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The origin of ferroan and magnesian anorthosites in the lunar crust

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1 Introduction

The widely accepted standard model for the lunar feldspathic crust is: the early Moon was wholly or mostly molten, forming Lunar Magma Ocean (LMO). Olivine and pyroxene crystallized first from that magma ocean and sank to form the Moon’s mantle. After ~80% of the LMO had solidified, plagioclase feldspar began to crystallize, floated in the dense Fe-rich melt (Snyder et al., 1992), and collected at the Moon’s surface to form a global crust of ferroan anorthosite (Shearer and Papike, 1999). However, as the observational data on lunar meteorites is continuously accumulated, the standard model received challenges (Pernet-Fisher and Joy, 2016; Shearer et al., 2015), such as the nearly constant composition of calcic plagioclase (An95–98) in the feldspathic crust (Xu et al., 2016)， the coexistence of ferroan and magnesian anorthosite (Gross et al., 2014), which is difficult to be explained by the standard model (Xu et al., 2016).

2 Model

At the initial stage of solidification, the surface temperature of the LMO is mainly controlled by the shines of the Sun and early Earth (Arpita et al., 2014), because the small planet, the Moon, cannot keep its primary atmosphere. Thus, solidification on the top of the LMO is important, and temperature gradient must exist and be kept between the solified lid and the interior of the LMO (Xu et al., 2016). Based on this hypothesis and paradigm, our model for the origin of the coexistence of ferroan and magnesian anorthosite in the lunar crust is: these melts for the ferroan and magnesian anorthosite are formed in the region that has a temperature gradient. Because temperature gradient causes compositional differentiation in silicate melt (Walker and Delong, 1982), and the liquidus of mafic melt is mainly controlled by the MgO content (Chen and Zhang, 2008; Niu et al., 2002)， therefore melts with a continuous spectrum from high to low Mg# can be formed from bottom up in the temperature-imposed region. In addition, plagioclases formed by these melts have high An content (Xu et al., 2016).

3 Implications

Chemical and isotopic fractionations (Richter et al., 1999; Walker and Delong, 1982) caused by temperature gradient have been shown very early in the laboratory, but unambiguous natural occurrence has not been found so far. We think one of important reasons is: the time for keeping the temperature gradient in interior and the margin of igneous intrusion or lavas, is too short to lead a significant fractionation in chemistry and isotope, since the thermal diffusion is several orders of magnitude faster than the mass diffusion. While the temperature gradient can be kept for several million years within the partially solified top of the LMO, thus significantly chemical fractionation must occur during the formation of the lunar anorthositic crust.

The initial cooling stage of planetesimal is similar to our model, and the formations of chondrules and chondrites are also related to this process (Sanders and Scott, 2012)， thus chemical fractionation caused by temperature gradient can be predicted in the chondrules and chondrites.

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