WATER IN THE EARLY DIFFERENTIATED ASTEROIDS: INSIGHT FROM APATITE IN BASALTIC EUCRITES.

M. Koike[1] , T. Iizuka[2], N. Takahata[1], Y. Sano[1], and M. K. Haba[3], [1]Atmosphere and Ocean Research Institute, the University of Tokyo, 277-8564, Chiba, Japan. Email: mizuho_k@aori.u-tokyo.ac.jp, [2]Department of Earth and Planetary Science, the University of Tokyo, 113-0033, Tokyo, Japan, [3] Institute of Geochemistry and Petrology, ETH Zürich, 8092 Zürich, Switzerland.

Introduction: Water plays key roles in environmental evolutions of terrestrial planets, such as climate changes, magmatic activities and habitability. Despite the importance, origin and timing of the water supply to the terrestrial planets have been unclear, while several plausible models are proposed (e.g. [1][2]). Eucrites, a group of HEDs (howardites-eucrites-diogenites) are crustal samples from differentiated bodies, most likely, asteroid 4-Vesta. Since eucrites have recorded the ancient planetary differentiation (~5 Myr after CAI [3]), they are expected to provide valuable insight to the conditions at early stage of terrestrial planet formation, including the water supply. Recent studies reported H_2O abundances and D/H ratios in some apatite [4] and nominally anhydrous minerals [5] from various eucrites, suggesting that Vesta's could contain significant amounts of water during the crustal formation or the later periods. However, most eucrites have suffered severe thermal/impact metamorphisms as well as hydrous alteration after their crystallization, which might have altered primary information. In this context, U-Pb chronology in the same apatite grains will be helpful for better understanding. Here, we report our in-situ analyses of U-Pb dating and water abundances, as well as D/H ratios, of apatite in three eucrites, Agoult, Stannern and Camel Donga.

Samples & Analyses: Agoult is an unbrecciated granulite. Its texture and trace element pattern indicate strong re-heating and partial re-melting after crystallization [6]. Stannern is a polymict breccia with incompatible element enriched compositions, possibly due to crustal contamination [7]. The reported Pb-Pb ages of zircon in Stannern and Agoult are identical at 4.55Ga [8][9], which is considered as the timing of global crustal reheating after initial planetary formation and differentiation. Camel Donga is a unique monomict breccia characterized by abundant metal-Fe. The metal texture and composition indicates post-crystallization reduction of igneous FeS and pyroxene at later thermal event [8]. The Pb-Pb age of its zircon is slightly younger at 4.53Ga [13].

Both U-Pb dating and water analyses were conducted using NanoSIMS instrument at AORI, Univ. Tokyo, Japan. All samples were mounted in epoxy resin, polished, baked at ~100˚C for overnight and kept in the SIMS vessel at < 5E-9 Torr for 1 week before analyses. Detailed analytical methods were explained in the previous works [11].

Results & Discussion: We analyzed several euhedral apatite grains (grains size of ~50-100µm) in Agoult, several anhedral to subhedral apatite grains (~10-100µm) in Stannern and Camel Donga. For each meteorite, concordant ^{238}U-^{206}Pb and ^{207}Pb-^{206}Pb ages are obtained. The total Pb/U ages [11] are: 4522 ± 11 Ma for Agoult, 4413 ± 64 Ma for Camel Donga, and 4130 ± 45 Ma for Stannern, respectively. Agoult is significantly older than Camel Donga, while Stannern is markedly younger. Moreover, all apatites are clearly younger than the zircons in the same meteorite. The younger apatite age suggest that U-Pb system in these apatites was reset at later event, such as reheating or impact, and primary igneous information in the apatites might have been erased. It is noted that Agoult apatite (4.52±0.01Ga) and Camel Donga zircon (4.53Ga) might have recorded the same event.

Water abundances and D/H ratios of the same apatite grains were also investigated. Apatite in Agoult is almost anhydrous (< 100 ppm as H_2O), while Camel Donga contains some water (≤ 1,000 ppm) with δD of -470 ± 370‰. Stannern has intermediate H_2O of ~ 280 ppm with δD= -330±180 ‰. Our results of water abundances are similar and/or lower than the previous study (~700-2,600 ppm [4]), while the D/H ratios are consistent and identical to those of the terrestrial water and carbonaceous chondrites within errors.

Among the analyzed three meteorites, Agoult apatite is the oldest and the most anhydrous. Our data suggest that Vesta's crust, at least in some deep part where Agoult located, was relatively dry after 4.52 Ga. The younger apatites, Camel Donga and Stannern, are more water-rich, which might be the results of later metamorphisms. Although this does NOT necessarily require "dry accretion" for Vesta, it is presumed that only apatites from unmetamorphosed meteorites may have kept the primary water records.

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