Early Biosphere: Origin and Evolution

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1. Introduction

We argue that the process of the origin and evolution of living organisms is indivisible from the process of the origin and evolution of biosphere, the global planetary system. The most general features of biosphere evolution as a directed process are formulated in the principle of "bio-actualism". It is demonstrated, that this principle, stated for Phanerozoic eon, hold for early biosphere up to the period of biosphere coming into being. To support this thesis we considered an episode of pre-Cambrian history – Vendian phytoplanktonic crisis.

Traditionally, the problem of the origin of life on Earth is the study of how biological life arose from inorganic matter and primary living organisms spread around the planet. Some philosophers and scientists such as Helmholtz and Arrhenius proposed the hypothesis of so-called "panspermia" and place the origin of life outside the Earth somewhere in cosmos. We suggest that such approaches are naive in view of modern progress of life sciences and astrophysics. It is clear that occasional appearance of some living forms (organisms) on any planet doesn't mean they will survive, settle and evolve there. These conceptions ignore the problem of longtime existence and evolution of the earliest forms of life on the Earth. Moreover, they overlook the problem of the origin of the biosphere – unique milieu for early organisms survivorship and reproduction. Therefore we suppose that origin of earthly life and the origin of the biosphere are aspects of a whole indivisible process (Levchenko, 2010, 2011). Hence, we consider the appearance of such conditions on the early planet, which guaranteed the origin and survivorship of organic life. We suppose also that primary organisms should be incorporated in natural geological processes, accelerating them and transforming surroundings in directions favorable for the creation of higher forms of life.

The abiogenesis (or biopoiesis) hypothesis claims that life emerged from non-living matter in early terrestrial conditions. This is the traditional approach to the question of life's origin. Main questions of abiogenesis hypothesis are reduced to an origin of biological membranes via emergence of ionic asymmetry of the cells and chiral asymmetry of biomolecules, and to the problem of the appearance of matrix synthesis and polymer molecules which are able to store hereditary information. Below we will give a brief review of the different hypotheses. In order to find out the regularities of the pre-biosphere development, features of processes of evolution and development for different biological systems were considered and the embryosphere hypothesis (Levchenko, 1993, 2002, 2011) proposed. According to it, the appearance of different sub-systems of primary organisms could happen independently from each other within an united functional system called an embryosphere. This is a system with a self-regulated process of that allows the interchange of substances between its different parts under the influence of external energy flows.

Many difficulties in the explanation of the origin of primary life can be surmounted if we suppose that surface of early Earth contained a large quantity of organic matter, for example, hydrocarbons. This assumption looks very plausible, accounting for the results of investigations of other bodies of Solar system, e.g. Titan (one of the big satellites of Saturn – Niemann et al., 2005). It is very likely also for at least earliest phases of planetary evolution that water and the hydrocarbon complexes (admittedly slightly like by composition to oldest oils) could be present simultaneously in considerable quantities on some planets of small and medium size. Early Earth had apparently appropriate surface temperature, water and some hydrocarbons in the liquid phase. "Water-oil" emulsion could be a fine matrix for the origin and long evolution of the initial forms of life on our planet (Levchenko, 2010). Such emulsion could be an appropriate material for forming of liquid structures of the pre-cell envelops and moreover, it could be a suitable food and chemical energy source for initial forms of life.

The second half of this chapter is devoted to the description of the earliest stages of biosphere development, in particular Riphean and Vendian periods of the history of Earth. Many known regularities of biological evolution already became apparent during these periods. Among these regularities one can note those that describe usual stages of biotic crises. Moreover, the different systemic principles as well as some conditions and mechanisms, necessary for the origin of biosphere and living organisms are also discussed.

2. What is Biosphere? Modern approaches

Though Eduard Seuss had coined the term **biosphere** more than hundred years ago, it is Vladimir Vernadsky's concept of the biosphere, formulated in 1926, that is accepted today (Vernadsky, 1989). Biosphere is a specific envelope of the Earth, comprising totality of all living organisms and that part of planet matter which is in constant material exchange with these organisms. Biosphere includes **geospheres** i.e. lower part of the atmosphere, hydrosphere and upper levels of lithosphere. Virtually, it is a spherical layer 6-12 km thick. In the view of Vernadsky, life is the geological force. Indeed all geological features at Earth's surface are bio-influenced. The planetary influence of living matter becomes more extensive with time. The number and rate of chemical elements transformed and the spectrum of chemical reactions engendered by living matter are increasing, so that more parts of Earth are incorporated into the biosphere. Life, as Vernadsky viewed it, is a cosmic phenomenon which is to be understood by the same universal laws that applied to the physical world. All his life Vernadsky was dreaming about creating the universal biosphere science, comprising not only biogeochemical processes, but also processes, peculiar to **noosphere** (part of planet where biogeochemical processes may depend on human activity).

Biosphere according to Vernadsky is a self-regulating system, including both living and non-living constituents. The work of living matter in the biosphere is manifested in two main forms: (a) chemical (biochemical) and (b) mechanical. Vernadsky made a detailed analysis of different forms of biochemical and mechanical transformations on environment activity of life and realized that there is no force on the face of the Earth more powerful in its results than the totality of living organisms. No phenomena in the biosphere are separated from life and biogeochemical cycles. To analyze these processes Vernadsky introduced the notions of "**living matter**" of the biosphere – the sum of its living organisms, "**inert matter**" – non-living substance and "**bioinert matter**", which is an organic composition of living organisms with not-living substance. The last concept is of special significance in the context of self-modification and indirect interactions in ecosystems. Soil is an example of bioinert matter. Great many living forms permeate soil and organize it. Biological activity of organisms constantly modifies this environment, and thus modifies organisms themselves, forming self-organized and self-modifying system. Vernadsky noticed, that bioinert matter have unusual physical properties. But indeed, soil being an open system demonstrates some properties of living tissue. Soil at the same time is an environment as well as an organic constituent part of the biosphere.

Vernadsky's ideas are very relevant now in the light of progress of the Earth system science and the interest in the role of life in global climate regulation. James Lovelock in his Gaia hypothesis virtually concentrated on this aspect of biosphere's self-regulation (Lovelock, 1988). Gaia hypothesis suggests that not only do organisms affect their environment; they do so in a way that regulates the biosphere's global climate to conditions that are suitable for life. Gaia phenomena include the regulation of local climate by marine algae that influence the formation of clouds over the oceans, global temperature regulation by biotic enhancement of rock weathering, the maintenance of constant marine salinity and nitrogen/phosphorus ratios by the aquatic biota, etc. Lovelock reflected about Earth "**geophysiology**": the temperature, alkalinity, acidity, and reactive gases that are modulated by life. According to his Gaia hypothesis (Lovelock, 1988), with the appearance of life, our planet had got self-regulatory, homeostatic properties, inherent to living biological organism. Particularly, aspects of surface temperature and chemistry are being self-supported at constant, comfortable levels for life forms for more than 3.6 Gya (i.e. billions of years – giga-years ago).

Biosphere or Gaia, which are almost synonyms nowadays, can be represented as a very specific, dynamic, constantly self-modifying, multilevel evolving system, composed of living, inert and bioinert components, which dynamically exchange. Wholeness of this system is provided by the dynamic interrelatedness of all components, participating in metabolic processes, local trophic cycles, local and global biogeochemical cycles. Living biological components fundamentally differ from inert non-living components. The former are active and goal-seeking systems, demonstrating wholeness and relative autonomy. The later are passive, submit to influence and do not demonstrate autonomy and wholeness; their dynamics is controlled by physical forces and activity of biological organisms. But, bioinert matter with high concentration of symbiotically related biological organisms of different taxa, like a vegetable mold demonstrates intermediate properties and that is true for the whole biosphere. Biosphere functioning, which includes processes, proceeding in a small time-scales does not differ in principle from the process of biosphere evolution, noticeable in geological time-scales. Even in the case of microevolution we cannot apply the model of Markov's chain, stochastic process, in which the role of previous history is reduced to the parameters of current state of the system. First of all, this state is unmanageable, because it should also include for example non-coding sequences of genome (e.g. transposons, etc.), which are potential source of innovation. Biosphere functioning as well as its evolution is a creative, developmental process. In the process of biosphere evolution all biotic components participate in the process of constant self-modification, extinction (destruction) and emergence (collective, mutual production). The abiotic components are open systems nevertheless; they are passive participators in biosphere processes and are subjected to biogenic and physical transformations. Biosphere is a dynamic and emergent system, and its components demonstrate "mutual co-construction". The only absolutely autonomous, self-constructive, self-modifying and self-constitutive system on Earth is the whole biosphere. Apart from biosphere as a whole, all biological organisms and super-organismic systems are half-open, semi-autonomous and more or less sustainable components of biosphere.

Though biological systems have some form of autonomy, they urgently depend on each other directly, through trophic and other classical ecological relationships, but also indirectly, via environment. Organisms interact with all components, which also interact with each other, and the nature of this interaction determines the selection pressure which organisms experience. Species populations evolve, it is possible that selection may occur on their environment-altering traits so that traits are favored, which change the global environment in some beneficial way for living organisms. Such reflections stimulate modeling experiments, demonstrating possibility of Gaia effect (Lovelock, 1988). In his work "The Self-Organizing Universe", E. Jantsch (1980) suggested, that Lovelock's "Gaia" is a multilevel autopoiesis, viz., a cyclically organized network of productions (syntheses, transformations, and destructions) of components, that recursively regenerate and support this very complicated network. "**Autopoiesis**", a neologism meaning "self-production" was coined by Chilean neurophysiologists and system theorists H. Maturana and F. Varela (1987) in the seventies of the 20th century. It is the name of a minimal formal model of life (autonomic biological cell), interacting with its environment holistically by adaptive change of structure ("structural coupling") for the sake of conserving the autopoietic organization. Structurally determined reactions on reciprocal perturbations bring about the co-evolution of the system and its environment. Autopoiesis is now accepted as a theoretical basis of contemporary cybernetics (the second – order cybernetics, von Foerster, 1974), sociology, management and robotics. Jantsch subordinated autopoiesis to the notion of specific self-organization, dissipative regenerative systems and virtually ignored phenomenological aspects of the theory. That led him to classify living cells, organisms, populations, ecosystems as autopoietic systems. The philosophy of radical constructivism and phenomenology of included autopoietic observer are excluded from consideration under the assumptions that Jantsch made.

The last two decades were marked by great progress in the development and critical analysis of Gaia theory – geophysiology as well as of the phenomenological aspects of autopoiesis. In the following sections we describe different phases of origin of life and earliest stages of its evolution in context of biosphere development.

3. Traditional approaches to the origin of life

The appearance and expansion of life on Earth is a versatile, very complex and long-term process. At present, there is no complete theory, exact scientific basis of the origin of life. However we can specify several clear-cut requirements for the emergence of life. First, it is accepted, that a double-layer membrane presence is necessary for maintenance of biological processes and thus for life origin (Baross & Hoffman, 1985; Deamer et al., 2002). Such membrane structures could form **phase-isolated system** which is crucial for substance interchange processes (Fox & Dose, 1977; Rutten, 1971). On the other hand the origin of life exactly requires mechanisms of heredity. According to many hypotheses, such mechanisms could arise on molecular basis of RNA, DNA and (or) proteins. The appearance of RNA and DNA is connected with the problem of rise of the nucleotides as well as with the problem of their abiotic polymerization to linear (non-branchy, non-cyclic) molecules. Also it is important to note that any considerations of origin of life have to give explanations of emergence of ionic asymmetry, chiral asymmetry and metabolism – see below section 3.2.

Of course, it is very difficult to cover the whole spectrum of hypotheses concerning of the origin of life; therefore we mention only some of them, which in our opinion, are basic ones. The majority of hypotheses of **abiogenesis** (**or biopoiesis)** concentrates only on specific aspects of life origin and cannot account for the whole picture. On the other hand, many holistic hypotheses which make efforts to describe the whole process are weak in details. As we have already mentioned, in this section we shall restrict our consideration to the hypotheses of chemical and successive biological evolution on Earth. It is worth noting here that biospheric approach leads to additional assumptions for the question of life's origin (section 4).

3.1 Hypothetical phases of the origin of life in the view of traditional approaches

The emergence of life is a process, which can be subdivided into several successive phases: 1) appearance of specific conditions on the Earth (or in space) in which synthesis of complex organic compounds could be possible; 2) formation of compartmentalized structures (membrane structures, liposomes and perhaps others) with half-permeable membrane which was able to selectively absorb and excrete different substances; appearance of the primordial substances interchange; 3) synthesis of chemical polymers (RNA, DNA) with specific properties within these structures; such self-replicable polymers could be relatively stable inside the compartment and they were able to keep the information about features of compartmentalized structures by means of variation of their own structure; 4) development of certain correspondence between features of compartmentalized structures and features of these polymers. Such correspondence is likely to have enhanced the stability of the whole system. Improving of the internal biochemical machinery: emerging of specialized catalysts (proteins); origin of genetic code: their structure came into correspondence with the structure of the polymers.

These stages, as they described above suggests that the transition from complex organic substances to biochemistry progressed like a chain of a successive events. In accordance with this point of view compartmentalized structures were able to be selective in absorption of the monomers and their subsequent polymerization. Nevertheless, there is no reason to reject the possibility of parallel (i.e. relatively simultaneous) realization of some of the stages.

3.2 Candidates for initial matrix. Membrane structures forming. Ionic and chiral asymmetry

There are several hypotheses concerning a problem of initial matrix or abiotic synthesis of the primordial informational polymer (most likely it was an RNA molecule – see Gilbert, 1986; Joyce & Orgel, 1993). Primordial informational polymer should be able to self-replicate (otherwise it cannot persist for a long time). Self-replicating, in its turn is based on two properties: preserving information about its own structure and catalytic activity, targeted on the same set of monomers. DNA, protein and RNA, in this respect, are the unique molecules. It was revealed for several small RNA that they are able to catalyze certain reactions of protein matrix synthesis (Cech, 1986). Because of their enzymatic activity they are called **rybozymes**. At present time, many scientists assume that RNA predated the appearance of DNA and proteins: the "RNA-World" hypothesis (Gilbert, 1986). In order to explain emergence of DNA and proteins many hypotheses invoke the idea of functional specialization: DNA has emerged as a special structure to secure storage of information, while proteins have specialized on just enzymatic functions.

A film of hydrocarbons mixture, which was apparently present on the early Earth, may have been a basis for membrane structures formation. Polyaromatic hydrocarbons are the probable candidates as templates for matrix synthesis of RNA. Hydrocarbons are reliable templates for RNA synthesis especially because they are widespread in the Universe and particularly, in the Solar System (section 5). "PAH World" (where PAH means polyaromatic hydrocarbons) is a novel chemical structural model for the formation of prebiotic informational oligomeric material, which could provide for the rise of the "RNA-world", now widely accepted (Platts, 2005). Under assumptions of this model, the primary binding of nucleotides may have been realized by virtue of photochemical and/or geohydrothermal derivations at the edges of PAH complexes (Platts, 2005).

RNA may have been synthesized using some clay minerals (for example, montmorillonite) as template (Ferris & Ertem, 1992; Cairns-Smith, 2005). The authors pay attention to some properties of clay minerals such as: (i) a significant diversity of surface structures which make them potentially storages of information ("crystal genes") and (ii) positive electric charge on the surface of some of these minerals (which in turn could facilitate interaction with RNA or RNA-like molecules carrying negative charge). Therefore the so called "genetic takeover" by RNA could arise on the basis of a primitive crystal gene which was functionally substituted and gradually displaced by it (Cairns-Smith, 2005). Another hypothesis suggests that ferro-sulphuric minerals, notably greigite (Fe_3S_4), due to its magnetic properties could be appropriate informational matrix for the first biological systems (Mitra-Delmotte & Mitra, 2010). There are also some extravagant hypotheses, concerning the origin of primary RNA and (or) DNA in cosmos, e.g. in cores of some comets. For example, Kaimakov (1977) proposed a mechanism of such synthesis which is based on particularities of sublimation of the water ice with solved nucleotides in vacuum.

Concerning of life origin Oparin (1966) wrote about hypothetical "coacervates" which have gel envelops, consisted of proteins and a gelatinous medium; mechanisms for the origin of lipid double-layer membranes, as found in real cells, have also been proposed later (Bangham, 1981; Fox & Dose, 1977; Rutten, 1971). Is it possible that membrane structures (we recognize this term following Bangham, 1981) have arisen independently from RNA and/or simultaneously with RNA (or RNA-protein complexes)? There are several simple physical mechanisms through which it could occur: 1) disturbance of hydrophobic films on the water surface due to the wave action (e.g. Goldarce, 1958; Rutten, 1971); 2) spontaneous self-assembling from dispersion in aqueous phase; what is more, this process may progress in an autocatalytic manner (Luisi et al., 1999; Monnard & Deamer, 2002); 3) forming from marine aerosols; the aerosols could be formed, for example, when gas bubbles from entrails of Earth reach the water surface, covered with an hydrophobic film (Dobson et al., 2000; Yakovenko & Tverdislov, 2003).

The first membranes may have consisted more simple hydrophobic substances than modern membranes which contain predominantly phospholipids (Deamer et al., 2002); it is important because in the absence of specialized transport proteins permeability of the membranes is too low. The primordial membrane vesicles may consist of fatty acids (Chen & Walde, 2010; Deamer et al., 2002). It is interesting that such clay mineral as montmorillonite (a candidate for initial matrix for RNA synthesis – see above) is able to accelerate the spontaneous conversion of fatty acid micelles into vesicles (Ferris & Ertem, 1992; Hanczyc et al., 2003). It is not clear whether clay minerals were responsible for forming membrane structures or if they emerged in aqueous medium? All in all, it seems that this process was likely to have occurred in the boundary between different phases (Chaykovsky, 2003; Fox & Dose, 1977; Rutten, 1971). In case of mineral-dependent mechanism it could be solid-aqueous phase whereas wave- and aerosol-dependent mechanism may apply to aqueous-gaseous phases. Ancient shallow-water hydrothermal vents might be a source both of gases and minerals; hence this source was likely to have provided for the generation of membrane structures on the early Earth.

Also, there are several hypotheses concerning the rise of ionic asymmetry between external environment and internal space of primary membrane vesicles. It is known that modern cells are able to maintain significantly bigger concentrations of potassium and calcium in their interior compared to the concentrations of these ions in the environment. For sodium and magnesium we can see an inverse pattern – in contrast to a cell, concentration of these ions are often relatively high in environment (for example, intercellular liquid of higher animals where ionic content resembles sea water). This asymmetry is important for biochemical processes in living cells; hence, conceptions of origin of life should account for this (Natochin, 2010). Membranes have the potential to maintain concentration gradients of ions, creating in that way a source of energy that is necessary to support transport processes across the membrane boundary and drive them (Deamer et al., 2002). Intensive water evaporation may provide concentration of prebiotic substances in primordial "dilute soup" (Monnard & Deamer, 2002). It was revealed, that the cooling of surface of water by means of evaporation can lead to ionic thermo-diffusion and provide increasing of concentration of calcium and potassium ions near to the surface of oceanic water. It is widely regarded that ions such as Na, K, Ca and Mg play very important roles in the energy processes of a cell. However, divalent cations have well expressed tendency to bind to the anionic head groups of amphiphilic (i.e. which have hydrophilic and hydrophobic parts) molecules, strongly inhibiting their ability to form stable membranes that can prevent self-assembly (Monnard et al., 2002). Nevertheless the vesicles could be formed as a film-coated microspray which forms when gas bubbles reach water surface covered with amphiphilic film and burst. If such single-layered microspray fall on the same amphiphilic film it may be covered with second ampiphilic layer due to hydrophobic interactions between molecules. This may lead to formation of a double-layer membrane structures with relatively rich interior with calcium and potassium as have been shown in experiments (Yakovenko & Tverdislov, 2003).

There is also another kind of asymmetry which should be considered in the context of the origin of life. As was discovered by Louis Pasteur in 1848 there are two types of molecules:

L-molecules (rotate polarized light leftwards) and D-molecules (rotate polarized light rightwards). At present time it is well-documented evidence that all living organisms include only L-amino acids in their proteins and only D-sugars in their nucleic acids. This chiral asymmetry of life (on the contrary a mixture of L- and D-isomers in equal quantities exist in the abiotic environment and have no optical activity on polarized light). Several mechanisms for emergence of such kind of asymmetry have been proposed based on experimental data. At first it was experimentally revealed that intensive evaporation of solution of both L- and D-amino acids leads to increasing of L-forms near the water surface (Yakovenko & Tverdislov, 2003). Therefore authors assume that existing fractioning of amino acids could be established by virtue of natural factors. Complex prebiotic chemical systems could emerge in conditions where L-forms of amino acids prevail over D-forms. Subsequently, "fixation" of L-amino acids in primary proteins could have arisen. However this hypothesis doesn't explain how RNA could be predated to proteins ("RNA-World" hypothesis – see above and Gilbert, 1986).

Another hypothesis claims that amino acid homochirality could be created by homochirality of RNA which in turn was inherited from mineral matrix structure (Bailey, 1998). Such considerations seem to be plausible although symmetry breaking processes have also been observed along crystallization (Viedma, 2001). There are a number of hypotheses on the problem of chiral asymmetry of life but we cannot describe all of them here. At the present time this question remains unsolved.

3.3 "Metabolism first" or "Replication first"?

We agree that the question of the origin of life is the question of the origin of the matrix synthesis (Chaykovsky, 2003; Gilbert, 1986; Kenyon & Steinman, 1969; Yakovenko & Tverdislov, 2003), and this is one of the central problems in the origin of life. However the question arises: what appeared first – "metabolism" (substances interchange) or replication? "Metabolism first" hypotheses try to offer plausible mechanisms on how membrane structures emerged or how prebiotic catalytic cycles evolved, whereas "replication first" hypotheses are focused mainly on formation of molecular replicating mechanisms (Mulkidjanian & Galperin, 2009). Obviously such division of hypotheses is rather conditional and depends on definitions of metabolism. Note, that "metabolism-first" hypotheses also could be subdivided in two classes: those which propose an existence of compartmentalized structures as a necessary condition for "metabolism" and those which consider primary "metabolism" as catalytic chemical cycles in surroundings. However such considerations seem to ignore the fact that metabolism is the property of living organisms only. If we define metabolism as selective chemical substances interchange between prebiotic system and its environment (like in the case of Oparin's coacervates) then we have to assume that compartmentalized structure predates "metabolism".

For "replication first" hypothesis appearance of membrane structure to allow for self--replicating RNA (or hypothetical RNA-like molecules) seems necessary. For example "Zinc World" hypothesis, where zinc sulfide (ZnS) is described as catalyst, considers some "standard" sequence of events: RNA → proteins → membranes (Mulkidjanian & Galperin 2009). In contrast Egel (2009) supposes that hydrophobic peptides could form primordial protein-dominated membranes before replicating RNA appear. In this case the sequence of events is: membranes + proteins → RNA.

"Metabolism first" and "replication first" hypotheses often resemble the well-known "egg--or-chicken" paradox. However there is no reason to oppose them to each other. The possibility of relatively independent emergences of membrane structures and matrix (apparently RNA) molecules should be considered: emergence of membrane structures and appearance of matrix synthesis could be parallel.

3.4 The deficiencies of traditional approaches

Most of the theoretical approaches to the problem of appearance of life in our planet include some abiotic mechanisms for the origin of primary organisms. In order to explain these mechanisms different chemical and (or) physical processes are being described. There are, for example, suggestions about the origin of the cell membrane, hypothesis concerning coacervates or other secluded structures, assumptions concerning mechanisms of genetic memory, energy processes etc (Fox & Dose, 1977; Kenyon & Steinman, 1969; Oparin, 1966; Ponnamperuma, 1972; Rutten, 1971). All of them consider various hypothetical ways for abiotic creation of different systems of organisms. The first principal defect of all these theoretical constructions is that the biosphere is described as some mechanical sum of all organisms but not as a united functional system which provides suitable conditions for the existence of its own components. These hypotheses are interesting because they sometimes use very exotic mechanisms to explain the origin of life. But all of them have several unavoidable defects because they usually require assumptions that are quite unlikely: 1) very peculiar conditions in localities where the life could arise and, thus, very low probability of origin of initial organisms; 2) very peculiar but relatively stable conditions for development of primary life; 3) very long period (at least 1 Gya) when such conditions have to exist. Moreover, it is not clear; 4) what is the food which was consumed by primary organisms during the period when initial life evolved; and 5) how the appearance of several trophic levels in primary biosphere could be explained.

4. The biosphere approach and the origin of life

There is also another point of view concerning the origin of the life and its evolution on Earth. It is based on the assumption that all living organisms on the planet depend on one another i.e. any life outside biosphere is impossible (Capra, 1995; Lovelock, 1991; Ludwig von Bertalanffy, 1962; Maturana & Varela, 1980; Vernadsky, 1989). In this view, the biosphere (or – in western tradition – Gaia) is considered a separate system of the highest structural level of life-organization. This system controls and directs evolution of living organisms and earthly ecosystems. Such assertion is named the **pan-biospheric** paradigm (Starobogatov & Levchenko, 1993; Levchenko, 2011). The problems of both biological evolution as well as the origin of life can be described within the framework of this paradigm. The above assumption leads us to several conclusions. Firstly, biological evolution has to be described in the context of the ecosystems evolution. This is named the **ecocentric** conception of evolution; according to it, the relationships between evolutionary processes on different levels of biological organization are inter-coordinated. In other words, the evolution on the species level and above (genus, familia, etc) can't take place without evolutionary changes of corresponding ecosystems and the biosphere. Some morphological variations can be restricted by necessity of preserving geochemical functions (Vernadsky, 1989). Known exceptions of micro-evolutionary processes are connected usually with neutral (ecologically-neutral) drift (Eigen, 1971). Only the biosphere is a relatively independent “whole” and live system, although it is, of course, dependent on geological and cosmic processes, in particular, in the interplanetary medium (Levchenko, 1997, 2002, 2011).

Secondly, to explain the development of the pre-biosphere environment, the **embryosphere hypothesis** – (see below and Levchenko, 1993, 2011) is proposed. According to it the appearance of different sub-systems of primary organisms could happen independently from each other (see above) within a unified functional system – the embryosphere. This is a system with self-regulated processes of interchange of substances between its different parts under the influence of external energy flows. Embryosphere isn’t another name for any hypothetic pre-biospheres, because it has some functional properties of living systems. There are various regularities in its appearance and existence in the past, and analogies between these regularities and processes of evolution and development could be described.

4.1 Hypothesis of embryosphere

Vladimir Levchenko (1993) identified several evolutionary principles that can be applied to organisms, ecosystems and the biosphere. In particular, there are: 1) principle of evolution of functions; it can be formulated as the intensification of processes providing important functions of the biosystem (e.g. organisms) during evolution; 2) principle of increasing of multi-functionality of separate sub-systems of organisms or ecosystems during evolution; 3) principle of superstructure (or over-basis): new functions do not replace previous ones but they subordinate old functions and are "superimposed" on them (see in detail Orbeli, 1979). These principles can be applied to the development of embryos as well. Comparing all these features of evolution and development, one can argue that the pre-biosphere is a system, which is self-preserved, and which is similar to primitive organism without generative organs. In other words, the pre-biosphere in this view is weakly differentiated system, which develops as embryo by means of successive differentiations. The pre-biosphere with above particularities was named by us **embryosphere** (Levchenko, 1993, 2002). Consecutive differentiation leads to complication of the embryosphere. Known in paleontology microfossils could be non-independent separate primary organisms but they are similar functionally to cell organelles. The embryosphere hypothesis is based also on the following assumptions: 1) the interchange of substances between the embryosphere parts occurs under influence of external energy flows; 2) embryosphere is a unified system with a closed circulation of substances; 3) the origin of different vital (prebiotic) processes could happen independently in different parts and regions of the embryosphere; 4) embryosphere is the system which is self-preserved and self-instructed (Eigen, 1971); in particular, this means, the system is able to switch between some branches of processes depending on external conditions in order to maintain important vital functions. Sustainability is one of the main requirement for existence of the primordial community, so the evolutionary process should not disturb this sustainability in any case (Zavarzin, 1993). In other words, the embryosphere is able to adapt its interactions with surroundings in order to survive.

This approach, which explains the origin of living organisms within embryosphere by means of successive coordinated differentiations, implies that the Earth had initially sufficient quantity of mobile substances (liquids, gases) for embryosphere functioning. The organic substances must have also been sufficient in order that primary life could evolve a long time, at least, hundreds of millions of years or more. The biosphere approach implies the existence of "biosphere memory". It is being reflected factually as irreversible results of previous evolutionary changes. At first, they create different evolutionary constraints at the organism level, for example, morphogenetic ones. Later, changes in biosphere surroundings modify factors which control directions of global evolutionary process (in other words, canalize it). The idea of auto- or self-regulation or even auto-canalization of the life evolution is important at this juncture (Chaykovsky, 2003; Levchenko, 1997; Levchenko & Starobogatov, 1994; Zherikhin, 1987) and it conforms to the general systems theory of Ludwig von Bertalanffy (1962) and approach of Lovelock (1991) as well as Capra (1995). One more else known fact about the biosphere evolution concerns the growth of the energy flow, which is used by the biosphere, during its evolution (Levchenko, 1999, 2002, 2011). We assume this regularity is fulfilled for the earliest biosphere and embryosphere too.

4.2 Bio-actualism principle

In our earlier works (Levchenko, 1999, 2002, 2011; Levchenko & Starobogatov, 1994; Starobogatov & Levchenko, 1993) we discussed some regularities which characterize different stages of biospheric evolution: 1) gradual expansion of the life to new, before lifeless conditions and areas; 2) complication of the structure of the biosphere, the appearance of new circulations and ecosystems; as regular consequence of that – the gradual increasing of biodiversity up to some optimal level for the current conditions; 3) gradual (although sometimes irregular) inclusion of more and more matter of the planet into the living processes of the biosphere; 4) gradual increasing of energy flow through the biosphere during its evolution; 5) relative steadiness of all circulations of the biosphere; the disturbance of balance between circulations leads to a biospheric crisis; 6) auto-regulation (auto-canalization) of the biosphere evolution: every evolutionary step leads to the creation of new specific conditions on the planet which constrain the availability of directions for the subsequent steps. Moreover, trends known in evolutionary physiology and used in the formulation of embryosphere hypothesis could also be taken into consideration (see above). At last, we have not to forget the Darwinian principles of mutability, competition and natural selection, which promote the raising of the most optimal variants during evolution (Levchenko, 2010, 2011; Levchenko & Kotolupov, 2010). For historical reasons these principles have been discussed for organisms but they can as valid for ecosystems and even for non-living components of nature.

We assume that all these regularities and principles can be applied not only for the last stages of the biosphere evolution but for all ones including most ancient stages and also for the case of the embryoshere. Using an analogy in geology, i.e. the **actualism principle**, proposed by Charles Lyell in 1830, we propose a **bio-actualism principle**. Of course, it is a subset of the more general actualism principle but we would like to emphasize here just the biological aspects of planetary changes. Sections 7 of this is devoted to the earliest known crises of the biosphere on the border between the Riphean and Vendian periods; the description of this exceptional event is given in a bio-actualism context.

4.3 The origin of primary organisms in the biosphere approach

When we talk about life we mean firstly living organisms (although ecosystems and biosphere are living ones too). The problem of the origin of primary organisms within a biospheric framework proceeds through the following phases (Levchenko, 2002): **1**) mixing, and the increasing complexity of the chemical components and structures (membranes including lipid membranes) of different parts of the embryosphere and **2**) self-organization of self-sustained reactions, which are preserving these structures (we suppose they are so called **cooperons** – Levchenko, 2011; Levchenko & Kotolupov, 2010). **3**) the successive structural and functional differentiation of the embryosphere and **4)** the appearance and using of the mechanisms of molecular memory (on the basis of RNA and DNA) to provide self-preserving functioning; perhaps as a consequence of natural selection of some functional modules among multitude of different self-sustained structures (Eigen, 1971; Kenyon & Steinman, 1969).

What could be the embryosphere system in this point of view? How could the life arise in the Solar system just in our planet? In order to come near to the answers to these questions, one can consider the conditions in some other planets of the Solar system.

5. Hydrocarbons in cosmos and in small planets of the Solar system

Astrophysical observations have revealed the presence of organic matter as well as carbonaceous compounds in the gas and solid state, refractory and icy, and ubiquitous in our and distant galaxies (Ehrenfreund & Cami, 2010). Complex **polyaromatic hydrocarbons** (**PAHs**) in the mid-infrared spectra were detected in two infrared galaxies (Yan et al., 2005). According to mathematical models, abiotic synthesis could occur simultaneously with the formation of protoplanet bodies in early stage of evolution of the Solar System from Nebula (Snytnikov, 2006).

Explanation of the origin of primary life can be made much easier if the presence of a large quantity of hydrocarbons at the Earth's surface is assumed. This assumption isn't too fantastic or improbable based on the results of different investigations of other bodies of the Solar system. For example the thermodynamical calculations demonstrate that abiotic synthesis of PAHs through the Fischer-Tropsch reaction and quenching of $CO + H_2$ was possible on the ancient Mars (Zolotov & Shock, 1999). PAHs were detected in the martian meteorite ALH 84001 in 1996 (McKay et al., 1996; Becker et al., 1999), although some scientists (Stephan et al., 2003) argue for their terrestrial origins.

Many satellites of the biggest bodies in the Solar systems (Jupiter and Saturn) have much hydrocarbons on their surfaces and atmospheres (Woolfson, 2000). In particular, Titan – the satellite of Saturn - has even oceans and seas of liquid hydrocarbon – methane. There are other, high-molecular hydrocarbons which are dissolved in these seas. The diameter of Titan is about 5150 Km; it is more than the diameter of Mercury (about 4880 Km) and less than in the case of Mars (about 6800 Km). The investigations of Cassini orbiter in 2005 have demonstrated, that Titan has dense atmosphere (pressure could amount to 1.6 Kg/cm^2), which consists of nitrogen mainly (more than 95%), methane, other gaseous hydrocarbons and ammonia. The temperature of the planet is quite low: it is approximately minus 160 degrees by Celsius. Therefore, the water on Titan (its quantity is also large) is only in "stone" solid form (Woolfson, 2000). The seas in the planet consist of liquid methane mainly, the color of the sky is yellow-orange. You can find beautiful reconstructions of Titan landscape made on the basis of the Cassini mission data (see one of such reconstructions by M. Zawistowski (Canada) on http://www.astrogalaxy.ru/271.html).

Is it possible that water and hydrocarbons are present simultaneously in considerable quantities on other, smaller planets, which are alike Earth? It is quite probable for at least the earliest stages of planetary evolution in the case of planets of Earth's group and satellites of big planets. This point of view isn't contrary to planetology (Kenyon & Steinman, 1969; Rauchfuss, 2008; Woolfson, 2000). Moreover, we know one contemporary planet of the Solar system with oceans and seas of liquid water on its surface. This is, of course, Earth, which has appropriate temperature of its surface for that. As water and hydrocarbons can be found on ancient planets together, then the evident question arises: could liquid water and liquid medley of hydrocarbons exist on the Earth surface somewhere jointly? If to remember that fossilized Precambrian and even Archean oils (the origin of which are not explained obviously by biological processes) are present in Earth then one can suppose the ancient Earth had on its surface somewhere medleys or emulsions of some liquid hydrocarbons (which dissolved into more heavy ones, probably PAHs) and water. The temperature of ancient Earth was apparently suitable in order for some of hydrocarbons (or ancient oils) to exist in liquid form. In these conditions hydrocarbons are insoluble in water and their thickness small, so the hydrocarbons films ("oil" films) on the surface of ancient seas seem quite possible. Furthermore, during evolution ancient hydrocarbons have decomposed and much carbon exists in other forms on the Earth's surface today – mainly as living substance.

If so, then water-"oil" emulsion could be fine surroundings for the origin and long evolution of the initial forms of life on our planet. Such emulsion could create liquid secluded structures (Fox & Dose, 1977; Kenyon & Steinman, 1969; Rutten, 1971) and, moreover, it could be suitable source of organic matter and chemical energy (i.e., food) for initial forms of life (Levchenko, 2010).

6. The joint origin of the biosphere and life on the Earth

All modern biological membranes consist mainly of phospholipids. However protocells may have been self-assembled from components which are different from normal ones in biochemistry of modern organisms (Ehrenfreund et al., 2006). Taking into consideration that organic substances such as hydrocarbons are widespread in space they could be convenient raw materials for membrane structures. Amphiphilic molecule has an electric charge in certain domain (so called hydrophilic domain) whereas other part of the molecule have no electric charge. Therefore such molecules can form a film with directional characteristics on the water surface.

We already have noted evidence that fatty acids could form membranes (section 3.2). One can consider fatty acids as probable derivatives of hydrocarbons. Then amphiphilic film (hydrocarbons with fatty acids) on the water surface can hypothetically play a role as a starting point for the origin of membrane structures (Rutten, 1971; Yakovenko & Tverdislov, 2003). Assemblies based on aromatic hydrocarbons may be the most abundant flexible and stable organic materials on the ancient Earth and some scientists discuss their possible integration into minimal life forms (Ehrenfreund et al., 2006). It is interesting to note that polyaromatic hydrocarbons, substantial quantities of which were detected in space, are not the most complicated compounds. According to data from recent observations there are also buckyballs (or fullerenes) C_{60} found in cosmic space, they comprise up to 0.1-0.6 % of carbon in the interstellar medium (Sellgren, et al., 2010). It seems that the Universe is plentiful of complex carbonaceous organic compounds, and chemical evolution of different complex substances is real cosmic phenomenon. So we can make a conclusion that hydrocarbon molecules could play a crucial role in the abiotic evolution of organic matter in space and on Earth, that in turn have provided origin of life on our planet.

One of the hypotheses concerning physical mechanisms of origin of pre-biological structures was proposed by L.V.Yakovenko and V.A.Tverdislov (2003). It describes the formation of marine aerosols with simple one-layer membrane; these aerosols are enriched by potassium and calcium. Moreover, it can explain the rise of the ionic asymmetry between external environment and internal space of pre-biological structure (section 3.2). Let's try to develop this hypothesis using our approaches presented in this chapter. We argue that liquid water and a film of liquid hydrocarbons on its surface create appropriate conditions for abiotic emergence of the asymmetric conditions that characterize the membranes. For this to happen the following conditions have to be met: 1) presence of large quantities of water (with dissolved inorganic and organic substances) and substantial quantities of hydrocarbons on the planet surface; 2) relatively stable surface temperatures, which allow for both water and hydrocarbons to exist in a liquid state (at that, hydrocarbons form a dispersed film on the water surface); 3) intensive water evaporation and, as consequence, appearance of considerable thermal gradient nearby the surface (this leads to higher concentration there of more massive ions Ca and K in contrast to Mg and Na ones; 4) the presence of sources of gas bubbles. They may appear as result of water choppiness or can be produced in shallow-water hydrothermal fissures. When gas bubbles come out on the water surface with the hydrocarbons film, they could originate specific microsprays which are secluded aerosol structures with simple membrane.

Such aerosols could be snatched by wind and raised in high parts of atmosphere where they could remain up to 2 years. They have higher internal concentration of potassium and calcium compared to sea water (see point 3). When such aerosols come back to natural water reservoirs without vigorous hydrocarbon film on the surface, aerosols could begin to be appropriate candidates to the role of pre-biological structures because they have secluded structure, both a membrane and high internal concentration of K and Ca ions. Taking into consideration that hydrocarbons are good solvents of many lipids and in particular phospholipids, it is not difficult to suggest that hydrocarbon membranes can concentrate lipids as well as other amphiphilic molecules from environment into their own composition. Of course, such chemical evolution is possible before and after aerosol stage(s). When concentration of amphiphilic molecules amount to some critical value, it can promote the appearance of aerosols with double-layer membranes (section 3.2 and Fox & Dose, 1977; Rutten, 1971). That is quite important in the context of the origin of life because all modern cells have phospholipid double-layer membranes.

In summary one can come to the following statements about the joint origins of the biosphere and life on the Earth:

1. The origin of the embryosphere was a necessary phase in the origin of the biosphere as well as life. In our opinion the conception of the biosphere has to be included to any definition of contemporary life. These statements are a conclusion of the pan-biospheric paradigm (see above) concerning of that any biological organism cannot exist outside the surroundings of the biosphere or embryosphere. This approach

conflicts with so called panspermic hypothesis of Arrenius (Ponnamperuma, 1972) because it supposes that the early lifeless Earth may be appropriate in order that "cosmic sperm" can settle down there. We don't disclaim entirely the panspermic hypothesis but suggest there are serious limitations for the environment where this hypothesis may be applicable.

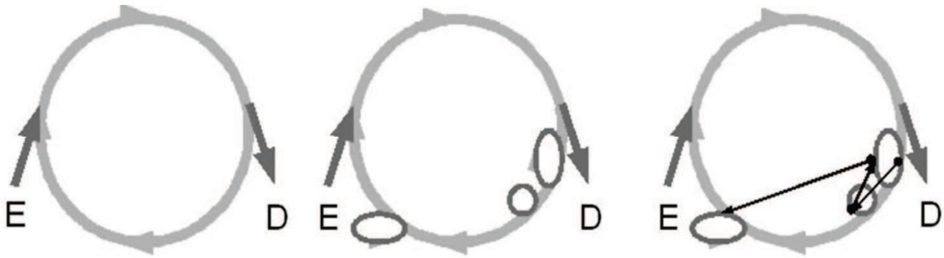

Fig. 1. Stages of evolution of embryosphere. On the left: the simplest natural circulation: the external energy (E) creates a circulation of substances and then is being dissipated as thermal energy (D). In the middle: the appearance of the micro-circulation events on the energy gradients of main circulation; this is possible when the micro-circulation processes accelerate some parts of main circulation. On the right: the appearance of immediate interactions (for example, by way of chemical catalysis) between different cycles of micro-circulations; the development of the controlling net of embryosphere.

2. The embryoshere hypothesis tries to explain how conditions, which are necessary for life, could be created without the contribution of life during early stages of the Earth's history. We argue that the origin of the embryosphere was connected with organization and evolution of the autocatalytic circulations of substances in early planet (in particular, in pristine "bouillon") under influence of external energy. The large-scale circulations can contain "micro-circulations"; moreover, some micro-circulations can use sometimes factors from other circulations. The competition for resources between different circulations results in the emergence of some of them that are able to be self-preserved. This tendency is conjugate with the organization of complicated nets of autocatalytic reactions. In cybernetic context these nets are the controlling mechanisms which provide the existence of the embryosphere – see Fig. 1.
3. The self-preserving embryosphere is connected with the development of the system of compensative, adaptive reactions in response to conditions of changes; different branches of the circulation processes are being switched on when surroundings vary. The mechanism can probably be the same as described for the physical evolution of the biosphere: when external "interruptions" of energy flow weaken some of existing processes, new compensative processes are originated (Levchenko, 2002). One can describe that in the terminology for mechanisms of auto-canalization and self--instruction (Eigen, 1971) for the chemical evolution of the planet (Fox & Dose, 1977; Kenyon & Steinman, 1969; Rutten, 1971). Self-instruction mechanism implies anticipatory behavior of the system (Rosen, 1991); in fact this is the possibility to change features of functioning using current internal instructions.
4. Every circulation, which is being self-preserved, supports its own dynamic structure (so called "cooperon" – see Levchenko, 2011; Levchenko & Kotolupov, 2010). New

circulations, which arise during evolution of the embryosphere, create new dynamic structures. These processes lead to gradual formation of such relatively stable environment on the planet, which is more suitable for the origin of pre-life and life. If the energy flow through embryosphere grows along time then preconditions of origin of different trophic levels of embryosphere appear.

5. The origin of primary organisms, within a framework of this biospheric conception, was a result of several continuous events and evolutionary processes described above in sections 3 and 4. Developed embryosphere sustains necessary conditions for that, the pre-biological processes promote the development of embryosphere.

Many of the self-supporting processes in biological cells of today (for example, the processes of energy transformation based on ADP <–> ATP transmutation cycles) could arise in some fragments of the embryosphere before the origin of independent organisms. In other words, some important processes in modern organisms may in general traits repeat ancient processes in embryosphere. The water-"oil" emulsion which very probably existed in large quantities on the surface of early Earth, was a suitable environment for the development of different physical and chemical processes in the embryosphere and later – in primitive biosphere. When hydrocarbons on the surface of the planet were largely exhausted, then life found the mechanism of photosynthesis (Levchenko, 2010, 2011).

7. The development of early biosphere. The biospheric crisis on the border between Riphean and Vendian

After the appearance of living organisms (apparently at the beginning of Archean (3.5 – 4 Gya), the further development of the biosphere (at the beginning, populated only by bacterial forms of life) was proceeding along directions which increased complexity of communities structure, appearance of new connections of trophic chains, and at the same time, changes of living surroundings as well as appearance of new habitats. After the long period of high volcanic activity, which ended approximately 1350 Mya (i.e. millions of years mega-years ago), the beginning of Proterozoic upper division – Riphean - of rather stable conditions were set on the planet. Variations in the changes in parameters narrowed in comparison to earlier times. It could mean the establishment or a strengthening of the role of either self-regulating mechanisms in biosphere or an ecosystem of higher complexity. These mechanisms "control" the processes occurring in a geospheres within some framework. The most dynamic and changing part of biosphere – living organisms – probably played an important role in such processes. In order to understand a role of biological communities in the history of Earth we have to remember that majority of global planetary processes are involved in different circulations. The changes of them lead to global modification of planetary conditions. The role of life is very important for biospheric circulations, and now there is considerable interlacing of biological and geological ones; hence, organisms are indeed a geological force (Vernadsky, 1989). As we have already noted above, biological (or, in early stages of the planet history, pre-biological) circulations could carry out a role of micro-circulation, which superimposed on natural abiotic circulations (Levchenko, 2010). This micro-circulations use available energy sources of surroundings.

Let's imagine the following model: surroundings, in which some cycles of exchange by substances and energy flows exist, favor the existence of a particular biological community.

When circulation in the system "biological community-environment" is being settled in some equilibrium state then biota is using all available energy resources, and it doesn't produce any superfluous production. Such system can exist factually eternally. But sometimes (due to changes in the external condition, availability of resources or due to modifications in biota) this balance can be disturbed that results in the community becomes unable to support the current level of circulation. The weakening of circulation provokes further disintegration and, finally can lead to a collapse of the system. Good examples of such sequences of events with positive feed-back can be found in a description of the cretaceous crisis (Zherikhin, 1978). Of course, any crisis events have important role in various biospheric and biocoenosis changes. We shall discuss briefly below the first known global biospheric crises, i.e the Vendian crisis.

7.1 Climate in Precambrian. Development of early life

The climate of the Earth changed all the time. Over long periods of time, the climate fluctuated not only periodically but also had irreversible changes which, took place in Precambrian (Semikhatov & Chumakov, 2004). The intensive volcanism, an abundance of carbonic acid gas and high temperatures limited the development of communities of organisms on the planet. But from the middle Riphean, about 1 Gya, periods of cooling started (some authors name them as glaciations). During those periods average temperatures dropped affecting environmental conditions. Semikhatov and Chumakov (2004) write about three periods in the Earth history. The first was a period without exposed glaciations (3.5 – 2.9 Gya) when there were no great cooling periods. After that the period from 2.9 to 1 Gya was an episodic known glacial period. And from 1 Gya till present time, the authors mark as a period of repeated glaciations.

Biological communities of the Precambrian period have been presented in paleontology basically by cyanobacteria which formed so-called bacterial floor-mats and maritime planktonic communities. First multicellular organisms also started to appear in Proterozoic (2.7 Gya) but were rare. Among other major events in Proterozoic it is necessary to note appearance of developed photosynthesizing communities (2 – 2.5 Gya) and eukaryotes. The first eukaryotes have most likely appeared 2.7 Gya, but they become to be widespread much later (Fig.2). Approximately 620 – 650 Mya (the end of Riphean) there was a sharp impoverishment of fossil microorganisms which a number of researchers attribute to the extinction of a majority of dominating forms. This important event was named Vendian phytoplanktonic crisis. After that deposits contain a lot of fossil remains of living communities again. These biological communities consisted already from eukaryotes and rather numerous multicellular organisms. Especially many multicellular animals appear in the unique and unusual fauna of Ediakaran (upper division of Vendian). In accordance with certain estimations (Fedonkin, 2006), structure of Ediakaran fauna comprised 67 % coelenterates, 25 % worm-like organisms and about 5 % arthropods. However several years after it was found out that the majority of the animals of Ediakaran fauna have no modern analogues. Most likely they were not predecessors of animals who appeared in Cambrian. Nevertheless they maintained suitable conditions for the further development of the Cambrian fauna. Also we should note the appearance of the first seaweeds with limy covers (Rozanov, 1986) and various other animals with limy covers and tubes (Fedonkin, 2006; Rozanov, 1986).

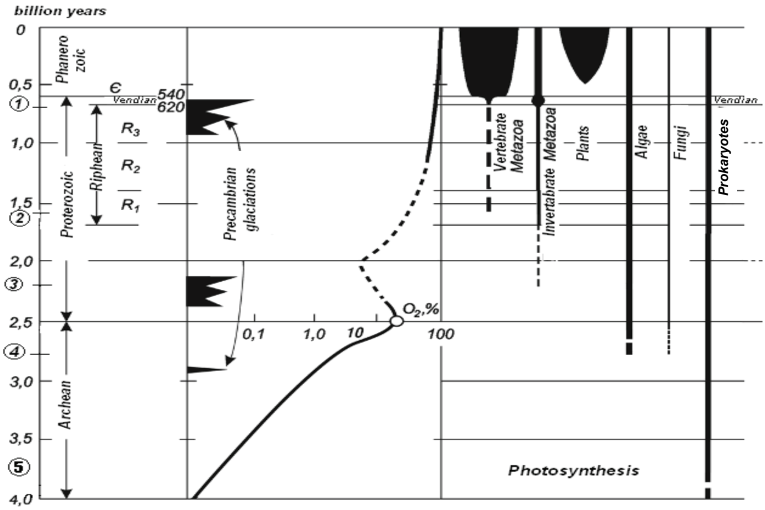

Fig. 2. The main events in early biosphere history (by Rozanov, 1986). In center: changes of the atmospheric oxygen concentration. On the right: times of appearance of some main taxa are given by full lines; dotted lines give possible presence of the group, but are unconfirmed or indirectly confirmed. In circles left: 1 – Vendian phytoplanktonic crisis; 2 – appearance of first hypothetic pre-vertebrate organisms (by hypothesis of Rozanov, 1986); 3 – developed photosynthesizing communities, appearance of first multicellular animals (invertebrate); 4 – in the sediments of this period first eukaryotes have been found; appearance of first plants and fungi; 5 – period of appearance of prokaryotes and probably mechanism of photosynthesis. The "flags" mean periodic glaciations, which took place in Precambrian.

Since Cambrian, *Sponges, Mollusks, Polychaetes, Bryozoans* and other elements of fauna start to be found; they have been usual for all Phanerozoic and continue today (Rozanov, 1986). Besides the remains of early Cambrian inhabitants, whose taxonomic status is definitely clear, there were also some groups of remains which can't be assigned to any known taxa. *Coelenterates* (jellyfishes, corals), though still rare, are known since early Cambrian. Regardless of scientific explanations of evolutionary events, there are some indirect evidence revealing changes in structure of biota on the Vendian and Cambrian border (Rozanov, 1986). There was an increase in variety of forms and abundance. This increase of ancient biodiversity has begun in Vendian and continued in early Cambrian (550 – 570 Mya). Ediakaran fauna disappeared as suddenly as it arose, making it difficult to connect it with the Cambrian "explosion". But for a relatively brief period between 650 – 620 Mya there was substantial impoverishment of plankton (Semikhatov & Chumakov, 2004), known as the Vendian phytoplanktonic crisis. This extinction of Proterozoic communities was the first ever documented and caused considerable changes in biosphere.

7.2 The first mass extinction, its possible reasons and consequences

In order to describe the reasons of Vendian Phytoplanktonic Crisis it is necessary to take into account earlier stages of biosphere development, before this first known mass extinction took place. Burzin (1987) viewed the crisis as irreversible changes of a system at the period from the beginning of Riphean (about 1500 Mya) to the Vendian (620 Mya). The author assumes that a hypothetical consumer has appeared in the food webs. Such consumers might eat away plankton organisms, and this might be the main internal reason of the crisis.

Let's see how it might be. Size classes of organisms demonstrate growth from early Riphean to Vendian (Veis, 1993). At the beginning of Riphean, organisms with the size of cells about 16 microns prevailed; at this time the large hypothetical consumer appears. During successive evolutionary changes the prey size reached 16-60 microns. More and more large--sized consumers were appearing and further, thus, forcing a prey to adapt and become more and more large-sized as well, till it has reached the size of 200-300 microns by the end of Riphean. It is the top size of prokaryotic cell. In principle instead of this strategy of avoiding of a predator (by increase of the cell size) there is also another one: formation of thorns and offshoots. But it is impossible for prokaryotes with their rigid cellular membrane that doesn't permit to exploit such way. Thus, cyanobacteria, being the basis of phytoplanktonic communities, cannot adapt to "pressure" of predators neither using larger sizes inaccessible for them, nor using either thorns. Therefore they have been factually by degrees almost eaten away that is proved by impoverishment of fossiled remains of a phytoplankton during this period (620-630 Mya). According to Burzin the elimination of cyanophyta by larger their consumers is the main reason of this crisis. However, except the internal reasons, crisis could be caused by external ones, in particular by decrease of orogenesis level (at which emission of carbonic acid grew). The intensity of this process probably synchronized with so called **galactic year** which has duration about 200 Mya (Marochnik, 1982; Woolfson, 2000). Known last decreases of orogenesis level was from Cretaceous till present, from Carboniferous till Permian as well as the end of Vendian (Ronov, 1976). It is logically to assume that the previous minimums and accordingly crises were around 800 Mya, and a little earlier 1 Gya, etc.

Further development of Vendian crisis, based on extinction of phytoplankton organisms was connected with decrease of food for predators of these organisms. That leads to their extinction too and the crisis reaches the bottom. Seemingly, in the end of Riphean it was a situation when reducers of dead biomass were insufficient. It reminds upper Carbonian (when a big amount of mortified biomass was accumulated), likely it was unfavorable for development of ancient cyanobacteria, and it might caused "second tide" of extinction.

Fossil samples demonstrate new increase of number of planktonic organisms about 620-570 Mya, but eukaryotes already dominate among them. As we have noted above the amassing of atmospheric oxygen could be connected with the insufficiency of reducers in biological communities. Mortified biomass of plankton is buried without aerobic oxidation. Of course, it led to disturbing of biospheric circulations as well as balance between biological and geological processes in biosphere. We can see relatively fast growth of the oxygen concentration along all Riphean (see Fig. 2) and establishment of almost constant level of it at the beginning of Cambrian. It could be related with so called great taxa radiation on the border of Vendian and Cambrian. The appearance of majority of new biological forms might had provided some stabilizing mechanisms. In this time many new groups of organisms has arisen; likely some of them are ancestors of many modern animal taxa, such as *Sponges, Mollusks, Polychaetes, Bryozoans* (Rozanov, 1986).

Some new biological forms, which appear as result of the crisis, give many different micro-taxa. They started to carry out more differentiated functions in new ecosystems but they have narrower ecological niches than Precambrian forms. That could be interpreted as the increase of "rigidity" of biosphere system (Slavinsky, 2006). Rigid systems with highly specialized forms have a shortcoming: loss of even one element can sometimes destroy the whole system (Malinovsky, 1970; Rautian & Zherikhin, 1997). Moreover, specialized forms are not able to evolve because they are well-adapted to current environmental conditions. On the other hand, ecosystems with such forms have an advantage: they are able to use available resources more effectively under appropriate conditions. Last statements can be illustrated by mass appearance of different reducers and predators in Cambrian biosphere. Deep functional reorganization of ecosystems and formation of additional circulations of substances permit them to use vegetable biomass more effectively. Therefore quantity of buried organic matter decreases. All this gave the possibility to establish more complicated but durable structure of biosphere and to increase essentially the level of biological diversity. Such changes occurred at the beginning of Cambrian.

7.3 The role and some regularities of crises and mass extinctions

Throughout all the history of a planet the shape of ecosystems changed. Changes affect floral and faunal communities, both in land and sea. Being formed throughout millions of years, steady communities of living organisms used resources of environment. They closed the major biogeochemical circulations, thereby maintained a balance of ecosystems. But external conditions were varied for a long time and broke this fragile balance. Appearance of new species, variations of orogenesis intensity and climate changes, other external influences on the biosphere, in particular, modifications of relief of surface of Earth and drift of continents changed the environment and led to reorganizations in ecosystems. One of the “tools” of elimination of such resource inefficiency in ecosystems were mass extinctions. They led to change in dominating biota. There was a point in the history of the biosphere, when they led to disappearance of up to 96 % of all sea species and 70% of land species of terrestrial vertebrates. It occurred in the Permian and is considered the greatest mass extinction of all times (Burzin, 1987; Malinovsky, 1970).

It is necessary to distinguish background extinction which in contrast to biotic crisis occurs more or less permanently. Mass extinction represents a fast (in geological scale of time), catastrophic change in dominant taxa (Armand et al., 1999). Some of the scientists name mass extinctions “global ecological crises” (Leleshus, 1986), others – “biocoenotic crises” (Rasnitsyn, 1987) or “planetary ecosystem reorganizations” (Krasilov, 1986). In respect to biological crisis Najdin and coworkers (1986) offers the term “biocoenotic turn”, underlining the fact that sharp changes occurred not only in biota, but also in the abiotic nature. All mass extinctions described in the literature developed under more or less similar scenarios. Phanerozoic crises, their possible reasons and consequences have been described in detail by paleontologists and ecologists. Among the various reasons we want to emphasize one that leads to the different parts of community becoming incompatible with one another. Owing to various critical changes in ecosystems and biological communities elimination of dominating, and then sub-dominating, species occurs. It in turn releases of ecological licenses (“vacant ecological niches” – Levchenko, 1997) and their occupation by more competitive and suitable species for new environmental conditions. Crises are an extremely important mechanism for the development of the biosphere, because they drive extinction of dominant species and allow rapid liberation of a great number of ecological niches. We assume that such events were favorable for species which weren't numerous in community earlier or were oppressed by dominants. These species may constantly be present in the ecosystems and could be referred as “cryptic biodiversity”. One can reveal that soon (30 – 50 Mya) after each Phanerozoic crisis new macro taxa have emerged. This effect is observed in Cambrian also, just after Vendian extinction.

Many authors (Armand et al., 1999; Rautian & Zherikhin, 1997; Sepkoski, 1996; Zherikhin, 1984, 1997) try to find the role of mass extinctions. Symptoms of crises and laws of their transition were developed. The system of indicators (extinction level, intensity of extinction), allow to compare stages and amplitude of different mass extinctions to estimate their global value by comparison with background extinction level (Alexeev, 2009). Studying all mass extinctions allows one to assess the significance as a crucial mechanism for biosphere development, playing the key role in the regulation of evolutionary processes and opening up possibilities for new diversifications. Summarizing above considerations and using approaches from our own earlier works (Levchenko, 1997, 2011; Starobogatov & Levchenko, 1993) as well as those from other authors (Armand et al, 1999; Kalandadze & Rautian, 1993; Zherikhin, 1984, 1987) a succession of events which characterize known crises and mass extinctions can be proposed:

Beginning of crises: 1) decreasing of the orogenesis level and the excretion of carbonic acid gas from Earth entrails; 2) intensive withdrawing of carbonic acid from biosphere due to geological processes (formation of coal in upper Carbonian and carbonates in Cretaceous), resulting in the reduction of quantity carbon which is accessible for life, lowering of organic matter production, increasing of the oxygen concentration in atmosphere, and a more continental climate; 3) “evolutionary search” for more effective producers, appearance and dissemination of new forms of organisms with new adaptations (before beginning of crisis they are as a rule eliminated by selection).

Development of crises: 4) crash and destruction of some large “traditional” biocoenoses, extinction of many taxa, elimination of community dominant organisms, release of some quantity of carbon from biospheric circulation; 5) use of liberated territories as well as free carbon for development and broad dissemination of new biological forms, including forms of so called cryptic biodiversity, radiation of taxa; 6) rise of new biocoenoses with new producers, increasing of biodiversity of the biosphere (Levchenko, 2011).

As we know from the planetary history after Cambrian the periods of decreasing of orogenesis were taking turns with periods of its increasing (Ronov, 1976). That promoted the development of new taxa up to the next crisis. We suppose that earlier crises of biosphere could be also connected with periodical variations of orogenesis. Moreover, one can assume that appearance of new adaptations of living organisms could be caused by some crises events.

8. Biosphere as an autopoietic-like system

Applying the criterion of the autopoietic system, (Varela, 1979), some scientists concluded that Gaia is a real autopoietic system. It should be noted here, that Francisco Varela denied that Gaia is an autopoietic system. He proposed that it is an autonomous system, a system from a wider class without regeneration of elements and border. But, there are problems with this interpretation of biosphere as well with the definition of autopoiesis itself. First, let us pose two questions, concerning interpretation of biosphere as an autopoietic system. What can we say about the biosphere environment? How can we explain Gaia development (**epigenesis**) as a result of Gaia and cosmos co-evolution through structural coupling?

It is clear, that in many relations biosphere is a self-determining system, and its interior milieu is the main source of perturbations, responsible for its development and evolution. How can we coordinate this fact with the role of environment in autopoiesis? Strictly speaking, autopoietic systems are not evolving in traditional sense. Is it possible to combine evolutionary and autopoietic mechanisms? Classical, pure autopoietic model looks non-productive and non-constructive when applied to biosphere. The idea of the "multilevel autopoiesis" first suggested by E. Jantsch looks promising, but it should be perfected and corrected. Biosphere can be represented as Russian matryoshka (Kazansky, 2004) of nested structure of autopoietic-like systems of different organizational levels (be it hierarchy or "holarchy"). "Space" between levels is filled by "metasystems" or sympoietic systems (Dempster, 2000). In biosphere we see alternation, interchange of system levels with rigid autonomy, autopoietic organization just as living cell, organism or some modular organisms and system levels with loose, population-like or community-like organizations. The latter are organizationally half-opened, "ajar", sympoietic, as Beth Dempster refers to them. These levels play the role of buffer between rigid organizational levels and local environments. This flaky structure makes it possible to realize multilevel evolutionary process.

From the systems point of view the simplest form of life – unicellular organism is a form of relative dynamic autonomy. This autonomy is provided by circular, closed recursive organization of metabolic processes and by cellular half-permeable membrane. Circular closed production organization means, that it organizes permanent reproduction via metabolic process not only of its structure, elements, but also of itself. Well-known conceptual descriptive half-formal model of autopoiesis by H. Maturana and F. Varela was a prelude to formalization of biologically dynamic autonomy. From this position, chemical circular closed organization of autocatalytic hyper-cycles of M. Eigen (1971) could be a predecessor of biogenesis in the form of proto-cells. But, of course, problem of the origin of biological membrane is a special problem, related with the presence of special bio-matrices.

Conditions of pre-biotic Earth was favorable for the origin of life, which arose **polyphyletically** i.e. independently or concurrently (see above sections 3 and 4). Many parallel, different and relatively independent proto-populations occurred at different times and at different locations on Earth. Almost instantly very thin film of primitive unicellular bacterial communities covered the surface of our planet. These bacterial communities included a minimal standard set – primary producers, consumers and reducers. As a result, biosphere, as a specific global environment and a system appeared. Organisms need in biogenous elements and other materials and resources. Sustainable existence and development of this system is possible only if needs of all organisms are balanced and resources are recycled. So, biosphere became a sort of global ecosystem with relatively closed cycles of biogeneous elements. Evolution of biosphere is really a process of co-evolution of biota and abiotic elements of biosphere (Lovelock, 1988; Starobogatov & Levchenko, 1993). This process of biosphere evolution can be described as the **punctuated**

epigenesis (Kazansky, 2004), an conceptual attempt to refine well known model of punctuated equilibrium suggested by Gould (see below). In this conceptual model the periods of gradual development, occasionally interrupted by structural crises, inevitably lead to organizational crises, characterized by the perturbation of the autopoietic organization, which brings to the self-construction of a new, superior structural level of the system. Traditionally, biological evolution is understood in a Darwinian sense as the historical development in succession of replications and reproductions. That is why Lovelock spoke about "Gaia epigenesis" or individual development. Gaia is developing internally, without reproduction, through periodical organizational self-transformations ("transfigurations"). It looks as a new form of open-ended organizational non-darwinian evolution of the autopoietic system with darwinian-like processes in its parts. This evolution can be represented as a gradual process of self-harmonization of the system of global biogeochemical cycles. This process reaches its peak, then eventually fails and brings to destabilization of biosphere organization, its reconfiguration and construction of a new, more complex one. Crisis begins with rising of promising basic element of new type, which could emerge in a new symbiogenesis (Margulis, 1987; Margulis & Guerrero, 1996). Then we observe expansion of this new structure, generation of new organizational levels with the accumulation of actual biodiversity. But, all this ends with contradictions on micro-level, provoked by inevitable perturbation of balance on micro-and macro-level followed by global crisis and transformation of biosphere (Kazansky, 2004, 2010). Some general aspects of interaction between different levels of life organization are given in Levchenko (2011).

The Cambrian or more precisely, the Ordovican time-rock period (about 500 Mya) is an enigmatic turning point in biosphere development, separating long stage of biological stagnation and stage of explosive increase of biological diversity. First endeavors to look on evolution of biosphere as a self-organizing system were undertaken by physicists P. Back and K. Sneppen in pure mechanistic model of **self-organized criticality**, or model of "**sand pile**" (Back & Sneppen, 1993). According to this paradigm, systems consisting of many interacting constituents exhibit some characteristic behavior. According to Kauffman (1995), all biological systems exist in dynamic steady state on the border between a region of parametric state with chaotic behavior and a region with rigid, determined behavior. System, having stable focus "at the edge of chaos" demonstrates properties, characteristic for self-organizing systems. Besides, in this states the system is most labile and evolvable (high ability to evolve).

P. Back and K. Sneppen revealed, that in the state of self-organized criticality probability distribution of sizes of fluctuation in the system is described by power-law slopes with long tail. Such type of distribution makes all processes and structures fractal, scale-free. Most changes occur through catastrophic events rather than a graduate change. As a result, we have punctuations, large catastrophic events that affect the entire system. Small fluctuations can have global effect. The model of self-organized criticality fall into conception of "**punctuated equilibrium**" (Gould, 1994; Gould & Eldredge, 1977). According to the model, evolution of biota demonstrates alternation of durable quasy-ordered states and more short-term avalanche-like processes of destruction (crises) by power law statistics. Crises are interpreted as mass extinctions of species and whole taxa. Biodiversity recovers in the periods of stasis. But, this pure mechanistic model well fit only with the statistics of global ecological crises only after Cambrian period. Kauffman (1995) was mistaken, when he applied it to so-called Cambrian explosion (Kovalev & Kazansky, 1999, 2000). In this case we really have fundamental change of global organization of biosphere. Biosphere had cardinally different types of organization in the Archean, Proterosoic and Phanerozoic eons. In the beginning of the Phanerozoic eon there was a leap from simple, organizationally closed systems, formed by biological dominants - cyanobacterial mats to stochastic, open, complex systems, which gave rise to multi-level open-ended creative evolution. The continuous noticeable taxonomic diversification started only about 500 Mya. Two principally different, mutually exclusive strategies of biological systems were dominating at these two biosphere ages. Rigidly structured life-cycles with aggressive, expansionistic behaviour of soliton-like population waves were distinctive characteristic of biota before Phanerozoic eon. In contrast, in the beginning of Phanerozoic eon we can see the emerging and fantastic development of multi-level cyclical organization of life (Kovalev & Kazansky, 1999, 2000). That is why any universal mechanistic model, like punctuated equilibrium cannot be applicable to the whole history of biosphere. We should separate fundamental, organizational crises in the evolution of biosphere, which are associated with mass extinction of the whole taxonomic units, but which does not change the global structure of biosphere. Transition from Archean to the Proterozic related with increase of atmospheric oxygen or Phanerozoic explosion of diversity of multicellular organisms are examples of organizational crisis. Model of **punctuated epigenesis** is the endeavor to conceptualize the idea of biosphere evolution as interchanging of periods of development and periods of crises.

9. Conclusions

Biosphere is a planetary, global expression of life activity and from the other side it is the only favorable milieu for durable existence of biota. Any living organism has relatively autonomous organization of metabolic processes and at the same time, all living creatures are fundamentally dependent on each other via trophic, behavioral, sexual relationships. Any organism is the element of many systems – group (family, flock, school, population, etc.), community, ecosystem and biosphere as a global planetary system. All organisms are included in local and global biogeochemical cycles. Systemic status of biosphere and mechanisms of its development (or evolution) are still debatable questions. But, it is clear, that biosphere have durable periods of gradual development and relatively short periods of uneven change. In some of these periods, often associated with so called global crises, structure of biosphere can radically change, as in the case of gradual increase of oxygen in atmosphere at the transition from the Archean to the Proterozoic, or in the period of Phanerozic explosion of biological diversity. We believe that biospheric crises are processes regulating texture and functioning of the biosphere. The crisis which took place on the border of Riphean and Vendian (630 Mya) has resulted in considerable changes of the early biosphere. Great Cambrian taxa radiation and the rise of role of predators in communities were important specific consequences of the crisis. Nevertheless, this Vendian phytoplanktonic crisis developed by the same way as that is known for more later Phanerozoic crises. We tried to discover the main traits of biospheric crises and present them in this chapter.

The question "what is the origin of life: either origin of organisms or origin of biosphere?" isn't correct because only whole biosphere is independent unit of life among all known living forms (Lovelock, 1991). There are two important regularities of the evolution of life on the Earth. The first one demonstrates the autocanalization of physical evolution of the biosphere – increase of energy flow which is used by life. That defines many traits of biospheric development and leads to the hypothesis of embryosphere. Embryosphere developed since the time of primitive chemical processes on the surface of our planet since early Archean up to modern biosphere. The second regularity demonstrates non predetermination of phenotypical realization of biological evolution, demonstrated, in particular, by ecologically neutral changes of some biological forms in standing ecosystems (Levchenko, 2011). Hence, it is reasonable to assume non-predetermination of origin of strongly concrete pre-biological structures in embryosphere.

We also suppose that life on Earth has arisen under conditions when liquid hydrocarbons and water could meet each other and interact during long period of time. At that the hydrocarbons, which seemingly were present at early planet in big quantity, could be appropriate food for initial forms of life. We don't disclaim traditional (abiogenesis or biopoiesis) approaches to the problem of origin of life; they could be promising especially taking into consideration great achievements in the fields of biophysical and biochemical methods and experimental techniques. More recently, new experimental methods, for example such as artificial designing of a "minimal cell", mathematical and computer modeling have been elaborated. But we suggest that the phenomenon of life isn't connected only with life of separated organisms; we believe following Vernadsky that life without biosphere is impossible and doesn't exist. In other words to understand what is life it is necessary to explore the biosphere. It seems we are living at a time when all massive of amounts of biological data could be generalized within a framework of some unified theory. We hope that hypotheses and principles suggested herein by us in general will stimulate new insights on the problems of origin and evolution of life not only on our planet but also in the wider Solar system and perhaps in the Universe.

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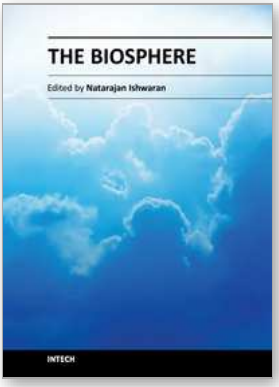

The Biosphere

Edited by Dr. Natarajan Ishwaran

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In this book entitled "The Biosphere", researchers from all regions of the world report on their findings to explore the origins, evolution, ecosystems and resource utilization patterns of the biosphere. Some describe the complexities and challenges that humanity faces in its efforts to experiment and establish a new partnership with nature in places designated as biosphere reserves by UNESCO under its Man and the Biosphere (MAB) Programme. At the dawn of the 21st century humanity is ever more aware and conscious of the adverse consequences that it has brought upon global climate change and biodiversity loss. We are at a critical moment of reflection and action to work out a new compact with the biosphere that sustains our own wellbeing and that of our planetary companions. This book is a modest attempt to enrich and enable that special moment and its march ahead in human history.

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