Composition of the hydrous lunar magma ocean and the crystallization process at the crust formation

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In the early history of lunar exploration, samples returned by the Apollo missions revealed that volatile elements are depleted on the Moon. It was also suggested that the volatile elements either survived or were accreted after the giant impact event that probably led to the formation of the Moon. However, the recent reanalysis of lunar samples have discovered hydroxyl or water. These observsions suggest that the Moon may not be entirely dry and contain some water. For example, Hui et al. (2013, Nature Geosci.) detected up to 2.7 ppm ware in plagioclase grains from the lunar highland crust sample. They suggest that the initial water content of the lunar magma ocean (LMO) was approximately 320 ppm. Lin et al. (2017, Nature Geoschi.) performed high-pressure, high-temperature experiments and estimate that the Moon may have contained 270-1650 ppm water at the time of LMO crystallization to yield the crustal thickness of 34-43 km based on GRAIL data. In order to constrain a plausible range of initial water contents, it is necessary to consider the influence of water in the whole process more petrologically.
To constrain the initial composition of the hydrous LMO, the calculation with the pMELTS and rhyilite-MELTS algorithm was performed to demonstrain the crystallization process.The initial water content were set to 10, 100, 1000, 2000 ppm water. The initial FeO, Al_2O_3 contents were set to 0.8 to 2.0 times those in the BSE (Bulk Silicate Earth) composition (McDonough and Sun, 1995, EPSL). In this stuidy, four different conditions among near maximum fractionation and near perfect equilibrium crystallization are simulated with adopting the parameter, suspended crystal fraction limit, "Xscfl" proposed by Sakai et al. (2014, Icarus). The calculation results were investigated with three conditions as follows : (1) the crustal thickness formed with anorthite, (2) the Mg# (= Mg/(Mg+Fe)) of the mafic minerals crystallized with anorthite, (3) the possibility of differentiation of anorthite.
The result of this research is tracking the entire process of the crystallization of initially hydrous LMO with thermodynamic caluculation. As the initial water content increased, the crystallization amount of olivine increased. The composition of melt at the time of plagioclase crystallization is poor in SiO_2 and the viscosity is smaller as the water content is higher. The CIPW normative calculation with the liquid composition at the time of plagioclase crystallization, the crustal rock which applied among anorthositic norite to gabbro norite in Clementine Classiification (Wieczorek et al., 2006, RiMG) . This suggests that the lunar crustal rocks that are consistent with observations can be created even under hydrated conditions.In this study, the crustal thickness and the Mg# of the mafic minerals crystallized with anorthite do not dependent on the initial water contents.
In this study, from the condition of liquid viscosity at the time of plagioclase crystallization and Mg# of mafic mineral, the minimum value and the maximum value of the initial FeO amount were restricted according to the initial water content. The larger the initial water content, the larger the minimum value of the initial FeO content and the smaller the maximum value. It is suggested that the initial FeO content under hydrated conditions was appropriate between 1.0 and 2.0 times BSE in this study. Depending on the constraints of lunar crust thickness, initial compositions with initial Al_2O_3 content is less than BSE should be more appropriate and the conditions which are close to the equilibrium crystallization should also be appropriate.

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