

Introduction to Plate Tectonics via Google Earth

Plate tectonics is a unifying framework for understanding the dynamic geology of the Earth. The theory posits that the outermost layers of the Earth (the crust and uppermost mantle) make up the brittle lithosphere of the Earth. The lithosphere is broken up into a number of thin plates, which move on top of the asthenosphere (middle mantle). The asthenosphere is solid, but flows plastically over geologic time scales. Plate interiors are relatively stable, and most of the tectonic action (earthquakes, volcanism) takes place where plates meet – where they collide at convergent boundaries, move away from one another at divergent boundaries, or slide past one another at transform boundaries.

Reconstructions of the Earth's tectonic plate locations through time are available, for example, at:

<http://www.ig.utexas.edu/research/projects/plates/recons.htm#movies>

<http://www.scotese.com/newpage13.htm>

<http://www.ucmp.berkeley.edu/geology/tectonics.html>

But how do we define plates and plate boundaries? On what are plate reconstructions and animations based? How do we know plates are moving, how can we track their positions in the past, and how can we predict their positions in the future?

To answer these questions, this assignment guides you through an examination of patterns on Earth – the topography of the earth's surface above sea level, the bathymetry of the ocean floor below sea level, and the distribution of earthquakes and volcanic rock ages. You'll then use geologic data to determine long-term average plate motions.

To do this, you'll use the program Google Earth, and Google Earth layers compiled from various sources.

A. Getting started with Google Earth

- On your computer, install the latest version of **Google Earth** from <http://earth.google.com/>
- Once installed, open Google Earth, under the Tools/Options/3D View/ menu choose the “**Decimal Degrees**” and **Meters Kilometers**” options and makes sure the “**Show Terrain**” box is checked.
- Open the View menu. Go ahead and experiment with the options, but in general you should just have the **Tool Bar**, **Side Bar** and **Status Bar** checked. Also on the View menu, hover over Navigation and you will see several options for the compass arrow and slide bars in the upper right corner of the Google Earth screen. “**Automatically**” is a good choice as it leaves a ghost of the image visible until you hover over it.
- Load the **DynamicEarth.kmz** file into GE. You should be able to double-click on the filename and it will open within GE. Or, you can download the file onto your computer, and open it in GE by using File/Open and navigating to the file.

Once the DynamicEarth.kmz is loaded, click and drag to move it from “Temporary Places” to “My Places.” Then save “My Places” by clicking File/Save/Save My Places. DynamicEarth.kmz will now be available every time you open GE on this particular computer.

When you exit, GE should save “My Places” for the next time.

But you should manually save “My Places” whenever you make significant changes to it, as GE does not autosave during a session.

Ok, with an active Internet connection, you now have an interactive view of the earth! Take some time to explore the Earth with Google Earth and figure out how the navigation works using the keyboard, your touch pad, your mouse. For example:

- Zoom in and out, move N, S, E, W, grab and spin the globe, etc. The resolution will change as you zoom. Clicking on the “N” of the navigation compass reorients the view so north is “up.”
- At top left, “search” (and fly to) any place of interest. Zoom in and click on the “street view” icon (orange stick figure under the compass at top right) to explore an area as if you were on foot
- Zoom in to see individual buildings, roads, cars, etc. (Find the crew team and motorboat on Lake Carnegie)
- Go 3D - zoom into a significant topographic feature (e.g. Mount Everest, the Grand Canyon, Niagara Falls). Hold the Shift key down and tilt the terrain using the Up/Down arrows to tilt the terrain, and spin the terrain using the Right/Left buttons. Do the same thing for topographic features on the ocean floor. Note that under Tools/Options/3D View you can increase the vertical exaggeration by up to 3x. This is useful to emphasize subtle features, but is pretty scary when you look at the Grand Canyon that way!
- On the Google Earth tool bar, click the clock-with-an-arrow icon to explore historical imagery in an area of interest (views through time of the Princeton campus, for example)
- By clicking and dragging, you can move things that you have found and want to save, from the “Search” menu into “My Places.” You can also re-organize “My Places” by adding and deleting items, changing the order of things, making subfolders, etc.
- Explore the built-in items under the Layers menu at bottom left, and Dynamic Earth layers in your Places menu.

Expand and contract the folders and subfolders, turn various items on and off, etc. For example, with the Dynamic Earth/**Volcanoes of the World** layer displayed, right-clicking on a volcano brings up an information box about it.

1. Find something interesting, significant, cool, etc. to share on Google Earth with your classmates at your first lab session. This can even be something that other people have developed – if you want to spend some time poking around on the web to see what others have found. Feel free to include more than one.

Give a brief description of your item(s) below:

B. Topographic Patterns Uncheck all of the layers and focus on topographic features of the earth.

Topography of the earth ABOVE sea level

2. Are mountains randomly distributed on the continents, or do they tend to occur in particular patterns (clusters, linear chains, arcs, etc.)?

3. Find Mt. Everest, the highest point on earth. Zoom in enough to see the summit, then pan your cursor around to locate the highest point (elevation shows up in the status bar at the bottom, as long as View/Status Bar is selected): _____ meters

Topography of the earth BELOW sea level

We are all relatively familiar with the topography of the Earth's surface above sea level, but less so with the bathymetry of the Earth below sea level. Before this was known, most people assumed that the seafloor was relatively flat and featureless, and personal experience with lakes and rivers suggested that the deepest part would be in the middle. Actual mapping of the sea floor, however, showed some surprises.

Such mapping began in the 1930's but accelerated during World War II with the advent of submarine warfare. Princeton Geosciences Professor Harry Hess played a pivotal role; as captain of the USS Cape Johnson he used the ship's echo-sounder to "ping" the seafloor and measure depth as the ship traversed the Pacific Ocean between battles. After the war, this data led him to propose seafloor spreading, a process crucial to the development of the theory of plate tectonics.

Modern methods to measure bathymetry include multi-beam echo sounders that map a wide swath of seafloor, and satellite measurement of variations in sea level due to variations in gravitational pull over bathymetric features – sea level is slightly lower over low spots on the sea floor and slightly higher over high spots.

On Google Earth, the bathymetry is shown in shades of blue: the darker the blue, the greater the depth. You can get Google Earth to draw topographic profiles by a) using the "Add Path" tool to draw a path across a region of interest; b) saving that path to My Places and c) right-clicking on the path in My Places and choosing "Show Elevation Profile."

Examine the Atlantic Ocean between North/South America and Eurasia/Africa. Note that the deepest part is not in the middle; instead there is an underwater mountain range that runs down the middle of the ocean.

4. Features like this are called mid-ocean ridges or spreading ridges (more on the “spreading” in lab). Zoom in enough to see that although the ridge is a topographic high, it also has a valley (the “rift valley”) running along the middle of it. In the space below, complete the topographic profile of the Atlantic Ocean floor between South America and Africa.



Scan around to see the ocean ridges in the Indian, Pacific and Southern Oceans.

5. If the earth’s lowest spots aren’t in the middle of the ocean, where are they? Focus on the west coast of South America, and in the space below complete the topographic profile of the Pacific Ocean floor from South America westward about 600 miles (1000 km).



The deep linear features, the lowest points on Earth, are called *ocean trenches*.

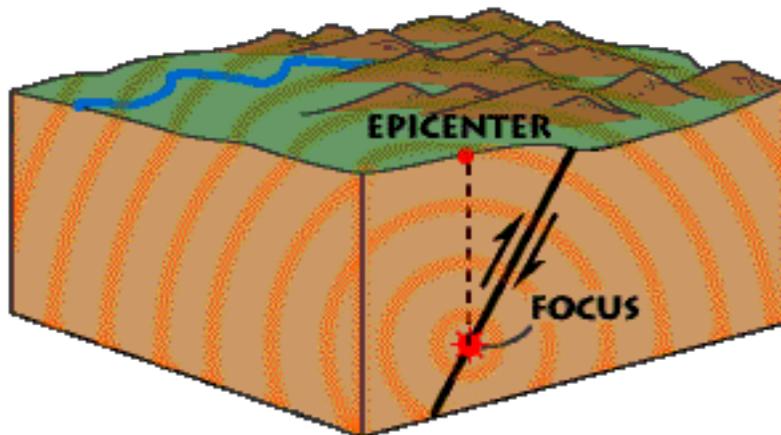
6. Using Google Earth, “fly to” Challenger Deep, the deepest place on Earth (once Google Earth gets you there, you may have to zoom out to see where you are). Where is it?
7. Challenger Deep reaches 11 km (36,000 ft) below sea level. Which is greater, the elevation of Mt Everest (see question 3) above sea level, or the depth of Challenger Deep below sea level, and by how much?
8. Give the locations of three other ocean trenches on earth.

C. Seismic Patterns

An earthquake is a vibration of Earth caused by the sudden release of energy, usually as an abrupt breaking of rock along planar fractures called *faults*.

Earthquakes originate at a point called the *focus* (or *hypocenter*) which is not at the surface of the earth, but instead at some depth within the earth. The *epicenter* of an earthquake is the point directly above the focus on either the land surface or seafloor; the depth of an earthquake has nothing to do with water depth, but instead is the depth in the solid earth from epicenter to focus.

Only rocks that are cold and brittle (the earth's *lithosphere*) can be broken in earthquakes. Rocks that are hot and ductile will stretch and deform slowly over time without breaking (the earth's *asthenosphere*) – and thus do not produce earthquakes. So observing where earthquakes occur, both horizontally and with depth, tells us something about where stress is concentrated, and also about the material properties of the earth.



Expand the Lab 1/Earthquakes item and click “on” the “Twenty years of large earthquakes” layer to show the epicenters of large earthquakes (those with magnitudes ≥ 6.0) during a 20-year period.

9. Describe any patterns you see in the distribution of earthquake epicenters over the Earth's surface - do they form lines, arcs, circles or clusters? Are patterns connected or disconnected?

10. The different colors of refer to the depths of the earthquakes. What color are the shallowest earthquakes? _____ The deepest? _____

11. Look closely at and around the Earth's ridges and trenches. The earthquake depth patterns associated with these features are different. Complete the chart below:

	In the vicinity of ridges. (Scan 1500km or so on either side)	In the vicinity of trenches. (Scan ~1500 or so km on either side)
Describe the depth or range of depths of earthquakes, and the distribution (symmetric or asymmetric?) Is there any pattern to the depth distribution?		

16. Using earthquake depths as evidence, is the Earth's lithosphere thicker in the vicinity of ridges or in the vicinity of trenches? Justify your answer.

D. Volcano Patterns

A *volcano* is an opening in the Earth's surface through which melted rock (*magma*), volcanic ash and/or gases escape from the interior of the Earth.

12. Leaving the earthquake layer on, click on the Active Volcanoes layer. Describe the relationship between the locations of most active volcanoes and locations of earthquakes:

E. Plate Boundaries

The theory of plate tectonics posits that the Earth's lithosphere is broken into a finite number of jigsaw puzzle-like pieces, or *plates*, which move relative to one another over a plastically-deforming (but still solid) asthenosphere. The boundaries between plates are marked by active tectonic features such as earthquakes, volcanoes, and mountain ranges and there is (relatively) little tectonic activity in the middle of plates.

Unclick all the layers, and then click on the "plate boundary model" layer (click the box to show it and then click the + or arrow to expand the legend). This shows plate boundaries and the names of major plates.

Find the boundary between the African and South American plates

13. Where is this plate boundary, relative to the coastlines of Africa and South America?

14. Now click the other layers on and off so that you can see relationships between plate boundaries and these features. If you did not have the "plate boundary layer" available to you, how could you determine where this plate boundary was? Be sure to consider topography/bathymetry as well as the earthquake and volcano layers. List several ways and be specific.

Travel westward across the South American plate to its boundary with the Nazca plate

15. Where is this plate boundary, relative to South America?

16. If you did not have the "plate boundary layer" available to you, how could you determine where this plate boundary was? List several ways and be specific.

F. Plate motion

Motion across the mid-Atlantic ridge: the South American plate vs. the African plate

Turn on the "Seafloor age" and the "Plate Boundary" Google Earth (GE) layers. The "Seafloor age" layer shows the ages of volcanic rocks that have erupted and cooled to form the ocean floor. Focus on the Atlantic Ocean. Note that the age bands generally run parallel to the spreading ridges. Seafloor age is a critical piece of evidence for plate tectonics; these are used to reconstruct how ocean basins have developed over time and predict how they may evolve in the future.

17. How many years does each colored band represent? _____

18. On average, continental crust is 2 billion years old; the oldest rocks are 3.8 billion years old, and some of the grains in those rocks are even older.

What is the age of the oldest seafloor? _____

On average, which is oldest – the continents or the ocean basins? _____

19. Find the South American plate, the African plate, and the Mid-Atlantic Ridge that marks the boundary between them. What happens to the age of the seafloor as distance increases away from the Mid-Atlantic Ridge?

20. Is crust being created or destroyed at this plate boundary (and other spreading ridges)? _____

21. Is this plate boundary divergent, convergent, or transform? _____

22. Focus on the northern Atlantic Ocean, near the east coast of the US and the northwest coast of Africa. How long ago did the northern Atlantic Ocean begin to open up or start spreading? Describe your reasoning.

23. Did the northern Atlantic Ocean basin start opening at the same time as the southern Atlantic Ocean basin? How much older or younger is the northern Atlantic basin than the southern Atlantic basin? Describe your reasoning.

24. Focus on a particular part of this plate boundary, and choose either the area of the mid-Atlantic ridge and choose either the South American plate side or the plate side. Use Excel (or other resource) to make a graph of *cumulative* distance away from the plate boundary (y-axis) vs. age (x-axis). Format the graph appropriate with title, axes, etc. Have Excel fit a trend line your data, and display the equation of the line and the R^2 value on the graph. (Recall that R^2 is a measure of how well the data fit a linear trend. If $R^2=1$, all the data points fall exactly on the line; if $R^2=0$ there is no significant linear trend.) Print out for submission with your report.
25. Describe the motion of your chosen plate relative to the mid-Atlantic ridge, based on this seafloor age data – the direction of motion, the average speed (slope of the best fit line) and whether or not speed and direction has been constant over time.
26. Compare these results to an independent data from the Tristan da Cunha Volcanic Island/Seamount chain on the African plate off the southwest coast of Africa as follows:
- To access this data, expand the Volcanic Island/Seamount chain layer on GE, then expand the AtlanticOceanChains layer, and then click to display Tristan da Cunha. You may need to click off Sea Floor age layer.
- These islands and seamounts are volcanic edifices built up on older seafloor, formed by eruption of magma from relatively stationary sources (“hot spots”) underneath the moving plates. The numbers are the radiometric ages in millions of years of volcanic rocks collected from each island/seamount.
- Does data from the Tristan da Cunha Volcanic Island/Seamount chain support the plate motion you deduced from the sea floor age data? Explain.
27. If two independent sets are good, a third is even better. Compare your results to data from the New England Seamount chain off the northeast coast of North America – these are on the North American plate on west side of the mid-Atlantic ridge. Does this data support the African plate motion deduced above? Explain.

Apply what you have learned – the Pacific Plate

28. Turn your attention to the Pacific plate. Note that the Pacific Ocean is comprised of several plates; we want to focus on the very large Pacific plate (not the Nazca plate, or Cocos plate, or Philippine plate or other plates.) The Pacific plate is “born” underwater at the East Pacific rise, the spreading ridge west of South America. It is being destroyed at convergent boundaries around its northern, western, and southern boundaries.
- a. Is the East Pacific Rise spreading faster or slower than the mid-Atlantic Ridge and how can you tell - without doing any calculations? Has the rate been constant over time?
 - b. Make and print out a graph (similar to what you did in question 24) for movement of the Pacific plate away from the East Pacific Rise.
 - c. Describe the motion of the Pacific plate relative to the East Pacific Rise, based on this seafloor age data - direction of motion, average speed and whether or not speed and direction has been constant over time.
 - d. Consider the Volcanic Chains in the Pacific Ocean (Hawaiian/Emperor, Louisville, and Easter Island). Do these data support the movement you deduce for the Pacific Plate? Explain.
 - e. What does the bend in the Hawaiian/Emperor chain indicate happened about 50 million years ago to the direction of Pacific plate movement?

G. Putting it all together:

29. Sketch a north-facing cross-section along $\sim 10^{\circ}\text{S}$ latitude from Africa westward to the middle of the Pacific Ocean ($\sim 130^{\circ}\text{W}$ longitude). Plate-wise, that would be from the African plate, across the South American and Nazca plates, and ending in the middle of the Pacific Plate - crossing 3 plate boundaries. Use the Google Earth imagery and layers to give the necessary detail so that you include and label the following:
- Sea level
 - Significant topographic features of the continents and the seafloor
 - Earthquake hypocenters (indicating depth below epicenter)
 - Volcanoes
 - Plate names and plate boundary locations
 - Appropriate vertical and horizontal scales.
 - Arrows indicating relative plate motion