Planetesimals: Early Differentiation And Consequences For Planets

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Planetesimals are small, rocky and icy planetary bodies that formed and evolved in the early solar system. Planetesimals play at least two important roles in planetary science. First, as the first generation of planetary objects, they served as the fundamental building blocks of planets. Intermediate in size between cm-sized pebbles and 1000-km-sized planetary embryos, they represent a critical and still enigmatic stage in planetary growth.

Because the formation of km-sized bodies is difficult to understand given the likelihood of erosive mutual collisions and rapid orbital evolution due to gas drag, solving this problem will provide fundamental constraints on the sizes of accreting bodies, the nature of turbulence in the nebula, and the intensity of nebular magnetic fields. Additionally, planetesimals, and their modern-day relics—asteroids, comets and Kuiper belt objects—are fascinating planetary worlds in their own right. They experienced a much broader range of thermal histories than planets; these diverse conditions produced a diversity igneous end states, from unmelted bodies, to partially melted bodies to fully molten and differentiated objects. Furthermore, their geologic evolution and internal structures were fundamentally sculpted by impacts and mutual collisions. In many ways, planetesimals are like the planets they became, but in other ways they are very unfamiliar places.

In 2017 Cambridge University press published an edited volume on planetesimals, summarizing the state of knowledge of this newly energized and rapidly-changing field [1]. Here we will present a review of research on planetesimals.

Iron meteorites demonstrate the existence of differentiated rocky planetesimals in the first 500,000 years after solids formed in the disk [2], and Vesta has differentiated into a metal core and silicate mantle (Raymond et al., this volume). Johansen et al. [3] suggest the icy asteroids formed between 2 to 4 My after calcium-aluminum-rich inclusions (CAIs). The breakthrough discovery of pebble accretion, which shows that pebble-sized objects accrete to form larger objects extremely efficiently through gravitational perturbation of their orbits, indicates that accretion timescale could have been as short as a few thousand years for 100 km objects [4]. This extremely short timescale supports the use of simple models that assume nearly instantaneous accretion relative to the timescale of ^{26}Al heating, although pebble accretion would have continued past the point of ^{26}Al activity, and coated the young planetesimals with unmelted rinds over ~1 million years [3].

The meteorite collection and the asteroid belt differ in their ratios of primitive and differentiated metal and silicate fractions compared to models of differentiation, but all also differ in their ratios of metal and silicate in the completed planets Mercury, Venus, and Earth. However, the combined effects of fluid and magma mobilization and loss and impact erosion necessarily created a broad taxonomy of planetesimals, each of which would contribute a different share of volatiles, metals, and silicates to growing embryos and planets. Furthermore, we may not have samples from the material that formed the terrestrial planets, since most of our meteoritic material originated from the asteroid belt in relatively recent times.

References

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Keywords: rocky and icy planetary bodies , erosive mutual collisions , rapid orbital evolution, asteroids, comets and Kuiper belt objects, meteorite collection , pebble accretion

