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MUTUAL EVOLUTION OF TERRESTRIAL ATMOSPHERE AND BIOSPHERE

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Összefoglalás - A földi légkör jelenlegi összetétele merőben eltér a Naprendszer többi bolygójának légkörétől. A Föld kialakulásakor megjelent az őslégkör, amelynek összetétele kissé hasonló volt az óriás bolygók ismert légköréhez. Ezt mintegy 4 milliárd éve fölváltotta a redukáló másodlagos légkör, amelyben túlsúlyban voltak az üvegház hatású gázok. A felszín fölmelegedésével megjelent a cseppfolyós víz és az óceán, az utóbbi otthont adott az első élőlényeknek. A fotoszintézis révén megjelent a légkörben az O_2, majd ezt követőn az ózon. Ettől kezdve a légkör és a szárazföldi és tengeri élővilág kölcsönhatásban fejlődött a jelenkorig. A légkör CO_2 változása több tényezőtől függ, ezek mérsékelhetik az emberi tevékenység hatását.

Summary - The present composition of terrestrial atmosphere differs remarkably from atmospheres of other planets in our Solar system. At the beginning of the history of Earth the primordial atmosphere was more or less similar to those in giant planets. This atmosphere was soon replaced by secondary one containing predominantly greenhouse gases but no oxygen. After rise of temperature liquid water appeared on the surface and formed oceans. The latter gave home to the first living creatures, and by means of photosynthesis the oxygen appeared in the atmosphere, and after that the ozone. Hence the atmosphere and biosphere have developed mutually up to the present time. The change in atmospheric CO_2 depends upon a great number of factors, so they can moderate the effect caused by human activity.

Key words: atmosphere both primordial and secondary, photosynthesis, atmospheric oxygen, carbon-dioxide, biosphere, paleoclimatic variations of temperature.

THE PRESENT TERRESTRIAL ATMOSPHERE

The mass of the planet earth is as much as $6 \cdot 10^{24}$ kg, the mass of terrestrial atmosphere is about $5.2 \cdot 10^{18}$ kg, i.e. the latter is less than one ppm of the former. The mass and volume ratios of main atmospheric gases are as follows (*Table 1*):

Atmospheric gases	Mass	Vol. ratios
N_2	$4.00 \cdot 10^{18}$ kg	78.00% volume
O_2	10^{18} kg	20.90 % "
Ar	$4.80 \cdot 10^{16}$ kg	0.93 % "
H_2O (water vapour)	$1.30 \cdot 10^{16}$ kg	0.25
CO_2	$1.80 \cdot 10^{15}$ kg	350 ppmv
CH_4	$1.04 \cdot 10^{13}$ kg	2 ppmv
O_3	$3.36 \cdot 10^{12}$ kg	650 ppbv

Table 1 The main atmospheric gases and their mass and volume ratios

Besides the atmosphere contains several other gases in very small ratios, like Ne, Kr, Xe, NO_x-s, CO, CFC-s and microsized solid and liquid particles, the so called aerosol.

The most abundant components of terrestrial atmosphere, the nitrogen and oxygen, take nearly 99 % of the atmosphere. Thus the Earth's atmosphere differs significantly from the atmospheres of the other planets in our solar system. In the atmospheres of the giant planets, like Jupiter, Saturn and Uran, there are abundance of hydrogen and helium, which are not able to escape, because of great gravity force of these planets and very low temperature.

However the atmospheres of Venus and Mars, nearest planets to the Earth, differ from terrestrial atmosphere, too. They contain much more carbon dioxide, but much less nitrogen and oxygen, e.g. the atmosphere of Venus consists of CO_2 in 98.8 %, of N_2 in 1.01 % and practically no oxygen, according to our present knowledge. So the atmosphere of inner planets consists predominantly of CO_2, while those of giant planets consist of H_2 and He and besides NH_3 and CH_4. Consequently the question arises: in what way did the terrestrial atmosphere develope producing so very peculiar composition?

PRIMORDIAL ATMOSPHERE, SECONDARY ATMOSPHERE (REDUCING, WITHOUT OXYGEN) APPEARANCE OF OXYGEN

The protoplanet Earth consisted of interstellar dust, solid materials and gases in a dispersal system. The gravitation force assembled heavier particles to the centre, while the gases started gradually forming an outer cover. This primordial atmosphere consisted of H_2, He, CH_4, H_2O, NH_3 and H_2S. It is supposed that mass of the earth was at this time manifold of the present mass. Nevertheless its gravity force was small and its temperature high, so H_2 and He escaped to the space. The water vapour largerly condensated, the other gases were undergone chemical reactions with lithosphere and infiltrated into that. It is plausible that the dissipation of the primordial atmosphere existed for 200-300 million years, and the Earth became a planet without atmosphere at least for an unknown period.

Afterwards gases escaped gradually through the rocks partly through volcanic activity, partly through several chemical reactions. Thus started the longlasted formation of secondary atmosphere consisting mainly of H_2O and CO_2, but there were smaller quantities of N_2, H_2 and S_2 present as well. Due to greenhouse effect of CO_2 and H_2O the global surface temperature rose from about -18, -10°C up to 0°C and above freezing-point, so liquid water appeared on the Earth's surface and gathered into oceans. About 3-4 billion years ago the atmosphere contained no free oxygen, therefore it has been called reducing atmosphere.

A great number of researchers have been engaged in questions relating to changing solar radiation, density and composition of the terrestrial atmosphere, as well as regulation of global surface temperature *(Budyko,* 1982; *Budyko, Ronov and Yanshin,* 1987; *Lamb,* 1988; *Rambler, Margulis and Fester,* 1989; *Lovelock and Margulis,* 1974; *Frakes et. al.,* 1992; *Mészáros and Pálvölgyi,* 1990; *Koppány,* 1993, 1996). In early phase of the evolution of terrestrial atmosphere, about 4 billion years ago, the solar luminosity was less by at least 30 % compared with the present value. The luminosity of the sun has increased gradually during the last 4 billion years. Meanwhile two very important events must have taken place: 1. Appearance of liquid water on the Earth's surface, in other words, the temperature had to exceed the freezing-point, 2. At some depth in water, organic systems appeared and began to transform the chemical composition of the atmosphere: e.g. release of O_2.

The first event may be explained by greenhouse effect of sufficiently dense atmosphere, or less planetary albedo, or by both. The reduction of atmospheric carbon-dioxide is partly the consequence of photosynthesis carried out by organic materials in deep water. The total photosynthetic reaction may be written in a simplified form as:

$$CO_2 + H_2O + \text{photon} = CH_2O + O_2$$

This process is accompanied by a release of O_2. The other consumer of the atmospheric CO_2 is the ocean itself.

However before the oxygen appeared in the atmosphere, there was not ozone and so the lethal UV radiation could reach the ground preventing the formation of living material on it. Only a water-layer at least with 10 m depth can absorb the lethal UV radiation. Hence the first living creatures could form and exsist in oceans.

On the other hand the comparatively high abundance of O_2 in the atmosphere is also the consequence of photosynthesis. For a long time it was assumed that the free oxygen is the product of photodissociation of water vapour. It may be written in form:

$$2\cdot H_2O + \text{photon} = 2\cdot H_2 + O_2$$

The very light H_2 has escaped and the amount of O_2 increased according to this theory. But nowadays the wellknown Urey-effect has been entirely accepted which establishes that as soon as the ratio of atmospheric O_2 reaches 0.001 PAL (Present Atmospheric Level), the photodissociation will stop, because the O_2 absorbs that band of UV radiation which is responsible for the photodissociation. The changes of mass of the atmospheric O_2 during the last 560 million years (Phanerozoic) can be estimated by equation:

$$\frac{dM(O)}{dt} = A(O) - B(O),$$

where A(O) is the income, B(O) the loss of O_2 mass. The income is product of photosynthesis, the loss is the consequence of consumption of O_2 by organic materials (oxydation). The difference between them in a def. period is considered proportional with organic carbon, accumulated in sediments on the whole Earth. In this relation the O_2 income is as follows:

$$A(O) = a(O)\cdot C_o,$$

where a(O) is the ratio berween masses of O_2 molecule and C atom, i.e. (32:12= 2.67), C_o stands for organic carbon accumulated in sediments during a relevant interval.

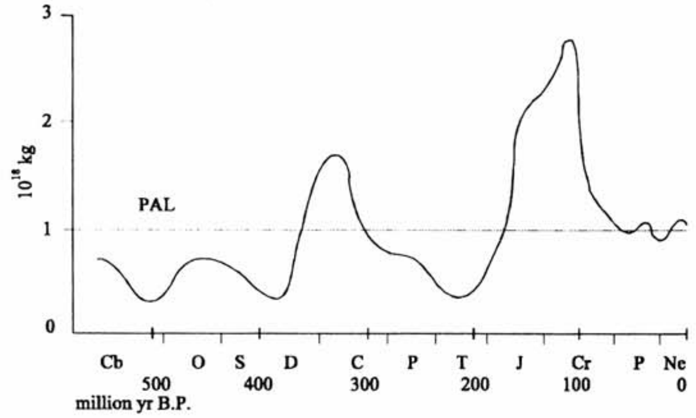

Fig. 1 Changes in oxygen mass in the Phanerizoic (*after Budyko, Ronov and Yanshin*, 1987)

Fig.1 presents the O_2 accumulation in the atmosphere with assumption of active contribution of the biosphere. The abundance of atmospheric N_2 must be the product of the biosphere as well. The simultaneous presence of CH_4 and O_2 in the atmosphere could not be explained without contribution of the biosphere. Namely due to the effect of the solar radiation the methane and oxygen will be converted to carbon-dioxide and water vapour:

$$CH_4 + 2 \cdot O_2 + \text{photon} = CO_2 + 2 \cdot H_2O.$$

Hence the atmospheric CH_4 reproduced continuously by the biosphere may control the O_2 amount in the atmosphere.

The ratio of atmospheric O_2 is crucial for the living materials. If the ratio of O_2 is below 15 %, there is very low chance to get fire. On the other hand, if the ratio exceeds 25 or 30 %, the danger of spontanous fire is extremely high (*Lovelock*, 1991).

The optimum O_2 densitiy, which was most favourable for its conversion into O_3, is about 0.001 of present density at sea level. At the time of the first appearance of atmospheric O_2, this optimum density was near the ground, but by increasing amount of O_2 the altitude of optimum densitiy has risen in hundreds of million years up to the present layer at 20-40 km above the ground. Thus ozonosphere has risen gradually from the ground to the stratosphere. This ozone layer has protected the living creatures on the surface against the lethal UV radiation.

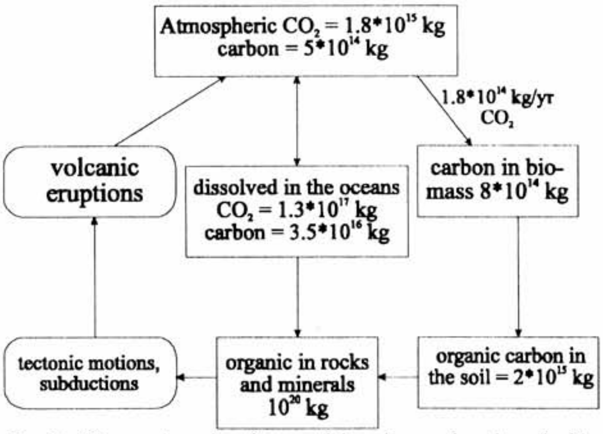

Fig. 2 The great cycle of terrestrial carbon and carbon-dioxide, respectively. The mass and migration rate relate to the present conditions.

The appearance of O_2 in the atmosphere might have been a great challenge for anaerob living creatures being exsisted before and accostumed to an environment without oxygen. At the same time the circumstances changed favourably for aerob species of plants and animals on the continents and sea surface. This change took place in the last 560 million years, i.e. in Phanerozoic.

VARIATIONS OF ATMOSPHERIC CO_2 IN PHANEROZOIC

The atmospheric gases are in continuous interrelation with the hydrosphere, lithosphere and biosphere. It is valid in case of CO_2. Below about 300°C the CO_2 can be absorbed by lithosphere in form of carbonates. Besides the hydrosphere and biosphere are also consumer of this gas.

Fig. 2 gives a very simple picture of great cycle of terrestrial CO_2 in earth-atmosphere system. Due to changing tectonic motions and volcanic activity the reduction and release of CO_2 could not maintain stable equilibrium in the atmosphere. This fact is reflected in remarkable variations of atmospheric CO_2 in Phanerozoic accompanied with variations of global surface temperature.

A rough relation was found between the doubling atmospheric CO_2 and rise in global temperature. Partly theoretical, partly experimental investigations lead to the approximative relation, as follows:

if CO_2 past : CO_2 present = $k>1$,

and $\log k : \log 2 = b>0$, here b is the number of doubling in CO_2, then

ΔT (T past - T present) = $b \cdot 2.5$.

One can test this relation using data given in *Fig. 3*. For example in Carboniferous: $k = 7.22$, $b = 3.67$ and $\Delta T = 9.2K$, according to estimation presented in *Fig. 3* $\Delta T = 11K$.
In Ordovician: $k = 7.5$, $b = 2.85$, $\Delta T = 7.13$, that presented in *Fig 3* $\Delta T = 7.5K$.
In Permian: $k = 11.11$, $b = 3.47$, $\Delta T = 8.6$, that presented in *Fig. 3* $\Delta T = 7.5K$.
In Jurassic: $k = 10$, $b = 3.32$, $\Delta T = 8.3K$, presented in *Fig.3* $\Delta T = 10.5K$.
For the sake of simple comparisons (*Tab. 2*):

	Calculation	**Assessment**
Ordovician, middle	7.13 K	7.5 K
Carboniferous, lower	9.2 K	11.0 K
Permian, lower	8.6 K	7.5 K
Jurassic, upper	8.3 K	10.5 K

Tab. 2 Explanation see in text

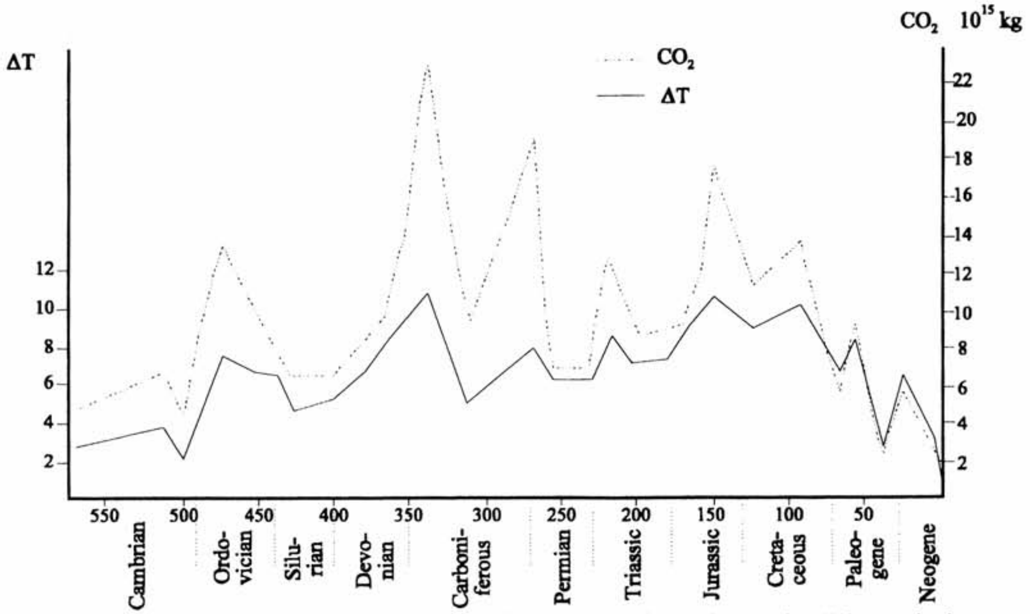

Fig. 3 Changes in mass of atmospheric CO$_2$ and global surface temperature in the Phanerozoic. ΔT denotes the departure from present value. (Making use of data given by *Budyko et. al.*, 1987.)

Of course there may be discrepancies both in calculation method and paleoclimatological assessment, but in the warmest periods of Phanerozoic the temperature data obtained in different ways are close to each other.

Similar comparisons can be made for cooler periods in Phanerozoic (*Tab. 3*):

	Calculation	**Assessment**
Cambrian, lower	3.7 K	3.0 K
Silurian	1.84 K	2.0 K
Oligocene	4.6 K	4.5 K

Tab. 3 Explanation see in text

VARIATIONS OF ATMOSPHERIC CO_2 IN RECENT YEARS

The amount of atmospheric CO_2 has been rising since the beginning of industrialization, i.e. since the end of 19th century from 280 ppmv to 360 ppmv. It is unlikely that an increase of CO_2 by 28 % within about 100 years occured any time in Phanerozoic. The human activity, namely the growth in motorization, industrialization, consumption of fossil fuels and depleting forest must be responsible for rapid changes in atmosphere.

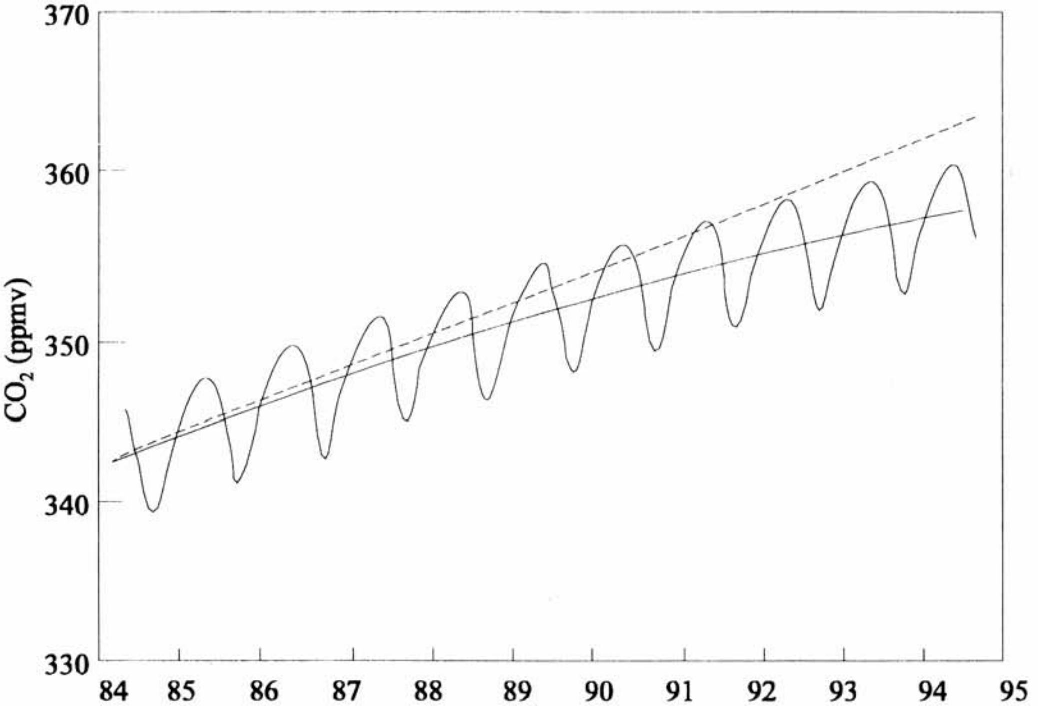

Fig. 4 Observations of CO_2 at the Izaña observatory. Trends: extrapolated with invariable rate (plotted), and actual (solid) (after *European Climate Support Network*, 1995)

What will happen to the climate if this change continues invariantly in the coming centuries? It was mentioned above in a previous chapter that the CO_2 cycle can not maintain stable equilibrium in atmospheric CO_2 (*Fig. 2*). This statement is supported by the fact that the rate of increase in atmospheric CO_2 has become slower in the recent decade, 1985-94 (*Fig.4*), as it has been pointed out by European Climate Support Network (1995). The variable growth

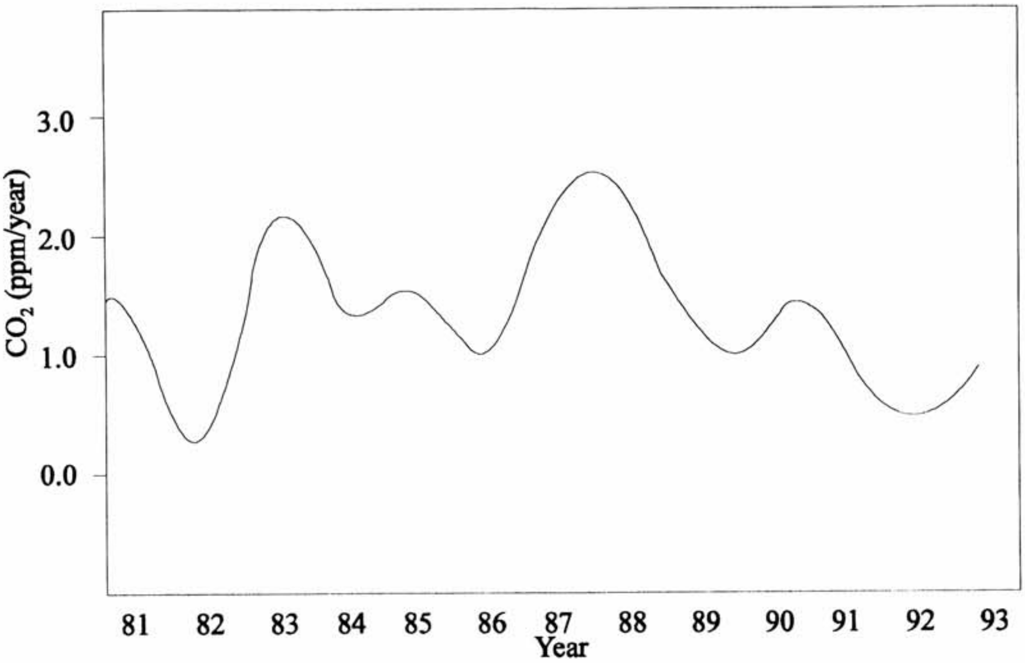

Fig. 5 A slow down in the growth rate of carbon dioxide levels in period 1981-93 (*after The Global Climate System Review*, 1995)

rate of atmospheric CO_2 is illustrated in *Fig. 5* published in The Global Climate System Review by WMO (1995). Consequently, the future of our atmosphere and global climate is rather doubtful in light of complicated interactions of a great number of factors which are active in earth-atmosphere system including the biosphere and human behaviour.

REFERENCES

Budyko, M. L., 1982: *The Earth's climate: Past and future*. Academic Press, New York, London.

Budyko, M. L., Ronov, A. B. and Yanshin, A. L., 1987: *History of the Earth's Atmosphere*. Springer Verlag, Berlin.

Climate of Europe, European Climate Support Network, 1995.

Frakes, L. A., Francis, J. E. and Syktus, J.I., 1992: *Climate modes of Phanerozoic*. Cambridge University Press.

Koppány, Gy., 1993: *Will the Earth remain habitable? Atmosphere and biosphere* (in Hungarian). Akadémiai Kiadó, Budapest.

Koppány, Gy., 1996: *Paleoclimatology* (in Hungarian). JATE Press, Szeged.

Lamb, H.H., 1988: *Weather, Climate and Human Affairs*. Routledge, London and New York

Lovelock, J. E. and Margulis, L., 1974: Atmospheric homeostasis, by and for the biosphere. The Gaia hypothesis. *Tellus, 26*, 1-10.

Lovelock, J. E., 1991: *Gaia* (in Hungarian). Göncöl zsebkönyvek, Budapest.

Mészáros, E. and Pálvölgyi, T., 1990: Daisyworld with an atmosphere. *Időjárás, 94*, 339-345.

Rambler, M. B., Margulis, L. and Fester, L.,: *Global Ecology. Towards a Science of the Biosphere*. Academic Press, New York, London.

The Global Climate System Review. UNDP. WMO, Geneva, 1995.