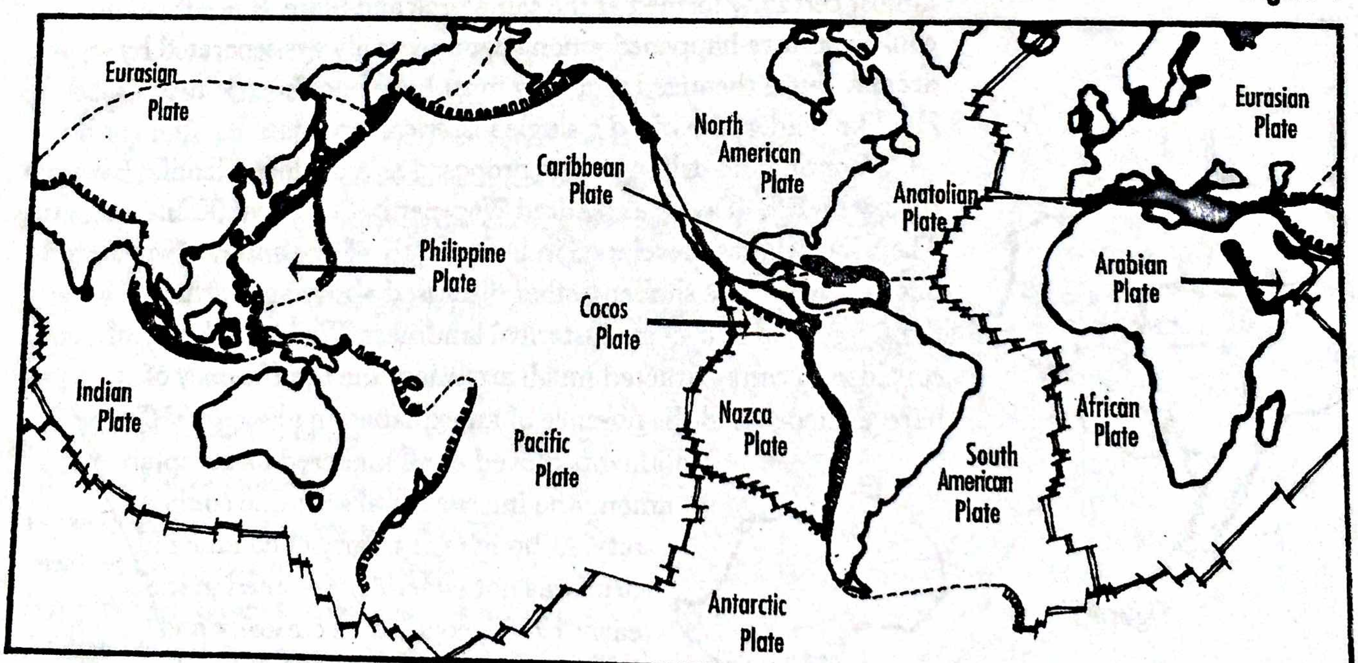
CLASS SET

Plate Tectonics

This is a very brief overview of what geologists today refer to as plate tectonics. The older term, "continental drift," is perhaps better known and was used by earlier theorists who developed the idea that the continents had not always been fixed in their current positions. The modern theory of plate tectonics states that the outer part of the Earth consists of relatively thin, rigid pieces called plates, and that these plates continually, if very slowly, move. It might be helpful to think of Earth as a hard boiled egg whose shell has been cracked into pieces that move over the egg white's surface. Today it is generally accepted among geologists that there are six large plates and a number of smaller ones moving over Earth's surface (Figure 1). Each plate is about 100 kilometers thick and has an area of thousands of square kilometers. At present the plates are moving at rates ranging from 1-20 cm/yr.

Figure 1



A Unifying Theory

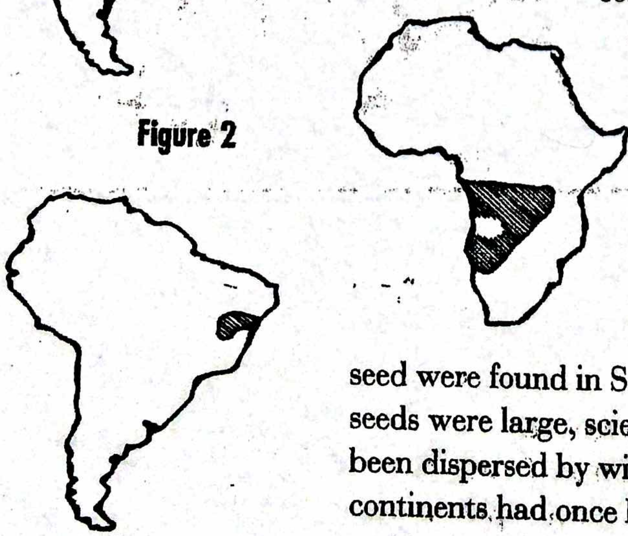
The theory of plate tectonics helps explain many geological phenomena, especially the existence and distribution of earthquakes, volcanoes, and mountain ranges. Plate tectonics provides quiero un sweetart

a unifying theory that explains large-scale geologic change over expanses of time, helps us understand why Earth's geological formations currently appear the way they do, and helps scientists predict changes in Earth's form that may occur in the future.

Modern world maps hold the same continental movement clues early theorists noticed from the maps that charted European naval exploration after the 15th century. Francis Bacon wrote in the early 1600s about the "good fit" between the coastlines of "old" and "new" worlds and, over 200 years later, similarities among certain plant fossils collected by Antonio Snider in Europe and America supported Bacon's observation. Snider also recognized the apparent fit between continental coastlines and, in trying to determine the geographic domain of fossil plants, he pieced the continents together like a jigsaw puzzle. Snider theorized that the continents had once been a single, huge landmass. Other hard evidence of continental movement came in 1885 when Eduard Suess found the same rock formations among several southern-hemisphere continents. The formations were identical in sequence and type, so they almost certainly formed at the same time and place. Since that could not have happened among continents always separated by oceans, Suess theorized that they must have once been joined. He, like Snider, theorized a single historical landmass.

Continental drift was first proposed as a distinct scientific theory by F.B. Taylor and Alfred Wegener in the early 1900s. Their hypotheses, developed independently of one another, were based on evidence similar to that discussed above and included the suggestion of a single historical landmass. While the theory of continental drift attracted much attention, the insufficiency of hard evidence and the absence of an explanation about how the continents moved at all hindered its acceptance among the international scientific community. Although the theory of continental drift was not generally accepted in the early 1900s, continuing curiosity and improving technology provided additional evidence in its support. Two examples are:

Figure 2



Fossil records. Remains of an extinct fern seed were found in South Africa, Australia, and India. Because the seeds were large, scientists thought it unlikely they could have been dispersed by wind or water. This implies that these three continents had once been closer together, if not actually joined.

Fossil remains of an extinct reptile, mesosaurus, were also found distributed among distinct areas of eastern South America and western Africa (Figure 2).

Paleomagnetism (ancient magnetism). Some types of rocks are weakly magnetic. When they were being formed certain iron-bearing minerals within them became aligned parallel to Earth's magnetic field, like a compass's needle; they "pointed" to magnetic north. After these rocks crystallized, the iron bearing minerals were "frozen" in place, and today they show the direction of magnetic north at the time they were formed. The frozen, internal "compass needles" of rocks formed at the same time among other continents show the direction of magnetic north at the same time in history for each continent. How does such data support the theory of continental movement? Figure 3 presents three hypothetical continents—A, B, and C; the arrows represent the direction of magnetic north for each continent. Note that the arrows do not point toward a common magnetic north. In Figure 3, it appears that magnetic north was in three different places at the same time, or that there were three entirely different magnetic norths. Yet, if the continents had moved since the rocks were formed, it would take only a single magnetic north pole to explain the current differences. In Figure 4, the hypothetical continents have been repositioned so the arrows point toward a common magnetic north.

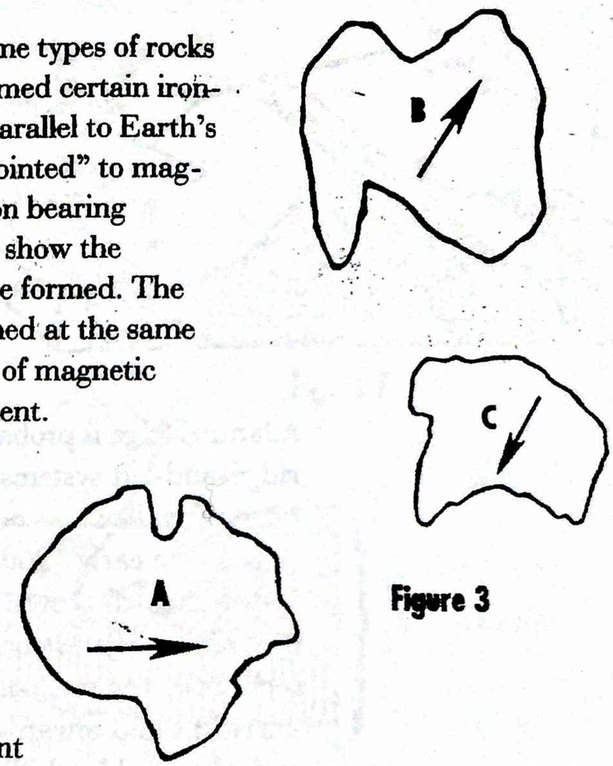


Figure 3

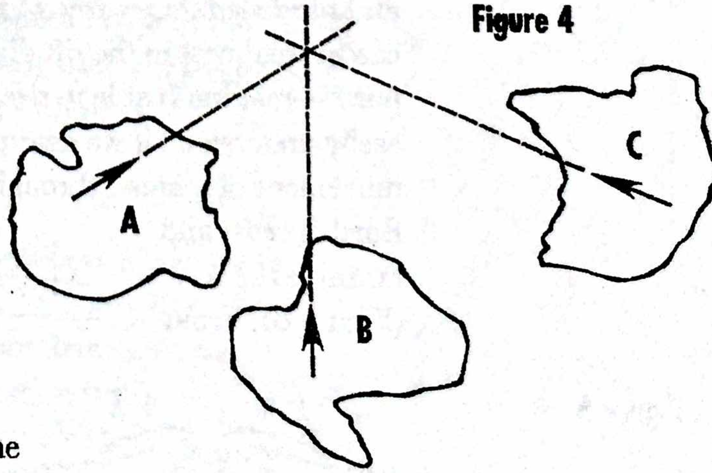


Figure 4

New Discoveries

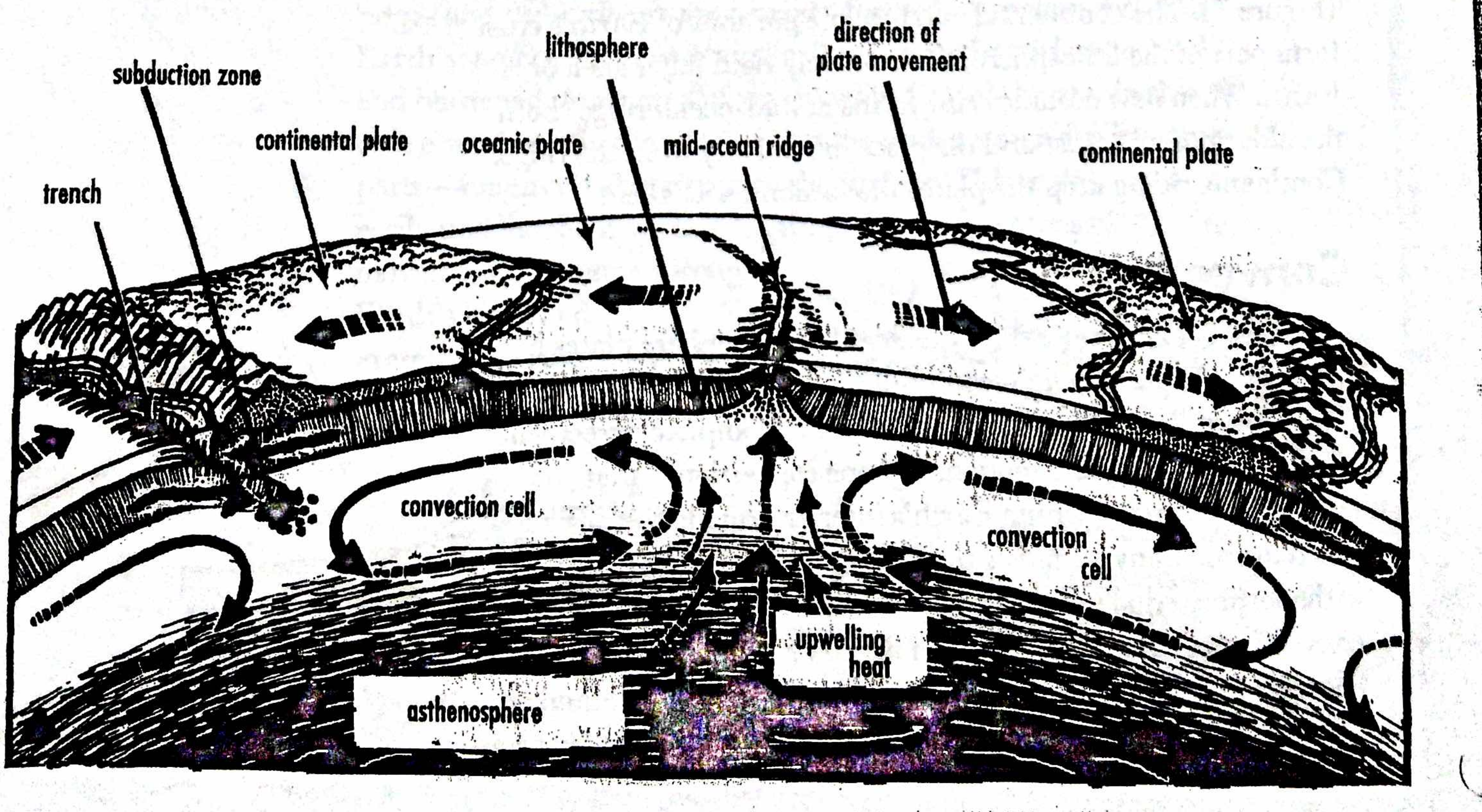
So far we have looked at several types of evidence that appear to support the theory that continents have moved. Overwhelming evidence for continental movement—now called plate tectonics—began to accumulate in the 1950s. With more sophisticated technology, scientists began systematic exploration of the world's ocean floors. While most of these scientists were not deliberately seeking data to either support or disprove continental movement, their findings became crucial to the development and general acceptance of the theory of plate tectonics.

They discovered a huge system of undersea mountains

Convection currents also can occur in hot solids, although their motion is very slow. Beneath the lithosphere is a portion of Earth's interior called the asthenosphere. The rock in the asthenosphere is rigid but, because it is extremely hot and under intense pressure, it does not behave like the rigid rocks found on Earth's surface. The rock in the asthenosphere has fluid characteristics and flows in various directions. The asthenosphere's fluid motion moves the lithosphere plates and the continents that ride atop them. Rifts, or cracks, appear periodically in the plates and become filled with new magma that rises from Earth's interior.

Even though ocean floors are continually spreading and new oceanic crust is continually being removed, Earth is not growing larger. While exploring the Pacific Ocean floor in the 1950s, scientists often found deep, narrow trenches quite near a continental coast, such as the one that parallels the western coast of South America. Trenches occur where one plate (the more dense one) sinks beneath another plate into Earth's interior (Figure 8), where the material that forms the sinking plate melts and becomes part of the asthenosphere. Figure 8 shows the relationship between convection cells, plate motion, mid-ocean ridges, and trenches.

Figure 8



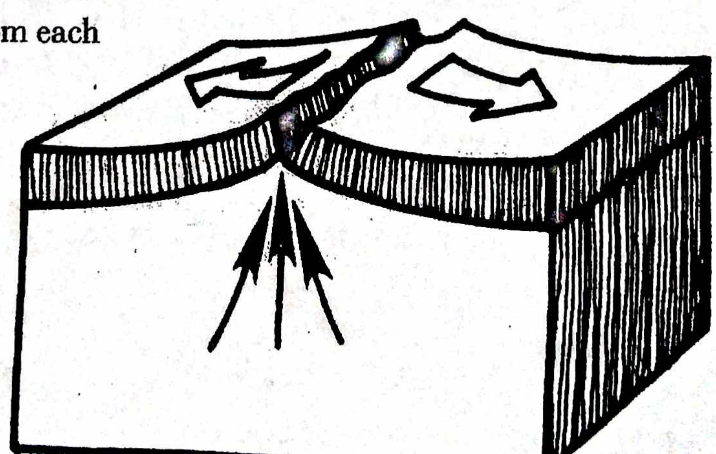
Ridge Push, Slab Pull

The belief of many geologists that convection currents within the asthenosphere act as the primary driving force of plate tectonics has recently been disputed by some scientists offering an alternative theory. Proponents of this alternate theory suggest that two forces play a significant role in causing plate movement: ridge push and slab pull. Both forces are related to gravitational and thermal effects. Scientists theorize that hot material within the mantle rises beneath oceanic ridges carrying not only mass to Earth's surface but heat as well. This heat causes the oceanic lithosphere to expand, thus creating an elevated ridge system. The result is that the youngest edge of the oceanic lithosphere rests on an inclined plane above the easily deformable asthenosphere below. Gravity causes the edge of the plate to slide down this inclined plane and push on the rest of the plate in the direction of plate motion, hence "ridge push." As the plate edge moves away from the ridge it also moves away from the heat source. Consequently, it subsides and contracts as it cools, causing the entire plate to become colder, thicker, denser, and heavier. Eventually it might become gravitationally unstable and plunge, or be subducted, into the mantle. As it is subducted, the low melting point fraction of the lithosphere will be boiled off (rich in water), and with increasing depth there may occur phase changes in some minerals into denser forms. The cold, dense, subducting plate will literally fall into the mantle, pulling on the remainder of the plate, hence "slab pull."

Boundary Types

Now that we have seen how plates are created and recycled, let us consider in more detail their edges or boundaries. There are three boundary types.

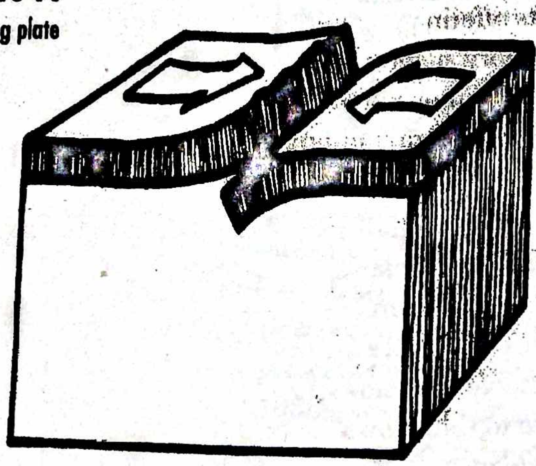
Figure 9
Diverging plate boundary



<u>Divergent boundary</u>. Occurs where two plates are moving away from each other, as along the mid-ocean ridges (Figure 9). New crust is formed at such boundaries by the upwelling of molten material from the Earth's interior. Earthquakes and volcanoes are most frequent in such areas.

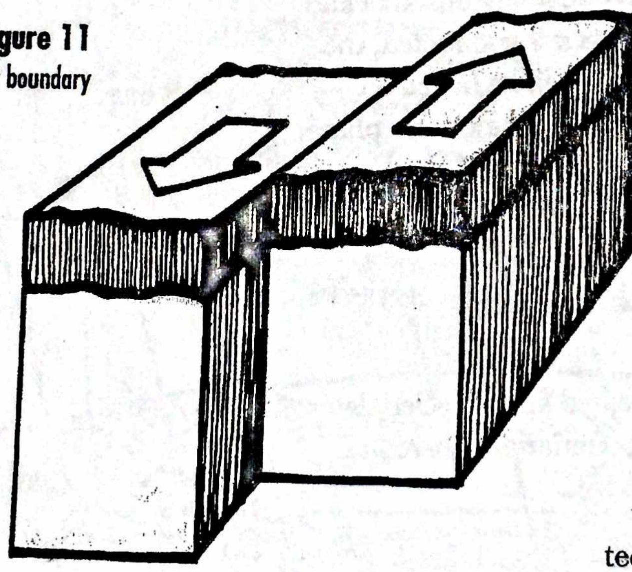
Convergent boundary. Occurs where plates move *toward* each other (Figure 10). One plate moves beneath the other into Earth's interior and a submarine trench is formed. If a continent rides on the edge of one of the colliding plates, the plate without the continent is more dense and will move beneath the continent-bearing plate, becoming reassimilated into the asthenosphere. Earthquakes and volcanoes may occur in such areas. The collision of two plates, each with a continent riding close to its edge, may result in the formation of a mountain range. The Himalayas were formed when the plate carrying India collided with the plate carrying China.

Figure 10
Converging plate boundary



Transform fault boundary. Occurs where there is no significant movement of two plates toward or away from each other. There is, however, *lateral* movement between the two plates (Figure 11). The San Andreas fault in California is a transform fault boundary. The friction generated by its lateral movement caused major earthquakes in San Francisco in 1989 and in Los Angeles in 1994.

Figure 11
Transform fault boundary



The theory of plate tectonics provides a unifying explanation for many geological phenomena that in the past were not well understood. These include volcanic and earthquake activity, the formation of large mountain chains, and the many features of the ocean floors. Investigation continues and will, scientists hope, result in an even better understanding of how and why Earth "works."