

Università di Trieste
LAUREA MAGISTRALE IN GEOSCIENZE SM62
Percorso Esplorazione Geologica

Anno accademico 2022 - 2023

Geologia Marina 953SM

Modulo 1.1 Oceani. Morfologia, struttura ed evoluzione

Docente
Angelo Camerlenghi
(con contributo di Martina Busetti)

The oceans

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

1. Oceans and seas of the world

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 the word is from sanscrit ACAYANA, in the sense of “containing the waters».

«un immenso fiume che cinge tutto lo spazio terrestre e che, scorrendo su se stesso, collega il mondo»

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

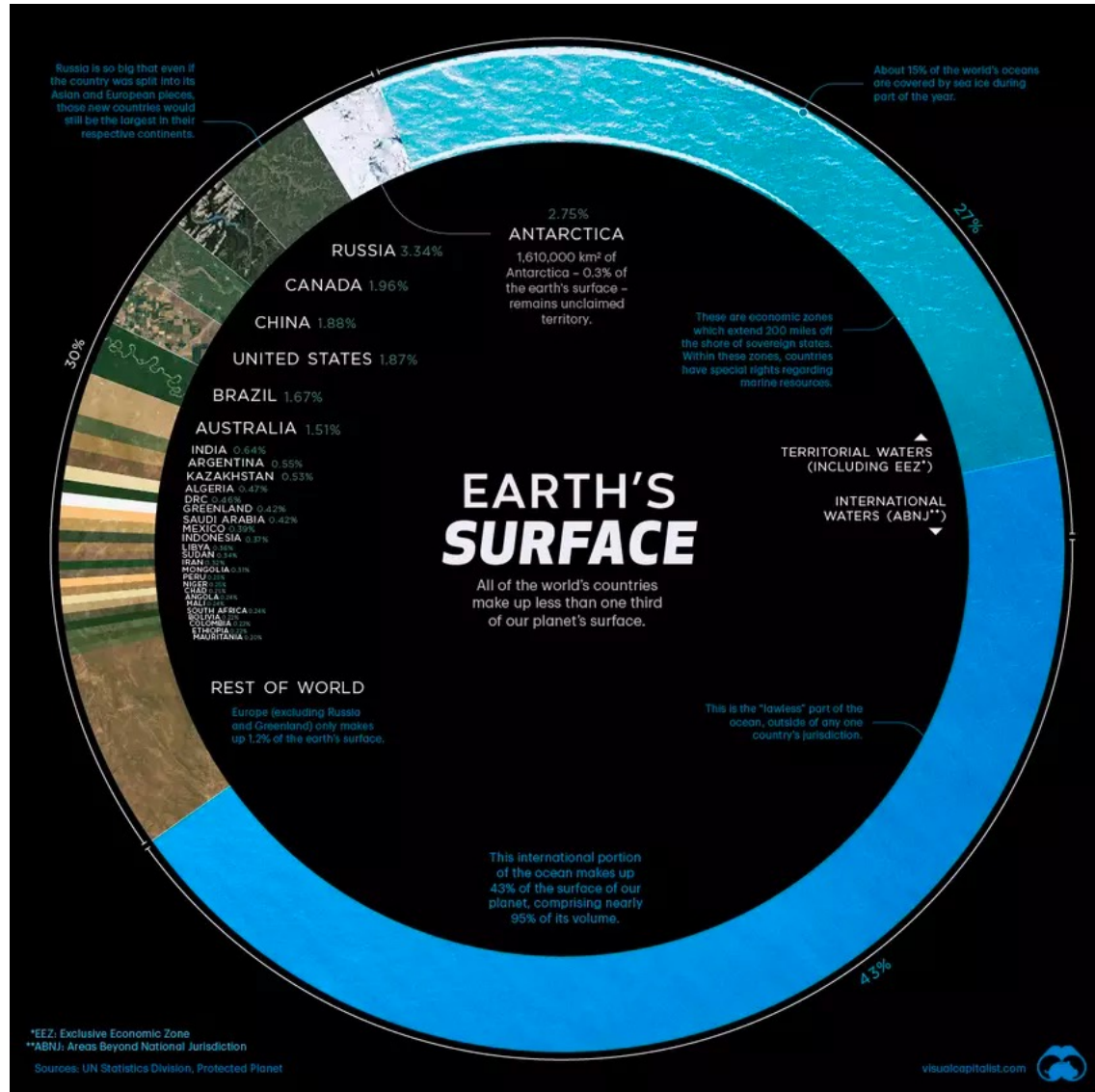


Okeanos - Fontana di Trevi



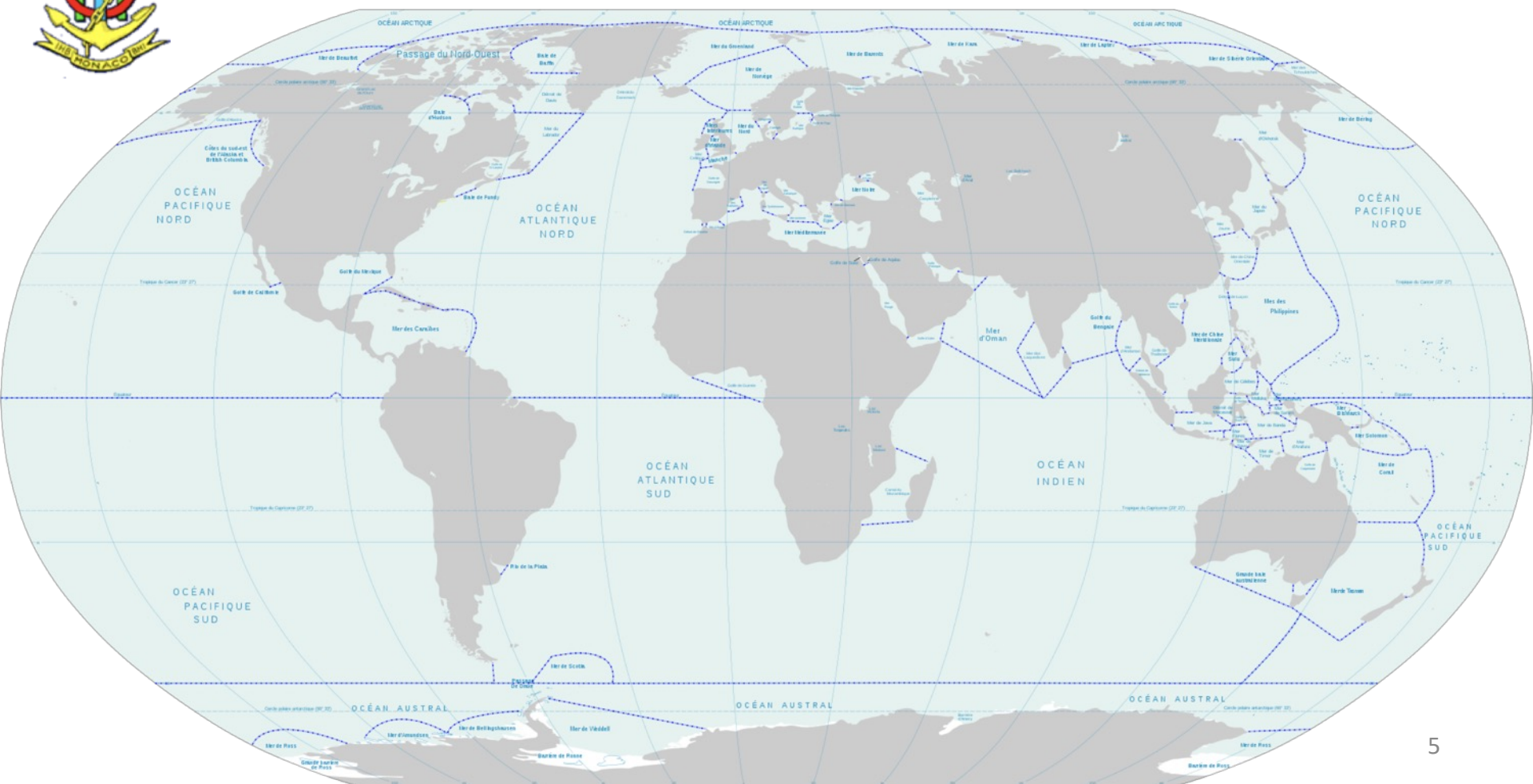
Oceans and Seas:

~ 70% of Earth Surface



*EEZ: Exclusive Economic Zone
**ABNJ: Areas Beyond National Jurisdiction
Sources: UN Statistics Division, Protected Planet

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





International Hydrographic Organization

Is the inter-governmental organisation representing the hydrographic community

The IHO ensures 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 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

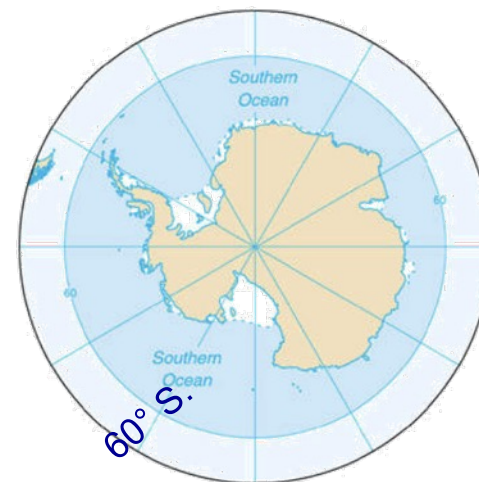


The oceans of the world

Arctic Ocean



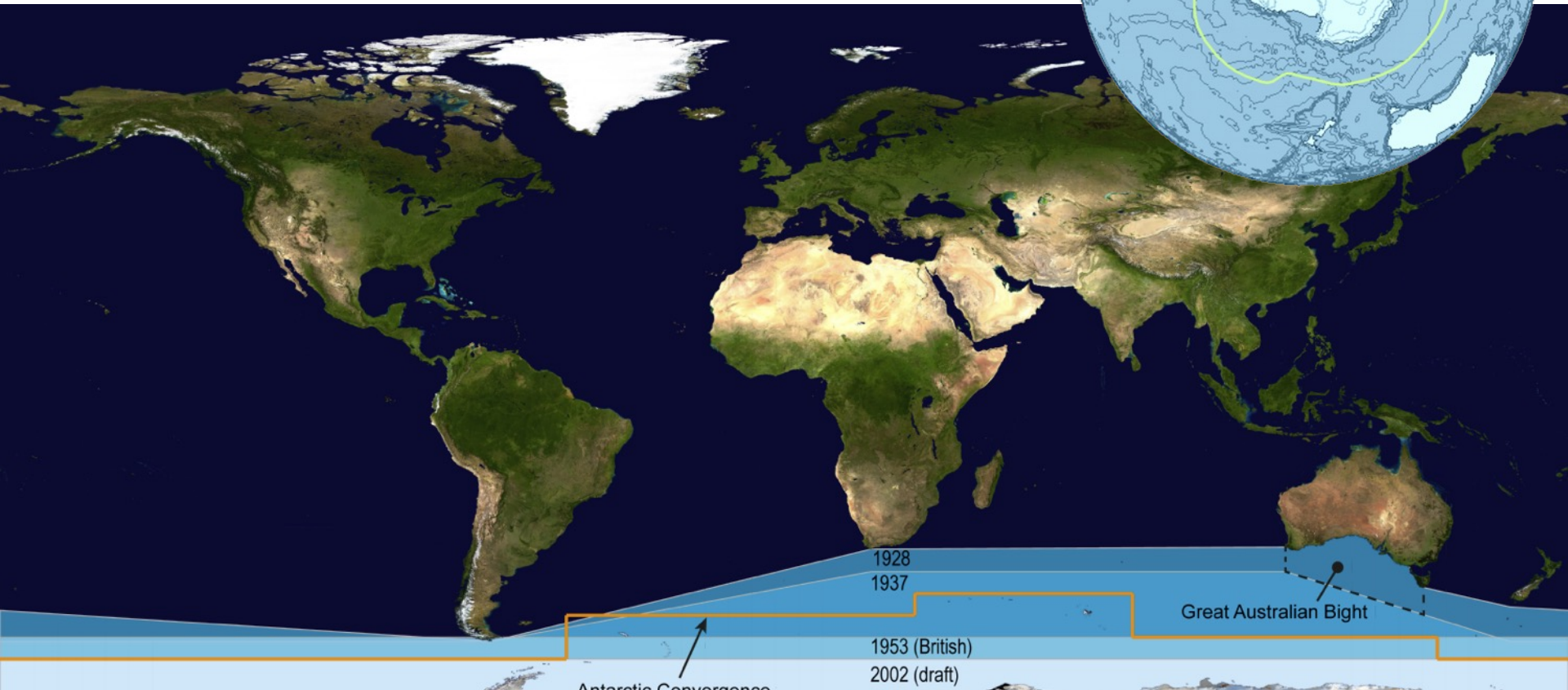
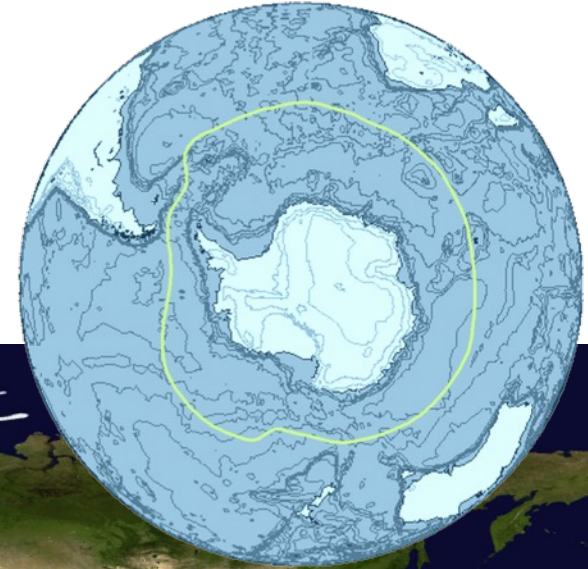
Southern Ocean



In 2000, the IHO published a draft definition of the Southern Ocean, surrounding Antarctica and extending to 60° S.

IHO's delineation of the Southern Ocean

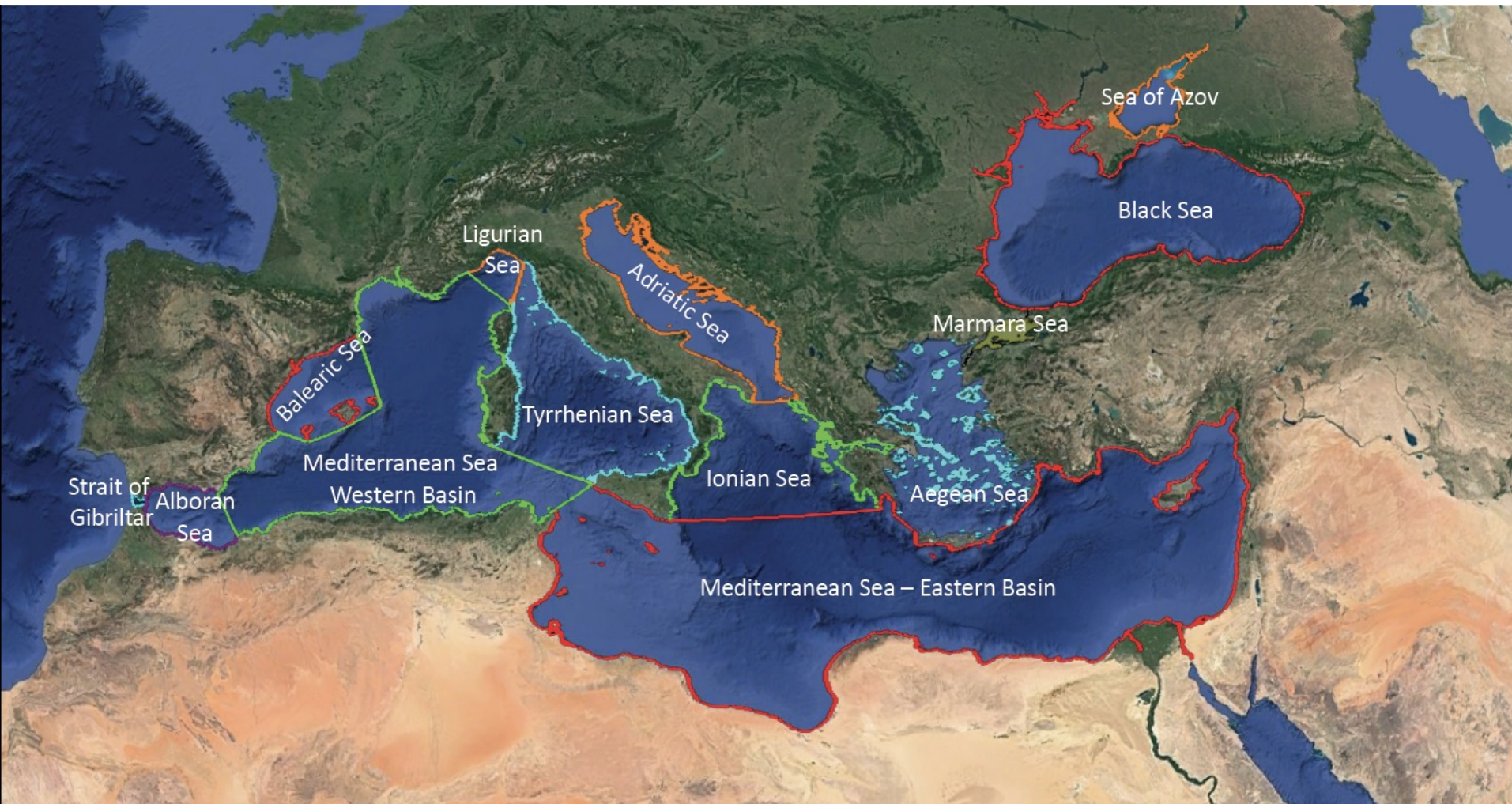
Antarctic Convergence: a curve encircling Antarctica, varying in latitude seasonally, where cold, northward-flowing Antarctic waters meets the relatively warmer water of the subantarctic



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

The seas of the Mediterranean formally defined by the IHO

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

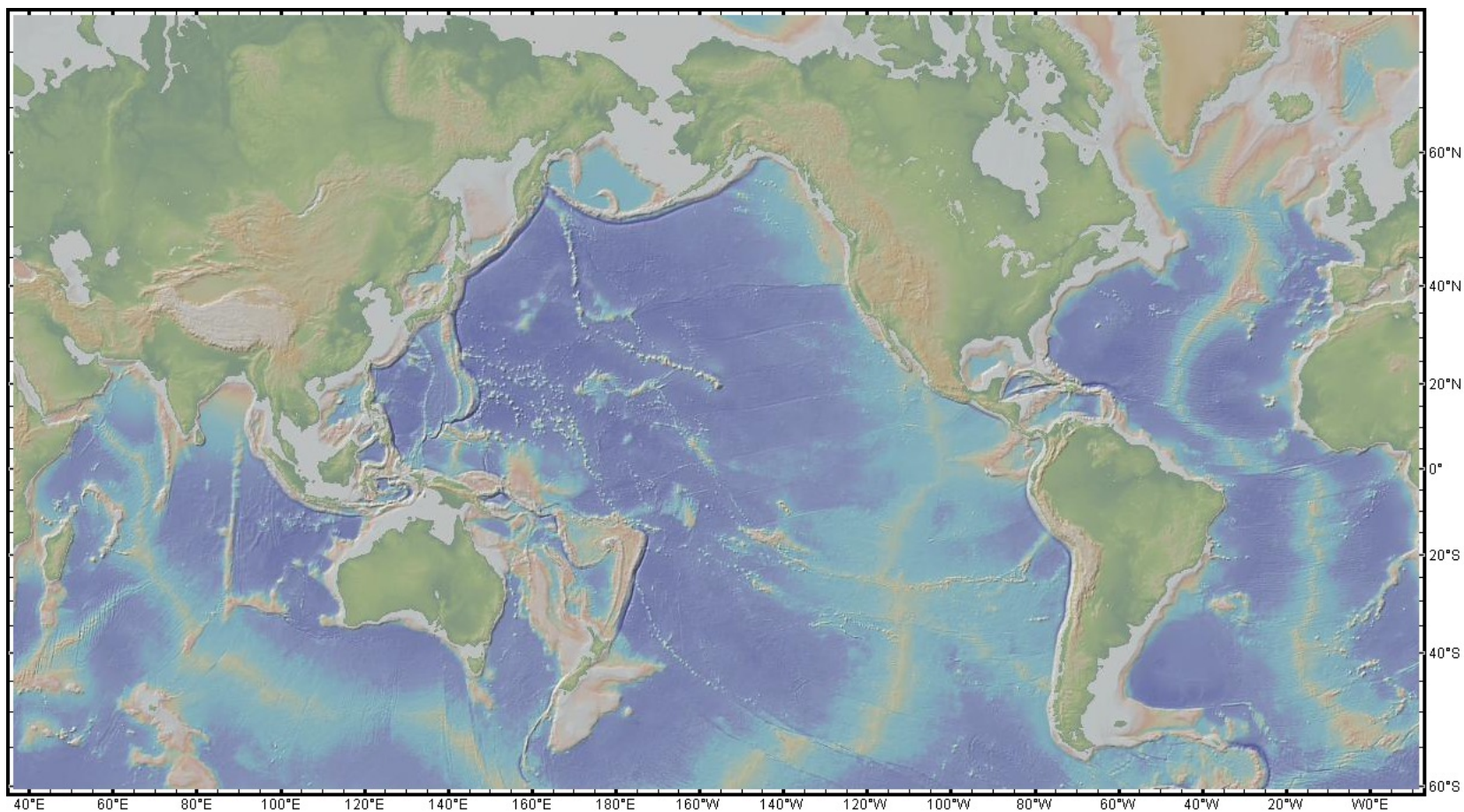


The seas of the Mediterranean

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



2. MORPHOLOGY OF THE OCEAN AND SEA FLOOR



OCEAN AND SEA FLOOR MORPHOLOGY

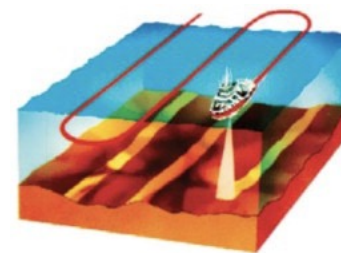
less than 5-10% of the ocean have been explored

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

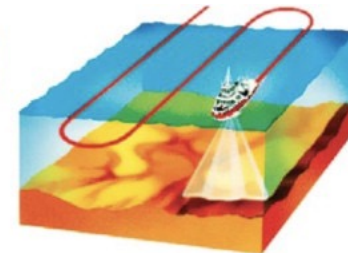
1) First instrument: the SONAR, constructed at the beginning of the 1900

2) Multi-beam sonar technologies, developed in the last decades of the 1900

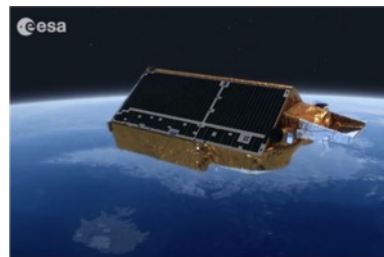
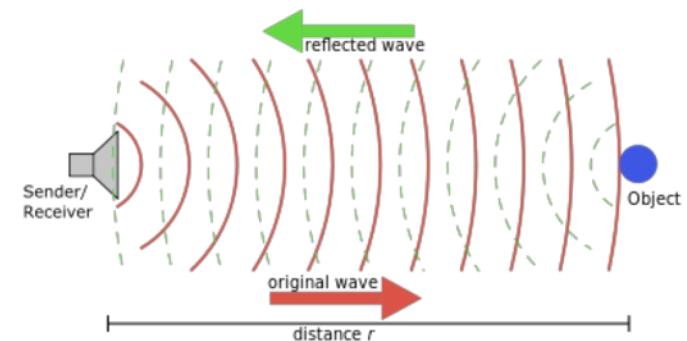
3) Satellite derived bathymetry and sea floor morphology developed in the last decades of the 1900



(a) Single-Beam



(b) Multi-Beam

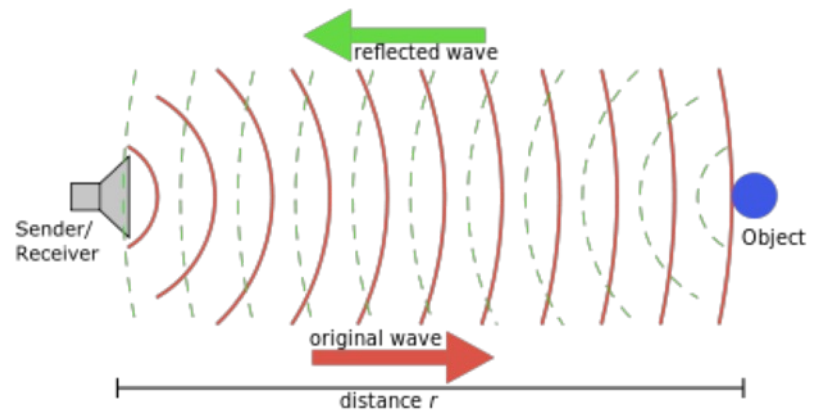
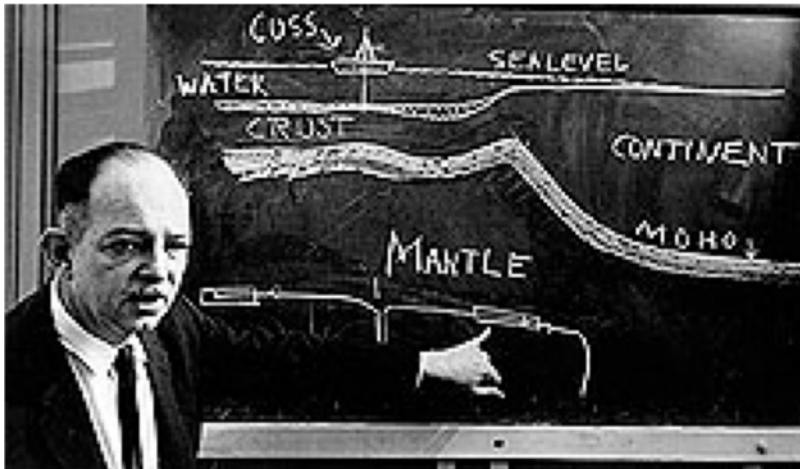


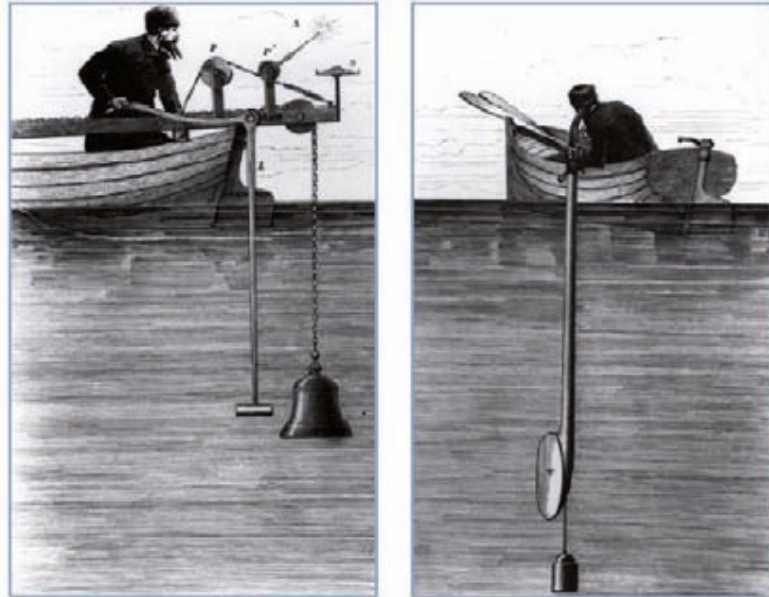
Harry Hess (1906 – 1969)

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, patented 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.





F

Colladon and Sturm's 1862 experiment to measure the speed of sound in Lake Geneva (J. D. Colladon: *Souvenirs et M moires*, Impr. Albert-Schuchardt, Geneva, 1893).

Given that the area of the seafloor is approximately 360 million square kilometers,³ and estimating the coverage of a typical deep-sea image to be approximately 4 square meters, we can estimate that to cover the world ocean with detailed optical imagery (i.e., create a Google Ocean at a scale commensurate with Google Earth), it would take about 90,000,000,000,000 images. Factoring in the time it takes to bring a vehicle down and back from the seafloor and the time it takes to capture the images, we are looking at something like 200 million years to completely image the seafloor using optical techniques – clearly an impossible task.

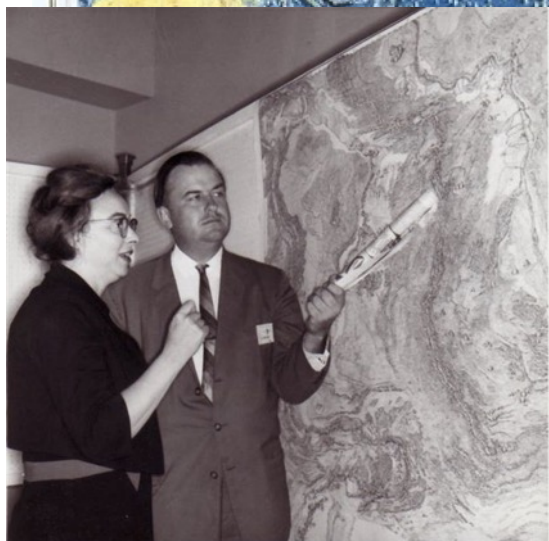
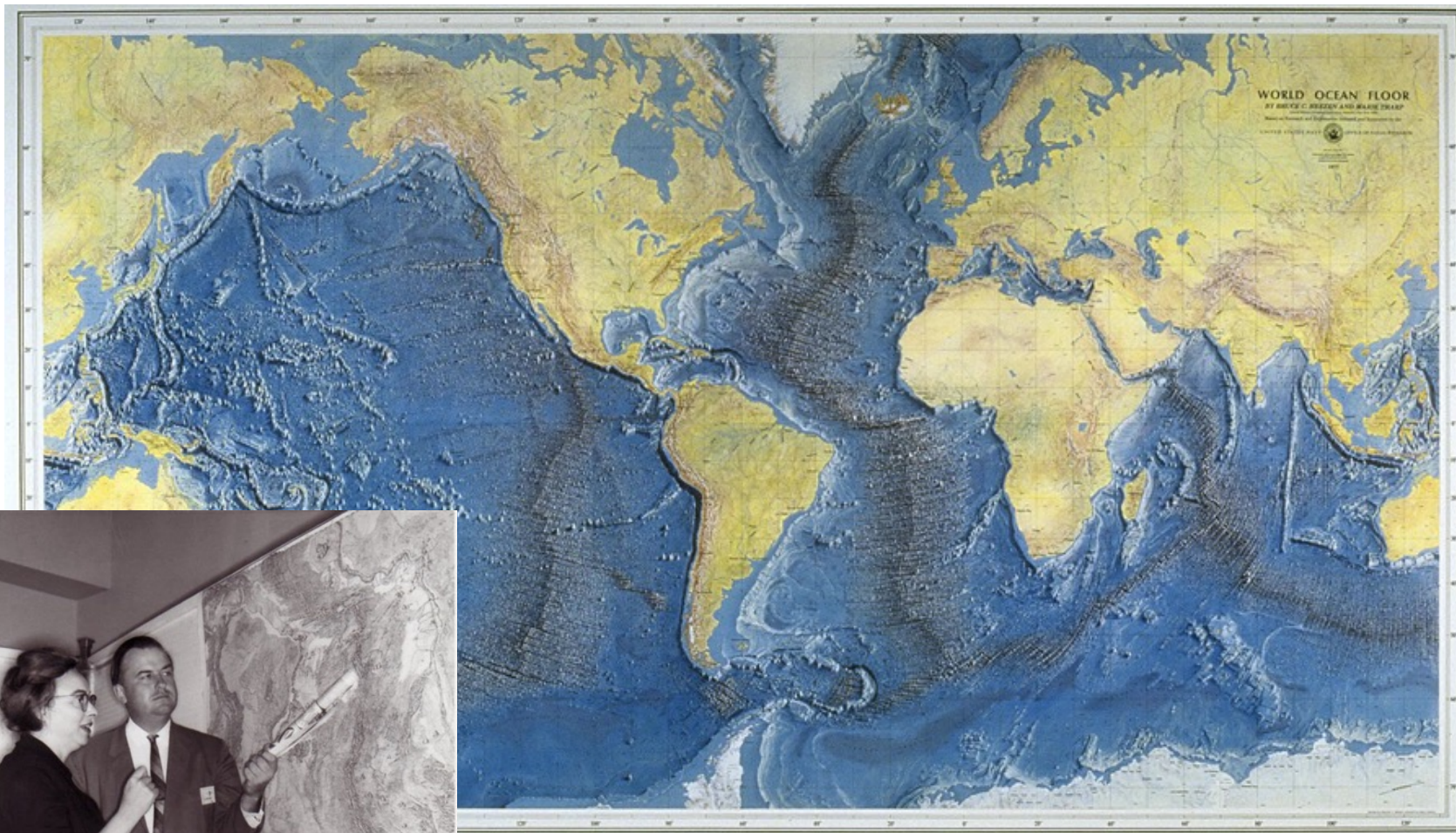
Modern multibeam echo-sounders capable of mapping the deep sea are large and expensive and are typically mounted on large (> 50m) vessels that are in themselves expensive to operate. It has been estimated that to map the deep (>200 m) portions of the world's ocean seafloor using current day technology would take more than 300 ship years and cost on the order of three to five billion dollars.

Mayer and Roach, 2021

The Quest to Completely Map the World's Oceans in Support of Understanding Marine Biodiversity and the Regulatory Barriers

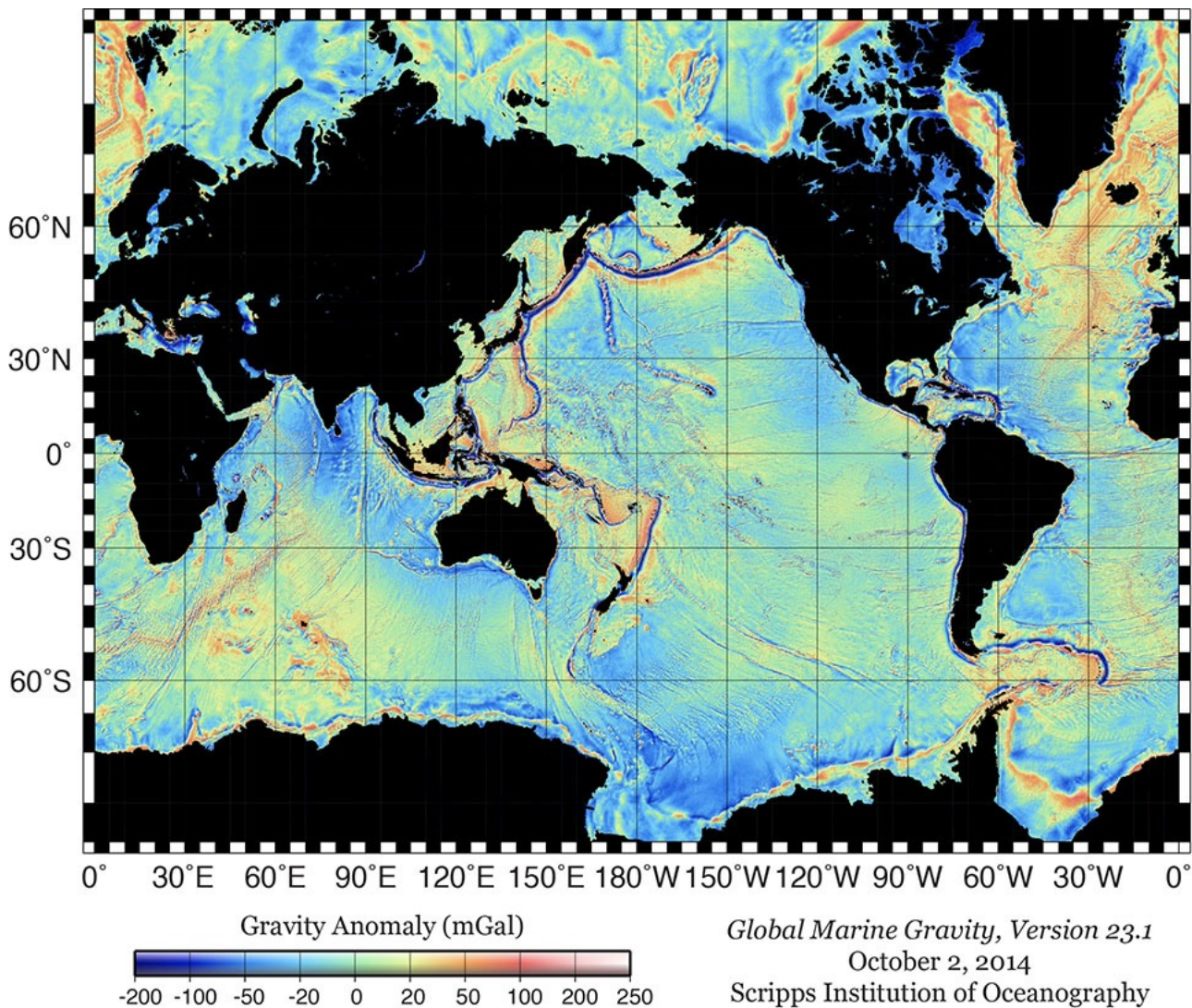
https://doi.org/10.1163/9789004422438_009

SEA FLOOR MORPHOLOGY 1977



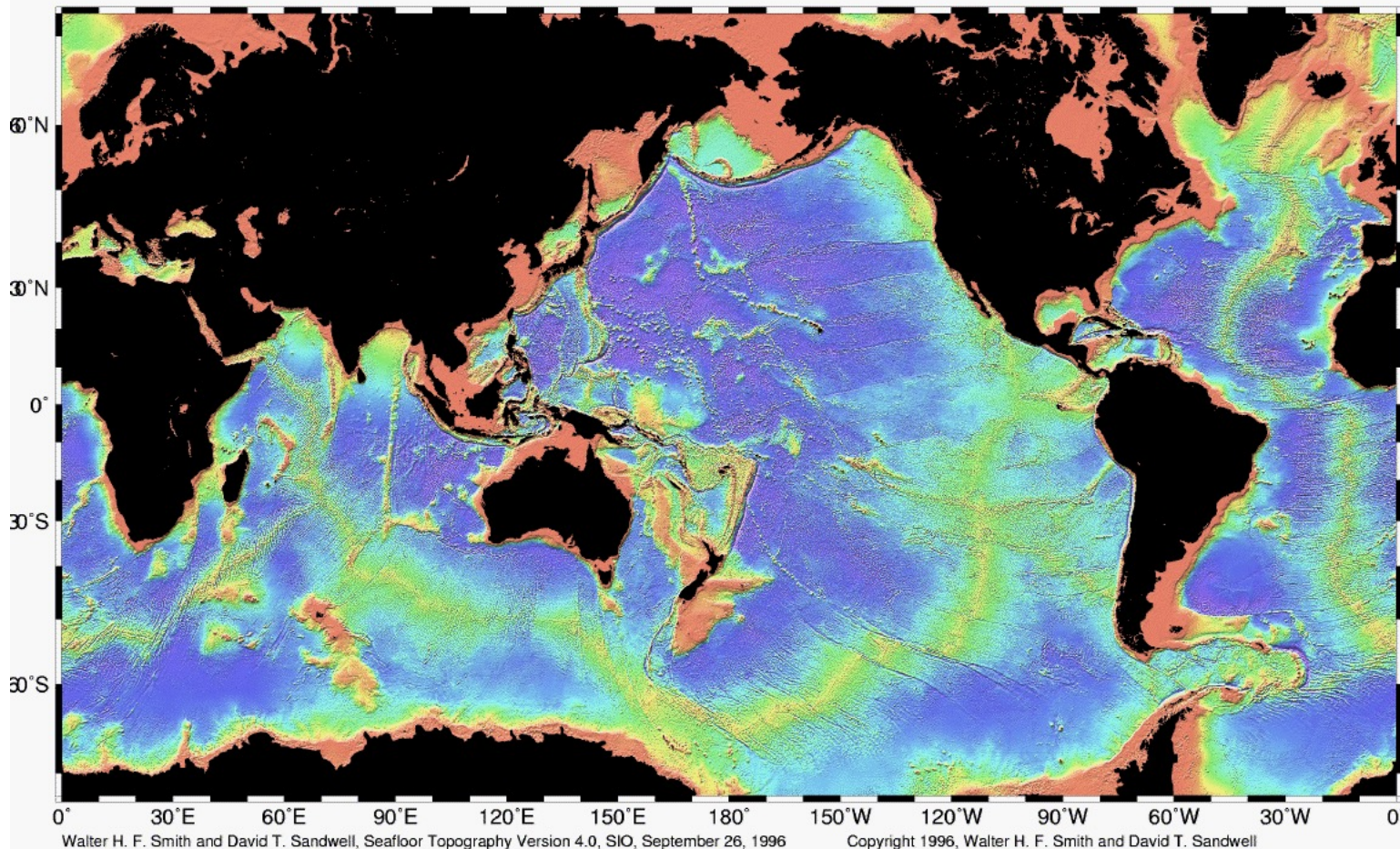
Marie Tharp and Bruce Heezen, oceanographers of the Columbia University's Lamont Geological Observatory. They discovered the 60.000 km of underwater ridges. The map was painted by Heinrich C. Berann.

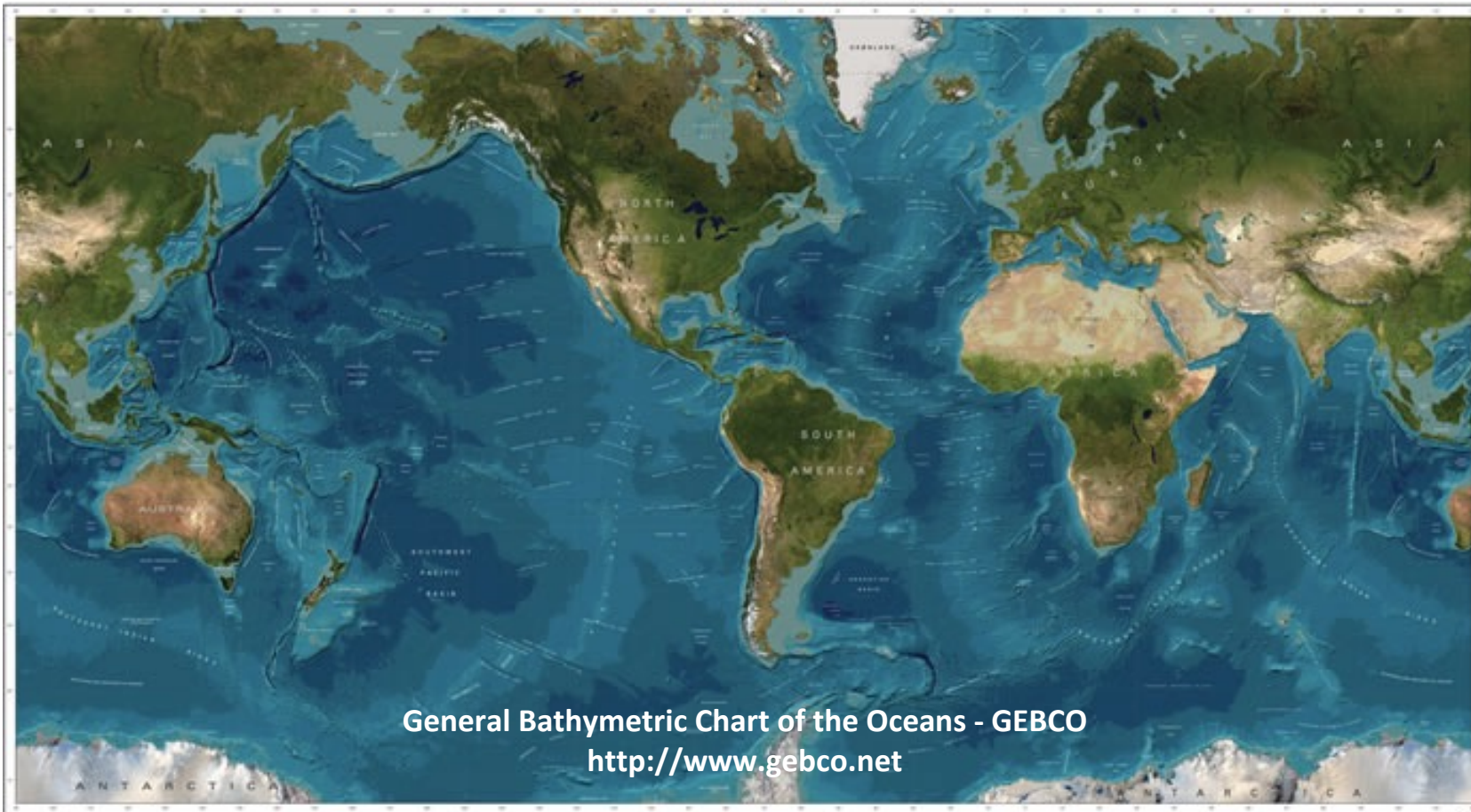
Global gravity map of the oceans - from GEOSAT and ERS-1



Smith and Sandwell, 1996

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





GENERAL BATHYMETRIC CHART OF THE OCEANS (GEBCO)
WORLD OCEAN BATHYMETRY



NOTES

1. This chart is based on the GEBCO 2022 Bathymetry Release (20220101) and is available at <http://www.gebco.net>.

2. The chart is based on the GEBCO 2022 Bathymetry Release (20220101) and is available at <http://www.gebco.net>.

3. The chart is based on the GEBCO 2022 Bathymetry Release (20220101) and is available at <http://www.gebco.net>.

4. The chart is based on the GEBCO 2022 Bathymetry Release (20220101) and is available at <http://www.gebco.net>.

Minimum Projection: Scale 1:20,000,000 on the Equator
 (Depth in color-coded meters)

Approved and authorized
 for the International Hydrographic Organization
 (IHO) by the International Geographical Commission
 (IGC) in 2002.

IGBCO World Map Cartographic Editorial Board
 (established December 2004)

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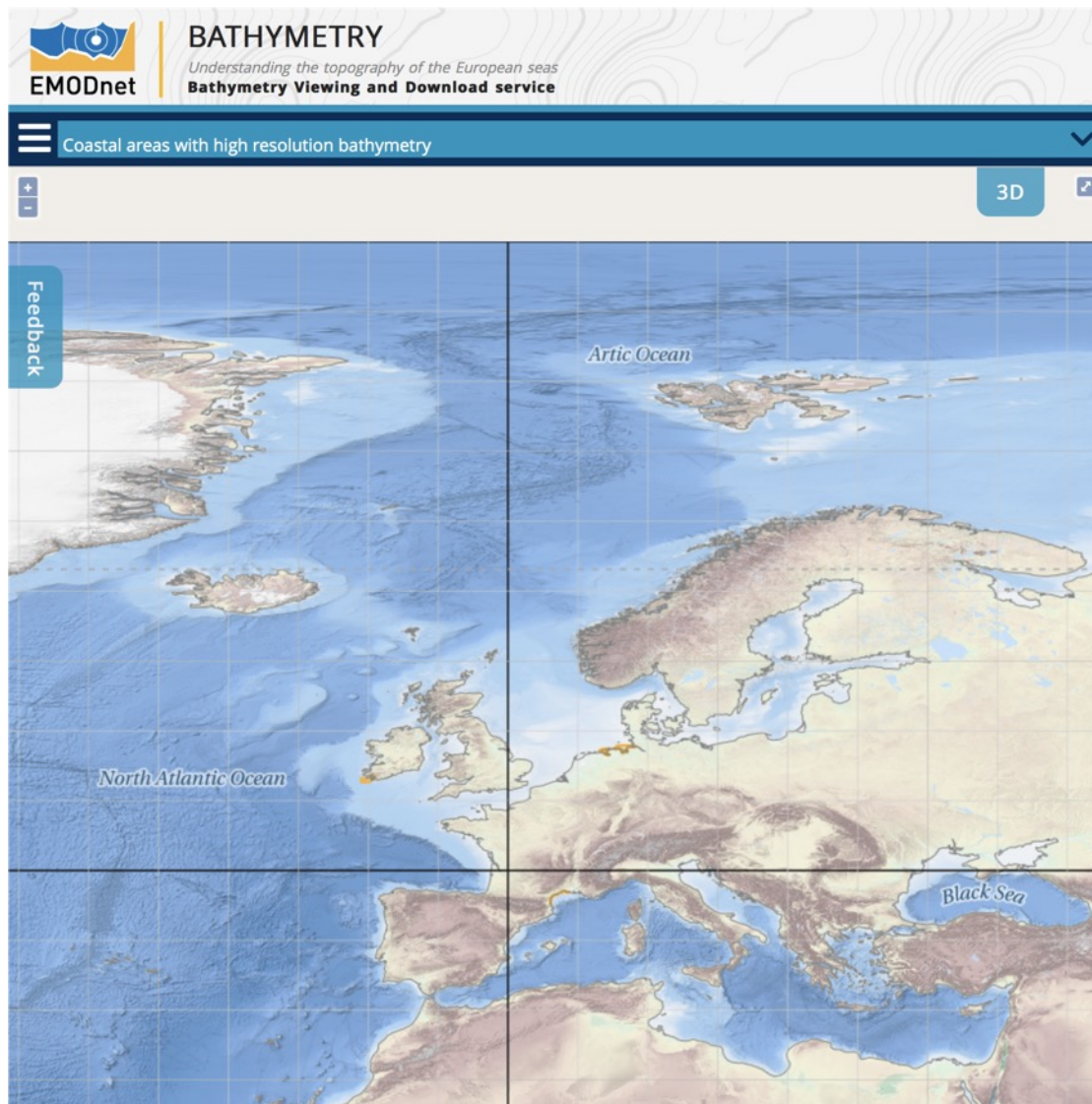
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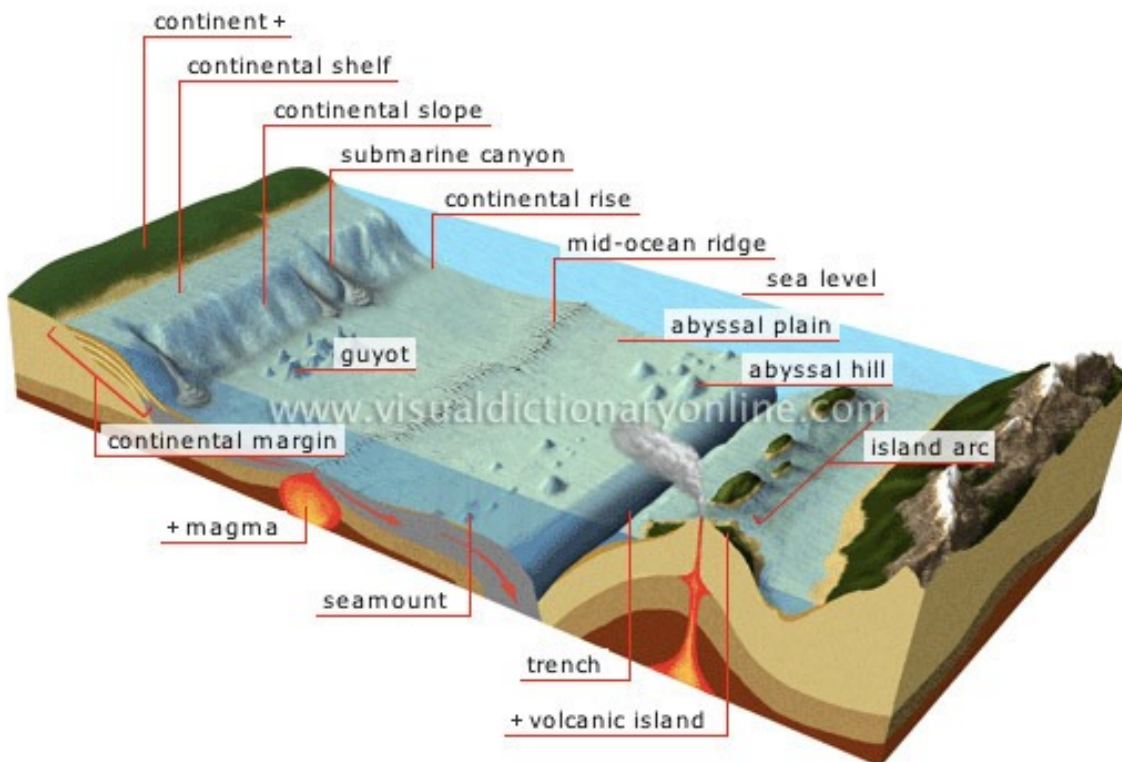


EMODNET

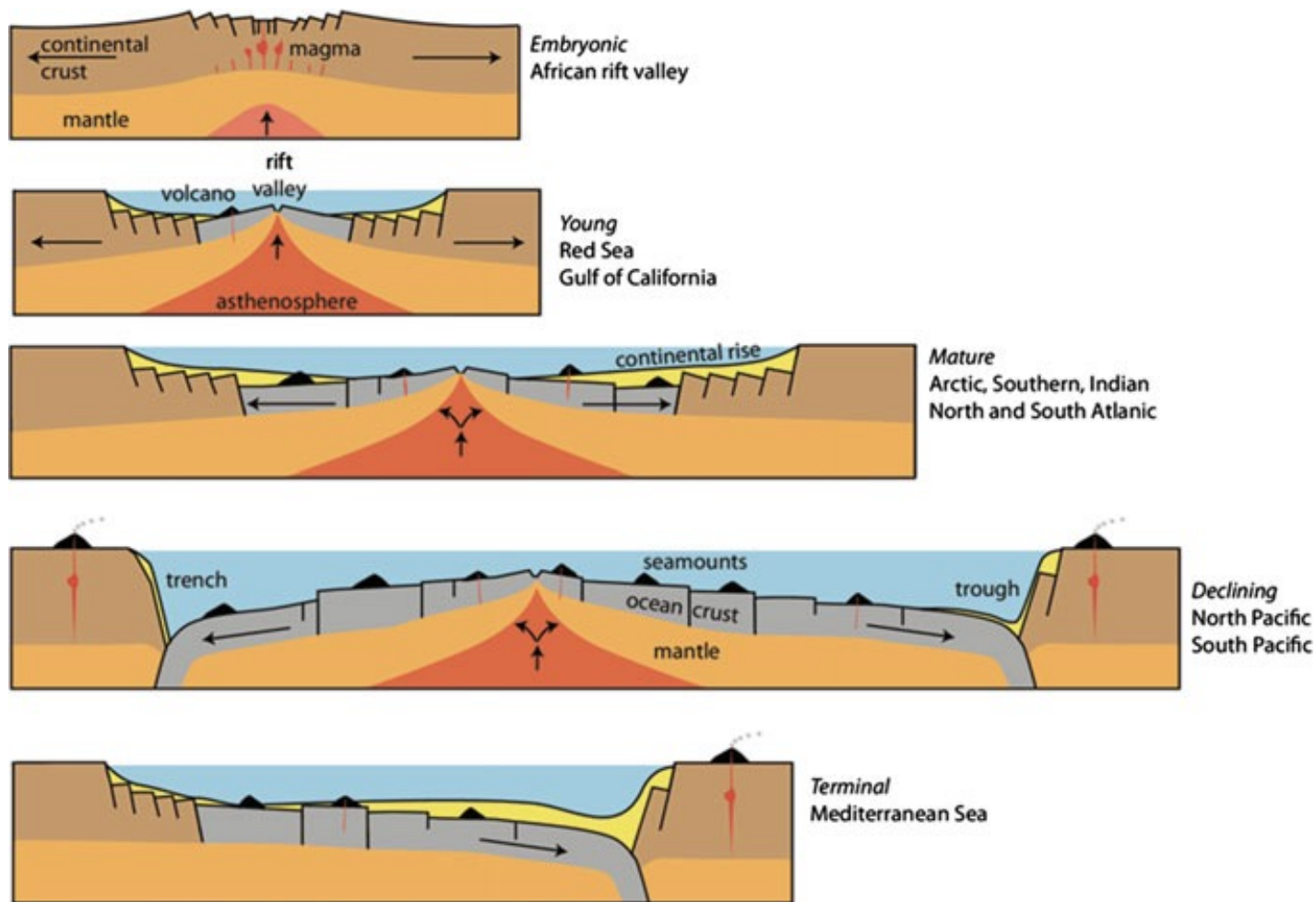
<http://www.emodnet.eu>



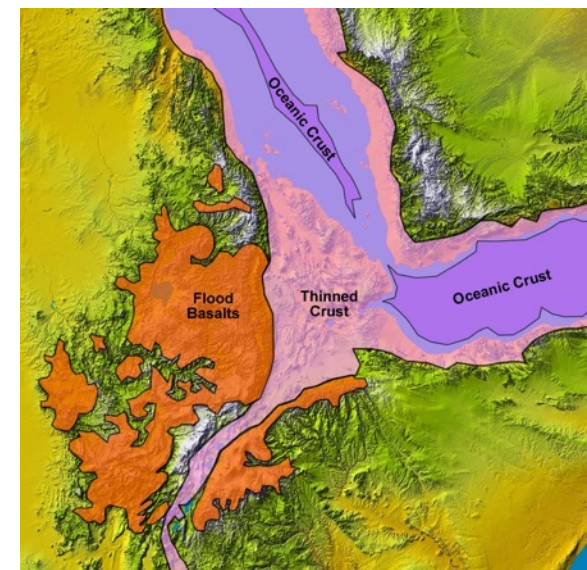
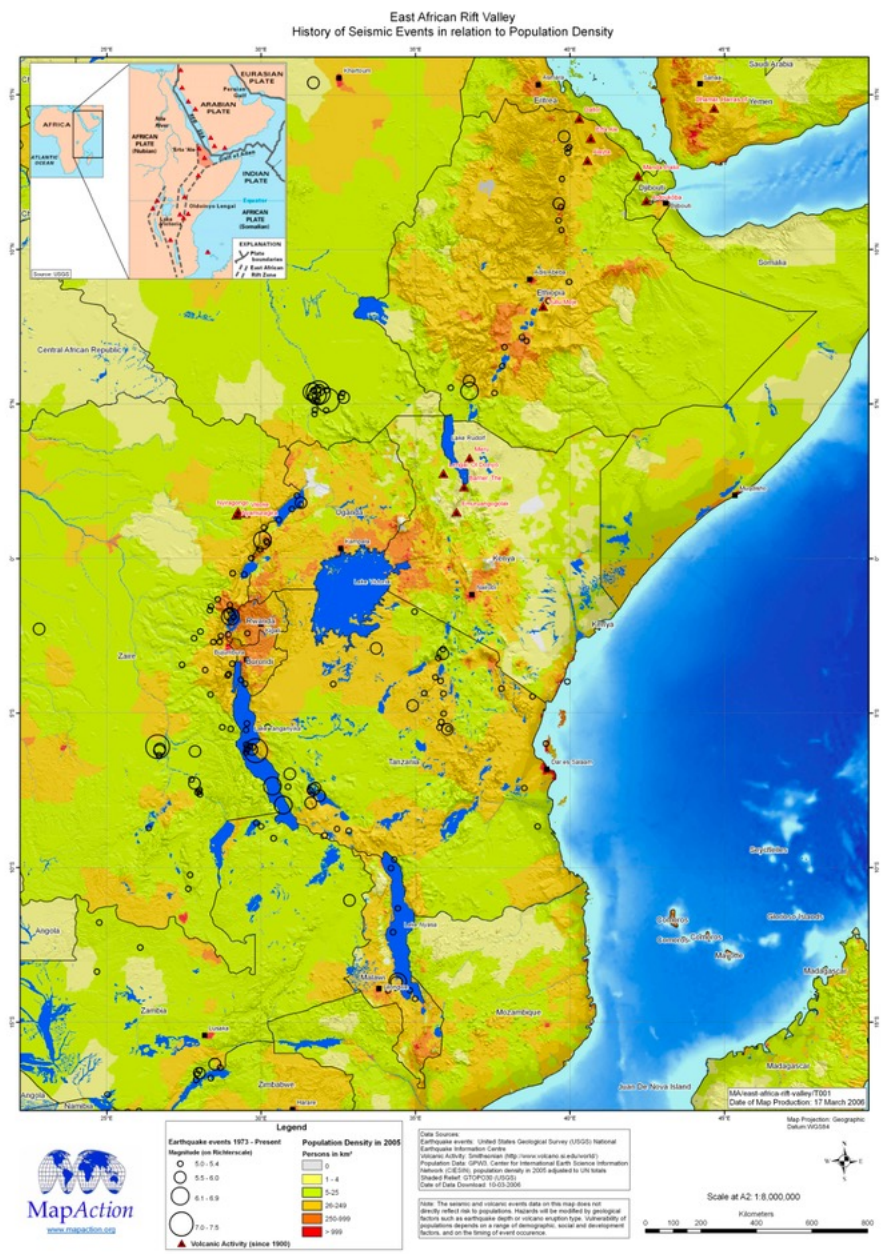
SEA FLOOR GEO-MORPHOLOGY

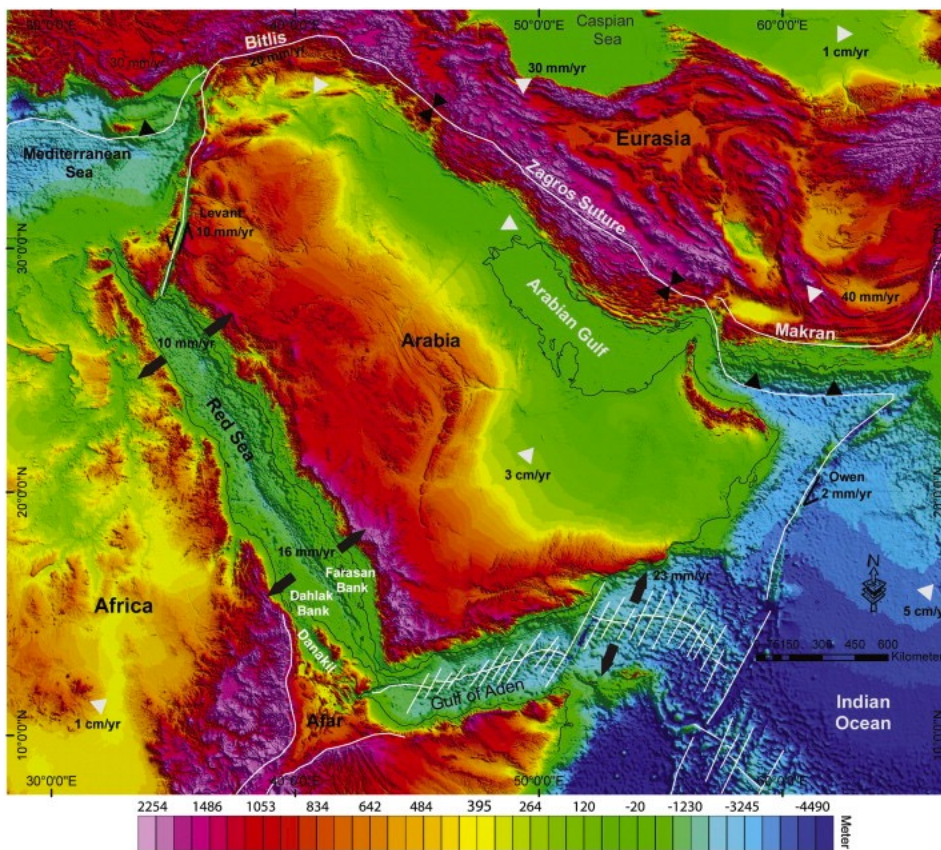


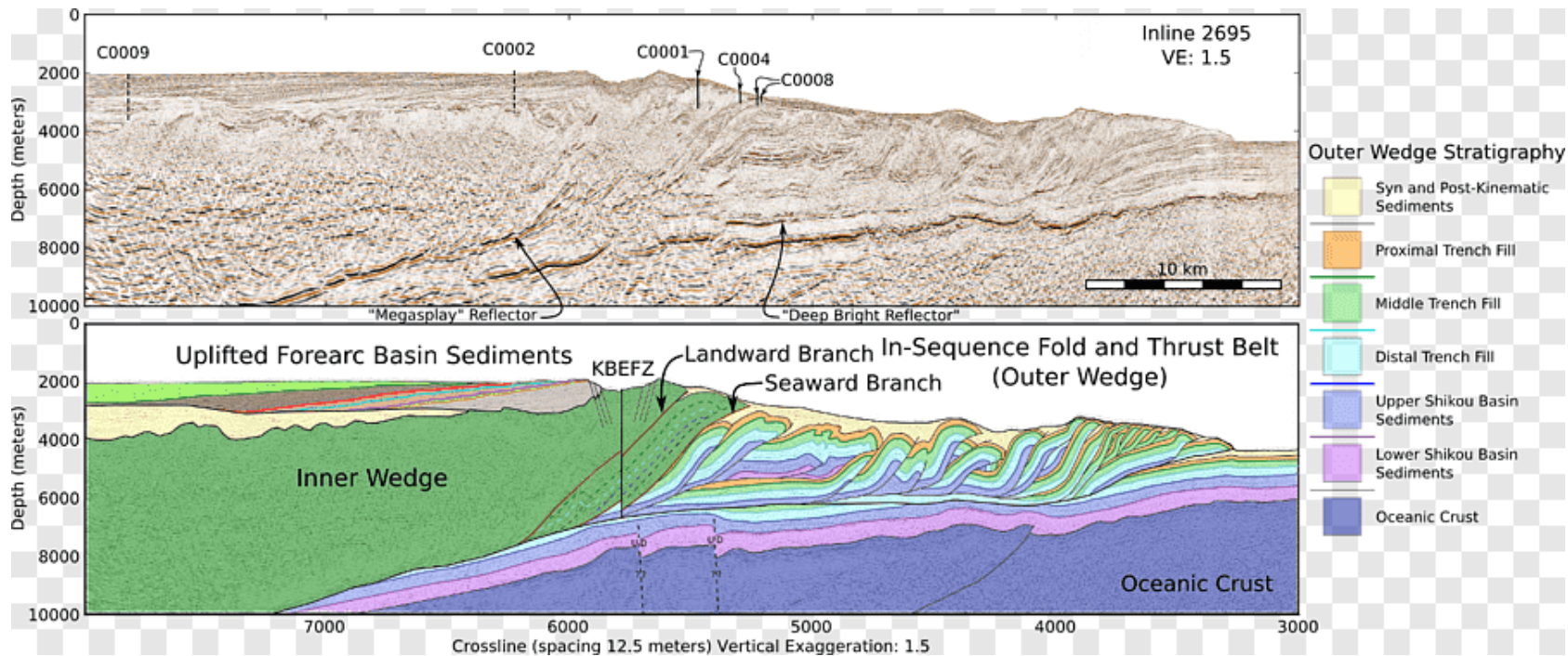
Wilson Cycle (Wilson 1966) of ocean basin evolution Reflected in geomorphology



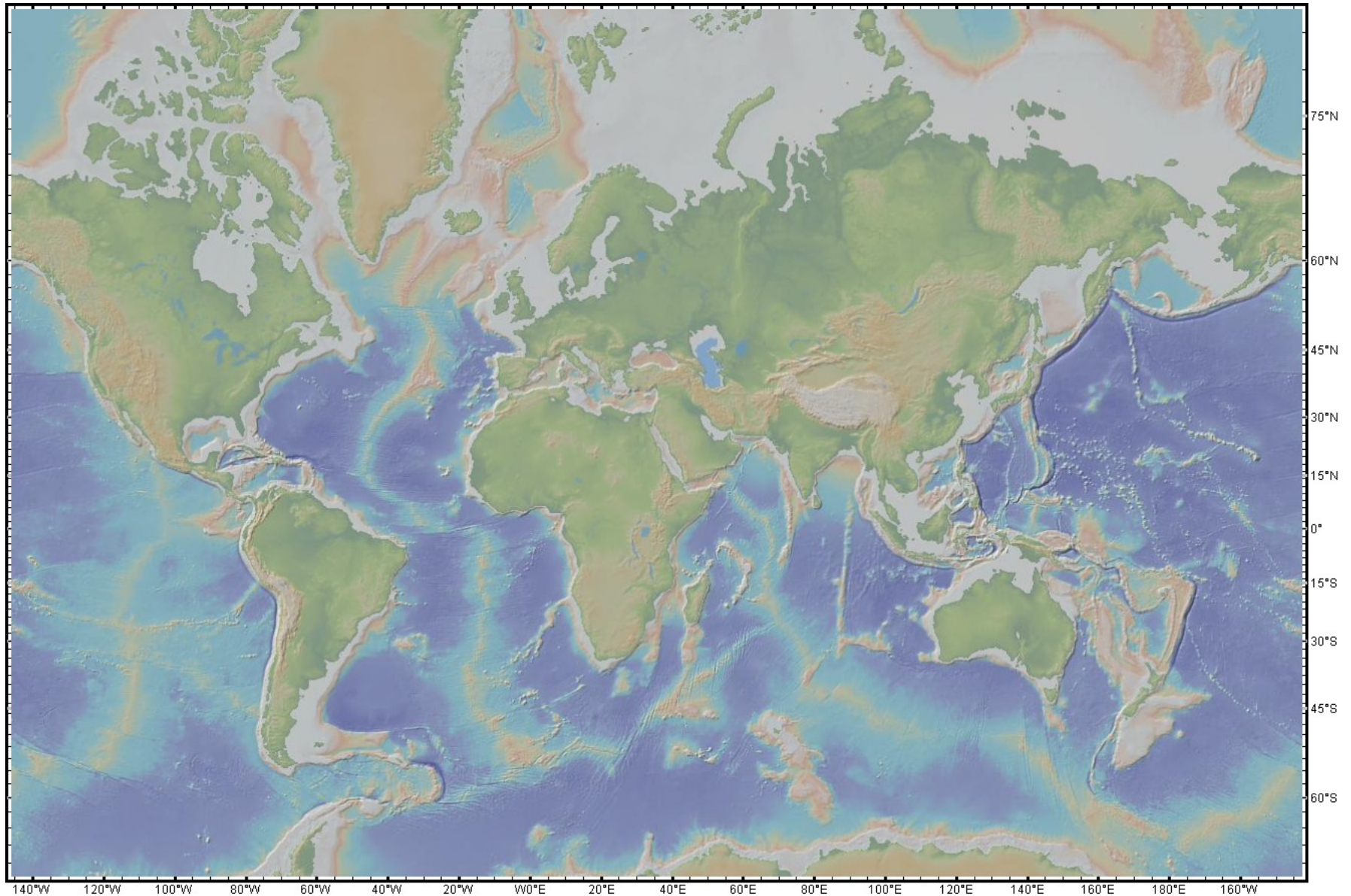
Harris and Macmillan-Lawler. In A. Micallef, Krastel, S., Savini, Al., 2018.
Submarine Geomorphology, Springer



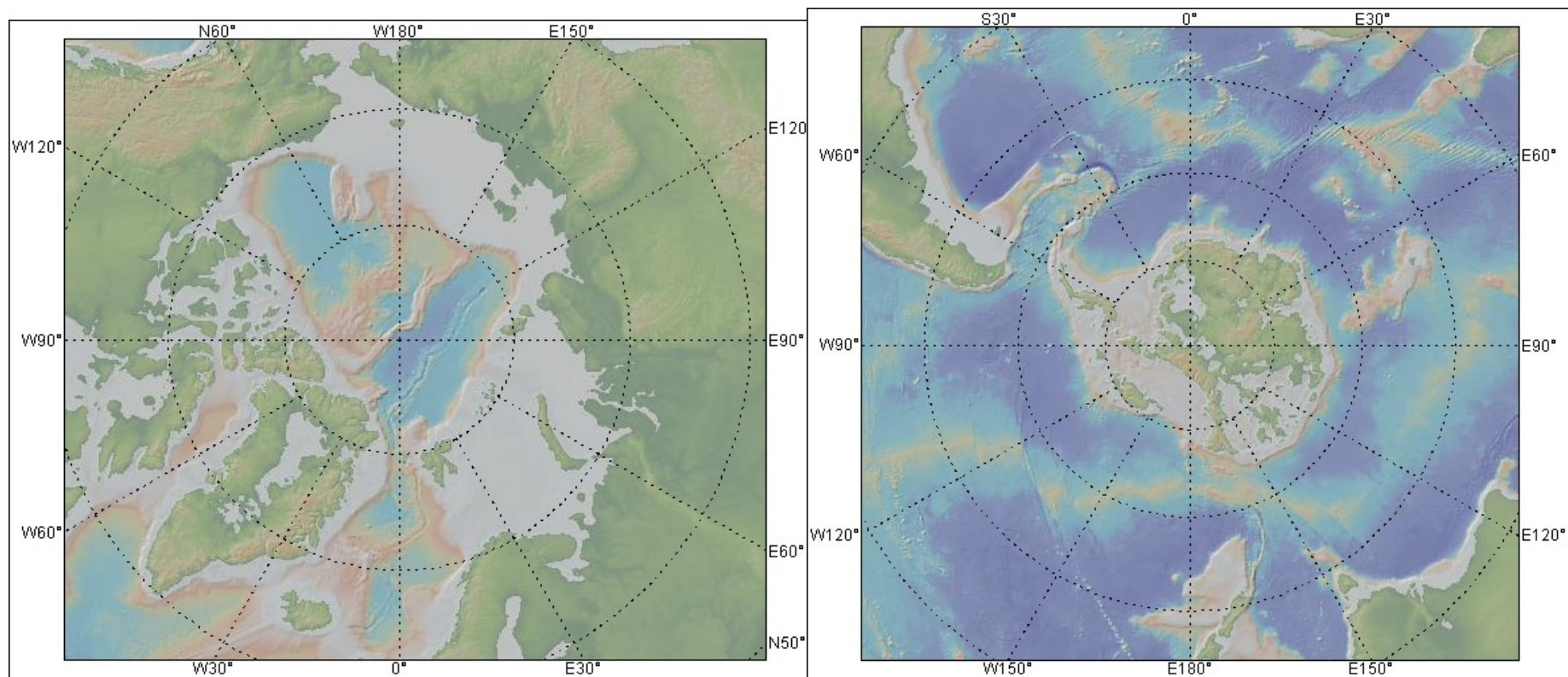




SEA FLOOR MORPHOLOGY



POLAR SEAS AND OCEANS



P.T. Harris et al. / Marine Geology 352 (2014) 4–24

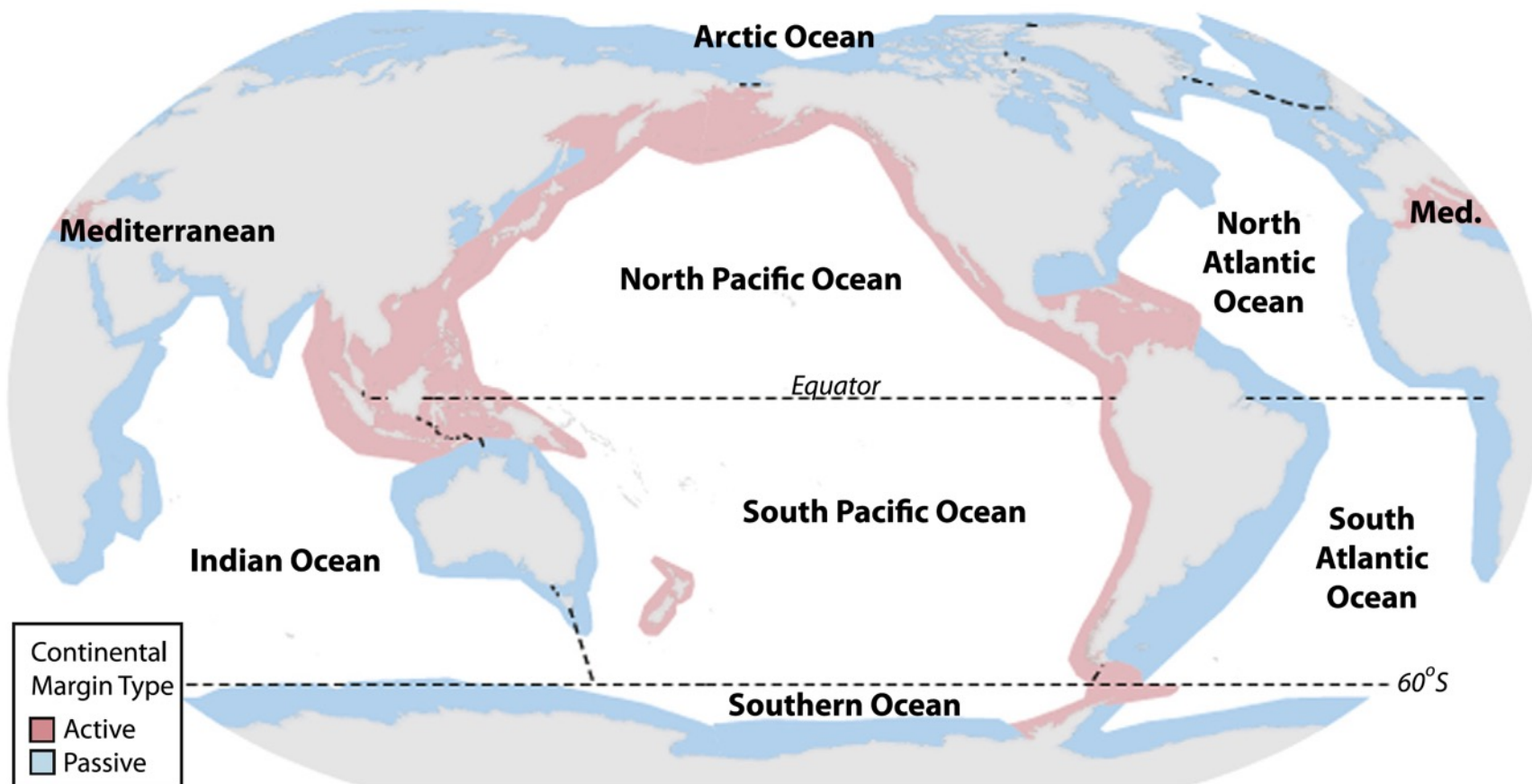
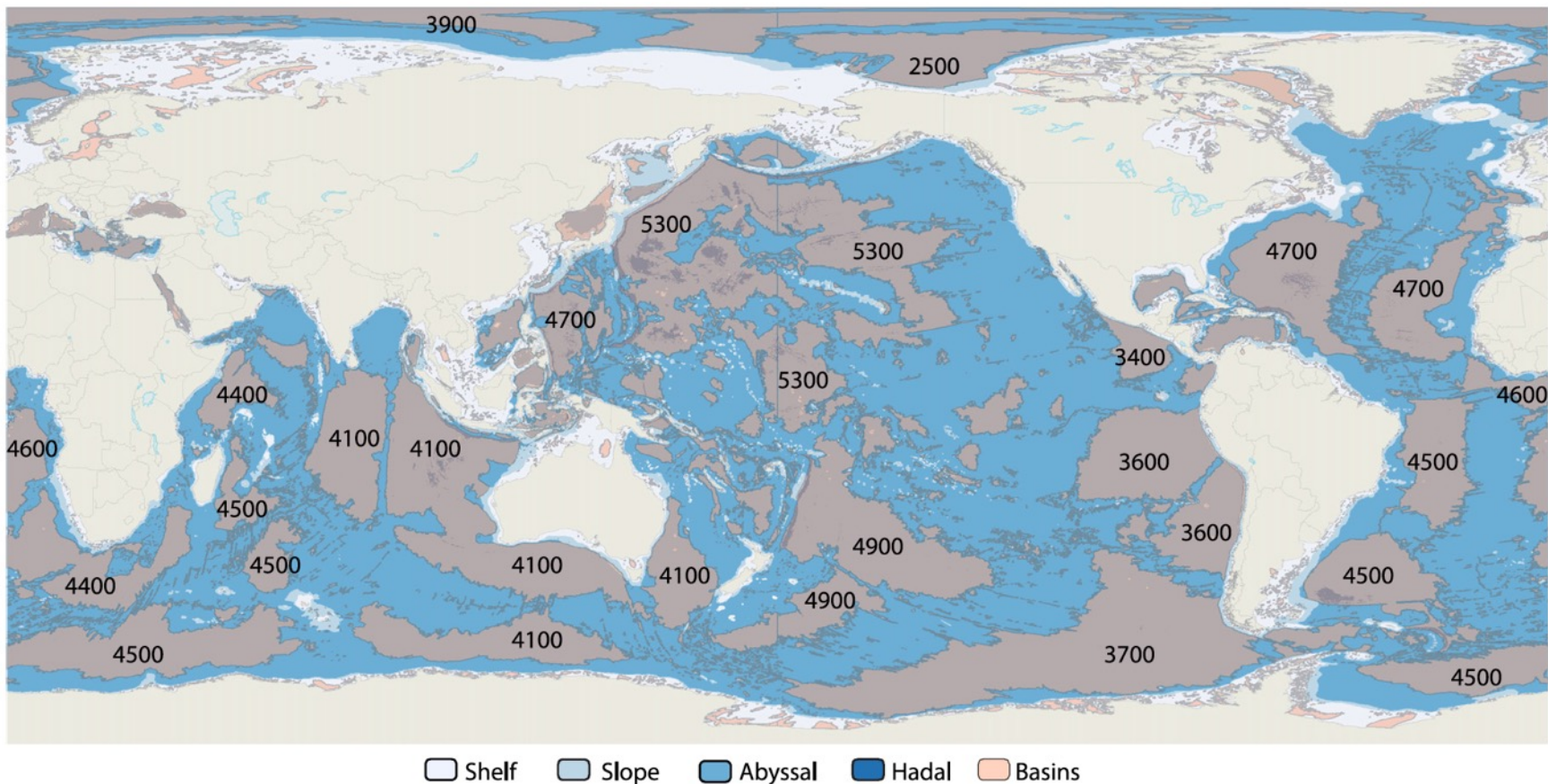


Fig. 2. Map showing the locations of active and passive continental margins and the eight ocean regions described in the text.

<http://dx.doi.org/10.1016/j.margeo.2014.01.011>



P.T. Harris et al. / Marine Geology 352 (2014) 4–24

Fig. 3. Basins mapped in this study. 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.

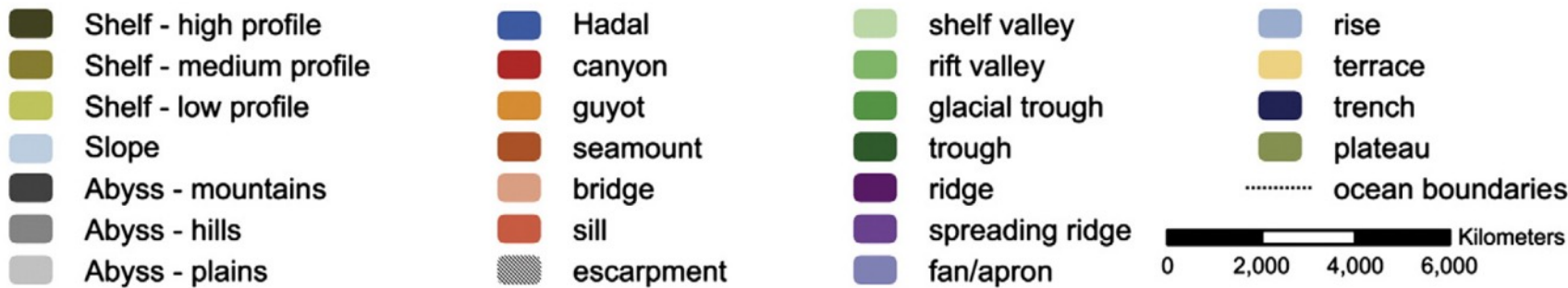
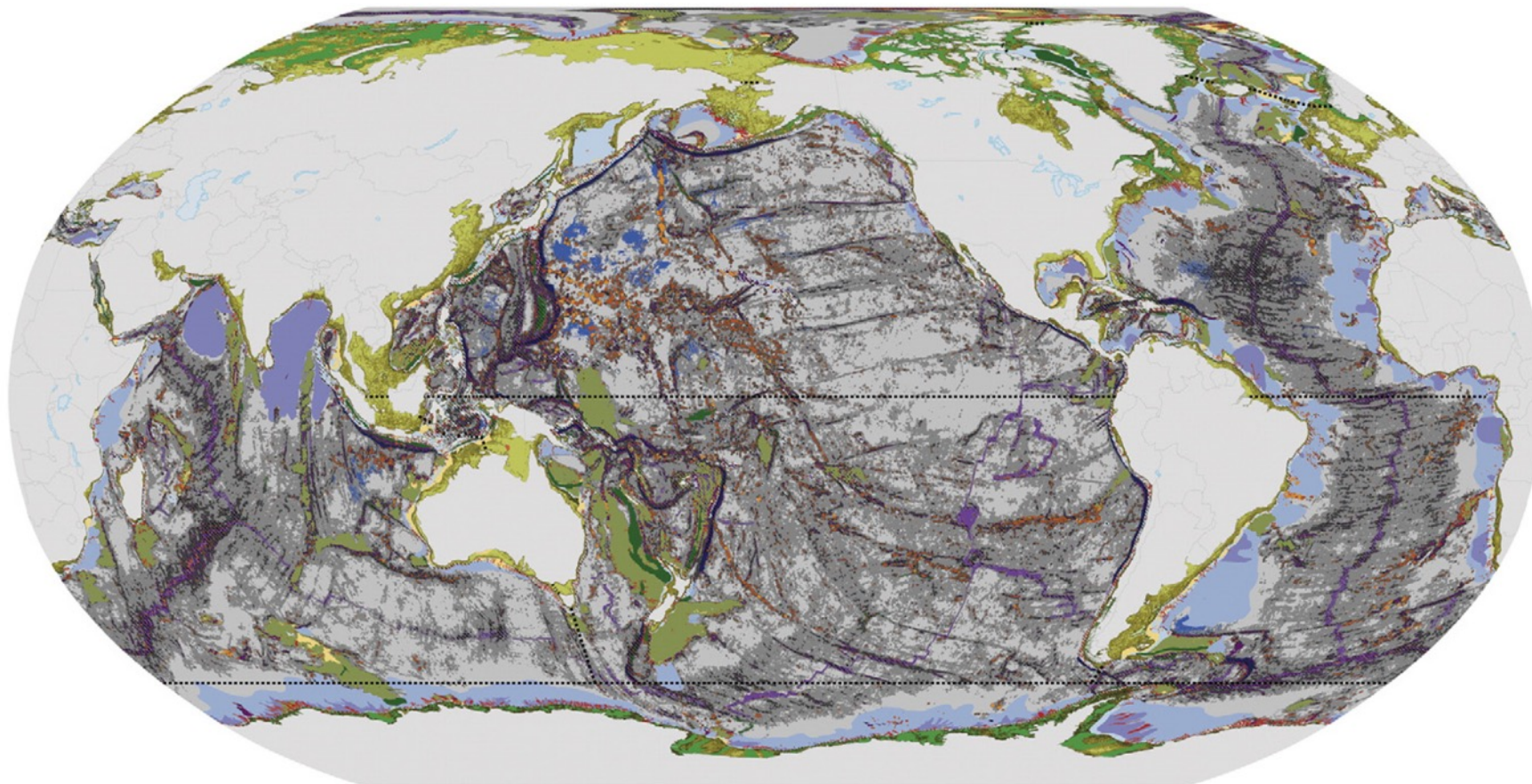
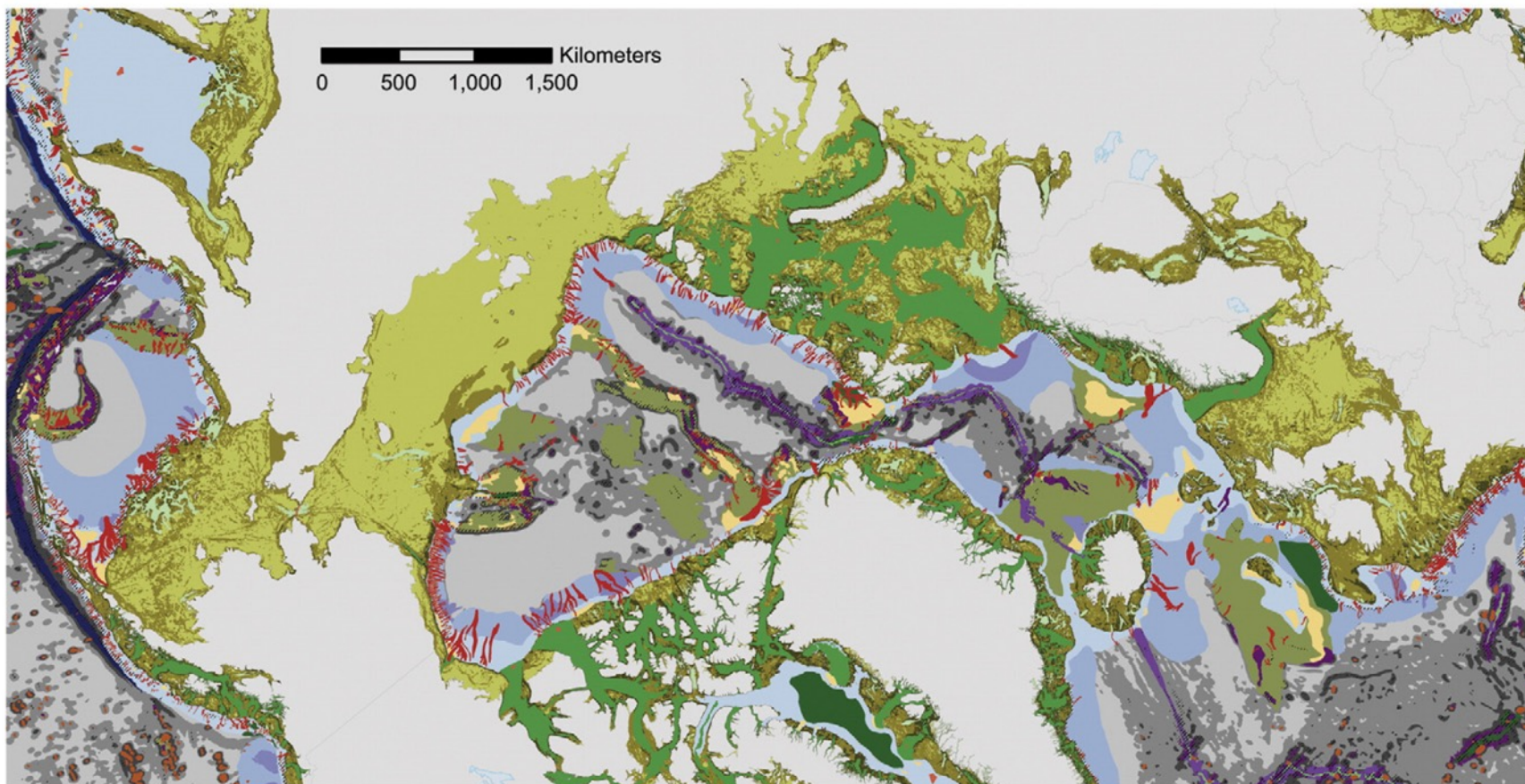
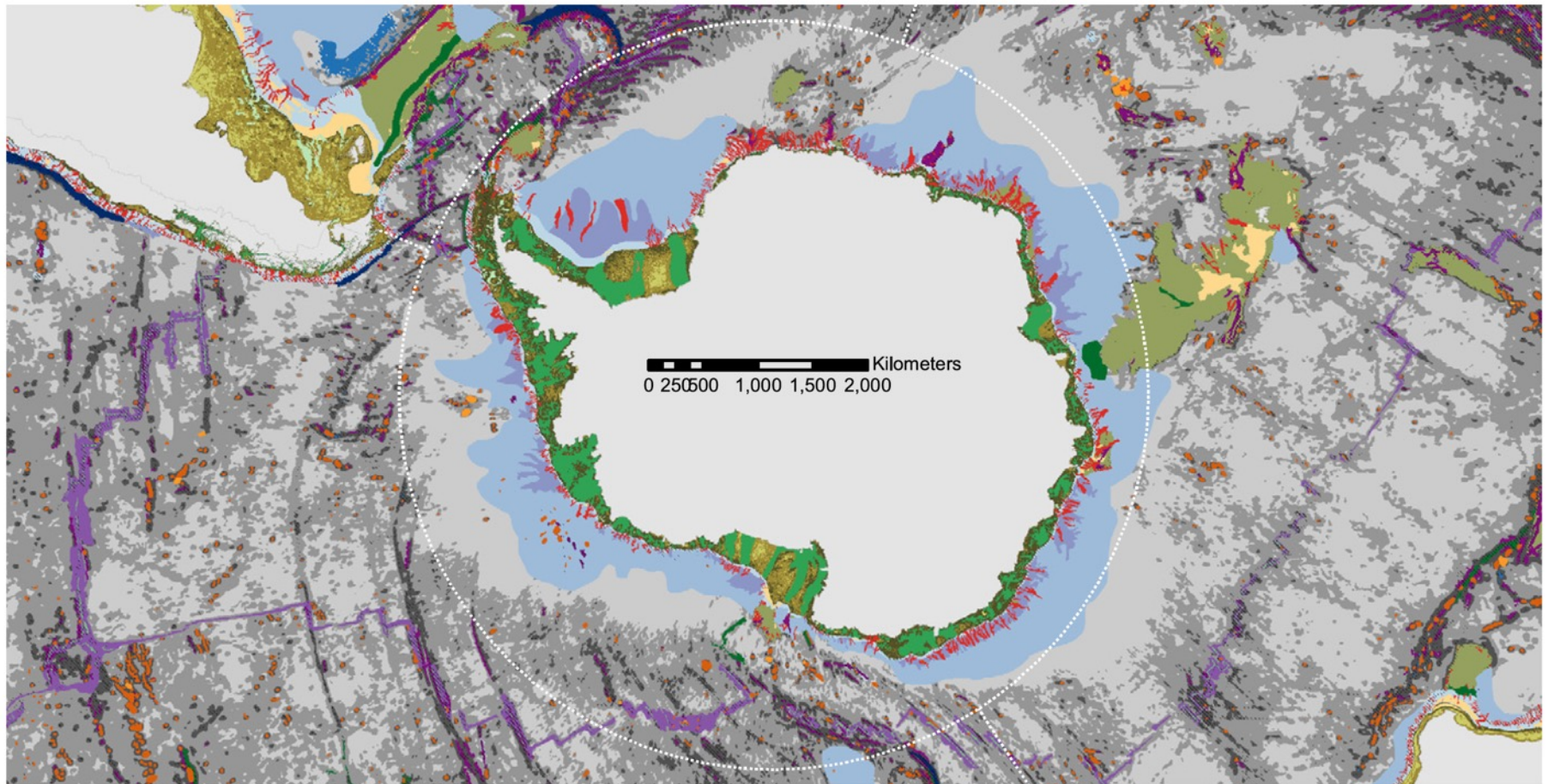


Fig. 4. Geomorphic features map of the world's oceans. Dotted black lines mark boundaries between major ocean regions. Basins are not shown.



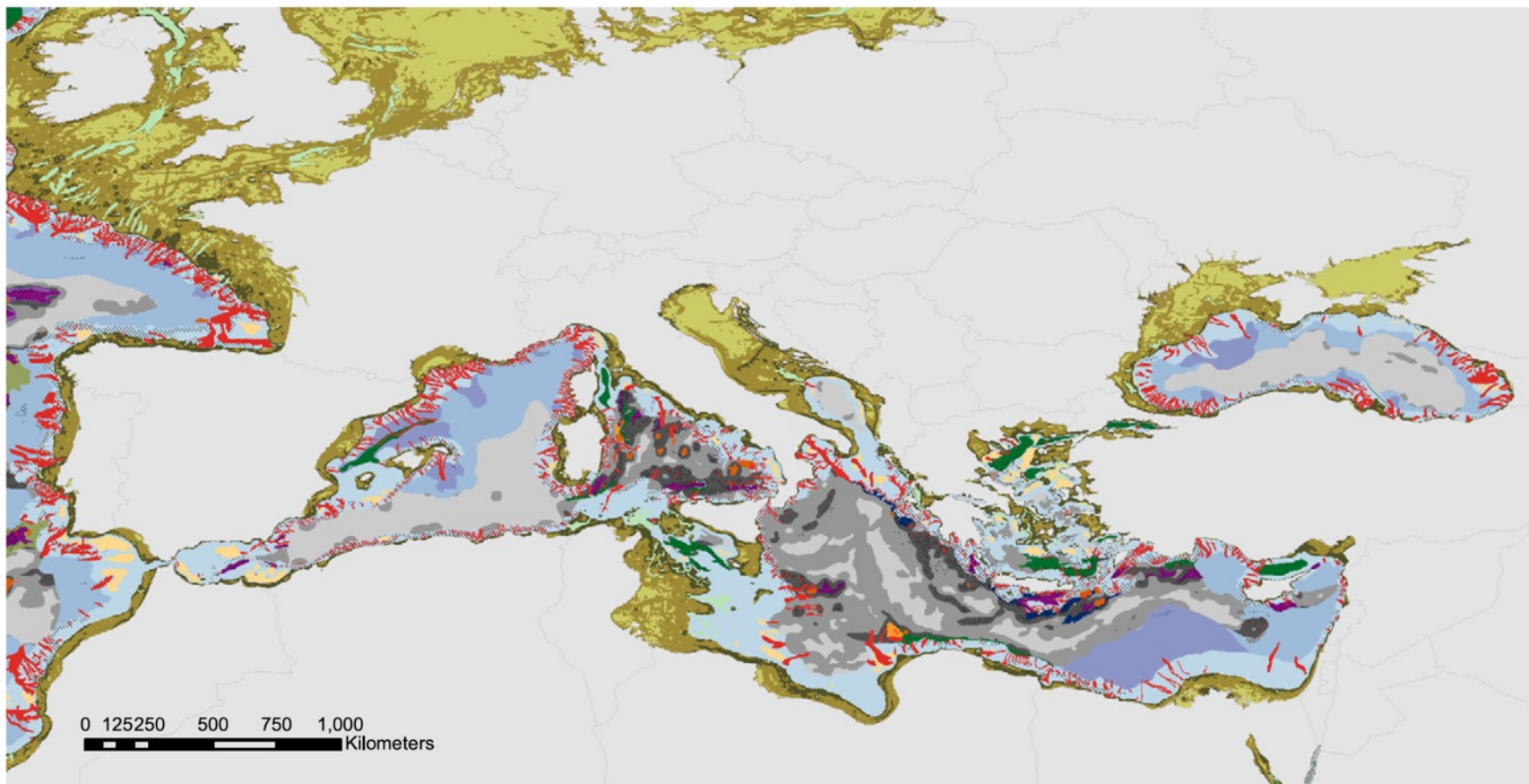
- | | | | |
|------------------------|------------|-----------------|---------|
| Shelf - high profile | Hadal | shelf valley | rise |
| Shelf - medium profile | canyon | rift valley | terrace |
| Shelf - low profile | guyot | glacial trough | trench |
| Slope | seamount | trough | plateau |
| Abyss - mountains | bridge | ridge | |
| Abyss - hills | sill | spreading ridge | |
| Abyss - plains | escarpment | fan/apron | |

Fig. 5. Geomorphic features map of the Arctic Ocean. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.



- | | | | |
|--|--|---|---|
|  Shelf - high profile |  Hadal |  shelf valley |  rise |
|  Shelf - medium profile |  canyon |  rift valley |  terrace |
|  Shelf - low profile |  guyot |  glacial trough |  trench |
|  Slope |  seamount |  trough |  plateau |
|  Abyss - mountains |  bridge |  ridge | |
|  Abyss - hills |  sill |  spreading ridge | |
|  Abyss - plains |  escarpment |  fan/apron | |

Fig. 12. Geomorphic features map of the Southern Ocean. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.

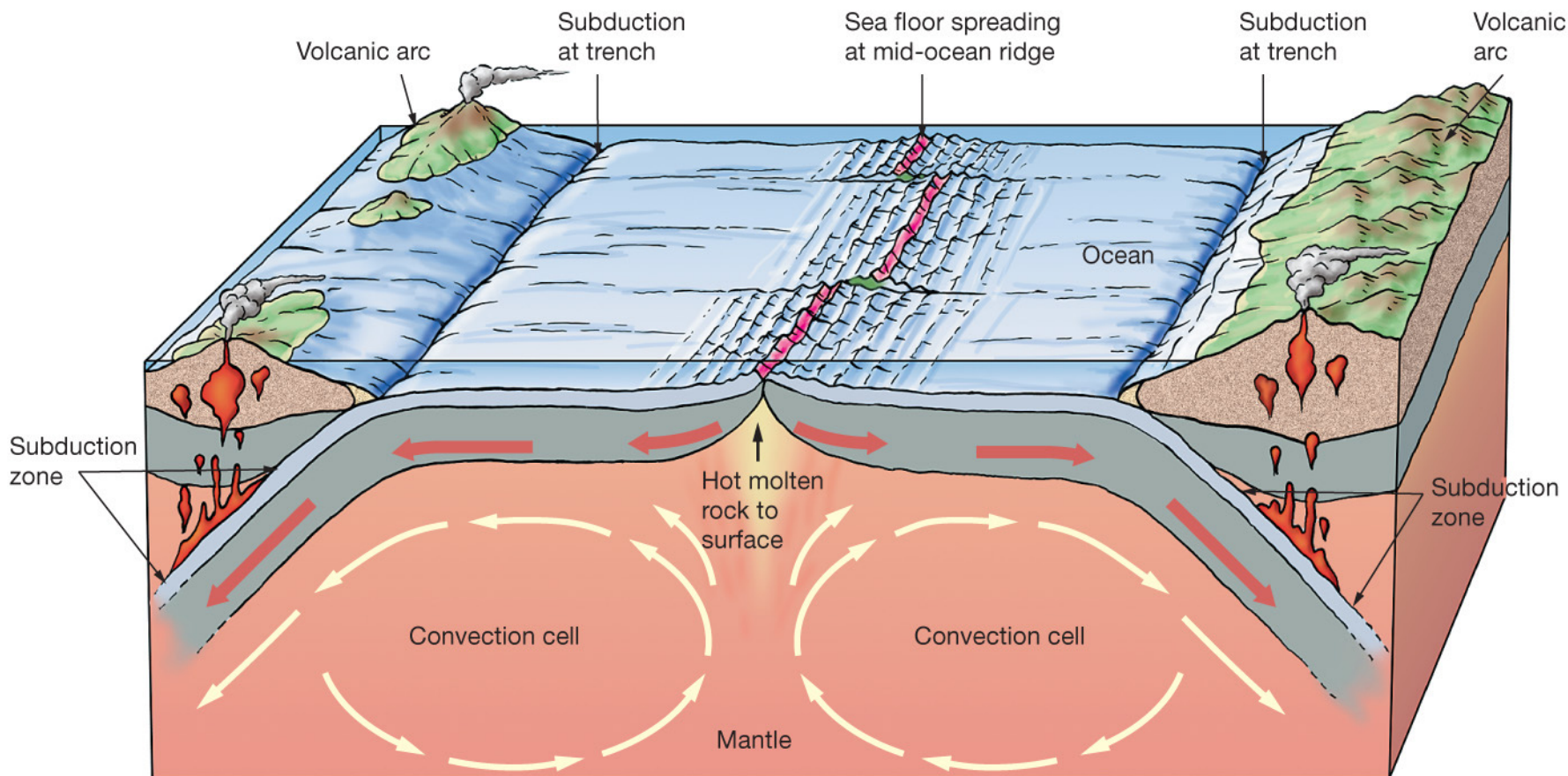


- | | | | |
|------------------------|------------|-----------------|---------|
| Shelf - high profile | Hadal | shelf valley | rise |
| Shelf - medium profile | canyon | rift valley | terrace |
| Shelf - low profile | guyot | glacial trough | trench |
| Slope | seamount | trough | plateau |
| Abyss - mountains | bridge | ridge | |
| Abyss - hills | sill | spreading ridge | |
| Abyss - plains | escarpment | fan/apron | |

Fig. 7. Geomorphic features map of the Mediterranean and Black Seas. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.

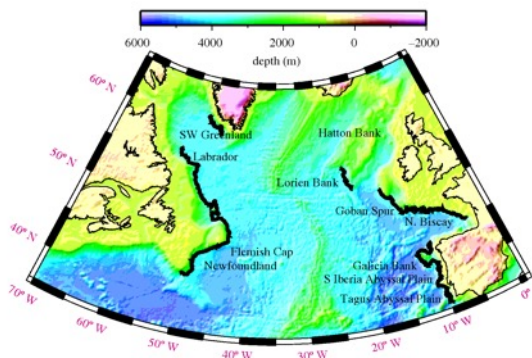
Plate Tectonic Processes

3. The geological structure of the oceans

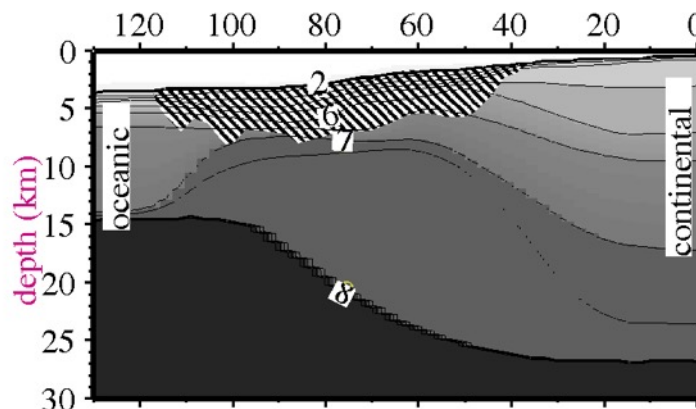


LITHOSPHERIC STRUCTURE INDICATORS

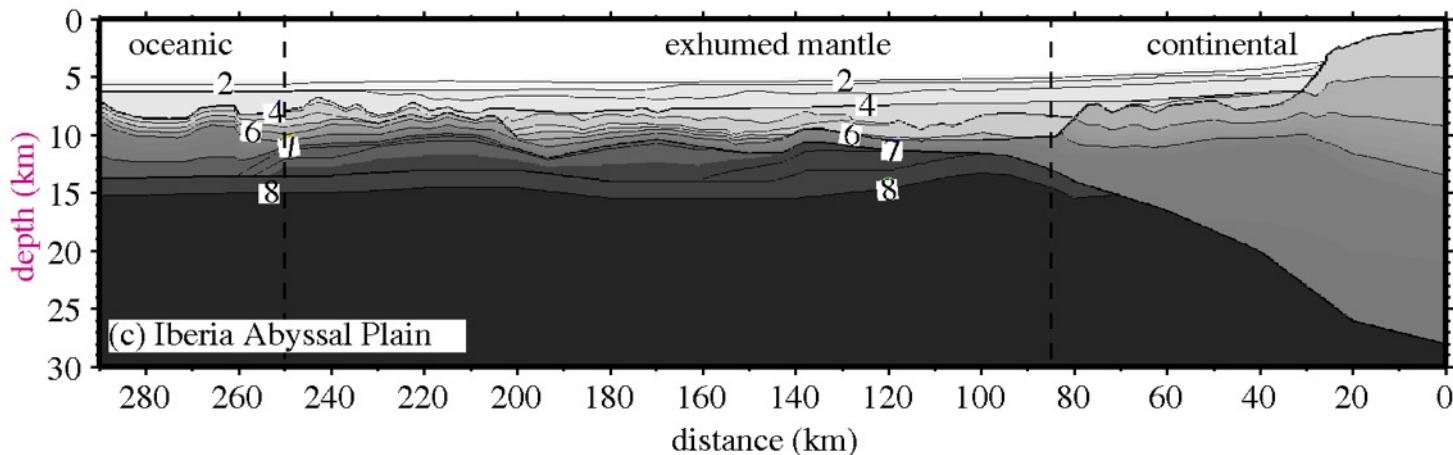
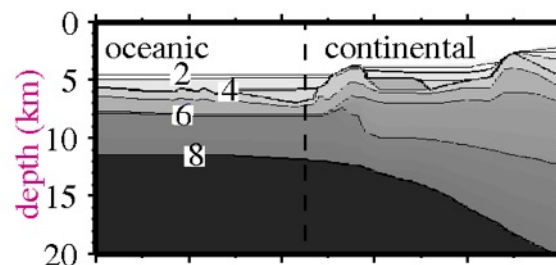
Seismic Velocity (V_p , V_s)



(a) Hatton Bank



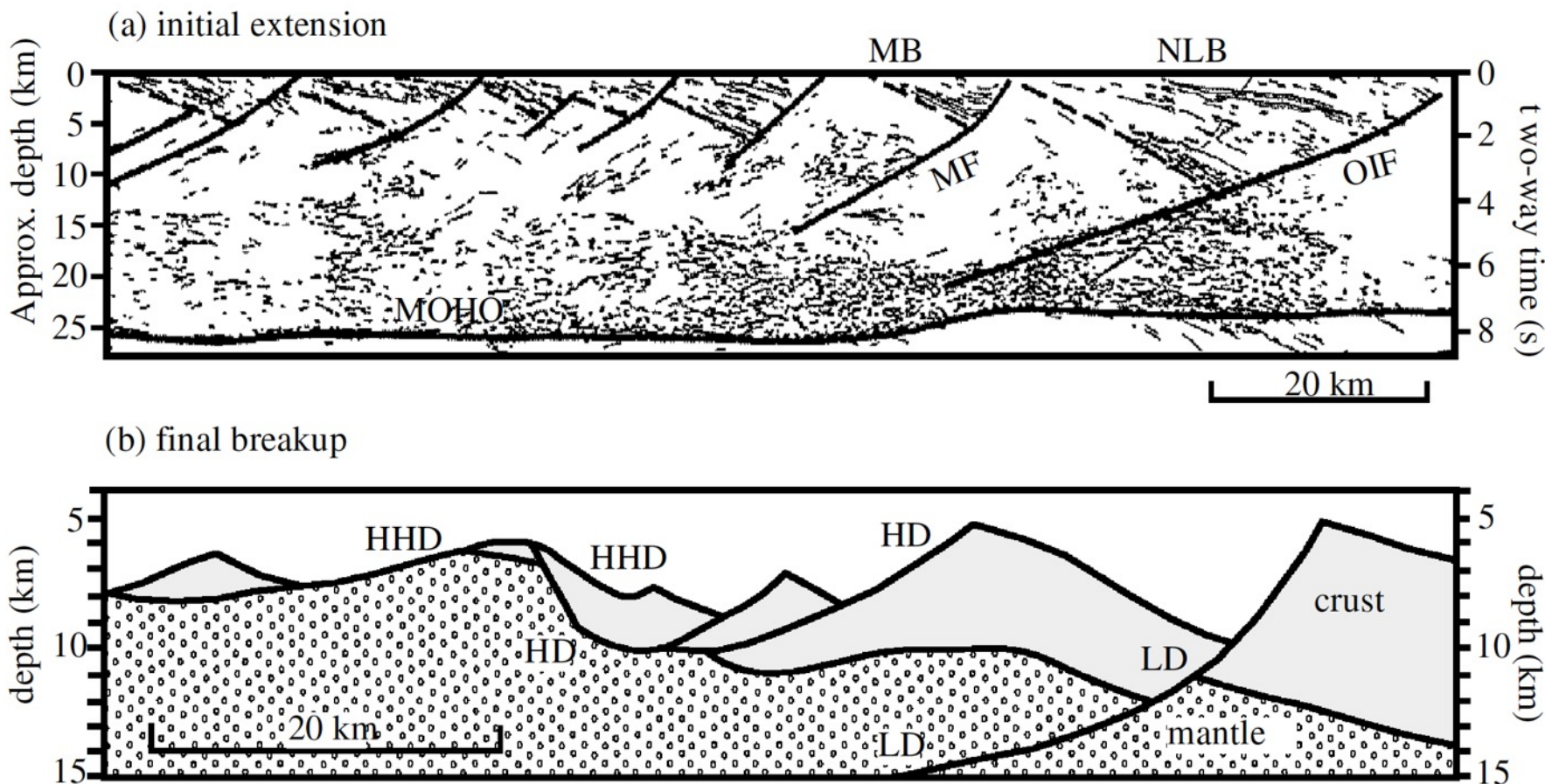
(b) Goban Spur



Minshull, 2002. The break-up of continents and the formation of new ocean basins. *Phil. Trans. R. Soc. Lond. A* 2002 **360**, 2839-2852

LITHOSPHERIC STRUCTURE INDICATORS

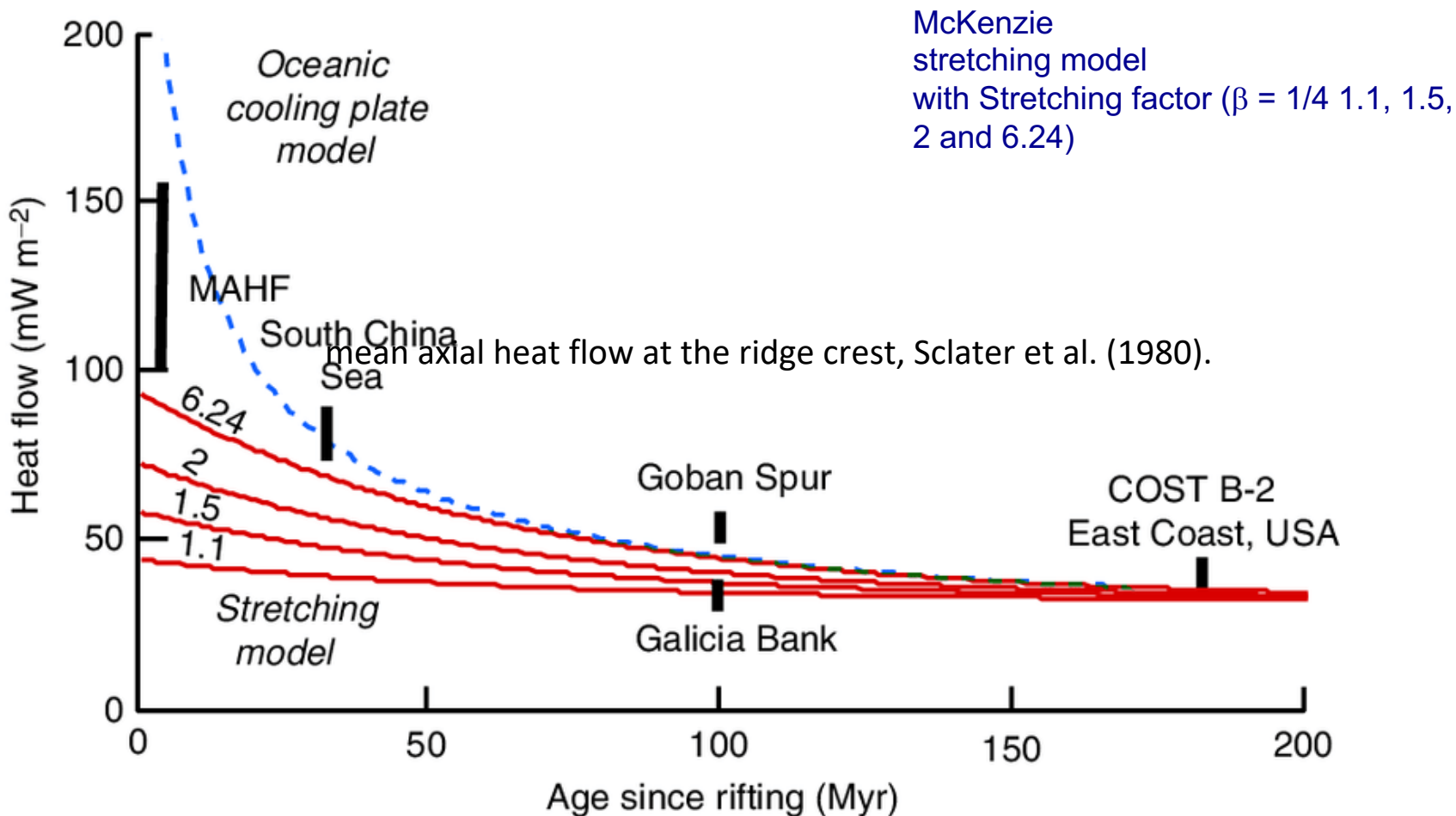
Structure from seismic reflections/refraction



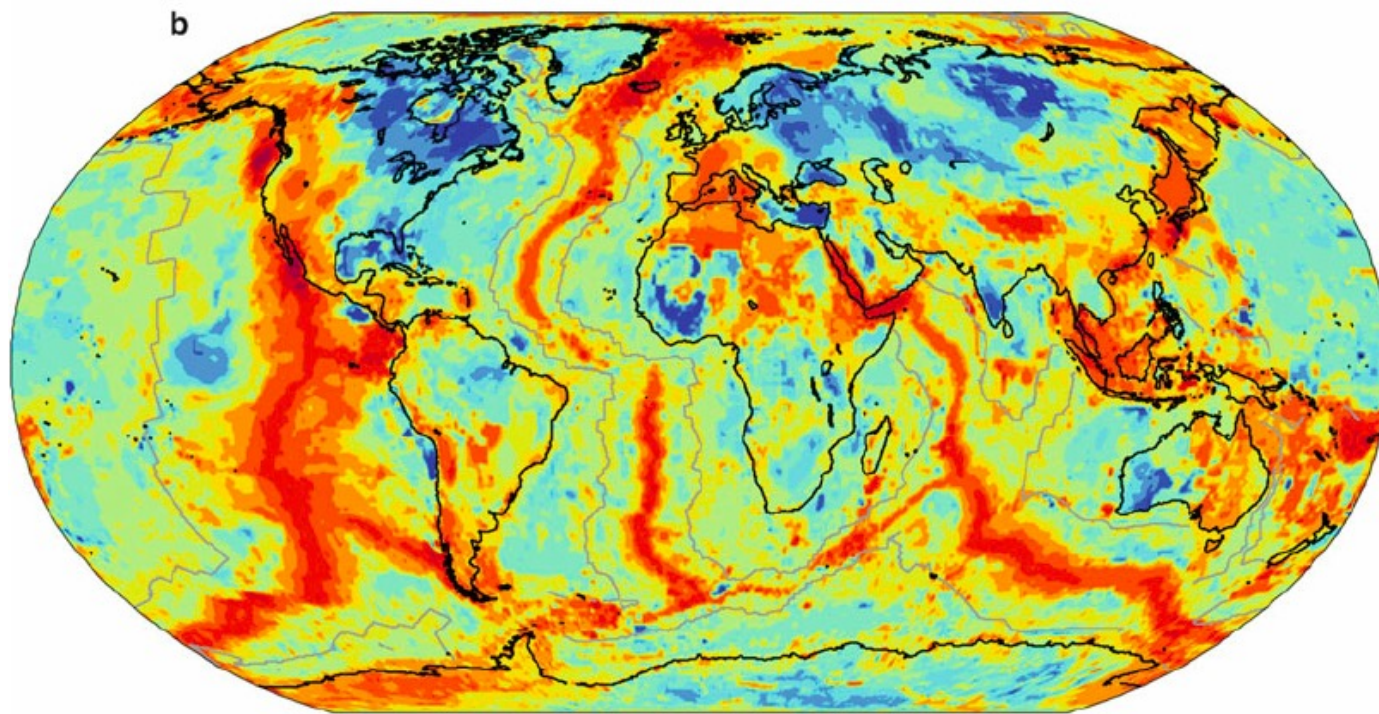
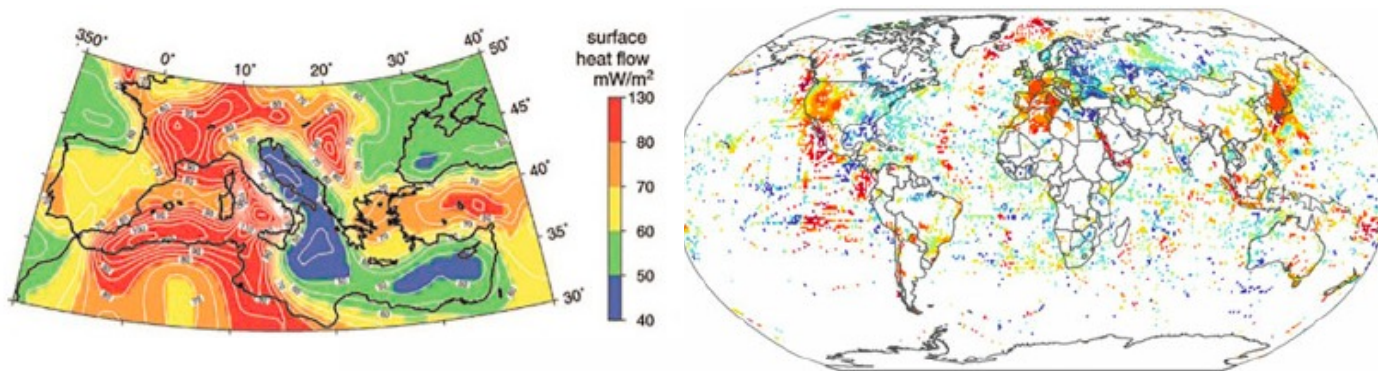
Minshull, 2002. The break-up of continents and the formation of new ocean basins. *Phil. Trans. R. Soc. Lond. A* 2002 **360**, 2839-2852

LITHOSPHERIC STRUCTURE INDICATORS

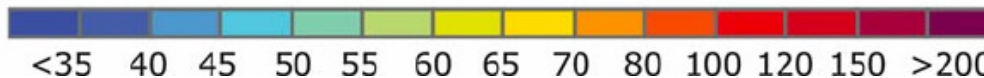
Heat Flow



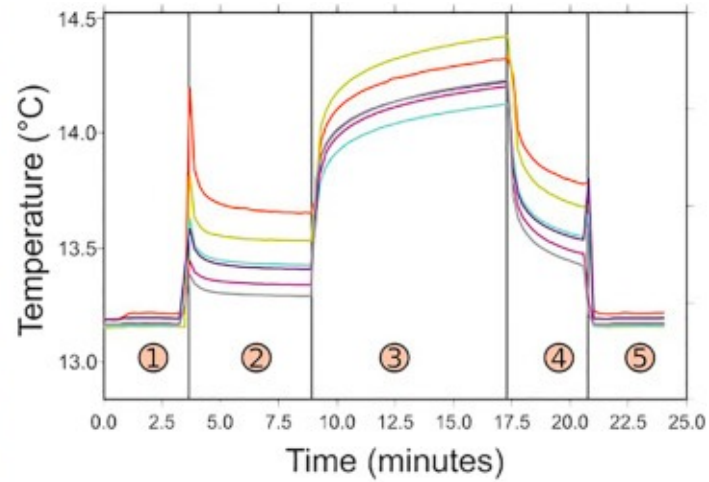
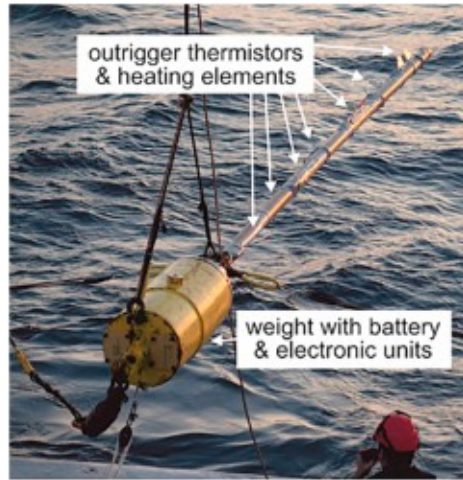
Watts, 2012. Models for the evolution of passive margins. In Phanerozoic Rift Systems and Sedimentary Basins DOI:10.1016/B978-0-444-56356-9.00002-X



Mean heat flow (mW/m^2)



Goutorbe et al. (2011)
Global heat flow trends resolved from
multiple geological and geophysical
proxies. *Geophysical Journal
International*, 187, 1405–1419.



Poort et al., 2020. Heat flow in the Western Mediterranean: Thermal anomalies on the margins, the seafloor and the transfer zones. *Marine Geology*, Volume 419, 106064

LITHOSPHERIC STRUCTURE INDICATORS

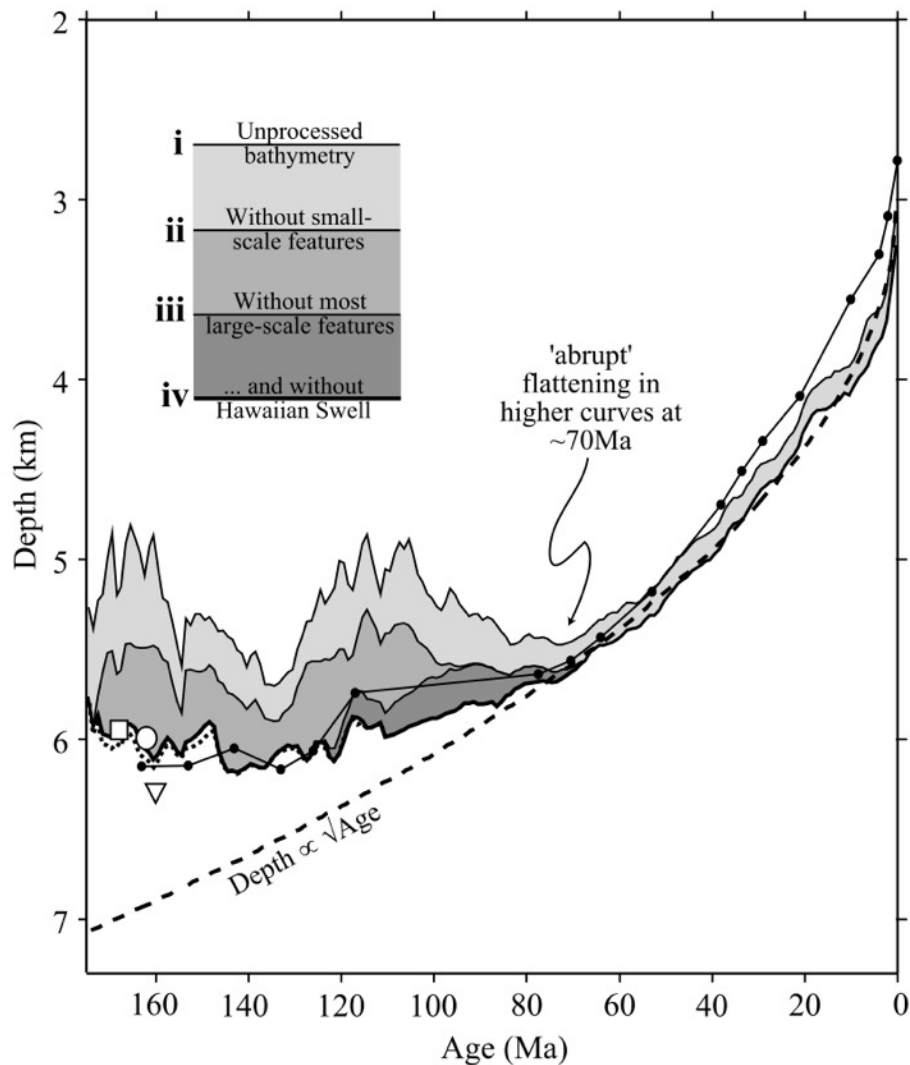
Age versus depth

Parsons and Sclater, 1977

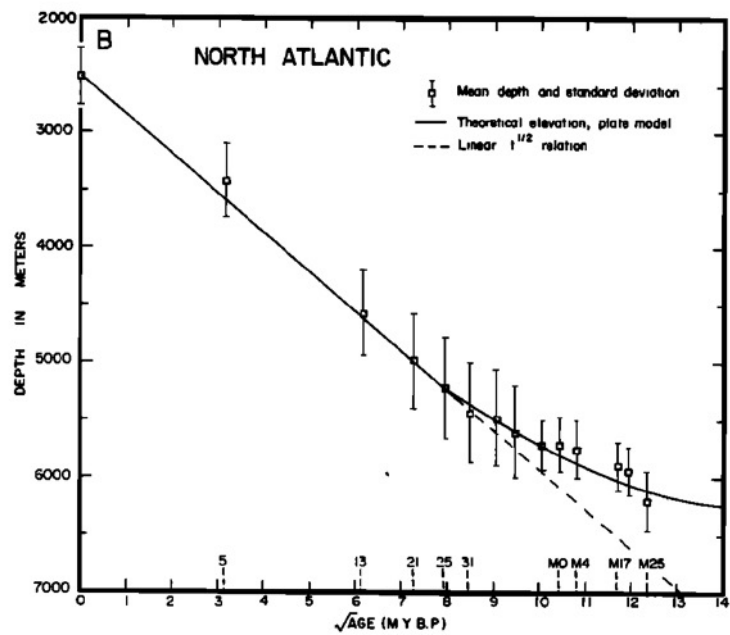
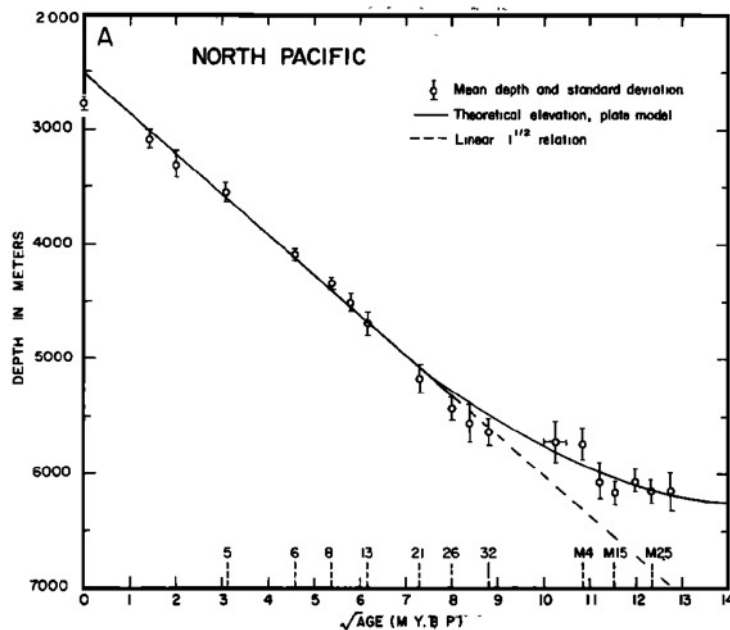
Stein and Stein, 1992

Doin and Fleitout, 1996

Hillier and Watts, 2005



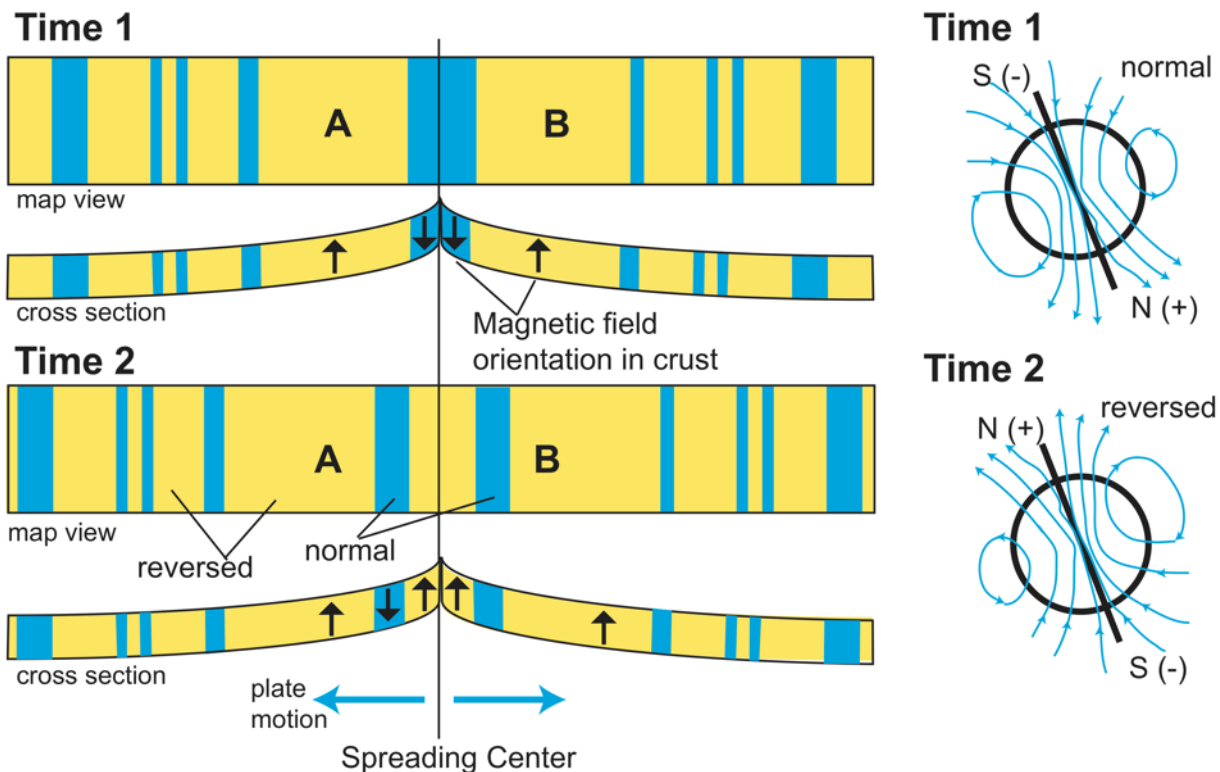
Hillier and Watts, 2005



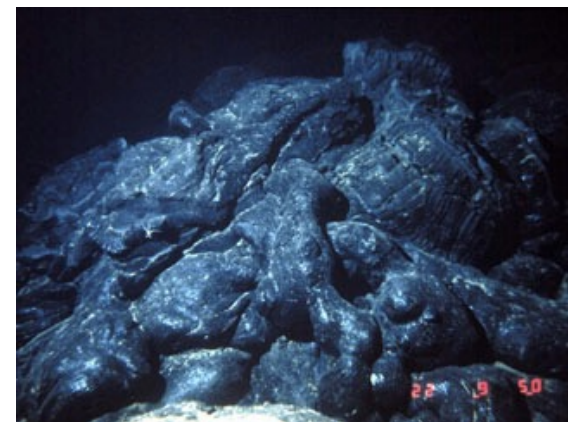
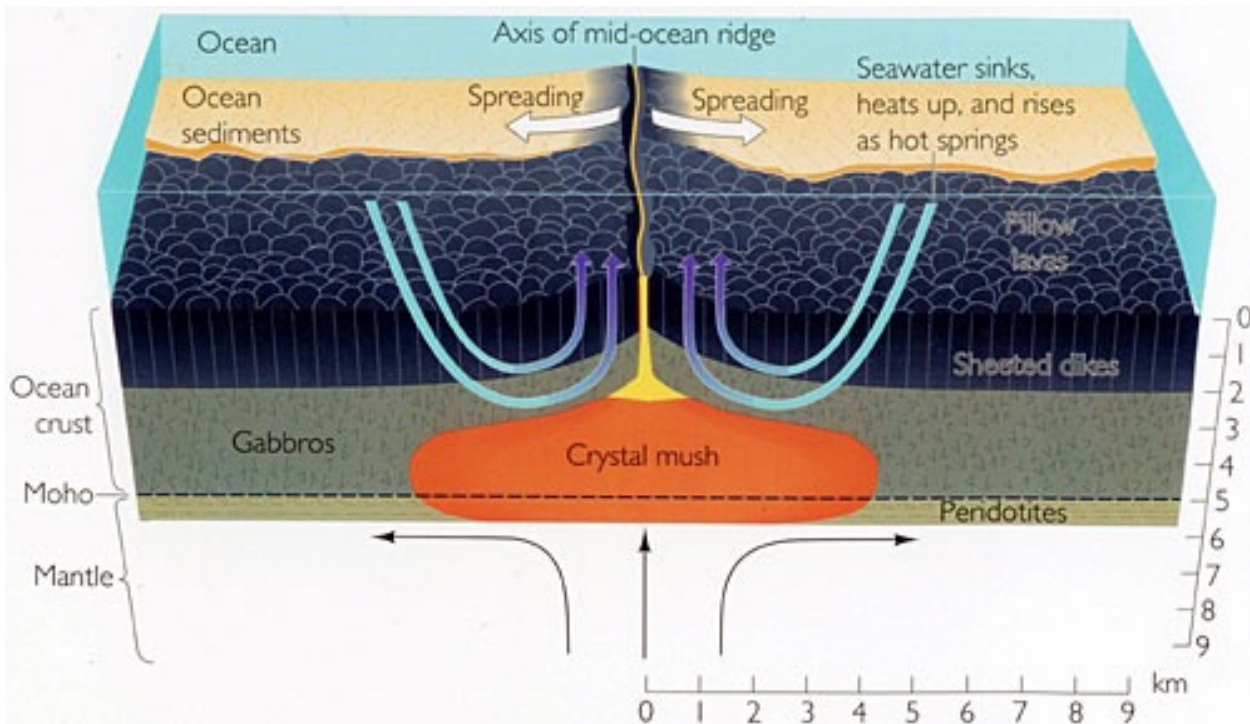
LITHOSPHERIC STRUCTURE INDICATORS

Magnetic anomalies

Certain minerals in the magma (e.g., magnetite) are sensitive to the Earth's magnetic field. As the magma cools, magnetic domains in these minerals will align with the Earth's magnetic field locking in the orientation (dip relative to horizontal) and polarity (field lines pointing out or field lines pointing in) of the magnetic field at that location.



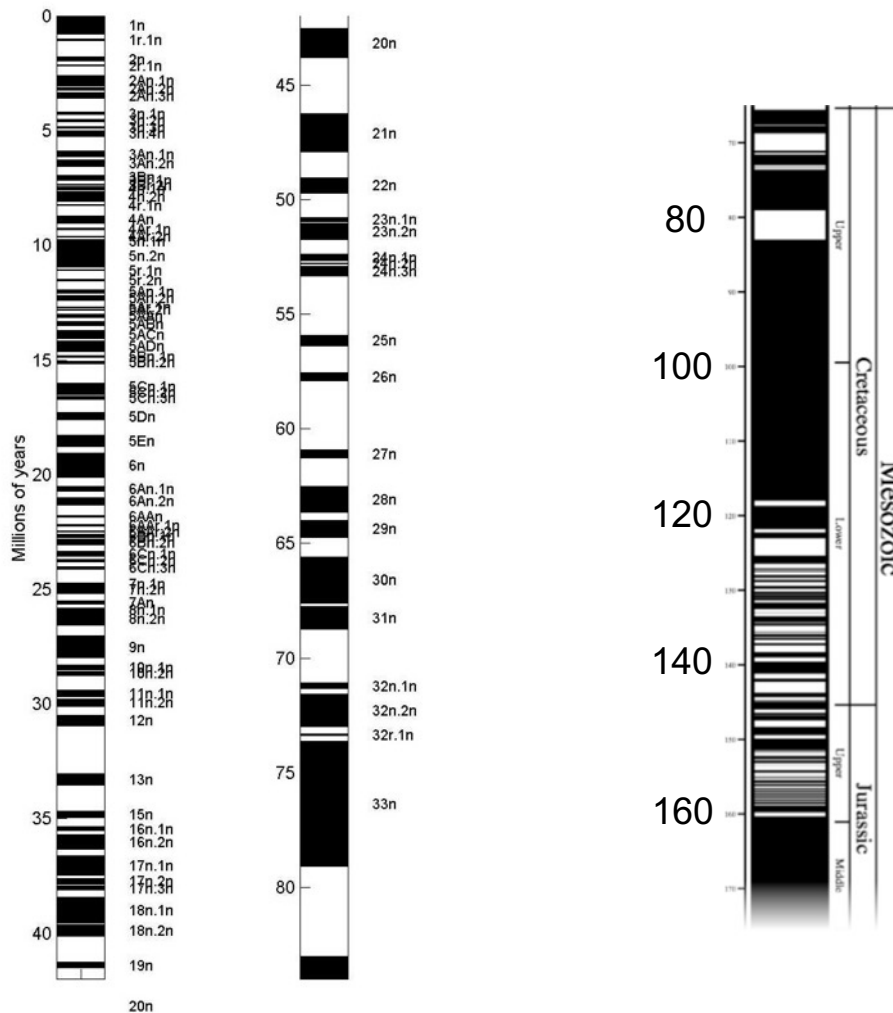
OCEANIC BASALTS RETAIN THE MAGNETIC ANOMALIES



OCEANIC SEDIMENTS RETAIN THE MAGNETIC ANOMALIES

Cande & Kent 1995

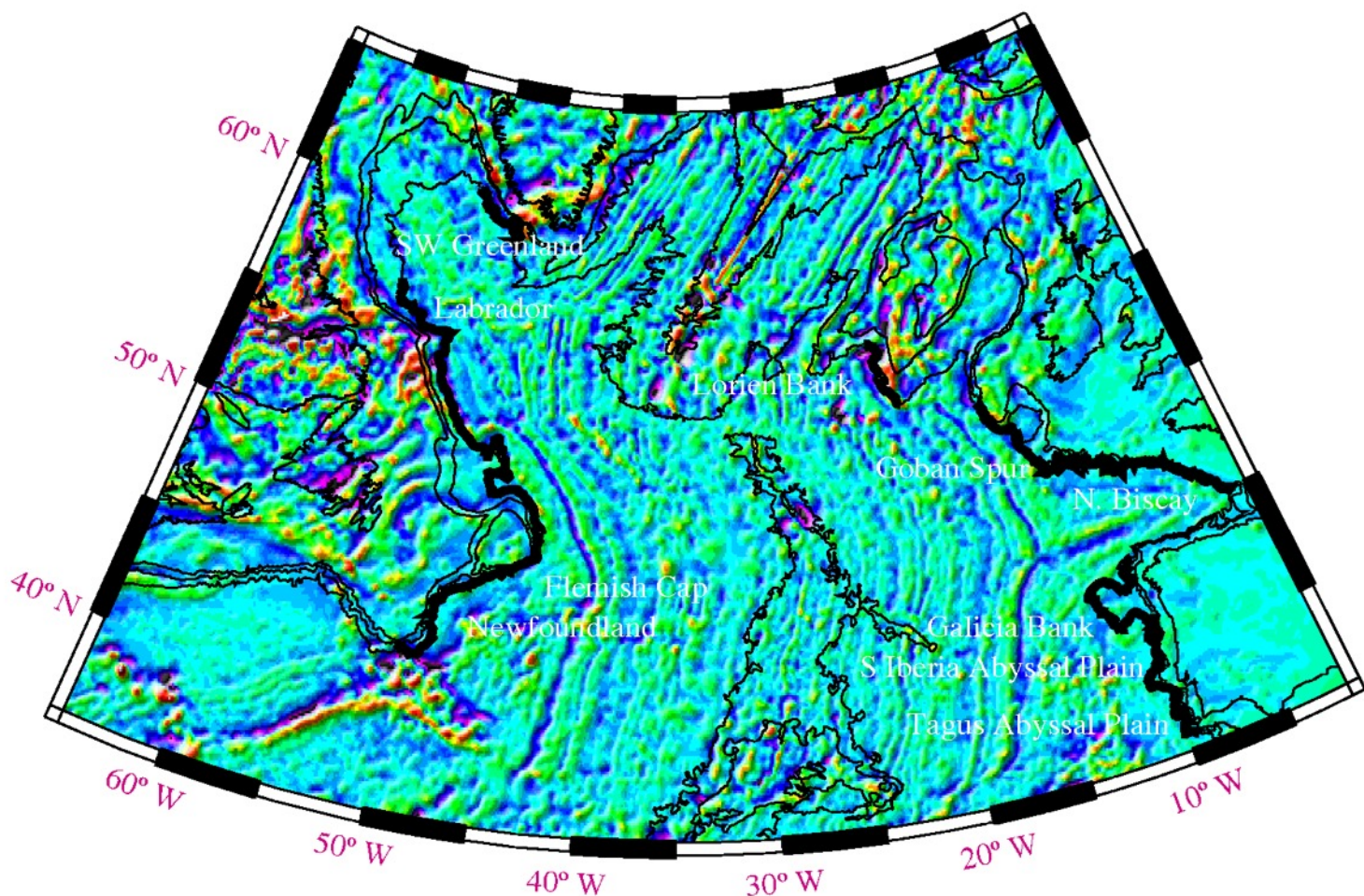
Geomagnetic Polarity Time Scale (GPTS)





Instruments to measure the earth magnetic field in the ocean:

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



Minshull, 2002. The break-up of continents and the formation of new ocean basins. *Phil. Trans. R. Soc. Lond. A* 2002 **360**, 2839-2852

LITHOSPHERIC STRUCTURE INDICATORS

Magnetic anomalies

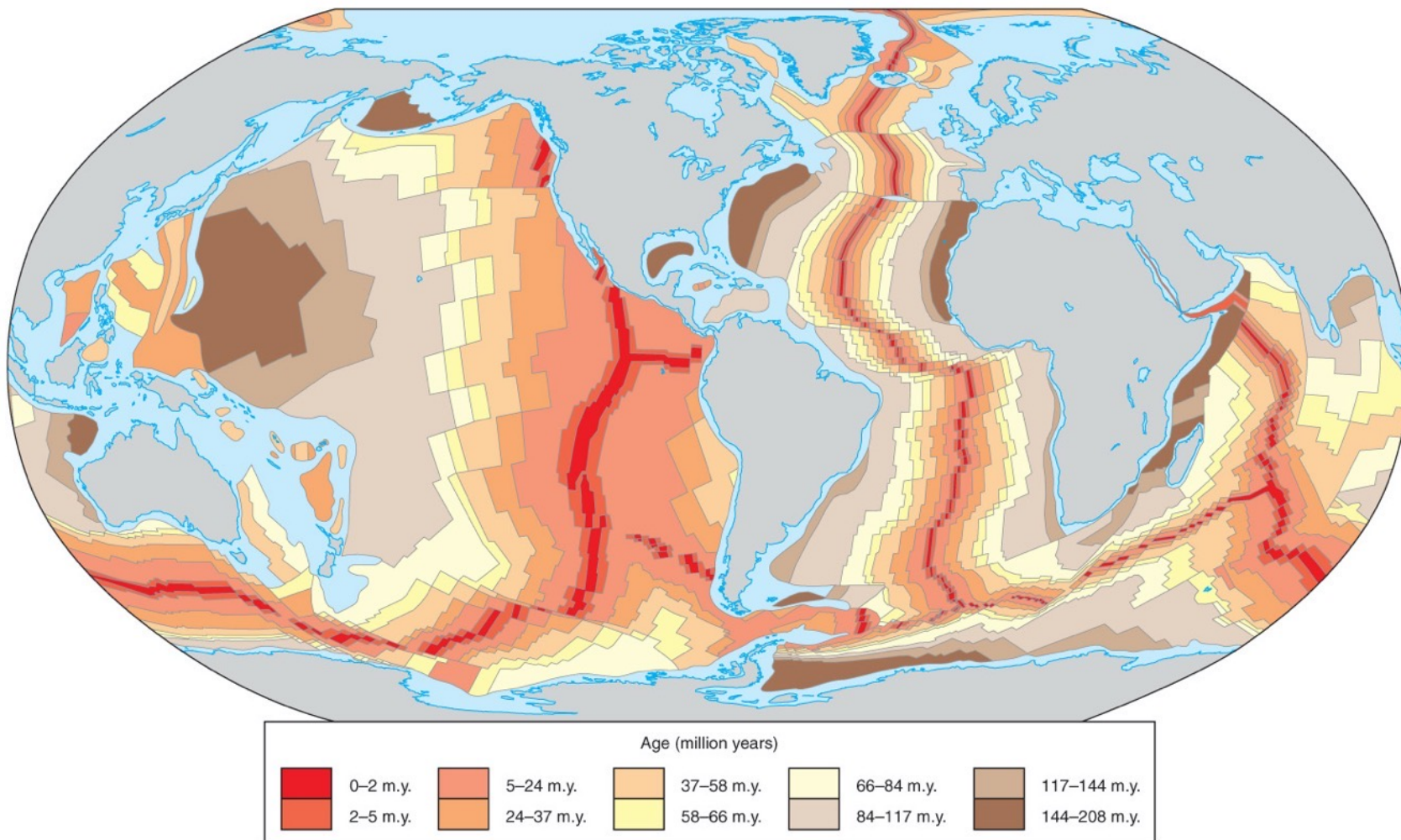
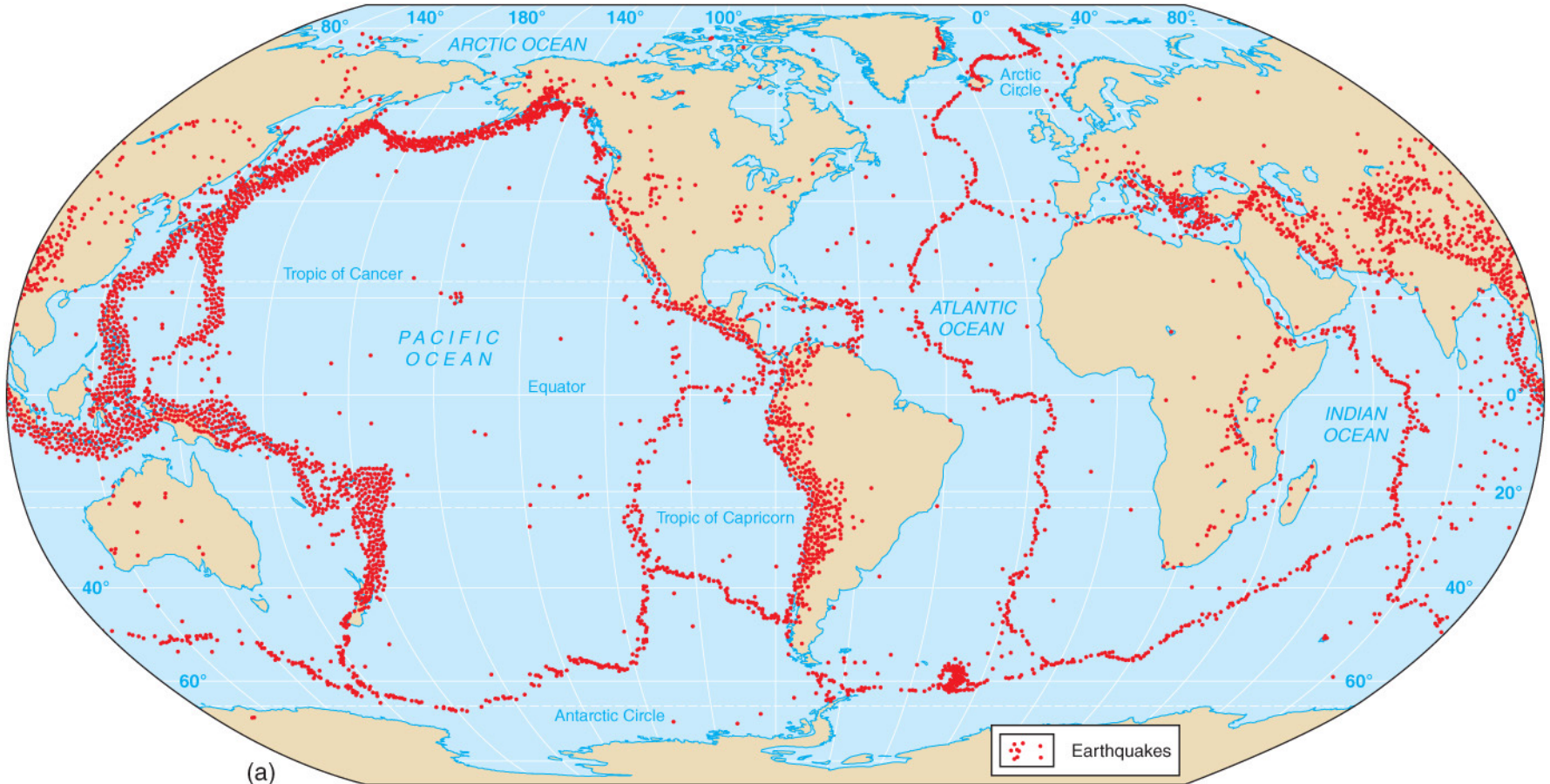
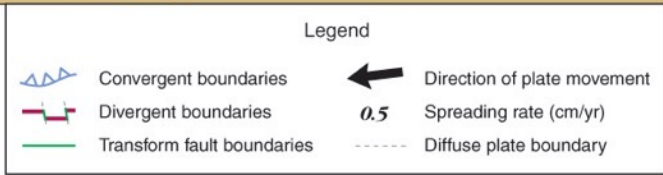
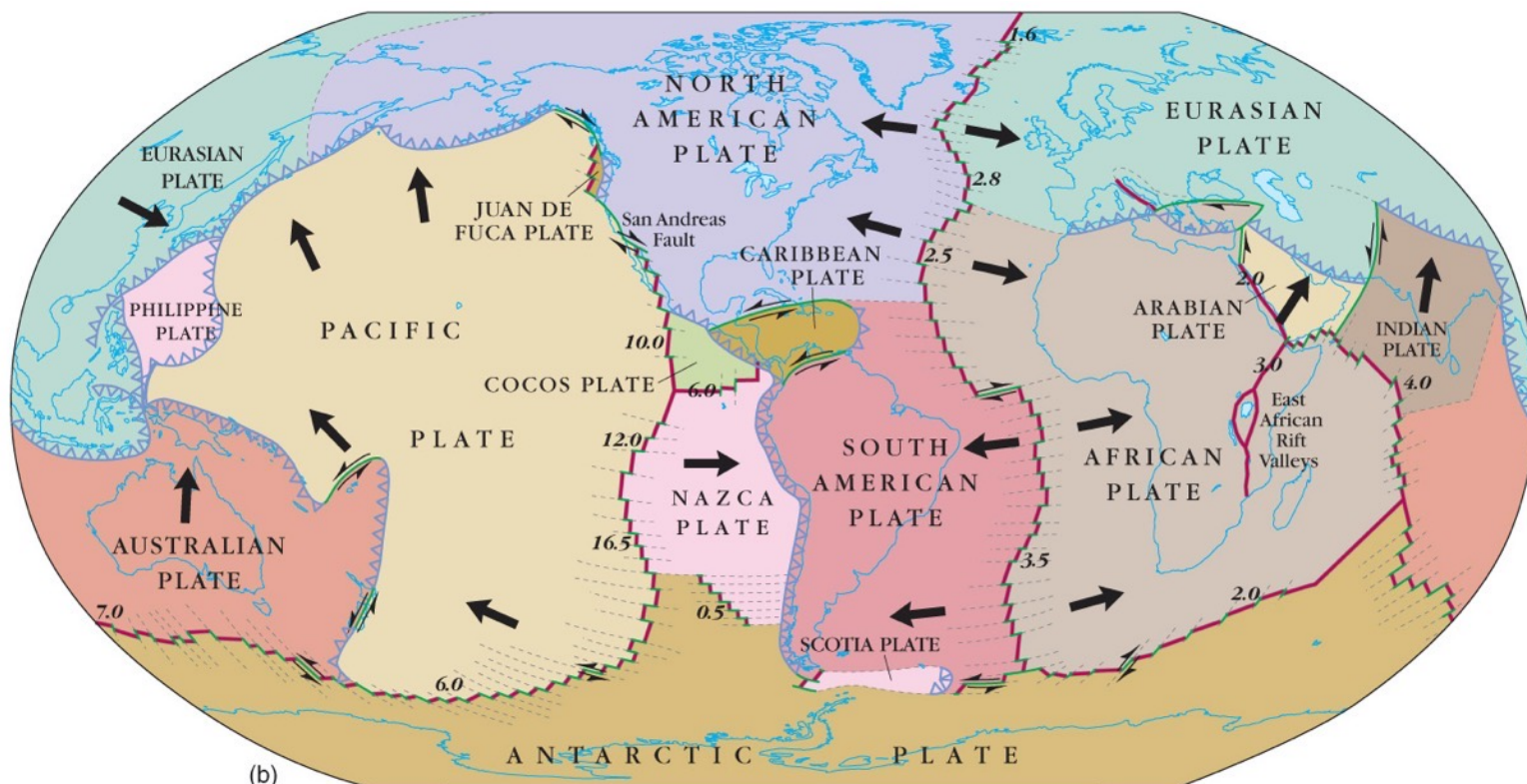


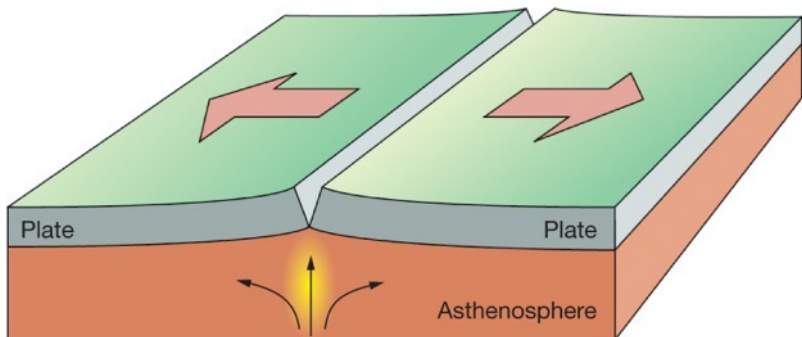
PLATE BOUNDARIES





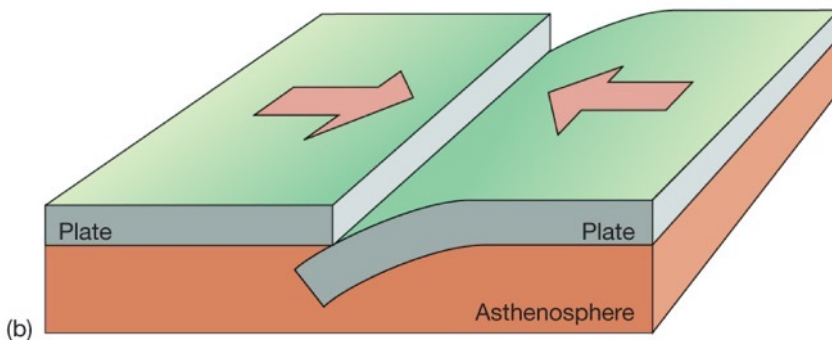
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PLATE BOUNDARIES



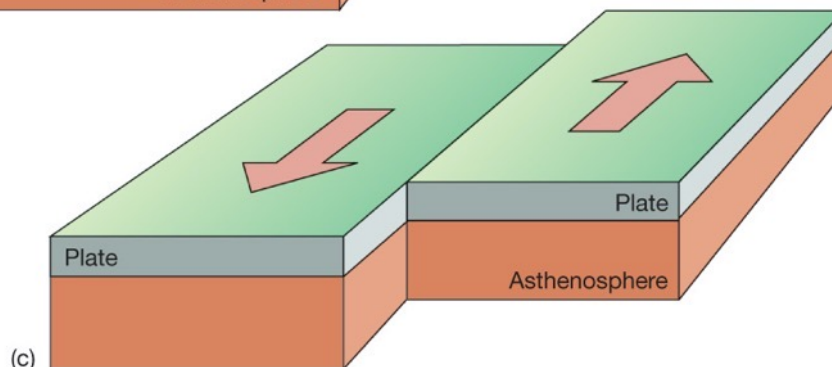
DIVERGENT (generally in the middle of the ocean)

(a)



CONVERGENT (generally along ocean margins)

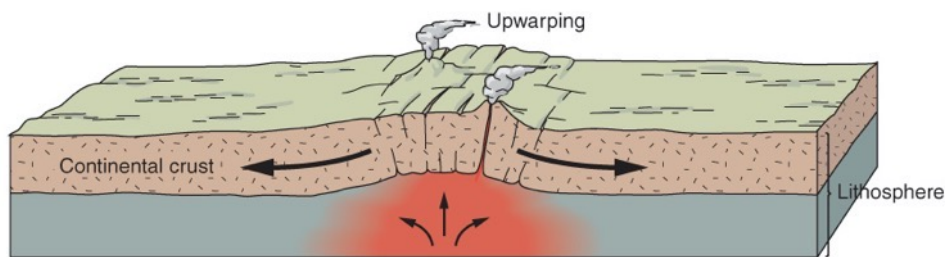
(b)



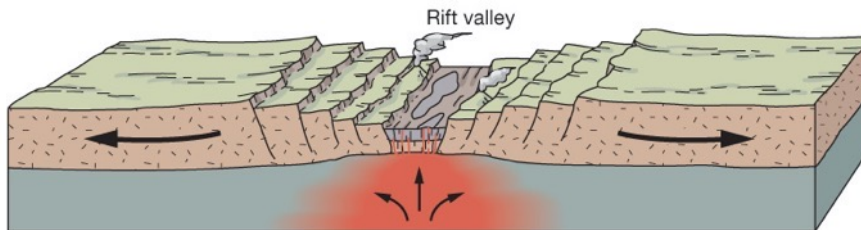
TRANSCURRENT (generally in the middle of the ocean)

(c)

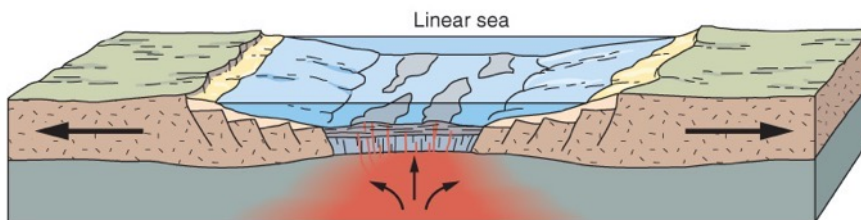
Generation of a Divergent Boundary



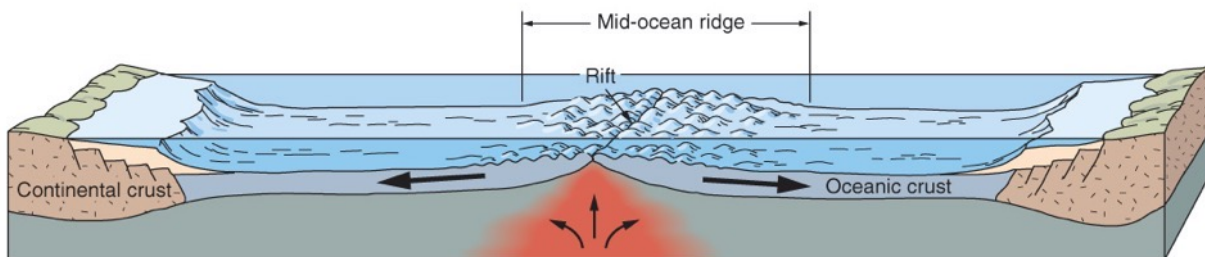
(a)



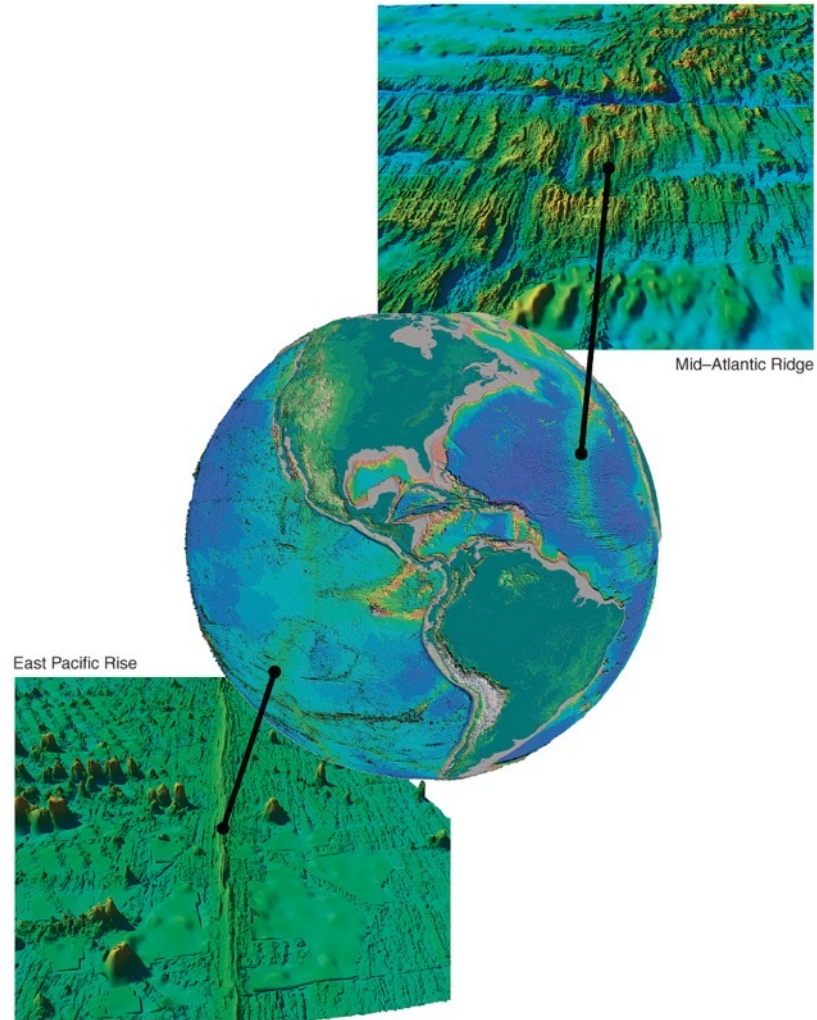
(b)



(c)



(d)



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

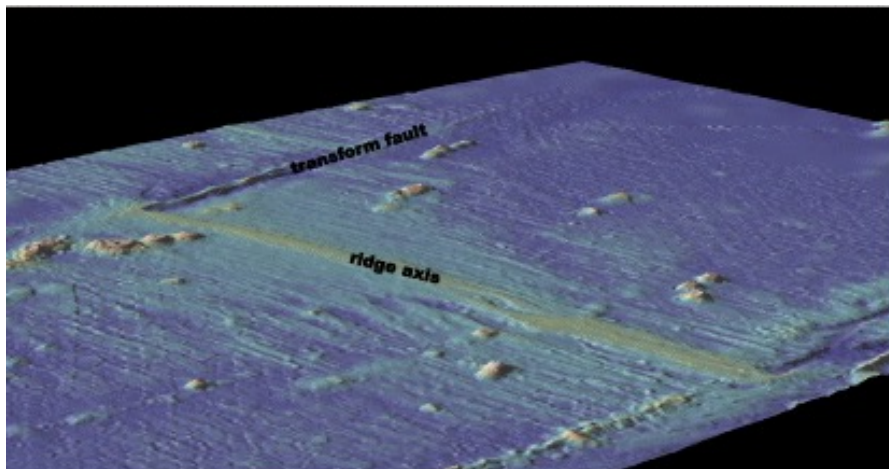


Mid-Atlantic Ridge: slow-spreading, narrow and rough



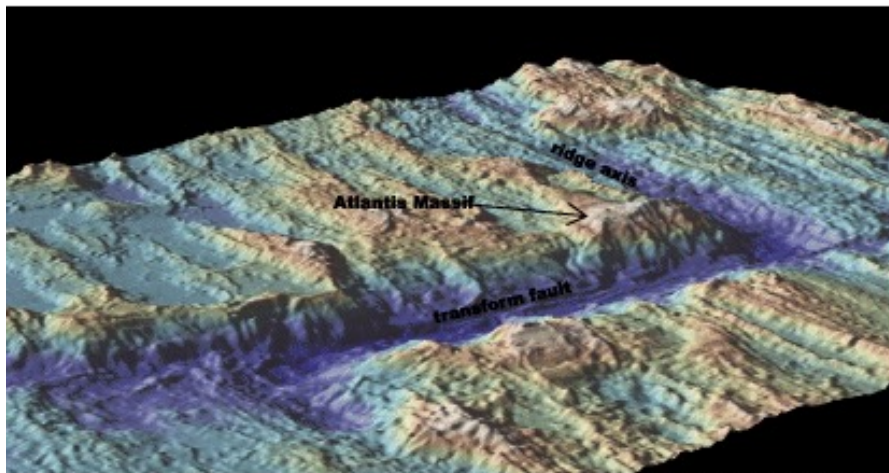
In places where **spreading is fastest** (more than 80 millimeters per year), the ridge has relatively gentle topography and is roughly dome-shaped in cross-section as a result of the many layers of lava that build up over time.

At **slow- and ultra-slow spreading centers**, the ridge is much more rugged, and spreading is dominated more by tectonic processes rather than volcanism.



(a)

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

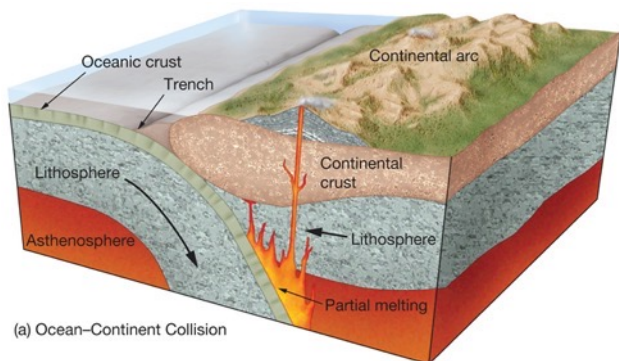


(b)

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

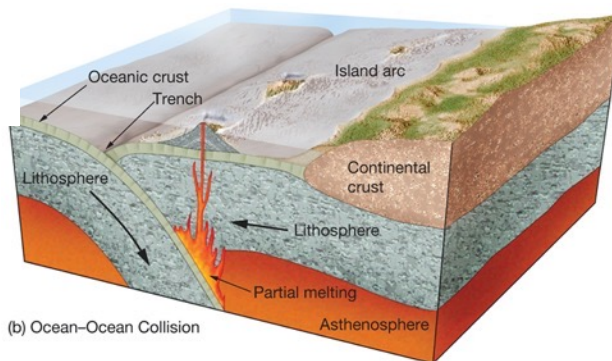
*Images made with GeoMapApp software with multibeam sonar data (each with 2°— vertical exaggeration).
(W. Haxby 2006, GeoMapApp; Marine Geosciences Data Management System, <http://www.GeoMapApp.org/>)*

Three Types of Convergent Boundaries



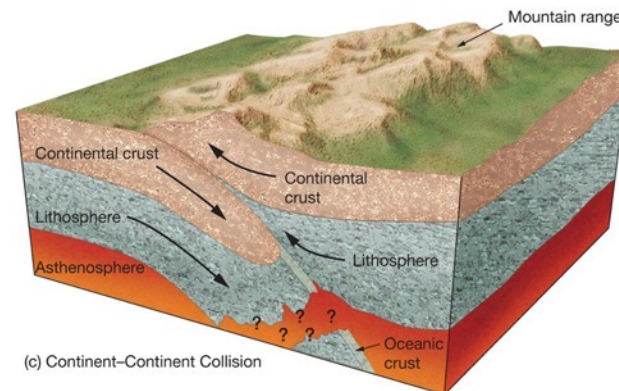
(a) Ocean-Continent Collision

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(b) Ocean-Ocean Collision

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(c) Continent-Continent Collision

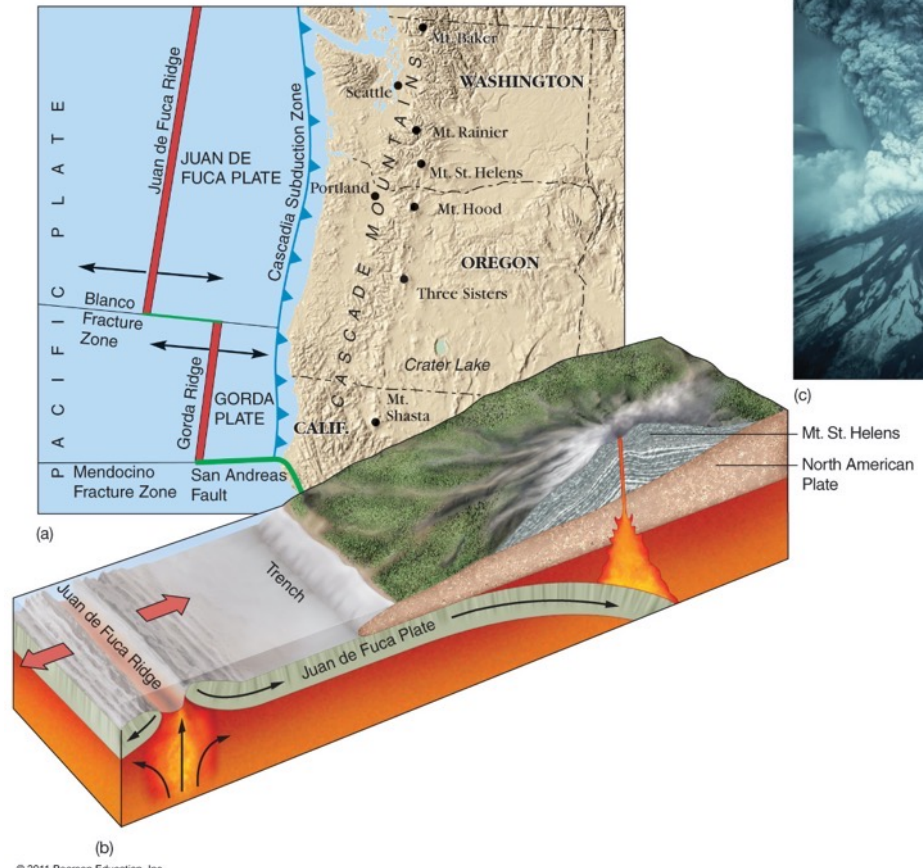
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Oceanic-Continental Convergence

Ocean plate is subducted

Continental arcs generated

Explosive andesitic volcanic eruptions



Continental-Continental Convergence

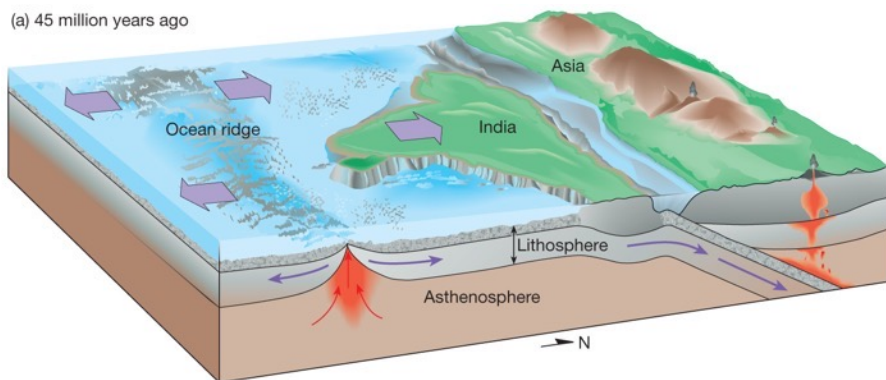
No subduction

Tall mountains uplifted

(c)



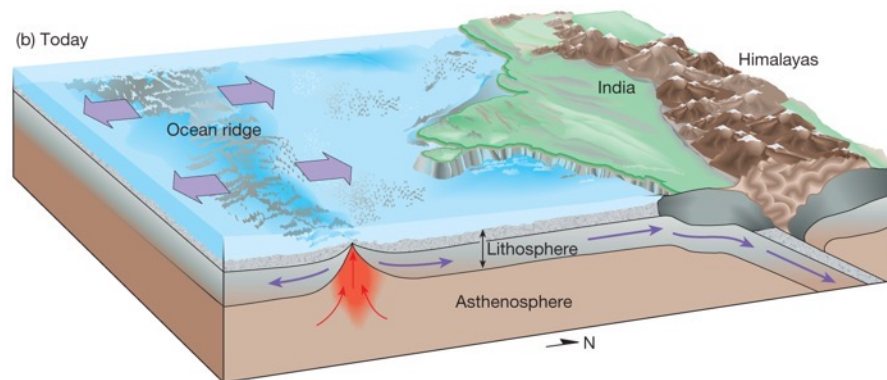
(a) 45 million years ago



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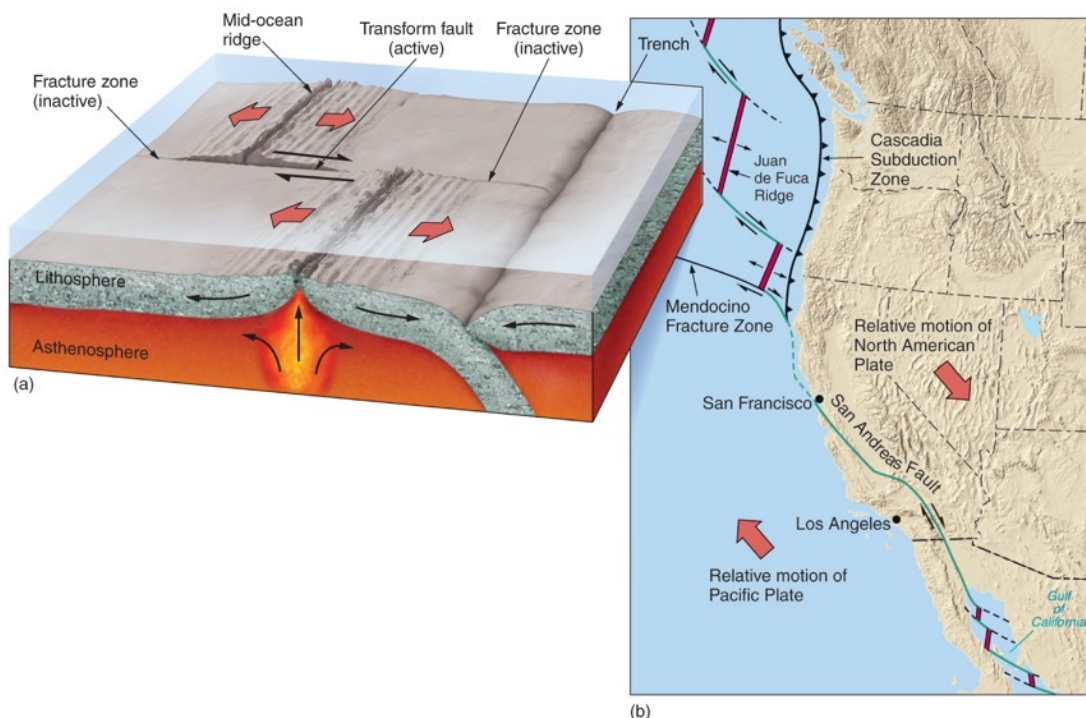
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(b) Today

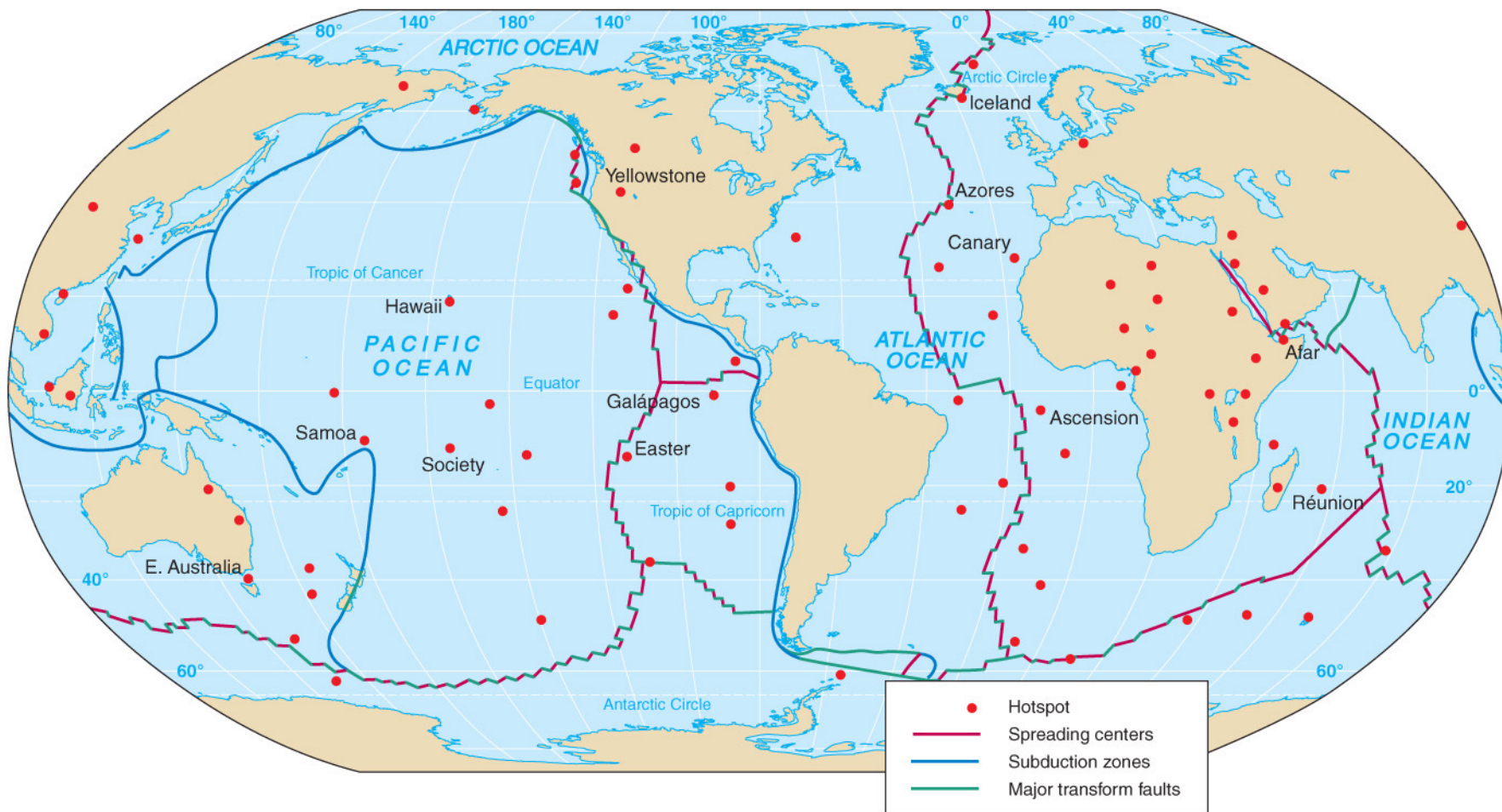


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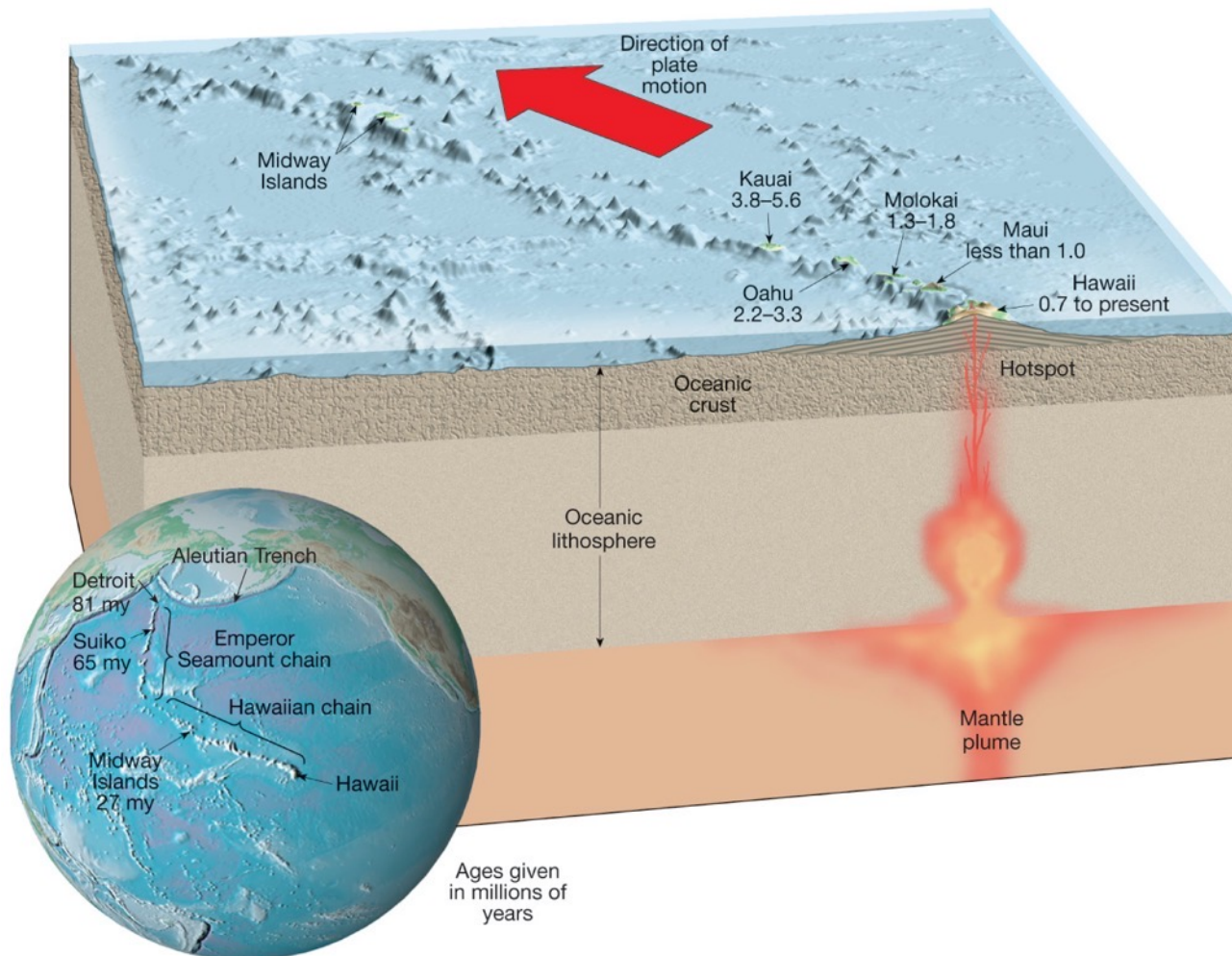
Oceanic Transform Fault – ocean floor only
Continental Transform Fault – cuts across continent
All transform faults occur between mid-ocean ridge segments.



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Hawaiian Island – Emperor Seamount Nematath



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Seamounts

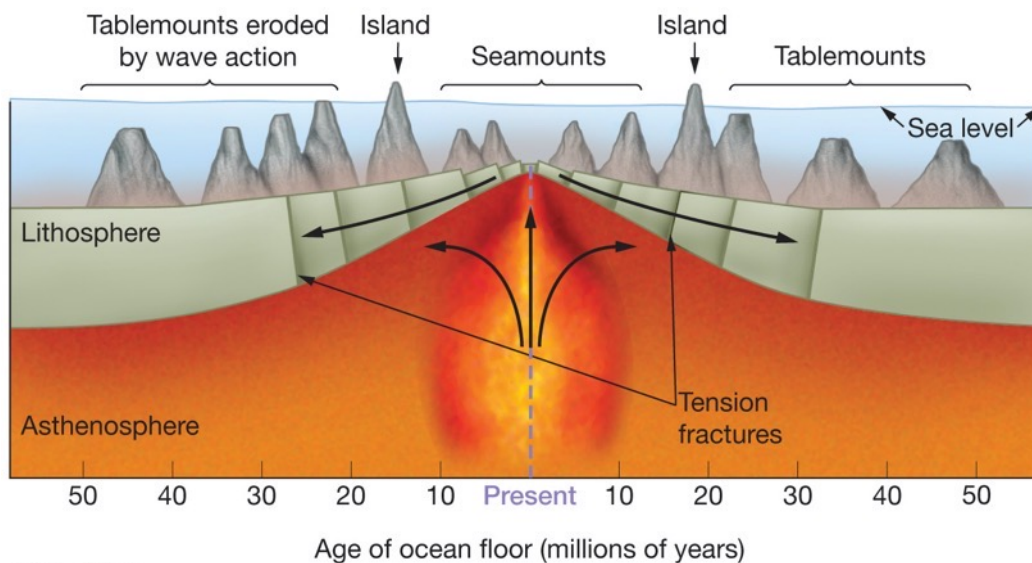
Rounded tops

Tablemounts or guyots

Flattened tops

Subsidence of flanks of mid-ocean ridge

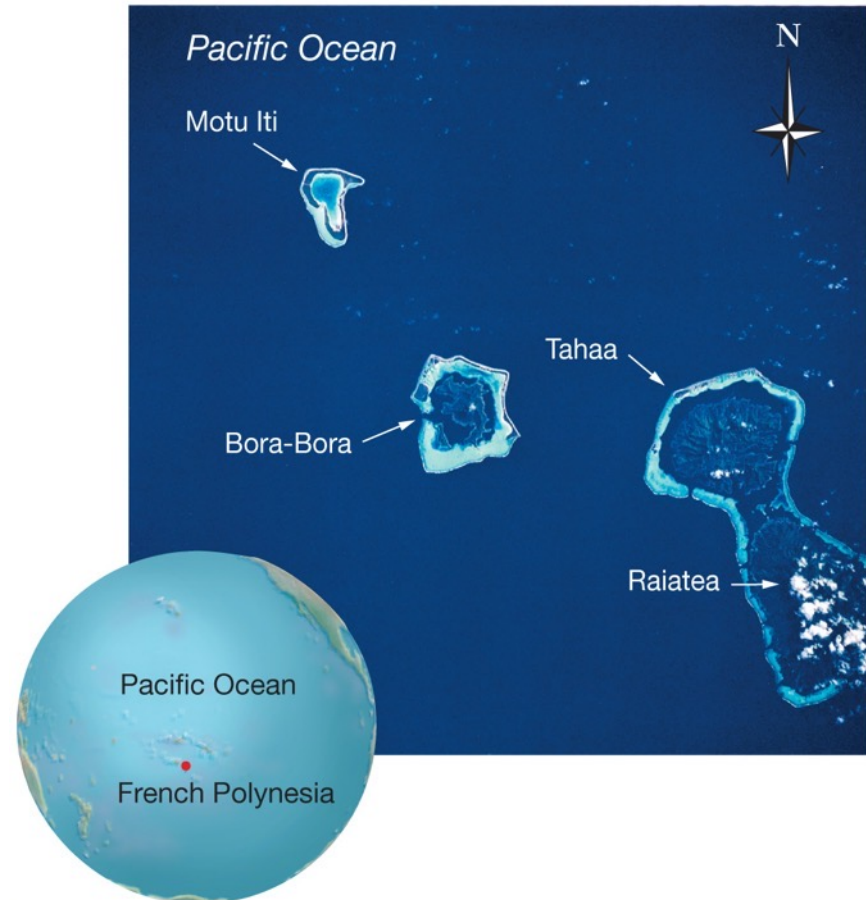
Wave erosion may flatten seamount



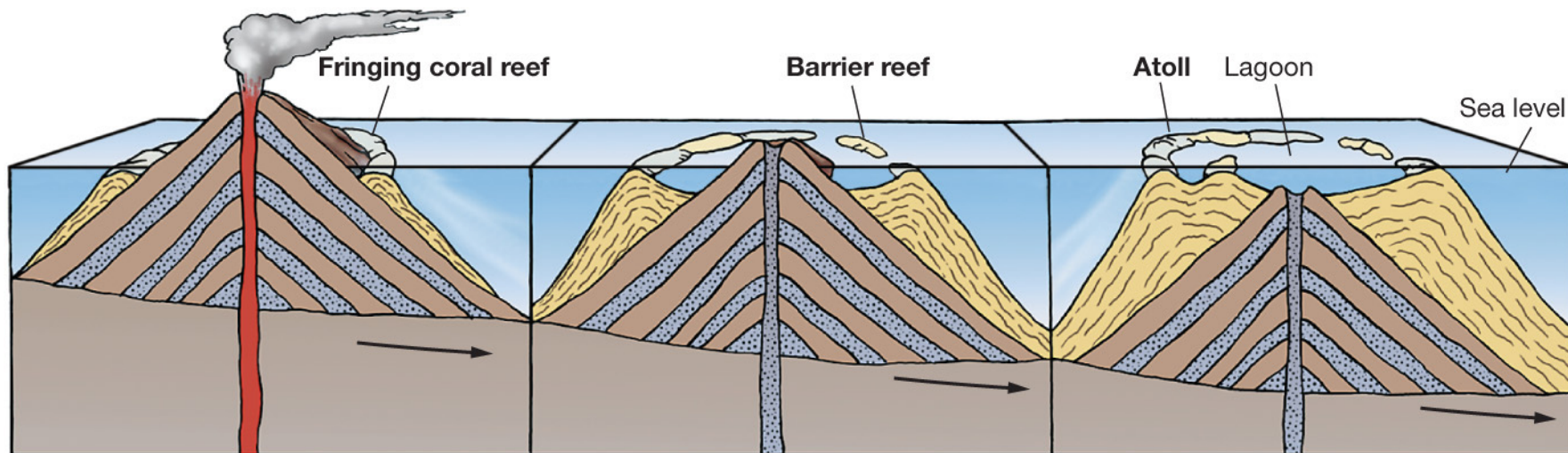
Fringing reefs – develop along margin of landmass

Barrier reefs – separated from landmass by lagoon

Atolls – reefs continue to grow after volcanoes are submerged



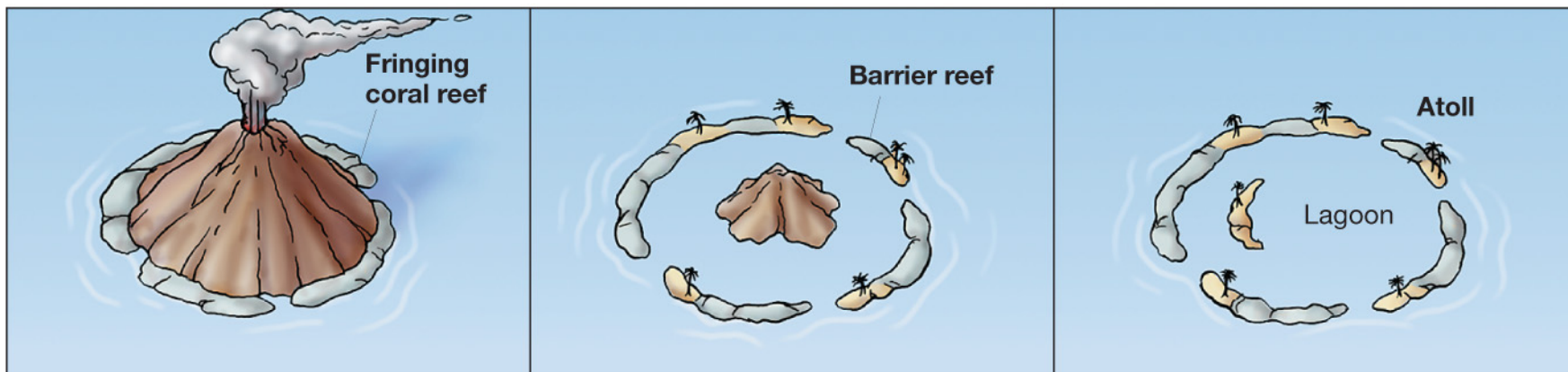
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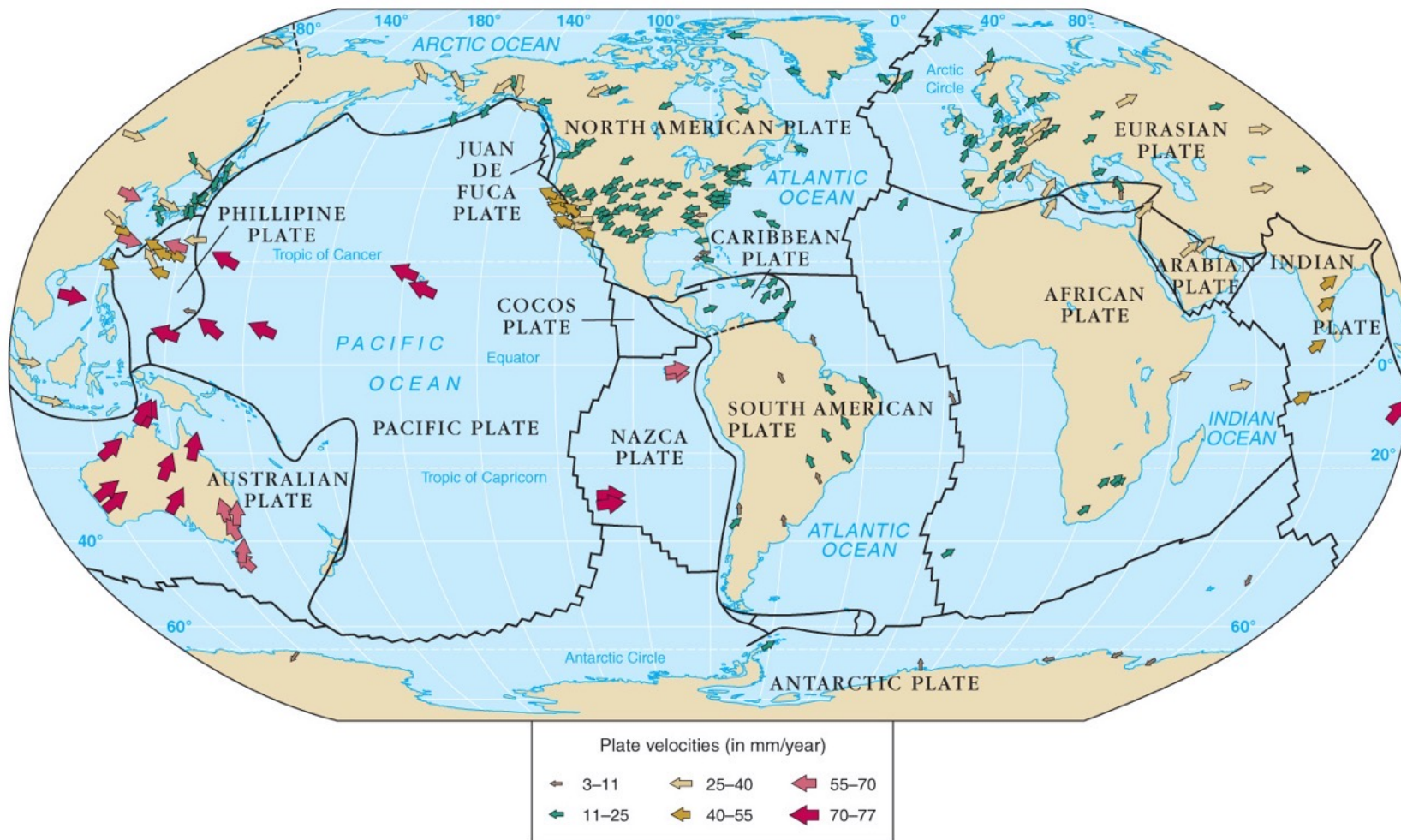
(a)

(b)

(c)



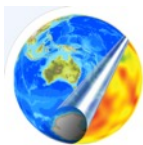
Detecting Plate Motion with Satellites



Wilson cycle

Stage, showing cross-sectional view	Motion	Physiography	Example
<p>EMBRYONIC</p>	Uplift	Complex system of linear rift valleys on continent	East African rift valleys
<p>JUVENILE</p>	Divergence (spreading)	Narrow seas with matching coasts	Red Sea
<p>MATURE</p>	Divergence (spreading)	Ocean basin with continental margins	Atlantic and Arctic Oceans
<p>DECLINING</p>	Convergence (subduction)	Island arcs and trenches around basin edge	Pacific Ocean
<p>TERMINAL</p>	Convergence (collision) and uplift	Narrow, irregular seas with young mountains	Mediterranean Sea
<p>SUTURING</p>	Convergence and uplift	Young to mature mountain belts	Himalaya Mountains

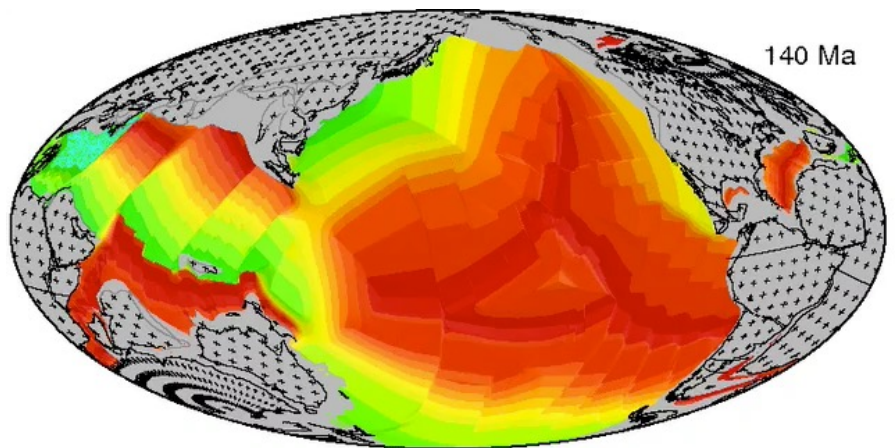
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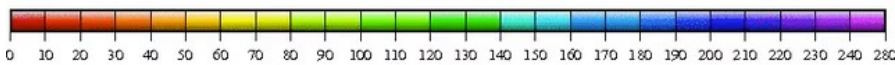
Earth**BYTE**

<https://www.earthbyte.org/>

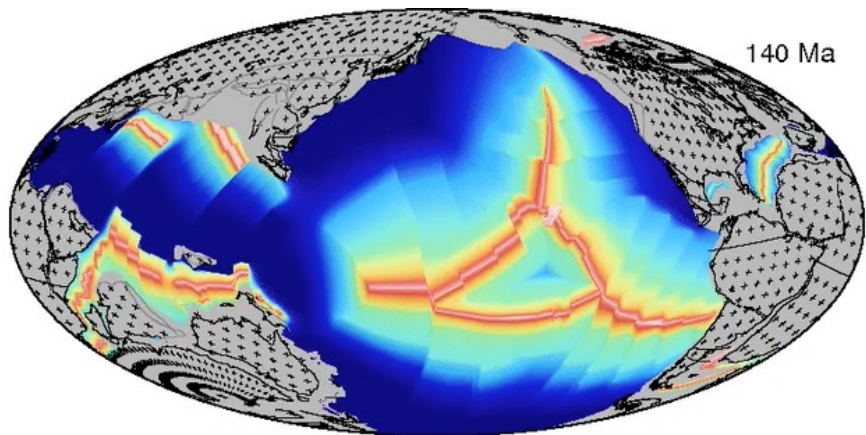
Building a Virtual Earth



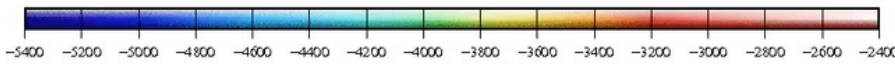
140 Ma



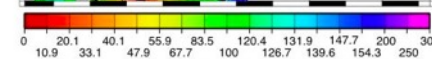
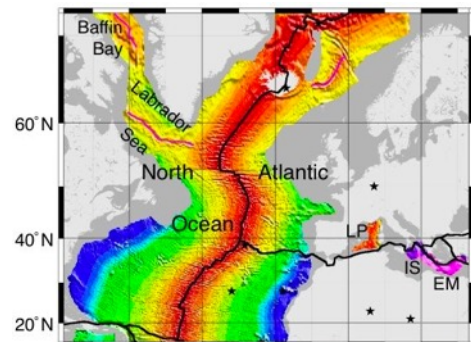
Age of Oceanic Lithosphere [m.y.]



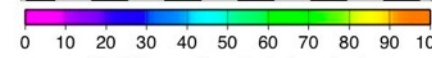
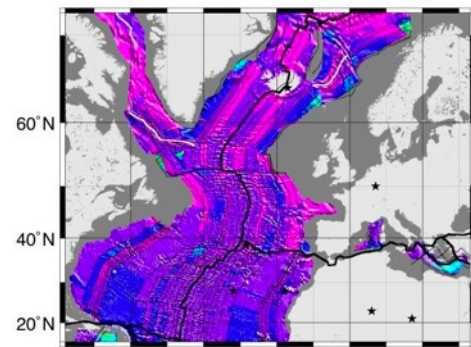
140 Ma



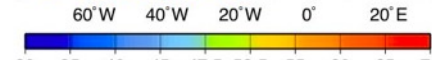
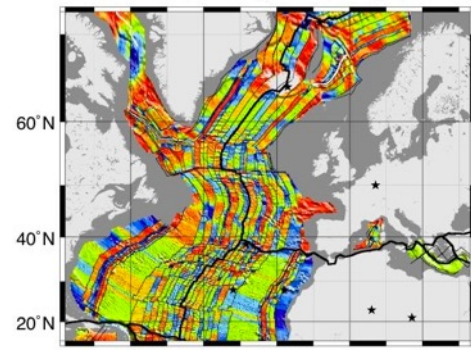
Depth to Basement [m]



Age of Oceanic Lithosphere [m.y.]



Half Spreading Rate [mm/yr.]



Crustal accretion [%]

MTD Gul of Mexico. IODP Exp..... Site U1322

