ESS / EARTHSYS 8: The Oceans

Activity 1

**The Shape of Ocean Basins and the Bathymetry of the Sea Floor**

**Guidelines:**

Students will work in small-groups to complete the assignment. All students must work together on each step of the activity. A single document will be turned in as a group (include everyone’s names) via email to instructors (Kate, Hannah, and Amber). The document should be clearly named as “LAST\_NAMES\_activity1.” You can answer the questions directly in this document, but please type answers in a different color text. The activity is due before the start of the next class (4/13).

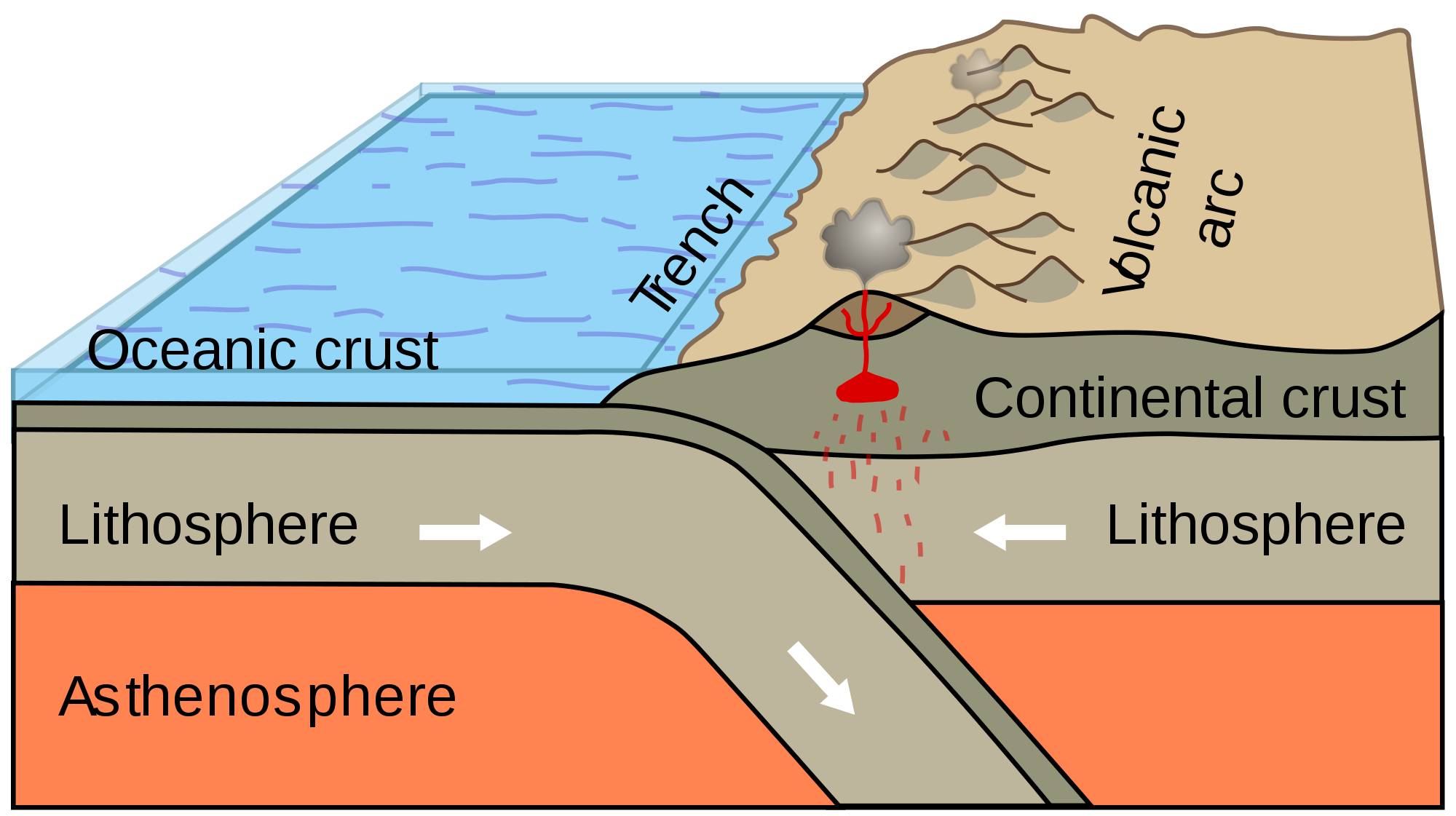
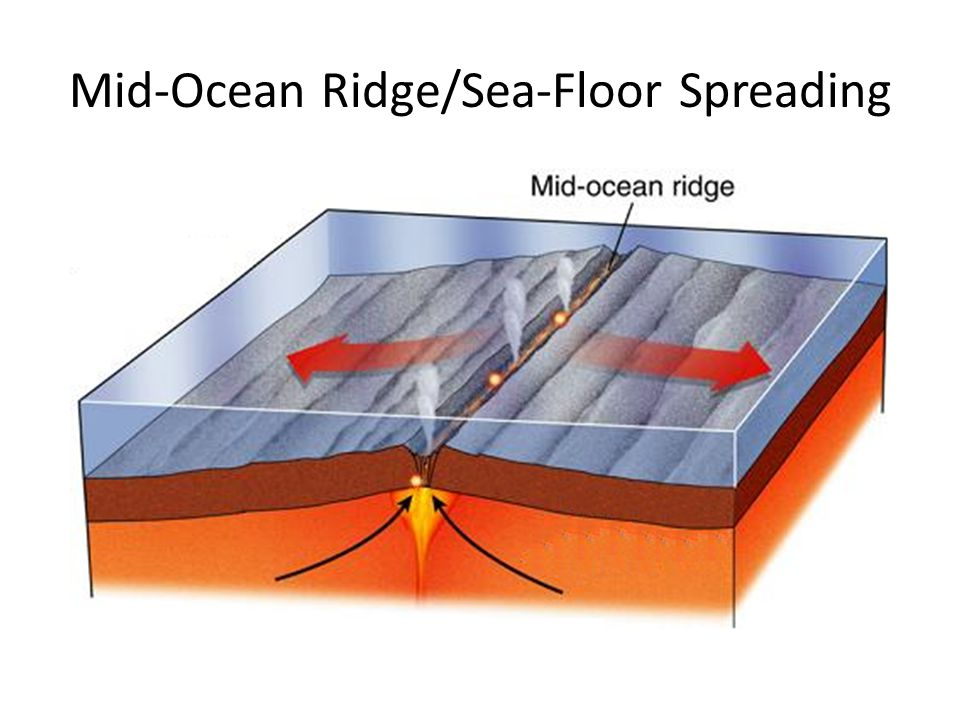
It is important to fully read all of the background information provided in this document – this will help you answer the questions in the activity. You may also consult your textbook, lecture notes, or reputable internet resources to aid you in your answers. For this activity, at least one member’s computer must have Google Earth (to download: <https://www.google.com/earth/download/ge/agree.html>).

**Summary:**

In the ocean, the shape of the sea floor varies based on physical, geological, and biological processes that occur on different temporal and spatial scales. In turn, the shape of the sea floor controls the physical and biological processes. For example, currents and tides are largely controlled by the overall shapes of the ocean basins, as well as by the smaller scale shapes of ocean ridges and seamounts. Similarly, biological processes are controlled by ocean depth and terrain. In this activity, we explore the formation of ocean bathymetry and its influence on physical and biological processes. We compare various ways of mapping the sea floor, focusing mainly on ship-based measurements and satellite altimetry data.

**Objectives:**

* Compare and contrast different methods for mapping the sea floor



a.

b.

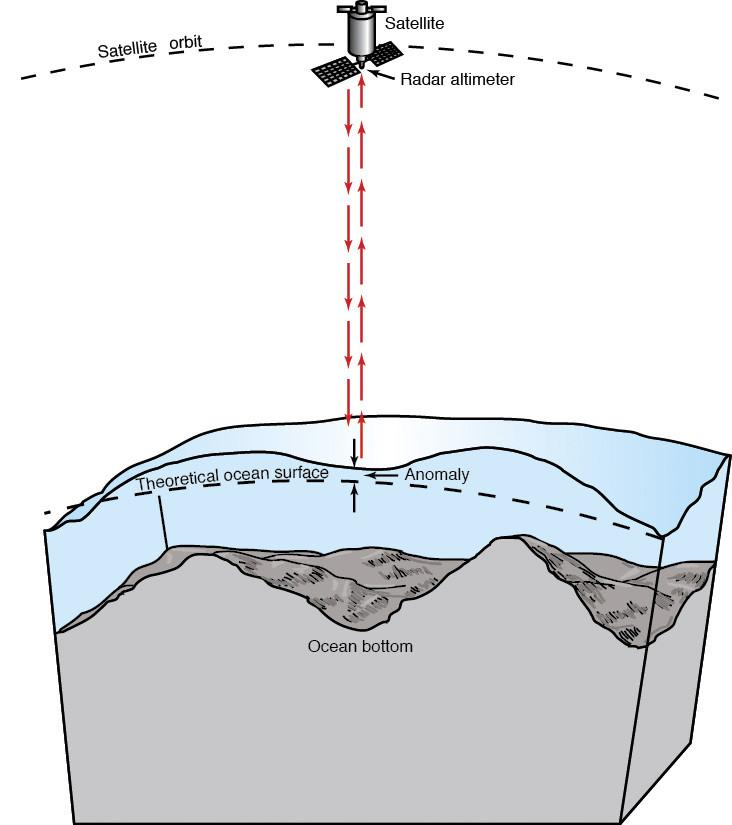
* Use satellite data to explore the shape of the sea floor
* Describe the basic pattern of sea floor bathymetry
* Compare various ocean provinces (continental margins, deep ocean basins, etc.) and describe what processes control the shape of the sea floor in different regions
* Hypothesize different ways in which the shape of the sea floor may impact physical and biological processes in the ocean

**Background:**

The topography of the sea floor (called “bathymetry”) primarily reflects the geologic history of the last 150 million years – only a small fraction of the Earth’s 4.5 billion year history! Why is the sea floor relatively so young? New oceanic crust is constantly being created at spreading centers (areas where two plates are pulling apart from each other), allowing fresh magma to rise from the mantle and create mid-ocean ridges (a). As these plates spread apart from each other, they cool and sink. Because oceanic crust is denser than continental crust, in the areas where ocean plates are crashing in to other plates, they are subducted (pushed underneath the surface of the Earth) and subsequently destroyed – and on Earth, the oldest surviving oceanic crust (furthest from the spreading centers) is not much older than 150 million years (b).

What controls the shape of the sea floor? On large temporal and spatial scales, ocean basins are continually changing as a result of plate tectonics, which creates big features like volcanoes, ridges, and trenches. At a finer scale, physical and biological processes, such as sedimentation, massive debris slides, and flowing currents, influence the shape of the ocean bottom.

However, relatively little is known about the bottom of the ocean, particularly in deep areas where several kilometers of water prevent easy access to the floor below. For example, the area west of the Pacific-Antarctic Ridge (a divergent plate boundary) was thought to be completely flat until in 1972 when a chain of large undersea volcanoes called the Louisville Seamount Chain was discovered. The chain spans a length about equal to the distance between New York and Los Angeles and is the longest chain of seamounts in the Pacific! Until recently, most of the data about the bathymetry of the sea floor came from ship-based surveys, which only covered very small regions (10%) of the sea floor; the rest was left to interpolation and guesswork.

Today, satellite altimetry provides a new method for mapping the sea floor (c). How can satellites orbiting thousands of kilometers above the surface of the earth measure the exact shape of the bottom of the ocean? The surface of the ocean has broad bumps and dips that mimic the topography of the ocean floor below; every 1000 m change in ocean depth results in a ~4 m rise or fall in sea level (c). These “bumps and dips” are caused by minute variations in Earth’s gravitational field. For example, a massive mountain on the ocean floor (a typical undersea volcano is 2000 m tall and has a radius of 20 km) attracts water towards it, causing a local bump in the ocean surface. These small changes in sea surface height – not visible to the eye – can be mapped very accurately from satellites using a high-resolution 10-15 km radar altimeter. An altimeter (such as the one on the TOPEX/Poseidon satellite; other important ones include ERS-1 and GEOSAT) sends a radar microwave pulse to the sea surface, which is reflected back to the satellite. The satellite records the time it takes for each signal to return, and from this we are able to obtain a detailed map of sea surface topography, which is then correlated to bathymetry. (The radar altimeter also measures wind speed and wave height.)

c.

*More info*: <http://www.ngdc.noaa.gov/mgg/bathymetry/predicted/explore.HTML>

*Originally created by David T. Sandwell (Scripps) and Walter H.F. Smith (NOAA). Modified by Molly Palmer, Kate Lewis, Kate Lowry, and Hannah Joy-Warren (Stanford University).*

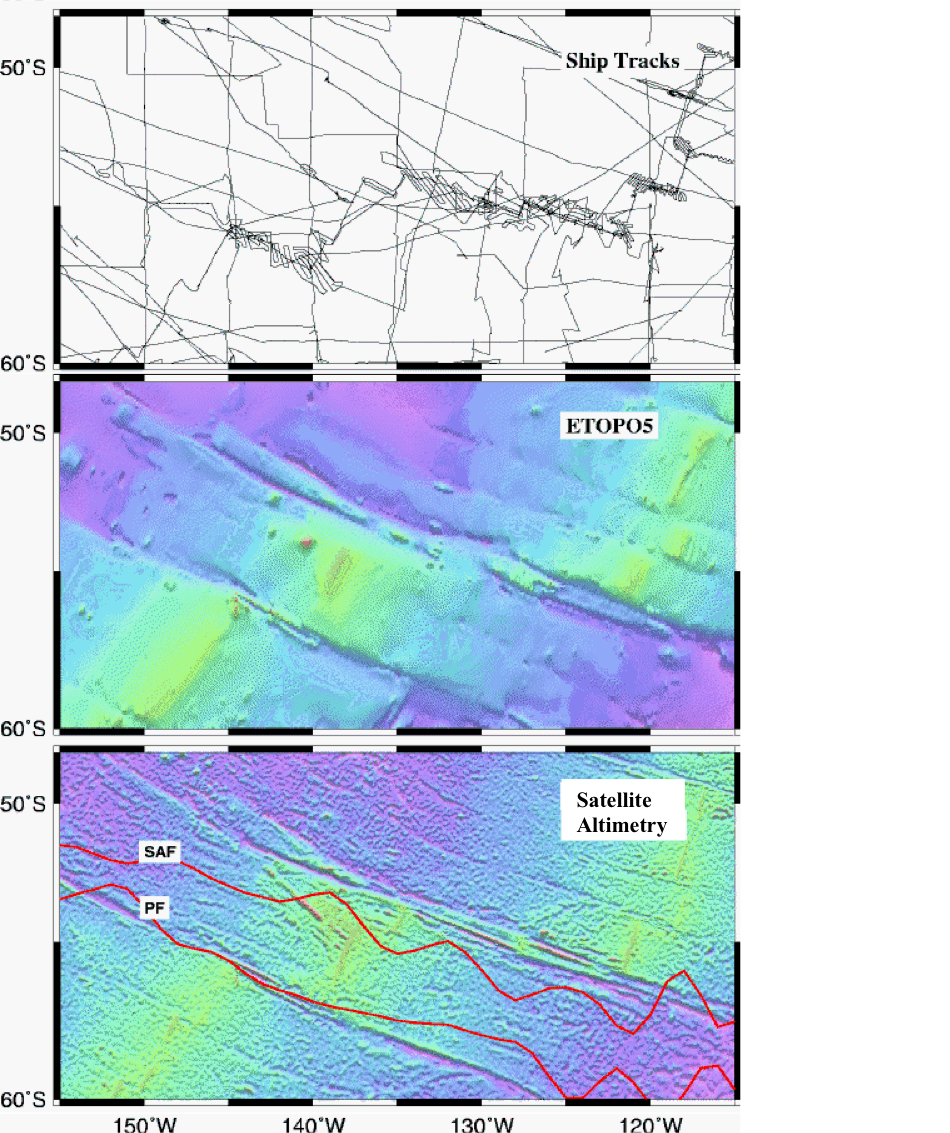
**Part 1: Using Satellite Altimetry Data to Map the Sea Floor**

**Part 1a: Comparing Ship-based Measurements to Satellite Data**

Mapping the bathymetry of the sea floor has traditionally been done using ship-based measurements. However, recent technological advances now allow us to measure small variations in the height of the sea surface using satellite altimetry data, which is then related to the underlying bathymetry.

The images you will be consulting for Part 1a (shown below) shows multiples maps of the same region of the sea floor located in the southern hemisphere Pacific Ocean. The top panel shows the historical ship tracks from which soundings measured by the US Navy and NOAA in 1988 were used to make the bathymetric interpolation for a digital global bathymetry map ETOPO5 (middle panel). The bottom panel shows predicted seafloor depth based mainly on satellite altimetry data (from GEOSAT; some ship-based soundings were also used; the red lines are the locations of the Sub-Antarctic Front and the Polar Front).

**Images for Part 1a**



*image from*: <http://topex.ucsd.edu/marine_topo/text/topo.html>

1. Examine the two bathymetry maps. How does the ship-based map (ETOPO5) compare to the satellite map? List at least 5 similarities or differences.

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| --- | --- |
| **Similarities** | **Differences** |
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2. Compare the ship tracks to the maps. What do the ship tracks appear to focus their mapping efforts on? How might this affect the maps created from this type of data?

3. Again consider the two bathymetry maps. The ETOPO5 map lacks the topographic expression of a 400 km long northwest-tending ridge at roughly 54°S, 140°W, minimum depth 135m. This ridge was first surveyed by a French expedition in December 1995.

3a. Why do you suppose this feature is not captured in the ETOPO5 map? Provide at least two ideas!

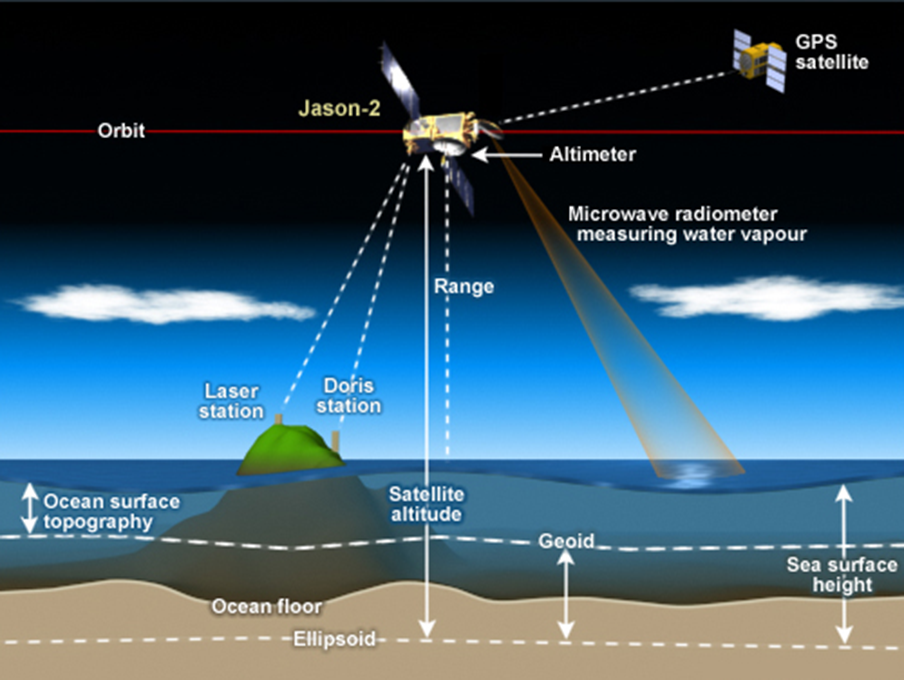
3b. Why is defining this type of feature in oceanographic maps important for predicting the physical oceanography and biological processes of the region? Give an example.

**Part 1b: Comparing Satellite Data to Predicted Topography**

On a broad scale, the ocean is approximately a smooth ellipsoid covering the surface of the Earth. However, in reality, small bumps and dips due to tiny variations in the gravitational field (such as from large mountains or deep trenches on the sea floor) cause the surface ocean to vary ±100 m in height. Although satellite altimetry data allows us to survey the full ocean much more rapidly than ship-based measurements, the process of converting satellite radar altimetry pulses into a detailed map of the ocean floor contains multiple levels of complication and uncertainty.

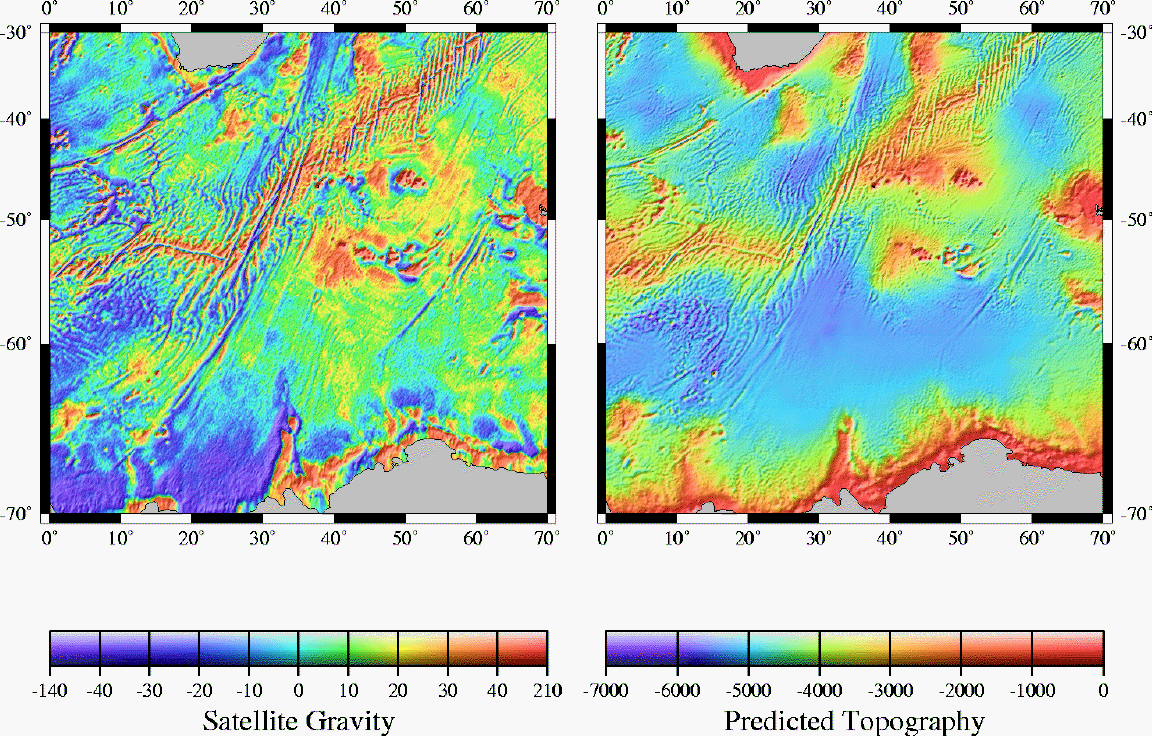
The major steps of creating bathymetry maps from satellites include:

* The satellite measures the time it takes a radar pulse to make a round-trip from the satellite to the sea surface and back.
* To convert this transit time into sea surface height, a number of very precise measurements must be made, including:
  1. The height of the satellite above the *idealized* surface of the ocean if there were no variations caused by gravity (e.g. the geoid);
  2. The height of the satellite above the *actual* ocean surface, determined by the microwave pulse;
  3. The direction and trajectory of the satellite (i.e., which direction the radar is facing when it sends the pulse);
  4. The influence of waves or other irregularities in the ocean surface on the apparent “height” measured.
* Then, a number of other corrections are made to the recorded height and transit time, including some complicated corrections for atmospheric delays (for example, water vapor slows down the returning microwave pulse) and the tidal cycle.

At this point, you have some sort of sea surface height or “gravity anomaly”, i.e., the deviation in the sea surface height caused by variations in the gravitational field below. The next steps – to get from gravity anomalies to ocean bathymetry – requires several more calculations and assumptions. An exact description of how this works is outside the scope of this class, but at a basic level, variations in the Earth’s gravitational field are not uniform or as easily understood as it might seem. A key example of this is that less dense, poorly compacted sediments have a much lower gravitational pull than more dense basement rock – meaning that areas covered by sediments may “appear” based on sea surface height to be a different depth than they actually are, and vice versa.

Thus, there are many assumptions and uncertainties in the determination of sea floor bathymetry from satellite altimetry data. As such, satellite data is often combined with other measurement types (e.g. ship-board multi-beam echosounder) to create the maps we use today to explore the ocean bottom.

**Images for Part 1b**



*image from*: <http://www.ngdc.noaa.gov/mgg/image/predictnew.gif>

1. “Images for Part 1b” show satellite gravity anomalies (left) computed from satellite altimetry data and the predicted topography of the sea floor (right) deduced from these gravity anomalies.

1a. Describe at least 3 differences between the two images. What patterns do you see in these differences?

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| **Similarities** | **Differences** |
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1b. Why do you suppose the maps are different? Suggest at least 2 reasons based on what you read above.

2a. In general, how do the satellite-generated maps compare to the maps created from ship-based measurements? List at least 2 comparisons.

Given all the complications described above, which type of map **and why** would you rather use to if you were…..

A sailor?

A submarine captain?

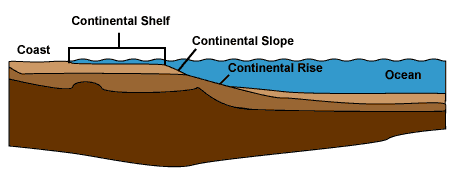
Looking for marine resources?

A scientist modeling ocean circulation?

2b. What other potential problems can you think of when using satellite data to map the sea floor? List at least two potential problems

**Open map using Google Earth for Parts 2 and 3:**[*http://www.ngdc.noaa.gov/mgg/global/relief/ETOPO1/tiled/ice\_surface/etopo1\_ice\_surface.kmz*](http://www.ngdc.noaa.gov/mgg/global/relief/ETOPO1/tiled/ice_surface/etopo1_ice_surface.kmz)

**Part 2: Exploring the Sea Floor: Continental Margins**



The above diagram depicts the general features of **continental margin** regions: the coast, continental shelf, continental slope, and continental rise, which all eventually transition to the deep ocean. There are two basic types of continental margins: **active** (associated with plate boundaries, plate convergence, and subduction zones leading to high seismic activity and typically narrow shelves) and **passive** (a continent-ocean transition on the same plate; low seismic activity and typically wide shelves). **Continental shelves** are gently sloping and shallow (average depth 130 m); they are geologically part of the continents, often simply eroded crust that is now submerged but was most likely exposed land during the last ice age. **Continental slopes** are the steeply sloping regions at the edge of the shelves; the angle and extent of continental slopes vary, but they are always accompanied by a rapid increase in depth (with active margins having typically much deeper continental slopes). The continental slope may be dissected by submarine canyons, show rocky outcroppings, and/or be bare of sediments. The **continental rise** is the more gently sloping region at the base of the continental slope, formed by the accumulation of sediment; a distinct continental rise is typically more distinguishable at passive margins where sediments have had longer and more stable periods to settle.

1. Use the Google Earth map “etopo1\_ice\_surface.kmz” to compare and contrast the continental margins of the east and west coasts of the United States. The “ruler” function will be useful for determining width.

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| *Compare and Contrast…* | **East Coast USA** | **West Coast USA** |
| **Continental Shelf**  Consider the following: Which is wider? What is the general shape of the shelf? Are there many canyons or other physical features? How does the shelf end – is there an abrupt transition? |  |  |
| **Active or Passive Margin?** |  |  |
| **Other Observations**  Consider the following: Is there a definite continental rise? What do you observe about the continental slope? Are these features easy to distinguish? Which features are most important for helping you describe the continental margin? |  |  |

2. Explore the Google Earth sea floor map. Where on Earth are the widest continental shelf regions located? List 2 of the widest shelf regions, and indicate why they are likely so wide.

4. What processes are most important in determining the physical features of continental margins? Suggest at least one process for each feature (shelf, slope, rise).

5. How might the physical features of the continental margin region affect ocean currents and circulation in the area? How might ocean currents affect the physical features of continental margins? Suggest 2-4 ways for both.

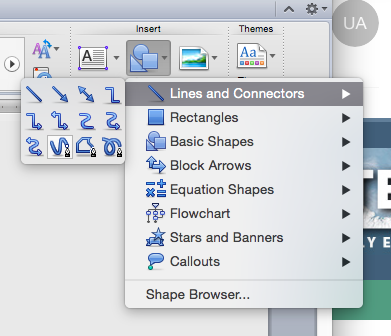
**Part 3: Exploring the Sea Floor: The Deep Ocean**

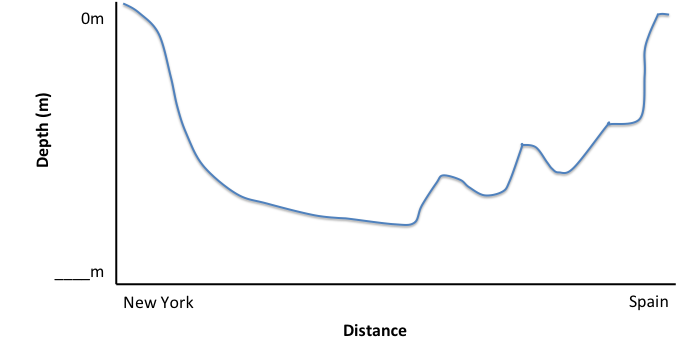
The deep-sea floor, between 4000 m and 6000 m, covers 30% of the Earth’s surface and is composed primarily of large flat plains extending from the base of the continental slope, which are broken up by ridges, abyssal hills, rises, fracture zones, and seamounts. These flat plains, called **abyssal plains**, have slopes of less than 1:1000 and are formed by the gradual process of sedimentation filling in the irregular topography of the oceanic crust. If an abyssal plain is isolated from other areas by ridges or continents, it is known as a **basin**. Low ridges may allow some exchange of water between adjacent basins, but higher ridges effectively cut off the basin from the transfer of water and marine organisms. Continuous mountain features, known as **mid-ocean ridges**, are formed where tectonic plates spread and extend across the deep ocean basins, covering approximately one-third of the sea floor at an average depth of 2500 m. **Fracture zones** are caused by tectonic activity as plates move toward and away from each other, thus roughening the appearance of the sea floor. These zones can run over a thousand kilometers in length and are prominent features on the sea floor—the ocean floor on either side of a fracture zone can vary by 1500 m in depth. Volcanic submarine peaks and islands develop in the middle of plates; peaks that extend more than 1 km above the abyssal floor are called **seamounts** (if flattened on top, they are called **guyots** or **tablemounts**), otherwise smaller peaks are simply called **abyssal hills**. Finally, geologic features called “**hot spots**” can create volcanic islands that reach the surface ocean, such as Hawaii, or remain below the surface, such as the Emperor Seamount Chain.

Biologic activity can also influence the shape of the sea floor. A **fringing coral reef** forms in the shallow waters adjacent to the shore of a volcanic island that reaches the surface of the ocean. As this island sinks in time due to geologic processes or rising sea levels, the coral reef continues to grow upward to reach the surface, becoming a **barrier reef**. Over time, as the island disappears below water, an **atoll** is left behind – a ring of coral surrounding a shallow lagoon (which is the top of the sunken and eroded volcano).

1a. Using the Google Earth map “etopo1\_ice\_surface.kmz” to explore your route, imagine you are travelling in a submarine from New York to Spain. Describe your journey. What general features do you encounter? What is the maximum depth reached? Minimum depth? Use the ruler tool to give an approximate length of your trip.

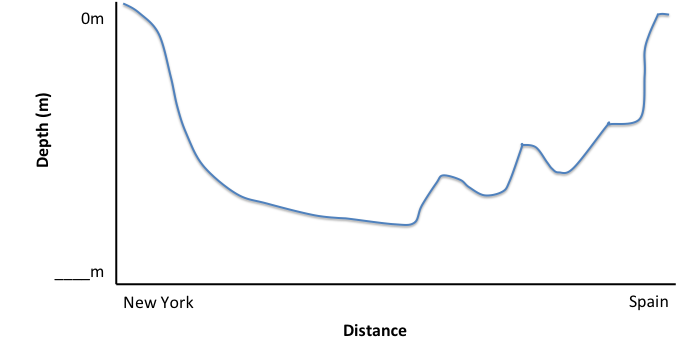
1b. Sketch a profile of your journey showing each major bathymetric feature on the chart below. Label the seafloor features and include a depth scale. (It may help to make depth readings every 100 km or so to get a good profile). *To sketch, you can draw the profile on paper and take a picture to include in the digital document. Or, you can draw a line along the axes below by inserting a shape (see below).*





2a. On your next trip, you travel by submarine from Japan to Baja California. Again, use the Google Earth map to explore your route. What general features do you encounter? What is the maximum depth reached? Minimum depth? Use the ruler tool to give an approximate length of your trip.

2b) Sketch a profile of your journey showing each major bathymetric feature on the chart below. Label the seafloor features and include a depth scale. (It may help to make depth readings every 100 km or so to get a good profile). *To sketch, you can draw the profile on paper and take a picture to include in the digital document. Or, you can draw a line along the axes below by inserting a shape.*



3. How do your profiles differ in the horizontal and vertical scale? What features are more prominent in your Pacific route than in your Atlantic route (and vice versa)?

4. The textbook described how mid-ocean ridges act as barriers between ocean basins, preventing the transfer and flow of water and marine organisms between basins. Brainstorm 2-3 different ways in which the different features you found on your routes may impact ocean circulation and biological processes.

References: Duxbury, A., et al., An introduction to the World’s Oceans Sixth Edition, McGraw-Hill, 2000; Thurman, H., Introduction to Oceanography Seventh Edition, Macmillan Publishing Co., 1994; and the various websites listed throughout this exercise, especially the data and links in NOAA’s National Geophysical Data Center, <http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html> and NASA’s topex mission website, http://sealevel.jpl.nasa.gov/mission/topex.htm



