

High-pressure and -temperature experiments simulating the lunar KREEP layer and constraint on its water content

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KREEP, being the acronyms for **K** (potassium), **R**are **E**arth **E**lements, and **P** (phosphorous), layer is the lunar structure formed between the mantle and crust during the late-stage lunar magma ocean (LMO) differentiation and consequently is thought to be enriched in the incompatibles (Warren and Wasson, 1979). Volatile elements such as H, F, and, Cl are also incompatible in the LMO, and thus they should have been highly concentrated in the latest residuum of the LMO, urKREEP (Greenwood et al., 2017). According to Hui et al. (2013), the urKREEP might contain 1.4 wt% H₂O, based on water content of plagioclase in the Highland anorthosite and the LMO differentiation model. Greenwood et al. (2017) concluded that the urKREEP might reach ~1.3–2.4 wt% H₂O, considering degassing and diffusion of hydrogen through the lunar volcanism and volatile contents obtained from glasses and apatite in KREEPy basalts. However, the estimated water contents of the KREEP layer are model-dependent, because original KREEP rocks have not been returned yet. Here we performed high-pressure and -temperature experiment of the analogue material for KREEP to constrain water content of the KREEP layer.

Terrestrial alkali basalt (Changbaishan) were selected for the starting material, and the powder samples were enclosed in inner graphite and outer Pt capsules with ~ 1.0–6.2 wt% H₂O. The capsules were compressed at 1.0 GPa and heated at ~1050–1300 °C for 24 h duration using piston-cylinder apparatus and then were immediately after quenched by cutting power. The recovered samples were measured by SEM and FT-IR analyses for observation of the textures and determination of the chemical compositions and water contents retained in each experiment.

As a result of the SEM analysis, mineral assemblages of the recovered samples were olivine, clinopyroxene, plagioclase, ilmenite, amphibole, apatite, and glass. The minerals occur as an euhedral crystal and have no zoning structure of the chemical compositions within the grains. Furthermore, $K_D^{Cpx-liq}$ [Mg-Fe] values of clinopyroxene against glass quenched from the liquid ($=\frac{[FeO^{Cpx}MgO^{liq}]}{[FeO^{liq}MgO^{Cpx}]}$) become 0.24–0.32. These facts demonstrates that almost all of the mineral crystals produced by the present high-pressure and -temperature experiments grew under equilibrium state. In addition, glasses quenched from the liquid show a homogeneous chemical composition in each recovered sample, implying no occurrence of melt immiscibility. Water contents of the glasses and modal abundance of the amphibole crystals obtained from FTIR and SEM analyses revealed that most of water remains in the capsules even after high-pressure and -temperature experiments. Amphibole is absent in the recovered samples below ~3.2 wt% H₂O. Since no hydrous mineral such as amphibole has been discovered in the Apollo/Luna samples and lunar meteorites as well as by remote sensing observation, amphibole is unlikely to form as a major mineral differentiated from the LMO. Therefore, the maximum water content of the KREEP layer can be constrained to ~3.2 wt% because of absence of amphibole in the recovered samples below this value, from the viewpoint of the present experimental conditions and starting materials. Focusing on the Procellarum KREEP terrane volcanism (PKT), existence of 3.2 wt% water leads to 120 °C

decrease in liquidus of the KREEP layer, suggesting that water might be one of the significant trigger for PKT volcanism.

Keywords: lunar water, KREEP, high-pressure and -temperature experiment, the Procellarum KREEP terrane