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Planet Earth – our oasis in space

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Planet Earth is unique in our solar system as an abode of life. In contrast to its planetary neighbours, the presence of liquid water, a benign atmospheric environment, a solid surface and an internal structure providing a protective magnetic field make it a suitable habitat for man. While natural forces have shaped the Earth over millennia, man through his technological prowess may become a threat to this oasis of life in the solar system.

Earth as part of the solar system

From the vantage point of space, which is now accessible to us humans, the Earth presents itself as a blue planet, dominated by the water that covers more than two thirds of its surface. Water is an essential prerequisite of life as we know it – i.e. based on carbon chemistry, for which water provides the ideal solvent. To assess our planet's special role as an abode of life and habitat for man it is instructive to compare it with its neighbours in the solar system, which was formed about 4.5 billion years ago out of a swirling cloud of gas and dust, material delivered by a supernova explosion. While the four inner planets, Mercury, Venus, Earth and Mars have solid surfaces, the outer planets Jupiter, Saturn, Uranus and Neptune are huge balls of gas, with little Pluto and its companion Charon now often relegated as an outsider as a 'transneptunian object' (TNO), like other small remnants of the formation of the solar systems in the so-called 'Kuiper belt'.

The Earth's atmospheric environment and the evolution of life

If we compare Earth with its immediate neighbours Venus and Mars, their different atmospheric composition is noticeable (Table 1). While Venus and Mars have CO_2 atmospheres with nitrogen as a trace constituent of a few percent, Earth has a predominantly N_2 atmosphere of 78% with oxygen at 21% as a secondary, but for us humans a most important, constituent. The surface pressure of Venus

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Table 1. Atmospheric components of terrestrial planets

Gas	Venus	Earth	Mars
CO_2	98%	360ppm	95%
N_2	1.8%	78%	2.6%
O_2		21%	0.0015%
^{40}Ar	200ppm	0.9%	1.6%
Pressure	90 bar	1 bar	0.007 bar

is about 100 times that of Earth, whereas that of Mars amounts to only about one hundredth that of Earth. Their surface temperatures also differ widely: Venus has a scorching temperature of 480°C compared with Earth's benign 15°C, while Mars has arctic temperatures of about–50°C.

It is now generally agreed that the atmospheres of the three 'terrestrial'planets have their origin in the degassing of volatiles from their interiors. (Mercury the planet closest to the sun has no atmosphere bound by gravity.)

About 50 years ago, the American geologist W. Rubey made a detailed inventory of the volatile substances exhaled by terrestrial volcanoes, which shows that, in addition to many trace constituents, the principal 'stable' degassing materials are H_2O, CO_2 and N_2. Normalizing to the current atmospheric pressure of N_2 at about 1 bar, the expected original pressures in the gas phase are indicated in Table 2. Thus, a 'steam atmosphere' before condensation into water would amount to 330 bar (equivalent to the gaseous phase of our oceans) and 70 bar for CO_2 before it was sequestered in carbonate rocks. Figure 1 shows a highly simplified scenario how the degassed volatiles on Earth were transformed into today's hydrosphere and atmosphere. It should be noted that the early atmosphere consisted principally of N_2 with traces of the greenhouse gases H_2O and CO_2. Today's important constituent O_2 is, paradoxical as it may seem, the product of primitive life (photosynthetic cyanobacteria) and began to accumulate in our atmosphere about 2 billion years ago. When its abundance became about a few

Table 2. Degassing products of terrestrial volcanoes (after Rubey, 1951; Holland, 1962)

Rubey Inventory

H_2O	CO_2	HCl and Cl_2	N_2	H_2, SO_2, HF, H_2, CH_4, NH_3, A
80%	17%	1.7%	0.2%	intraces
330	70		1 bar	

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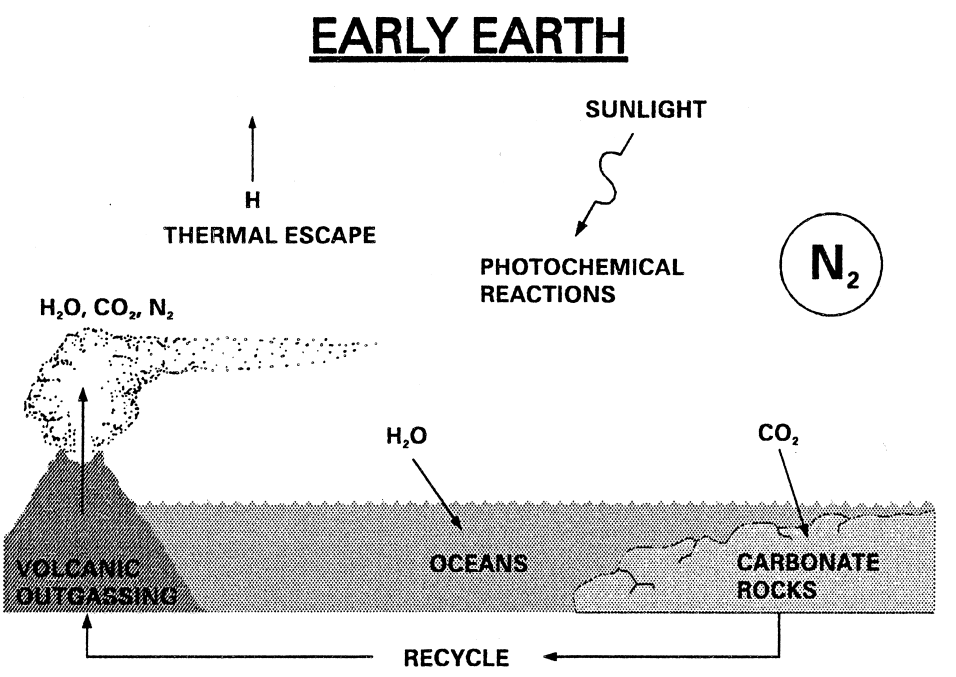


Figure 1. Early Earth.

percent of the present atmospheric level, ozone (O_3) could be formed by photochemical reactions in the stratosphere, providing a protective shielding from harmful solar ultraviolet radiation (in the range from 200 to 300 nm) for the building blocks of life (DNA) equivalent to 10 m depth of water. At that time (about 600 million years ago) multi-cellular life began to spread over land.

The picture presented here is in contrast to the long held view of a highly reducing atmosphere of the early Earth, consisting of CH_4, NH_3, H_2 etc – which, according to the postulates of chemists, particularly A. Oparin and J. B. S Haldane in the 1920s, would be essential for the chemical evolution of life. A gaseous mixture of this kind with water and an energy source of electric discharges was used in the landmark experiment of Miller and Urey in 1953, in which amino acids were formed. This important result convinced many that the early atmosphere must have been like this, a 'dogma' that persisted for several decades, until the observed atmospheric composition of our neighbours, Venus and Mars, focused new attention on the Rubey inventory of terrestrial volatiles. Not only had there never been any geological evidence for a highly reducing atmosphere, leading by photo-dissociation to a hydrogen dominated upper atmosphere, but according to our current understanding of atmospheric escape this would persist for only a short life time of about 10 million years.

Today it is assumed that the atmosphere (without O_2) and the hydrosphere of

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the Earth were delivered by degassing in about 200 million years. The sometimes-argued origin of the Earth's oceans as influx from comets is now discounted, since the observed ratio of deuterium to hydrogen (D/H) in ocean water would allow at most a 10% contribution from comets. An atmosphere with N_2 and traces of CO_2 (although non-oxygenic) creates some problems for the synthesis of prebiotic molecules and the chemical evolution of life, and today it is even acceptable that the organic building blocks of life may have been delivered to Earth by comets and meteorites known to contain such material. Beyond that, the possibility for the synthesis of organic molecules by mineral catalysts in hot springs has now been shown to exist. Under reducing conditions, near oceanic 'hot smokers' at the boiling point of water, iron-nickel sulfides can polymerize CO_2 into amino acids, peptides and even drive a peptide cycle involving oxidation reactions from CO to CO_2.

Although the transition from prebiotic chemistry to life is still shrouded in ignorance, this may have happened almost 4 billion years ago. There is indirect evidence of life processes from C^{12}/C^{13} anomalies (the lighter carbon isotope being preferred by life) in the oldest rocks on Earth (3.85 billion years ago), although no real fossils of primitive life have been found. The presence of stromatolites and banded iron formations (BIF) more than three billion years ago suggest that cyanobacteria may already have begun to produce O_2.

In the long evolutionary path punctuated by large cosmic impacts and half a dozen severe global glaciations (ice ages), life has survived finally to evolve into man, using the planet as his habitat.

Terra firma – our solid Earth

According to recent ideas, our planet Earth formed amazingly quickly after the origin of the solar system. It took less than 50 million years (based on recent information on the radioactive decay of rare isotopes of hafnium into wolfram) for the nascent Earth in a molten state, called 'magna ocean', to begin to segregate heavy elements (iron) into a core and so begin forming an incipient crust. During this period, the impact of a body of the size of Mars tore out a part of the young Earth and out of these two bodies our Moon was formed. Its large size and proximity are also responsible for the stability of the Earth axis (varying by only 2 degrees over a period of 40 000 years) and thus assuring a reasonably stable climate.

Based on a century's worth of observations, primarily from the propagations of seismic waves originating in earthquakes, the inner structure of our planet is now being understood in terms of several regions: the uppermost lithosphere (including the crust), the mantle of silicates and a core divided into two parts, the

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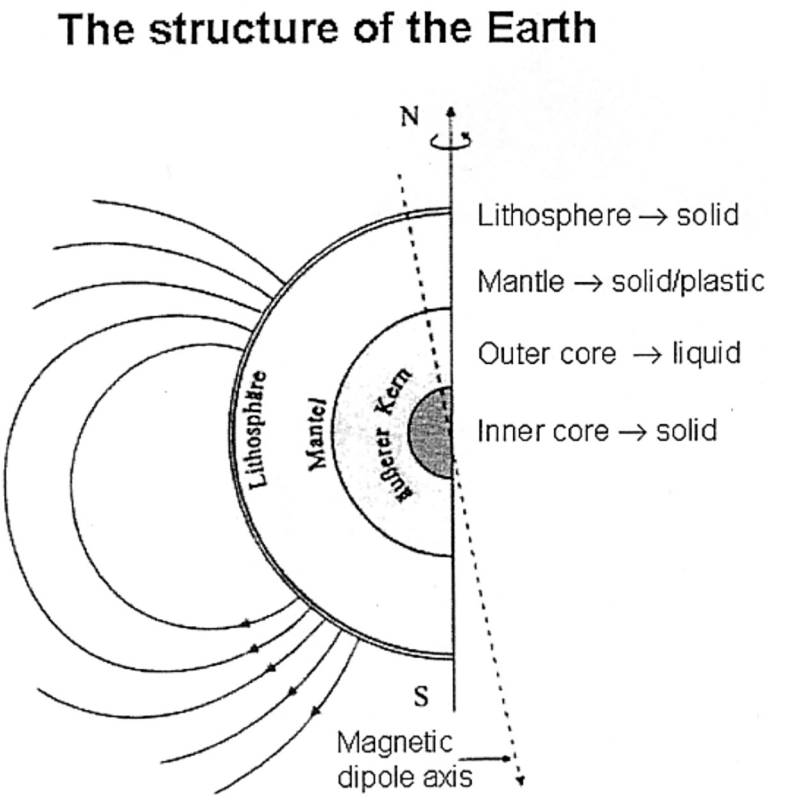


Figure 2. The structure of the Earth.

outer core consisting of liquid iron and the inner core of iron and nickel, where a temperature comparable to the sun's surface (5500°C) is reached (Figure 2).

The outer core consisting of an electric conductor (liquid iron), as the result of convective motions and the Earth's rotation, is the generator of our magnetic field which, on the outside, resembles a dipole field of a bar magnet. Our Earth shares this magnetic property with five other planets (Mercury, Jupiter, Saturn, Uranus and Neptune), whereas Venus and Mars are non-magnetic, although the latter has magnetic crustal anomalies that must have their origin in an ancient magnetic field in the first 500 million years, but which is now extinct.

The surface of the Earth is not static but dynamic, as first suggested by Alfred Wegener in the first quarter of the 20th century, with continents separating from a supercontinent (Pangea) and moving away from each other (Figure 3). His revolutionary theory of continental drift found no general acceptance since he could not identify a physical force responsible for the motion of the continents. His vindication came 30 years after his death in the concept of plate tectonics, with lithospheric plates consisting not only of continents but parts of the ocean floor. Figure 4 shows that about a dozen plates are moving against or away from

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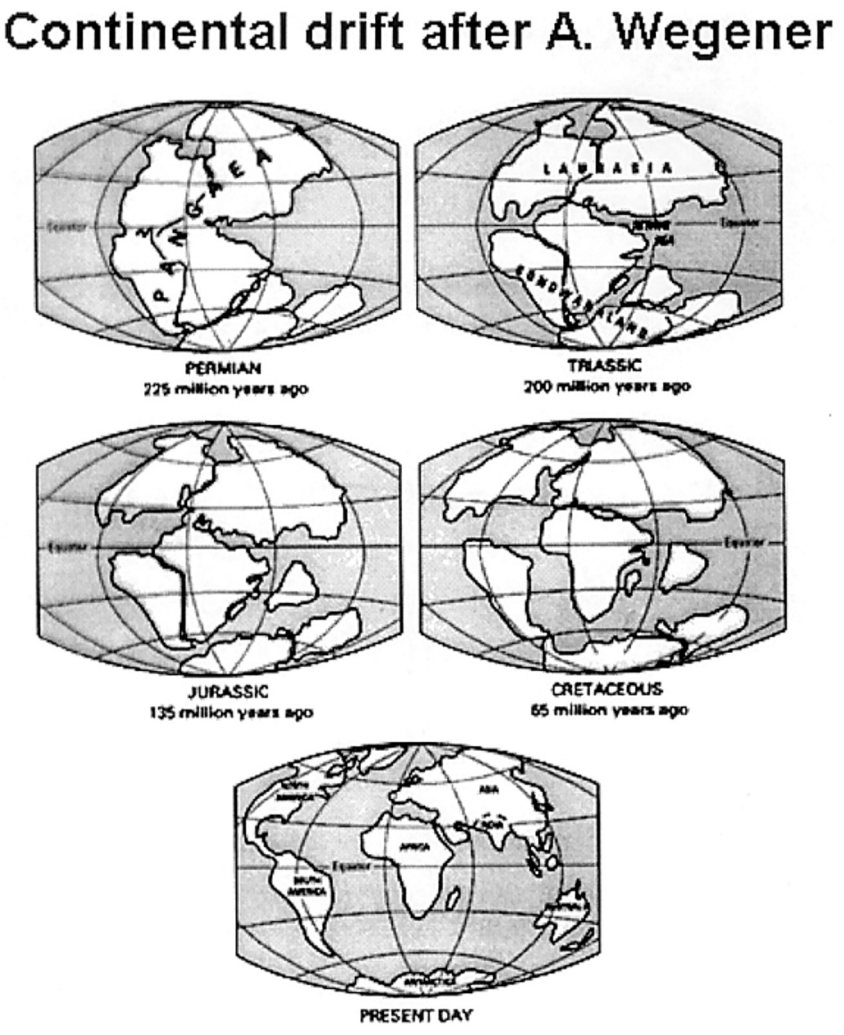


Figure 3. Continental drift, after A. Wegener.

each other, causing at their boundaries volcanism, earthquakes, mountain building and spreading of the ocean floor. The driving force for these plate motions is today understood in terms of 'mantle convection' – requiring a 'wet' planet – with velocities of a few centimetres per year, causing over millennia, large separations of continents.

The geomagnetic field extending from the Earth into space is now known to be confined to the 'magnetosphere' resulting from the interaction of the solar wind (a plasma of protons and electrons – continually emitted from the sun at speeds of about 400 km/s) with the Earth's dipole field. On the sunward side the 'magnetopause', the obstacle to the solar wind lies at about 10 Earth radii, while

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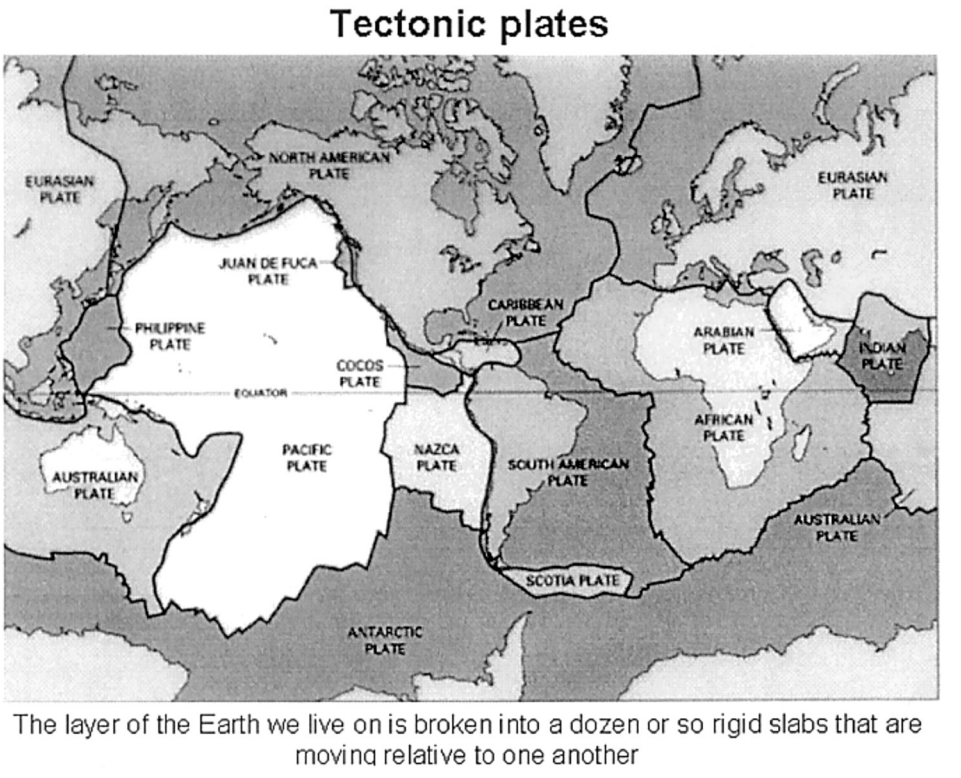


Figure 4. Tectonic plates.

on the nightside a 'magnetic tail' is formed reaching far beyond the orbit of the moon (Figure 5).

Inside the magnetosphere are the trapped energetic particles of the Van Allen belt, which is the result of the interaction of cosmic rays with the atmosphere. Around polar caps the interaction of the solar wind with the geomagnetic field leads to the beautiful auroral displays caused by energetic particles impinging on the atmosphere above 100 km.

Man's impact on our planet

Whereas the face the Earth and its environment were shaped for millennia by natural forces, during the past centuries man's activities have already become noticeable. During the past three centuries, an area corresponding to that of the Australian continent has been deforested, while an area equivalent to the USA and Mexico has been transformed into agricultural land. Next to these changes in land

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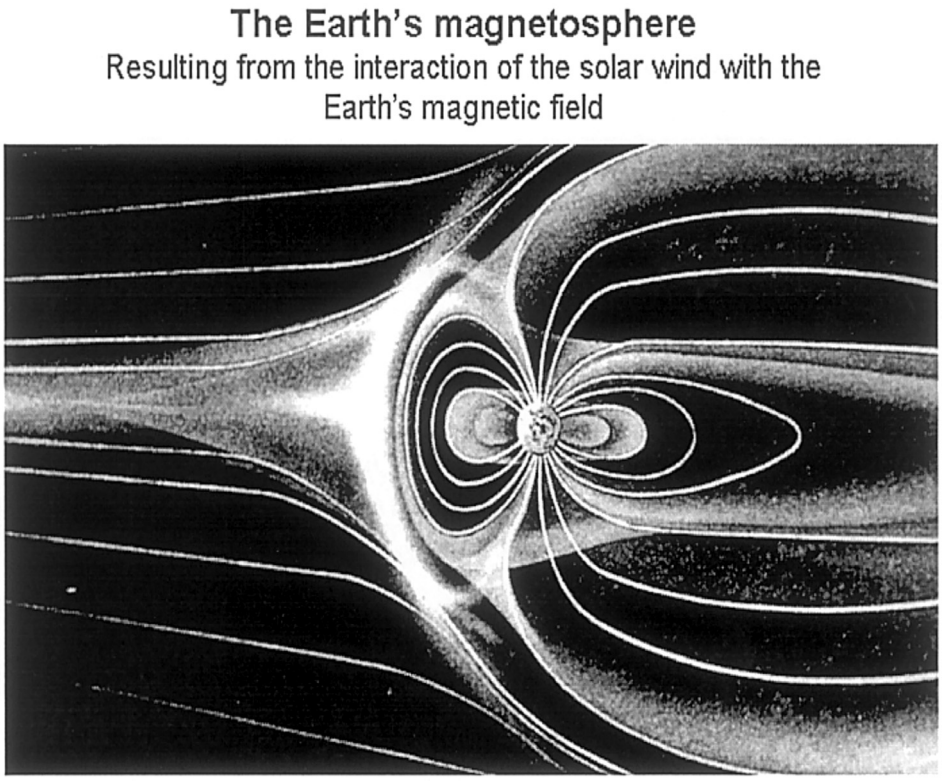


Figure 5. The Earth's magnetosphere, resulting from the interaction of the solar wind with the Earth's magnetic field.

use, man's activities have introduced trace gases into the atmosphere that play an important role in the greenhouse effect and thus in global climate. Whereas the natural greenhouse effect due to the H_2O and CO_2 makes our global temperature of 15°C possible, without it Earth would be an ice house. By the burning of fossil fuels to satisfy our energy consumption, atmospheric CO_2 content has increased by 30% since pre-industrial times, with attendant anthropogenic contributions to global warming. Other anthropogenic trace gases have caused an impact on our protective ozone layer; in particular, chlorine bearing chemicals have led, by catalytic chemical reactions, to a decrease of ozone content whose greatest manifestation is the seasonally appearing 'ozone hole' over the Antarctic, which now seems to be stabilizing because of the prohibition in the use of these substances.

Man's ability to modify his environment has already been demonstrated; it remains for civilized humankind to live up to our species designation, *homo sapiens*, by maintaining our planet as an oasis in space.

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Siegfried Bauer is Emeritus Professor of Meteorology and Geophysics at the University of Graz. Austrian by birth he spent the first part of his career working at the NASA Goddard Space Flight Center in Maryland, USA, but in 1981 he returned to his alma mater, to the chair that Alfred Wegener of Continental Drift fame had occupied. His research has focused on the atmospheres of the bodies in the solar system and their role in the evolution of life. He is a Member of the Academia Europaea, the Austrian Academy of Sciences and the International Academy of Astronautics (Paris).

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