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. The present oceans of the Earth
2. Morphology of the ocean sea floor
3. Structure of the ocean
4. Evolution of the ocean

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

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

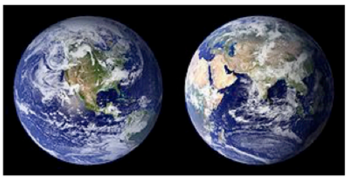
http://www.etimo.it/?term=oceano

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 are important because they:

- Cover 71-72% of the Earth surface
- Contain the 97% of the water of the Earth

but less than 5-10% has been explored



The present Oceans of the world

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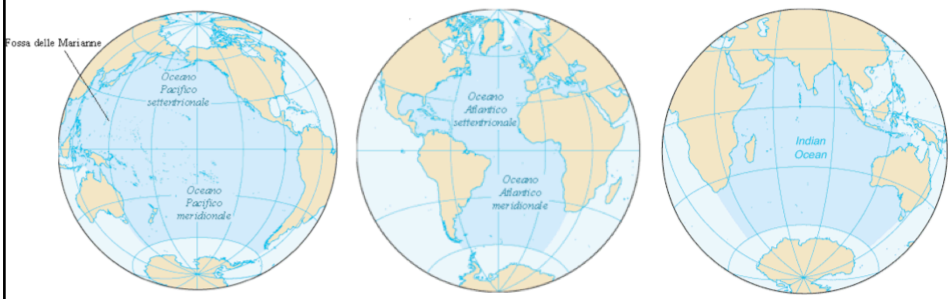
There are also many seas (smaller branches of an ocean); seas are often partly enclosed by land. The largest seas are the South China Sea, the Caribbean Sea, and the Mediterranean Sea.



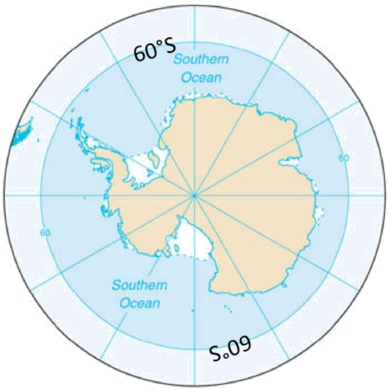
In the 1953, the International Hydrographic Bureau defined three oceans:

- the Pacific Ocean
- the Atlantic Ocean
- the Indian Ocean

Artic Ocean

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, anche perché presenta le caratteristiche geologiche di un oceano (formazione 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.

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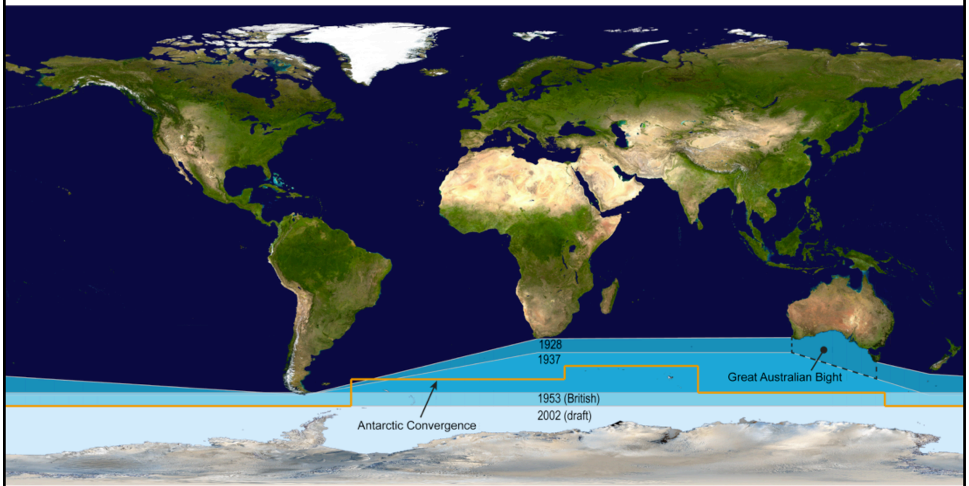
Nella primavera del 2000 l'International Hydrographic Bureau delimitò un nuovo oceano, l'Oceano Meridionale, *Southern Ocean*, che circonda il continente Antartico e si estende fino al parallelo 60°S.
Questo nuovo oceano è stato definitivo in seguito all'attività di ricerca antartica in quanto nella 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.

IHS's delineation of the Southern Ocean



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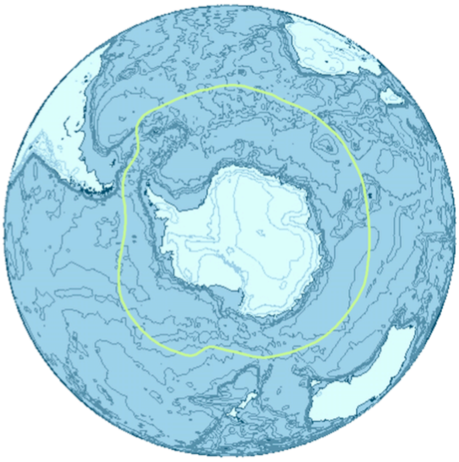
The Antarctic Convergence: a possible limit of the Southern Ocean



Antarctic Convergence

a curve encircling Antarctica, varying in latitude seasonally, where cold, northward-flowing Antarctic waters meets the relatively warmer water of the subantarctic 10

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

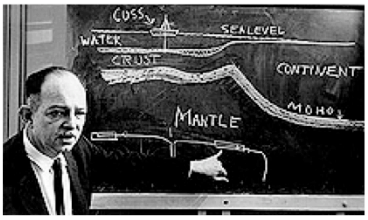
SEA FLOOR MORPHOLOGY

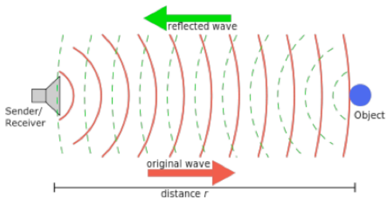
Harry Hess (1906 – 1969)

Professor of geology at Princeton University

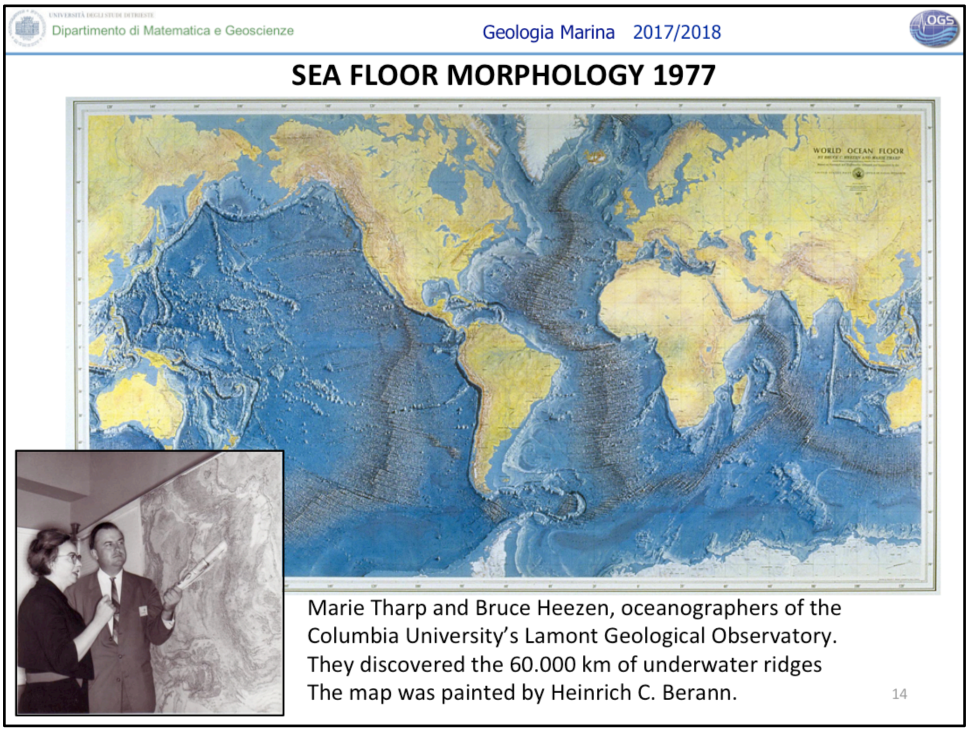
During the Second World War, Hess was the captain of a ship equipped with a SONAR (SOund NAvigation and Ranging, invented in 1917 by Paul Langevin).

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.





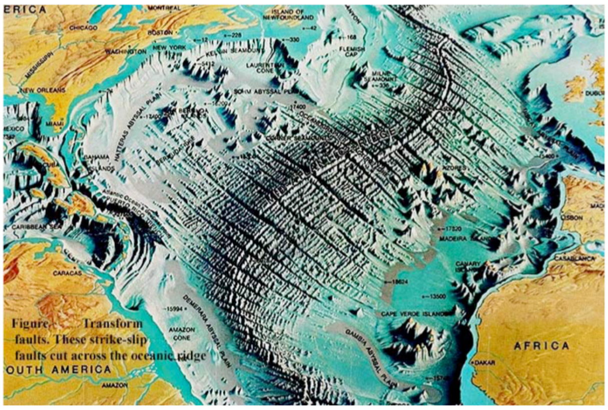
The SONAR principle



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 Hezeen'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.

Mid-Ocean Ridges



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

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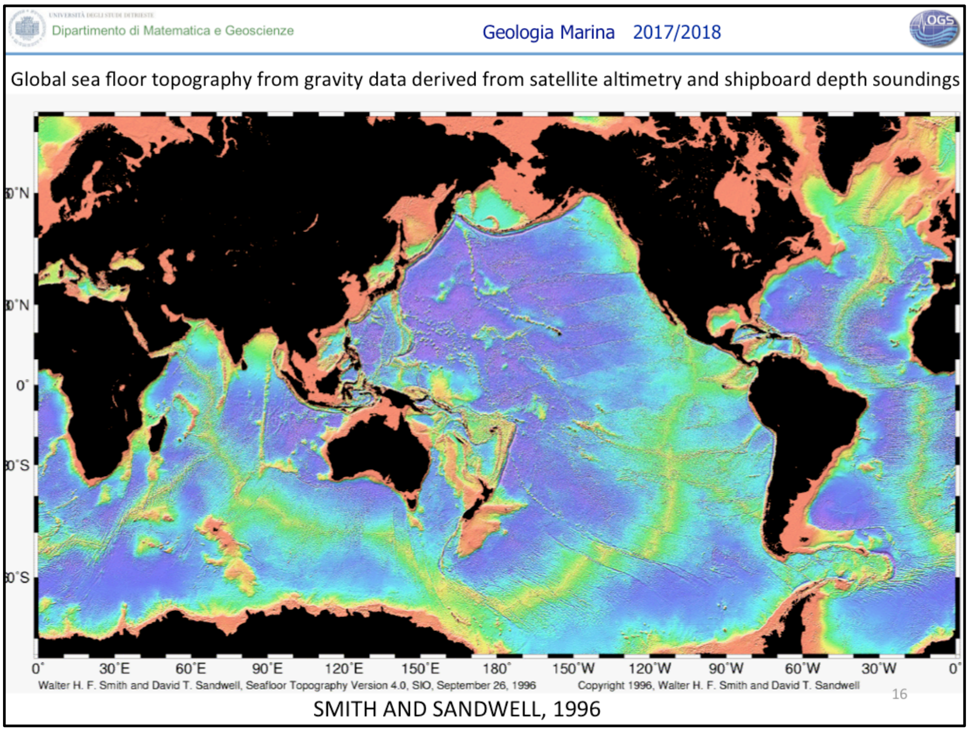
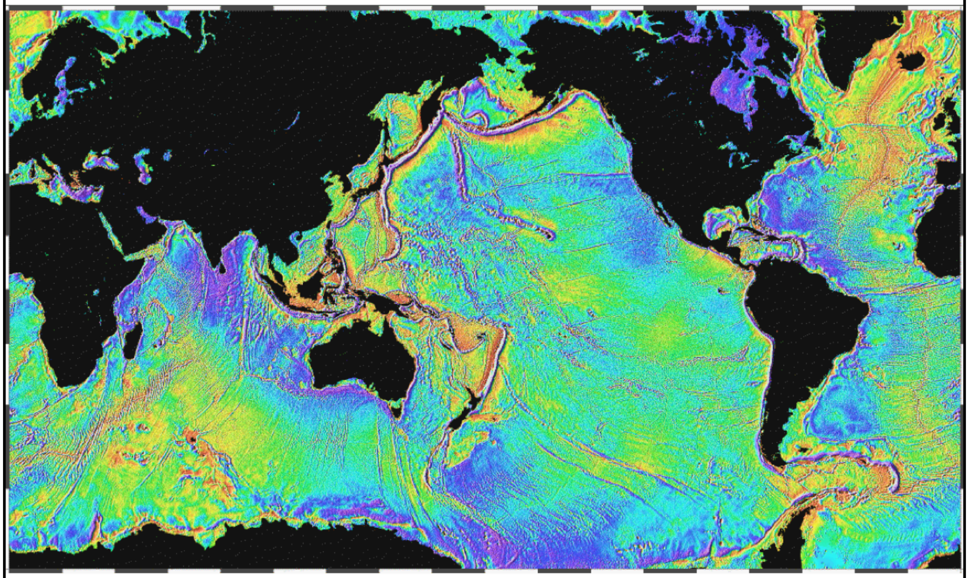
Dorsali oceaniche:
Lunghe catene costituite da un allineamento di centri vulcanici sottomarini attivi.
I vulcani si elevano di circa 1000-2000 metri dai fondi oceanici.
Al centro della dorsale ci può essere una valle larga circa 25-30 km e profonda circa 1000 metri.
Complessivamente le dorsali oceaniche costituiscono una catena sottomarina continua lunga 60.000 km.



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

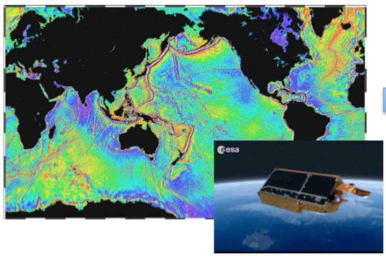
A new color poster has been prepared displaying measured and estimated seafloor topography. The poster is printed in a Mercator projection from data gridded uniformly at intervals equivalent to 2 minutes longitude at the equator. This new estimate of seafloor topography was obtained from shipboard depth 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.

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

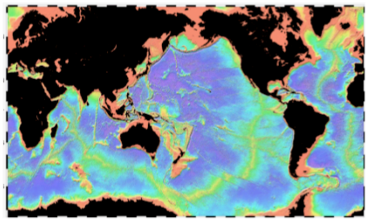


SMITH AND SANDWELL, 1996

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



Global sea floor topography
from gravity data and shipboard depth soundings

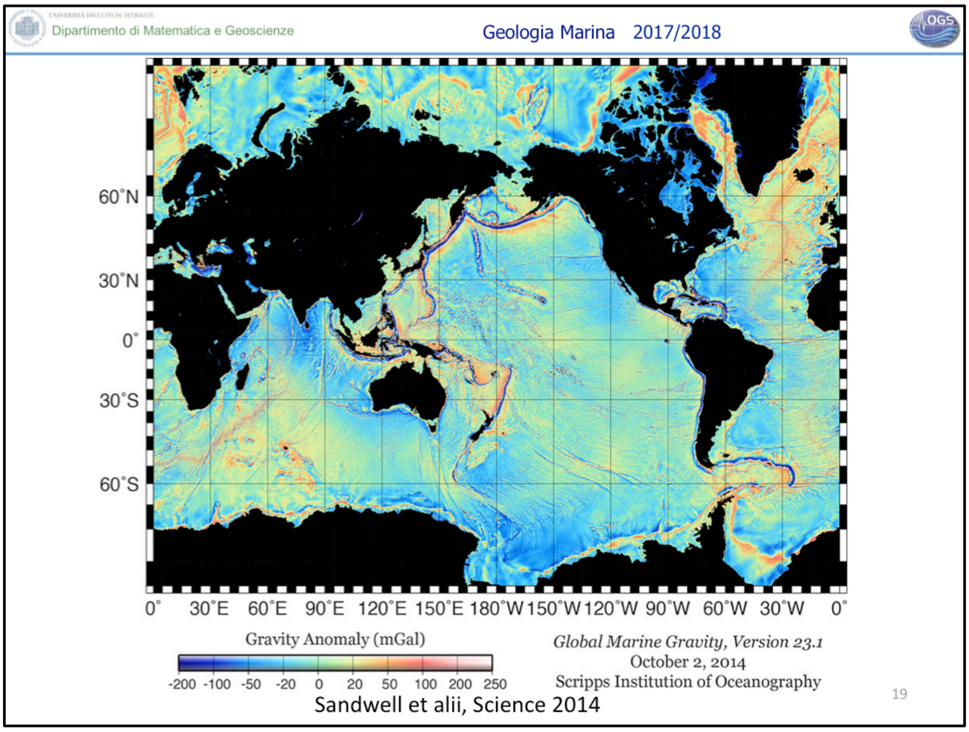


SMITH AND SANDWELL, 1996

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

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

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



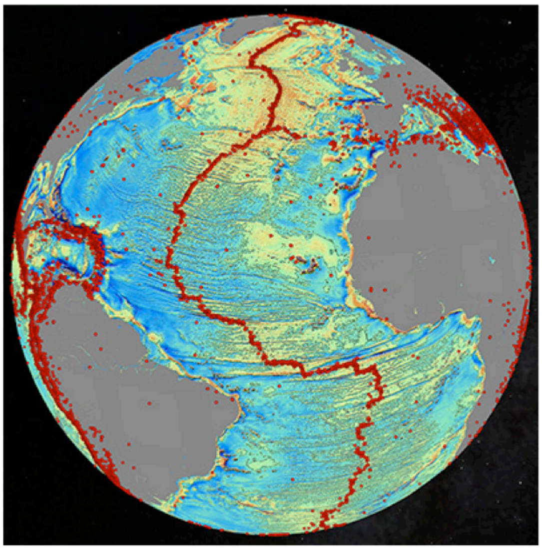
http://www.nature.com/news/gravity-map-uncovers-sea-floor-surprises-1.16048#/ref-link-1

maggiore 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.

Marine gravity model of the North Atlantic

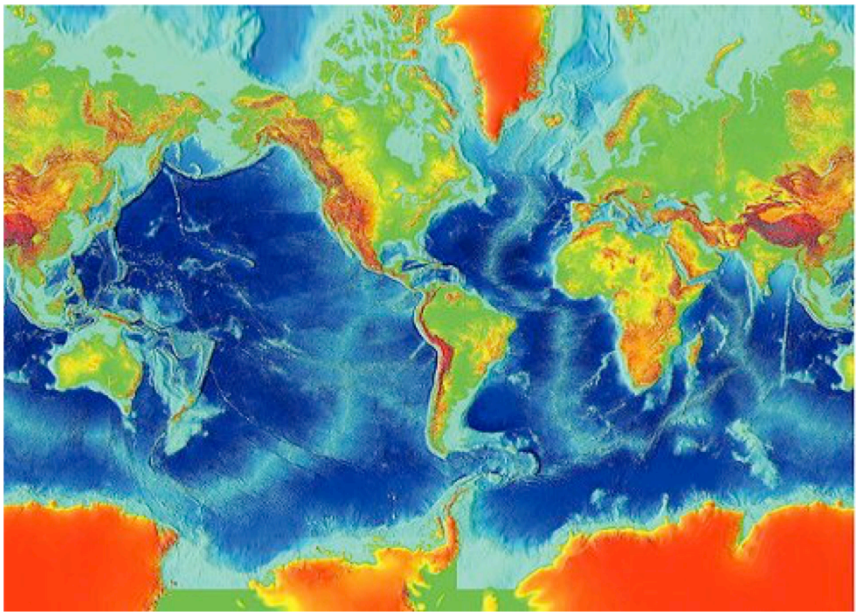


Red dots show locations of earthquakes with magnitude > 5.5 and they highlight the present-day location of the seafloor spreading ridges and transform faults.

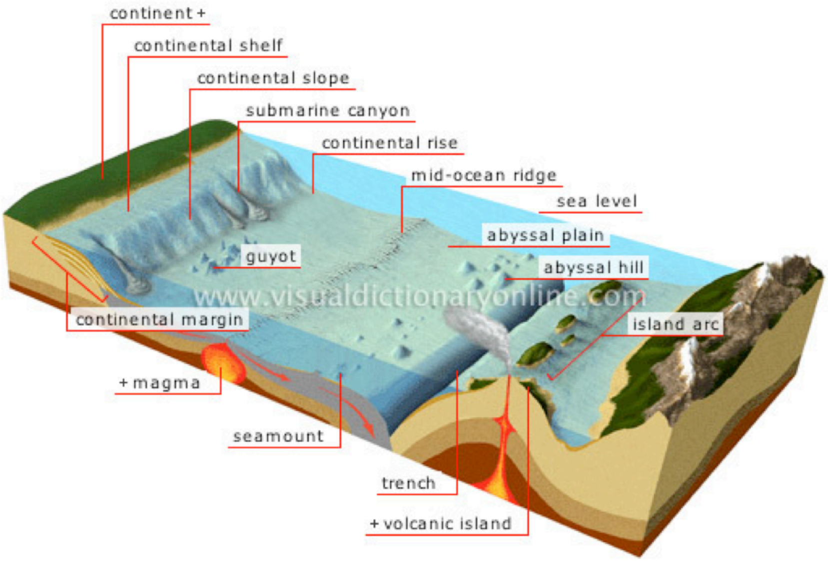
This gravity information shows the details of the plate tectonic history of the rifting of these continents including the subtle signatures of fracture zones that are currently buried by sediment.

Sandwell et alii, Science 2014

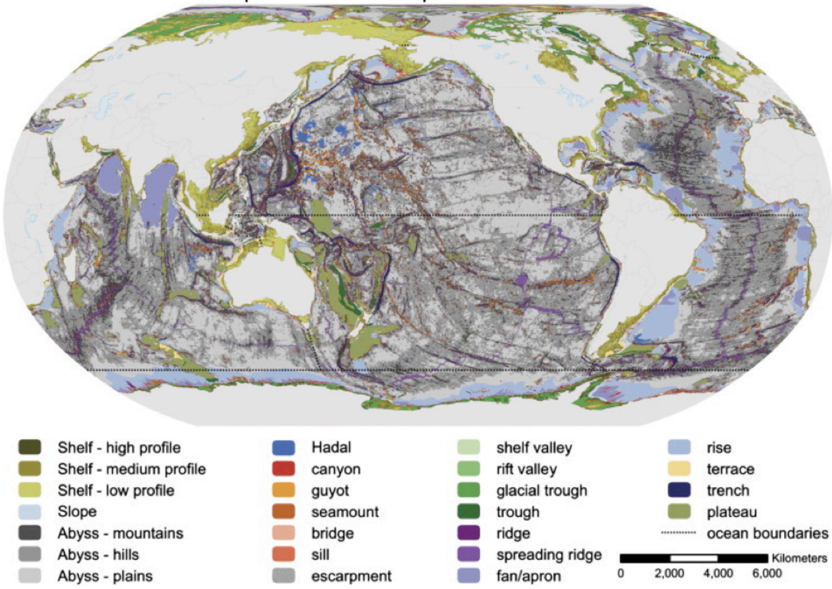
SEA FLOOR MORPHOLOGY



SEA FLOOR MORPHOLOGY

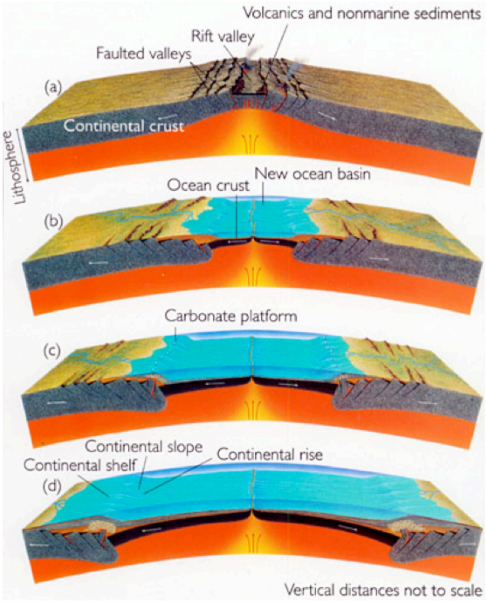


Geomorphic features map of the world's oceans.



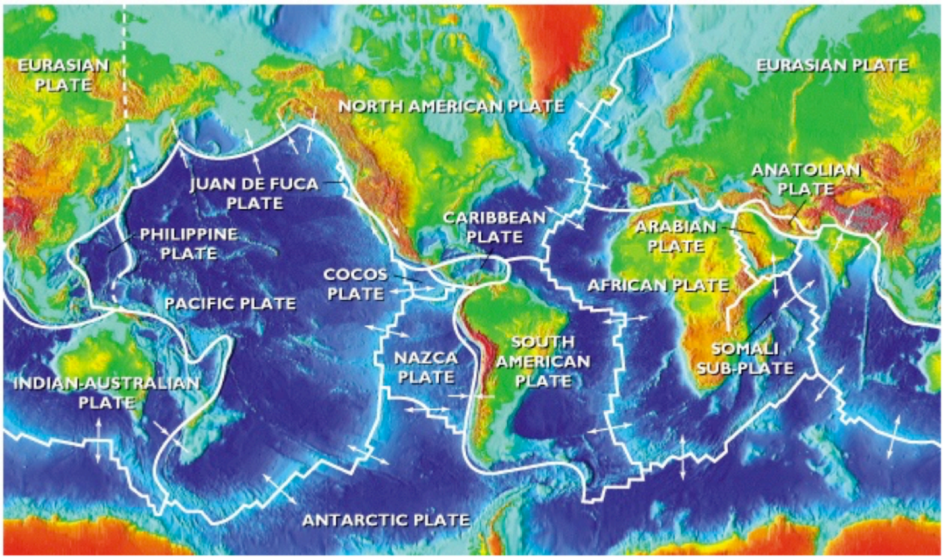
Harris, Macmillan-Lawler, Rupp, Baker, 2014. **Geomorphology of the oceans.** Marine Geology, 352, 2014, 4–24. http://dx.doi.org/10.1016/j.margeo.2014.01.011

The Ocean formation

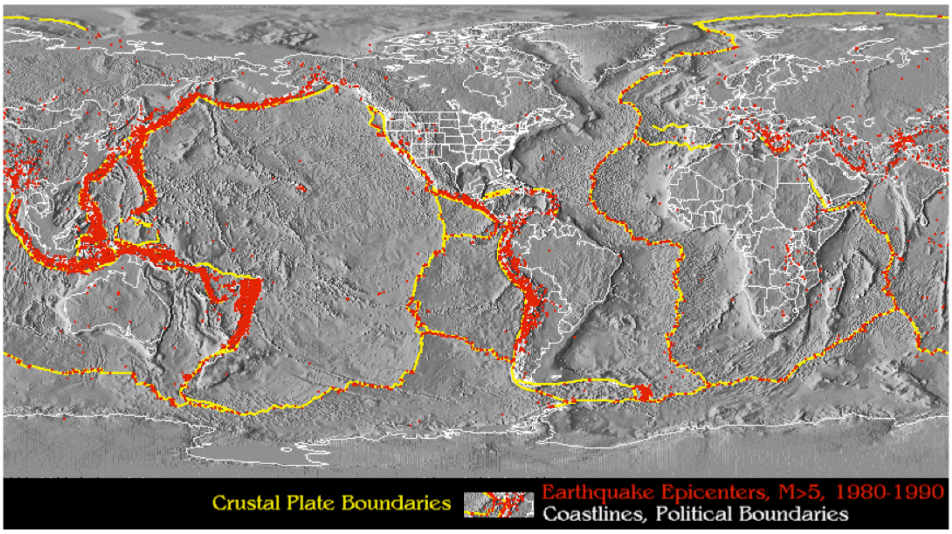


continental rift

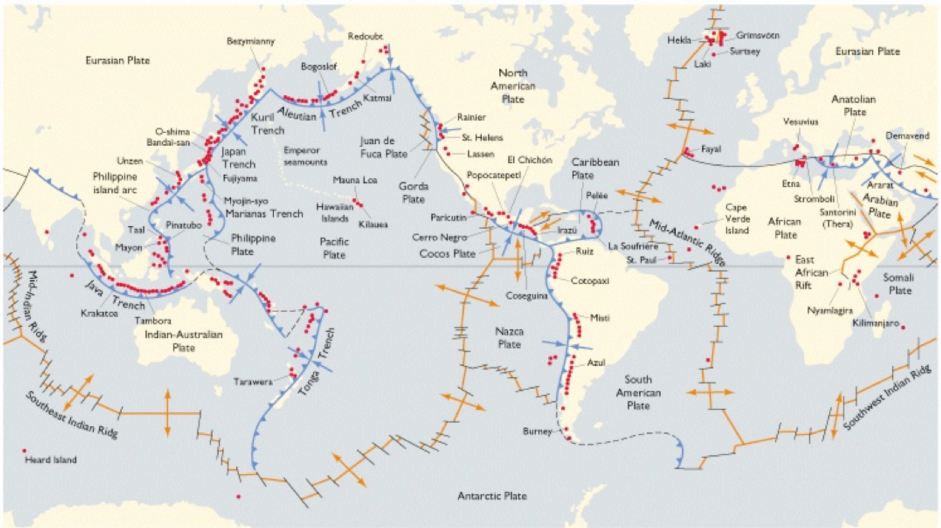
SEA FLOOR MORPHOLOGY

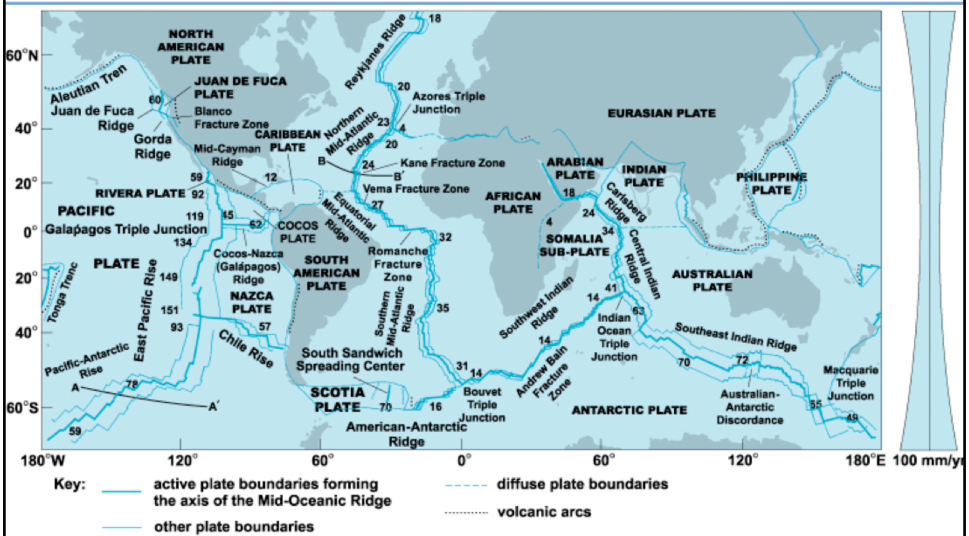


Mid-oceanic ridge system is 60,000 km long, 2000 km wide, 3000 m high



Shallow earthquakes at the Ocean Ridges


Eurasian Plate
Bezymianny
Redoubt
Bogoslof
Katmai
Aleutian Trench
Kuril Trench
O-shima
Bandai-san
Japan Trench
Fujiyama
Unzen
Philippine island arc
Emperor seamounts
Juan de Fuca Plate
Mauna Loa
Hawaiian Islands
Kilauea
Gorda Plate
Myojin-syo
Marianas Trench
Taal
Pinatubo
Mayon
Philippine Plate
Pacific Plate
Mid-Indian Ridg
Java Trench
Krakatoa
Tambora
Indian-Australian Plate
Tarawera
Tonga Trench
Southeast Indian Ridg
Heard Island
North American Plate
Rainier
St. Helens
Lassen
El Chichón
Popocatepetl
Paricutin
Cerro Negro
Cocos Plate
Caribbean Plate
Pelée
Irazú
La Soufrière
St. Paul
Ruiz
Cotopaxi
Coseguina
Misti
Nazca Plate
Azul
South American Plate
Burney
Antarctic Plate
Hekla
Grimsvötn
Surtsey
Laki
Fayal
Mid-Atlantic Ridge
Eurasian Plate
Anatolian Plate
Vesuvius
Demavend
Etna
Stromboli
Santorini (Thera)
Ararat
Arabian Plate
Cape Verde Island
African Plate
East African Rift
Nyamlagira
Kilimanjaro
Somali Plate
Southwest Indian Ridg

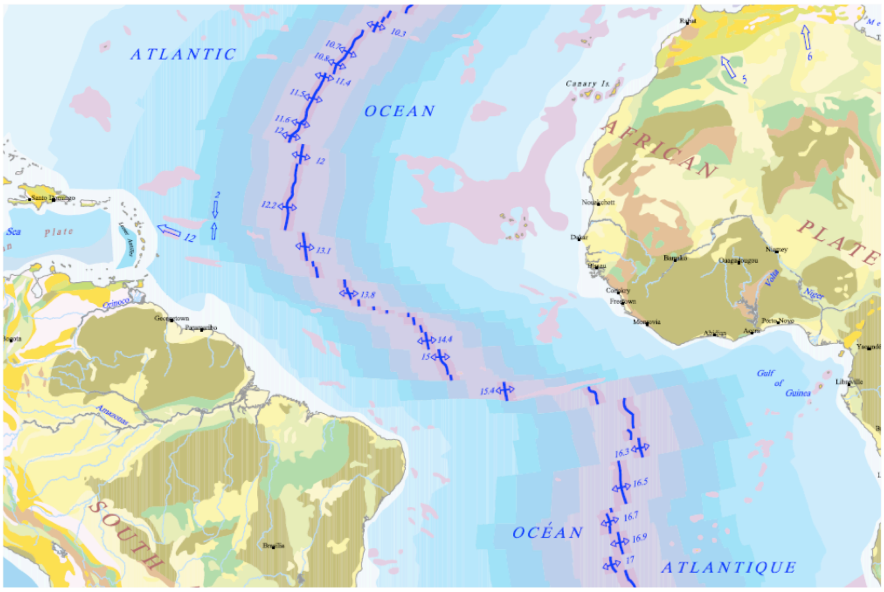


Mid-Oceanic Ridge system

Paired lines on either side of the axis show the amount of crust generated in the last 10 million years at the current opening rates.

Dotted lines show the volcanic arcs, which are lines of volcanoes and volcanic islands formed from magma rising from the subducted plate. The distortion caused by plotting these lines on a Mercator projection is indicated by the hourglass-shaped graph on the right, which gives the amount of crust generated at a 100 mm/yr opening rate (1 mm = 0.04 in.).

half spreading rate in mm/year



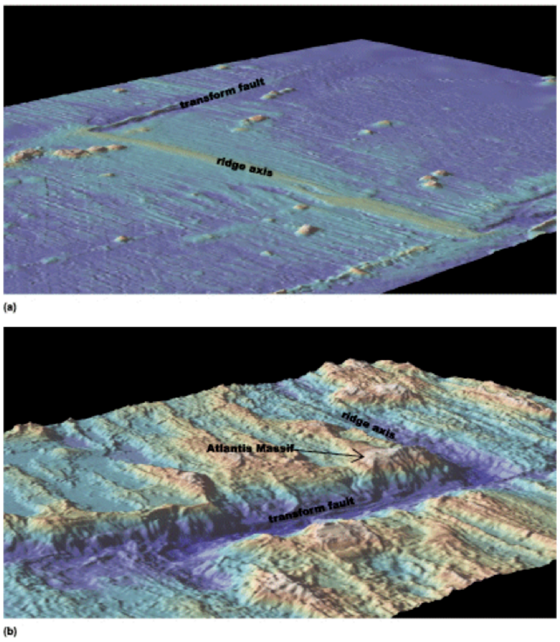
half spreading rate in mm/year

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

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

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

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



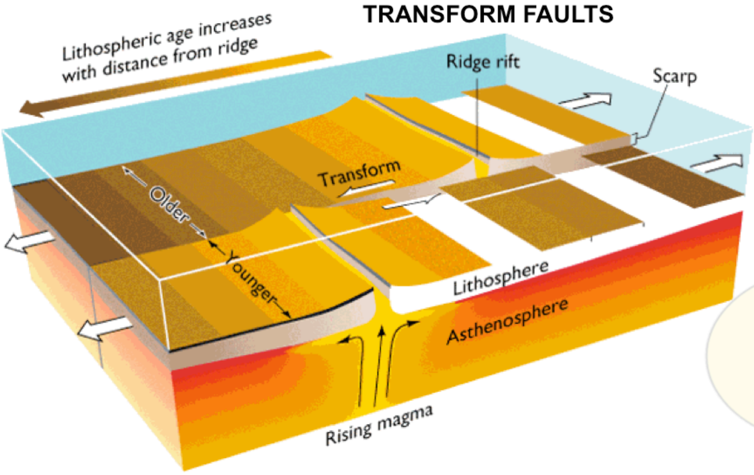
Oblique view of fast- and slow-spreading mid-ocean ridges, showing differences in morphology along the ridge.

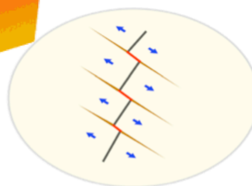
a) Fast-spreading East Pacific Rise at 19°S, viewed toward the north.

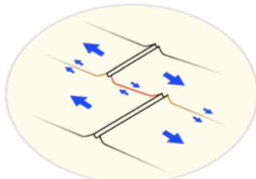
b) Slow-spreading Mid-Atlantic Ridge at 30°N and the Atlantis transform view toward the northeast.

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

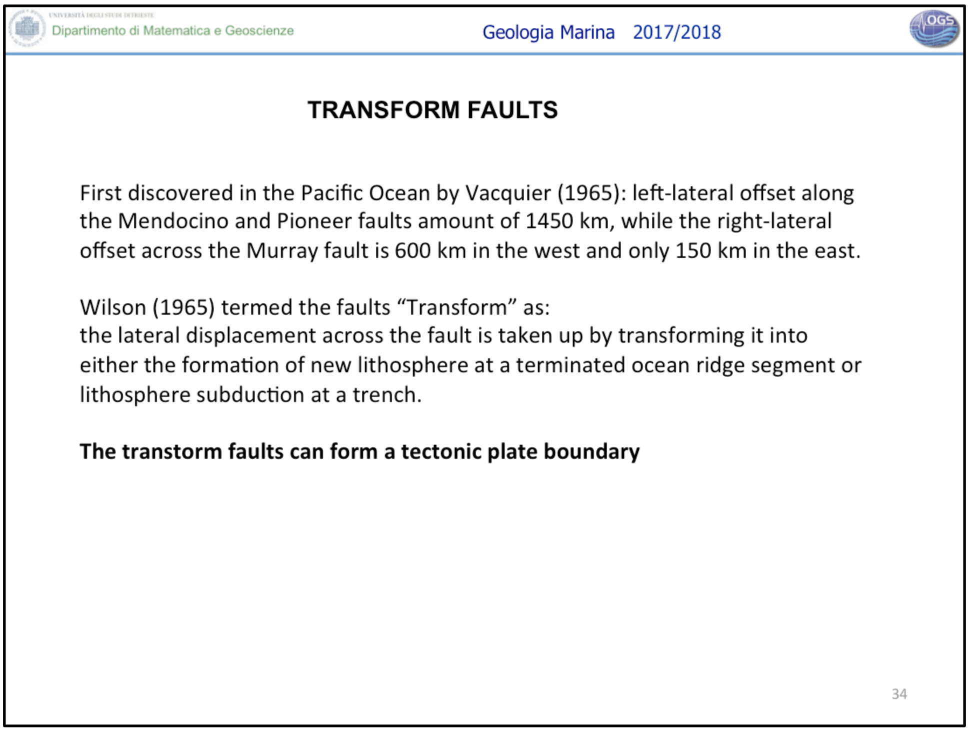
TRANSFORM FAULTS



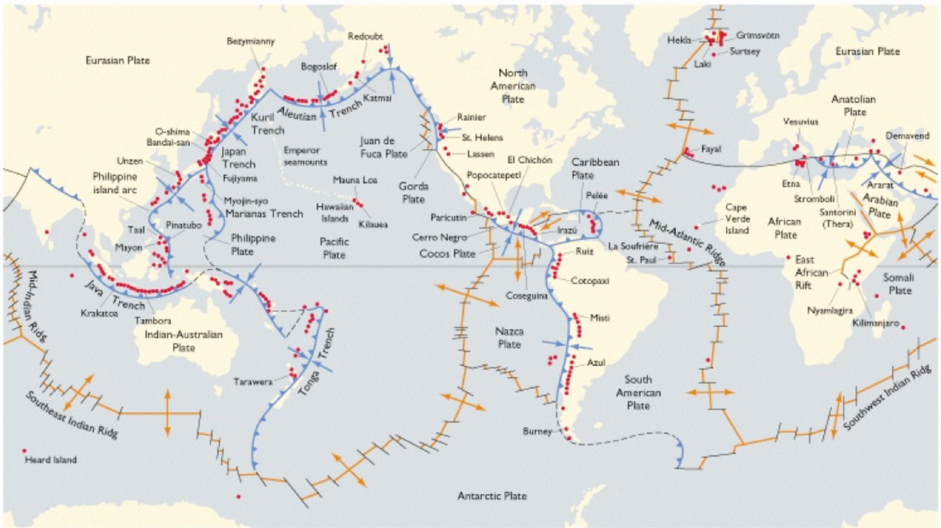




A transform fault or transform boundary, also known as conservative plate boundary since these faults neither create nor destroy lithosphere, is a type of fault whose relative motion is predominantly horizontal in either sinistral or dextral direction.



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.


Eurasian Plate
Bezymianny
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Japan Trench
Unzen
Fujiyama
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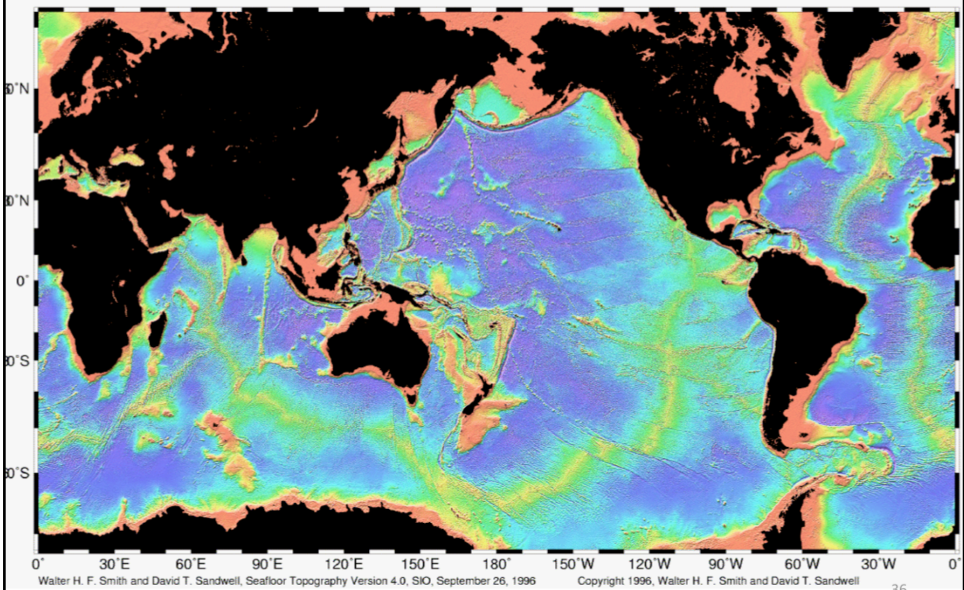
Philippine island arc
Myojin-syo
Marianas Trench
Mauna Loa
Hawaiian Islands
Kilauea
Gorda Plate
Taal
Pinatubo
Mayon
Philippine Plate
Pacific Plate
Paricutin
Cerro Negro
Cocos Plate
Mid-Indian Ridg
Java Trench
Krakatoa
Tambora
Indian-Australian Plate
Tonga Trench
Tarawera
Southeast Indian Ridg
Heard Island
North American Plate
Rainier
St. Helens
Lassen
El Chichón
Popocatepetl
Caribbean Plate
Pelée
Irazú
La Soufrière
St. Paul
Ruiz
Cotopaxi
Coseguina
Misti
Nazca Plate
Azul
Burney
South American Plate
Antarctic Plate
Hekla
Grimsvötn
Surtsey
Laki
Fayal
Mid-Atlantic Ridge
Eurasian Plate
Anatolian Plate
Vesuvius
Demavend
Etna
Stromboli
Santorini (Thera)
Ararat
Arabian Plate
Cape Verde Island
African Plate
East African Rift
Somali Plate
Nyamlagira
Kilimanjaro
Southwest Indian Ridg

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



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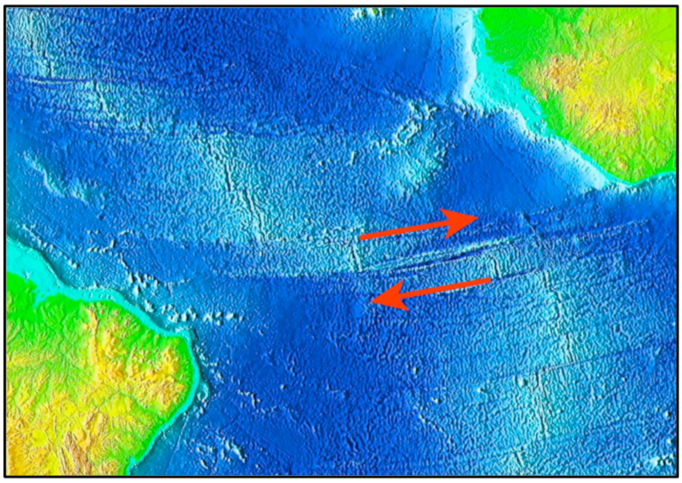
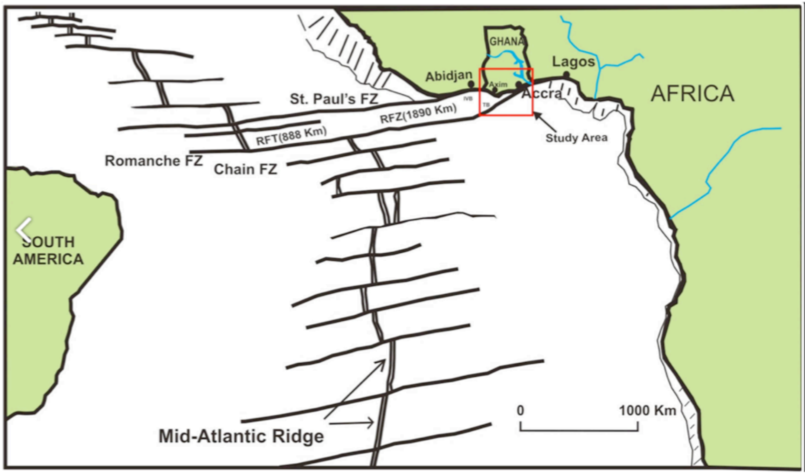
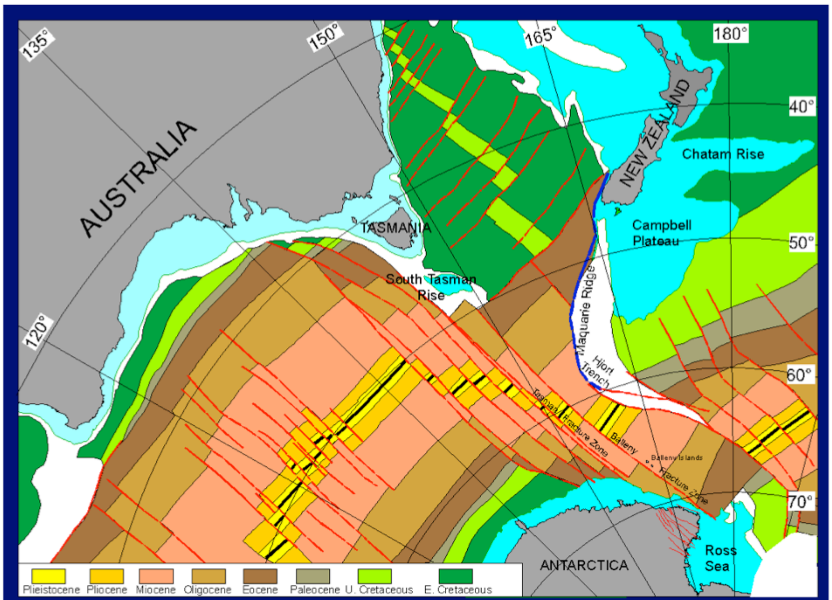
SMITH AND SANDWELL, 1996

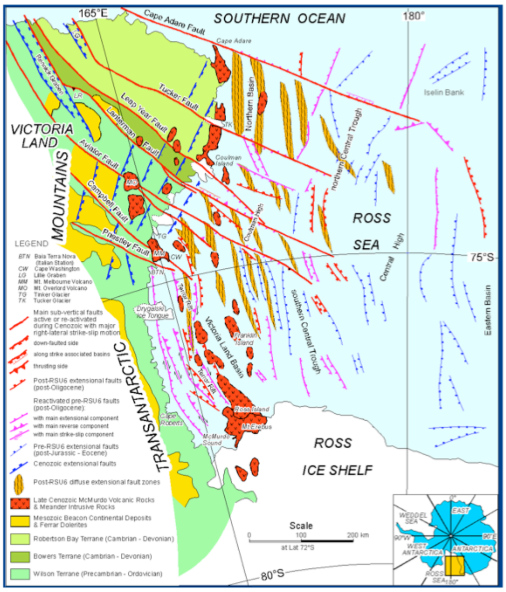


The Romanche Trench bisects the Mid-Atlantic Ridge just north of the equator at the narrowest part of the Atlantic between Brazil and West Africa.


GHANA
Abidjan
Lagos
AFRICA
Axim
Accra
St. Paul's FZ
RFZ(1890 Km)
RFT(888 Km)
Study Area
Romanche FZ
Chain FZ
SOUTH
AMERICA
0
1000 Km
Mid-Atlantic Ridge



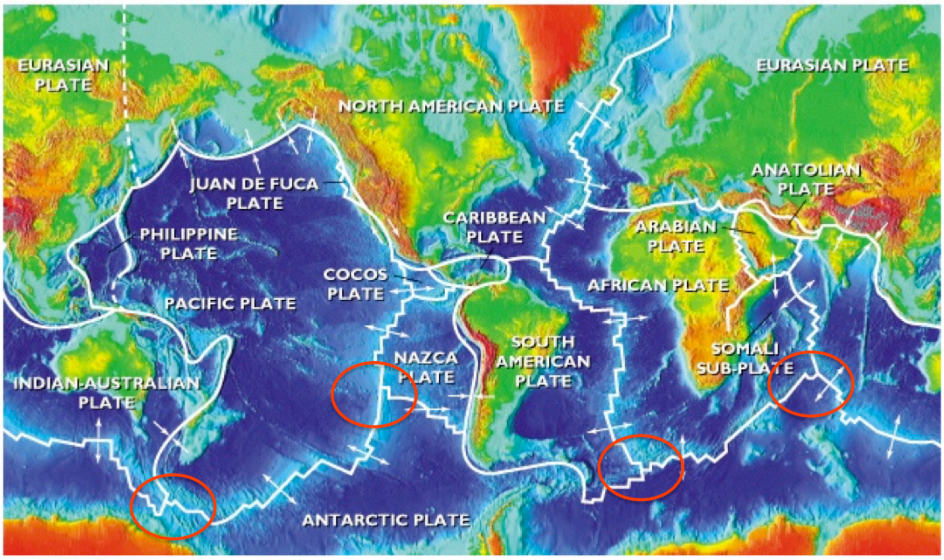
Modified from Hayes, 1991

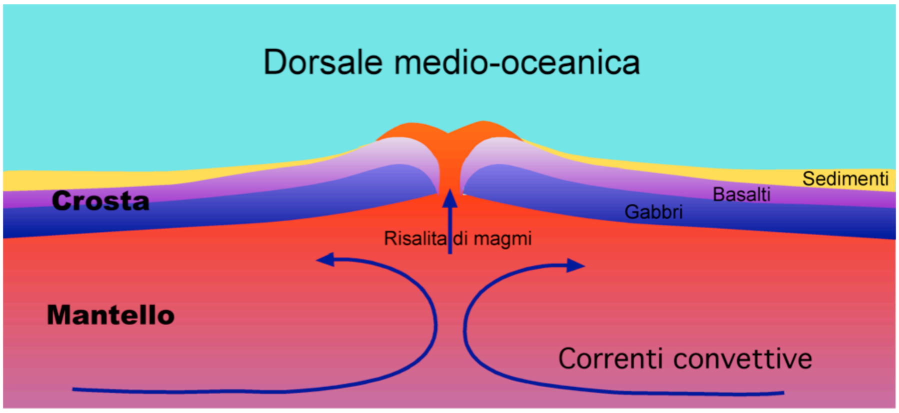


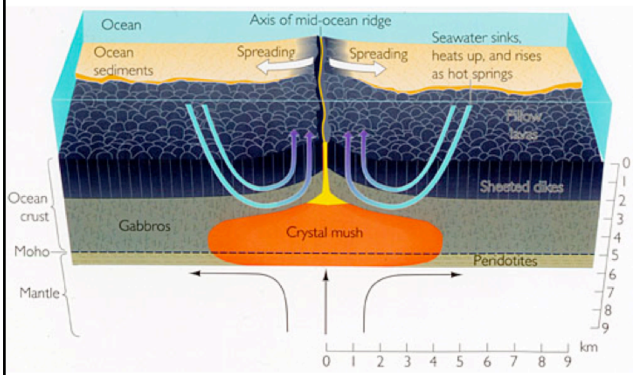
La faglie principali nella Terra Vittoria Settentrionale e nel Mare di Ross.

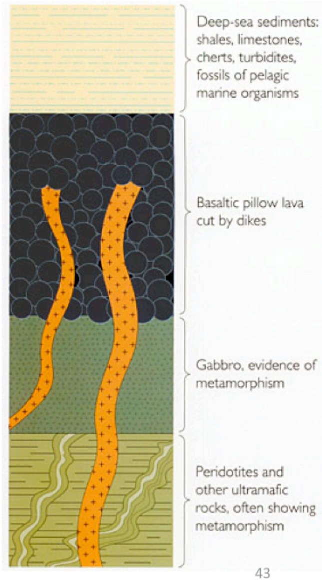
Salvini et al., 1997, Journal of Geophysical Research

Triple junction



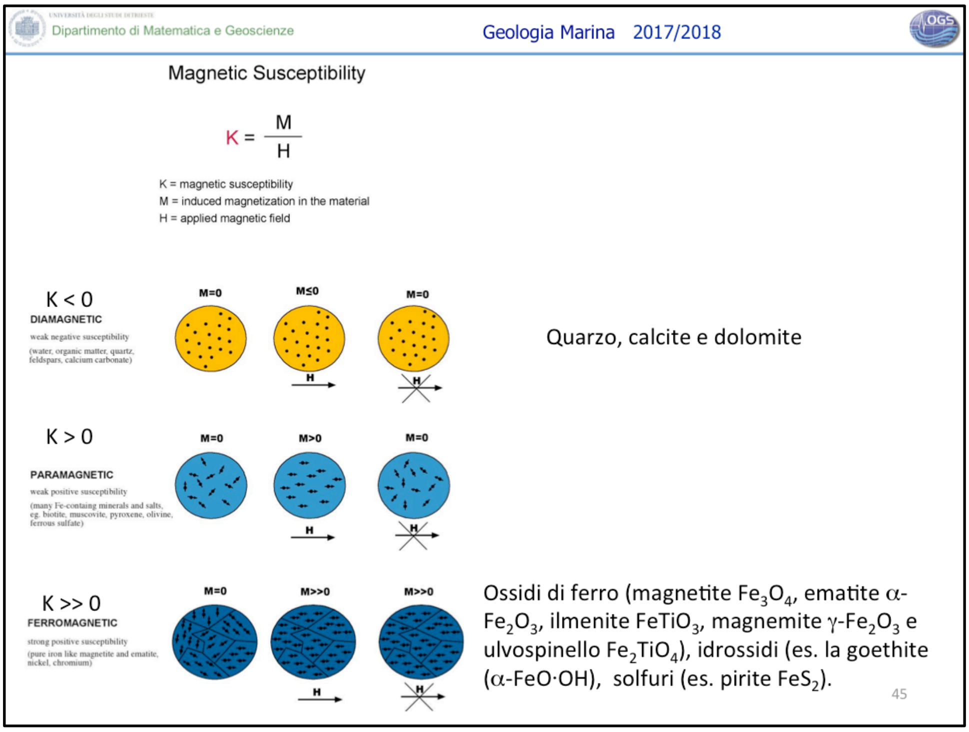

Dorsale medio-oceanica
Sedimenti
Basalti
Gabbri
Crosta
Risalita di magmi
Mantello
Correnti convettive





Oceanic plates thin crust (MOHO at about 6 km)
Oceanic plates thicken as they cool (boundary between convecting and non-convecting mantle deepens)
Colder (older) plates sink (subduction)
Examples: Pacific, Nazca, Cocos, Phillipine
On-land examples of ocean crust: ophiolites
- Oceanic crust emplaced upon continents
- Thickness of 8-10 km
- Ophiolite stratigraphy same worldwide => same processes operate worldwide

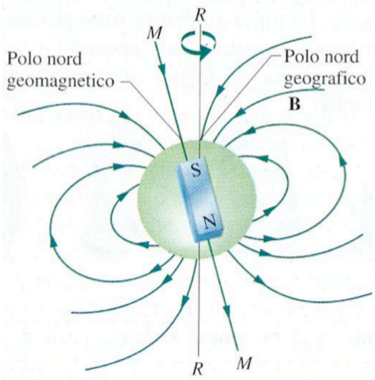
The compositions of materials erupted at the mid-ocean ridges are tholeiitic basalts called **m**id-**o**cean **r**idge **b**asalts (MORB).

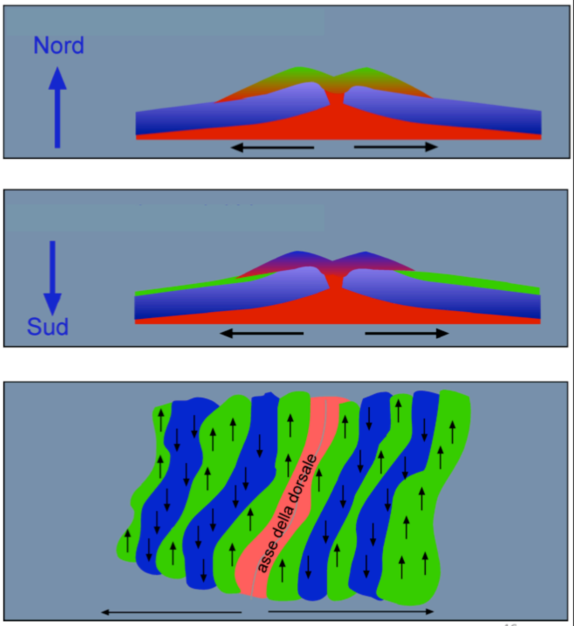


Le lave eruttate lungo le dorsali medio oceanici sono basalti thoelitici indicati anche con il termine di MORB (Mid-Ocean Ridge Basalt), contenenti tra i vari minerali anche ossidi di ferro.
Gli ossidi di ferro si magnetizzano secondo il campo magnetico terrestre, e dalla misura di tale magnetizzazione si può dedurre la direzione del campo magnetico terrestre al momento della solidificazione del magma.
La suscettivita' magnetica (k) e' il parametro significativo della capacita' del materiale di magnetizzarsi e di creare un disturbo nel campo inducente:
$k = M/H$
Dove k è la suscettività magnetica, M è l'intenstià di magnetizzazione e H è il campo magnetico esterno.
I materiali possono essere:
diamagnetici, con $k < 0$
paramagnetici , con $k > 0$
ferromagnetici, con $k >> 0$
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 (Fe_3O_4), ematite(α-Fe_2O_3), ilmenite ($FeTiO_3$), magnemite (γ-Fe_2O_3)e ulvospinello (Fe_2TiO_4), gli idrossidi come la goethite ((α-$FeO \cdot OH$), i solfuri come la pirite (FeS_2).

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

Present magnetic filed

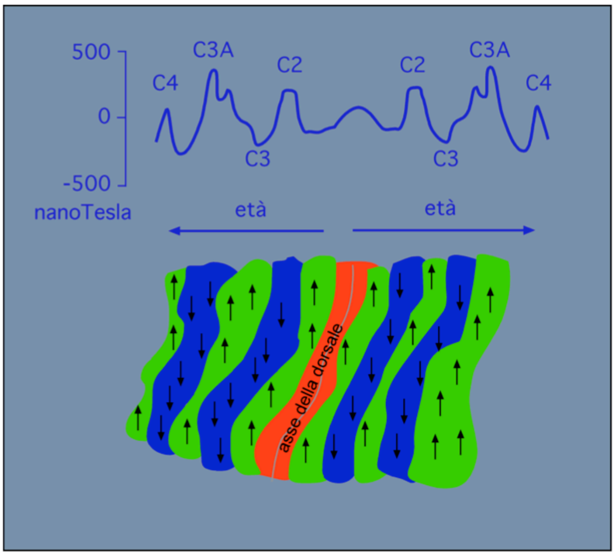




Instruments to measured the earth magnetic field in the ocean:

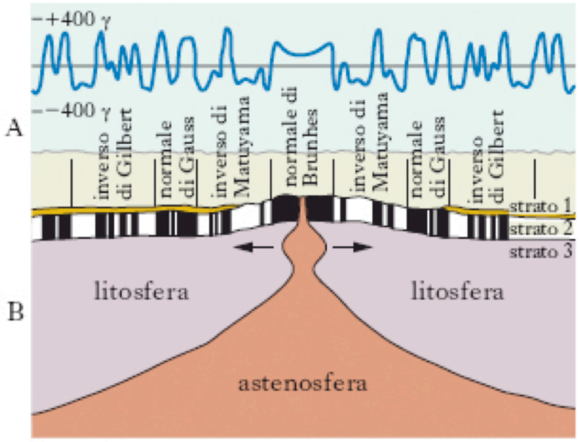
- magnetometer

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

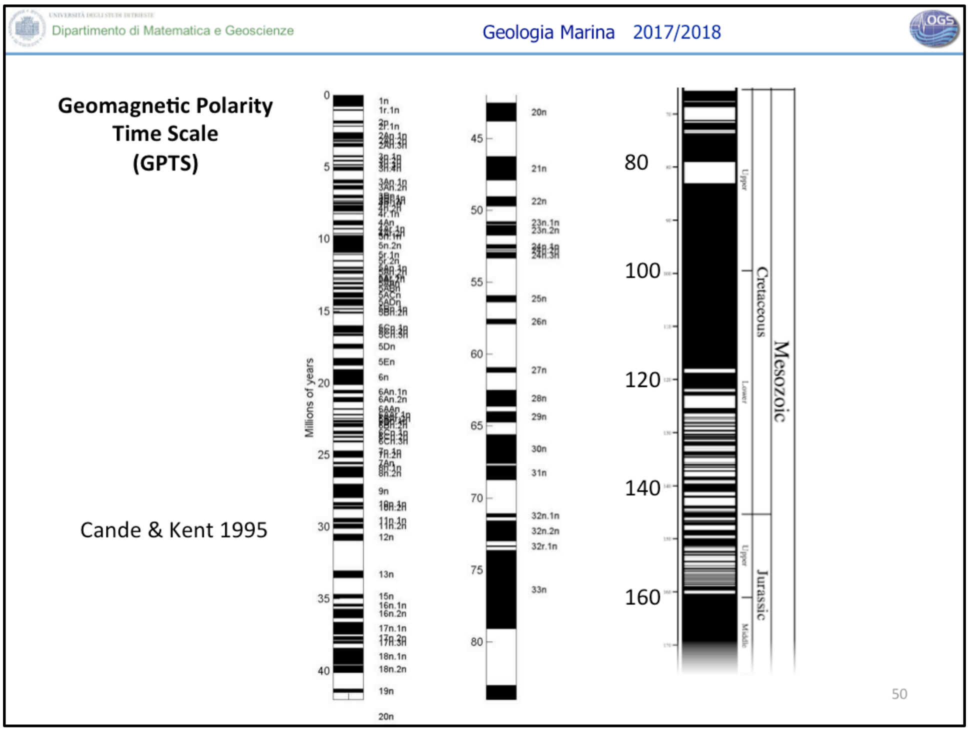


The magnetic anomalies are numbered as C*n* (Chrone *n*) or A*n* (Anomaly *n*)
(C1 or A1 is the youngest and C23 or A23 is older).

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 and una anomalia magnetica, numerata in modo convenzionale come C1, C2, ecc…. dove C sta per *chron*.



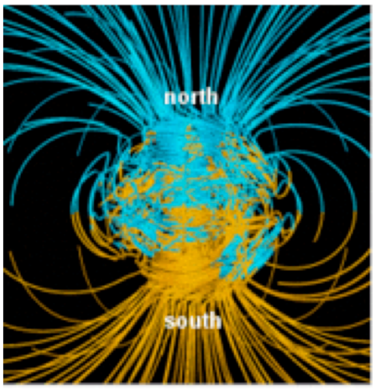
1 - sedimenti non magnetici
2 - colate e strato di basalto a cuscini (altamente magnetico: in nero, polarita normale; in bianco, polarita inversa)
3 - crosta oceanica a gabbri (debolmente magnetica)



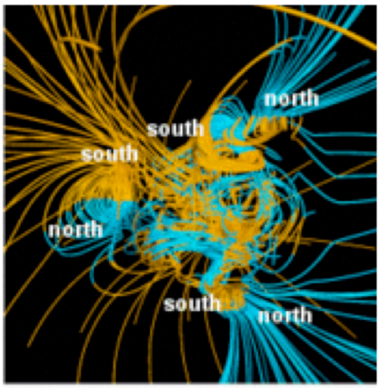
http://deeptow.whoi.edu/gpts.html

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.

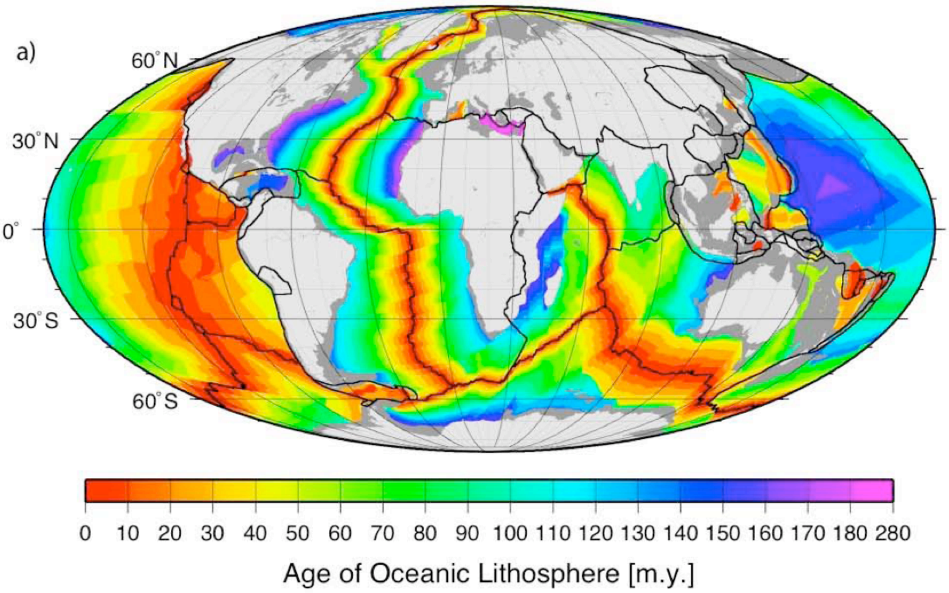


between reversals



during a reversal

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



From Muller et al., 2008

Stato termico dei ridge e piane abissali

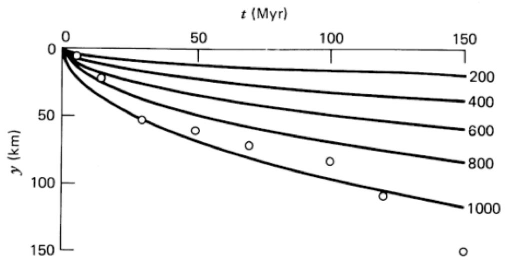
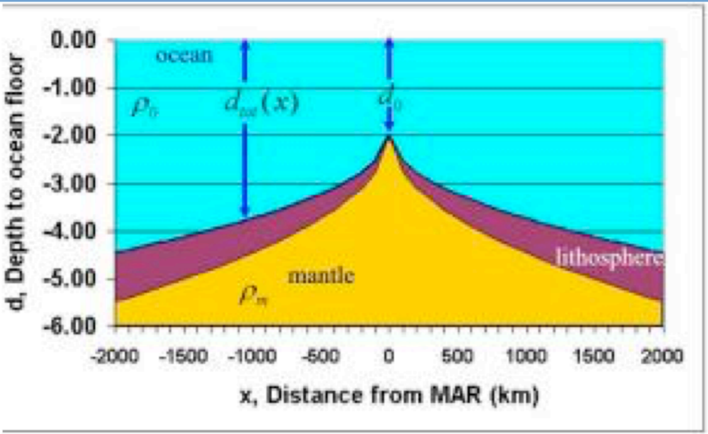
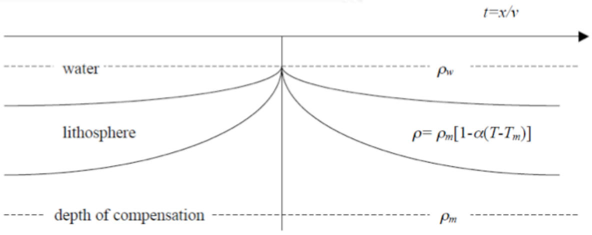


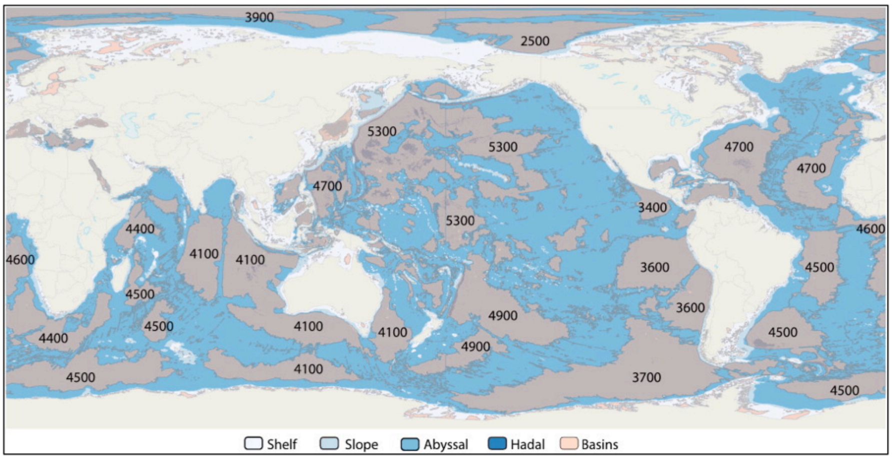
Figure 4-24 The solid lines are isotherms, $T - T_s$ (°K), in the oceanic lithosphere from Equation (4-125). The data points are the thicknesses of the oceanic lithosphere in the Pacific determined from studies of Rayleigh wave dispersion data. (From A. R. Leeds, L. Knopoff, and E. G. Kausel, Variations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

Cooling of oceanic crust





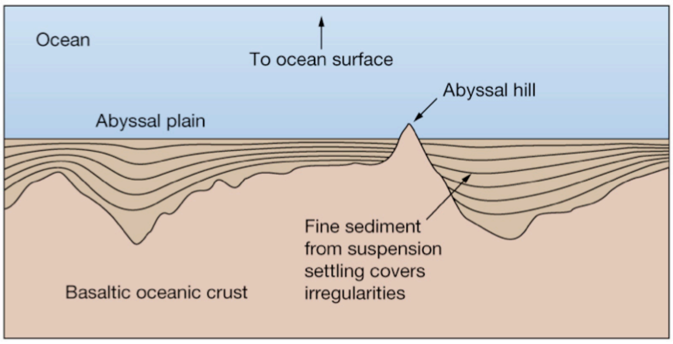
Basins in the oceans



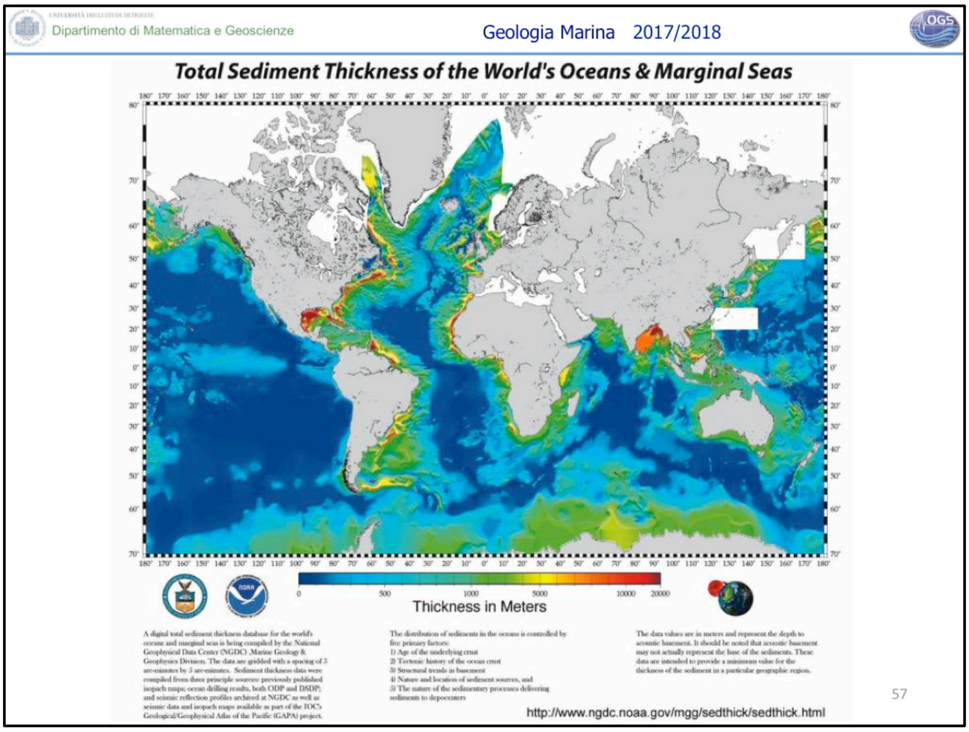
The numbers indicate contour depths of major ocean basins based on the most shallow, closed, bathymetric contour that defines the basin outline, illustrating that the deepest basins are located in the northwest Pacific.

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

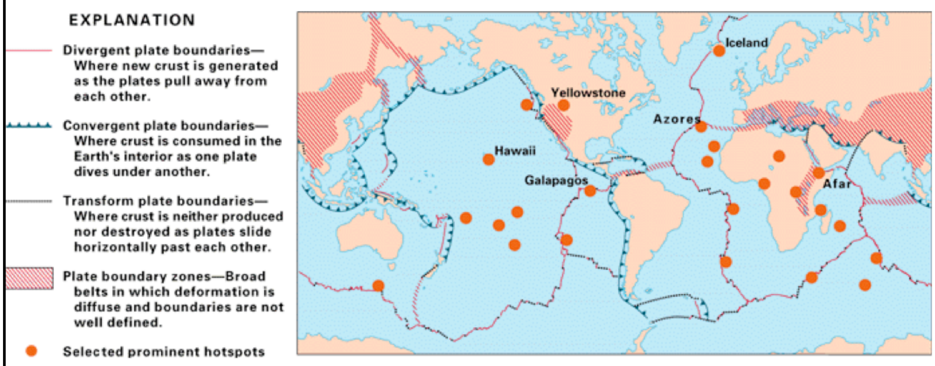
Abyssal Plain



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.

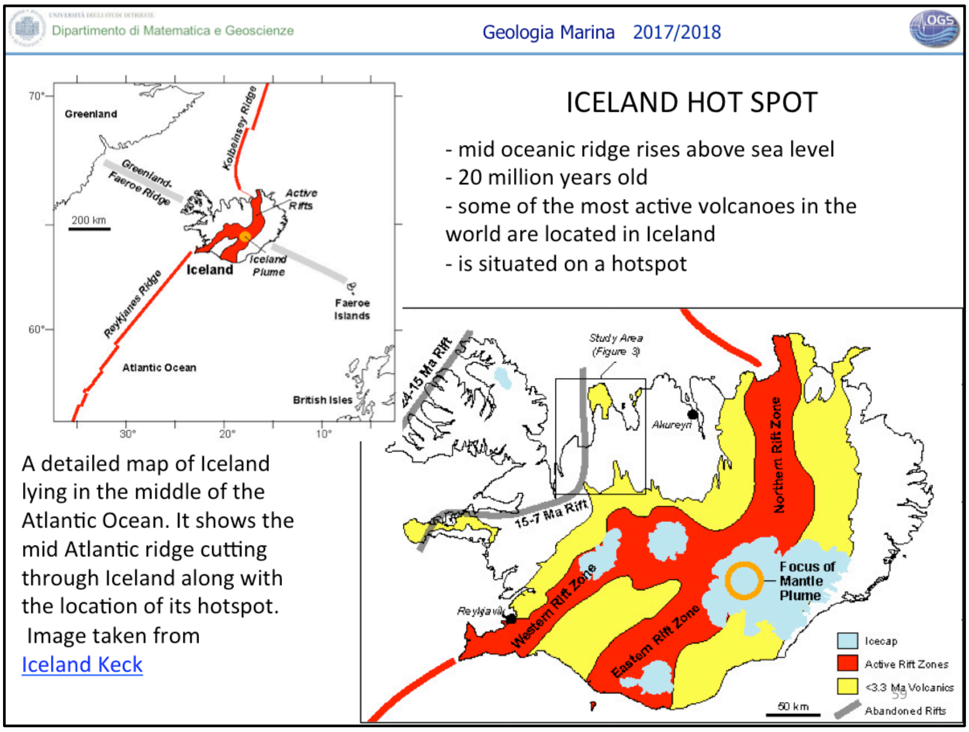

Dipartimento di Matematica e Geoscienze
Geologia Marina 2017/2018
OGS
Total Sediment Thickness of the World's Oceans & Marginal Seas
0
500
1000
5000
10000
20000
Thickness in Meters
A digital total sediment thickness database for the world's oceans and marginal seas is being compiled by the National Geophysical Data Center (NGDC) ,Marine Geology & Geophysics Division. The data are gridded with a spacing of 5 arc-minutes by 5 arc-minutes. Sediment thickness data were compiled from three principle sources: previously published isopach maps; ocean drilling results, both ODP and DSDP; and seismic reflection profiles archived at NGDC as well as seismic data and isopach maps available as part of the IOC's Geological/Geophysical Atlas of the Pacific (GAPA) project.
The distribution of sediments in the oceans is controlled by five primary factors:
1) Age of the underlying crust
2) Tectonic history of the ocean crust
3) Structural trends in basement
4) Nature and location of sediment sources, and
5) The nature of the sedimentary processes delivering sediments to depocenters
The data values are in meters and represent the 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
57

HOT SPOT



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.

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 Kerguellen Plateau (in the southern Indian Ocean).

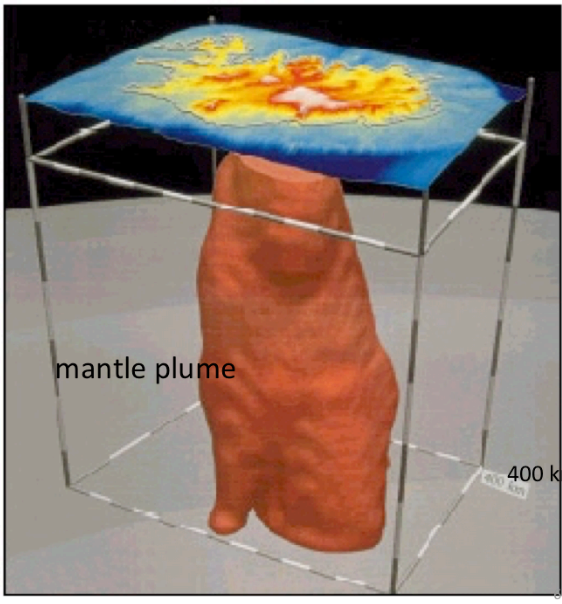


An underwater mountain chain known as the mid ocean ridge or the mid Atlantic ridge circles the globe and is one of the largest mountain ranges on Earth. The mid Atlantic ridge consists of underwater seamounts, volcanoes, and spreading ridges. However, at one location in the Atlantic, the mid ocean ridge 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 2017/2018

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).

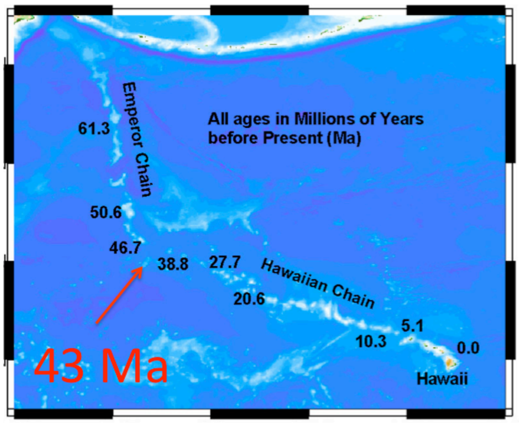


http://www.abc.net.au/science/news/img/iceplume.htm

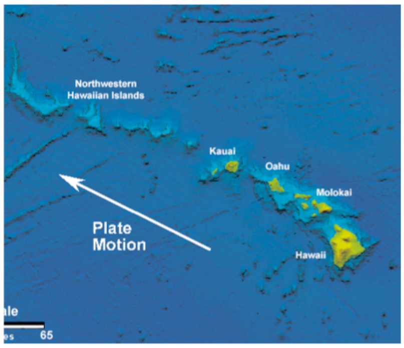
The column of the Iceland plume, shown to a depth of 400 km. The plume head is already dispersed from the plume by buoyant flow into and along the rift. The starting plume head, hundreds of degrees hotter than normal mantle, spreads sideways, incorporates surrounding mantle, and buoyantly uplifts a region 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 Earths 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.



HAWAII HOT SPOT



The Hawaiian Ridge-Emperor Seamounts chain:
- extends some 6,000 km,
- composed by 80 volcanoes
- started 70 Ma ago, and sharp bend indicates change of motion at 43 Ma, possibly due to India-Asia collision
- is stationary

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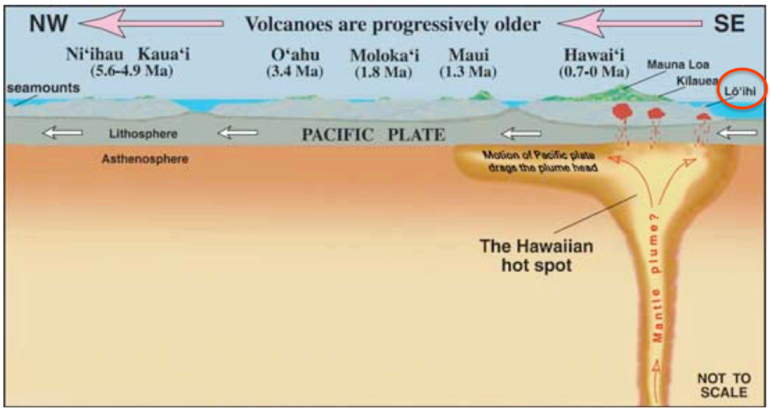
Over the past 70 million years, the combined processes of magma formation, volcano eruption and growth, and continued movement of the Pacific Plate over the stationary Hawaiian "hot-spot" have left a long trail of volcanoes across the Pacific Ocean floor. The Hawaiian Ridge-Emperor Seamounts chain extends 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.

HAWAII HOT SPOT



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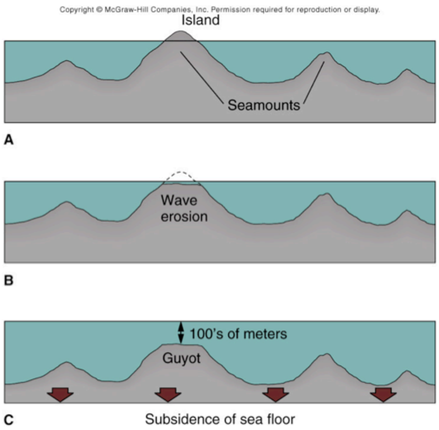
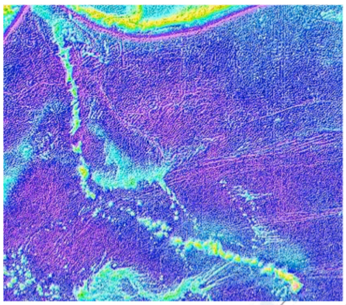
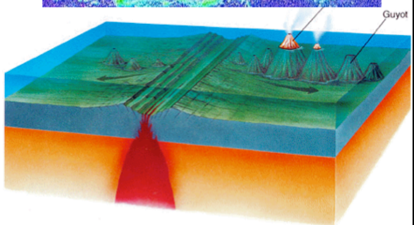
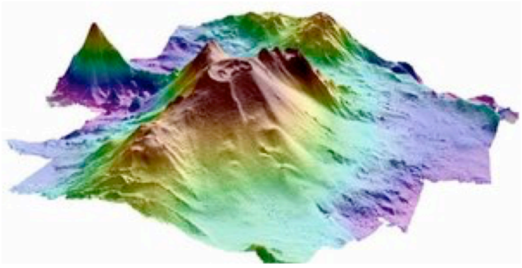
Morphological Features
Seamounts, volcanic island and guyots



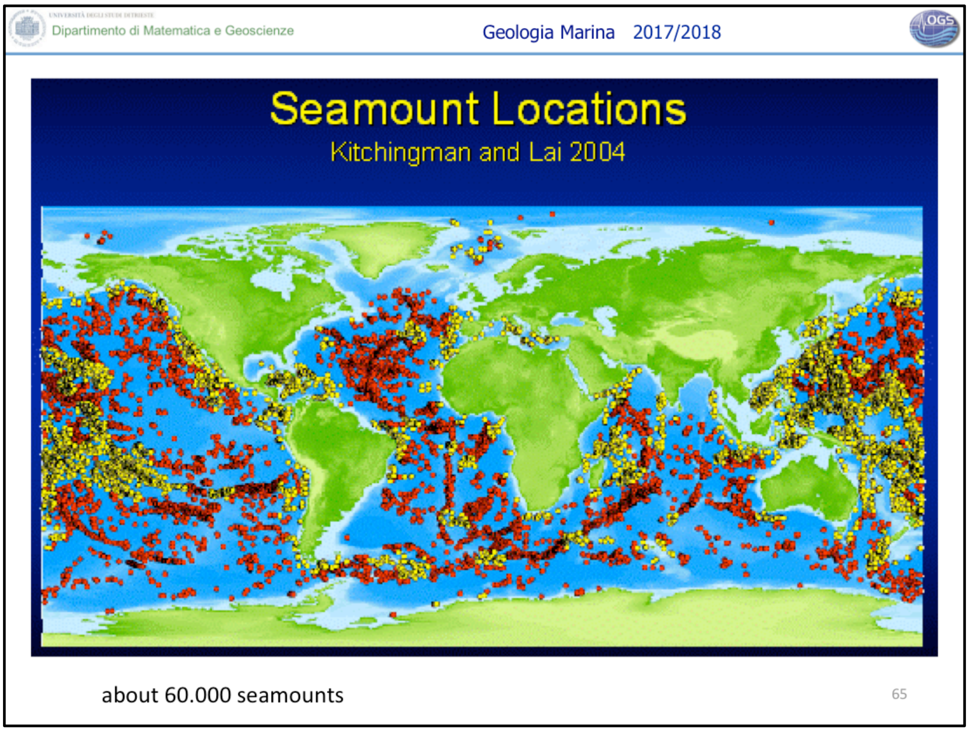




SEAMOUNT



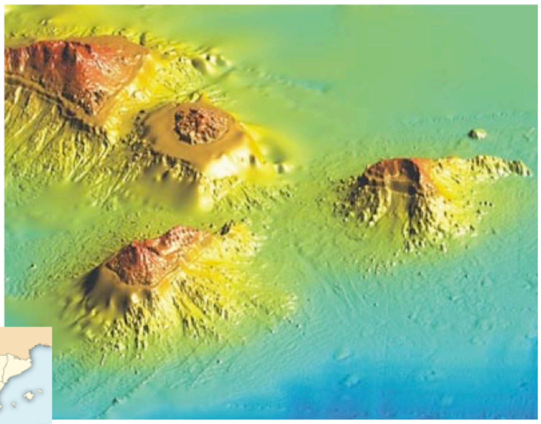
Seamounts: undersea mountains rising from the bottom of the sea with a minimum elevation of 1,000 meters, that do not break the water's surface.
Seamounts are usually isolated and cone-shaped, are mostly volcanic and therefore found on oceanic crust, formed near mid-oceanic ridges, hotspot and island-arc 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.



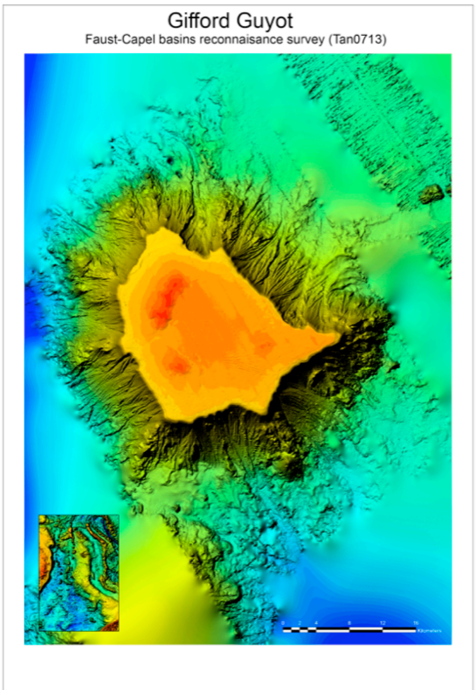
Kitchingman, A., Lai, S., 2004.
Inferences on potential seamount locations from mid-resolution bathymetric data.
Fisheries Centre Research Reports 12 (5), 7–12.

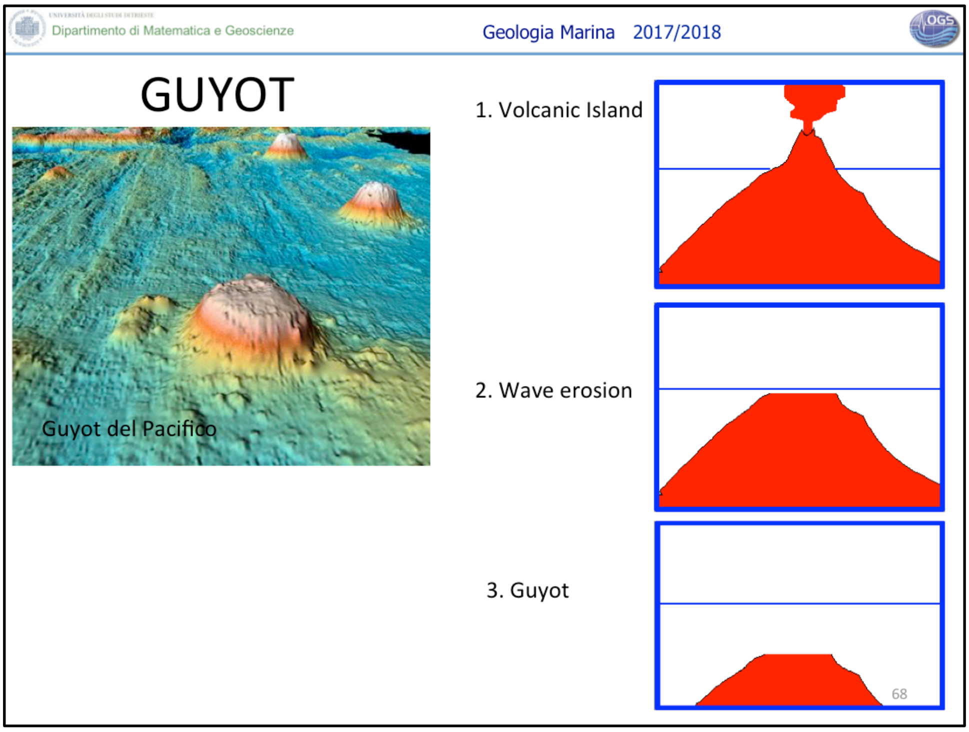
http://yale.databasin.org/datasets/1c6af28887364008969f94c7e9df796e

Volcanic Island



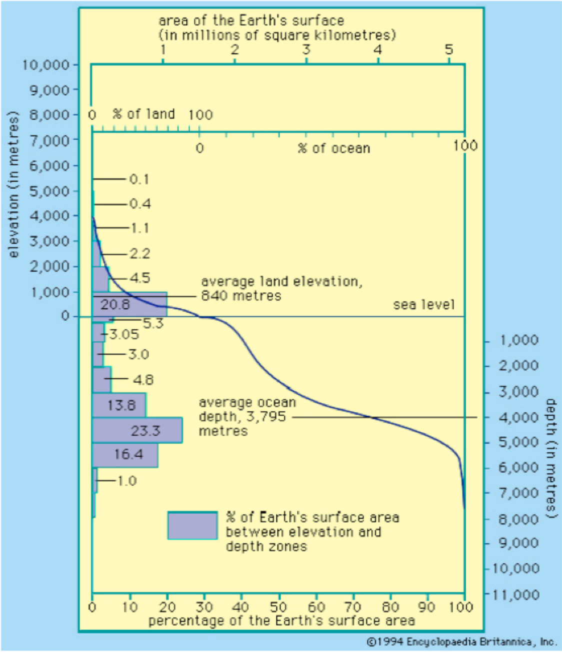
Isole canarie


Gifford Guyot
Faust-Capel basins reconnaisance survey (Tan0713)

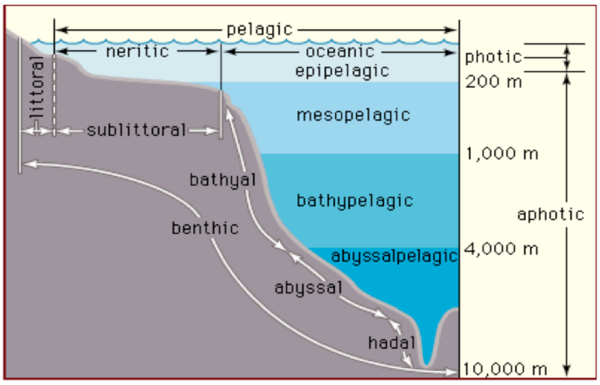


Seamounts and **Guyots** are volcanoes that have built up from the ocean floor, sometimes to sea level or above. Guyots are seamounts that have built above sea level. Erosion by waves destroyed the top of the seamount resulting in a flattened shape. Due to the movement of the ocean floor away from oceanic 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.

The classification


area of the Earth's surface
(in millions of square kilometres)
1 2 3 4 5
elevation (in metres)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0 % of land 100
0 % of ocean 100
0.1
0.4
1.1
2.2
4.5
20.8
5.3
3.05
3.0
4.8
13.8
23.3
16.4
1.0
average land elevation, 840 metres
sea level
average ocean depth, 3,795 metres
depth (in metres)
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
% of Earth's surface area between elevation and depth zones
0 10 20 30 40 50 60 70 80 90 100
percentage of the Earth's surface area
©1994 Encyclopaedia Britannica, Inc.

Classification of the Marine Zones



Temperature

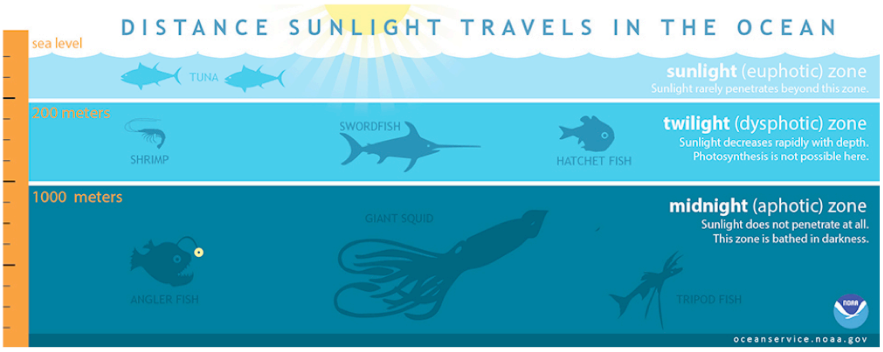
T= 12° C
at about 700-1000 m depth
in the tropic

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



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

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).

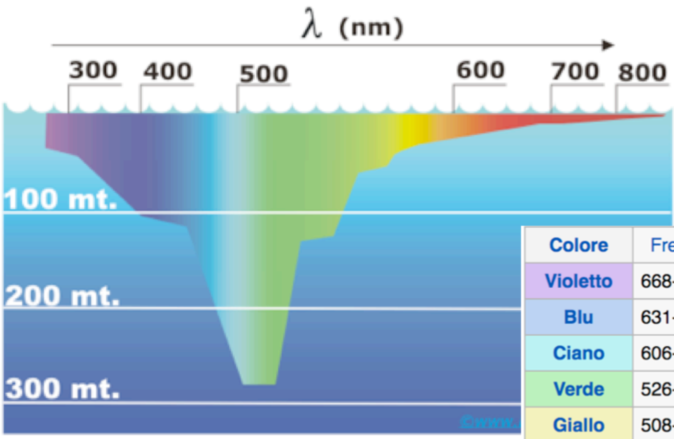
The ocean is divided into three zones based on depth and light level. The upper 200 meters (656 feet) of the ocean is called the euphotic, or "sunlight," zone. This zone contains the vast majority of commercial fisheries and is home to many protected marine mammals and sea turtles.

Only a small amount of light penetrates beyond this depth.

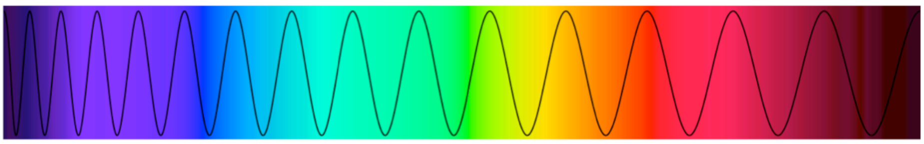
The zone between 200 meters (656 feet) and 1,000 meters (3,280 feet) is usually referred to as the “twilight” zone, but is officially the dysphotic zone. In this zone, the intensity of light rapidly dissipates as depth increases. Such a miniscule amount of light penetrates beyond a depth of 200 meters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

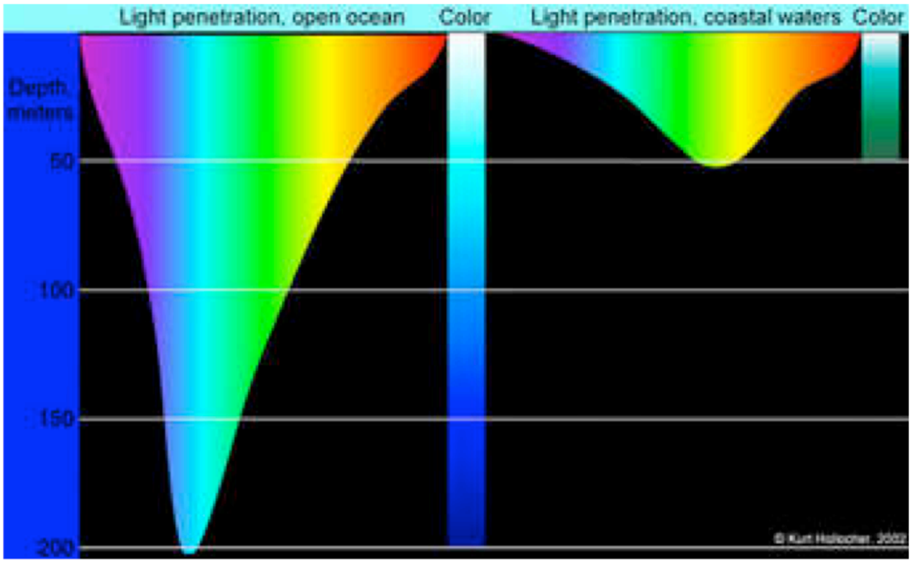
The aphotic, or “midnight,” zone exists in depths below 1,000 meters (3,280 feet). Sunlight does not penetrate to these depths and the zone is bathed in darkness.

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



Colore	Frequenza	Lunghezza d'onda
Violetto	668-789 THz	380–450 nm
Blu	631-668 THz	450–475 nm
Ciano	606-631 THz	476-495 nm
Verde	526-606 THz	495–570 nm
Giallo	508-526 THz	570–590 nm
Arancione	484-508 THz	590–620 nm
Rosso	400-484 THz	620–750 nm




Light penetration, open ocean
Color
Light penetration, coastal waters
Color
Depth, meters
50
100
150
200
© Kurt Hollocher, 2002

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 meterorites 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 oxigen 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.

These cycles were well established about 1 billion years ago.
Since then the chemically composition of the oceans has remained constant.

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

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

Gli oceani nel passato

Map courtesy of CR Scotese, PALEOMAP Project

L'Oceano Tetide (o semplicemente Tetide) era un braccio oceanico disposto in senso Est-Ovest che, nei tempi geologici compresi tra il Permiano ed il Miocene separava l'Africa settentrionale dall'Europa e dall'Asia.
L'apertura dell'Oceano Tetide avvenne circa 250 milioni di anni fa, tra il Permiano ed il Triassico inferiore e portò alla separazione tra un blocco continentale settentrionale (Laurasia) ed uno meridionale (Gondwana). L'allontanamento delle due parti del Pangea proseguì fino al Giurassico, quando i movimenti delle placche tettoniche si invertirono ed iniziò una contrazione dell'Oceano Tetide stesso.
Il movimento dell'Africa era solidale con quello della placca adriatica, che forse ne rappresentava una parte settentrionale. La collisione della placca adriatica con il continente europeo chiuse la Tetide nella regione centrale del Mediterraneo, dando origine alla catena montuosa delle Alpi. Altre microplacche intrappolate tra le due maggiori (africana ed europea) contribuirono a formare altre catene montuose europee orientate generalmente in direzione Est-Ovest, mentre nella zona mediorientale la placca arabica collideva con l'Asia. A completare la chiusura della Tetide, l'India, staccatasi dal continente meridionale di Gondwana durante il Giurassico, si scontrò con l'Asia dando origine alla catena himalayana.

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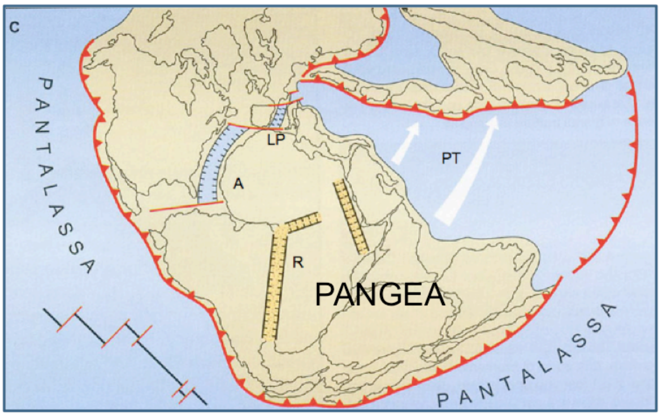
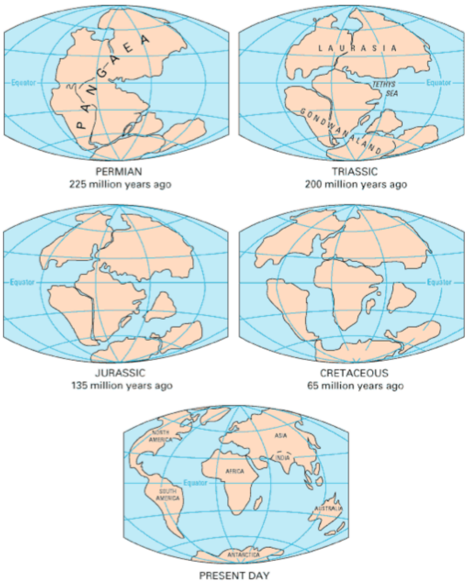
ATLANTIC OCEAN: initial stage



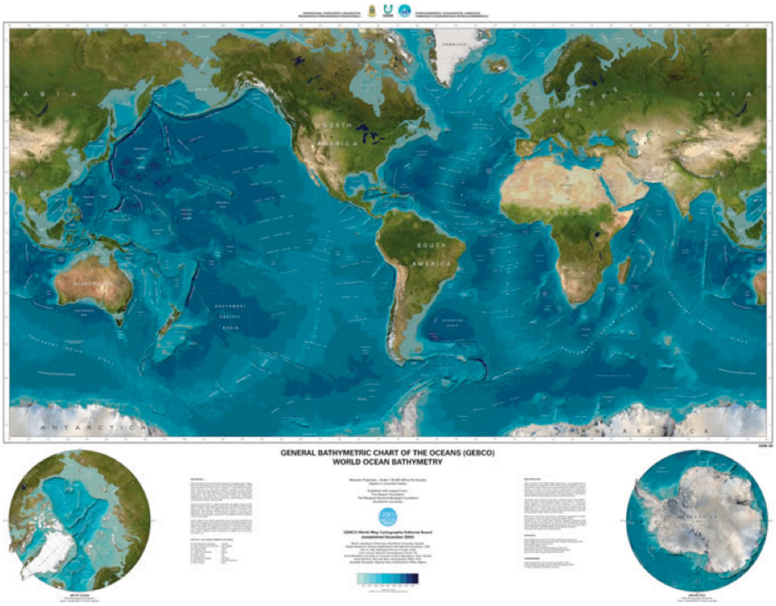
Fragmentation of the Pangea (Late Giurassic):

- 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



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



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.

Functions

The principal work undertaken by the IHO is:

•To bring about a close and permanent association between national hydrographic offices.

•To study matters relating to hydrography and allied sciences and techniques.

•To further the exchange of nautical charts and documents between hydrographic officers of member governments.

•To tender guidance and advice upon request, in particular to countries engaged in setting up or expanding their hydrographic service.

•To encourage coordination of hydrographic surveys with relevant oceanographic activities.

•To extend and facilitate the application of oceanographic knowledge for the benefit of navigators.

•To cooperate with international organizations and scientific institutions which have related objectives.

•The IHO develops hydrographic and nautical charting standards to be agreed upon by its Member States. All Member States then follow those standards in their surveys, nautical charts, and publications. The almost universal use of the standards means that the products and services from the world's hydrographic and oceanographic offices are increasingly consistent and recognisable for all seafarers and for other users. Much has been done in the field of standardisation since the Bureau (now the IHO) was founded.

Web sites

http://www.oceanleadership.org/

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

Woods Hole Oceanographic Institution
http://www.whoi.edu/main/ocean-topics

NOAA National Geophysical Data Center
http://www.ngdc.noaa.gov

Ocean gravity
http://topex.ucsd.edu/grav_outreach/index.html#natlanticano

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