Following accretion,

a deep terrestrial magma ocean…

- Siderophile elements (Fe-Ni) to the core, leaving behind the early (primitive) silicate mantle/ BSE (bulk silicate Earth).
- From the primitive silicate earth, the crust (continental and oceanic) was extracted from the early primitive mantle.

The timing of core formation

In order for any radioactive decay system to be of use in dating a process, that process must be able to fractionate the parent element from the daughter element.

The two decay schemes with elements of contrasting properties are Hafnium–Tungsten (Hf–W) and Uranium–Lead (U–Pb).

Of the two systems, U–Pb involves long-lived isotopes, whereas the Hf–W scheme has a much shorter half-life – it is much easier to illustrate the principles of the approach to this problem using the Hf–W system.

Hf and W during core formation, both elements are refractory and so were accreted to the Earth in chondritic proportions.

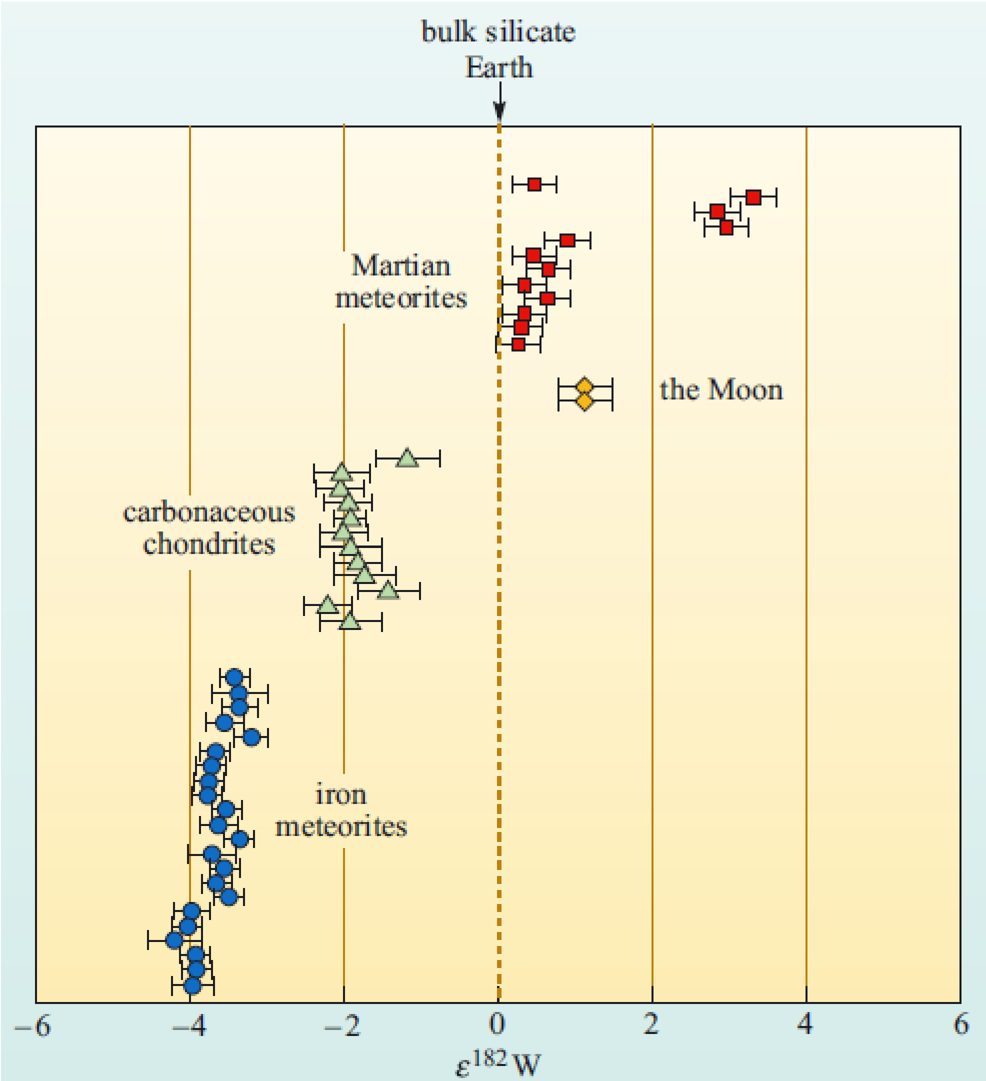
Assuming the bulk silicate Earth has a chondritic Hf/W ratio, how will the Hf/W ratio of the core and mantle differ from that in chondrites?

The core will have an Hf/W ratio lower than chondrites because W is siderophile and will be enriched in the core. Hf, being lithophile, will remain in the mantle, which will have an Hf/W ratio greater than in chondrites.

182Hf decays by β decay to 182W with a half-life of 8.9 Ma.

If the core separated from the mantle magma ocean while 182Hf was sufficiently abundant, what would happen to the 182W/184W ratio of (a) the mantle and (b) the core?

At the time of element fractionation, the 182W/184W ratio of both core and mantle would be similar. However, with time, that of the mantle would increase rapidly because of its high Hf/W ratio, while that of the core would increase less rapidly because of its low Hf/W ratio.



The effect of Hf/W fractionation on W isotopes is well illustrated by measurements of W isotopes in iron meteorites.

metal from iron meteorites has low 182W/184W ratios (low ε182Hf) lower than both chondritic meteorites and the silicate Earth (the mantle). The simplest explanation for this is that these metals sampled early Solar System tungsten before live 182Hf had decayed.

The tungsten isotope difference between early metals, carbonaceous chondrites and the bulk silicate Earth reflects the Hf/W ratio of the material that formed the Earth and its fractionation during the lifetime of 182Hf. As a result of core formation, the bulk silicate Earth has an elevated Hf/W ratio (~15) relative to chondrite meteorites (Hf/W ratio ~1).

Therefore, provided that the Earth’s core formed early, i.e. during the lifetime of 182Hf, an excess in the 182W atomic abundance in the bulk silicate Earth relative to chondrites or iron meteorites will be generated.

The conclusion from the extinct Hf–W system is that planetary differentiation occurred while 182Hf was still present.

As its half-life is 8.9 Ma, this implies that the core and mantle must have separated within the first few tens of millions of years of Earth history.

Needless to say, the detailed interpretation of W isotopes in planetary bodies is more complex than described here, but the principles remain the same.

The data for chondrite meteorites, some of which are independently dated, yield an $\varepsilon^{182}W$ value of around –2, relative to the bulk silicate Earth (and the Moon), which has a much higher Hf/W ratio. These differences have been modelled with core separation between 30 Ma and 50 Ma after the start of the Solar System.