Lecture 5: Marine Provinces

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We learned about the processes that shape the surface of the Earth in the previous lecture, now let's look more closely at **Ocean Structures and the Seafloor**

Bathymetry

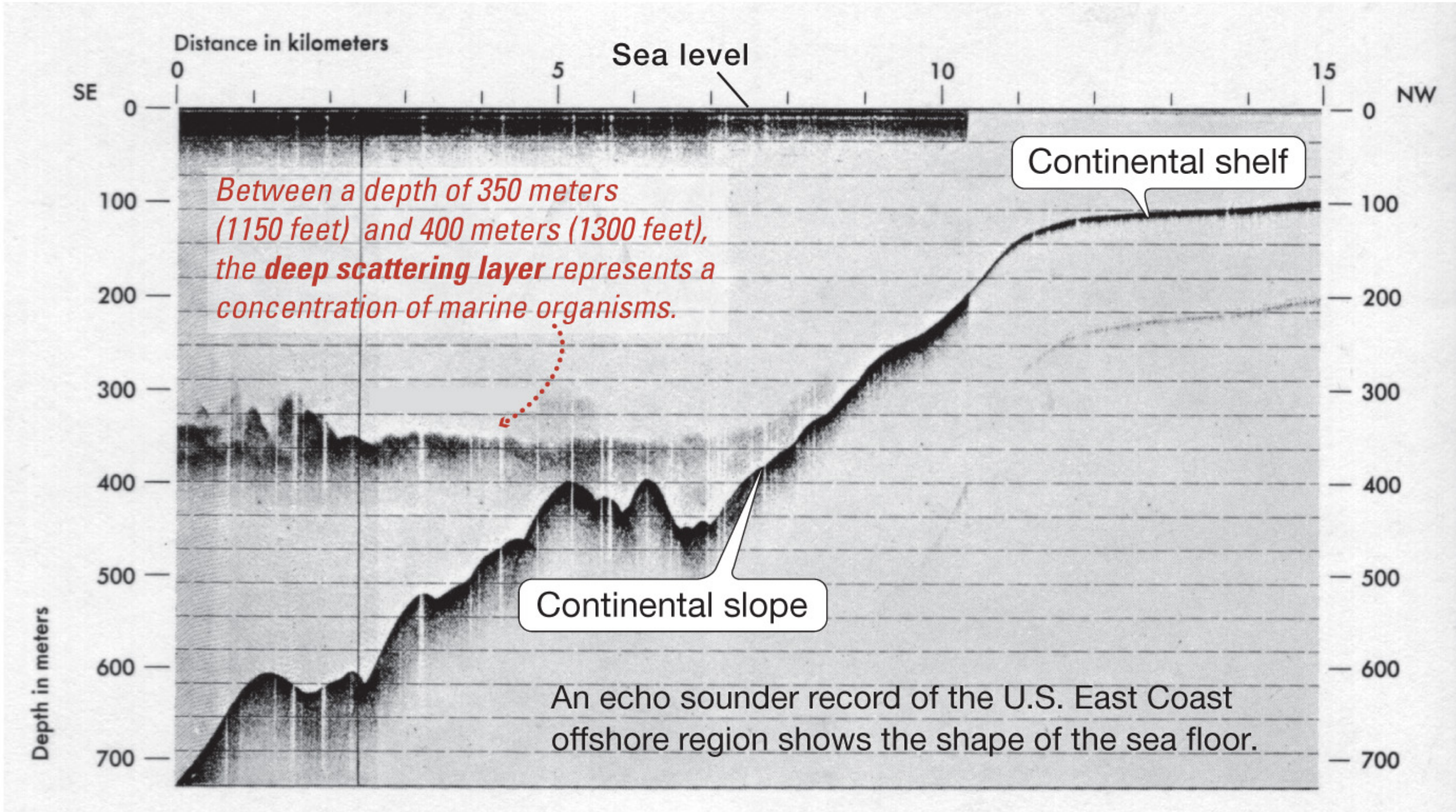
Before we layout the general features of the ocean sea floor, it is worth considering how the sea floor is measured. The goal is to measure bathymetry (measurement of the ocean depth) and using these bathymetries to define the ocean seafloor topography (a map of surface elevation). The topography varies dramatically because of undersea mountains, valleys and expansive flat plains.

The earliest known measurements of ocean depth were made in the Mediterranean Sea ~85 BC by an explorer named Posidonius. He wanted to know how deep the world's oceans are. He attempted to do this by lowering a weight down nearly 2 kilometers until it hit the seafloor. The act of measuring water depth was called soundings - sidenote here because this terminology becomes confusing with modern sonar which uses actual sound to measure depth, but back then it was also called soundings but the word is based on the root 'sund' which refers to swimming or being underwater. This approach of lowering weights to the bottom and measuring how much line was out to get to the bottom was used for the next several centuries. The unit they used for measurement was the fathom. The fathom was based on the outstretched arms of a sailor (later it was standardized to six feet). The fathom was chosen because it represented the rate at which the line could be drawn back up on deck (if you have ever had to haul line back on deck by hand, you will understand why this makes sense).

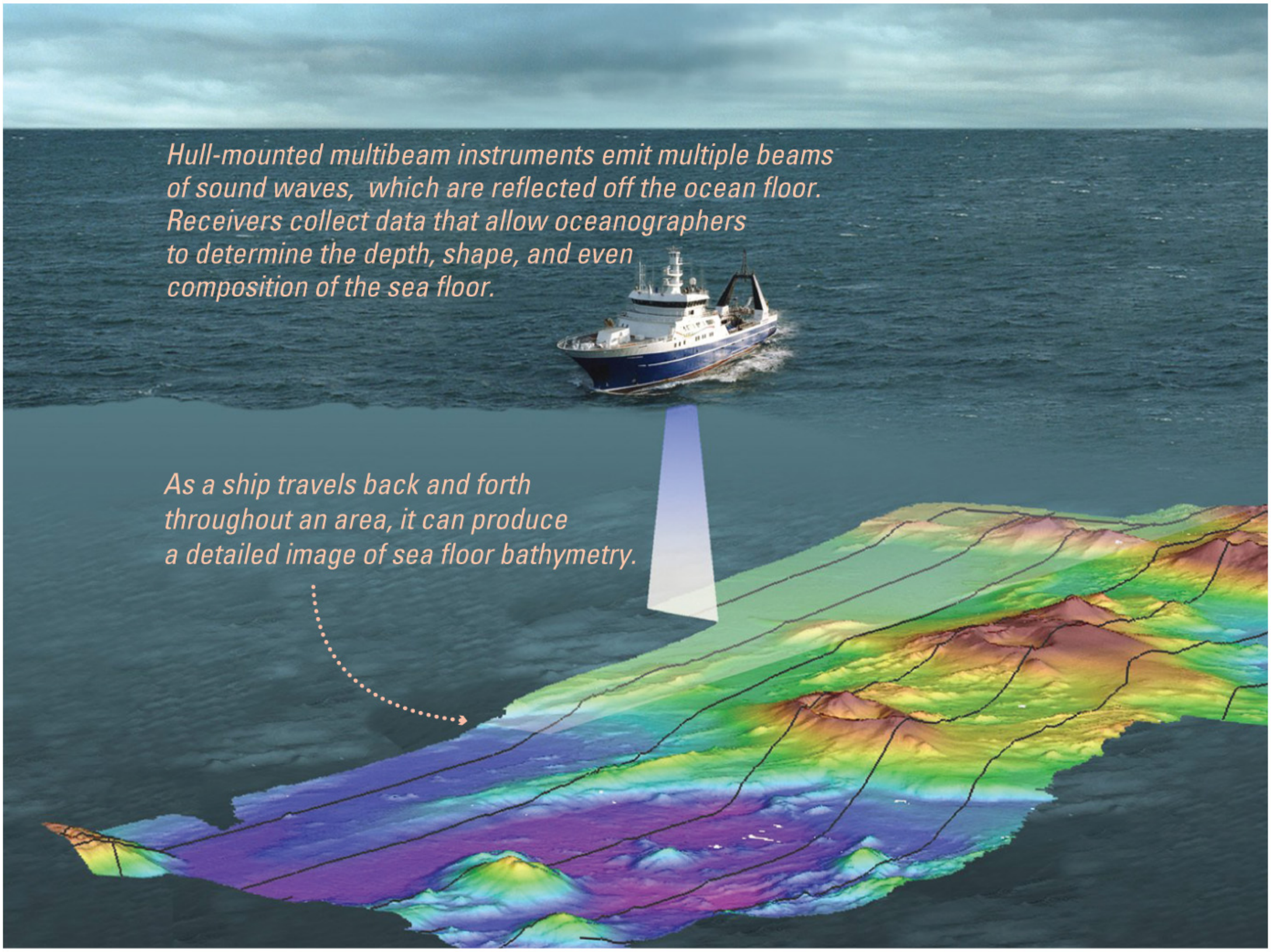
The first global map was made by the HMS Challenger during its long mission around the planet. They showed that deep sea floor was not entirely flat, rather there existed mountains and valleys. While a big step forward, these maps were still very sparse.

Echo Sounding

The main approach that has been used to fill in the gaps was the development of the **echo sounder (http://en.wikipedia.org/wiki/Echo_sounder)** in the early 1900s. An echo sounder sends out a small sound signal (sometimes called a ping. Remember from the movie "The Hunt for Red October" the Russian sub commander keeps ordering his mates around, "Fire one ping only" - this is an old reference, but a cool movie). The sound signal travels down through the water and it bounces off anything of a different density. The density difference it hits can be the sea floor or it can be a sea animal. This approach works because ocean water is good at transmitting sound. However, this approach is not precise and cannot provide fine details of the sea floor, particularly when the bottom is very uneven. Nonetheless, echo soundings in 1925 were the first to discover the mid-Atlantic Ridge (this feature and the processes that form it should be familiar from last lecture).

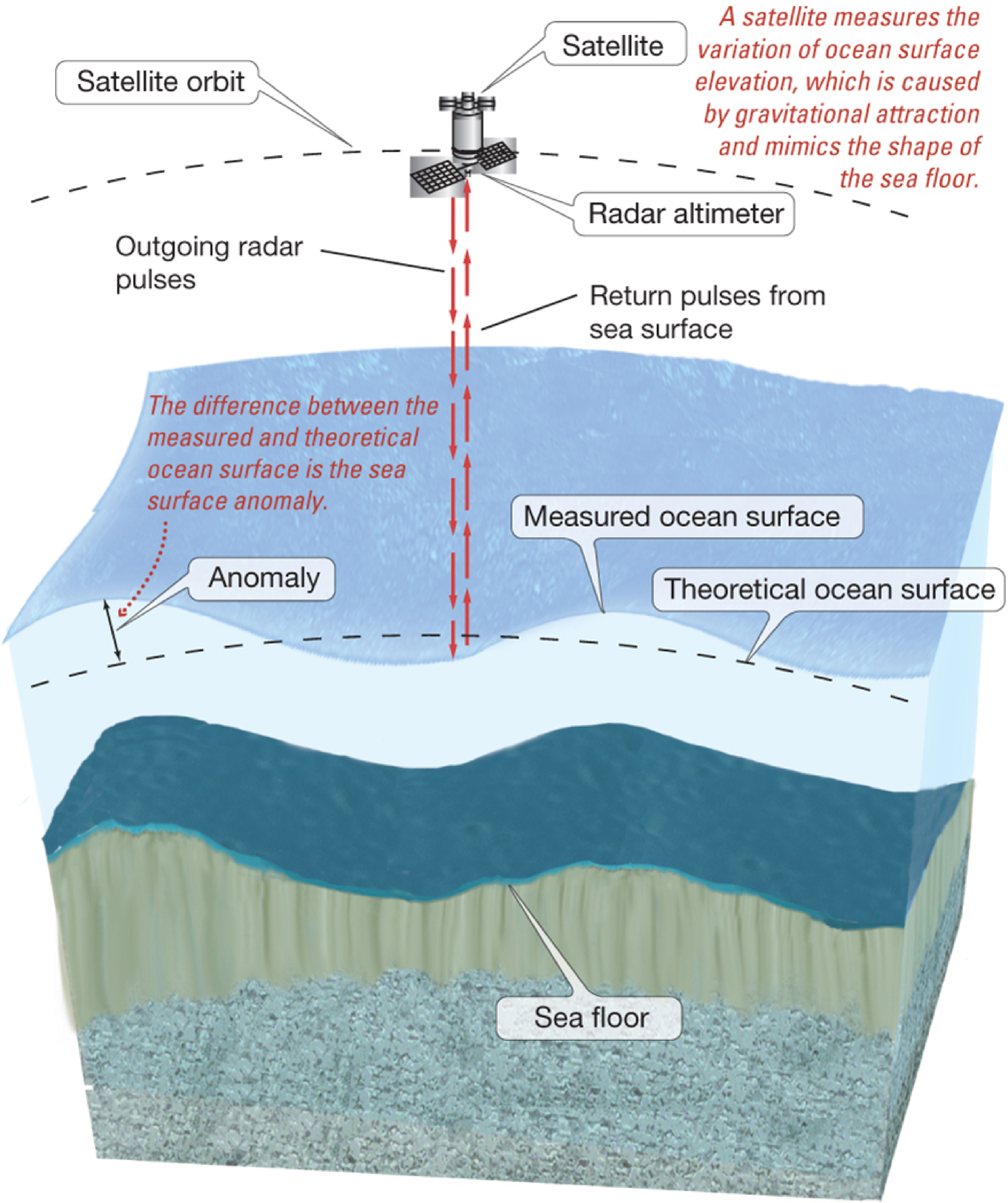


Echo sounding was honed dramatically during World War II in order to hunt for submarines and better map the ocean. Continued interest resulted in development of the precision depth recorder (PDR), which used a high frequency sound signal. The systems could resolve features down 1 meter! Echo sounding has been improved in recent decades by using multiple frequencies through the use of *multi-beam echo sounders* and *side scan sonar*. The multi-beam approach consists of multiple sound signals sent at multiple sound frequencies, and the reflected signal is captured by hull-mounted receivers. These systems provide high resolution maps of the bottom, yet we have still not been able to map the entire sea floor using this approach



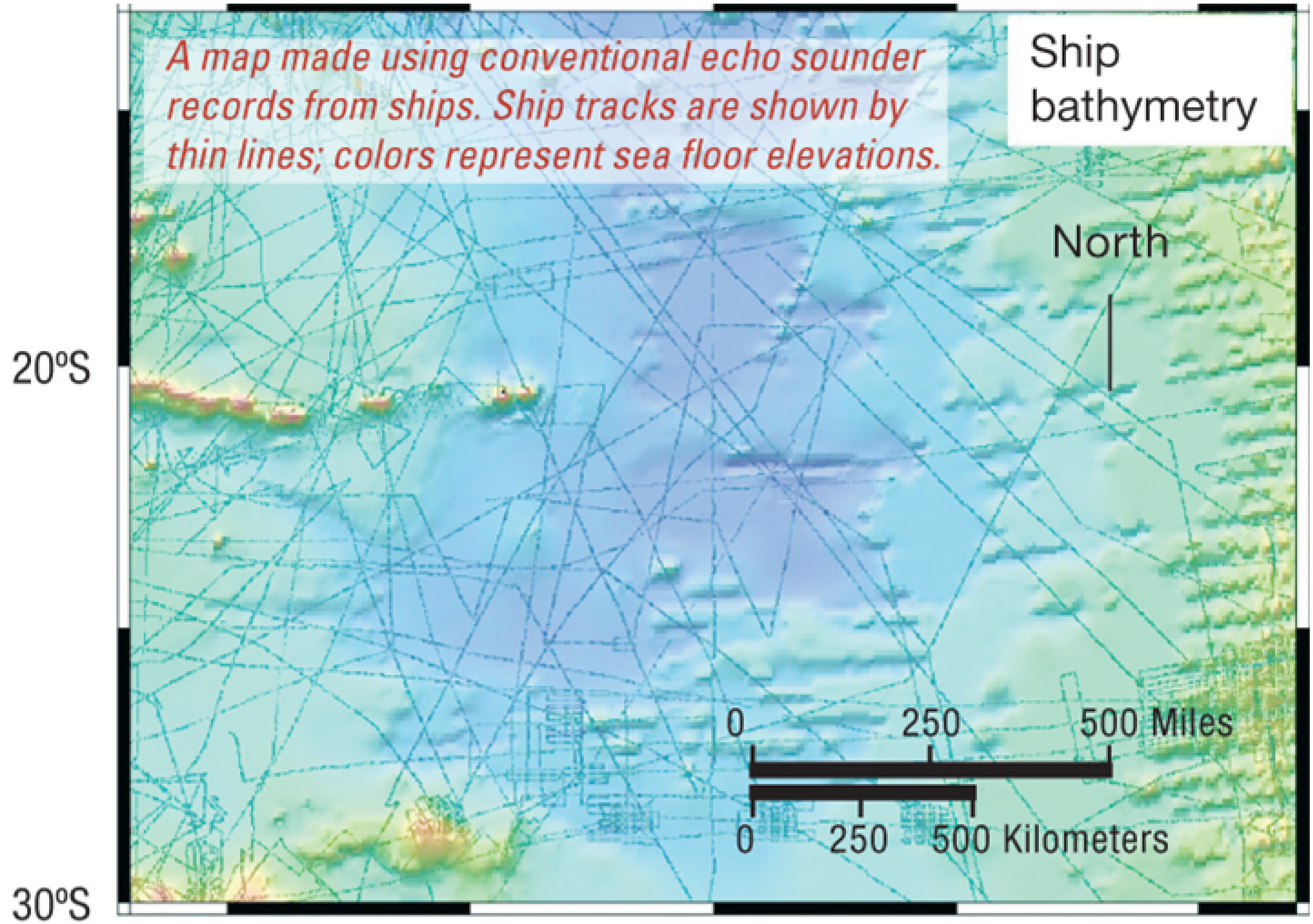
Satellite Imaging

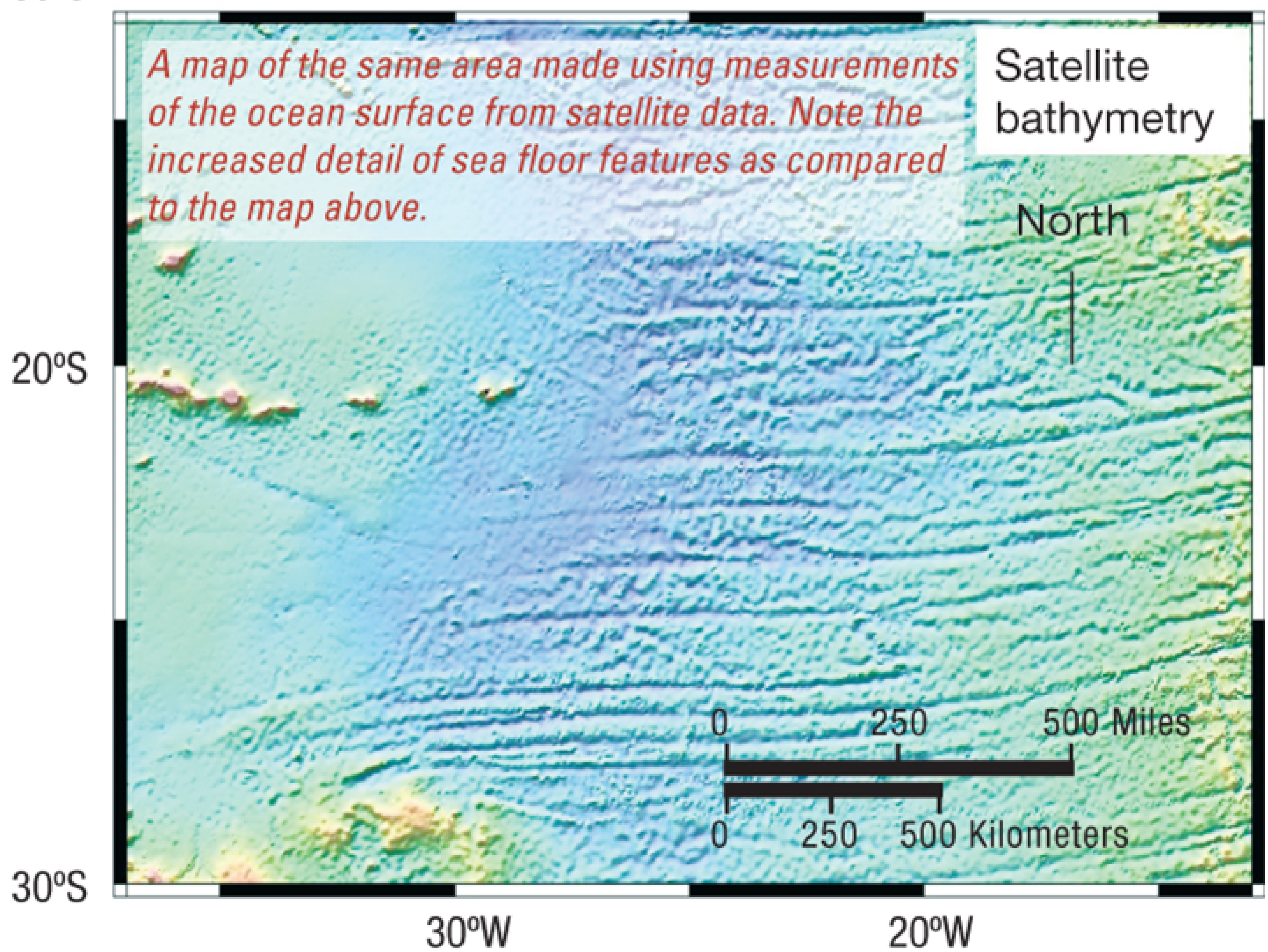
There are increased efforts to map the sea floor from space. That is a wild concept! How could this be possible?! The approach is based on the discovery that the sea floor influences the Earth's gravitational field. Deep trenches are correlated with lower gravitational attraction (depressions in the sea surface) and rises in sea floor, such as sea-mounts, exert higher gravitational pull (elevations in the sea surface). For instance, a sea mount (2000 meters high) creates a bulge of water that is ~2 meters high on the ocean surface. These irregularities can be detected with satellites using microwave beams, which bounce off the sea surface (these systems have accuracy around 4 centimeters).



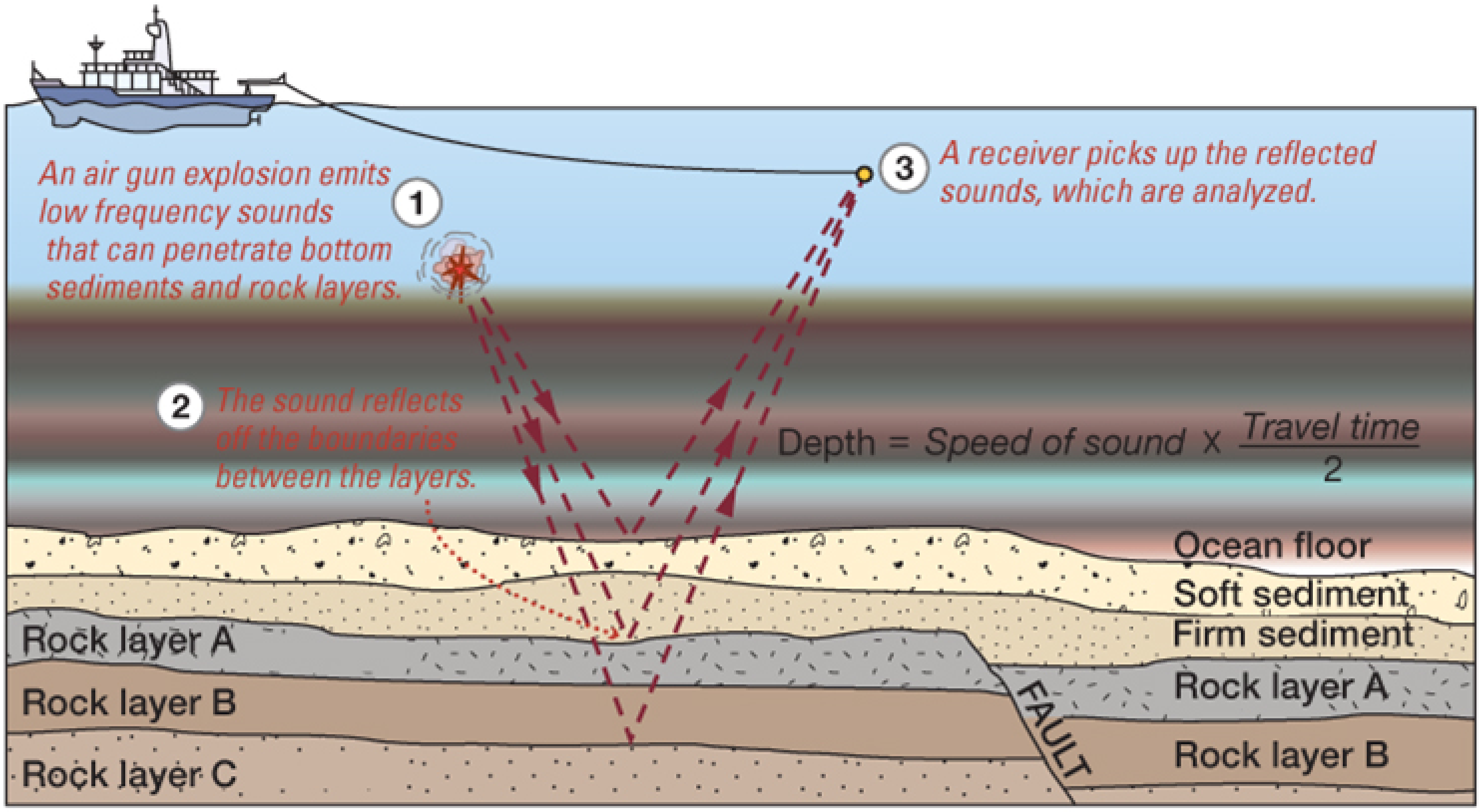
As technology has improved over the past century, we have been able to map the bottom of the ocean in much greater detail and we have a much more comprehensive picture of the features hidden in the ocean depths.

Recall previous lectures that discussed how these features are formed. The image below shows how much the technology has changed our view of the bottom of the ocean.

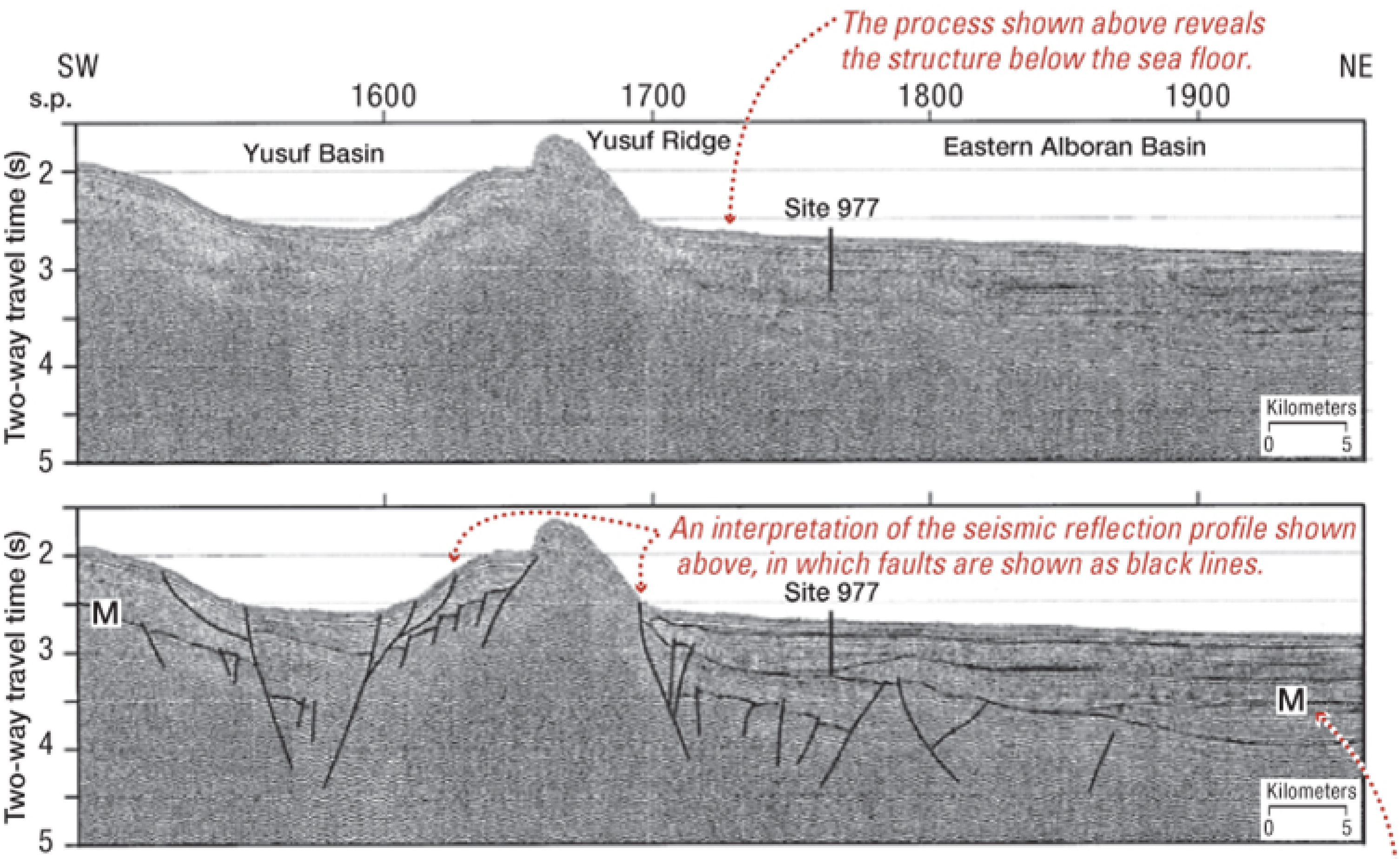

A map made using conventional echo sounder records from ships. Ship tracks are shown by thin lines; colors represent sea floor elevations.
Ship bathymetry
North
20ºS
30ºS
0 250 500 Miles
0 250 500 Kilometers


A map of the same area made using measurements of the ocean surface from satellite data. Note the increased detail of sea floor features as compared to the map above.
Satellite bathymetry
North
20ºS
30ºS
0 250 500 Miles
0 250 500 Kilometers
30ºW
20ºW

Another way that we are able to map, not just the bathymetry of the ocean, but also the bottom composition (what the bottom is made of) is seismic reflection. A ship can deploy an air gun explosion in the water that emits low frequency sound. Those low frequencies can penetrate sediments and rocks and are reflected back off of boundaries in the bottom between different rock or sediment types. The reflected sound can be detected using a receiver towed behind a boat. These reflections are called seismic reflection profiles and can be used in mineral of petroleum exploration. The depths of different layers can also be used to map the structure of the sea floor and even map fault locations.



(a) A ship conducting seismic profiling. Note that depth can be determined by knowing the speed of sound in seawater and the travel time of the sound.

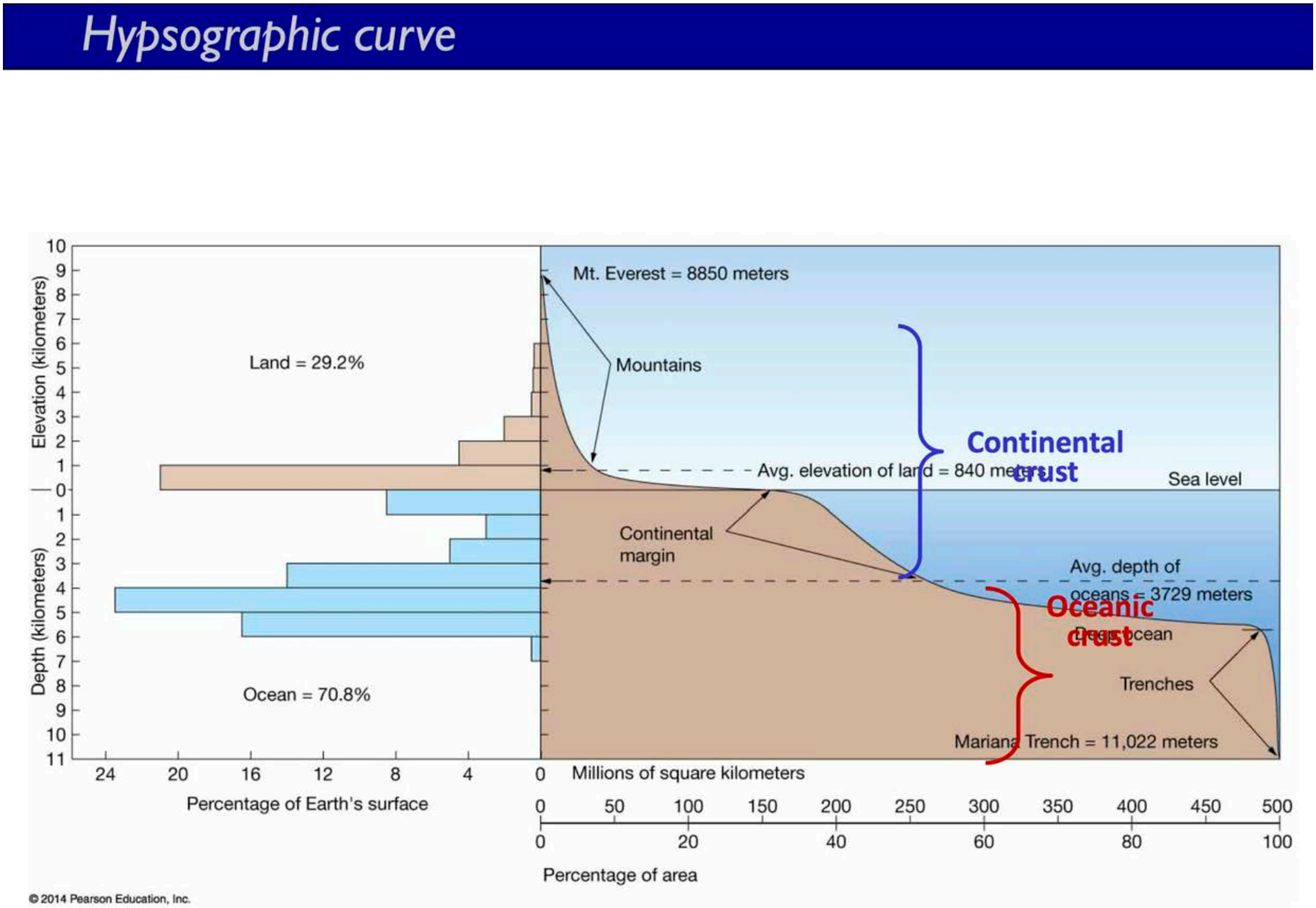


(b) Paired seismic reflection profiles (raw *above*, interpreted *below*) of the western Mediterranean, showing the location of JOIDES Resolution Drill Site 977.

M = M-reflector, which is a layer of evaporite minerals (salts) that was created during the drying up of the Mediterranean Sea approximately 5.5 million years ago.

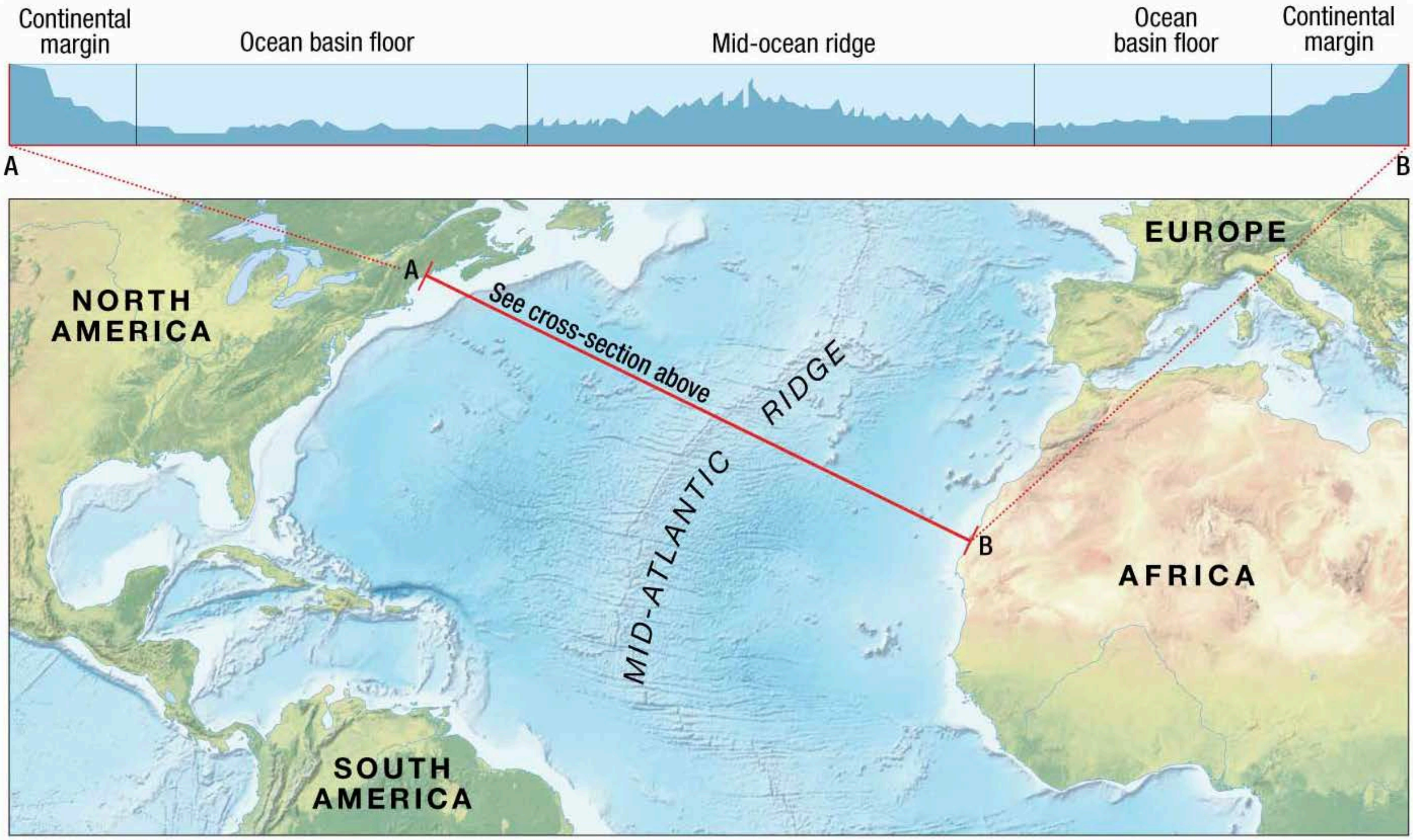
Hypsographic Curves

A hypsographic curve shows the relationship between the height of the land and the depth of the oceans, which provides insight into the percentage of the Earth's surface at specific elevation ranges. The curve shows that ~71% of the Earth's surface is covered by the ocean surface, and that the average depth is 3682 meters. *In contrast the average height of land is only 840 meters. Can you think why this might be the case (hint: isotasy)?*

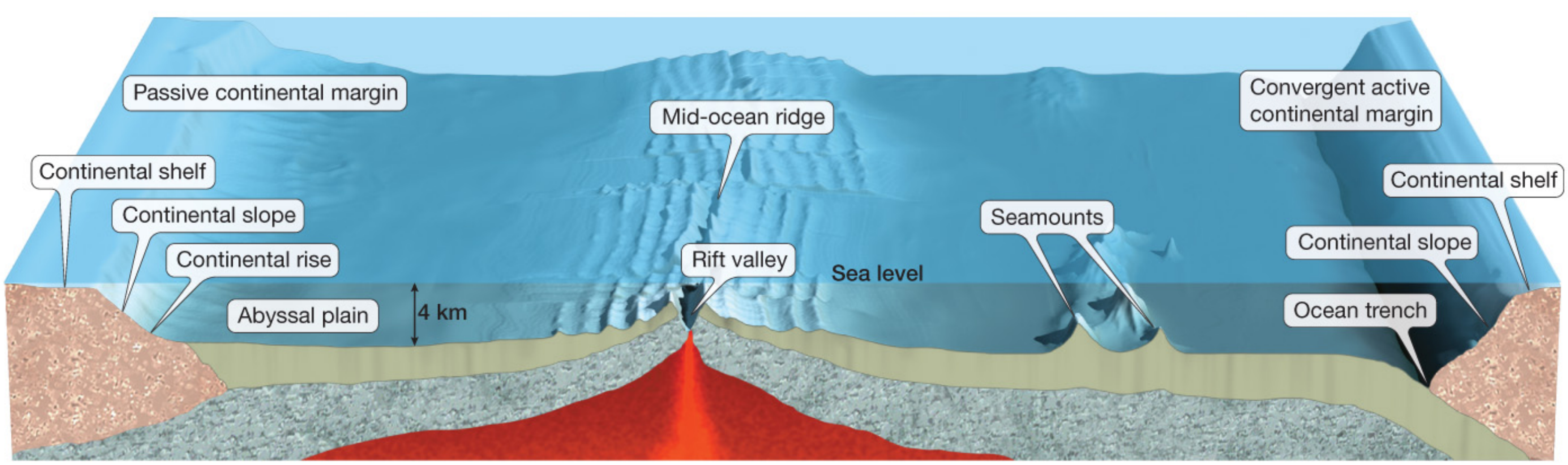


<u>**Ocean Topography**</u>

Oceanographers and mariners used to think that the ocean gets deeper in the parts of the ocean that are furthest from land. We now know that isn't necessarily true. There are all kinds of features out in the ocean, from submerged ancient volcanos, deep caverns, mountain ranges and more! For convenience, however; we carve up the ocean into specific regions (sometimes called provinces). The three major provinces are the Continental margins, Deep ocean basins, and Mid-ocean ridges. These should all sound a bit familiar from previous lectures. See the image below to see how the provinces lay out as you cross the Atlantic from Maine to central Africa. Each of these provinces have number of associated features that we will discuss in detail below.

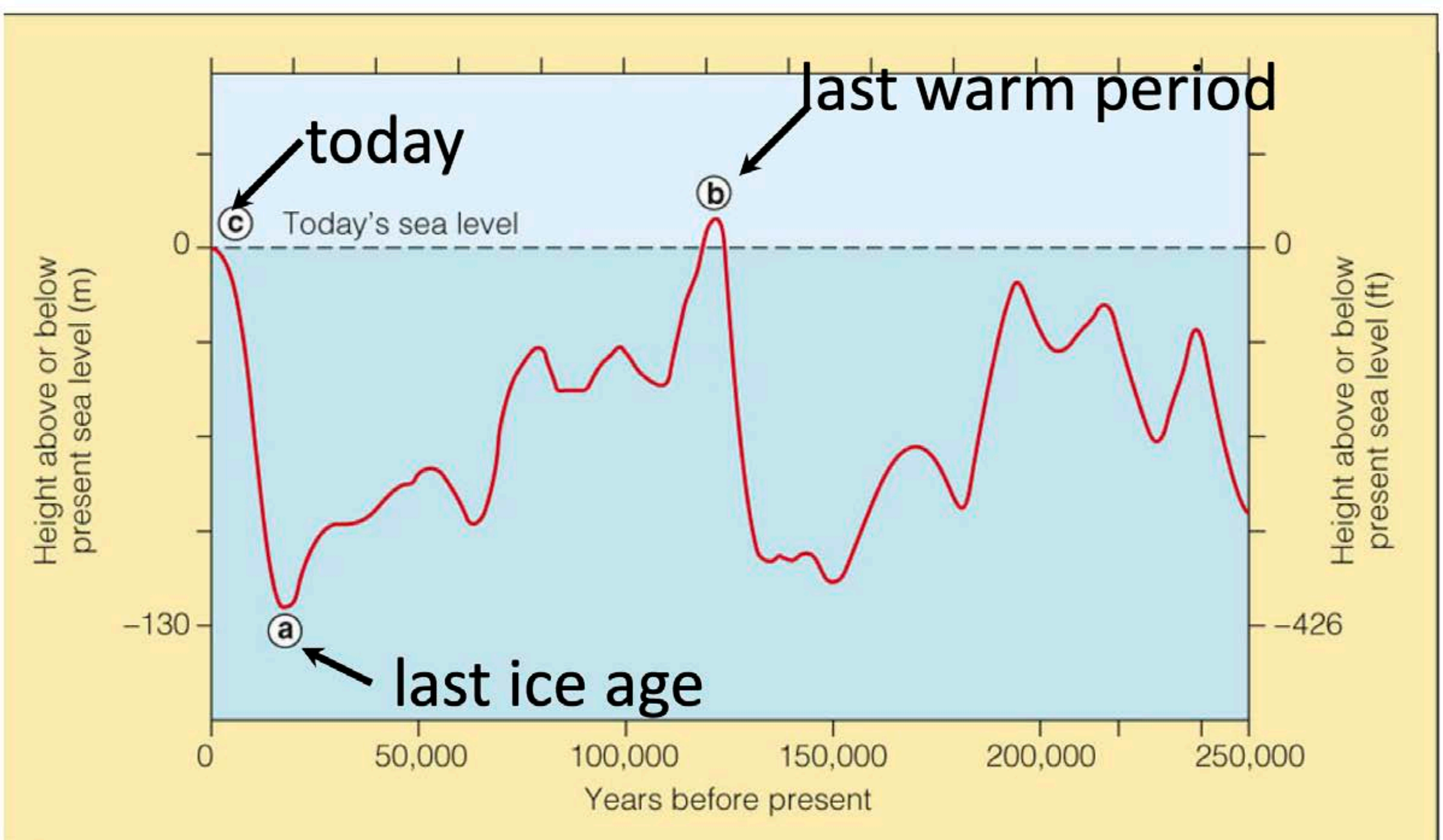


Continental margins: Continental margins are the submerged regions beside land continents. They can be further divided into specific regions, such as continental shelves, continental slopes, and submarine canyon. The margins are often classified as either active or passive. Passive margins are embedded within lithospheric plates and usually do not have major tectonic activity. A good example of this is the East coast of the United States and many continental slopes and shelves. On the other hand, active margins are associated with lithospheric plate boundaries and exhibit a great deal of tectonic activity. There are two types of active margins: convergent and transform (recall these from last lecture). Convergent active margins are associated convergent continental plate regions. Transform active margins are associated with the transform fault regions. An example of a convergent margin is western South America where the Nazca Plate is being subducted beneath the South American Plate. An example of a transform margin is coastal California, which runs along the San Andreas fault (see the figure showing a map of the plate boundaries in the previous lecture). The image below shows a diagram of a passive continental margin on the left, and an active continental margin on the right.



Continental shelves: Continental shelves are a feature of continental margins. Shelves are the generally flat region of seafloor extending from the shore until there is an increase in the slope angle. This increase in the slope angle is called the shelf break. Shelves are generally covered with marine sediments and continental crust below. Geologically, the submerged continental shelf is part of the continent. Much of the continental shelves are within certain countries' economic exclusive zones (areas of the ocean that one specific country has rights to) and thus their use is hotly debated given the presence of oil, fish, etc. These places tend to be locatinos o high biological productivity. Globally, the average continental shelf is ~70 kilometers wide, but the continental shelf off New Jersey is almost twice the size. The biggest continental shelf is offshore the Arctic and span a maximum of 1500 km. The size of the continental shelves varies with sea level changes over geologic time. During cold times (glacial periods), much of the globe's water is tied up in ice and the sea level is low. When the Earth is warm (interglacial periods), there is little ice and the sea level is high, precisely what is happening now with sea level rise.

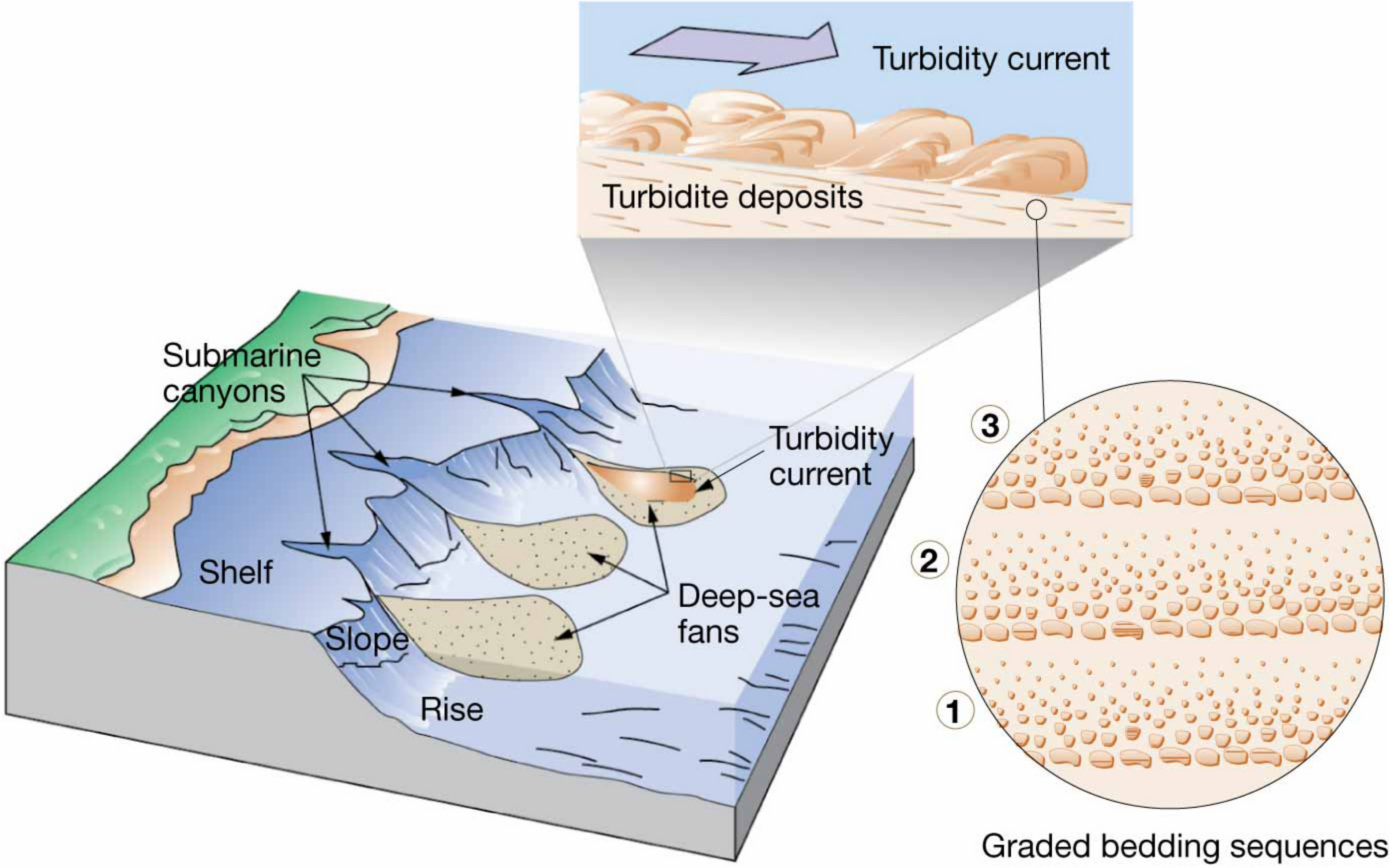
The main factors that affect the characteristics of a specific continental shelf are plate tectonics (whether it is an active or passive margin), sediment accumulation (this happens on passive margins), tectonic processes (these occur at active margins), ocean currents which can sweep away sediments, and sea level which determines the width of a given shelf. Sea level has fluctuated over geological time scales, with sea level rising and falling as global temperatures change and water stored in glaciers and ice caps melt or freeze. During the last ice age, for example, a lot of water was held as solid ice in ice caps on land which meant less water in the ocean and sea levels were lower than they are today. These lower sea levels corresponded to shorelines that were much further out to sea on the continental shelves than we know today. Imagine being able to walk miles and miles out onto the shelf off New Jersey? That would have been cool – cold in fact, because it was an ice age!



*Continental slopes***:** The continental slope is just offshore the continental shelf. They are regions of relatively steep slopes, and where the deep ocean begins (think mountain ranges). The global average for continental slope angle is 4 degrees, but it can vary between 1 and 25 degrees. (Remember that while these may be steep compared to the continental shelves, it still takes ~ 70 km to descend only ~3,500 m). Along convergent margins the slopes descend into deep-sea canyons.

Submarine canyons: The slopes often have submarine canyons, which are deep, narrow, and typically V-shaped underwater valleys. They can be large, for example the canyon offshore Monterey California, the Monterey Canyon is about the size of the Grand Canyon. Some of these canyons were carved by rivers (like the Grand Canyon) when sea level was low – those are canyons that are exclusively located on the continental shelf. Canyons that span the continental slopes are ones that were created by strong turbidity currents, like the Monterey Canyon. Turbidity currents are underwater avalanches, which can be triggered by earthquakes, the unstable build-up of sediment, or hurricanes. The dense current is a mixture of water and sediment, and can have thickness of liquid concrete! They can carry big boulders down a submarine canyon and are very effective at eroding the sea floor. In 1929 a major earthquake triggered a turbidity current in the Hudson Canyon off New York that broke 13 submarine telegraphic cables up to 1000 km off shore. These are strong currents!

*Continental rise***:** The continental rise is the transition between the margin and deep seafloor. It usually consists of a lot of rubble and debris. These rises are formed by the turbidity currents and the material that these currents carry. Heavier objects fall out of the currents faster than smaller ones (these sediments that are carried by the currents are called turbedites), and thus they form lamination layers over time. One current deposits material and then later a second current lays down another layer, and so on. The layers created are distinct and grade in size upwards into layers called graded bedding. These turbidity processes are impacted by the slope of the rise that currents move along. These turbedite deposits are called deep-sea fans (from above the look fan-shaped) and they can be dramatically large. The world's largest fan is the Indus Fan and it extends a mind boggling 1800 kilometers!!! It is found south of Pakistan.



(a) Turbidity currents move downslope, eroding the continental margin to enlarge submarine canyons. Deep-sea fans are composed of turbidite deposits, which consist of sequences of graded bedding (*inset*).

We will discuss the other provinces, Deep Ocean Basins, and Mid-Ocean Ridges next lecture.