



**Università di Trieste
Corso di Laurea in Geologia**

Anno accademico 2016 - 2017

Geologia Marina

Parte I

Modulo 1.2 Oceani. Morfologia, struttura ed evoluzione

Docente
Martina Busetti



The oceans

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

1. Etymology

The term Ocean derives from Ὠκεανὸς (ΟΚΕΑΝΟΣ), greek river-god that was believed to surround the world, the external sea (not the Mediterranean).

But the rooth of word are from sanscrit ACAYANA, in the sense of "containing the waters.



Okeanos Fontana di Trevi

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



3

<http://www.etimo.it/?term=oceano>

Okeanos, nella mitologia greca, è uno dei Titani, figlio di Urano (Cielo) e di Gaia (Terra), sposo di Teti, padre delle Oceanine e di tutte le divinità fluviali del mondo. Omero lo descrive come un immenso fiume che cinge tutto lo spazio terrestre e che, scorrendo su se stesso, collega il mondo.

The oceans and the seas are important because they :

The Blue Planet



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



The present Oceans of the world





International Hydrographic Organization

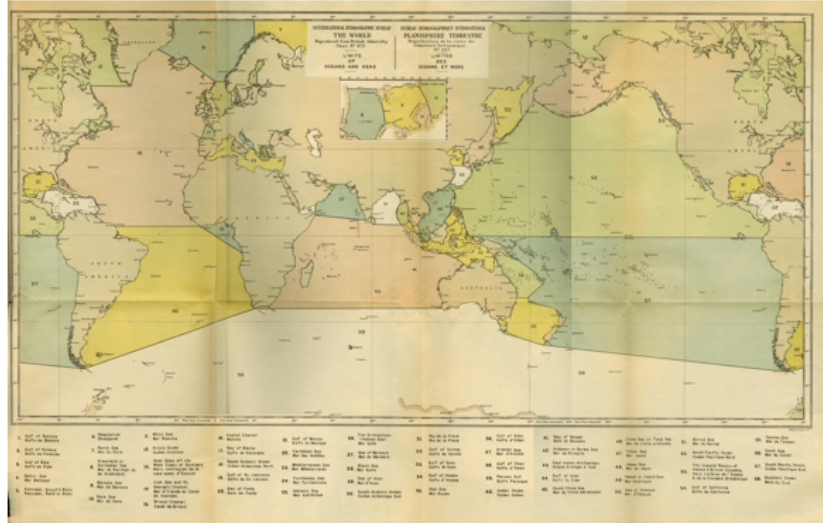
It is the [inter-governmental organisation](#) representing the [hydrographic](#) community. It enjoys observer status at the [UN](#) where it is the recognised competent authority on hydrographic surveying and [nautical charting](#).

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

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

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

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



The oceans of the world

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

Pacific Ocean



Atlantic Ocean



Indian Ocean



The oceans of the world

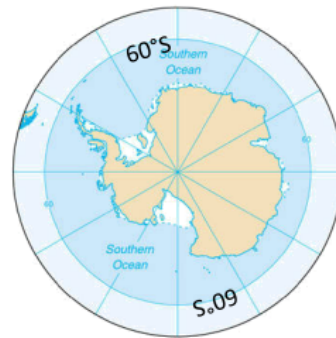
Arctic Ocean

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



Southern Ocean

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



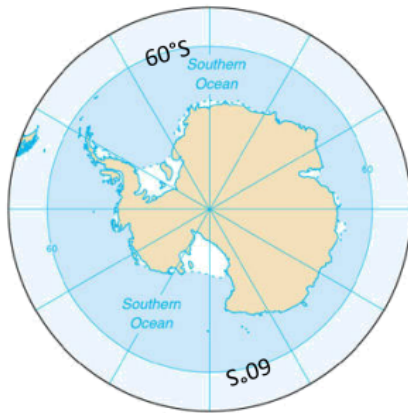
9

Successivamente è stato definito anche l'Oceano Artico.

Nella letteratura anglosassone è definito come Arctic Ocean, mentre nella lingua italiana è chiamato Mare Artico o Mare Glaciale Artico.

Il nome corretto è Oceano Artico perché presenta le caratteristiche geologiche di un oceano (presenza di crosta oceanica).

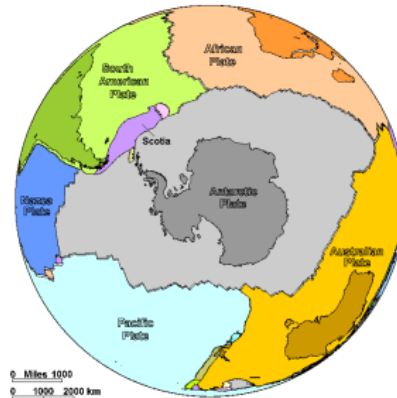
Southern Ocean



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

the Southern Ocean

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



10

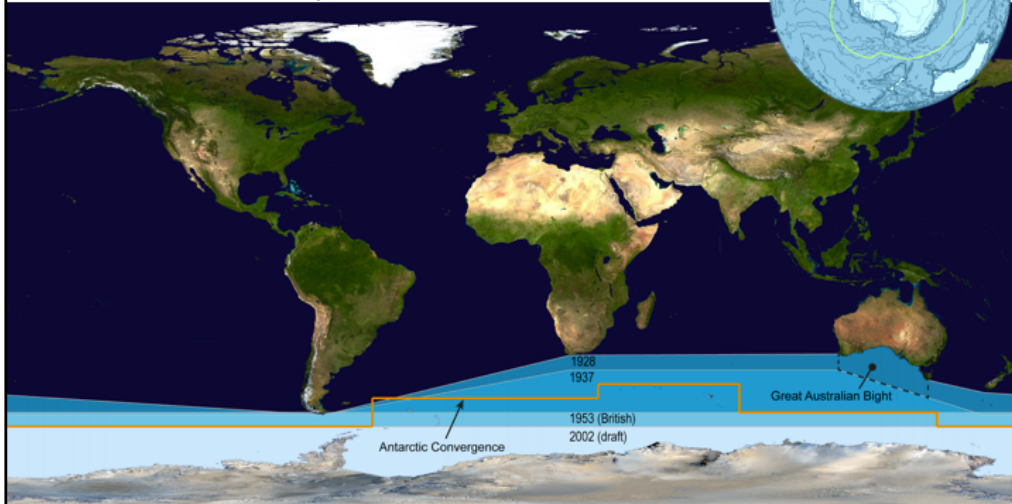
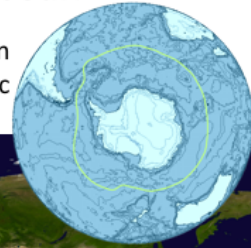
Nella primavera del 2000 l'International Hydrographic Bureau delimitò un nuovo oceano, l'Oceano Meridionale, *Southern Ocean*, che circonda il continente Antartico e si estende fino al parallelo 60°S.

Questo nuovo oceano è stato definitivo in seguito all'attività di ricerca antartica in quanto nella letteratura scientifica venivano definiti come Southern Ocean tutti gli oceani che circondavano l'Antartide, anche se non ha una caratterizzazione geologica specifica.

Il parallelo di 60°S circonda l'Antartide senza attraversare terre emerse ma solo oceano.

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





The seas of the Mediterranean

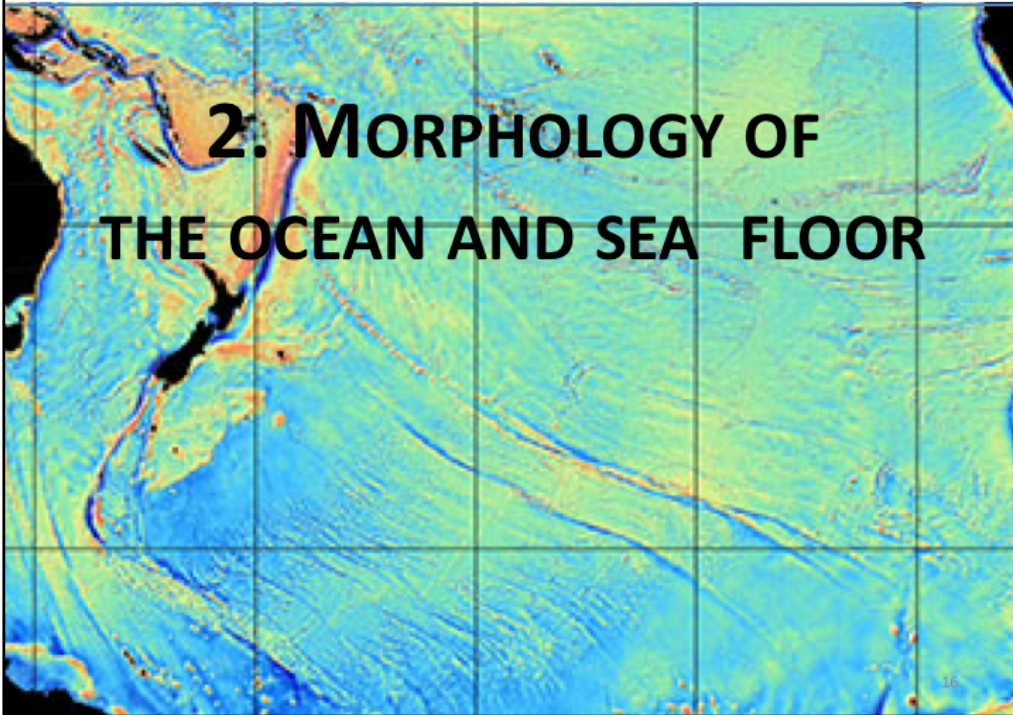
from latin "Mediterraneus": medi > between terraneus > land

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





2. MORPHOLOGY OF THE OCEAN AND SEA FLOOR





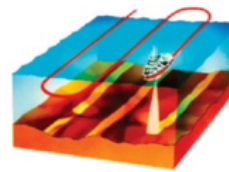
OCEAN AND SEA FLOOR MORPHOLOGY

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

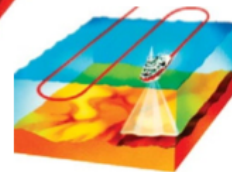
To investigate the oceans and seas we need appropriate instruments and technologies:

5-10%

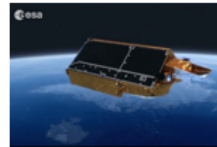
- 1) First instrument: the SONAR, constructed at the beginning of the 1900
- 2) Multibeam technologies, developed in the last decades of the 1900
- 3) Satellite derived bathymetry and sea floor morphology developed in the last decades of the 1900



(a) Single-Beam



(b) Multi-Beam



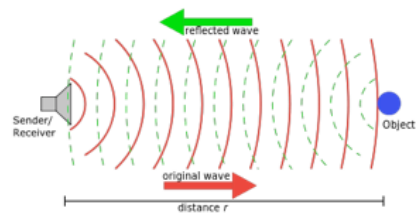
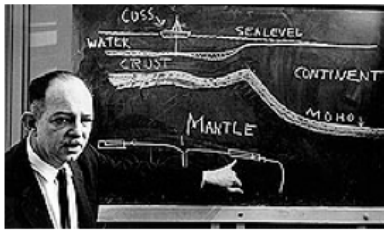


Harry Hess (1906 – 1969)

Professor of geology at Princeton University

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

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




The SONAR principle

UNIVERSITÀ DEGLI STUDI DI PADOVA
Dipartimento di Matematica e Geoscienze

Geologia Marina 2018/2019

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.

19

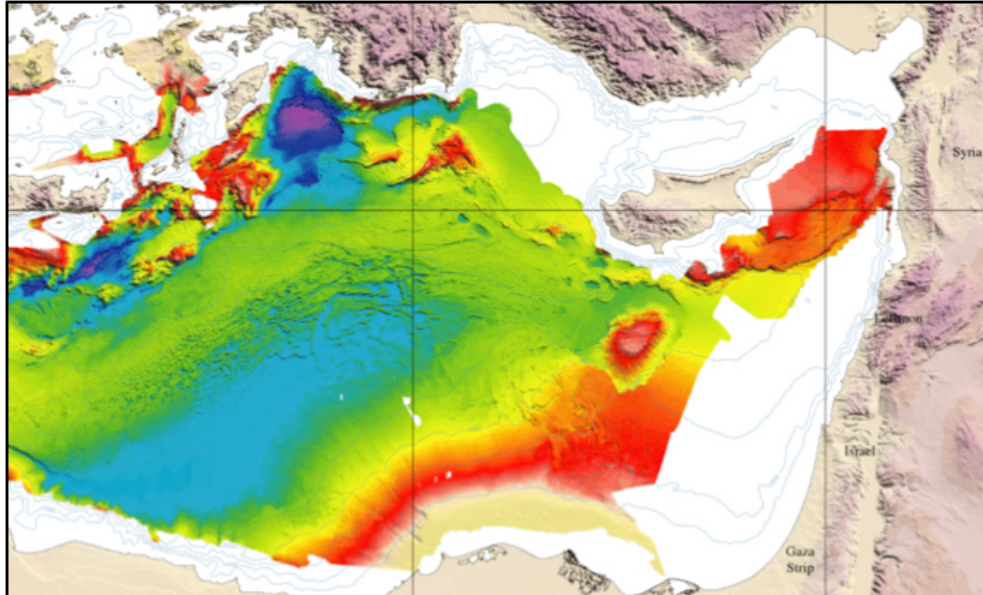
http://c250.columbia.edu/c250_celebrates/remarkable_columbians/marie_tharp.html

Marie Tharp (1920–2006)
Oceanographer
Faculty 1948–83

A pioneer of modern oceanography, Tharp was the first to map details of the ocean floor on a global scale. Her observations became crucial to the eventual acceptance of the theories of plate tectonics and continental drift in the earth sciences. Working with pens, ink and rulers, Tharp drew the underwater cartography, longitude degree by latitude degree, based on data from sonar readings taken by pioneering earth scientist Maurice Ewing and his team. Piecing maps together in the late 1940s and early 1950s, she and colleague Bruce Heezen discovered a 40,000-mile underwater ridge girdling the globe. By this finding, they laid the foundation for the conclusion from geophysical data that the sea floor spreads from central ridges and that the continents are in motion with respect to one another—a revolutionary geological theory at the time. Years later, satellite images proved Tharp's maps to be accurate. Tharp came to Columbia in 1948 to work as Ewing's research assistant. Following him to the new Lamont Geological Observatory, she provided much of the data and analyses for Ewing and Heezen's scientific papers. In recent years, she has been honored for her contributions by the Library of Congress, the Women's Committee of the Woods Hole Oceanographic Institution, and the place where it all began, now the Lamont-Doherty Earth Observatory.

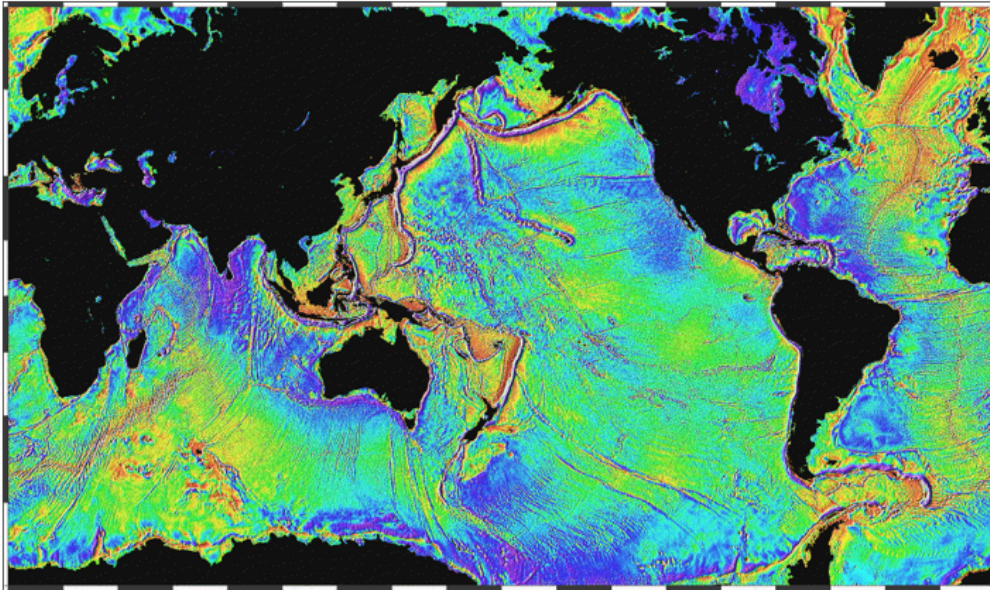


Sea floor mapping from multibeam data

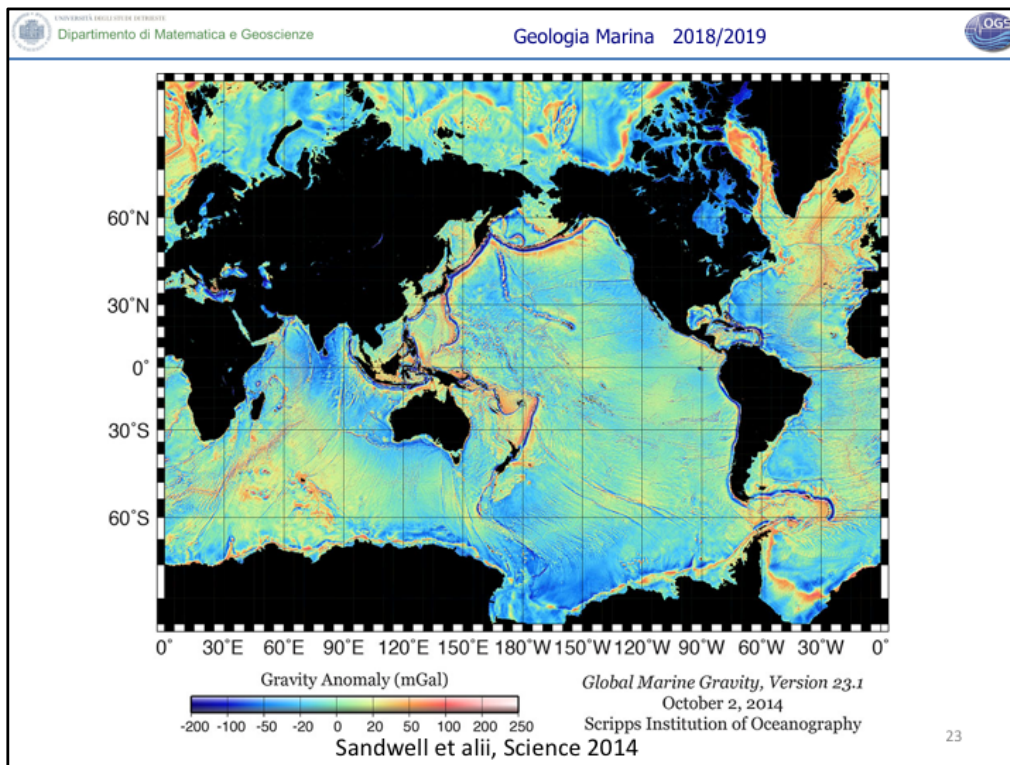




Global gravity map of the oceans - from GEOSAT and ERS-1



SMITH AND SANDWELL, 1996



<http://www.nature.com/news/gravity-map-uncovers-sea-floor-surprises-1.16048#/ref-link-1>

maggior risoluzione e maggiori dettagli, scoperta nuovi elementi morfologici

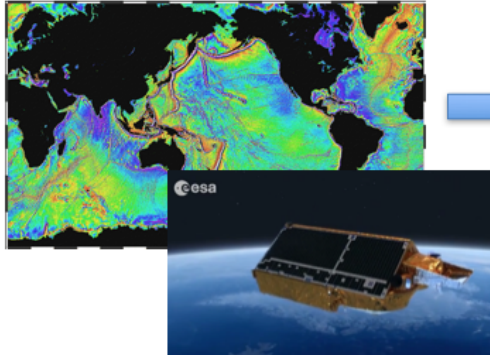
Sandwell et alii, Science 2014

Abstract:

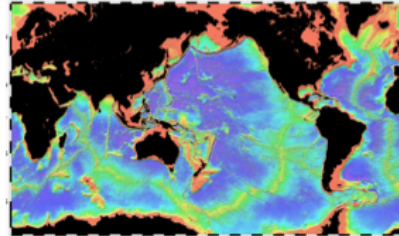
Gravity models are powerful tools for mapping tectonic structures, especially in the deep ocean basins where the topography remains unmapped by ships or is buried by thick sediment. We combined new radar altimeter measurements from satellites CryoSat-2 and Jason-1 with existing data to construct a global marine gravity model that is two times more accurate than previous models. We found an extinct spreading ridge in the Gulf of Mexico, a major propagating rift in the South Atlantic Ocean, abyssal hill fabric on slow-spreading ridges, and thousands of previously uncharted seamounts. These discoveries allow us to understand regional tectonic processes and highlight the importance of satellite-derived gravity models as one of the primary tools for the investigation of remote ocean basins.



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



Global sea floor topography
from gravity data and shipboard depth soundings

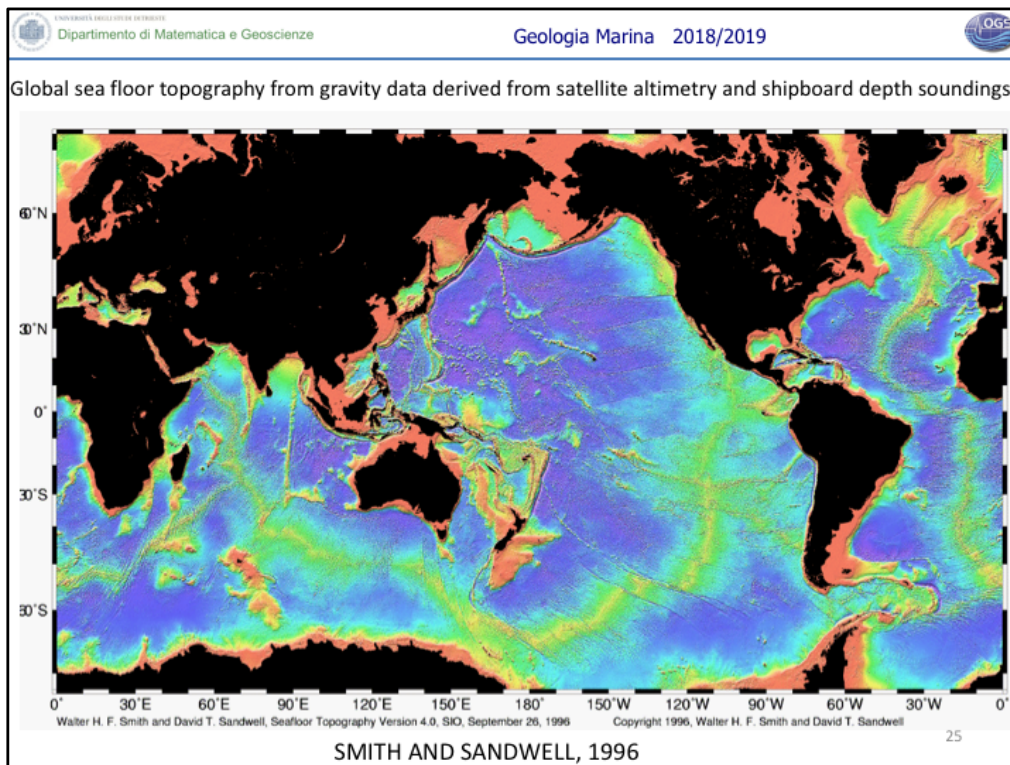


SMITH AND SANDWELL, 1996

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

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

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



<http://www.ngdc.noaa.gov/mgg/fliers/97mgg03.html>

A new color poster has been prepared displaying measured and estimated seafloor topography. The poster is printed in a Mercator projection from data gridded uniformly at intervals equivalent to 2 minutes longitude at the equator. This new estimate of seafloor topography was obtained from shipboard depth soundings combined with gravity data derived from satellite altimetry to produce a gridded representation of seafloor topography for all ice-free ocean areas within +/-72 degrees latitude. The depth data were obtained by screening 6905 surveys from the NGDC (Marine Trackline Geophysics CD-ROM version 3.2), the Scripps Institution of Oceanography and Lamont-Doherty Earth Observatory databanks, and other data, using quality control procedures based on those of Smith [J. Geophys. Res. 98, 9591-9603, 1993]. The satellite gravity field combines all data from the ERS-1 and GEOSAT satellites including the data declassified in 1995; it has an RMS accuracy of 3-5 mGal and a resolution of 20-30 km wavelength [Sandwell and Smith, J. Geophys. Res. 102, 10,039-10,054, 1997].

The method [Smith and Sandwell, Science 277, 1956-1962, 1997] is an improvement on one developed earlier for GEOSAT data south of 30 degrees S [Smith and Sandwell, J. Geophys. Res. 99, 21,803-21,824, 1994]. The new topographic map is visually quite different from the satellite gravity field. Isostatically compensated topography stands out in full relief, and edges are sharper due to the inclusion of ship data and the downward-continuation of the gravity field. Dramatic scarps are seen such as at the eastern edge of Manihiki Plateau. The topography map shows seafloor structure while the gravity map includes sub-seafloor anomalies. In addition to this poster, digital data will be available at a later date on CD-ROM. The disc will contain the 2x2 minute digital data for the Measured & Estimated Seafloor Topography as binary raster files and formatted for use in GMT (Generic Mapping Tool). The GEOSAT gridded 2-minute gravity data will also be on the CD-ROM.

General Bathymetric Chart of the Oceans - GEBCO

<http://www.gebco.net>



Gridded bathymetry data

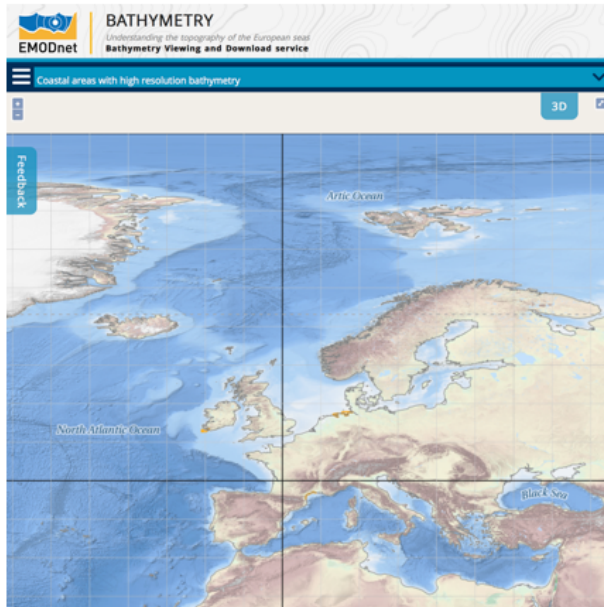
GEBCO's gridded bathymetric data sets are global terrain models for ocean and land and include the

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

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

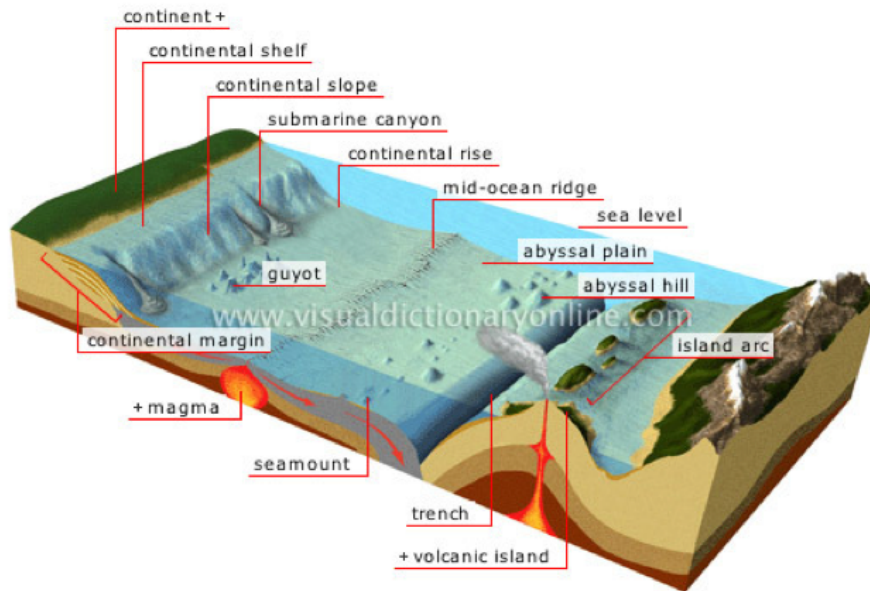


EMODNET
<http://www.emodnet.eu>



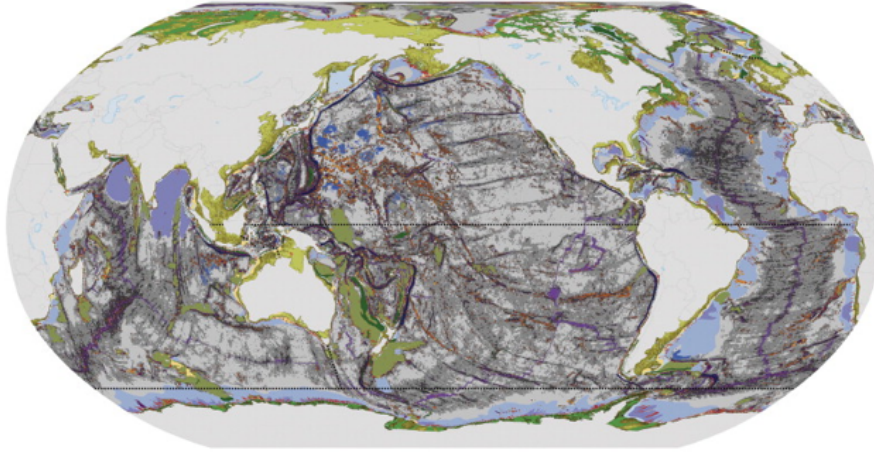


SEA FLOOR MORPHOLOGY

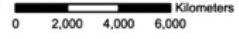




Geomorphic features map of the world's oceans.



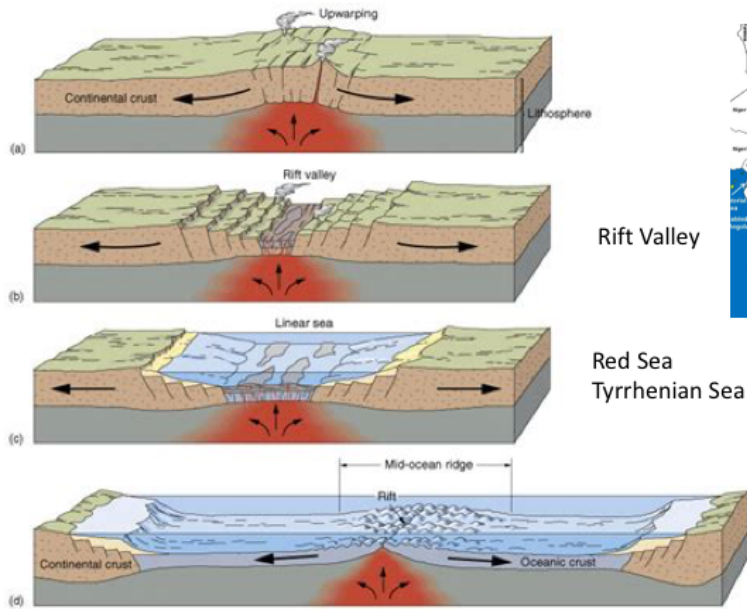
- | | | | |
|------------------------|------------|-----------------|------------------|
| Shelf - high profile | Hadal | shelf valley | rise |
| Shelf - medium profile | canyon | rift valley | terrace |
| Shelf - low profile | guyot | glacial trough | trench |
| Slope | seamount | trough | plateau |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



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



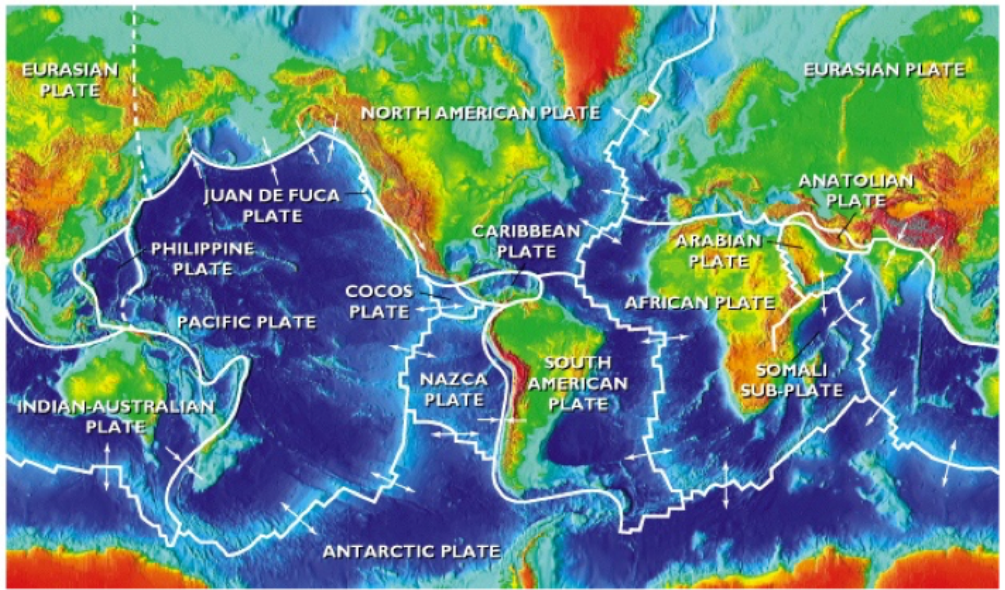
3. The structure of the ocean



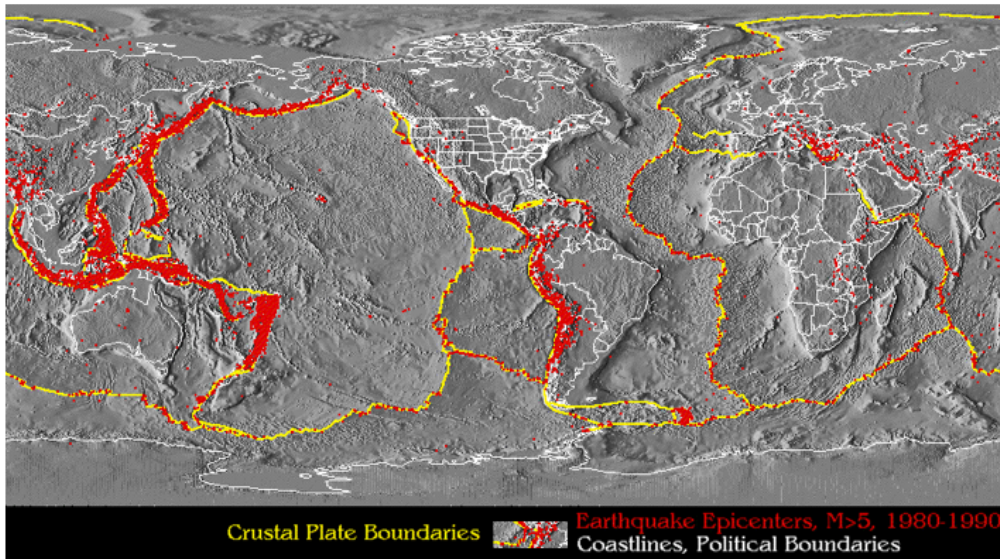
Rift Valley

Red Sea
Tyrrhenian Sea

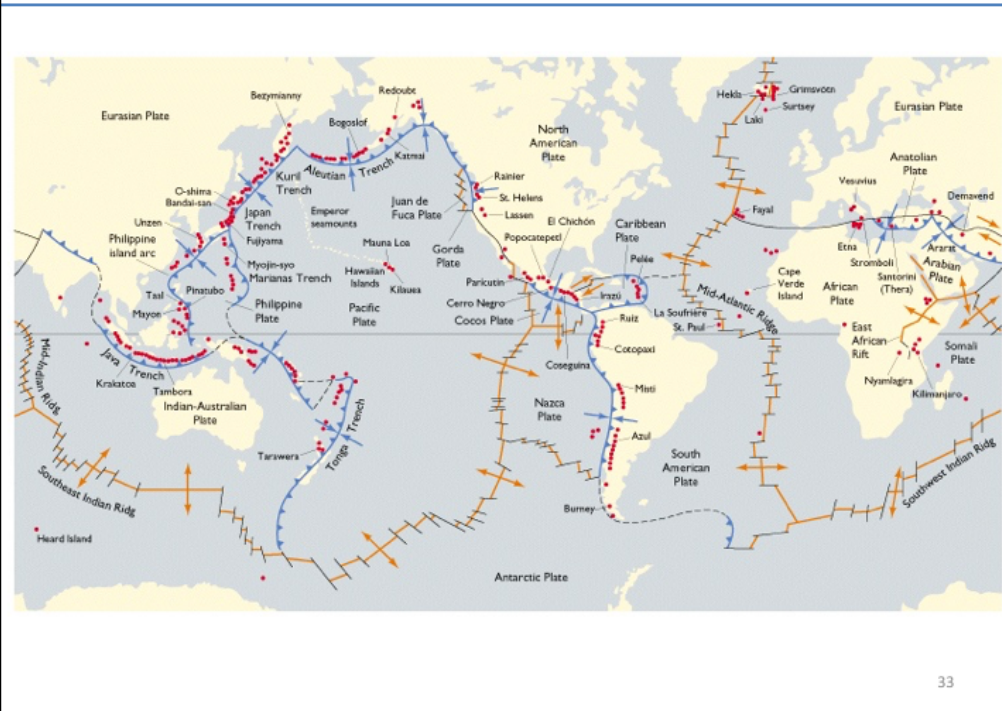
PLATES OF THE WORLD

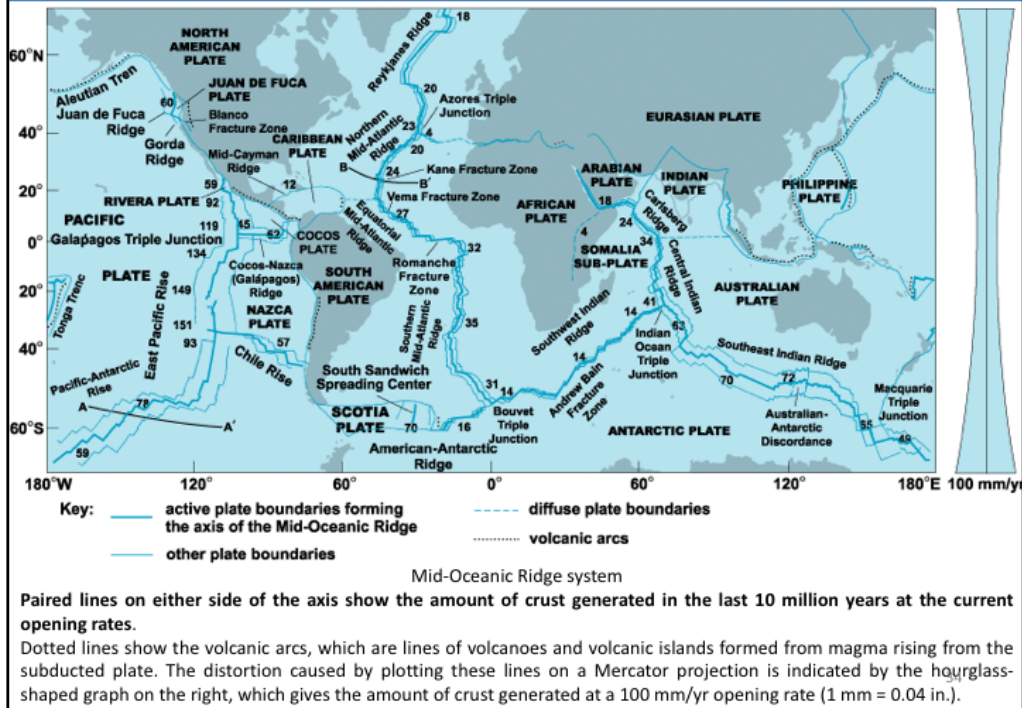


Mid-oceanic ridge system is 60,000 km long, 2000 km wide, 3000 m high



Shallow earthquakes at the Ocean Ridges







half spreading rate in mm/year

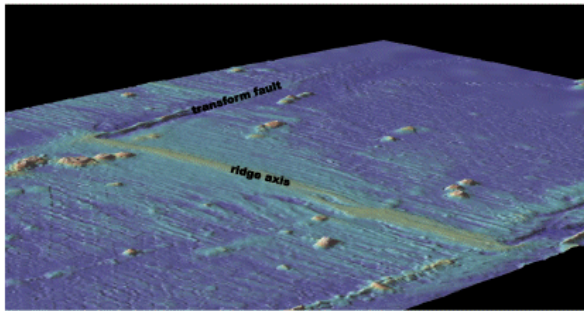
Pacific-Antarctic Ridge: fast-spreading, broad and smooth**Mid-Atlantic Ridge: slow-spreading, narrow and rough**

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

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

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

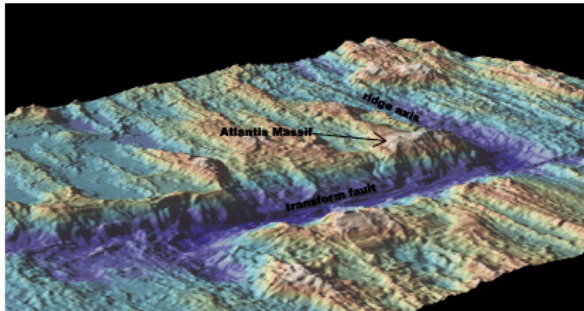
37



(a)

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

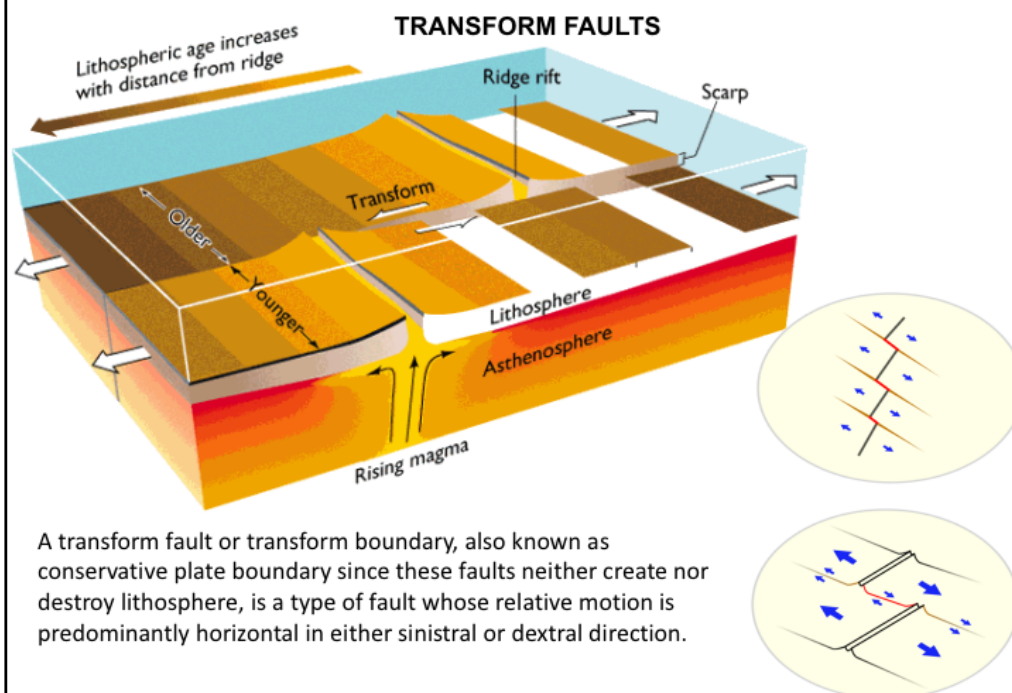
a) *Fast-spreading East Pacific Rise at 19°S, viewed toward the north.*



(b)

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

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



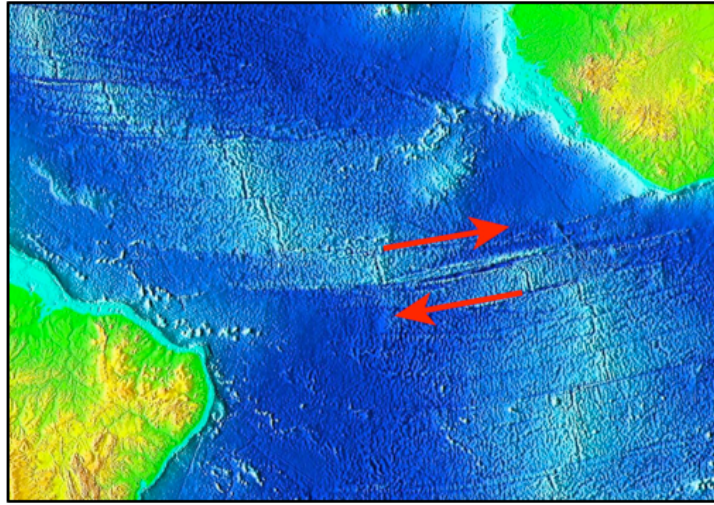
TRANSFORM FAULTS

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

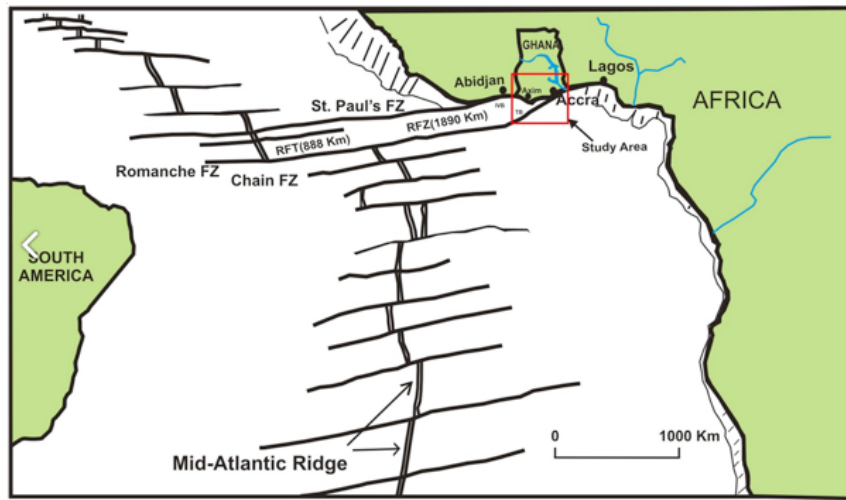
Wilson (1965) termed the faults "Transform" as: the lateral displacement across the fault is taken up by transforming it into either the formation of new lithosphere at a terminated ocean ridge segment or lithosphere subduction at a trench.

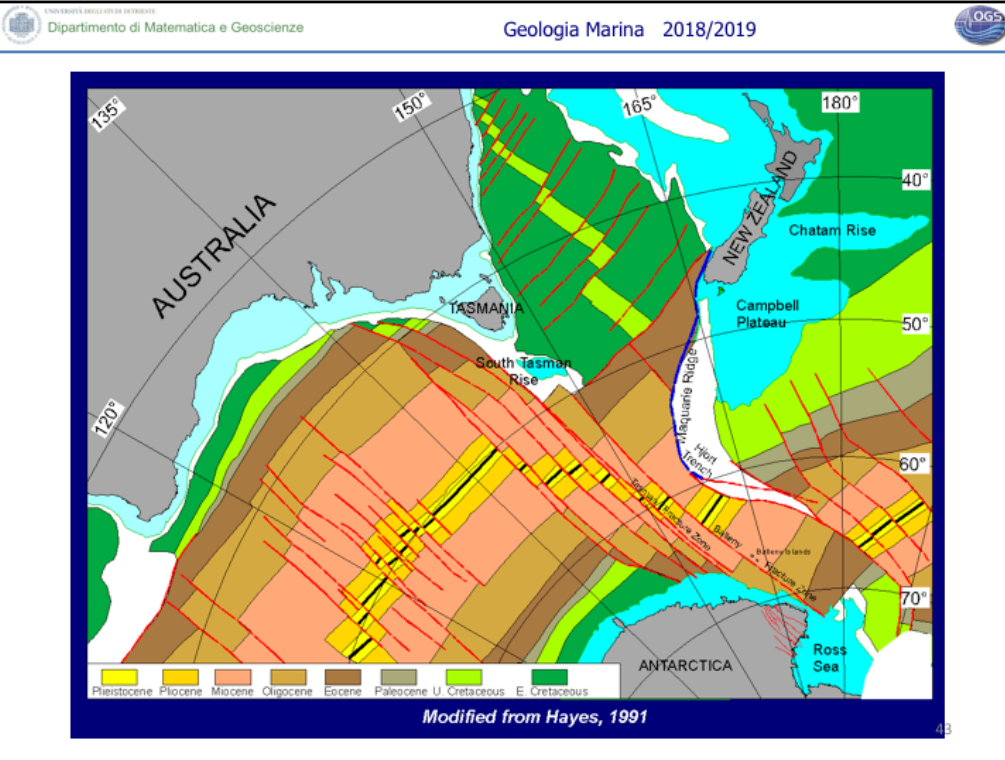
The transform faults can form a tectonic plate boundary

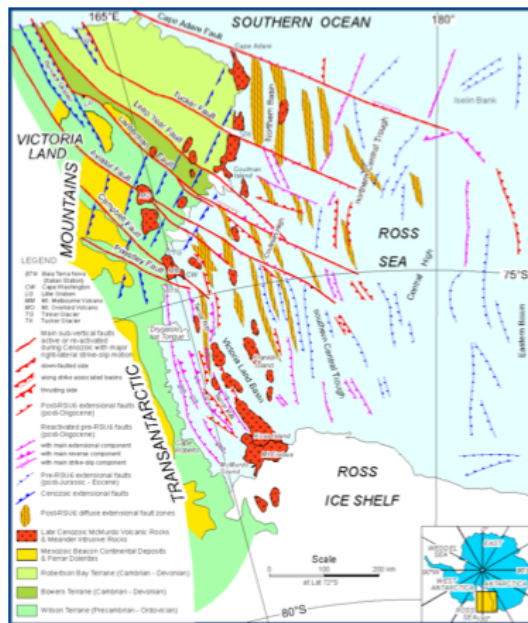
Il movimento laterale attraverso la faglia è assorbito attraverso la trasformazione di nuova litosfera in corrispondenza del ridge oceanico, o dalla subduzione della litosfera nelle fosse.



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



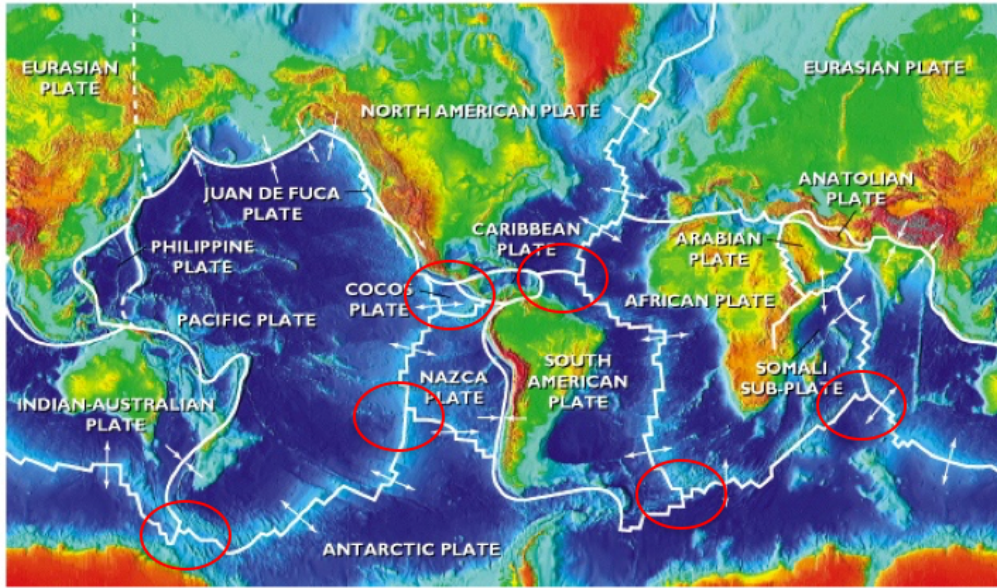


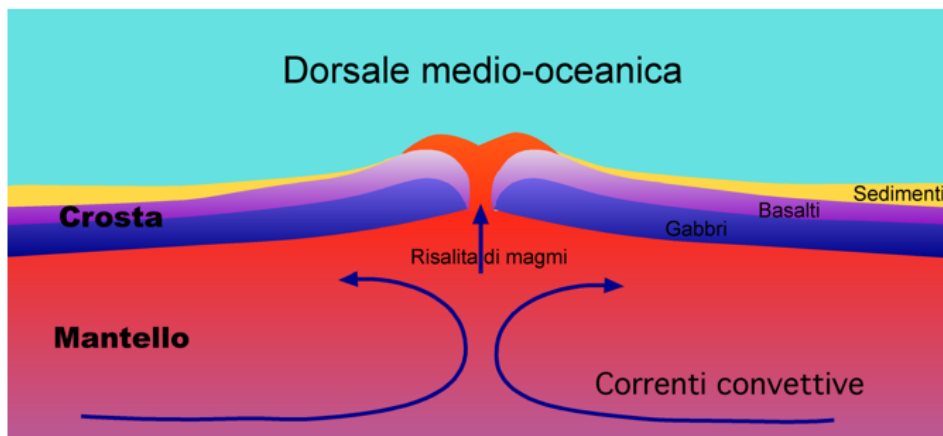


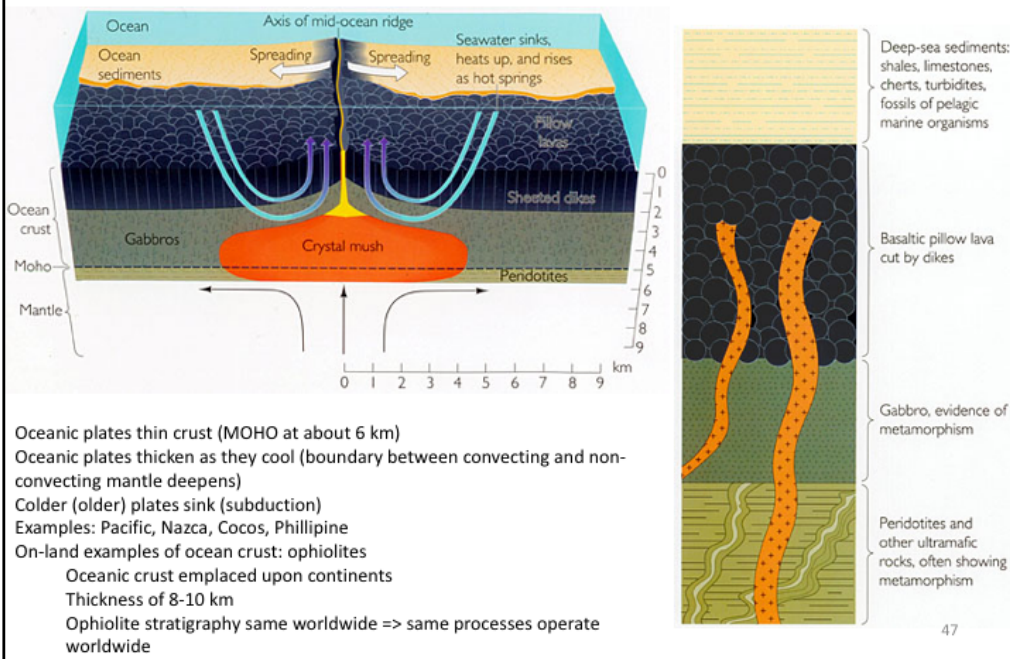
La faglie principali nella Terra Vittoria Settentrionale e nel Mare di Ross.

Salvini et al., 1997, Journal of Geophysical Research

Triple junction







Pillow lava along Juan de Fuca Ridge



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

Dipartimento di Matematica e Geoscienze Geologia Marina 2018/2019

Magnetic Susceptibility

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

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

K < 0
DIAMAGNETIC
weak negative susceptibility
(water, organic matter, quartz, feldspars, calcium carbonate)

Quarzo, calcite e dolomite

K > 0
PARAMAGNETIC
weak positive susceptibility
(many Fe-containing minerals and salts, e.g. hematite, magnetite, pyroxene, olivine, ferrous sulfate)

Ossidi di ferro (magnetite Fe₃O₄, ematite α-Fe₂O₃, ilmenite FeTiO₃, magnemite γ-Fe₂O₃ e ulvospinello Fe₂TiO₄), idrossidi (es. la goethite (α-FeO·OH), solfuri (es. pirite FeS₂).

K >> 0
FERROMAGNETIC
strong positive susceptibility
(pure iron like magnetite and hematite, nickel, chromium)

49

Le lave eruttate lungo le dorsali medio oceanici sono basalti tholeitici indicati anche con il termine di MORB (Mid-Ocean Ridge Basalt), contenenti tra i vari minerali anche ossidi di ferro.

Gli ossidi di ferro si magnetizzano secondo il campo magnetico terrestre, e dalla misura di tale magnetizzazione si può dedurre la direzione del campo magnetico terrestre al momento della solidificazione del magma.

La suscettività magnetica (k) è il parametro significativo della capacità del materiale di magnetizzarsi e di creare un disturbo nel campo inducente:

$$k = M/H$$

Dove k è la suscettività magnetica, M è l'intensità di magnetizzazione e H è il campo magnetico esterno.

I materiali possono essere:

diamagnetici, con $k < 0$

paramagnetici, con $k > 0$

ferromagnetici, con $k \gg 0$

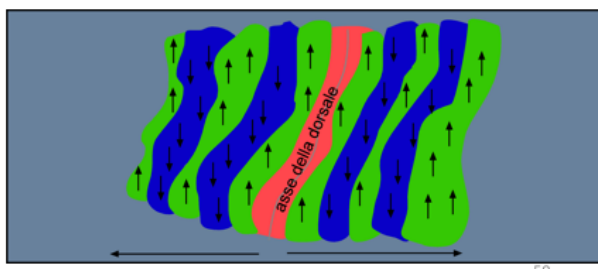
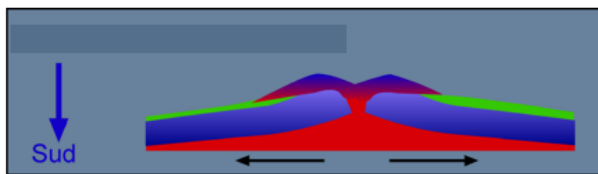
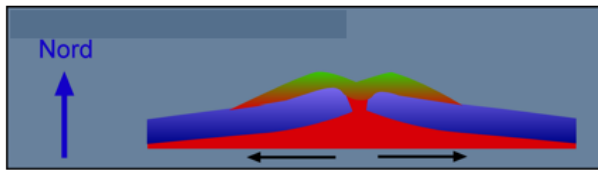
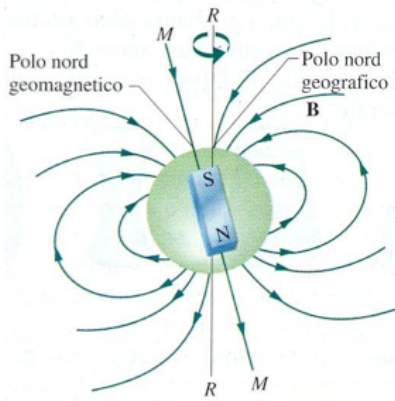
Sono diamagnetici il quarzo la calcite e la dolomite, sono paramagnetici la maggior parte dei minerali costituenti le rocce, mentre sono ferromagnetici:

gli ossidi di ferro come magnetite (Fe₃O₄), ematite (α-Fe₂O₃), ilmenite (FeTiO₃), magnemite (γ-Fe₂O₃) e ulvospinello (Fe₂TiO₄), gli idrossidi come la goethite ((α-FeO·OH), i solfuri come la pirite (FeS₂).

Quando il magma eruttato si solidifica, i minerali ferromagnetici contenuti nelle lave (principalmente la magnetite) presentano una magnetizzazione indotta che conserva la direzione originaria del campo e non risente delle sue variazioni.

Poiché il campo magnetico terrestre presenta dei periodi a polarità normale (le linee di flusso escono dal polo sud e entrano al polo nord) e periodi a polarità inversa (le linee di flusso escono dal polo nord e entrano al polo sud), i minerali ferromagnetici presenteranno rispettivamente polarità normale o inversa.

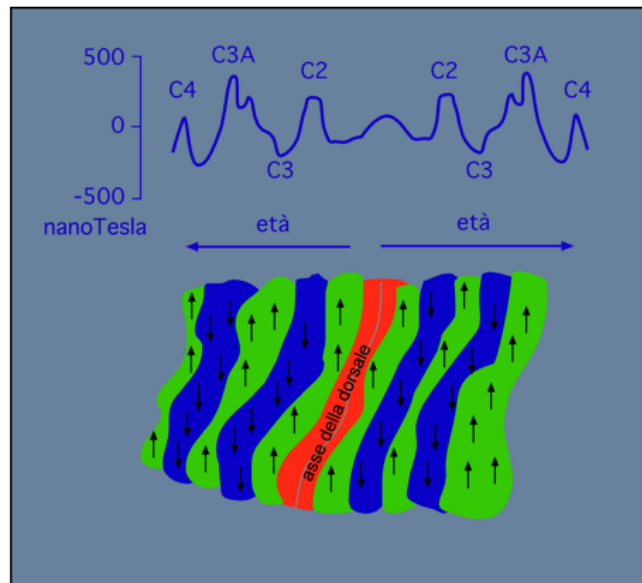
Present magnetic field





Instruments to measure the earth magnetic field in the ocean:

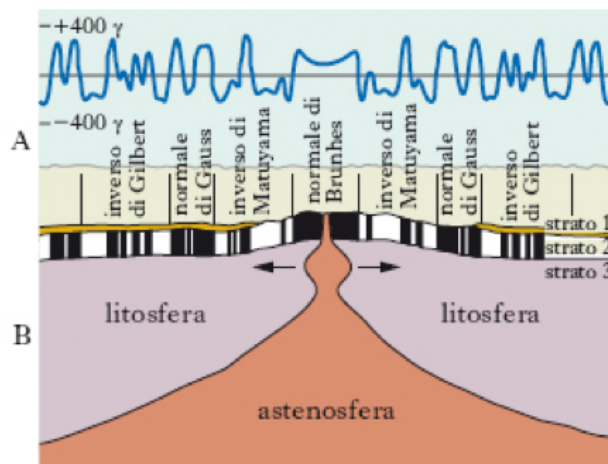
- magnetometer
- gradiometer composed by two magnetometers to filter time variation in the magnetic field



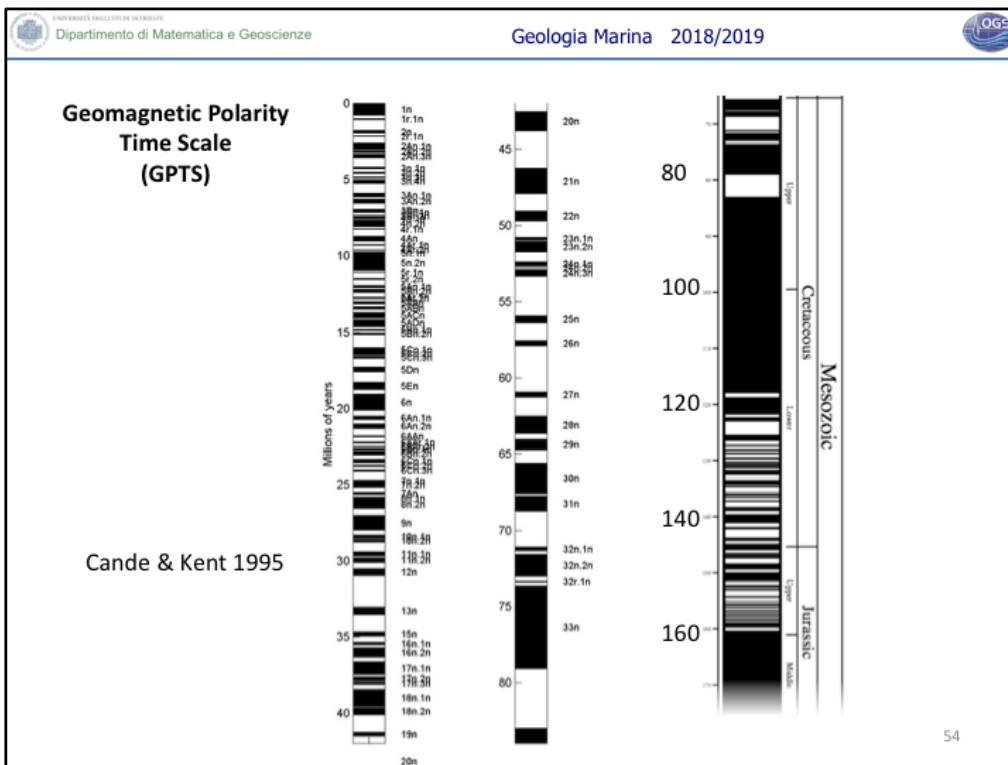
The magnetic anomalies are numbered as C_n (Chron n) or A_n (Anomaly n) (C_1 or A_1 is the youngest and C_{23} or A_{23} is older).

52

Dalla misura del campo lungo un profilo trasversale alla dorsale oceanica si ottiene una curva con intensità del campo magnetico positive e negative. Ogni picco corrisponde ad una anomalia magnetica, numerata in modo convenzionale come C_1 , C_2 , ecc.... dove C sta per *chron*.



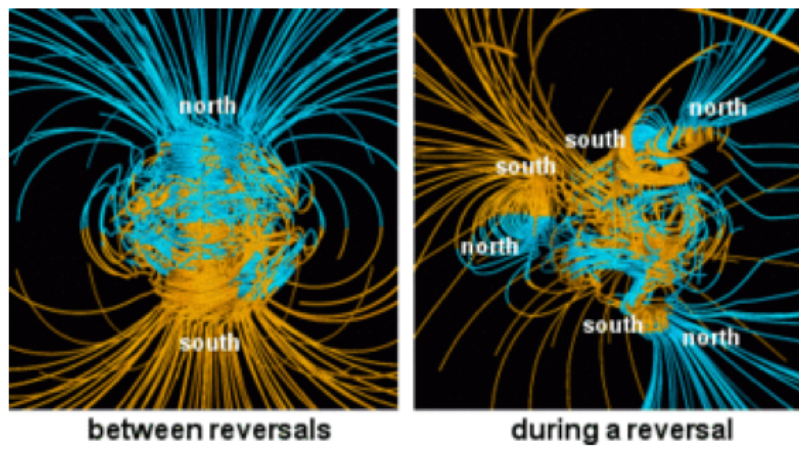
- 1 - sedimenti non magnetici
- 2 - colate e strato di basalto a cuscini (altamente magnetico: in nero, polarita normale; in bianco, polarita inversa)
- 3 - crosta oceanica a gabbri (debolmente magnetica)



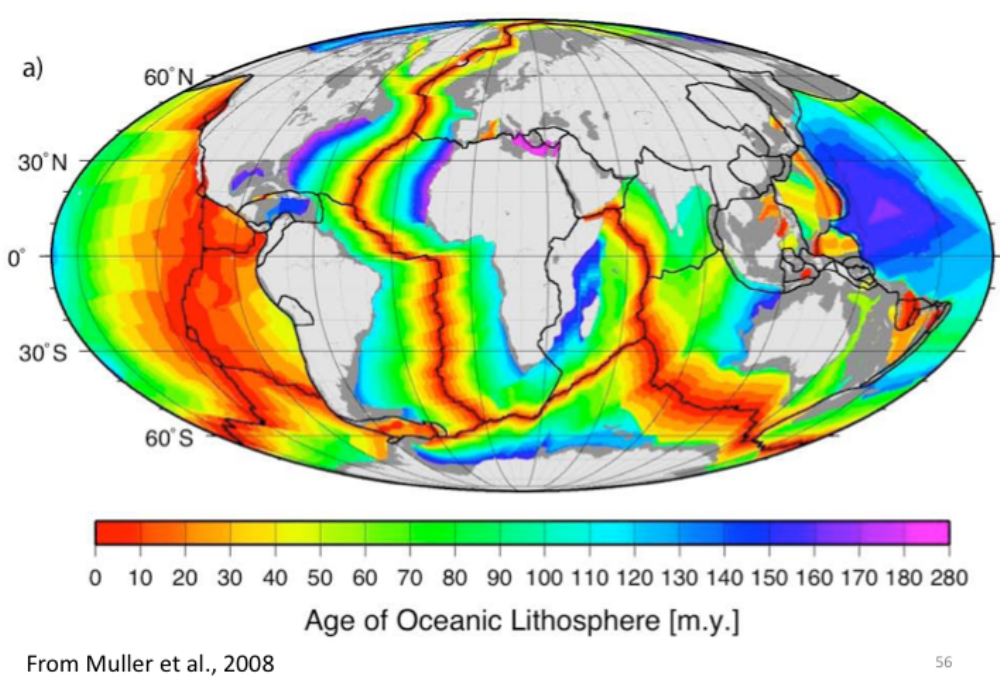
<http://deeptow.whoi.edu/gpts.html>

The Geomagnetic Polarity Time Scale (GPTS)

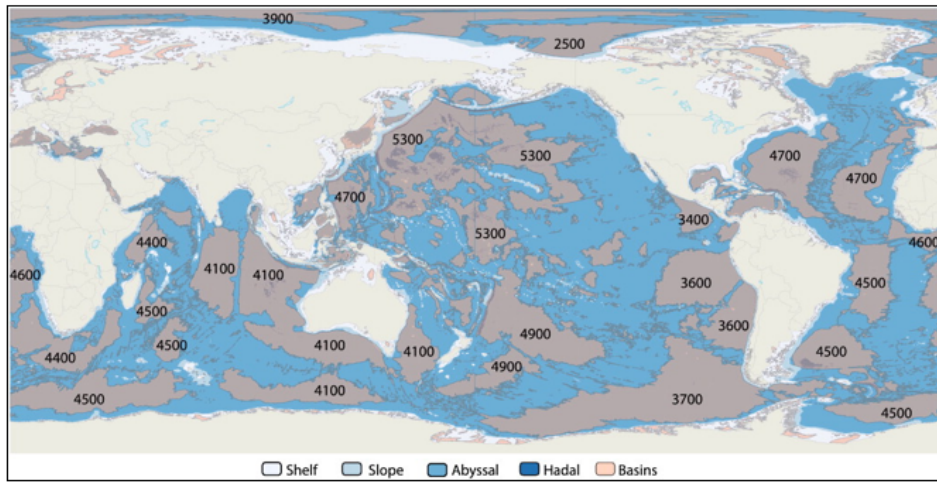
The Geomagnetic Polarity Time Scale (GPTS) has been constructed from an analysis of magnetic anomalies measured over the ocean basins and tying these anomalies to known and dated magnetic polarity reversals found on land. In general, positive anomalies represent periods when Earth's magnetic field was pointing north as it is today, while negative anomalies represent periods in Earth's history when Earth's magnetic field pointed to the south pole. The first marine magnetic anomaly based timescale was constructed by [Jim Heirtzler and Gcolleagues in 1968](#). Most recently the timescale has been tuned or adjusted for Earth's orbital variations and climatic response as measured in marine sediment records. The presently accepted timescale that is in most widespread use is the Cande and Kent 1995 timescale. The present timescale extends back to approximately 155 million years with potential extension in age to about 175 million years (Jurassic age) from the oldest ocean crust in the world.



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



Basins in the oceans



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

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

Stato termico dei ridge e piani abissali

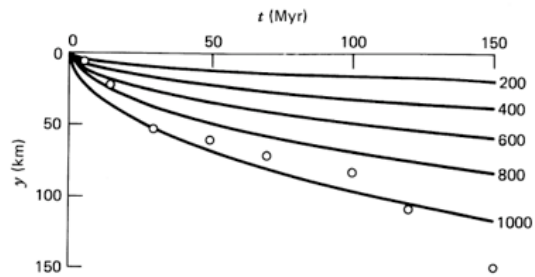
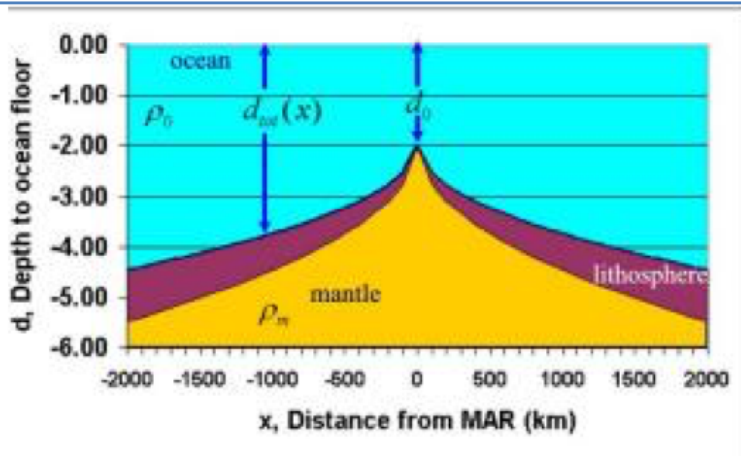
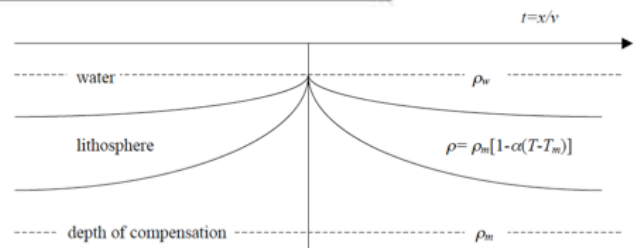


Figure 4-24 The solid lines are isotherms, $T - T_s$ ($^{\circ}\text{K}$), in the oceanic lithosphere from Equation (4-125). The data points are the thicknesses of the oceanic lithosphere in the Pacific determined from studies of Rayleigh wave dispersion data. (From A. R. Leeds, L. Knopoff, and E. G.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



Cooling of
oceanic crust

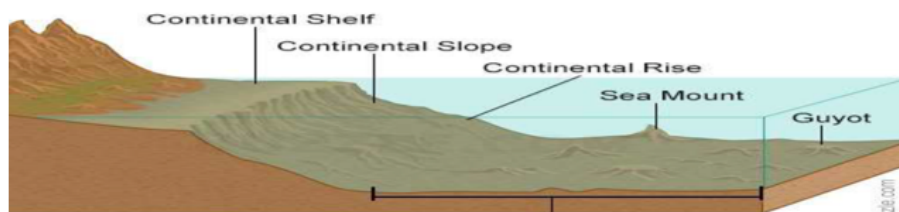


Abyssal floor

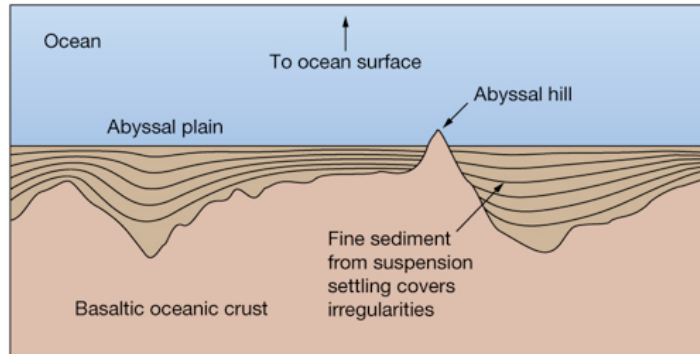
Abyssal floor are broad, relatively smooth surfaces and consists of:

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

Cross section of the Ocean floor

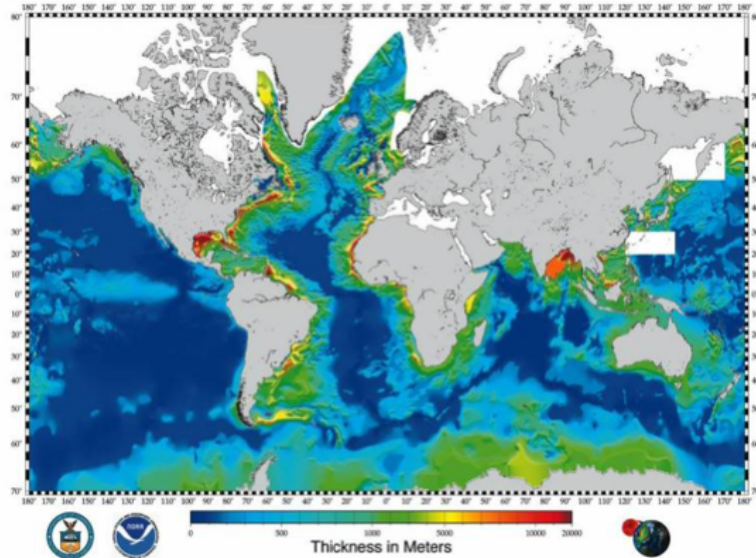


Abyssal Plain



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

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



A digital total sediment thickness database for the world's oceans and marginal seas is being compiled by the National Geophysical Data Center (NGDC), Marine Geology & Geophysics Division. The data are gridded with a spacing of 3 arc-minutes by 3 arc-minutes. Sediment thickness data were compiled from three principle sources: previously published seepath maps, ocean drilling results, both ODP and IODP, and seismic reflection profiles archived at NGDC, as well as seismic data and seepath maps available as part of the IOCC's Geological Oceanographic Atlas of the Pacific (GOSAP) project.

The distribution of sediment in the oceans is controlled by five primary factors:
1) Age of the underlying crust
2) Tectonic history of the ocean crust
3) Structural trends in basement
4) Nature and location of sediment sources, and
5) The nature of the sedimentary processes delivering sediments to depressions.

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

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

HOT SPOT

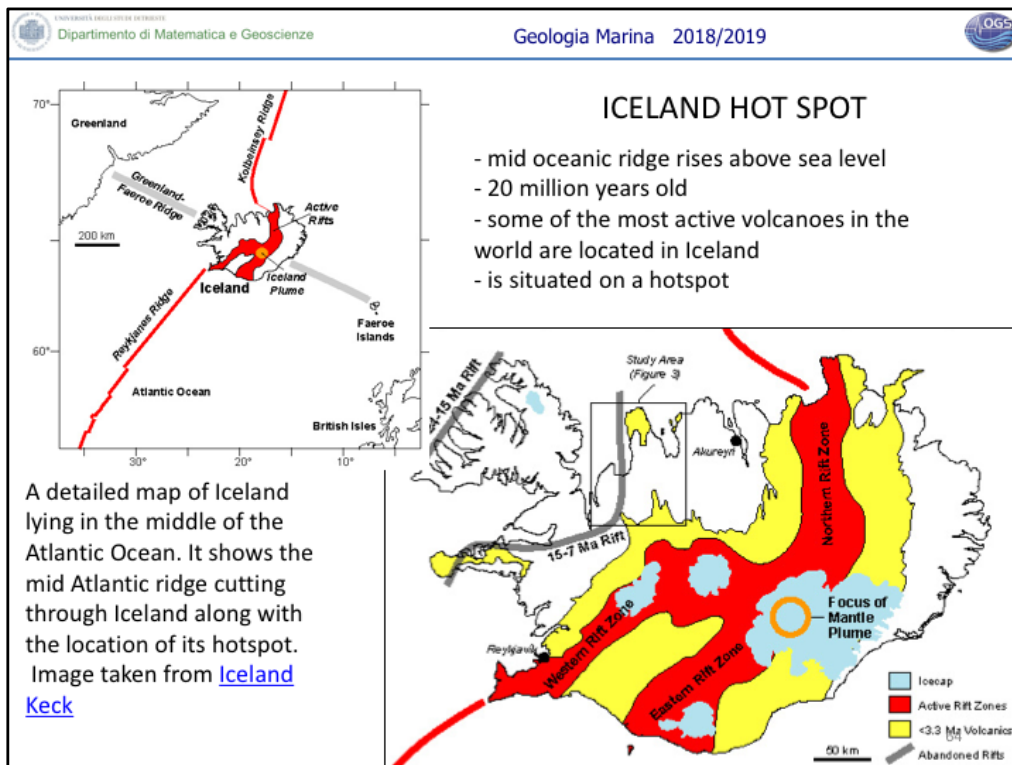
EXPLANATION

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

Hotspots are places where molten rock from the earth's mantle is erupting at the surface. They are in the middle of the plate.
 Two hypothesis:
 a) the hotspots move relative to the earth;
 b) the hotspots are fixed to the earth.

63

Hotspots are places where molten rock from the earth's mantle is erupting at the surface. Hawaii and Iceland are hotspots. Some scientists think the hotspots move relative to the earth. Other scientists think the hotspots are fixed to the earth. Hotspots leave their marks on the plates as the plates move across them. If you look at Hawaii, you'll notice a linear feature (the Hawaii-Emperor seamount chain) on the Pacific plate. This feature was made by the Hawaiian hotspot as the Pacific plate moved over it. In the northwest Pacific you can see a whole series of seamount chains that were formed by hotspots. Hotspots can also create large igneous provinces, such as the Ontong Java Plateau (northeast of Australia) and the Kerguelen Plateau (in the southern Indian Ocean).



An underwater mountain chain known as the mid ocean ridge or the mid Atlantic ridge circles the globe and is one of the largest mountain ranges on Earth. The mid Atlantic ridge consists of underwater seamounts, volcanoes, and spreading ridges. However, at one location in the Atlantic, the mid ocean ridge rises above sea level. It cuts straight through the middle of one of the largest islands in Europe, Iceland. This makes Iceland one of the most geologically active places on Earth. Iceland is located east of Greenland in the middle of the North Atlantic Ocean. Iceland is around 20 million years old, which is rather young geologically speaking. Some of the most active volcanoes in the world are located in Iceland. This is due to Iceland remaining situated on a hotspot. A hotspot is an area under the crust that is relatively hot that receives energy from a thermal plume. [Historical volcanism in Iceland](#) provides more information on Iceland's volcanoes and their past eruptions.

Dipartimento di Matematica e Geoscienze Geologia Marina 2018/2019

ICELAND HOT SPOT (or mantle plume)

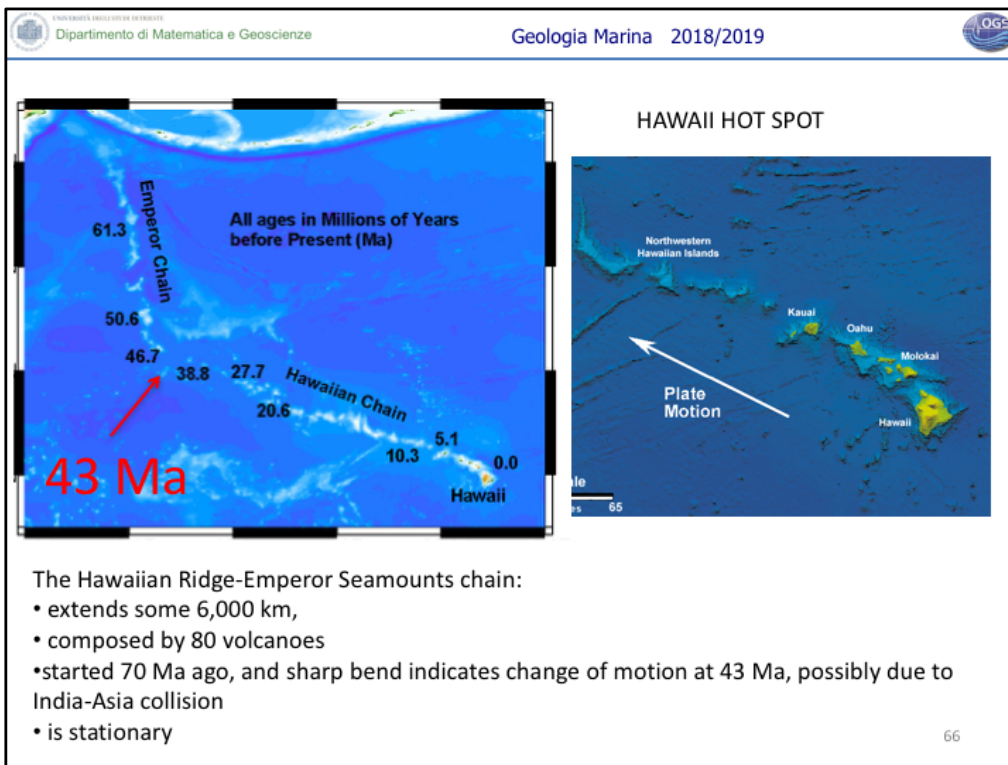
The starting plume head, **hundreds of degrees hotter than normal mantle**, spreads sideways, incorporates surrounding mantle, and buoyantly uplifts a region roughly 1000 km in diameter to produce a **topographic bulge about 1 km high**.
(Image by D. Müller, University of Sydney).

<http://www.abc.net.au/science/news/img/iceplume.htm>

The column of the Iceland plume, shown to a depth of 400 km. The plume head is already dispersed from the plume by buoyant flow into and along the rift. The starting plume head, hundreds of degrees hotter than normal mantle, spreads sideways, incorporates surrounding mantle, and buoyantly uplifts a region roughly 1000km in diameter to produce a topographic bulge about 1 km high. Image courtesy Dr Dietmar Müller, University of Sydne.

Origin of the Hotspot

The origin of the Iceland hotspot began with the breakup of the supercontinent Pangaea. As the Eurasian plate and the North American plate began to diverge, magma from underneath the crust rose up through the open rift and spilled over filling the valleys. This repeated activity of magma rising and cooling created the island of Iceland. Iceland was found to act more geologically complex than simple tectonic processes alone. Normal sea floor spreading and transform faults conflicted with the Icelandic tectonic processes. The crust underneath Iceland remained thin with a mantle plume that formed below the surface. A mantle plume or hotspot is a hot, narrow upwelling of molten material from the Earth's mantle. The mantle plume hypothesis is popular among scientists which states portions of the mantle are hotter than average, thus melting the mantle. However, Iceland geology contradicted this hypothesis as research suggested that a shallow thermal plume existed. It takes greater depth to form a thermal plume as the process of a rising, spreading plume is unhurried. Although it was debated that the plume is not shallow, rather, it plunges deeper than scientists believed and it is just difficult to discern. Seismic tomography has taken place to study the mantle plume.

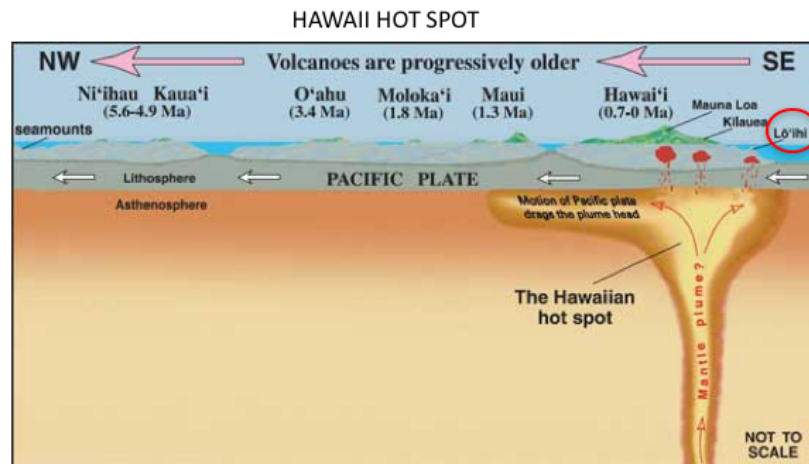


Over the past 70 million years, the combined processes of magma formation, volcano eruption and growth, and continued movement of the Pacific Plate over the stationary Hawaiian "hot-spot" have left a long trail of volcanoes across the Pacific Ocean floor. The Hawaiian Ridge-Emperor Seamounts chain extends some 6,000 km from the "Big Island" of Hawaii to the Aleutian Trench off Alaska. The Hawaiian Islands themselves are a very small part of the chain and are the youngest islands in the immense, mostly submarine mountain chain composed of more than 80 volcanoes. The amount of lava erupted to form the Hawaiian-Emperor chain is calculated to be at least 750,000 cubic kilometers.

Map of part of the Pacific basin showing the volcanic trail of the Hawaiian hotspot-- 6,000-km-long Hawaiian Ridge-Emperor Seamounts chain. (Base map reprinted by permission from World Ocean Floor by Bruce C. Heezen and Marie Tharp, Copyright 1977.)

A sharp bend in the chain indicates that the motion of the Pacific Plate abruptly changed about 43 million years ago, as it took a more westerly turn from its earlier northerly direction. Why the Pacific Plate changed direction is not known, but the change may be related in some way to the collision of India into the Asian continent, which began about the same time.

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

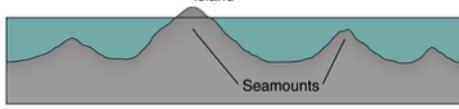


As the Pacific Plate continues to move west-northwest, the Island of Hawaii will be carried beyond the hotspot by plate motion, setting the stage for the formation of a new volcanic island in its place. In fact, this process may be under way. **Loihi Seamount**, an active submarine volcano, **is forming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

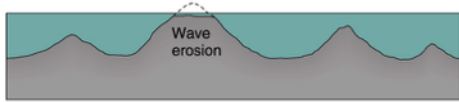
Morphological Features

Seamounts, volcanic island and guyots

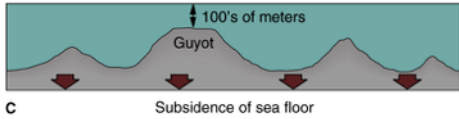
Copyright © McGraw-Hill Companies, Inc. Permission required for reproduction or display.



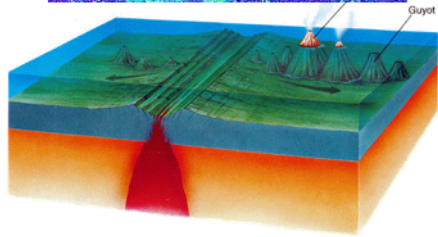
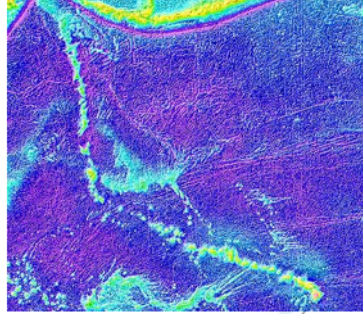
A



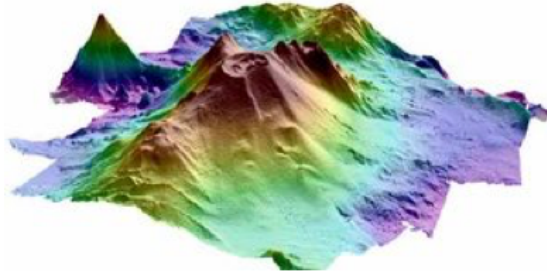
B



C



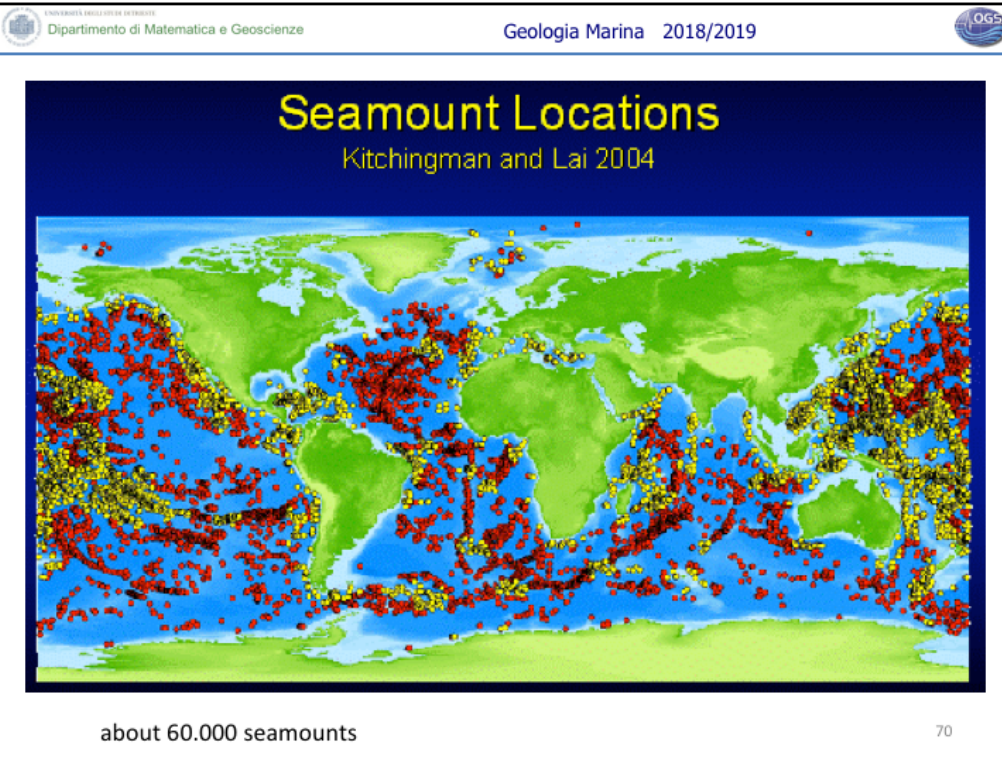
SEAMOUNT



Seamounts: undersea mountains rising from the bottom of the sea with a minimum elevation of 1,000 meters, that do not break the water's surface.

Seamounts are usually isolated and cone-shaped, are mostly volcanic and therefore found on oceanic crust, formed near mid-oceanic ridges, hotspot and island-arc convergent settings.

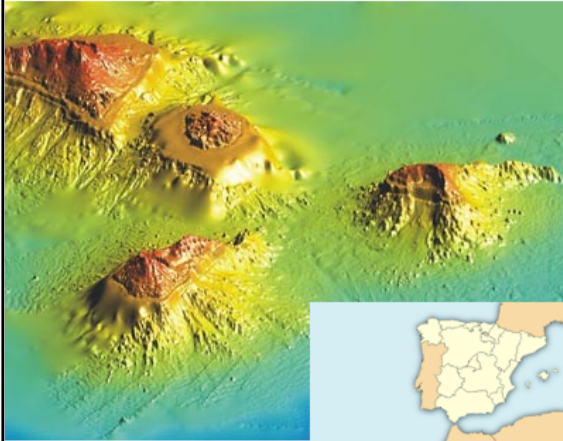
A seamount tall enough to break the sea surface is called an oceanic island, e.g., the islands of Hawaii, the Azores and Bermuda.



Kitchingman, A., Lai, S., 2004.
Inferences on potential seamount locations from mid-resolution bathymetric data.
Fisheries Centre Research Reports 12 (5), 7–12.

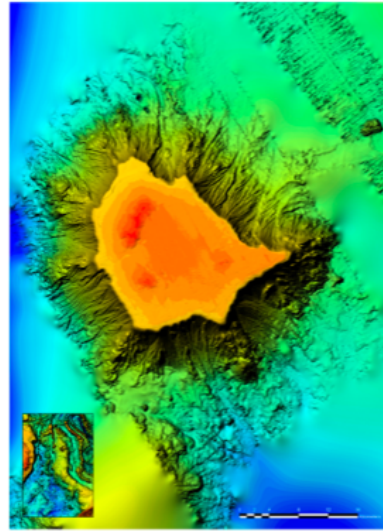
<http://yale.databasin.org/datasets/1c6af28887364008969f94c7e9df796e>

Canary Islands (Atlantic Ocean)



Volcanic origin

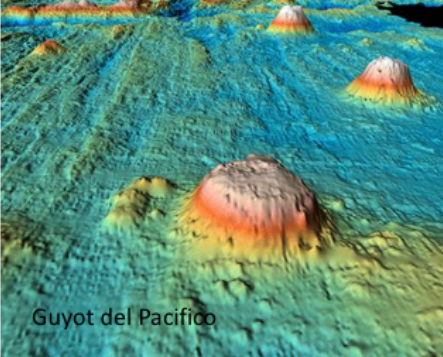
Gifford Guyot (Tasman Sea)



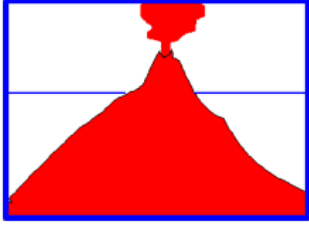
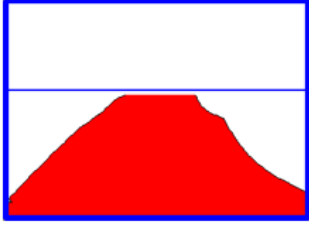
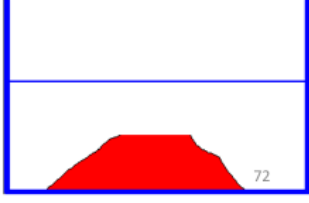
UNIVERSITÀ DEGLI STUDI DI PADOVA
Dipartimento di Matematica e Geoscienze

Geologia Marina 2018/2019

GUYOT



Guyot del Pacifico

1. Volcanic Island 
2. Wave erosion 
3. Guyot 

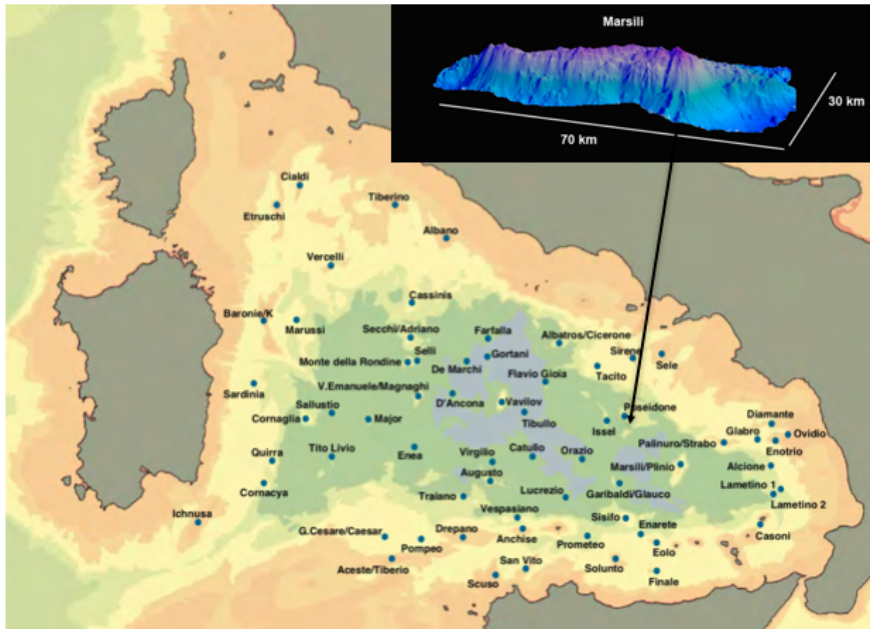
72

Seamounts and **Guyots** are volcanoes that have built up from the ocean floor, sometimes to sea level or above. Guyots are seamounts that have built above sea level. Erosion by waves destroyed the top of the seamount resulting in a flattened shape. Due to the movement of the ocean floor away from oceanic ridges, the sea floor gradually sinks and the flattened guyots are submerged to become undersea flat-topped peaks. We know that the tops of guyots were once at the surface because they contain evidence of fossils such as coral reefs that only live in shallow water. Seamounts conversely represent volcanoes that did not reach sea level so their tops remain intact and are shaped like volcanoes on land.

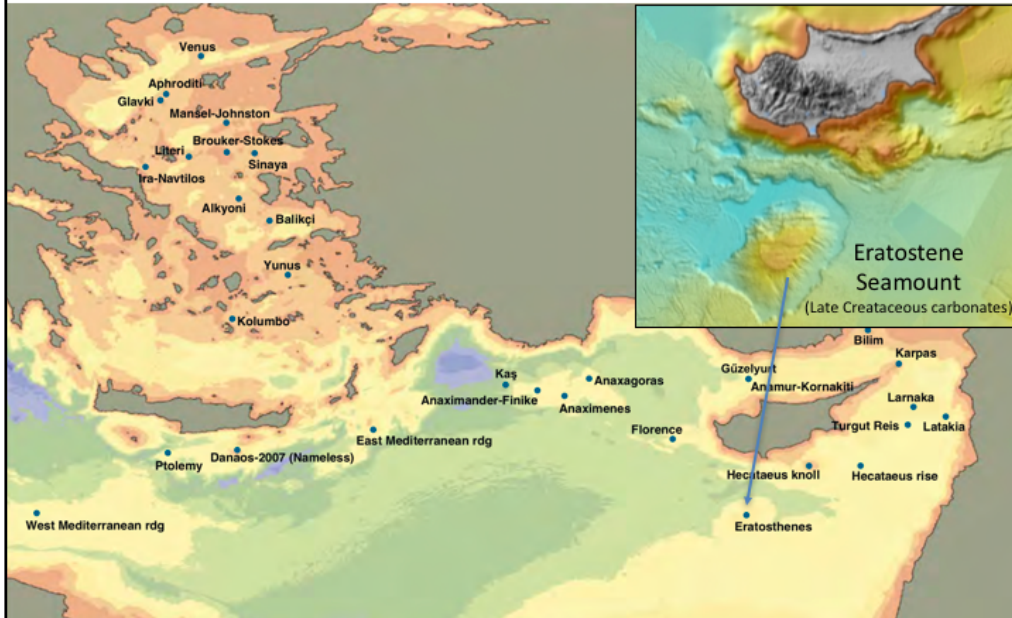
Seamounts in the Mediterranean



Seamounts in the Mediterranean

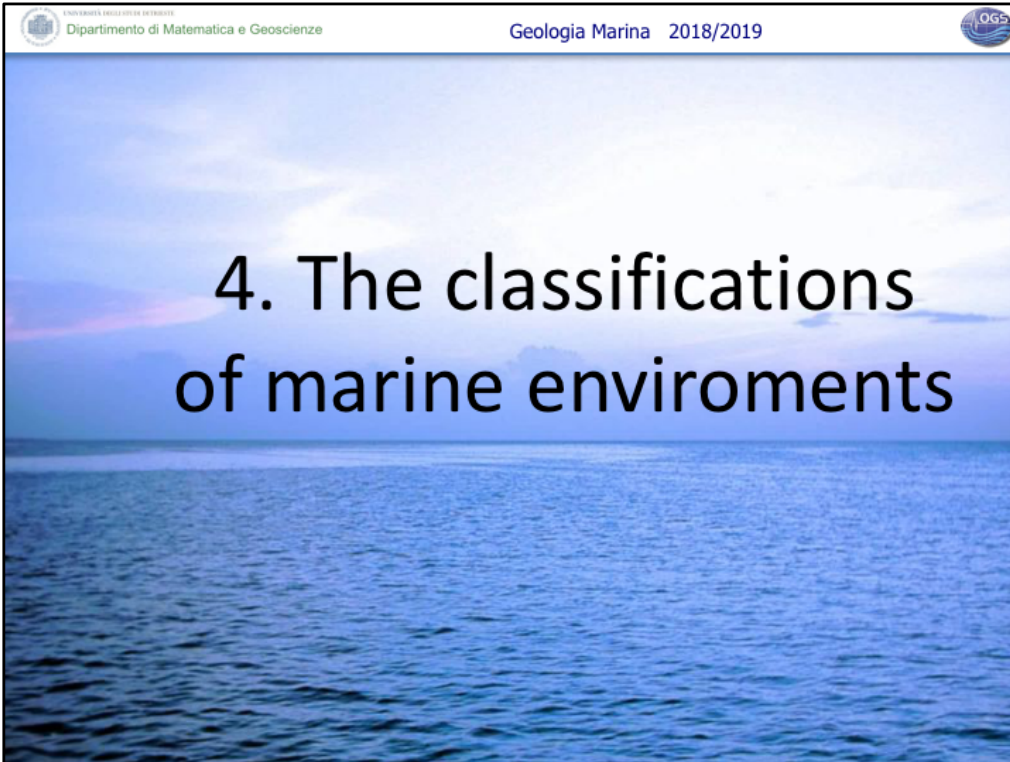


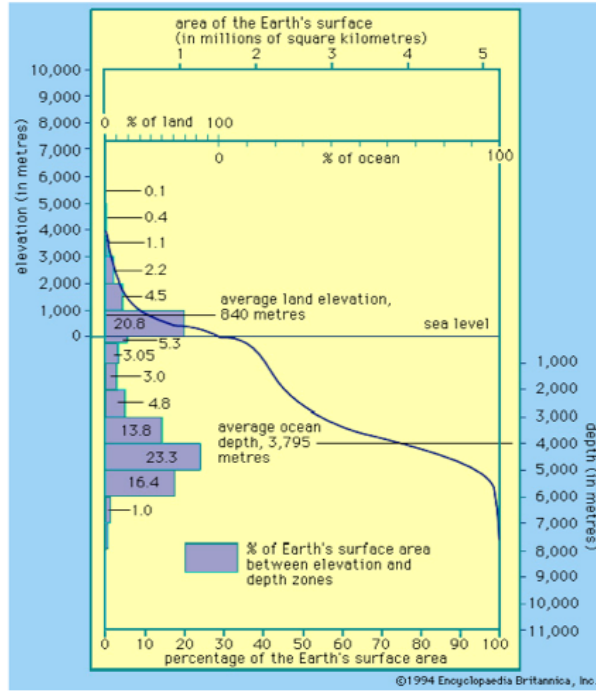
Seamounts in the Mediterranean Sea



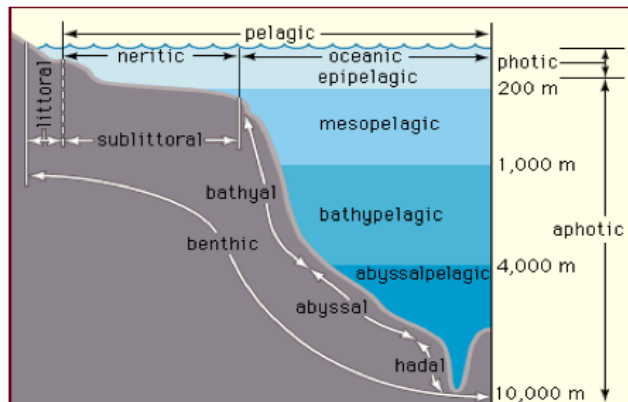


4. The classifications of marine environments





Classification of the Marine Zones



Temperature

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

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

Environmental classification:

- Littoral
- sublittoral
- bathyal
- abyssal
- hadal

Light classification:

- photic
- aphotic

Pelagic:

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

DIPARTIMENTO DI MATEMATICA E GEOSCIENZE Geologia Marina 2018/2019

DISTANCE SUNLIGHT TRAVELS IN THE OCEAN

sea level

200 meters

1000 meters

sunlight (euphotic) zone
Sunlight rarely penetrates beyond this zone.

twilight (dysphotic) zone
Sunlight decreases rapidly with depth. Photosynthesis is not possible here.

midnight (aphotic) zone
Sunlight does not penetrate at all. This zone is bathed in darkness.

oceanservice.noaa.gov

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

79

Sunlight entering the water may travel about 1,000 meters (3,280 feet) into the ocean under the right conditions, but there is rarely any significant light beyond 200 meters (656 feet).

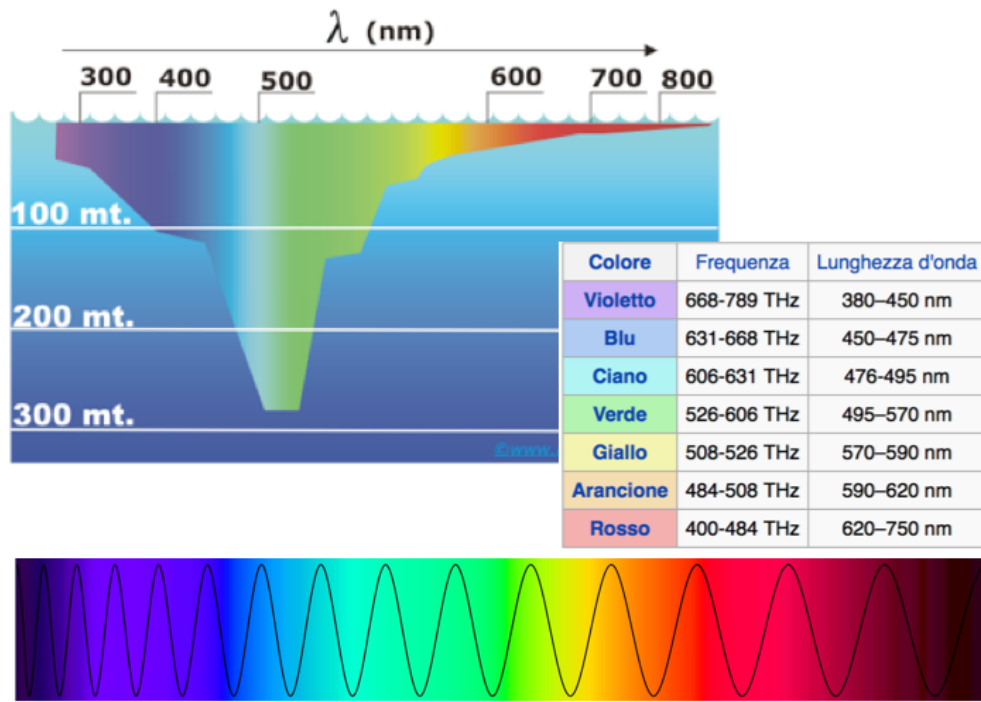
The ocean is divided into three zones based on depth and light level. The upper 200 meters (656 feet) of the ocean is called the euphotic, or "sunlight," zone. This zone contains the vast majority of commercial fisheries and is home to many protected marine mammals and sea turtles.

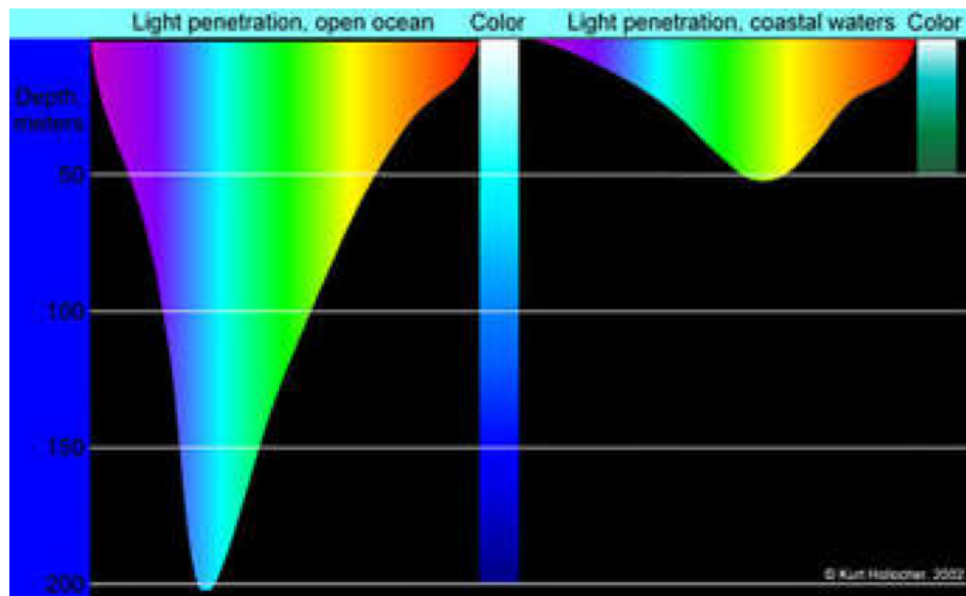
Only a small amount of light penetrates beyond this depth.

The zone between 200 meters (656 feet) and 1,000 meters (3,280 feet) is usually referred to as the "twilight" zone, but is officially the dysphotic zone. In this zone, the intensity of light rapidly dissipates as depth increases. Such a miniscule amount of light penetrates beyond a depth of 200 meters that photosynthesis is no longer possible.

The aphotic, or "midnight," zone exists in depths below 1,000 meters (3,280 feet). Sunlight does not penetrate to these depths and the zone is bathed in darkness.

'Photic' is a derivative of 'photon,' the word for a particle of light.







5. Ancient Oceans

The origin of the water of the ocean

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

- outgassing whereby gases are released from molten rock in the mantle of the planet by volcanic activity;
- bombardment by comets and meteorites bringing with them gases which contributed to the Earth's atmosphere (some meteorites are formed by 20% of water).

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



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

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

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

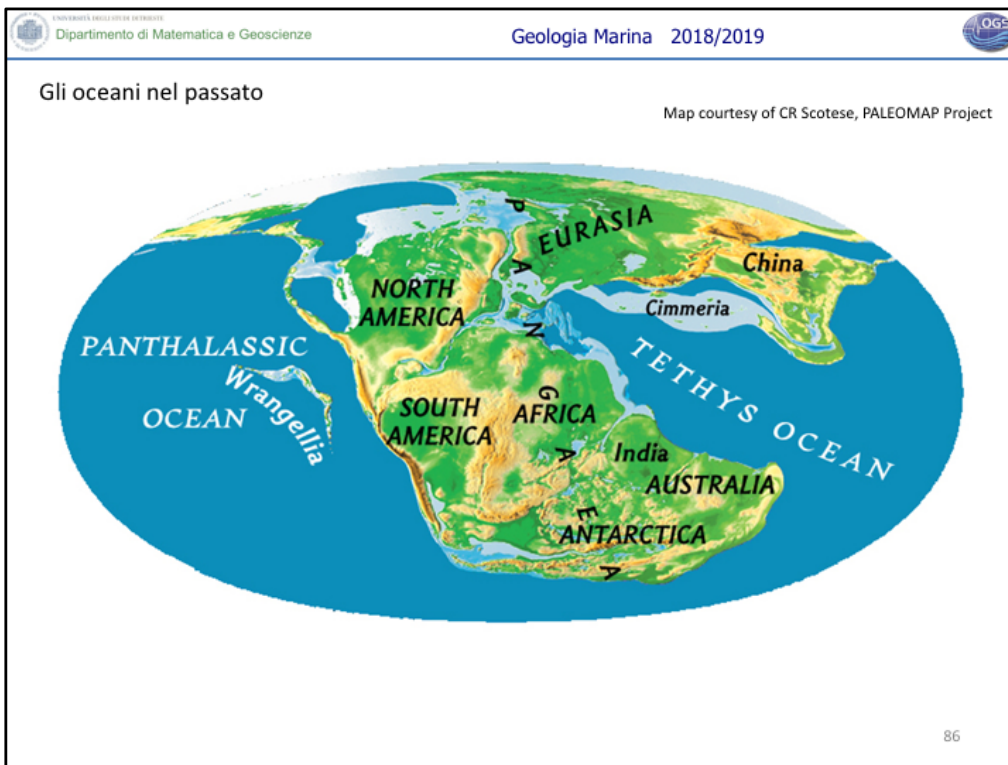
The geochemical cycles had their beginnings here, with minerals entering the oceans from the land and sky and minerals leaving the oceans through tectonic activity and by evaporation/deposition processes.

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

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

- formed in the Cambrian, about 510 million years ago,
- disappear in the Devonian, about 400 million years ago.

Nel primo Paleozoico la maggior parte della crosta continentale faceva parte del paleocontinente Gondwana (comprendente la futura Africa, Sud America, Eurasia del sud, Australia ed Antartide), posizionato in corrispondenza del Polo Sud. Tra 650 e 550 milioni di anni fa (Ediacarano) il continente Laurentia (contenente la parte nord est del futuro Nord America), insieme al Baltica e al continente siberiano si separarono dal Gondwana, muovendosi in direzione nord verso l'equatore. Questo movimento portò all'apertura dell'Oceano Giapeto tra Gondwana, Baltica e Laurentia. Nel primo Ordoviciano (480 milioni di anni fa), il microcontinente Avalonia (comprendente frammenti dell'attuale New England, Terranova, Nuovo Brunswick, Nuova Scozia, Irlanda del sud, gran parte dell'Inghilterra e del Galles, i Paesi Bassi e la Germania del nord) iniziò a separarsi dal margine settentrionale del Gondwana.



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

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

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

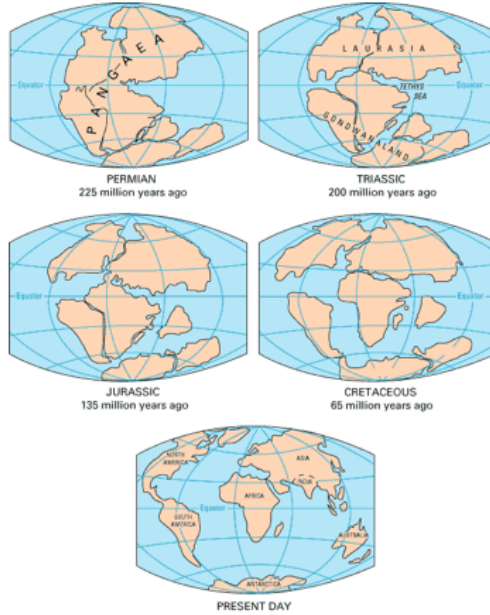
ATLANTIC OCEAN: initial stage



Fragmentation of the Pangea (Late Giurassic):

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

The break up of Pangaea



Bibliography

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

Web sites

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

Documentary

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