

Università di Trieste
Corso di Laurea in Geologia

Anno accademico 2019 - 2020

Geologia Marina

Parte I

Modulo 1.1 Oceani. Morfologia, struttura ed evoluzione

Docente
Martina Buseti

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 (ὨΚΕΑΝΟΣ), 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 Fontana di Trevi

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



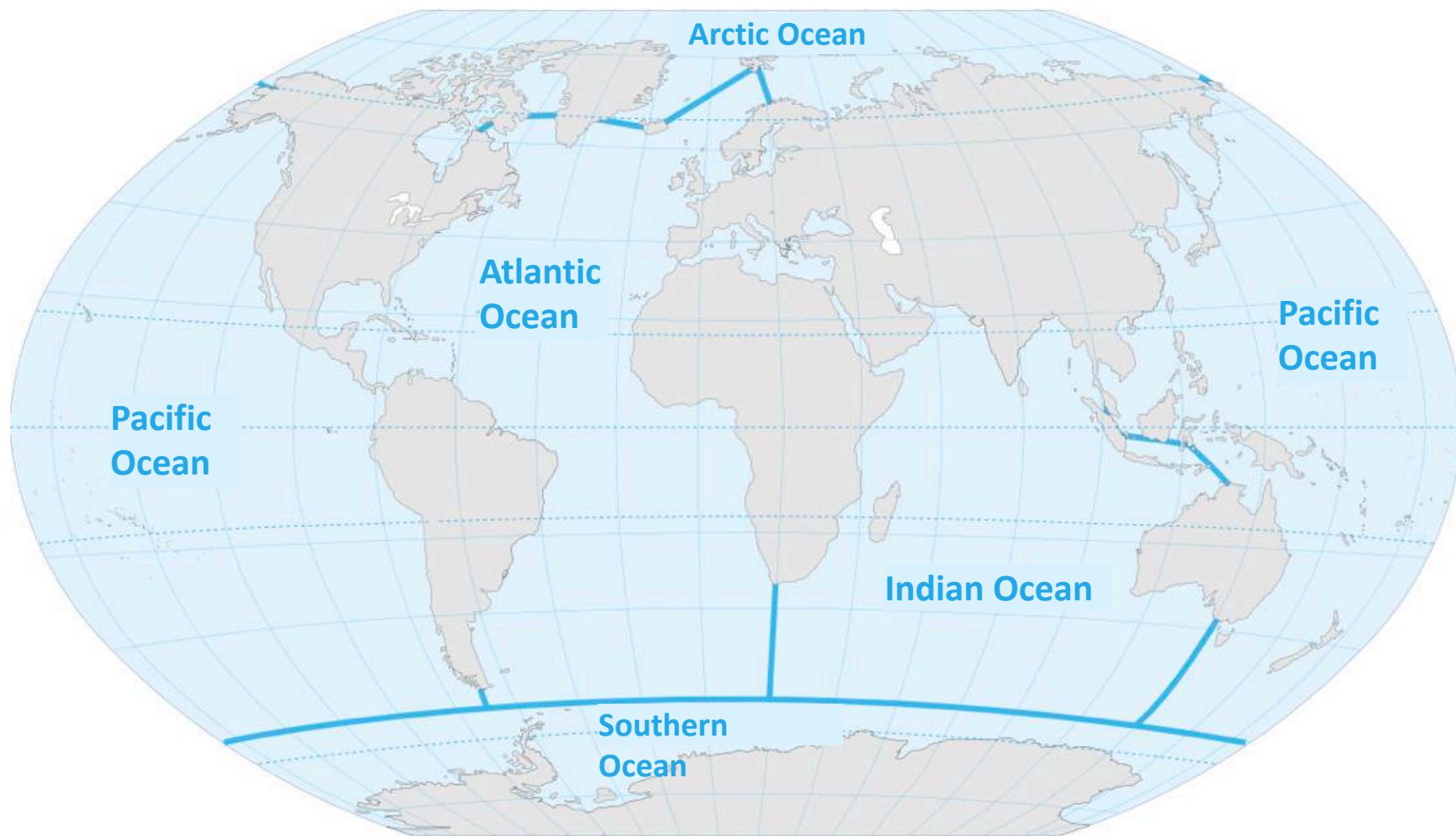
The oceans and the seas are important because they :

The Blue Planet

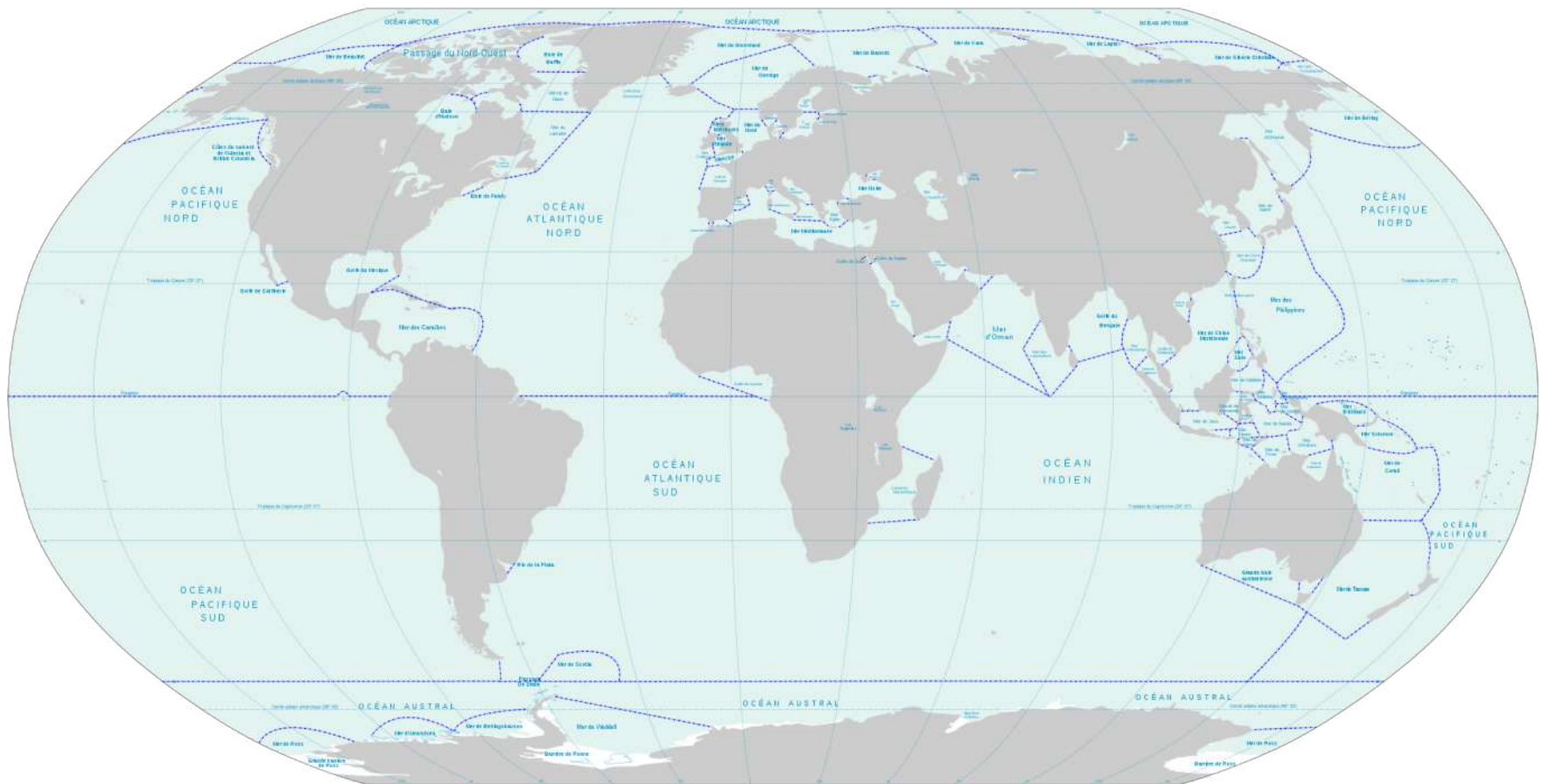


- cover 71-72% of the Earth surface
- contain the 97% of the water of the Earth
- but less than 5-10% have been explored

The present oceans of the world



The limits of the oceans and seas defined by the International Hydrographic Organization (IHO)



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](#).

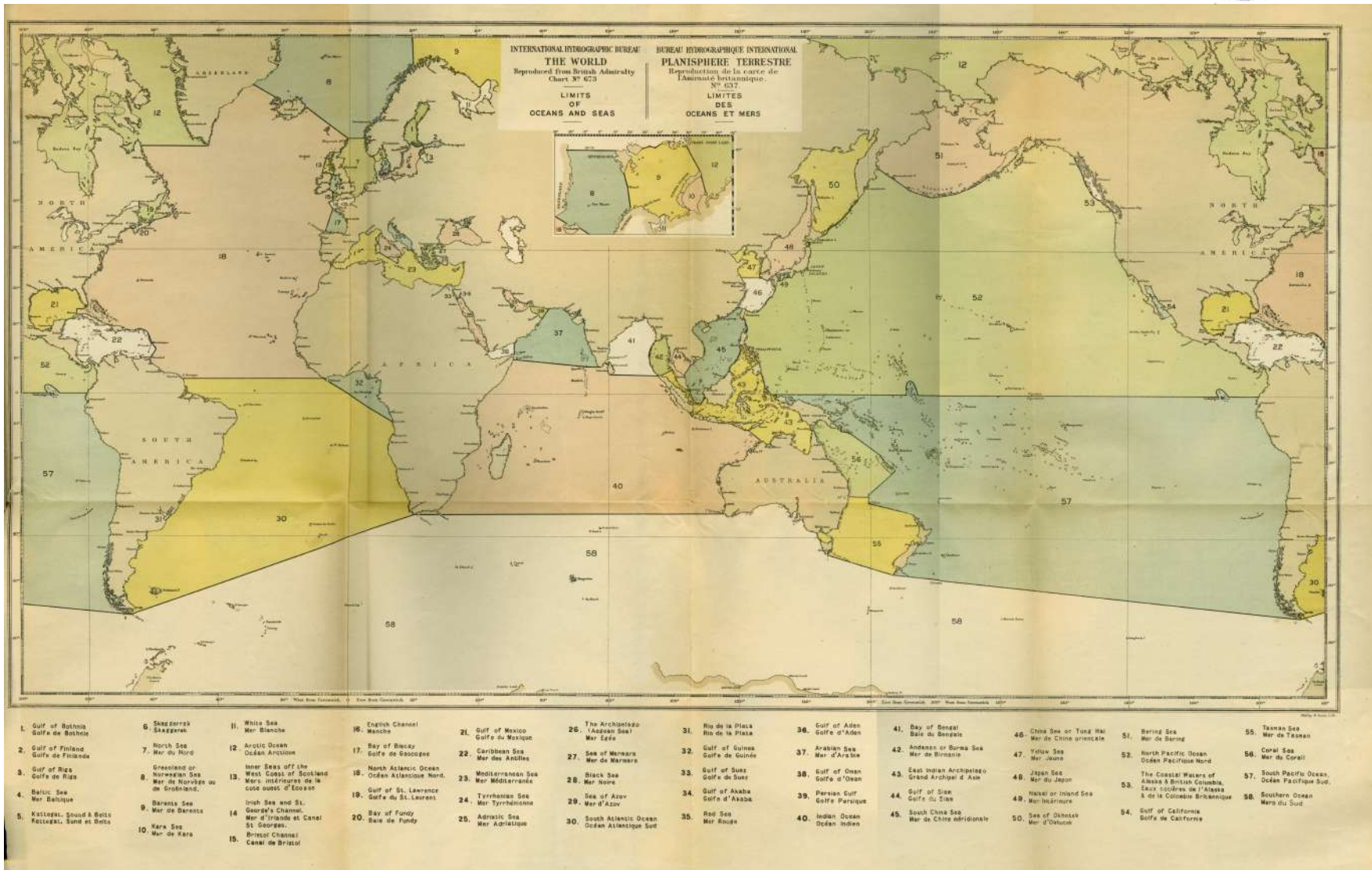
A principal Aim of the IHO is to ensure that all the world's seas, oceans and navigable waters are surveyed and charted.

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

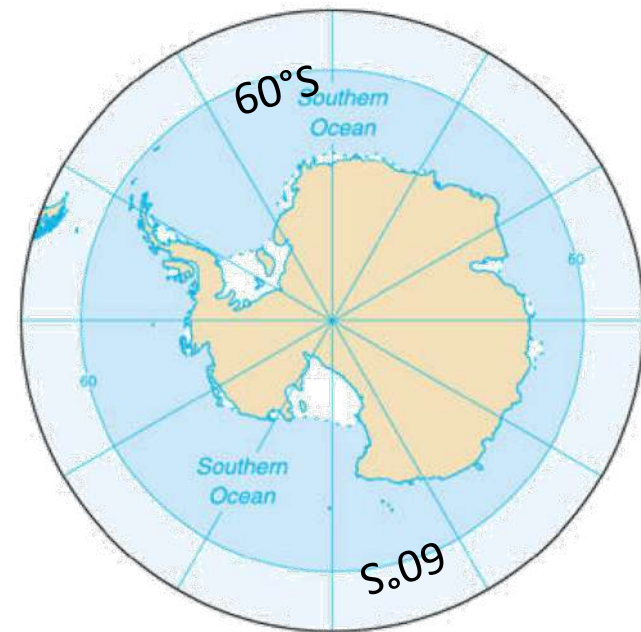
Arctic Ocean

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

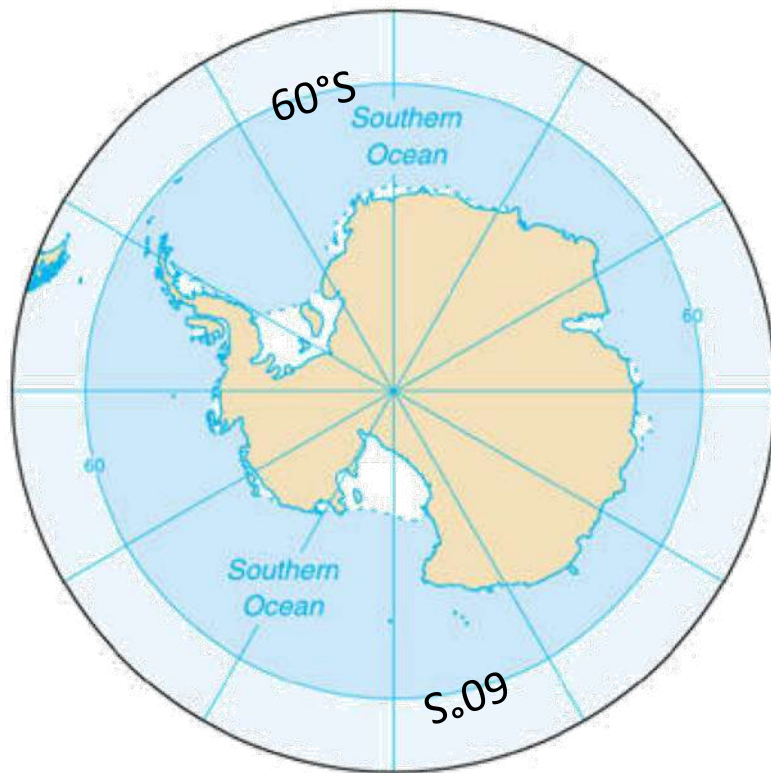


Southern Ocean

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.**



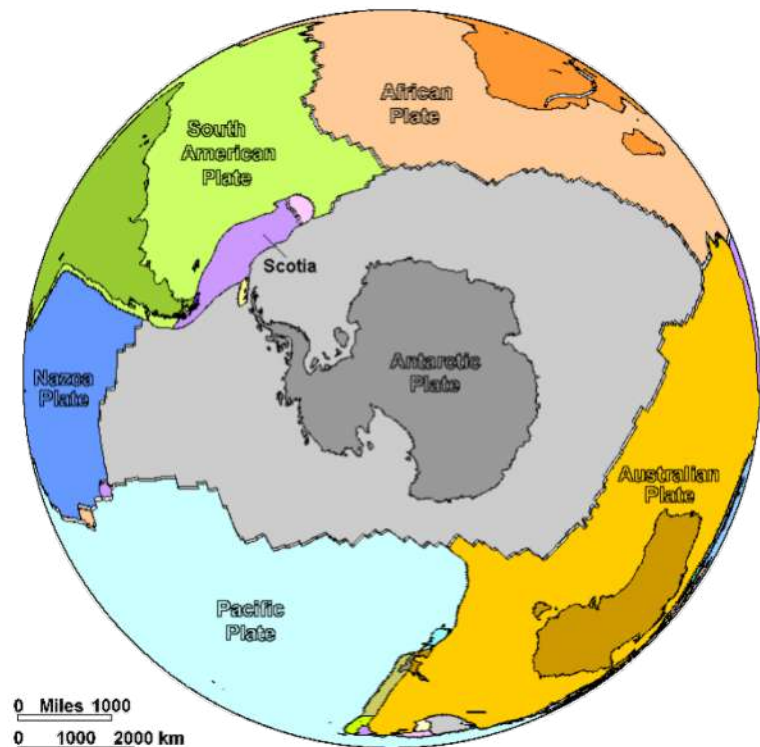
Southern Ocean



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

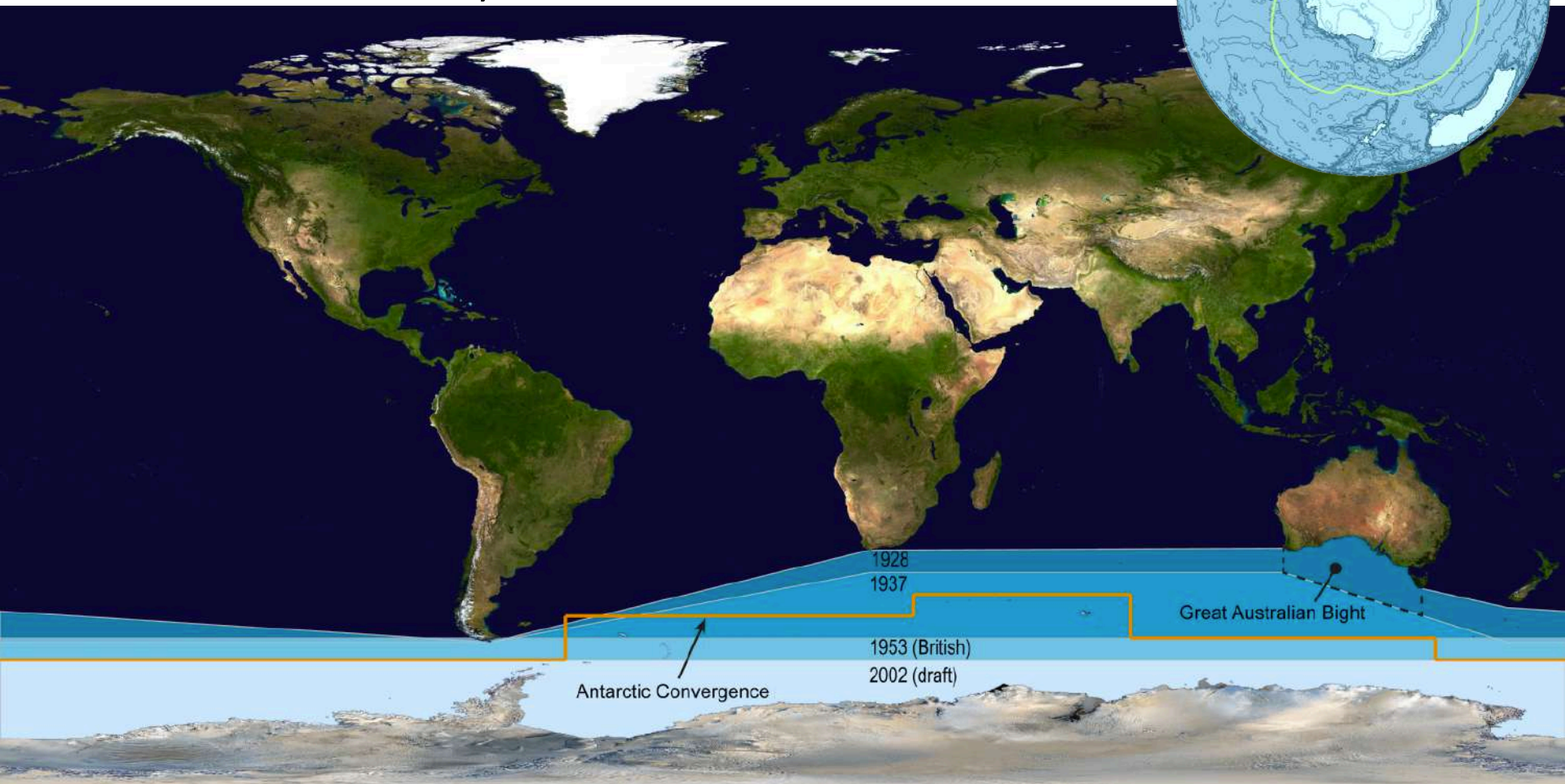
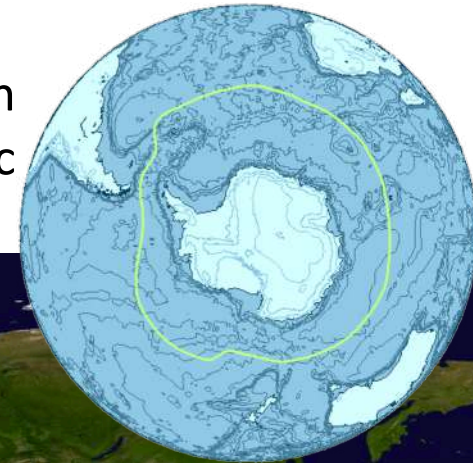
the Southern Ocean

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



IHO's delineation of the Southern Ocean

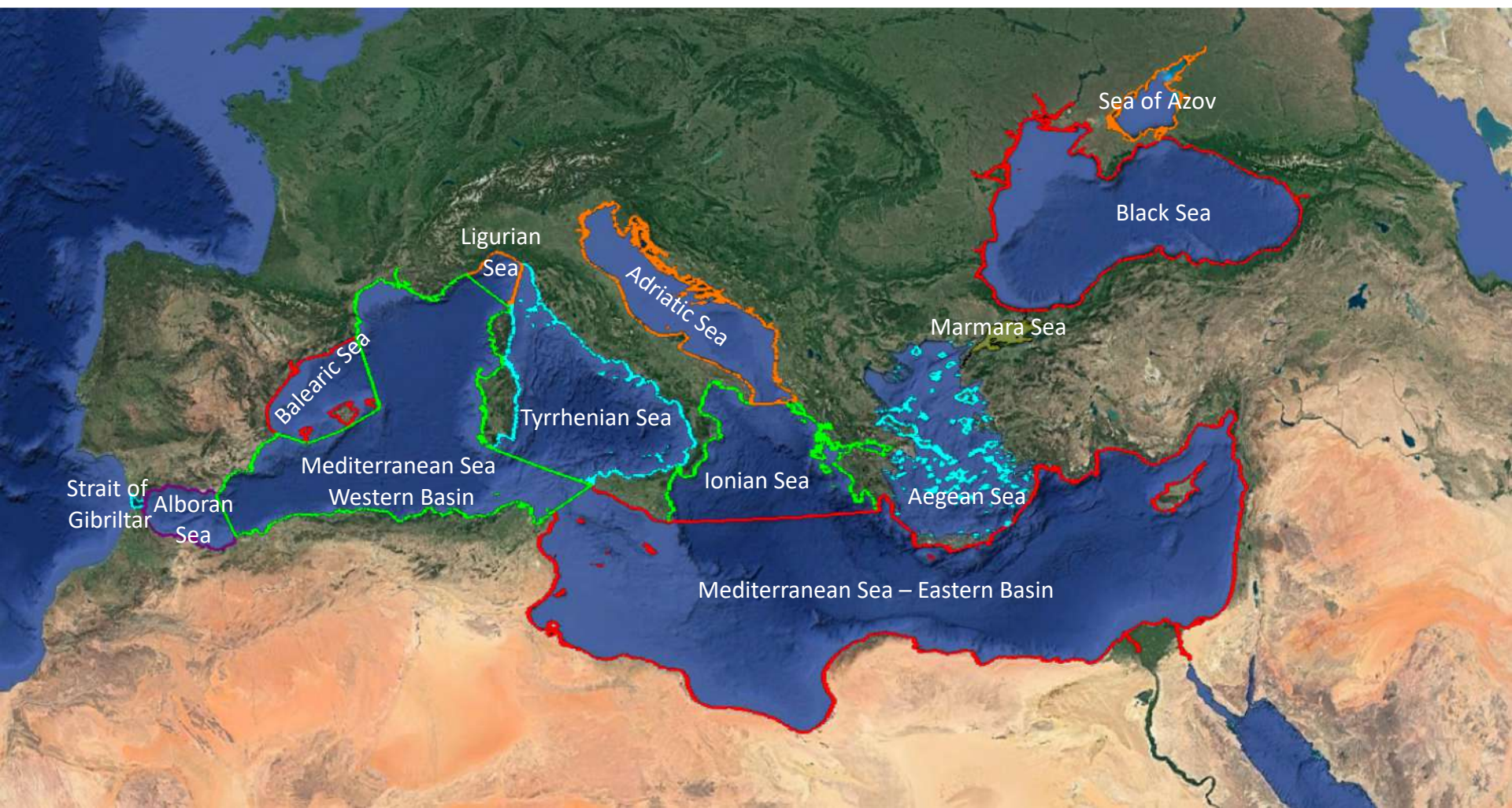
Antarctic Convergence: a curve encircling Antarctica, varying in latitude seasonally, where cold, northward-flowing Antarctic waters meets the relatively warmer water of the subantarctic



| 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 |

[illegible]

The seas of the Mediterranean formally defined by the IHO



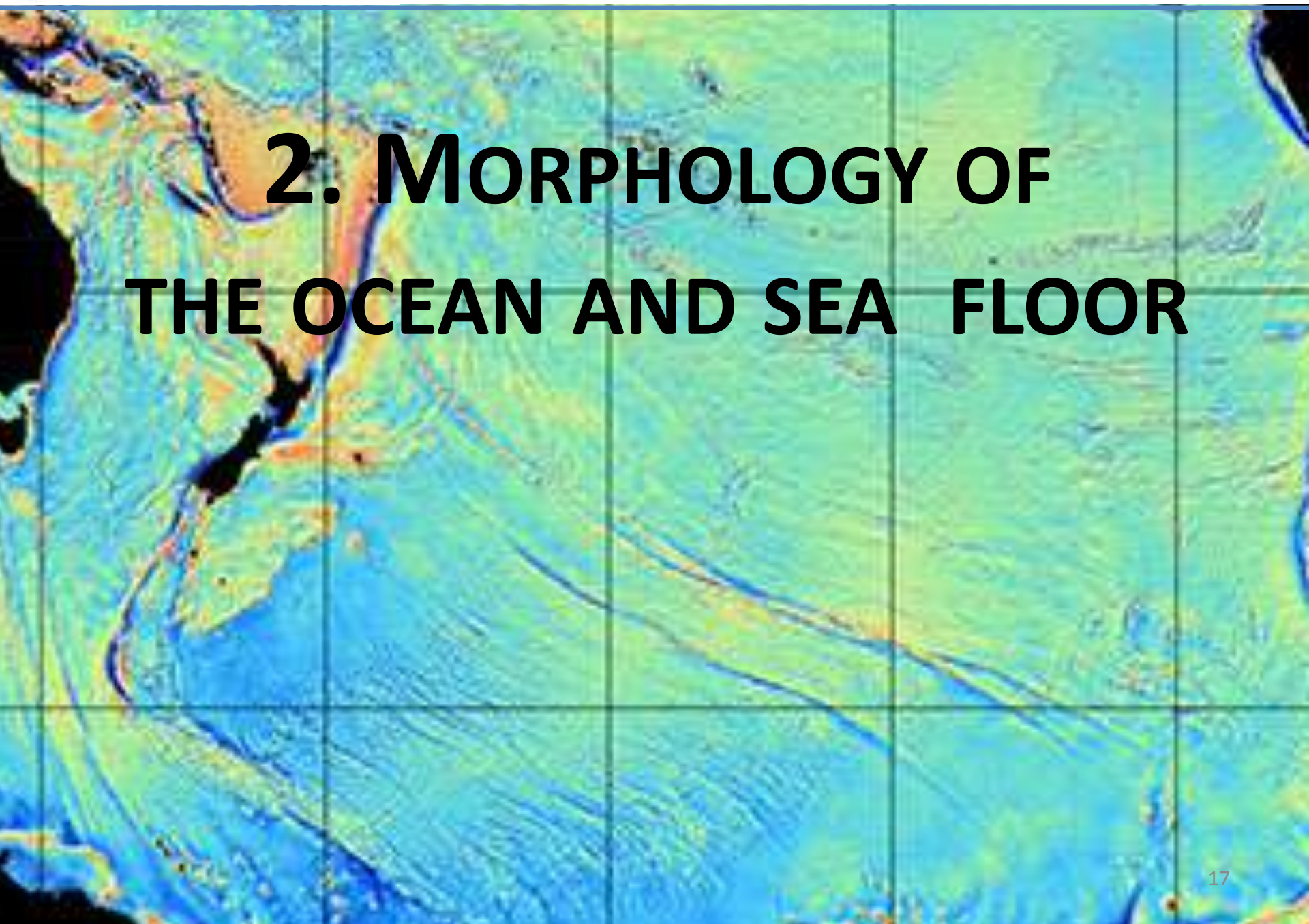
The seas of the Mediterranean

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





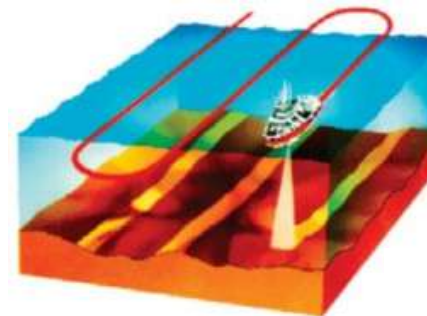
OCEAN AND SEA FLOOR MORPHOLOGY

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

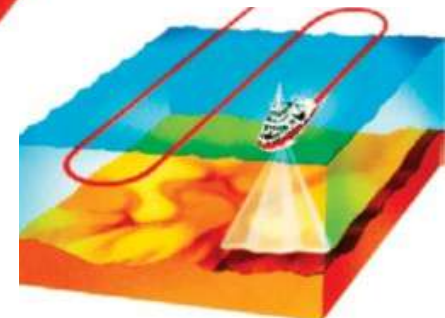
To investigate the oceans and seas we need appropriate instruments and technologies:

5-10%

- 1) First instrument: the SONAR, constructed at the beginning of the 1900
- 2) Multibeam technologies, developed in the last decades of the 1900
- 3) Satellite derived bathymetry and sea floor morphology developed in the last decades of the 1900



(a) Single-Beam



(b) Multi-Beam



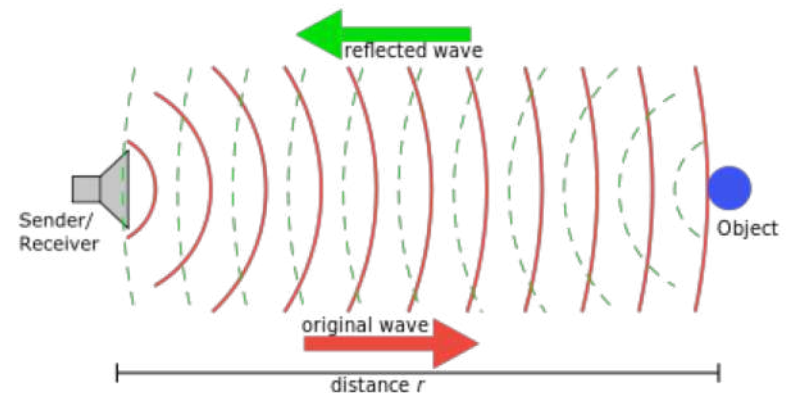
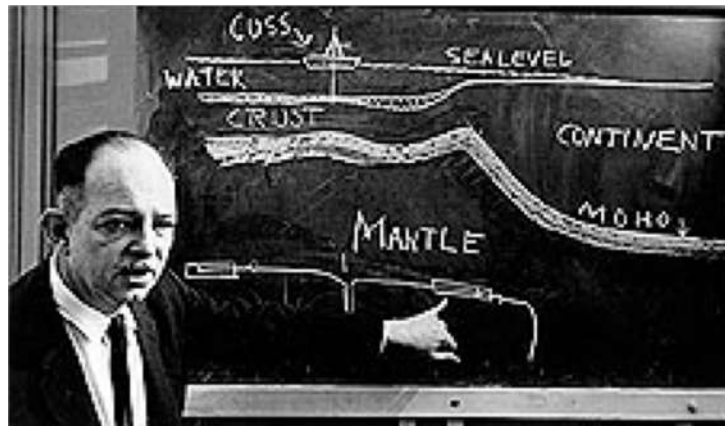


Harry Hess (1906 – 1969)

Professor of geology at Princeton University

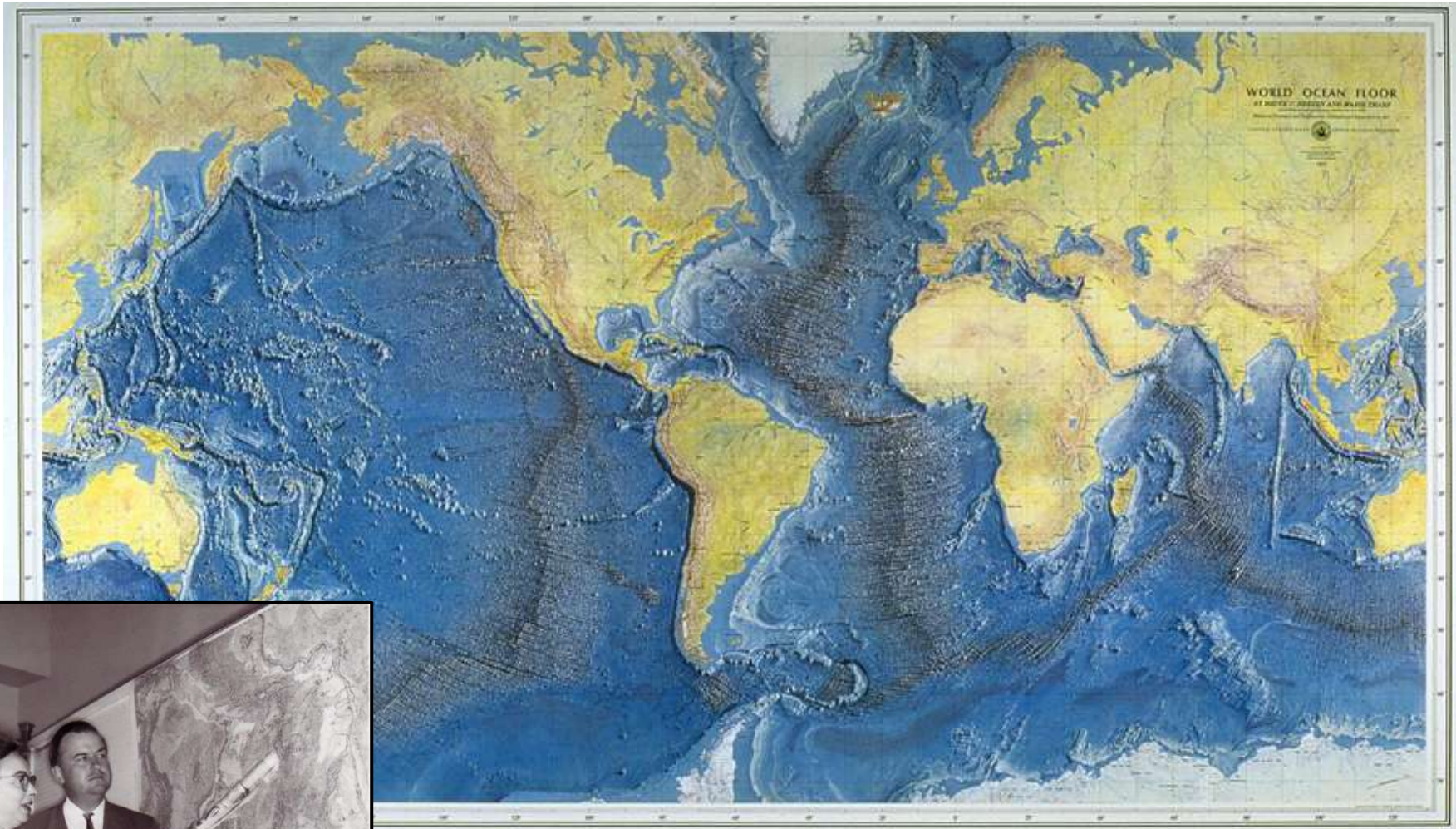
During the Second World War, Hess was the captain of a ship equipped with a SONAR (SOund NAvigation and Ranging, invented in 1917 by Paul Langevin).

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.



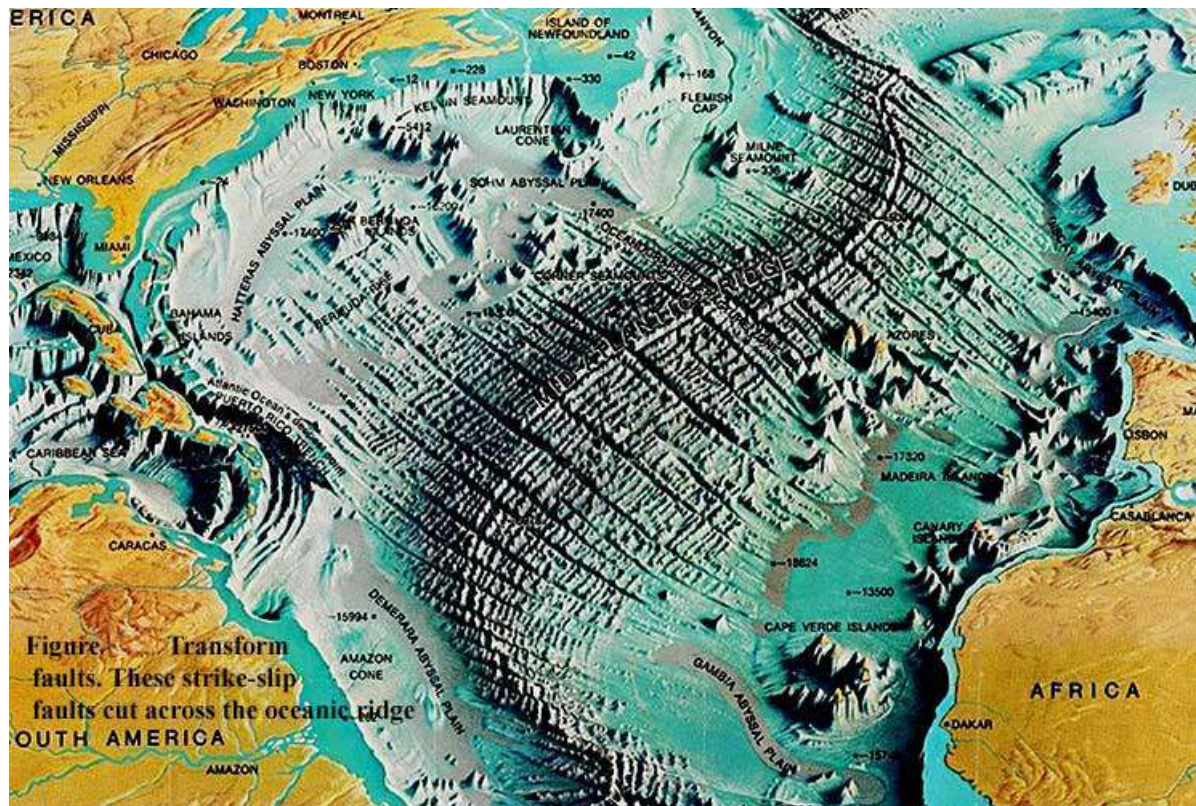
The SONAR principle

SEA FLOOR MORPHOLOGY 1977



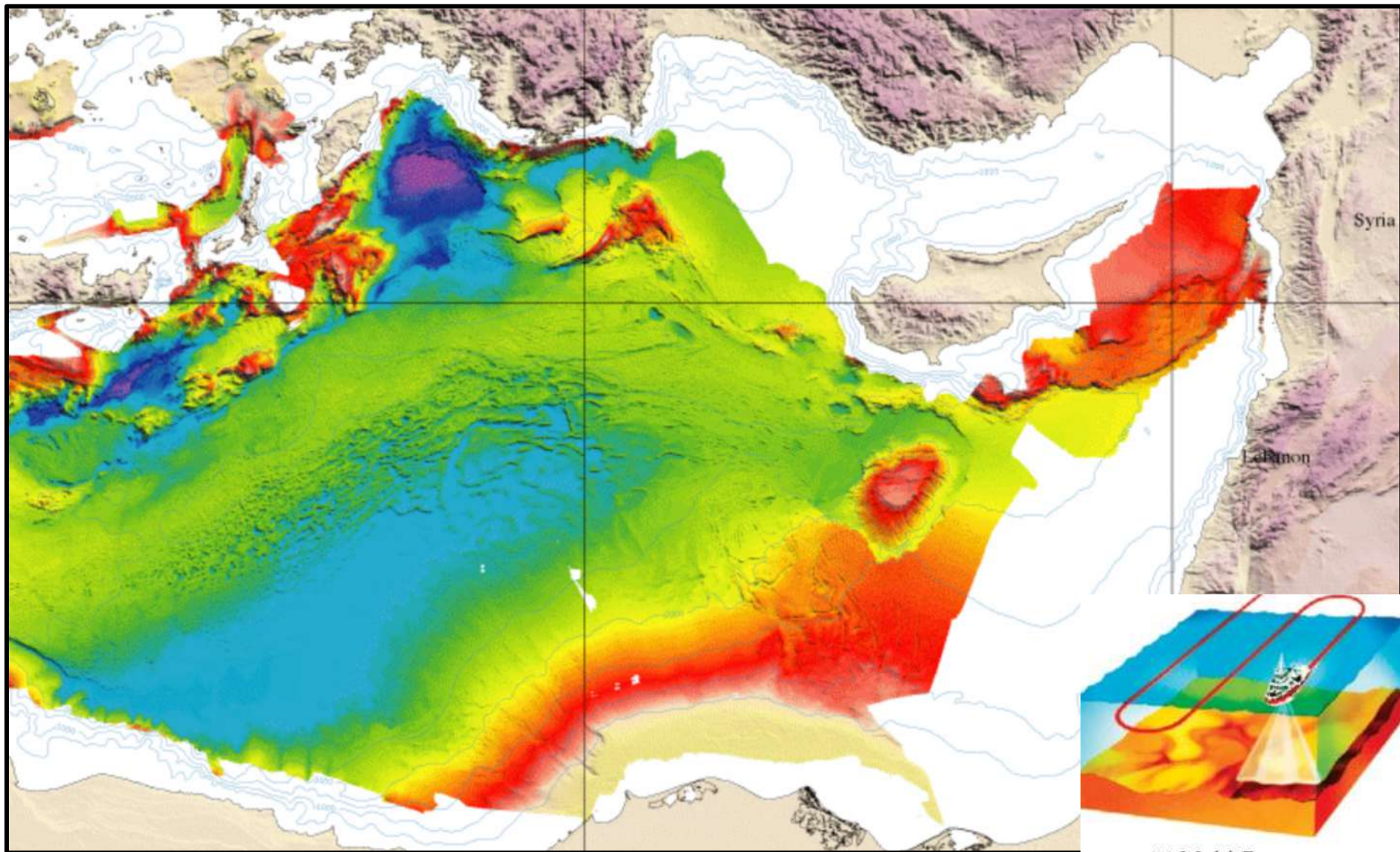
Marie Tharp and Bruce Heezen, oceanographers of the Columbia University's Lamont Geological Observatory. They discovered the 60.000 km of underwater ridges. The map was painted by Heinrich C. Berann.

Mid-Ocean Ridges



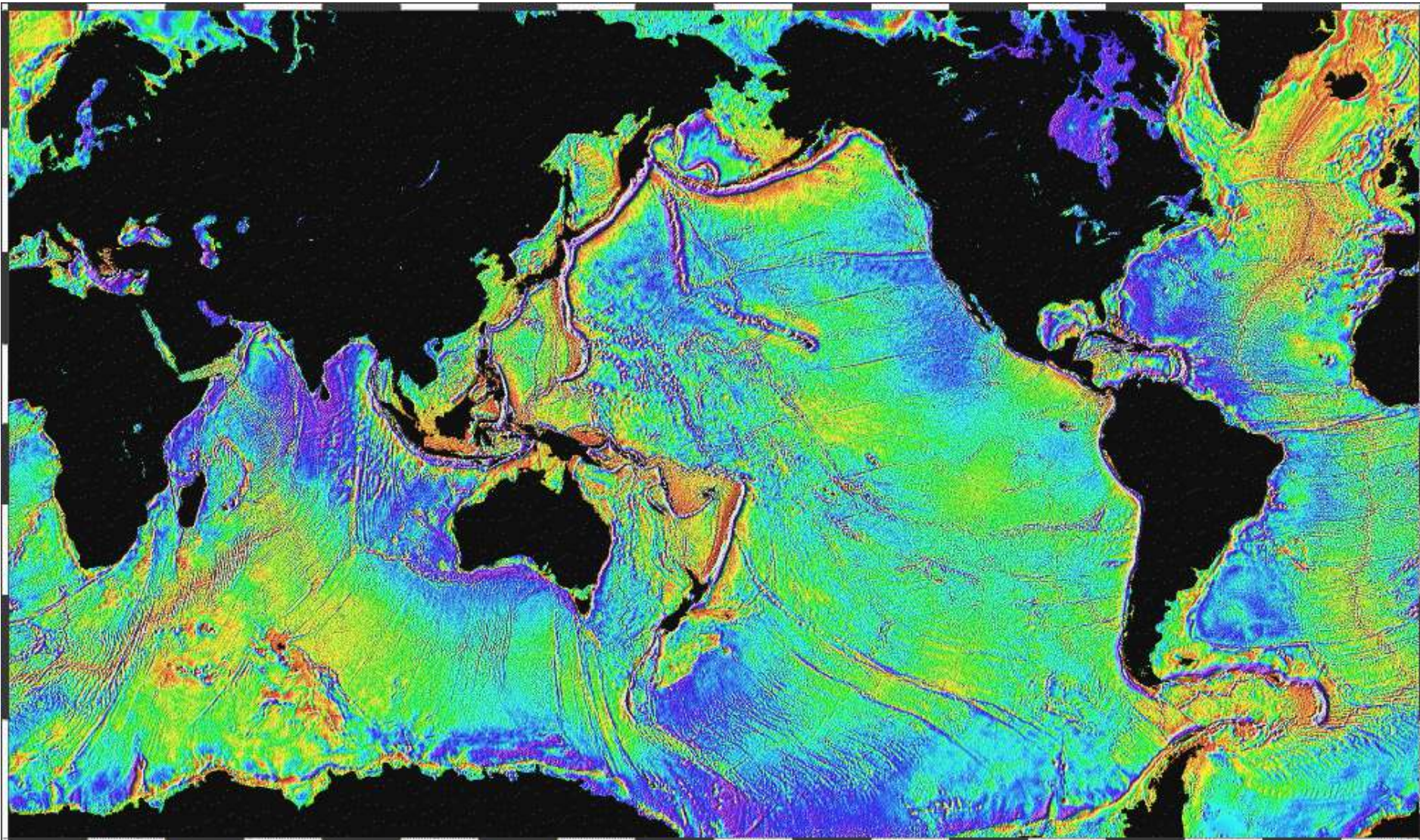
- The largest feature of the ocean floor.
- Linear belt of submarine mountains and active volcanoes about 60.000 km long.
- Plate boundaries: new magma forces its way up between two plates and pushes them apart.

Sea floor mapping from multibeam data

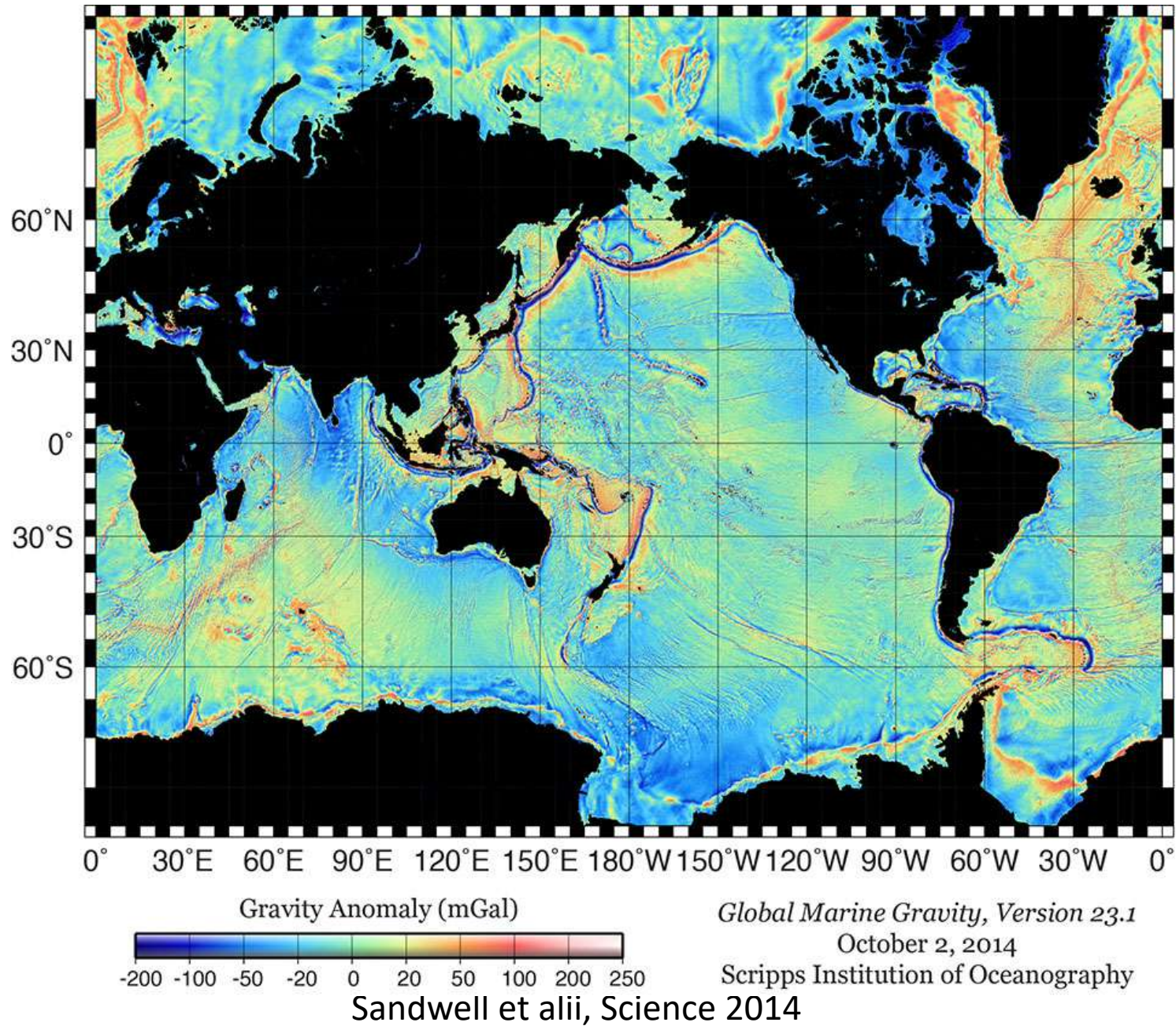


(b) Multi-Beam

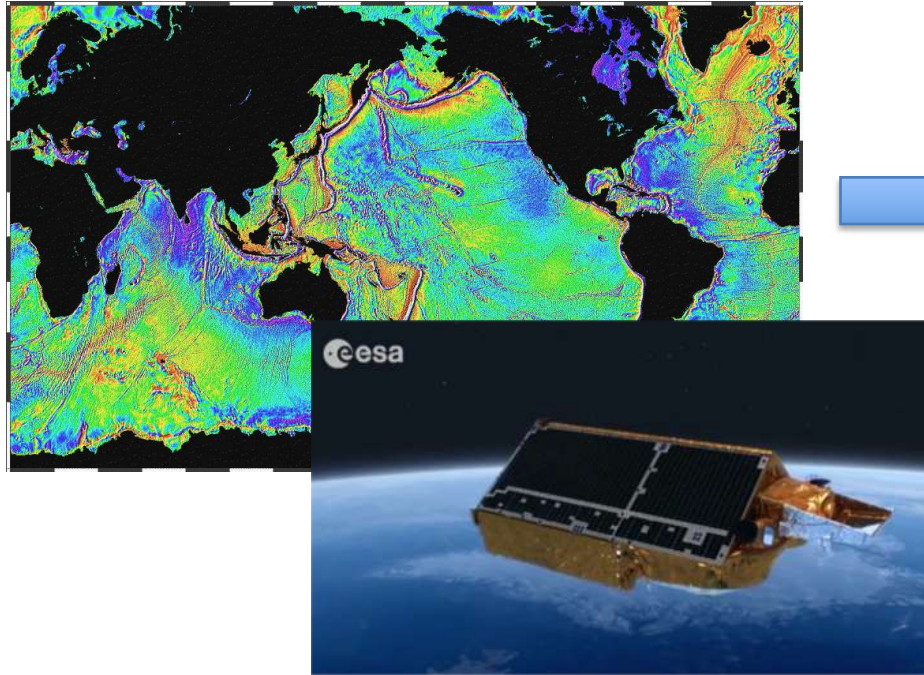
Global gravity map of the oceans - from GEOSAT and ERS-1



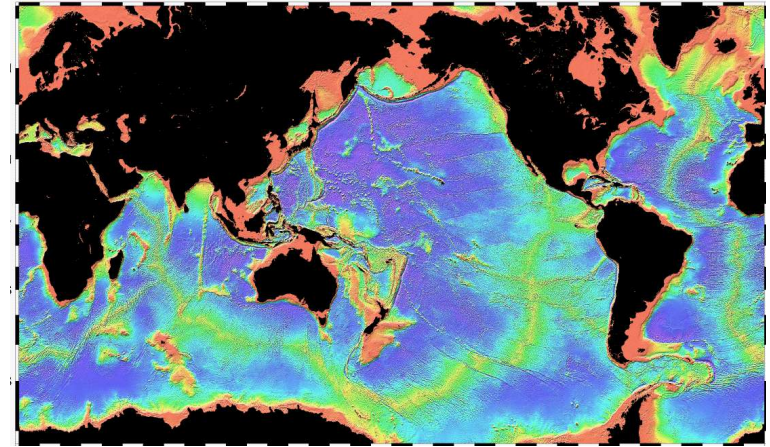
SMITH AND SANDWELL, 1996



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



Global sea floor topography from gravity data and shipboard depth soundings



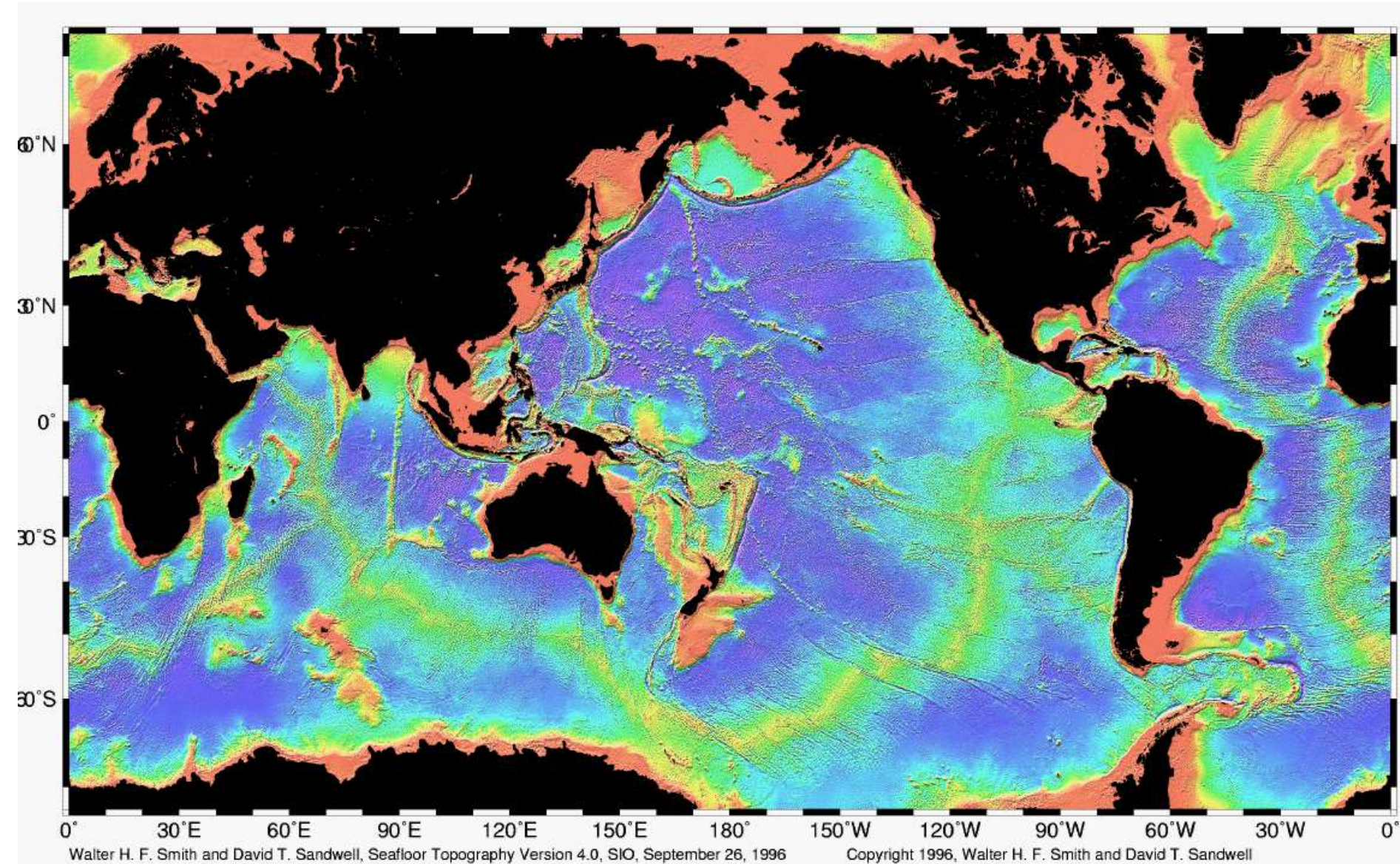
SMITH AND SANDWELL, 1996

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.

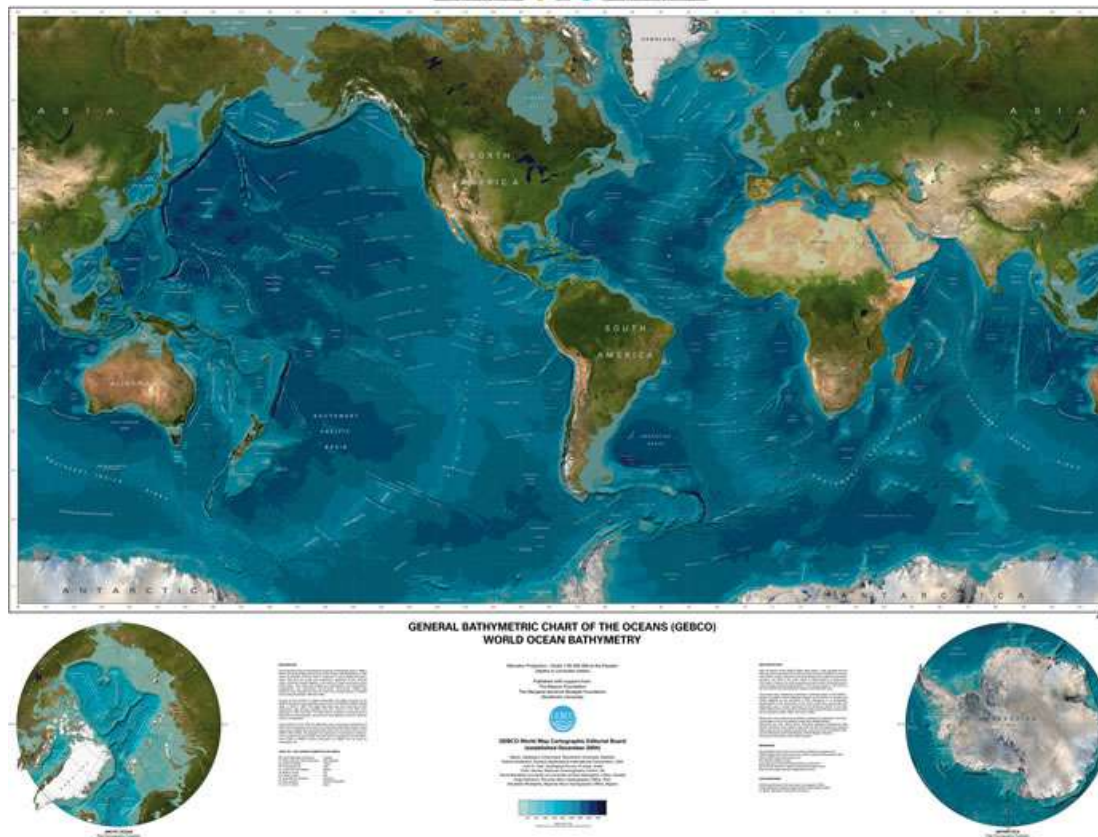
Global sea floor topography from gravity data derived from satellite altimetry and shipboard depth soundings



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

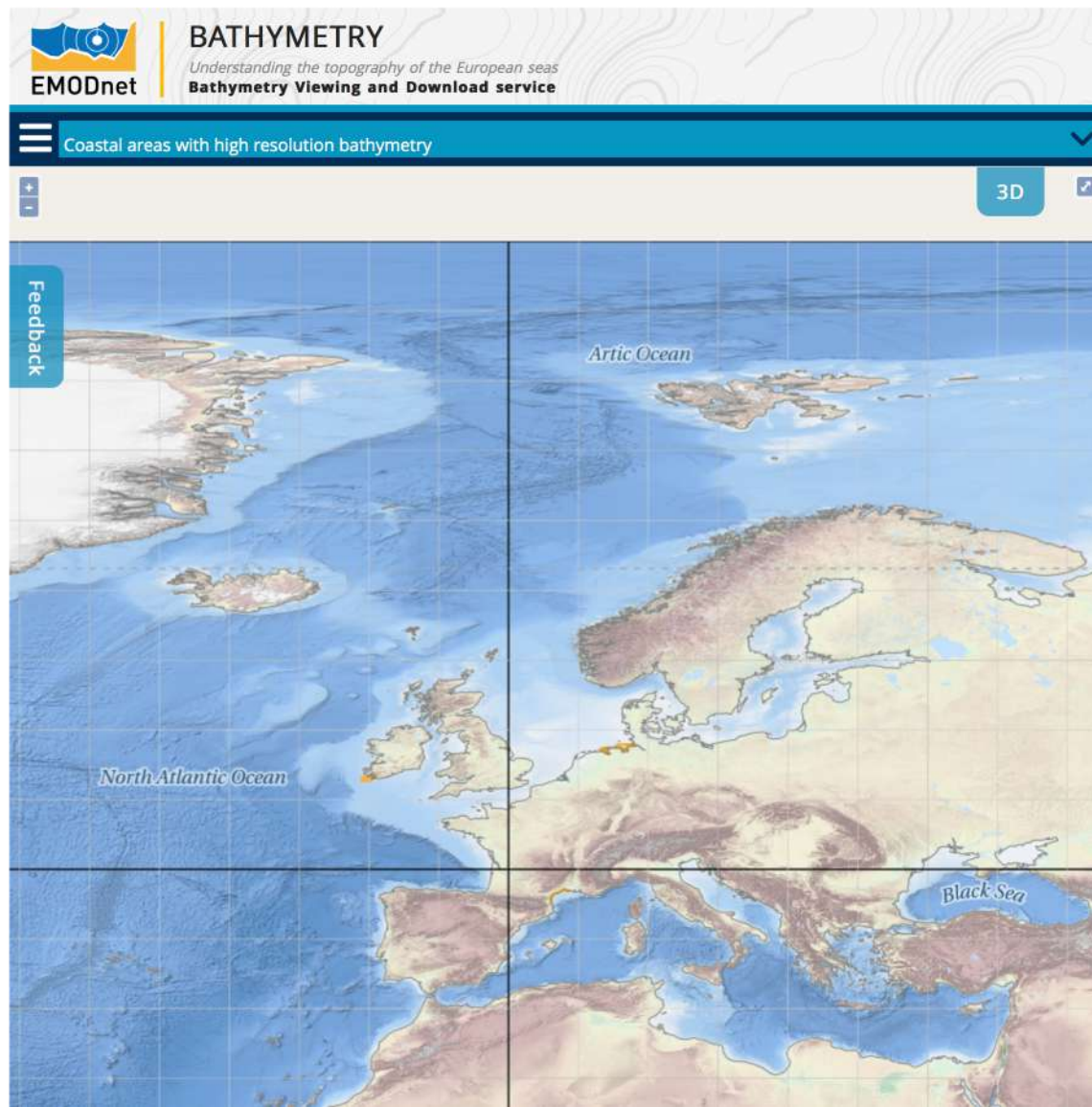
- GEBCO 2014 Grid — a global 30 arc-second interval grid
- GEBCO One Minute Grid — a one arc-minute interval grid. Last updated in 2008. Please note that there are no plans for further development of this data set.

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

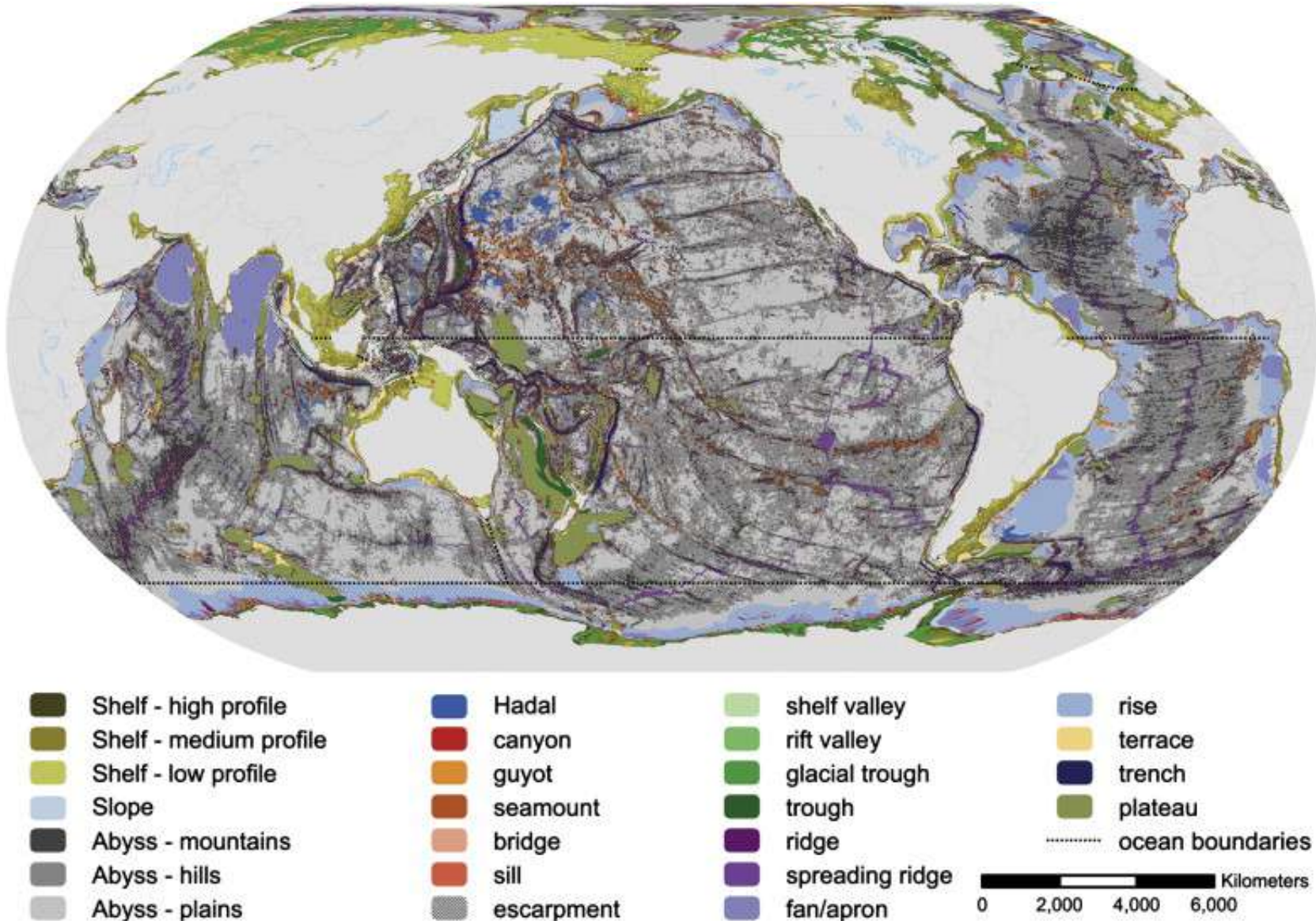
<http://www.emodnet.eu>



SEA FLOOR MORPHOLOGY

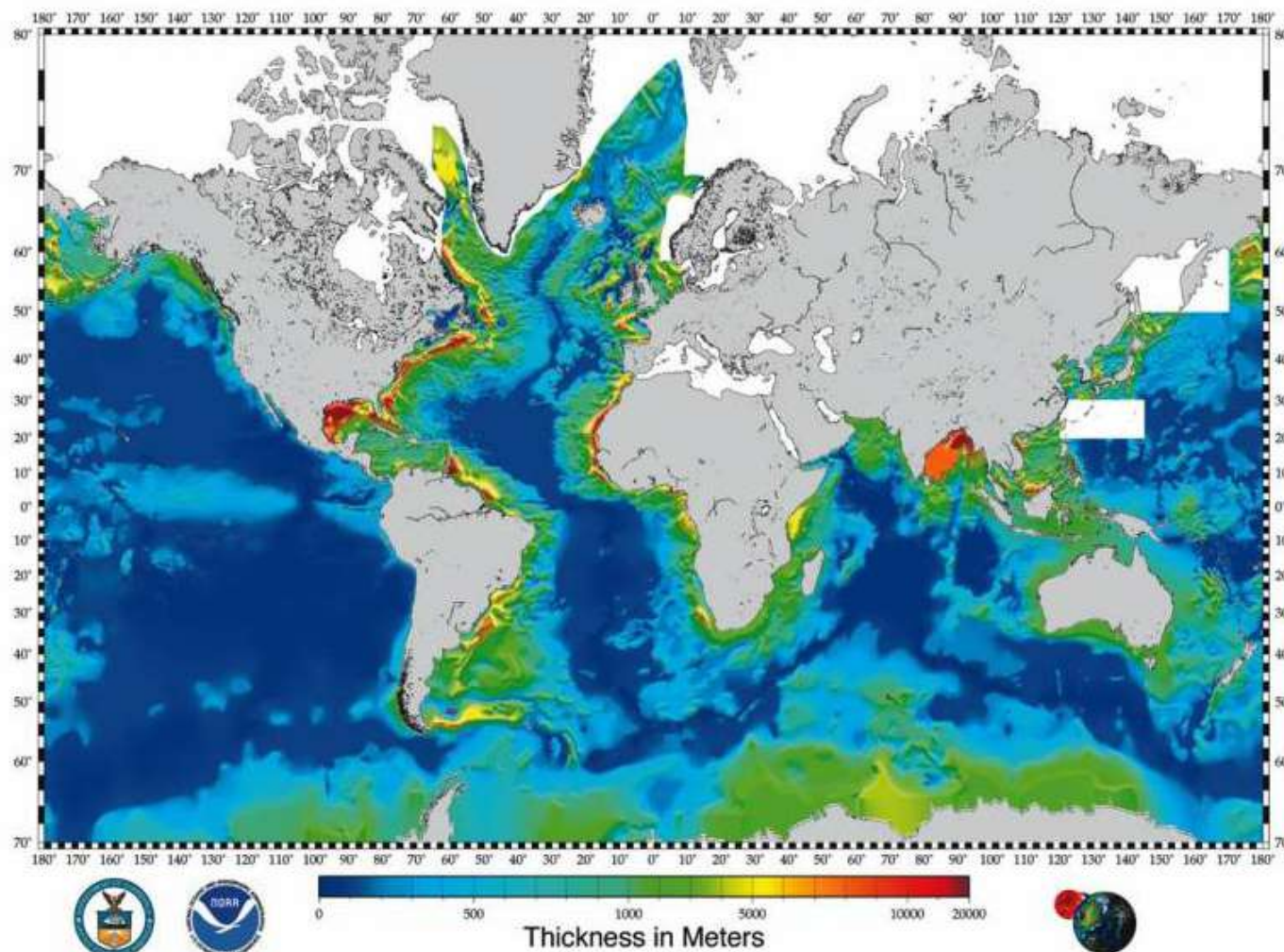


Geomorphic features map of the world's oceans.



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>

Total Sediment Thickness of the World's Oceans & Marginal Seas



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. 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.

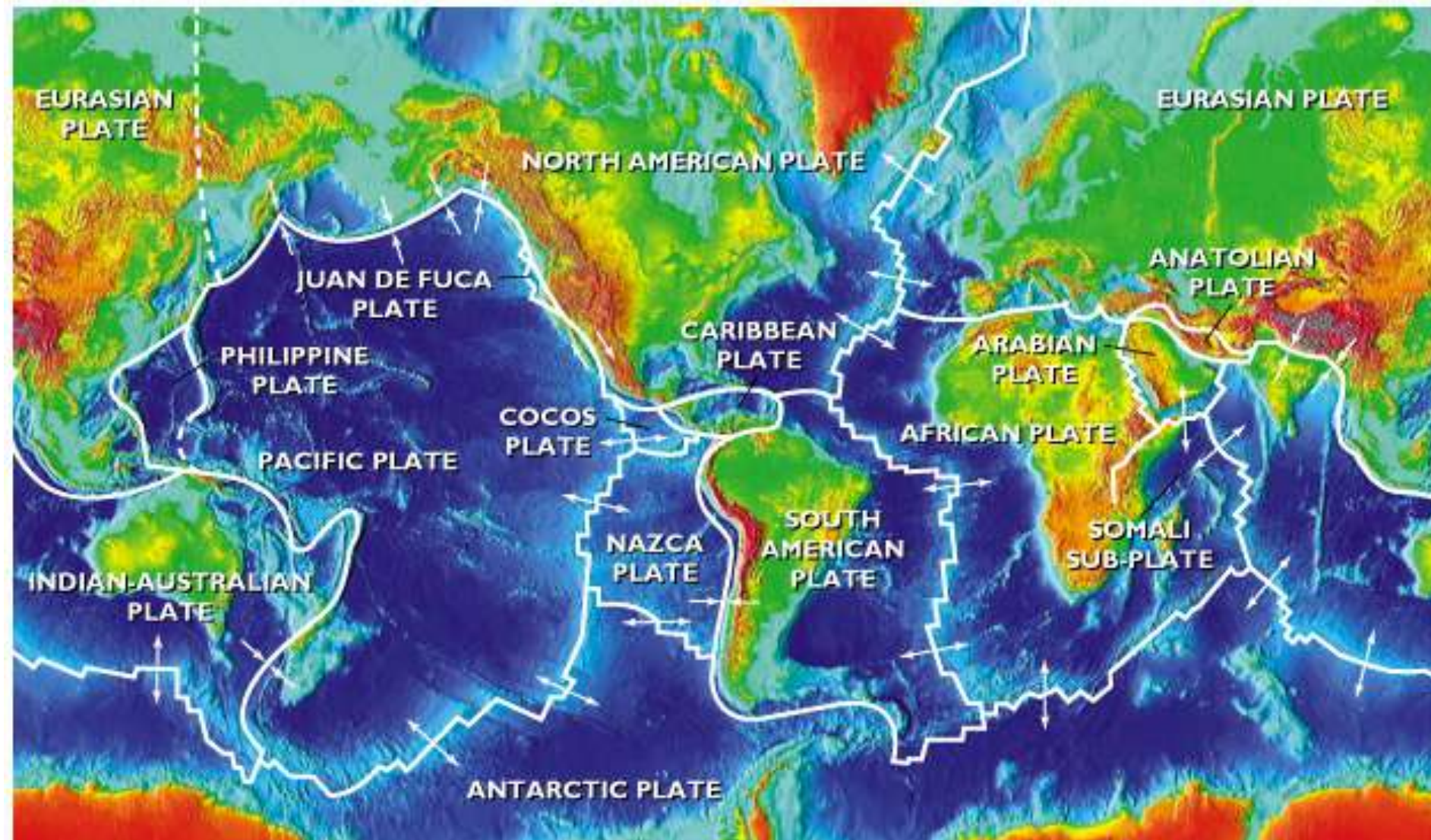
The distribution of sediments in the oceans is controlled by five primary factors:

- 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

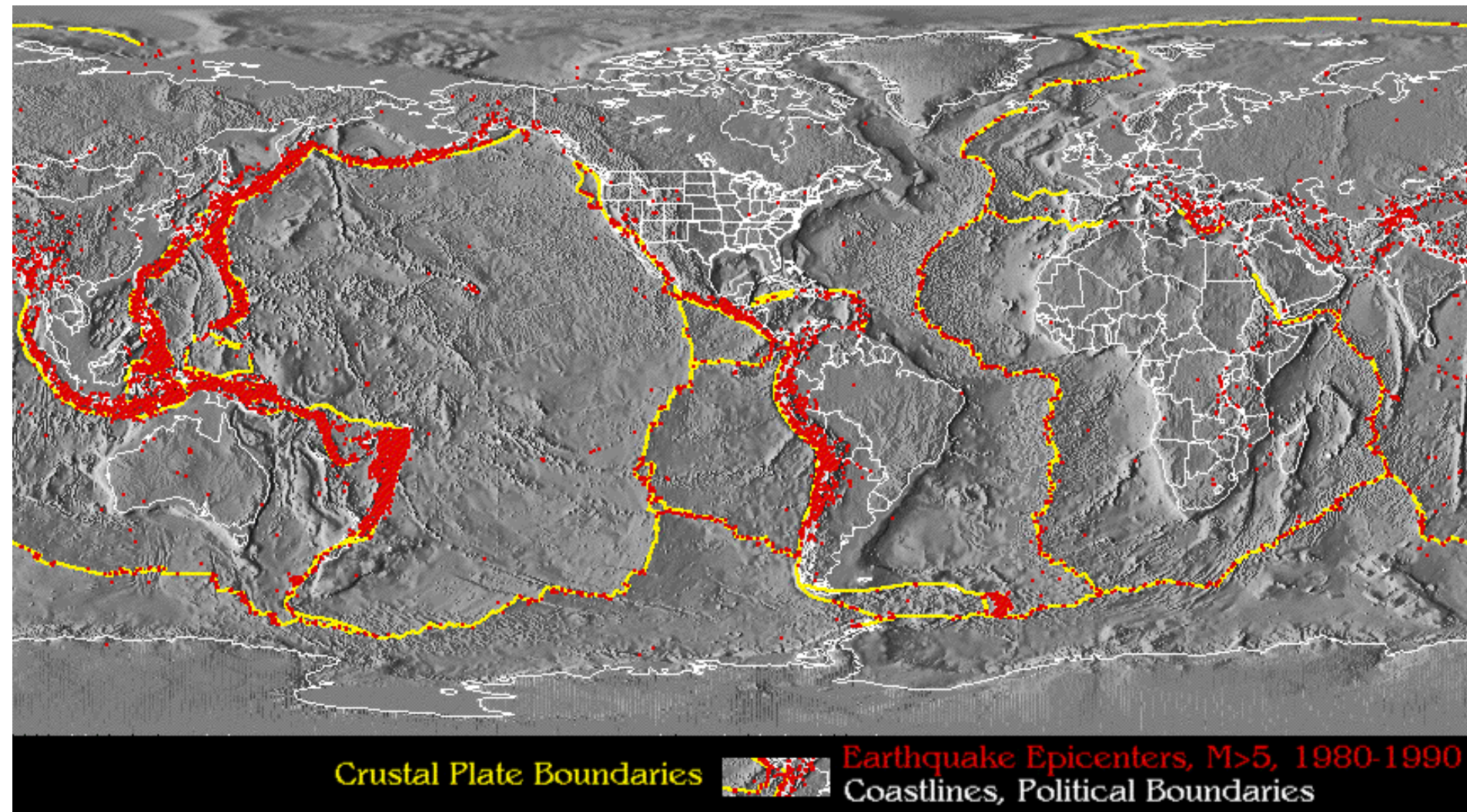
The data values are in meters and represent the depths to acoustic basement. It should be noted that acoustic basement may not actually represent the base of the sediments. These data are intended to provide a minimum value for the thickness of the sediment in a particular geographic region.

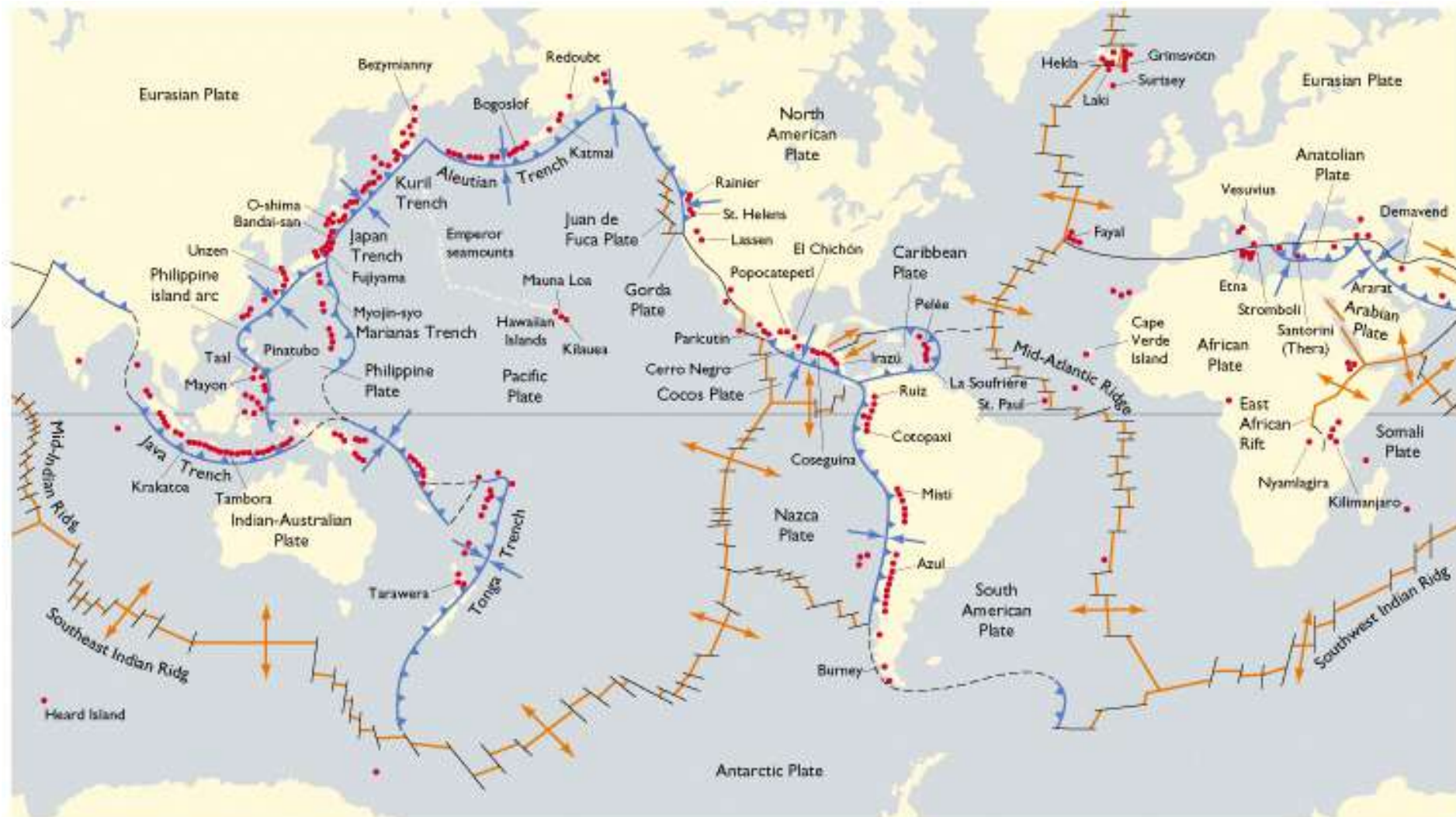
<http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html>

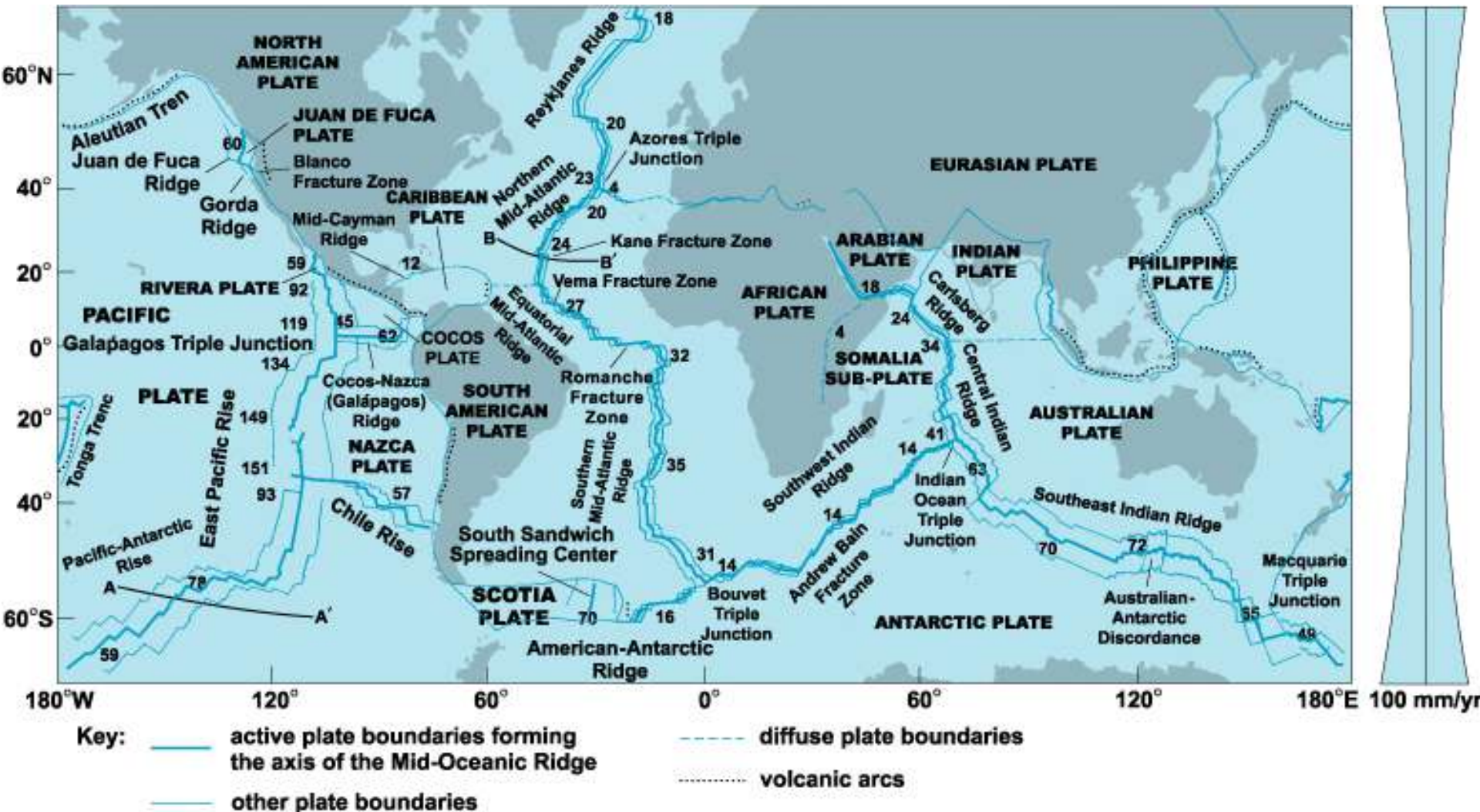
PLATES OF THE WORLD



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



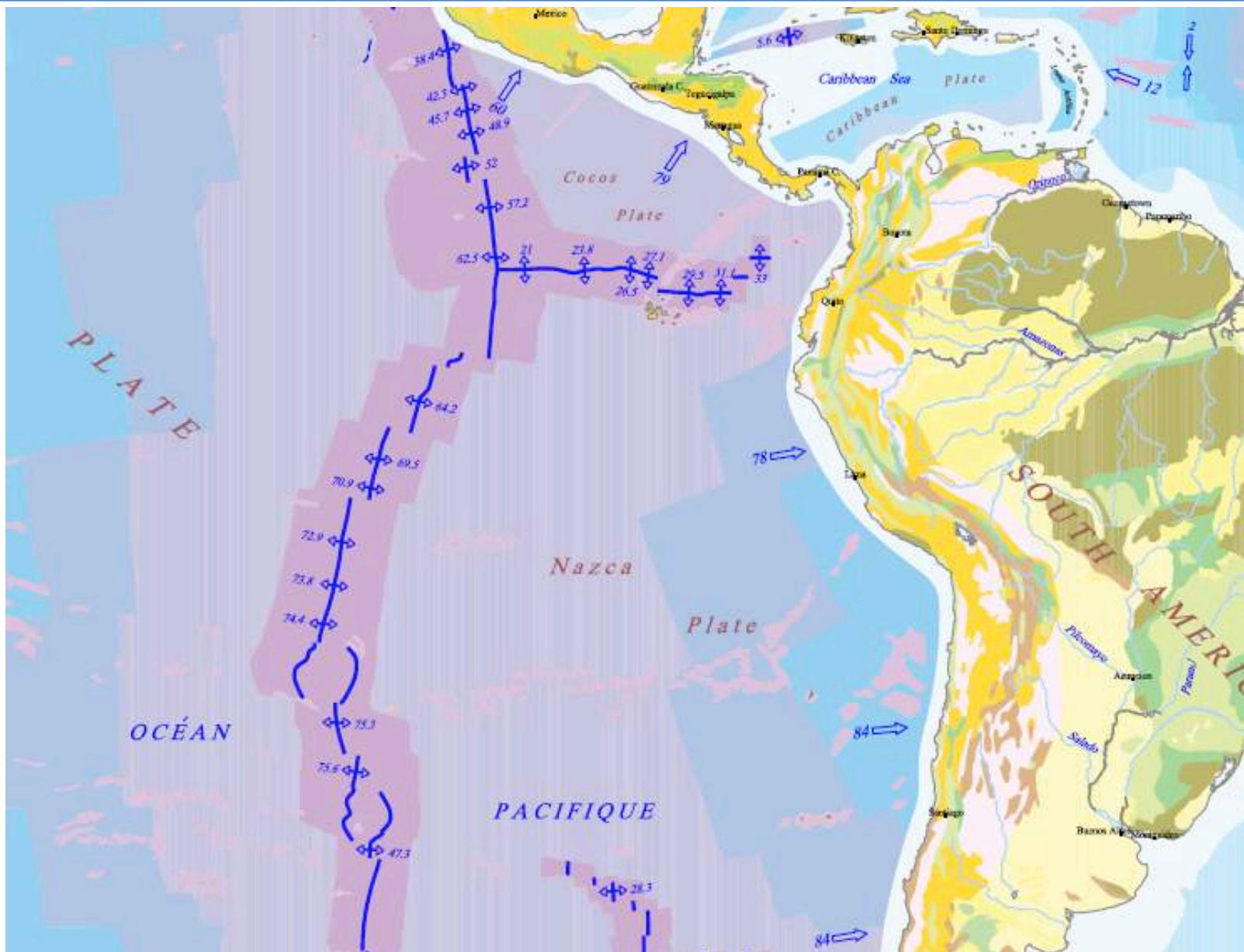




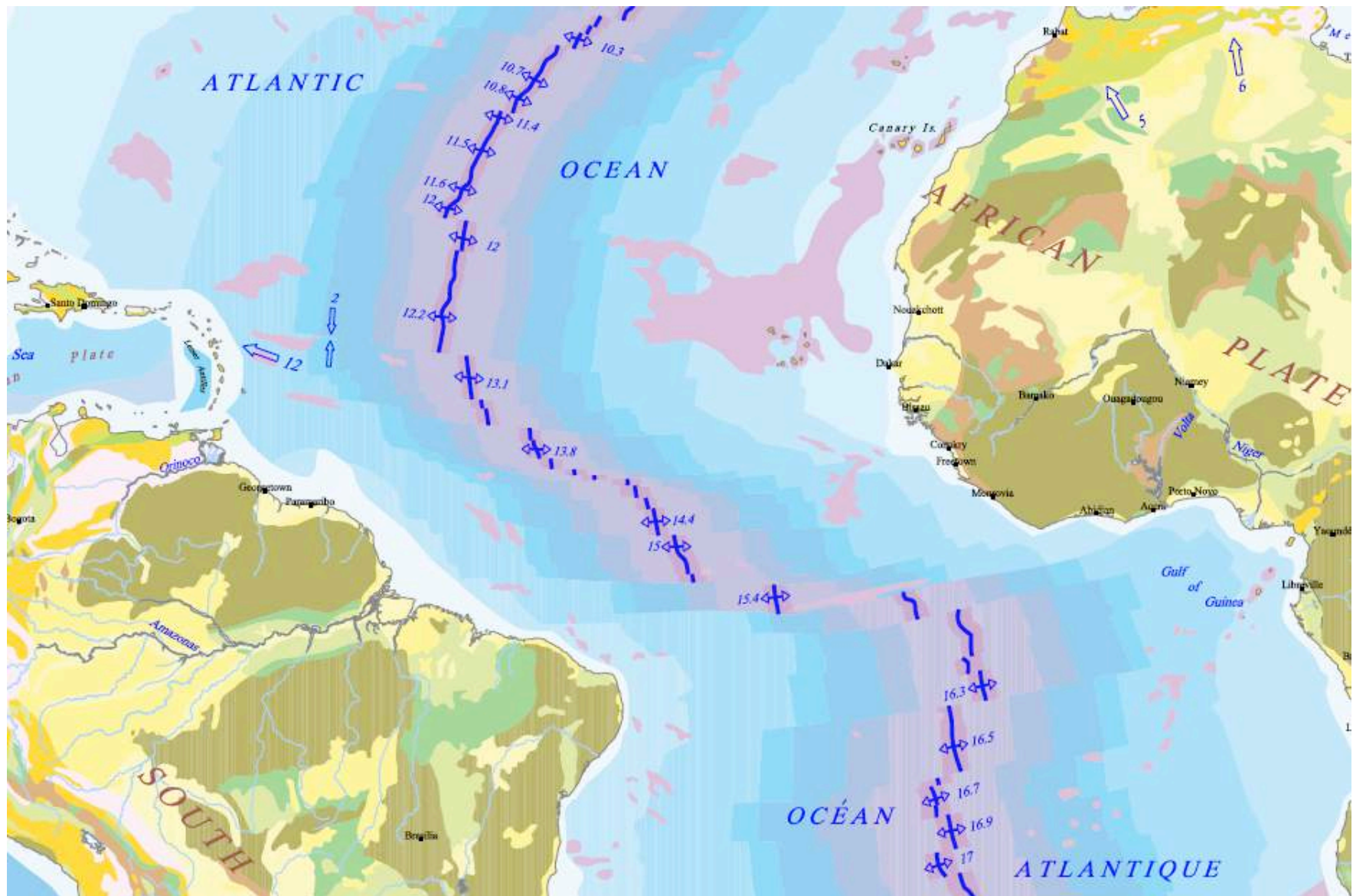
Mid-Oceanic Ridge system

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



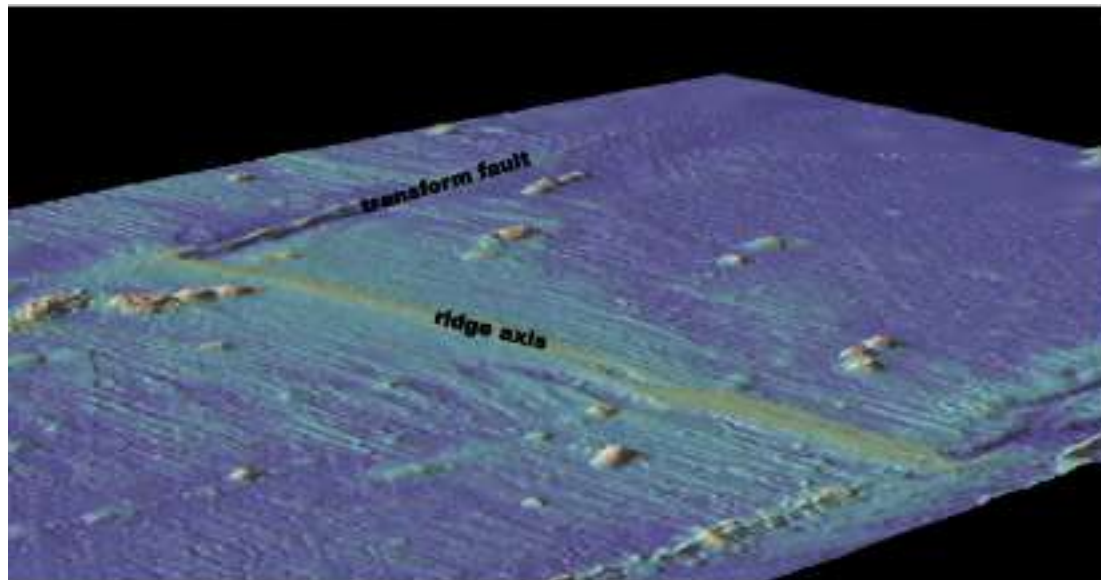
Mid-Atlantic Ridge: slow-spreading, narrow and rough



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.

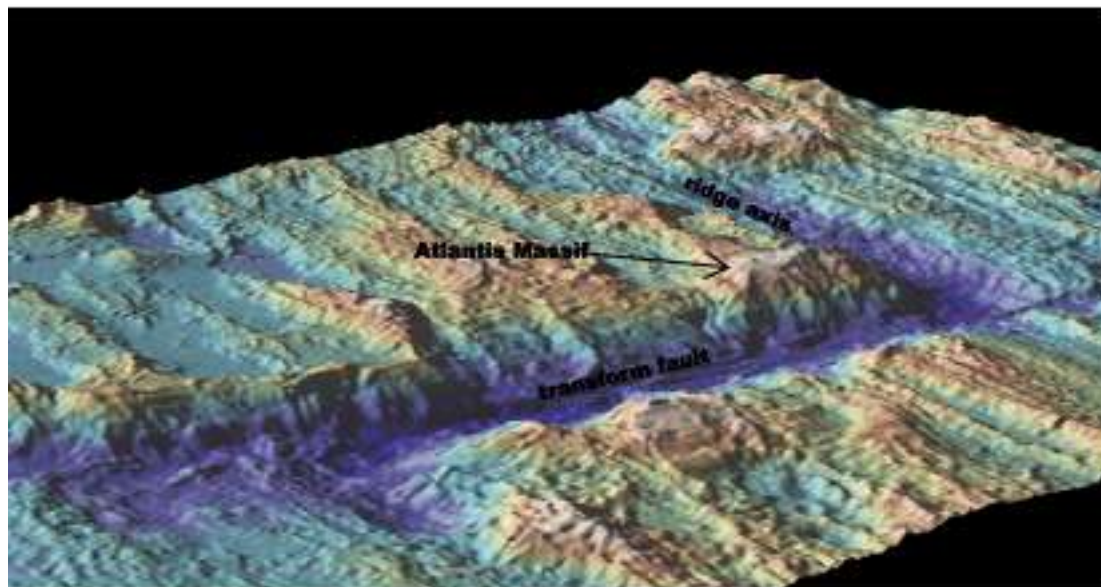
The more prominent ridges and valleys on the flanks are fracture zones (transform fault zones) that were crossed at an oblique angle.
(After B. C. Heezen, *The deep-sea floor*, in S. K. Runcorn, ed., *Continental Drift*, Academic Press, 1962)



(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.*



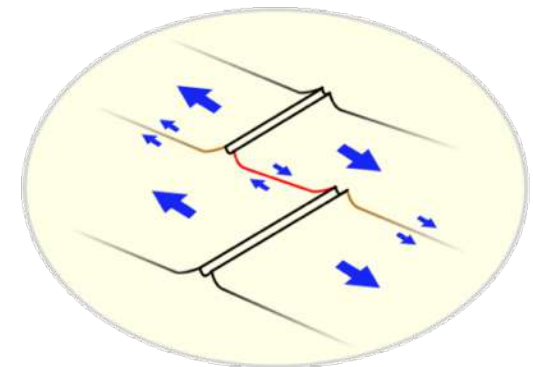
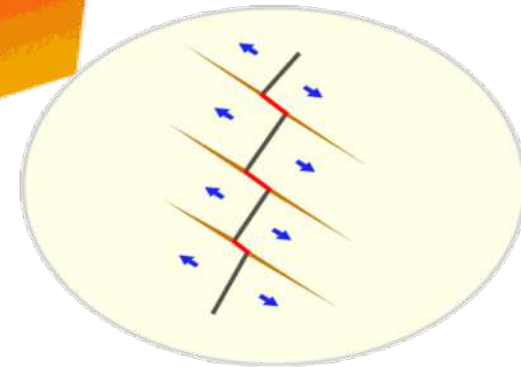
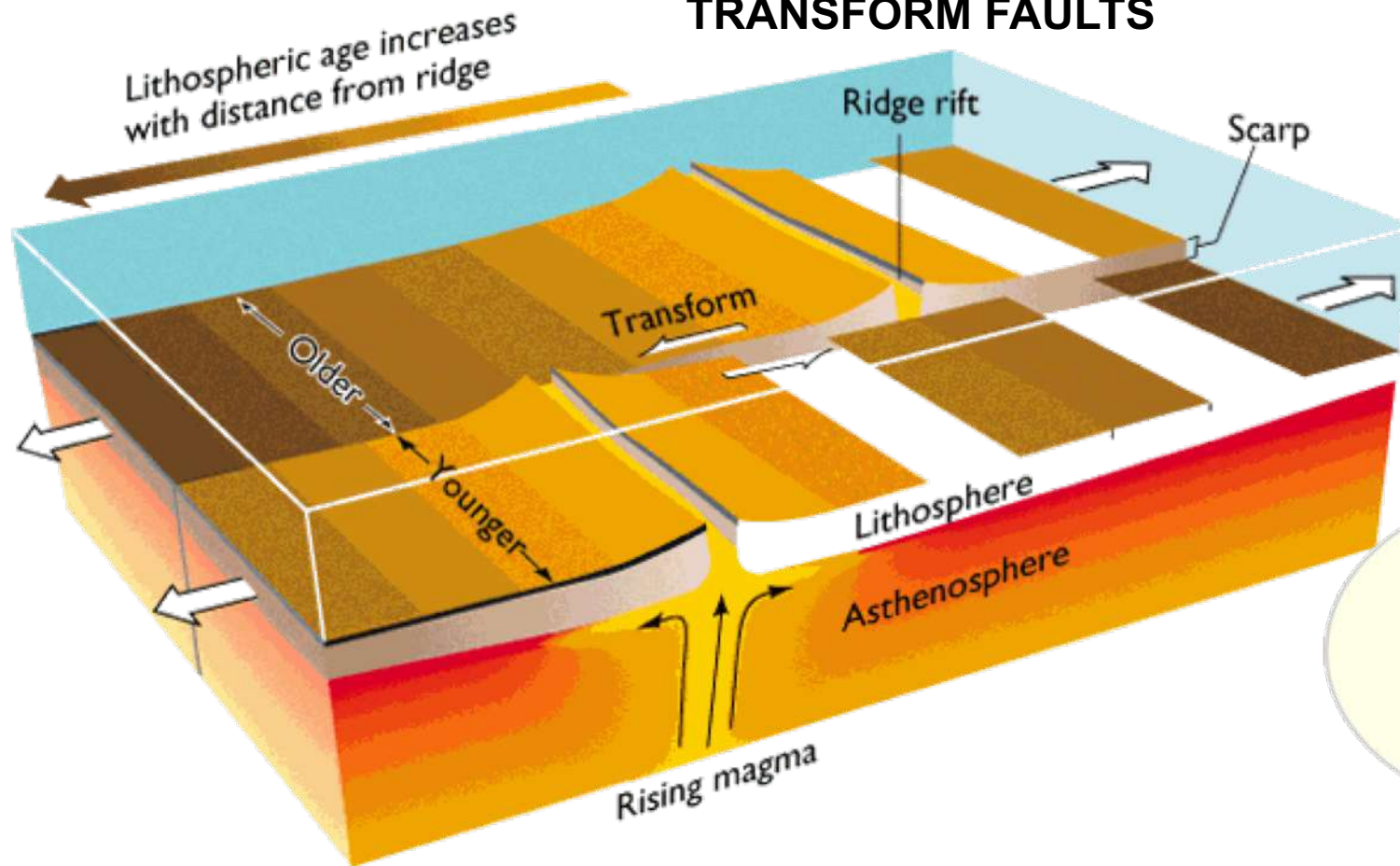
(b)

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



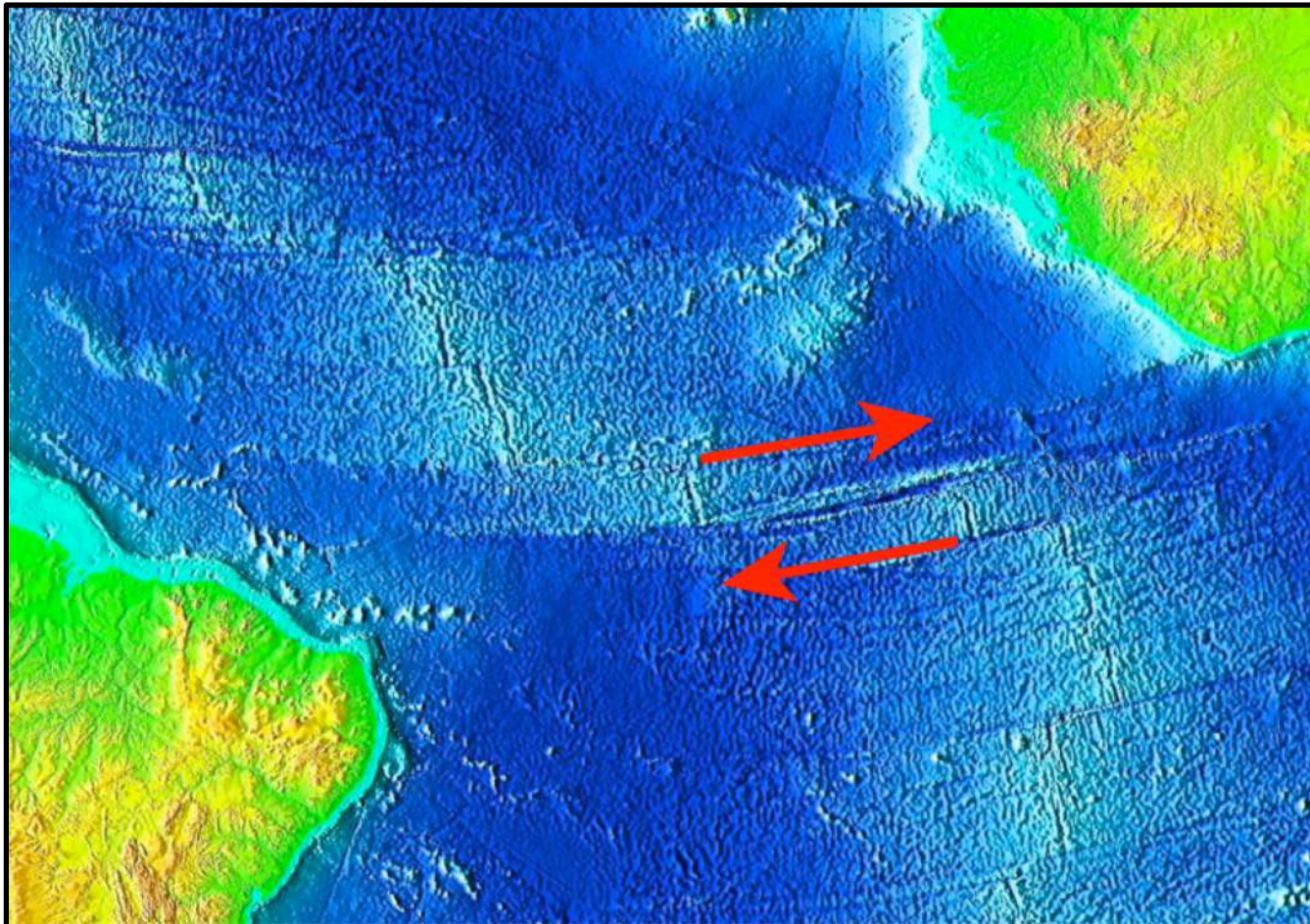
A transform fault or transform boundary, also known as conservative plate boundary since these faults neither create nor destroy lithosphere, is a type of fault whose relative motion is predominantly horizontal in either sinistral or dextral direction.

TRANSFORM FAULTS

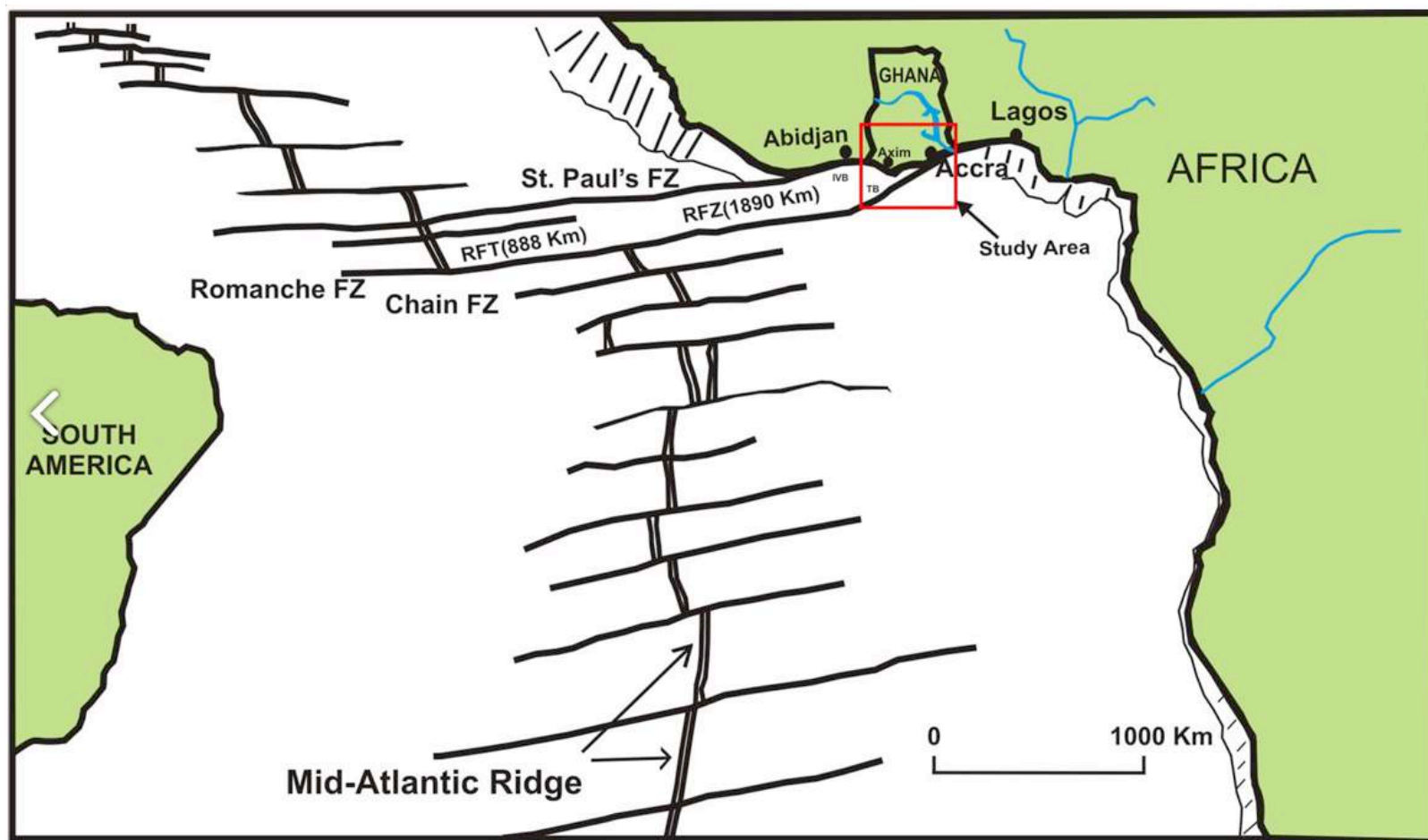
First discovered in the Pacific Ocean by Vacquier (1965): left-lateral offset along the Mendocino and Pioneer faults amount of 1450 km, while the right-lateral offset across the Murray fault is 600 km in the west and only 150 km in the east.

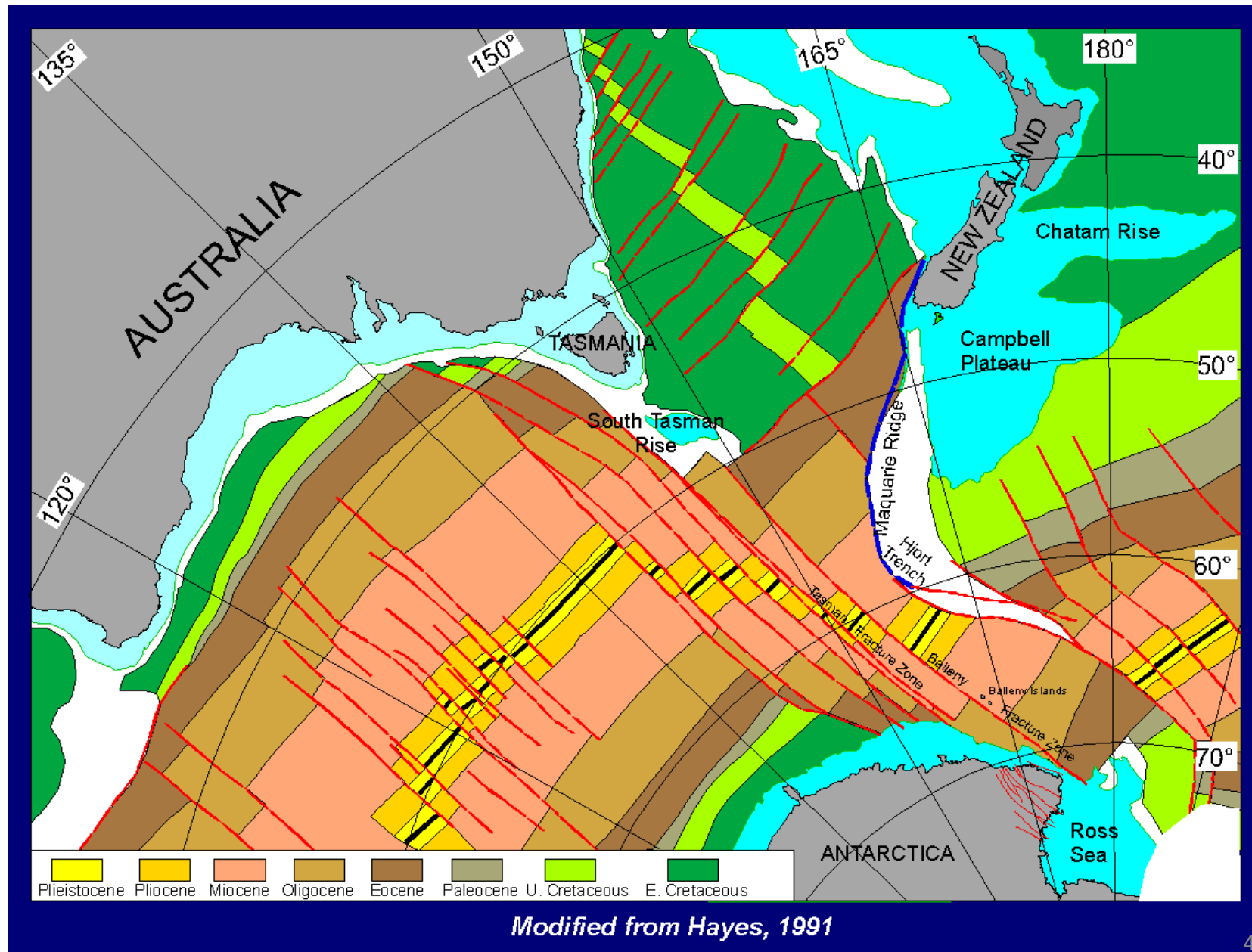
Wilson (1965) termed the faults “Transform” as:
the lateral displacement across the fault is taken up by transforming it into either the formation of new lithosphere at a terminated ocean ridge segment or lithosphere subduction at a trench.

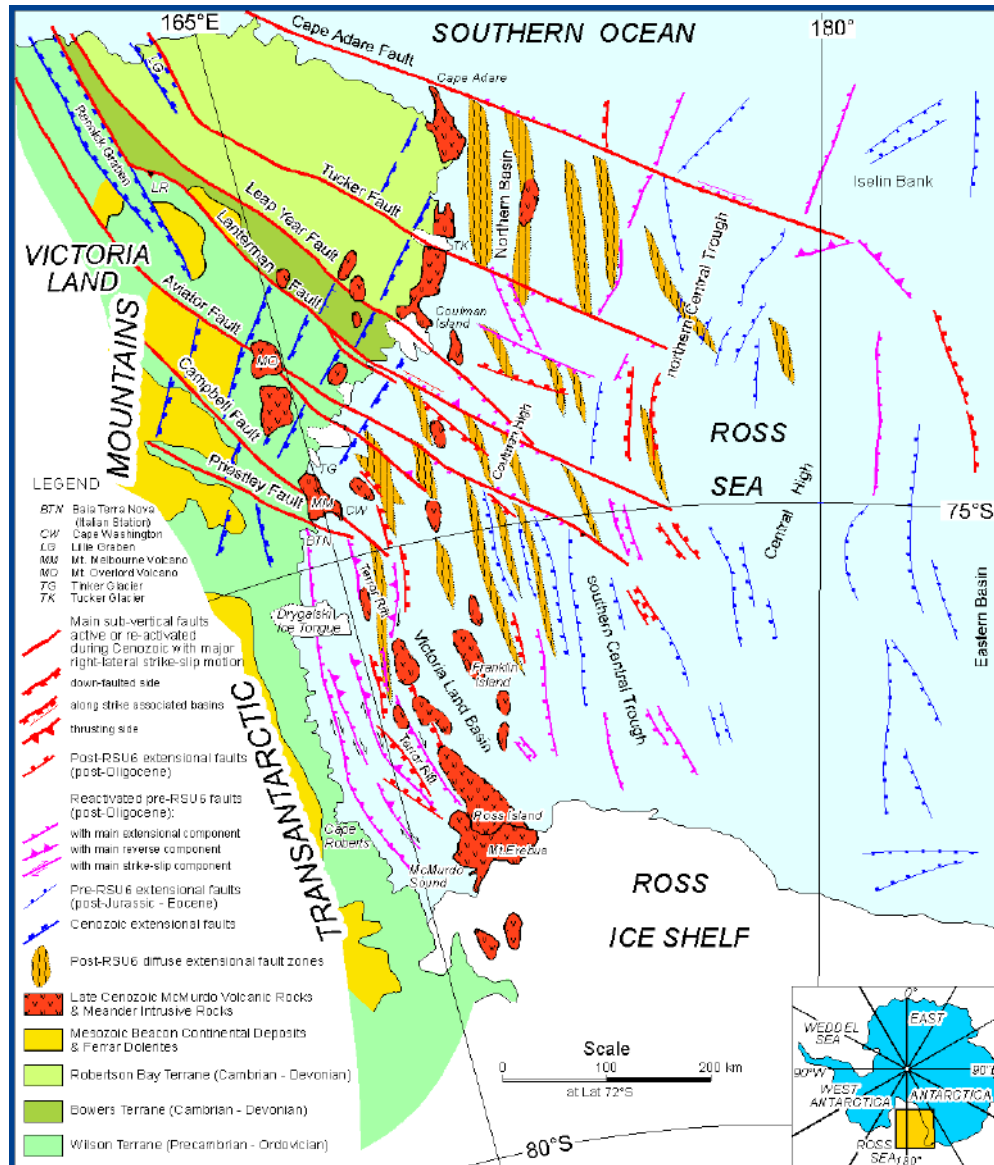
The transform faults can form a tectonic plate boundary



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.

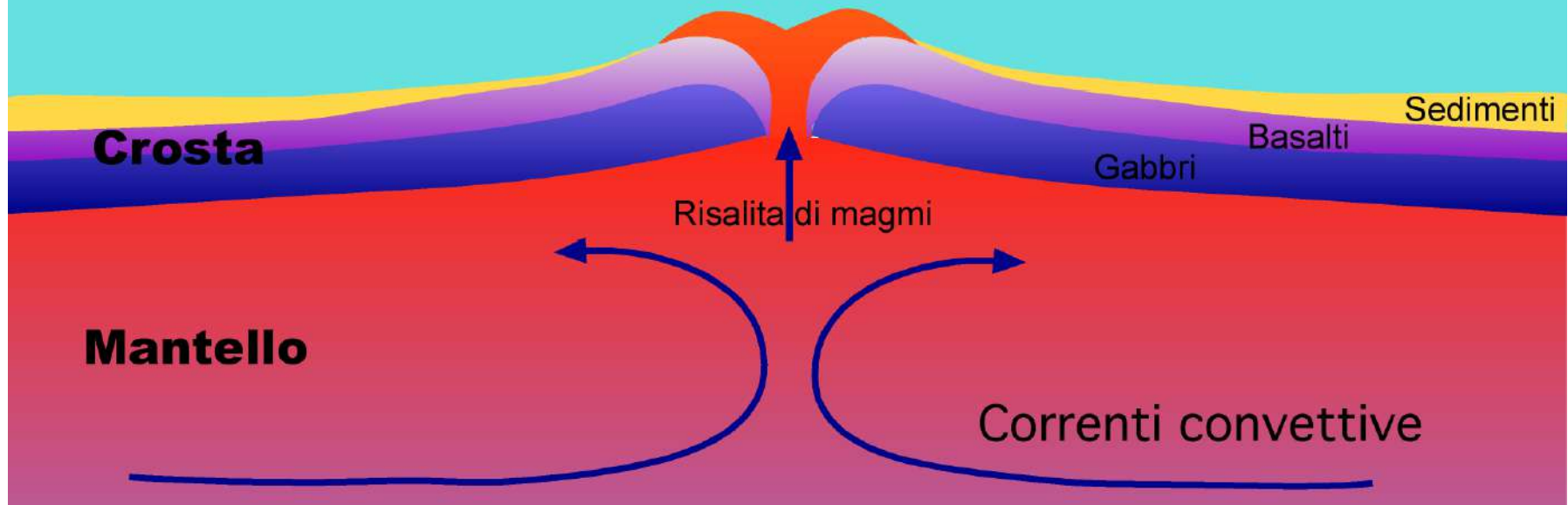


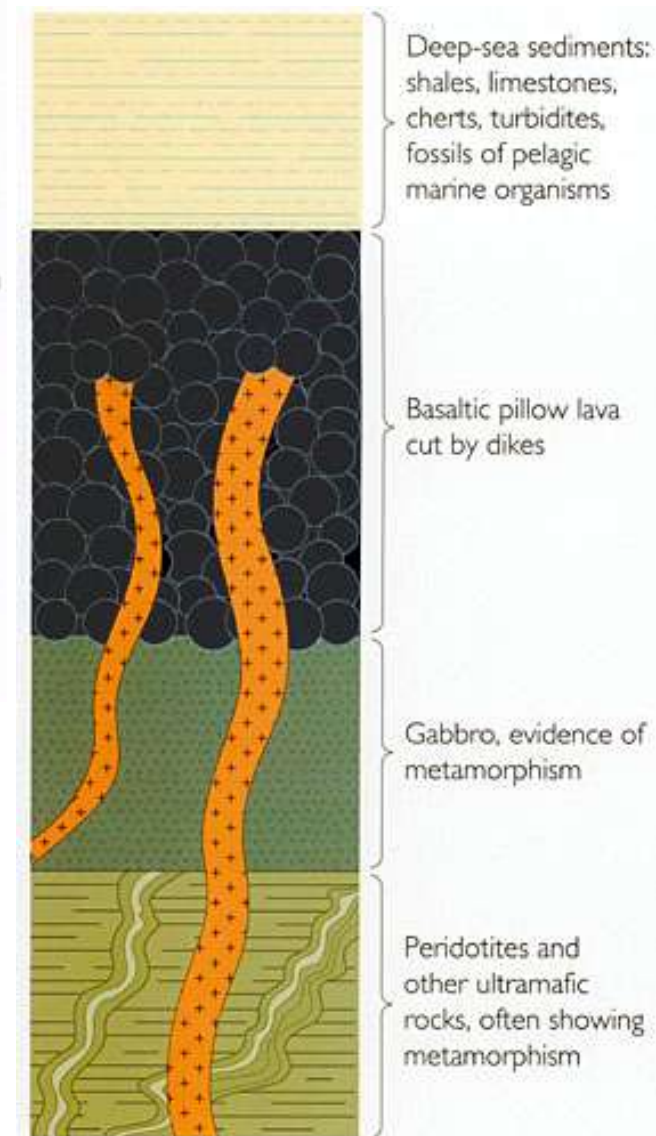
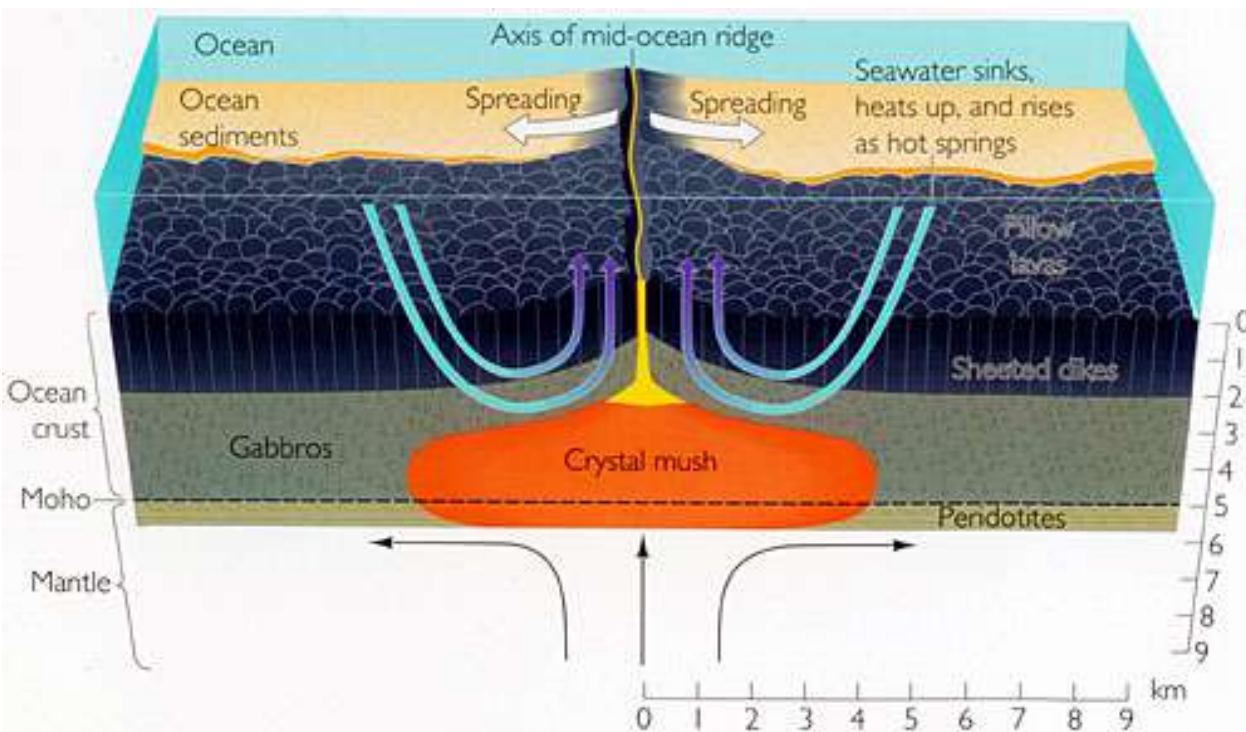




La faglie principali nella Terra Vittoria Settentrionale e nel Mare di Ross.

Dorsale medio-oceanica





Deep-sea sediments:
shales, limestones,
cherts, turbidites,
fossils of pelagic
marine organisms

Basaltic pillow lava
cut by dikes

Gabbro, evidence of
metamorphism

Peridotites and
other ultramafic
rocks, often showing
metamorphism

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

Pillow lava along Juan de Fuca Ridge



The compositions of materials erupted at the mid-ocean ridges are tholeiitic basalts called **mid-ocean ridge basalts (MORB)**.

Magnetic Susceptibility

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

K = magnetic susceptibility

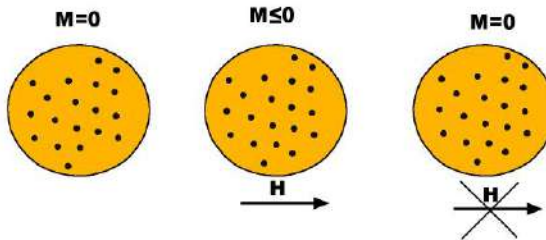
M = induced magnetization in the material

H = applied magnetic field

$$K < 0$$

DIAMAGNETIC

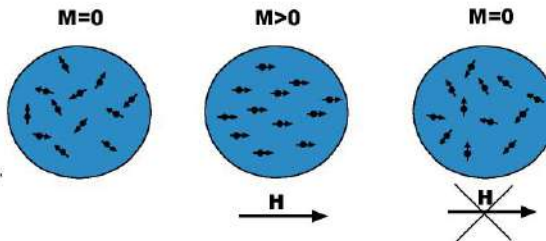
weak negative susceptibility
(water, organic matter, quartz, feldspars, calcium carbonate)



$$K > 0$$

PARAMAGNETIC

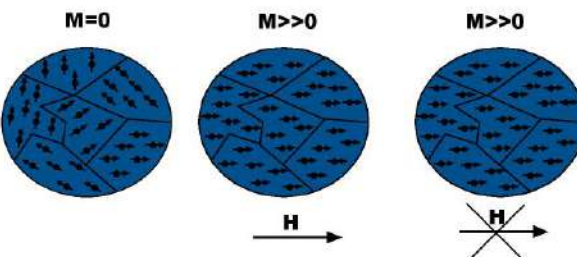
weak positive susceptibility
(many Fe-containing minerals and salts, eg. biotite, muscovite, pyroxene, olivine, ferrous sulfate)



$$K \gg 0$$

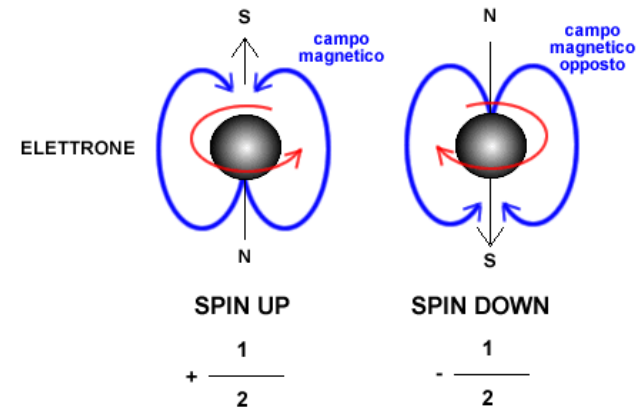
FERROMAGNETIC

strong positive susceptibility
(pure iron like magnetite and hematite, nickel, chromium)



rotazione oraria

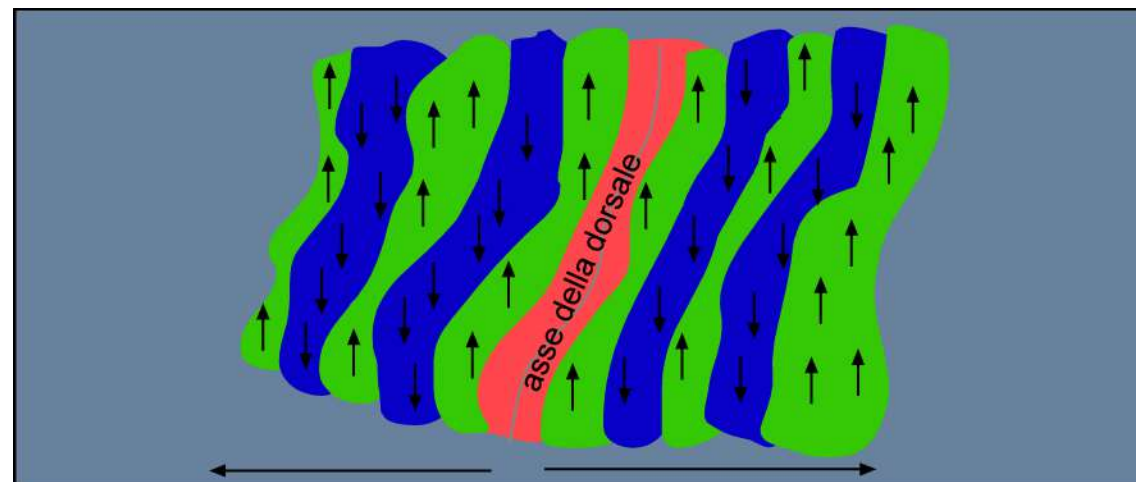
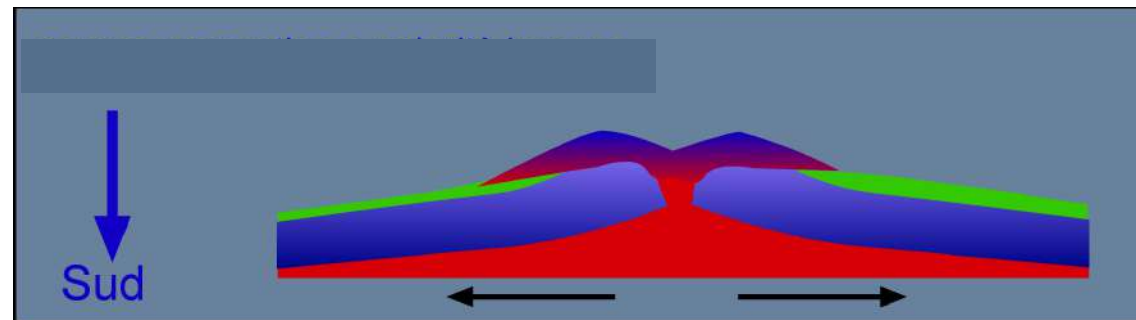
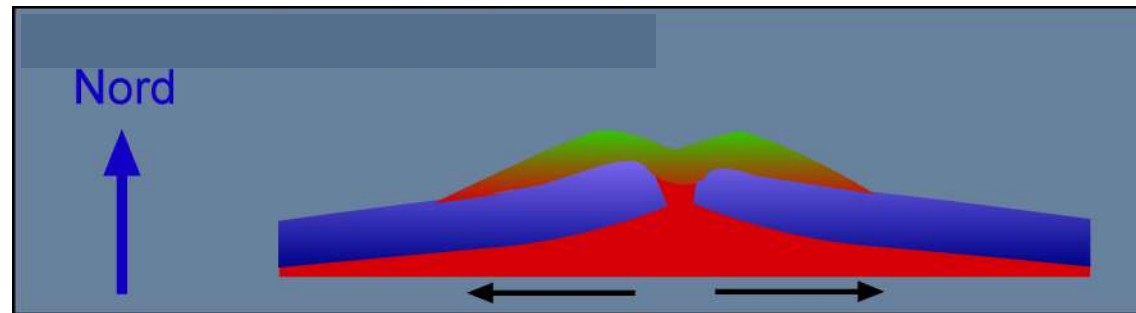
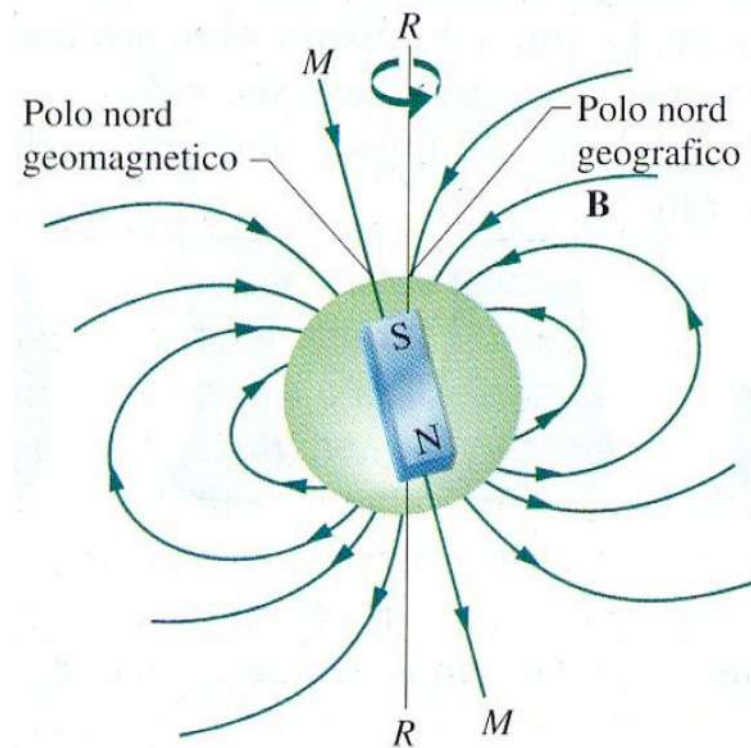
rotazione antioraria



Quarzo, calcite e dolomite

Ossidi di ferro (magnetite Fe_3O_4 , ematite $\alpha\text{-Fe}_2\text{O}_3$, ilmenite FeTiO_3 , magnemite $\gamma\text{-Fe}_2\text{O}_3$ e ulvospinello Fe_2TiO_4), idrossidi (es. la goethite ($\alpha\text{-FeO}\cdot\text{OH}$), solfuri (es. pirite FeS_2).

Present magnetic field

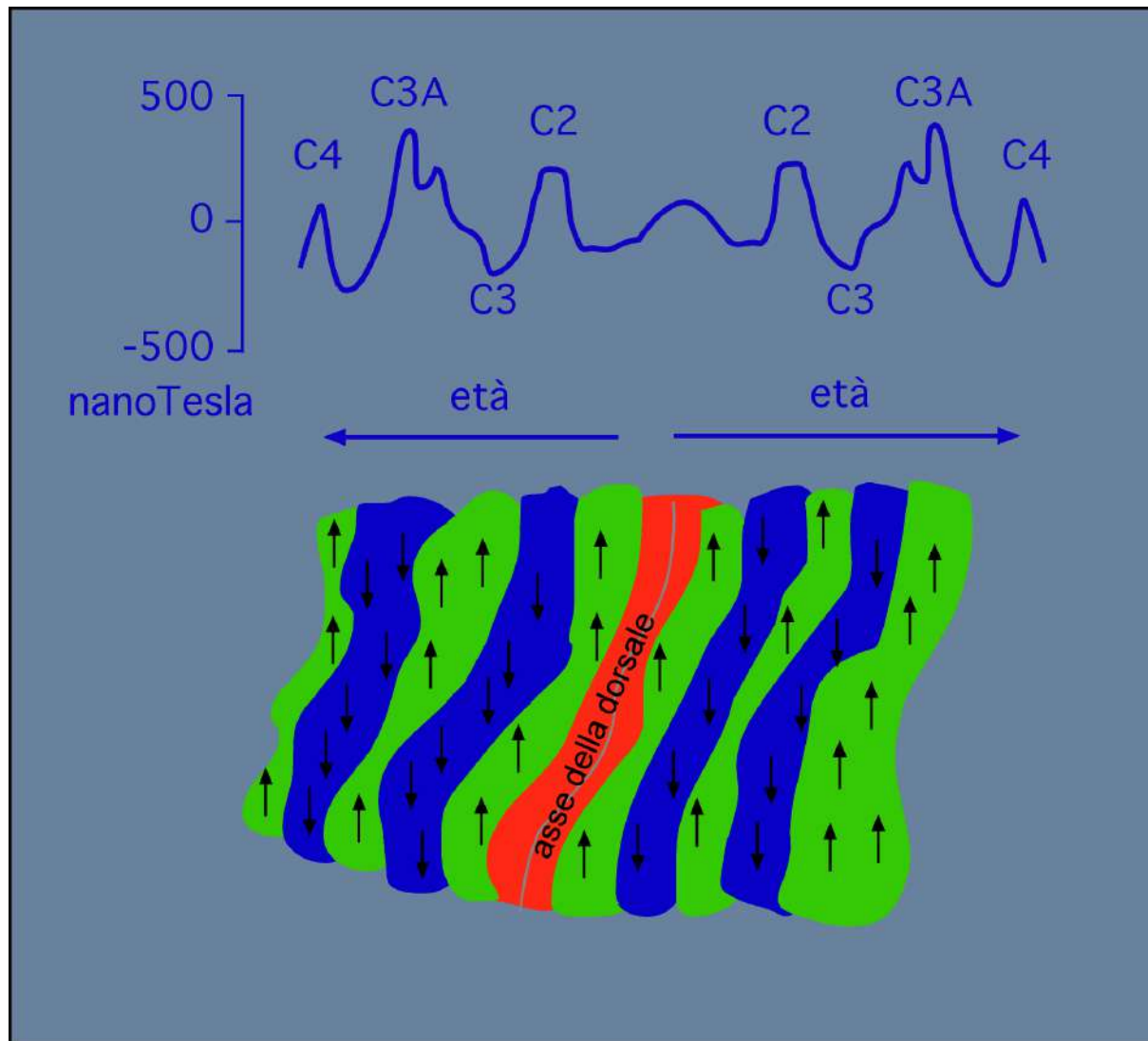




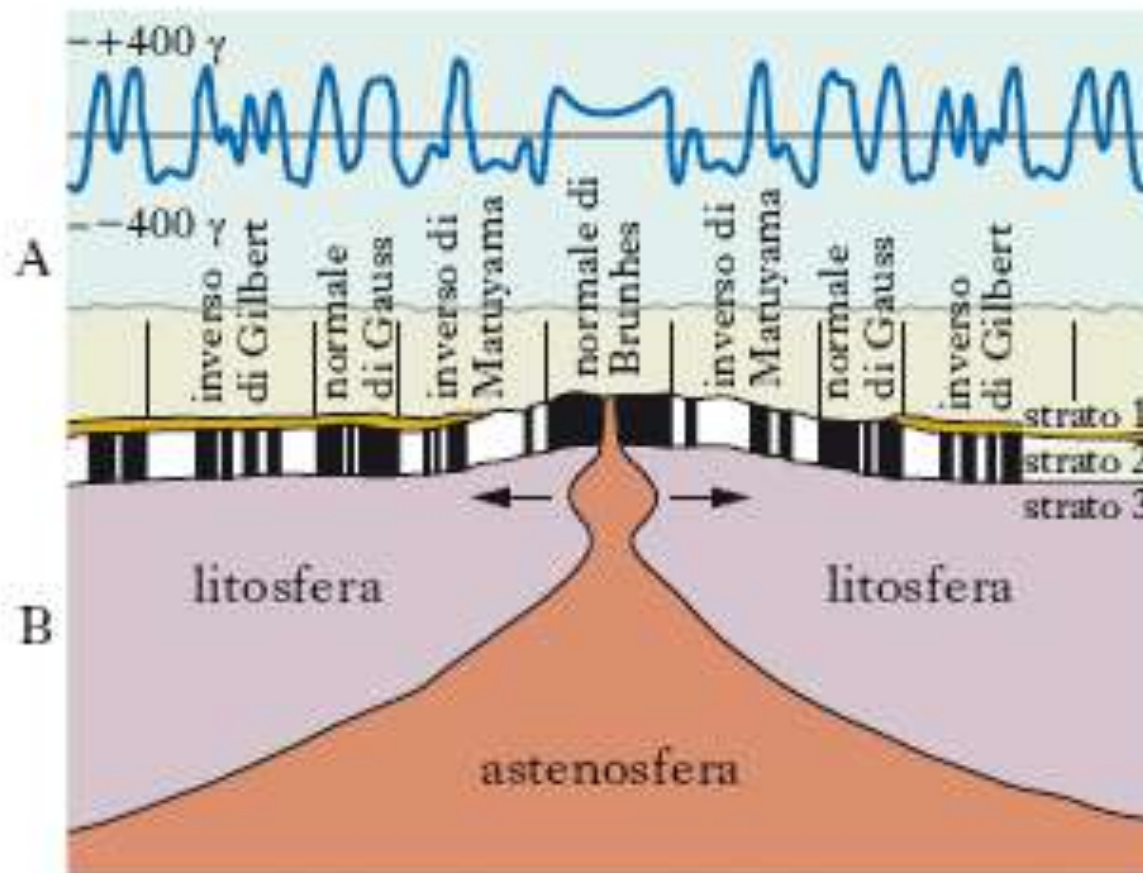
Mare di Ross (Antartide) 2002 – M/N Italica

Instruments to measured the earth magnetic field in the ocean:

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



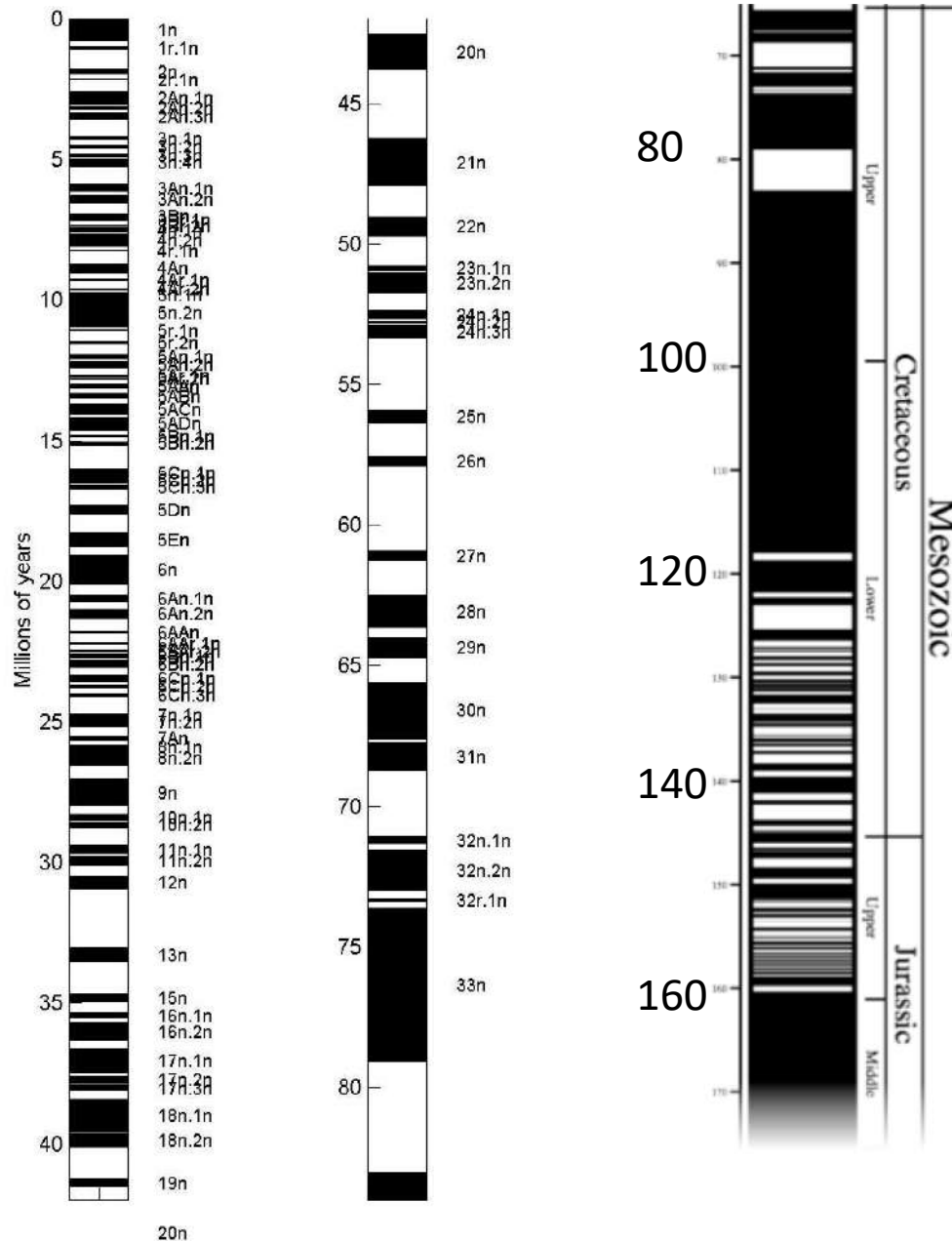
The magnetic anomalies are numbered as C_n (Chrono n) or A_n (Anomaly n) (C_1 or A_1 is the youngest and C_{23} or A_{23} is older).

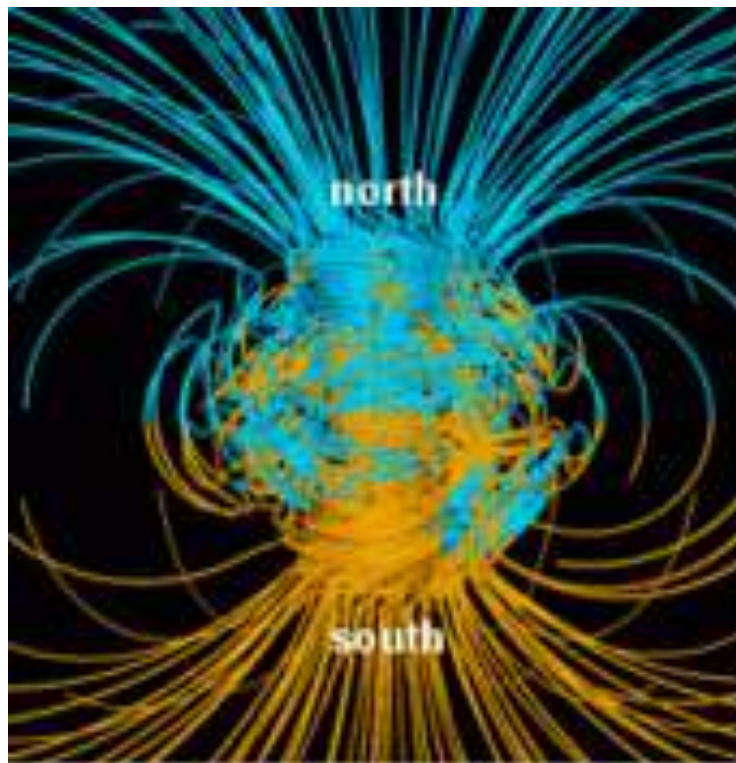


- 1 - sedimenti non magnetici
- 2 - colate e strato di basalto a cuscini (altamente magnetico: in nero, polarita normale; in bianco, polarita inversa)
- 3 - crosta oceanica a gabbri (debolmente magnetica)

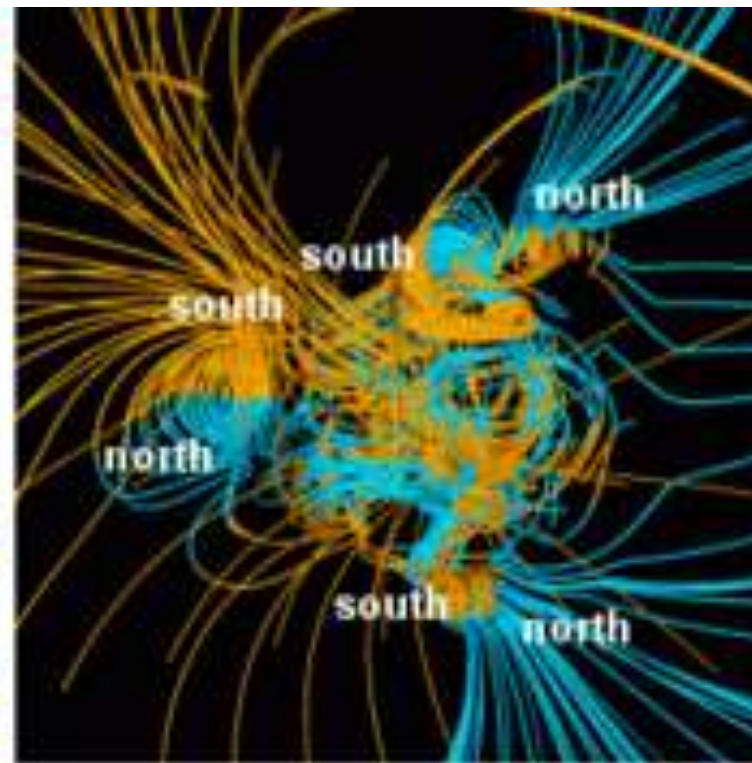
Geomagnetic Polarity Time Scale (GPTS)

Cande & Kent 1995



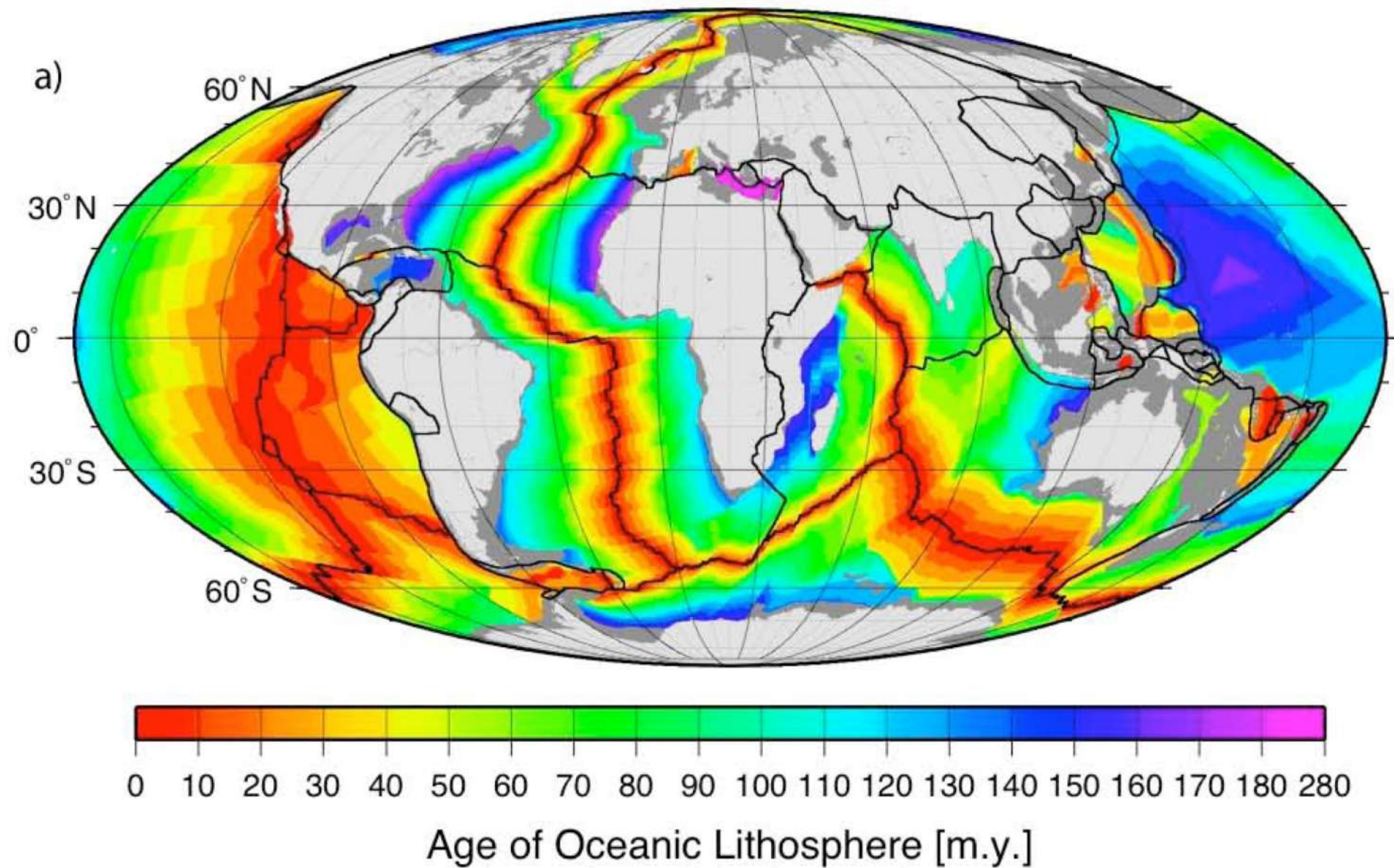


between reversals

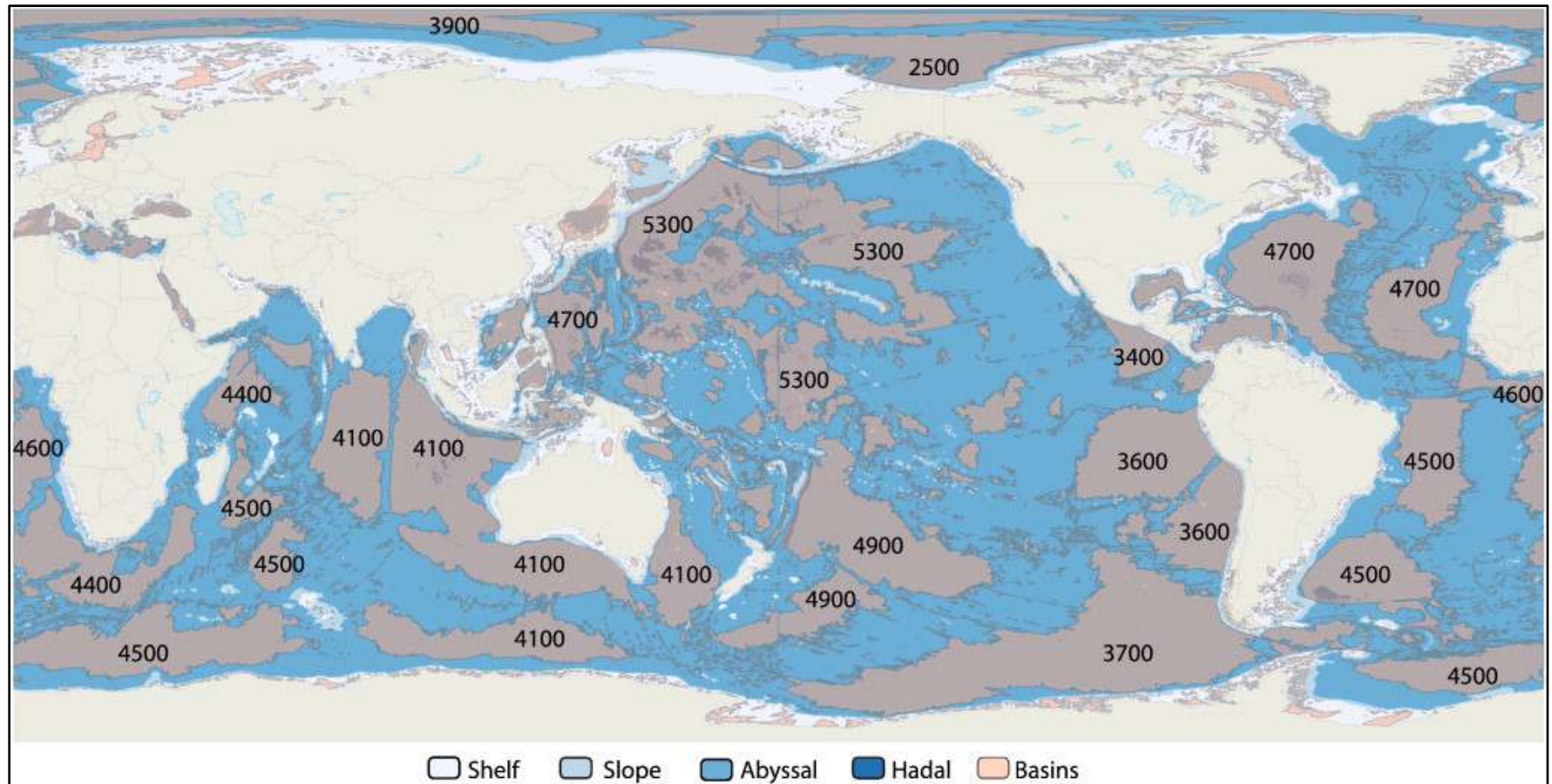


during a reversal

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.



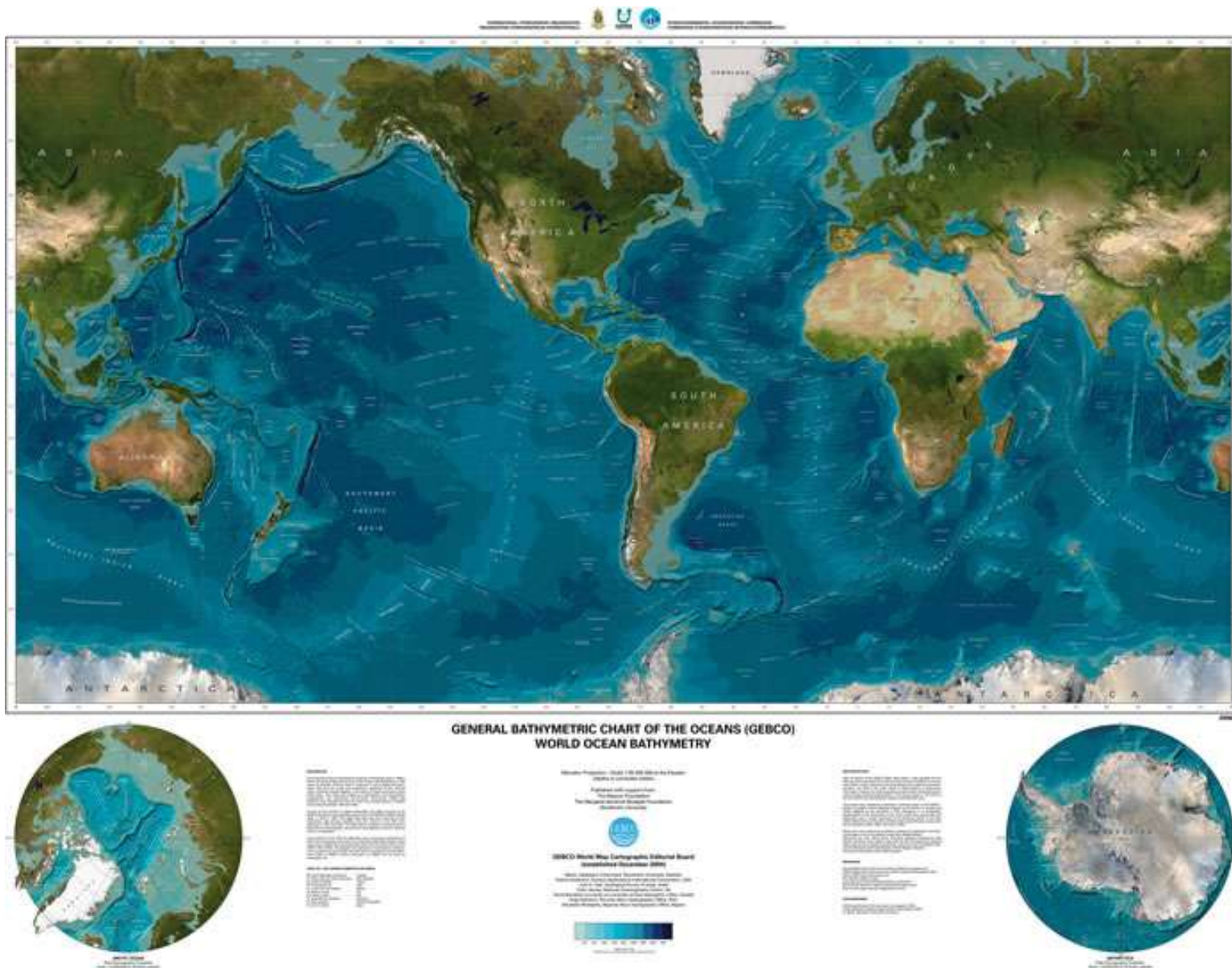
Basins in the oceans



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.

General Bathymetric Chart of the Oceans - GEBCO

<http://www.gebco.net>



Stato termico dei ridge e piane abissali

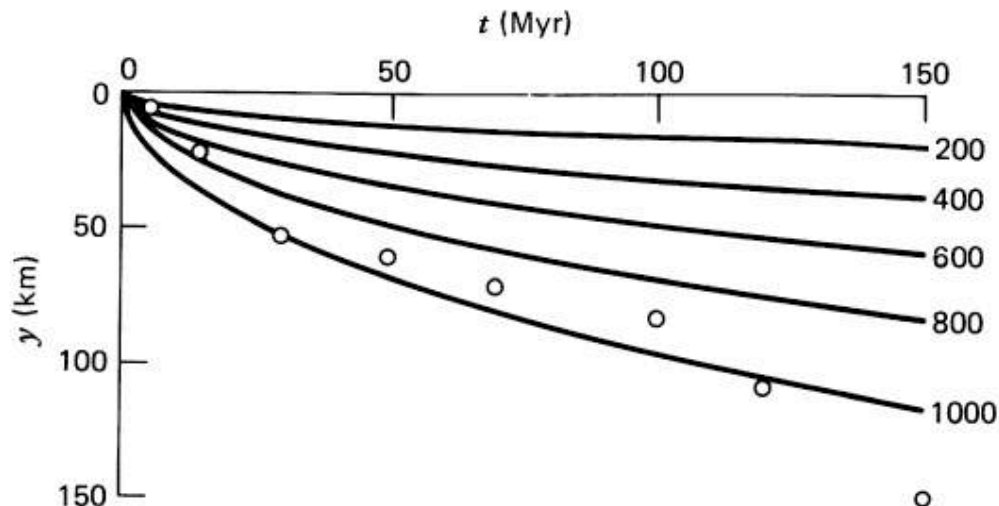
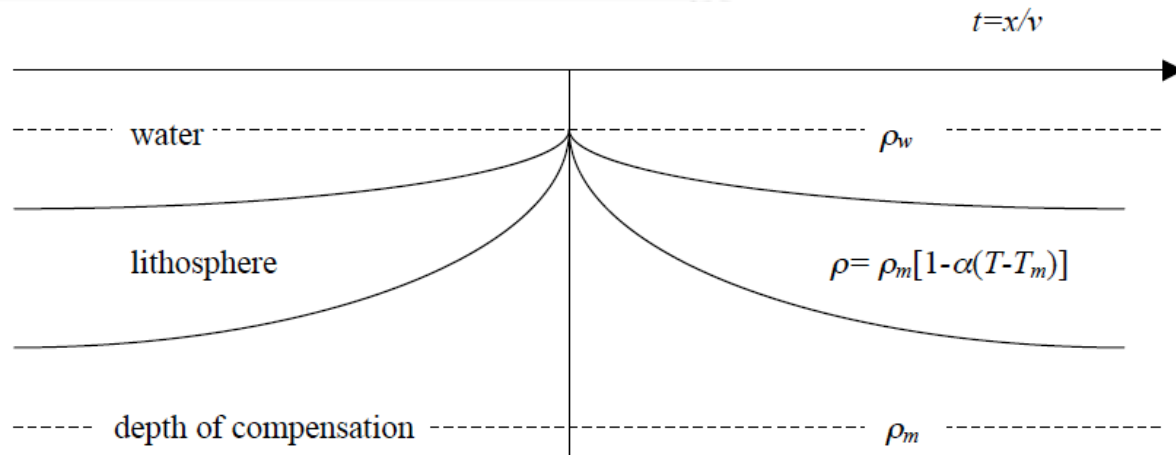
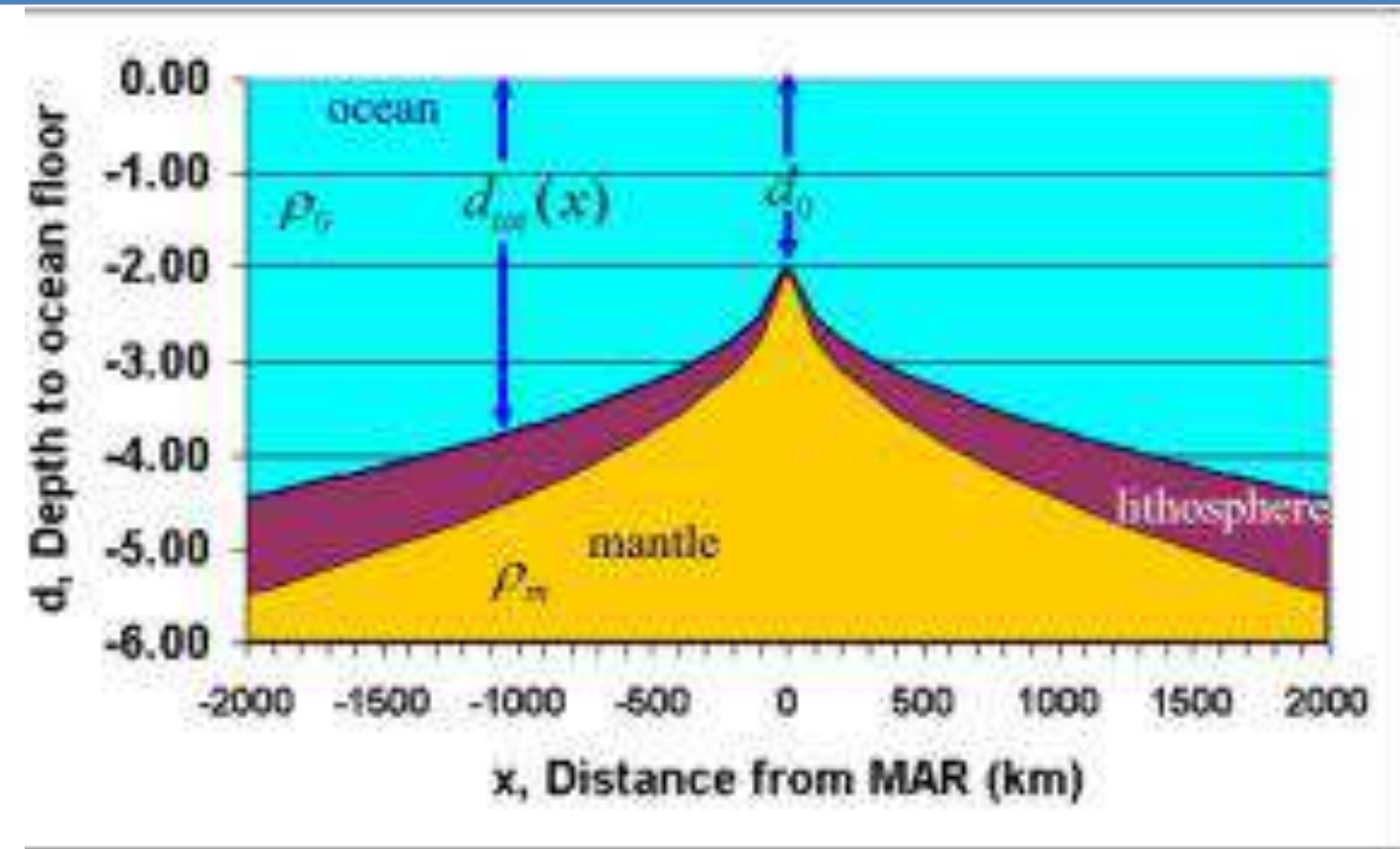


Figure 4-24 The solid lines are isotherms, $T - T_s$ ($^{\circ}\text{K}$), in the oceanic lithosphere from Equation (4-125). The data points are the thicknesses of the oceanic lithosphere in the Pacific determined from studies of Rayleigh wave dispersion data. (From A. R. Leeds, L. Knopoff, and E. G.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

Cooling of oceanic crust

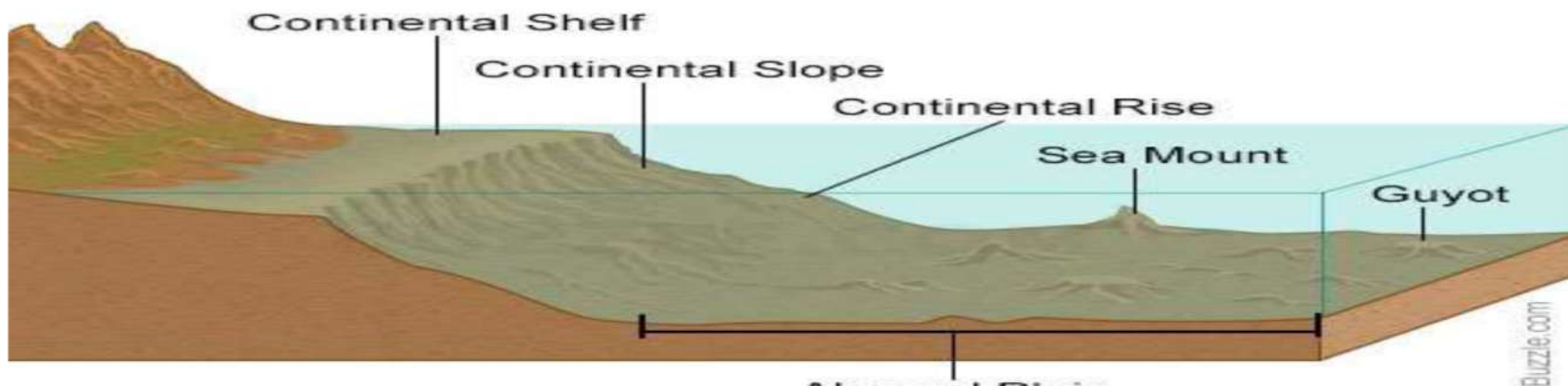


Abyssal floor

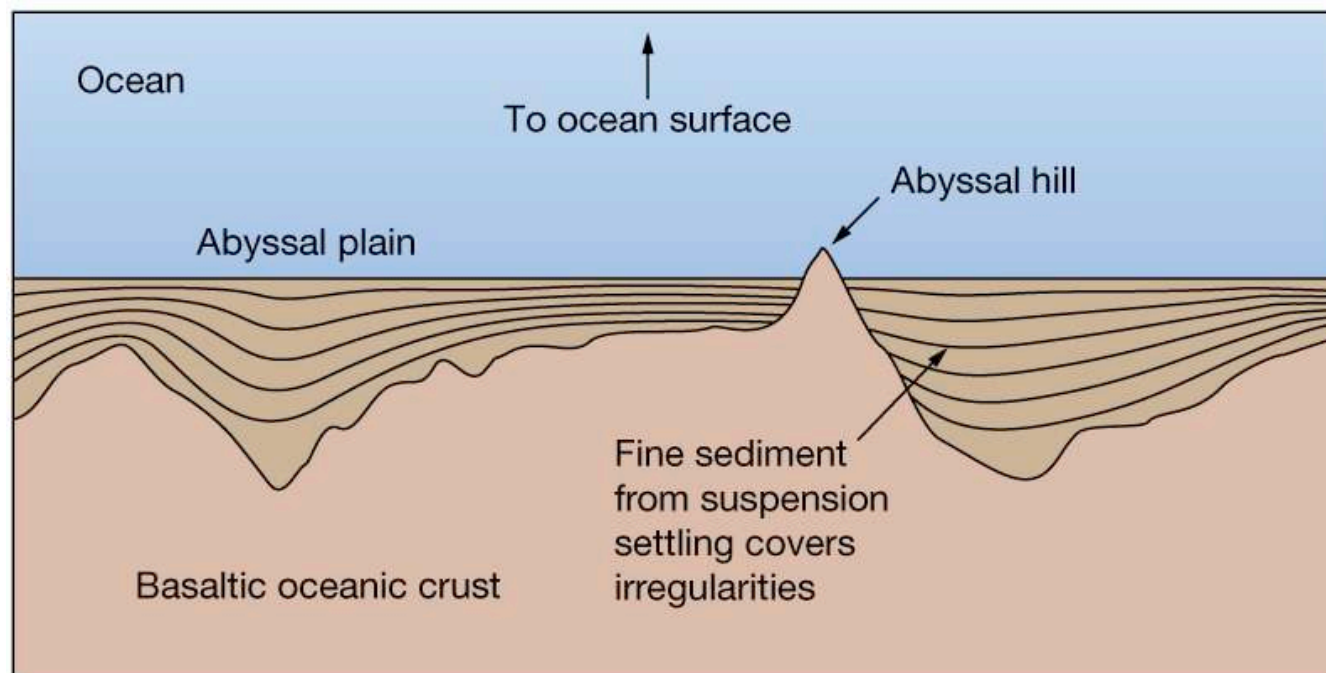
Abyssal floor are broad, relatively smooth surfaces and consists of:

- **Abyssal plains:** the flattest of all Earth's surface area. They are composed of sediments, most of which came from continents and can be more than one km thick
- **Abyssal hills:** small, rolling hills often occurring in groups near ocean ridges system

Cross section of the Ocean floor



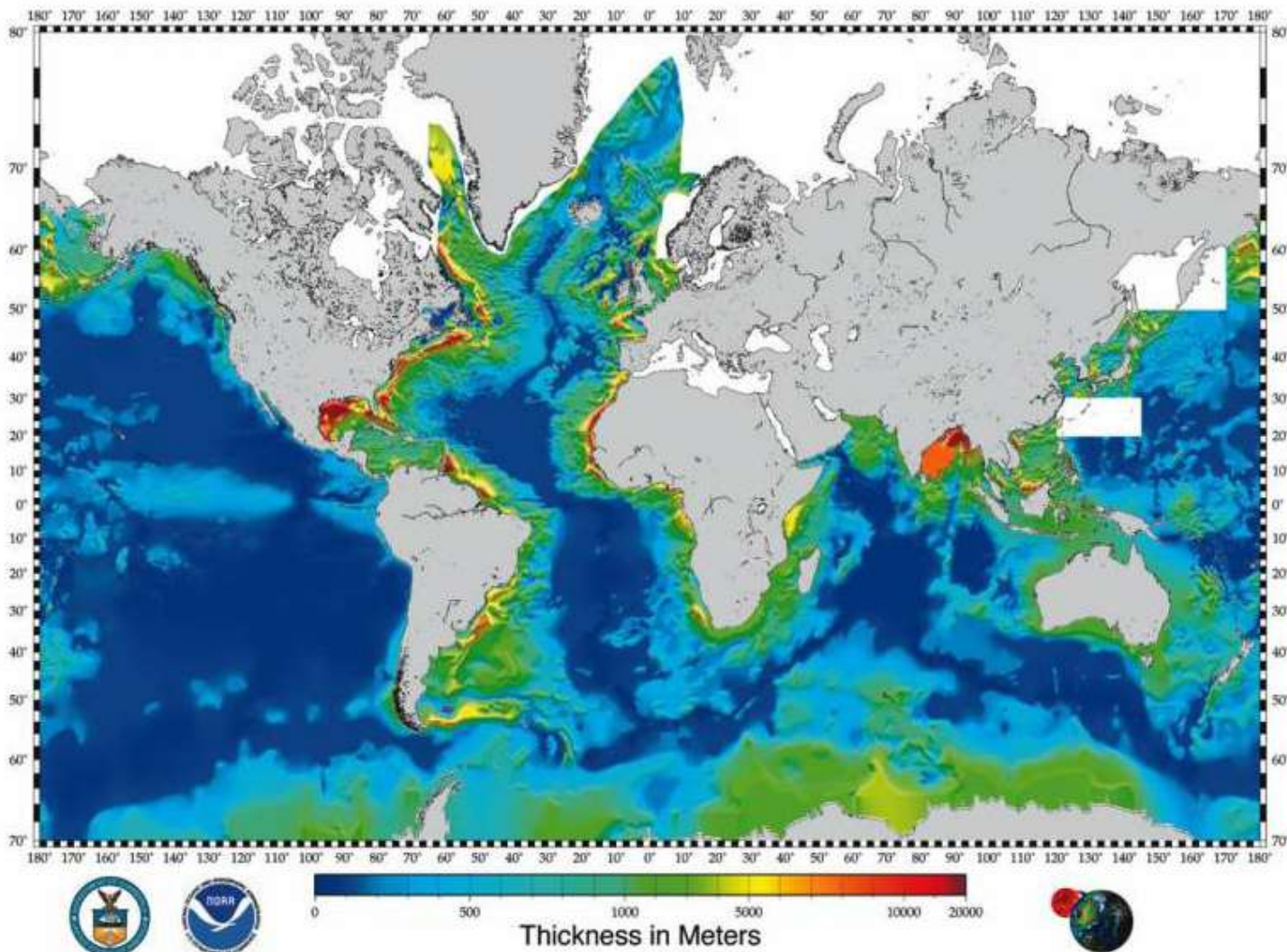
Abyssal Plain



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



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 (GAPAP) 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

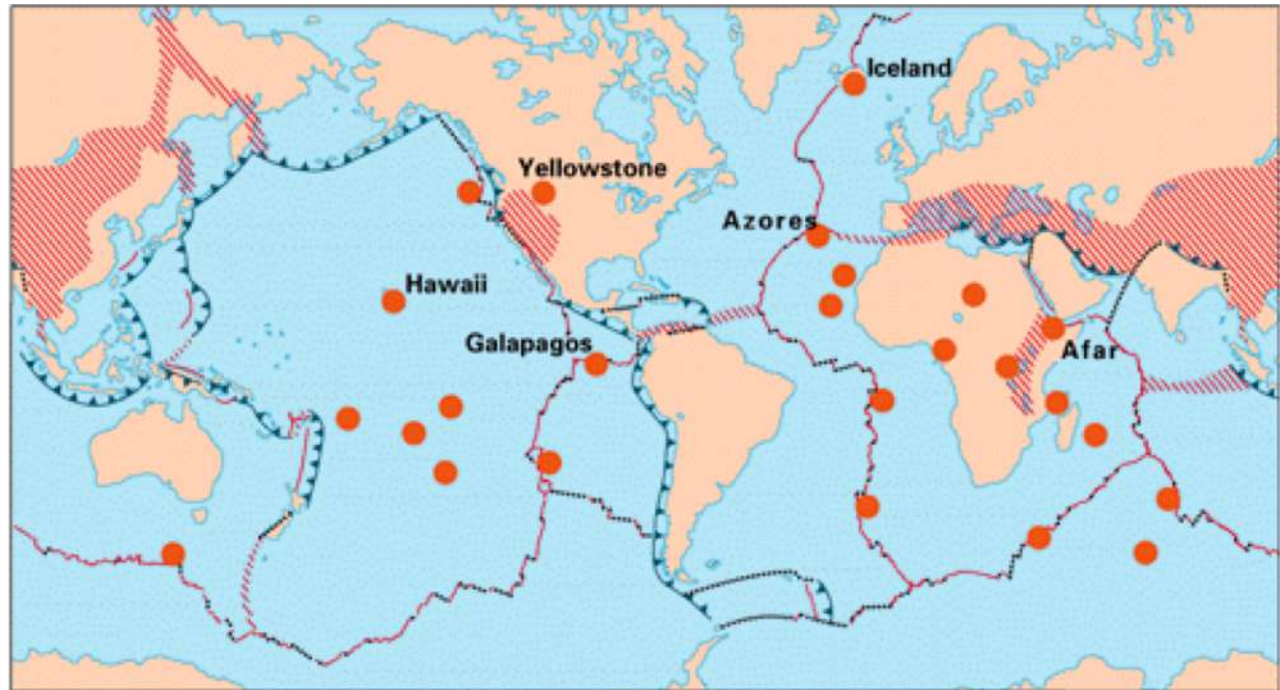
The data values are in meters and represent the depth to acoustic basement. It should be noted that acoustic basement may not actually represent the base of the sediments. These data are intended to provide a minimum value for the thickness of the sediment in a particular geographic region.

<http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html>

HOT SPOT

EXPLANATION

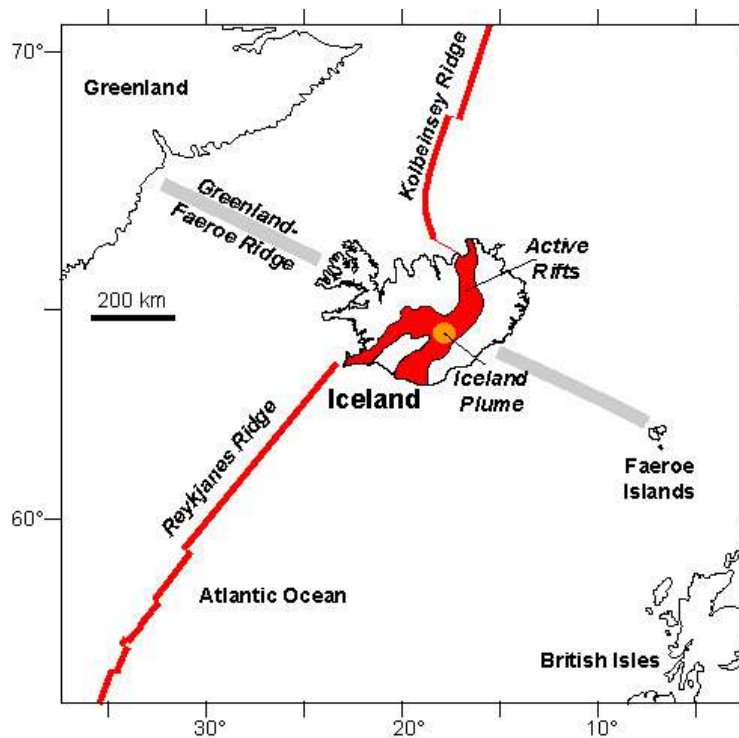
-  Divergent plate boundaries—
Where new crust is generated
as the plates pull away from
each other.
-  Convergent plate boundaries—
Where crust is consumed in the
Earth's interior as one plate
dives under another.
-  Transform plate boundaries—
Where crust is neither produced
nor destroyed as plates slide
horizontally past each other.
-  Plate boundary zones—Broad
belts in which deformation is
diffuse and boundaries are not
well defined.
-  Selected prominent hotspots



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.

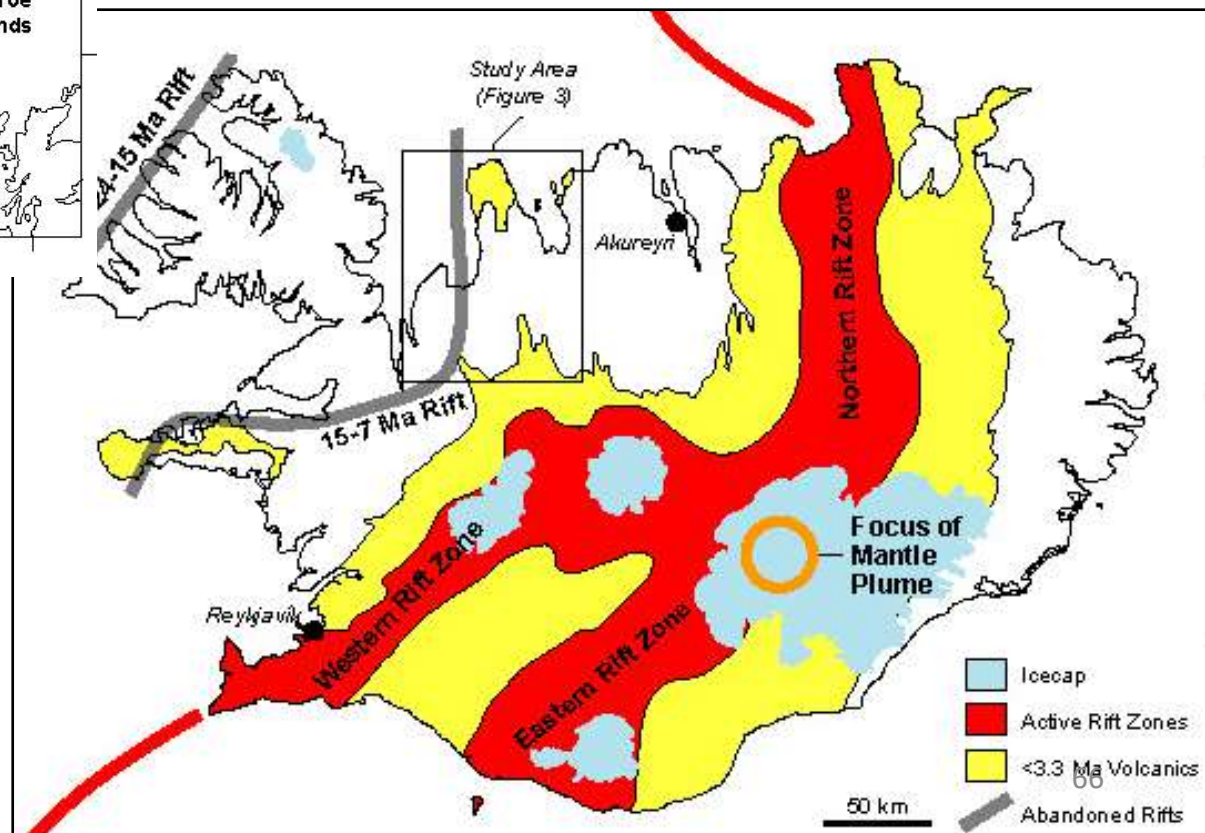


ICELAND HOT SPOT

- 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.

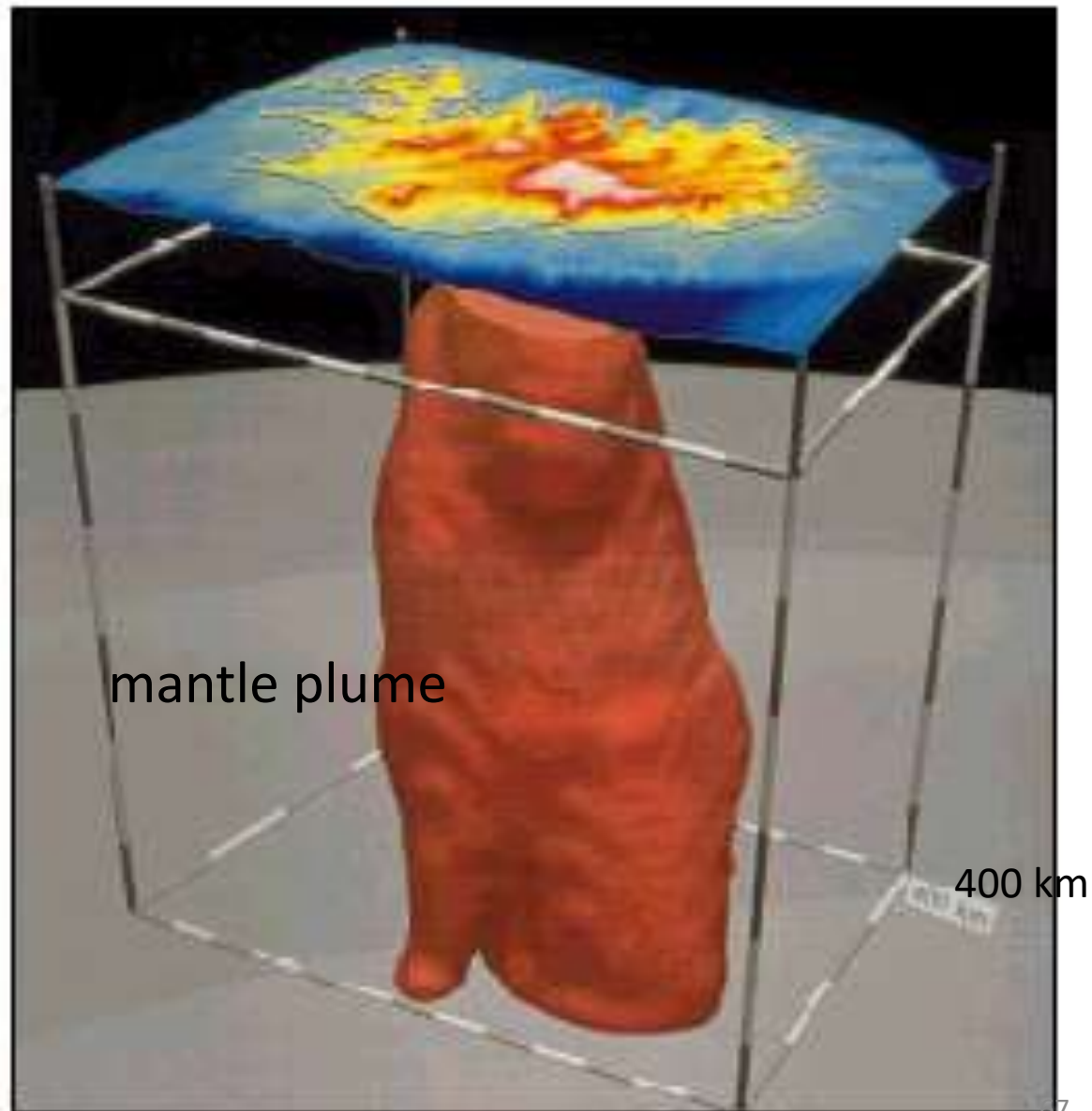
Image taken from [Iceland Keck](#)

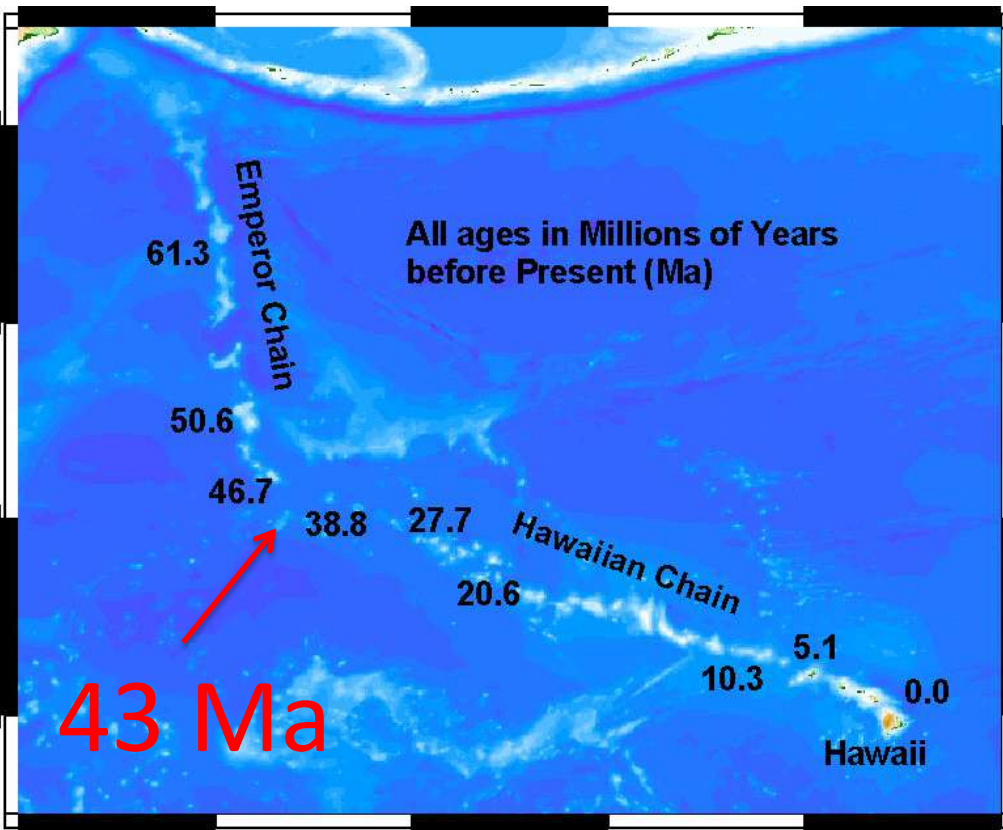


ICELAND HOT SPOT (or mantle plume)

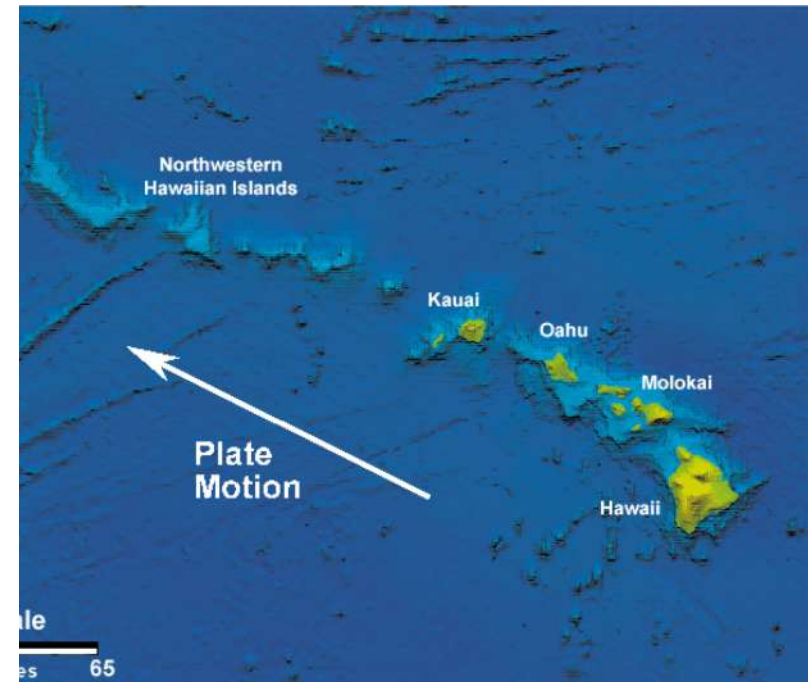
The starting plume head, **hundreds of degrees hotter than normal mantle**, spreads sideways, incorporates surrounding mantle, and buoyantly uplifts a region roughly 1000 km in diameter to produce a **topographic bulge about 1 km high**.

(Image by D. Müller,
University of Sydney).





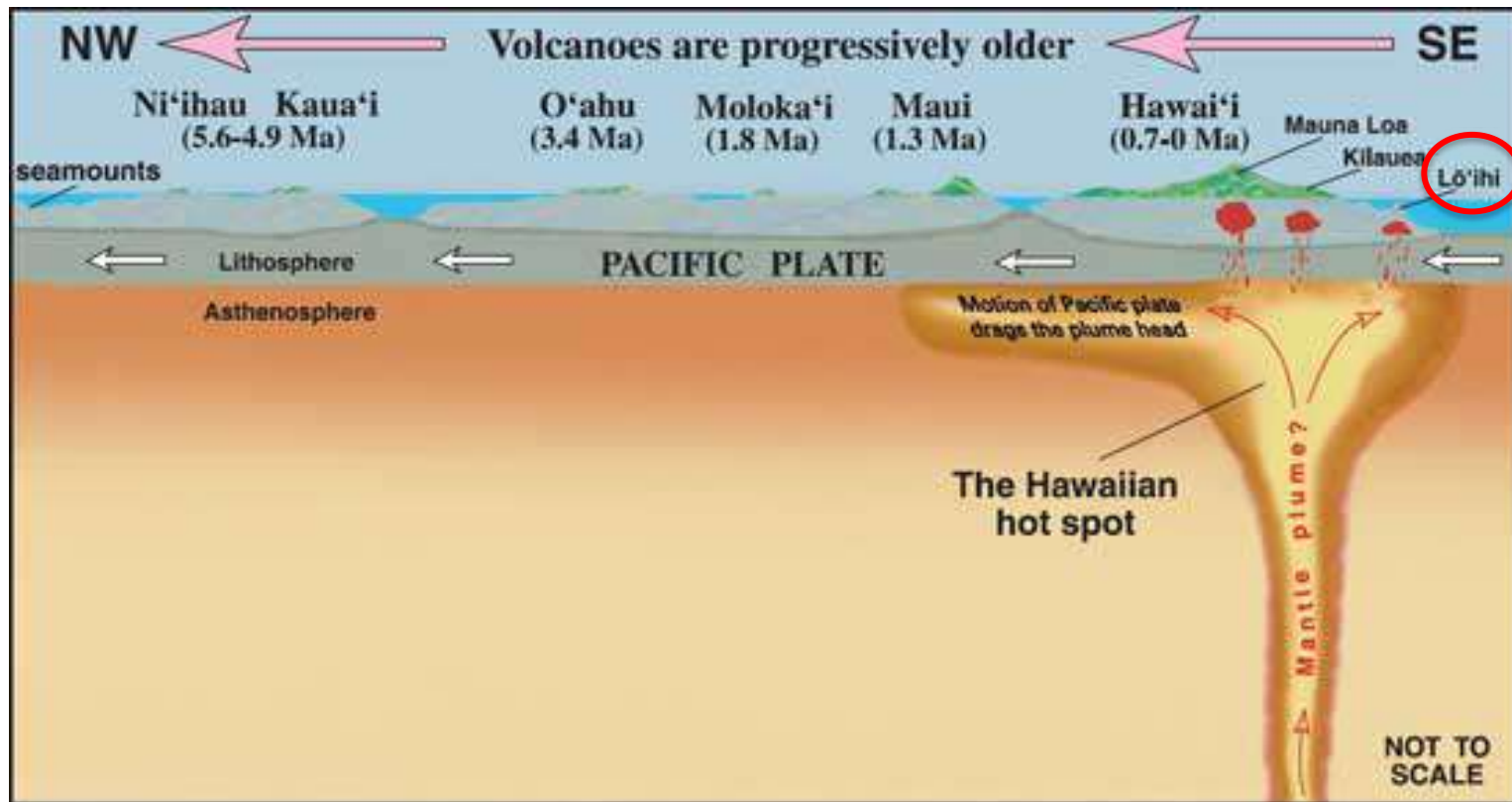
HAWAII HOT SPOT



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

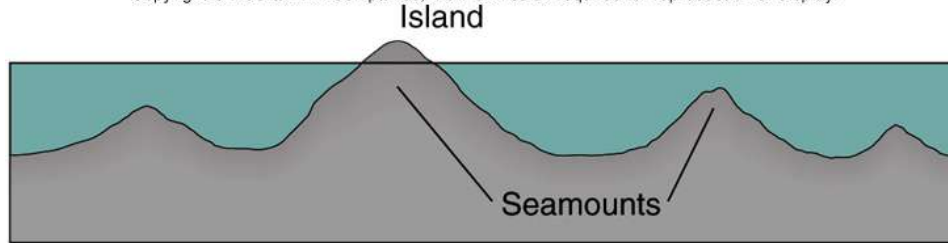


As the Pacific Plate continues to move west-northwest, the Island of Hawaii will be carried beyond the hotspot by plate motion, setting the stage for the formation of a new volcanic island in its place. In fact, this process may be under way. **Loihi Seamount**, an active submarine volcano, is **forming 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.

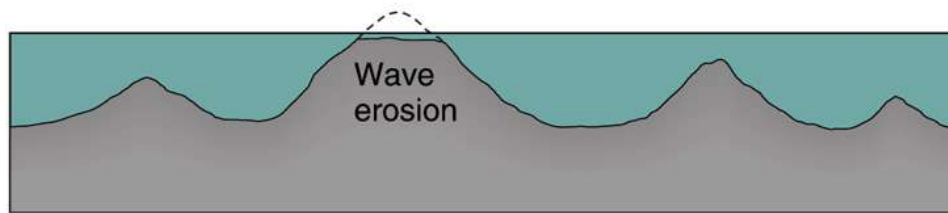
Morphological Features

Seamounts, volcanic island and guyots

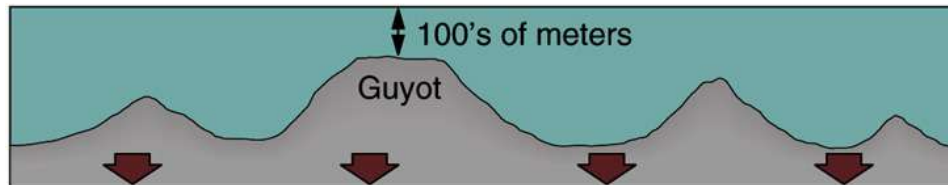
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A

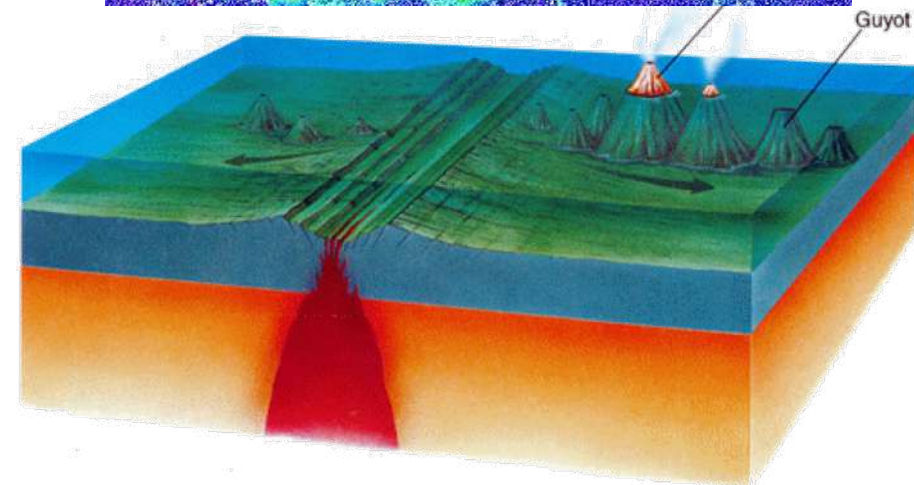
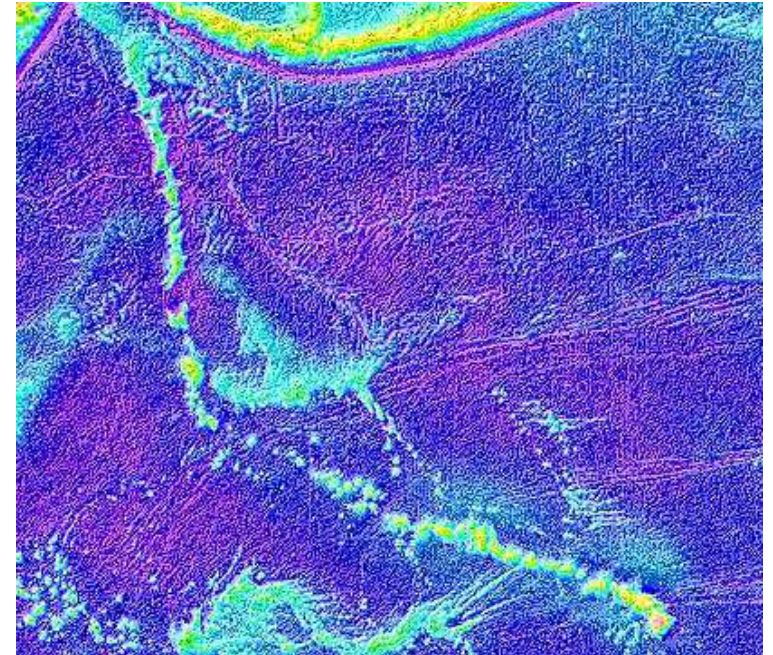


B



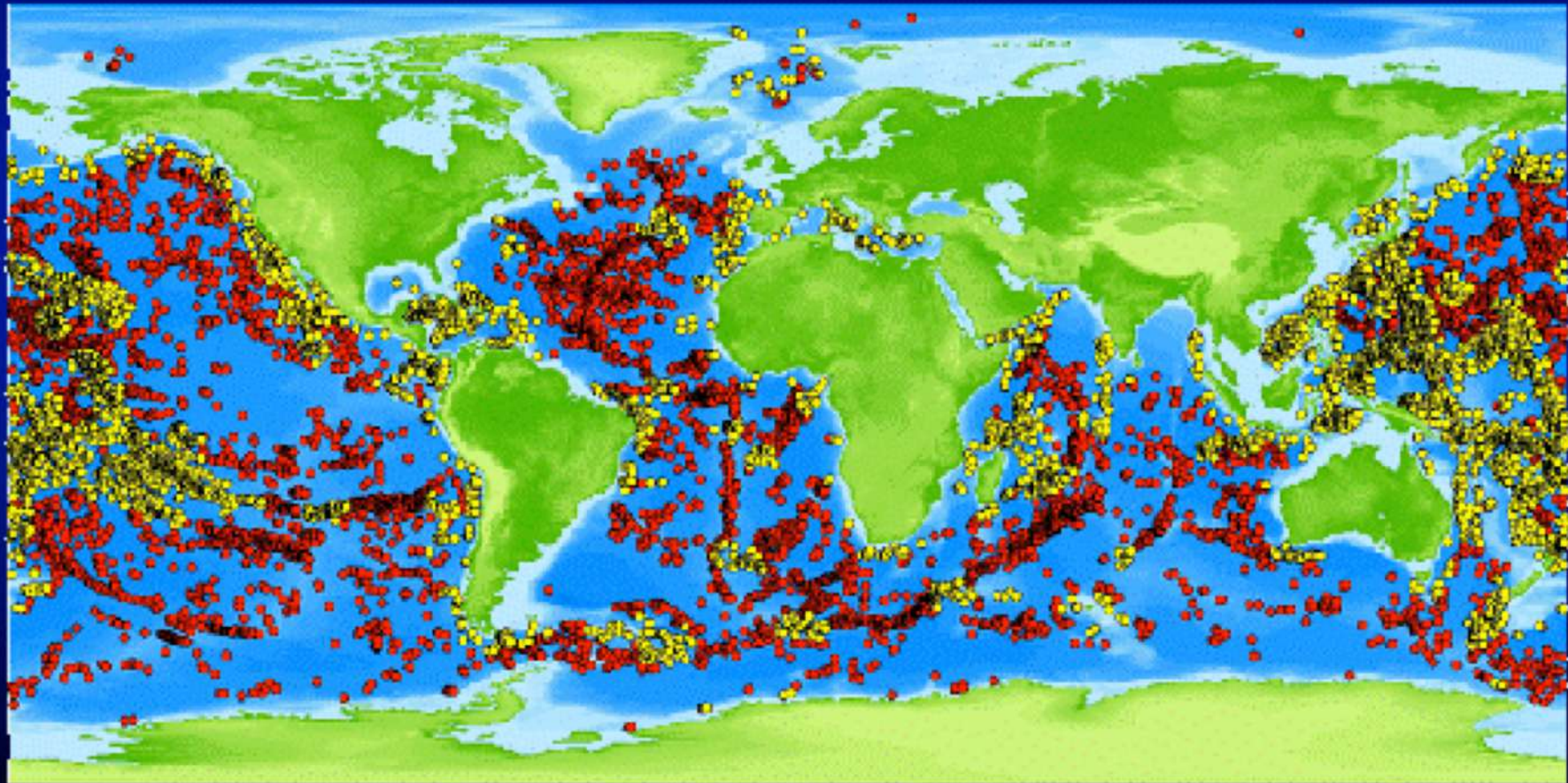
C

Subsidence of sea floor



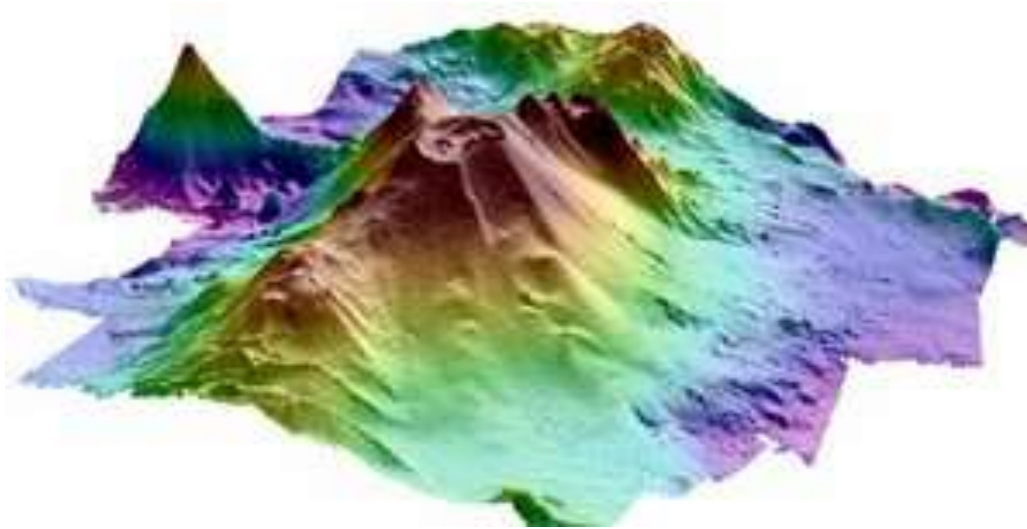
Seamount Locations

Kitchingman and Lai 2004



about 60.000 seamounts

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.

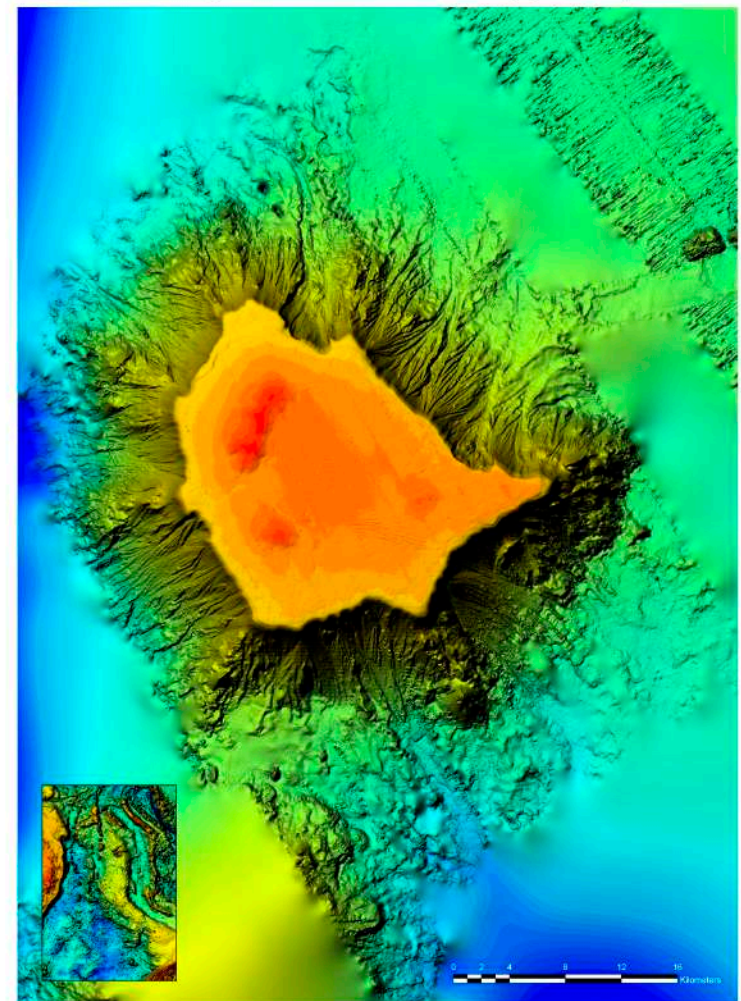
A seamount tall enough to break the sea surface is called an oceanic island, e.g., the islands of Hawaii, the Azores and Bermuda.

Canary Islands (Atlantic Ocean)

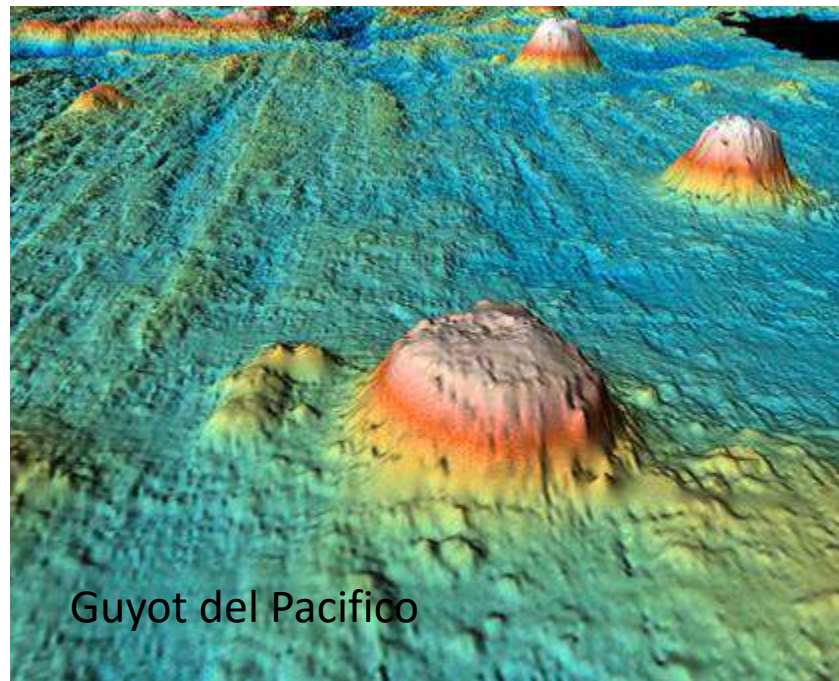


Volcanic origin

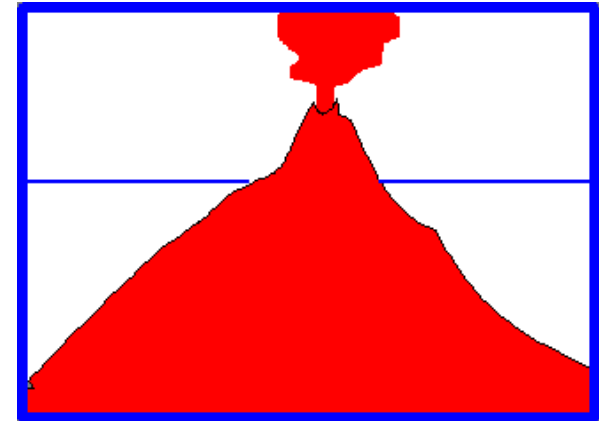
Gifford Guyot (Tasman Sea)



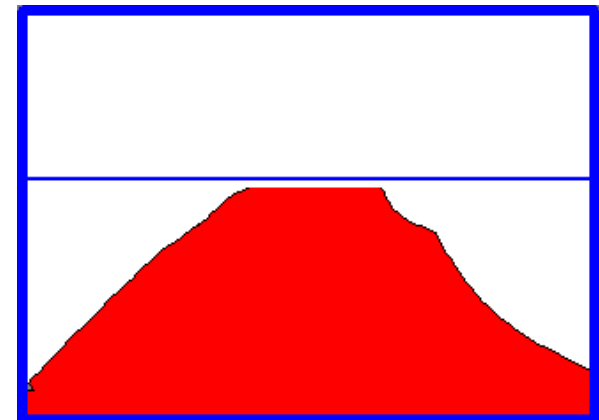
GUYOT



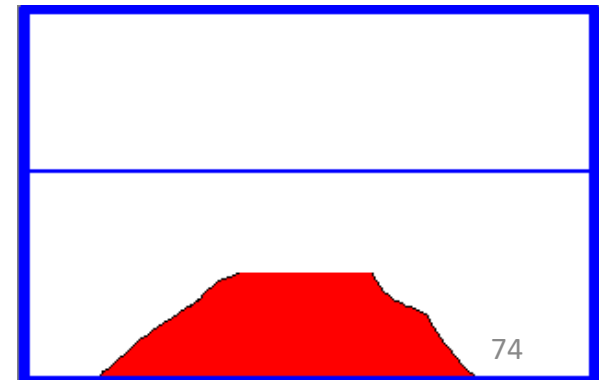
1. Volcanic Island



2. Wave erosion



3. Guyot

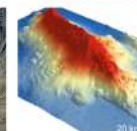
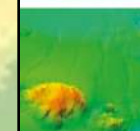


Seamounts in the Mediterranean

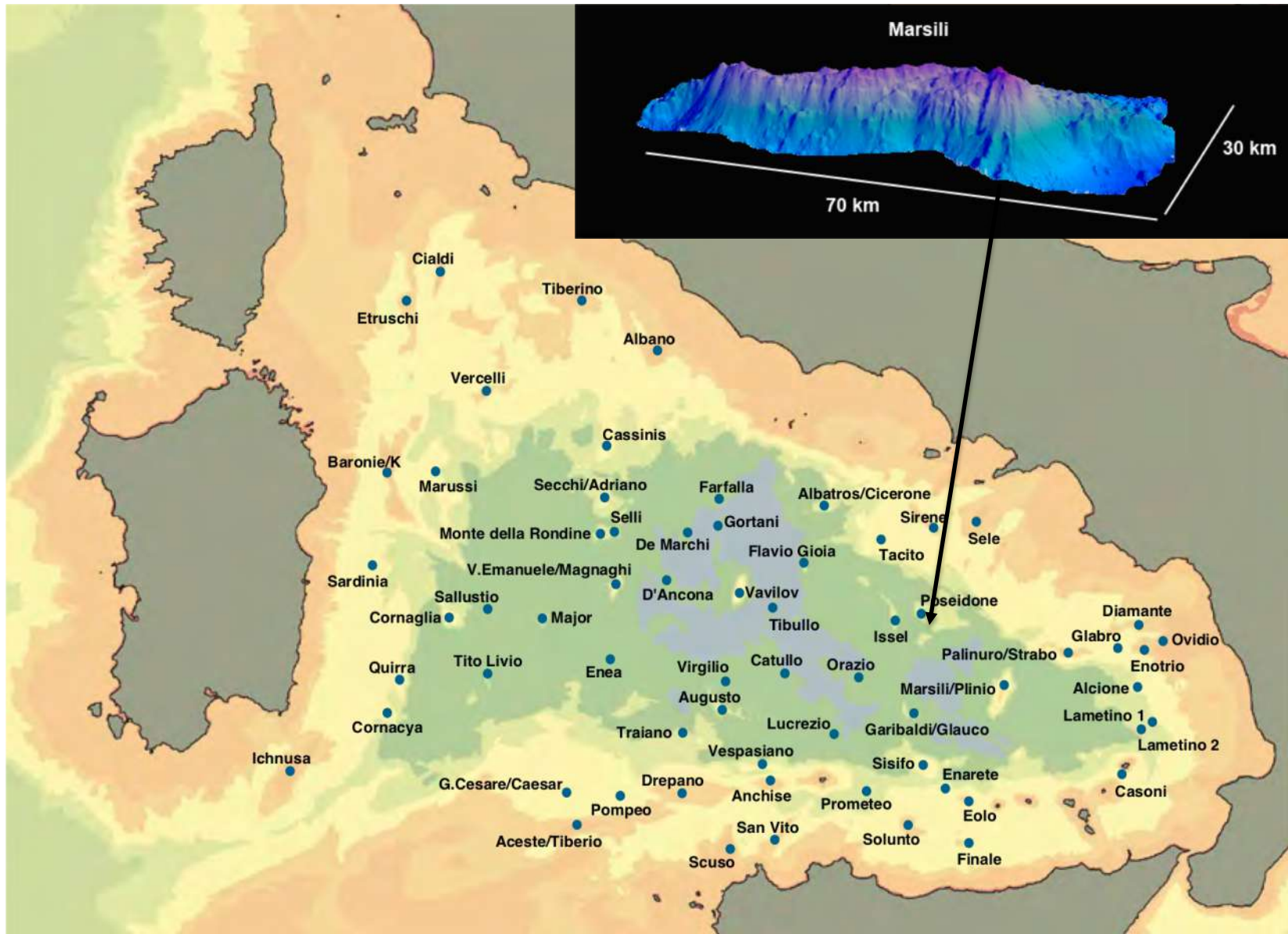


Atlas of the Mediterranean Seamounts
and Seamount-like Structures

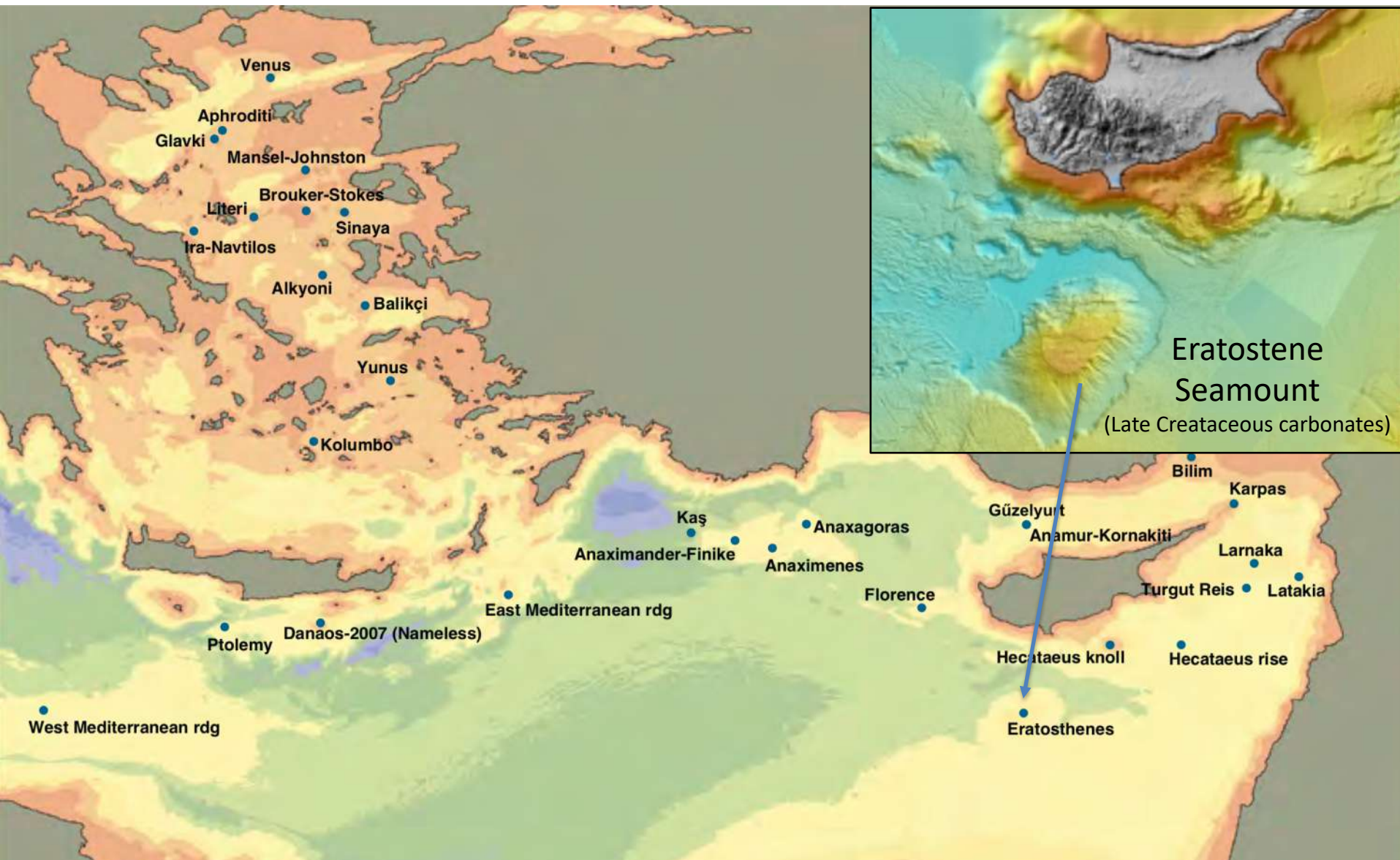
Maurizio Würtz and Marzia Rovere (Editors)



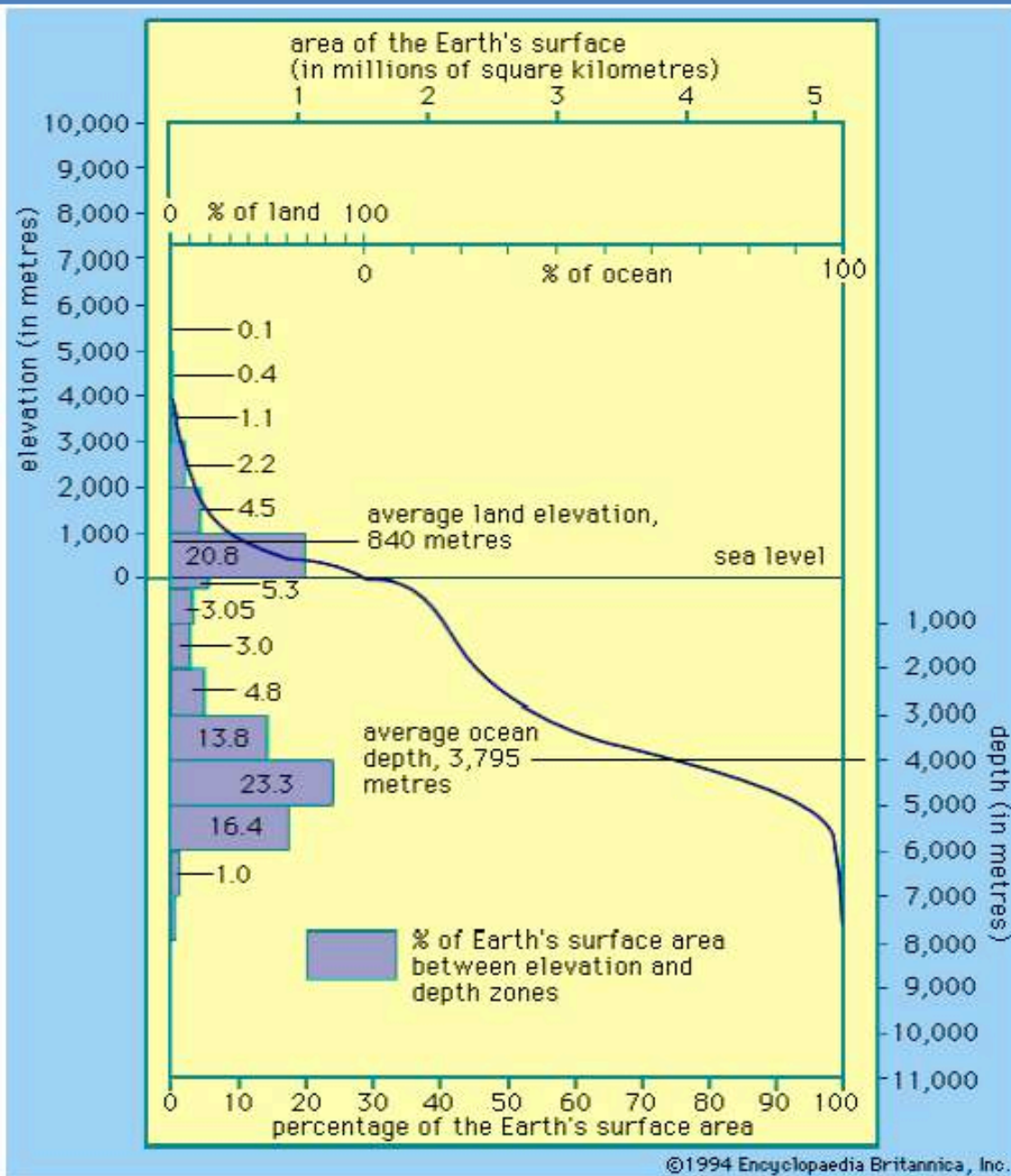
Seamounts in the Mediterranean



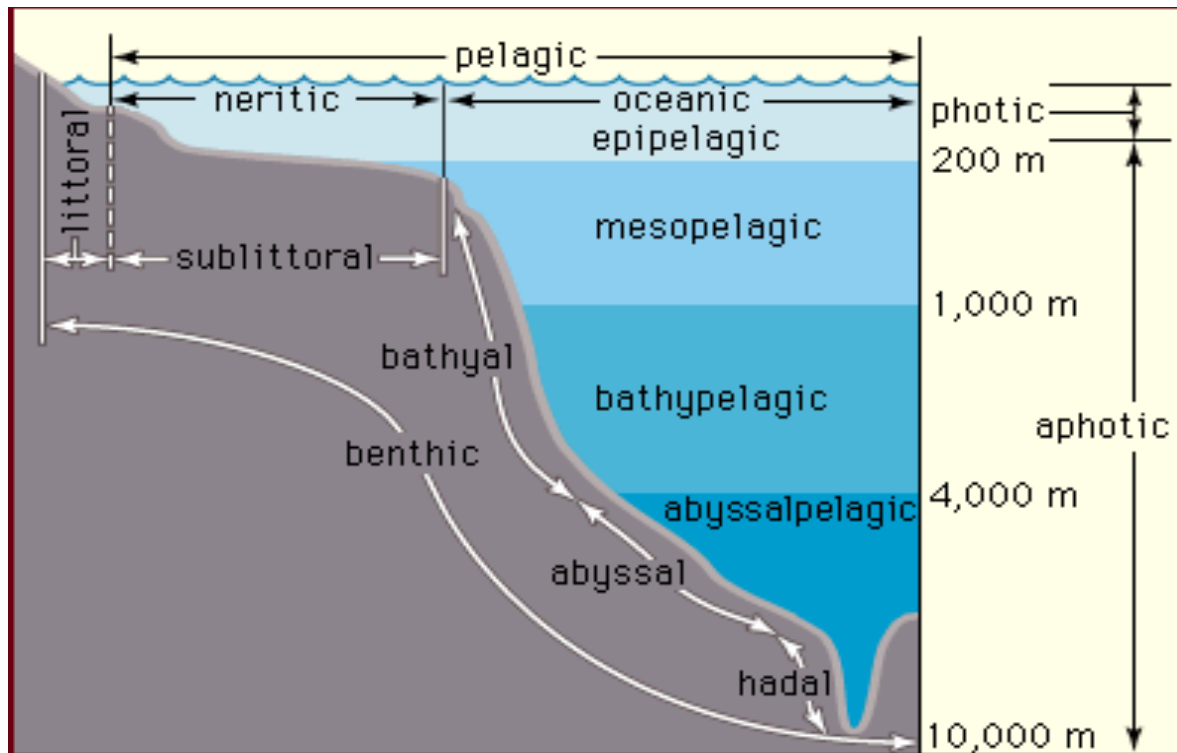
Seamounts in the Mediterranean Sea



4. The classifications of marine environments



Classification of the Marine Zones



Temperature

$T = 12^{\circ}\text{C}$
at about 700-1000 m depth
in the tropic

$T = 4^{\circ}\text{C}$
at about 4000 m depth
in the tropic

Environmental classification:

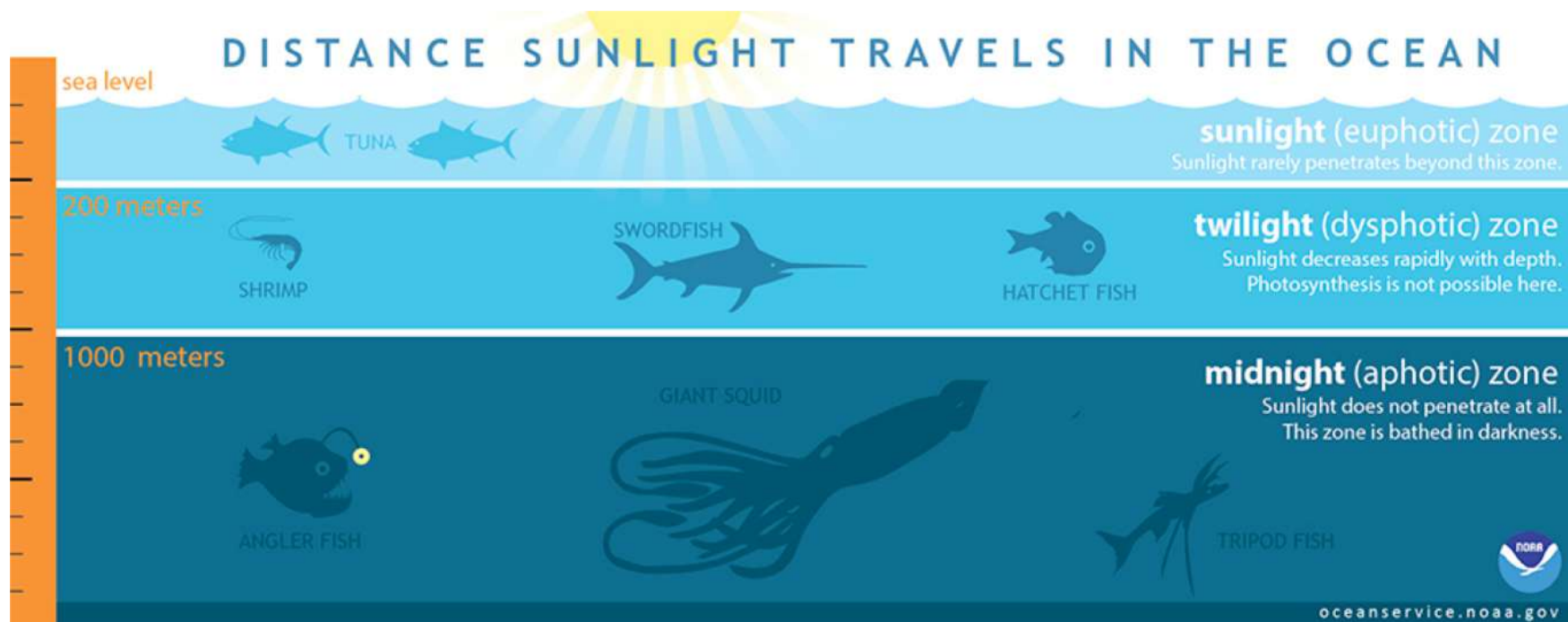
- Littoral
- sublittoral
- bathyal
- abyssal
- hadal

Light classification:

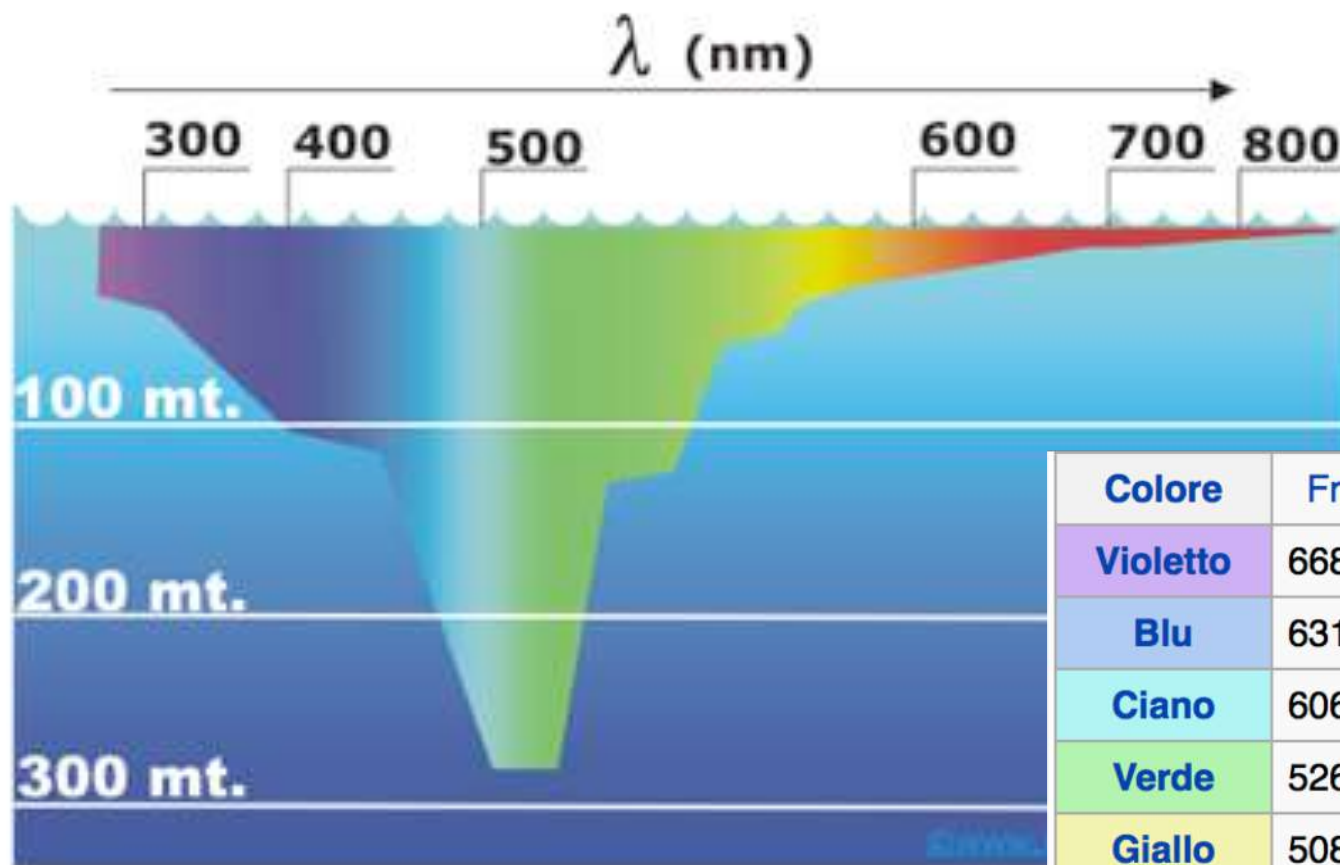
- photic
- aphotic

Pelagic:

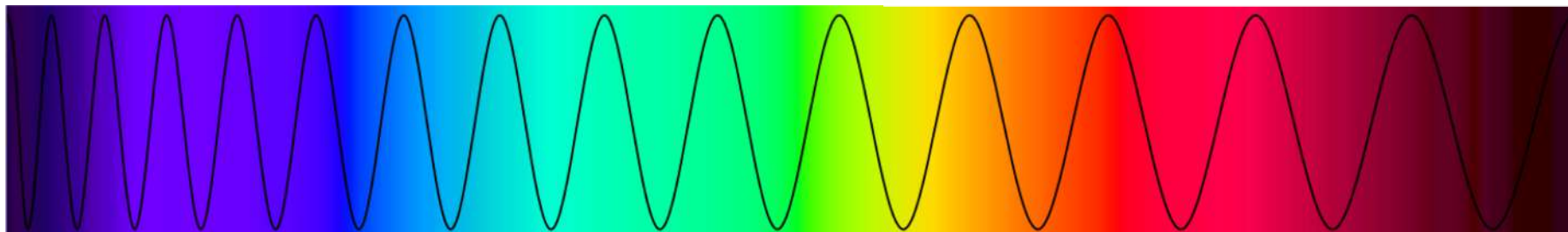
- neritic
- oceanic:
 - epipelagic (photic zone)
 - mesopelagic (down to $T=12^{\circ}\text{C}$)
 - bathypelagic ($12^{\circ}\text{C} < T > 4^{\circ}\text{C}$)
 - abyssalpelagic
 - hadalpelagic

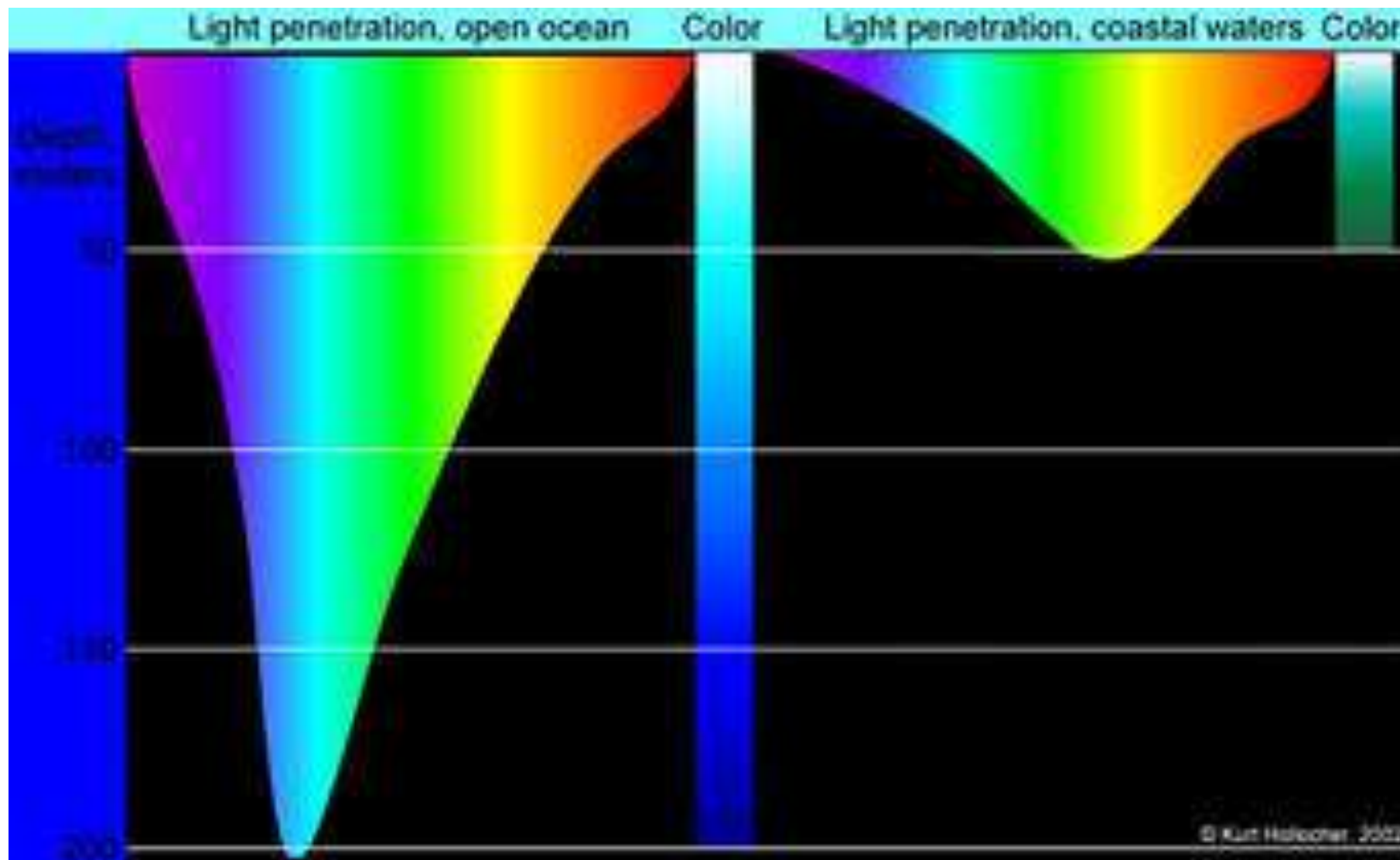


Such a miniscule amount of light penetrates beyond a depth of 200 meters that photosynthesis is no longer possible.



| 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 |





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 meteorites 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 oxygen 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 Laurentia 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

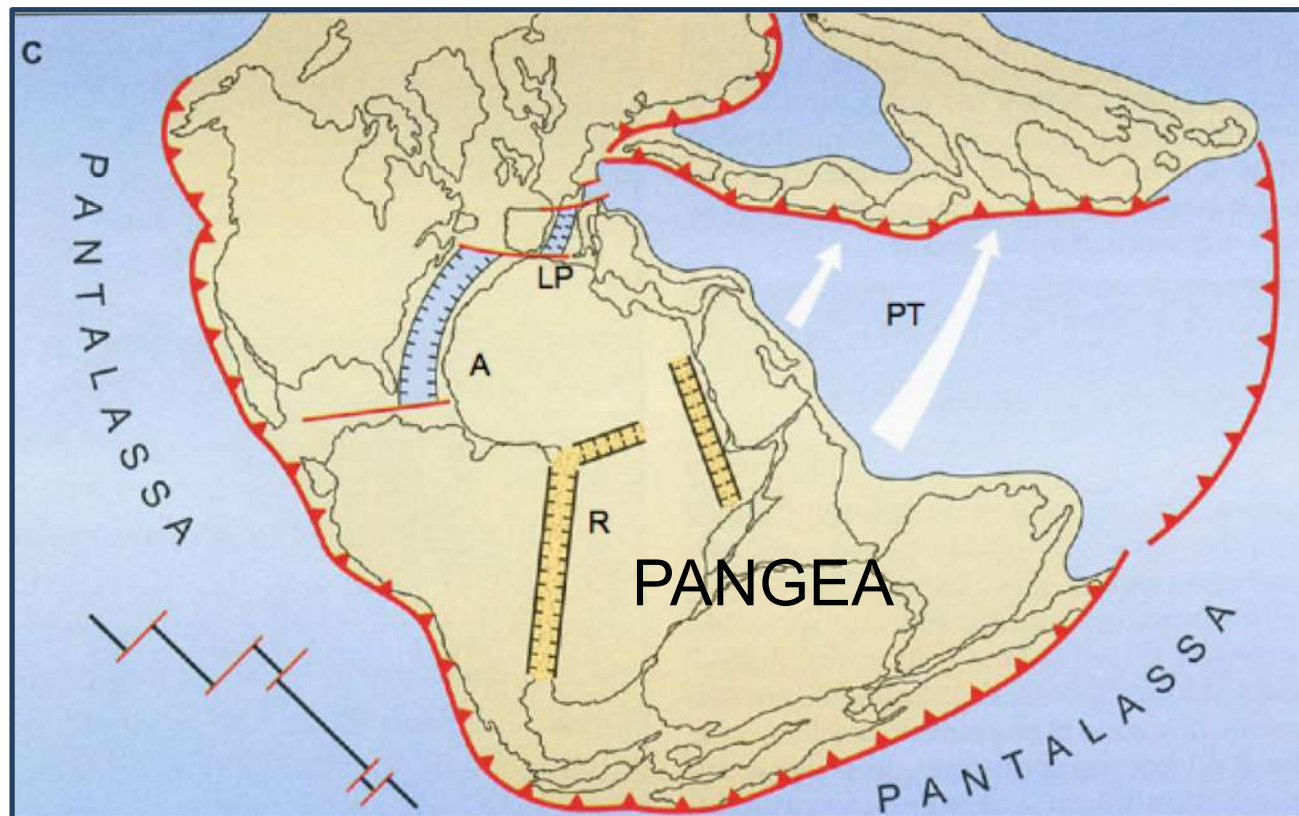


L'Oceano Tetide (o semplicemente Tetide) era un braccio oceanico disposto in senso Est-Ovest che, nei tempi geologici compresi tra il Permiano ed il Miocene separava l'Africa settentrionale dall'Europa e dall'Asia.

L'apertura dell'Oceano Tetide avvenne circa 250 milioni di anni fa, tra il Permiano ed il Triassico inferiore e portò alla separazione tra un blocco continentale settentrionale (Laurasia) ed uno meridionale (Gondwana). L'allontanamento delle due parti del Pangea proseguì fino al Giurassico, quando i movimenti delle placche tettoniche si invertirono ed iniziò una contrazione dell'Oceano Tetide stesso.

Il movimento dell'Africa era solidale con quello della placca adriatica, che forse ne rappresentava una parte settentrionale. La collisione della placca adriatica con il continente europeo chiuse la Tetide nella regione centrale del Mediterraneo, dando origine alla catena montuosa delle Alpi. Altre microplacche intrappolate tra le due maggiori (africana ed europea) contribuirono a formare altre catene montuose europee orientate generalmente in direzione Est-Ovest, mentre nella zona mediorientale la placca arabica collideva con l'Asia. A completare la chiusura della Tetide, l'India, staccatasi dal continente meridionale di Gondwana durante il Giurassico, si scontrò con l'Asia dando origine alla catena himalayana.

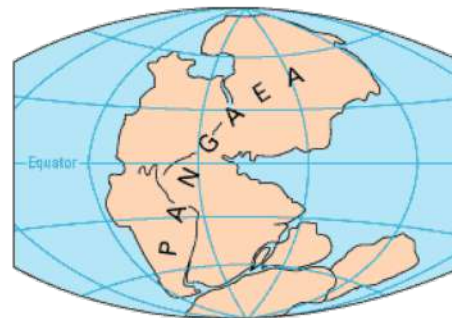
ATLANTIC OCEAN: initial stage



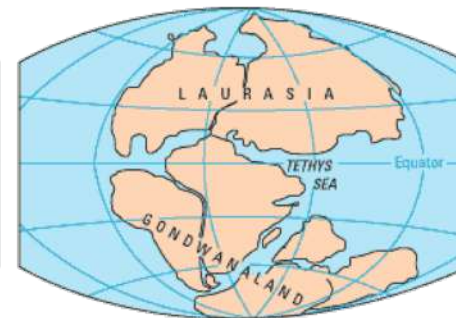
Fragmentation of the Pangea (Late Giurassic):

- 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

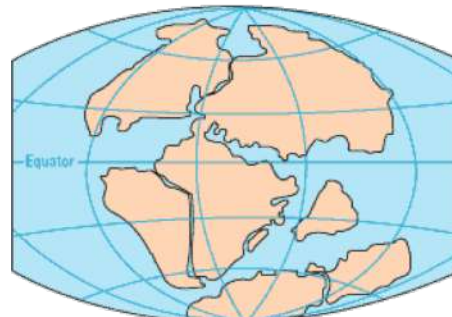
The break up of Pangaea



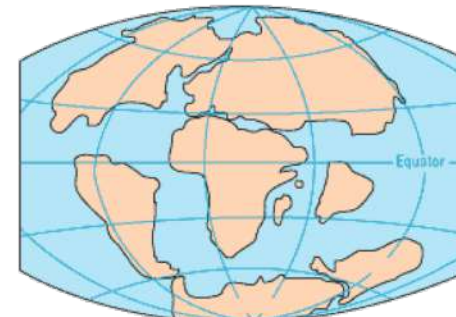
PERMIAN
225 million years ago



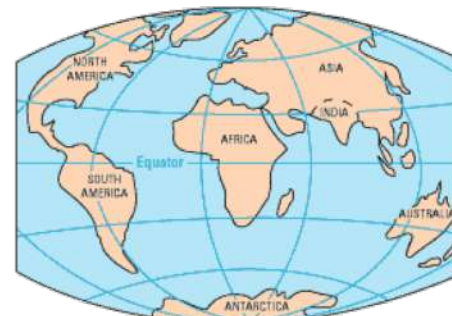
TRIASSIC
200 million years ago



JURASSIC
135 million years ago



CRETACEOUS
65 million years ago



PRESENT DAY

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|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
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| 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>

FINE