IRREVERSIBLE EVOLUTION OF THE TERRESTRIAL PLANETS: GEOLOGICAL AND PETROLOGICAL DATA.

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Introduction: Current existing hypotheses dealing with the origin and inner evolution of solid terrestrial planets (Earth, Venus, Mars, Mercury, Moon) are underlain mostly by a diversity of physical and geochemical speculations and simulations. A princepal disadvantage of these hypotheses is their abstract nature and complete ignoring of data on the tectonomagmatic evolution of these bodies. However, these data provide an important information about specific mechanisms of planetary formation and development, which is necessary for elaborating a modern theory of their evolution. The Earth has been much better studied compared to the other planets [1], therefore we will discuss the main questions of planetary tectonomagmatic evolution using the Earth as example.

Tectonomagmatic evolution of the Earth. *Origin of the primordial crust (Pregeological stage):* There are two major hypotheses:(1) it initially was basaltic and sialic crust was produced later at convergent plate boundaries, and (2) it was initially sialic. Both models require a global melting of chondritic material to form the primordial Earth's (and other planets) crust; such magmatic ocean had some hundred km deep. Due to differences between adiabatic and melting-points gradients, its solidification had to proceed in bottom-top direction [2] and resulted in accumulation of low-temperature derivates in outer shells of the planets. Geological data, namely granite-dominated Archean Earth's crust and results of studying of detrital zircon from Australia [3] supports the primordial-sialic crust hypothesis. Formation of such crust was responsible for primary depletion of the upper mantle matter. The whole gas envelope that surrounded the proto-Earth was likely supplemented with volatiles escaping from the solidifying magmatic ocean. Upon the cooling of the Earth's surface to temperatures <100^{o}C, water condensed and formed the ocean and primary atmosphere [4]. The Moon which is four times smaller than the Earth has a basic primordial crust. Such a difference can be explained by different depths of their magmatic oceans [5].

*Tectonomagmatic processes in the Archean and early Paleoproterozoic***:** The major Archean tectonic structures were large oval-like granite-greenstone terranes (GGTs) and their separating granulite belts. The GGTs consisting of irregular network of greenstone belts (10-15% of the area) "submerged" in tonalite-trondhjemite-granodiorite (TTG) matrix, which, probably, represents strongly reworked primordial crust. GGTs were areas of extension, uplifting and denudation, whereas the granulite belts were dominated by compression, sinking and sedimentation. Mantle-derived magmatism, represented by high-Mg komatiite-basaltic and boninite-like melt, was located within greenstone belts, which formed jointly specific large igneous provinces (LIPs). Source of these magmas was depleted mantle. By the Paleoproperozoic the crust became rigid as it follows from formation of rift structures, dike swarms, and large mafic-ultramafic layered intrusions, which together formed LIPs. Character of the tectonomagmatic activity remained almost the same: cratons, appeared on the place of GGTs, and separated them granulite belts. Magmatism was dominated by siliceous high-Mg series (SHMS). The appearance of LIPs requires location beneath them the first generation mantle superplumes, consisting of depleted mantle material. Heads of these plumes spreaded at depths of 200-450 km. Such a situation can be described in terms of plume-tectonics typical of the Early Precambrian.

*Cardinal change in the Earth's tectonomagmatic evolution***:** The period of 2.3 to 2.0 Ga was characterized by voluminous eruption of geochemical enriched Fe-Ti picrites and basalts similar to the Phanerozoic within-plate magmas. Change of magmatic activity ultimately triggered the processes of plate tectonics which are still active. At the beginning, character of tectonic activity did not change: lava flows developed in the riftogenic structures; dike swarms and large layered intrusions were formed. A drastic change of the tectonic pattern occurred at ~2 Ga, for form first Phanerozoic-type orogens. Since then, the subduction of the ancient sialic continental crust is a permanent process and these materials has stored in the "slab graveyards", revealed in the mantle by seismic tomography [6]; as a result, the continental crust has been gradual replaced by the secondary basaltic (oceanic) crust. Thus, during the period from 2.3 to 2.0 Ga, the composition of mantle melts and tectonic processes were irretrievably changed.

Simultaneously, important compositional changes occurred on the Earth's surface, accompanied by changes in the atmosphere (it became oxidative) and hydrosphere, developed global glaciations, among sediments appeared phosphorites and hydrocarbons as well as aerobic organisms in biosphere [7]. We suggest that it was a result of arriving of qualitative new material on the surface. From this point onwards general tendencies of evolution of the ecological processes also have not changed in general.

We believe that the ascending of the 2nd generation (thermochemical) mantle superplumes, enriched in Fe, Ti, K, Na, P, and other incompatible elements, were responsible for these changes. Those plumes were generated at the core-mantle boundary (CMB) in D" layer and this process is active till now. The superplumes draw away the heat from the liquid core resulting in its solidification, which, according to [2], goes upwards and thus provide the growth of the inner (solid) core. Such a process relieves big amounts of the fluids, dissolved in the melt, and initiates the ascent of the thermochemical plumes. Their matter possessed less density and could reach shallower depths. Spread of their heads led to active interaction with outer shells, resulted in crust rupturing, oceanic spreading, formation and movement of plates, subduction, etc., i.e. to plate tectonics. So, the Continental-oceanic stage of the Earth's evolution began.

Tectonomagmatic evolution of the Moon and other terrestrial planets: Data obtained on samples of lunar soil recovered by American and Soviet missions indicate that the oldest magmatic activity occurred on the Moon at 4.4-4.0 Ga, and its products are preserved at highlands. These are volcanics of a low-Ti magnesian suite and their plutonic analogues: layered mafic-ultramafic intrusions [8]. Judging on chemistry, mineralogy, geochemistry, and isotopic composition, they were close to rocks of the terrestrial Paleoproterozoic SHMS [5]. Another type of products of lunar highland magmatism (KREEP basalts and their intrusive analogues) were continuously produced from 4.34 to 4.0 Ga [9], and generally resembles magmatism of the phase of transition to Continental-oceanic stages on the Earth. At approximately 3.9-3.8 Ga basaltic mare magmatism occurred simultaneously with the development of large mare depresssions. Most researchers believe that maria were produced as a consequence of catastrophic impact events. However, the structures of the maria most closely resemble those of terrestrial oceans or flood basalt provinces (significantly thinned crust and powerful basaltic volcanism). By analogy with the Earth, we suggest that lunar highland magmatism was related to the ascent of mantle plumes of the 1st generation, which consisted of the depleted mantle material. Mare magmatism was likely induced by the ascent of mantle thermochemical plumes (2nd generation), whose development was initiated at the mantle and liquid metal core boundary. Intensity of magnetic field on the Moon reached a maximum also at ~3.9 Ga and gradually decreased until 3 Ga [10], which support idea of existence of the liquid core during mare magmatism. So, the Moon was developed at the same, but shortening scenario compare to Earth.

There are two major type of morphostructures on Mars and Venus also: vast lowlands, covered with basalt flows, and old elevated territories of complicated topography**,** composed by lighter material (*tesserae* on Venus and *terra* on Mars). It evidence that these planets were also formed in two stage. During the earlier one, their primary lithosphere was produced via the solidification of global magmatic oceans and subsequent activity of mantle plumes of the 1st generation. The second stage was marked by dynamic processes associated with extensive basaltic magmatism, probably, related to the ascent of thermochemical superplumes from their CMB. Like on the Earth, red sedimentary rocks and global glaciations appeared on Mars at the middle stage of its development [11]. From this follows that ecology on its surface was also undergone by cardinal transformations, which was, probably, linked with arrival of principally new material on its surface.

Causes of the Earth's and terrestrial planets evolution: From the preceding data follow that later 2.5 billion years after the Earth formation and 1.5 billion year – the Moon, previously absent new geochemical-enriched material has become to involve in tectonomagmatic processes. Where this enriched material was "conserved" and how it was activated? From our view, the established succession of events could be provided only by a combination of two independent factors: (1) Earth originally was heterogeneous, i.e. formed due to the heterogeneous accretion, and (2) the downward heating of the Earth (from surface to core) was occurred and accompanied by the cooling of its outer shells. The most likely cause of the centripetal heating of the Earth was a zone/wave of heat-generating deformation directed inside the planet. According to experimental data, such waves are appeared in revolving bodies at the stage of acceleration of their rotating around axes [12]. Such inward-directed zone could appear after completion of the Earth's accretion as a result of gravitational compaction of the newly-formed body and corresponding gradual shortening of its radius. According to law of conservation of angular momentum, the acceleration of Earth's (and other solid planets) rotation around its axis had to led to appearance of such wave. That wave on its way through interior of the Earth heated deep mantle material and generated first superplumes. It finally reached the metallic core, melted it and produced secondary thermochemical plumes. Such superplumes have responsible for practically all tectonomagmatic activity to be the major mover of tectonic processes. From this follows that liquid metallic core is an energetic "heart" of the Earth now. After it's solidification tectonomagmatic processes come to the end, how it occurred on the Moon, Venus, Mars, and Mercury.

Concluding remarks: All terrestrial planet bodies have been self-developed systems, evolved on the close scenario, which provides cardinal change of tectonomagmatic processes at the middle stages of their evolution. The established succession of events could be explained by a combination of two independent factors: 1) the bodies originally were heterogeneous, and 2) the downward heating of them was followed by the cooling of its outer shells. As a result, the primary metallic core material was long time remained untouched and began to involve into global tectonomagmatic processes essential later. Evolution of all of them, except the Earth, is completed and they are "dead" bodies now.

References: [1] Bogatikov, O.A., Sharkov, E.V. (2008) *Petrology 16, 629-651*. [2] Jeffries, H. (1929) *The Earth, 2nd Ed*. London: Cambridge Univ. Press. [3] Harrison, T.M. et al. (2005) *Science 310, 1947-1950*. [4] Rollinson, H. (2007) *Early Earth systems. A geochemical approach*. Oxford-Carlton: Backwell Publ. [5] Sharkov, E.V., Bogatikov, O.A. (2001) *Petrology 9, 97-118*. [6] Karason, H., van der Hilst, R. D. (2000) *Geophys. Monogr. 121, 277–289*. [7] Melezhik, V.A. et al. (2005) *GSA Today 15, 4-10*. [8] Snyder, G.A. et al. (1995) *J. Geophys. Res. 100 (E5), 9365-9388*. [9] Snyder, G.A. et al. (2000) *The Origin of the Earth and Moon*. (University Arizona Press), 361-395. [10] Rancorn, S.K. (1983) *Nature 304, 589-596*. [11] The Geology of Mars (2007) Cambridge Univ. Press. [12] Belostotskii, Yu.G. (2000) *Fundamentals of the Universe* (Nauka, St. Petersburg) (in Russian).