Native Iron Nodules in Basites – Xenoliths of the Earth Core

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Abstract. Summary of the published data has shown that native iron nodules, which are rarely found in the basic intrusions, are characterized by a higher content of low-temperature condensates of the protoplanetary disk (Ge, Ag, Cu) and a lower content of high-temperature condensates (Os, Ir, Ru, Pt, Rh, Pd, Ni, Co, Au) compared to iron meteorites. Such meteorites have signs of formation from the fragments of the cores of minor planets. This fact and obtained evidence of hot heterogeneous accretion of the Earth, the early formation of the Earth's core compared to the mantle and the growth of the primary content of low-temperature condensates from the inner parts of the core to the outside suggest the capture and the ascent of substance of outer core by mantle plumes, and basic magmas formed in them. This explains the peculiarities of their composition, their very rare presence in basites, and sometimes a huge mass of nodules (up to tens of tons). In case of such xenogenic origin, nodules of native iron are chemically unequilibrium with basites. This is the reason of the development of reaction cohenite-magnetite and cohenite-sulfide rims on their contact and an increase of ferruginosity of olivine in basites. The formation of the lower mantle material from the earliest high-temperature condensates of the protoplanetary disk explains the decreased content of potassium, sodium, water, and other lithophile components in the nodule-containing basites. The content of volatile components lowers the crystallization temperature of melts. Therefore, the loss of them under the influence of decompression at the low-depth stages of ascent led to rapid solidification of magmas, protected the iron nodules from subsidence, and explains their location mainly in the upper parts of the main intrusions, despite the high density of iron.

1. Introduction

Boulders of native iron were first discovered by A. E. Nordsheld on the coast of the Disco island (Greenland) [5]. Iron bodies here are contained in basites. Later inclusions of native iron were found in the basic rocks of Germany and the Siberian platform [4, 7]. It is noteworthy that, they sometimes have a huge mass, up to tens of tons. In the recently discovered nodule from the sill above the Zarya kimberlite pipe on the Siberian platform, iron has the α-Fe structure and the unit cell parameter a=0.260 nm. Its hardness is 1080 – 1150 MP [10]. Microprobe analysis showed the content in it 93.92 – 97.81 weight. % Fe, 2.14 – 4.02 % C, 0.40 – 0.74 % Ni, 0.72 – 1.22 % Co, 0.97 % Cu. According to semiquantitative spectral analysis, it contains tenths of a percent of Al, Si, Ca and hundredths of a percent of Ti, Mg. Inclusions of cohenite, various in shape, are widely distributed in basites. Troilite occurs at the borders and in the form of teardrop-shaped particles in the iron. Grains of graphite and magnetite occur. In other basites of the Siberian platform, taenite, ilmenite, cliftonite, sulfides, moissanite are present in iron, as well as very small (usually fractions of a millimeter) grains of native copper and intermetallic compounds [4].
2. Existing ideas about the genesis of native iron

The composition of the earth's iron is close to the composition of meteorite iron. Calculated cooling rates of iron meteorite matter in the first degrees in a million year indicate that, they are fragments of planet cores with a radius of hundreds of kilometers [1]. The origin of terrestrial iron is usually associated with the processes of reduction of iron oxides in the basic magmas under the influence of carbon of assimilated sedimentary rocks [3, 5] or as a result of infiltration of hypothetical reduced mantle fluids [4]. However, there is a large amount of data that contradicts the idea of such a genesis. Iron-containing basites usually do not have visible contacts with carbonaceous sedimentary rocks, and there is no native iron where these contacts exist [4]. Micro-inclusions of iron are also present in the rock-forming minerals of basites, which began to crystallize at the deep stages of the rise of the basic magmas before their penetration into the sedimentary strata. The rare presence of magnetite containing highly oxidized iron in basites also indicates that they did not undergo reduction processes.

It is experimentally determined that the presence of volatile components reduces the melting point of rocks at high pressure by many hundreds of degrees. Therefore, in the case of infiltration of fluids, rocks of the upper mantle would have completely melted. This is contradicted by the available geophysical data on their predominantly solid state. The presence of magnetite and the high content of trivalent iron (up to ten percent or more) in most mantle rocks and magmas contradict the assumption that highly reducing conditions exist in them.

With the approach of native iron to the nodules, there is no depletion of basites with iron. On the contrary, olivine ferruginosity increases from 25-45 % in distant areas of gabbro-dolerites of the Dzhaltulsky Intrusion of the Siberian platform to 50-60 % near the contact with the nodules and up to 90 % inside the nodules. [4]. This clearly shows that iron was moved by diffusion not from the host magmas to the nodules, but from the latter to the magmas. That is, the nodules are not chemically unequilibrium with the host basites and were not formed in them. Therefore, they are of xenogenic origin. The currently determined existence of rising ap mantle plumes allows us to assume the capture and removal of xenoliths from the earth's core by them and the basic magmas that were formed in them.

3. Mechanism of capture of core xenoliths by basic magmas

New data obtained in recent decades on the origin of geospheres allow us to reconstruct the mechanism of removal of the core xenoliths. Calculations have shown that the release of potential energy during accretion of the Earth led to the release of about 9000 cal/g [6]. Under the influence of such a huge heat release, its substance could warm up to 34 thousand degrees, which indicates a hot accretion of the Earth. This is confirmed by the presence of magmatic fractionation trends in mantle xenoliths from kimberlites and Early Cambrian crystalline complexes, a decrease in the average isotopic ages and crystallization temperatures of their various rocks in the formation sequence during fractionation, and the projection of the oldest geothermal gradients into the region of very high temperature on the earth's surface (up to 1000o C) [9]. These and many other data clearly indicate the formation of geospheres as a result of fractionation of the global magma ocean, which was formed as a result of impact heat release during accretion. The sharp chemical disequilibrium of mantle rocks with metallic iron, the distribution of H2O and CO2 on Earth, rather than H2 and CO [6], and many other data indicate that silicate and iron particles were never mixed in the interior part of the earth's, consequently, accretion was heterogeneous.

These data indicate that, the core was formed earlier than the mantle as a result of the amalgamation of iron particles of the protoplanetary disk mainly under the influence of magnetic forces [9], since these forces were billions of times more powerful than the forces of gravitational attraction. The silicate bodies that fell on the formed core melted under the influence of the impact heat release. The bottom part of the magma ocean, formed as a result of the impact heat release, was
crystallized and fractionated under the influence of increasing pressure load of the resulting upper parts. Cumulates formed the ultrabasic substance of the mantle. Residual melts ascended and subsequently formed an acidic crystalline crust and continental lithosphere (Fig. 1). Due to the gradual accumulation of lithophile components in the late condensates of the protoplanetary disk and in the forming magma ocean, the content of these components in the mantle increases from the bottom up.

The fall of large planetesimals led to the appearance of impact craters on the bottom of the magmatic ocean. The mostly basic melts that filled them, solidified quickly with compression, since they were under pressure above solidus. They formed eclogite. Judging by the size of impact basins on the moon, the volume of the basic rock bodies in the mantle can reach millions of cubic kilometers. The earliest of these bodies could contain xenoliths of the outer parts of the core. It is obvious that, due to the reduced density compared to the surrounding ultrabasic cumulates, the bodies of the basic rocks could ascend and carry the xenoliths out of the iron core. Decompression remelting of these rocks led to the formation of large volumes of basic magmas, sometimes containing nodules of native iron.

Xenoliths were formed from the outermost parts of the core, generated from the last iron condensates in the protoplanetary disk. Therefore, iron nodules in comparison with iron meteorites should have been enriched with low temperature condensates and depleted in high temperature ones. This is fully confirmed by the results of comparing the content of trace elements in meteorite and earth iron. According to the Fig. 2, the higher the condensation temperature of the element, the lower its content in the earth's iron in comparison with the meteorite. Thus, the earth's iron often contains the most high-temperature Os and Ir (condensation temperature, respectively, about 1600 and 1400 K) about 100 times less than the meteorite iron. The Au content (with a condensation temperature of about 1200 K) is only about 8 times less. The amount of relatively low-temperature Ag (about 850 K) is often, on the contrary, 12 times more than in meteorite iron.

**Figure 1.** Evolution of genetic processes and magmatism in the history of the Earth. Rise of various magmas: 1 – acidic, 2 – basic, 3 – komatiite, 4 – rapakivi and autonomous anorthosites, 5 – alkaline-ultrabasic, 6 – kimberlite, 7 – oceanic and traps sometimes with nodules of native iron.
Figure 2. Dependence of the ratio of the most common contents of siderophile elements in meteorite and earth’s iron (m/e) from the condensation temperature of these elements (T, K) in the protoplanetary disk. Dotted line – average line of correlation [8].

The xenogeneic origin of iron in basites is the reason for its chemical disequilibrium with the host silicate melt, the formation of cohenite-magnetite and cohenite-sulfide reaction shells around teardrop-like iron particles, and the preservation of magnetite in the host basites.

Iron was initially in the form of different sized bodies, which caused approximately its same distribution in basites. Over a long period of plastic flow of matter, during plume rising, these bodies were rounded and sometimes severely deformed, which explains the features of their morphology. Sometimes the large initial size is the cause of the gigantic mass of some inclusions. The iron in the inclusions was in the molten state for a significant part of the rise. This led to partial mechanical mixture of iron and silicate melts, formed as a result of decompression during the mantle plume rise. It explains the presence of iron-silicate parts in the nodules and the teardrop-like shape of iron particles in them. The molten state of iron causes the presence of its teardrop-like inclusions in the rock-forming minerals of basites.

The formation of iron-containing magmas of basites from the lowest-temperature condensate-poor lower mantle material explains the decreased content of potassium and other lithophile components in these rocks. For example, in the iron-bearing Khuntukan intrusion of the Siberian platform, the average K2O content according to 29 analyses is 0.39 % [4], which is 2 – 3 times less than in most basites that do not contain iron nodules. The sill of the Zarya pipe contains 0.38% of it, which is almost 2 times less than in traps (on average 0.65 %). The amount of sodium, phosphorus, and water in the studied iron-bearing basites is significantly lower, since they are also late low-temperature condensates of the protoplanetary disk [6]. But the contains MgO much more (on average 8.93 %) compared to traps without native iron (6.60%), since this component condensed during the early stages of mantle accretion. This is confirmed by the formation of iron-bearing magmas from the substance of the deepest parts of the mantle and iron nodules from the substance of the late outer parts of the core.

The predominantly solid-phase state of the plumes at the deep stage of ascent prevented iron inclusions from subsidence, despite their very high specific weight (7.87 g/cm3). Solidification of the upper parts of the rising magmatic columns due to the release of volatile components from them [9] prevented the nodules of native iron from subsidence and prevented the outflow of magmas on the earth's surface. This phenomenon explains the seemingly paradoxical confinement of iron nodules usually to near-surface intrusive varieties of basites and the location of the nodules most often in their upper parts [4].
4. Conclusions
Thus, the obtained results indicate the presence the substance of the deepest and most mysterious geosphere – the iron core, in some upper parts of the crust. The study of this substance can help solve many genetic problems of this geosphere.

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