Chapter 6
Example Investigations into Plate Tectonics

If you are not a geology or marine geology specialist, you may not be aware of the wonderful investigations that can be done using the earth data on the CD. This chapter describes some of these investigations. The descriptions are not intended to be distributed to learners as models of investigations, but to inform you, the teacher, of the possibilities so you can help guide your students in their own investigations. All figures are captured from the "Our Dynamic Planet" CDROM maps and data displays.

Observing the Earth: What's "interesting" about the earth?

As I began to use these materials, I asked my students to identify "interesting" features on the earth. I was met with blank stares. "What does interesting mean?," they asked. Hmmmm…. Seems that students don't find it obvious what I think is interesting. So, I had to ponder on this and come up with how I determined whether a feature was interesting. The answer lies in the recognition of patterns and relationships. So, let's look at a map of the earth and see what I mean.

I usually introduce this exercise by asking students to go to the world map in their lab manual, and to mark up "features" that I suggest. The next step is to access the MAP on the CD and explore the features they identify in greater detail. The exercise could go deeper by asking students to make descriptions of the features, share them with the class, and get feedback on how their descriptions could be improved.

I concentrate first on topographic features. Here are some examples of what I notice. First, the fact that the earth is divided into continents and oceans is interesting. When you look at the elevations on the CD MAP software, you will notice that the continents and oceans seem to divide into two distinctly different depth regimes.

The continents are mostly high, and the oceans are mostly deep. This implies that they are made from two different kinds of material. It is found that continental crust is less dense than oceanic crust. Over long time periods, both continents and crust "float" on the underlying mantle, and because less dense materials float higher, the less dense continents float higher.

I then ask students to find and mark features that are: a) arcuate, b) linear, and c) continuous. The world map in figure 6.1 has some of these features marked. It is handy, at this point, to have a world map where some of the identified features are named, so students begin to get acquainted with their names. In the western Pacific, the Aleutian Trench, Japan Trench, and Bonin Trench (from north to south) are marked. Linear features are (from north to south from arrows originating at the top of the map) the Mendocino Fracture Zone, Hawaiian Island chain, and Tonga Trench. The north-south linear feature in the far east is the Ninety East Ridge. The two linear features indicated at the bottom of the map are un-named transform faults that connect two segments of a spreading center.

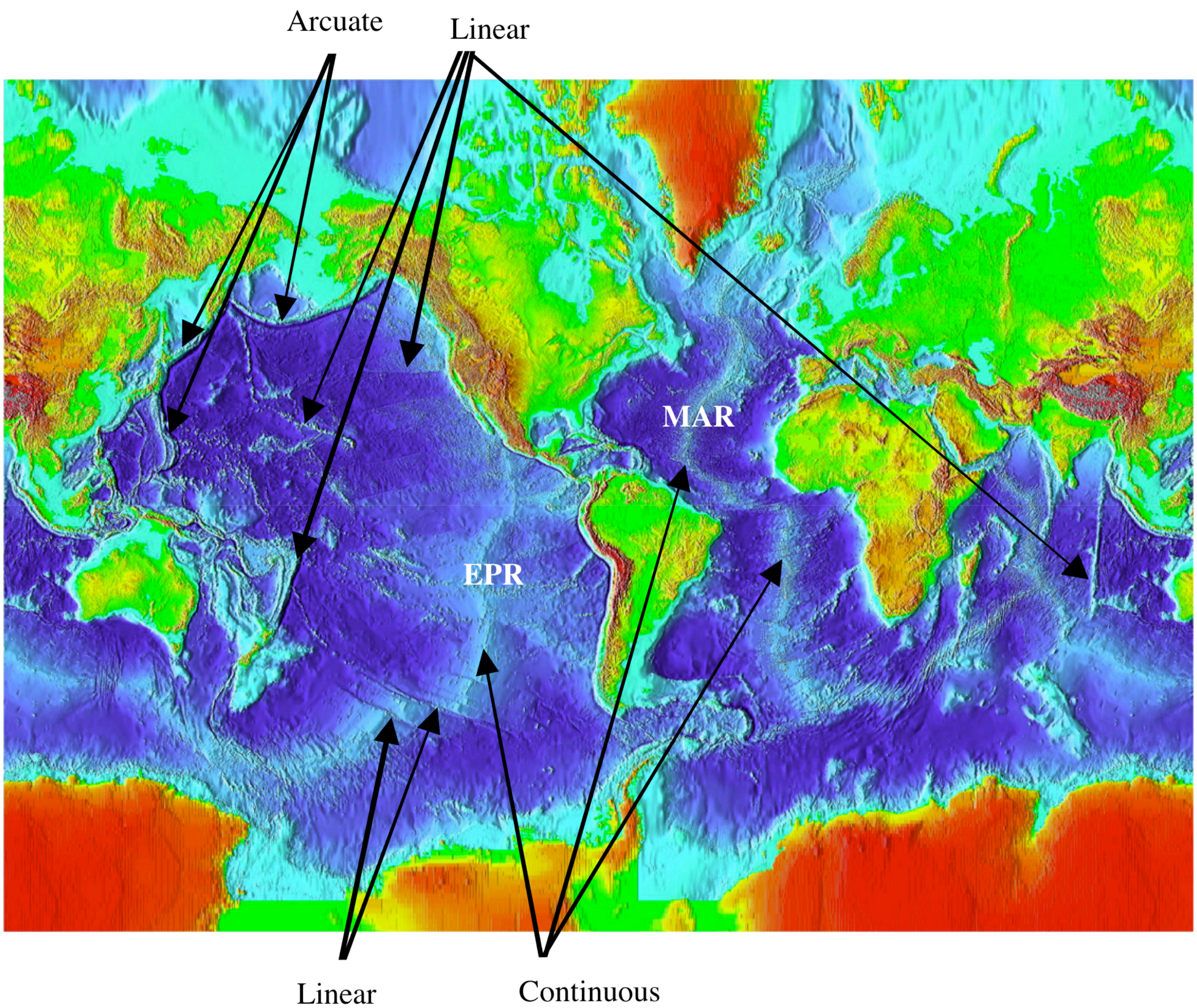


Figure 6.1. World map. What's "interesting" about the features that you see on this map?

Continuous features are (west to east) the East Pacific Rise (EPR), Mid-Atlantic Ridge (MAR). The continuous Mid-Atlantic Ridge extends the entire N-S length of the Atlantic Ocean and follows a line halfway between North America/South America and Europe/Africa. The East Pacific Rise intersects North America and travels south within the Pacific Ocean and south of Australia into the Indian Ocean. Notice how the Hawaiian Island Chain begins at the island of Hawaii, but after a certain length, it makes a sharp bend to the north.

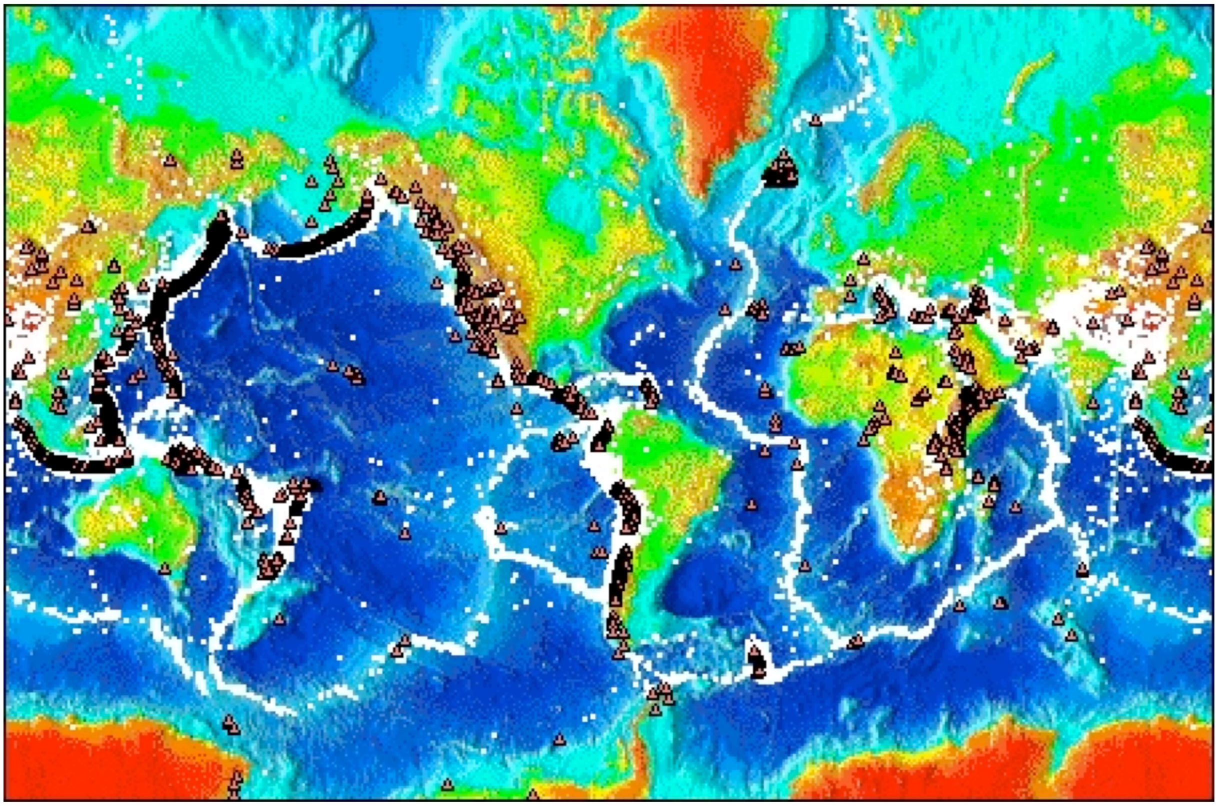


Figure 6.2. World map with quakes and volcanoes plotted. The white dots are quakes and the triangles represent volcanoes.

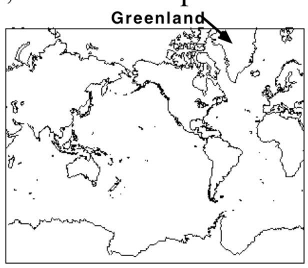
The map of figure 6.2 shows earthquakes and volcanoes plotted on the map. Now we can notice that the quakes plot on top of many of the topographic features that were noticed previously. Also, volcanoes (dark triangles) plot over the top of some of the dense earthquake zones, but not others. We are now beginning to notice that there are relationships between elevation, earthquake epicenters, and volcano locations. Why are some features are dense with volcanoes and others have no volcanoes? We might also ponder why volcanoes occur in regions where there are few quakes. For example the Hawaiian island chain has volcanoes at one end, but very few earthquakes at any point along it.

Figure 6.2 illustrates a limitation of the volcano data. We know that there are many seafloor volcanoes, but researchers have not mapped the seafloor completely, so they are not in the volcano database that was used to make the plot. So, we can't make inferences about the lack of volcano activity in oceanic regions where there are no volcanoes that appear above sea level and appear as islands.

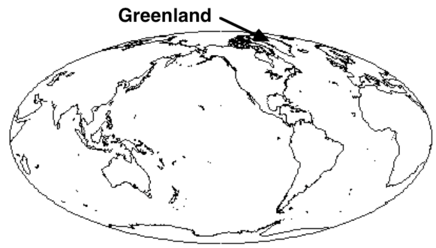
All of the features and relationships that have been identified so far can be explained using the theory of plate tectonics. The next activity is to ask students to use the "Our Dynamic Planet" CD to explore and describe the features that they identified in more detail. Learners should be encouraged to describe features quantitatively (depth, length, shape) and the relationships between the various data types (elevation, quakes, volcanoes, seafloor age, island age). Hopefully, this will begin to whet their appetite to learn why these features are related.

Map Projection Distortion

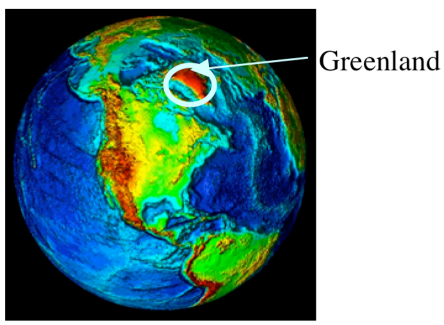
The maps contained within the "Our Dynamic Planet" CD are all drawn with a Mercator projection. This projection is easy for data plotting and angles are shown faithfully. Its disadvantage is that it exaggerates the size of features that are near the north and south poles. Notice how large Greenland looks on the map in figure 6.3 below. The Molleweide projection shows Greenland at a size much closer to its actual size and the orthographic is designed as a view from space, so is most representative.



Mercator Projection



Molleweide Projection



Orthographic (view from space)

Figure 6.3. Comparison of relative size of Greenland for 3 different map projections.

Small Area Description

In my class, I ask students to pick a problem in plate tectonics for further investigation. They are notified that this is preliminary to a science paper assignment of about 1800 words in length (discussed in detail, later). Students often have difficulty picking a topic. I usually start them out by asking them to make a map of the plates of the earth, showing the type of boundary at the plate margins. This requires them to recognize the 3 boundary types and how to determine them using data. I then pick one of the small areas (defined in the software) for an in-depth investigation that must be one to two pages long, not including figures. This is graded strictly and returned promptly. From that point, they are on their own. It is often necessary to get students started by asking leading questions. Learners will not immediately recognize a valid problem in plate tectonics. Class and group discussions of possible topics for investigation are important.

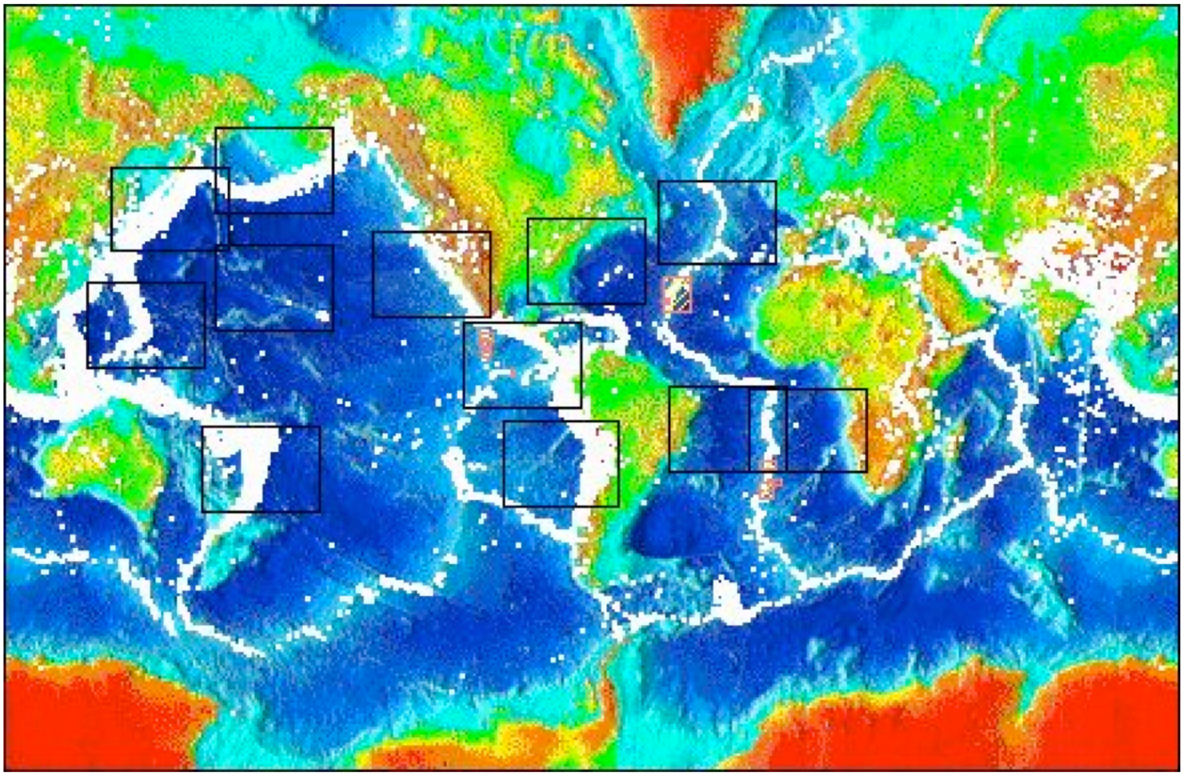


Figure 6.4. World map with all quakes greater than magnitude 5 for dates between Jan. 1 1966 and Jan. 1, 1996. The black rectangles outline areas where detailed maps can be accessed.

Identifying Plate Boundaries

Plate boundaries are extremely easy to identify once you realize that earthquakes indicate relative movement between two sides of a fault. So, quakes will be concentrated at plate boundaries. Figure 6.4 shows a world map with the quakes plotted on it. The black rectangles on the map indicate areas where the most detailed maps can be accessed. Notice that there are high resolution maps indicated by smaller cross-hatched rectangles. These are accessed by clicking inside the rectangle, then selecting the clicked region from the "Clickspots" popup menu. The map on the screen can also be magnified at an arbitrary location by 4 for a more detailed look at a particular region.. Use the index map at the upper right hand side of the screen to center the map on a particular location.

The major plates can be identified by tracing over the earthquake belts. Figure 6.5 shows the 7 major plates traced on the map of figure 6.4. Several smaller plates are indicated by single letters.

There are many complexities in the details of the individual plate boundaries, so be careful not to over-interpret the data. For one thing, the earthquake locations can be inaccurate by as much as 50km in the oceanic regions that are distant from the seismic stations that record the data used to locate them. For another, some important plate boundaries are diffuse and not defined by a single fault. For example, the San Andreas fault that divides the Pacific Plate from the North American Plate is part of a very diffuse boundary that begins in the west at the continental shelf in the ocean, and ends hundreds of miles to the east in the "basin and range" province of Nevada and Arizona. You can see that this must be true because of the spread of earthquakes away from the boundary zone. Can you find other regions where quake activity indicates a diffuse plate boundary?

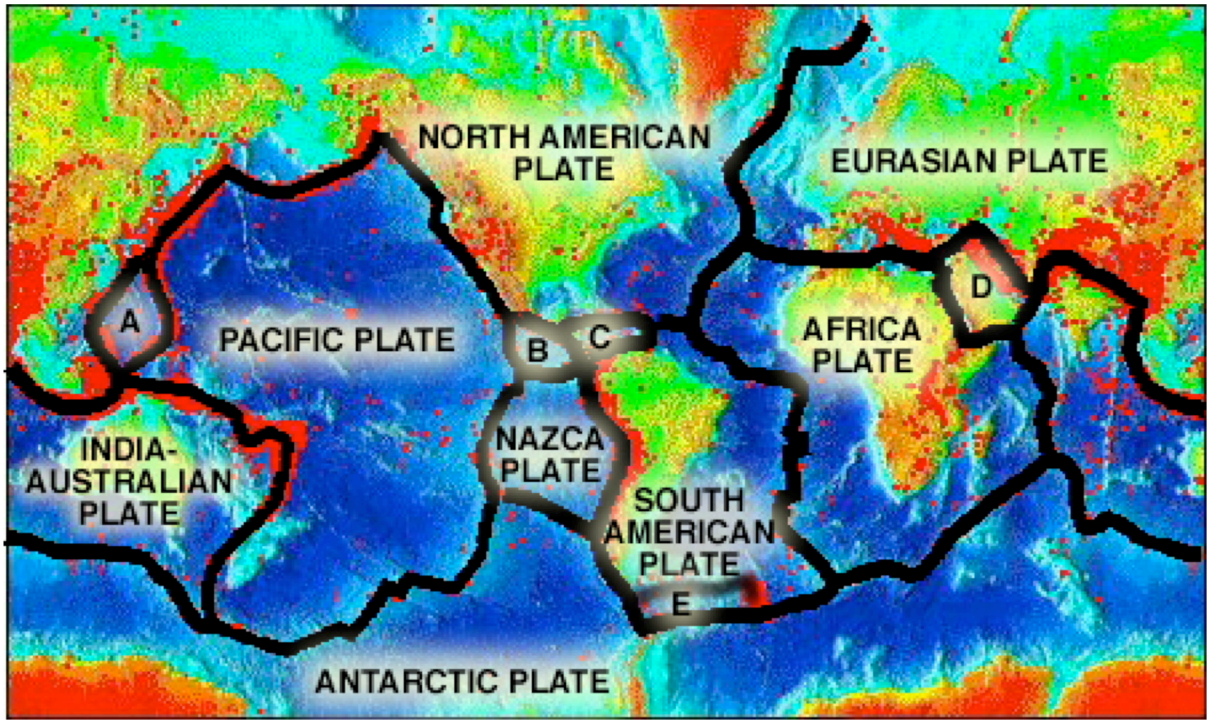


Figure 6.5. The 7 major plates of the earth are found by tracing the earthquake locations. Smaller plates are: A) Phillippine Plate, B) Cocos Plate, C) Caribbean Plate, and D) Arabian Plate.

Some plate boundaries have a complex geometry. An example is in Southeast Asia, where a complex intersection of subduction zones complicates the plate motion, making the location of the plate boundaries uncertain from the data on the CD.

Plate Boundary Types

Now that the major plate boundaries have been identified by simply tracing over a map of the earthquake epicenters, let's go into more detail and attempt to determine the boundary type, which could be convergent (subduction zone), transform, or divergent (spreading center). Be sure to refer to Chapter 4 for cross section diagrams of the plate boundary types. Even better, watch the virtual plate tectonics lecture on the "Our Dynamic Planet" CD.

Convergent boundaries:

A convergent boundary is most often manifested as a "subduction zone" (see figures 4.1 and 4.5). This is not always the case, as the collision between India and Eurasia demonstrates (described in the virtual plate tectonics lecture on the CD). A subduction zone is generally characterized by a) a trench, b) a descending pattern of quakes, and c) a line of volcanoes parallel to the trench. An arcuate line of islands (caused by the volcanoes) generally parallels the trench when two plate segments of oceanic lithosphere collide. When oceanic lithosphere collides with continental lithosphere (South America), a trench and mountain range are observed.

Let's look at two subduction zones, the classic Tonga-Kermadec subduction zone, and the subduction zone off the west coast of South America.

Tonga-Kermadec
Figure 6.6 shows a detailed map of the Tonga-Kermadec region.

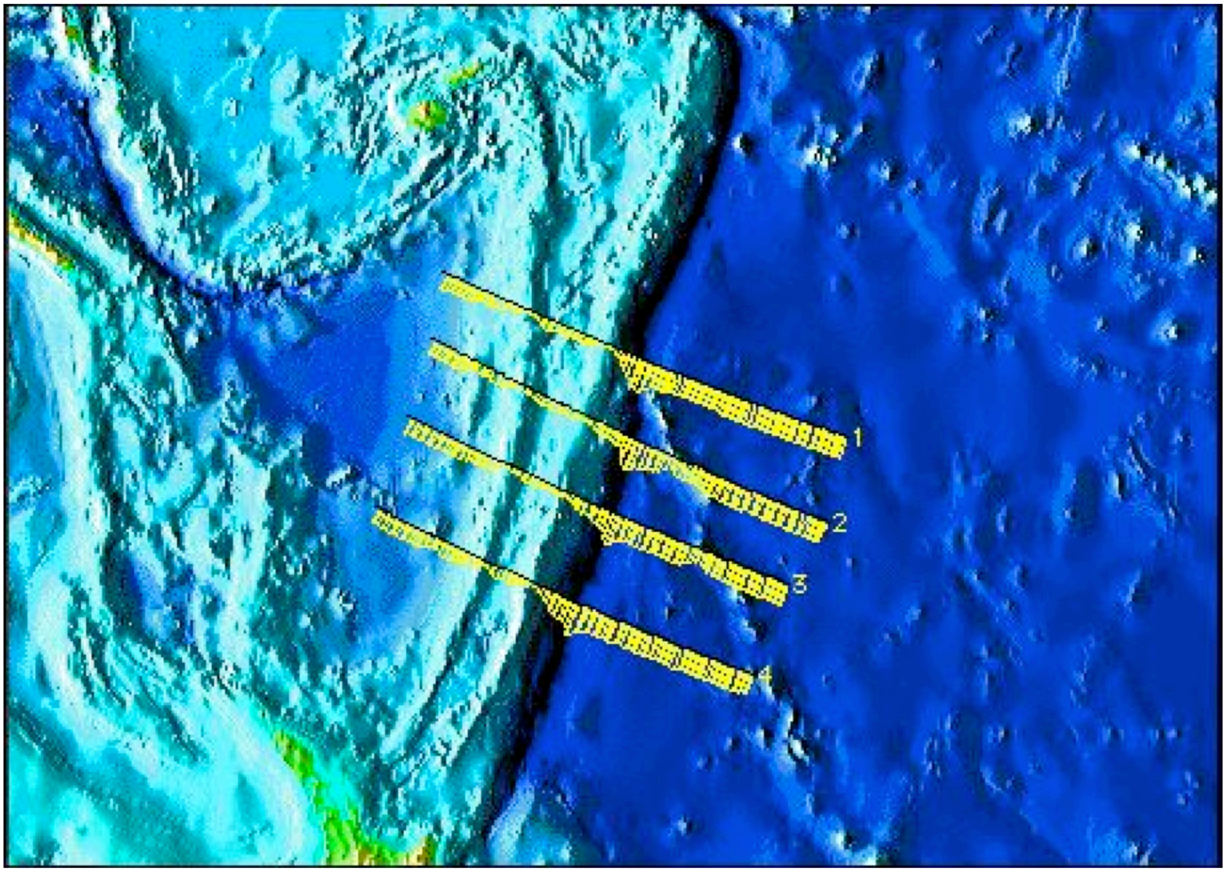


Figure 6.6. Tonga Kermadec region showing 4 profiles across the trench.

Figure 6.7 shows an elevation profile across the trench, and figure 6.8 illustrates how multiple elevation profiles can be combined into a single plot. There is no fine adjustment of the alignment of the multiple plots, so it is necessary to make the profiles carefully to make them match.

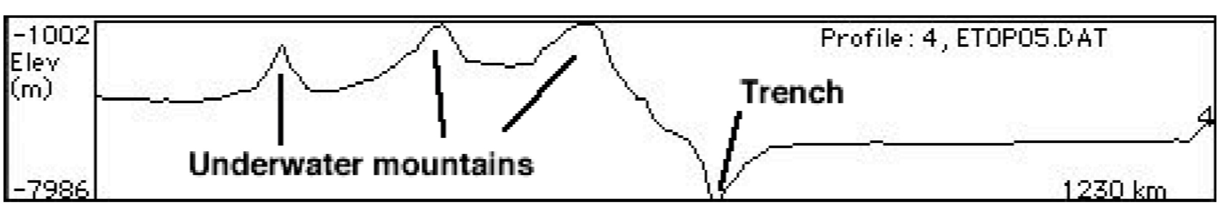


Figure 6.7. Elevation profile # 4 across the Tonga Kermadec trench, shown in figure 22.

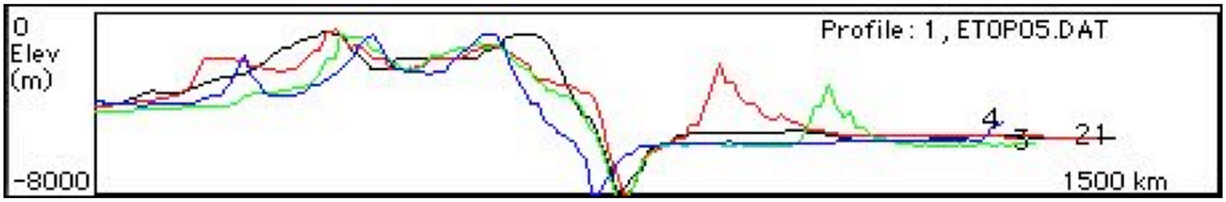


Figure 6.8. Combined plot of the 4 profiles across the Tonga Kermadec trench. Plots with multiple profiles can be set up using the "Display Options" popup menu on the Map screen.

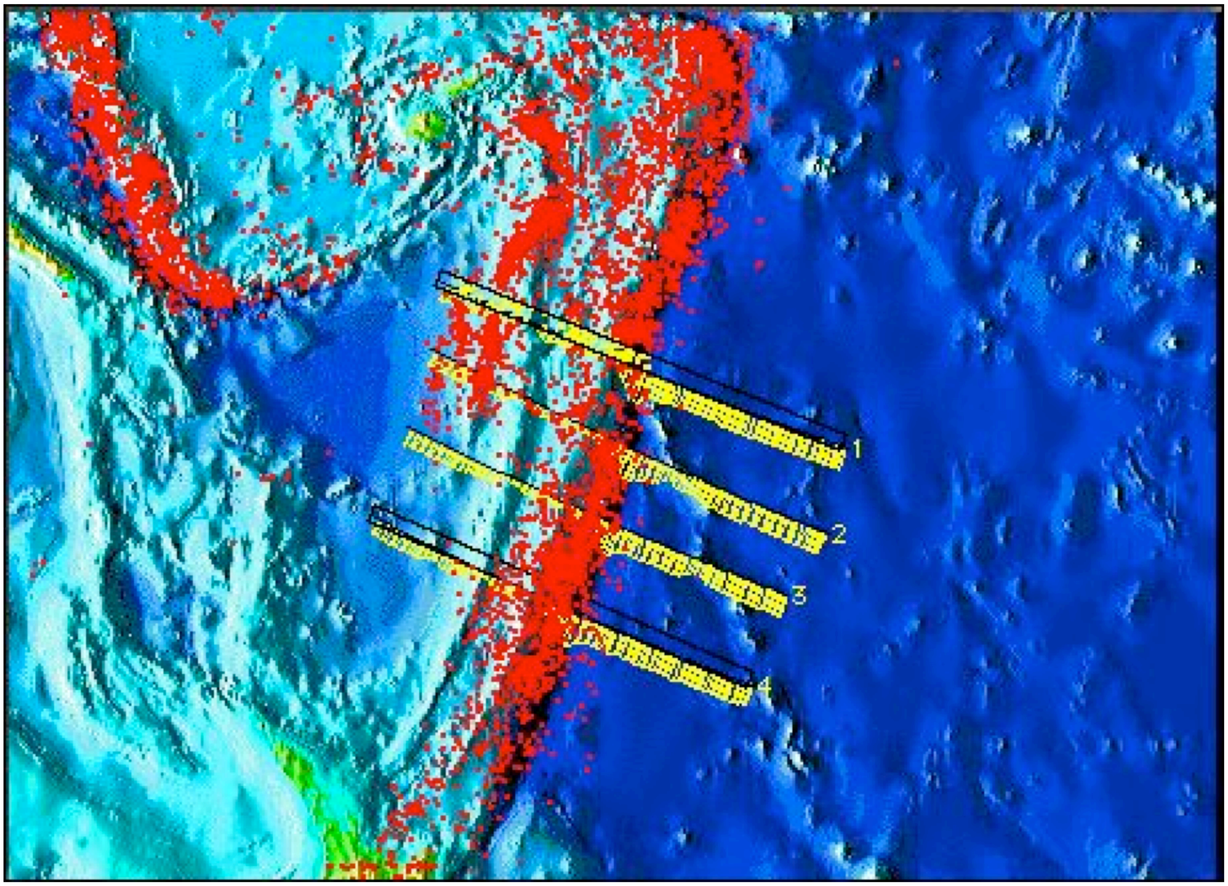


Figure 6.9. Earthquake plot of the Tonga Kermadec region. Notice the S shape to the seafloor structure and quake locations. This indicates that there will be some complexity in the geometry of the subduction zone.

The four profiles clearly delineate a trench feature with underwater mountains to the west. Figure 6.9 shows a plot of the earthquake epicenters with a hypocenter profile in figure 6.10 and 6.11. Note that the term "epicenter" refers to the earthquake's location as viewed from a map (horizontal location only). The "hypocenter" is a reference to the location that has both horizontal and depth information. The horizontal locations of quakes are generally more accurate than the vertical location. In oceanic regions, far from land-based seismic stations, care is required in interpreting earthquake depths. Quakes lining up at particular depths (along a horizontal line) indicates that there was not enough information in the seismogram to assign a precise depth. When this happens, the computer program that computes depth will set it to a predetermined value.

Figure 6.10. Earthquake cross section plot along profile 4. The black rectangle around the profile defines the region where the quakes are taken for this plot. Variation along the subduction zone is expected, so it is important to examine a number of profiles.

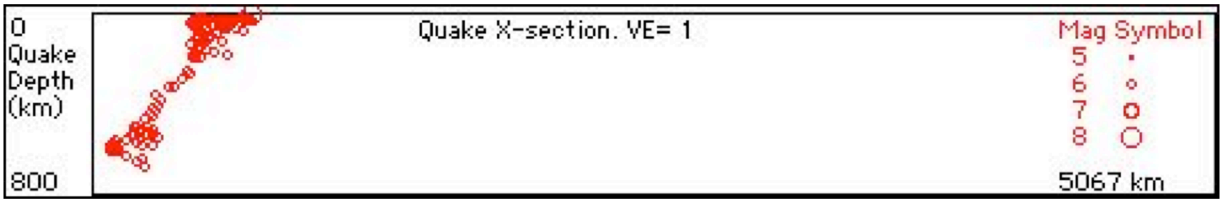


Figure 6.11. This is a plot of the same data shown in figure 6.10. The difference is that the vertical exaggeration of the plot has been set to 1. This makes it easier to determine the angle of the subducting slab. This can be set using the "Display Options" popup menu.

We have observed that there is a trench topographic feature and a descending pattern of earthquakes along the Tonga Kermadec trench. This is suggestive of a subduction zone. What about the volcanoes? Figure 6.12 shows volcanoes plotted in this region.

Notice that the volcanoes along the NNE section of the trench lie somewhat to the west of the topographic trench. I wonder if this distance varies for different trenches. Could it be related to the subduction angle of various subduction zones? After all, if the volcanoes are caused by melting of the sediments being dragged down by the penetrating slab, and if magma melts at a certain depth, the volcanoes for a shallow dipping slab should be further away from the trench than they are for a steeply dipping slab. The slab dip can be observed in the quake cross section plots.

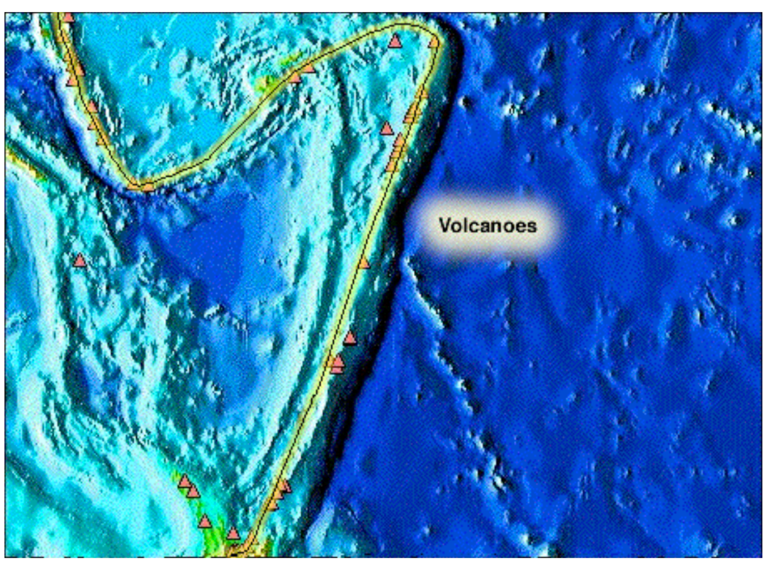


Figure 6.12. Plot of volcanoes for the Tonga Kermadec trench region. A line has been drawn to hilight the triangles showing the volcanoes. When in the MAP software, click on a volcano to get its last eruption date and eruption history.

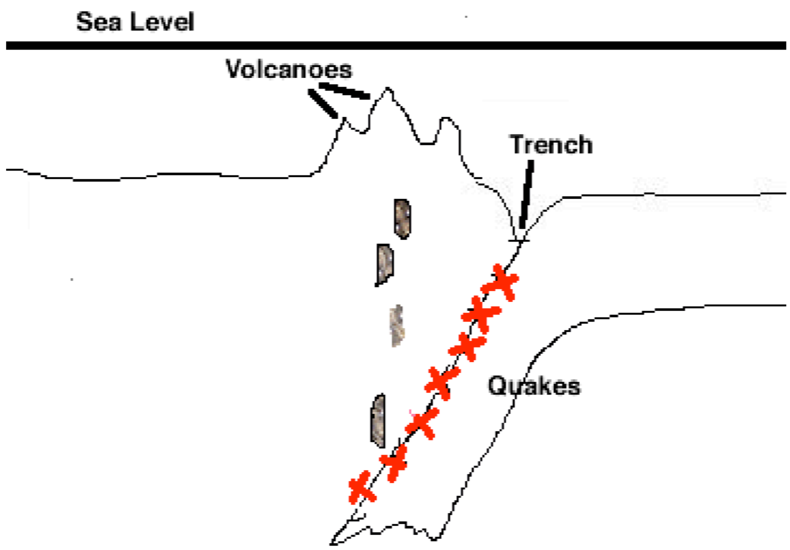


Figure 6.13. Cross section of model for Tonga Kermadec region. The trench, quakes, and volcanoes are shown.

So, the Tonga Kermadec trench region has topography, quakes and volcanoes in agreement with the model of a subduction zone. Figure 6.13 shows a cross-section model of this plate boundary. The locations of the trench, quakes, and volcanoes are shown on the diagram.

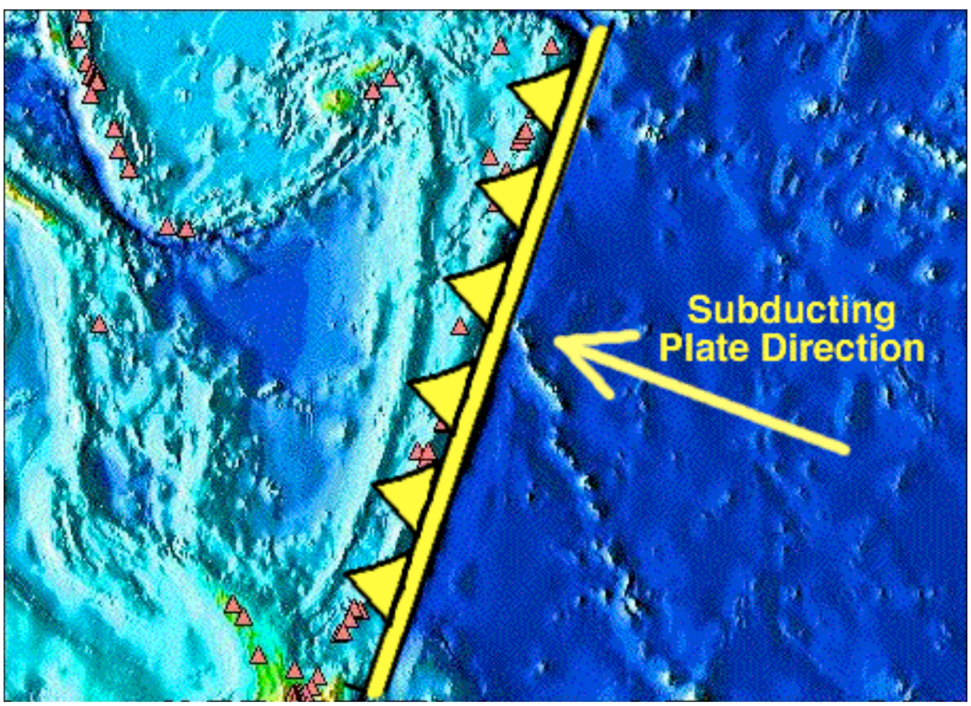


Figure 6.14. The plate boundary in this region, with the yellow line with the "teeth" pointing in the direction of subduction, is how this section of the plate boundary should be drawn.

A common student mistake: This discussion of the Tonga Kermadec plate boundary models the kind of presentation that we hope students will be able to make. First, the data are discussed and presented as maps, and plots. A discussion was made about how the data support a model of a subduction zone. Then a cartoon drawing showing how the model and are data correspond. A common mistake that students make is reversing the model so that it shows the subducting zone descending from left to right, rather than from right to left as shown above. This is done in direct contradiction to the descending earthquake pattern that delineates the subducting slab moving from right to left. Why is this? I think that it means that the student is still not thinking critically about the findings of the study. It would be an interesting cognitive study to find out why this happens.

West Coast of South America

Figure 6.15 is a detailed map of the region off of the west coast of South America, with earthquakes and volcanoes plotted. Notice that all of the profiles except one show a dip that indicates a trench. There is a dense belt of earthquake activity along the coast, with volcanoes along the Andes mountains. This fits with the model of figure 4.5 where an oceanic plate subducts beneath a continent. We also notice that there is a gap in the volcanoes. Can we explain this gap using earthquake cross-sections?

Figure 6.16 shows 6 earthquake cross-section profiles, two in the volcano gap and the others across the volcanic region. We need to be careful of comparing the quake cross section plots because the vertical scales are different. The vertical scale on quake profile 1, 5, and 6 are in the neighborhood of 150-0 km, and the vertical scales on profiles 2, 3, and 4 are roughly 600-0 km. We expect variation because the quake distribution is somewhat random and a cross section may miss deeper events. The investigator could improve the clarity of the plots by turning off auto scaling and using a single vertical and horizontal scale for each quake plot.

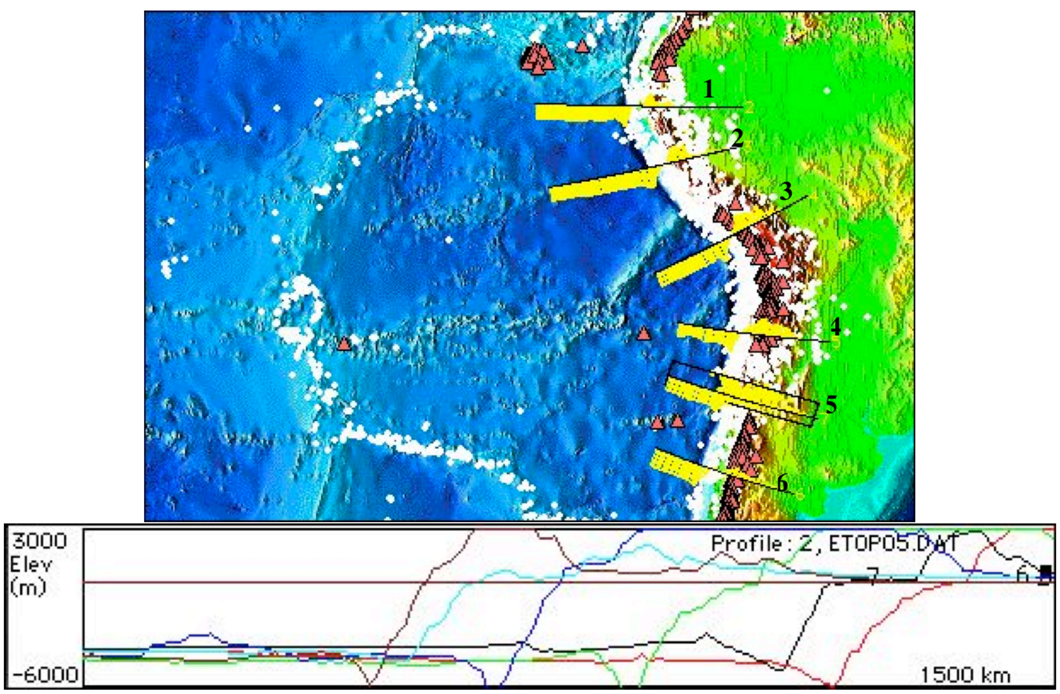


Figure 6.15. Detailed map of west coast of South America, with quakes and volcanoes plotted. The profiles all show trench features, except for the southernmost profile. The trench shows up at different locations on the profile plots because the profiles are not exactly lined up on the map.

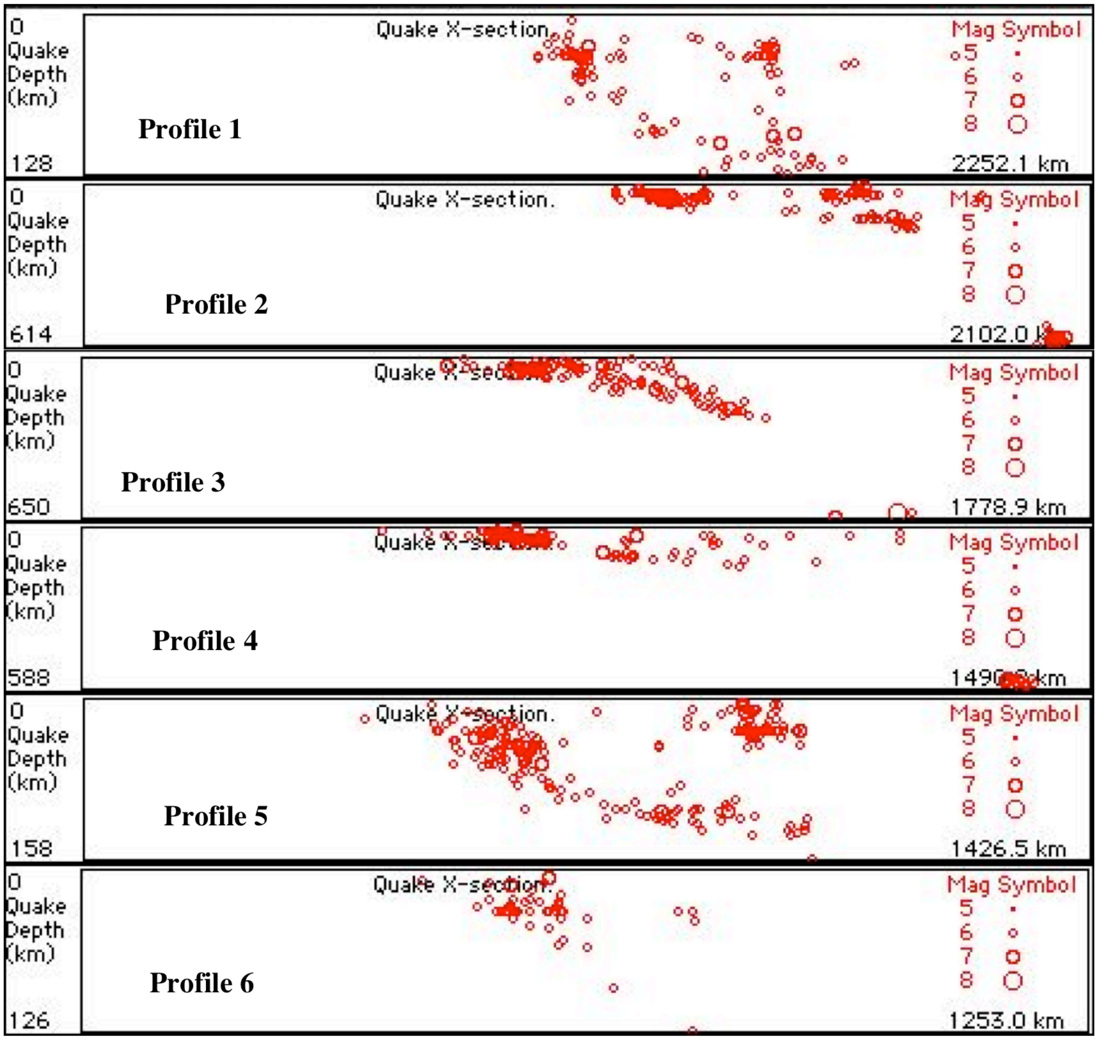


Figure 6.16. Earthquake cross-section plots along profiles 1 to 6 (top to bottom) of figure 6.15.

Profiles 1 and 2 are in the northern gap in volcanoes and profile 5 is in the southern gap. The other profiles have deep earthquakes, but the deeper quakes seem clustered at the deepest depth of the plot, while there seems to be little obvious difference in the distribution of the shallower earthquakes.

A complicating factor is that very large quakes are located (entered into the database) by where the fault rupture initiates, so it will appear as a single point on the map. But, for the huge Chili quake of 1960 (surface wave magnitude 8.6), the rupture was almost 1,000 miles long (see http://www.seismo-watch.com/EQSERVICES/NotableEQ/May/0522.Chile.html for more information). Generally there are a large number of aftershocks in the region where a large earthquake ruptures, so even though a large quake is represented as a single point on the map, its aftershocks will fill in the gaps. For the vast majority of quakes the rupture dimensions are much smaller and this is not a concern.

Understanding the volcano gap has been the topic of detailed seismic investigations in South America. It was found that the subducting plate flattens out at a shallow depth and the classic pattern of subduction to 600-800 km does not occur there. There will be many areas on the earth where the broad behavior of plate tectonics will vary from the simple theory. In practice, these variations are investigated through in more detailed earthquake studies where portable instruments are deployed near to the structure under investigation. Learners can find some of this information by searching the web (a good starting location is the U.S. Geological Survey site at: http://earthquake.usgs.gov/).

Comparing the Pacific and Atlantic Ocean Basins

Here is a great opportunity for learners to explore two major features of the earth, and to develop powers of scientific observation. Let's look at a world map and note some of the most obvious differences. It's a good idea to start with the world map shown in figure 6.17. The lighter blue (gray in black and white) in the ocean basins indicates shallower water. Notice the "s" shaped ridge down the center of the Atlantic ocean. A similar feature exists in the Pacific ocean basin, but it is mostly in the southern and eastern parts of the basin.

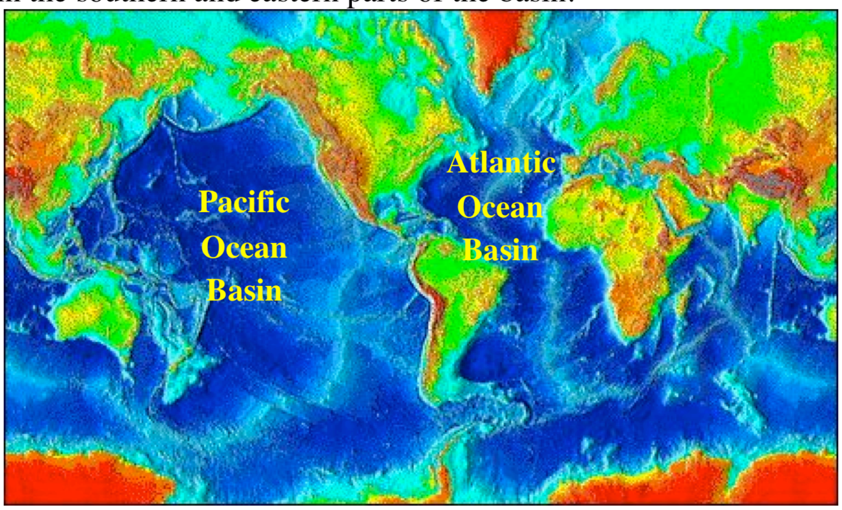


Figure 6.17. World map. Notice the differences between the Pacific and Atlantic ocean basins.

The differences in the two ocean basins may also show up in the topography, so let's look at elevation profiles. Figure 6.18 shows two profiles across each of the ocean basins. Most students don't look at the labels on the profile plots, so it is important to draw their attention to the fact that the profiles are different lengths. The one across the Pacific is 14,756km long and the one across the Atlantic is 7,423km long. The profiles paths are curved because they are following a great circle path along a map with a Mercator projection. The deepest part of the profiles are –7071m (Pacific) and –5427m (Atlantic).

Reminder: Each of the profile plots of figure 6.18 is "autoscaled" by default. This means that the axes are set to the maximum and minimum values of the data being plotted. This helps us a lot when browsing the data, but when comparing plots we need to keep this in mind. It is generally clearer if they are plotted on the same scale. This can be by accessing the "Elevation Plot" option under the "Display Options" popup menu on the MAP screen.

Each of the profiles cross the ridge indicated by a lighter color on the map. This location is indicated as A and B on the profiles. The age is also plotted on the profile and shows that the age is a minimum at the location of the ridge and increases away from the ridge, for both profiles. The Pacific profile also crosses the Tonga Trench. Can you identify it on profile A?

Figures 6.2 and 6.4 show a world map with quakes and volcanoes plotted. The differences between the two ocean basins are quite striking. Most of the quakes and volcanoes of the Pacific are around the edges of the basin (remember the many unobserved volcanoes on the seafloor), but there are very few quakes or volcanoes at the edges of the Atlantic ocean basin.

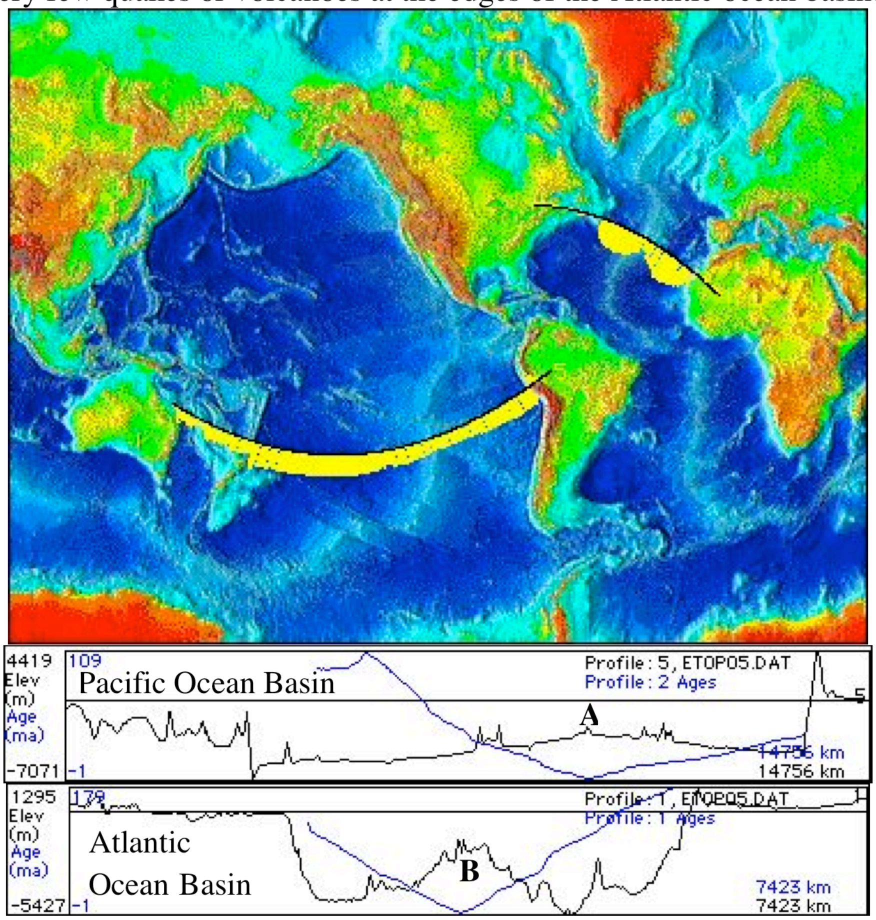


Figure 6.18. A comparison of elevation profiles across the Pacific and the Atlantic ocean basins.

Remember that quakes mostly fall along faults, so we can infer relative motion between crustal segments from quake locations. Volcanoes are evidence for hot magma rising from beneath the lithosphere, onto the earth's surface. They are abundant at subduction zones. The absence of

The terms "crust' and "lithosphere" are often confused. The lithosphere refers to the "plate' of plate tectonics. In the classic theory, it is rigid and moves as a unit over the software asthenosphere. Quakes within plates let us know that most plates are not perfectly rigid, though. The crust is a shallower layer that was originally defined by the velocity which seismic waves travel through it. It's thickness is about 5 km in oceanic regions and 25 to 60 km in continental regions, while the lithosphere is generally 100-150 km thick.

volcanoes, quakes, and trenches at the edges of the Atlantic ocean basin means that the Atlantic ocean basin to the west is probably connected to the North American and South American continents while the portion of the basin to the east is connected to the European and African continents. The minimum age at the ridge crest is the site of creation of new oceanic lithosphere and divides the two plates.

This is a good time to explore the two ocean basins using the MAP software. Use the profile tool to measure distances. How high is the Mid-Atlantic Ridge relative to a nearby mountain range? What is the vertical exaggeration of the elevation plots? Does the minimum age relationship occur along the entire ridge? What is the oldest age in each of the ocean basins? Note that there is no age data on continents and some of the ocean because the ages were computed from magnetic anomaly patterns, which are not clear on continents.

The East Pacific Rise and Mid-Atlantic Ridge (fast vs slow spreading)

The mechanics of seafloor spreading at spreading centers has been an active area of research during the last 20 years. Remarkable communities of unique life that doesn't depend on sunlight have been discovered at hot springs where seawater circulates deep into the hot crust. The seawater dissolves minerals from hot rocks and nourishes a food chain with "extremophiles" (bacterial living at extreme temperatures ~300^{O}C.) at its base. There is evidence that the earth has been completely covered in ice several times in its history, and these sites would provide are reservoir for life forms that could not exist at the surface. It has also been proposed that life originated at hot springs at spreading centers.

It was first noticed that the speed at which mid-ocean ridges spread has a strong effect on their topography. Fast spreading centers are smooth and low, while slow spreading centers are extremely mountainous. First, let's see how we can use the data on the CD to determine spreading rate.

Determining Spreading Rate:
The basic idea is to measure the age at a specific distance, then divide the distance by the age. First, we'll do a segment of the East Pacific Rise (EPR). Figure 6.19 shows a profile made perpendicular to the ridge (so that the maximum age increase and the profile direction match up). The profile begins at age 0 ma and goes out to 18 ma (millions of years). The distance of the profile is 748 km. So, the spreading rate is:

$$rate = \frac{748km}{18ma} = \frac{748x10^6\,mm}{18x10^6\,yrs} = 41mm/yr$$

So, the spreading rate (called the half-spreading rate, because objects on each side of the spreading center will separate at twice this amount), is 41 mm/year, which is considered quite fast.

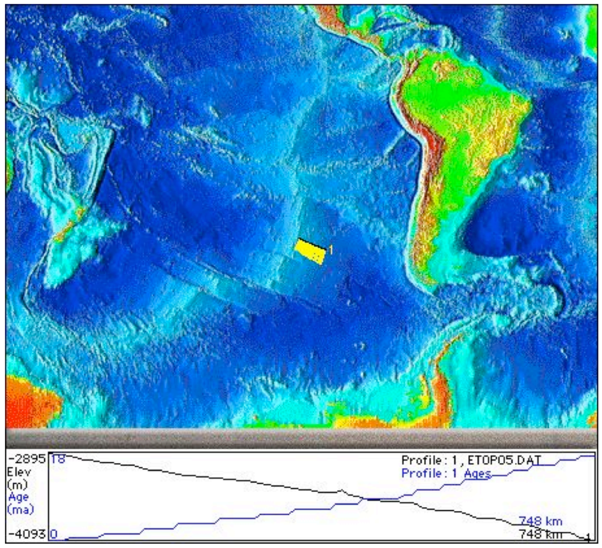


Figure 6.19. Calculating spreading rate for the East Pacific Rise at about 45° South latitude.

Now, let's look at the spreading rate for the Mid-Atlantic Ridge (MAR). Figure 6.20 shows a map and profile sections.

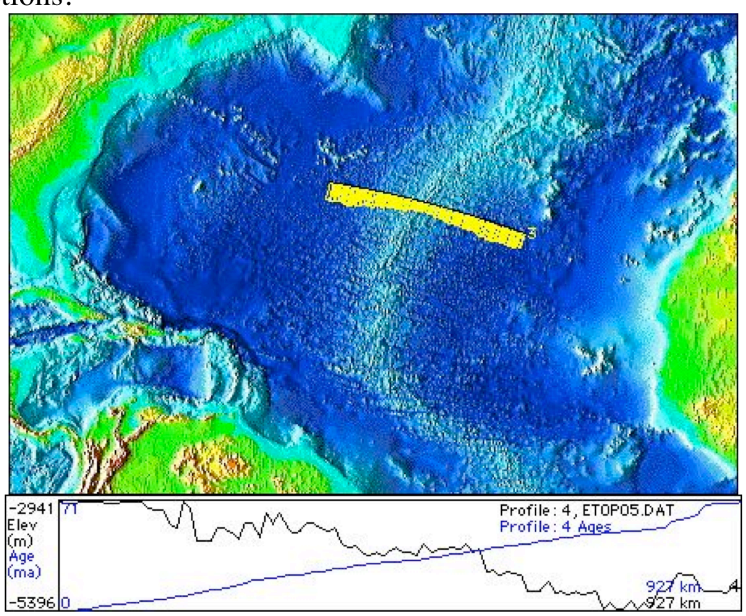


Figure 6.20. Data for Mid-Atlantic Ridge spreading rate calculations.

For the MAR data above, the profile distance (bottom profile) is 927 km and the age difference is 71 ma. So, the spreading rate is:

$$rate = \frac{927km}{71ma} = \frac{927x10^6 mm}{71x10^6 yrs} = 13mm/yr$$

So, the MAR segment sampled spreads at less than half the rate of the EPR segment that was sampled. A topic for further investigation is whether all locations on the spreading center(s) spread at the same rate. If not, why? Learners might also try to find the fastest spreading rate.

The character of the two spreading segments studied is very different. Compare the two profiles of figure

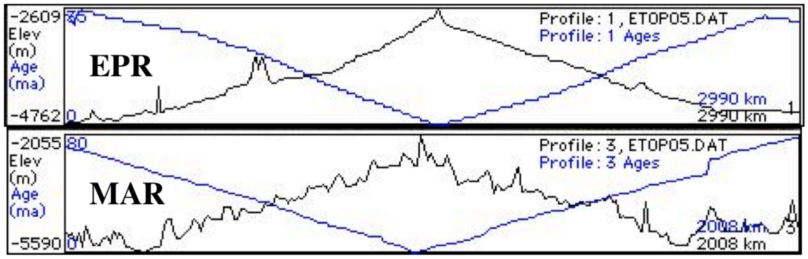


Figure 6.21. Profiles across EPR and MAR, for the profiles shown in figure 6.19 and 6.20.

To make the comparison, we need to first check the plot axes, since autoscaling was used for both plots. Notice that the EPR plot spans a vertical distance of 1993 meters, while the MAR profile spans a vertical distance of 3535 meters. The horizontal scale is about a third longer for the EPR profile. An expanded scale would make mountains look flatter, but the longer scale on the EPR plot is not enough to hide the fact that the roughness of the MAR profile is much greater than that of the EPR profile.

The CD software allows an examination of the differences between the EPR and MAR in greater detail. To access this greater detail, display “Small Area Maps” from the “Data Display” popup menu.

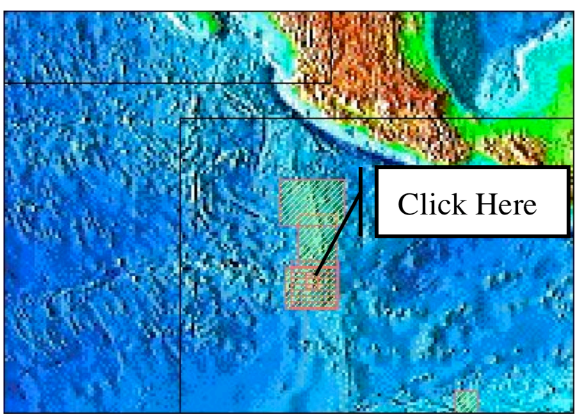


Figure 6.22. Small Area Map showing locations of detailed elevation maps of the EPR.

Figure 6.22 (left) shows locations of detailed data on the EPR. Click on the area indicated and then select “epr.9n”. If you don’t see this in the clickspots list, click again until it comes up. Select “epr.9n” and you will see an image like figure 6.23, which is a detailed grayscale map of the EPR at a lattitude of approximately 9N. This is a site that has been studied by numerous expeditions that include dives with the Alvin submarine, detailed seafloor mapping of elevation, magnetism, and gravity, biological observations, and seawater chemistry studies.

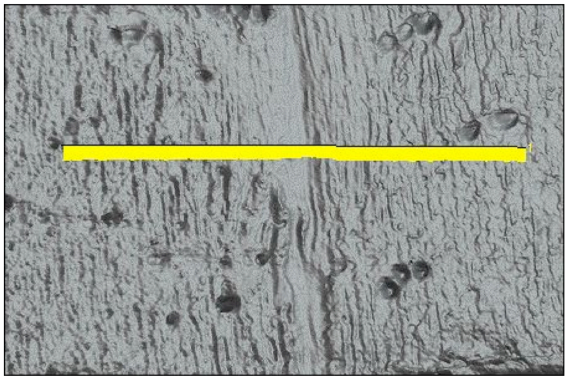
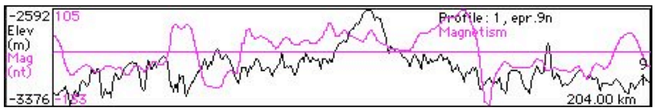


Figure 6.23. Rendering of detailed elevation data from the EPR at 9^{O}N latitude.

Figure 6.23 shows a map view of this region. The length of the indicated profile is only 204km, so shows a great more detail than the profile of figure 6.21, which has a length of almost 3,000 km. In the profile plot at the left, elevation and the magnetization of the crust, rather than its age.



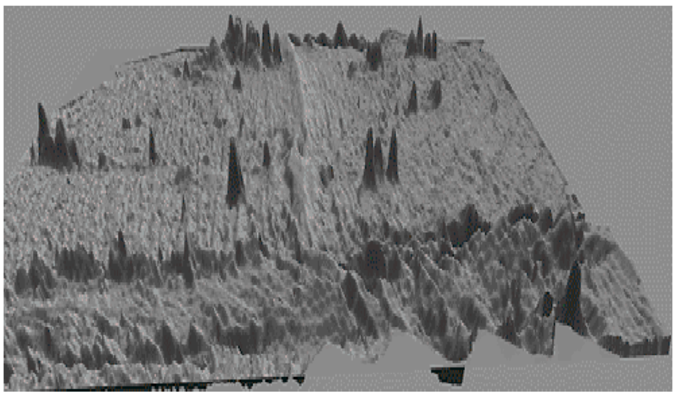


Figure 6.24 (left), shows an oblique view of fig. 6.23 (click on the map with the option key down). There are numerous mountains (they look more peaky than they really are, because the vertical scale is exaggerated). There is also a regular pattern of linear hills and valleys parallel to the ridge crest. Because of this regularity, and their parallel orientation, one would suspect that a spreading-related process created them.

Figure 6.24. Oblique view of EPR at the detailed study site.

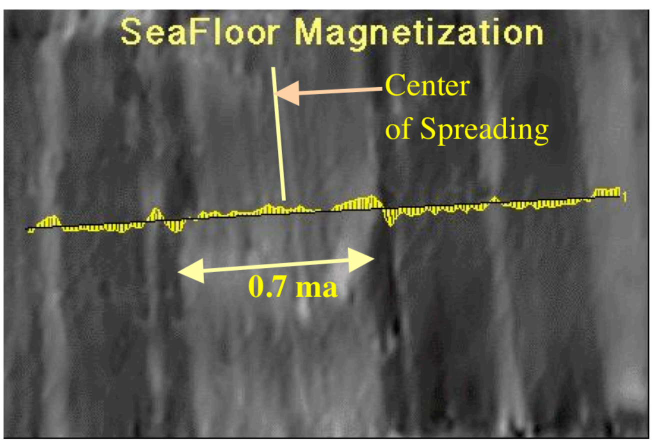


Figure 6.25. Magnetism of the seafloor at the detailed study area. The crust represented by the lighter area over the spreading center took 0.7 ma to form.

Figure 6.25 shows the magnetism of the crust of gi 6.23. Seafloor magnetism is the used to get the seafloor age for most of the ocean. The first magnetic reversal occurs at about 0.7ma. The timing of the magnetic reversals has been worked out, so the age was determined by finding the reversal boundaries on the seafloor, and using the known dates of the reversals to compute the seafloor age.

Now let's examine the MAR. Figure 6.26, 6.27, and 6.28 show views of the detailed area on the Mid-Atlantic Ridge. To access it, choose the small area maps from the "Data Display" popup menu and select MAR from the clickspots list. There are several maps available, and the ones discussed are somewhat typical.

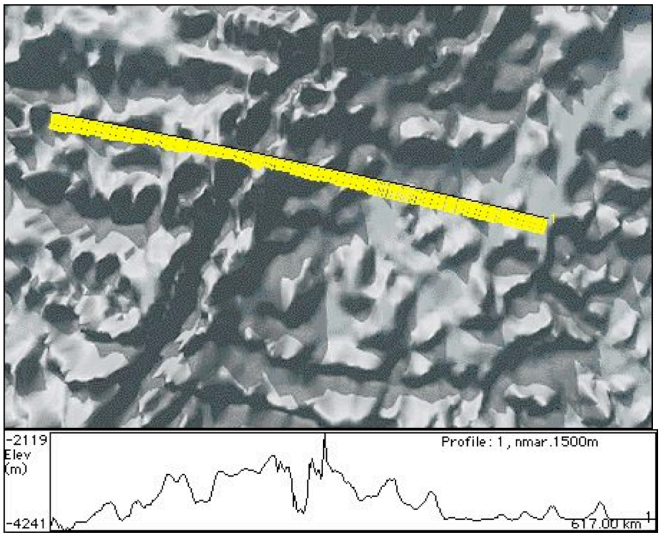


Figure 6.26. Rendering of MAR detailed map, labelled nmar.1500m. The spacing of elevation points is 1.5 km.

Figure 6.26 shows a rendering of a detailed elevation grid with spacing of 1.5km (the ETOPO5 grid for the global elevation map has 5km spacing). In the profile below figure 6.26, there is a deep valley at the center of the ridge. This is characteristic of slow spreading centers.

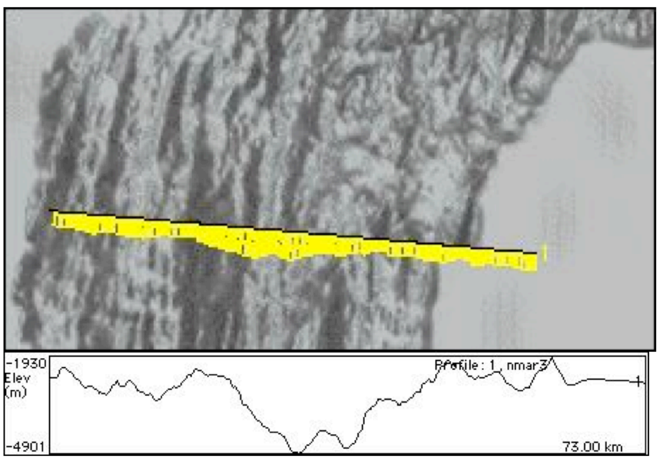
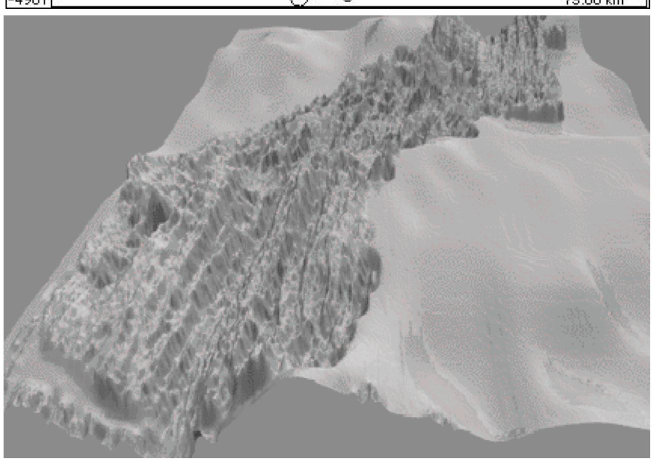


Figure 6.27. MAR topography from elevation grid with 0.1km spacing.

Figure 6.27 (left) shows an even more detailed image created from an elevation grid spaced about 0.1km. The axial valley of the spreading center is also shown, and is almost 3km deep at this location. The figure was created from a very detailed elevation map connected to one with less detail further away from the spreading center. This means that the apparent smoothness of the topography is an artifact of the data, which is not available at the same detail further away from the ridge axis. The figure to the left shows an oblique view of this rendering.



Ideas for other investigations

In the following discussion, I suggest possible investigations that can be conducted with the CD. As a teacher, you may have some ideas of your own, and the idea is to explore. I offer the following as starting places.

1. Determining plate boundary types: I ask my students to find evidence for the theory of plate tectonics. Most of them concentrate on showing evidence for models of the three types of plate boundaries (divergent, convergent, transform). The more diligent ones study hot spots or contrast the Pacific and Atlantic ocean basins.

2. Comparing subduction zones: Different subduction zones dip into the earth at different angles. Could this be related to: a) age of the subducting crust, b) seafloor depth, c) distance of volcanoes from trench? I also notice that in the pattern of earthquakes, there are often gaps at intermediate depths. Could this be because the rocks that melt along the subduction zone (to form the magma that creates surface volcanoes) creates a zone of aseismic slip (few quakes) occurs? Possibly there is some other reason. To study this, it would be necessary to measure subduction zone dips, then distance between volcanoes and trench, then work out the depth where the magma is coming from. Then, the depth where quakes are sparse could be compared. It would be necessary to do this for several subduction zones. Figure 6.28 shows the geometry. **X** is the distance between the trench and volcanoes, **d** is the depth to the zone of sparse earthquakes, and **Φ** is the angle of subduction measured from the earthquake plot cross-section. The data must satisfy **d/X** = tan(**Φ**). You can measure **Φ** and **d** from quakes alone, and you calculate X using X= d/tan(**Φ**). You can also measure X using the profile tool to get the distance between the trench and volcanoes. If the two values of X agree, you have support for the theory that the sparse zone of quakes is due to melting of the subducting slab.

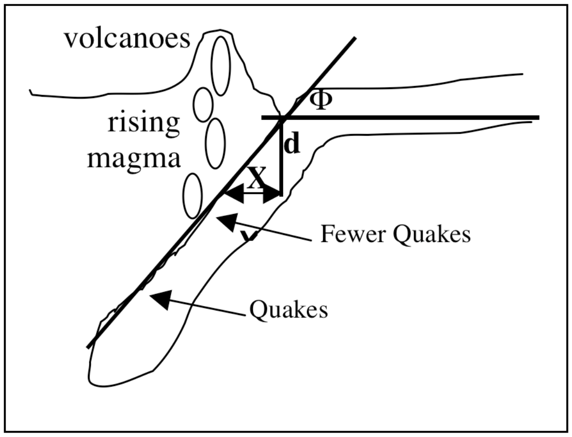


Figure 6.28. Geometry for a study possibly relating the location of sparse quakes at particular depth for a subductiong zone to location of surface volcanoes.

<u>What's really happening:</u> It turns out that the subducting plate is a bit more complex than we first imagine it. Because the subducting slab is moving with respect to the upper surface of the lithosphere ("hanging wall"), it would seem likely that the boundary between the slab and the hanging wall generates quakes much like a transform fault generates them (fig 6.28). This means that all quakes would occur along the zone of slip. This doesn't happen, though, because once the fault gets to a certain temperature (temperature rises as depth increases), aseismic slip (no quakes) dominates. This effect is why California's San Andreas fault has almost no quakes deeper than 15km, even though the fault penetrates (and slips) much deeper. Our first ideas are correct near the surface, where the slip surface is responsible for most of the quakes. The shallower part of the slab is pulled down by gravity, so is stretched. But near its deepest part, it hits more resistant material and is compressed. The stretching at the surface and compression near the bottom is what causes the quakes. The zone in of fewer quakes is the transition zone between stretch and compression, where there is not enough stress to cause quakes. To understand this, you need to think of the slab as somewhat elastic, rather than completely rigid. This was discovered by using earthquake "fault plane solutions", which allow us to determine the orientation of slip surfaces for earthquakes. You could not figure this out from the data in the "Our Dynamic Planet" CDROM.

Further comments: For a stronger investigation, you would want to make the measurement at a number of different subduction zones. It would probably not work for some. Maybe there would be some other pattern or relationship that would provide a clue. Is there really a relationship? Maybe: what do you think? Allow for the possibility of a negative result.

3. Hot Spots: One of the data types that can be displayed is island ages. The age of the island of Hawaii is very young (<1-2ma), yet the seafloor adjacent to Hawaii is much older. Hawaii is at one end of a long island chain. The ages get progressively older as the distance from Hawaii increases. The investigator might plot age vs distance and show a linear relationship. The slope of the plot has units of velocity. Does this "velocity" agree with plate velocity measured by looking at differences in age at two locations on the seafloor near Hawaii and dividing them into the distance between the two age locations? It should. How does one account for the abrupt change in the trend of the island chain, to the North? Do other island chains show a compatible age-distance relationship? What does this say about the velocity and direction of motion of the Pacific Plate?

4. Seafloor depth vs age relationship: An interesting relationship between seafloor depth and age has been discovered. The investigator/learner might explore how depth varies with distance from a spreading center for various spreading rates. This should show that the depth increases faster for slow spreading centers. But, if the depth is plotted vs the age, we can see that the spreading centers tend to agree with each other.

Other learning goals:

Some of the above suggested investigation topics require the student to use data plotting and trigonometry skills. Real earth data sometimes has a lot of variation, or noise, so the learner must decide whether the theory is wrong, or whether the data vary due to random changes in the earth that would be expected.

Some future "to do's":

The investigation of plate tectonics can motivate students to use their math and critical thinking skills. It would be useful to identify activities that support specific math learning goals. The investigations that I have suggested will probably need modification and adaptation for specific K-12 learning levels. Plate Tectonics is contained in most of the state standards, so carefully worked out lesson plans tied specifically to these standards would be useful. In all grade levels, writing and presentation of results to peers should be included as a fundamental part of doing science.