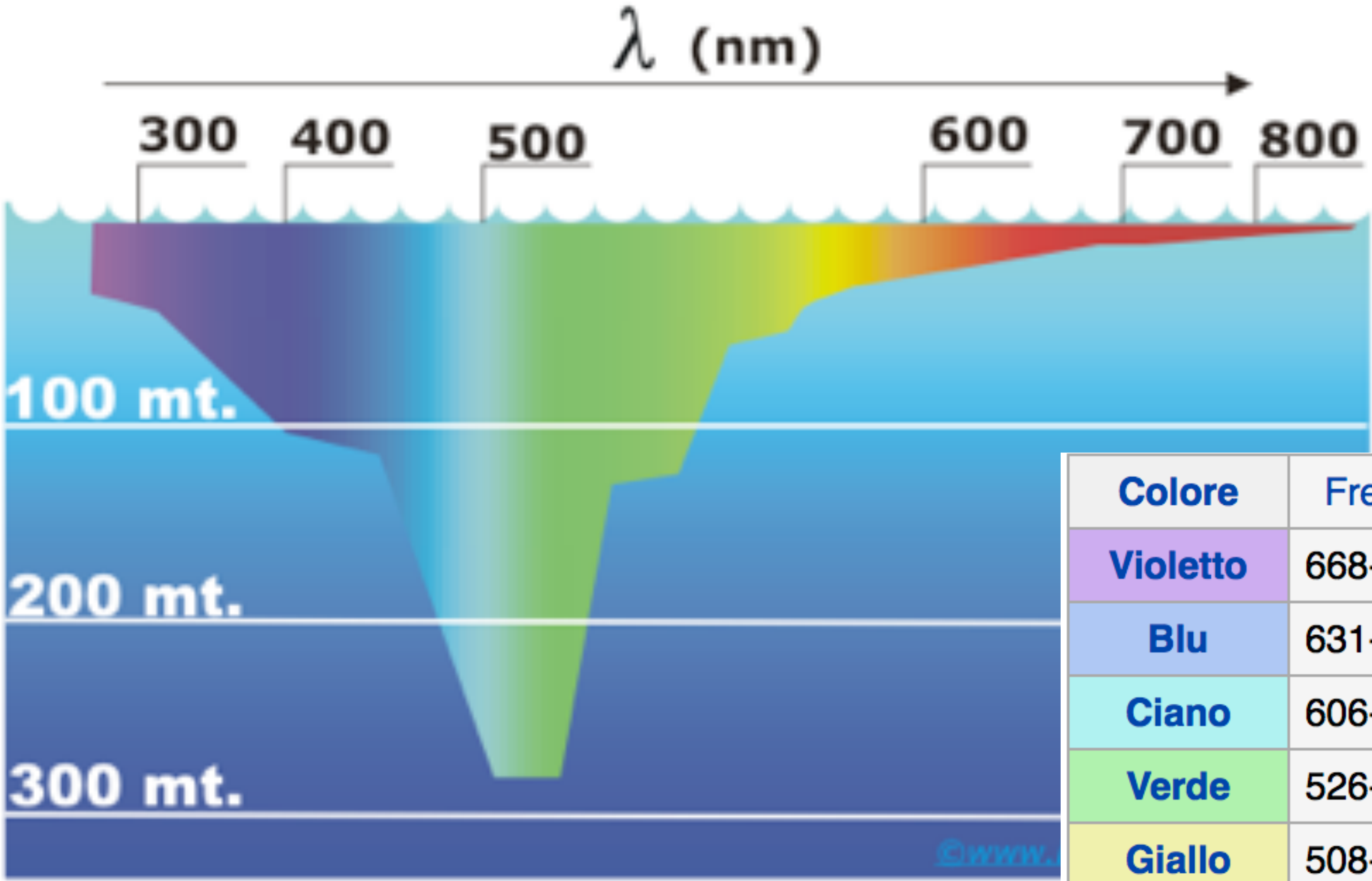
Environmental classification:
- Littoral
- sublittoral
- bathyal
- abyssal
- hadal

Light classification:
- photic
- aphotic

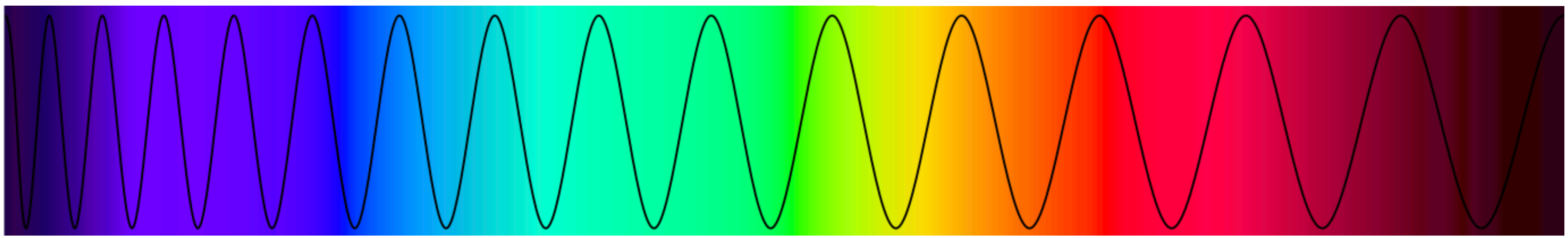
Pelagic:
- neritic
- oceanic:
  - epipelagic (photic zone)
  - mesopelagic (down to T=12°C)
  - bathypelagic (12°C < T > 4°C)
  - abyssalpelagic
  - hadalpelagic

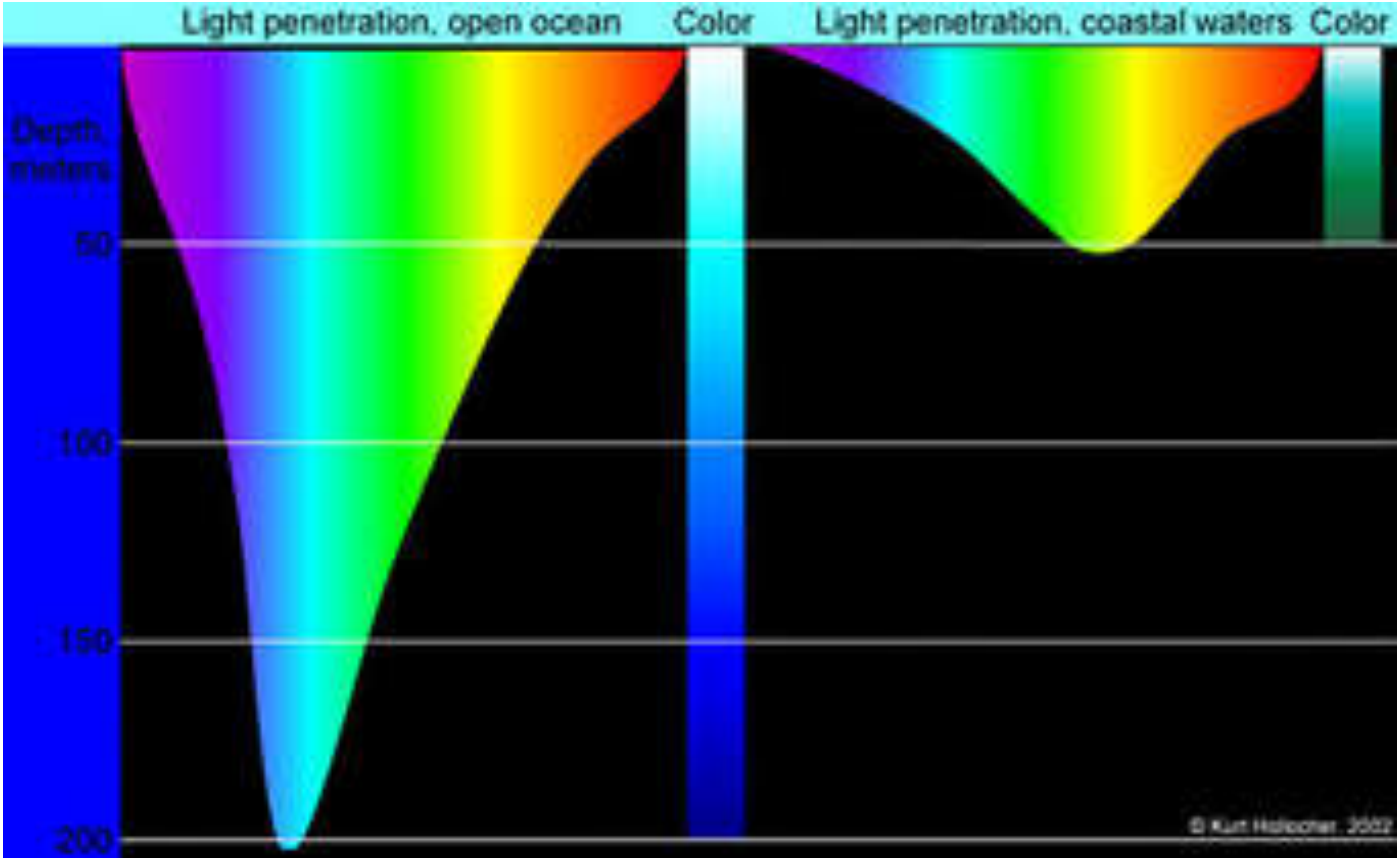


Such a miniscule amount of light penetrates beyond a depth of 200 meters that photosynthesis is no longer possible.



Colore	Frequenza	Lunghezza d'onda
Violetto	668-789 THz	380–450 nm
Blu	631-668 THz	450–475 nm
Ciano	606-631 THz	476-495 nm
Verde	526-606 THz	495–570 nm
Giallo	508-526 THz	570–590 nm
Arancione	484-508 THz	590–620 nm
Rosso	400-484 THz	620–750 nm




Light penetration, open ocean
Color
Light penetration, coastal waters
Color
Depth meters
50
100
150
200
© Kurt Hollocher, 2002

5. Ancient Oceans

The origin of the water of the ocean

The water of the paleo-oceans formed on Earth 3.8 billion years ago (the Earth is 4.5 b years old) by two sources:

- outgassing whereby gases are released from molten rock in the mantle of the planet by volcanic activity;

- bombardment by comets and meterorites bringing with them gases which contributed to the Earth's atmosphere (some meteorites are formed by 20% of water).

Some of the gases in the new atmosphere were methane (CH_4), ammonia (NH_3), water vapor (H_2O), and carbon dioxide (CO_2).

The water on Earth stayed in gaseous form until the planet's surface cooled below 100°C.

At this time, **3.8 billion years ago**, water condensed into rain and poured onto the land. Water collected in low lying areas which gradually became the primitive oceans.

At **3.5 billions years ago**, the first photosynthetic organisms appeared, and they produced oxigen that enreached the primitive atmosphere.

The geochemical cycles had their beginnings here, with minerals entering the oceans from the land and sky and minerals leaving the oceans through tectonic activity and by evaporation/deposition processes.

At **1 billion years ago** these cycles were well established and since then the chemically composition of the oceans has remained constant.

The **Giapeto Ocean**, between the Laurentua and Baltica continents

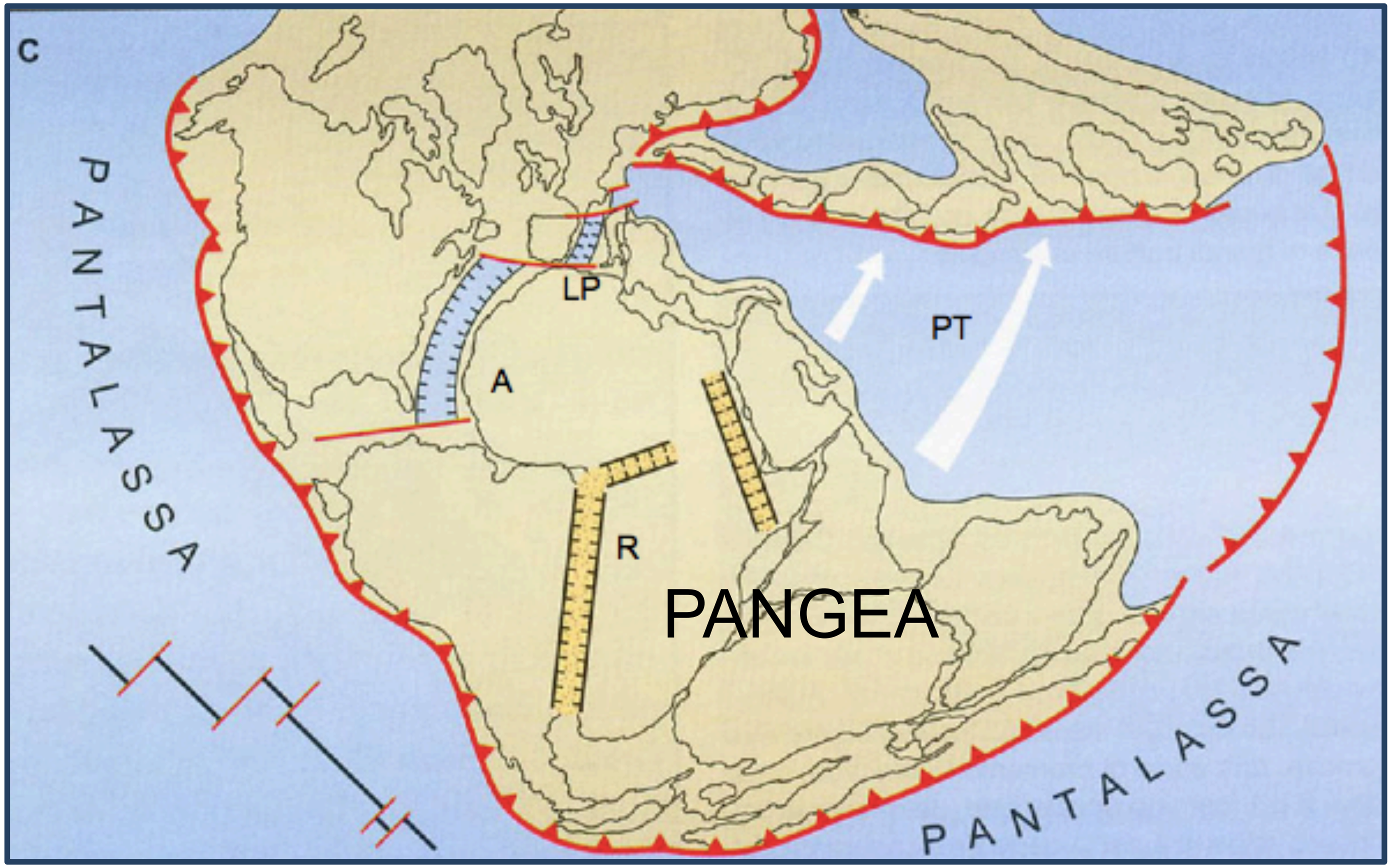
- formed in the Cambrian, about 510 milion years ago,

- disappear in the Devonian, about 400 milion years ago.

Gli oceani nel passato

Map courtesy of CR Scotese, PALEOMAP Project

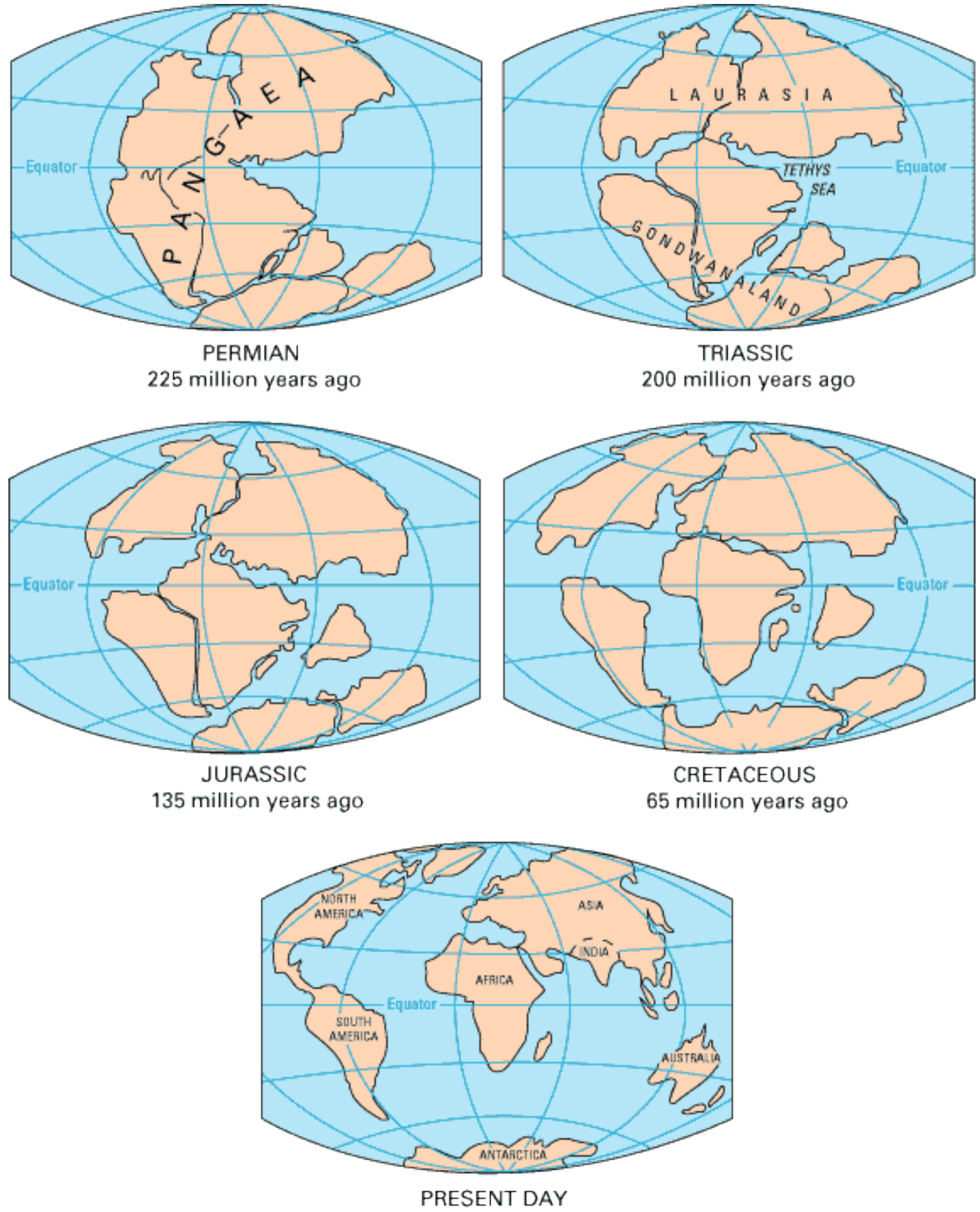
ATLANTIC OCEAN: initial stage



Fragmentation of the Pangea (Late Giurassic):

- Opening of the Central Atlantic (A) and the Ligurian-Piedemont Basin (LP – western Tethys)
- Continental rifting of the future Southern Atlantic (R)
- Subduction of the Paleo Tethys (PT) in the Permo-Triassic

The break up of Pangaea



Bibliography

Philip Kearey, Keith A. Klepeis, Frederick J. Vine, 2009, Global Tectonics, 3rd Edition, Wiley-Blackwell

Web sites	
International Hydrographic Organization	https://www.iho.int
General Bathymetric Chart of the Oceans	https://www.gebco.net
The Mediterranean Science Commission	http://www.ciesm.org
EMODnet	http://www.emodnet.eu
NOAA National Geophysical Data Center	http://www.ngdc.noaa.gov
Marine Regions	http://www.marineregions.org
Woods Hole Oceanographic Institution	http://www.whoi.edu/main/ocean-topics
Paleomagnetism	http://www.minerva.unito.it/SIS/Paleomagnetismo/paleo4.htm
Plate tectonic	http://www.ucl.ac.uk/EarthSci/people/lidunka/GEOL2014/Geophysics1-%20Plate%20tectonics/PLATE%20TECTONICS.htm
Ocean gravity	http://topex.ucsd.edu/grav_outreach/index.html#natlanticano

Documentary	
Drain the ocean	https://www.youtube.com/watch?v=83YSzkB4L7Q