

Introduction to Plate Tectonics via Google Earth

The theory of plate tectonics posits that the Earth's lithosphere (crust and upper mantle) is broken into a number of jigsaw puzzle-like plates which move relatively to one another over a plastically-deforming (but still solid) asthenosphere (mid and lower mantle). The boundaries between plates are marked by a variety of topographic and tectonic features, and there is relatively little tectonic activity in the interior of plates.

The following exercises explore some of the evidence used to locate and interpret tectonic plates and plate boundaries.

Getting set up 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 make 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. Work through the following:
 - 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 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!
 - 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.
- Under Dynamic Earth, turn on the Plate Boundary Model layer to see the boundaries of 14 large and 38 small tectonic plates as defined by Bird, P. (2003), *An updated digital model of plate boundaries*, *Geochemistry Geophysics Geosystems*, 4(3), 1027.

Topography of the continents and bathymetry of the sea floor

Uncheck all of the layers and focus on the topography of the earth.

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 echosounder 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 multibeam echosounders which 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. This is termed an *ocean ridge* or *spreading ridge* (more on spreading later). Zoom in enough and/or draw a profile (see above) to see that although the ridge is a topographic high, it also has a valley (the "*rift valley*") in the middle. Scan around to see the ocean ridges in the Indian, Pacific and Southern Oceans.

So 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 note the deep linear ocean trench about 100km off shore that runs along the length of the continent. Scan around to see the ocean trenches in the other oceans.

1. Search" and "fly to" *Mt. Everest*, the highest point on Earth's land surface and *Challenger Deep*, the lowest point on Earth's seafloor. Use the Status Bar to get the elevation/depth of each. Which is greater, the elevation of Mt. Everest above sea level or the depth of Challenger Depth below sea level and by how much, what %?

Seismicity

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. An earthquake initiates at its *hypocenter* or *focus* at some depth below the land surface or sea floor. The *epicenter* of the earthquake is defined as the point on the earth's surface above the hypocenter.

Only rocks that are relative cold and brittle (the earth's lithosphere) can be broken in earthquakes. Rocks that are hot and ductile will deform 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.

Under Dynamic Earth, expand the **Seismicity** layer and click on the **Twenty years of large earthquakes** layer to show the epicenters of relatively large earthquakes (those with magnitudes ≥ 6.0) from 1993-2012. The color of each symbol indicates the depth to hypocenter for each earthquake. Zoom in and out, pan around and explore the global seismicity.

2. Epicenter distribution: describe any patterns you see in the distribution of epicenters over the Earth's surface - do they form lines, arcs, circles or clusters? Are patterns connected or disconnected?
3. Earthquake depth: examine the regions on and around Earth's ocean ridges and ocean trenches; the earthquake depth patterns associated them are different. Describe the patterns associated with ridges vs. trenches. Then, using earthquake depths as evidence, discuss whether the Earth's lithosphere is thicker at ridges or at trenches.
4. Earthquake frequency: click off the other earthquake layer(s), and click on the USGS Earthquakes colored by age layer. Expand this layer until you see a list of the number of earthquakes of each magnitude that have occurred in the last week. Make a semi-log plot of # of earthquakes (log scale) vs. magnitude, and then use this data to extrapolate the number of earthquakes of magnitude 0 that have occurred in the past week (yes, earthquake can have magnitudes of 0 and < 0 ; more on magnitude later).

Volcanism

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. Under Dynamic Earth, compare the **Volcanoes of the World** layer and the **Twenty years of large earthquakes** layer and note how volcanoes are always associated with earthquakes, but not the other way around.

Seafloor Age

Turn off the **Seismicity** and **Volcanism** layers, and turn on **Seafloor age**. This layer shows the ages of volcanic rocks that have erupted and cooled to form the seafloor - seafloor age is a critical piece of evidence for plate tectonics. Focus on the Atlantic Ocean. Note that the 10 million-year-old age bands run parallel to the mid-Atlantic ridge.

Keeping the **Seafloor age layer** displayed, turn on the **Plate Boundary Model** layer. Note that the model places the boundary between the North/South American plates and Eurasian/African plates along the mid-Atlantic ocean ridge where the seafloor is young, and that seafloor age increases symmetrically on either side of the ridge. This is used to support the idea that lithosphere is being created at mid-ocean ridges, and that mid-ocean ridges mark *divergent* plate boundaries.

Using geologic data to determine plate motion

5. Movement of the North Atlantic plate

- Use data from Google Earth Seafloor age layer to calculate the rate at which the North Atlantic plate has been moving away from the mid-Atlantic ridge over the last 100 million years or so. Use the Ruler tool from the tool bar to measure distance, and give your answer in mm/ year or km/my.
- Did the northern Atlantic Ocean basin begin opening at the same time as the southern Atlantic Ocean basin? How much older or younger is the South Atlantic than the North Atlantic? Describe your reasoning.
- Find the East Pacific Rise, the spreading ridge west of South America. Without doing any calculations - is this ocean ridge spreading faster or slower than the mid-Atlantic ridge? How can you tell?

Turn off the sea floor age layer, and turn on the **Volcanic Chains** layer. This shows the ages of volcanic rocks on oceanic islands and seamounts, formed by volcanic eruptions superimposed on older seafloor.

6. Movement of the Pacific plate Focus on the Hawaiian Island/seamount chain. Zoom in so that the numbers representing the ages of the rocks in the chain (in millions of years) are displayed.

- Assume that this chain is generated by a stationary plume or "hot spot" which periodically erupts to form a volcanic island or seamount atop the ocean floor. What is the implied velocity (speed and direction) of the moving Pacific plate over the last 41 million years? Again, use the Ruler tool from the tool bar to measure distance and the volcanic ages to give time, and give your answer in terms of mm/ year or km/my.
- Now assume that the chain is generated by a moving hot spot under a stationary plate. What is the implied velocity (speed and direction) of the moving hot spot over the last 41 million years?
- Turn the seafloor age layer back on. With which of the two options above is it consistent? Explain.
- Find the Louisville chain in the southern Pacific Ocean (on the Pacific plate east of New Zealand). Does it support your choice? Explain.

Putting it all together

- 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