HEATING HISTORY OF IGNEOUS RIM FORMATION DEDUCED FROM MICRO-SCALE MIGRATION OF OXYGEN ISOTOPES

N. Matsuda[1], N. Sakamoto[2], S. Tachibana[1,3] and H. Yurimoto[1,4], [1]Department of Natural History Sciences, Hokkaido University, Sapporo 060-0810, Japan (e-mail address: nozomi@ep.sci.hokudai.ac.jp), [2]Isotope Imaging Laboratory, Creative Research Institution, Hokkaido University, Sapporo 001-0021, Japan, [3]UTokyo Organization for Planetary and Space Science (UTOPS), University of Tokyo, Tokyo 113-0033, Japan. [4]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Kanagawa, 252-210, Japan.

Introduction: The ubiquitous occurrence of igneous rims across the chondrite groups suggests that igneous rim formation commonly occurred in the solar nebula and is related to chondrule formation [e.g., 1-3]. The rim formation process is not well understood compared with chondrule formation, especially the heating duration to form the igneous rim. Olivine grains within igneous rims sometimes contain extreme ^{16}O-rich areas in their interiors [3]. Such extreme ^{16}O-rich olivines cannot form during chondrule formation because the oxygen isotopic compositions of the minerals crystallized from the melted chondrules are typically close to those of the rocky planets [4]. Therefore, the extreme ^{16}O-rich olivines are the igneous rim feedstocks and heating process survivors from the igneous rim formation. The rim formation process could be traced from the extreme ^{16}O-rich olivine. In this study, we focus on two-dimensional chemical and oxygen isotopic distributions in an igneous rim of a chondrule within CV_{oxA} chondrite with sub-micrometer resolution in order to constrain the rim formation process.

Sample and Analytical methods: A porphyritic FeO-poor olivine chondrule with an igneous rim in a polished thin section of Northwest Africa 3118 CVoxA chondrite was used in this study. The petrographic observation and chemical analysis were performed by FE-SEM (JEOL JSM-7000F) equipped with an EDS (Oxford X-Max 150). Crystal orientation analysis was conducted by an EBSD (Oxford HKL) on the FE-SEM. Point analyses of oxygen isotopes of individual rim grains were performed using a secondary ion mass spectrometer (Cameca ims-1280HR). Quantitative oxygen isotope distribution within the rim was obtained by the Hokudai isotope microscope system (Cameca ims-1270 + SCAPS).

Results and discussion: The chondrule with type I porphyritic texture is completely surrounded by a coarse-grained igneous rim. The coarse-grained rim is mostly dominated by olivine. The olivine grains are rich in FeO compared with those within the host chondrule (Fa_{2-5}). The FeO contents show a bimodal distribution with peaks at MgO-rich (Fa_{11-22}) and FeO-rich (Fa_{40-49}) compositions. The oxygen isotopic composition ($\delta^{17}O = 2.0 \pm 1.8$ (2σ) ‰, $\delta^{18}O = 8.1 \pm 3.6$ ‰), the mass-dependent isotope fractionation, and the porous texture filling between the MgO-rich olivine grains indicate that the FeO-rich olivine precipitated from an aqueous fluid with ^{16}O-poor composition on the parent body. The MgO-rich olivine shows Fe-Mg chemical zoning at the interface to the FeO-rich olivine (Fa_{40-49}), indicating that Fe-Mg inter-diffusion occurred during the aqueous alteration on the parent body. The disturbance of Fe-Mg distribution in the MgO-rich olivine (Fa_{11-22}) due to the aqueous alteration is only limited to a 1 μm scale. Under the parent body alteration condition, no oxygen isotopic disturbances can be achieved at a scale greater than 0.1 μm using any oxygen self-diffusion coefficients. The oxygen diffusion scale across the FeO-rich and MgO-rich olivine is smaller than the spatial resolution of the oxygen isotopography (0.8 μm). The MgO-rich olivine, a primary phase of igneous rim formation, has oxygen isotopic compositions of $\delta^{17}O = -5.6 \pm 3.2$ ‰, $\delta^{18}O = -0.7 \pm 3.6$ ‰, and sometimes contains extreme ^{16}O-rich areas ($\delta^{17, 18}O = \sim-30$ ‰) nearly <10 μm across. We detected an oxygen isotopic migration of about 1 μm at the boundaries of the extreme ^{16}O-rich areas, which should reflect oxygen diffusion during the rim formation. Considering oxygen self-diffusivity, the igneous rim formation could have continued from several hours to several days at near liquidus temperatures (~2000 K) in the solar nebula. The calculated heating duration was similar to those for a chondrule formation event that was molten for up to several tens of hours [e.g., 5, 6], suggesting that the igneous rim was also formed during transient heating events.

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