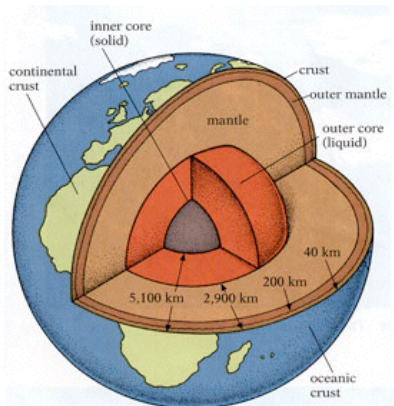


AS THE EARTH FORMED, MATERIALS BECAME STRATIFIED

We are not certain how the solar system formed; we have only hypotheses. But as astronomers probe ever deeper into the secrets of the universe and gather more evidence, these hypotheses become increasingly convincing. The one most widely held today is that the universe is 15 to 20 billion years old, and that the sun and its planets formed about 4.6 billion years ago from a cloud of cosmic dust and gas. Most of this material condensed into a single compact mass, the sun. Within the remainder of the dust and gas cloud, lesser centers of condensation began to form. These became the planets, of which the earth is one.

As the earth condensed, a stratification of its components took place, with the heavier materials, such as iron and nickel, moving toward the center and lighter substances becoming more concentrated nearer the surface. Among these lighter materials must have been hydrogen and helium, which formed the first atmosphere. But unlike larger planets such as Jupiter and Saturn, the earth was too small, and its gravitational field too weak, to retain this first atmosphere and eventually all the gases escaped into space.

As time passed, the components became further stratified into three distinct regions, with the dense iron and nickel accumulating in the center to form the core, the less dense silicates of iron and magnesium forming a partly molten mantle surrounding the core, and the lighter substances remaining near the surface (see figure below). As the surface of the earth cooled, the surface materials, composed primarily of the lighter silicates, solidified to form a crust. This crust is quite thin compared to the diameter of the earth—about the thickness of an eggshell compared to the diameter of an egg. The crust solidified into massive plates resting on the molten mantle. These plates are moved about by the upwelling of new crust in some places and sinking of old crust in others. We shall learn more about this in Unit 8. The intense heat in the interior of the earth also tended to drive out various gases, which escaped primarily by volcanic action. These gases formed a second atmosphere for the earth.



Interior of the Earth. The earth consists of three zones that vary in chemical composition: the core, mantle, and crust. The core consists mostly of iron, with some nickel. The inner core is solid whereas the outer core is liquid (i.e., molten). The mantle is the largest zone; it is composed of primarily of iron and magnesium silicates. The upper layer of the mantle is solid and rigid while the inner layer is partly molten and plastic. The crust forms a thin skin over the earth's surface. It is differentiated into the oceanic crust, under the sea floor, and the thicker continental crust. The crust varies in composition. The thickness of the crust is exaggerated in this diagram.

THE EARLY ATMOSPHERE CONTAINED NO FREE OXYGEN

We must know something about the probable early composition of this second atmosphere to understand the conditions under which life arose. Our present atmosphere contains about 78 percent molecular nitrogen (N_2), 21 percent molecular oxygen (O_2), 1 percent argon, and 0.033 percent carbon dioxide (CO_2), as well as traces of rarer gases such as helium and neon. But available evidence indicates that when the atmosphere first formed it contained virtually no free oxygen and was therefore not an oxidizing atmosphere, as the present one is. The most widely accepted model of the

earth's early atmosphere assumes that it was made up primarily of the gases known to be produced by present-day volcanoes. These gases are H_2O , CO , CO_2 , H_2S , N_2 and H_2 ; in such a mixture, hydrogen cyanide (HCN) and formose (H_2CO) are easily formed and would probably also have been present. Much of the water vapor present in the primitive atmosphere may have come from comets colliding with the earth, since comets are largely water. Methane is also believed to have been present, since there are literally oceans of methane gas out in space and surrounding some stars. Note that this model envisions an early atmosphere in which there is no free oxygen but an abundance of hydrogen.

Centuries of Rains Formed the Oceans

Initially, most of the earth's water was probably present as vapor in the atmosphere, a condition leading to torrential rains as the earth cooled and the water vapor condensed. The centuries-long rains would have filled the low places on the crust with water and given rise to the first oceans. As rivers rushed down the slopes of early continents, they must have dissolved away and carried with them salts and minerals of various sorts, which slowly accumulated in the seas. Atmospheric gases probably also dissolved in the waters of the newly formed oceans.

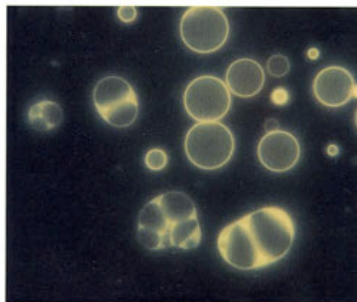
Small Organic Molecules Formed Abiotically

If the early earth had an oxygen-poor atmosphere, as many astronomers and geochemists believe, and the primitive seas contained a mixture of salts, CO_2 , H_2S , HCN, CH_4 , NH_3 , formose, and N_2 , how were the more complex organic molecules formed? The molecules thought to have been present in the primitive seas are thermodynamically stable; there is no tendency for these materials to react spontaneously with each other to form other compounds. Yet for life to have arisen it would seem that at the very least the critical building-block materials, particularly amino acids and the purine and pyrimidine bases, would have been necessary. How might these compounds have been formed on the primitive earth?

There are two basic hypotheses to account for the accumulation of complex organic compounds on the early earth. The first hypothesis suggests that the complex organic molecules came from asteroids and meteors striking the earth – i.e., an extraterrestrial synthesis. Many of these extraterrestrial objects are rich in complex organic molecules created during the formation of the solar system billions of years ago (see figure below). Because the early atmosphere was denser than today's, incoming objects would have been slowed before striking the earth's surface. Some astronomers estimate that from 106 to 107 kilograms of complex organic molecules could have survived impact annually. It is possible, therefore, that the early earth had a vast supply of the complex molecules necessary for the evolution of life without any need to synthesize them out of simpler substances.



A



B

A carbonaceous chondrite meteorite. (A) The golf-ball-sized fragment is part of a meteorite that fell near Murchison, Australia, in 1969. Tiny particles of organic compounds, accounting for 1-2% of the fragment's weight, are scattered throughout the stone. (B) When the organic material is extracted, some of the molecules self-assemble into vesicles. The yellow-green color is produced by the fluorescence of polycyclic aromatic hydrocarbons, a class of extremely complex organic molecules.

The second, more conventional, view of the development of organic molecules is the one discussed in your textbook. According to this hypothesis, complex organic molecules were generated from the small inorganic compounds already present. These molecules reacted with one another to form larger, more complex organic molecules. To do so, some external source of energy must have been acting on the mixture since these molecules are quite stable. One possible energy source would have been solar radiation, including visible light, ultraviolet (UV) light, and X rays; of these, ultraviolet light would probably have been the most important. Remember that the primitive atmosphere contained virtually no oxygen and therefore no ozone layer; it is the ozone layer that screens out much of the ultraviolet radiation from the sun. The ultraviolet radiation would have been much more intense on the early earth than it is today. A second important possibility is energy from electrical discharges, such as lightning, while a third is heat from the earth's core and the sun. Experimental support for this hypothesis was provided in 1953 by Stanley L. Miller. Miller's experiment is discussed in detail in your text.

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