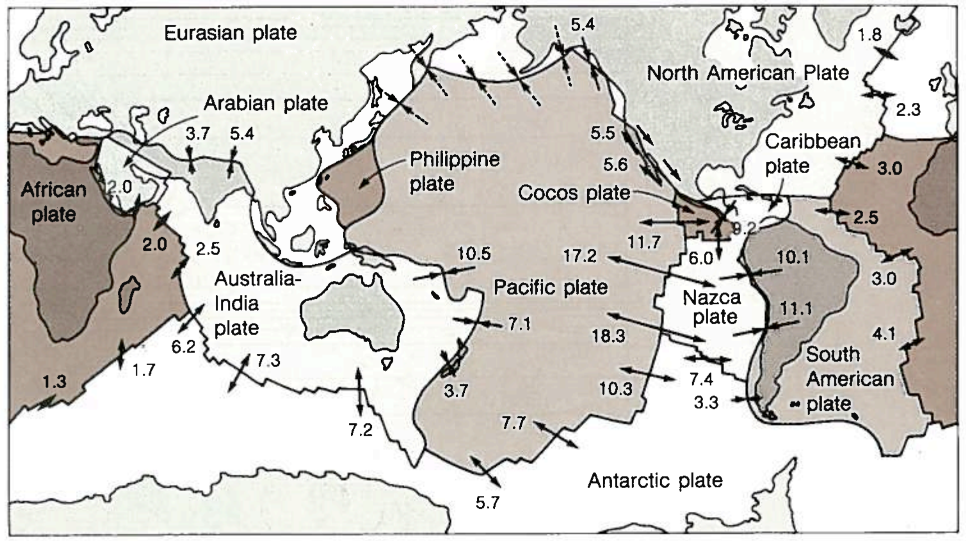

Figure 19-6
Relative velocities and directions of plate separation and convergence in centimeters per year. Opposed arrowheads indicate convergence at trenches, except for Himalayas. Diverging arrowheads indicate plate separation at ocean ridges. Parallel and opposed arrowheads, as along the San Andreas fault in California, indicate transform faults, where plates slide past each other. [From "Convection Currents in the Earth's Mantle", by D. P. McKenzie and Frank Richter. Copyright © 1976 by Scientific American, Inc. All rights reserved.]

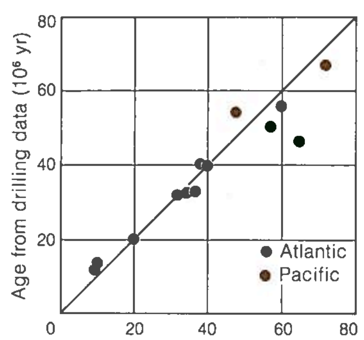

Figure 19-7
A comparison of ages of igneous rocks at different distances from mid-ocean ridges with ages obtained from fossils in the sediments immediately above the igneous rock. The igneous rocks were dated from their magnetic anomaly pattern. The sediments were recovered by deep-sea drilling operations. The 45° line is a theoretical one, implying perfect agreement between these two methods of dating the sea floor. The substantiation of the "magnetic" ages by deep-sea drilling, shown by the close fit of the experimental points to the theoretical line, lends strong support to the concept of sea-floor spreading. [After C. L. Drake.]

It was a great triumph for the magneticians, who worked out spreading rates, when the first results of the Deep Sea Drilling Project were announced. This joint project of the major oceanographic institutions and the National Science Foundation had as its primary goal to drill through the sediments of the sea floor at many places in the world's oceans. By studying the sedimentary cores, it is possible that the history of the ocean basin can be worked out directly, in contrast to the indirect methods of magnetic anomalies. Since sedimentation begins as soon as an ocean exists, the age of the oldest sediment in the core, adjacent to the basaltic bedrock, dates the ocean floor at that spot. The age is obtained from the fossils found in the cores. Sediments older than about 150 million years have not been found, attesting to the "youth" of the sea floor. The sediments become older with increasing distance from mid-ocean ridges, confirming the prediction of the seafloor-spreading hypothesis. Figure 19-7 is a plot of the ages determined from drill cores from the Atlantic and Pacific Oceans against ages predicted from the magnetic data. It is remarkable how close the experimental points approach the straight line, with slope of 1, which is theoretical and represents perfect agreement. In our opinion, one that is generally but not universally shared, this agreement clinches the concept of magnetic stratigraphy and the hypothesis of seafloor spreading.

As an interesting aside, we have included a photograph of the drilling vessel Glomar Challenger (Fig. 19-8). It is 400 feet long, and amidships it carries a drilling derrick 140 feet high. The only ship of its kind in the world, it has the capability of lowering drill pipe several kilometers to the sea floor and of drilling thousands of meters into the sediments and underlying volcanic rock. Before the ship could accomplish such a feat, a technological breakthrough had to be made. A means had to be devised to hold the ship stationary, regardless of current, wind, or waves, during drilling. Otherwise, the drill pipe would break off. The problem was solved by developing a positioning device that uses sound waves from acoustic beacons planted on the sea floor. Any change in the ship's position is sensed by a computer that monitors the time of arrival of the sound pulses. The same computer controls bow and stern side thrusters and the ship's main propulsion to keep the vessel on station. The Glomar Challenger was the answer to those who said when lunar exploration started, "It's better to explore the ocean's bottom than the backside of the Moon." We ended up doing both.

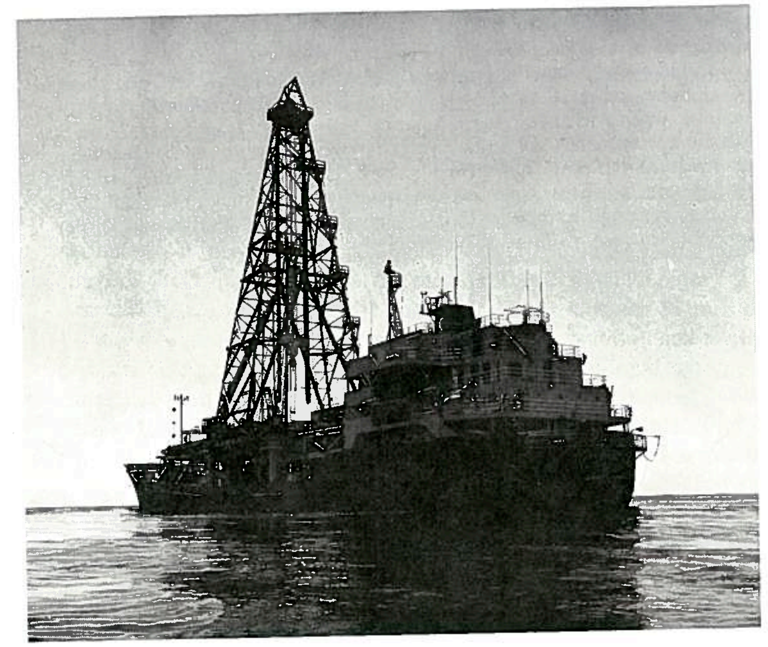

Figure 19-8
The deep-sea drilling vessel Glomar Challenger, a unique facility capable of recovering cores of sediment and underlying igneous rock from the floor of the deepest oceans. The deep-sea drilling program was originally an American one; it is now jointly supported and operated by the United States, the U.S.S.R. and other countries. [From National Science Foundation.]

Geometry of Plate Motion. If the individual plates behave as rigid bodies, which seems to be a reasonable first assumption, several interesting and useful geometric consequences follow. By "rigid" we simply mean that the distances among three points on the same plate—say, New York, Miami, and Bermuda—do not change, no matter how the plate moves. But the distance between New York and Lisbon will of course increase because the two cities are on different plates, which are being separated along a narrow zone of spreading on the mid-Atlantic ridge. Listed here are some geometric principles, mostly self-evident, that govern the sliding of plates on a plane:

1. Along transform faults, surface area is conserved; that is, it is neither created nor destroyed. Stated simply, no overlap, buckling, or separation occurs at such boundaries; the two plates merely slide past one another. Look for a transform fault if you want to deduce the direction of plate motions, because the orientation of the fault *is* the direction of relative sliding of two plates, as Figures 1-18 and 17-15 show. Surface area is obviously not conserved at zones of convergence or divergence where plates are subducted or created. The plates can move perpendicularly or obliquely to the trend of convergent boundaries, which are therefore not as reliable indicators of directions of movement as transform faults or divergence zones.

2. Magnetic anomaly stripes and isochrons are roughly parallel and symmetrical with respect to the ridge axis along which they were "created." Look at Figure 18-17 to see why this must be so. Since each magnetic strip or isochron marks the edge of an earlier plate margin, isochrons that are of the same age, but on opposite sides of an ocean ridge, can be brought together to show the positions of the plates and the configuration of the continents as they were in that earlier time. By this means we can reconstruct, for example, the opening of the Atlantic Ocean, as shown in Figure 19-9.

3. The point at which three plates meet is called a **triple junction.** Figure 19-10 shows an example of a point at which a spreading zone, a subduction zone, and a transform fault meet. If the relative motion between two pairs of plates is known, we can solve for the third by using a simple equation (see Box 19-1).

An example of an actual triple junction is the point where the Pacific, Cocos, and Nazca plates meet (see inside front cover). Three spreading zones meet at this junction, as shown in the enlarged view in Figure 19-11. The unknown motion, found by vector addition, was that between the Nazca and Pacific plates, the motions between the Pacific-Cocos and Cocos-Nazca plates having been worked out from transform faults and magnetic-anomaly stripes. The arrows show the resultant plate movements. Note