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The formation and early differentiation of the Earth

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The currently accepted model of planetary formation is that the cloud and dust surrounding the young sun accreted in about 104 yr to form 10 km size planetesimals. Gravitational interactions and collisions between planetesimals progressed to generate a few tens of moon to Mars-sized planetary embryos in $\sim$1 M.yr. Earth grew from these embryos through a succession of impacts, culminating in the moon-forming giant impact. The energies of impact, combined with the energy of radioactive decay means that the growing Earth would have frequently been covered by a thick molten layer, a "Magma Ocean" which assisted in differentiation.

Apart from the insight provided by these models, the principal evidence for the earliest history of the Earth comes from the chemical and isotopic compositions of the silicate mantle and crust, collectively called the "Bulk Silicate Earth"(BSE). Since the Earth has close chemical affinities with undifferentiated chondritic meteorites, the chemical and isotopic similarities and differences between BSE and undifferentiated meteorites enable us to constrain better the processes of accretion and differentiation of the early Earth.

BSE is depleted in siderophile elements such as Ni, Co, Au and Pt relative to undifferentiated meteorites because these elements were partitioned into the core. We now have a large number of experimental data on how elements partition between metal and silicate which enable us to determine how Earth segregated its core. Simultaneous consideration of the depletion factors of a large number of elements in BSE lead to the following general conclusions: (1) The average pressure of core segregation on Earth was high $>$30 GPa , implying depths of $>$800 km. (2) Earth began as a small, strongly reduced body and became more oxidised as it grew. (3) Si and S are major components of the "light" element in Earth's core.

Short and long-lived radionuclide systems constrain the timing of accretion and differentiation. 182 Hf (t¬¬1/2=9 M.yr) which is lithophile decays to siderophile 182W. The 182W isotope anomaly of BSE constrains the Earth to have been 90% accreted within $\sim$25 M.yr of the origin of the solar system. The long-lived 235,238U (lithophile) - 207,206Pb (siderophile) system can only be consistent with the 182Hf-182W system, however, if Pb was lost to the core or to space at the time of the moon-forming impact 80-140 M.yr after the origin of the solar system.

Crystallisation of the lower mantle led to the production of silicate perovskites of (Mg,Fe)SiO3 and CaSiO3 composition. These minerals are unusual in their affinity for elements which are not readily accommodated in the upper mantle- U, Th, Zr, Hf, Fe3+ for example. From experimentally- measured partitioning of these elements between perovskite and silicate melt we are able to show that almost all chemical evidence of an early magma ocean has been obliterated by mantle convection. The one current exception is the 142Nd (product of 146Sm decay) anomaly of the upper mantle which implies a higher than chondritic Sm/Nd ratio of BSE. Either there is a corresponding high Nd/Sm reservoir "hidden" in the Earth or some material with high Nd/Sm was lost from Earth during accretion. A final attribute of silicate perovskite is its affinity for Fe3+ which is so strong that it can force disproportionation of Fe2+ to Fe3+ plus Fe (metal). This means that the relatively high Fe3+/Fe2+ ratio of the mantle may have been internally generated by perovskite crystallisation rather than produced by recycling of oxidised Fe through subduction.