Università di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE SM62A

Percorso Esplorazione Geologica

Anno accademico 2026 - 2027

Geologia Marina 953SM

Modulo 1.1 Oceani. Morfologia, struttura ed evoluzione

Docente

Laura De Santis

(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), housband of **Teti**, and father of all the fluvial divinities.


Okeanos - Fontana di Trevi





Karl Weyprecht naval officer based in Trieste conceived the International Polar Year of 1882–1883

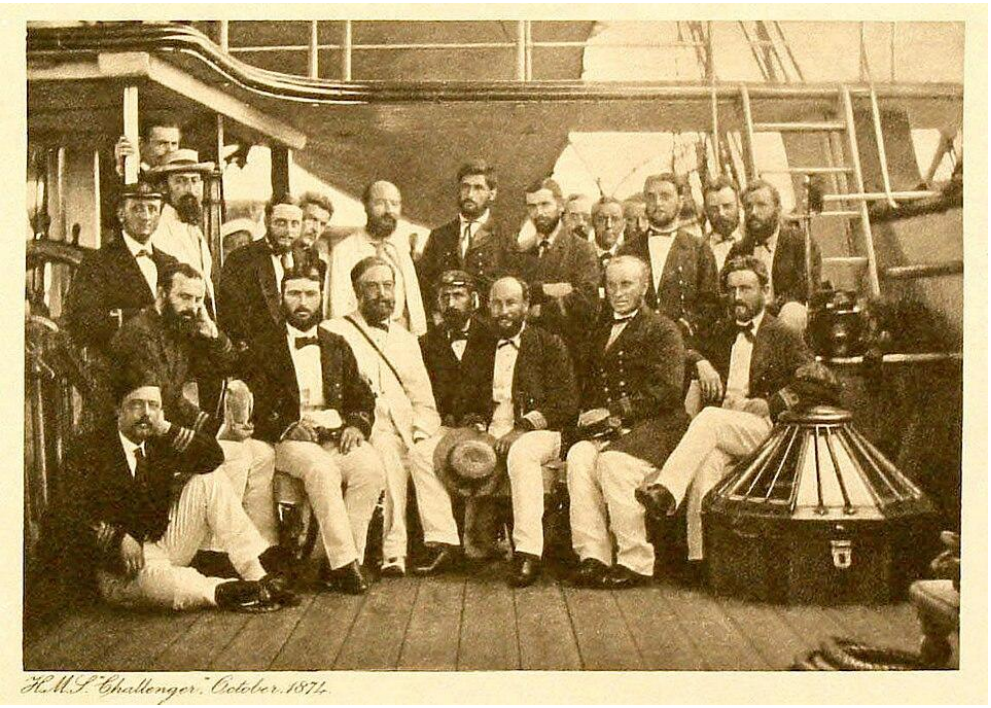
=> the birth of international scientific research (scientific projects carried out through collaboration between nations).

The first IPY was followed by:
the synchronized Antarctic expeditions of 1901–1903,

- the International Polar Year of 1932–1933,
- the International Geophysical Year of 1957–1958,
- the concurrent and linked International Polar Year, International Heliophysical Year, International Year of Planet Earth, and International Electronic Geophysical Year, which took place between 2007 and 2009

The next IPY will be in 2030-31

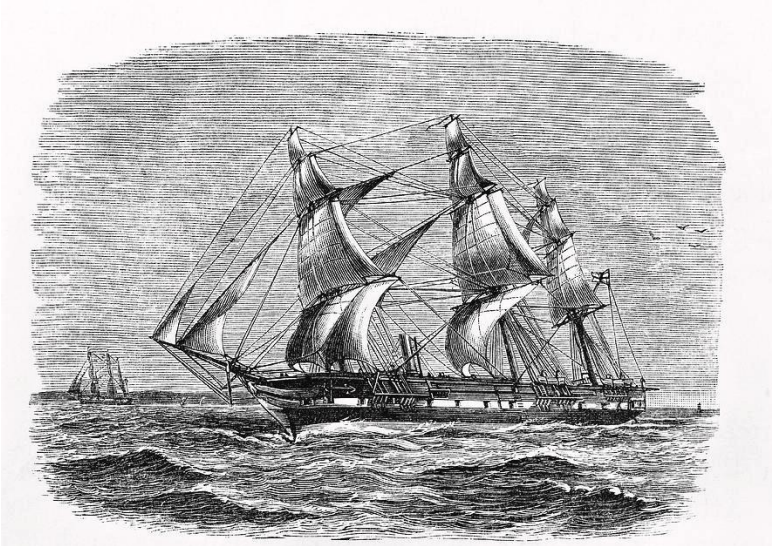
La spedizione Challenger del 1872-1876 : prima circumnavigation scientifica della storia dedicata interamente allo studio degli Oceani



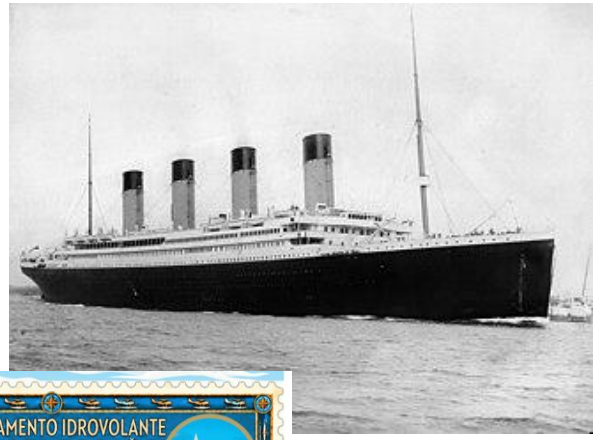
- 70.000 miglia nautiche (oltre 127.000 km) Atlantico, l'Antartico, il Pacifico e l'Indiano
- scoperte e catalogate 4.717 nuove specie marine, =>la vita esiste oltre i 550 metri di profondità
- Misurato il punto più profondo nell'oceano Pacifico oltre 8.000 metri nella Fossa delle MarianneDeep (il cui punto più basso prende oggi il nome di Challenger Deep)

Comandanti:
George Nares (1873-74),
Frank Tourle Thomson (184-76)

Spedizione proposta dallo scozzese Charles Wyville Thomson dell'Università di Edimburgo e della Merchiston Castle School, la Società Reale di Londra



Royal Navy (UK)



Marine echosounder technology developed in the XX century for:

- safety navigation (e.g. iceberg detection, after the Titanic dysaster in 1912)
- for war strategy (detection of submarines)
- civil business (e.g. the historic Trieste seaplane base (Idroscalo Trieste) 1926

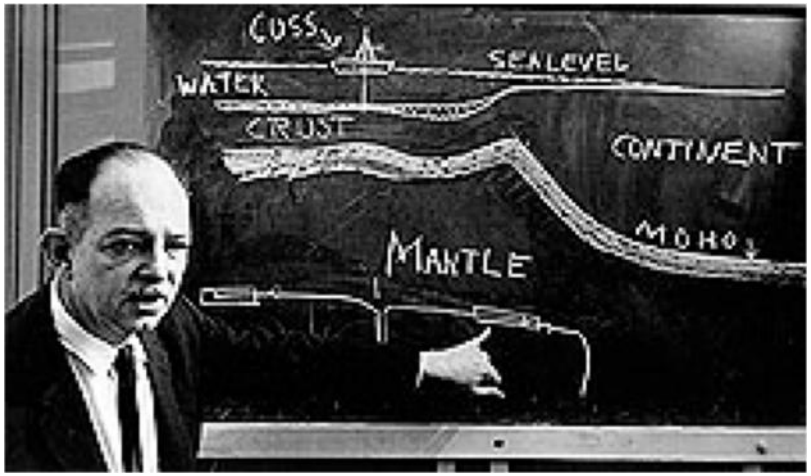


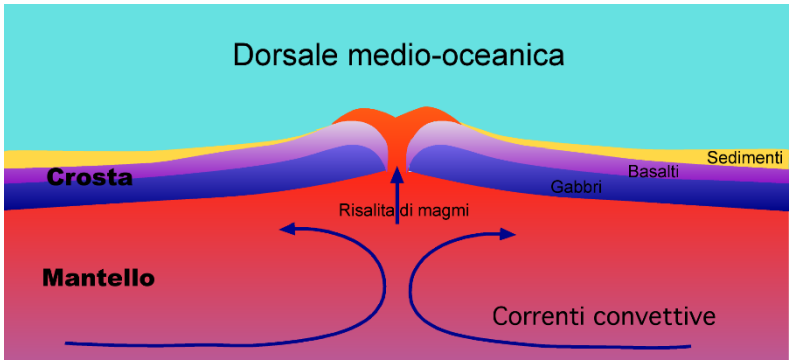
Harry Hess (1906 – 1969)
Professor of geology at Princeton University
During the Second World War, Hess was the captain of a ship equipped with a SONAR
(SOund NAvigation and Ranging, patented in 1917 by Paul Langevin) employed for safety navigation and war strategy.

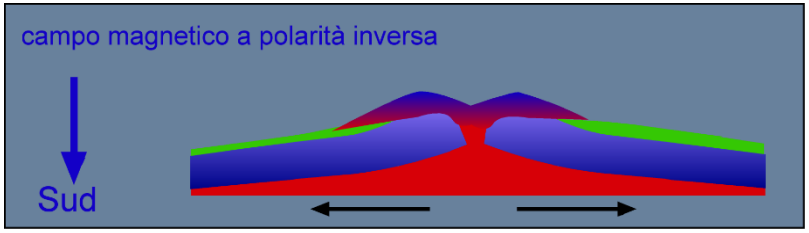


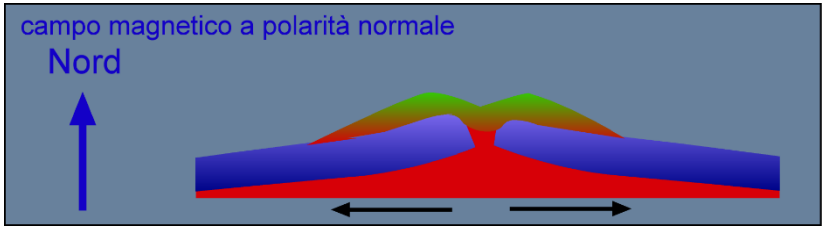
Hess published the first bathymetric map of the Pacific.

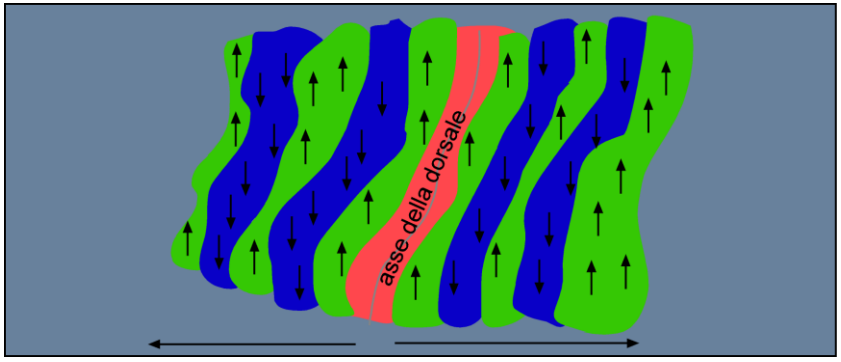
Hess discovered the Mid-oceanic ridges and the guyots, and in the ’62 he published the Sea floor Spreading theory, fundamental for the Plate Tectonic theory.











Oceanic floor rocks have different magnetic polarity with stripes of progressive older age away from the mid-oceanic ridge

"*Magnetic anomalies over oceanic ridges", Nature 1963*



(figure A. Camerlenghi OGS)

SEA FLOOR MORPHOLOGY 1977



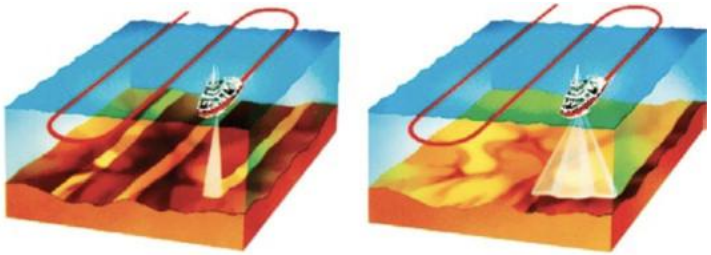
Marie Tharp and Bruce Heezen, oceanographers of the Columbia University's Lamont Geological Observatory.
They discovered the 60.000 km of underwater ridges The map was painted by Heinrich C. Berann (used telephone company data)

OCEAN AND SEA FLOOR MORPHOLOGY

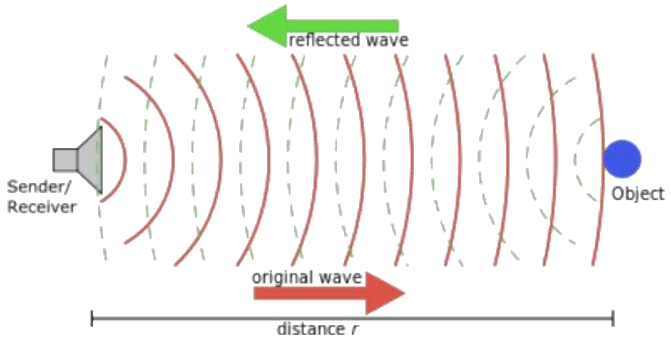
less than 5-10% of the ocean have been explored

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

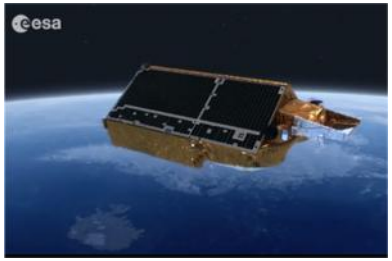
1) First instrument: the SONAR, constructed at the beginning of the 1900

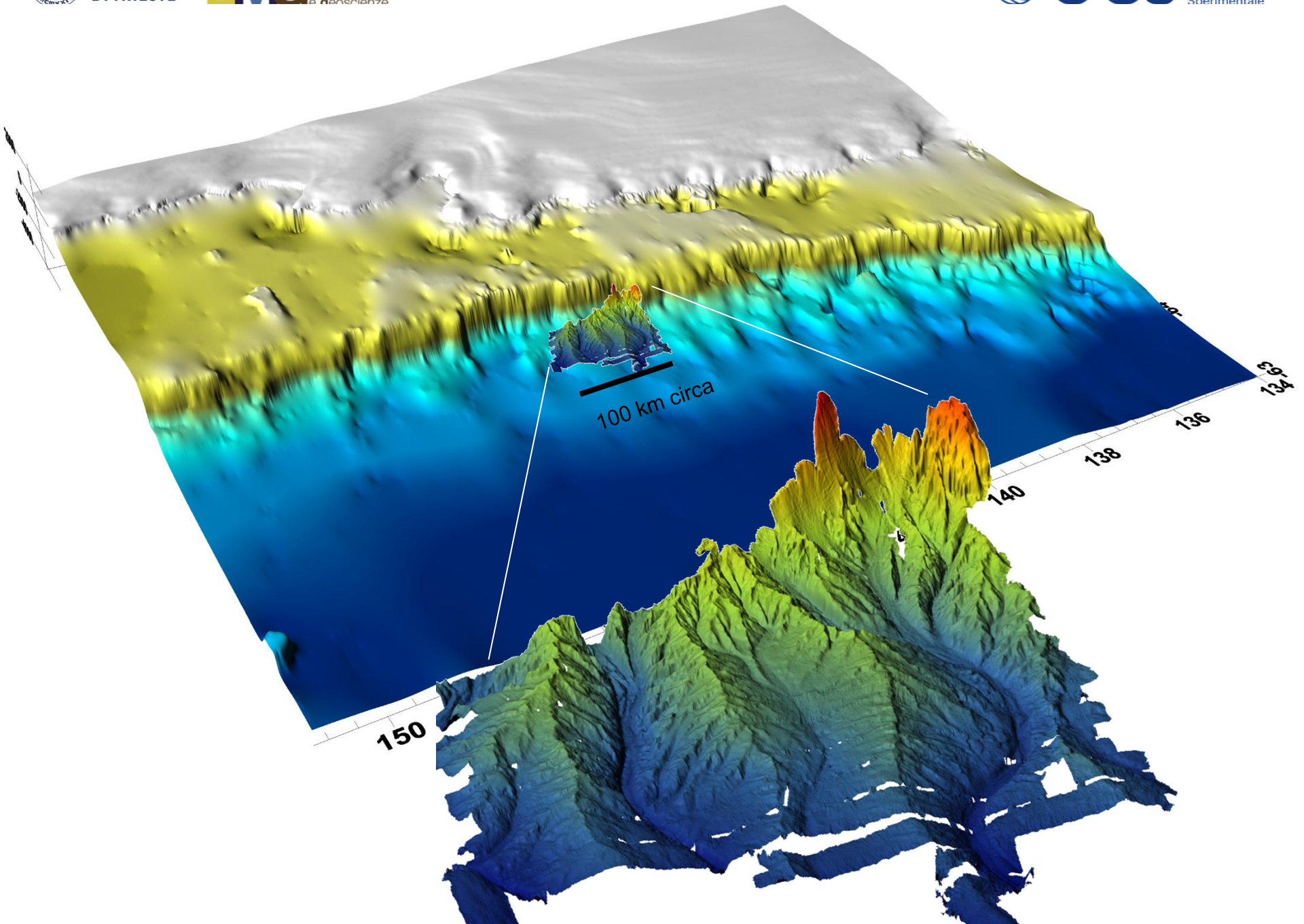


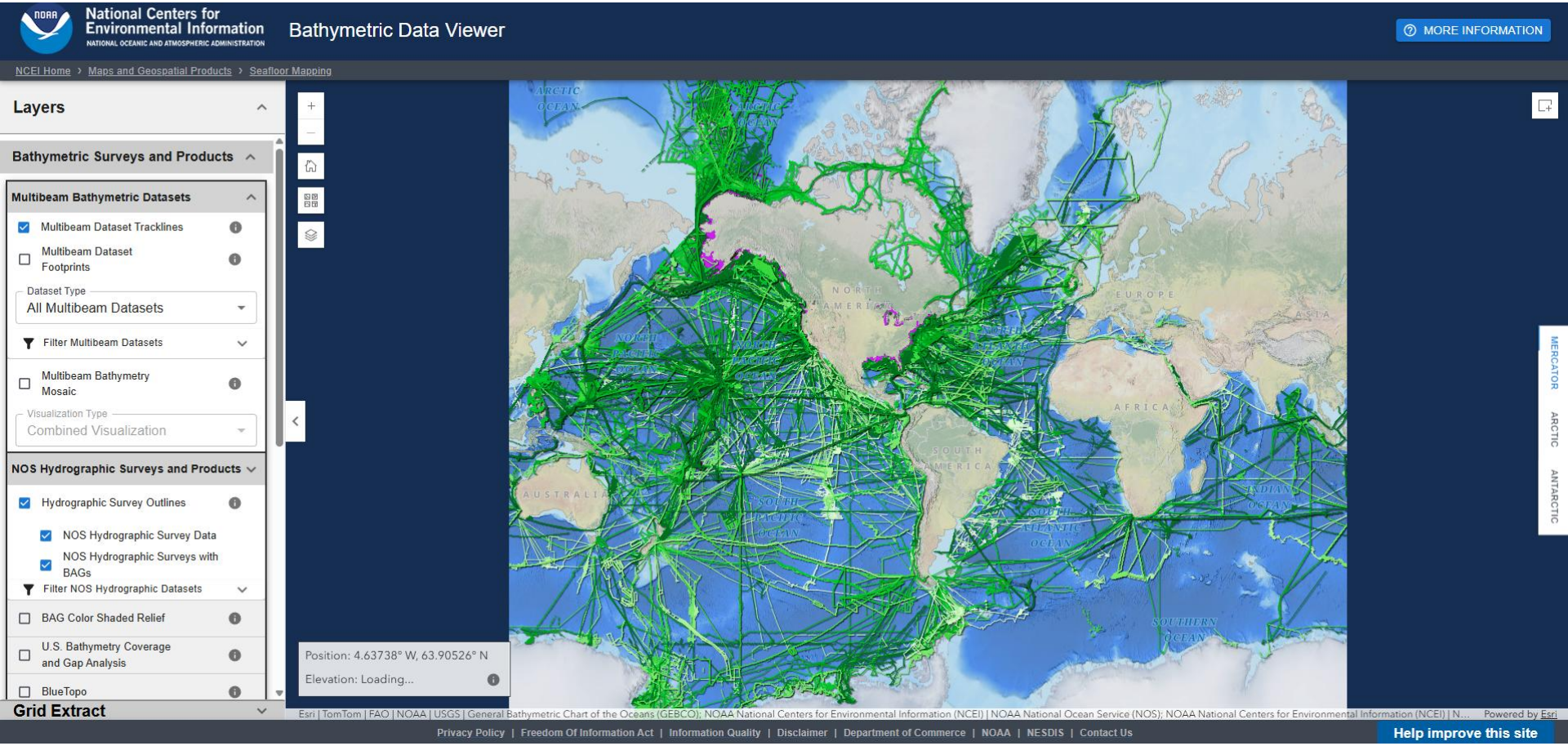
2) Multi-beam sonar technologies, develop in the last decades of the 1900



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




100 km circa
150
140
138
136
134

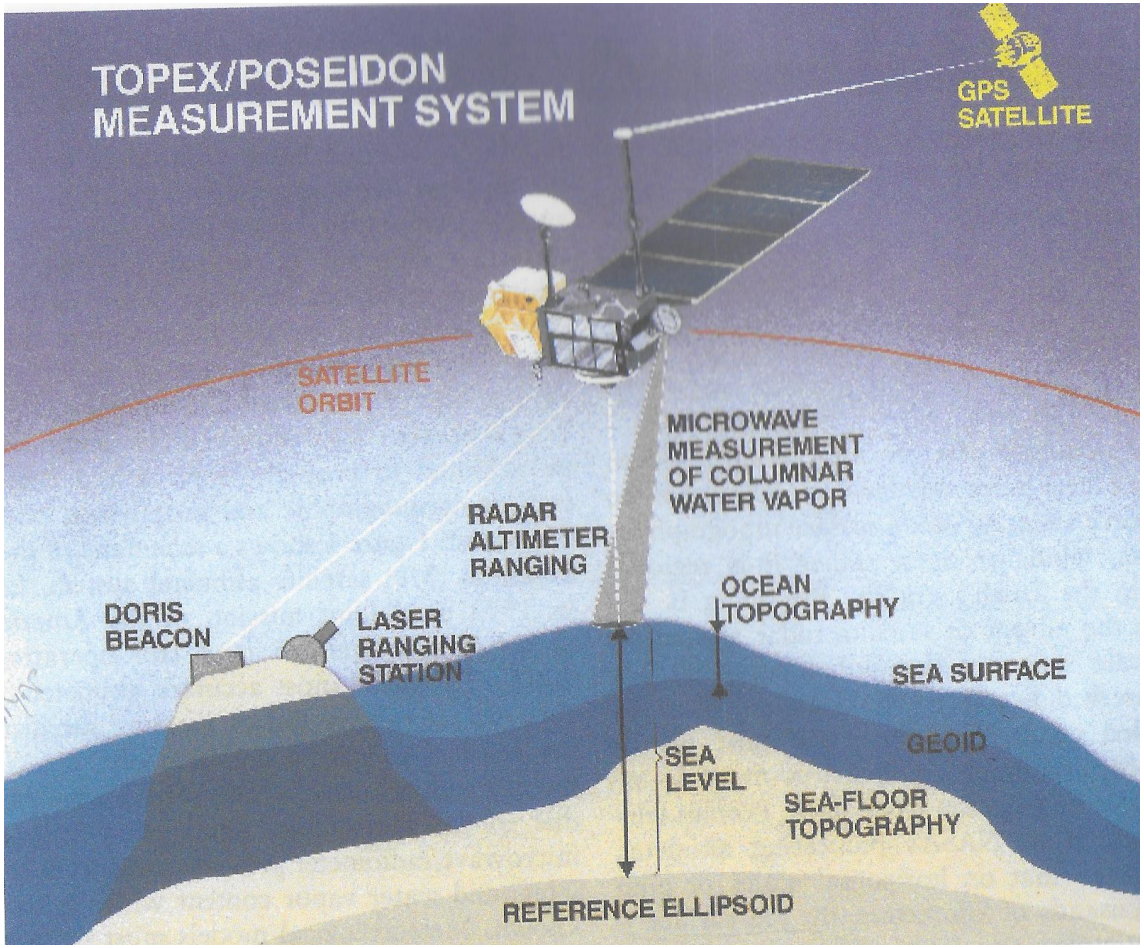

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Layers
Bathymetric Surveys and Products
Multibeam Bathymetric Datasets
Multibeam Dataset Tracklines
Multibeam Dataset Footprints
Dataset Type
All Multibeam Datasets
Filter Multibeam Datasets
Multibeam Bathymetry Mosaic
Visualization Type
Combined Visualization
NOS Hydrographic Surveys and Products
Hydrographic Survey Outlines
NOS Hydrographic Survey Data
NOS Hydrographic Surveys with BAGs
Filter NOS Hydrographic Datasets
BAG Color Shaded Relief
U.S. Bathymetry Coverage and Gap Analysis
BlueTopo
Grid Extract
Position: 4.63738° W, 63.90526° N
Elevation: Loading...
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Help improve this site

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.

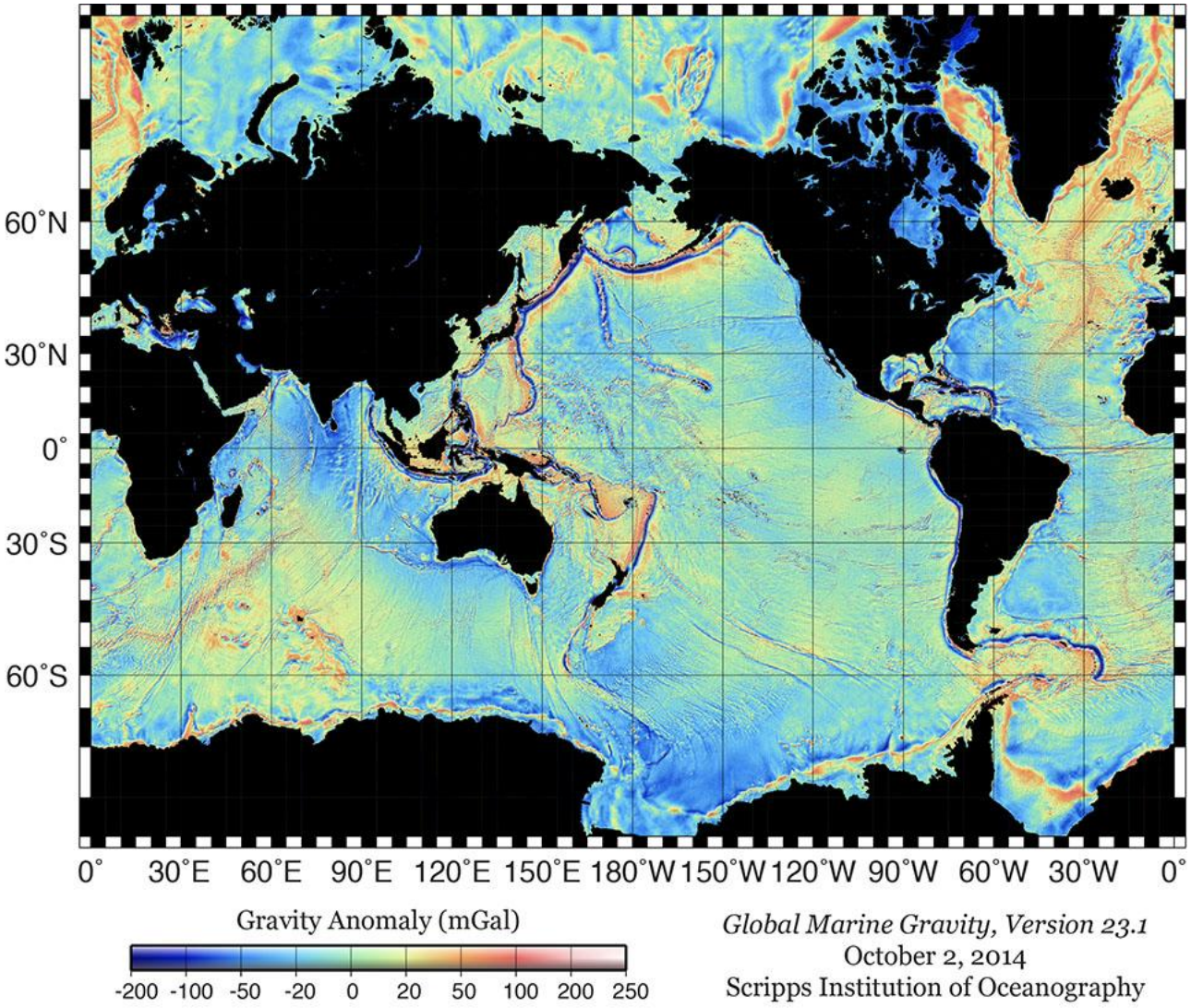
Mayer and Roach, 2021
The Quest to Completely Map the World's Oceans in Support of Understanding Marine Biodiversity and the Regulatory Barriers https://doi.org/10.1163/9789004422438_009

The sea surface mimics the sea bed that is not flat because the actual shape of the Earth varies with the Earth's gravity (Geoid)



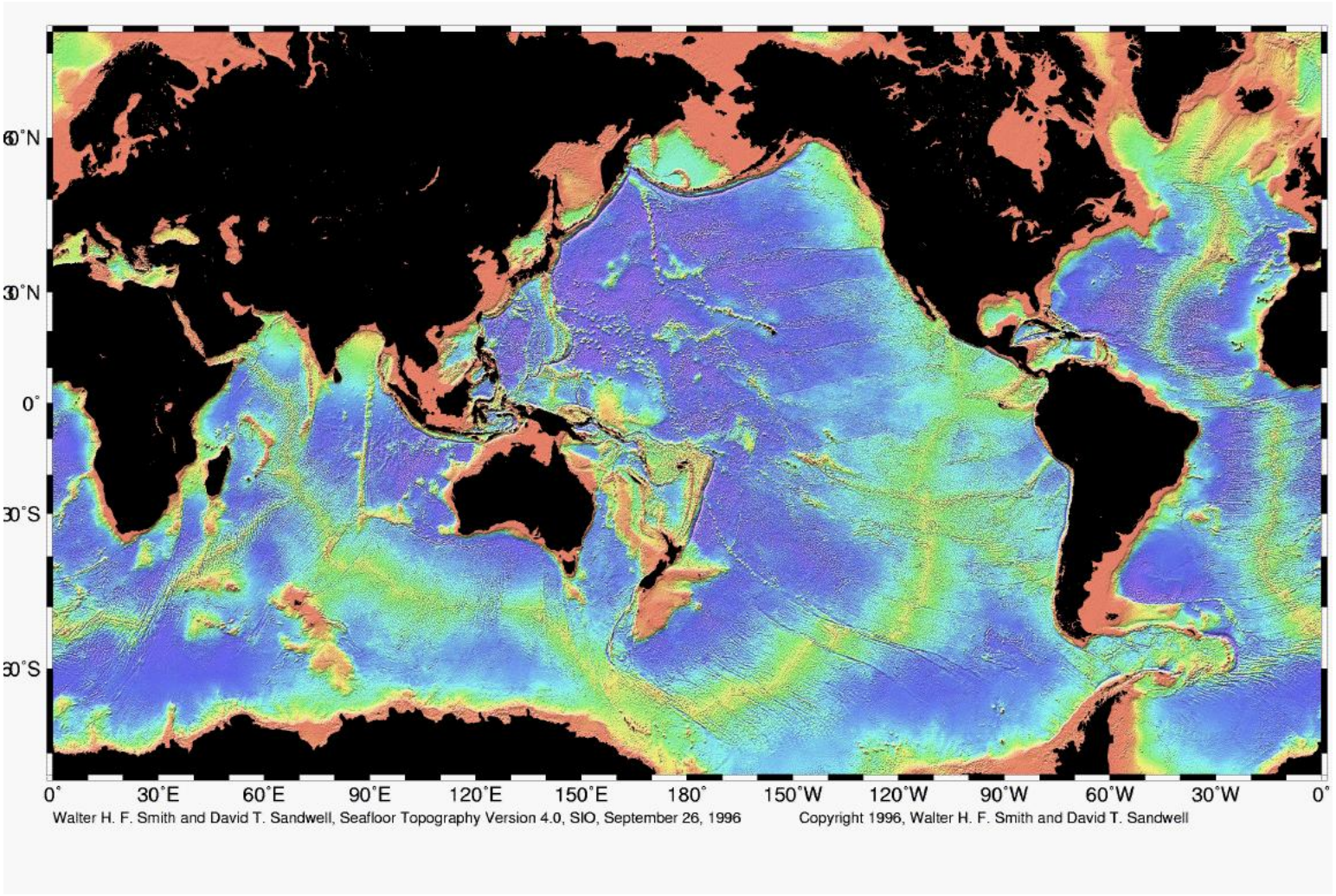
Topex Poseidon 1992 (precision 2 cm)

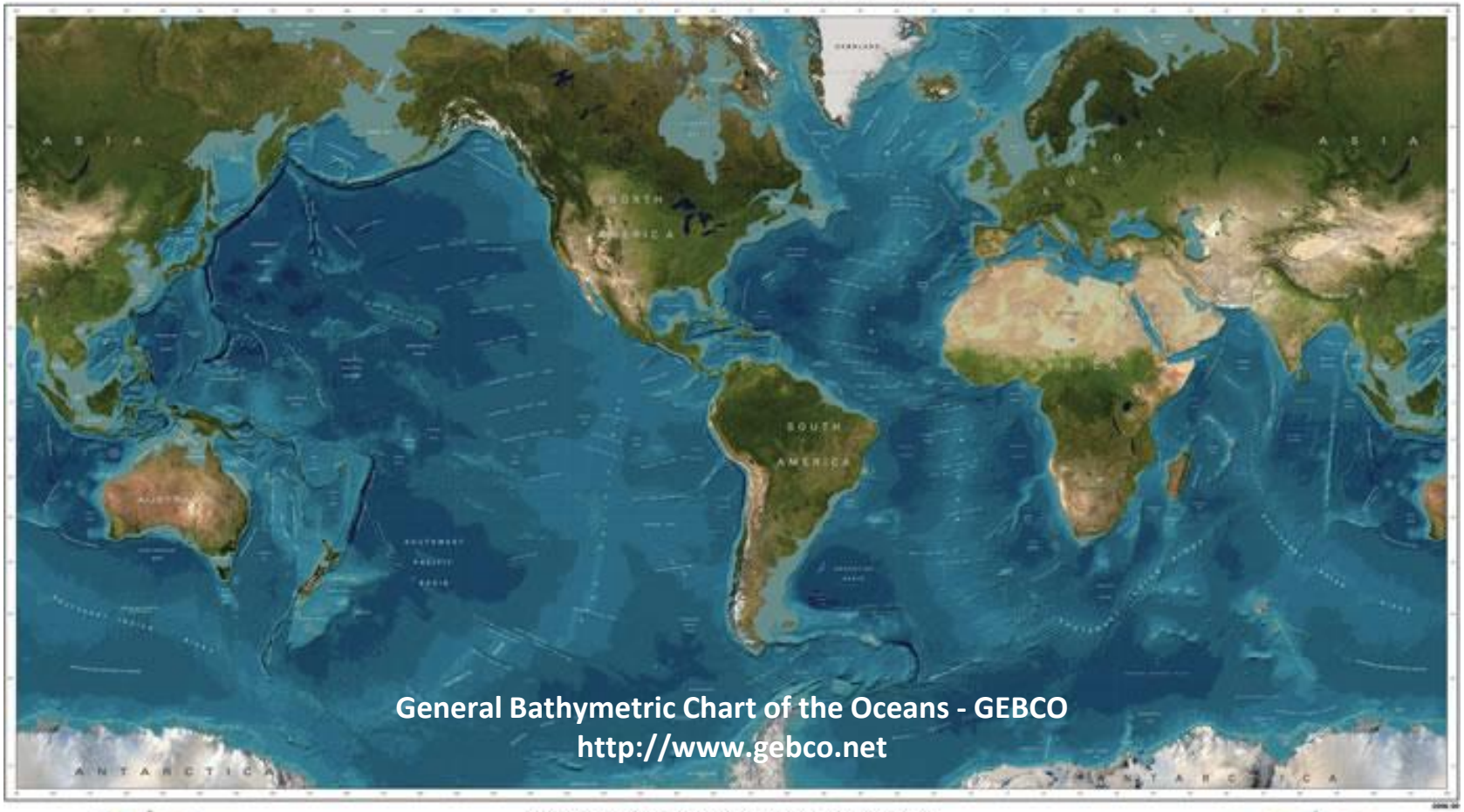
Global gravity map of the oceans - from GEOSAT and ERS-1



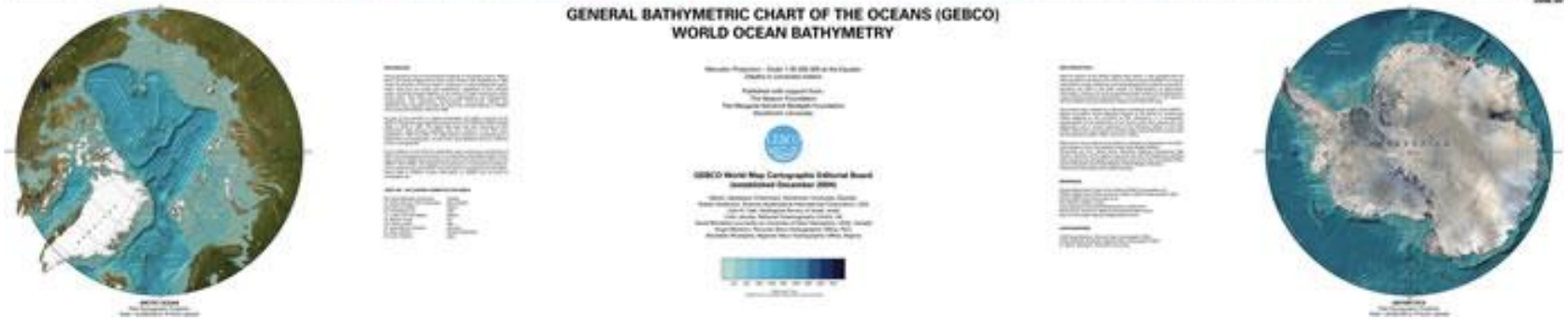
Smith and Sandwell, 1996

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





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



Global mean sea level over the last 15 years: altimetric measurements

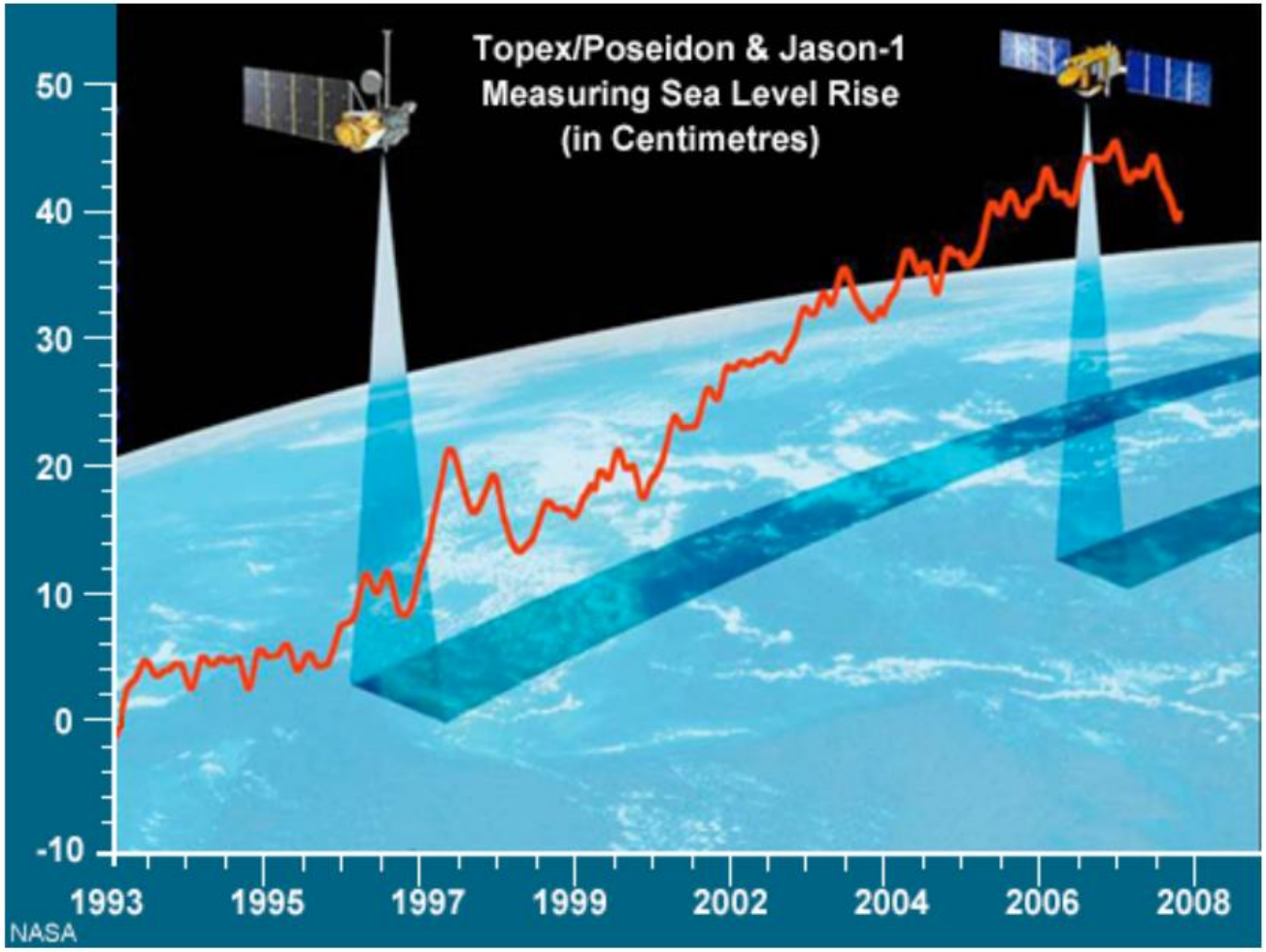
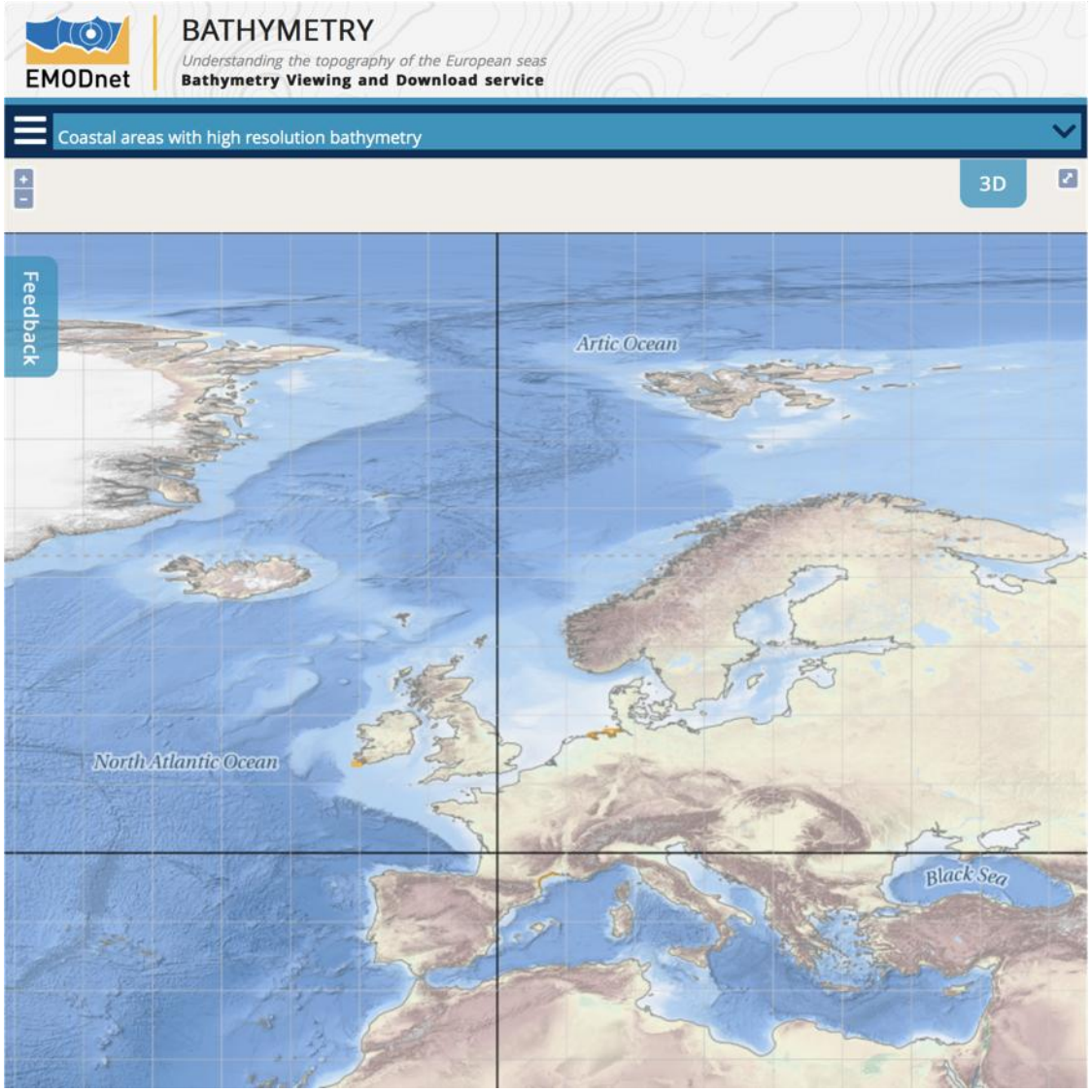


Figura di F. Colleoni

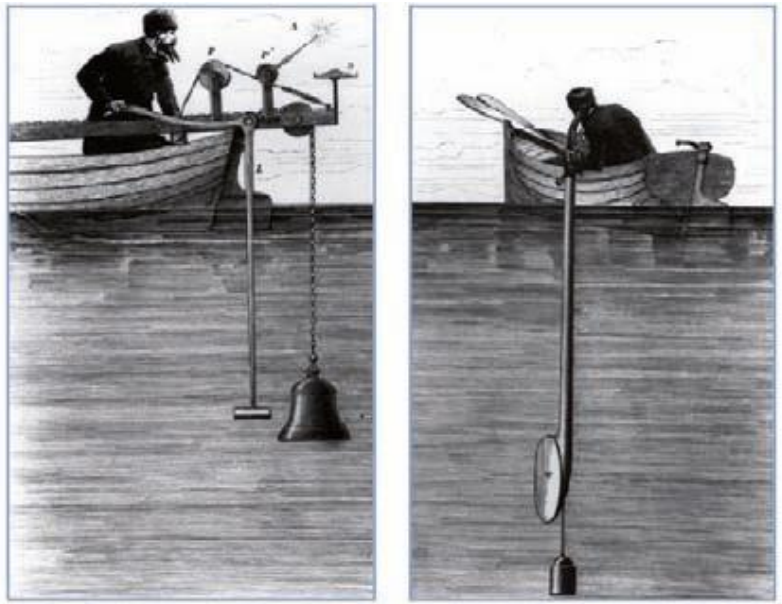
EMODNET

http://www.emodnet.eu

bathymetry, geology, physics, chemistry, biology, seabed habitats and human activities



The European Marine Observation and Data Network (EMODnet) is the European Union's in situ marine data service, managed by the European Commission (EC) Directorate-General Maritime Affairs and Fisheries (EC DG MARE) and funded by the European Maritime Fisheries and Aquaculture Fund. Established in 2009, EMODnet plays a pivotal role as a trusted source of in situ marine environmental and human activities data and data products, serving a diverse user base across various sectors.



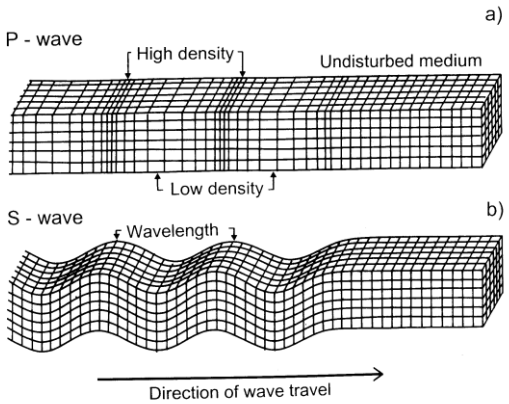
Colladon and Sturm's 1862 experiment to measure the speed of sound in Lake Geneva (J. D. Colladon: Souvenirs et Mmoires, Impr. Albert-Schuchardt, Geneva, 1893).

Seismic waves – waves that travel through the Earth

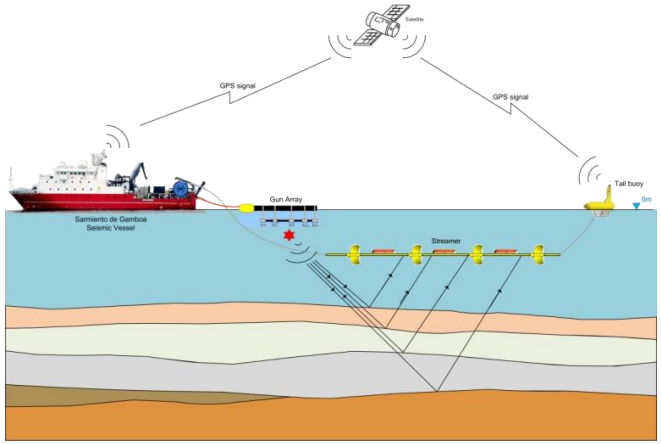
Reflection methods use reflected waves to characterise the subsurface

Active methods generate seismic waves using a seismic source

Marine seismic: special case where sources and receivers are in the water layer - generate and record P-waves only

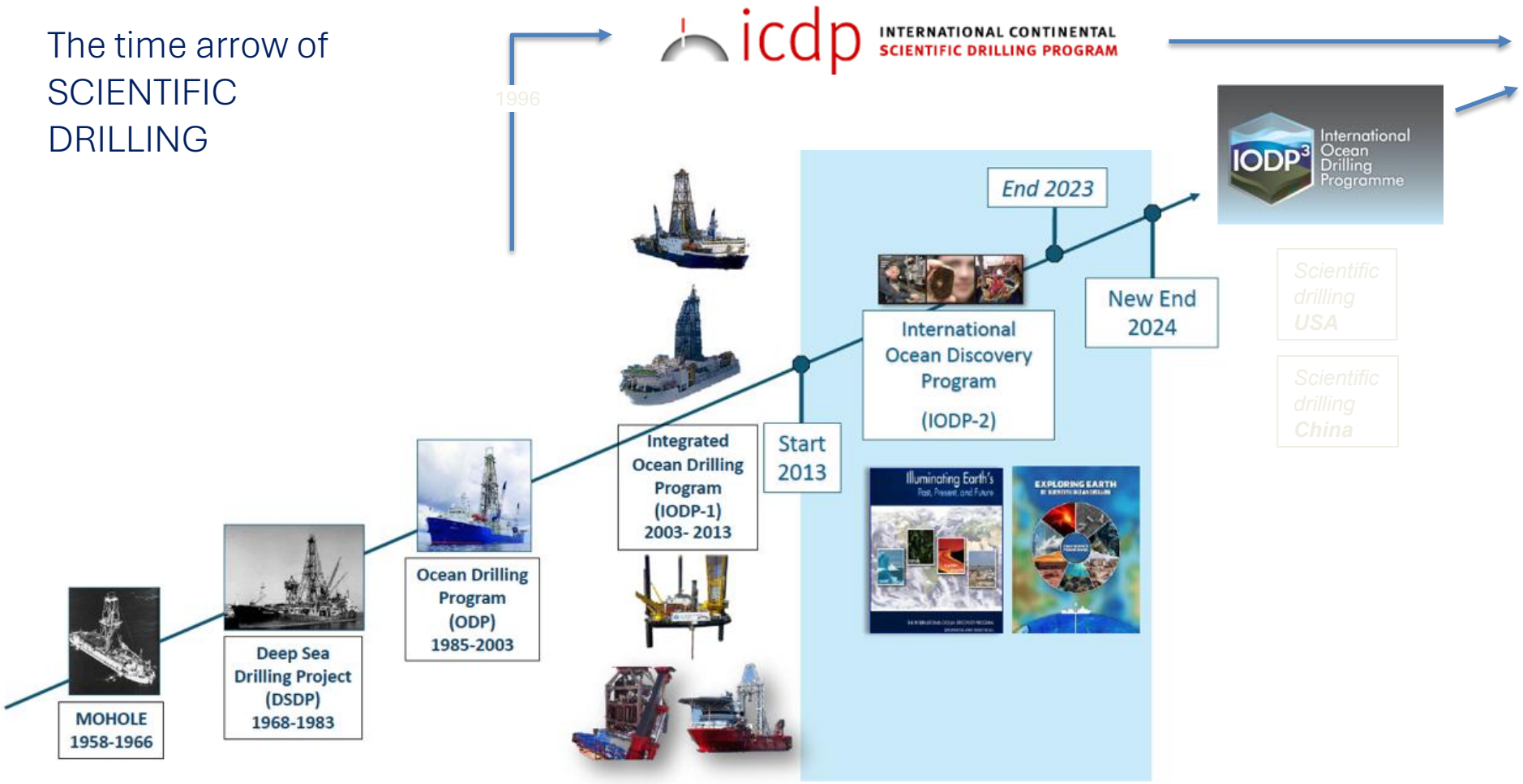


Keary, Brooks and Hill (2002)



http://www.utm.csic.es/index.php/en/servicios/sismica

The time arrow of SCIENTIFIC DRILLING

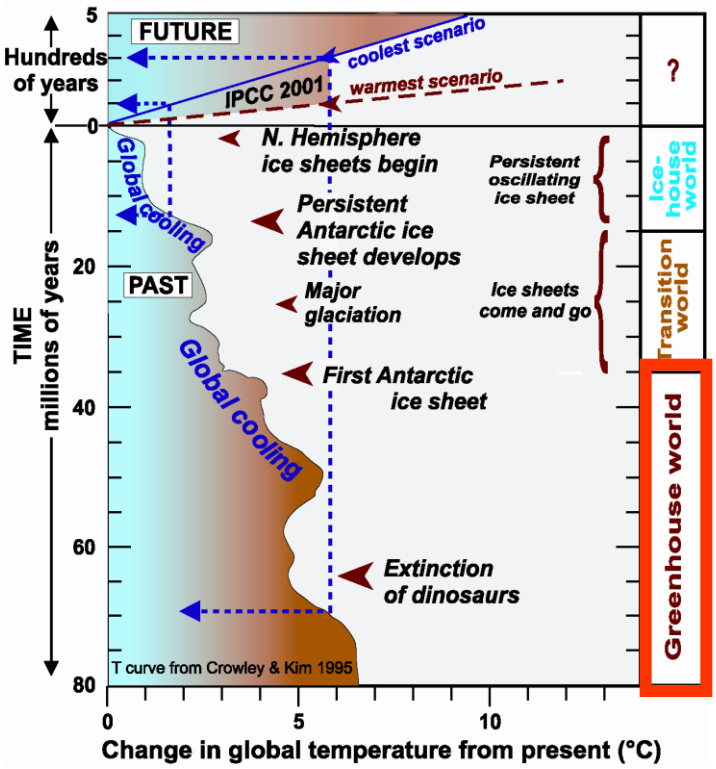


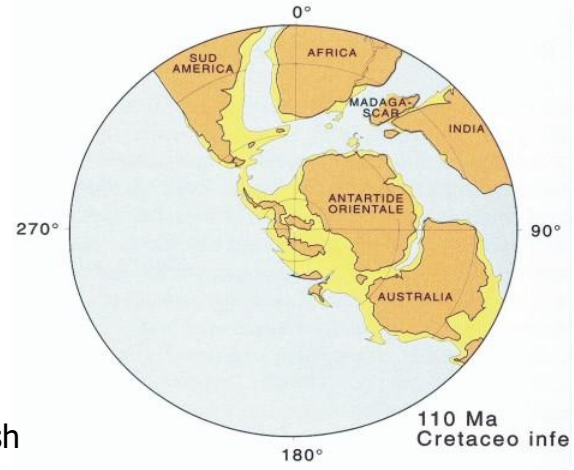
The International Ocean Discovery Program (IODP)
is an international marine research collaboration that explores Earth's history and dynamics using ocean-going research platforms to recover data recorded in seafloor sediments and rocks and to monitor subseafloor environments
http://www.iodp.org



(Azolla event, Brinkhuis, Schouten, et al., *Nature*, 2006)



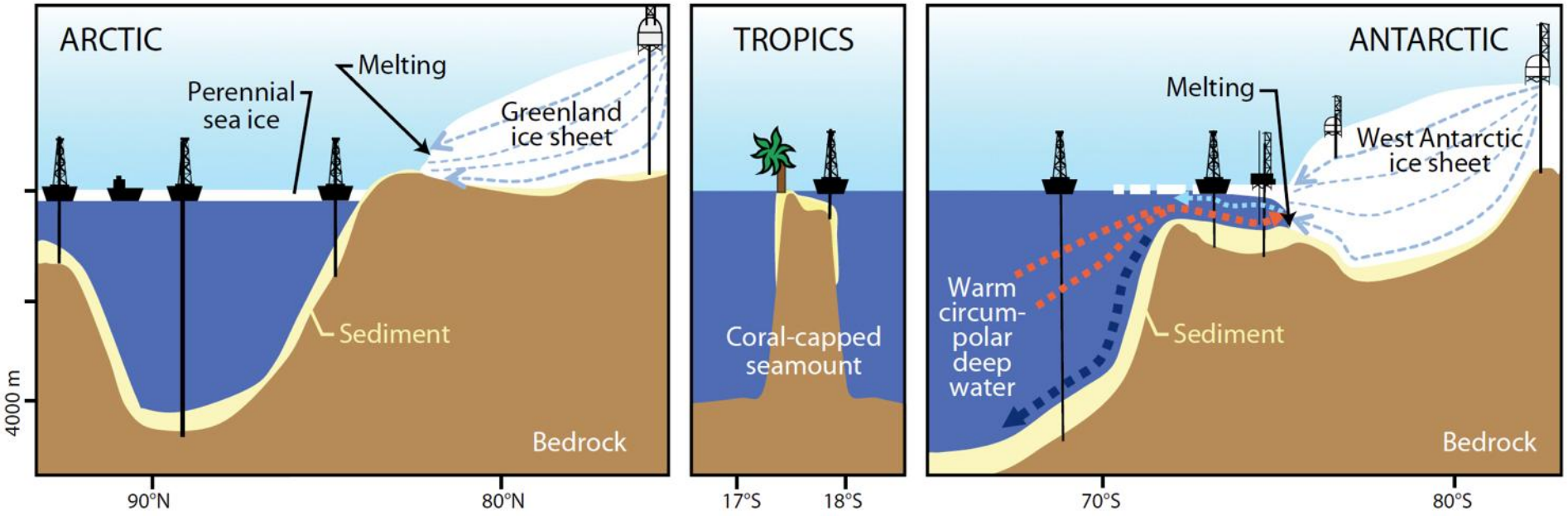




Middle Cretaceous forest on Antarctica;

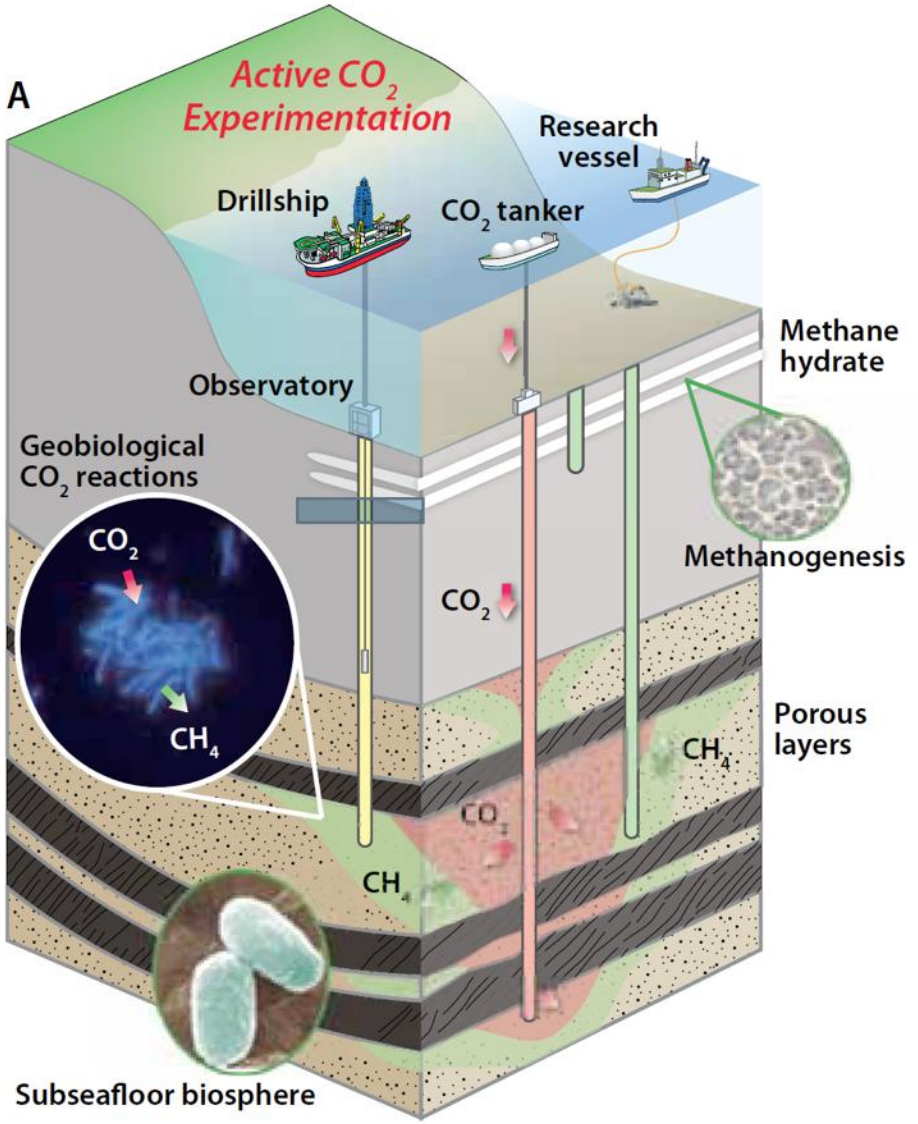
painting by Robert Nicholls, with permission for use by the artist and by the British Antarctic Survey who commissioned the painting

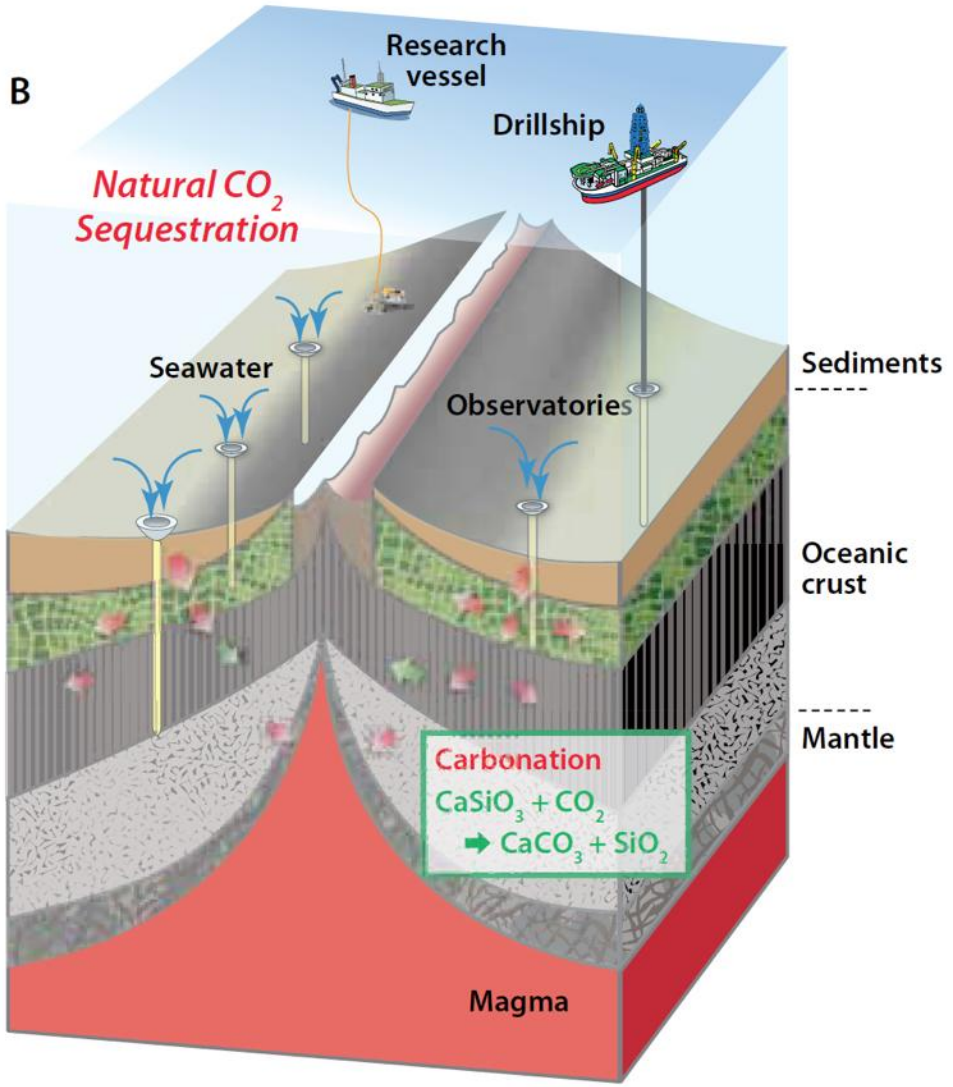
Climate and Ocean Change: Reading the Past, Informing the Future



Elements of this figure were adapted from Schoof (2010)

Biosphere Frontiers: Deep Life, Biodiversity, and Environmental Forcing of Ecosystems



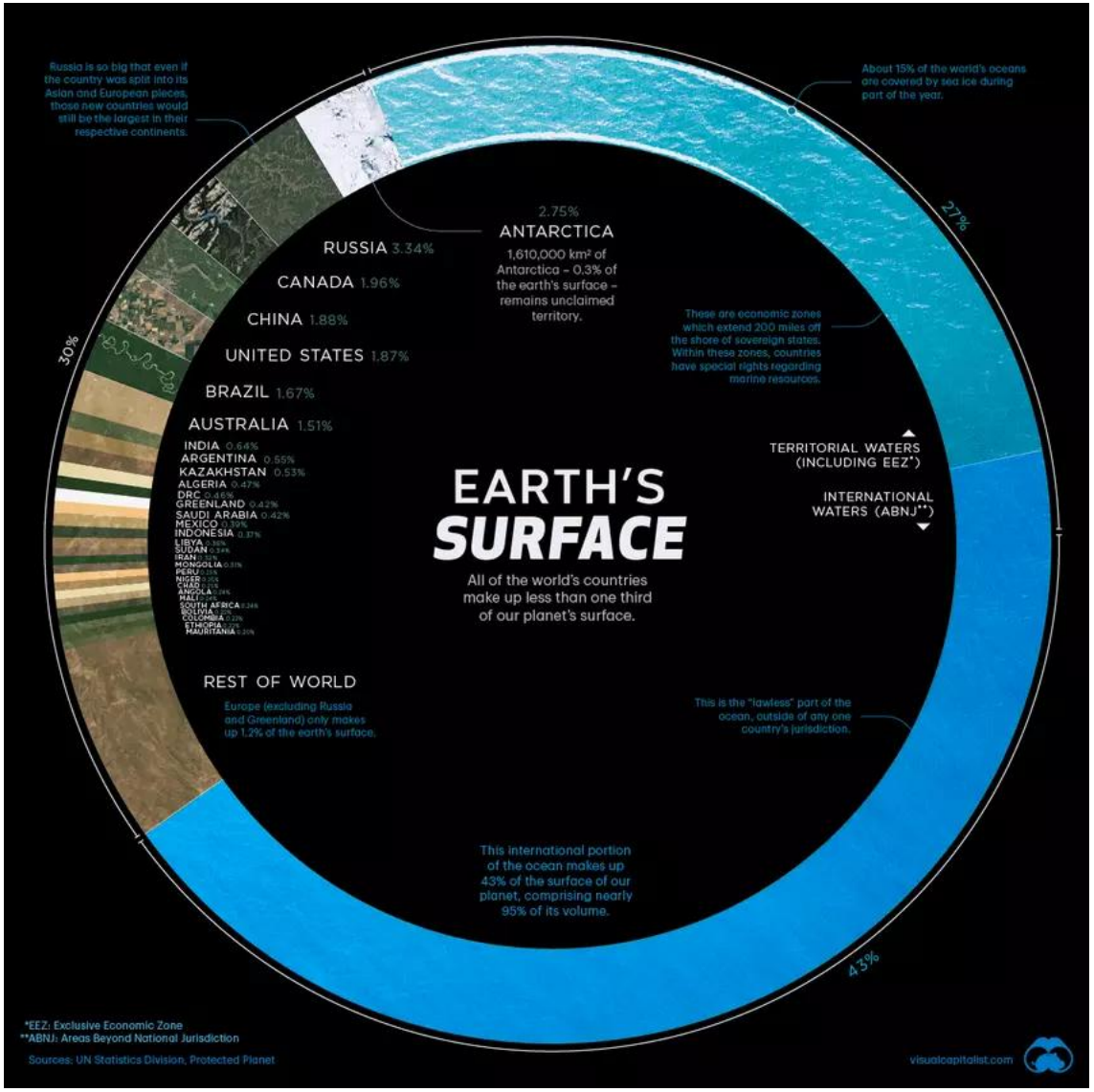


F. Inagaki, JAMSTEC

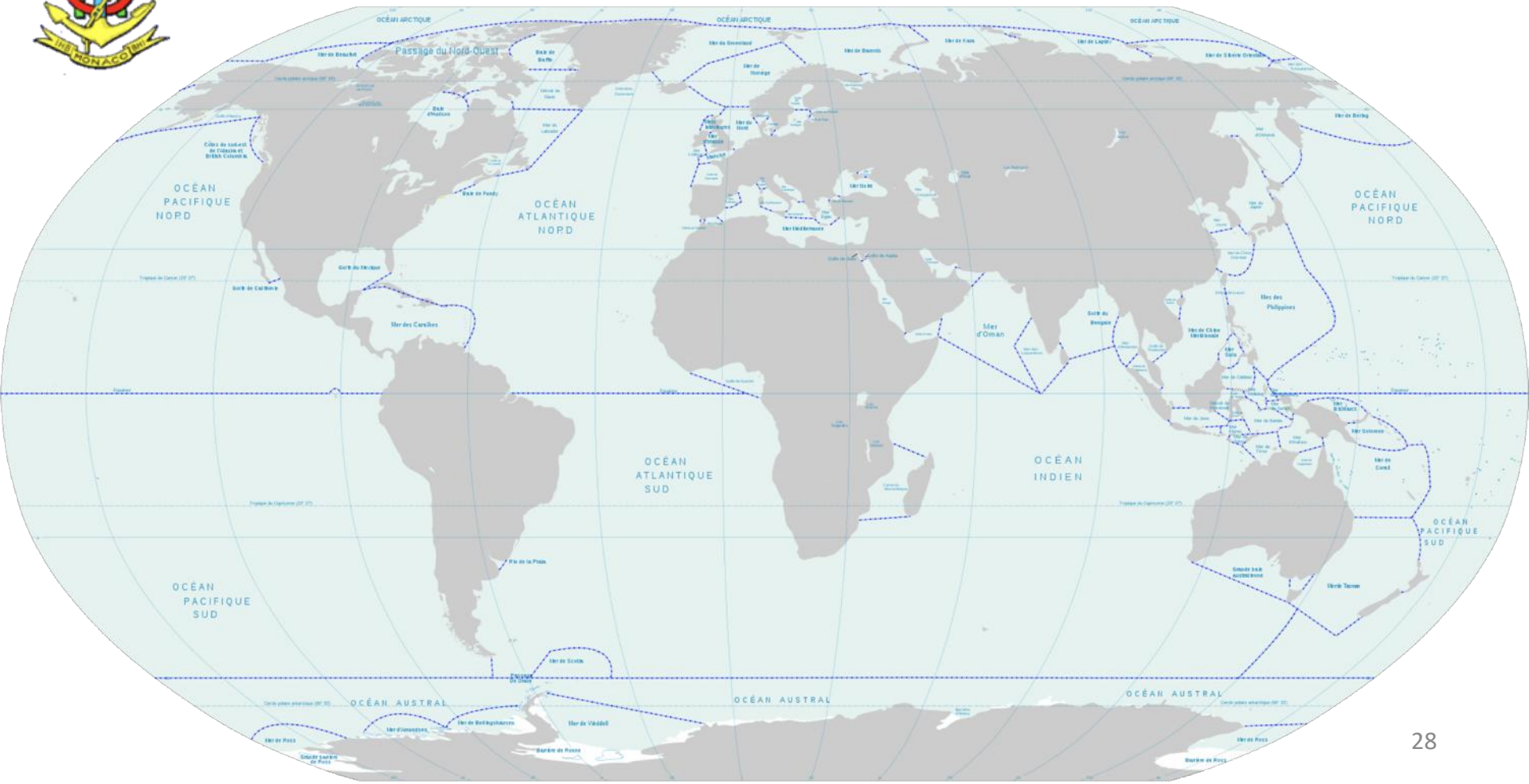
Oceans and Seas:

~ 70% of Earth Surface

International boundaries are defined under the United Nations Convention on the Law of the Sea (UNCLOS)



The limits of the oceans and seas international boundaries 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



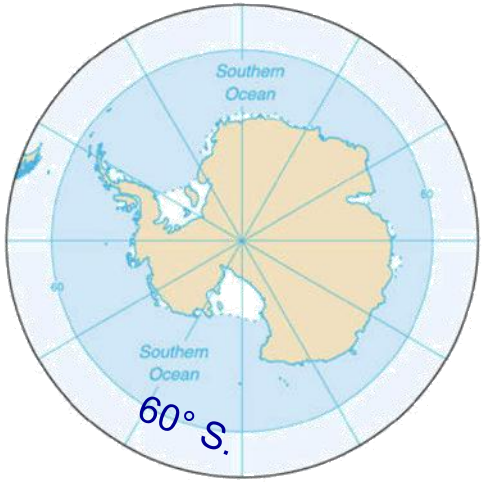
The oceans of the world

Artic Ocean



The Arctic Ocean extends south to about 60°N.

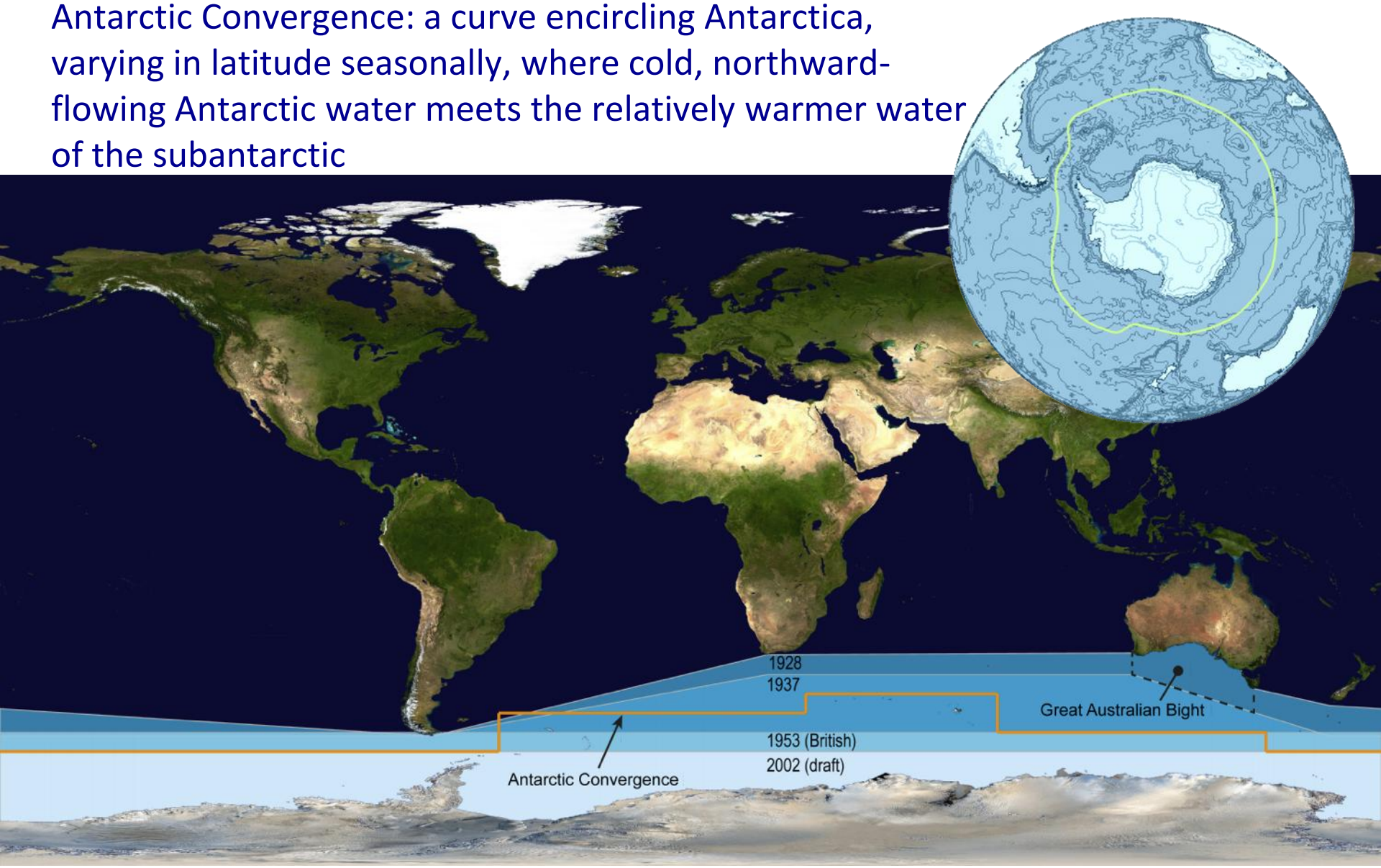
Southern Ocean



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 water meets the relatively warmer water of the subantarctic



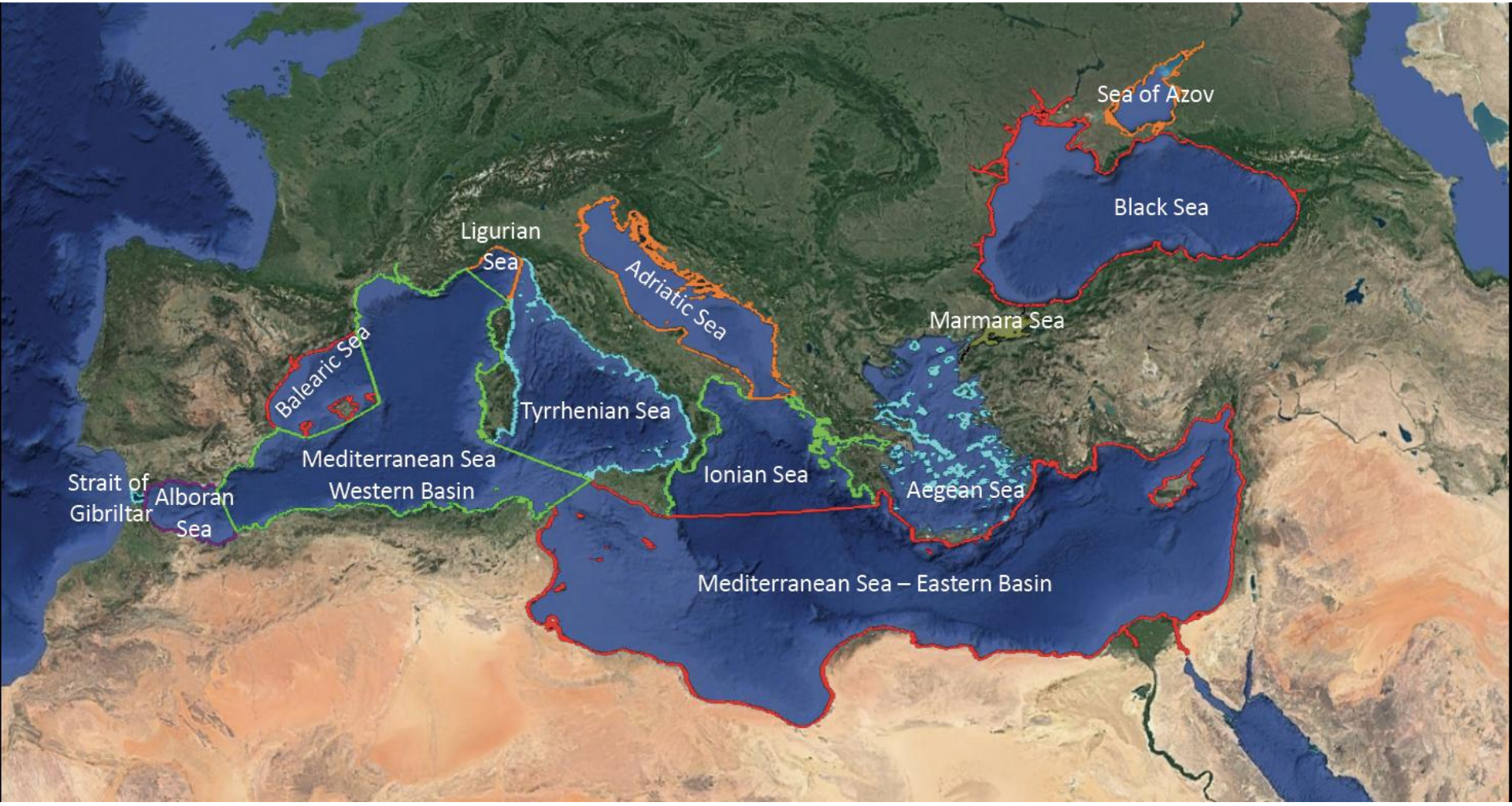
Ocean	Area	Average Depth (m)	Deepest depth (m)
Pacific Ocean	165,250,000 km^2	4,028 m	Mariana Trench 11,033 m
Atlantic Ocean	106,400,000 km^2	3,926 m	Puerto Rico Trench 8,604 m
Indian Ocean	73,560,000 km^2	3,963 m	Java Trench, 7,725 m
Southern Ocean	20,330,000 km^2	4,000 to 5,000 m	the southern end of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

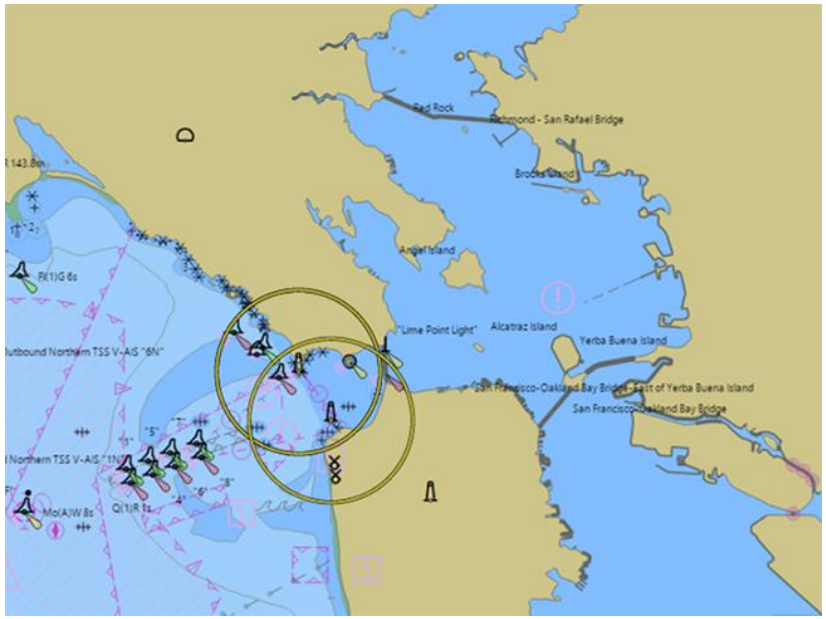


The seas of the Mediterranean

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



MARINE NAVIGATION
National Oceanic and Atmospheric Administration
U.S. Department of Commerce



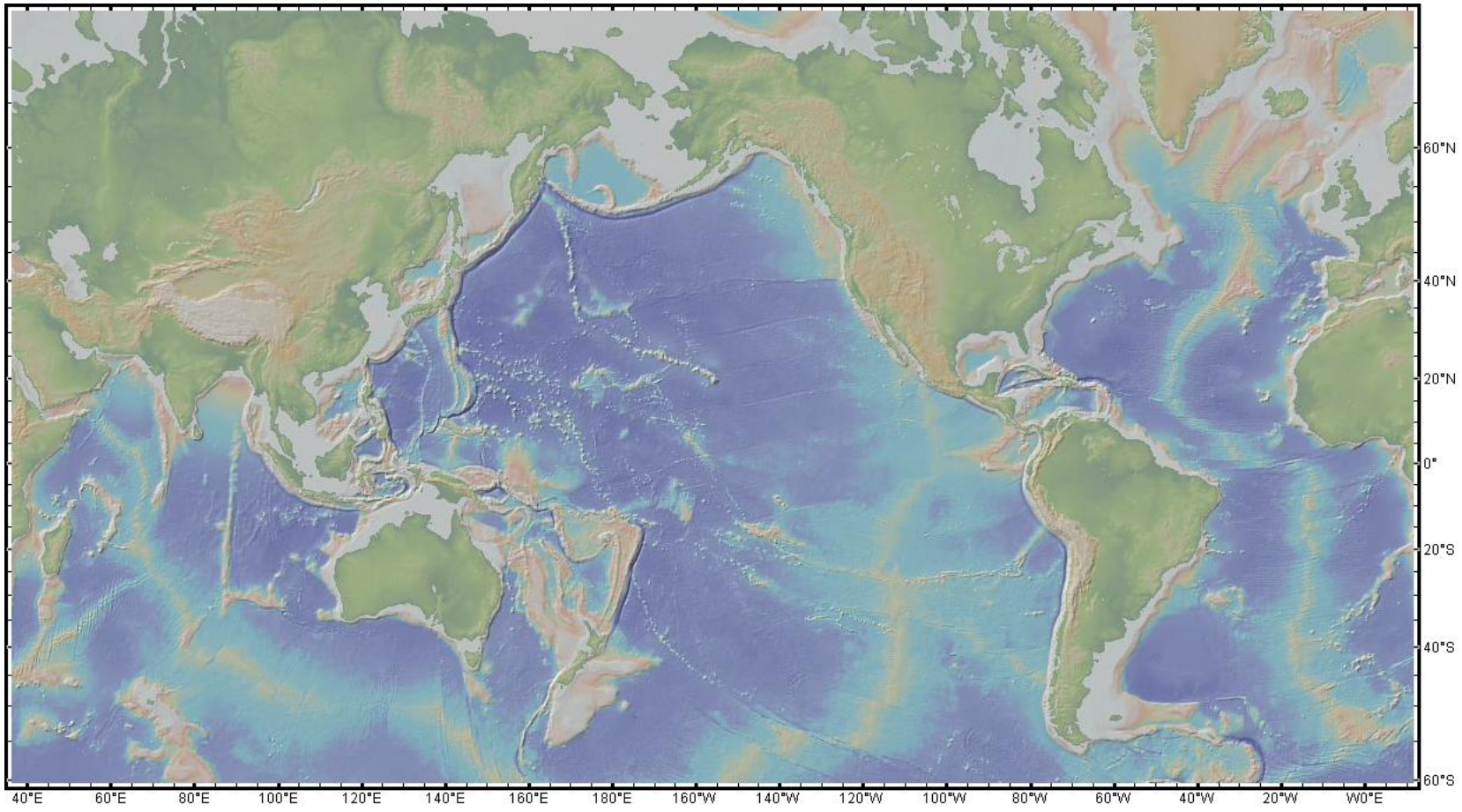
Typical small scale portrayal of ENC data showing entrances to San Francisco Bay

MARINA MILITARE
ONLINE SHOP ISTITUTO IDROGRAFICO

Carte Nautiche

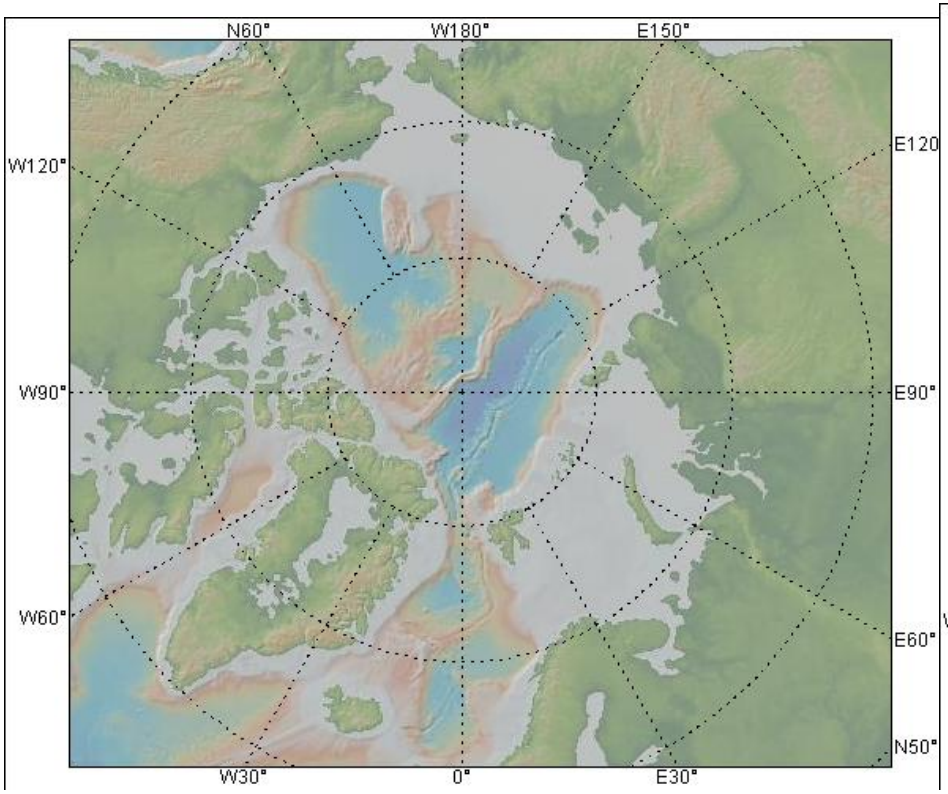


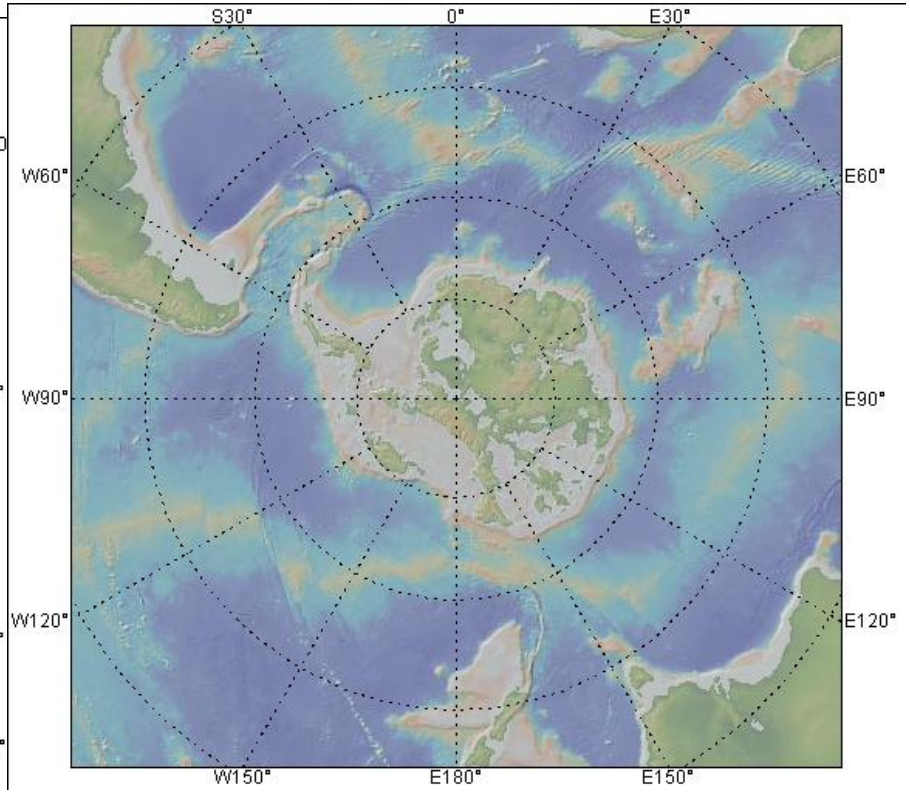
MORPHOLOGY OF THE OCEAN AND SEA FLOOR



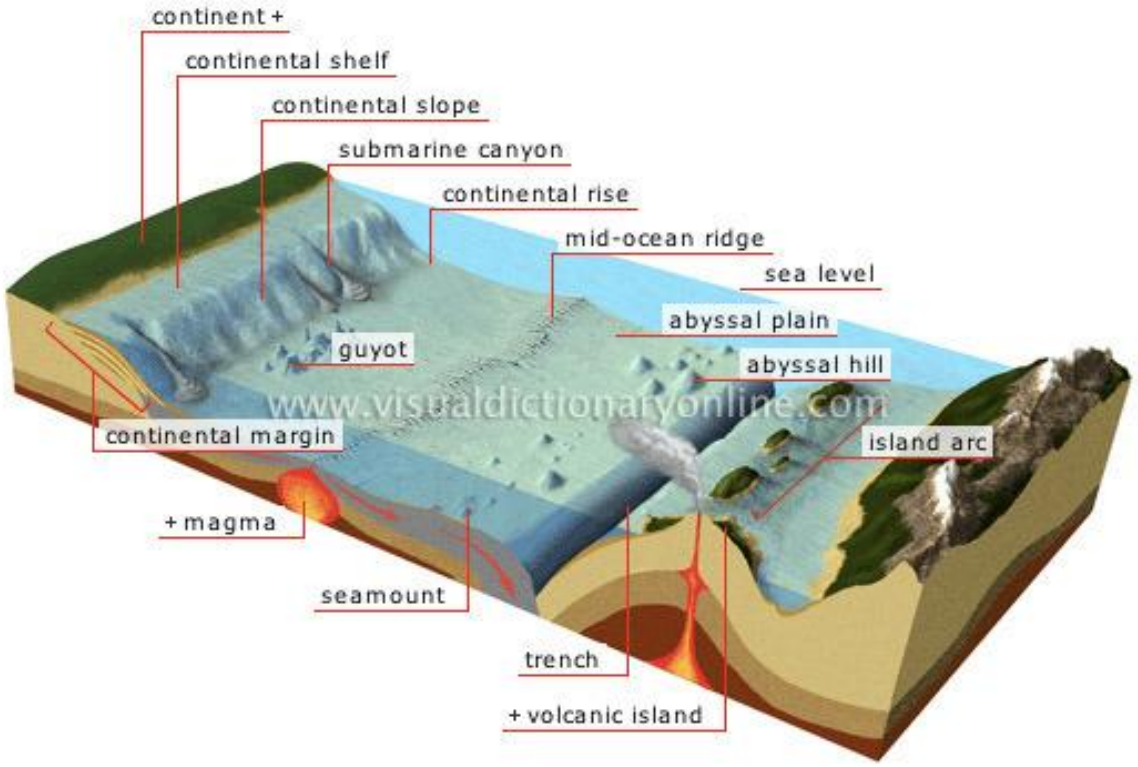
Geo Map App

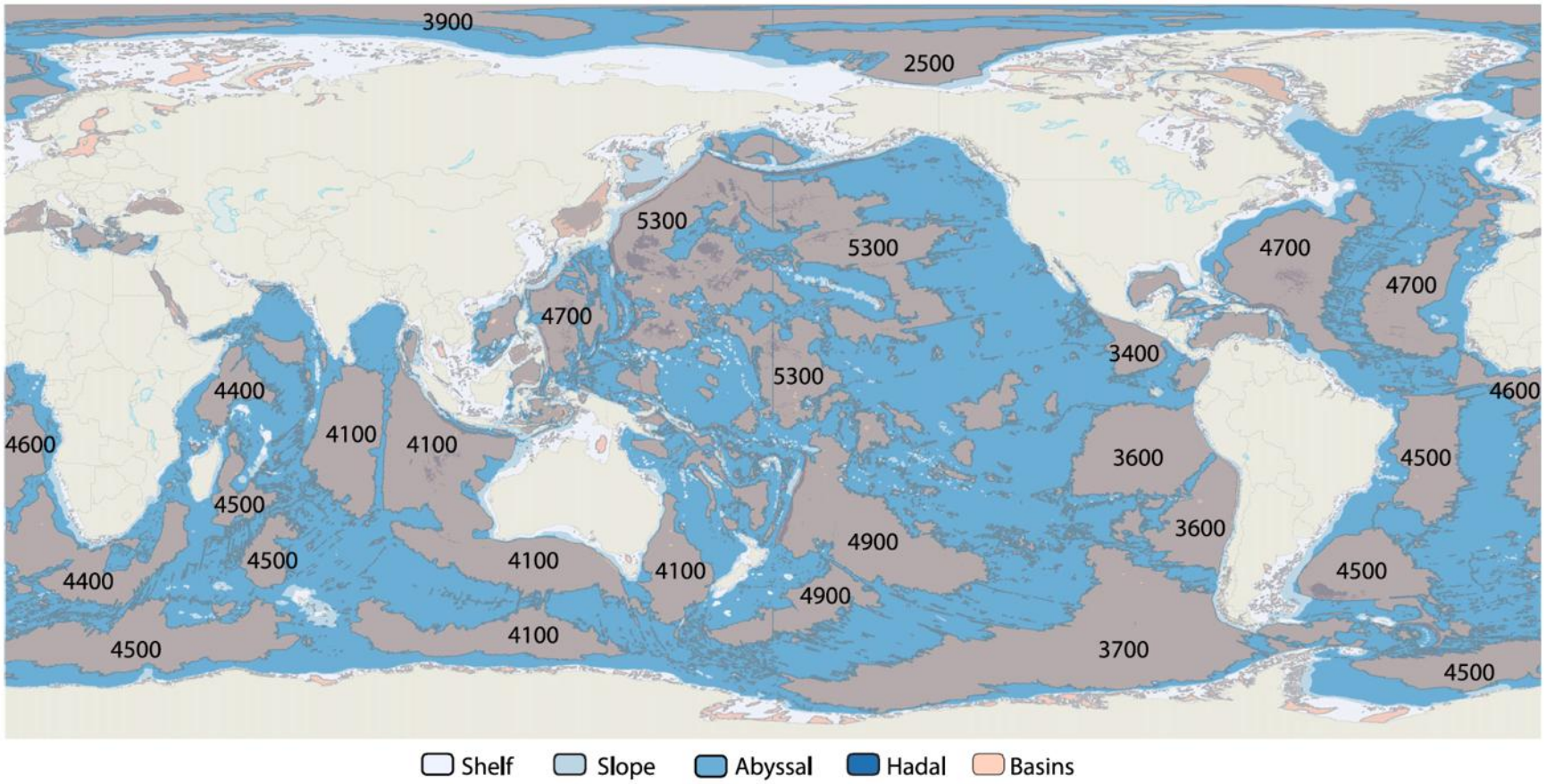
POLAR SEAS AND OCEANS





SEA FLOOR GEO-MORPHOLOGY





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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.

0-200 meters

200-2.000 meters

2000-6.000 meters

6000-11.000 meters

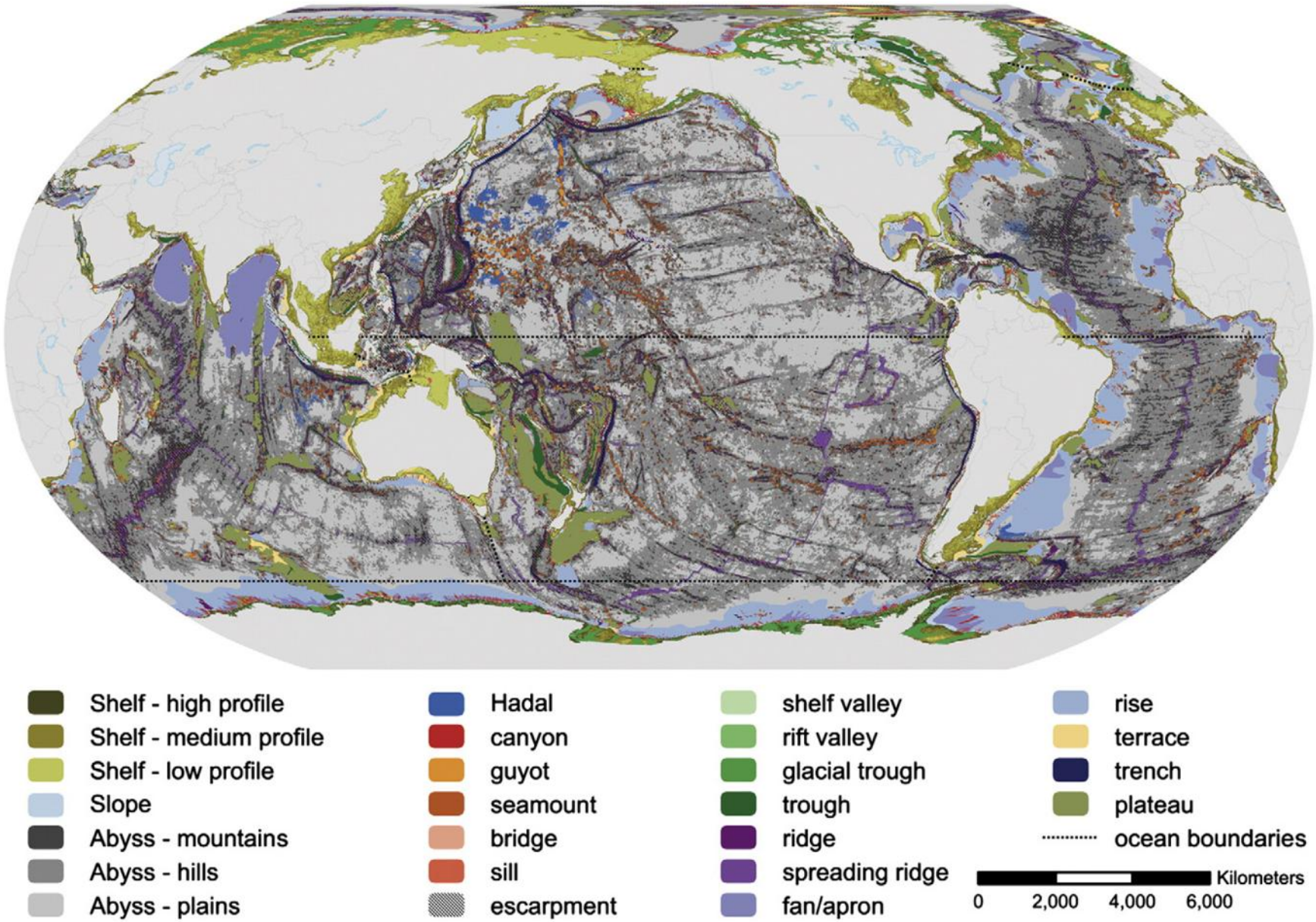


Fig. 4. Geomorphic features map of the world's oceans. Dotted black lines mark boundaries between major ocean regions. Basins are not shown.

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

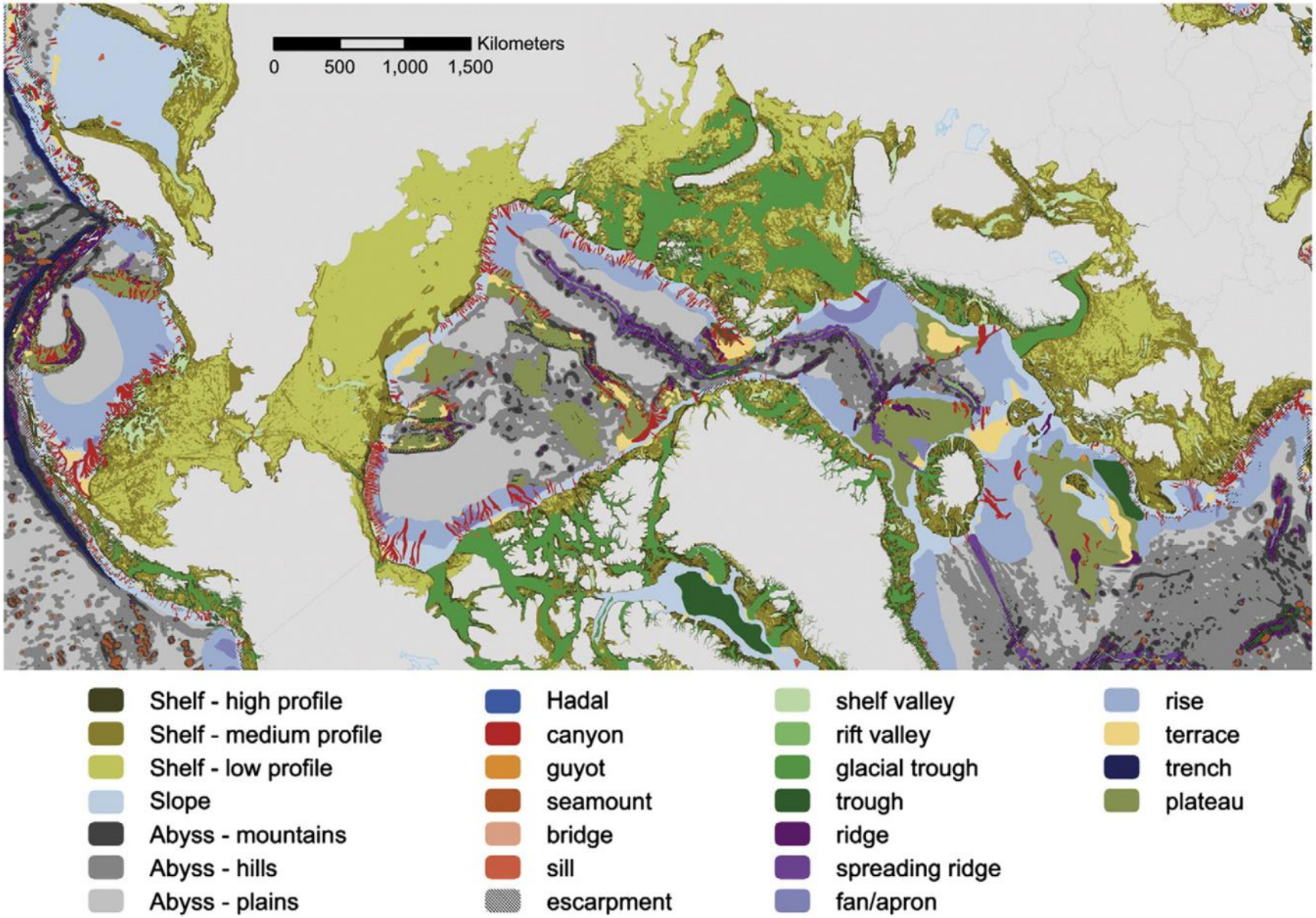


Fig. 5. Geomorphic features map of the Arctic Ocean. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.

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

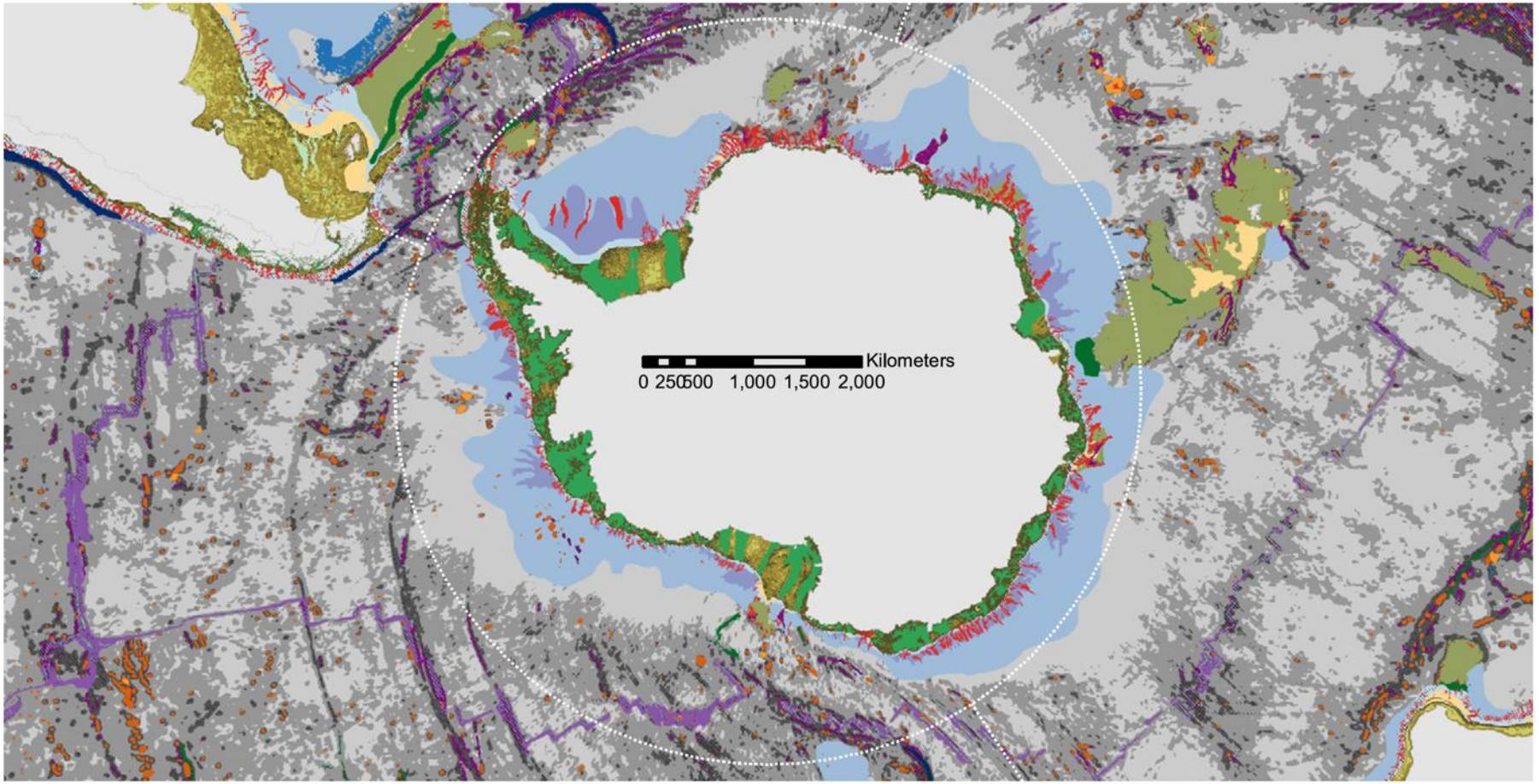


Fig. 12. Geomorphic features map of the Southern Ocean. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.

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

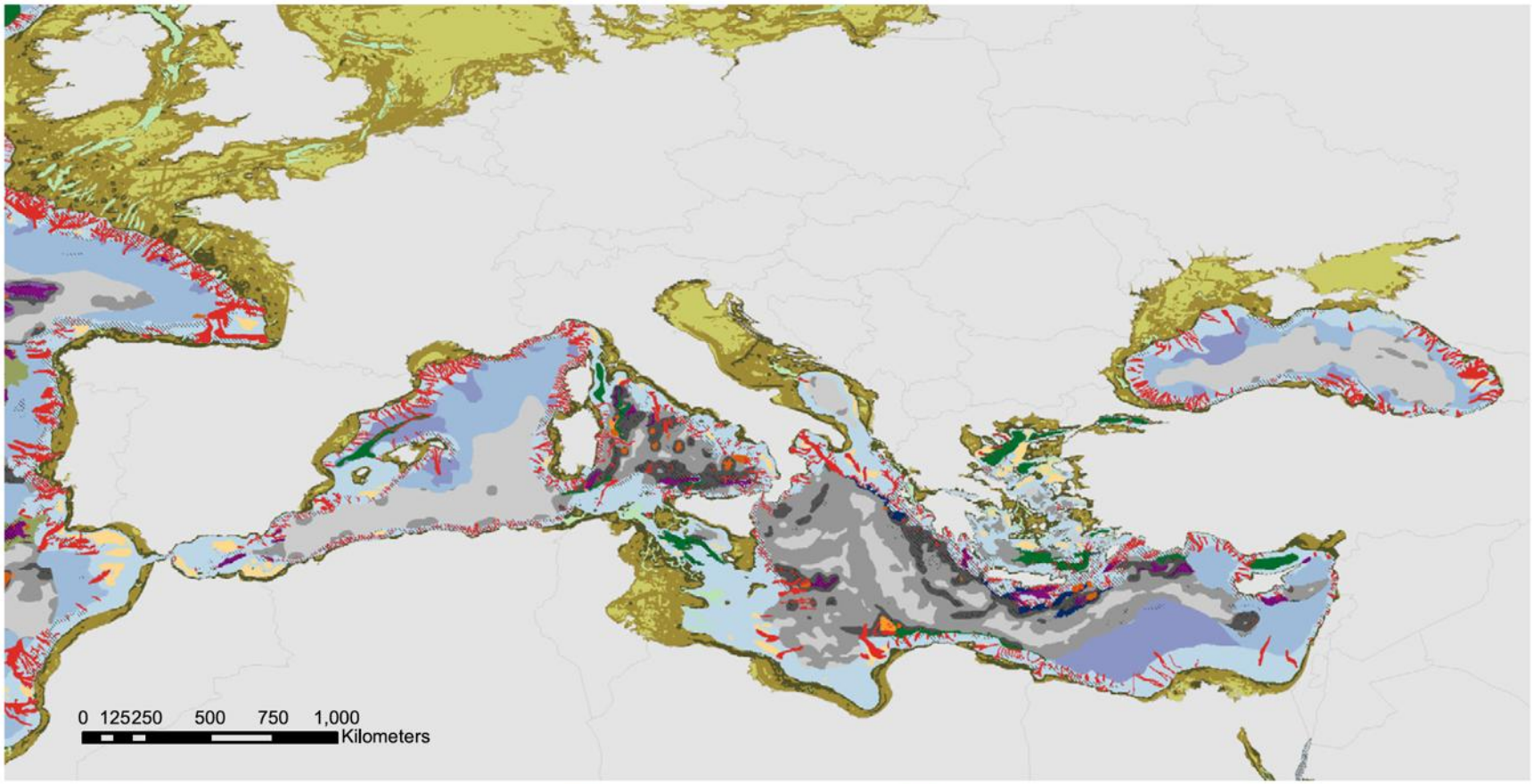
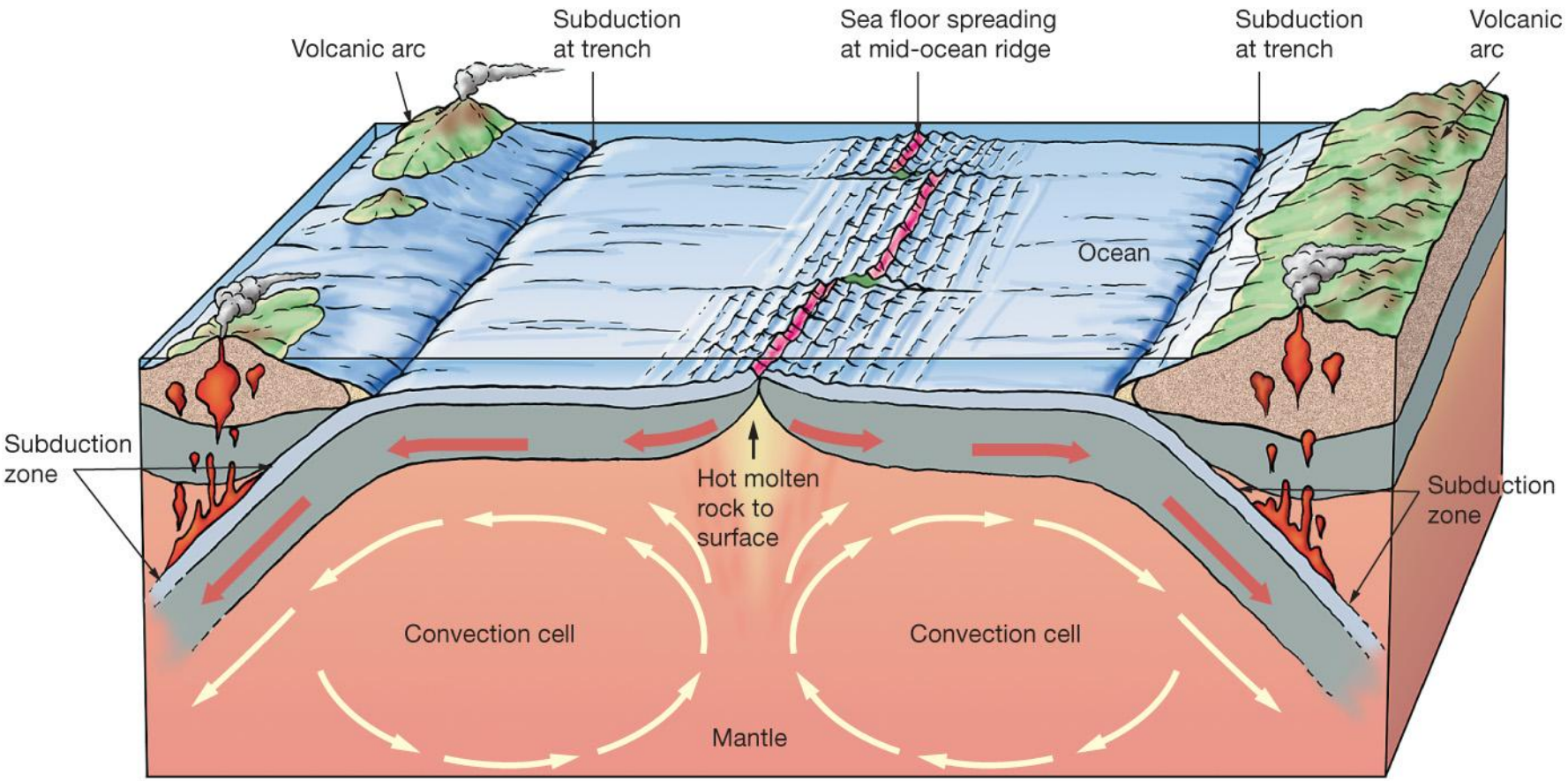


Fig. 7. Geomorphic features map of the Mediterranean and Black Seas. Dotted white lines mark boundaries between major ocean regions. Basins are not shown.

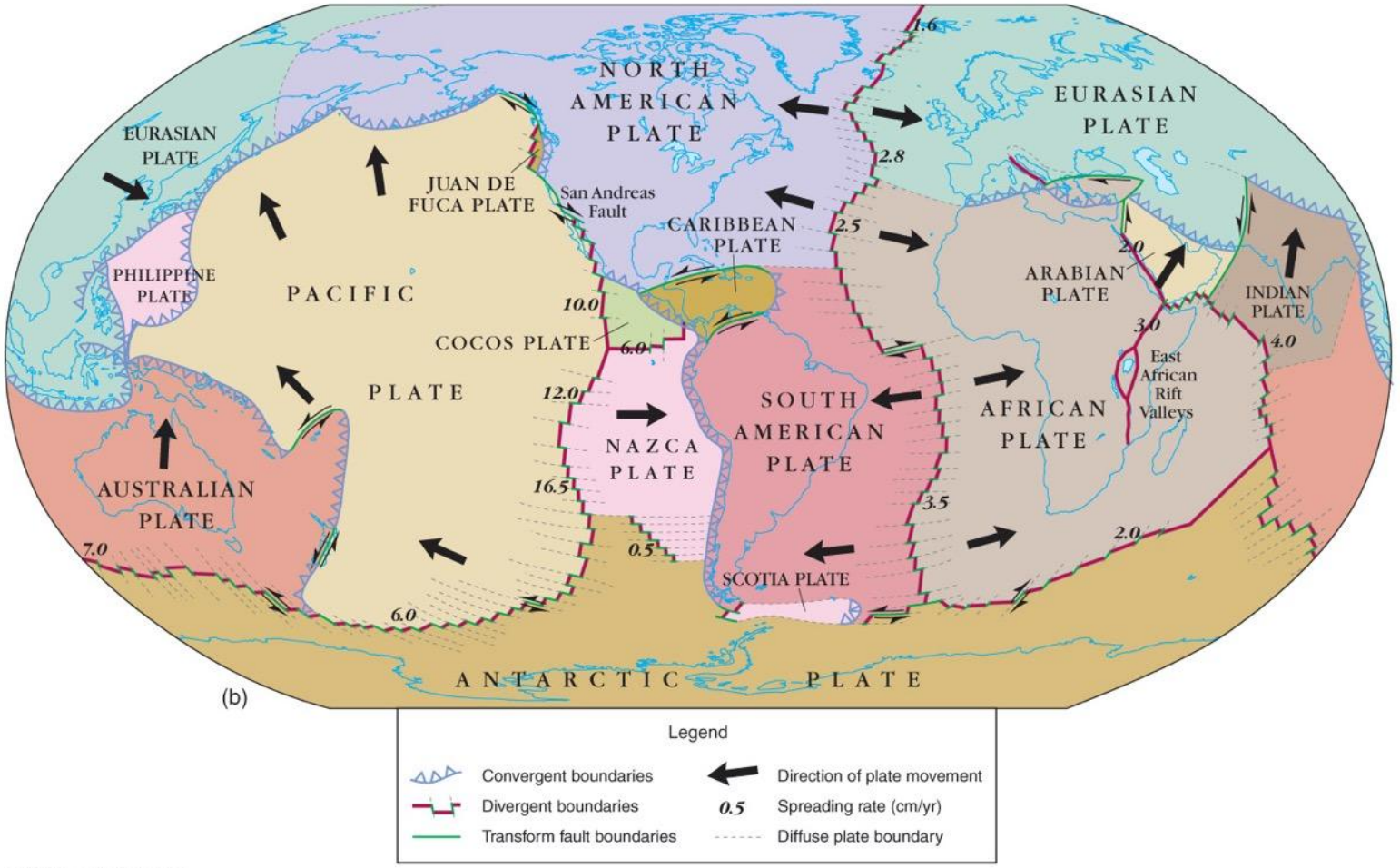
Harris et al., 2014. Geomorphology of the oceans. Marine Geology

3. The geological structure of the oceans



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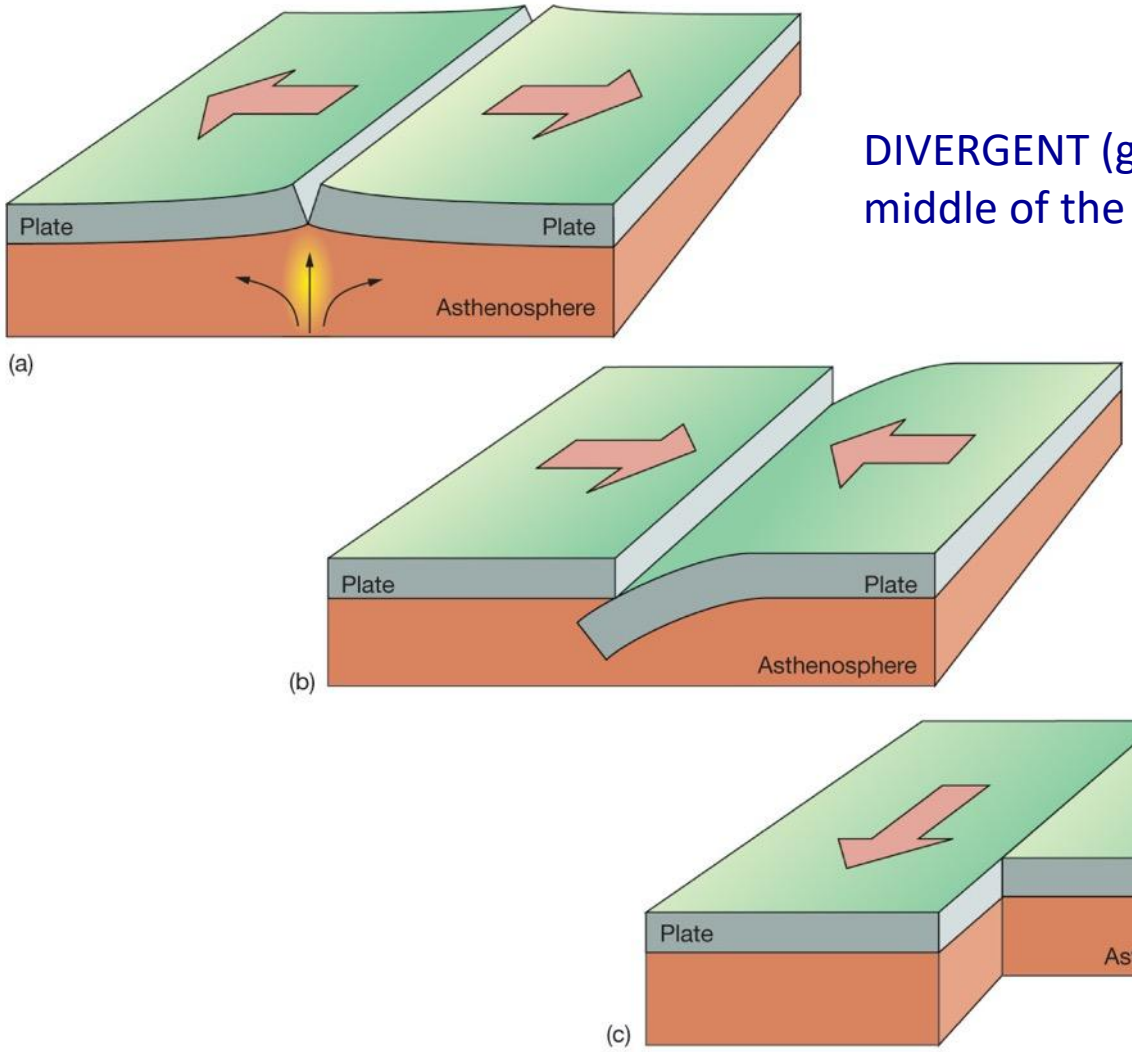
PLATE BOUNDARIES



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PLATE BOUNDARIES



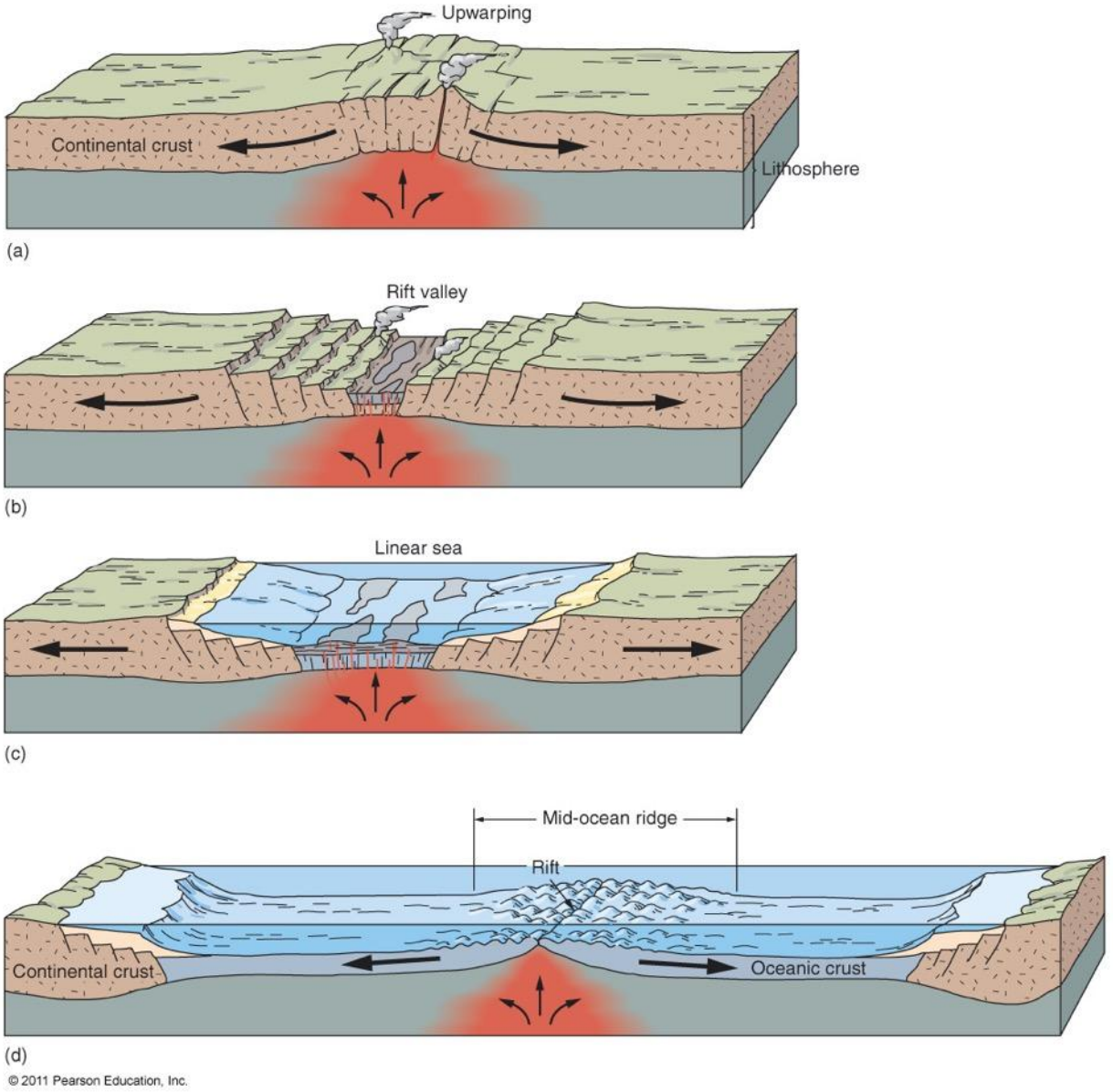
DIVERGENT (generally in the middle of the ocean)

CONVERGENT (generally along ocean margins)

TRANSCURRENT (generally in the middle of the ocean)

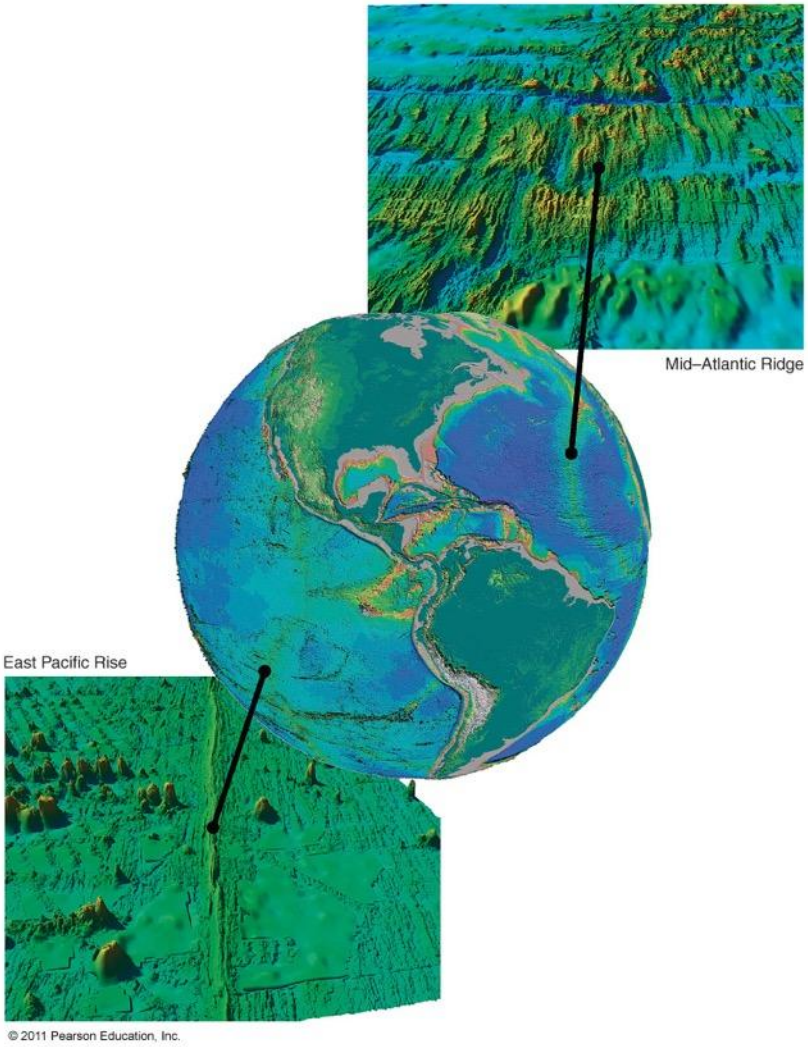
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Generation of a Divergent Boundary



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Types of Spreading Centers

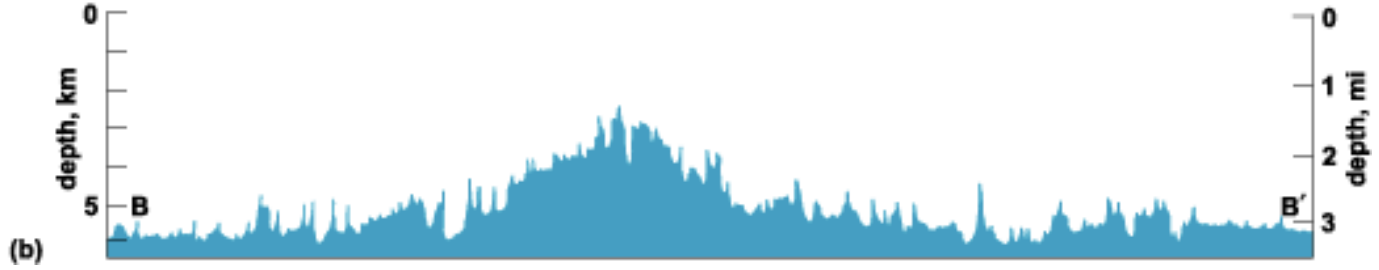


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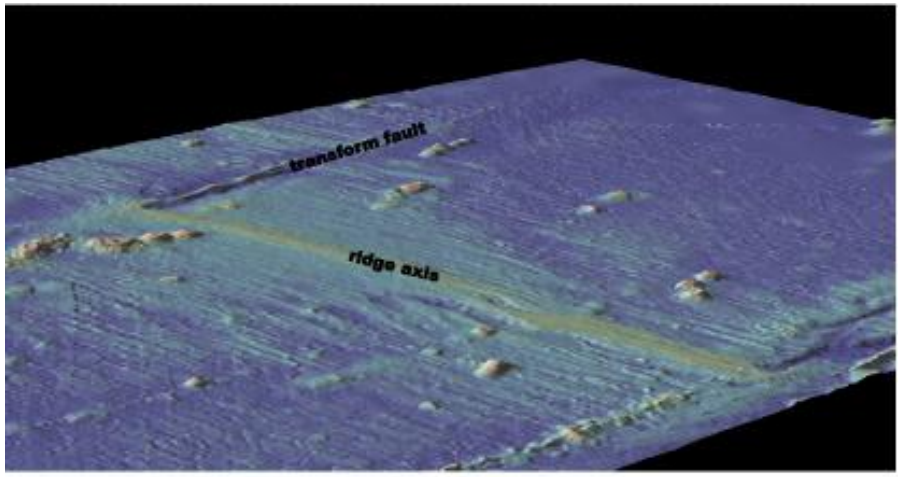
Pacific-Antarctic Ridge: fast-spreading, broad and smooth



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

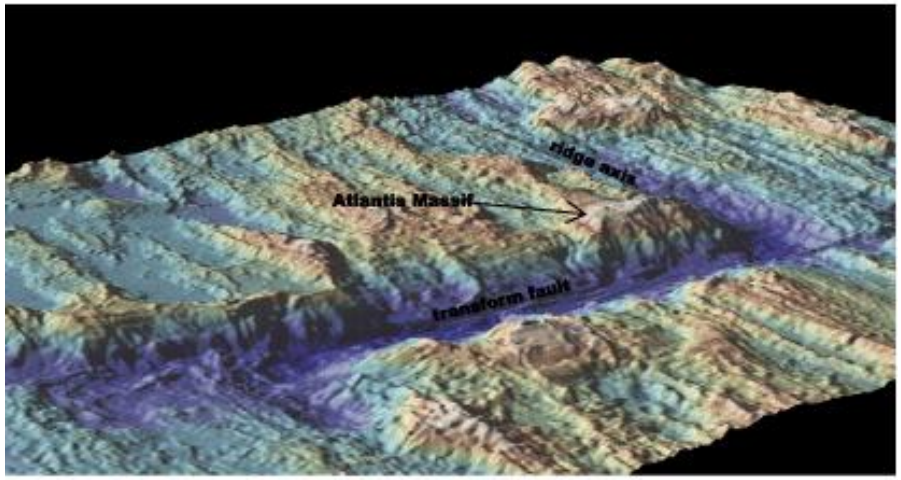


In places where **spreading is fastest** (more than 80 millimeters per year), the ridge has relatively gentle topography and is roughly dome-shaped in cross-section as a result of the many layers of lava that build up over time.
At **slow- and ultra-slow spreading centers**, the ridge is much more rugged,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



(a)

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

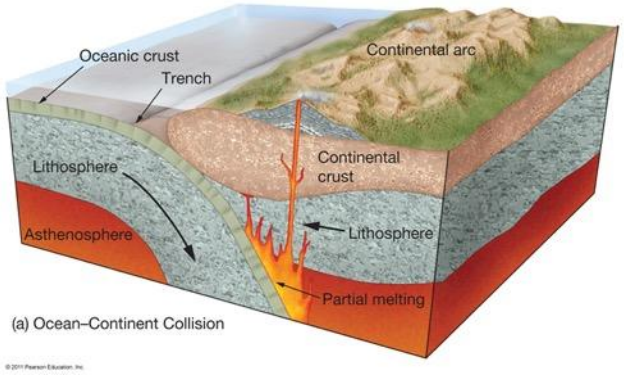


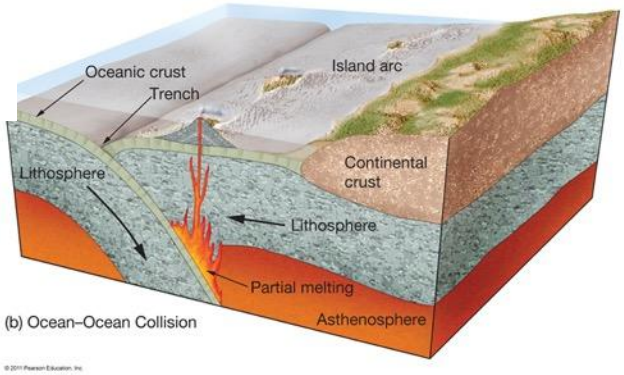
(b)

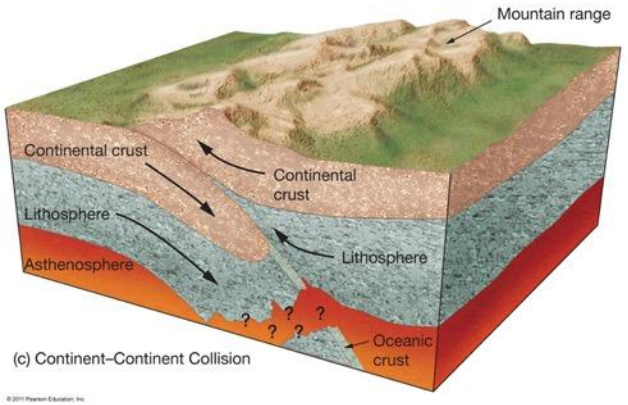
Slow-spreading Mid-Atlantic Ridge at 30°N and the Atlantis transform view toward the northeast.

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



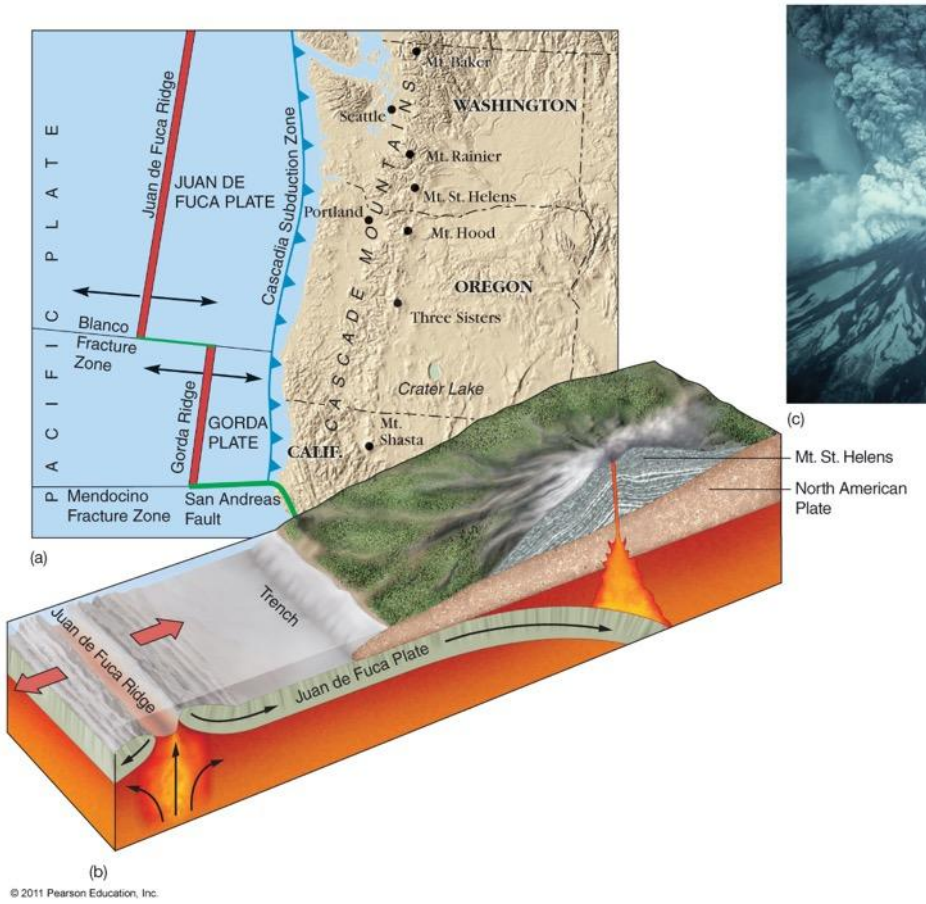




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Oceanic-Continental Convergence

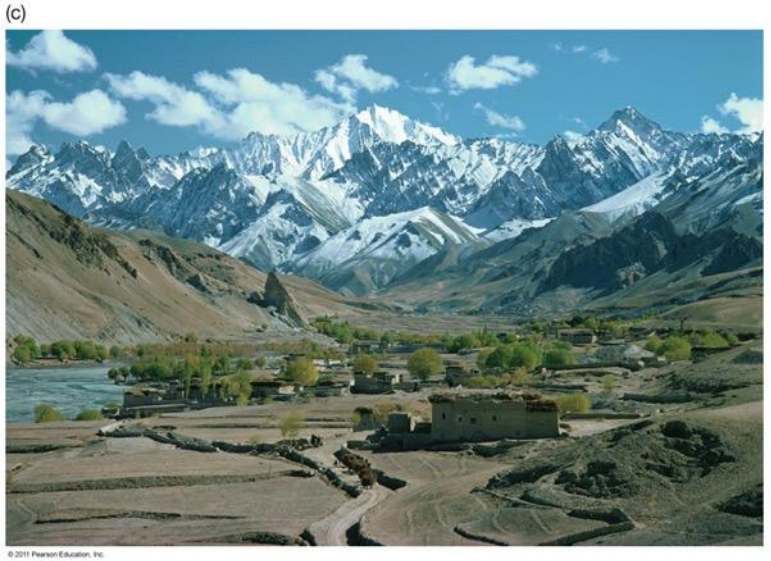
Ocean plate is subducted
Continental arcs generated
Explosive andesitic volcanic eruptions

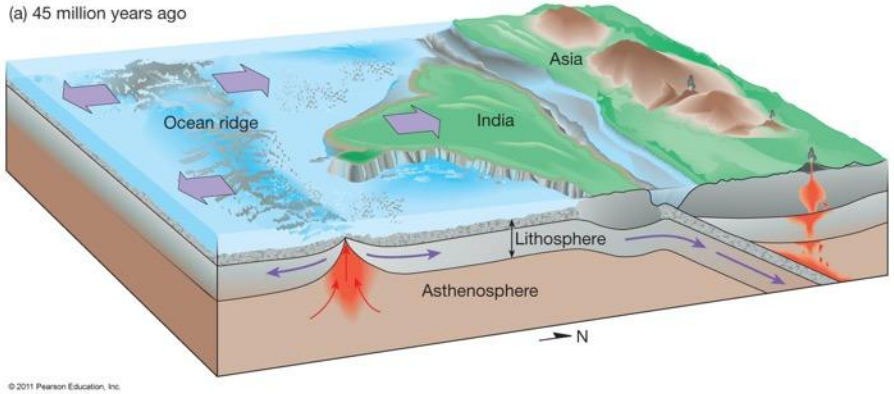


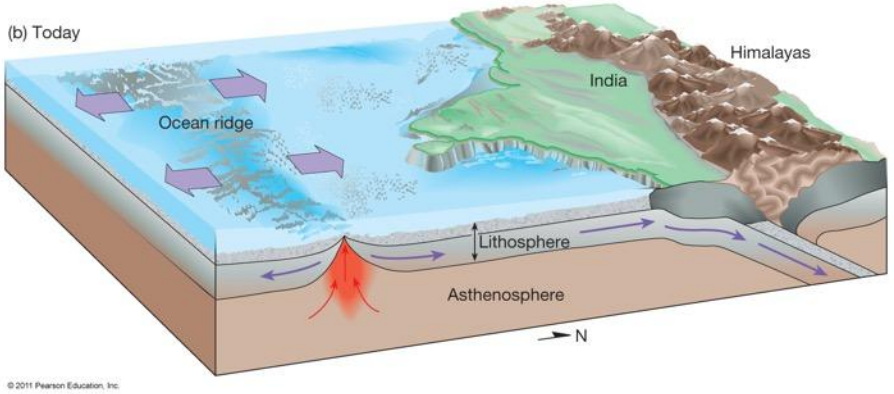
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Continental-Continental Convergence

No subduction
Tall mountains uplifted





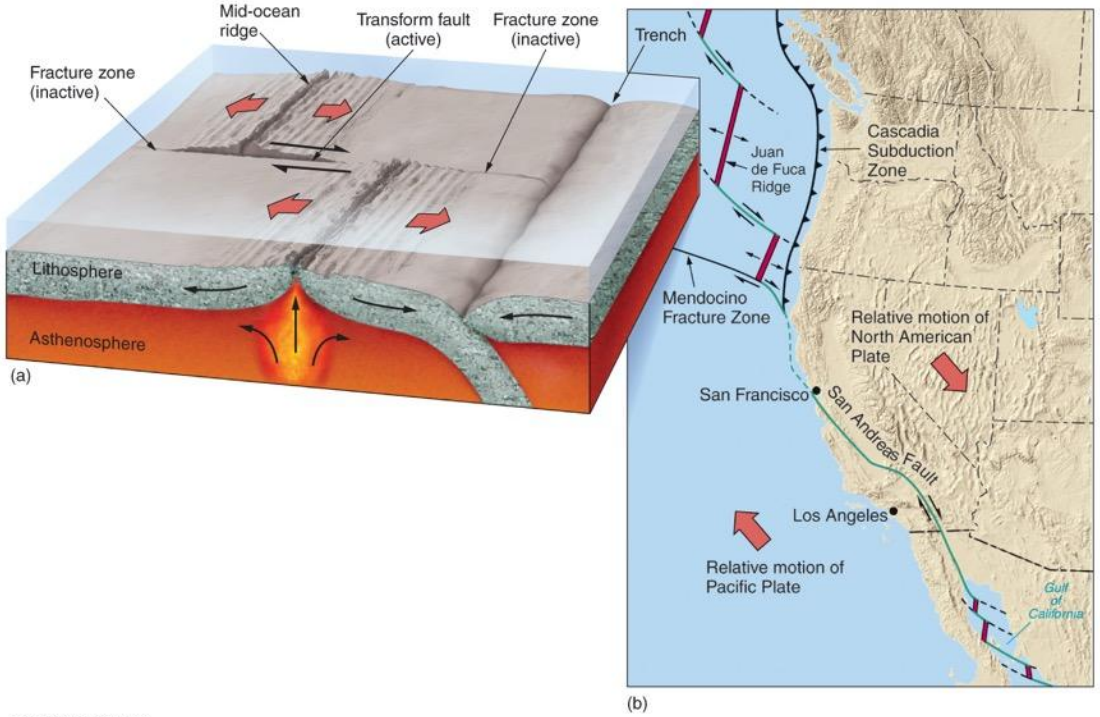


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Transform Boundary Features

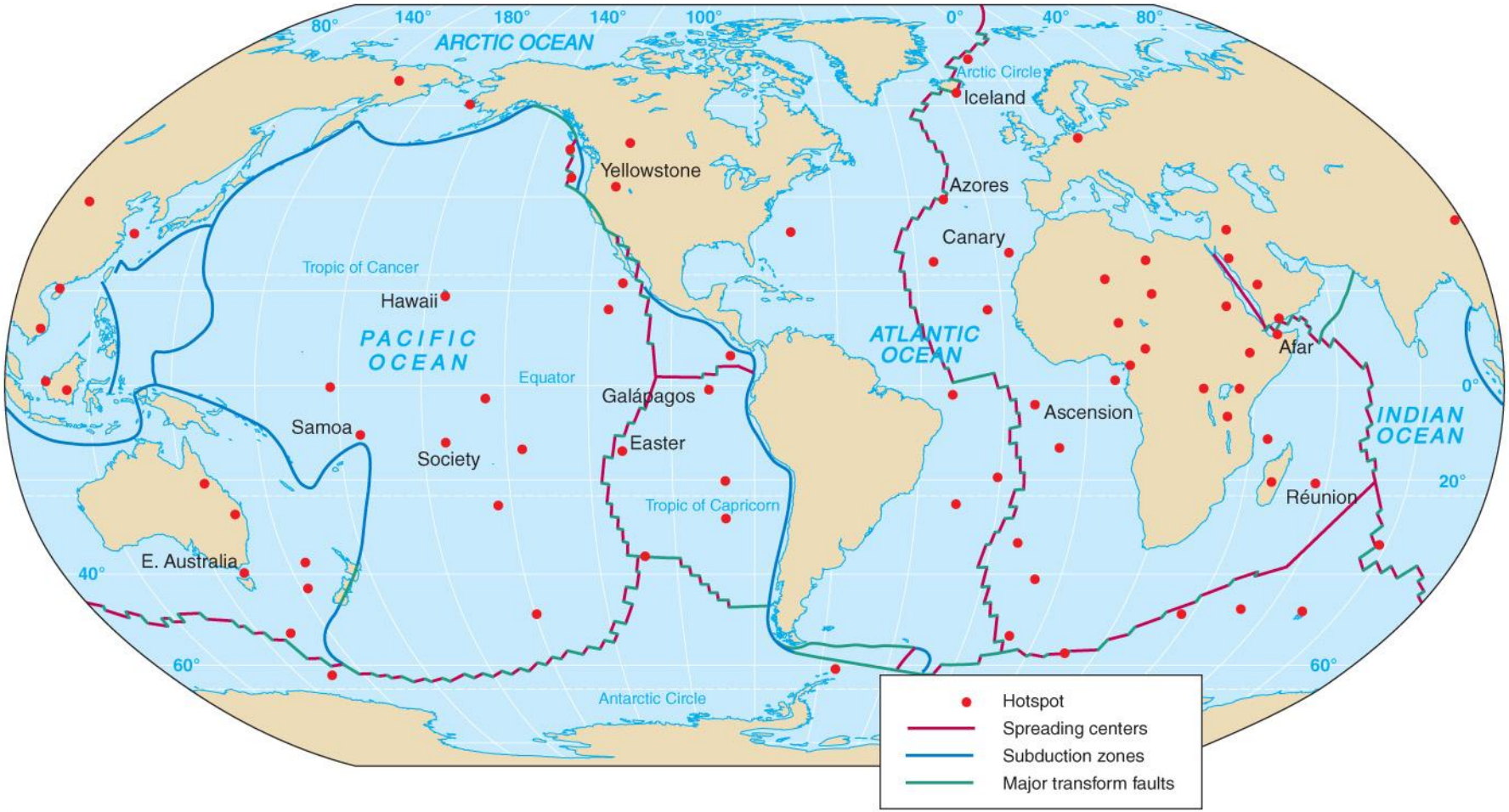
Oceanic Transform Fault – ocean floor only
Continental Transform Fault – cuts across continent

All transform faults occur between mid-ocean ridge segments.



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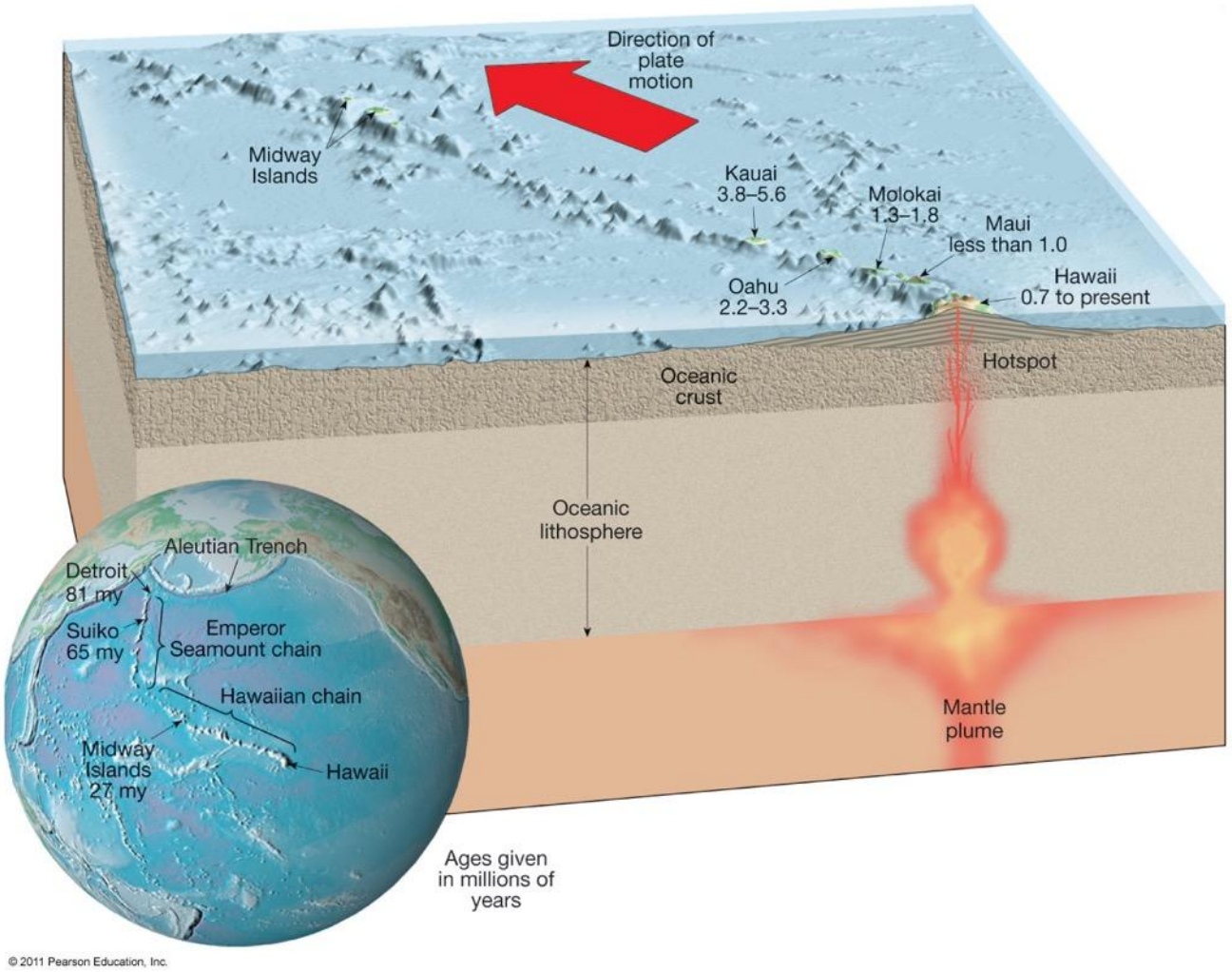
Global Hotspot Locations



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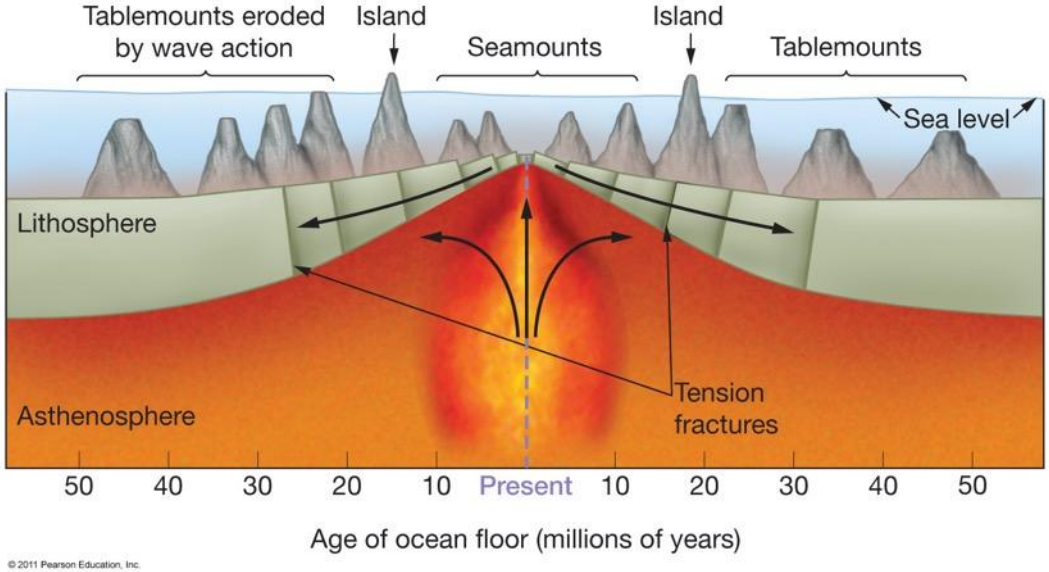
Hawaiian Island – Emperor Seamount Nematath



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Seamounts

Rounded tops
Tablemounts or guyots
Flattened tops
Subsidence of flanks of mid-ocean ridge
Wave erosion may flatten seamount



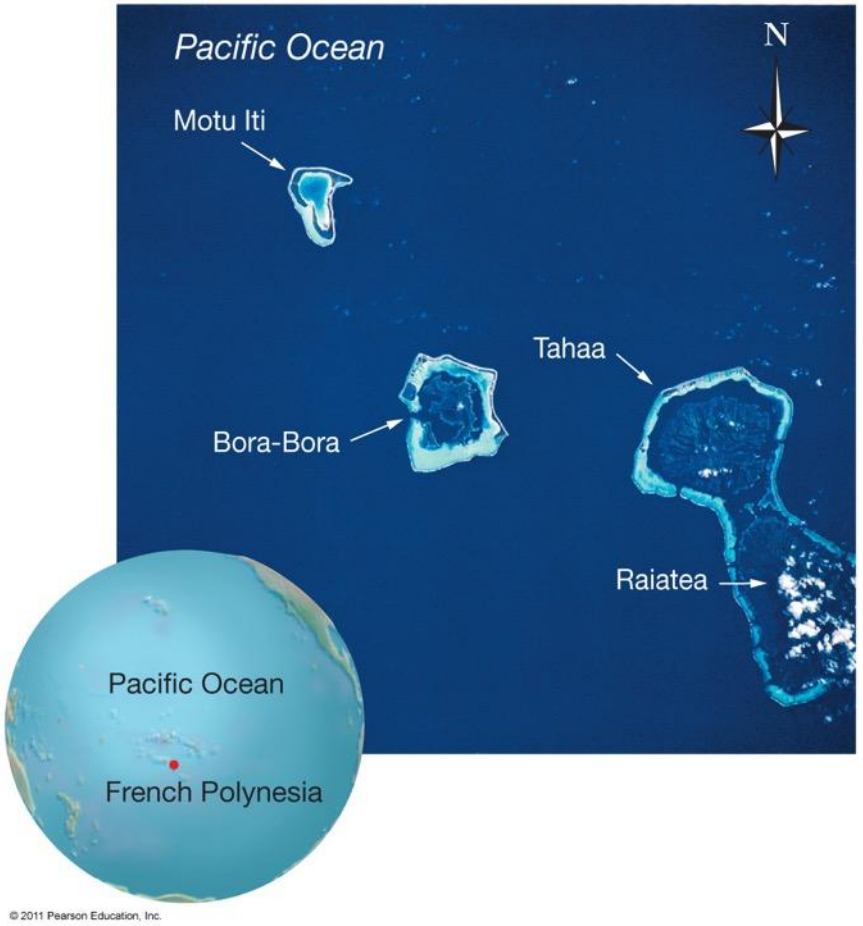
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Coral Reef Development

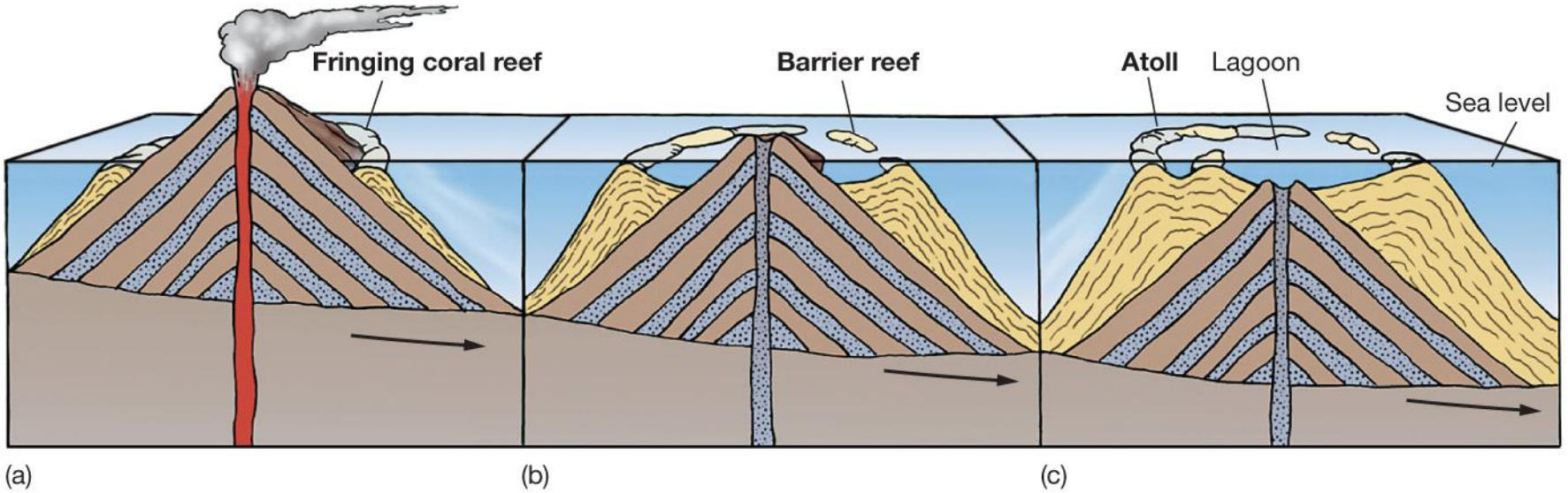
Fringing reefs – develop along margin of landmass

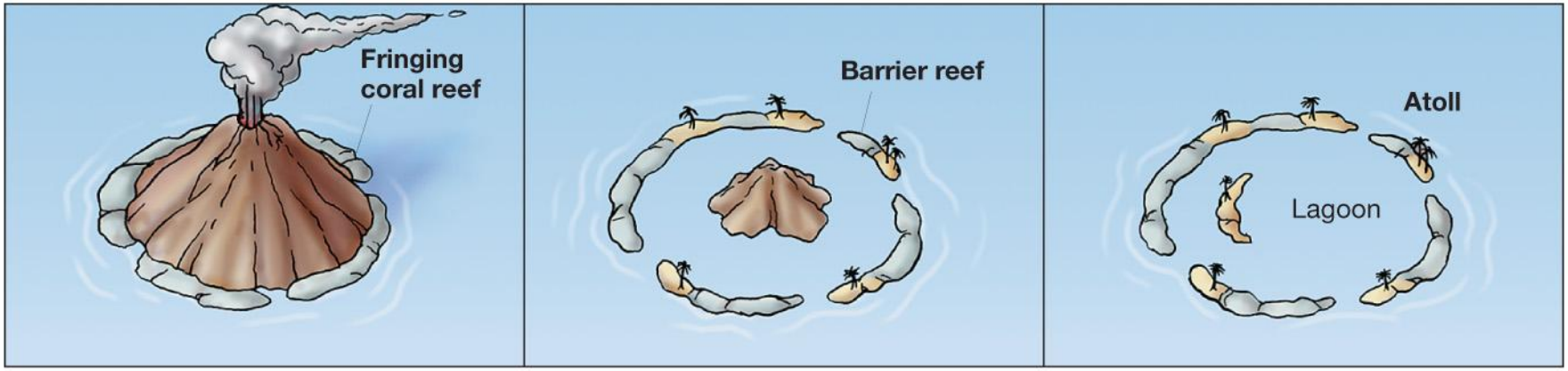
Barrier reefs – separated from landmass by lagoon

Atolls – reefs continue to grow after volcanoes are submerged



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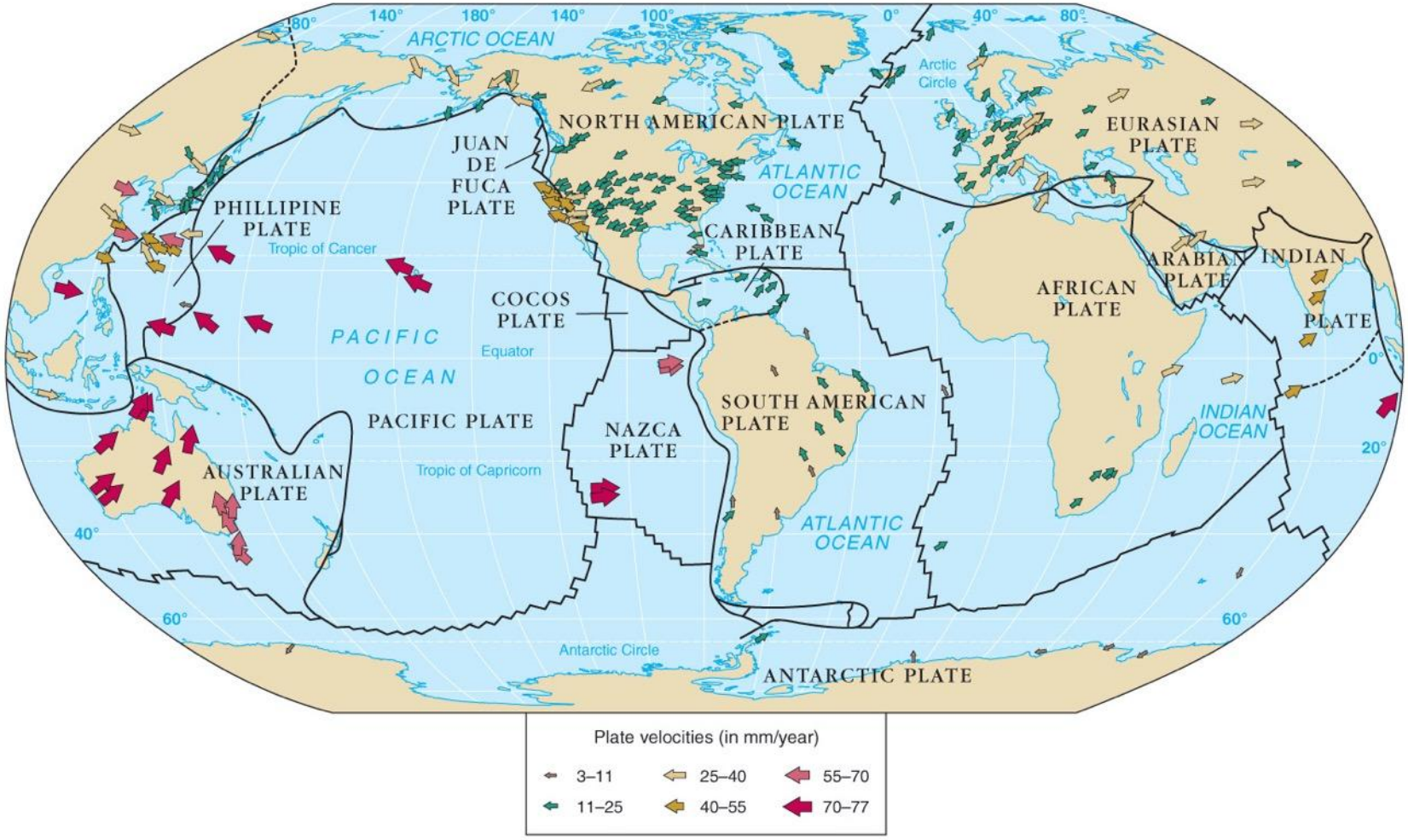




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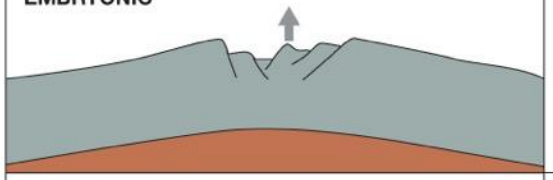
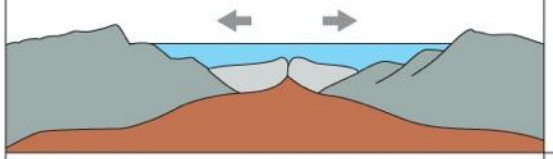
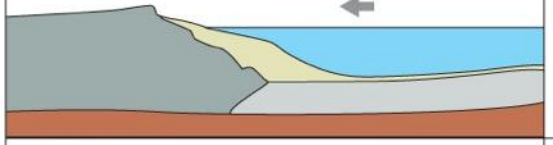
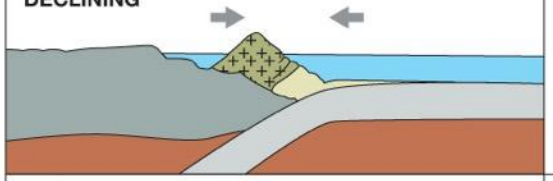
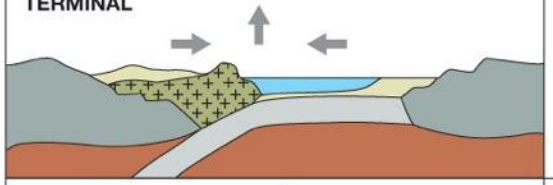
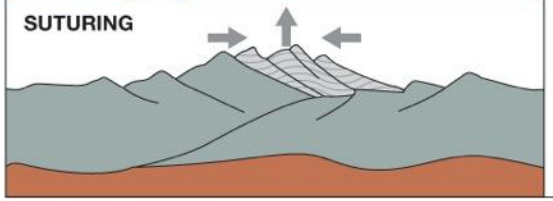
Detecting Plate Motion with Satellites



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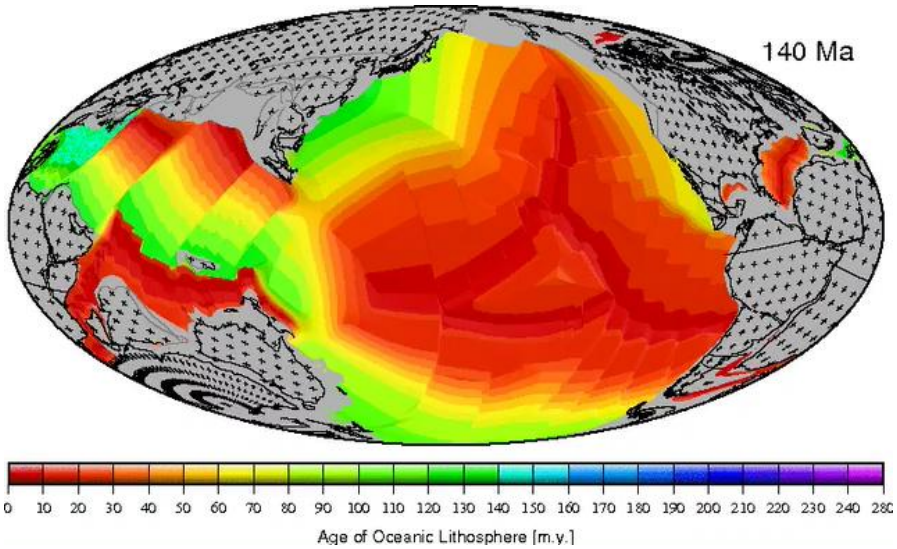
Wilson cycle

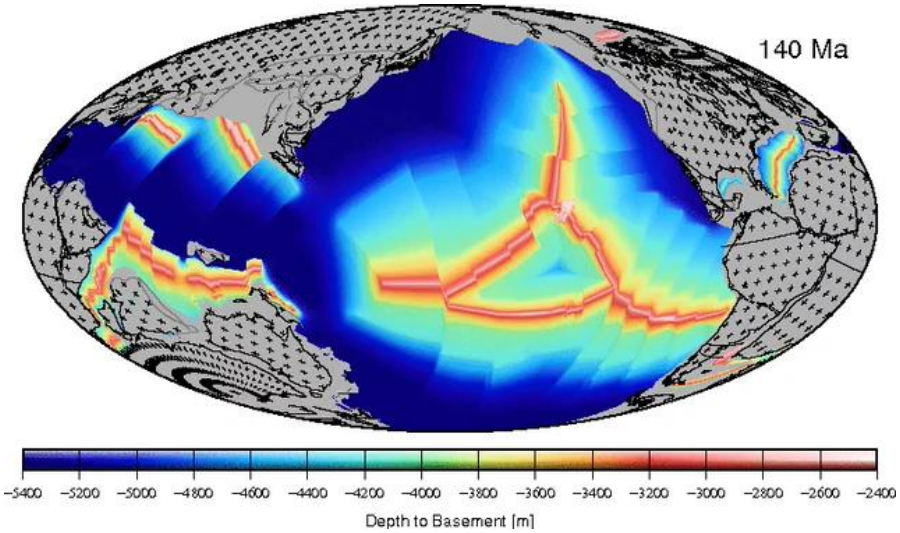
Stage, showing cross-sectional view	Motion	Physiography	Example
EMBRYONIC 	Uplift	Complex system of linear rift valleys on continent	East African rift valleys
JUVENILE 	Divergence (spreading)	Narrow seas with matching coasts	Red Sea
MATURE 	Divergence (spreading)	Ocean basin with continental margins	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

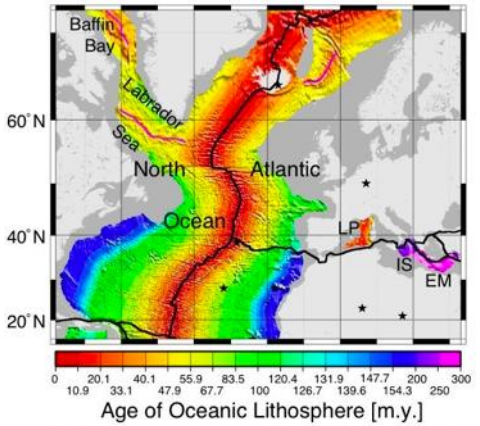
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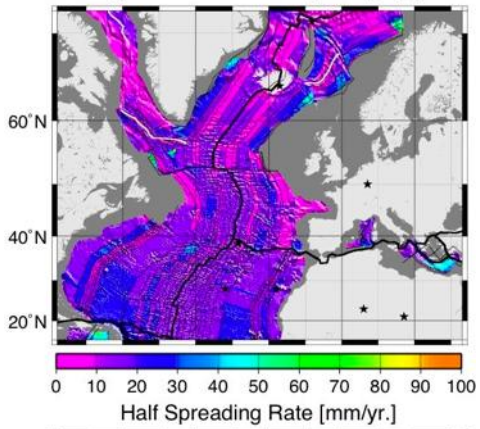
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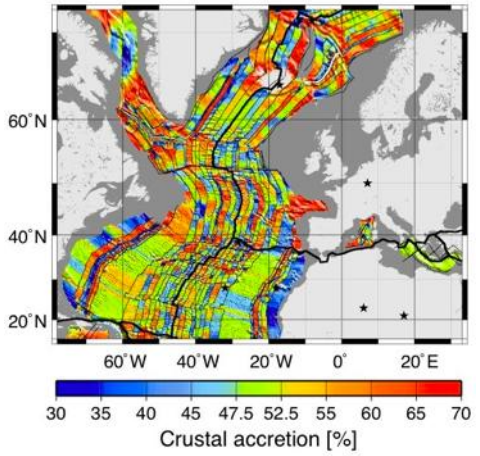
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Building a Virtual Earth
https://www.earthbyte.org/











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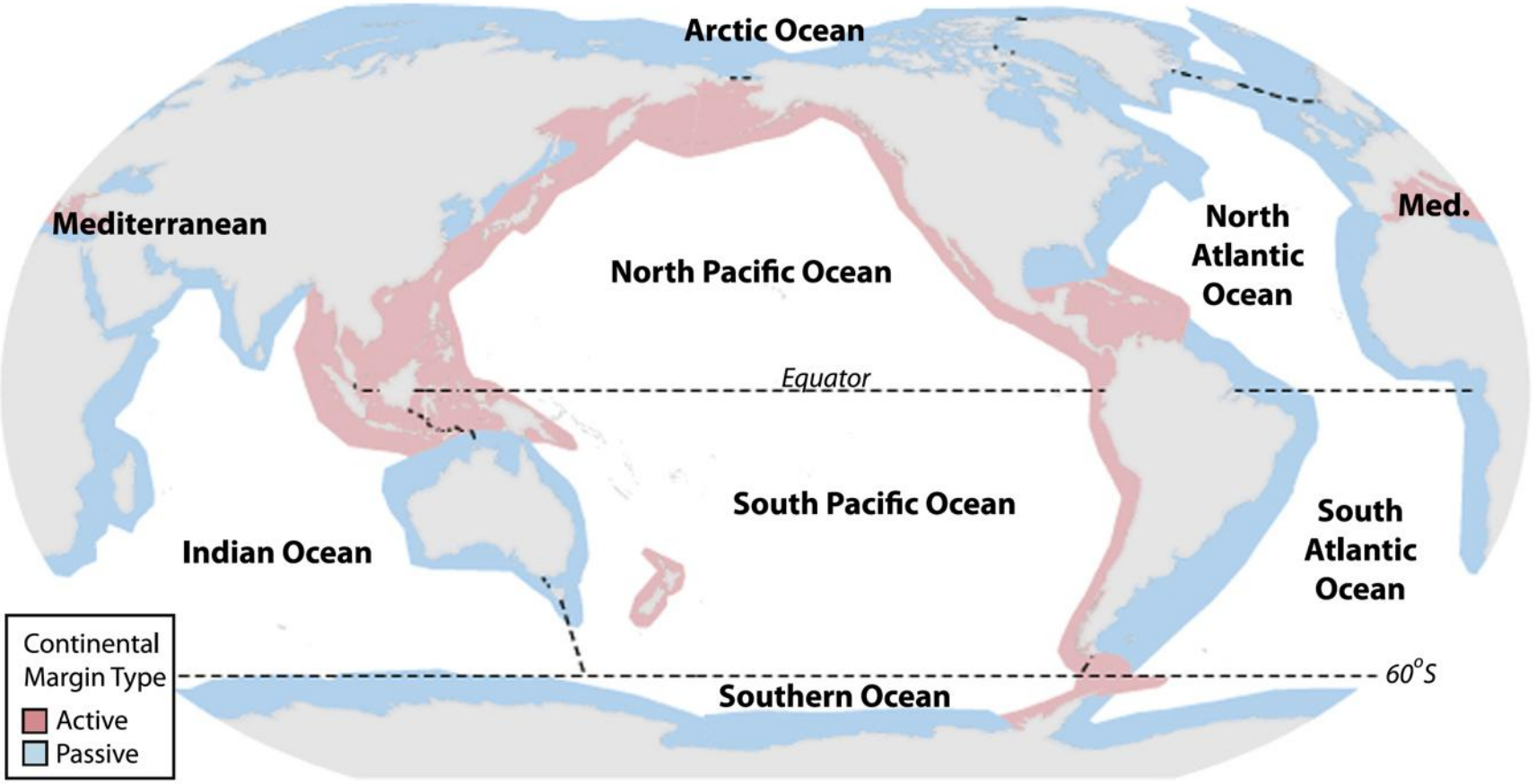
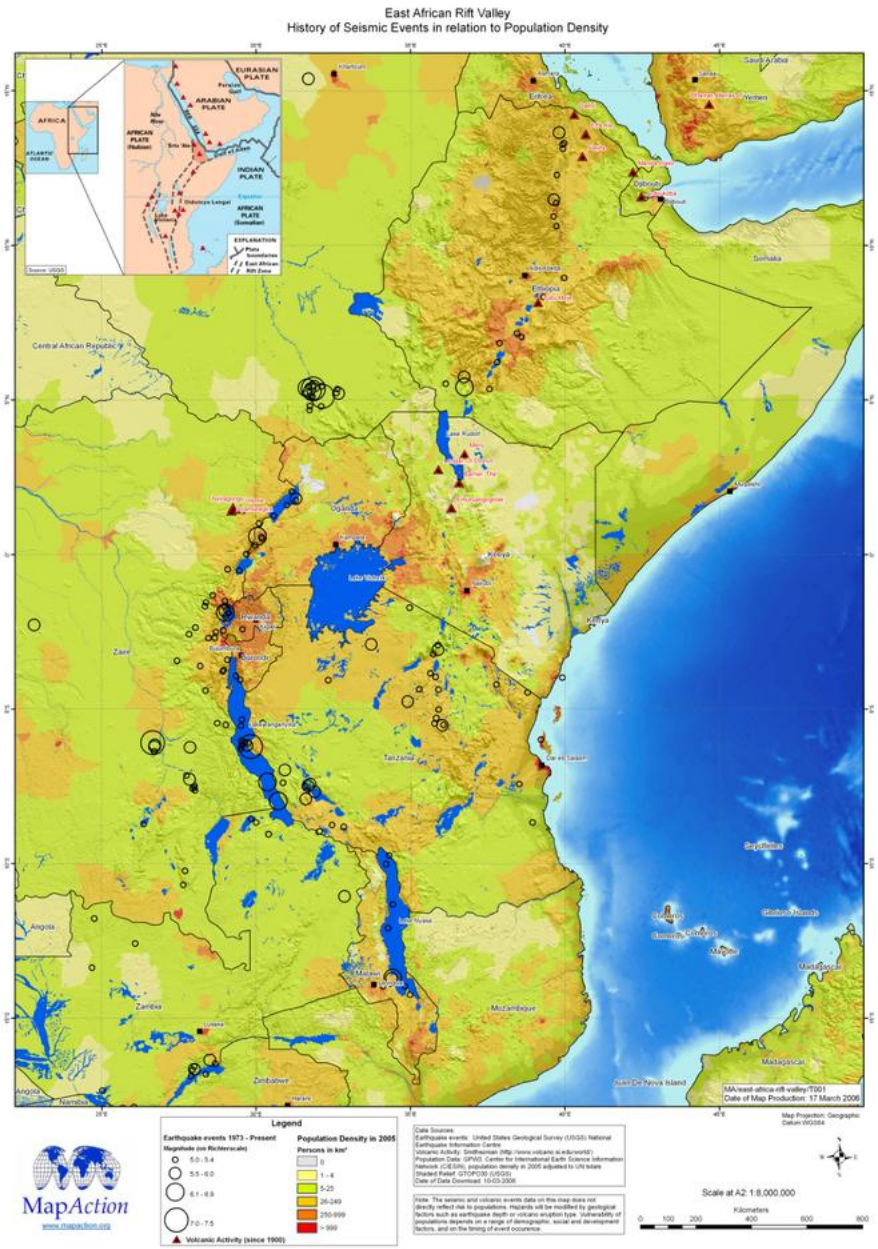
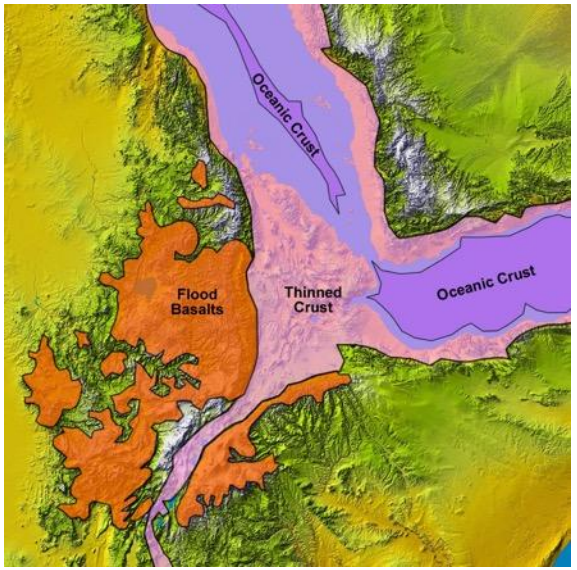


Fig. 2. Map showing the locations of active and passive continental margins and the eight ocean regions described in the text.

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



MODERN RIFTS



MODERN RIFTS

