Chapter 8

The Early Ages

The Archean

The formative phase of Earth and Moon took place 4.6 to 3.9 billion years ago. At the end of the formative phase, the Earth's first "real" geological epoch, the Archean, began. During this long period of time, which lasted up until 2.5 billion years ago, many geologically significant events took place. Many of the first rocks were formed during this period, although some already existed 4 billion years ago. These are observed in the oldest sections of the Earth, the relatively immobile cratons—substantial parts of the continental plates that have been almost entirely undisturbed since the Precambrian era. Yet only a few of these old rocks survived the strong meteorite flux and the intense volcanism of the early Earth. Some minerals (not rocks) can be traced back as far as 4.2 billion years.

On the Moon, the last giant impacts took place 3.9 to 3.8 billion years ago, when very large meteorites hit its front side, forming the large circular basins visible from Earth. At that point, 700 million years of strong flux came to an end.

The Earth and the Moon were undoubtedly hit by the same meteorite bombardments. (Our planet may have been plagued by a slightly heavier onslaught because of its stronger gravitational pull.) The larger Earth also cooled much more slowly than the Moon and, as a result, developed a strong internal convection and heavy volcanism. As our planet's surface was continuously reworked by all of these events, only a few rocks with greenschist facies survived.

At this time, the luminosity of the early Sun was about 25 percent less than today. But the Earth, though cooler, was not cold. It had an absorbing carbon dioxide atmosphere, similar to that of our neighbor planets Venus and Mars. Through volcanic eruptions, large quantities of carbon dioxide and water were exhaled, which led to the first rains and the earliest lakes and oceans. It is possible that some water reached the Earth by way of icy meteors, but it is difficult to estimate the relative significance.

The Emergence of Early Marine Life Forms

Shortly after the end of the strong meteorite bombing, about 3.8 billion years ago, first signs of primitive life began to appear. Today, we still find marine algae from that epoch incorporated in so-called *stromatolite limestones*, where they appear in the form of green-blue spherules, or spherical lamellae (see Figure 8.1). These first organisms developed a primitive photosynthesis, producing oxygen that combined with iron of valency 2 in ferric oxide (Fe_2O_3). This insoluble form of iron created the sedimentary *banded iron formations* (BIF). Today, these types of rocks, which

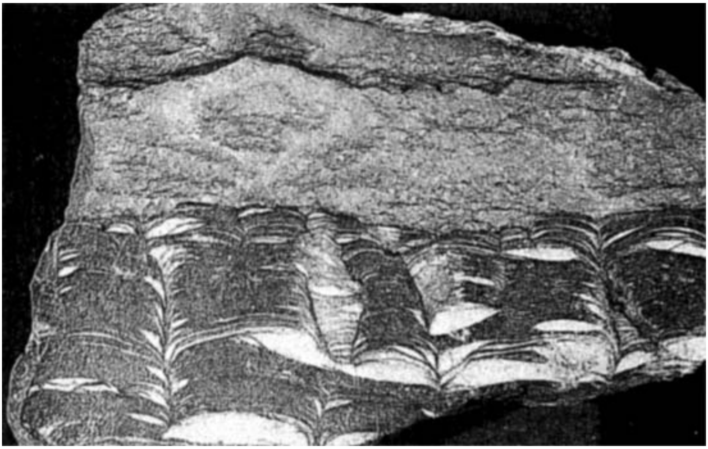

FIGURE 8.1 Stromatolite limestones from the Archean age show the first traces of life forms. The arc-like lamellae are believed to be remnants of colonies of blue algae.

were formed exclusively during the Archean and early Proterozoic ages, are the richest iron resources worldwide. Figure 8.2 shows an example of such BIF rock. It contains lamellae of chert (a siliceous rock) alternating with bands of ferric oxides (*hematite* and *limonite*) that exhibit a red and blue color.

Together with the production of oxygen, which was restricted to the oceans for at least 2 billion years, the amount of carbon dioxide, the main atmospheric gas, slowly decreased. This shift occurred because of the effects of rain: the carbon dioxide was removed, “washed out” from the atmosphere, and combined with calcium, hydrogen, and oxygen to form limestone, or coal and petroleum. At the seafloors, it mixed with mud and sediments to form carbonates.

Oxygen Enters the Atmosphere

In the early Proterozoic, about 2 billion years ago, oxygen entered the atmosphere. Up until that time, the oxygen, which was produced by photosynthesis in the sea, had combined with all the available iron until it reached the point at which it influenced the atmosphere and some continental rocks. Under the influence of oxygen (which then may have been only 1 percent of the atmospheric composition), *continental red beds* appeared, showing large amounts of ferric iron in the form of banded streaks (see Figure 8.3). Some oxygen on the continental shelves may have given rise to the first cell structures and, later, to oxygen-breathing organisms.

In the early Archean, the Earth was still hotter than today. Scientists estimate that, at least in the thinner lithosphere, temperatures were about 200 degrees Celsius higher. This caused a slightly different form of volcanism and produced the *greenstone-*

FIGURE 8.2 Red banded iron formations (BIF) from the Archean age today provide the largest iron resources worldwide. These deposits were formed as the photosynthesis of early organisms created oxygen, which, in turn, combined with iron particles to form solid ferric oxide (Fe_2O_3).

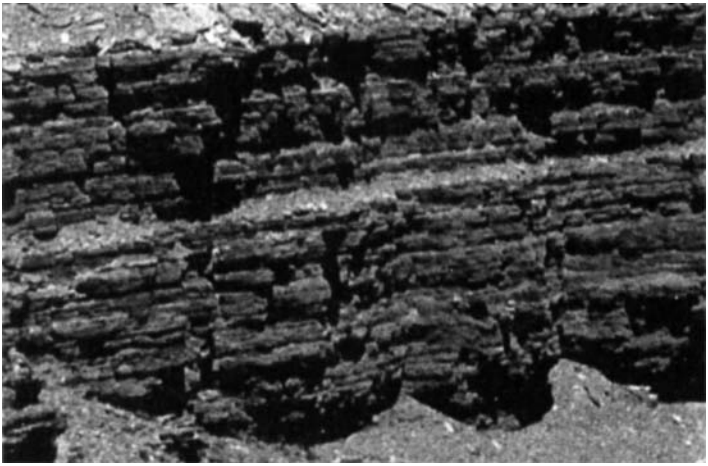

FIGURE 8.3 Continental red beds from the early Proterozoic age. Oxygen slowly entered the atmosphere and combined with iron to form ferric oxide (Fe_2O_3).

granulite belts and the higher-grade *granulite-gneiss terrains*, both of which are found in all old cratons. They are considered the first major contribution to the Earth's crust. The greenstone belts appear as elongated structures, but they have to be differentiated from the *orogenic belts*, which appear later, with the advent of plate tectonics. Greenstone belts are primarily composed of mafic-ultramafic lavas and some sediments, their green color being created by fine grained epitidote and chlorite. They stopped forming between 2 and 1 billion years ago, in the mid-Proterozoic age.

Even higher temperatures were needed for the origin of the so-called *komatiites*, magnesium-rich rocks from very hot ultramafic lava that often contains diamonds. Formed only in the Archean, they provided valuable ores for the kimberlites of today's South Africa. It seems strange that very near to the kimberlites there are other rocks that were created in a cold environment. Apparently, there must have been a temperature difference between about 1000 and 300 degrees Celsius at crustal depths of over 40 kilometers. This could be explained by a very narrow convection cycle, in which hot material was transported upward and cold material downward. An example for high crustal temperatures is early banded gneiss of granulite facies (metamorphosis at 600 to 700 degrees Celsius), while amphibolite facies (metamorphosis at 500 to 600 degrees Celsius) needs only slightly lower temperatures, showing a slight chemical similarity to the Moon's terra rocks.

The Proterozoic

The Proterozoic began 2.5 billion years ago. Life was established, but still on a microscopic scale. Multi-celled organisms began to develop only at the very end of this epoch, around 1 billion years ago. The continuous cooling of the Earth led to the growth of a rigid outer shell composed of the crust and the uppermost mantle, i. e., the *lithosphere.*

The Development of Plate Tectonics

By the time the lithosphere had developed, rifts and mobile belts, huge shelves, and large mountain chains began to form. About 1.9 billion years ago, the Skelefte mountain range developed in northern Europe. Its shallow subduction zone is still observable today by reflection seismology. Between 1.2 and 0.9 billion years ago, a very long mountain belt stretching from the Grenvillan area in eastern North America to the Svecofennian region in southern Sweden developed. Several continents accumulated to form the "super-continent" *Rodinia.* Thus, the motions of plate tectonics were well established. Two observations support this assumption. First, the appearance of *blueschist* in the middle of the Proterozoic is notable. Blueschist can only be created in the low-temperature, high-pressure environment of a steep oceanic subduction zone. Fast subductions carry cold material to great depth and pressure. Second, the formation of the first *ophiolites* can be observed. (Ophiolites are oceanic rocks thrown on land during a massive ocean–continent collision, and they are only found in strong convergence zones of mobile plates.) The super-continent Rodinia lasted at least from 1 billion to 650 million years ago. It then broke apart, but, nevertheless, it had lived longer than the later *Pangea* of Alfred Wegener's hypothesis. It was speculated that another super-continent in the Proterozoic preceded Rodinia, but scientific observations are as yet too vague. Another hypothesis assumes that there is a 500-million-year cycle, during which continents accumulate, stay together for some time, and disperse again. This theory is based on considerations of heat flow. If—possibly by chance—a super-continent has been formed, heat release from the interior is hampered by the thick continental lithosphere. Heat accumulates and forms magmas that rise, creating ridges or rifts, which finally lead to a spreading and dispersal of continents. The statistics might be poor, but the physical explanation makes sense.

The Formation of Today's Atmosphere

During the Proterozoic age, the atmosphere changed dramatically. Oxygen reached the present level. Carbon dioxide was, except for a very small fraction, expelled from the atmosphere and began to generate carbonates at the bottom of oceans and lakes. The noble gas argon increased as potassium decayed. However, the eventual dominance of oxygen-producing photosynthesis and the incorporation of carbon into the carbonates at the seafloor provided our planet with its present unique atmosphere, which is so much different from the carbon dioxide atmospheres of our neighbor planets Mars and Venus.

At the end of the Proterozoic, life forms had not yet evolved the hard skeletons that could have allowed us clearer fossil evidence of organisms in the epoch. However, that development came about very soon, at the beginning of the Phanerozoic age, approximately 570 million years ago. But before the "evolutionary burst" and the diversification of life could begin, the Earth experienced a terrible cooling, which transformed it into a kind of "snowball" (see Chapter 14).