The accretion and differentiation of Earth under oxidizing conditions†

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ABSTRACT

We present a new approach to model planetary accretion and continuous core formation, and discuss the implications if Earth accreted under conditions initially more oxidized than the modern day mantle. The modified model uses the same partitioning data that were previously used to model accretion under reducing conditions, however, changing the partitioning between accreting metal and silicate mantle means that reducing conditions fail to meet expected core/mantle values. Instead, the model requires conditions more oxidized than the modern day mantle to converge and to yield expected elemental core/mantle distribution values for moderately siderophile elements. The initial oxygen fugacity required to provide the crucial level of oxidation is approximately ΔIW ~ −1.2 to −1.7 and thus is in the range of carbonaceous and ordinary chondrites. The range of peak pressures for metal silicate partitioning is 60–6 GPa and oxygen fugacity must decrease to meet modern FeO mantle contents as accretion continues. Core formation under oxidizing conditions bears some interesting consequences for the terrestrial Si budget. Although the presented partitioning model can produce a Si content in the core of 5.2 wt%, oxidizing accretion may limit this to a maximum of ~3.0 to 2.2 wt%, depending on the initial fO2 in BSE, which places bulk earth Mg/Si ratio between 0.98–1.0. In addition, under oxidizing conditions, Si starts partitioning late during accretion, e.g., when model earth reached >60% of total mass. As a consequence, the high P-T regime reduces the accompanied isotope fractionation considerably, to 0.07‰ for 5.2 wt% Si in the core. The isotope fractionation is considerably less, when a maximum of 3.0 wt% in the core is applied. Under oxidizing conditions it becomes difficult to ascertain that the Si isotope composition of BSE is due to core-formation only. Bulk Earth’s Si isotope composition is then not chondritic and may have been inherited from Earth’s precursor material.

Keywords: Terrestrial accretion, core formation, Si isotopes, terrestrial building blocks

INTRODUCTION

The formation of the Earth’s core was one of the most significant differentiation processes during planetary formation and evolution. Accreting metal and silicate components segregating under chemical equilibrium created a net flux of siderophile elements into the core, thereby modifying the chemical composition of the silicate component. Knowing the exact chemical composition of the Earth’s core is therefore fundamental to the understanding of Earth’s origin and the composition of if it is very building blocks (e.g., McDonough 2003 and references therein). Unfortunately, direct sampling is not possible due to the inaccessible location of Earth’s core and therefore, the accurate composition of the core will remain elusive. Compositional constraints will have to rely on indirect approaches, such as theoretical models of core and mantle composition (e.g., Allègre et al. 1995; McDonough and Sun 1995; McDonough 2003), laboratory high P-T experiments (e.g., Thibault and Walter 1995; Li and Agee 1996; Righter and Drake 1997; Li and Fei 2004; Walter and Trønnes 2004; Chabot et al. 2005; Wade and Wood 2005; Corgne et al. 2008; Jephcoat et al. 2008; Wood et al. 2009; Bouché and Jephcoat 2011; Siebert et al. 2011) and geo/cosmochemical studies (Palme and O’Neill 2003). For such comparisons it is paramount to have a sound understanding of the conditions that prevailed during the formation of the core and accompanied metal-silicate equilibration. The partitioning of elements between the metal core and the silicate mantle depends on several parameters, such as temperature (T), pressure (P), oxygen fugacity (fO2), and the composition of the metal and silicate phases in question, all of which evolved during accretion as a result of planet growth and chemical evolution (e.g., Wade and Wood 2005; Corgne et al. 2008; Wood et al. 2009; Siebert et al. 2013).

To infer P, T, and fO2 conditions of core formation, a common approach is to use experimental results of elemental partitioning (commonly siderophile and chalcophile elements) in accretion models. This is done in an attempt to simulate metal-silicate partitioning during core formation under different conditions, and to match the results of such accretion models with compositional models for core and mantle compositions. One key aspect of such core formation models is the parameterization of the elemental partitioning between metal and silicate. To that end, experimental data are used to obtain regression parameters, typically called a, b, c, and d (Righter and Drake 1997; Righter et al. 1997; Wade and Wood 2005; Corgne et al. 2008; Wood et al. 2009; Siebert et al. 2013). Despite large variations in these regression parameters among published data sets (cf. compilation in Siebert et al. 2011), most models of continuous core formation predict initial planetary