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Chapter 17

The Birth of the Oceans

The Oceanic Rift

The closer we get to modern science, the more delicate the historian's task: How should we present new discoveries that have not matured sufficiently; in other words, discoveries that have not undergone the ample scrutiny and judgment that earlier scientific findings have? In addition, geology is undergoing a revolution that challenges most of its major concepts; these circumstances may or may not be of help to the historian.

It is, however, not preposterous to state that for the last twenty-five years geology has been dominated by the study of oceans. Richard Field of Princeton University is quoted as having said in the 1930s that he "was convinced that the Earth would not be understood as long as investigations were limited to its emerged third portion [continents]."[1] For quite some time, **bathymetric studies** had revealed a ridge of unknown significance in the middle of the Atlantic. In 1954 the seismologist Jean-Pierre Rothé of Strasbourg showed that the systems of midoceanic ridges extending through various oceans formed an active **seismic belt.**[2] According to Xavier Le Pichon, professor at the Collège de France in Paris, Maurice Ewing, director of Lamont-Doherty Geological Observatory at Columbia University, and his co-worker Bruce Heezen proposed the hypothesis that this belt corresponded to a system of troughs similar to that recognized in the middle of the Mid-Atlantic Ridge. Le Pichon recalled that upon joining Lamont-Doherty in 1959 he was sent on a worldwide search for this puzzling trough, called **rift**, which eventually became the key to the new geology.[3]

The Mid-Atlantic Ridge, discovered a century ago when the first telegraph cables were laid on the seafloor, is 1,000 kilometers wide. It rises 2,000 meters or more above the surrounding abyssal plain, which reaches about 6,000 meters depth. The central part of the ridge, characterized by intense seismic activity, is occupied by a rift about 30 kilometers wide and 2,000 meters deep. Explorations conducted by Lamont-Doherty Geological Observatory traced this structure for more than 60,000 kilometers across all oceans. According to Le Pichon, "It became evident that any well-founded model of the evolution of the Earth could not ignore the existence of the rift system."[4]

The Conveyor Belt

In 1962 Harry H. Hess of Princeton University explained the role of the rift in a paper, "The History of Ocean Basins," in a multiauthor volume published by the Geological Society of America.[5] Applying the concept of convection currents, he proposed that the ocean floor is continuously being produced in the rift of ridges by rising deep-seated magma, which in turn plunges into deep trenches, stretching along the margins of the Pacific and other oceans. Between the zones of rising and plunging, the ocean floor moves, pushed by the tangential force of convection currents, something like a conveyor belt. Continents are carried along by this movement.

Because the concept of continental drift was now related to the renewal of the ocean floor, the focus of investigations began shifting from continents to oceans. During World War II, Hess was commander of a U.S. Navy ship that criss-crossed the Pacific, undertaking bathymetric surveys. During this research, Hess discovered the flat-topped seamounts for which he coined the name **guyots**. He considered these volcanic cones—rising from the seafloor, and whose summits are often today buried in deep water—to have been originally truncated by wave action at sea level and thereafter submerged during the sinking of the ocean floor (subsidence). Hess searched for an explanation and finally came up with the concept of the conveyor belt, which could also account for many other aspects of the behavior of the oceanic crust.

Hess considered his idea highly hypothetical and tried it out on

many of his colleagues before publication, thus losing precious time. His paper was therefore preceded by R. S. Dietz's short article proposing views very similar to those of Hess.[6] Although Dietz did not claim to be the inventor of the new theory, he suggested calling it **seafloor spreading**. He was also the first to point out that the sliding surface was not located at the lower boundary of the earth's crust but at a much greater depth.

The reader will remember that Wegener believed in continents of sial floating over sima. Following Andrija Mohorovičić (1890–1936), seismologists recognized a more important boundary, one separating the crust from the underlying mantle.[7] Holmes located the sliding surface at the base of the crust, underneath both continents and oceans (see fig. 16.2), thus answering the objections of Wegener's opponents. Dietz went further and assumed the sliding surface to be at a much greater depth, at the boundary between **lithosphere** and **asthenosphere**.

Changes between Wegener's ideas and the new ones are drastic. Continents no longer drift freely at the surface of a fluid, but are

The Earth's Concentric Envelopes

The shallow zones of the earth can be subdivided in at least two ways. The first division is made between crust and mantle, the second between lithosphere and asthenosphere.

1. The earth's crust is the most external envelope of the globe. It is a few kilometers thick under the oceans and several tens of kilometers (about thirty) under the continents. The mantle underlies the crust and extends to a depth of 2,900 kilometers. The boundary between crust and mantle is a discontinuity; that is, a sharp increase of the velocity of seismic waves, called Mohorovičić discontinuity after the Yugoslavian seismologist who discovered it in 1909. The oceanic crust consists of basalt, whereas the continental crust contains rocks richer in silica (of the composition of granite). The mantle is assumed to consist of peridotite, a darker rock containing less silica than basalt.
2. The lithosphere (from the Greek *lithos*, stone) includes the crust and the upper mantle. This envelope is about 100 kilometers thick, rigid, and divided into plates. It overlays the asthenosphere (from the Greek *asthenos*, devoid of force), a more fluid layer produced by partial melting of rock materials.

The boundary between lithosphere and asthenosphere was proven by seismology: the velocity of seismic waves decreases slightly when they penetrate the asthenosphere.

enclosed in "plates" extending beneath and around continents under the oceans. Objections of geophysicists to Wegener's theory (see previous chapter) were removed because the asthenosphere has the fluidity the sima lacked. Moreover, like the carapace of a reptile, plates cover the entire surface of the earth. These plates can be renewed on one side only if consumed on the other. The new theory thus implies generation of oceanic crust along midoceanic ridges and consumption of that crust in **oceanic trenches**.

Fossil Magnetism

Paleomagnetism, that is, the reconstruction of the past magnetic field of the earth, played a critical role in the final formulation of the theory of seafloor spreading. Before the publication of Hess's paper, observations were made which revamped the theory of Wegener. These observations showed that lavas produced by volcanoes, in particular basalts, contain magnetic minerals, which orient themselves according to the earth's magnetic field and maintain that orientation upon cooling of the lavas. Once the minerals solidify, the magnetism they possess will remain "frozen" in this position. Hence, the magnetic field that existed on the earth at the time of lava eruption was, so to speak, fossilized. It became possible to reconstruct that particular magnetic field so long as the orientation of the sample was carefully recorded before collection.

Magnetized minerals not only indicate the direction to the poles, they also provide a means of determining the latitude of their origin. The first measurements made in the 1950s indicated that in the past the poles were not at the same location as today. Scientists at Cambridge University showed that the magnetic north pole was during the Precambrian in the middle of the Pacific Ocean, near Hawaii. Subsequently, it migrated westward, reaching Asia, south of Japan, at the end of the Paleozoic, and eventually moving across Siberia to its present location.

Even more interesting was the discovery made when scientists repeated their measurements in North America: the position of the magnetic north pole, at any given time, was different in other continents. The first set of observations made in Europe did not imply a reciprocal displacement of continents because the magnetic poles could have migrated with respect to a fixed terrestrial crust, as was often assumed in the past. The second set of observations made in North America, however, contradicted such an interpretation because the magnetic poles remain stationary at a given time. If their respective magnetic poles were apparently different in Europe and in North America, then in the past the two continents must have had a different position from today. In order to find their *relative* position at a given time, it was necessary to "move" hypothetically one of the continents until the poles of the two sets of measurements coincided. Eureka! Europe and North America were next to one another in the past, just as Wegener had proposed.

Paleomagnetism provided an additional surprise which, at first glance, did not seem related to continental drift but which, through a number of other studies, eventually supported it. The study of relatively recent lavas (less than a few million years old) showed a magnetism close to the present magnetic field; this appeared quite normal. However, in some instances, the orientation was reversed: the south magnetic pole was at the location of the north magnetic pole. At first it seemed preposterous to accept true reversals of the geomagnetic field because self-reversal magnetization of certain rocks exists. The problem changed, however, after completion of thousands of measurements indicating that lavas of the same age displayed magnetic fields of the same orientation but of either normal or reverse polarity. The conclusion was reached that geomagnetic reversals were real but as yet unexplained. The question became far more complex upon discovery that during the last four million years the magnetic field had undergone four reversals and that during each of these episodes additional changes had taken place. Further discussion of this problem is beyond the scope of this book.

The Decisive Hypothesis

During the latter part of the 1950s, scientists at Scripps Institution of Oceanography criss-crossed the Pacific, recording in continuous profiles the present-day magnetic field. The purpose of this investigation was not to measure **remanent magnetization** in lavas, but to record the intensity of the present-day earth's magnetic field at the surface of the ocean.

When measurements of the intensity of the magnetic field at a given place were compared to calculations made beforehand, an appreciable difference was found, called a magnetic anomaly. This is comparable to a gravity anomaly, which represents the difference at a given place between the calculated pull of gravity and the measured value. Surprisingly, anomalies detected at sea were approximately ten times larger than those previously known on continents. Furthermore, if positive and negative anomalies were represented on a map, they appeared as parallel bands forming a zebra-skin pattern. At first it was thought that anomalies resulted from the disturbing effect on the earth's magnetic field of magnetic masses located beneath the ocean floor, but not exceeding three kilometers of depth.

In reality, these anomalies were the expression of geomagnetic reversals and provided the answer to the question: How is new oceanic crust generated? The decisive hypothesis was proposed in 1963 by Lawrence Morley, Fred Vine, and Drumond Matthews.[8] They assumed that magnetic anomalies resulted from lavas produced in turn during periods of normal magnetic field (positive anomalies) and periods of reversed magnetic field (negative anomalies). In other words, basaltic lavas poured onto the ocean floor on both sides of the rift, cooled, and then moved away from their original position before new lava was extruded. If a reversal in the earth's magnetic field took place between lava outputs, the result would be a series of parallel bands of basalt, each band having minerals with a different magnetic orientation and each band being progressively older as one moves away from the Mid-Atlantic Ridge. These differences might very well account for the regular, parallel zebra-skin pattern.[9]

According to the hypothesis of the conveyor belt, oceanic crust is being continuously generated in the rifts of midoceanic ridges. Therefore, the zebra-skin pattern on both sides of the ridges strongly supports the theory of seafloor spreading because it explains all observations on the distribution of magnetic anomalies. Indeed, the value of a scientific theory lies as much in its retroactive explanation of facts that had remained enigmas as in its prediction of new facts.

Subduction

The retroactive power of a theory applied also to the problem of the disappearance of older oceanic crust. In 1935 the Japanese geophysicist K. Wadati had shown that the **foci** of earthquakes along the eastern coast of Asia were located on a plane inclined at about 40° that dipped under Asia.[10] The shallowest foci were below the Pacific and the deepest beneath Siberia and China. These observations were repeated by H. Benioff after World War II, but still no explanation seemed plausible.[11]

The theory of the conveyor belt, which requires oceanic crust to be consumed in the same amount as it is generated (to ensure a constant surface), explains the Benioff or Wadati-Benioff zones, which become **subduction** or sinking zones of the lithosphere into the asthenosphere, while rifts become zones of accretion or of generation of the new lithosphere. The term *subduction* was introduced as early as 1951 by the Swiss geologist André Amstutz in his pioneer studies of the structures of the Penninic Alps; he used the term in a sense that is remarkably in agreement with current theories of **plate tectonics**.[12]

Another example of the retroactive character of the new theory is B. Gutenberg's recognition in the 1920s of a "soft layer" at a depth below 100 kilometers where seismic waves moved at low velocity. This layer was reinterpreted in the 1960s as the boundary between lithosphere and asthenosphere. In summary, the theory of seafloor spreading was able to synthesize scattered observations, some of which had remained unexplained for a long time.[13]

The Synthesis: Plate Tectonics

The keystone to the theory of plate tectonics remained to be put into place. In 1965 Harry H. Hess was at Cambridge University on sabbatical leave from Princeton. The geology department was directed by Edward Bullard, who in 1956 provided one component to Hess's theory. He showed that heat flow along midoceanic ridges was greater than at any other place on earth. Vine and Matthews, also at Cambridge, had just presented their hypothesis (mentioned above) on magnetic anomalies. Tuzo Wilson, who had supported Hess's theory all along, was also at Cambridge; he was the first to use the term *plates* (in 1965), and presented a model of their behavior in terms of plane geometry.[14]

The final act was put together by three young scientists, Jason Morgan, Dan McKenzie, and Xavier Le Pichon, representing the three main institutions—Princeton, Cambridge, and Lamont—that had provided the most important components of the theory. Like Hess, Jason Morgan was from Princeton. On April 19, 1967, he showed in an oral presentation to the American Geophysical Union that all the investigated phenomena led to the concept that the surface of the earth consists of rigid plates that move with respect to the others. He explained the geometry of the plates in terms of a spherical surface rather than a plane.[15] Dan McKenzie from Cambridge

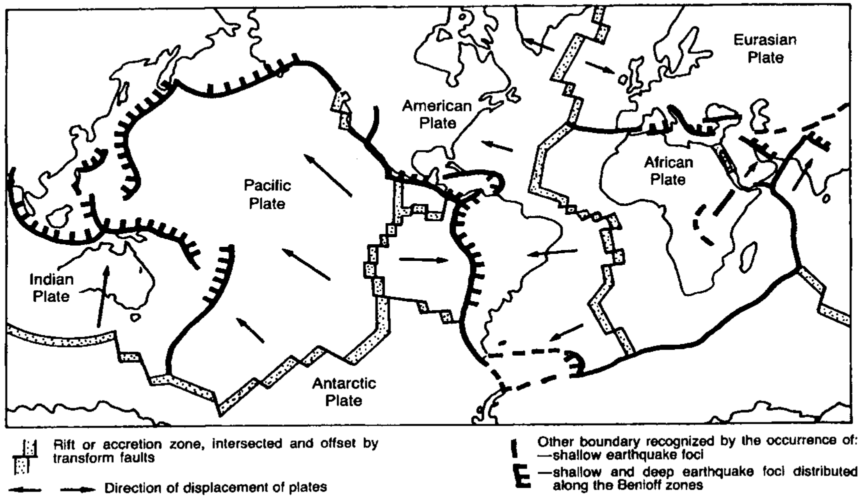

Figure 17.1. Boundaries of the Six Lithospheric Plates (Modified from X. Le Pichon, "Sea-floor Spreading and Continental Drift," Journal of Geophysical Research 73 [1968]: 3675, fig. 6. Copyright © by the American Geophysical Union, used with the author's permission).

University, working at Scripps Institution of Oceanography, contributed to the new ideas in September of the same year in a paper presenting similar ideas.[16] Finally, Xavier Le Pichon, who had been at Lamont since 1959, presented the final synthesis with a sketch of only six large lithospheric plates (compared to the dozen or so Morgan had visualized). His article appeared in June 1968, two months after that of Morgan (see fig. 17.1).[17]

The Writing of History

This history of geology is nearing its end. Future studies belong to science and not to history. The reader will have noticed that the untangling of each scientist's contribution to plate tectonics is clearly a difficult task. Many names were cited in these few pages alone. Many others deserved to be mentioned. It is evident that it is easier to remember only a few figures for past periods because the collective memory has forgotten the great majority of the contributors. Past centuries seem to render history less difficult because our ignorance unjustly preserved only a few luminaries whose reputations survived the effects of "erosion" better than the rest.

How many authors quoted in this chapter will be remembered fifty or a hundred years from now? It is difficult to answer this question without running the risk of being blamed later on. Oversight has already taken its toll. For instance, Lawrence Morley, who slightly preceded Vine and Matthews, had his article rejected by *Nature* so that it ultimately appeared after theirs. Consequently, his name is omitted in general presentations, which attribute the hypothesis solely to Vine and Matthews. It is true that history might have been written differently had the many protagonists of these discoveries published in a multiauthor work instead of presenting their own versions independently.

When trying to give to all authors their fair share, I perhaps run the risk of citing some whose contributions were modest and inconclusive. Historians who study in detail secondary authors of a given period are well aware of the problem. Are they not often tempted to exaggerate the contributions of these authors and become hero worshippers? Any historical approach is by nature subjective and often biased.

Furthermore, historical "clearinghouses" are often unfair. History is written by the winners, by powerful institutions or cliques rather than individuals. Moreover, time wipes out original and penetrating works to the benefit of a few trailblazing ones, which remain isolated. However, time also has a regulating effect by revealing the turning points in scientific thinking.

Analysis of contemporary science is just as tricky. Its turning points are still unclear, and the direction of its development is even more obscure. Nevertheless, this book cannot reach a final conclusion without indulging in this kind of speculation, as uncertain as it might be. For instance, I have emphasized the recurrence of certain fundamental ideas opposing each other, such as continuity versus discontinuity and irreversible versus reversible (cyclic) change. The debate between uniformitarians and catastrophists rested on these two issues. It is still alive, although most scientists are aware today that uniformitarian and catastrophist concepts interact in most geological processes.

Continuous Movement

Plate tectonics clearly supports continuity. Earthquake foci along Benioff zones express the repeated episodes of sinking of the lithosphere, while contemporaneous movements open the lips of rifts. Indeed, the tectonic activity of the earth goes on forever.

In the nineteenth century, Élie de Beaumont had already stated that a continuous process (secular cooling) generated discontinuous "revolutions." However, the relationship between these processes remained problematic, so in the end he favored a continuous mechanism that deformed the crust in a uniform manner and a discontinuous process that suddenly accelerated the movement.

Today, more or less continuous movements of the crust are established. For instance, southern Calabria has risen about 1,500 meters in 1.5 million years, at an average rate of one millimeter per year. Such examples of "neotectonics" (present-day tectonic movements) might convert some geologists to a concept of continuity using seafloor spreading as the mechanism, which occurs at the average rate of a few centimeters per year.

Discontinuity in Many Geological Fields

A certain amount of discontinuity is intrinsic to stratigraphic methodology. If discontinuous variations of faunas did not occur, long-distance correlations would lack precision. After Darwin, biological evolution was assumed to be gradual, but in 1970 a new school of paleontologists took a position against gradualism, stating that evolution is discontinuous. According to the theory of "punctuated equilibria" of Niles Eldredge and Stephen Jay Gould, each species remains in equilibrium for a certain length of time, and then undergoes a sudden change.[18] However, this theory satisfies stratigraphers only if the rupture of equilibrium had a sufficiently global impact to ensure a simultaneous change from one continent to another and hence be of interest for synchronous tectonic phases.

In sedimentology, discontinuity and the concept of the high-energy "rare event" are now widely accepted. Studies of deposits produced by recent tropical hurricanes (**tempestites**) and of earthquake-triggered **tsunamis** have provided textural data that allow geologists to identify similar beds in the geological record and to map their global distribution as a function of plate tectonics.[19] Rare events thus interfere with cyclic sedimentation and show that catastrophes interact with uniformitarian sedimentary processes.

Discontinuity occurs also in structural geology. In 1939, Hans Stille was a powerful supporter of the concept (see chapter 16). He

believed that global tectonic "phases" occur synchronously all over the world at more or less regular intervals, phases separated by periods of tectonic quiescence. Each phase lasted about 300,000 years. He created the presently used terminology of tectonic phases, which he named after the region where they are best displayed, such as **Taconic** phase or **Laramide** phase (see appendix). These designations indicate that these global events had more accentuated effects locally.[20]

Continuous Mountain Building

Stille's phases punctuated the earth's history into periods. In that respect, his phases were a modern equivalent of the systems of Élie de Beaumont in number and in relative suddenness. However, between these two authors came Suess and Bertrand, who divided the earth's history into much longer cycles. Each cycle included continuous processes, and each cycle built a mountain range. In summary, the unit was the chain or, as it is called today, the orogene or **orogenic belt**; and the history of the earth since Early Paleozoic no longer consisted of about twenty phases but of three orogenes: Caledonian, Hercynian, and Alpine.

The concept of discontinuity had lost its former meaning. Although each orogeny itself consisted of tectonic phases, each one was separated from the following by another type of discontinuity. At a certain time the movements of the crust, which for about 200 million years had folded and uplifted a segment of the earth's crust, changed location and became active in another part, leaving the former one to the action of erosion and to oscillations of epicontinental seas. The Hercynian chain during the Mesozoic is a typical example.

Plate tectonics attributed the opening of new oceans to tectonic stresses. Can we not assume that new rifts become active whenever stresses change their place of action? The fundamental discontinuity of the earth's history would thus consist of changes of certain rift systems. Periodically, the lips of rifts would be sealed while others would open. If these revolutions were equated to the three orogenic cycles, there would be three cycles for the 600 million years separating the Present from the end of the Precambrian, hence the figure of 200 million years mentioned above.

Structural geology, conceived in the framework of plate tectonics, shows that mountain ranges are built along the boundary of two plates; but several modes of collision occur, depending on whether plates carry continents or not. A continent consists of light material that cannot sink into the asthenosphere. It may be called "the foam of the earth," as suggested by Claude Allègre.[21] An entirely oceanic plate such as the Pacific plate can sink under the Asian continent along the well-known oblique zone discovered by Wadati and Benioff. When two continental plates collide, as happened between India and Asia or between Africa and Europe, high mountains like the Himalayas and the Alps are formed. The collision of these gigantic blocks generates highly complex structures in which the concepts of continuity and discontinuity are associated. However, this answer is not satisfactory because it is overgeneralized and needs to be examined in detail. Plate tectonics represents a synthesis of many problems that until a few years ago remained unsolved, but plate tectonics does not provide the key to mountain building.

A Lost Past

Wegener visualized a supercontinent breaking up at the end of the Paleozoic, but said nothing about earlier times. His drift pertained to about 250 million years, that is, to no more than one-twentieth of the earth's history. His opponents asked him to explain older mountain ranges, but data were not available at the time. Today it is generally accepted that continental masses of variable sizes and shapes have always drifted as a function of changing rift systems, and that they were separated and joined repeatedly, as shown by recent detailed reconstructions of Paleozoic paleogeographies.[22] Their history is therefore irreversible, and Wegener's supercontinent (Pangea) at the end of the Paleozoic was only an unusual and fleeting episode in an otherwise widespread global dispersal of continental masses during the earth's history (figs. 17.2 and 17.3).

What is the basic lesson of plate tectonics? We have learned that seafloor spreading introduced a positive component to the history of the earth: new ocean floors are being created. But the theory is also related to the concept of subduction, according to which ancient oceans were consumed and thus disappeared forever. This is indeed the basic lesson of plate tectonics: what is gained in midoceanic ridges is lost in subduction zones. Present-day oceans are young. For instance, during the Jurassic the Atlantic Ocean was no more than a narrow depression in the then-joined continents of Africa and South

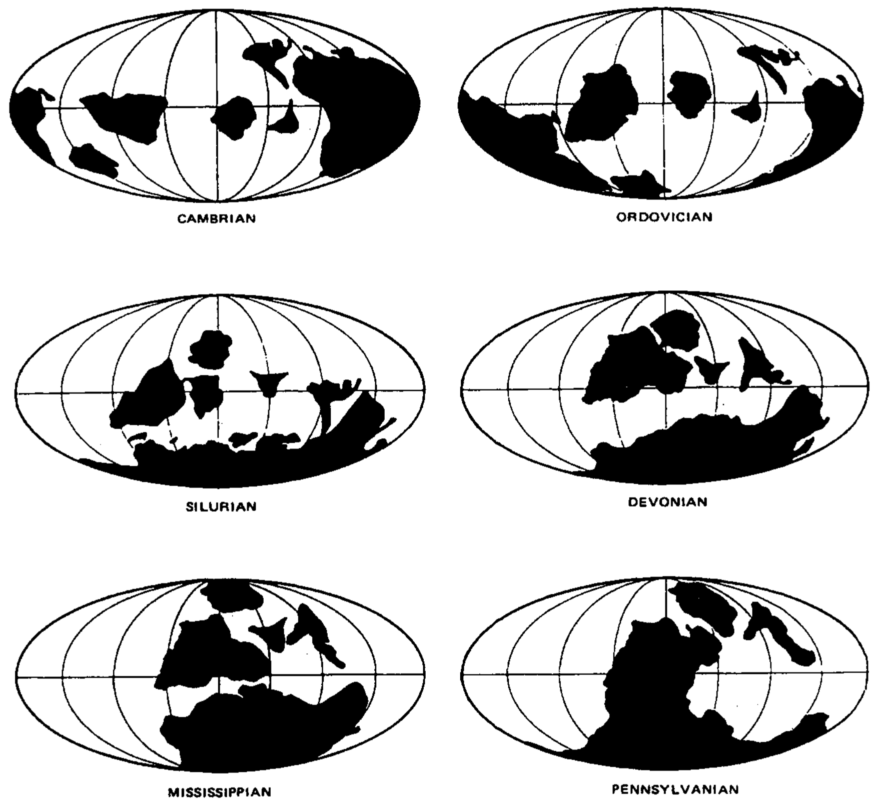

Figure 17.2. Relative Positions of Drifting Continental Masses during the Time Interval Cambrian through Pennsylvanian (From Don L. Eicher and Lee McAlester, The History of the Earth, *1980, frontispiece. Reprinted by permission of Prentice-Hall).*

America, like the present-day Afar depression (512 feet below sea level) trending southwest from the area of Djibouti on the Gulf of Aden into the African continent. Subsequently, it resembled the Red Sea when waters invaded it during its widening. Today, its opposite shores are 6,000 kilometers apart. But this young ocean was preceded by others forever lost in the depths of the asthenosphere. In summary, the new geology discovered the oceans, but it also taught that these oceans do not hold the key to the past because former oceanic archives were destroyed by subduction. This key can only have been preserved on continents or not at all.

For our understanding of physical and biological planetary events,

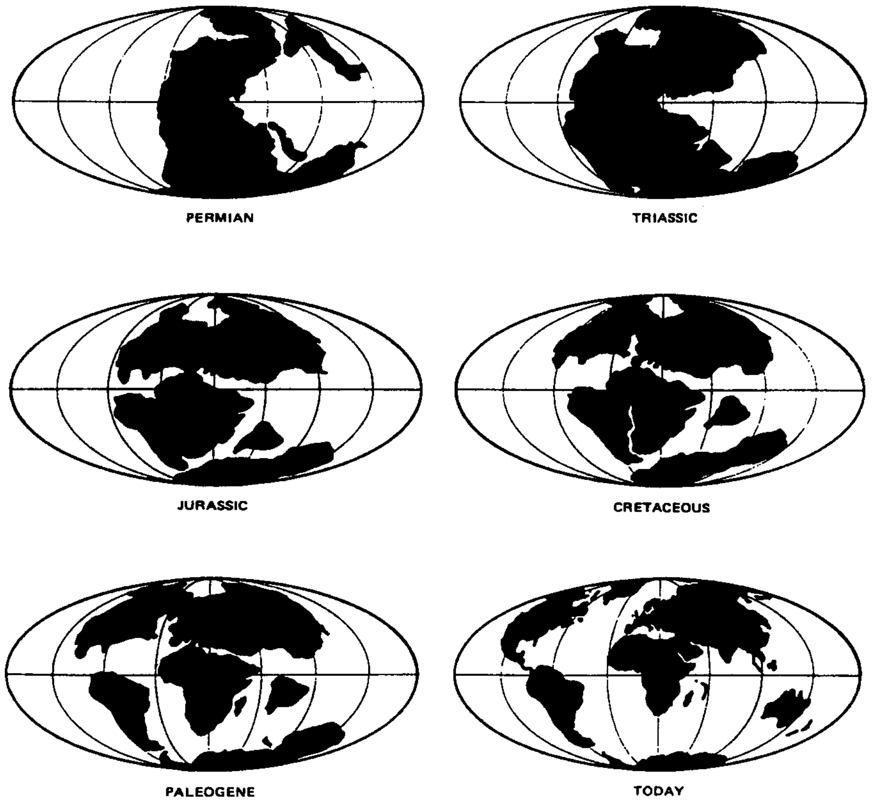

Figure 17.3. Relative Positions of Drifting Continental Masses during the Time Interval Permian through Present (From Don L. Eicher and Lee McAlester, The History of the Earth, *1980, frontispiece. Reprinted by permission of Prentice-Hall).*

the destruction of oceanic archives by subduction is certainly a real loss since oceans always occupied three-quarters of the earth's surface. Only very few remnants of oceanic sediments have been preserved in mountain ranges. We should, however, point out that although oceanic archives were certainly thick layers of mud, they were not rich in fossils in comparison with the relatively thin but very highly fossiliferous shallow water deposits laid down on continental shelves and marine embayments by numerous marine transgressions during the **Phanerozoic.** The record of shallow water sediments represents, therefore, the only key to the geological past of the earth, at least before the Cretaceous.

The Geologist of Tomorrow

The most fascinating aspect of science is that each answer raises new questions. This is particularly true for geology today as it undergoes a major revolution that is changing many of its major concepts. This revolution is far from being completed. However, Le Pichon exaggerated a little when he stated, together with Tuzo Wilson, that this revolution is only an extension of the Copernican revolution.[23] In reality, geology was born and developed in the period after Copernicus. The present-day revolution testifies to the superiority of geophysical methods over those of other "classical" branches of geology. Indeed, the next focus of investigation is to use such methods to discover the motor responsible for the movement of lithospheric plates, and consequently to understand how rift systems changed position during geological time. But the necessity of interaction between the various branches of geology remains of fundamental importance.

Let us analyze a typical example of modern interdisciplinary geological methods. For many years, geologists noticed that the end of the Mesozoic corresponded to a drastic renewal of fauna and flora, with, in particular, the sudden and simultaneous disappearance of dinosaurs on continents and ammonites in the oceans. Hypotheses to explain this global event are of current interest.

Because the end of the Mesozoic was a time of major marine regression, at first only incomplete sequences were available. For instance, in the Paris Basin the sea withdrew at the end of the Cretaceous and returned only in Early Eocene, after a span of time which is difficult to estimate. But several sedimentary sequences were recently discovered in Northern Italy, Denmark, and on the bottom of the Atlantic Ocean, which display uninterrupted sedimentation between Mesozoic and Cenozoic times. These continuous sequences allowed paleontologists to measure the rate of renewal of species. Although the magnitude of faunal changes varied according to environments and to zoological groups, and although the changes were not perfectly simultaneous, it became clear that an enormous biological gap indeed occurred at the boundary of the Mesozoic and the Cenozoic. The cause remains controversial, but abundant data at least allowed geologists and biologists to quantify the problem and to demonstrate its reality.

Geochemistry, combined with detailed paleontology, provided new markers of this discontinuity. Luis W. Alvarez and his co-workers discovered that the sediments at the transition from Mesozoic to Cenozoic contain an abnormally high amount of **iridium**, a rare trace metal on earth.[24] Because iridium occurs in asteroids and meteorites, its unusual content at the Cretaceous-Cenozoic interface has oriented research toward an extraterrestrial explanation for the paleontological catastrophe: the impact on earth of a comet, asteroid, or large meteorite.[25]

It has become generally accepted that comets or meteorites may indeed be agents of mass destruction on earth even if the impacting body is only ten kilometers in diameter. If the impact occurred on land, it could be compared to a nuclear explosion, vaporizing rocks, generating earthquakes, and ejecting melted and pulverized rock particles that darken the skies; if at sea, the impact would generate gigantic tsunamis. The long-term effects would be even more drastic: global dust clouds, triggering a period of darkness and cold; global wildfires; acid rain; and possibly a long-term **greenhouse effect**. This scenario does not belong to science fiction because tiny metallic spherulites of meteoritic origin and layers of soot have recently been found on a worldwide basis in sediments of the Cretaceous-Cenozoic boundary. Moreover, this catastrophic event may not be as unique as it originally seemed: earlier extinctions in the paleontological record seem to have taken place at intervals of about 26 million years, perhaps indicating a periodicity of the fall of extraterrestrial bodies on earth.[26]

In short, in the fields of structural geology, stratigraphy, paleontology, and sedimentology, that is, in the entire domain of earth sciences, catastrophic events, whether of terrestrial or extraterrestrial origin—perhaps even cyclic with long periodicities—are today considered to have interfered throughout all of geological time in the continuous or short-periodicity movements of our planet's irreversible evolution. Buffon's interplanetary catastrophes and Lyell's uniformitarian concepts are finally considered partners.

The word *geology*, born about two centuries ago, is being gradually replaced by the term *geosciences*. The new term expresses more planetary concerns, since the repository of archives available to earth sciences has enormously increased in recent years. Moreover, the geosciences are interested not only in earth and its satellite, but also in all the planets of our solar system, thus tending to become cosmosciences. Why should earth not show the effects of events that occurred in the history of the planets that surround us?