To Dr. Gamow
Cordially from H. Strughold

The Oxygen Belt in the Planetary System

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The Oxygen Belt in the Planetary System

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The possibility of life on other planets is frequently associated with the presence of oxygen in their atmospheres. This is understandable because for the kind of life that we know, oxygen is the key element that releases the potential chemical energies contained in the foodstuffs, which then appear in the form of heat, movement and other forms of energy. The biochemical reaction which accomplishes this is the biological oxidation in the cells. This biological reaction leads to a breakdown of the food-stuff molecules, down to the smallest possible components like water and carbon dioxide. Consequently, the gain of energy therein is high. Only biological oxidation has made possible the development of living creatures to higher stages.

There is another energy producing biological reaction which takes place without the presence of free oxygen. This is the simple splitting of the foodstuff molecules, a reaction which does not lead to a breakdown into the smallest possible components. The amount of energy gained in this process, also called fermentation, is therefore low, sufficient however for lower organisms. Though free molecular oxygen is not required in this process, oxygen is somehow involved insofar as the respective foodstuff molecules contain oxygen intramolecularly. As we know it, based on carbon as the basic structure atom, life centers around oxygen as the basic energy releasing atom. For this reason the higher organisms require an ample supply of free molecular oxygen from the surrounding environment.

Quadrillions of tons of oxygen are contained in the terrestrial atmosphere and in the oceans. Up to an altitude of 15,000 feet, its concentration is high enough that settlements, even of such oxygen hungry creatures as men, can be found. But how about the oxygen problem on other planets? In order to understand this we must not only consider the planets in their present state of development but also in their former stages during their historical evolution. Well founded theories on the historical development of the earth's atmosphere have recently been advanced by Kuiper,[3] Urey[11] and others. They will serve as a basis for the considerations that follow. We shall begin with the chemistry of the protoatmosphere of the earth.

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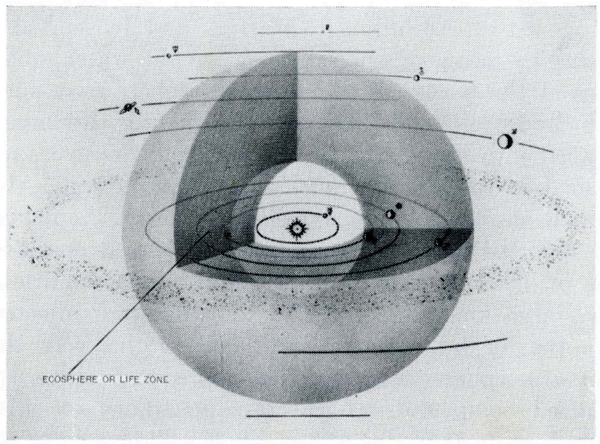

Fig. 3. Ecosphere or Life Zone of the planetary system comprises Venus, Earth, and Mars. Within the ecosphere lie the oxygen, liquid-water, and biotemperature belts—all essential to support life as we know it.

The protoatmosphere of the earth is understood as that gaseous envelope which surrounded our planet during its developmental stage as a protoplanet (Fig. 2). This stage represents the range of time during which the accumulation of cosmic dust and planetesimals into a planetary body was completed or nearly

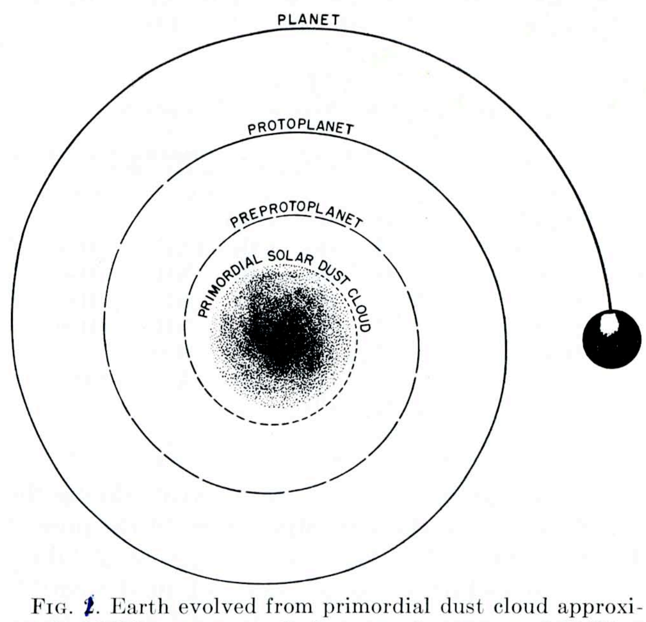

Fig. 2. Earth evolved from primordial dust cloud approximately 5 billion years ago. In its protoplanet stage, 2.5 billion years ago, earth's surface formed into a semisolid or solid crust.

completed and the surface was formed into a semi-solid or solid crust. It was the transition period from pregeological to geological time—some two and a half billion years ago.

At this primordial stage the earth's atmosphere contained essentially hydrogen and the hydrogen compounds methane (CH_4) and ammonia (NH_3), water vapor and helium. Its chemistry was marked by the predominance of hydrogen. It was a gaseous sphere of reducing and reduced chemicals, which did not deserve the prefix "atmo", i.e., for "breathing." Soon, however, under the influence of ultraviolet of solar radiation a change set in. According to Harteck and Jensen,[1] and Poole[5], by means of photodissociation the water molecules at the border of the protoatmosphere were split into hydrogen and oxygen. The lighter hydrogen escaped into space; the heavier oxygen, however, remained. With the appearance of this initial oxygen, the protoatmosphere attained oxidizing power. Ammonia was oxidized to free nitrogen and water; and methane was oxidized to carbon dioxide and water. Additionally, large amounts of carbon dioxide were injected into the air by volcanic eruptions. In this way the protoatmosphere was enriched more and more by oxidized compounds. With the appearance of chlorophyl, more than one and one-half billion years ago, this change was accelerated by the progress of photosynthesis. The oxygen, thus abundantly produced, oxidized the remaining hydrogen compounds. The excess of oxygen accumulated to rather large amounts, such as are observed in the present day atmosphere. This stock of atmospheric free oxygen amounts to 1.2 quadrillion metric tons.

TABLE I

Main Components of the Terrestrial Protoatmosphere and Atmosphere of the Earth in Their Order of Abundance

Protoatmosphere	H_2	He	Ne	H_2O	NH_3	CH_4	A
Atmosphere	N_2	O_2	H_2O	A	CO_2		

TABLE II

Components of the Planetary Atmospheres

Planet	Most Important Probable Atmospheric Components in Order of Their Abundance				
Pluto	H_2	He	(CH_4)		
Neptune	H_2	He	CH_4	(NH_3)	(H_2O)
Uranus	H_2	He	CH_4	(NH_3)	(H_2O)
Saturn	H_2	He	CH_4	NH_3	(H_2O)
Jupiter	H_2	He	CH_4	NH_3	(H_2O)
Mars	N_2?	A?	CO_2	H_2O	
Earth	N_2	O_2	H_2O	A	CO_2
Venus	N_2?	CO_2			
Mercury	—	—	—		

Such was probably the course of events during the transformation of the protoatmosphere to the present day atmosphere in which we live. About 2 billion years ago hydrogen was predominant in the earth's gaseous envelope as an active chemical agent; today oxygen is the dominant agent. In the hydrogen atmosphere of the remote past, microorganisms such as hydrogen bacteria, methane bacteria, and ammonia bacteria could have found a suitable environment, if some initial oxygen had been already available, but not higher organisms. They are oxygen creatures par excellence. So much about the historical development of the Earth atmosphere.

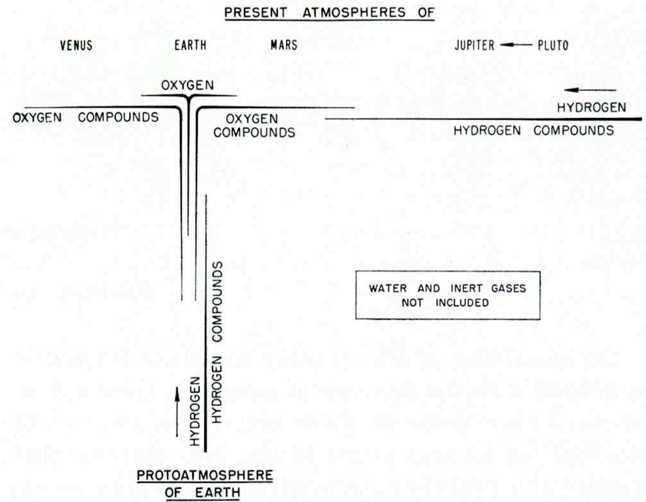

Fig. 2. Photochemical transformation of planetary atmospheres is possible only in a certain distance range from the sun: the farther a planet from the sun, the less transformed its atmosphere.

When we now consider the present day atmospheres of other planets, we find an extremely interesting parallel to what we have just discussed.

Astrophysics teaches us that the atmospheres of the outer planets—Pluto, Uranus, Neptune, Saturn, and Jupiter, consist of hydrogen and the hydrogen compounds (methane and ammonia and frozen water). Mars contains oxidized compounds like carbon dioxide but no free oxygen or only traces of it. Because of its lower gravitational pull, which is only 38 per cent of that of the earth, proto-Mars probably lost its free oxygen into Space. Venus has a completely oxidized atmosphere and also no free oxygen. The higher temperature of proto-Venus, due to its nearness to the Sun, was probably the cause of its oxygen loss. Mercury, the smallest of the planets and the closest to the Sun, could not possibly hold an atmosphere because of its very high temperature and its low gravitational pull.

In considering the evolution of the protoatmosphere of Earth to the present day atmosphere, we see a transformation from a hydrogen and hydrogen compounds containing atmosphere, into an oxygen and oxygen compounds containing atmosphere, caused by the radiation of the Sun. In contrast the planets from Pluto to Jupiter show even today, the original atmospheric chemical components: hydrogen and hydrogen compounds. From Mars to Venus, however, we deal with oxidized atmospheres. Apparently a photochemical transformation of planetary atmospheres is possible only in a certain distance range from the Sun. Thus, we can make the interesting observation: we find the same course of events when we consider the planetary system from the remote distance from the Sun to its neighborhood, as we find it when considering the evolution of the Earth's atmosphere from the remote past to the near present: a transformation of reduced to oxidized atmospheres (Fig. 2). Chronologically, the atmospheres of the outer planets may all be about the same age as those of the inner planets, but they are apparently younger with regard to their material metabolism as effected by the Sun's radiation. If this is so, then indeed we recognize in the chemical composition of the planetary atmospheres—in their sequence from the outer to the inner planets—a recapitulation of the ontogeny of the earth's atmosphere to use a phrase famous in Paleobiology.

In this paper, however, our interest is concentrated upon the realm of the oxidized atmospheres found on Mars, Earth and Venus. Under these, the Earth is outstanding with its additional rich supply of oxygen. We can call this zone in which planets with oxidized atmospheres are found: the *oxygen belt in the planetary system*. Only in this belt the photochemical transformation of the original planetary atmospheres was possible. Only in this belt, therefore, organisms are conceivable which depend upon oxygen or more generally on oxidation processes. Oxygen, however, is only one important ecological factor. Another is the presence of water in the liquid state. This too is only possible in a certain distance range from the Sun (*"liquid water belt"*).[6] The factor which controls this condition is the temperature. The temperature range which permits water in the liquid state includes also the somewhat smaller temperature range which permits active life (*biotemperature belt*).

All of these three mentioned ecological belts are found in about the same distance range from the Sun. Therefore, we can consider them as parts of a belt which can be best designated with the more general term—the life zone or *"ecosphere"* of the Sun. In this ecosphere in the planetary system the oxygen belt invites our special interest from an astrophysical point of view as well as a biological one.

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