CLASS 27: GEOLOGY OF THE OCEAN FLOOR

INTRODUCTION

The oceans cover about 70 % of the globe. They contain important resources such as fish, fossil fuels (oil, gas, methane hydrates), heavy minerals (gold, diamonds, cassiterite) as well as sand and gravel. The oceans also provide major transportation routes and offer many opportunities for recreation.

Marine sediments and sedimentary rocks are a detailed archive of earth history. Most of what we know of evolution comes from fossils incorporated in oceanic deposits. Most long-term climate change evidence is also found in marine sedimentary rocks. The oceans are the main water source for precipitation on land and, last but not least, phytoplankton produce much of the oxygen that we breathe.

Today we'll look at some of the technical advances on which our knowledge of the sea floor is based. Then we'll look at marine sediments.

STUDYING THE OCEAN FLOOR

Before the nineteenth century almost nothing was known of the sea floor. Widely spaced soundings yielded depth information around some harbors and other shallow places. Meager sampling gave information on surficial sediments of continental and island shelves.

During the 1800's substantial progress was made. The main technical advance is that soundings were done with steel wire instead of hemp rope and the winches were driven by steam, not muscle power. This new equipment was used primarily to survey routes for transoceanic telegraph cables. These surveys gave us our first hints of the mid-ocean ridge system. Geologists such as Darwin and Dana demonstrated that most ocean islands are basalt volcanoes with or without limestone caps.

The "Titanic" disaster and submarine warfare in the Great War of 1914-1918 led to rapid development of SONAR technology. Sound waves were used to measure water depth. Initially a survey ship would stop (to be quiet), emit an acoustic pulse and listen for return echo. Timing was done using a stop watch. In the late 1920's it became possible to measure depths from a moving ship and record the echoes as a profile on a roll of paper. The German research vessel “Meteor” mapped the Mid-Atlantic Ridge between Africa and South America in great detail.

In the 1950’s echo-sounding became routine and many deep-sea cruises contributed to a much more complete mapping of ocean depth. Seismic reflection sounding, first developed in the Oklahoma “oil patch” in the 1920’s, was employed to map sediment thickness and stratification. Sediment cores up to ten meters long were taken systematically throughout the oceans and deep oil wells were drilled on the shallow continental shelf. Basalt and peridotite were dredged from the mid-ocean ridges.

The 1960’s saw the introduction of deep drilling throughout the deep seas. These wells, 100’s to 1000’s m deep, gave detailed information including samples right down to into the basalt crust. During this decade plate tectonic theory was proposed and soon accepted by most earth scientists (we’ll study the evidence soon).

From the 1970’s to the present there has been continuous development and use of “multi-beam” echo-sounders and “side-scan” sonars that permit mapping of wide swaths on both sides of a ship, not just a narrow profile under the ship. At the same times detailed analysis of satellite orbits has given us an essentially complete view of all the major bathymeteric features of the ocean basins. Extremely detailed studies of the seafloor have been made possible by deep research submersibles such as “Alvin”. Now let’s look at some results.

GLOBAL TOPOGRAPHY AND BATHYMETRY

Ocean water covers about 71% of the globe but only about 60% of the globe is covered with ocean crust. The difference is explained by the fact that the shallow continental shelves have continental crust.

Mean continental elevation is about 800 m with a maximum of over 8000 m at Mount Everest. Very little land has elevations over 2000 m. Note that the high elevations of Greenland and Antarctica are caused by lots of ice, not by rock. The high areas are in narrow mountain chains located along active (collisonal) plate margins.

The average depth of the ocean is 3800 m with the deepest water exceeds 11000 m in the Marianas Trench. Except for the very edges, the shallowest sea floor is found along the mid-ocean ridges. These are flanked by deeper basins on either side.

THICKNESS OF SEDIMENTS AND SEDIMENTARY STRATA

Deep wells and seismic soundings give us very good estimates of the thickness of sediments and sedimentary rock almost everywhere on earth. These deposits are rich in many useful resources such as fossil fuels, metal ores, fertilizers and construction materials. They also preserve a record of earth history and organic evolution.

Except in mountain belts the strata on the continents seldom exceed 2000 m in thickness. The old Precambrian shields of Canada, Scandinavia and Siberia are almost without sedimentary strata; repeated glaciation has apparently stripped it all away. The Precambrian shields of South America, Africa, India and Australia have little sedimentary material also. The explanation is that these areas have been stable for so long that erosion has dominated their history.

Most of the ocean has only a few hundred meters of sedimentary material. One reason is that the ocean floors are very young. The other is that sedimentation rates are very low in most places far from shore. The thickest deposits are found in the deltas and submarine fans (cones) of big rivers such as the Mississippi, Amazon, Orinoco, Ganges and so on. These rivers all drain high mountains. Big deposits are also found offshore of glacial troughs (Saint Lawrence, Antarctica) and under passive continental margins. There are also very thick deposits in the Caspian Sea and Persian Gulf.

SEDIMENTS ON THE ATLANTIC PASSIVE MARGIN OF NORTH AMERICA

Let’s take a cruise from Cape Cod southeastward to the Mid-Atlantic Ridge. What sediments would we find on and under the sea floor?

On the shelf water depths rarely exceed 100-200 m. The surficial sediments are mostly left over from the Ice Ages when glaciers advanced far out on the shelf and locally the sealevel was lower. These sediments have been “reworked” (eroded and moved around) during the subsequent rise of sealevel. Sand and gravel are the most common sediment. Because of abundant oxygen at these shallow depths, the grains are reddish with iron oxide coatings. At present little active sedimentation is occurring.

The continental slope extends from the edge of the shelf down to about 2500 m depth. The slope is the steepest part of the Atlantic passive margin. The most common sediments are silt and clay. Colors are gray from organic carbon and green from reduced iron compounds. These dark colors are a result of low oxygen dissolved in the water (see ES501, Oceanography, for a more detailed explanation). The steep slope is the site of intense mass wasting leading to numerous gullies and submarine canyons. Sediment accumulates on the slope for a while but most eventually moves to deeper water.

The continental rise is located between about 2500 m and more than 5000 m. The slope of the rise is much less than that of the continental slope. The rise is largely built of huge overlapping fans or cones. Big levied channels route coarse sediments across the rise and onto the deeper abyssal plains. Sand and gravel are found in the channels whereas the overbank deposits are silt and clay.

At greater depths we find the abyssal plains. These are the flattest large areas on earth with gradients of less than 1 m per km. They are built up of turbidity current deposits and debris flow deposits interbedded with red clays.

Even farther from shore but at somewhat shallower depths are the abyssal hills. The sediments here are primarily red eolian clays draped over rugged basalt terrain produced at the axis of the mid-ocean ridge. The ridge itself is covered with calcium carbonate ooze, a limey deposit produced by planktonic organisms such as foraminifera and pteropods. The youngest parts of the ridge have not yet accumulated significant amounts of sediment.

HOW SEDIMENT GETS TO THE DEEP SEA

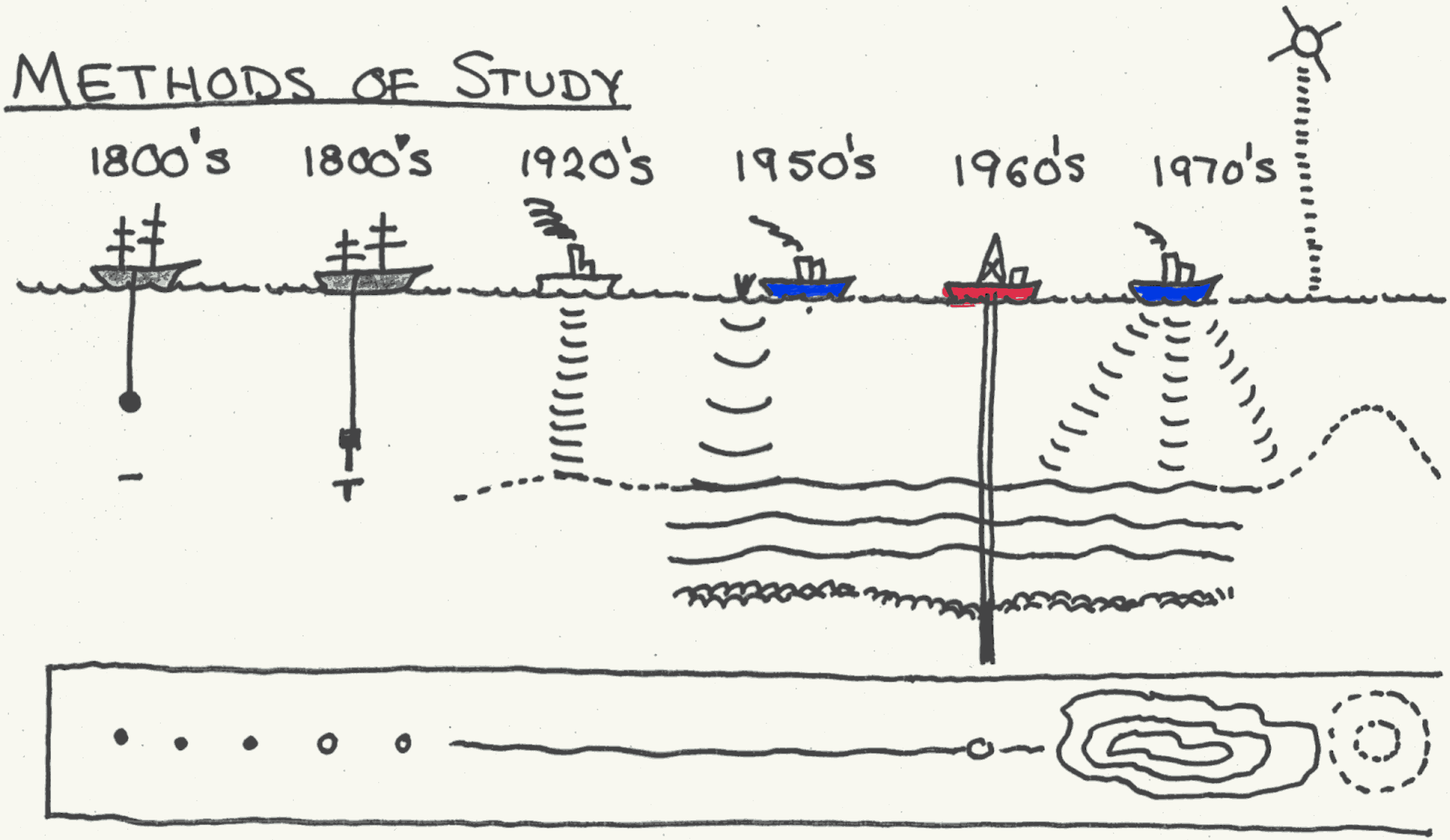
Turbidity currents and debris flows both move sediment from temporary resting places on the continental slope down to the rise and abyssal plains. Turbidity currents are flows driven downslope by gravity. The concentration of sediments in a typical flow is similar to that in a muddy river on land. As the currents reach the rise and/or abyssal plains they slow down and begin depositing sediment. At any given place the first sediment laid down is coarser than the last. In other words the deposits are “graded”. A typical large flow might last for a few days and lay down a meter of sediment. Then centuries might go by as red clay accumulates and the site awaits the next flow.

Like turbidity currents, debris flows are driven downhill by gravity. The difference is that debris flows are much denser; they are similar to wet cement flowing out of a mixer. Nevertheless they can travel hundreds of kilometers over gentle slopes. The sediments tend to be poorly sorted and inversely graded. As with turbidites the debrites are laid down rapidly between long periods of slow red clay accumulation.

In contrast to turbidity currents and debris flows, which go downhill, contour currents run parallel to the bathymetric contours. On the east coast of the USA the currents flow southward over the continental rise. They act somewhat as wind does on land. The silts and clays are carried away and eventually are deposited where the currents wane. The sand is concentrated into ripple marks and dunes. Much of the rise is covered by well-sorted, cross-bedded, sandy “contourites”.

Ocean currents and winds carry fine sediment out to the deep sea where it eventually settles to the ocean floor. Plankton such as foraminifera and diatoms often are the major sediment producers far from land.

METHODS OF STUDY



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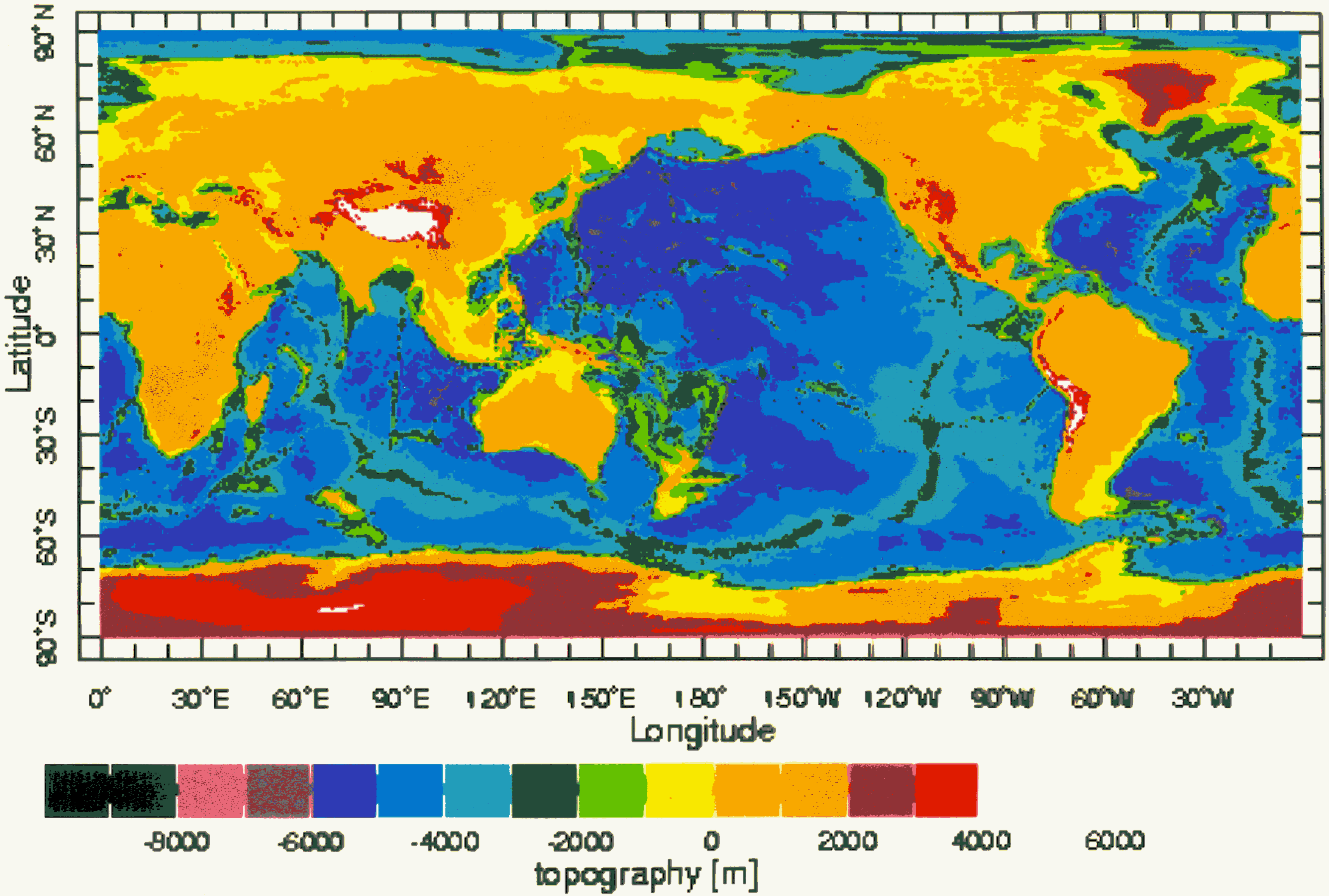
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60°N
30°N
0°
30°S
60°S
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Latitude
0°
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60°E
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120°E
150°E
180°
150°W
120°W
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Longitude
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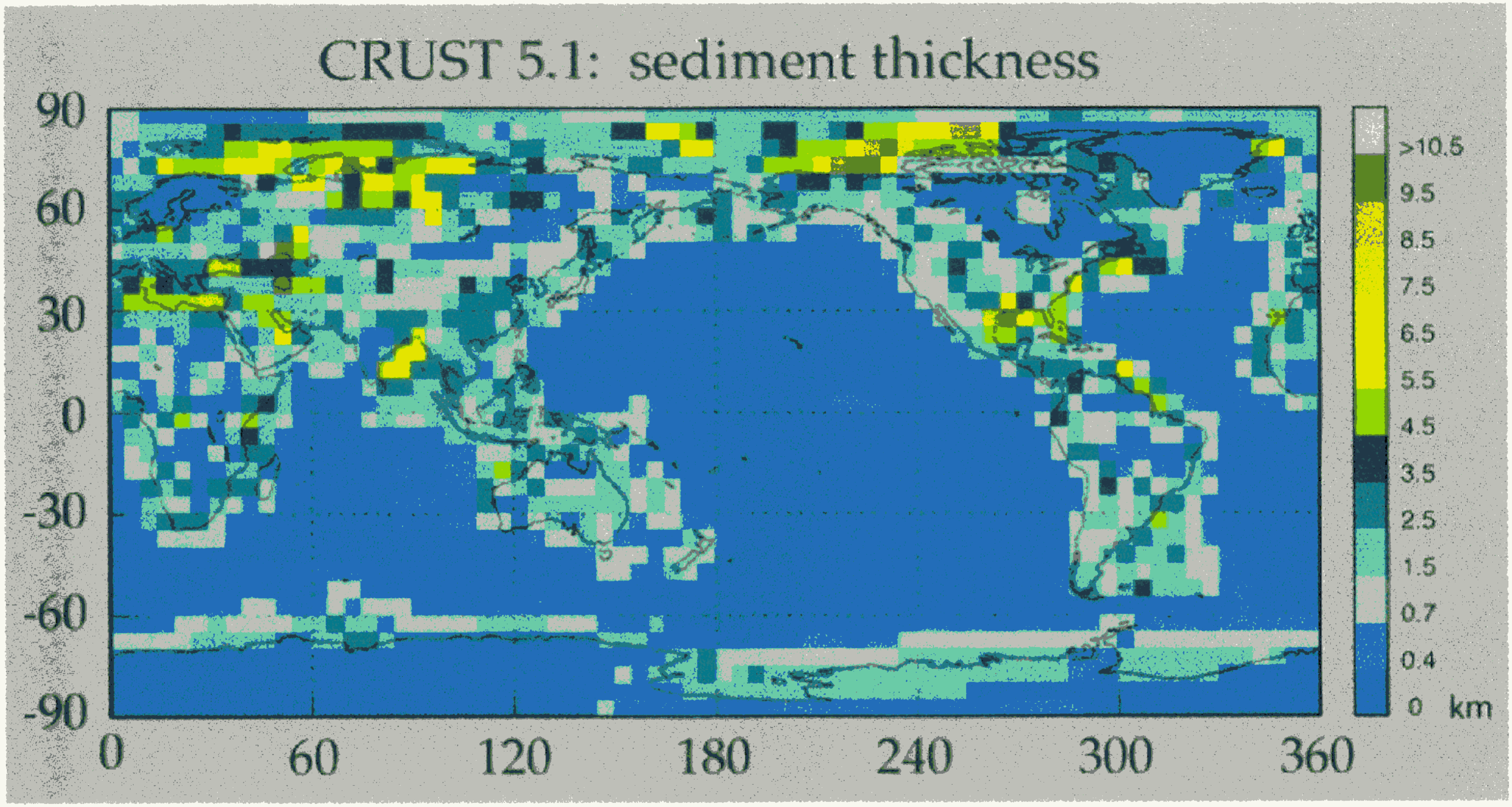
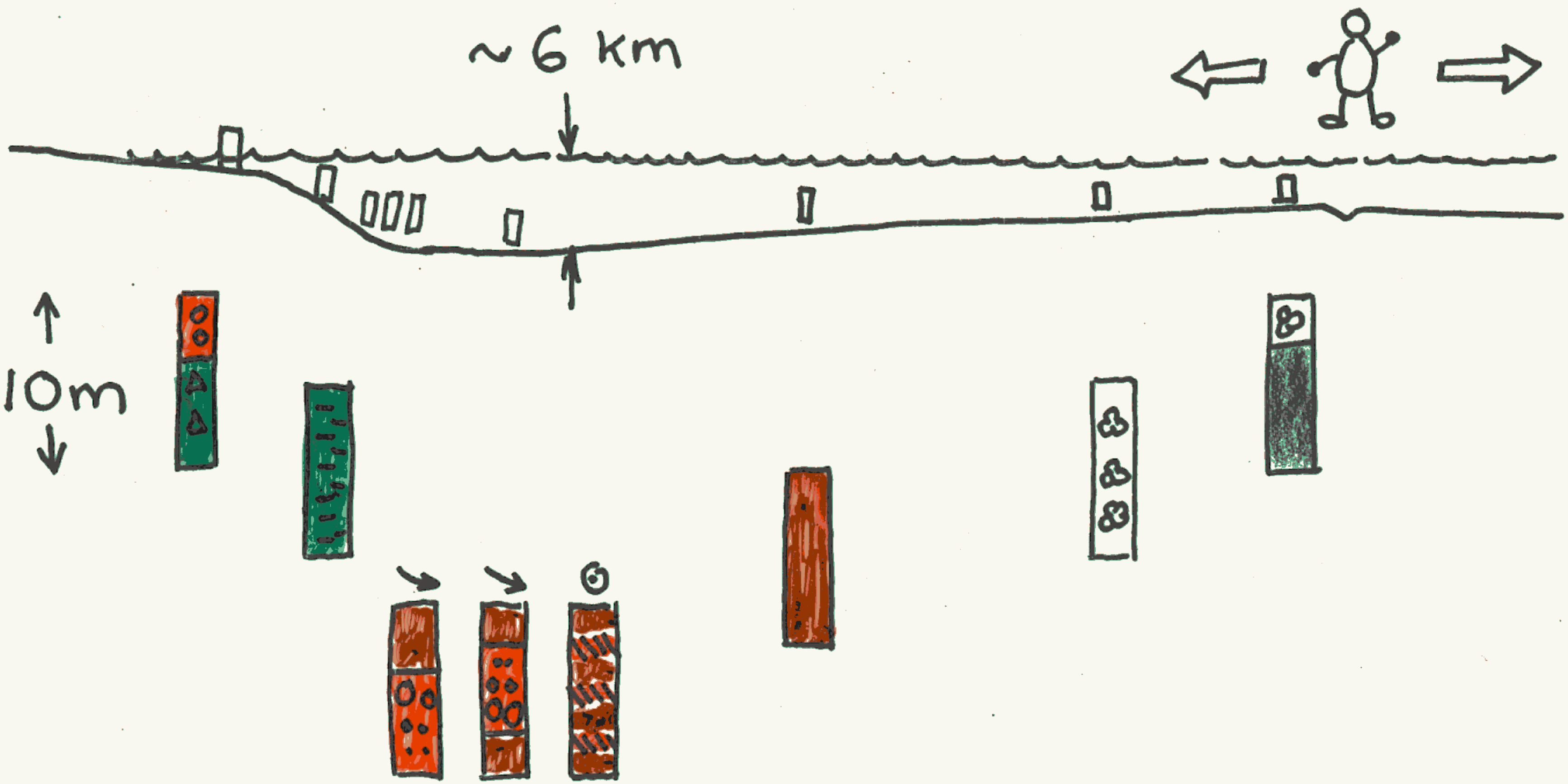
2000
4000
6000
topography [m]


CRUST 5.1: sediment thickness
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
>10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.7
0.4
0 km

Ocean Sediments



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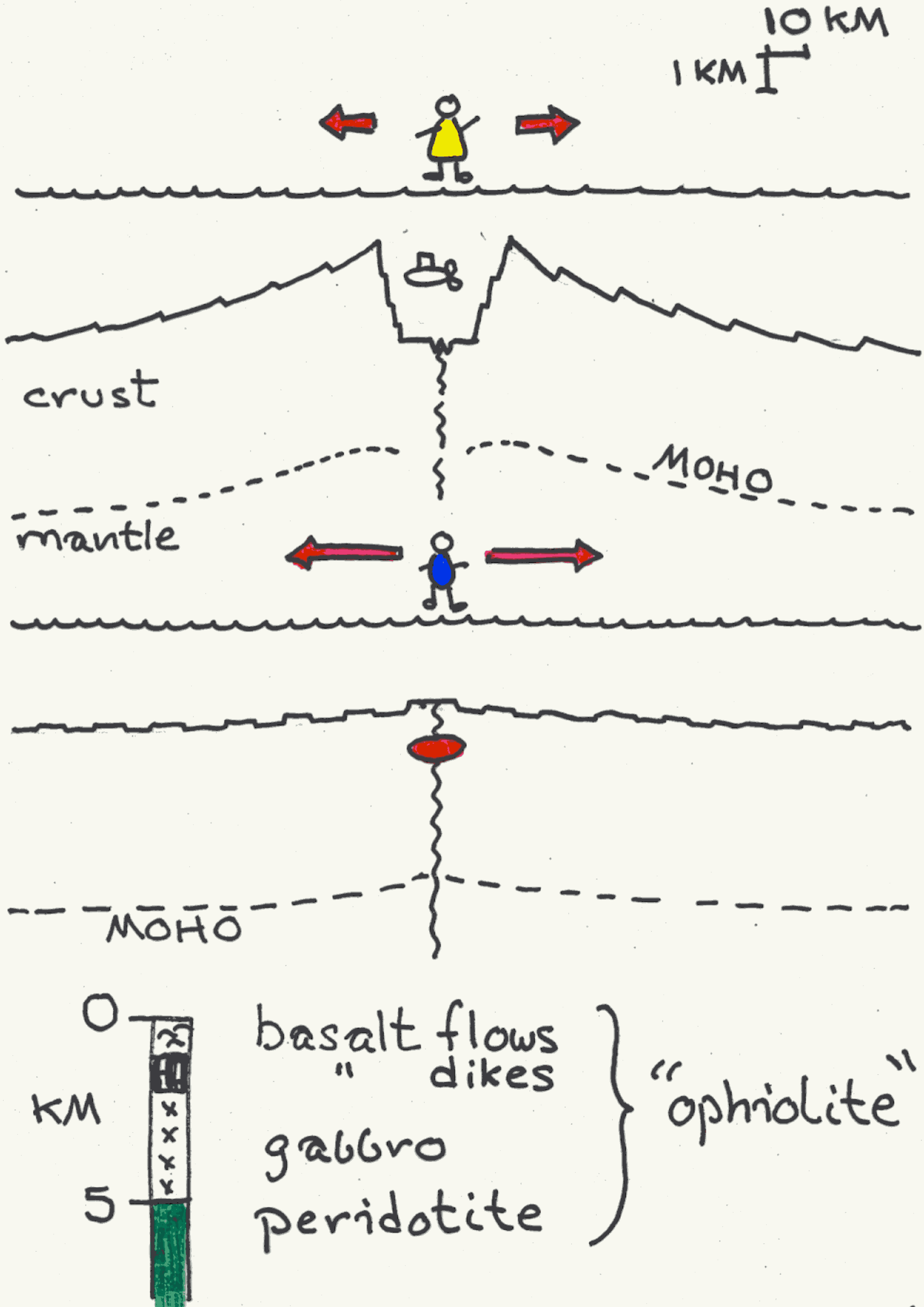
MID-OCEAN RIDGES



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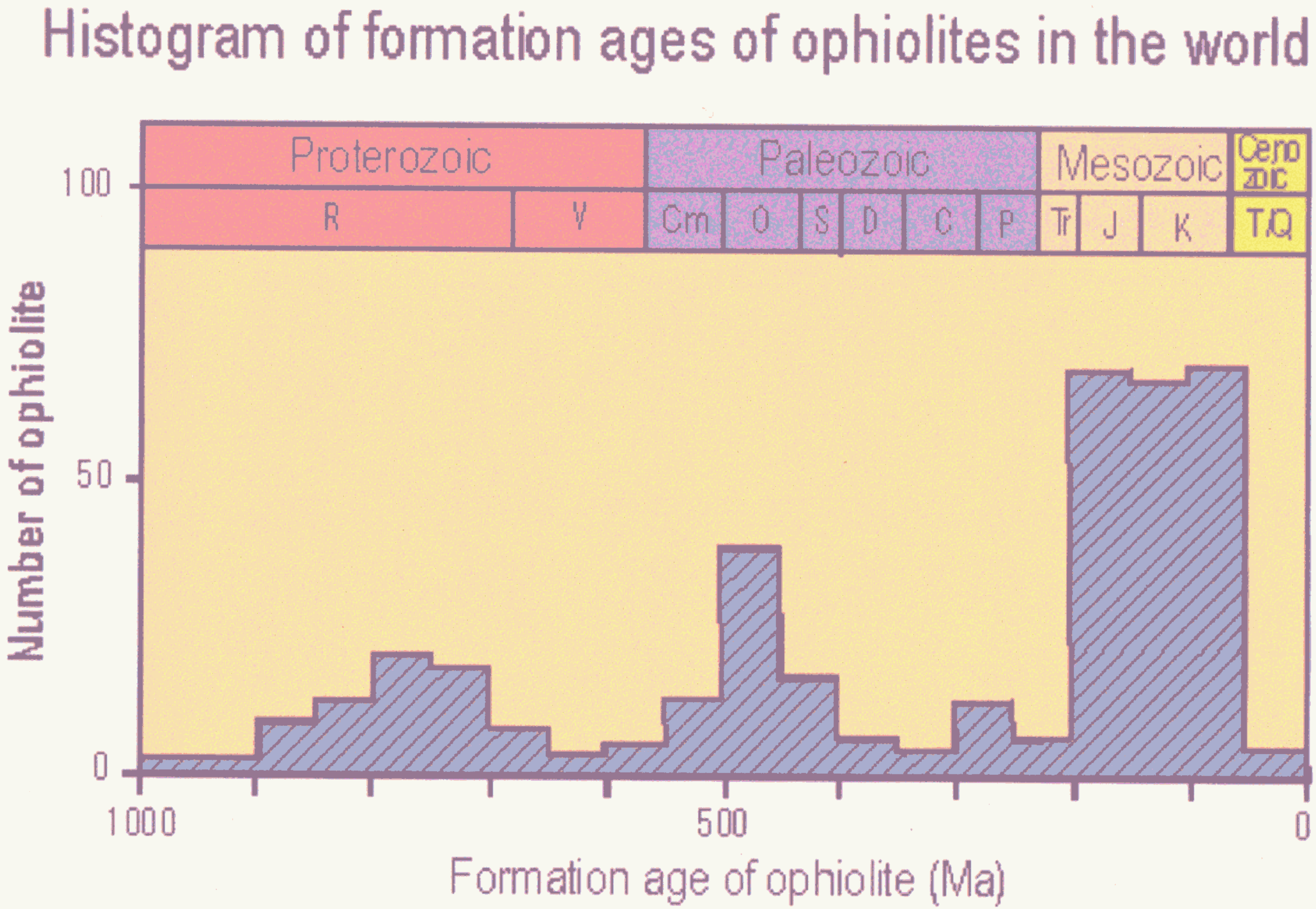
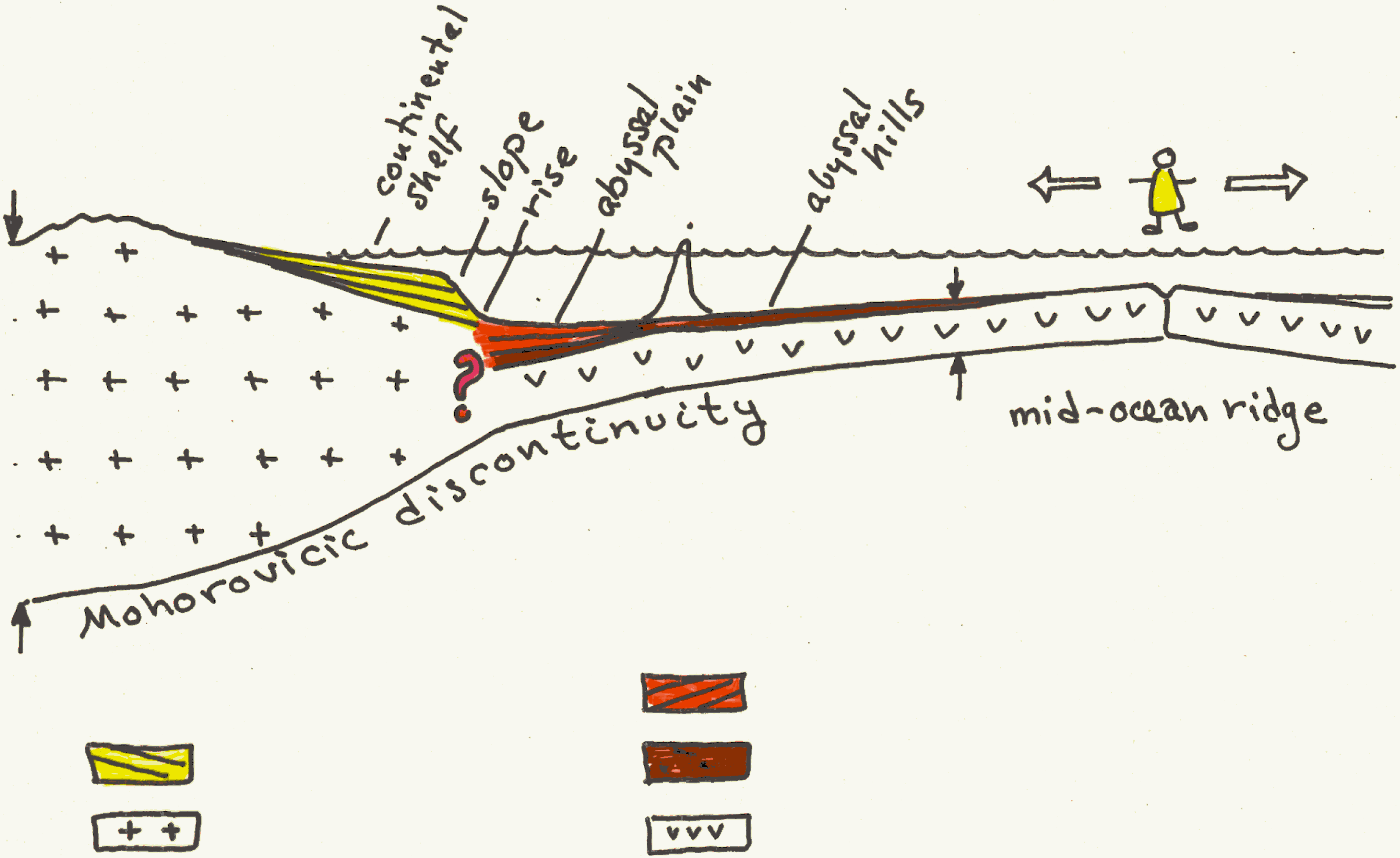
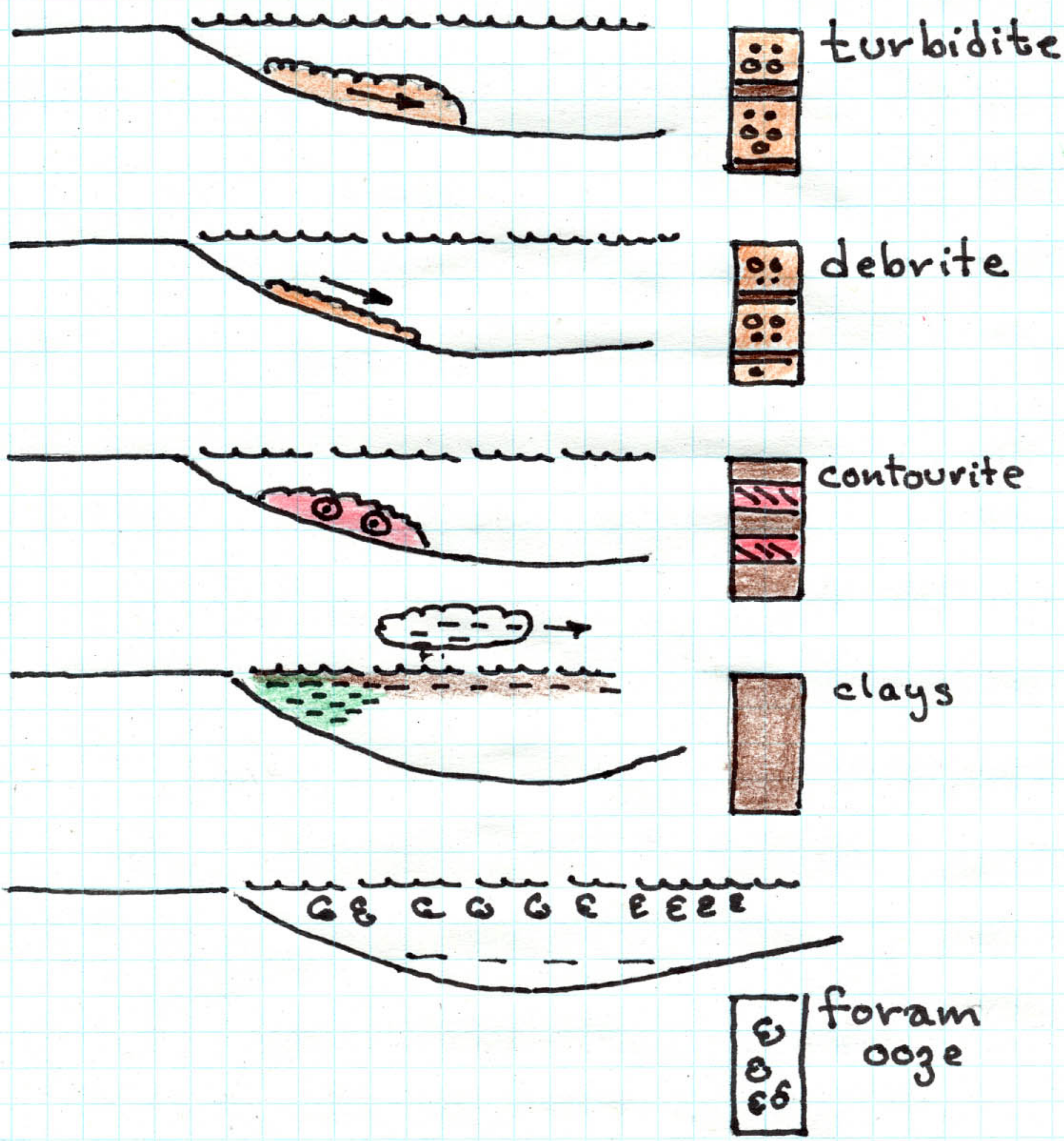


Histogram of formation ages of ophiolites in the world
Proterozoic
Paleozoic
Mesozoic
Ceno zoic
R
V
Cm
O
S
D
C
P
Tr
J
K
T/Q
100
50
0
Number of ophiolite
1000
500
0
Formation age of ophiolite (Ma)


continental
shelf
slope
rise
abyssal
plain
abyssal
hills
mid-ocean ridge
Mohorovicic discontinuity
?

FSB, 2001

OCEAN SEDIMENTS



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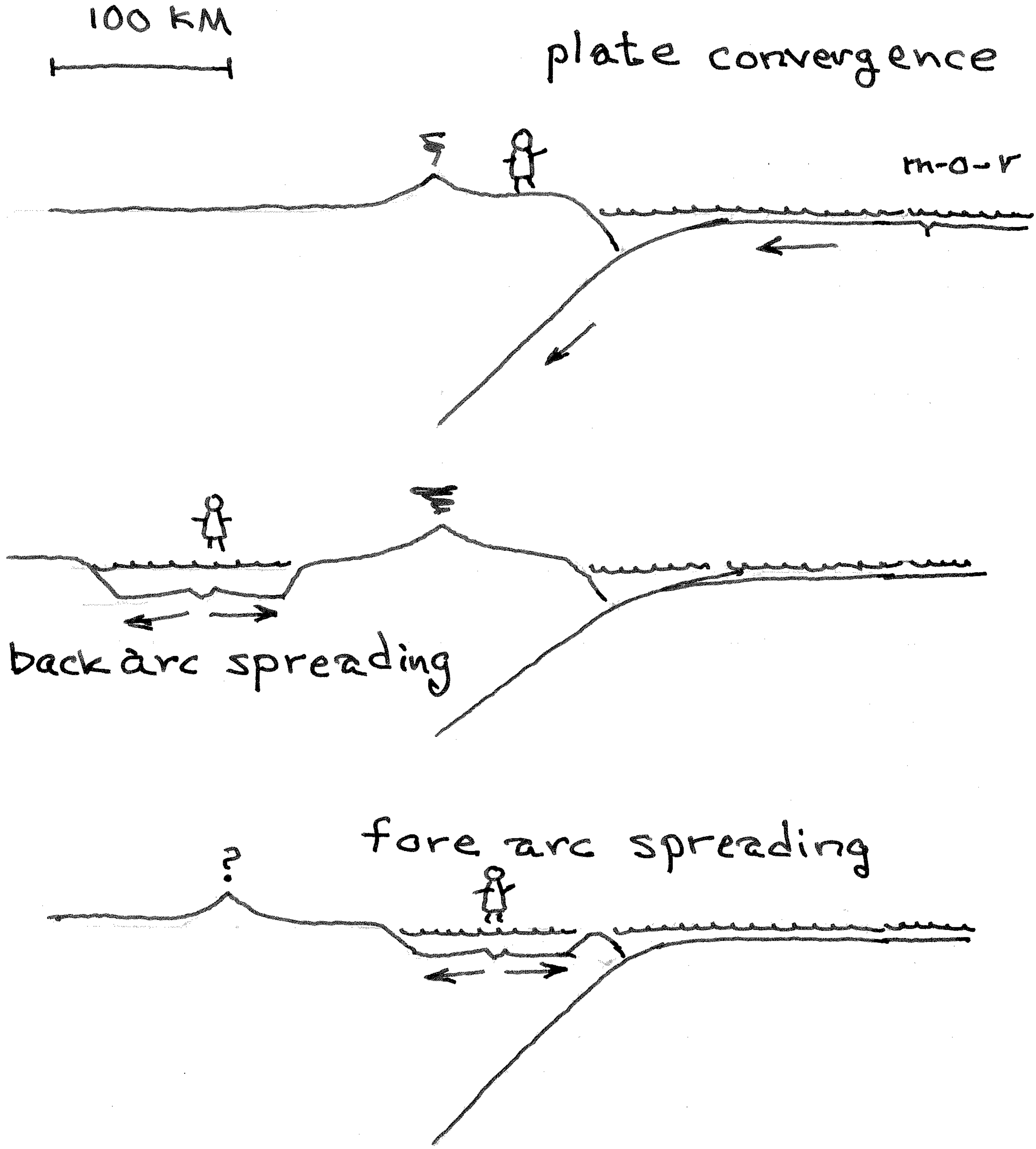
100 KM
plate convergence
m-o-r
back arc spreading
fore arc spreading
?

FSB, 2008