

Goals

1. To use the December 2004 Sumatra Tsunami as an introduction to marine geology and physical oceanography. The earthquake and the related tsunami are excellent examples of the *interconnectedness* of ocean processes, a concept we will emphasize often this semester.
2. To introduce the use of the ArcReader GIS program. GIS (Geographical Information Systems) are used increasingly more often by in the Earth and Ocean scientists. Like professional scientists, we will use this GIS program to visualize spatial information from the oceans.
3. By the end of this exercise, you will have become familiar with
 - a. the relationship between earthquakes, tectonics, and seafloor bathymetry
 - b. the causes of tsunamis
 - c. the effects of tsunamis in general and how they manifested in the Indian Ocean in December 2004.

What to Do

1. Follow the directions given in class to start the computers, start the ArcReader program, and open the “lab1_tsunami” file.
A large map of the Earth should open in front of you. A legend should be visible off to the side showing various “layers” with little boxes to check them “on” or “off.”
2. Click the “Historical EQs” box on. You should see a map of historical earthquakes appear on the screen on top of the large map of the Earth.
3. Click on and off a few of the other layers to see what they do.

I. Earthquakes and Seafloor Bathymetry**1. Global Topography**

Click on the “Global Topography” layer. Turn all the other layers off.

Zoom in on the explanation at the bottom or to the right of the map. Highlight the little magnifying glass icon at on the toolbar of the program and then make a square on the map where you want to zoom in. The explanation at the bottom or right of the map provides a key for the colors that represent the depths below sea level of the ocean floor and elevation above sea level of the continents.

What are the maximum depths, in kilometers, of the ocean basins?

~11km

What colors represent deeper water?

Dark blues

What colors represent shallower water?

Lights blues

What are the maximum elevations, in kilometers, of the highest mountains of the continents?

~9km

The shape of the land above sea level is called *topography*. Ignoring Antarctica for the moment, which two continents have the highest topography?

2. Seafloor Bathymetry

Now let's investigate the shape of the seafloor. Seafloor **topography is called *bathymetry*.**

Mid-Ocean Ridges are large ridges, or elongated shallow areas, that generally occur near the middle of ocean basins.

Deep-Sea Trenches are long deep trenches that contain the deepest bathymetry of the ocean basins. They usually occur adjacent to land masses with chains of volcanoes or parallel to volcanic island chains.

Click *on* the "Trench-Ridge Example" layer. Zoom into the shaded area labeled "Mid-Ocean Ridge." Click the "Trench-Ridge Example" layer *on* and *off* to see what the bathymetry looks like along a good example of a mid-ocean ridge. Note the shallow water along the crest of the ridge and the linear fracture zones that cut across the ridge perpendicularly.

Zoom back out to see the entire Earth.

Click *on* the "Trench-Ridge Example" layer. Zoom into the shaded area labeled "Deep-Sea Trench." Click the "Trench-Ridge Example" layer *on* and *off* to see what the bathymetry looks like along a good example of a deep-sea trench. Note the deep water along the trench. The deepest location in all of the oceans occurs near the southern portion of this shaded region, south of the Mariana Islands. Note also the chain of islands that parallels the deep-sea trench just to the west of this particular trench. These islands are mostly active volcanoes. Active volcanoes also occur on the islands of Japan and on the Kamchatka Peninsula.

Zoom back out to see the entire Earth.

Zoom into the area just a few kilometers off the western coast of South America. This area is a (circle one) **deep-sea trench or mid-ocean ridge.**

Zoom into the southern Atlantic Ocean. The feature mid-way between South America and southern Africa is a (circle one) **deep-sea trench or mid-ocean ridge.**

3. Big Earthquakes of the last 100 years

Zoom back out to the whole Earth. Turn *off* the “Trench-Ridge Example” layer and turn *on* the “Ten Significant EQs” layer. These are the ten largest earthquakes of the last 100 years, essentially since modern seismological measurements have been employed. The number listed with each of the earthquakes is its *magnitude*, a measurement of how large the earthquake is.

Which earthquake has the highest magnitude in the last 100 years?

Chile, 1960

Where does the Sumatra, 2004 earthquake rank in terms of highest magnitude of earthquakes in the last 100 years?

4th largest, according to the USGS: <http://earthquake.usgs.gov/eqinthenews/2004/usslav/>

Now, Zoom in to get a closer look at the bathymetric or topographic features associated with each of the large earthquakes. Is each of these earthquakes associated with a deep-sea trench, a mid-ocean ridge, or neither? Complete the following table with your findings by checking the appropriate box. The first one is done for you to show that the Kamchatka, 1923 earthquake is associated with a deep-sea trench.

Earthquake	Deep-Sea Trench	Mid-Ocean Ridge	Neither
Kamchatka, 1923	√		
Kamchatka, 1952	√		
Rat Islands, 1965	√		
Kurile Islands, 1963	√		
Assam-Tibet, 1950			√
Banda, 1938	√		
Chile, 1960	√		
Equador, 1906	√		
Aleutians, 1957	√		
Alaska, 1964	√		
Sumatra, 2004	√		

Most of the ten biggest earthquakes of the last 100 years associated with (circle one) **mid-ocean ridges** / **deep-sea trenches**.

Based on your results, is the Sumatra, 2004 earthquake similar or dissimilar to most of the other largest earthquakes of the last 100 years in terms of the bathymetric feature it is associated with? Please explain.

The Sumatra, 2004 EQ is **similar** to all but one of the ten largest EQs of the last 100 years. It occurs near a deep-sea trench, as do most of the other ten largest EQs.

4. Earthquake Distribution

Turn *on* the “Historical EQs” layer. This layer shows significant global earthquakes of magnitude greater than 5, color coded by magnitude with higher magnitude earthquakes having larger symbols and warmer colors. Click this “Historical EQs” layer *on* and *off* to answer the following questions.

Mid-ocean ridges are associated with a (circle one) **wide** / **thin** band of **lower** / **higher** magnitude earthquakes.

Deep sea trenches are associated with a (circle one) **wide** / **thin** band of **lower** / **higher** magnitude earthquakes.

Most of the world’s earthquake energy appears to be released at (circle one) **deep-sea trenches** / **mid-ocean ridges**.

Based on location, regional earthquake history, and the nearby bathymetric features, the Sumatra, 2004 Earthquake was (circle one) **typical** / **atypical** of events expected in this region over a long period of time. Please explain why.

The Sumatra region is home to many big EQs over the time people have been recording EQs. Some of these EQs have been quite big. In addition, the tectonic setting of the Sumatra region, specifically near a convergent margin as evidenced by the deep-sea trench, also indicates a region typically home to large EQs.

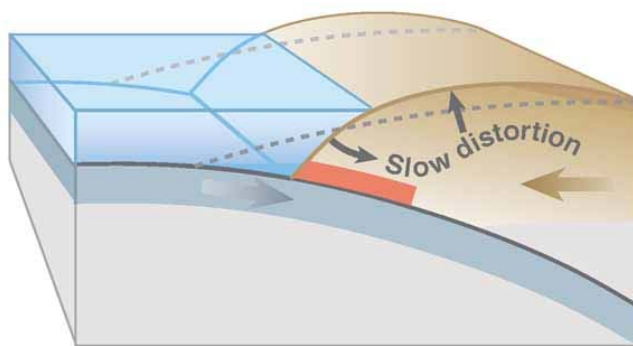
5. Causes of Tsunamis.

USGS Circular 1187 is an excellent summary of lessons learned from previous tsunamis associated with large earthquakes. It was written and published in 1999, well before the 2004 Sumatra EQ and tsunami. Open and read this document at:

<http://pubs.usgs.gov/circ/c1187/>

(At home, you can find a copy of this document on the class website and print a color copy for yourself by clicking on and saving the pdf version of the file.)

In the section called, “The 1960 Tsunami and the Earthquake in Chile That Caused It”, seafloor processes that cause tsunamis are explained. What must happen on the seafloor to generate a tsunami? Be specific. **The seafloor must move in a vertical manner. The larger the movement on the seafloor, the larger the tsunami will be. The seafloor movement could also be caused by an underwater landslide.**

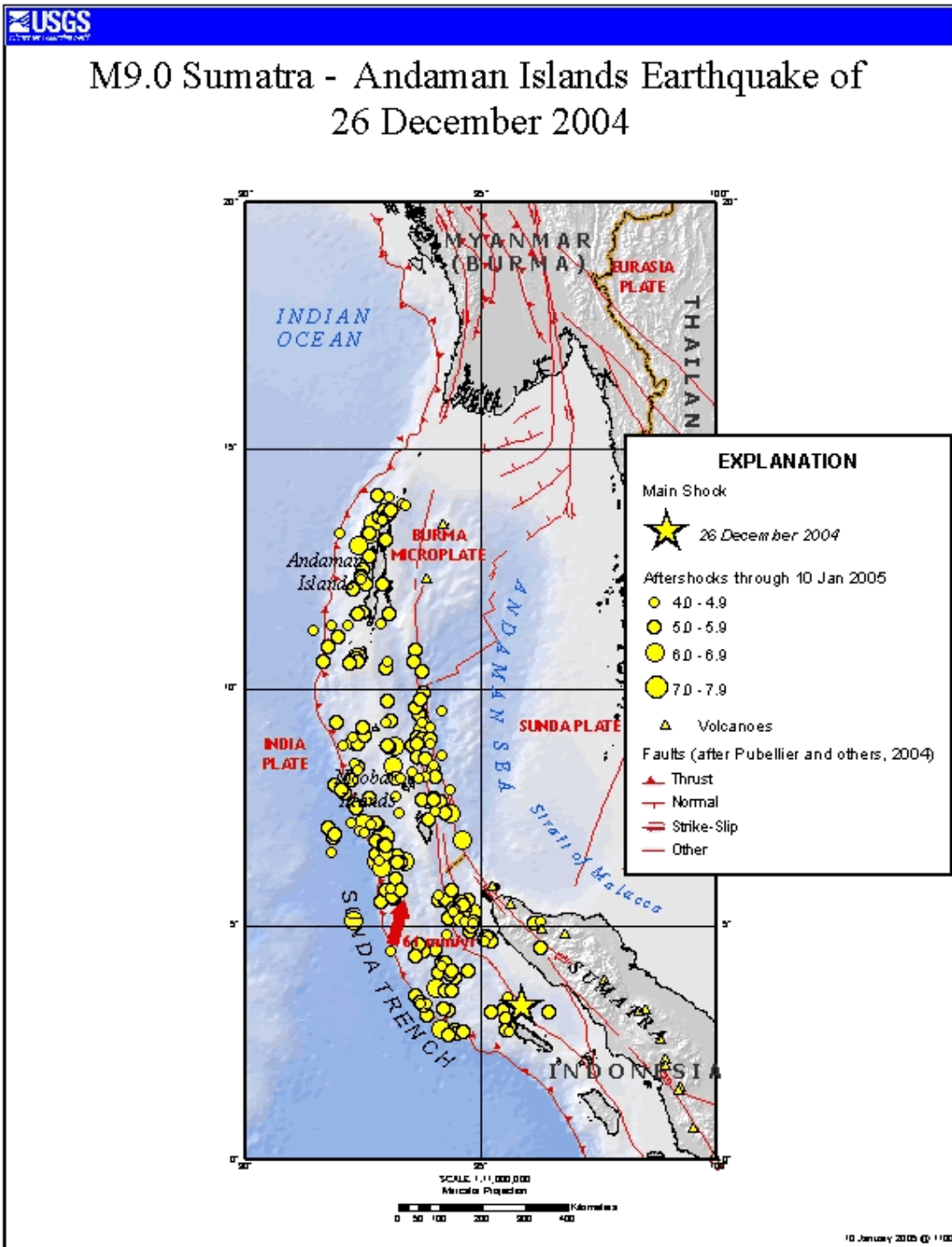


The figure at left is from the USGS Circular. On this image, where is the deep-sea trench discussed in earlier sections of this lab? Shade and label it on this image with your pencil. **Near the left side of the red bar.**

What process causes deep-sea trenches to form? (The marine geology word for this process is “subduction.”) **Plates moving towards each other and one plate sinking, or**

moving beneath, another plate.

Why do you think that most of the Earth’s earthquake energy is released near deep-sea trenches? **Because the plates are moving towards each other. Lots of energy is likely to build up.**



This image shows the main shock and aftershocks of the Sumatra, 2004 Earthquake. The distribution of aftershocks shows the region that “ruptured”, or moved, during the earthquake. The area of rupture of the Sumatra, 2004 earthquake is (circle one) **much bigger** / **about the same size** / **much smaller** than/as the 1960 Chile EQ and/or the 1700 Cascadia EQ. To answer this question, use the scales on the maps presented in the section called “Similar Tsunamis, Similar Strategies for Survival” in the USGS circular.

For more clues to the question about rupture zone size on the previous page, see the map at: http://earthquake.usgs.gov/eqinthenews/2004/usslav/rupture_area-nw.html

In the Circular section entitled “Similar Tsunamis, Similar Strategies for Survival”, graphs show that the length of time between large regional EQs, such as those that occurred in Chile and Cascadia is (circle one) **days / weeks / years/ hundreds of years / thousands of years.**

6. Effects of Tsunamis

In this last section, I’d like you to compare what was known about tsunamis through documentation of the Chile EQ tsunami in 1960 and presented in the USGS Circular, and what happened in the 2004 Indian Ocean Tsunami. In other words, in this section, think about whether the effects of the 2004 Indian Ocean Tsunami were predictable or not.

Start by reading and looking at the pictures in the remaining sections of the USGS Circular (<http://pubs.usgs.gov/circ/c1187/>) and summarizing the known characteristics of large tsunamis.

Write the major characteristics of things to expect during a tsunami here:

Water rises continuously. Sea level may fall first. Lots of debris in flowing water Buildings destroyed. Earthquakes may be foreshocks to the main earthquake.	Roads and bridges washed out. Coastline severely altered. Lots of homeless people. Many people survive Earthquake but then die in Tsunami Coastal waters rise.
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Next, research the effects of the 2004 Indian Ocean Tsunami.

Required places to start your research include before-and-after satellite photos available at:

<http://homepage.mac.com/demark/tsunami/1.html>

Other good satellite sites (suggested but not required) are:

http://www.digitalglobe.com/images/tsunami/Banda_Aceh_Tsunami_Damage.pdf

and

http://www.digitalglobe.com/images/tsunami/Sri_Lanka_Tsunami_Damage.pdf

and

http://www.digitalglobe.com/images/tsunami/Meulaboh_Tsunami_Damage.pdf

Also required is viewing some digital videos shot mostly by surprised citizens unlucky enough to be near the beach when the tsunami came in. (location of digital videos TBA)

Write the major characteristics of the 2004 Indian Ocean tsunami here. Use the resources suggested here and any others that you know of or that you can find.

Nearly all the things predicted by the studies of the earlier tsunamis:

[Roads and bridges washed out \(see satellite images\)](#)

[Many homeless \(satellite images and numerous news reports\)](#)

[Sea level fell first in some areas. \(news report of 10 year old girl saving many tourists\)](#)

[Lots of debris in water \(see amateur videos\)](#)

[Coastline severely altered \(see satellite images\)](#)

[Many people survived the Earthquake but then died in the Tsunami \(news reports hardly mention the EQ any more\)](#)

[Buildings destroyed \(see satellite photos and videos\).](#)

7. Comparison of older and recent tsunamis

What are the similarities that occurred in the 1960 Chile EQ Tsunami and the 2004 Sumatra EQ Tsunami? Write here a list of effects that happened in 2004 that were similar to the things that happened during the 1960 Chile EQ Tsunami, and thus could have been predicted to occur once a large EQ struck.

Almost *all* of the things predicted by the USGS Circular to happen during a tsunami actually happened. See how similar the lists in the previous two questions are.

Were there any effects of the 2004 Sumatra EQ tsunami that were *not* expected based on work on the 1960 Chile EQ Tsunami? If so, what were they?

No obvious and important ones that I can think of.

8. Main points of this lab

Please summarize the main points of this lab by briefly explaining the relationship between deep-sea trenches, great earthquakes, displacement of the seafloor, and the generation of tsunamis.

The magnitude 9.0 Sumatra 2004 Earthquake occurred close to a deep-sea trench and in an area where many large EQs have occurred in the past. These two observations suggest that the Sumatra EQ is not unusual or atypical in any way. We could predict that if large earthquakes are to occur on the Earth in the future, the Sumatra area is one of the places where this might occur. We do not, however, know **when** in the future the earthquakes will occur. Deep-sea trenches are associated with subduction zones, which form at convergent margins where one plate slips beneath another. Most of the Earth's earthquake energy is released in these areas as the two plates grind towards each other.

Finally, briefly summarize the main effects of tsunamis in general as documented in the USGS Circular and how these effects manifested tragically around the Indian Ocean in December of 2004.

Water rises continuously: See many amateur videos that show the water rising continuously; the water just seems to continuously flow onto shore.

Sea level may fall first: Not sure if you can see this on any of the videos, but see the news story about the 10-year old science student.

Lots of debris in flowing water: One of the most striking things about the amateur videos is all the debris in the water. People are hit with this debris and are either injured or killed.

Buildings destroyed: Very evident in the satellite images; some images show whole city blocks or villages wiped out.

Roads and bridges washed out: Lots of satellite images show major roads and bridges in coastal areas destroyed.

Coastline severely altered: Satellite images show lots of examples of this. Looks similar to when a hurricane hits the southeast coast of North America.

Lots of homeless people.: Lots of news stories document this problem.

Many people survive Earthquake but then die in Tsunami: This one is hard to document because the tsunami was a much greater hazard and it is hard to differentiate whether damage was caused by the tsunami or by the earthquake.