**SPECIAL COLLECTION: BUILDING PLANETS: THE DYNAMICS AND GEOCHEMISTRY OF CORE FORMATION**

**How to make a planet: An introduction†**

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**ABSTRACT**

The Special Collection “Building Planets: The dynamics and geochemistry of core formation” aims to combine cutting edge experimental, analytical, and modeling results with review articles defining the state of the science and current challenges to our understanding of the origin, geophysics, and geochemistry of planetary cores. Our goal is to highlight novel and interdisciplinary approaches that address aspects of core formation and evolution at the atomic, grain, and planetary scales.

**Keywords:** Core formation, geochemistry of planetary materials, geodynamics of planets, highly siderophile elements, experimental petrology, meteoritics

**INTRODUCTION**

A common attribute of the terrestrial planets is the existence of a metallic core surrounded by a silicate mantle. The segregation of metal from silicate in early, undifferentiated material is one of the most important steps in the evolution of terrestrial solar system bodies. The separation of Fe-rich metal from a magnesium silicate matrix imparted a strong geochemical signature on early silicate mantles due to the preferential incorporation of siderophile (metal-loving) elements into the core. However, estimating the bulk silicate earth (BSE) composition and that of other terrestrial bodies by way of candidate planetary bulk compositions requires not only an understanding of its timing and the associated geochemical ramifications, but the knowledge of the physical core-forming process under different conditions (O’Neill and Palme 1998; Yin et al. 2002; Rudge et al. 2010; Rubie et al. 2007, 2011).

Core formation on Earth occurred simultaneously with the accretion process and was complete within about 30–100 million years of the beginning of the Solar System (e.g., Lee and Halliday 1997; Yin et al. 2002; Kleine et al. 2002). Some smaller bodies (<100 km) may have formed their cores entirely through the percolation of metallic liquids through a solid silicate mantle, but planets as large as Earth likely experienced significant melting that aided efficient segregation of the core from the mantle (e.g., Stevenson 1990; Karato and Murthy 1997; Solomatov 2000; Rubie et al. 2003; Canup 2008; Elkins-Tanton 2012). Although some aspects of this process are well established, there are still important open questions regarding the details of core formation both geophysically and geochemically. The suggestion of an early magma ocean on Earth has persisted for decades (e.g., Stevenson 1990; Abe and Matsui 1986; Dahl and Stevenson 2010; Rubie et al. 2011) and is supported by both geophysical and geochemical evidence. The heat supplied to Earth by a combination of impacts, radioactive decay by short-lived isotopes such as $^{26}$Al and $^{40}$Fe, thermal blanketing effects of a dense atmosphere, and gravitational energy from metal segregation was sufficient to melt large portions of the Earth early in its history. In particular, the energy supplied by the large moon-forming impactor may have melted a substantial portion of the entire mantle (i.e., Tonks and Melosh 1993; Canup 2004; Halliday 2004). Geochemical arguments for a terrestrial magma ocean are derived from the abundance of siderophile elements in the Earth’s mantle, and their experimentally determined partition coefficients between molten silicate and liquid metal at high pressures and temperatures (e.g., Li and Agee 1996, 2001; Righter et al. 1997; Righter and Drake 1999; Chabot et al. 2005; Cottrell et al. 2009; Righter 2011; Siebert et al. 2012). Based on these two lines of evidence, a basic view of the magma ocean scenario for core formation evolved. In this simplest scenario, a significant portion of the accreting, chondritic Earth is melted, creating a deep magma ocean with heat supplied from impacts, radioactive decay, and metal infalling. New accreting material has a roughly chondritic composition and is fully melted and incorporated into the deep magma ocean on impact. The metallic and silicate components in the magma ocean are emulsified, and small, immiscible droplets of metallic liquid “rain down” through the magma ocean, maintaining chemical equilibrium with the silicate as they fall. Upon hitting a rheological boundary, defined by the mantle liquidus and assuming a short liquidus/solidus interval, the metallic droplets pool together, forming a liquid metal pond, and record this as the pressure, temperature, and $f_{O_2}$ conditions of their last equilibration with the mantle. Once a sufficient mass of liquid metal has ponded at the top of the solid mantle, due to a Rayleigh-Taylor instability it descends through the solid portion of the mantle as large diapirs. The diapirs settle into the core at a fast enough rate that they do not further equilibrate with the surrounding mantle, especially because equilibration would be rate limited by extremely slow diffusion within the solid silicate minerals.

Over the past several years, much effort has been put forth to model this magma ocean scenario from both a geochemical and geodynamic perspective, and results have indicated that the

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