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Development of geological processes on the Earth and their impact on the early biosphere

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Abstract

Though life has been already existed in the Paleoarchean, biosphere started rapid development only in Paleoproterozoic from about 2.4-2.3 Ga. It was practically coincided with period of irreversible change of tectonomagmatic activity on the Earth, when high-Mg magmatism of the early Precambrian, derived from depleted mantle, gave place to the geochemical-enriched Fe-Ti basalts [12]. New type of magmas was characterized by elevated and high contents of elements which are required for metabolism and fermentation. It suggests that this event acted as a trigger for environmental changes and rapid evolution of biosphere, supplying a qualitatively new biophilic material to the Earth's surface. Venus and Mars developed at the same scenario; very likely, that at the beginning liquid water occurred on them; however, processes of the planetary development were favorable for the biosphere evolution only on the Earth.

1. Introduction

It is known that the Earth's ecological systems in the Middle Paleoproterozoic were subjected to essential changes, which promoted to acceleration of the biosphere expansion and development, and finally led to the appearance of multicellular organisms. Though life has been already existed in the Paleoarchean [10], the multicellular organisms appeared only in the middle Paleoproterozoic (~ 2.0 Ga ago) [9]. What was occurred with ecological systems and why? What was a trigger for such changing? We try to answer on these questions using complex of geological, petrological and geochemical data.

2. Development of tectonomagmatic processes on the Earth

According to modern models, the primordial crust could be basic or sialic in composition; both models require a global melting of a primary chondritic material for its formation. Due to theory of solidification, hardening of such magma ocean had to proceed upwards and resulted in accumulation of low-temperature derivates of granite composition at the surface; geological and geochemical data support this idea: data available evidence that on Hadean stage of the Earth's evolution (before 4 Ga) granitic rocks were predominated on its surface and liquid water existed [3, 11, 12]. Biosphere could appear only after solidification of global magma ocean and cooling of its surface till to possibility of liquid water existence. The evidence of life being on the Earth were found in rocks of the Isua complex (3.8 Ga), where underwater pillow lavas widely developed [8].

2.1. Early Precambrian stages (Archean and early Paleoproterozoic, ~4 to ~2.4 Ga)

Granite-greenstone terranes (GGTs) and their separating granulite belts were the major tectonic structures [12]. The GGTs matrix consists on plagiogranites (likely, strongly reworked primordial sialic crust) with irregular network of greenstone belts (not more 10-15% of area). The latter formed mainly by high-Mg komatiite-basaltic and boninite-like lavas with subordinate sediments. Such magmas were derived from mantle sources, depleted by easily-melted components; geochemical features of this magmatism had low contents of biophile elements.

Presence in Archean sediments of detrital pyrite, uraninite, siderite, etc. testifies that Archean atmosphere was rather differ from the modern. It was composed mainly by N_2 and CO_2 [4]. It was not led to growth of greenhouse effect due to constant moved away CO_2 in form of sedimentary carbonates in water of the World Ocean and processes of weathering on land. Localities of primitive life in the Archean usually developed near hot springs on sea floor or in glassy chilled crusts of lava flows [1, 8].

2.2. Cardinal irreversible change of the Earth's tectonomagmatic evolution

Cardinal change in character of magmatism occurred within period from 2.35 to 2.0 Ga when the early Precambrian high-Mg magmas, gave place to the geochemically-enriched Fe-Ti picrites and basalts, similar to the Phanerozoic within-plate magmas [13]. These magmas were characterized by elevated and high contents of Fe, Ti, Cu, P, Mn, alkalis, LREE, and other incompatible elements (Zr, Ba, Sr, U, Th, F, etc.). Their appearance was considered with ascending of thermochemical plumes which generated at the core-mantle boundary and this process is active till now [12]. Material of such plumes enriched in fluid components and their heads extended on shallower levels; it resulted in appearance of plate tectonics, which began to act from 2 Ga and led to change of primitive plume tectonics by modern plate tectonics. Ancient continental (sialic) crust became replace by secondary oceanic (basaltic) crust; the former has gradually involved in subduction process and stored in the “slab graveyards”, revealed in the mantle by seismic tomography. As a result, composition of hard Earth’s surface was cardinally changed: basaltic (oceanic) crust has grown up and forms ~60% of the present-day Earth’s crust now.

All microorganisms of that period caused the decomposition of inorganic matter and served as active agents of biological weathering, playing an important role in biogeochemical cycle of biophile elements, including aforementioned metals, and correspondingly supply the World Ocean. A large-scale influx of alkalis presumably neutralized its water, making it more suitable for life, while input of Fe-group metals, P, and other trace elements, which are required for metabolism and fermentation, rapidly expanded the possibility for development of biosphere. Judging on appearance of oxidative atmosphere ca. 2.3 Ga (Great Oxidation Event) [2, 6], it promoted to explosion of photosynthesizing organisms.

The manifestation of this geochemically enriched magmatism was correlated with the first finds of eucaryotic heterotrophic organisms at ~2 Ga, for example, in the black shales and phosphorites of the Paleoproterozoic Pechenga complex, Kola Peninsula [9]. The vital activity of the organisms significantly increased the oxygen content in atmosphere, which was marked by the formation of cupriferous red beds at all Precambrian shields, generation of the first hydrocarbon deposits (shungites, Karelian craton) and phosphorites [6].

3. Summary and Conclusions

So, from ~2.35 Ga the tectonomagmatic processes started to involve previously absent geochemical-enriched material. Where this material stored and how it was activated?

The established succession of events could be provided only by combination of two independent factors: (1) the Earth originally was heterogeneous, i.e. iron core appeared first and chondrite (silicate) envelope next, and (2) downward heating of the Earth occurred, which was accompanied by the cooling of its outer shells [12].

Because the peak of magnetic field strength on the Earth (ca 2.4-2.3 Ga; [7] was almost coincided with the change of tectonomagmatic activity, we suggest that material of primordial iron cores was completely melted then and previously absent thermochemical mantle plumes began to generate. However, according to paleomagnetic data, the magnetic field on the Earth already existed about 3.45 Ga [7]. Because the new material began to participate in tectonomagmatic process much later, the liquid iron, responsible for the magnetic field in Paleoarchean, occurred due to heating of chondrite material of the primordial mantle. This iron flowed down through the silicate matrix as heavy eutectic Fe+FeS liquid, and accumulated on the surface of still cold solid primordial core; it generated magnetic field, but did not participate in the geodynamic processes.

Data available on Venus and Mars suggest that their tectonomagmatic evolution also occurred at the close scenario [12]. Two major types of morphostructures, which are vast plains, composed by young basaltic crust, and older lightweight uplifted segments with a complicated topography, can evidence about two-stage evolution of these planets. If we dry the Earth’s oceans, we will see the same picture.

Presence of drainage systems on Mars and valleys on Venus assumes existence of liquid water on early stages of their development. Like on the Earth, red beds and global glacials appeared on the Mars at the middle stage of it’s evolution, and may be at this period ancient microorganisms existed on Mars [5]. Powerful eruptions of gigantic volcanoes of Tharsis and Elysium, probably, led to fall of temperature and disappearance of liquid water on Mars which terminated biosphere evolution. In contrast to Mars, on Venus speeded up greenhouse effect appeared, which led to dry and very hot surface, unsuitable for life also. So, starting conditions for biosphere origin and development were close on them, however.

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