Sea Level Change and Historical Earthquakes of Sumatra from Coral Growth Rings—Advanced (Longer) Version

The Sumatra region is prone to earthquakes because it lies at the boundary of two of Earth's shifting tectonic plates. The Indian Ocean crust is creeping steadily northeast and subducting beneath Sumatra. The steady horizontal movements, and pulses of faster horizontal motion that occur during earthquakes, are recorded by GPS stations on the islands. But GPS has only been recording horizontal land motion since the 1980s, so it can't tell us about earthquakes that happened long ago. GPS vertical motion data are not reliable, and are lacking for underwater regions like those at subduction zones.

In order to figure out how often large earthquakes happen in the Sumatra region, scientists have turned to coral micro-atolls. They also use coral records to reconstruct progressive sea-level changes. In this lab, you will use data from real corals collected in Sumatra to track the sea-level and earthquake record of the region over the past century.

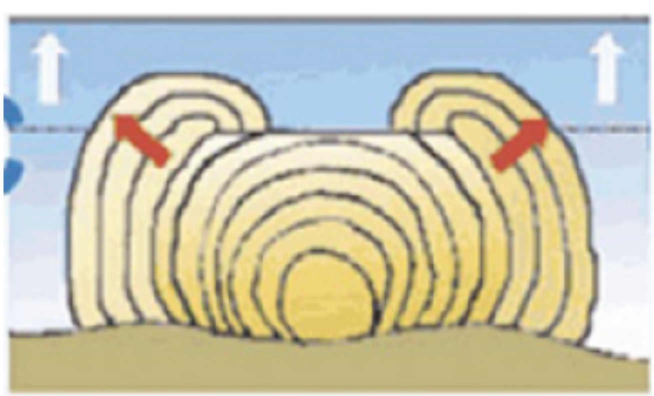
TOOLS

1) Figures 1–5 (including a location map) are included with this lab. You will refer to and annotate the coral figures to answer the following questions. For photos, illustrations, and animations related to coral growth and stranding, and for news coverage related to Sumatra earthquakes and tsunami, visit: **http://www.tectonics.caltech.edu/outreach/highlights/sumatra**
2) Colored pencils, ruler, calculator. Optional: graphing program such as Excel or MatLab.

OBJECTIVES

When studying earthquakes, scientists often concentrate on **coseismic** displacement of land along faults. In recent years, we have learned that there are also **interseismic** land level shifts in earthquake-prone regions. In this assignment, you will use coral **microatolls** to measure both **coseismic** and **interseismic** land-level changes. You will learn that corals provide precise data on

1) *how* land level changes
2) *when* a historic earthquake happened



Part I—Definitions and Context.

1) **Atoll—**

Coral heads from Sumatra are considered "microatolls" because each head is a small, circular "island." (The outer ring is alive but the inner area is submerged and inactive.)

Referring to this website,
http://www.tectonics.caltech.edu/outreach/highlights/sumatra/coral.html
explain how coral grows, and what each growth band represents.

What coral genus serves as a sea-level and seismic record in Sumatra? Can this coral type serve this purpose everywhere it grows? Why/Why not?

2) **Coseismic—**

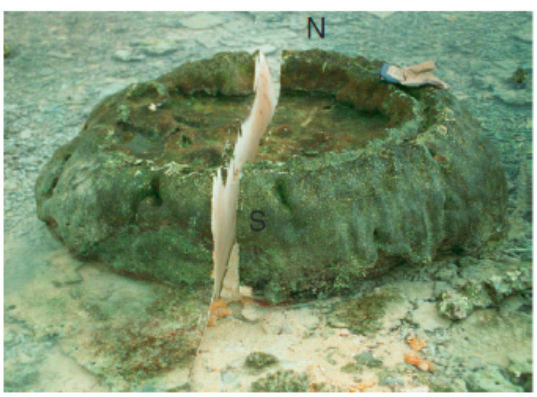
How long is a typical coseismic period?

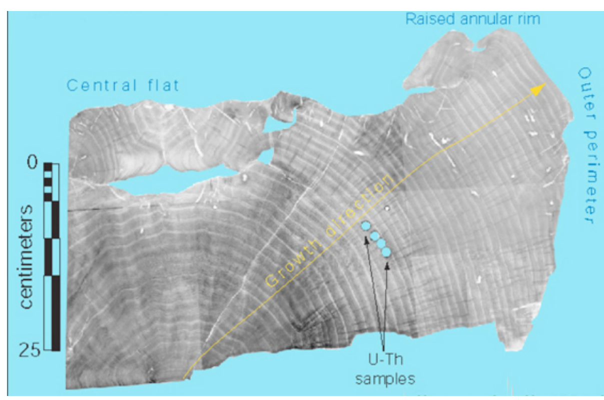
3) **Interseismic—**

How long can an interseismic period be? (Give an estimate of the range—shortest and longest)

4) **Unconformity** (general definition)—

What does an unconformity indicate about *time* in the geologic record?





Part II—Data Analysis

1) The upper part of Figure 2 is a vertical cross section through a coral microatoll from Bai (see map of Figure 1 for location). This cross section shows how the coral grew by adding a band each year, expanding outwards over time from right to left in the sketch. Each two-digit number indicates the year that band grew (all years in the 20th century). The last one grew in 1997, the year the slab was cut. The outer edge is the living part of the coral.

a) Using the scale bar, estimate the growth rate of the coral (measure the distance between several bands and give the average).

b) What does the top of each growth ring (HLS = "highest level of survival") represent in terms of water/tidal level?

c) Make a list of HLS over time, starting in 1964. (Use the scale at the left of the sketch.) Then plot your data on the graph below the coral cross section OR on a computer graphing program of your choice.

NOTE: some bands are incomplete, so you will need to exercise your scientific judgment to either trace these lines to completion, or eliminate them from your analysis.

2) Based on your understanding of an unconformity, do you agree that there are unconformities in the coral record as well? Use the coral section with colored lines on Figure 3 to guide your understanding of coral growth-ring unconformities.

a) What does an unconformity look like in the coral cross section?

b) What does an unconformity represent in the growth pattern of a coral?

c) To familiarize yourself with coral unconformities, on the coral sketch of Figure 2, mark each clear unconformity with a color (they are already indicated with a bolder line).

d) For what time period (give the years) is the record incomplete because of erosion? How can you tell?

3) The upper part of Figure 4 is a cross section of coral microatoll Tb1 from Bendera (see Figures 1a and 1b for location), which is on Tanabala Island. The 1949 ± 20 date is the *radiometric* U-Th age. All the other ages come from counting back from the outermost band, which we know grew in 2000. You may assume that these counting ages are correct.

a) On the blank graph below the coral cross section, plot HLS versus year from 2000 back to 1927. For this coral, plot the 2000 HLS as zero elevation. Plot only the growth bands that are long and continuous; ignore the shorter growth bands at the top left of the coral. Use different styles or colors of dots to distinguish where you clearly have HLS unconformities from where you only have minimum HLS and from where you think the uppermost part of the slab has been eroded.

4) The sketch in the middle of Figure 5 is a cross section of coral microatoll Tb2 from Bendera (see Figures 1a and 1b for location). Microatoll Tb2 comes from a site very close to microatoll Tb1 (Figure 4).

There is historical evidence that a large earthquake occurred in this region in 1935. We can also see from the growth rings that the site was uplifted during the 1935 earthquake. Again, you may assume the counting ages on this head are completely correct.

a) On the blank graph below the coral cross section, plot the HLS histories. Use different styles or colors of dots to distinguish where you clearly have HLS unconformities from where you have only minimum HLS and from where you think the uppermost part of the slab has been eroded. Ideally you will use data from both "wings" of the microatoll, but if this lab is taking you a long time, concentrate on data from only the right wing. If you use data from both wings and from the middle parts, use different colors and symbols to distinguish the various data types *and* sources.

The vertical axis is not numbered. You'll have to figure out what the actual values should be so that the data you plot from this head are in the same absolute reference frame as the data from Tb1. However you plot the absolute numbers, you should find that the vertical axis covers a total of 40 cm, i.e., each tick on the axis is 1 cm and each horizontal bar represents 5 cm.

Part III—Interpretation

Use your plots and the sketches of the coral slabs to answer the following questions:

1) **Figure 2**—the first coral you looked at:

a) From 1964–1997, has this coral been emerging, submerging, or both? How can you tell?

b) Calculate the coral's **average** rate of emergence and/or submergence over the 40-year period.

c) During this period, global sea level has been rising by about 2 mm/y. Use this record to correct your answer from 3b and determine the site's **actual average** tectonic uplift or subsidence rate.

d) Do you think your result indicates coseismic or interseismic motion? Why?

e) Is there an unconformity every year? Why or why not?

2) **Figure 4**—the second coral slab

a) From 1930–2000, has this coral been emerging, submerging, both, or neither? If both, what has been the predominant trend?

b) Calculate the average rate(s) of emergence or submergence during this time. Is there any suggestion of sudden events within this period? How can you tell?

c) Correct for global sea-level rise to obtain the site's actual tectonic uplift or subsidence history during this time period.

d) Is there any suggestion of a change in uplift or subsidence rate over time? Would you call your results in (c) coseismic or interseismic? Why?

3) **Figure 5**—the third coral slab; the second in the *set of two* from Bendera

a) Calculate the average rate(s) of emergence or submergence from 1900–1935.

b) Correct for global sea level rise to obtain the site's actual tectonic uplift or subsidence history during this time period.

c) How much of a difference do you generally see in coeval elevations from the left wing to the right wing? This should be obvious if you used both sides of the coral to generate your plot from question #4 in the last section, but it should still be fairly easy to compare if you did not. What does this tell you about the precision of HLS on any given head?

4) Comparing corals from Bai and Bendera.
a) Using the Figure 1 map, your sketches from coral heads Bai and TB1, and your answers from this section to discuss how uplift and subsidence from 1960–2000 differed on the two islands.

b) What does this suggest about interseismic effects with respect to distance from the subduction zone?

5) Comparing corals from Bendera (**Figure 6**)
Based on *in situ* surveying of heads TB1 and TB2 (Figs. 4 and 5), we know that the highest point on microatoll Tb2 is 55 cm higher than the highest level of growth on Tb1 in 2000.

a) Quantify the 1935 coseismic effect (i.e., total uplift). Include reasonable uncertainties.

b) How do the subsidence rates before and after 1935 compare? How does this tie in to your answer in 2 (d)?