Earth formation: Combining physical models with isotopic and elemental constraints

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Models of Earth formation have undergone substantial refinement in recent years, although their basic characteristics differ little from the "classic" views of Safronov and Wetherill. In these models, Earth accumulation can be mostly completed in 10 Ma but may extend out over tens of millions of years and the source material for Earth is derived from a fairly wide range of circumsolar distances of condensation or first accumulation. Both of these conclusions may still undergo revision as dynamicists seek a better understanding of the role of small bodies and dissipation in the formation process. But it seems unavoidable that giant impacts occurred and these events are likely to set the stage for lunar formation and the initial state of Earth, including much of the physics that governs core formation, initial core temperature, siderophile abundances in the mantle, possible differentiation of the mantle into a layered structure and formation of Earth's initial atmosphere and hydrosphere. I will focus here on some recent efforts to understand Hf-W and what his may tell us about core formation (both timing and process). I will also talk about oxygen isotope puzzle: Why is Earth and Moon so similar. I will argue that the Hf-W story does not require early (~10Ma) earth formation because it tells core formation time and this process may have taken place in large part in precursor bodies rather than Earth itself. I will also argue that the oxygen isotopic similarity may be an out come of a giant impact scenario in which the lunar-forming disk equilibrates isotopes with Earth on a timescale ~100 years, even though the Mars-mass projectile might have had a Mars-like isotopic character.

The oxygen isotope composition of the sun

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The oxygen isotope composition of the Sun is one of the outstanding issues in cosmochemistry. Refractory inclusions show up to 6 % enrichment in ^{16}O relative to terrestrial which was originally ascribed to a nucleosynthetic input to the solar system. With the discovery of non-linear fractionation in the Earth's atmosphere it appears more likely that a chemical mechanism is responsible. Clayton (2002) has proposed that photochemical predissociation and self shielding lead to preferential enrichment of ^{16}O in CO gas, and ^{17}O, ^{18}O-rich water ice. Recently Yurimoto and Kuramoto (2004) have proposed that the ^{16}O anomaly is inherited from the molecular cloud precursor. In both of these models, the Sun will have a composition that is ^{16}O-rich, in this case, at least as ^{16}O-rich as refractory inclusions.

We have measured the oxygen isotopic composition of solar wind in lunar metal grains (Ireland et al., 2004). The oxygen implanted in the grains is depleted in ^{16}O by 54 ± 5 ‰ relative to terrestrial oxygen. Rather than having the ^{16}O-enriched composition of refractory inclusions, the Sun is depleted in ^{16}O, and does not match any prior prediction.

If the Sun is depleted in ^{16}O, it cannot be reconciled with a solar nebula predissociation model, but can be accomodated in a model of molecular cloud inheritance. Specifically, removal or partial removal of the C^{16}O gas in the star-forming region will move the nebula to a heavier oxygen isotope composition.

If molecular cloud inheritance is the source of the oxygen isotopic systematics observed, it has profound implications for our view of the early solar system. Thermal processing in the early solar system simply unmixes the refractory ^{16}O-rich components from the molecular cloud dust. Refractory inclusions cannot be direct solar condensates, rather they must be predominantly remelted residues of dust from the molecular cloud, potentially with recondensation of evaporated material. Fractionation of volatile elements may take place in the star-forming region leading to abundance differences between dust in the accretion disk and in the Sun.

References

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