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Accretion of the Earth: Constraints from Element Abundances and Isotope Compositions of Bulk Silicate Earth

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A common characteristic of al rocky materials originating from small and undifferentiated bodies of the Solar System is their near to solar relative abundances of refractory elements. The volatile elements show variable degrees of depletion in the moderately volatile elements. This depletion correlates with the respective condensation temperatures of the elements. The different known Solar System materials show variability in some isotopes due to their different nucleosynthetic origins. The variability in neutron-rich isotopes of the Fe-group elements indicates only two major sources for these isotopes that were then heterogeneously distributed in the solar nebula prior to accretion of planetesimals.

The element and isotope composition of bulk silicate Earth (BSE) cannot be modeled as a simple mixture of known meteorites compositions with different isotope and element abundances. It can be modeled as a mixture of two components: A) strongly volatile element depleted and reduced material, not represented by known meteorites, but with affinities to the ordinary chondrite reservoir; B) volatile richer and oxidized material that is possibly represented by material from the carbonaceous chondrite reservoir. This two-component mixture reproduces the lithophile element pattern of BSE when combined in a ratio of 9:1. The two components originated from different parts of the solar system with the larger component (proto-Earth) having accreted at a shorter and the smaller component (Theia) at a larger solar distance. Thus the BSE composition attests to mixing of material that originated from the volatile element-poor and the volatile-rich regions of the Solar System resulting in a slightly hydrated rocky planet in the inner Solar System. Constraints from Pb and Sr isotope compositions of the Earth indicate that this mixing occurred at ca. 4.50 Ga and corresponds to the giant impact that also formed the Moon. This late addition of material to the Earth provides a mechanism for the delivery of volatiles that made the Earth a habitable planet.