Core formatio conditions that satisfies both the Ni abundance and W isotope ratio

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Core-mantle differentiation is one of the most dramatic events in the Earth's history. As a result of core formation, the Earth's mantle is depleted in siderophile elements. Amounts of siderophile elements retained in the mantle give important clues for estimation of core formation condition.

It is well known that the observed mantle abundance of Ni is larger than that predicted from low-pressure partitioning experiments. Recent high-pressure experimental studies show that the high-pressure partitioning can resolve this problem. It is proposed that the observed Ni abundance is consistent with the equilibration of mantle with iron at 43-59 GPa. In other words, the lower part of the mantle is not equilibrated with iron. We call this suggestion 'non-equilibrium of the mantle.'

W isotopic ratio depends on the core formation condition. Hf-W chronometer is used to determine the age of the core formation. Assuming the complete equilibration between the mantle and metallic iron, Yin et al. (2002) estimated the age of the core formation at 30 Myr after the formation of iron meteorites. However, as noted before, mantle abundance of Ni suggests 'non-equilibrium of the mantle' which is apparently inconsistent with the assumption adopted in the Hf-W chronometry.

According to the recent planetary formation theory, the terrestrial planets should have experienced the multiple giant impacts. The dynamic simulations of the giant impact indicate that the core of impactor chould rapidly combine with the Earth's core. This means that the metallic iron of the impactor has limited opportunity to equilibrate with the Earth's mantle. I call this indication 'non-equilibrium of the metal.' The effects of multiple occurrences of the giant impacts and 'non-equilibrium of the metal' are barely considered in explaining the Ni abundance and W isotopic ratio so far.

As described above, the different core formation scenarios are adopted in Ni abundance problem, Hf-W chronometry and the recent planetary formation theory. Here, we considered the effect of multiple giant impacts, non-equilibrium of the metal and non-equilibrium of the mantle, and investigated core formation condition and timing that satisfies both of Ni abundance and W isotopic ratio.

Our model is based on the recent planetary formation theory and has four parameters: the number of giant impacts, the core formation timing, the equilibration rate of the early earth's mantle and the equilibration rate of the impactor's core.

This study suggests two possibilities of the core formation condition.

1. Relatively shallow magma ocean was formed. Pressure at bottom of the magma ocean reached 45 GPa.

2. Deep magma ocean reaching core-mantle boundary was formed. In this magma ocean, about 10 % of the impactor's core was equilibrated.

The former case would require reconsideration on the nature of giant impacts because the dynamic simulations of the giant impact have indicated the formation of deep magma ocean. In the latter case, two important constraints on the protoplanet would be derived; the protoplanet should have had the core and the protoplanet should have experienced the re-equilibration event between the core and the mantle 17 Myr after the formation of iron meteorites.

It is interesting to note that such a protoplanet is quite similar to Mars. W isotopic ratio of the SNC meteorites indicates that Mars should have experienced re-equilibration event between the core and the mantle 17 Myr after the formation of iron meteorites. In addition, calculated Ni abundance in the protoplanets agrees well with the Ni abundance of Martian mantle inferred from SNC meteorites.