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Atomic-scale mixing between MgO and H_2O in the deep interiors of water-rich planets

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Astrophysical surveys so far have suggested that water-rich planets could be common [1] (including Uranus and Neptune in our Solar System). In the conventional interior model of water-rich planets, it has been assumed to have separate layers of atmosphere, ice/fluid, rocky mantle and metallic core [2]. However, recent studies have proposed the existence of heavy elements in the ice/fluid layer of Uranus, challenging the conventional view [3]. In addition, chemical interaction and thermodynamic processes of major rock-forming minerals at the H_2O–rock interface conditions of the water-rich planetary interiors have been scarcely explored.

We have performed laser-heated diamond-anvil cell experiments on two rock-forming minerals, olivine ($(Mg_{0.9},Fe_{0.1})_2SiO_4$) and ferropericlase ($(Mg_{0.9},Fe_{0.1})O$), in water at the pressure and temperature conditions expected for the water-rich planets. During laser-heating, we collected X-ray diffraction (XRD) data at beamlines 13-IDD of GSECARS at APS and P02.2, the ECB of PETRA III at DESY. Our dataset covers pressures between 20 and 80 GPa. After high-pressure and high-temperature experiments, we conducted chemical and textural analysis using focused ion beam (FIB) and scanning electron microscope (SEM) at Yonsei University.

During laser-heating, Si-rich high-pressure phases were formed, such as bridgmanite ($(Mg,Fe)SiO_3$) and stishovite (SiO_2), from the high Mg/Si ratio of starting composition (olivine). The formation of Si-rich phases from Mg-rich starting composition suggests dissolve of MgO into H_2O-liquid during laser-heating at high-pressures. This was also found for $(Mg_{0.9},Fe_{0.1})O$ ferropericlase starting material. The intensity of the diffraction peak of ferropericlase was dramatically decreased at high-pressure and high-temperature conditions, which indicates that $(Mg_{0.9},Fe_{0.1})O$ is soluble in H_2O-liquid. From chemical analysis, we found the dome-like structures, which showed that domes are Mg-rich and below the domes is Si-rich. Between Mg-rich and Si-rich regions, porous structures (almost empty) were positioned, meaning that MgO-rich fluid existed at high-pressure and high-temperature conditions. In summary, the textural and chemical analysis combined with XRD data indicates a selective leaching of MgO preferentially from silicate during laser heating, making MgO-dissolved in high-temperature fluid, which peaks between 20 and 40 GPa and above 1,500 K [4].

For water-rich planets with 1–6 Earth masses, the chemical reaction at the deep H_2O–rock interface would lead to high concentrations of MgO in the H_2O layer. For Uranus and Neptune, our experiments indicate that the top ~3% of the H_2O layer of them, the pressure and temperature conditions of which have been achieved in this study, would have a large storage capacity for MgO. If an early dynamic process enables the H_2O–rock reaction, the topmost H_2O layer may be rich in MgO, possibly affecting the thermal history of the planet.

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