THE ROLE OF TITANIUM ON DIFFERENTIATION OF MAGMA OCEAN OF SMALL BODIES.

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Introduction: The Moon has a radius of ~1700km, which is larger than planetesimals by factors, and its initial evolution would give us important clues to understand the formation and evolution of planetesimals [1]. The lunar crust and mantle are thought to have formed by fractional differentiation during cooling of the whole scale lunar magma ocean (LMO) (e.g., [2]). Mare basalts that erupted several hundred million years later are grouped into three types by the abundance of Ti, high-Ti, low-Ti, and very low-Ti. Although the Clementine remote sensing data suggest that there are continua among them [3], the source of Ti-rich basalt may be related to the late-stage overturn of the highly fractionated magma ocean products [1, 4]. Therefore, the role and behavior of Ti during cooling of LMO should be strongly related to Moon's later evolution, which may be also important for planetesimals.

Purpose: The present study aims to evaluate the role of Ti on crystallization of LMO by thermodynamic and fluid dynamic modeling. The roles that should be evaluated are phase relations and composition of minerals and melt, viscosity and density of melt, and resulting differentiation processes. This is a companion paper with [5].

Model: The differentiation model is based on [6]. At first, bulk silicate Moon composition is assumed, for which equilibrium crystallization was calculated with MELTS or pMELTS at the pressure corresponding to the middle depth of LMO. Titanium is enriched in accordance with Al (and Ca), because they behave as refractory elements in cosmochemical environments. The refractory elements and Fe are varied as parameters. Crystals were separated from a convective magma ocean when the fraction of crystal vol.% becomes lager than a critical value X (=0.1 to 0.4). The chemical composition and depth of residual LMO was calculated by converting the volume of separated minerals to the thickness above the core. The depth of LMO is assumed to be 1000km. Then, the same procedures were repeated until anorthite appears as a liquidus phase.

Results: Chemical composition of melt at the time of anorthite crystallization does not vary largely regardless of the degree of enrichment of Ti, which may due to the small abundance. They are, however, slightly included in mantle minerals; clinopyroxene contains ~0.2-2.2 wt% and spinel 0.2-1.6 wt% when the refractory element abundance is twice of BSE. The trace abundance of Ti in mantle minerals results in the enrichment of Ti in the residual melt almost proportional to Al. The viscosity and density of the melt calculated with [7,8] show that the density is slightly influenced if the enrichment degree becomes high, however, its effect is negligibly small compared to the role of Fe (Fig. 1). The negligible role of Ti on the density and viscosity of residual melt during differentiation is always the case for different differentiation mode (from equilibrium to maximum).

Although the Ti enrichment has been characterized for mare basalts, present study show that Ti has little roles on differentiation of LMO. Considering the small initial abundance, crystallization of ilmenite at the very late stage would neither play a critical role in the mantle overturn at the later stage nor mantle phase relations even if it is enriched by twice of BSE. The present argument would be applicable to planetesimals with smaller size than the Moon.

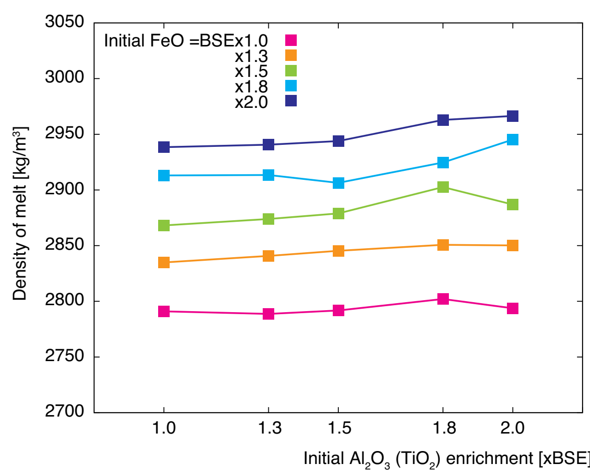

Fig. 1. Density of LMO melt at the time of anorthite crystallization for X=40 (X:critical crystal separation factor). The contents of refractory elements (Al, Ca, and Ti) and Fe are varied as parameters.

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