Università di Trieste
LAUREA MAGISTRALE IN GEOSCIENZE SM62
Percorso Esplorazione Geologica

Anno accademico 2023 - 2024

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

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».

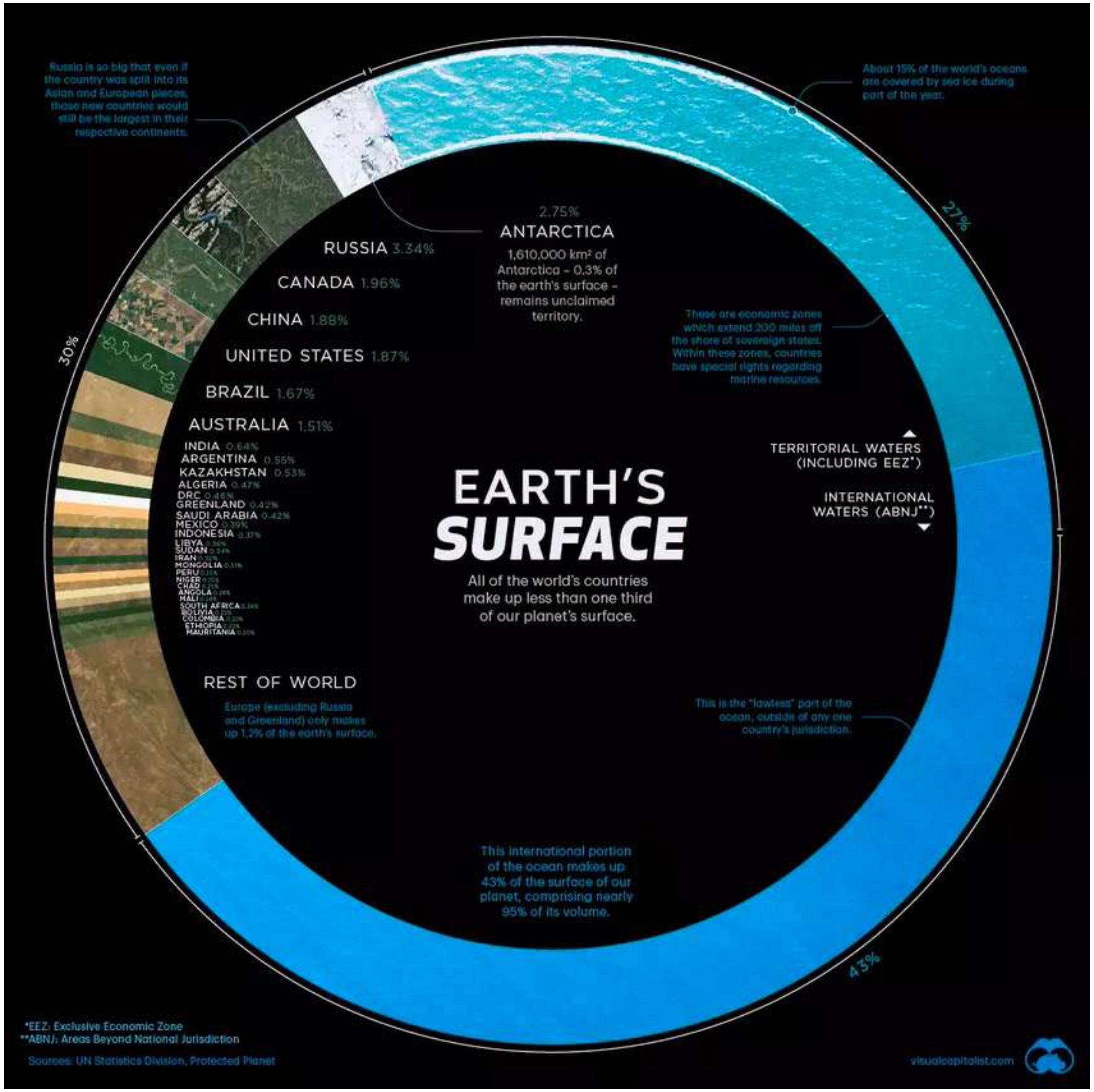
«un immenso fiume che cinge tutto lo spazio terrestre e che, scorrendo su se stesso, collega il mondo»

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

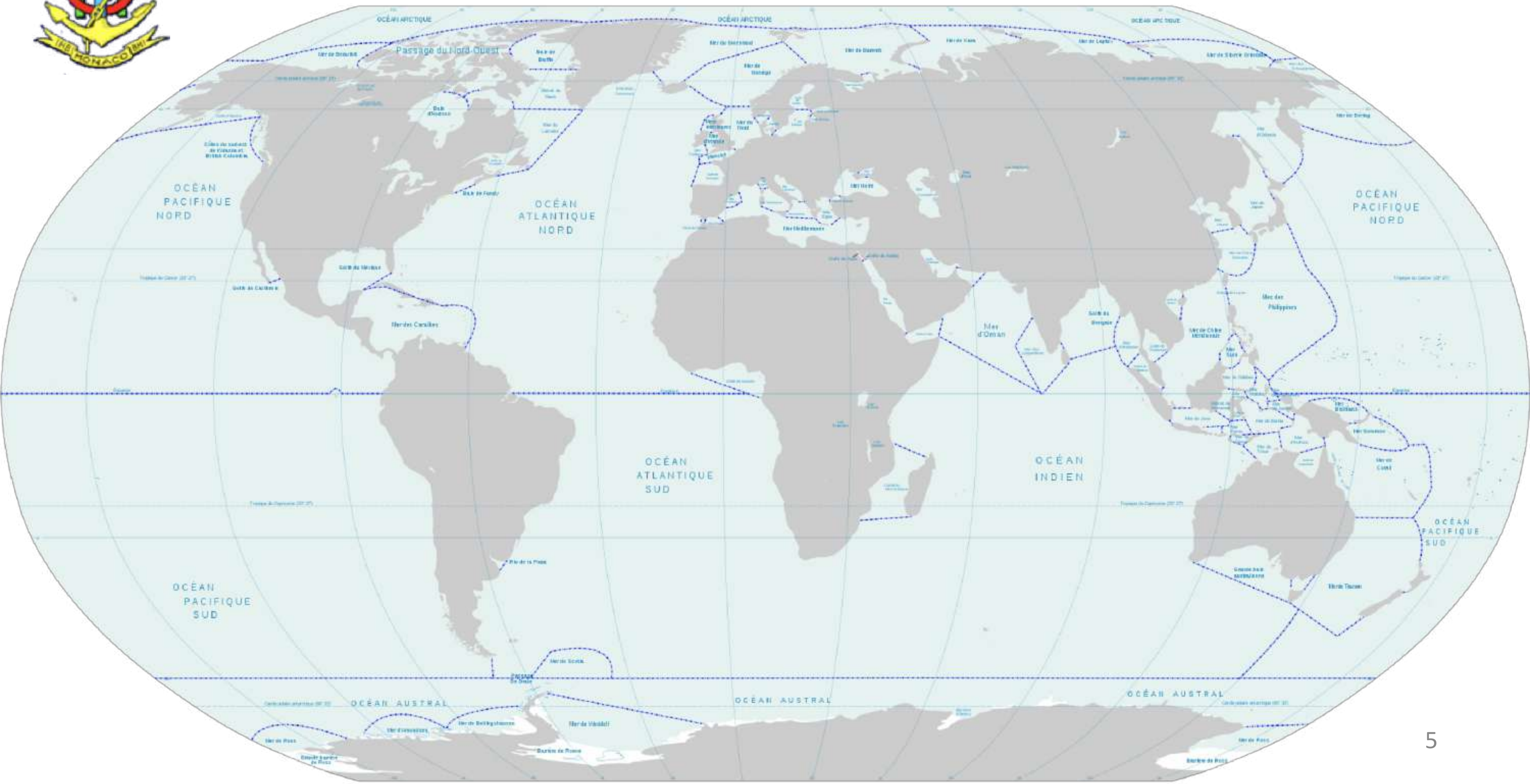

Okeanos - Fontana di Trevi

Oceans and Seas:

~ 70% of Earth Surface



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

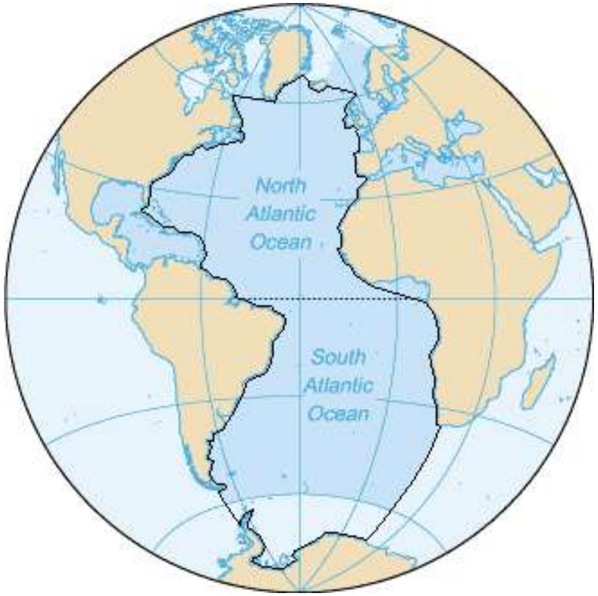
The IHO ensures that all the world's seas, oceans and navigable waters are **surveyed** and **charted**.

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

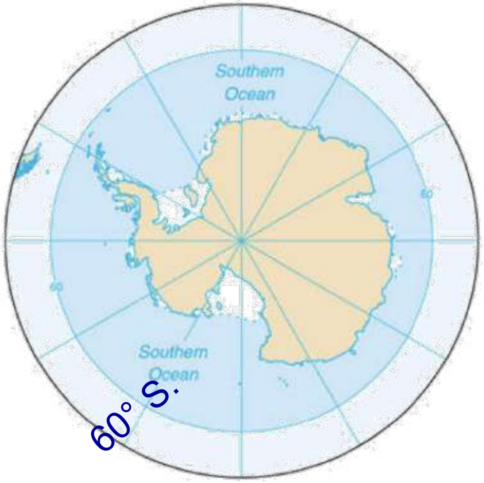


Indian Ocean

The oceans of the world

Artic Ocean

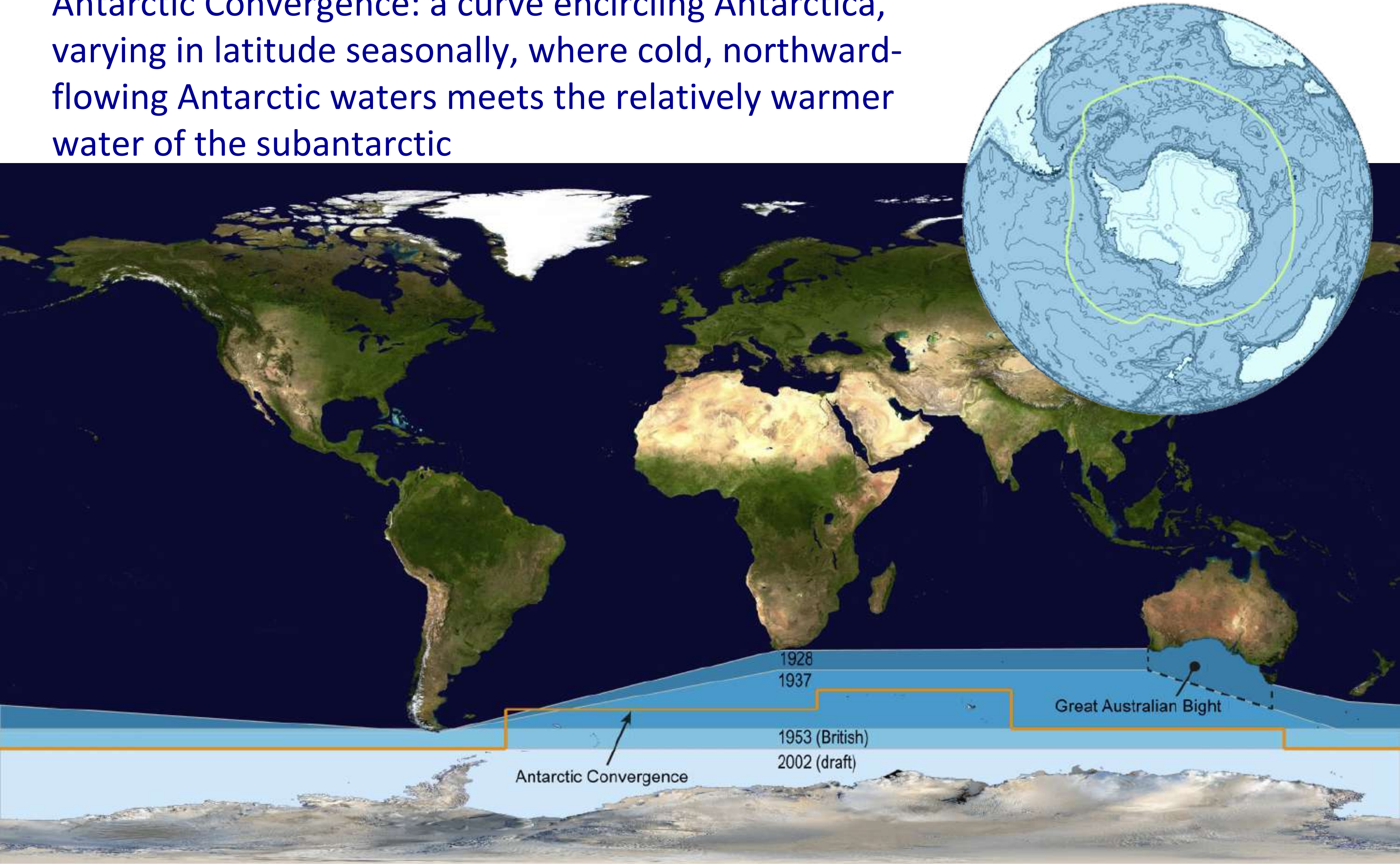
Southern Ocean



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

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

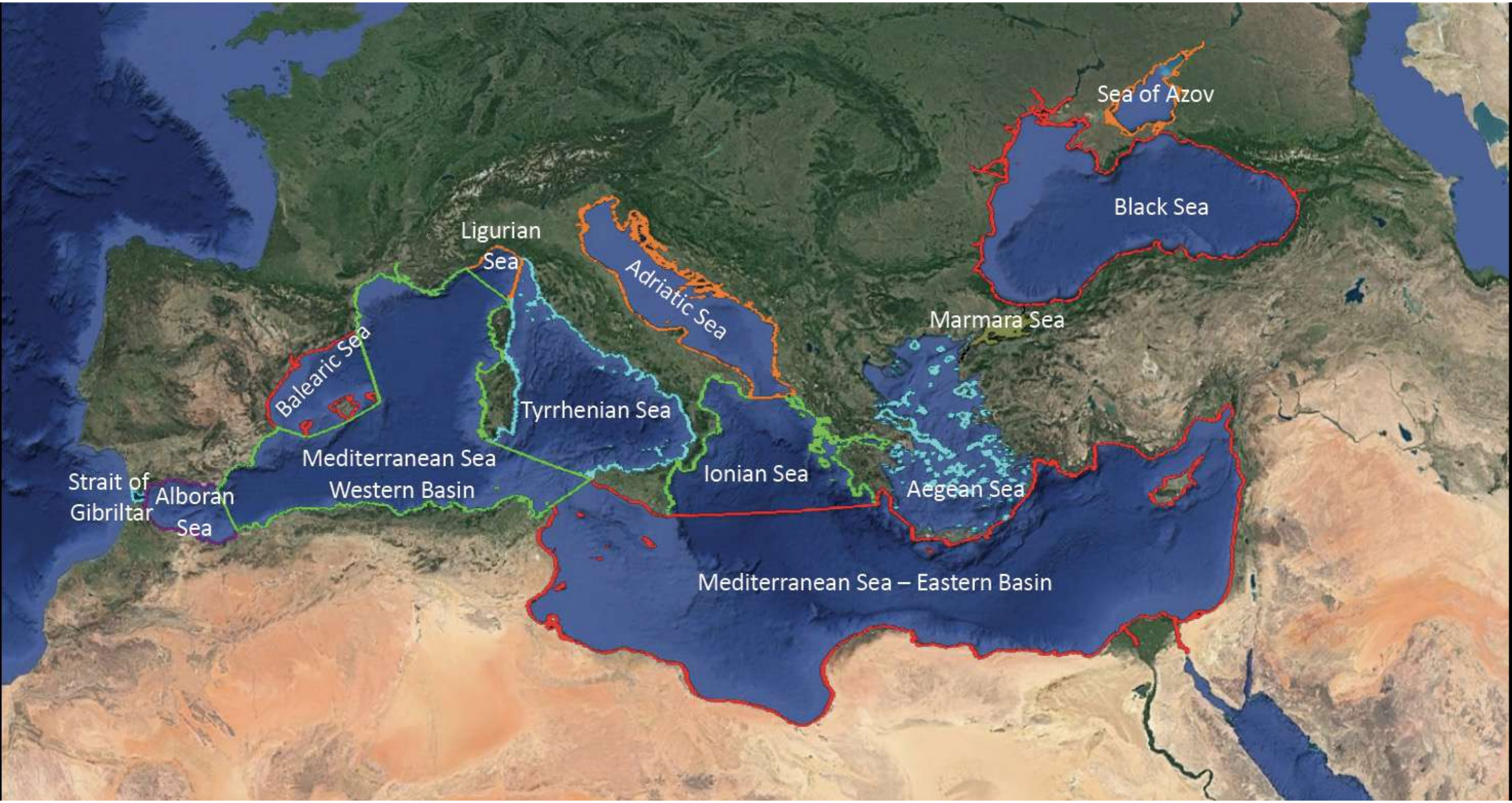


Ocean	Area	Average Depth (m)	Deepest depth (m)
Pacific Ocean	165,250,000 km^2	4,028 m	Mariana Trench 11,033 m
Atlantic Ocean	106,400,000 km^2	3,926 m	Puerto Rico Trench 8,604 m
Indian Ocean	73,560,000 km^2	3,963 m	Java Trench, 7,725 m
Southern Ocean	20,330,000 km^2	4,000 to 5,000 m	the southern end of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

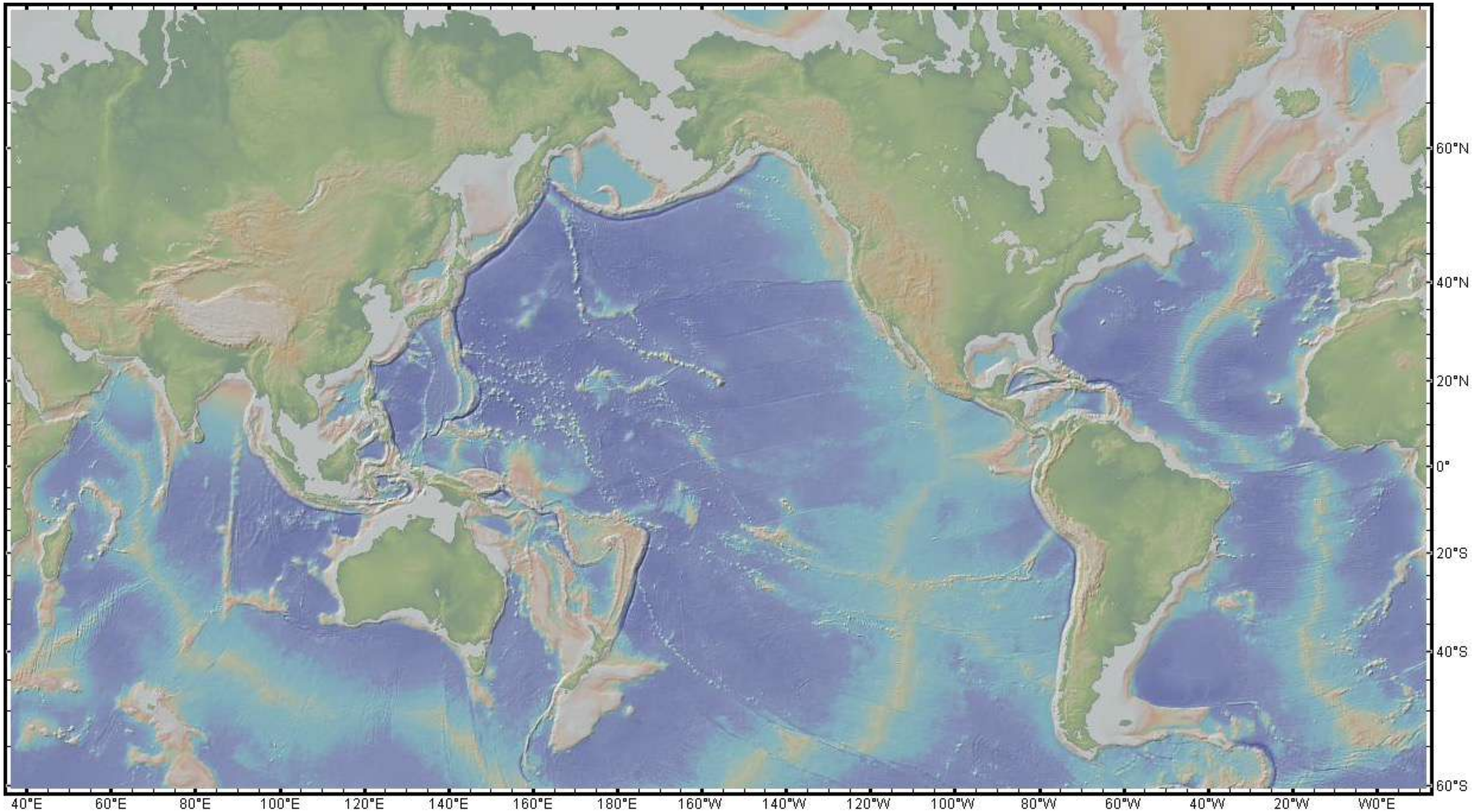
from latin "Mediterraneus": medi > between terraneous > land



The seas of the Mediterranean

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

2. MORPHOLOGY OF THE OCEAN AND SEA FLOOR



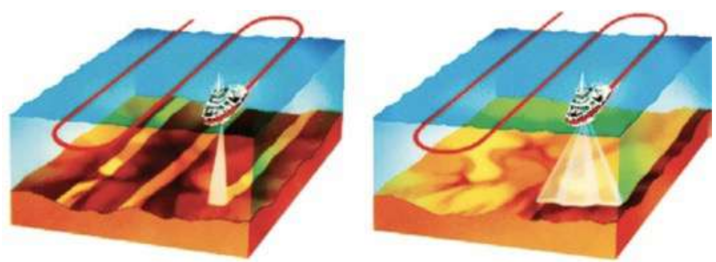
Geo Map App

OCEAN AND SEA FLOOR MORPHOLOGY

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

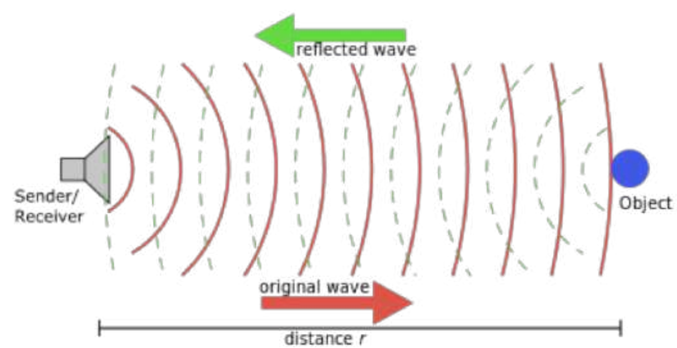
To investigate the oceans and seas we need appropriate instruments and technologies:

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



(a) Single-Beam (b) Multi-Beam

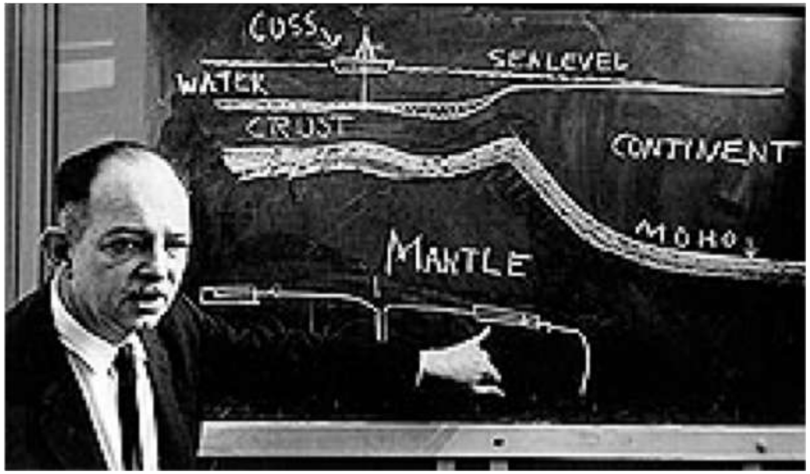
2) Multi-beam sonar technologies, develop in the last decades of the 1900

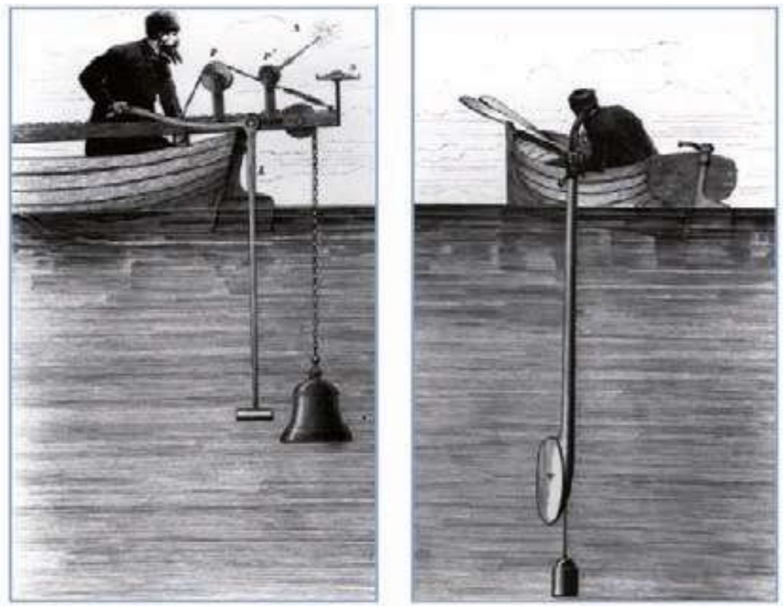


3) Satellite derived bathymetry and and sea floor morphology developed in the last decades of the 1900

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

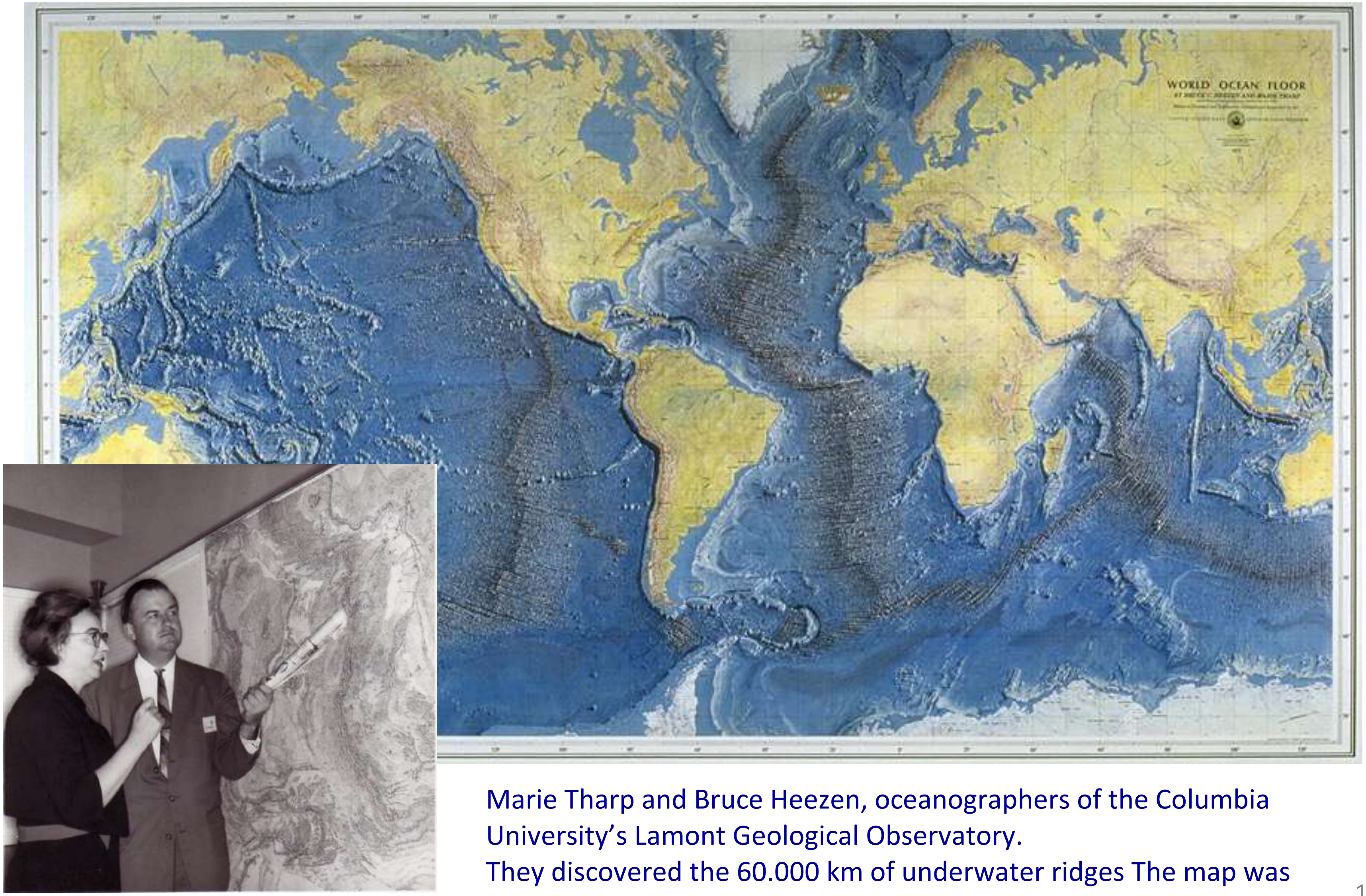
Colladon and Sturm’s 1862 experiment to measure the speed of sound in Lake Geneva (J. D. Colladon: Souvenirs et M moires, Impr. Albert-Schuchardt, Geneva, 1893).

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.

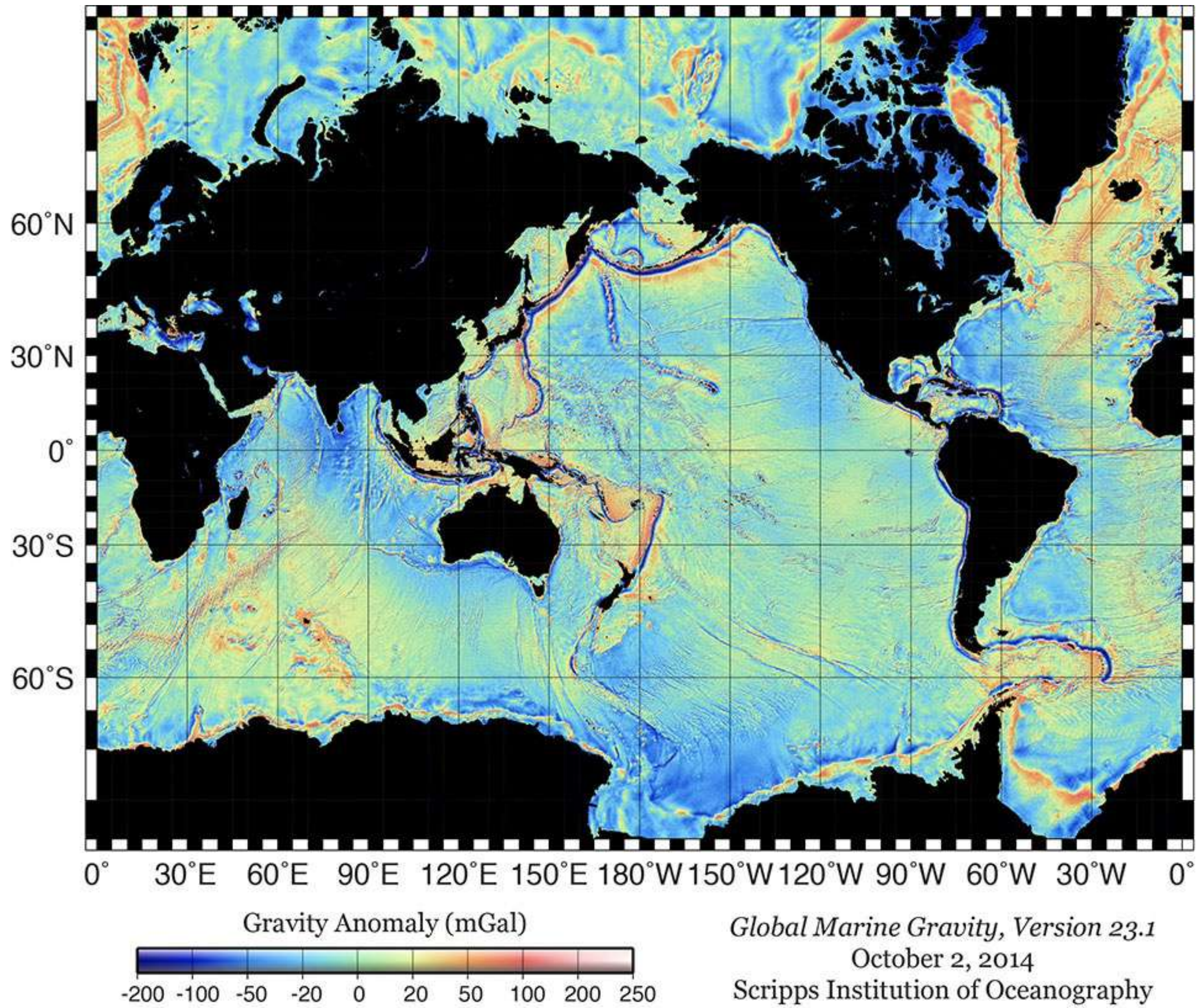
Mayer and Roach, 2021
The Quest to Completely Map the World's Oceans in Support of Understanding Marine Biodiversity and the Regulatory Barriers
https://doi.org/10.1163/9789004422438_009

SEA FLOOR MORPHOLOGY 1977



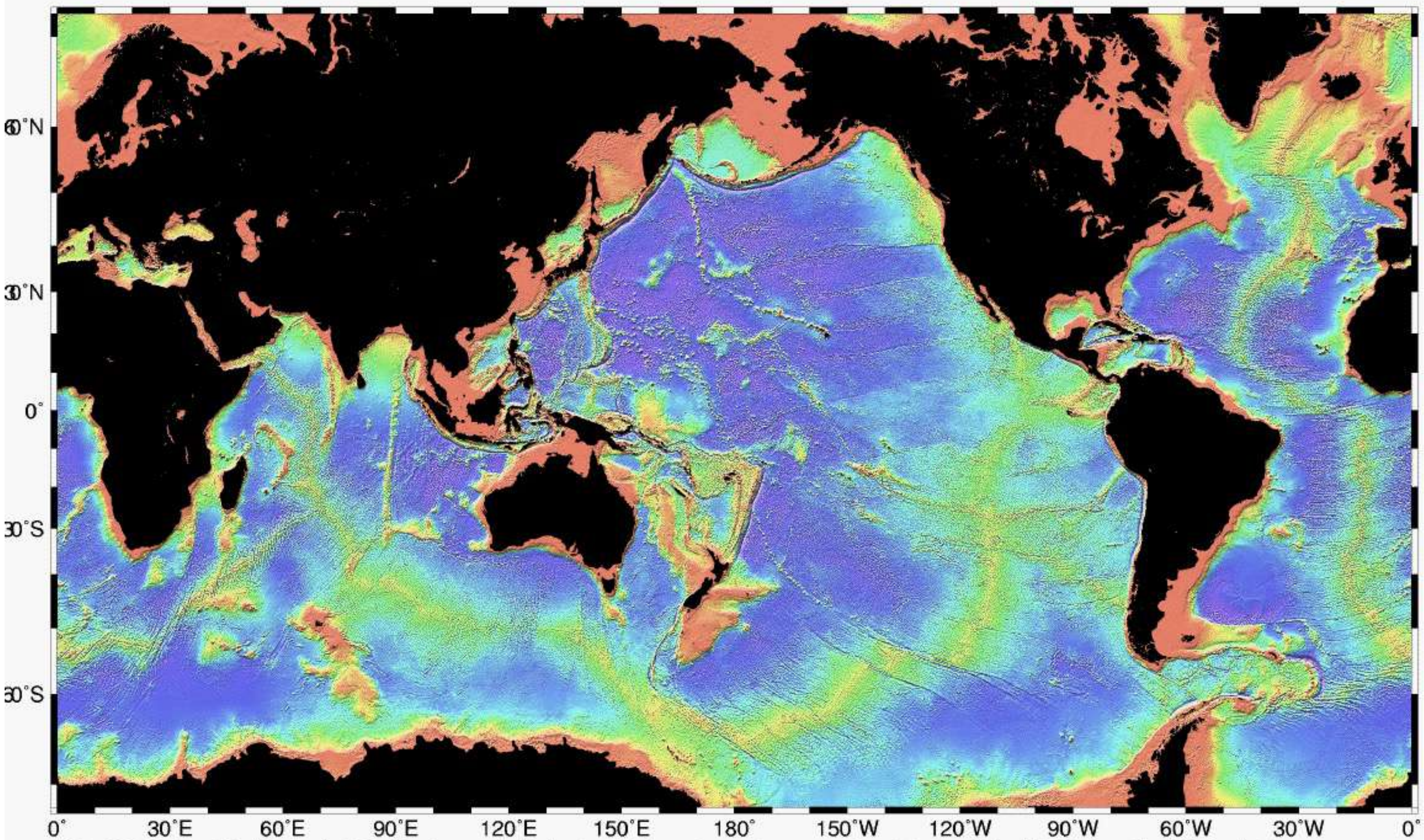
Marie Tharp and Bruce Heezen, oceanographers of the Columbia University’s Lamont Geological Observatory.
They discovered the 60.000 km of underwater ridges The map was painted by Heinrich C. Berann.

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

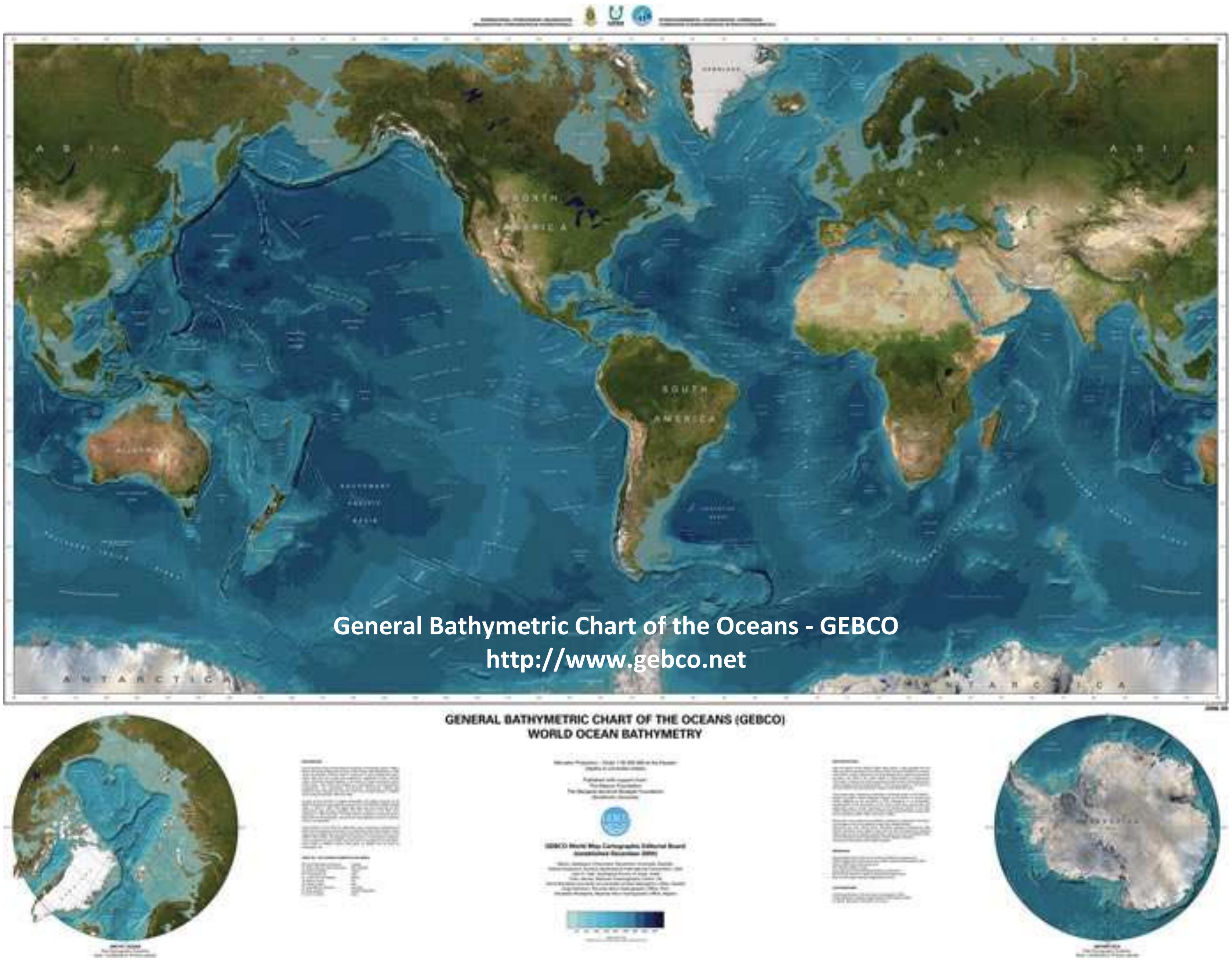


Smith and Sandwell, 1996

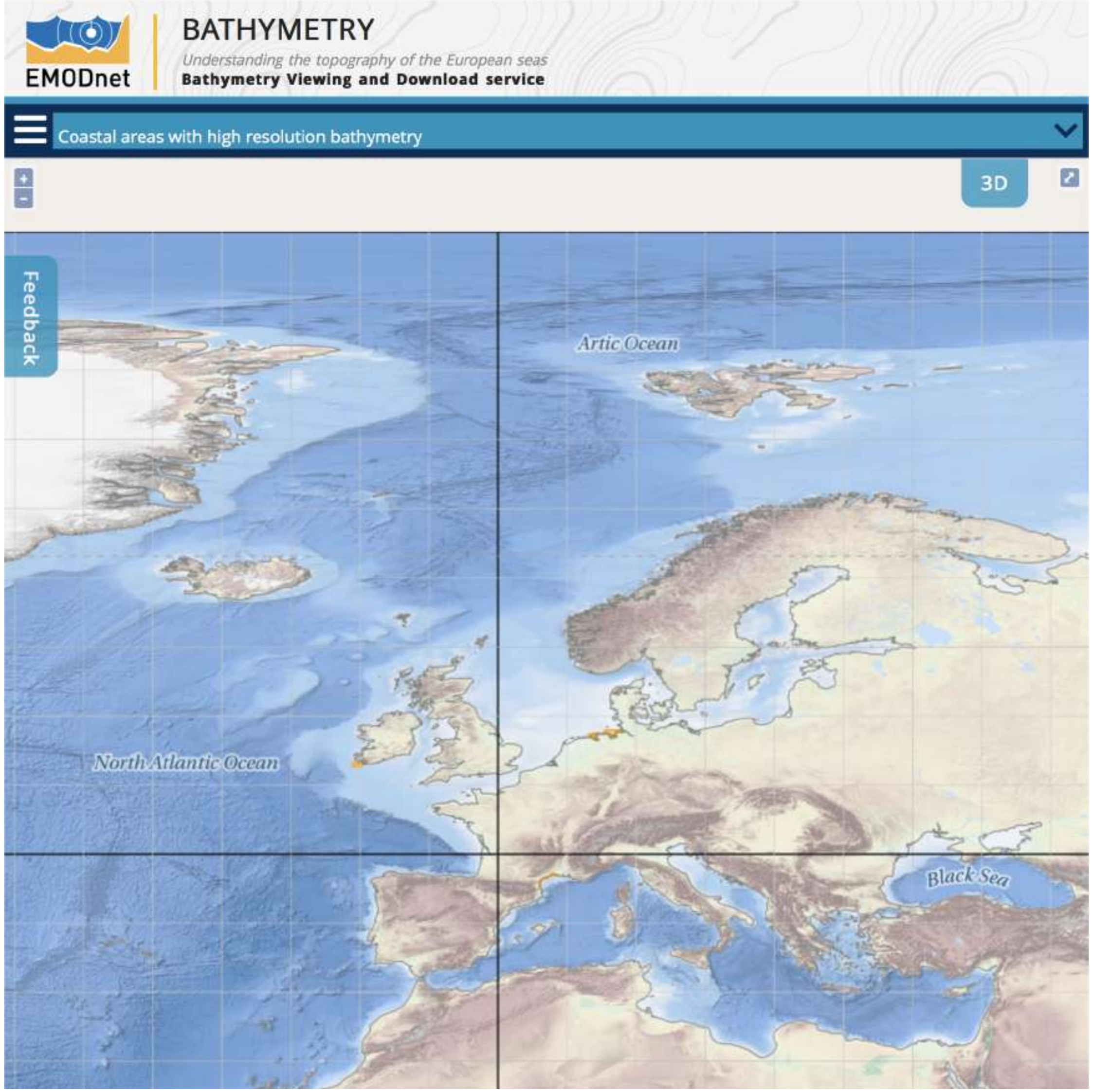
Global sea floor topography from gravity data derived from satellite altimetry and shipboard depth soundings



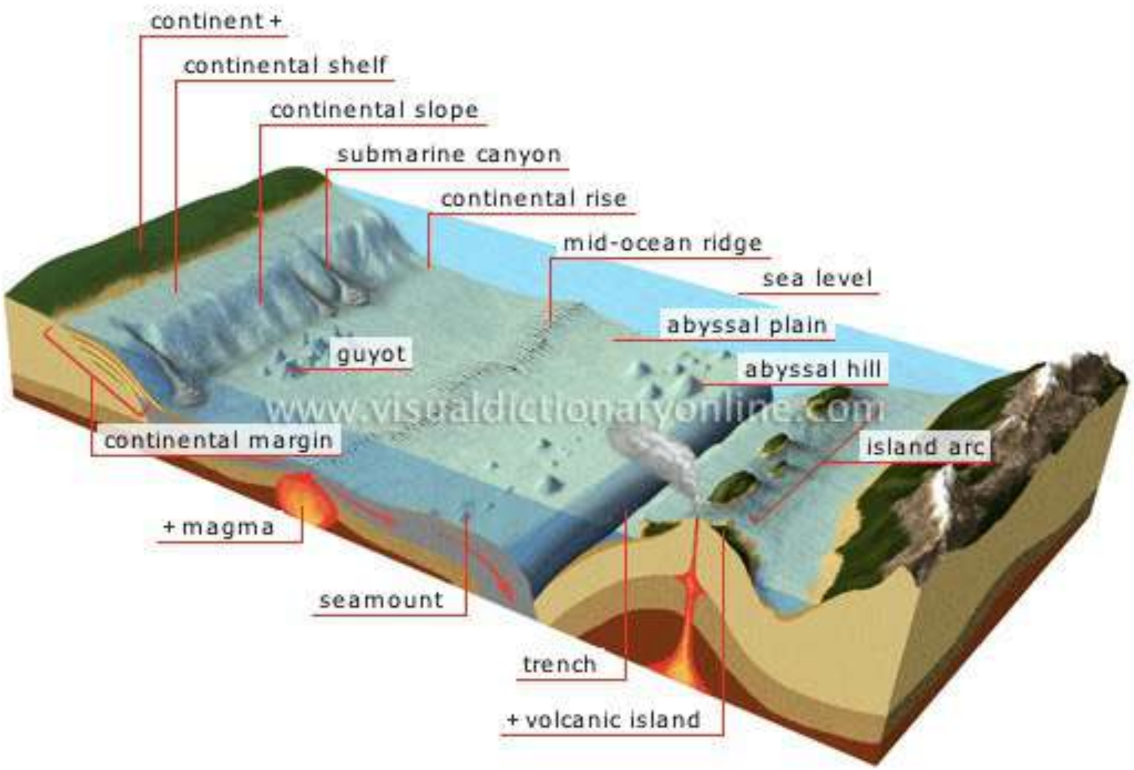
Walter H. F. Smith and David T. Sandwell, Seafloor Topography Version 4.0, SIO, September 26, 1996


General Bathymetric Chart of the Oceans - GEBCO
http://www.gebco.net
ASIA
NORTH AMERICA
SOUTH AMERICA
EUROPE
ANTARCTICA
GENERAL BATHYMETRIC CHART OF THE OCEANS (GEBCO)
WORLD OCEAN BATHYMETRY

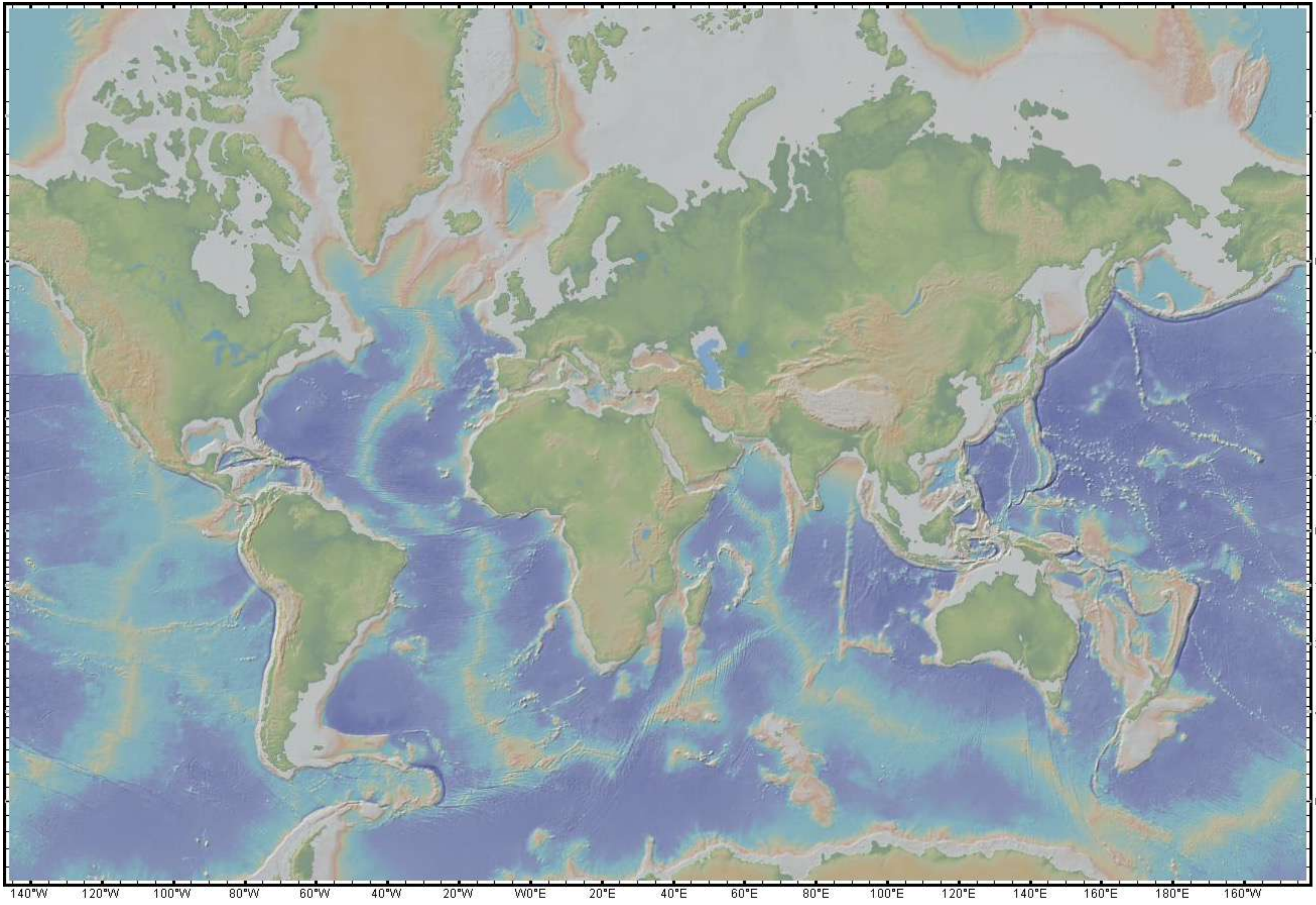
EMODNET
http://www.emodnet.eu



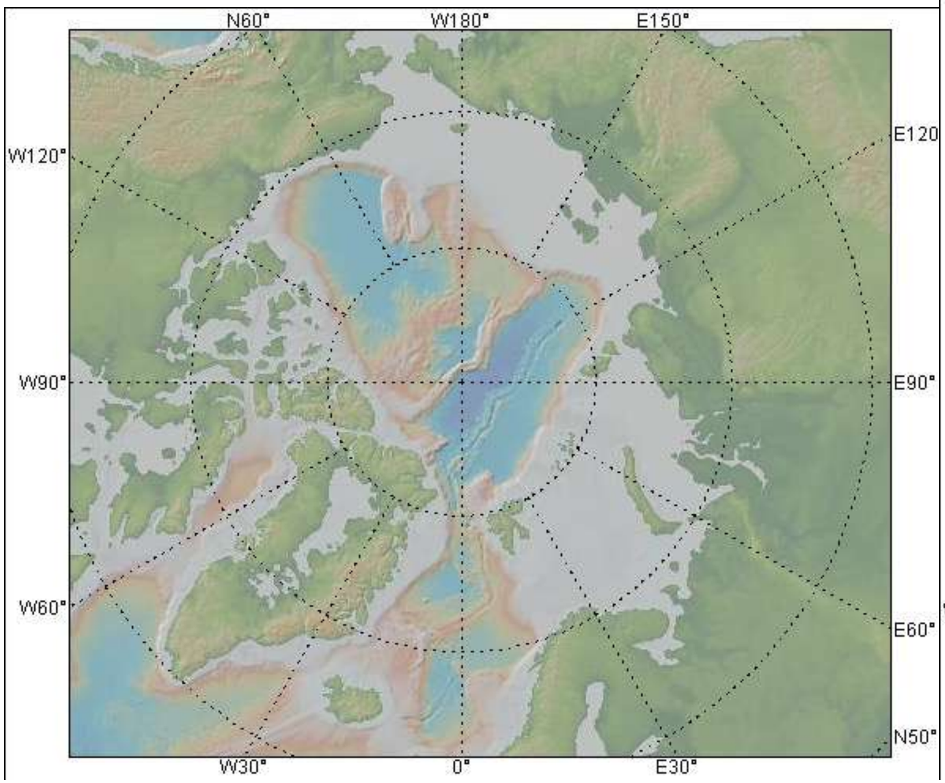
SEA FLOOR GEO-MORPHOLOGY

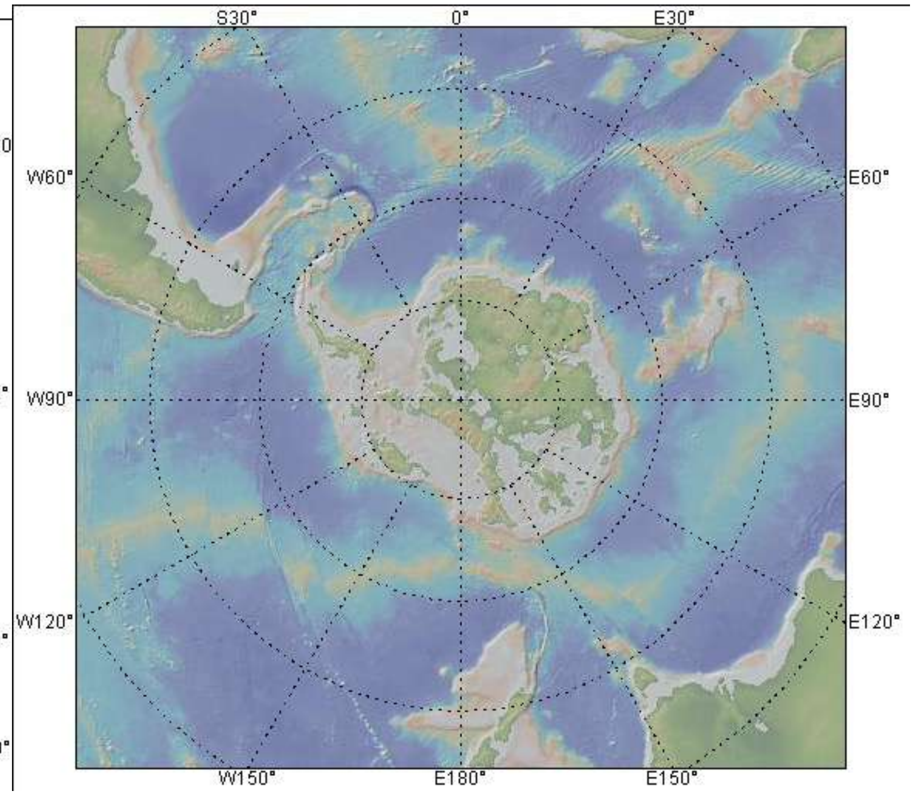


SEA FLOOR MORPHOLOGY



POLAR SEAS AND OCEANS





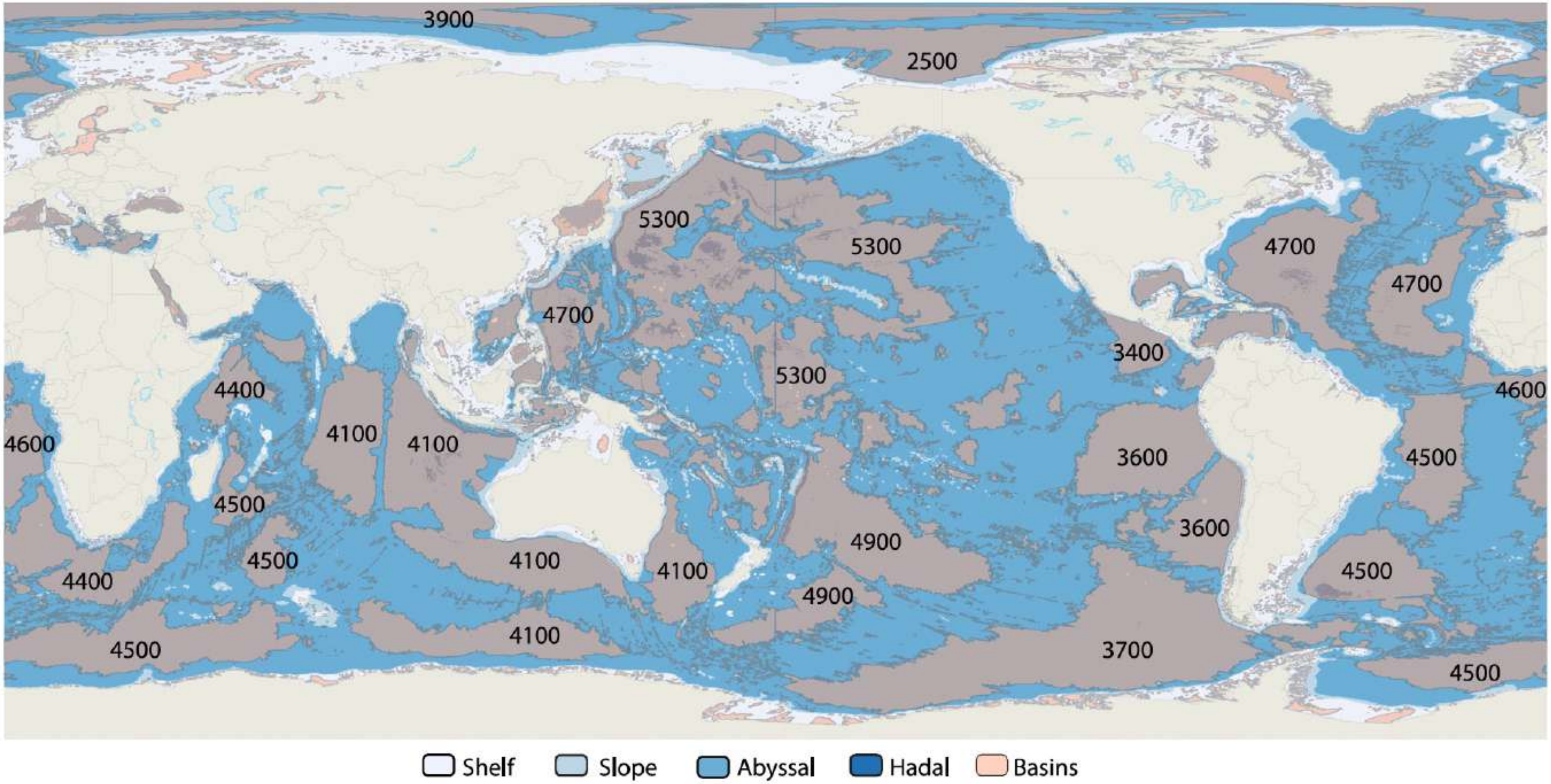


Fig. 3. Basins mapped in this study. The numbers indicate contour depths of major ocean basins based on the most shallow, closed, bathymetric contour that defines the basin outline, illustrating that the deepest basins are located in the northwest Pacific.

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

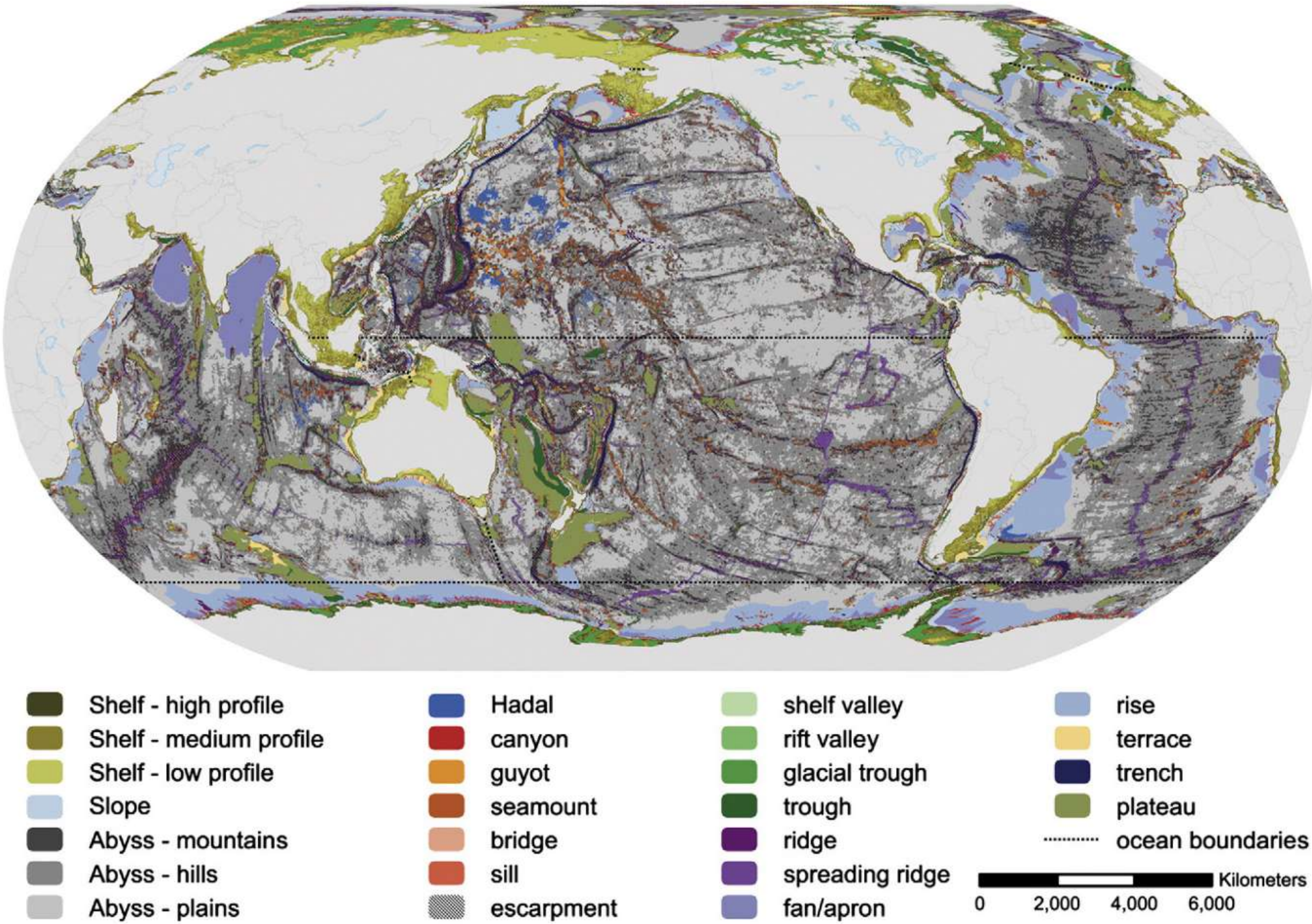


Fig. 4. Geomorphic features map of the world's oceans. Dotted black lines mark boundaries between major ocean regions. Basins are not shown.

Harris et al., 2014. Geomorphology of the oceans. Marine Geology

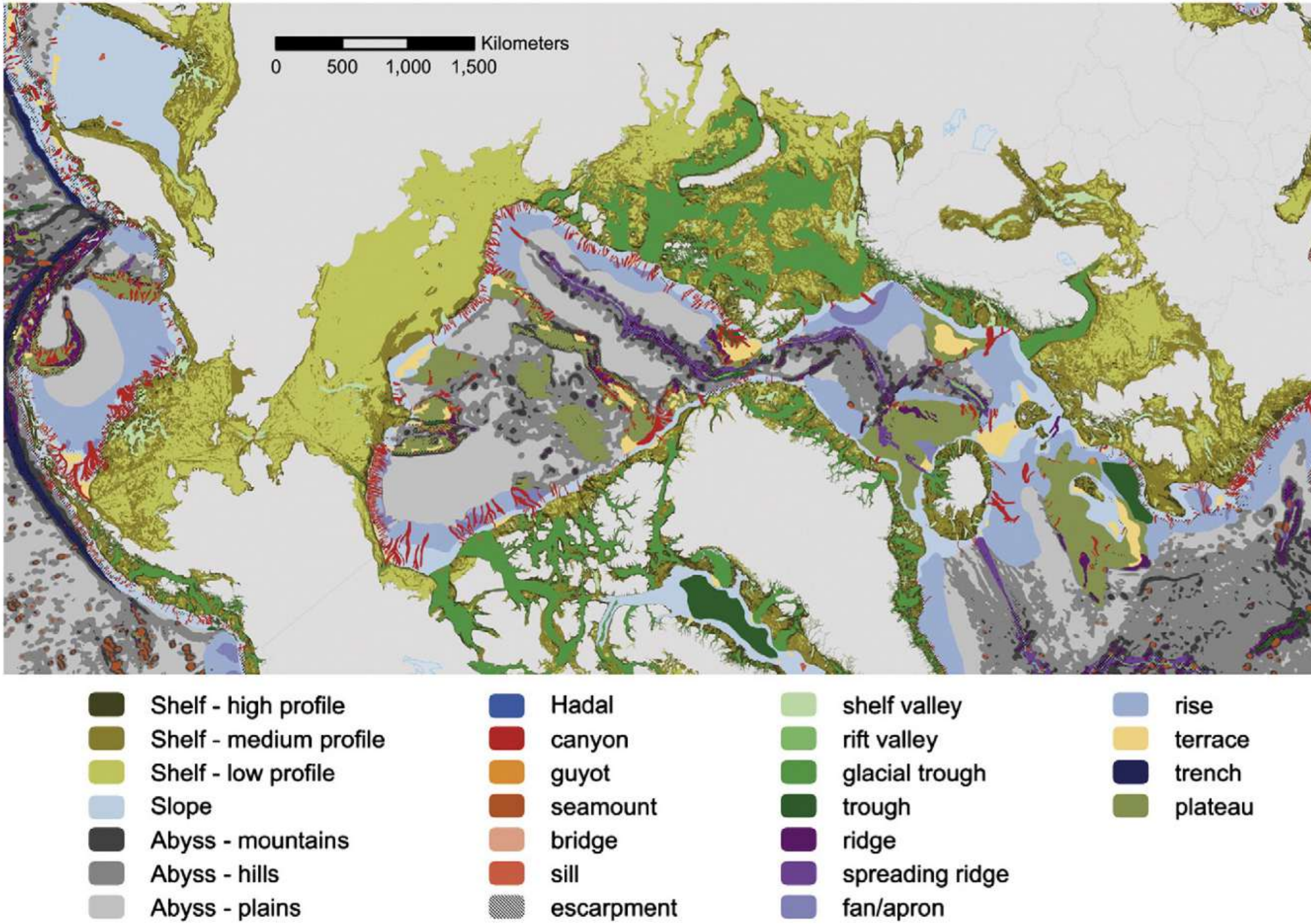


Fig. 5. Geomorphic features map of the Arctic Ocean. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.

Harris et al., 2014. Geomorphology of the oceans. Marine Geology

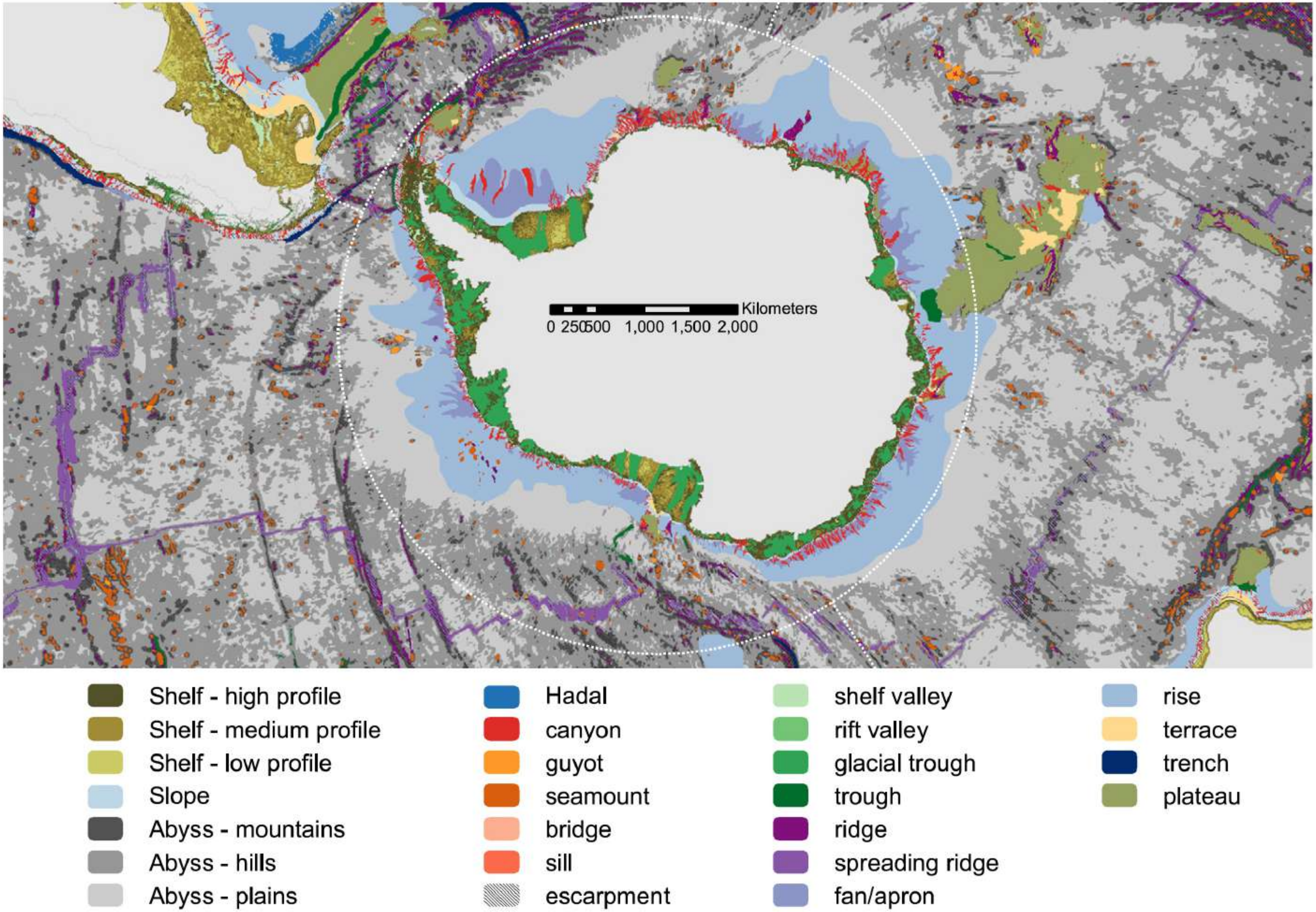


Fig. 12. Geomorphic features map of the Southern Ocean. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.

Harris et al., 2014. Geomorphology of the oceans. Marine Geology

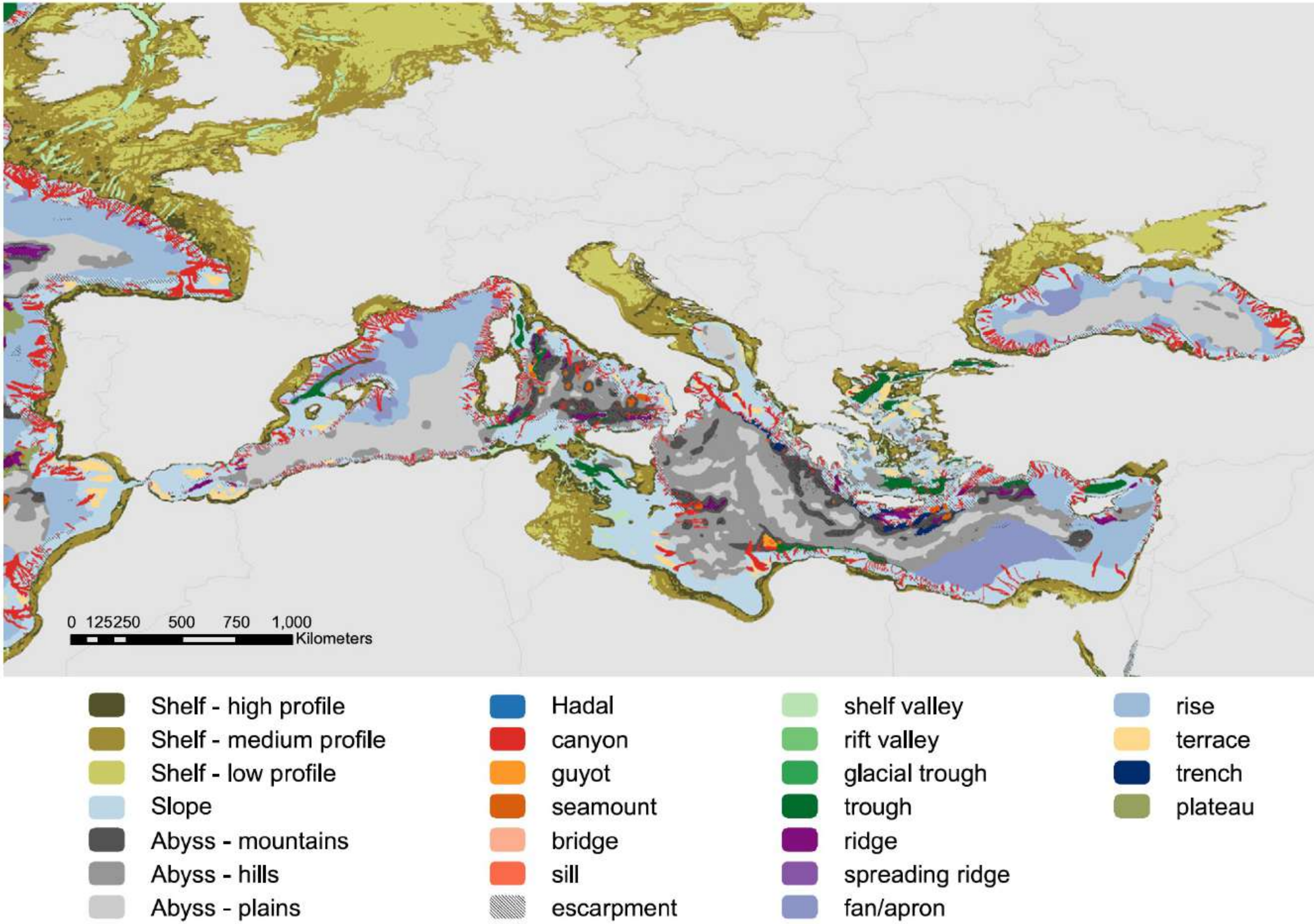


Fig. 7. Geomorphic features map of the Mediterranean and Black Seas. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.

Harris et al., 2014. Geomorphology of the oceans. Marine Geology

3. The geological structure of the oceans

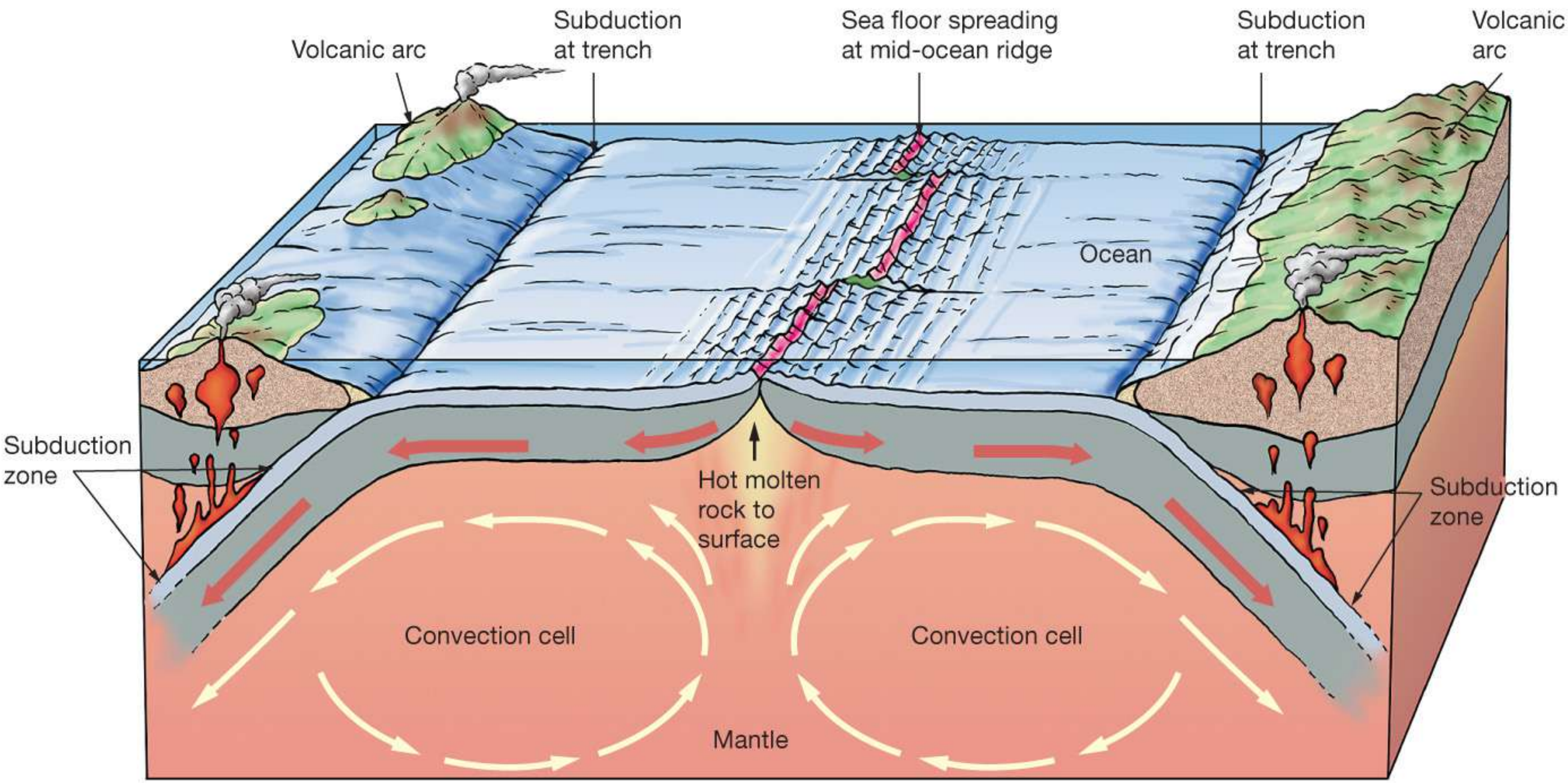


PLATE BOUNDARIES

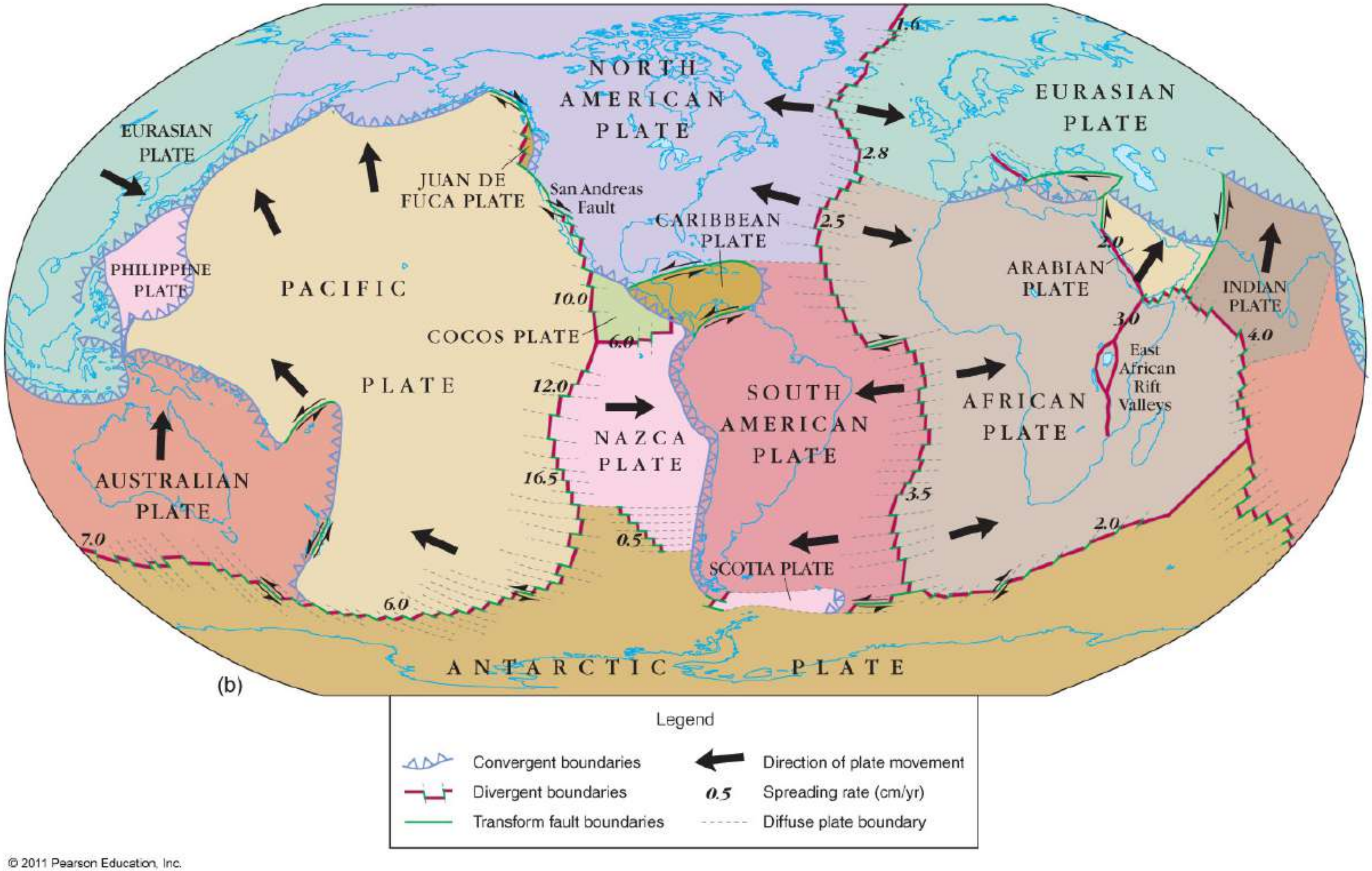
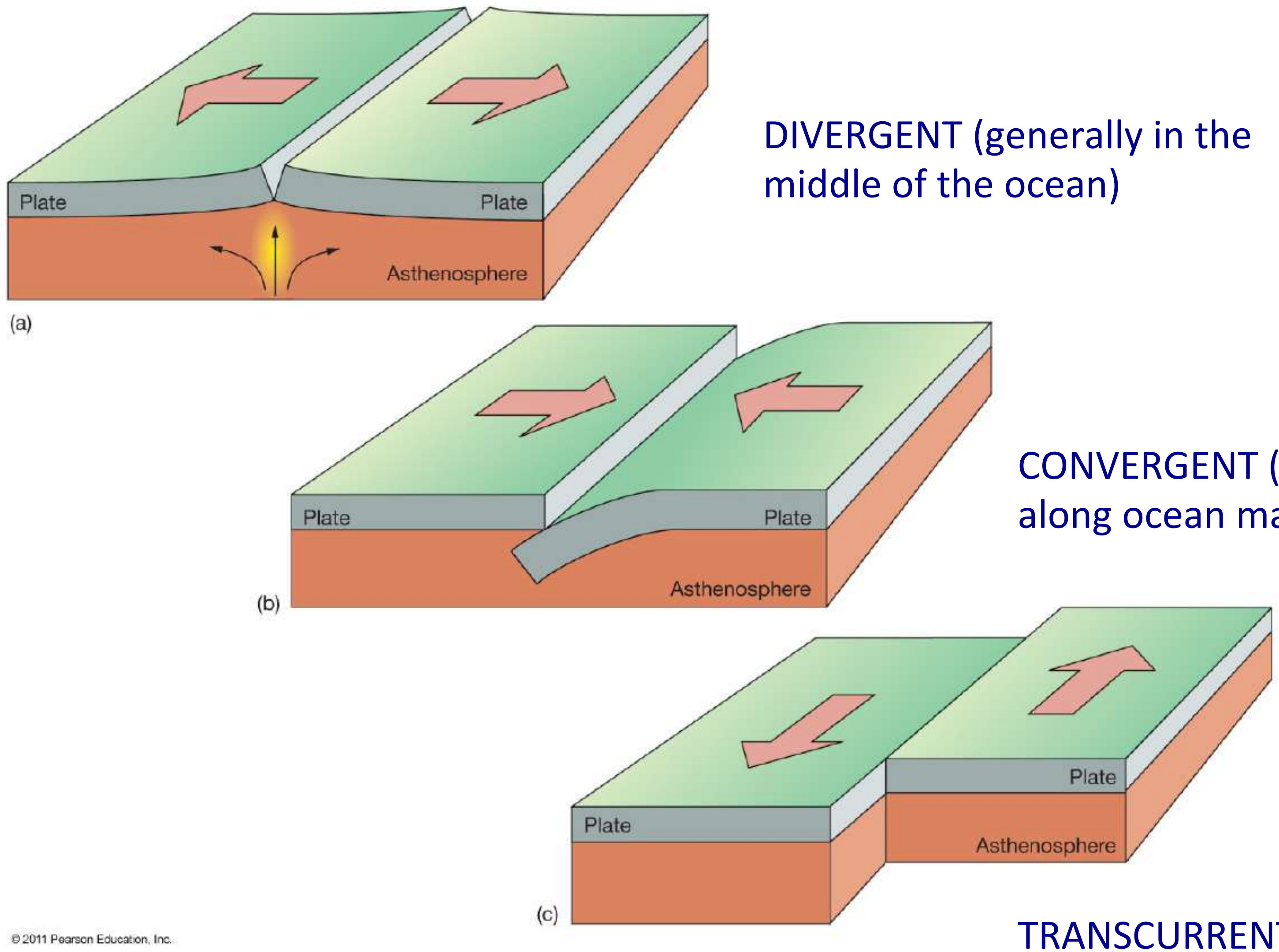


PLATE BOUNDARIES

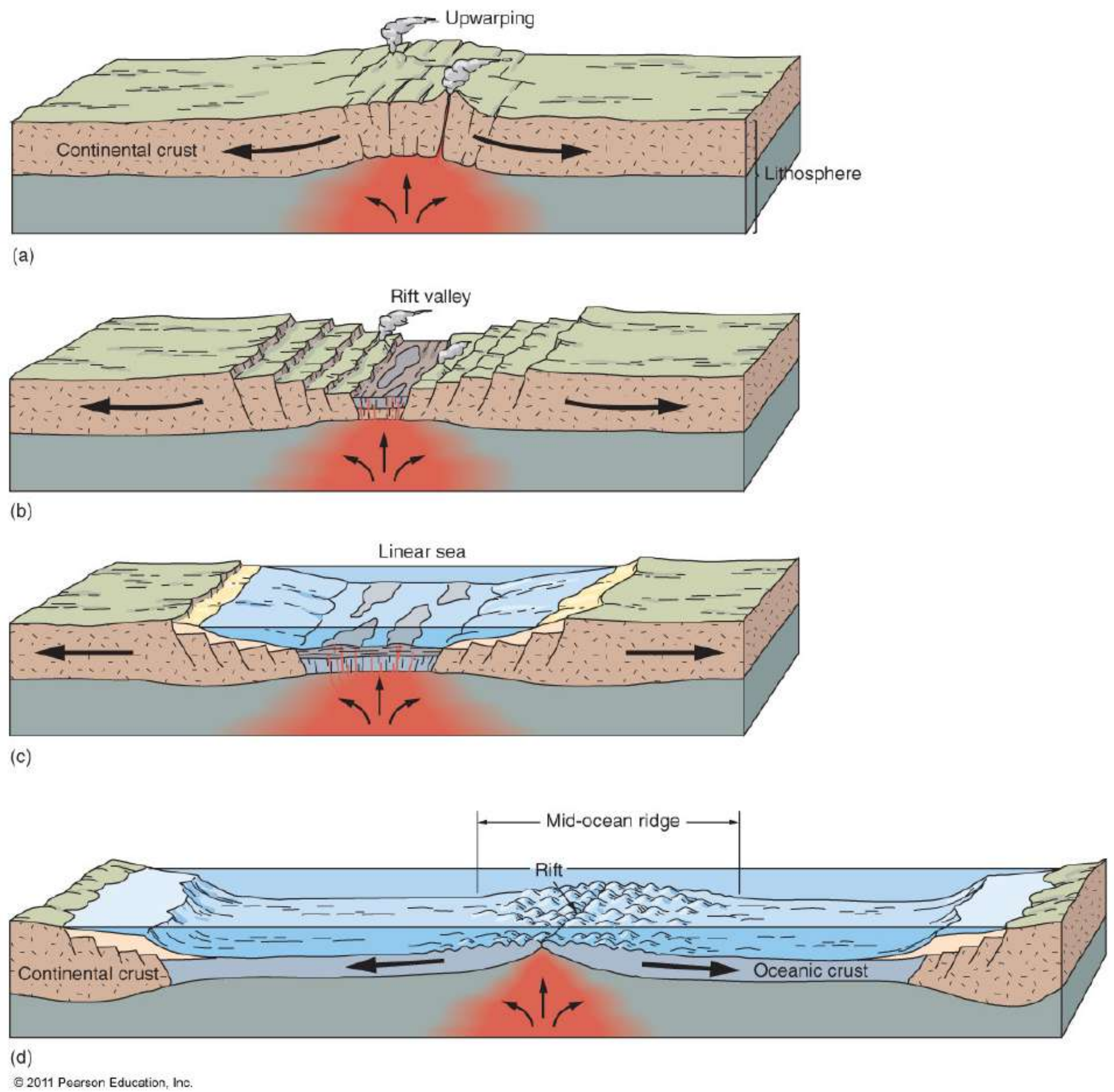


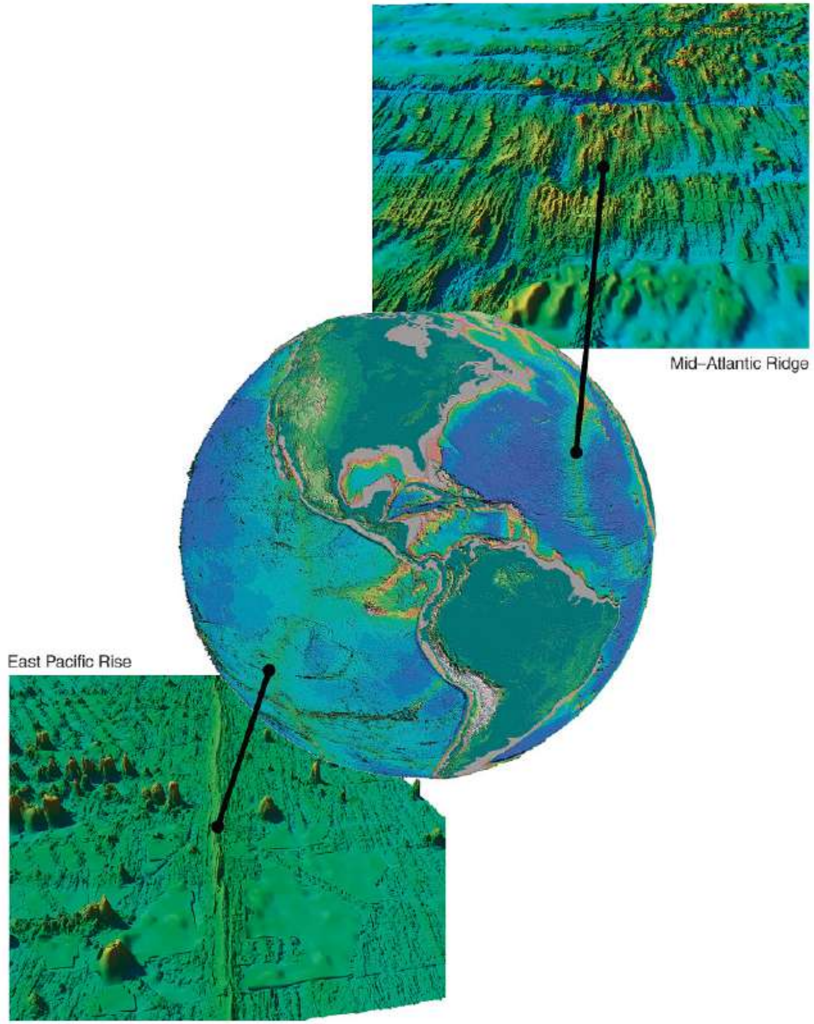
DIVERGENT (generally in the middle of the ocean)

CONVERGENT (generally along ocean margins)

TRANSCURRENT (generally in the middle of the ocean)

Generation of a Divergent Boundary

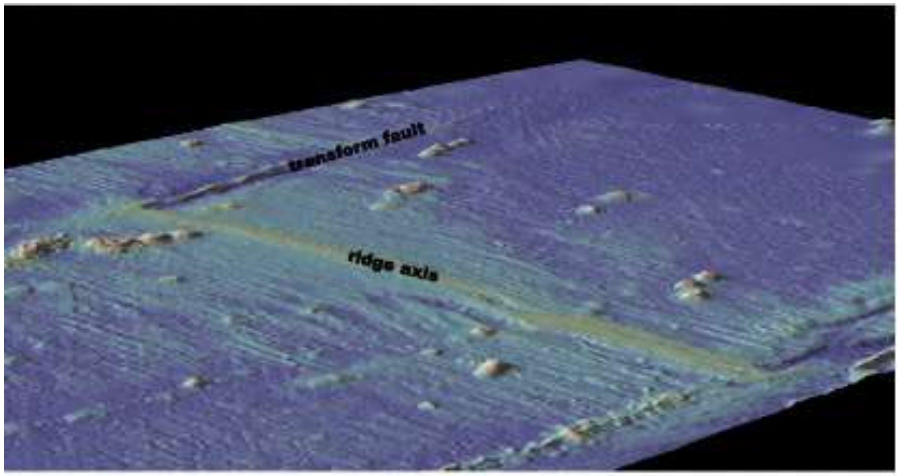



Mid–Atlantic Ridge
East Pacific Rise
© 2011 Pearson Education, Inc.

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

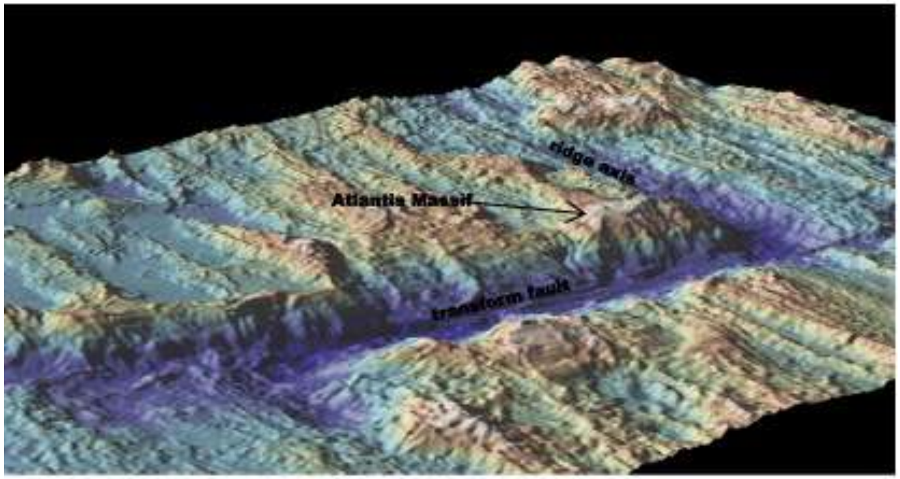
Mid-Atlantic Ridge: slow-spreading, narrow and rough

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.

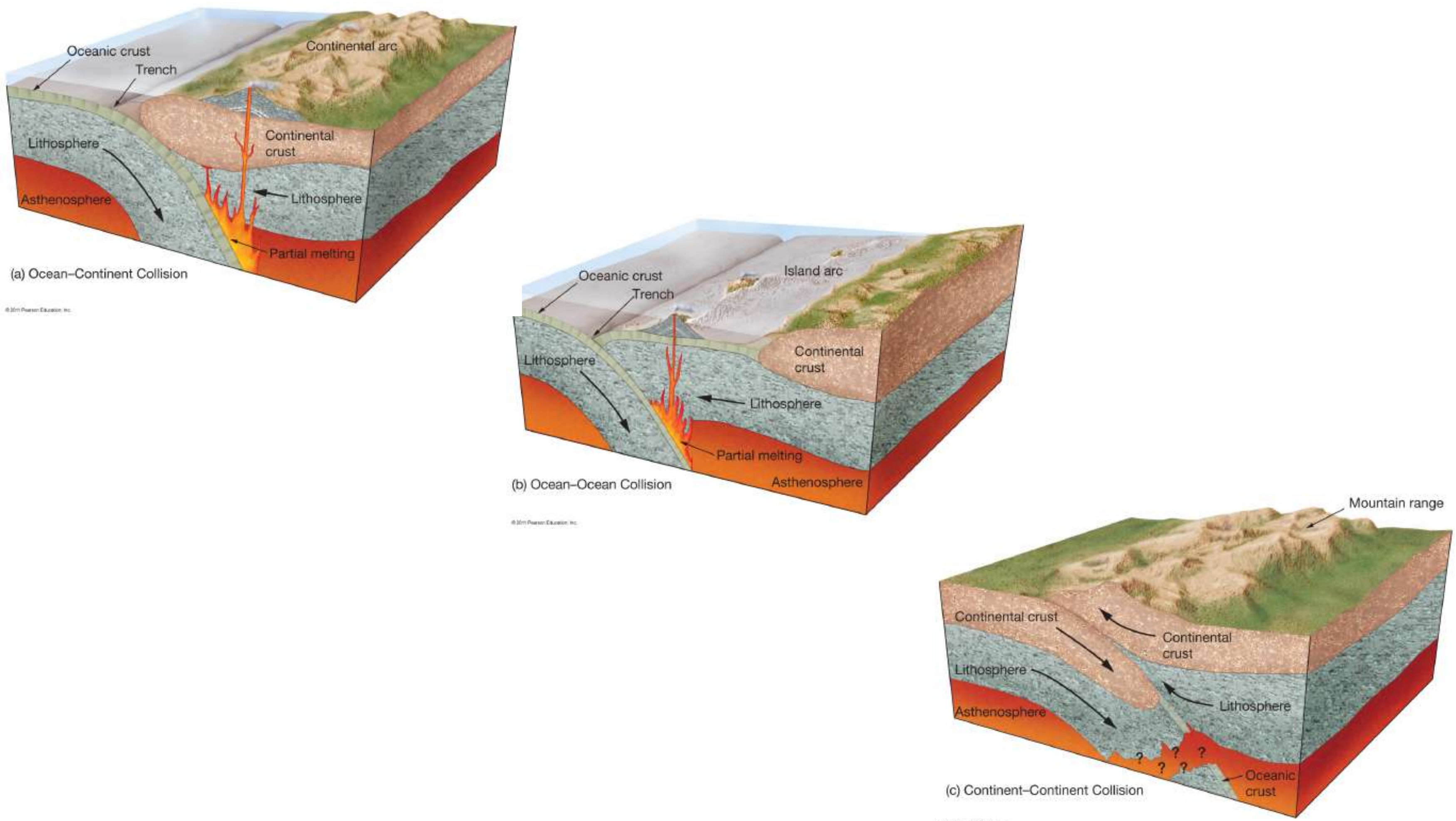


(b)

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

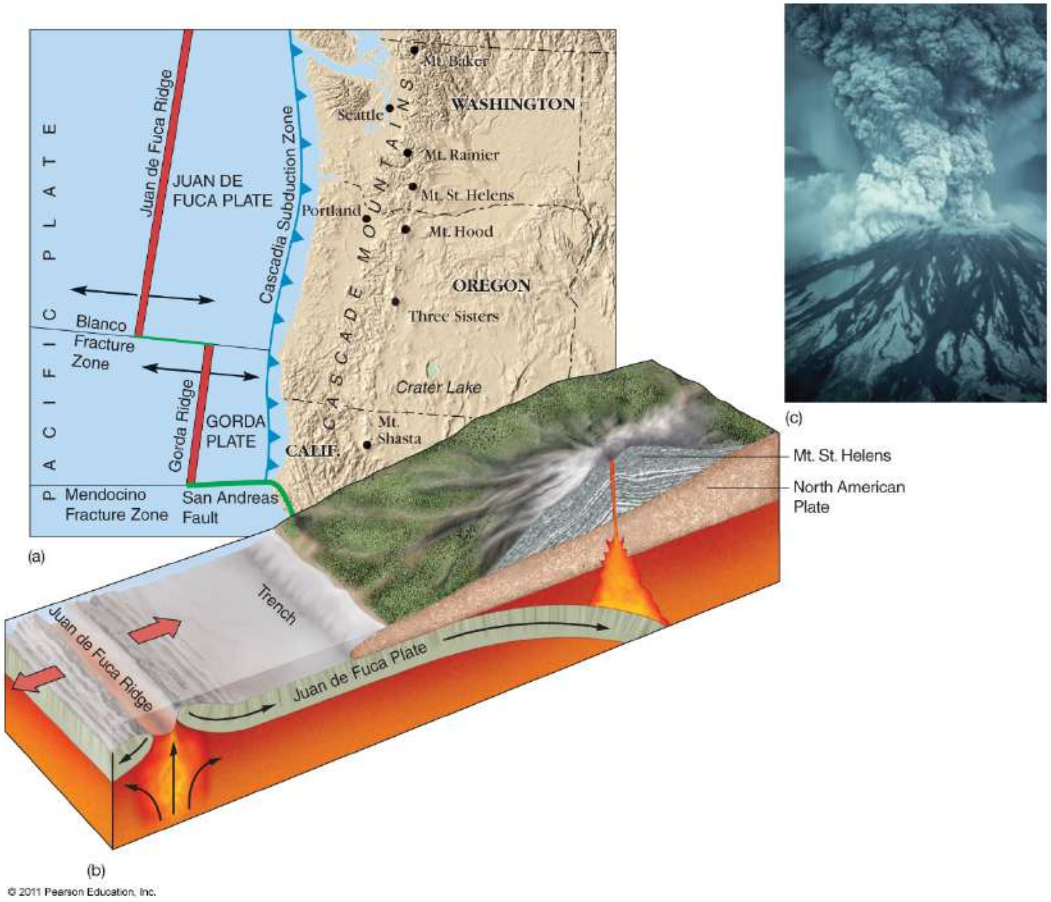


Oceanic-Continental Convergence

Ocean plate is subducted

Continental arcs generated

Explosive andesitic volcanic eruptions



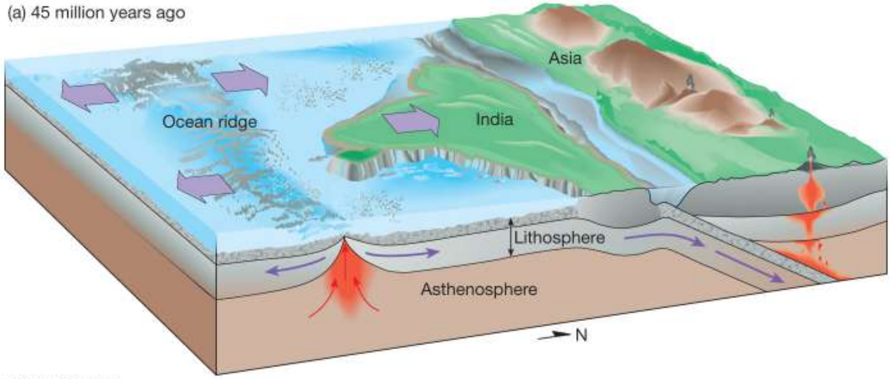
Continental-Continental Convergence

No subduction

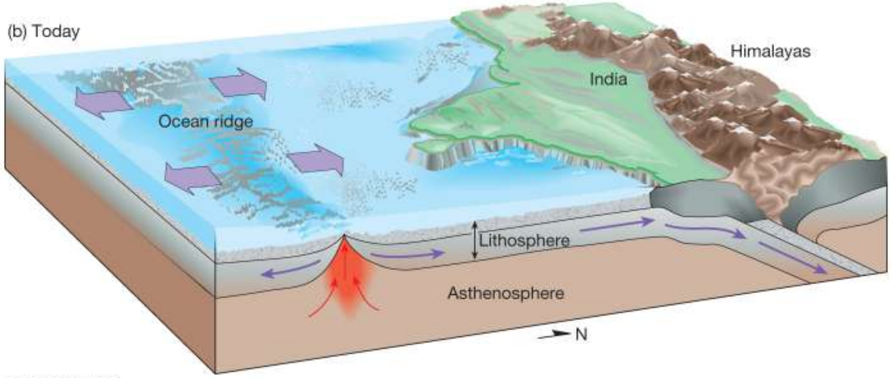
Tall mountains uplifted

(c)

(a) 45 million years ago

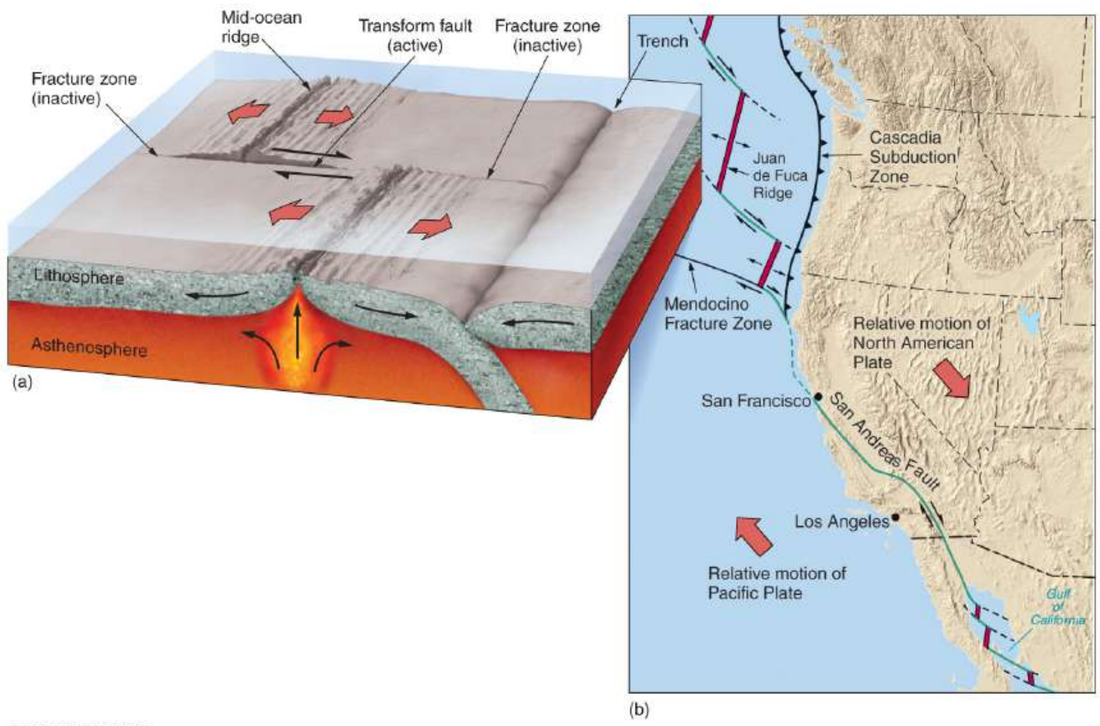


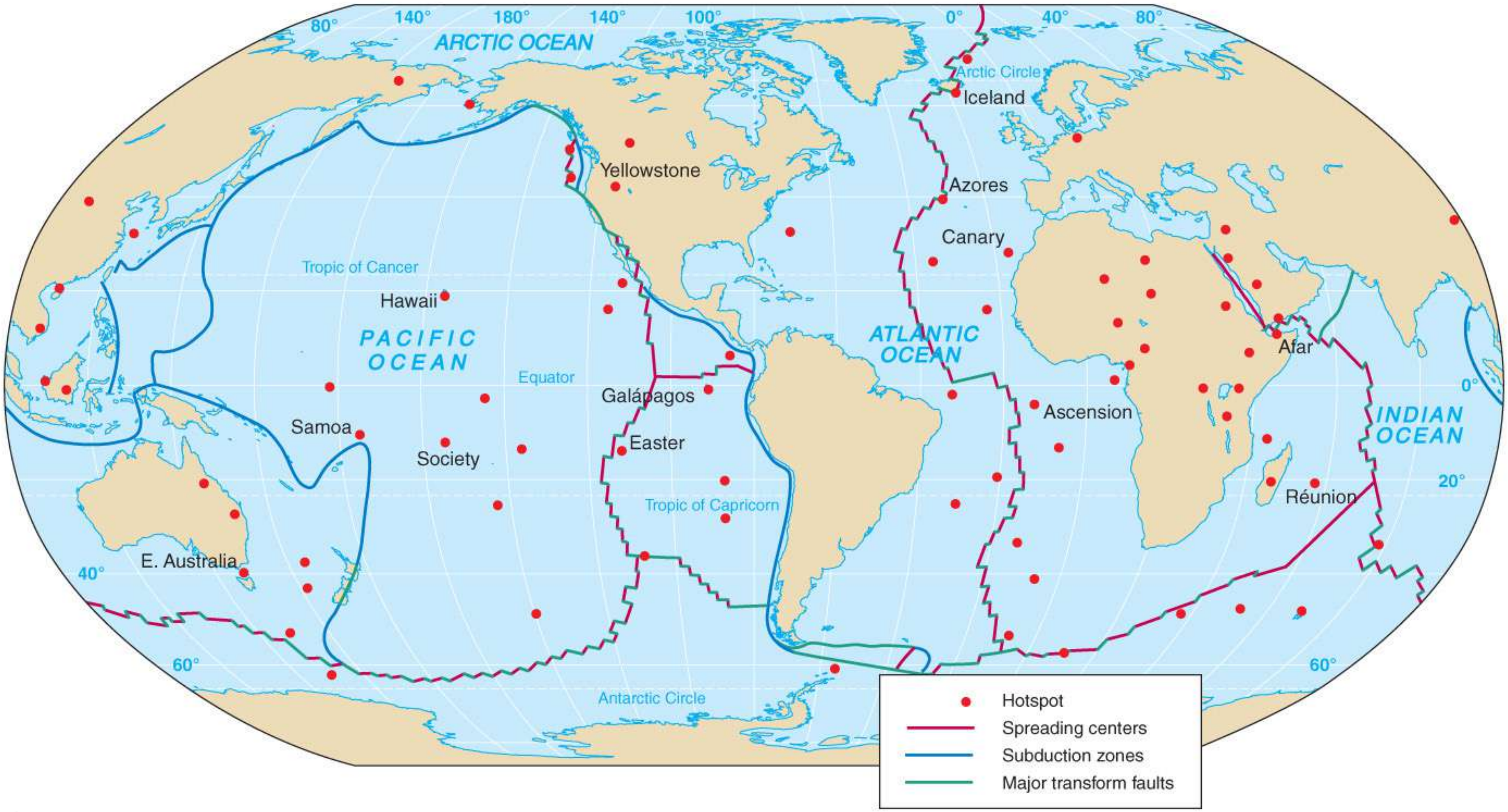
(b) Today



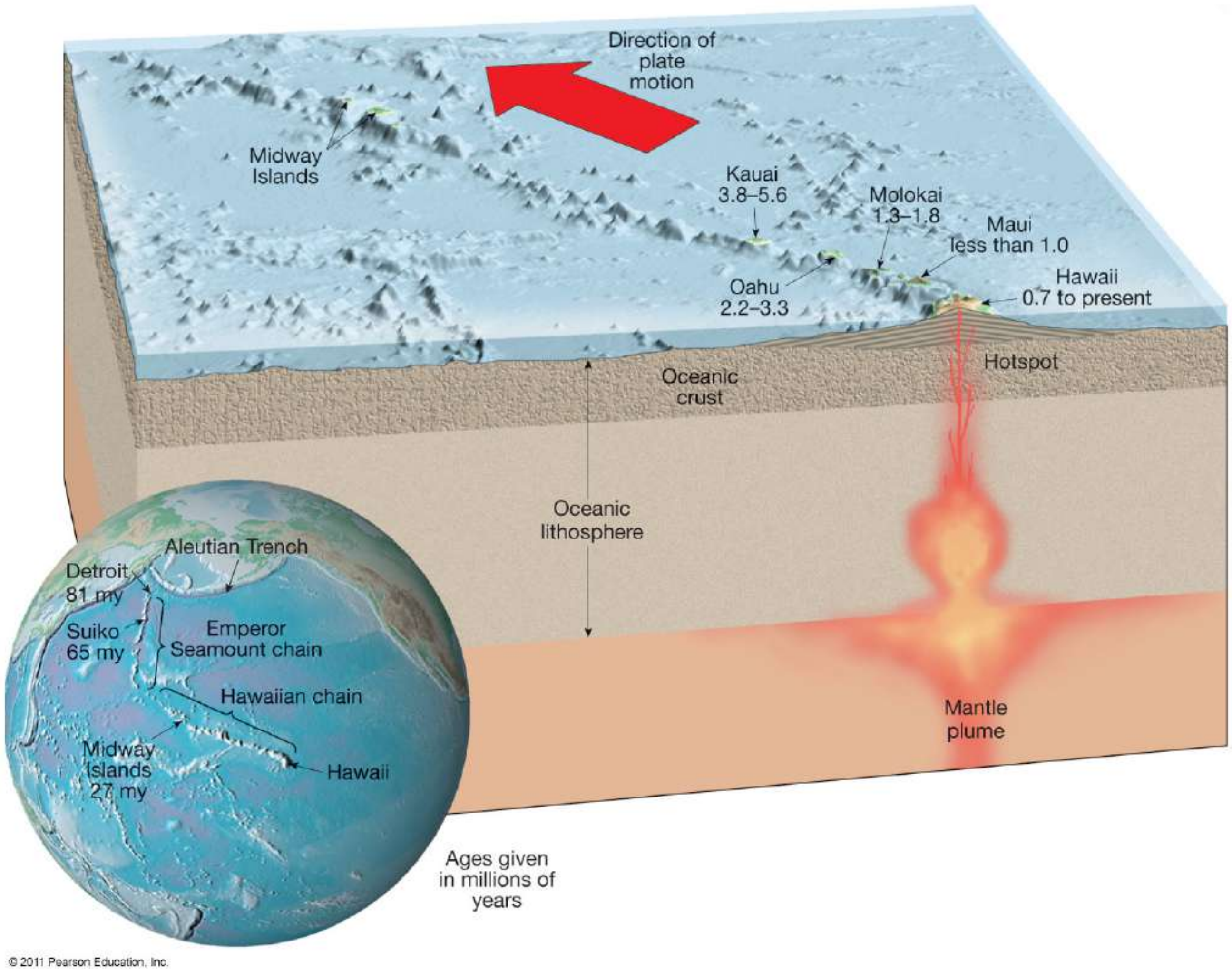
Oceanic Transform Fault – ocean floor only
Continental Transform Fault – cuts across continent

All transform faults occur between mid-ocean ridge segments.




ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
Iceland
Azores
Canary
Yellowstone
Hawaii
Galápagos
Easter
Samoa
Society
E. Australia
Ascension
Afar
Réunion
Hotspot
Spreading centers
Subduction zones
Major transform faults

Hawaiian Island – Emperor Seamount Nematath



Seamounts

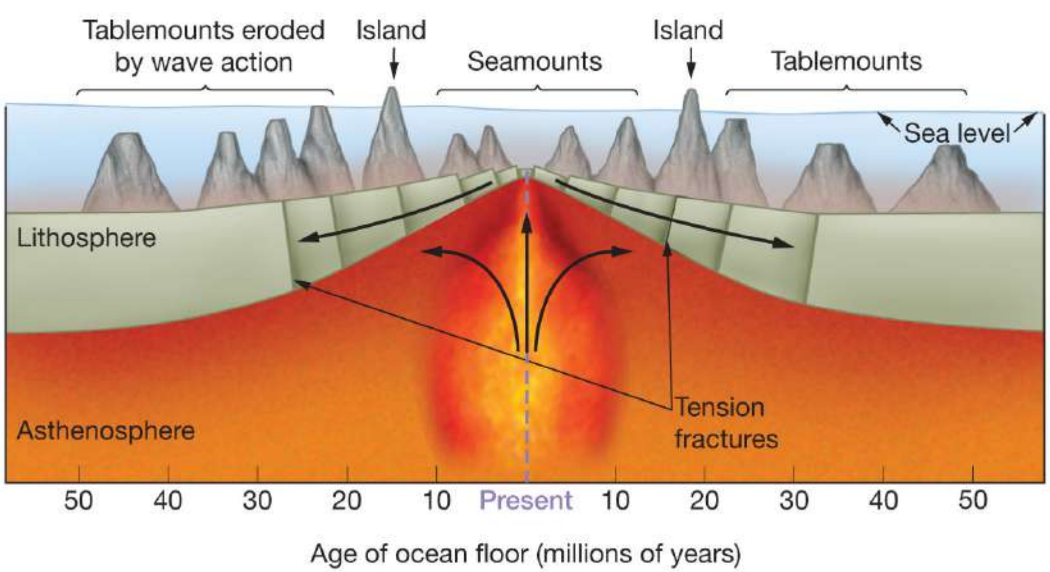
Rounded tops

Tablemounts or guyots

Flattened tops

Subsidence of flanks of mid-ocean ridge

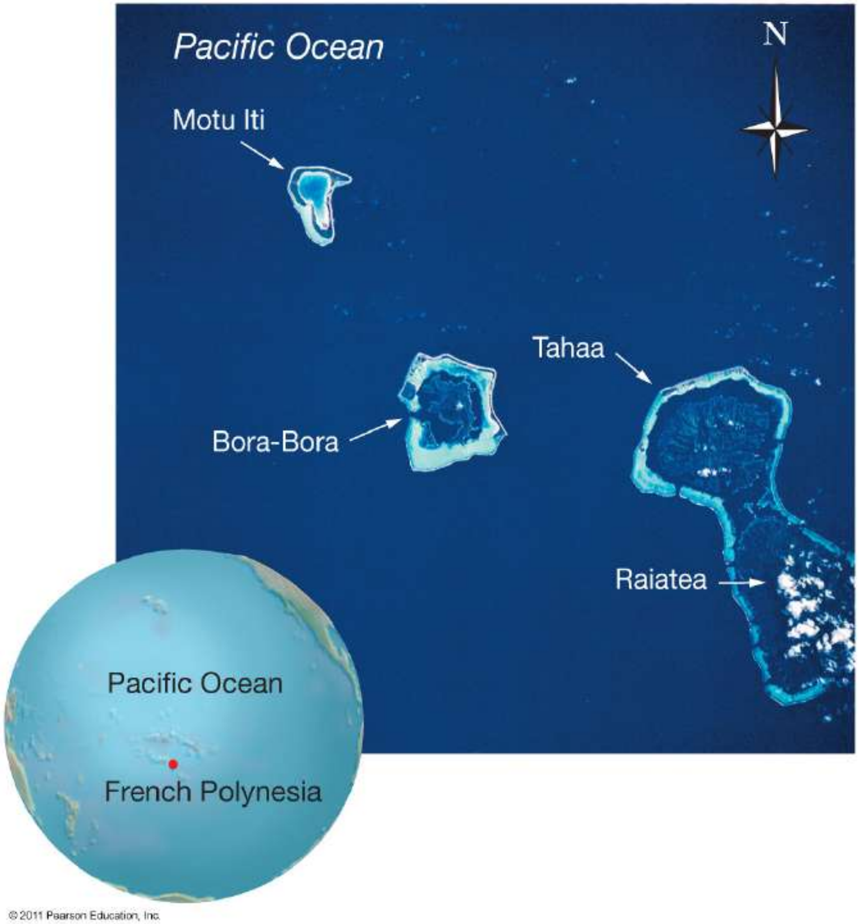
Wave erosion may flatten seamount

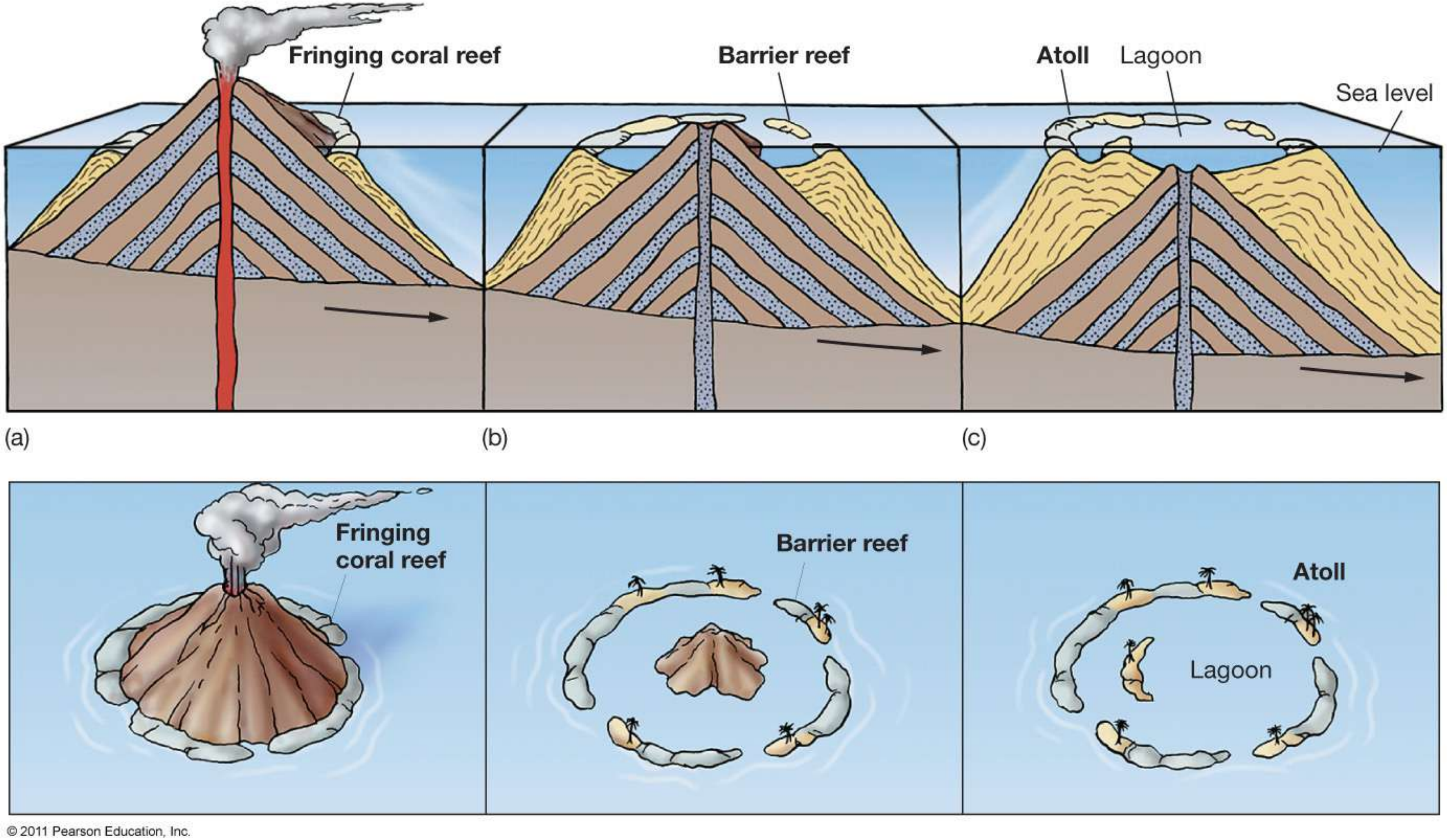


Fringing reefs – develop along margin of landmass

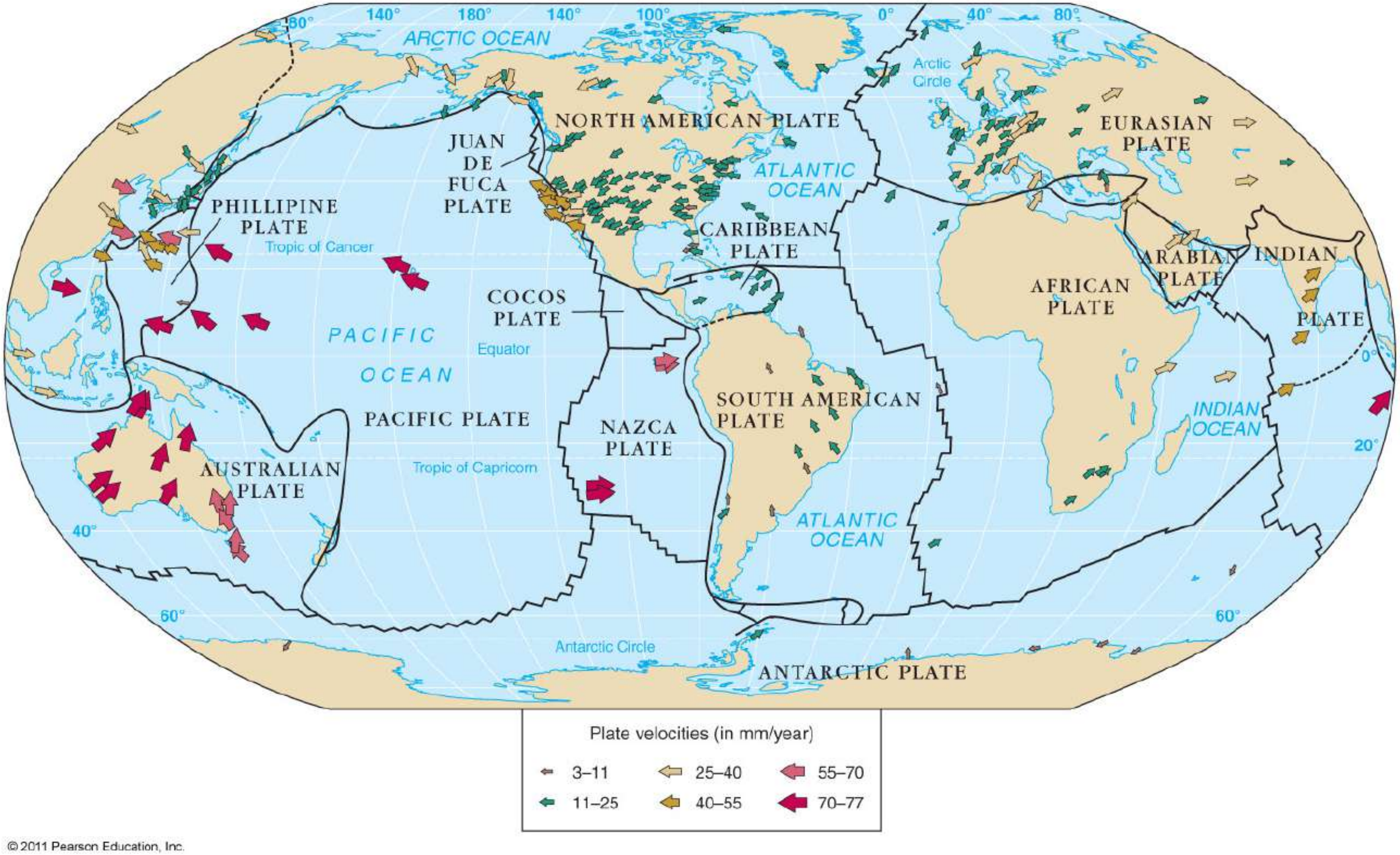
Barrier reefs – separated from landmass by lagoon

Atolls – reefs continue to grow after volcanoes are submerged

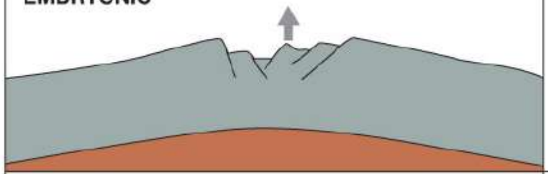
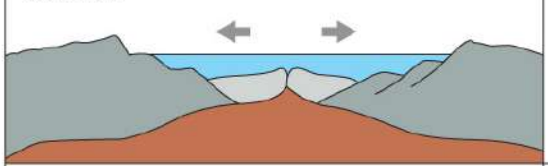
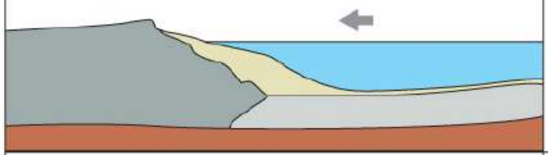
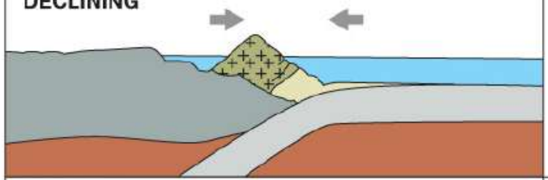
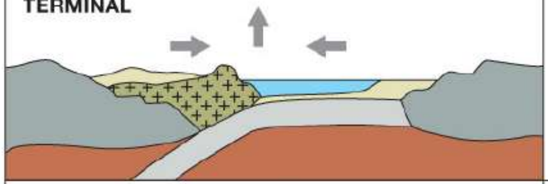
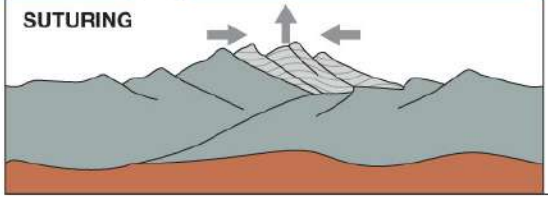



Fringing coral reef
Barrier reef
Atoll
Lagoon
Sea level
(a)
(b)
(c)
Fringing
coral reef
Barrier reef
Atoll
Lagoon
© 2011 Pearson Education, Inc.

Detecting Plate Motion with Satellites

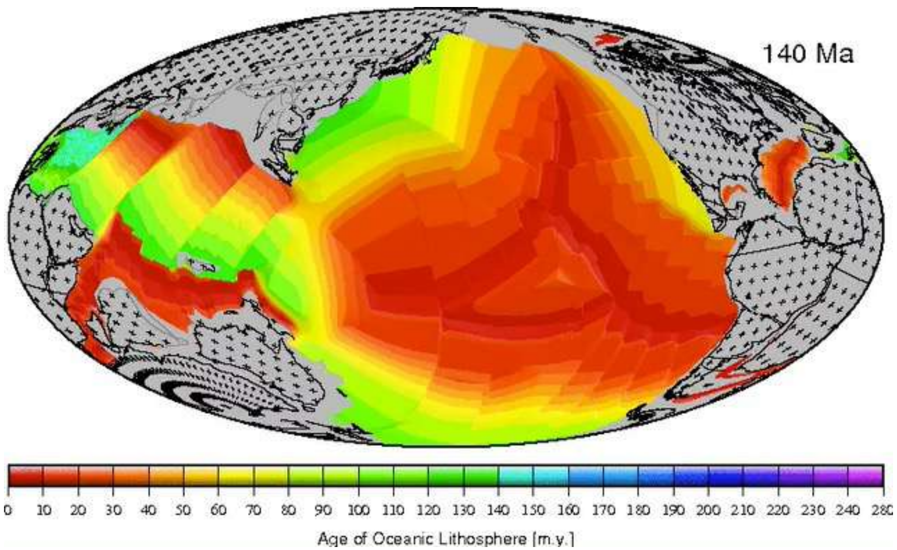


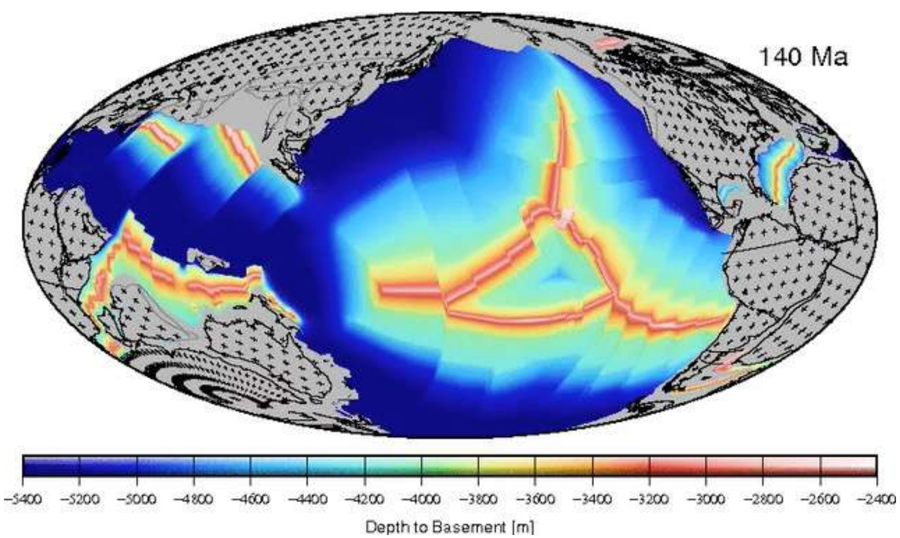
Wilson cycle

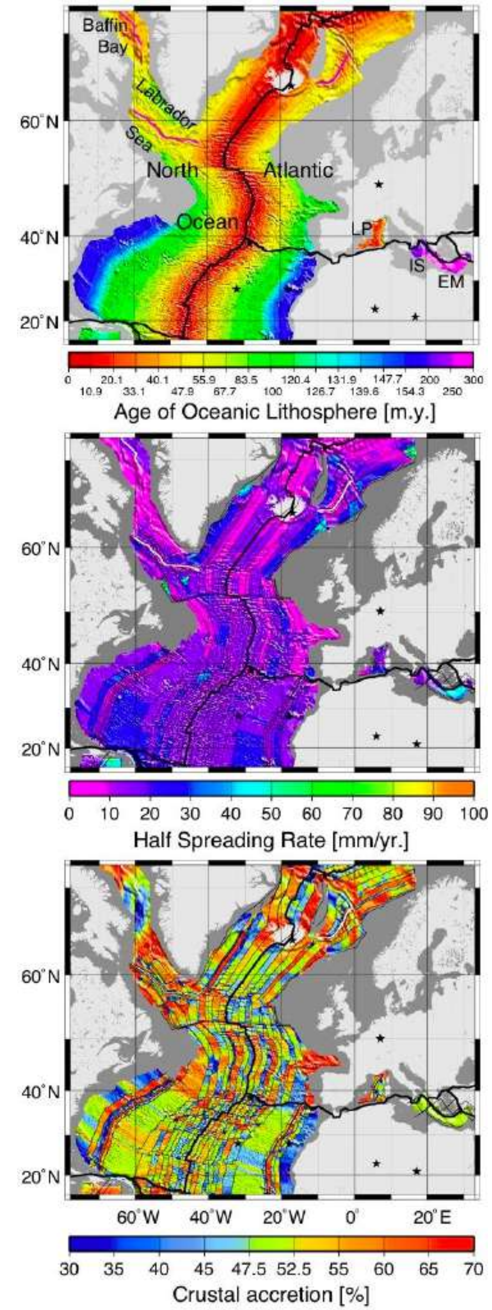
Stage, showing cross-sectional view	Motion	Physiography	Example
EMBRYONIC 	Uplift	Complex system of linear rift valleys on continent	East African rift valleys
JUVENILE 	Divergence (spreading)	Narrow seas with matching coasts	Red Sea
MATURE 	Divergence (spreading)	Ocean basin with continental margins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

EarthBYTE
Building a Virtual Earth

https://www.earthbyte.org/







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

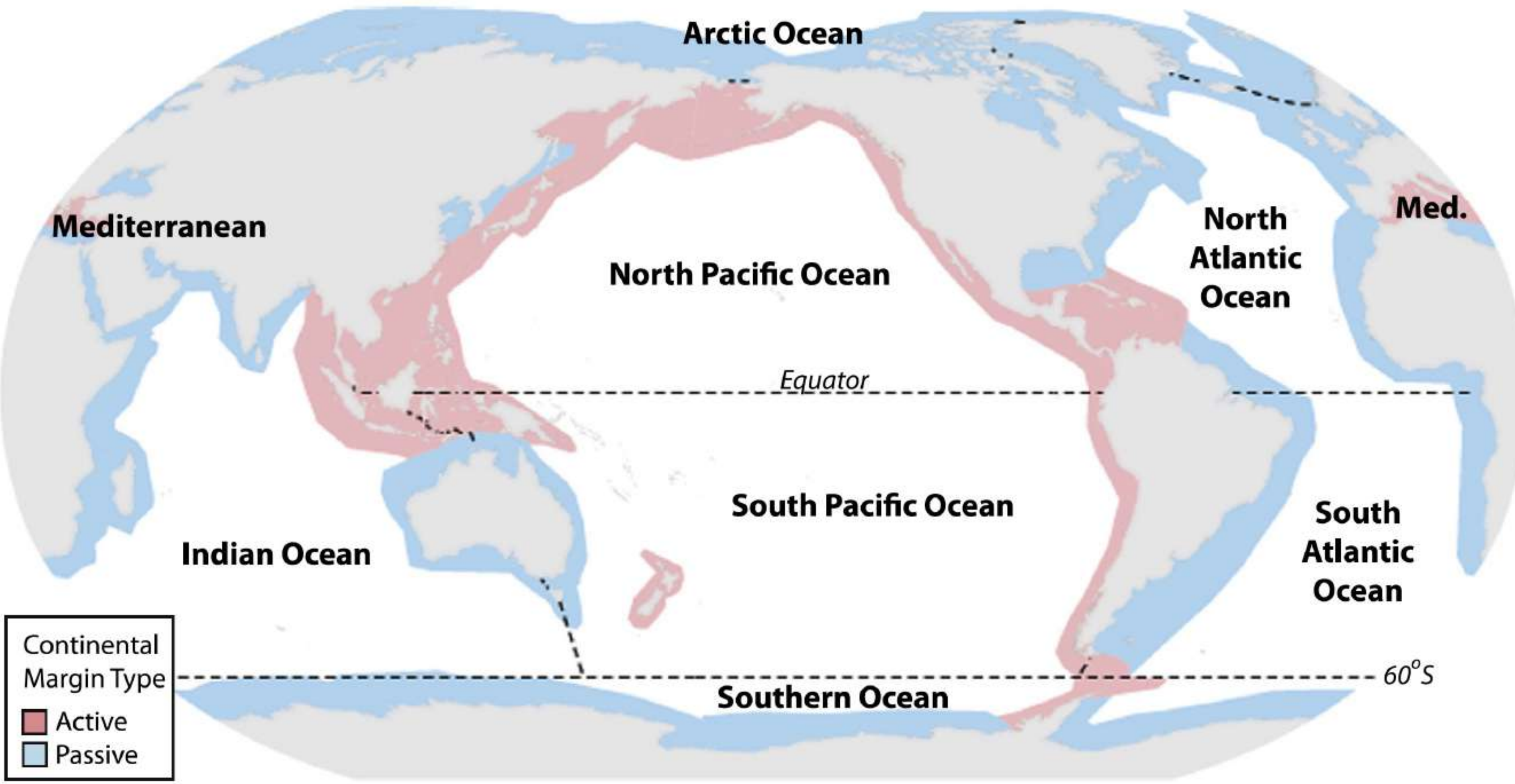
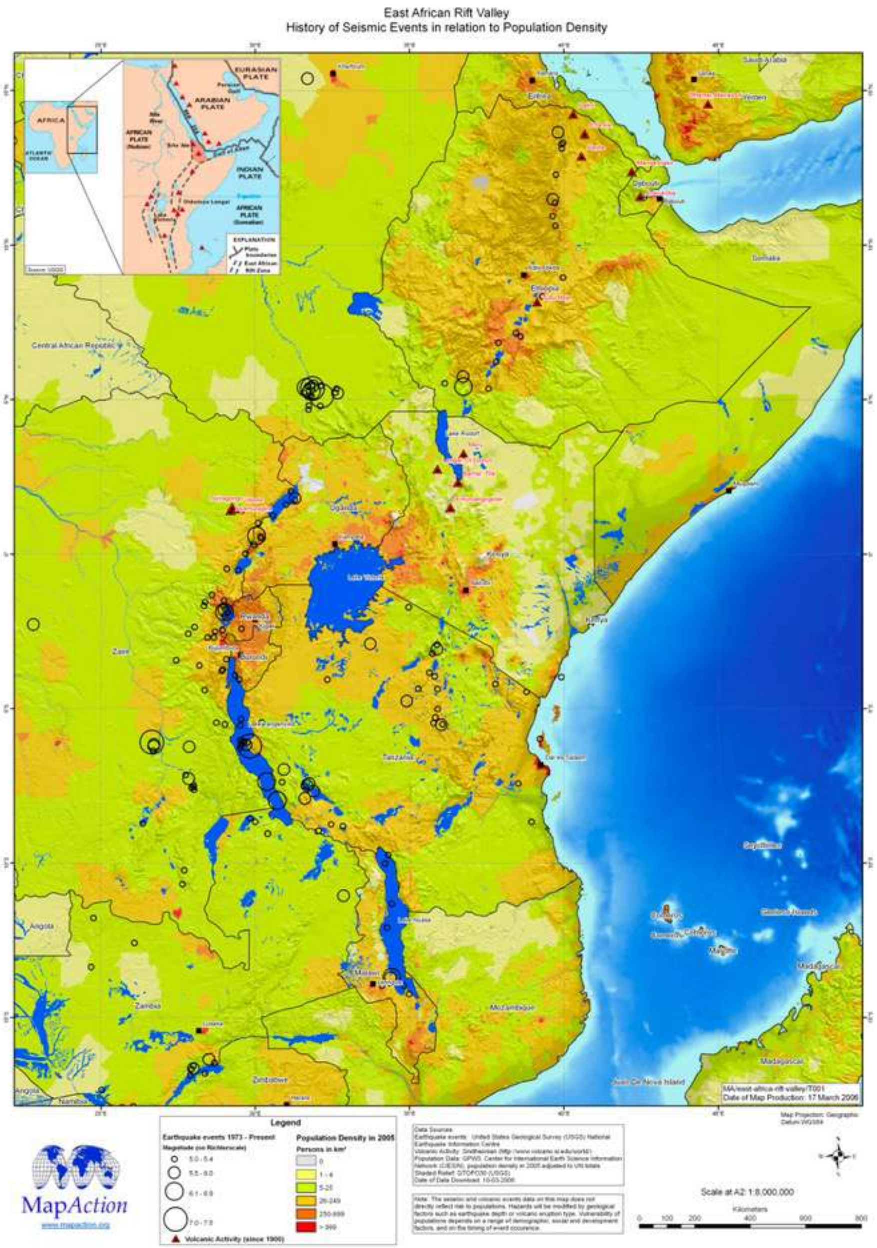
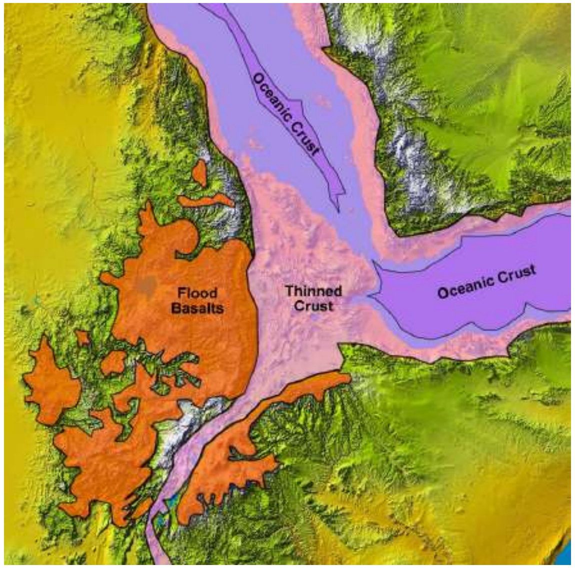


Fig. 2. Map showing the locations of active and passive continental margins and the eight ocean regions described in the text.

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

MODERN RIFTS





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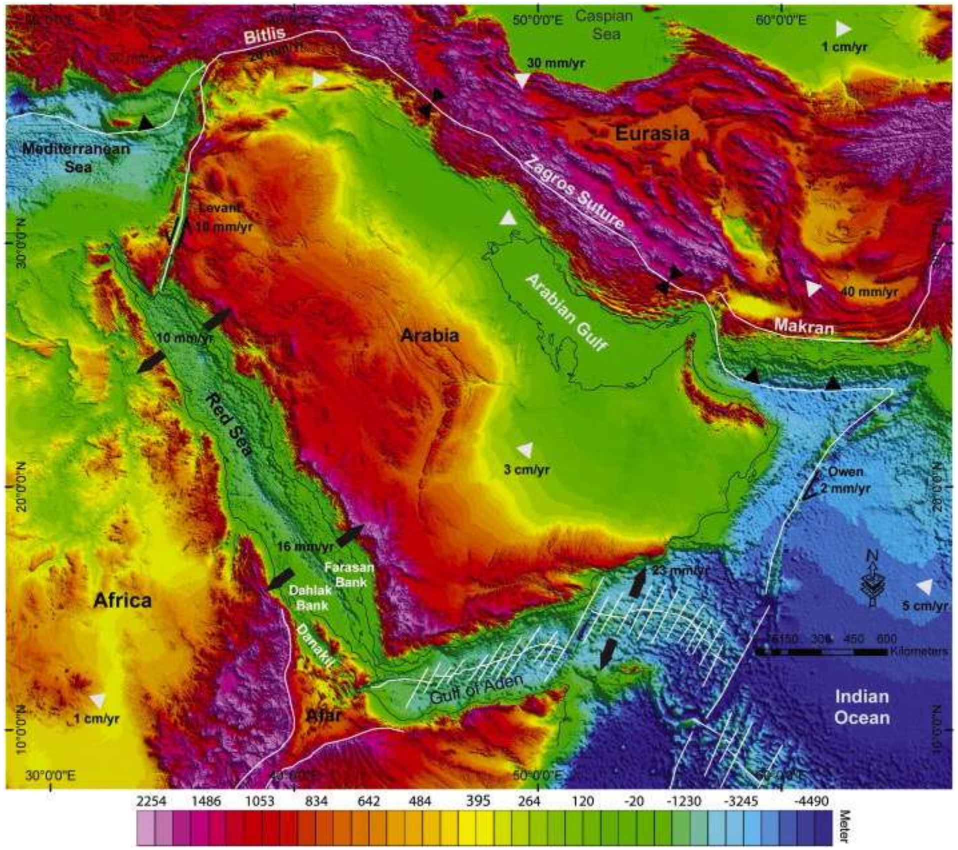
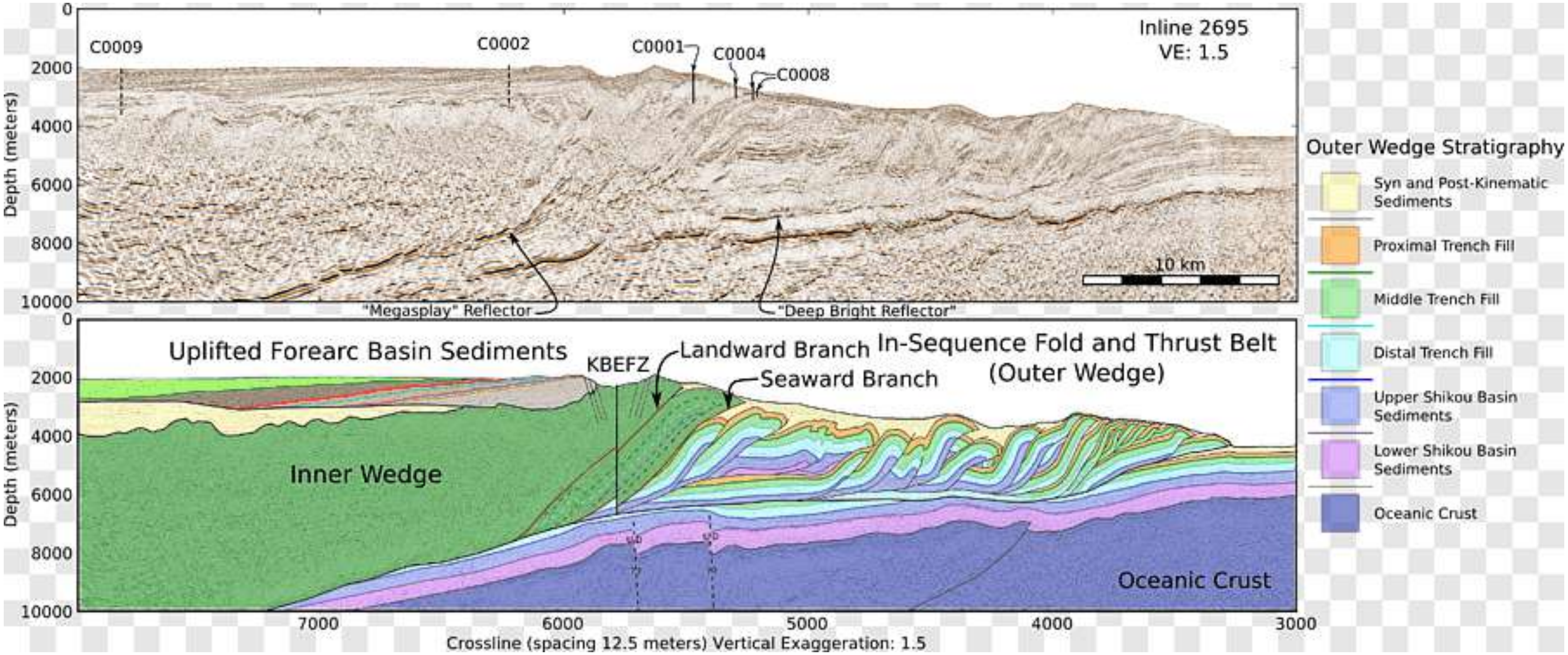
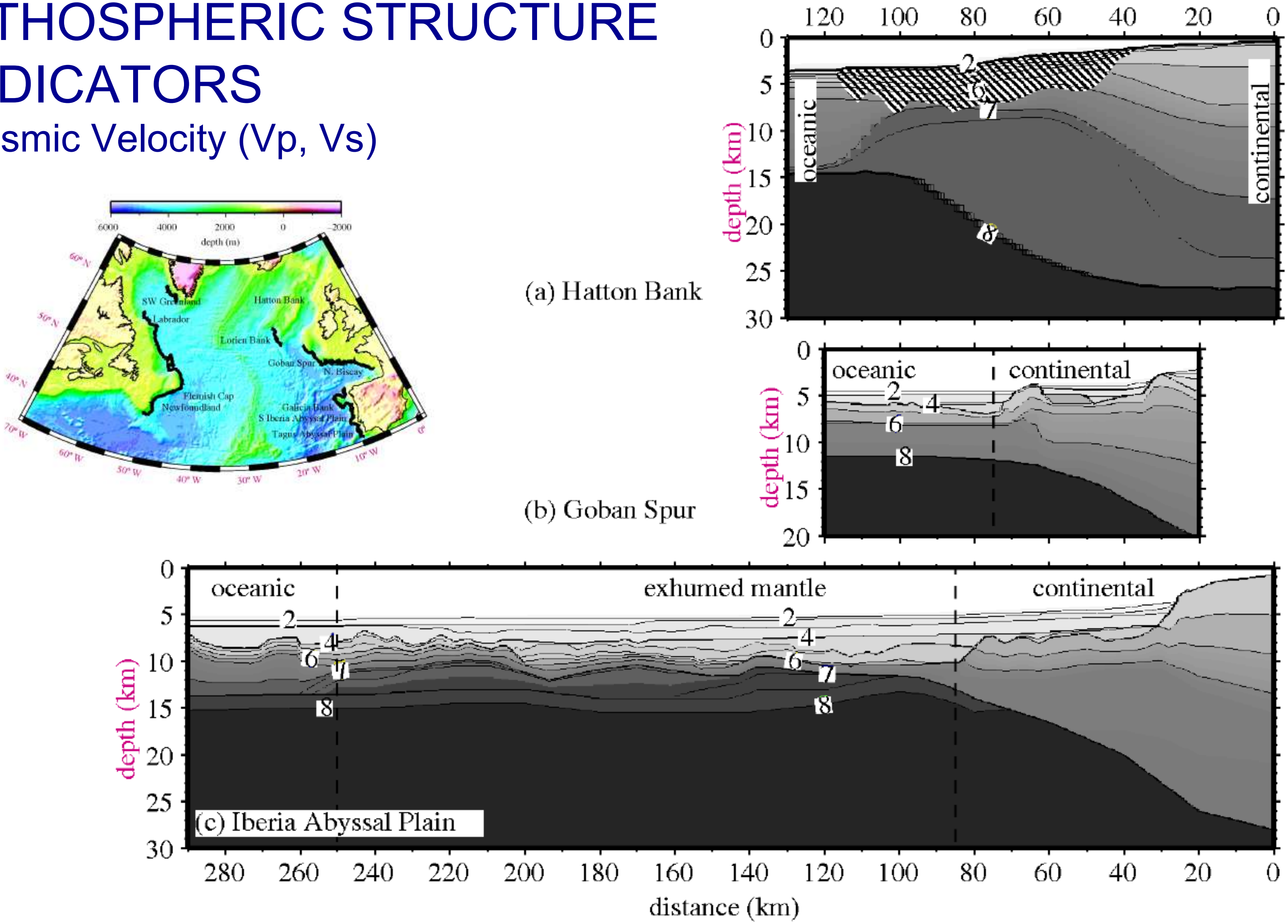


MODERN SUBDUCTION ZONES



LITHOSPHERIC STRUCTURE INDICATORS

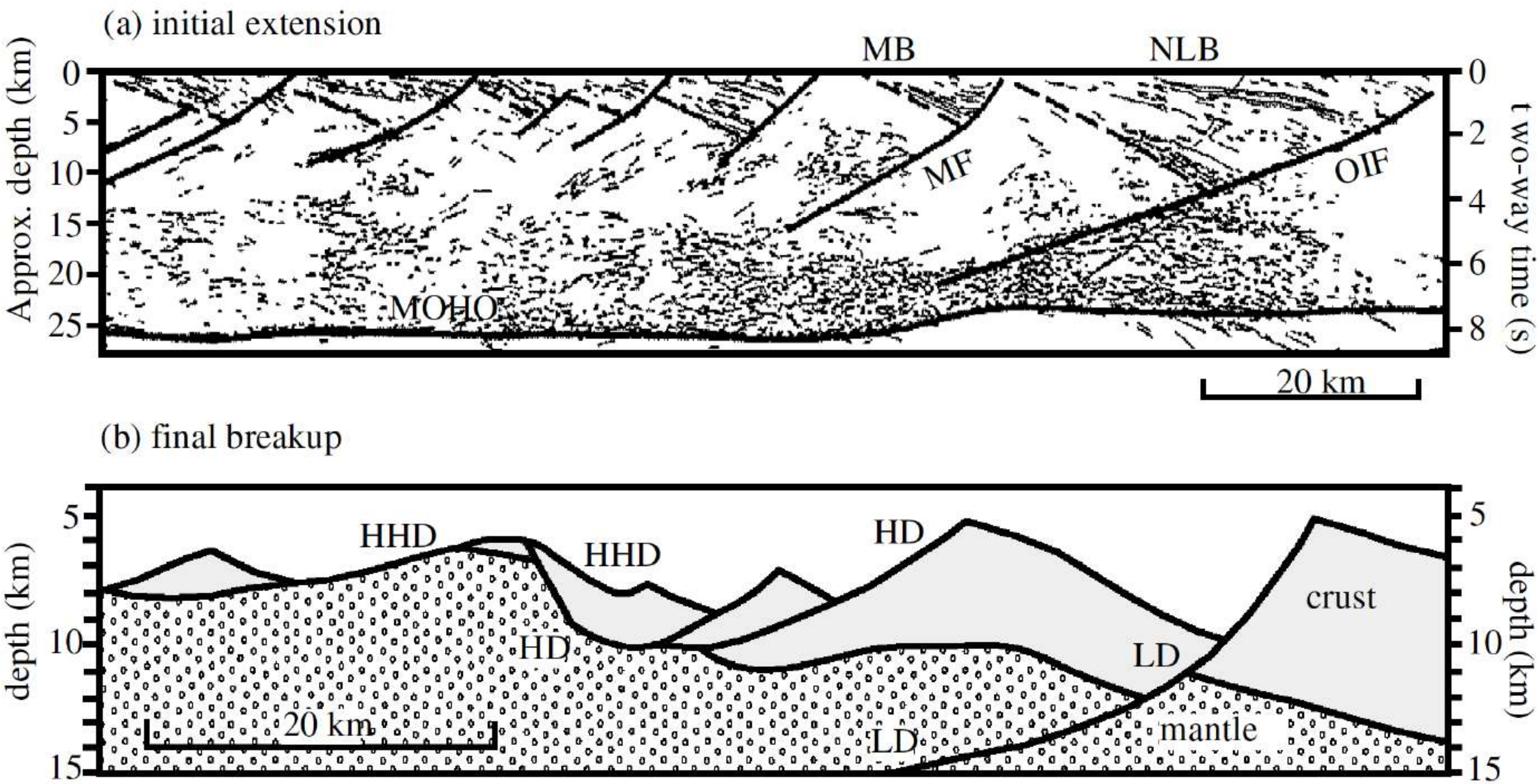
Seismic Velocity (Vp, Vs)



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

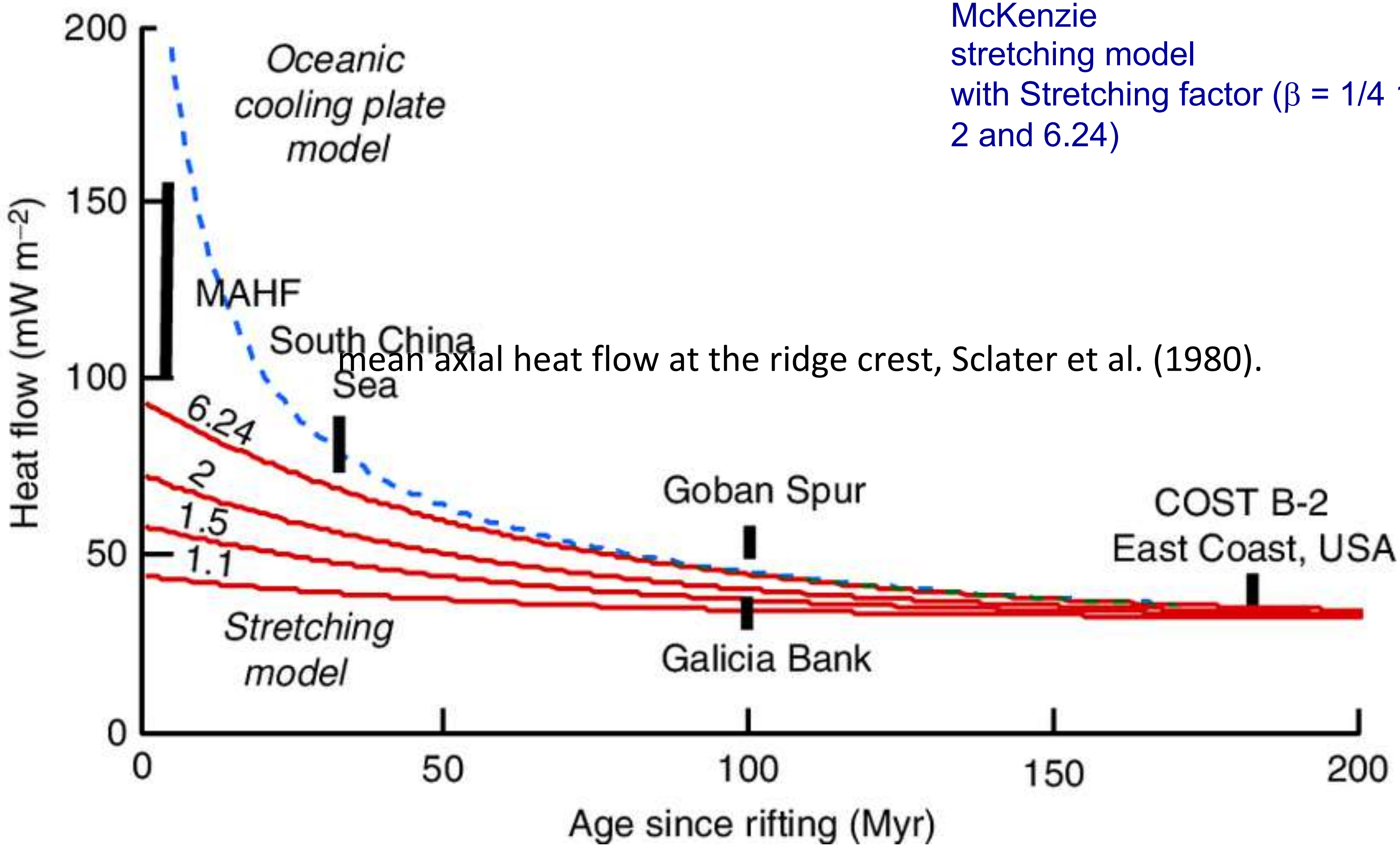


Minshull, 2002. The break-up of continents and the formation of new ocean basins. *Phil. Trans. R. Soc. Lond. A* 2002 **360**, 2839-2852

LITHOSPHERIC STRUCTURE INDICATORS

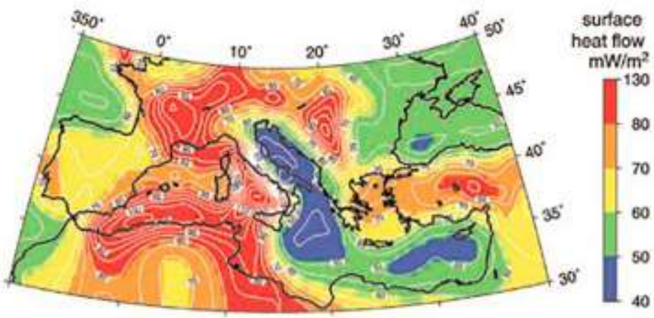
Heat Flow

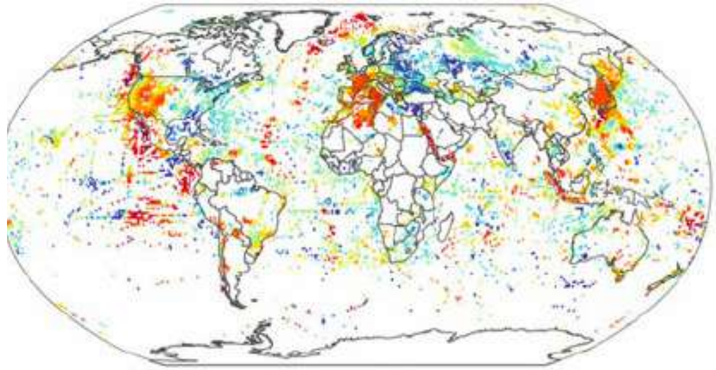
McKenzie stretching model with Stretching factor (β = 1/4 1.1, 1.5, 2 and 6.24)



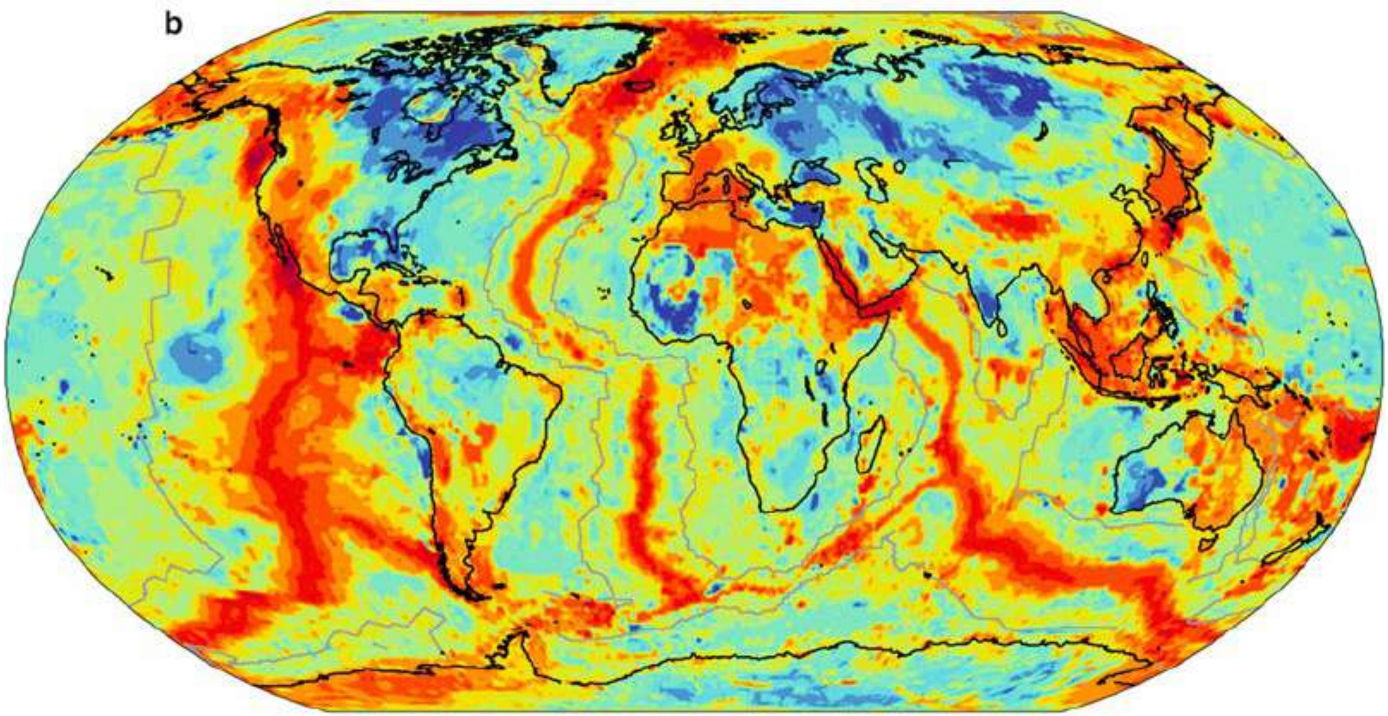
mean axial heat flow at the ridge crest, Sclater et al. (1980).

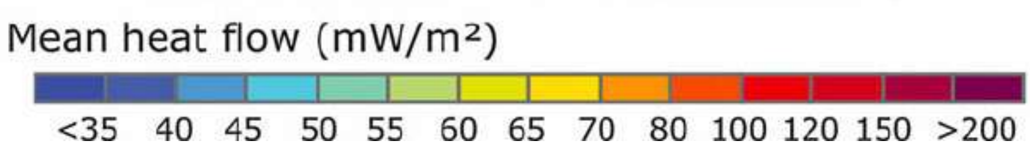
Watts, 2012. Models for the evolution of passive margins. In Phanerozoic Rift Systems and Sedimentary Basins DOI:10.1016/B978-0-444-56356-9.00002-X





b

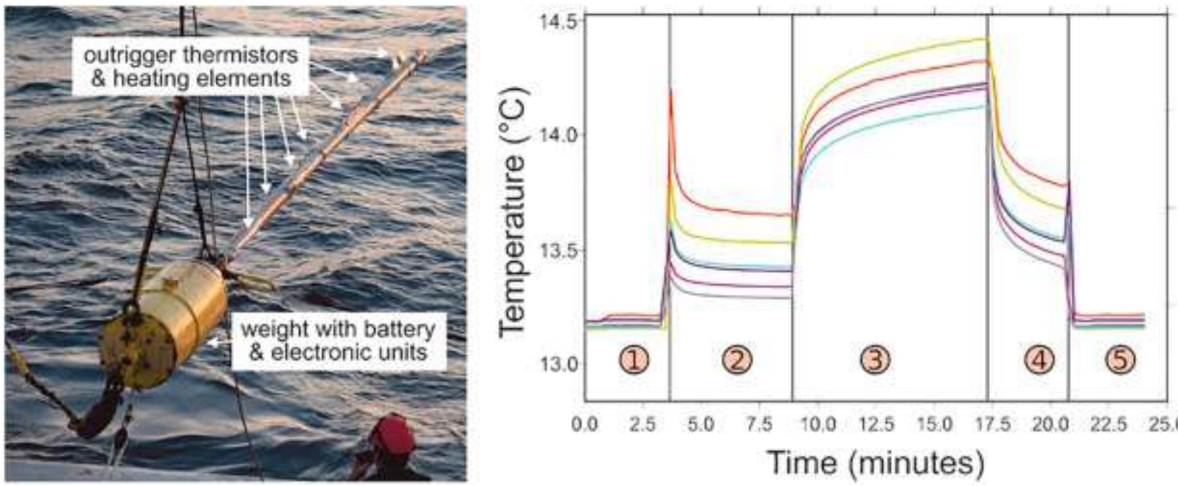




Goutorbe et al. (2011)
Global heat flow trends resolved from multiple geological and geophysical proxies. Geophysical Journal International, 187, 1405–1419.

Flusso di calore q = K *Δ**t/**Δ**z** (**mWxm^{-2}**)

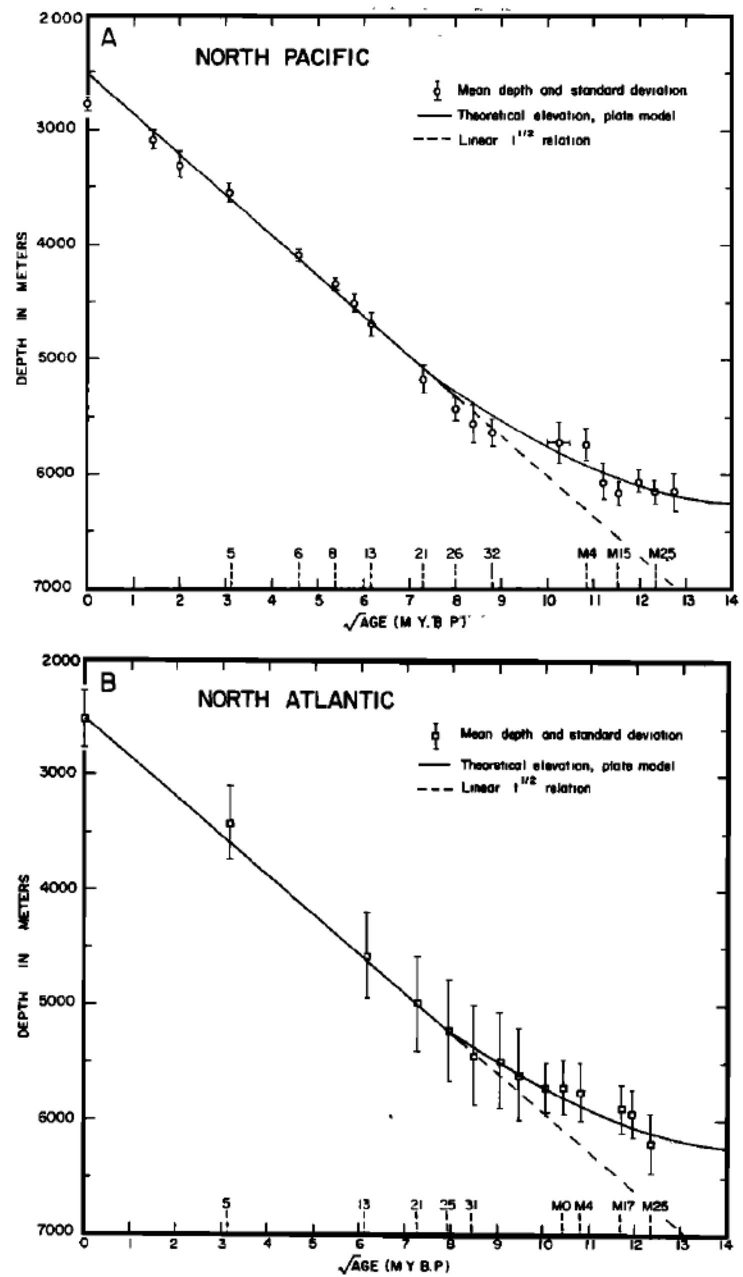
K = conducibilità termica



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

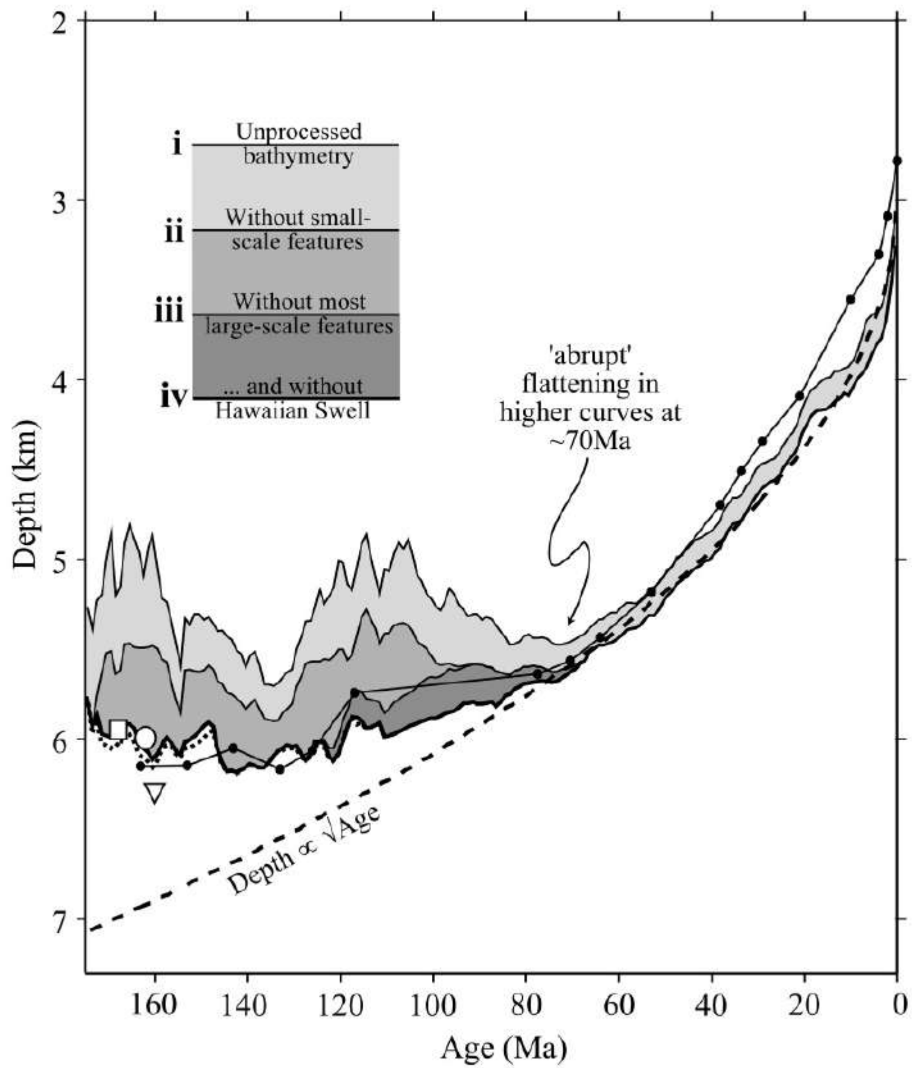


Parsons and Sclater, 1977

LITHOSPHERIC STRUCTURE INDICATORS

Age versus depth

Parsons and Sclater, 1977
Stein and Stein, 1992
Doin and Fleitout, 1996
Hillier and Watts, 2005

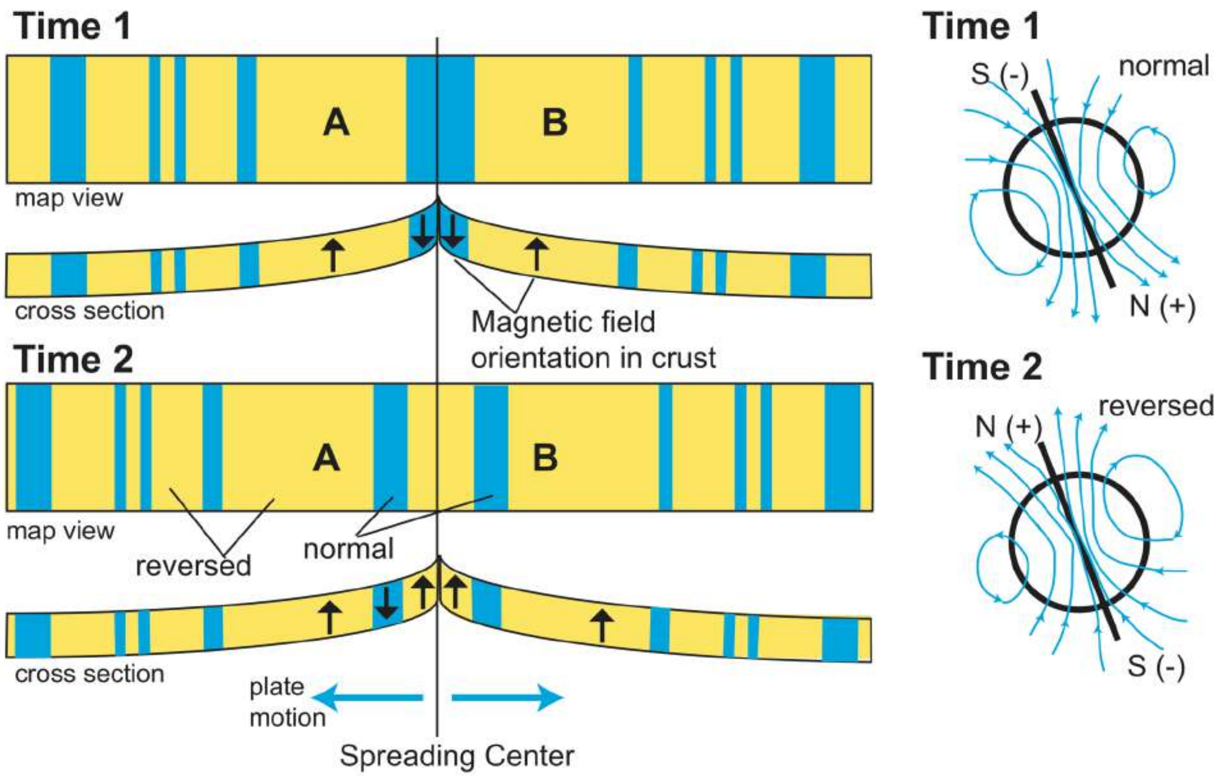


Hillier and Watts, 2005

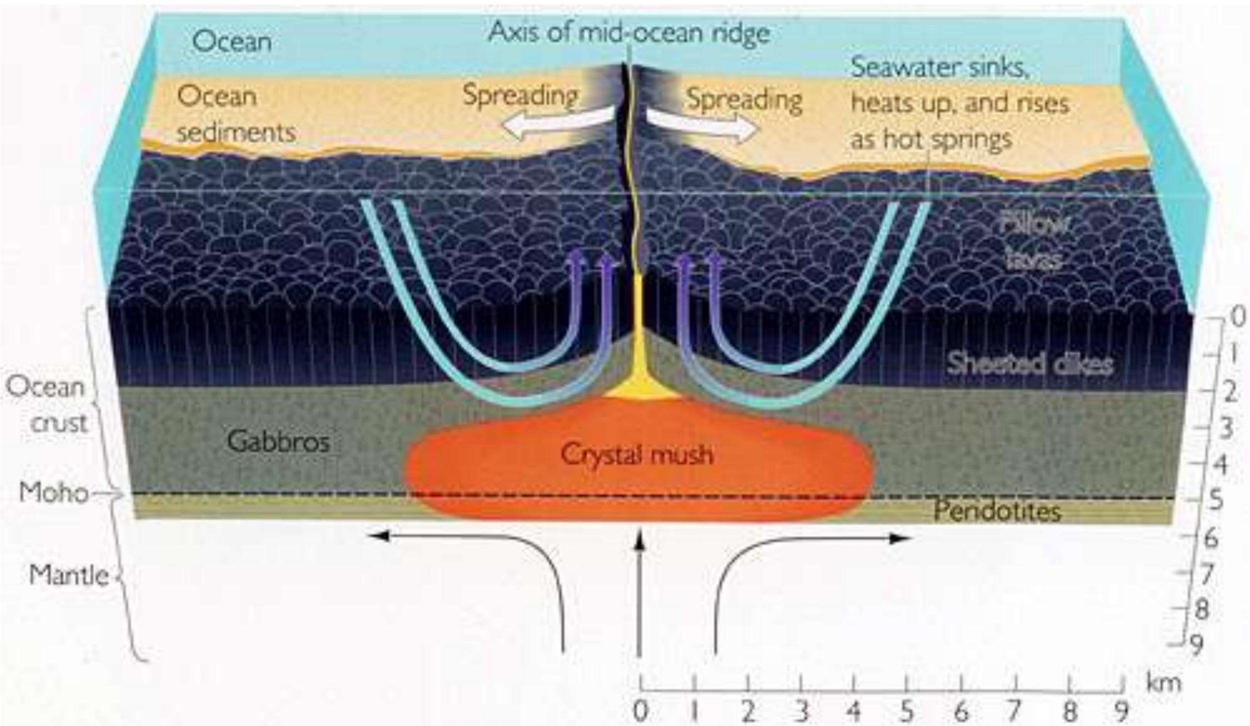
LITHOSPHERIC STRUCTURE INDICATORS

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.



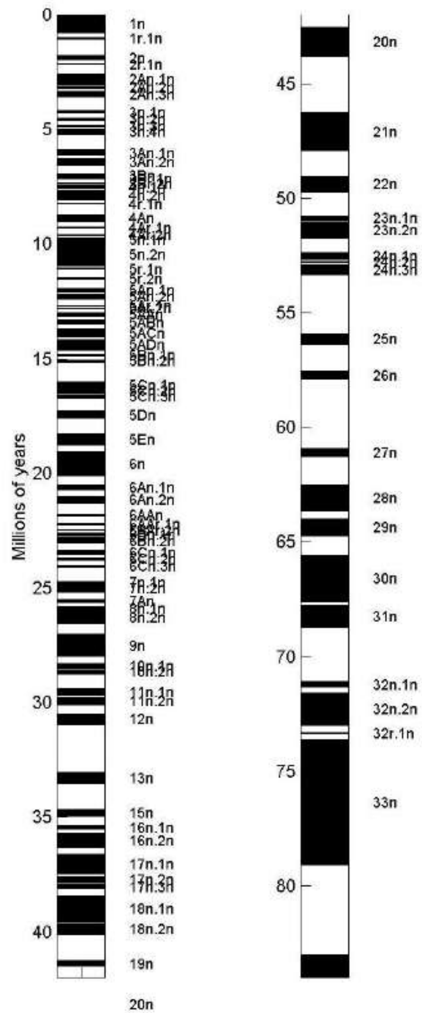
OCEANIC BASALTS RETAIN THE MAGNETIC ANOMALIES

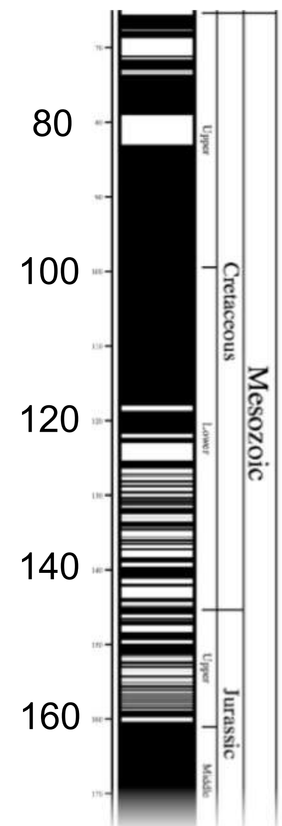


OCEANIC SEDIMENTS RETAIN THE MAGNETIC ANOMALIES

Geomagnetic Polarity Time Scale (GPTS

Cande & Kent 1995

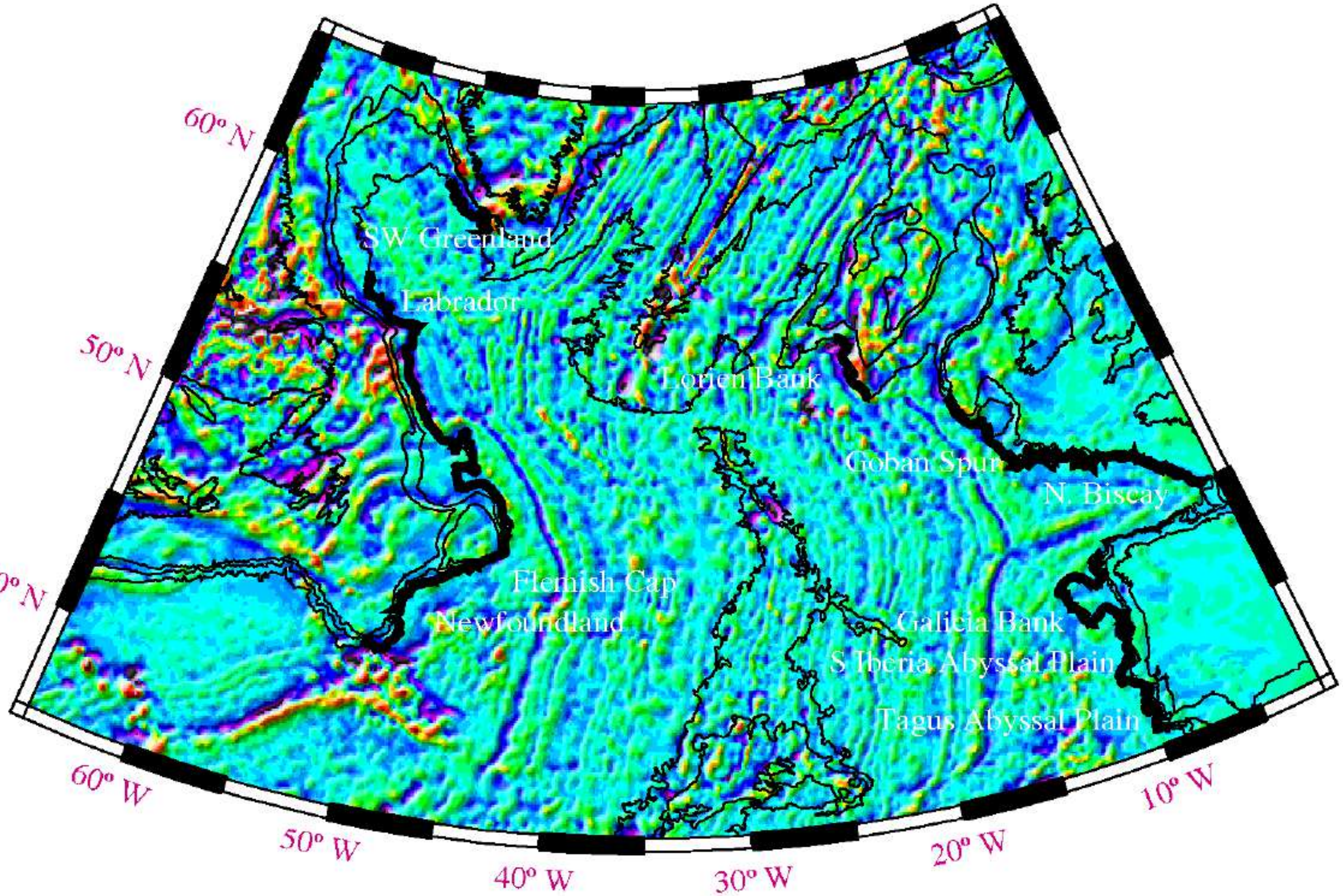




Instruments to measured the earth magnetic field in the ocean:

- 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

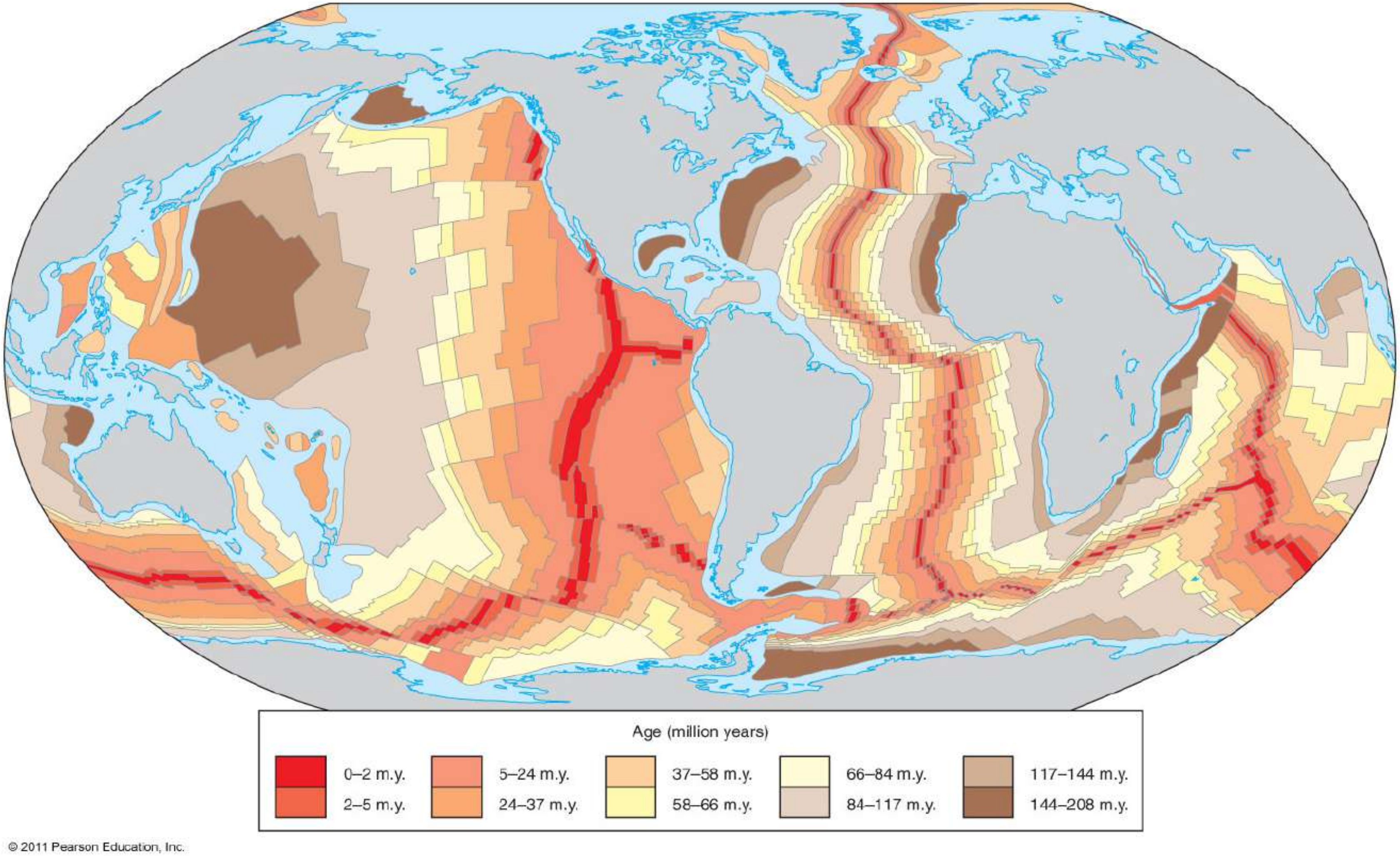
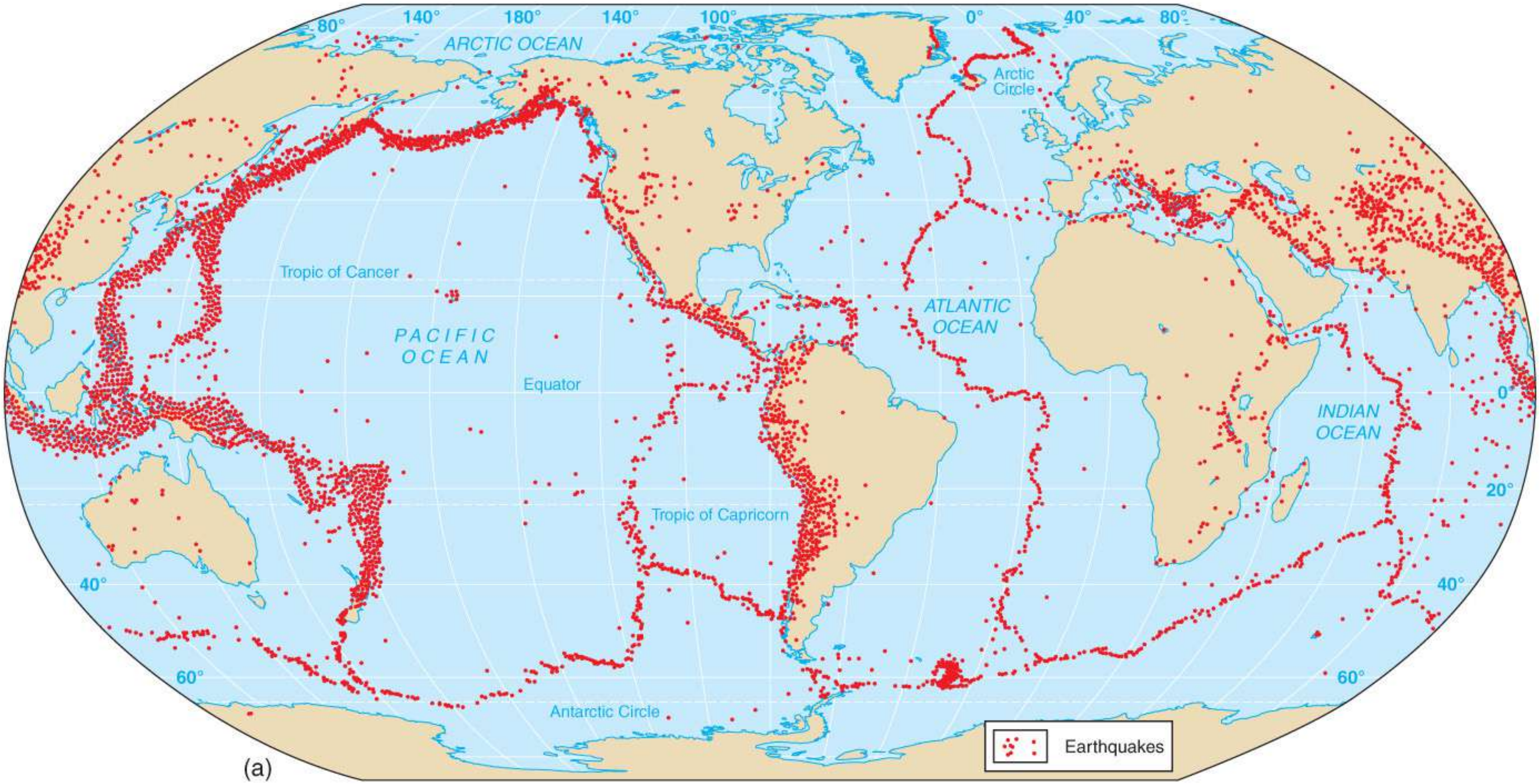


PLATE BOUNDARIES



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