

GEOSCIENCE 001 LAB 3: REUNITE GONDWANA!

modified from Adam Maloof

INTRODUCTION

A combination of the Cold War, a large defense budget, and the influence of a Navy admiral who was also a geophysicist led to a massive bathymetric and magnetic exploration of the ocean basins. A surprising discovery was a nearly continuous ridge near the centers of many of the ocean basins; the sea floor on either side of these ridges dropped in a symmetrical, exponential fashion. An even more surprising revelation from this exploration was the discovery that magnetic anomalies (deviations in the Earth's magnetic field) formed linear patterns parallel to and symmetric about those ridges.

Armed with the observation from terrestrial rock magnetism that the earth's magnetic field switches polarity sporadically, researchers proposed that these magnetic anomalies were due to the magnetization of rocks formed at mid-ocean spreading ridges. New crust, cooling through the Curie temperature, would record the Earth's magnetic field at the time of cooling, and then this ocean crust magnetization would interact with the Earth's present day magnetic field, leading to the anomalies. This hypothesis was further strengthened by correlation of the reversal pattern as seen on the sea floor with that observed in sequences of terrestrial lava flows that spanned the last 20 Ma or so. Thus, geoscientists were able to develop maps of the age of the sea floor based on magnetic anomalies.

In this lab, we will use magnetic anomaly data to reconstruct the *paleogeography* of the Indian Ocean and its surrounding continents, which collectively comprise **Gondwana**, the southern portion of the supercontinent **Pangea**. The theory behind this is very simple: to determine the geography at a given time in the past, remove all the ocean crust which has been formed since that time. All that remains then is to close the gaps. We will do this for three discrete stages in the tectonic evolution of the Indian Ocean: 35Ma, 80Ma, and 120Ma (Ma=mega annum, i.e., a million years into the past). We will also explore in more detail the origins of the Seychelles Islands, where something interesting happened about 64 Ma.

First: Study the Maps

Examine the set of 4 identical maps provided. You will use one of the copies to color on, and the other three to cut-up. You should be able to recognize the continental margins of Africa, Madagascar, Arabia, India, Indonesia, Australia, Asia, and Antarctica. The heavy black line represents the spreading ridges — the Carlsberg Ridge, the Southeast Indian Ridge, and the Southwest Indian Ridge. The intersection of these ridges is called a *Triple Junction*.

Perpendicular to the ridges are a series of *fracture zones* (thin black lines), which represent either fossil or active *strike-slip boundaries* between plates. As such, they record the direction of *relative* (**not**, *absolute*) motion between two adjacent plates. Fracture zones are parallel to plate motion and age changes. Notice that there are some other fracture zones that have no obvious relation to the present-day ridges.

Parallel to the ridges (in most spots) and perpendicular to fracture zones you'll notice another set of lines called *isochrons*, or lines of constant age. The isochron labeled 35 represents ocean crust that is 35 Ma — this is the same as magnetic anomaly 13 as seen on

the larger map of the world's magnetic lineations (note that at the bottom of this map, there is a chart that shows the ages of the major magnetic anomalies). There are two separate isochrons drawn, corresponding to the different ages we are going to reconstruct. (The third age — 120 Ma — corresponds to the coastlines.) Notice that the isochrons further away from the modern mid-ocean ridge (e.g. 80 Ma) have no clear geometrical relationship with the ridges active today. Perhaps spreading in the past was oriented differently than spreading is today.

Finally, note the dashed lines which criss-cross the ocean. These are ship-tracks along which a magnetometer was towed. Previous workers have completed the difficult task of interpreting the magnetic data from these cruises and identified the magnetic anomalies and thus isochrons on the tracks.

EXERCISES

1. Age Map of the Indian Ocean

Your first task is to use the isochrons to create an colorized age map of the Indian Ocean sea floor. Remember that the age of the ocean crust increases in a direction perpendicular and way from the ridge, and parallel to the fracture zones. Color in this map so that you at least 5 different color bands representing different age ranges (e.g., 0-20Ma, 20-35Ma, and so on). You may find it helpful to consult the large map of all the magnetic anomalies. It is common to label young oceanic crust with warm colors, and old oceanic crust with cool colors. Be sure to include a color key on this map.

2. 35 Ma Reconstruction

a) Leaving the colored map intact, cut out all sea floor younger than 35Ma on one of your other maps. Assume in this and all subsequent stages that Asia and Antarctica do not move (i.e. their absolute motion is zero, which could be tested by looking at hotspot tracks). Now, move the remaining pieces back to their positions before the sea floor you just removed was created. Remember that you must move pieces of crust along fracture zones. Notice that you cannot accomplish this task and keep both Asia and Antarctica stationary without making a couple more cuts — consult a map of present day plate boundaries to decide where to make these cuts. Do this carefully, keeping in mind that you need to separate the Indian/Australian Plate from the Asian Plate, and the African Plate from the Ind/Aus Plate and the Asian Plate.

Tape your reconstruction down on a blank sheet of paper — label it 35 Ma Reconstruction and turn it in with the rest of your lab.

b) There should be some large areas where there is no material at all. What do these areas represent?

c) What has happened to this missing material?

d) Using a red pencil, trace out the spreading ridges that were active at 35 Ma. Do these ridges correspond exactly to the ones in the present-day map? Describe the similarities and differences. What does this tell you about the nature of spreading centers?

3. The Seychelles

The Seychelles Islands, located NE of Madagascar are unusual among mid-oceanic islands in that they are composed mainly of granites rather than basaltic lavas; they represent a sliver of continental crust, whose precise shape can be seen in some of the world maps around the lab room. How did this crust get there? We'll look for some answers in the magnetic anomalies.

a) Study the magnetic anomalies (on the large map) between Madagascar and the Seychelles. These anomalies mean that there was a spreading ridge between Madagascar and the Seychelles.

When did it form? _____

When did it stop? _____

b) Now get a piece of tracing paper and draw (on the same sheet) three approximate paleogeographic maps of Madagascar, the Seychelles, and India at the following three times — 85 Ma (anomaly 34), 65 Ma (anomaly 28), and 63 Ma (anomaly 27). Your maps should show the continental margins, spreading ridges, and major transform faults. This is tricky because the magnetic anomalies are not mapped everywhere (that's why these are *approximate* maps), but don't forget to utilize the major fracture zones, which show you the directions or paths of relative motion.

c) Summarize, in words, how the Seychelles came to be stranded in the middle of the Indian Ocean.

4. 80 Ma Reconstruction

Repeat step 2a for 80Ma, then tape your reconstruction down on a blank sheet of paper — label it 80 Ma Reconstruction and turn it in with the rest of your lab.

5. 120 Ma Reconstruction

Repeat step 2a for 120 Ma (at this time, all of the current sea floor will be gone, so you'll be cutting around the continental shelves, colored gray on your map.). Tape your reconstruction down on a blank sheet of paper — label it 120 Ma Reconstruction and turn it in with the rest of your lab.

6. Paleolatitudes and Velocities

Igneous rocks from the Deccan Traps in India, an area of active volcanism from about 100-60 Ma, as well as some sedimentary rocks, record the local inclination of the Earth's magnetic field at the time of their formation. Paleomagnetists have collected cores from these sites and carefully analyzed the magnetic directions recorded by these rocks. A table of some of these data is included below, with additional columns for entering your calculations:

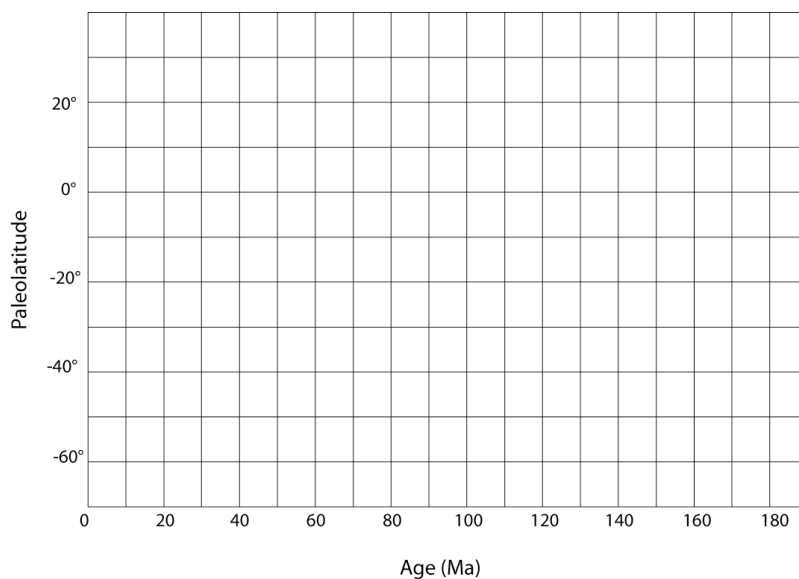
Age (Ma)	Inclination(°)	Paleolatitude(°)	Velocity (cm/yr)
180	-65		No entry here
100	-60		
65	-25		
20	+17		
0	+20		

In this table, negative inclinations indicate magnetic arrows pointing up from the surface.

a) Using the following relation

$$\text{paleolatitude} = \tan^{-1}(\tan(\text{inclination})/2),$$

convert the inclinations above to paleolatitudes and plot them on the graph below. The X-axis should be time in millions of years before present (180 to 0) and the Y-axis should be paleolatitude (-90° to 90°).



b) Then, plot three more points on your graph that show the latitudes at which India is found in your three reconstructions (you may need to lay your reconstructed maps on top of the uncut map, which has the latitude lines intact).

c) Are the paleolatitudes determined by these two different methods consistent?

d) Next calculate the velocities and enter them in the table above, assuming the motion of India was mainly due north (helps to know that there are 111 km per degree latitude). For 100 Ma, enter the velocity for the time period between 180 Ma and 100 Ma, for 65 Ma, enter the velocity for the time period between 100 Ma and 65 Ma, and so on.

e) Describe how the velocity has changed over time. Do the velocity changes make sense in light of the time of collision between India and Asia (very first contact about 60 Ma) and the time of major uplift (around 20 Ma)? The paleolatitude graph should be helpful here since the slope of this curve is directly related to the velocity. Explain your reasoning.

