5.2.2: Continents and Ocean Basins

Overview

Unlike the other inner planets, the surface of the Earth is at two predominant levels, one averaging 2,750 feet (840 m) above sea level, making up the continents, where we all live, and the other averaging 12,100 feet (3,700 m) below sea level, making up the ocean basins (Figure 2-2). If you were able to look at the Earth with the water removed, the continents, together with their submerged continental shelves, would appear as gigantic plateaus, with steep slopes down to the ocean basins below (Figure 2-3a, b, 2-4). With the seawater removed, the dry land of the North American continent would appear as a high plateau relative to the deep-sea floor.

Figure 2-3a shows the Earth with the water removed. Continents are large plateaus above sea level, and ocean basins, in blue, show oceanic spreading centers in very light blue and trenches, marking subduction zones, in very dark blue. Figure 3b shows the Earth divided into tectonic plates, with subduction zones marked by heavy black lines and ocean spreading centers by narrower lines. Large earthquakes are shown as red dots. Note the Pacific Ring of Fire. Figure 2-4 shows the Gorda Plate with the water removed, with narrow lines marking the present and former position of the Gorda spreading center. Most earthquake energy is released along these plate boundaries, although the spreading centers are also marked by earthquakes (Figure 2-5).
Imagine yourself flying northward along the northern California coast with all the seawater removed (Figure 2-4). You would look westward from the Oregon and northern California Coast Range to a narrow continental shelf, which, indeed, was dry land at the height of the ice ages when sea level was nearly four hundred feet lower than it is today. Beyond that, the land slopes downward for thousands of feet to the present deep ocean floor, part of the Gorda Plate (Figure 2-6). North of the Columbia River, the deep slope off the coast of Washington is cut by a series of twisting canyons rivaling the Grand Canyon in size. The Strait of Juan de Fuca is a broad valley separating the Olympic Peninsula from Vancouver Island, which is itself connected to the mainland by a series of islands. Puget Sound is another valley, similar to the Willamette Valley. But it is the steep slope between the continental shelf and the deep ocean floor that dominates the scene. It’s as though people living on the Pacific coast were in Tibet, looking down to the plains of India far below (figures 2-3a, 2-4).

The reason for the different levels is that the continents and ocean basins are made up of different kinds of rock. Continental rocks are rich in the light-colored minerals quartz and feldspar, which combine to make up the principal kind of rock in the continent, which is granite (Figure 2-2). You can find good exposures of light-colored granitic rocks in the Coast Mountains of British Columbia, the North Cascades of Washington, including the Alpine Lakes Wilderness Area east of Seattle, the Wallowa Mountains of Oregon, and the Sierra Nevada of California (which John Muir, because of their light color, called “The Mountains of Light”).

Ocean-basin rock, on the other hand, is predominantly basalt, which contains the light-colored mineral feldspar but is dark brown to black, because its color is dominated by dark minerals like pyroxene and magnetite. The mountains on the east side of the Olympic Peninsula, visible from Seattle on a clear day, are composed of basalt, with most of it deposited on an ancient ocean floor about fifty-five million years ago. Basalt lava flows also characterize the Columbia Plateau and Columbia Gorge, although these rocks were formed on the continent, not in an ocean basin. Basaltic rocks are common on other planets, whereas continental granitic rocks are not.

The third type of rock called peridotite underlies both the continents and the ocean basins, and this is made up of dense
minerals such as pyroxene and olivine. This dark rock has no feldspar and thus it is heavier than either basalt or granite. Peridotite is also brittle and strong at much higher temperatures than either basalt or granite, a fact that will become significant when we consider in Chapter 5 the environment of deep earthquakes beneath the Puget Sound region.

Peridotite does not form naturally at the Earth’s surface. It is found at the surface only in special circumstances where great tectonic forces have raised it up to view. As it comes to the surface, it absorbs water, and the green streaky rock that results is called serpentine, which has been designated the state rock of California. Serpentine and peridotite are found at various places in the North Cascades of Washington, the Blue Mountains of Oregon, and the Klamath Mountains of Oregon and northern California. From a distance, terrain underlain by peridotite or serpentine may appear a weathered reddish-brown, and it does not support as much vegetation as other types of rock. The Twin Sisters range east of Bellingham, Washington, is made up almost entirely of olivine, one of the minerals in peridotite, and the mountains south and west of Mt. Stuart, in the North Cascades north of Ellensburg, Washington, are made up of peridotite.

During the four and a half billion years of Earth history, convection currents sweeping at extremely slow speeds through the Earth’s interior have resulted in the gradual accumulation of granite and basalt near the surface, much like scum floating on the top of a large pot of slowly boiling soup. Granite and basalt float on top because they are lower in density than peridotite.

Basalt and granite make up the crust, and the underlying heavy peridotite makes up the mantle, which extends all the way down to the top of the molten outer core of the Earth at 1,800 miles (2,900 kilometers) depth. The boundary between the crust and the mantle is called the Moho (Figures 2-1 and 2-2), shorthand for the name of the Croatian seismologist, Andrija Mohorovičić, who discovered it in 1909. The Moho beneath the continents is commonly at depths of 20 to 40 miles (35 to 70 kilometers), deepest beneath mountain ranges, whereas the Moho beneath ocean basins may be no more than 6 miles beneath the seafloor.

The continents, made up of granite, which has relatively low density, stand higher than the ocean basins underlain by basalt and peridotite for the same reason that icebergs float on the ocean, or ice cubes float in a glass of ice tea. And if you look at the ice cubes in your tea, you will see that there is quite a lot of ice below the surface of the tea. This ice of lower density beneath the surface balances and buoys up the ice that sticks up above the water. For the same reason, the granitic crust of the continents extends to depths in the Earth much greater than the basaltic crust of the ocean basins (Figure 2-2). The basaltic crust beneath ocean basins is relatively thin, and its relation to the mantle is more like the water freezing on the surface of a pond.

But how can we use ice and water as a comparison with a solid rock? Water is a liquid, and the crust and mantle are solids.

This comparison is valid for two reasons. First, rock at great depth is weak because it is subjected to blast furnace temperatures beneath the brittle-ductile transition. Second, the tectonic processes that cause continents to rise above ocean basins are extremely slow. We know from experiments that if the temperature is high enough, rock can flow as a solid, although it does so very slowly, fractions of an inch per year. This process, well known in metalworking, is called hot creep.
We have seen that earthquakes occur in the brittle upper crust, but not in the hot, plastic lower crust which is too weak to store strain energy that could be released as earthquakes. The reason for this is the abundance in the crust of the light-colored minerals quartz and feldspar, minerals that become soft and weak at relatively low temperature, about 575°F. For this reason, the upper crust beneath the continents is strong, but the lower crust is soft and weak. Oceanic crust, on the other hand, is so thin (Figure 2-2) that all of it is strong, and so is the upper mantle. Peridotite, the rock of the mantle, is made up of olivine and pyroxene, minerals that are still very strong at temperatures that prevail below the Moho, as high as 1,400-1,500°F. These temperatures are reached at depths that may be as much as sixty miles (one hundred kilometers).

The part of the outer Earth that is brittle and strong is called the **lithosphere**, and the weak part below is called the **asthenosphere**. Beneath the ocean basins, the lithosphere includes the thin crust and part of the upper mantle. Beneath the continents, the upper crust is brittle, but the lower crust is not. Below the Moho, the upper mantle may also be brittle and form the lowest layer of the continental lithosphere. So the continental crust can be compared to peanut butter between two crackers; both crackers are crunchy (brittle), but the peanut butter is soft (ductile lower crust). For the oceanic lithosphere, you don’t have any peanut butter, and the crunchy cracker is a lot thicker.

The flow of solid rock in the asthenosphere produces strain in the strong lithosphere. It is the response of the lithosphere to this strain that causes earthquakes. All earthquakes occur within the lithosphere, including slabs of oceanic lithosphere that have been forced downward hundreds of miles into the asthenosphere.