EPSC Abstracts
Vol. 9, EPSC2014-33-1, 2014
European Planetary Science Congress 2014

Formation Cores of the Terrestrial Planets: Evidence from evolution of tectonomagmatic processes and paleomagnetic data for the Earth and the Moon

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Abstract

Geological and petrological data on evolution of tectonomagmatic processes on the Earth and the Moon evidence that their primordial iron cores were formed as a result of heterogeneous accretion from material, existed in the Solar system in the early stages of its development. Very likely, that these cores were embryos of the terrestrial planets. Judging on cardinal reorganization of the planets' geodynamics and appearance of new, enriched type of mantle-derived magmatism, material of these primordial cores began to involve in tectonomagmatic processes only at the middle stages of their development. Modern cores of the planetary bodies are formed by mixture of material of the primordial cores and iron of chondrite origin

1. Introduction

Our knowledge about formation and evolution of cores of the terrestrial planets based now on different physical and geochemical speculations and models. The main disadvantage of such hypotheses are their abstract character and ignoring any data on tectonomagmatic evolution of those planets. At the same time, magmatic processes have carried information about evolution of material of the planets' interiors and realize uninterruptedly record of their changing throughout their history. Related tectonic processes express character of deep-seated geodynamic processes. Jointly, they provide possibility for understand how and why evolution of the terrestrial planets occurred and what role their cores played in these processes.

Now the most investigators follow Safronov's [6] and Ringwood's [5] idea suggest that the Earth were formed as a result of homogeneous accretion. It presumes that toward the close to it accretion, temperatures in the Earth had maximum of about 2200^{o}C at the depth of 1400 km. Presence of FeS in original condensate, from which the Earth formed, gave possibility to generate dense low temperature (about 1000^{o}C) eutectic (FeS-Fe) liquid, This liquid had to sink rapidly through the silicate rocks and accumulated in the Earth's center to form its core. Also very popular idea that before 4.45 Ga the Earth was affected by a megaimpact that resulted in the Moon formation, which likely occurred after core formation on the both Earth and impactor [1].

So, if the model of homogenous accretion is correct, the Earth and the Moon interiors from ~4.45 Ga had to develop at the same way with systematic trend from geochemical-enriched to depleted mantle sources. However, in reality situation quite the contrary: magmatic rocks of the first half of the Earth's and the Moon's evolution were derived from depleted sources and only at the middle stages of their development in global scale appeared geochemical-enriched melts accompanied by cardinal change of tectonomagmatic activity [7 and references herein]. Very likely, that leading role in this process played material of their primordial cores.

2. Tectonomagmatic evolution of the Earth and the Moon

For a long time of the Earth's beings (about 4.5 Ga), three evolutionary stages occurred which cardinally and irreversible changed its deep-seated processes [7]. After formation of the primordial sialic crust, Nuclearic Stage began, which was lasted from ~4.0 Ga to ~2.6 Ga and changed by Cratonic Stage (2.6-2.35 Ga). The predominant type of geodynamics then was linked with ascending of mantle superplumes of the first generation, composed by depleted ultramafic material.

The critical change of the Earth's tectonomagmatic evolution occurred in the range 2.35-2.0 Ga, when Continental-Oceanic Stage began. Intensity of magnetic field, generated by liquid iron core, drastically increased at that time; it reached maximum over the whole Earth's history and continued decreasing afterward [4, 6]. Geochemical-enriched Fe-Ti picrites and basalts, similar to the Phanerozoic within-plate magmas. firstly appeared then in large quantities as well as first geological evidences of plate tectonics practically on all Precambrian shields. We suggest that such changes were linked with ascending of mantle superplumes of the second generation (thermochemical), originated at the boundary of liquid iron core and silicate mantle (CMB) like as the modern mantle plumes. Material of these superplumes has contained fluid components enriched in Fe, Ti, P, alkalis, and other incompatible elements (Nb, Ta, Hf, etc). Such superplumes reached more shallow levels and extending of their heads lead to active interaction with rocks of rigid upper shells. Evidently; it was the main reason for appearance of the Phanerozoic type of activity (plate tectonics). As a result, gradually replacement of ancient sialic crust for the secondary basaltic (oceanic) has happened since then and continue till now.

The same cardinal change of tectonomagmatic processes on the Moon started at about 4.2 Ga when volcanics of Mg suite, derived from depleted mantle, were changed by geochemical-enriched KREEP suite. It was followed by formation of large depressions of lunar maria with powerful basaltic volcanism at 3.9-3.8 Ga. The maria usually are treated as a results of huge meteorite impacts ("Lunar Cataclysm") [2 and references herein]. However, structure of the maria and geochemistry of their basalts, which are close in composition to aforementioned terrestrial plume-related magmas (high contents of Fe, Ti, as well as Nb, Ta, Hf, etc.). Judging on their composition and structure, the maria very likely were a result of ascending of the mantle plumes and close in origin to the terrestrial large igneous provinces [7]. Like on the Earth, this transition was accompanied by sharp increasing of the magnetic field intensity, reached a maximum approximately 3.9 Ga (till 1 Gs) and gradually decreased until 3 Ga [3] when eruptions of maria basalts were completed [2].

3. Discussion and conclusion

Where this geochemical-enriched material was stored and how it was activated? From my view, the established succession of events could be provided only by a combination of three independent factors: (1) the Earth and the Moon originally were heterogeneous, with silicate mantle and primordial iron core, i.e. formed due to the heterogeneous accretion, (2) primordial iron core was not chondrite origin, and (3) heating of the planets was occurred downwards (from surface to core) and accompanied by the cooling of their outer shells.

The most probable, the centripetal heating of the Earth and other terrestrial planets was be realized by a zone (wave) of heat-generating deformation directed inside the planets. Such wave, according to experimental data, appears under acceleration of a body's rotation around axis. I suggest, that those zone of deformation appeared after completion of planets accretion; acceleration of their rotation occurred due to law of conservation of momentum as a result of materials compaction and shortening their radii. That waves moved through the interiors of the planets heating deep mantle material and generating first superplumes, composed by depleted (because separation of the primordial crust) material. Finally, they reached the primordial metallic cores, melted its and produced secondary thermochemical plumes, which are still active on the Earth, but already absent on the other terrestrial planets, which iron cores hardened by this time.

However, according to paleomagnetic data, the magnetic field of the Earth existed over 3.45 Ga [4] truly,. Because new material started to participate in tectonomagmatic processes only at 2.35 Ga, very likely that on the surface of the primordial core accumulated liquid iron material, occurred owing to heating of chondritic matter by the aforementioned thermal wave. The iron liquid, generated by magnetic field in Archean, was not participated in geodynamic processes; only melting of the primordial metallic core, composed of juvenile material, could lead to the cardinal change in the evolution of our planet in the Paleoproterozoic. Similar processes probably occurred in the Moon as well. So, the iron cores of the planets seemingly have complicate origin and consist of both material of primordial cores and matter from chondrite substance, which was added to it later during convection after the melting of the primordial cores.

Cores of the terrestrial planets play important role in their structure, however, geophysical data provide little information on their geochemical characteristics. Fortunately, some iron meteorites represent fragments of cores of small planetary bodies, and contain important information, which can be used in the analysis of processes of the cores formation in the large planets. According to [9], the composition of meteorites iron should reflect the chemical heterogeneity that existed in the Solar system in the early stages of its development, when the terrestrial planets were born. Some of the iron meteorites were parts of their embryos. Study of W isotopy and siderophile elements in the composition of planetary bodies showed that they were strongly fractionated compared to chondritic material, i.e., truly, part of the material of these cores was not chondrite origin.

It should be particularly emphasized the role of non-chondrite material of the primordial iron cores in evolution of the terrestrial planetary bodies. So even on the Moon, where the core forms only 2% by mass, its melting led to appearance of large maria depressions of with thin crust and powerful basaltic volcanism. On the other terrestrial planets (Earth, Venus, and Mars), the process passed further, leading to extensive development of the secondary basaltic crusts. The situation on the poorly studied Mercury is not sufficiently clear.

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