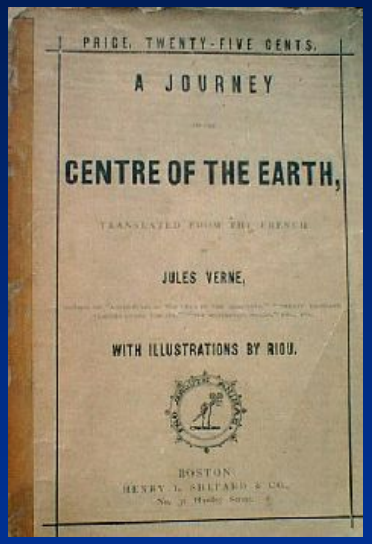
Geochemical evolution of the Earth mantel and crust

Part 1: Mantle geochemistry

Mantel geochemistry

Snæfellsjökull, Iceland



Stromboli, Sicily

Recommended reading

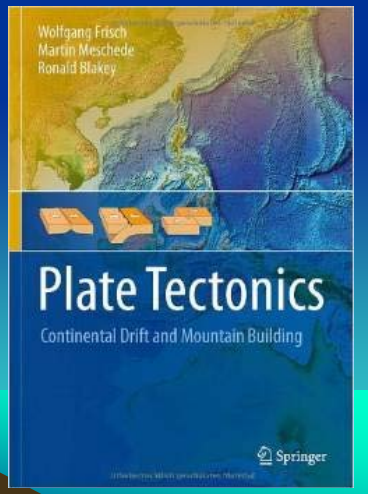
Allègre, J.C. (2008) Isotope Geology, Cambridge University Press, 512.

Rollison, H. (2007) Early Earth Systems - A Geochemical Approach, Blackwell Plublishing, 285

White, M.W. (2013) Geochemistry, Wiley-Blackwell, 637

White, M.W. (2015) Isotope Geochemistry, Whiley-Blackwell, 496

Wilson, M. (1991) Igneous Petrogenesis – A Global Tectonic Approach, Harper Collins, 466



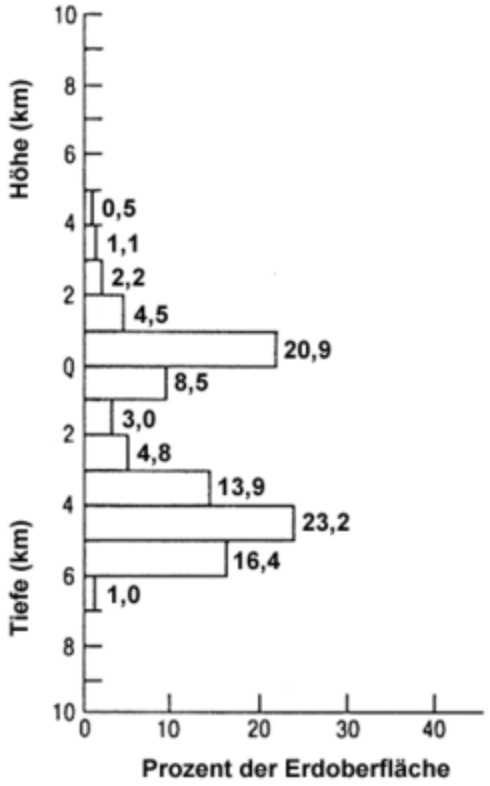
Overview mantle geochemistry

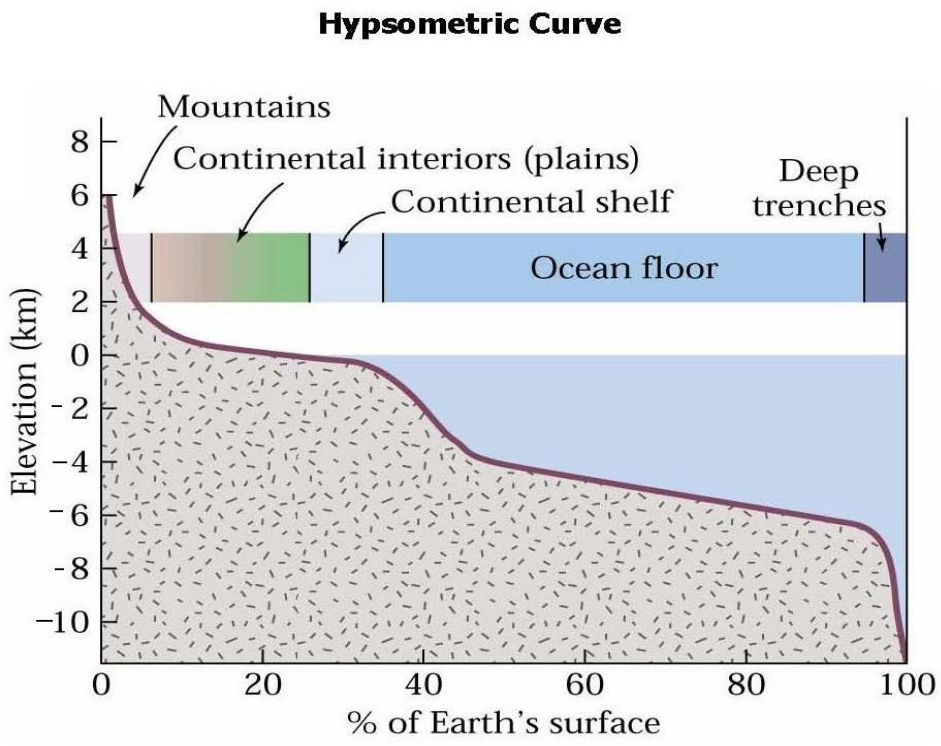
- Oceanography
- Plate tectonics
- Mid-ocean ridge systems
- Oceanic crust
- The Earth interior
- Magma formation in the mantle
- Basalt types
- MORB petrogenesis
- Ocean intraplate volcanism
- Mantle reservoirs

Not all lectures deal with geochemistry and isotope geochemistry!

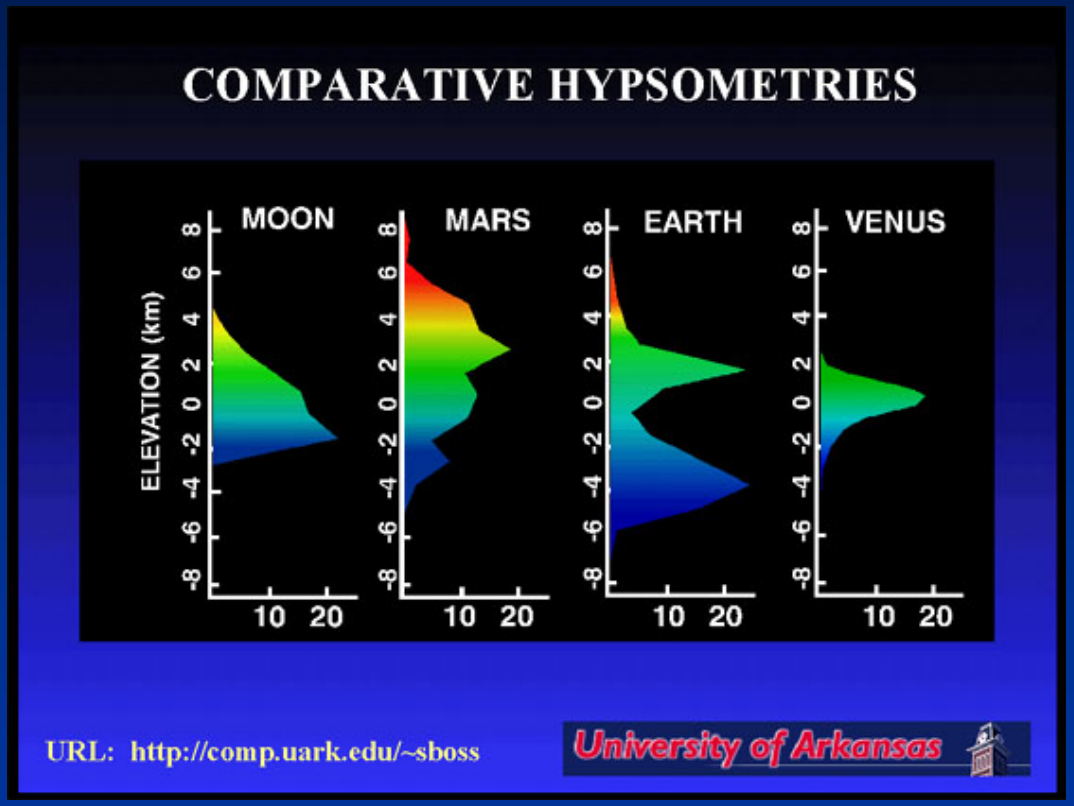
Hypsometric curve

HYPSOMETRIC CURVE of Earth is unique in that it is BIMODAL



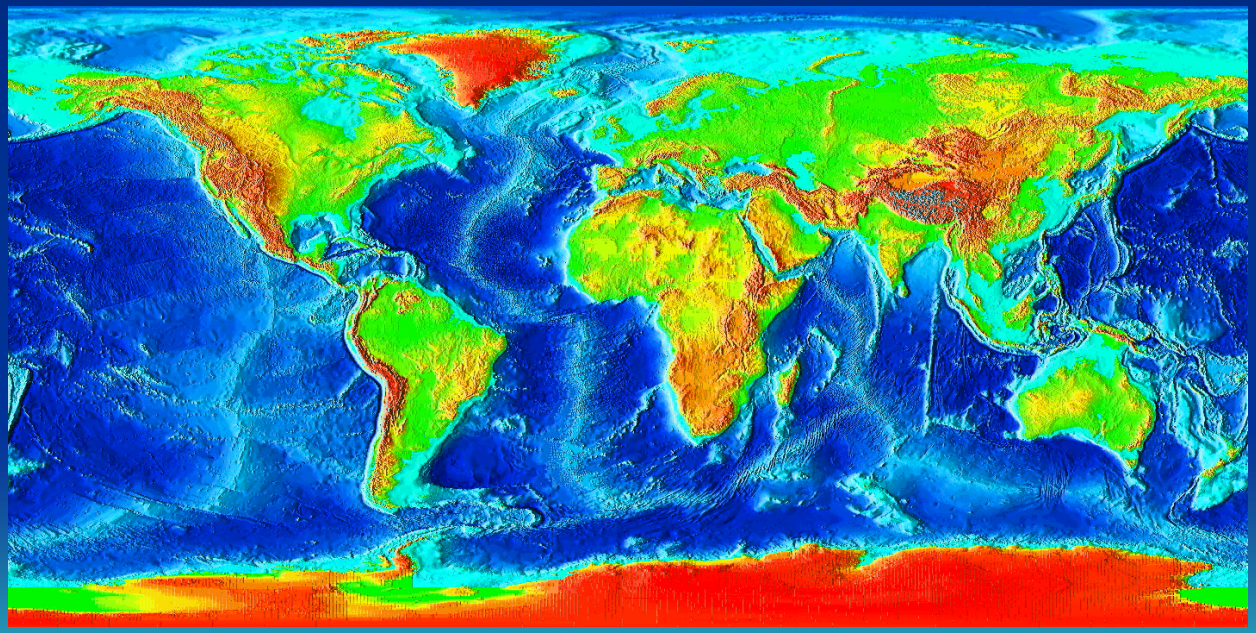


Hypsometric curve



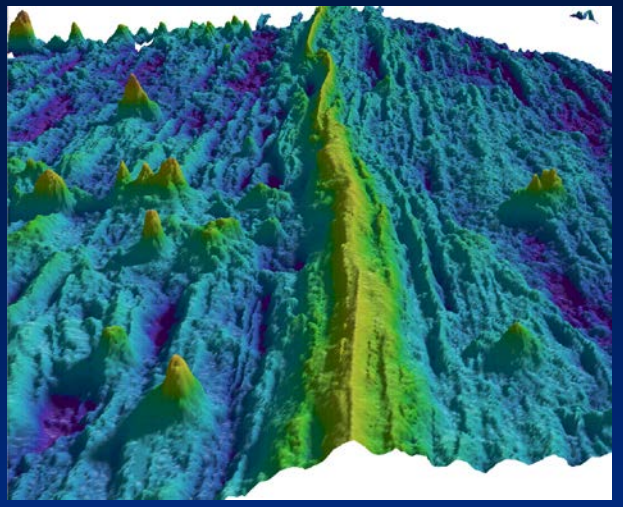
The Oceans

Ocean	Surface Area (million km^2)	Water Volume (million km^3)	Avg. Depth (km)	Max. Depth (km)
Pacific	180	700	4.0	11.0
Atlantic	93	335	3.6	9.2
Indian	77	285	3.7	7.5
Arctic	15	15	1.1	5.2



Ocean crust

Covers about 70% of the Earth's surface

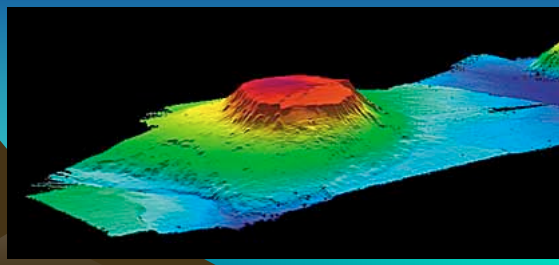


Abyssal plains
Flat, deep ocean floor
Depth may be 3 - 5 km
Sediments bury topography of oceanic crust

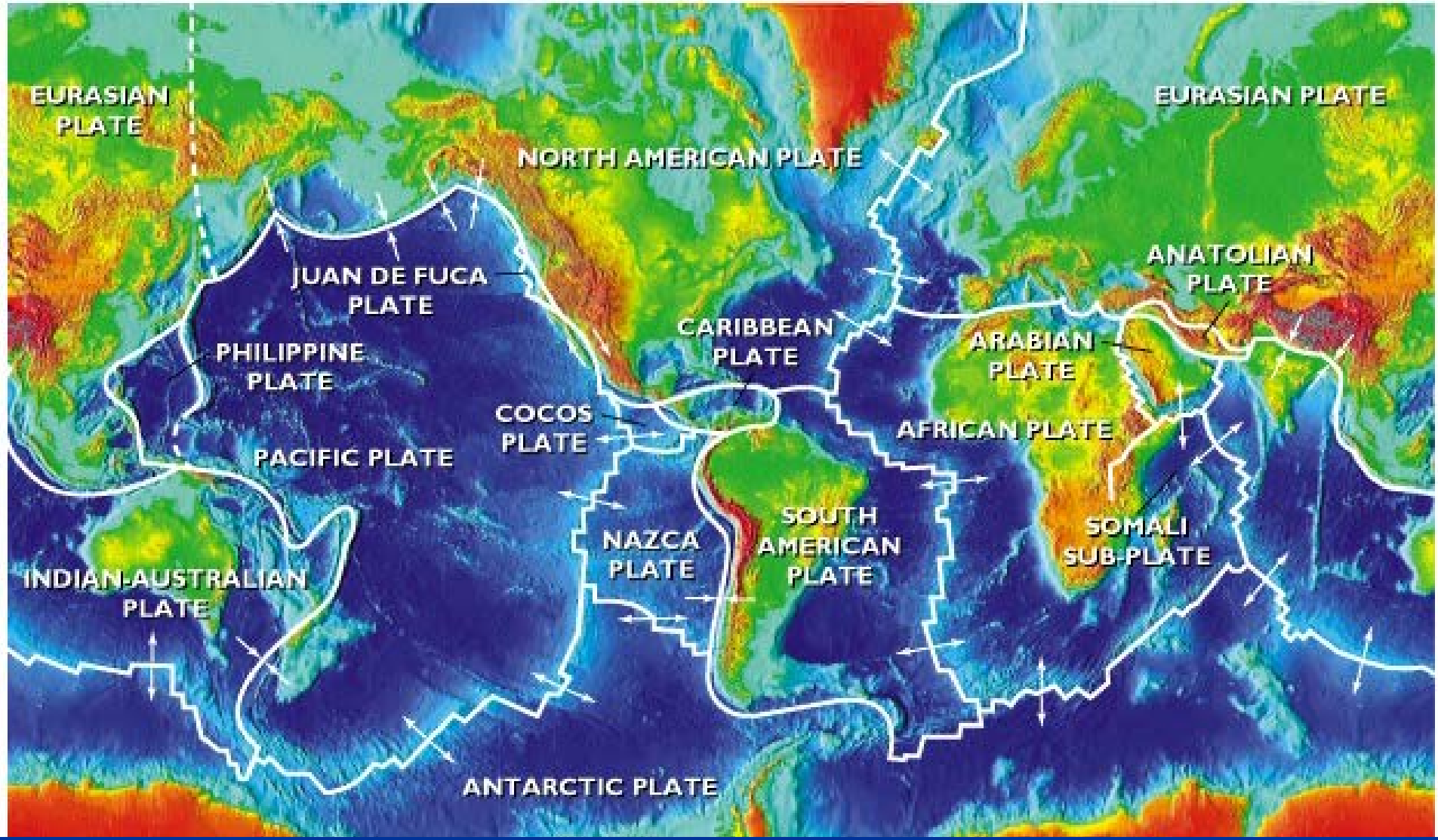
Deep sea trenches
The deepest part of the oceans
May exceed 10.000 m deep
Mariana trench and Tonga trench in the Pacific Ocean (subduction zones) - more than 11.000 m

Mid-ocean ridges
continuous range of undersea mountains winding through 60.000 km of the world’s oceans

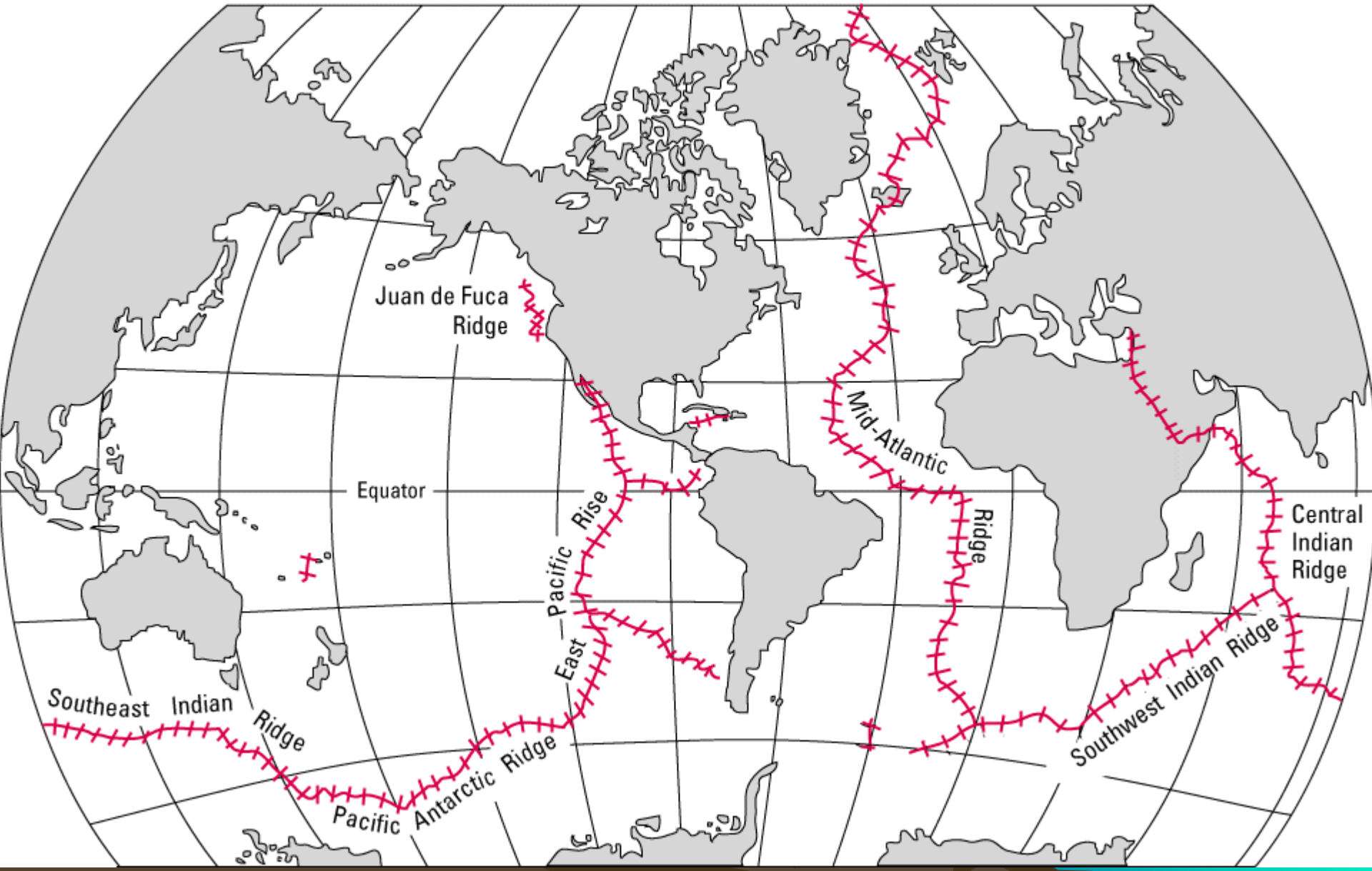
Seamounts
Undersea volcanic peaks which formed along mid-ocean ridges or over hot spots
May be eroded flat on top and called *guyots (tablemount)*
May be ringed by coral reefs called *atolls*



~14 tectonic plates today



Mid-ocean ridge systems



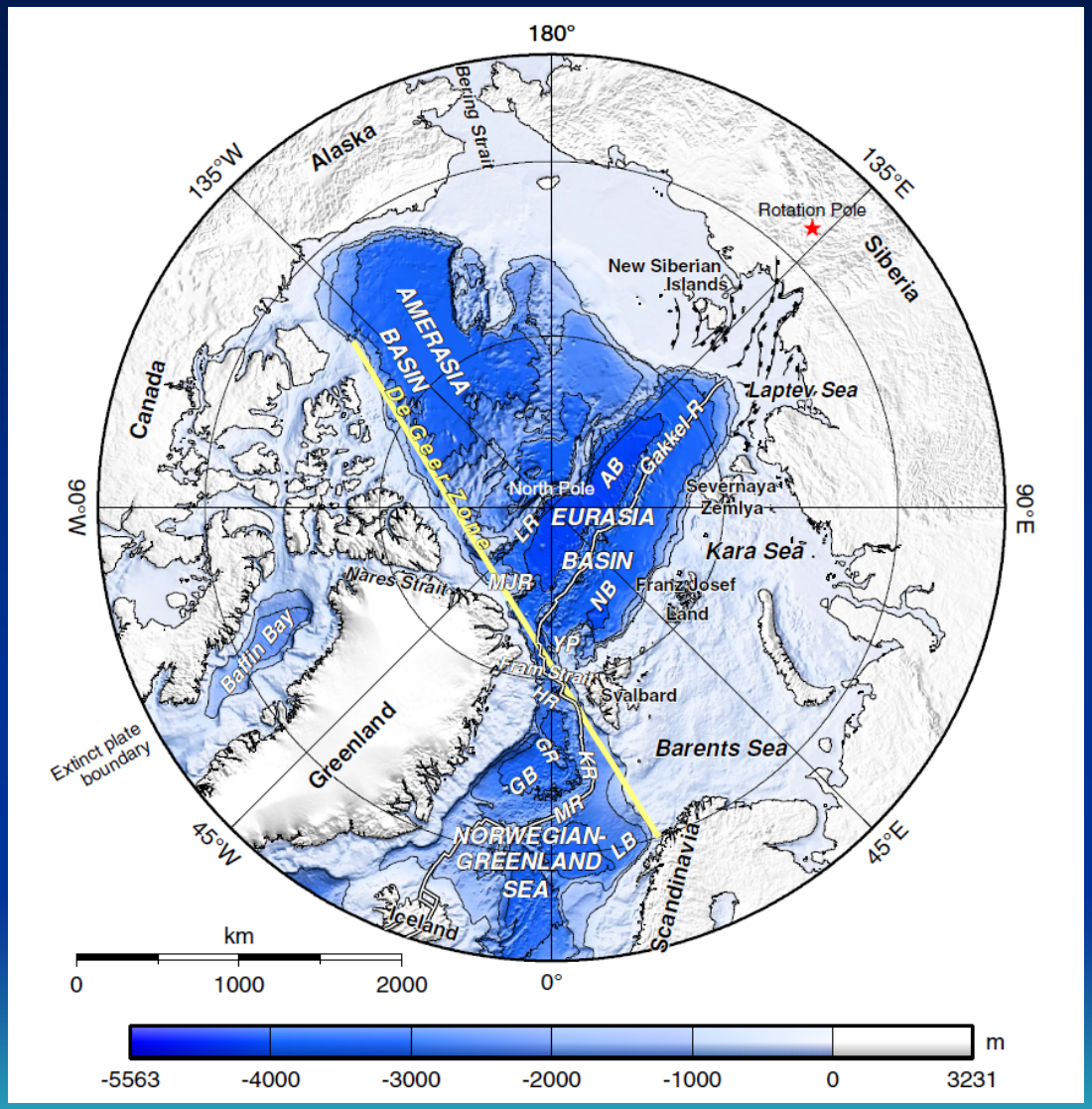
Arctic-Atlantic mid-ocean ridge systems

Mid Arctic ridge:

- Gakkel Ridge (1,800 kilometers from Greenland to Siberia)

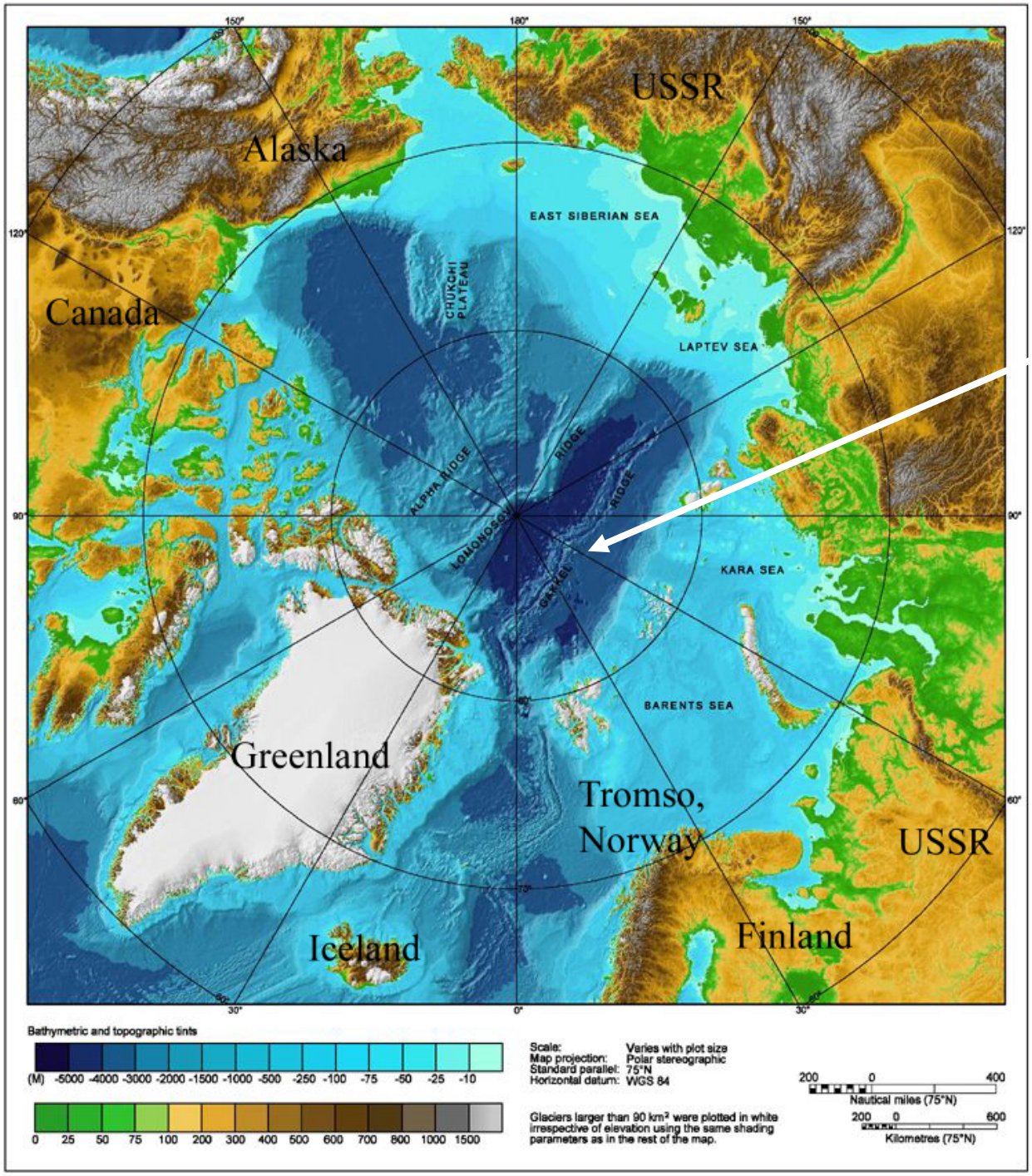
Mid Atlantic ridge

- Molloy Ridge (west of northern Svalbard)
- Vestnesa Ridge (west of Svalbard)
- Knipovich Ridge (~ 73.5°N, 8°E to Fram Strait west of Svalbard)
- Mohns/Jan Mayen Ridge ~ 73.5°N, 8°E)
- Kolbeinsey Ridge (North of Iceland to Jan Mayen Island)
- Reykjanes Ridge (South of Iceland)
- Central Mid-Atlantic Ridge (south of 53°N)
- Azores-Gibraltar Ridge
- South-Central Mid Atlantic Ridge (8°N to the Azores)
- Bouvet triple junction



- HR Hovgård or Vestnesa Ridge
- KR Knipovich Ridge
- MR Mohn Ridge
- Kolbeinsey Ridge
- Jan Mayen Island
- Reykjanes Ridge

Ultraslow: Gakkel ridge

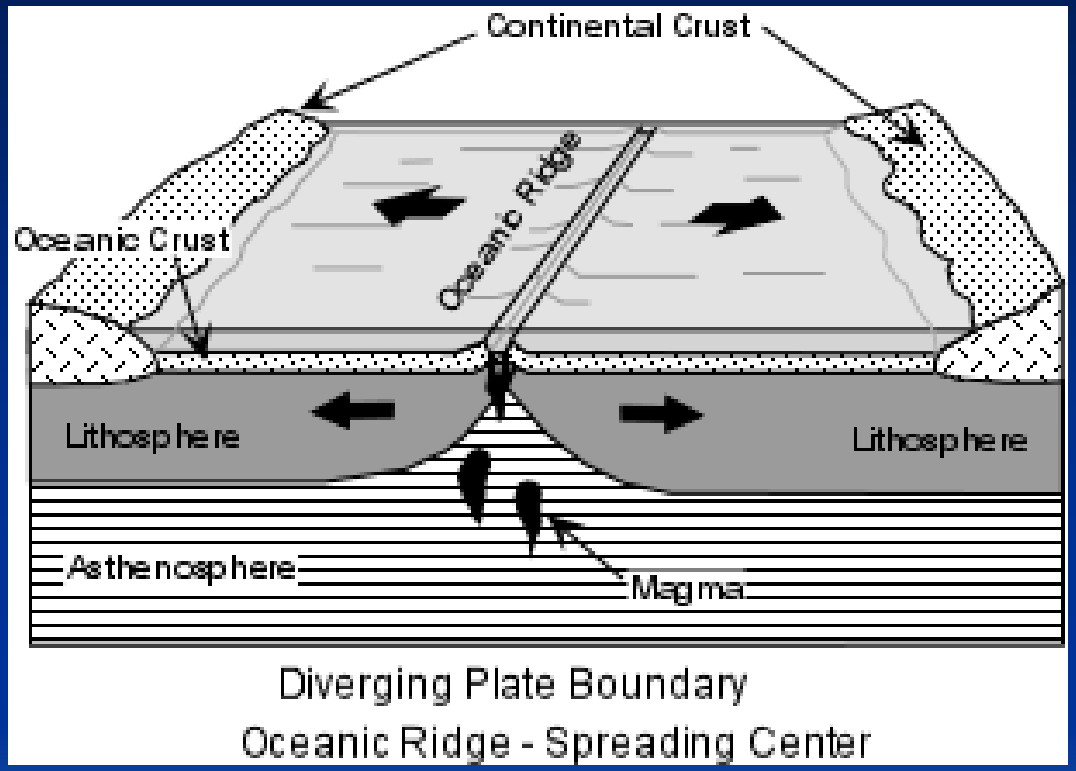


spreading rates only
6 - 13 mm/a

Mid-ocean ridge systems

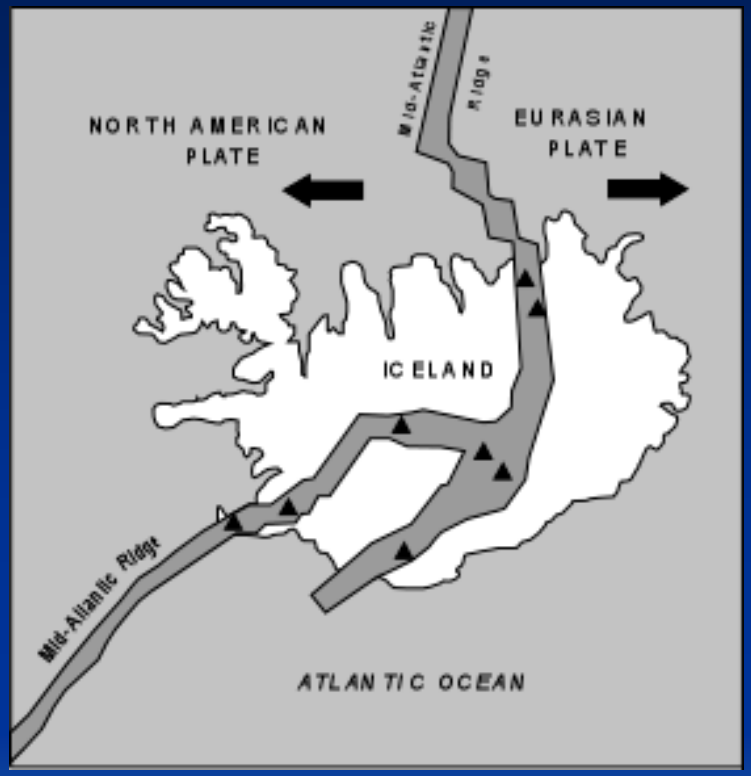
- ~ 60,000 km long mountain chain
- interface between lithosphere, hydrosphere, and biosphere
- responsible for ~ 90% of the Earth's volcanic activity
- produce 20 km^3 annual output of new crust release
- about 25 % of the Earth's heat loss

Mid-ocean ridge systems

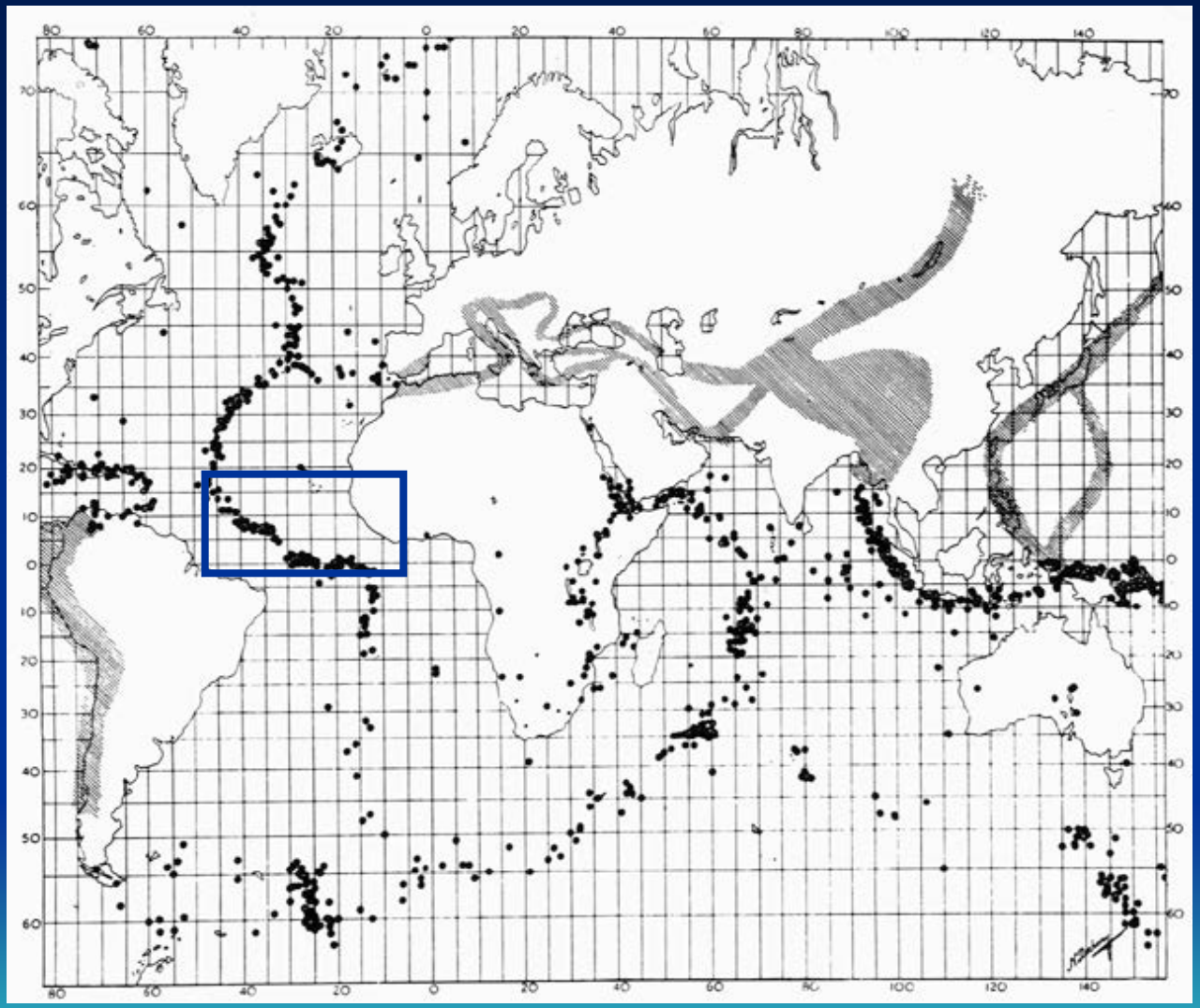


Diverging Plate Boundary

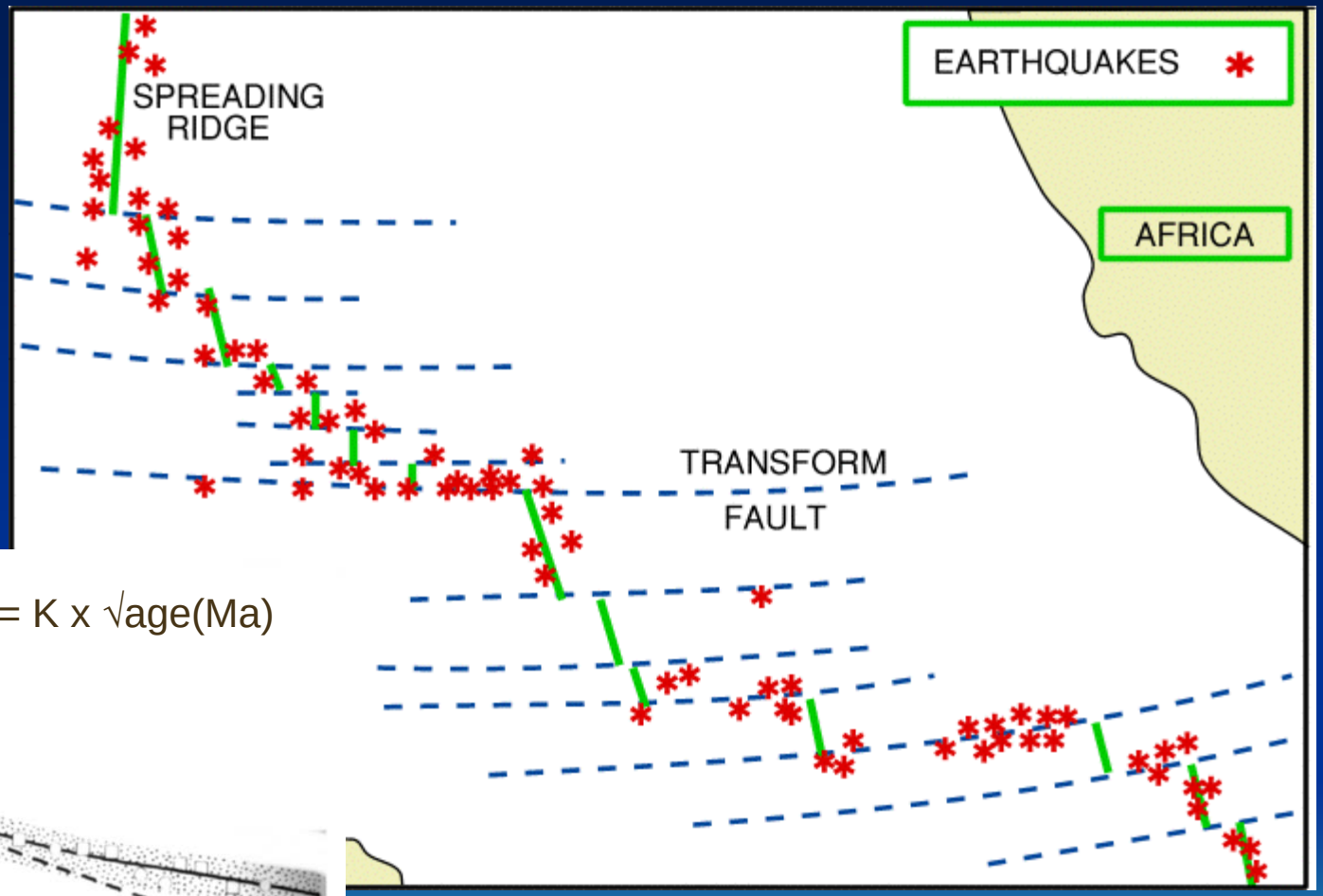
Oceanic Ridge - Spreading Center



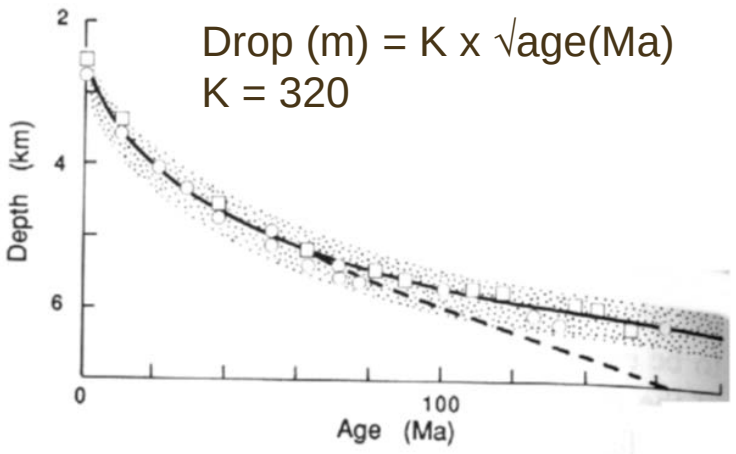
Concentration of earthquakes along oceanic trenches and speading ridges



Transform faults

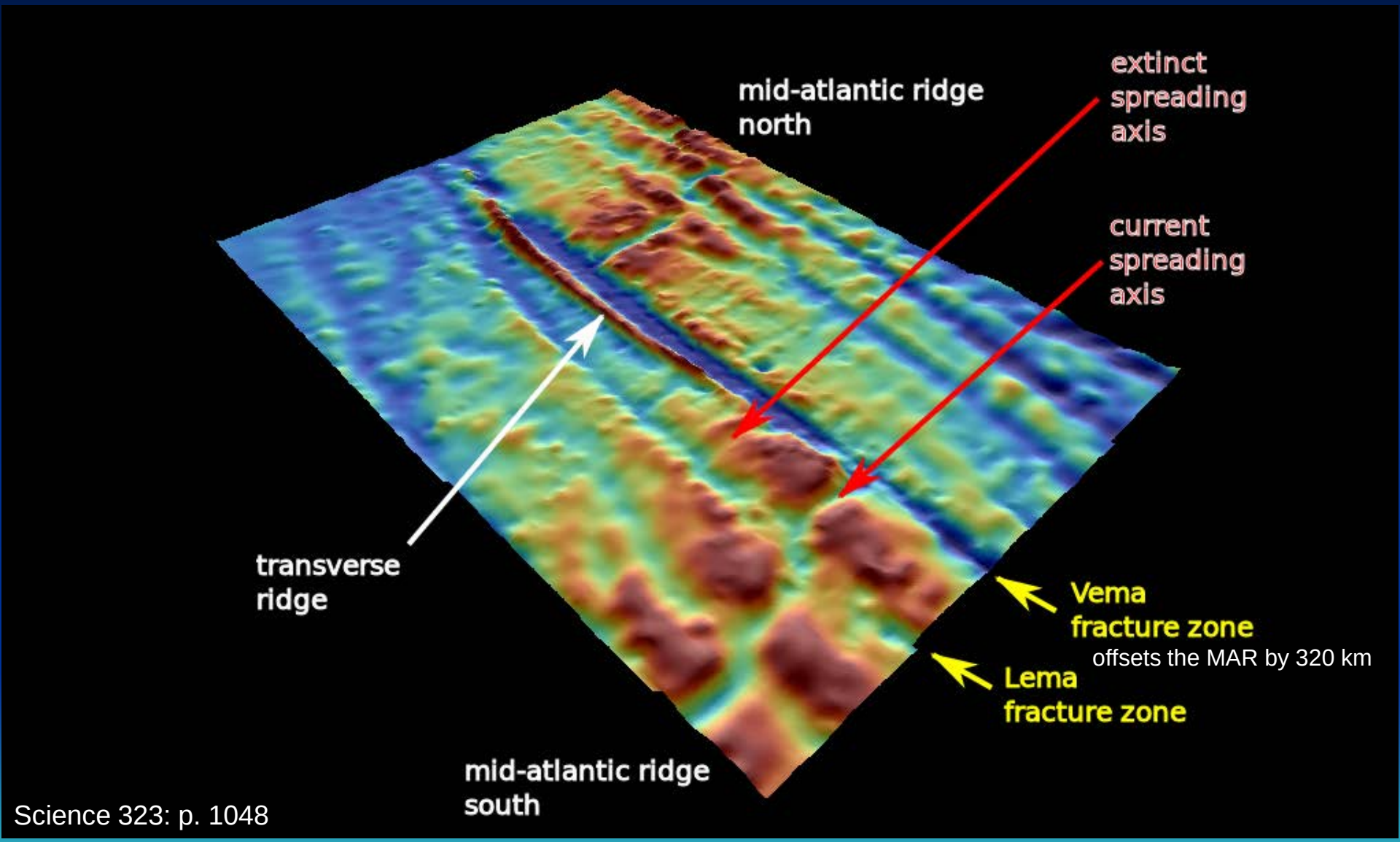


Drop (m) = K x √age(Ma)
K = 320

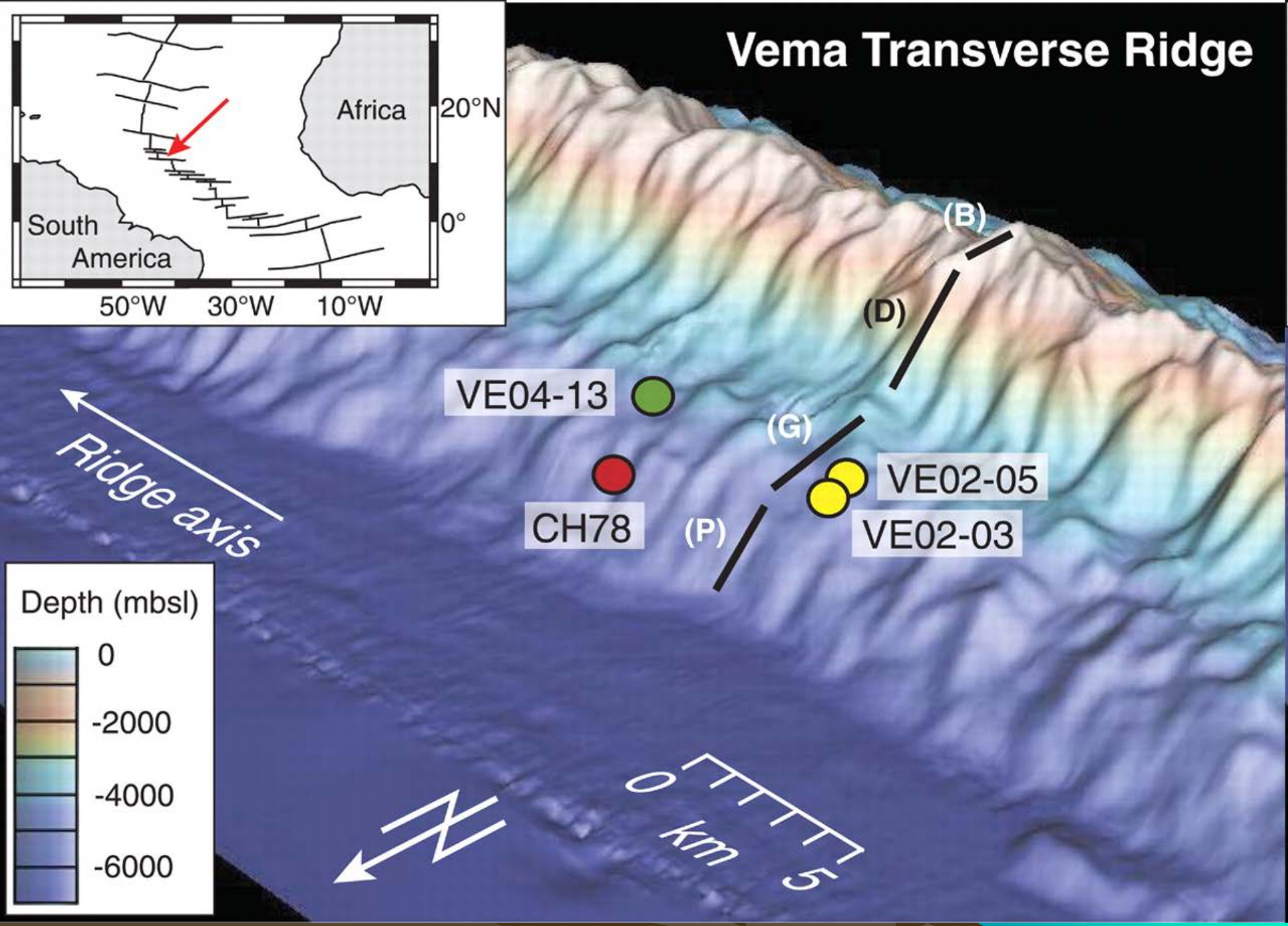


Ocean floor cools and becomes heavier with time and sinks into the matle

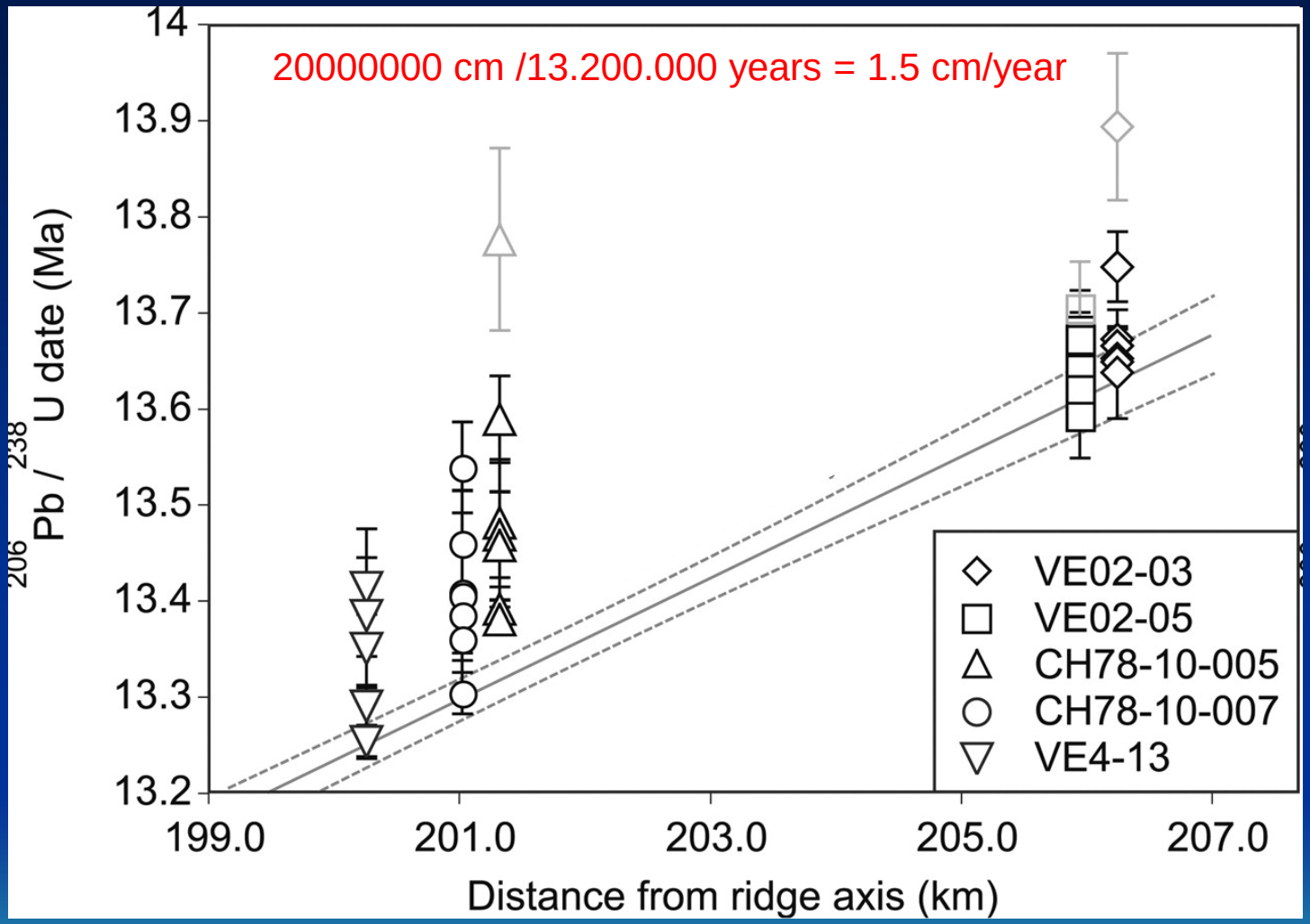
Vema transverse ridge



Science 323: p. 1048


Vema Transverse Ridge
Africa
South America
20°N
0°
50°W
30°W
10°W
(B)
(D)
(G)
(P)
VE04-13
CH78
VE02-05
VE02-03
Ridge axis
Depth (mbsl)
0
-2000
-4000
-6000
N
0
5
km

Ocean crust accretion rates



Lissenberg et al. 2009 Science 323: p. 1048

Deep Sea Drilling

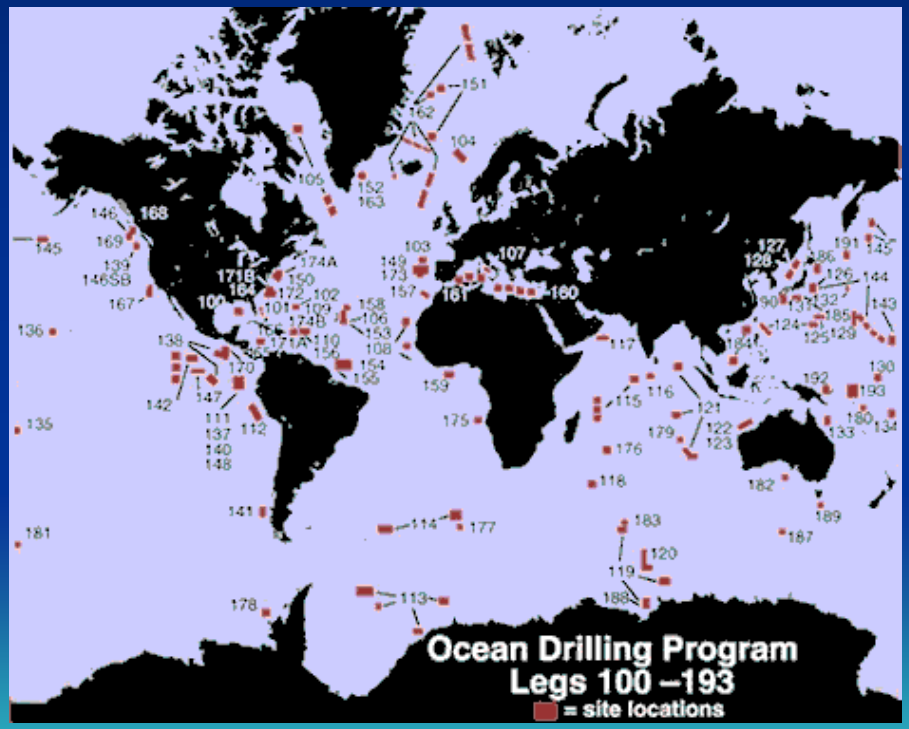
In the beginnings…..

Mohole Project (AMSOC)

deeper drilling never took place

Deep Sea Drilling Project

first of three international scientific ocean drilling programs that have operated over more than 40 years



Glomar Challenger

IODP

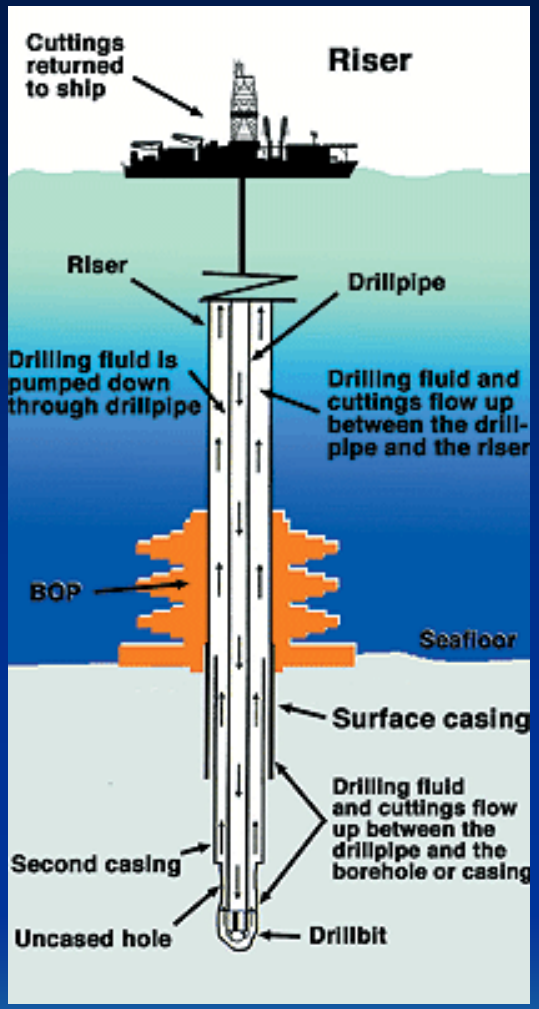
International Ocean Discovery Program

http://www.iodp.org/

Chikyu (*jap*. “Planet Earth”)

New drilling method
with **riser system**
mud used instead of seawater
(mud circulation system)

Chikyu can drill more than 7,000 meters below the seafloor in water depths that exceed 2,000 meters



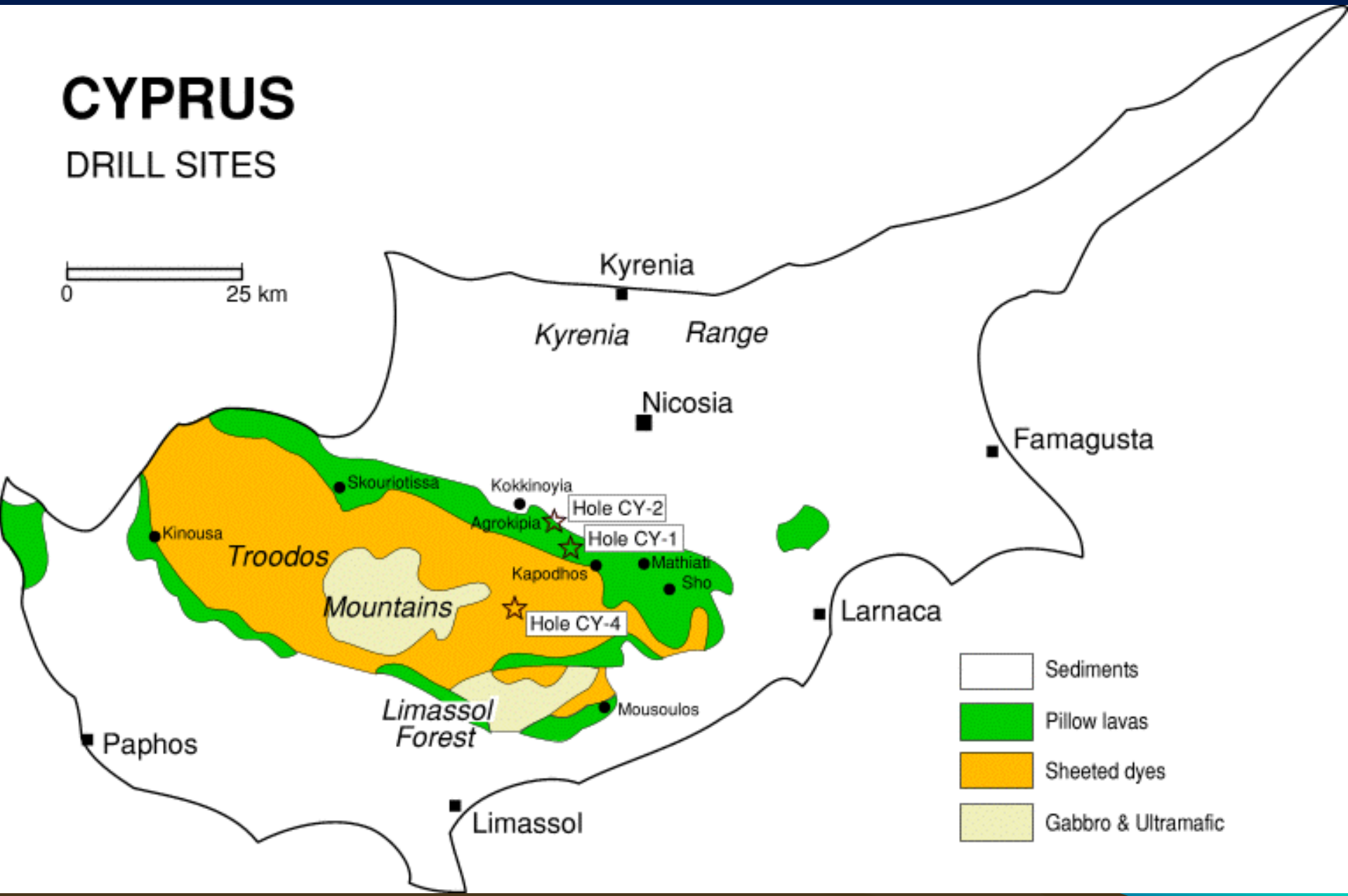
Oceanographic research vessels

German fleet:
Sonne (image)
Polarstern
Meteor
Maria S. Merian

Sources of mantle material

- ***Dredge samples from oceanic crust***
- ***Nodules and xenoliths in basalts***
- ***Kimberlite xenoliths***
  - Diamond-bearing pipes blasted up from the mantle carrying xenoliths from depth
- ***Ophiolites***
  - Slabs of oceanic crust and upper mantle
  - Thrust at subduction zones onto edge of continent

Sources of mantle material - ophiolites

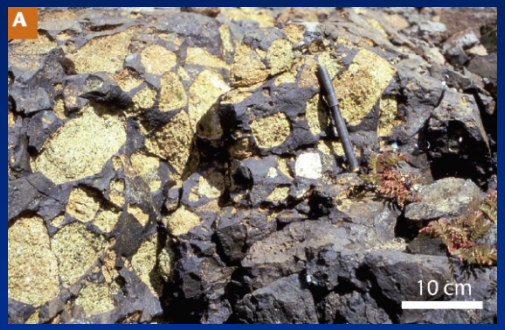


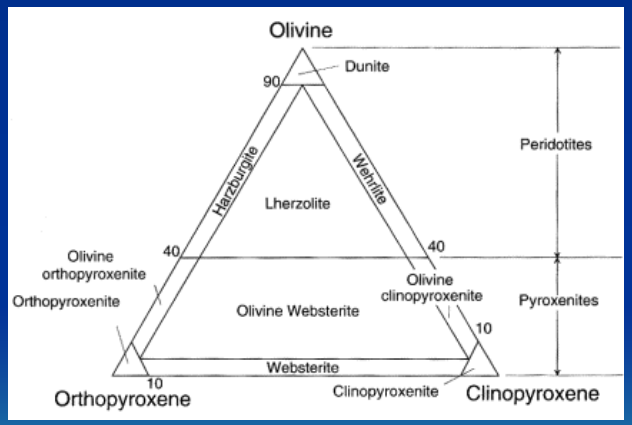
Mantle rocks: peridotite (green) in basalt lava

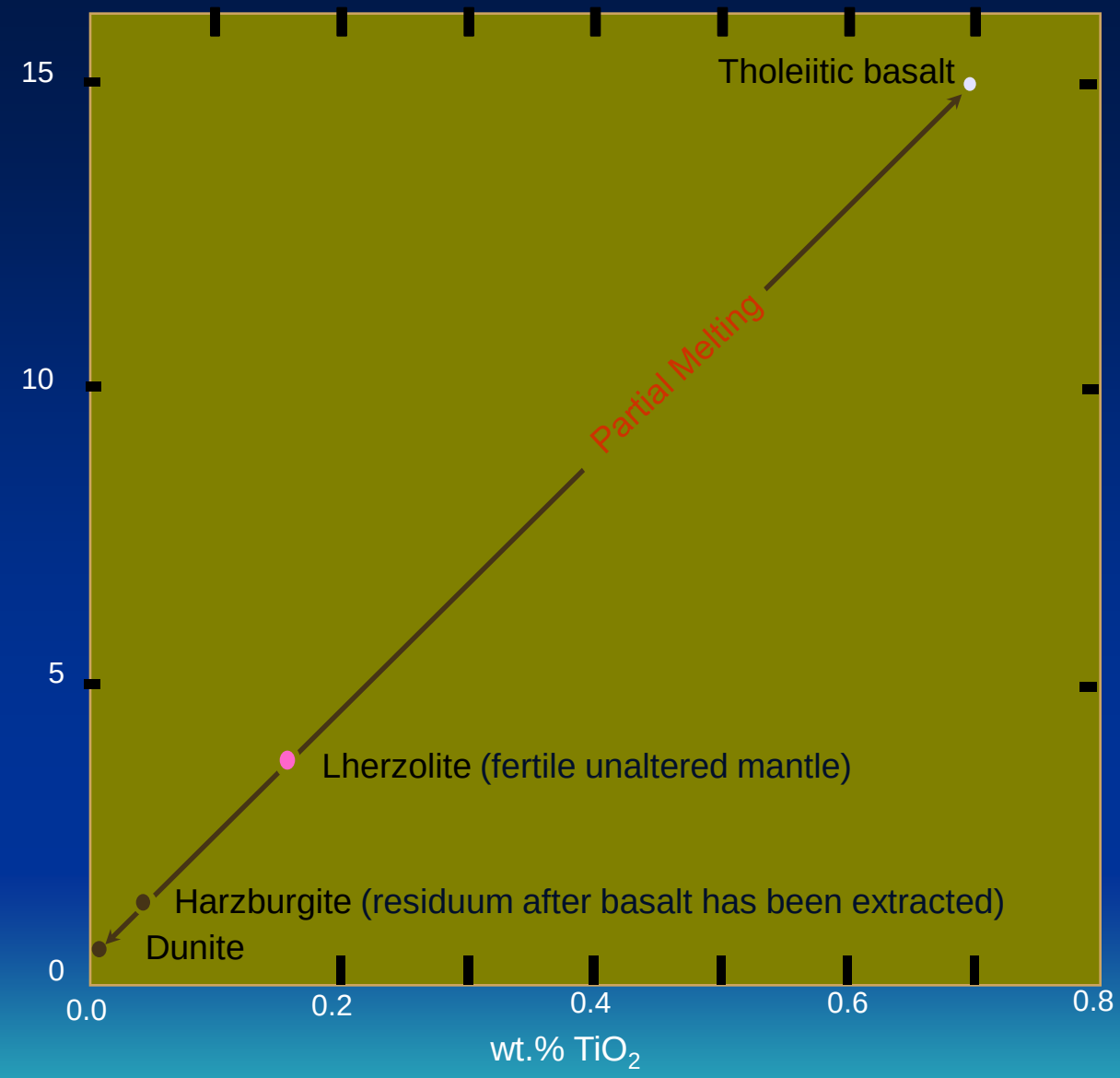
Melting of peridotite mantle extracts basaltic liquids to form ocean crust, leaving a residue of harzburgite (ol+opx)

Lorand et al. (2008) *Elements*

Mantle rocks: fertile vs. refractory mantle







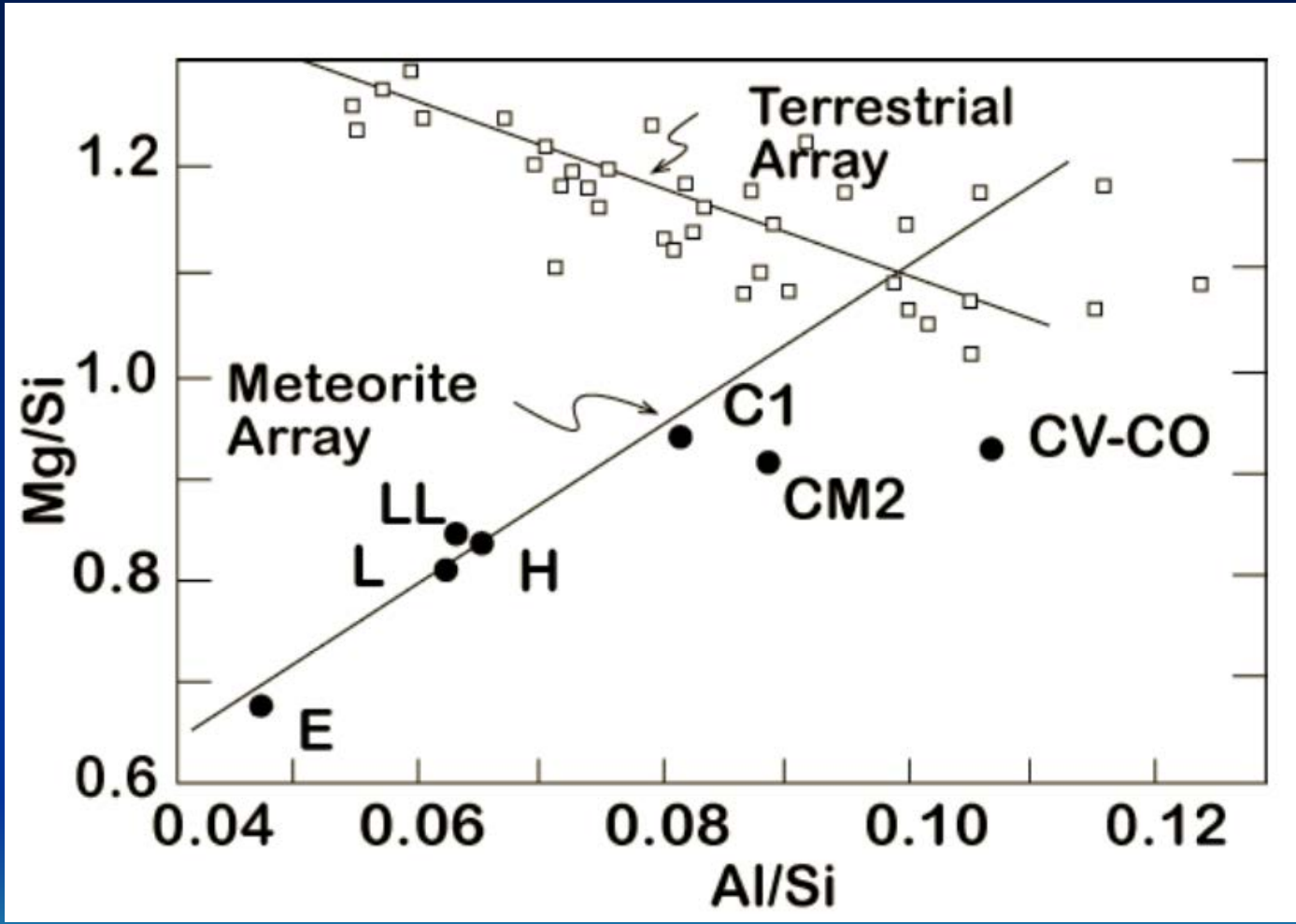
Brown & Mussett (1993)
The Inaccessible Earth

Major element compositions of the earth's mantle

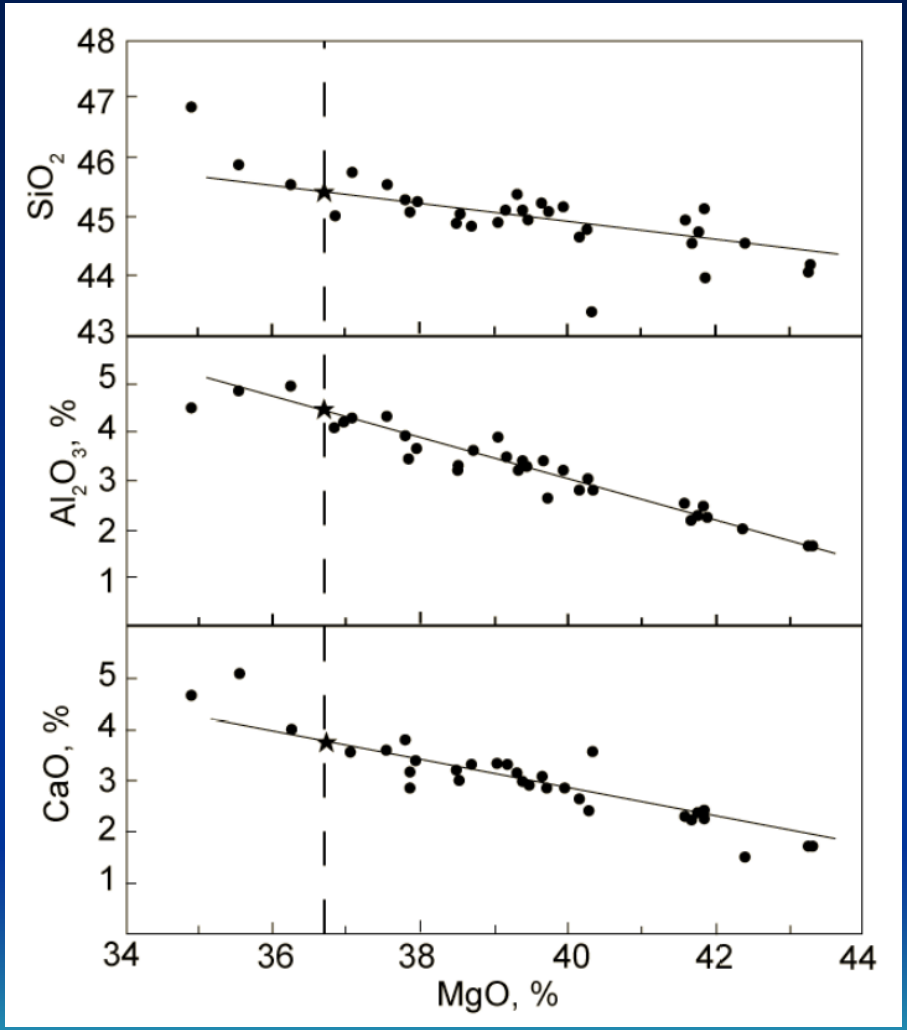
	CI Chondrites	CI Chondritic Mantle[1]	Hart & Zindler[2]	McDonough & Sun[3]	Palme & O'Neill[4]	Lyubetskaya & Korenga[5]	O'Neill & Palme[6]
SiO_2	22.89	49.77	45.96	45.0	45.4	44.95	45.40
Al_2O_3	1.60	3.48	4.06	4.45	4.49	3.52	4.29
FeO	23.71	6.91	7.54	8.05	8.10	7.97	8.10
MgO	15.94	34.65	37.78	37.8	36.77	39.95	36.77
CaO	1.30	2.83	3.21	3.55	3.65	2.79	3.52
Na_2O	0.671	0.293	0.332	0.36	0.33	0.30	0.281
K_2O	0.067	0.028	0.032	0.029	0.031	0.023	0.019
Cr_2O_3	0.387	0.409	0.468	0.384	0.368	0.385	0.368
MnO	0.250	0.112	0.130	0.135	0.136	0.131	0.136
TiO_2	0.076	0.166	0.181	0.20	0.21	0.158	0.183
NiO	1.371	0.241	0.277	0.25	0.24	0.252	0.237
CoO	0.064	0.012	0.013	0.013	0.013	0.013	0.013
P_2O_5	0.212	0.014	0.019	0.021	0.20	0.15	0.015
Sum	69.79	100.0	100.0	100.2	99.8	100.0	

[1]After removing volatiles and siderophile elements and some oxygen from mantle to form core. Hart and Zindler (1986)
[2]Hart and Zindler (1986)
[3] McDonough and Sun (1995)
[4]Palme & O'Neill (2003)
[5]Lyubetskaya & Korenga (2007)
[6] calculated from the equations of O'Neill & Palme (2008).

Geochemical/cosmochemical fractionation diagram



Geochemical fractionation diagram



Intersection at MgO = 36,77%

Palme & O´Neill (2003)