A SHORT TIMESCALE FOR CAI RIM FORMATION.

T. Yoshizaki[1,*], T. Nakamura[1], D. Nakashima[1], N. Sakamoto[2], H. Ishida[1] and S. Itoh[3], [1]Tohoku University, Sendai, Japan ([*]tacasy22@dc.tohoku.ac.jp); [2]Hokkaido University, Sapporo, Japan; [3]Kyoto University, Kyoto, Japan.

Introduction: Calcium-aluminum-rich inclusions (CAIs) are the oldest dated solar system solids [1] that can provide us a key to understand physicochemical processes which occurred in the early solar system. Their mineralogy, isotopic compositions and occurrence in carbonaceous chondrites and cometary samples indicate that they have formed near the proto-Sun and transported to outer nebula [e.g., 2]. CAIs are often surrounded by multilayered Wark-Lovering (WL) rims [e.g., 3], which are considered to record the last high-T stage of the CAI formation and possibly transport history of CAIs in the solar nebula [e.g., 4]. Several scenarios are proposed for the origin of WL rim formation: condensation [e.g., 3], evaporation [5], nebular metasomatism [6] and a combination of them [e.g., 7]. Redox condition during the WL rim formation remains controversial [8, 9]. Duration of this event is estimated to be < 2 Myr based on ^{26}Al-^{26}Mg dating [e.g., 10], but detailed timescale is still unclear. Here, we discuss conditions and timescale of formation process of a WL rim on a compound CAI *R3C-01* from Roberts Massif 04143 (CV_{red}).

Methods: Petrology and mineralogy of *R3C-01* were studied using FE-SEM/EDS/EBSD and FE-EPMA/WDS at Tohoku University. Quantitative oxygen isotope imaging (isotopography) and spot analysis were performed with the isotope microscope system at Hokkaido University, consisting of the Cameca ims-1270 and SCAPS ion imager. Preliminary results for the inner parts of this CAI are reported by [11, 12].

Results and Discussion: *R3C-01* is an irregular-shaped type A CAI that is composed of five compact-textured lithological units and the WL rim. The innermost layer of the WL rim is composed of semi-continuous spinel intergrown with tiny Al,Ti-diopside. The second one consists of melilite-spinel intergrowth, which is surrounded by a diopside layer. Limited part of melilite is replaced by anorthite, suggesting short post-formation heating of the CAI [13]. The diopside layer is compositionally zoned outward from Al,Ti-rich to -poor and shows high Ti^{3+}/Ti^{tot} (0.4–1.0), suggesting rim formation under low f_{O2} [9]. The outermost layer of the WL rim consists of compact-textured forsterite and Fe,Ni-metal. Olivine show low-iron, manganese-enriched (LIME) composition, that can form only by condensation at low f_{O2} [14]. Decrease of refractoriness outwards the WL rim is also consistent with an equilibrium condensation origin [e.g., 3].

O-isotope imaging of the inner *R3C-01* reveals that minerals with high O diffusivity (e.g., reversely-zoned melilite with Åk-rich core) are ^{16}O-poor, and they show sharp boundaries with ^{16}O-rich minerals [11]. WL rim phases are ^{16}O-rich, indicating that the isotopic heterogeneity of the inner CAI should have been established before the WL rim formation, possibly by solid-state isotopic modification of ^{16}O-rich precursor in a ^{16}O-poor reservoir [4], or aggregation of isotopically distinct grains. Therefore, the subsequent annealing of the CAI during the WL rim formation must have been short enough to preserve the grain-scale O-isotopic disequilibrium in the interior CAI. Occurrence of ^{16}O-rich melilite ($Åk_{\sim5}$) adjacent to reversely-zoned, ^{16}O-poor melilite ($Åk_{\sim5}$ at the grain boundary) indicates that the scale of O-isotope exchange between these grains was smaller than the spatial resolution of the isotopography (< 1 μm) [15]. Using $x^2 \sim Dt$ and D from [16], the duration of the subsequent heating of *R3C-01* is estimated to have been < 10^3–10^5 hours at T range of 1100–1400 K, which corresponds to condensation temperatures of spinel and LIME olivine [14, 17]. This duration is long enough for fine-grained proto-CAI to become compact [e.g., 18]. The short timescale of the WL rim formation is also consistent with limited occurrence of anorthite replacing melilite in *R3C-01* and Al-Mg systematics of the other WL rims [e.g., 10].

The short duration of post-formation heating of CAIs suggests that the CAIs were rapidly removed from hot inner region of the solar nebula by outward turbulent flow [e.g., 2, 19] or disk winds [e.g., 20]. The rapid removal of CAIs from inner nebular region might have resulted in transport of CAIs beyond several AU before proto-Jupiter formation, which created a pressure bump and hindered inward drift of CAIs to the inner solar system [21–23], and thus caused refractory element enrichment in carbonaceous meteorites compared to non-carbonaceous ones [e.g., 24, 25].

References: [1] Connelly JN et al. (2012) *Science* 338:651. [2] Ciesla FJ (2007) *Science* 318:613. [3] Wark DA & Lovering JF (1977) *Proc LPSC* 8:95. [4] Simon JI et al. (2011) *Science* 331:1175. [5] Wark DA & Boynton WV (2001) *MAPS* 36:1135. [6] Ruzicka A (1997) *JGR* 102:13387. [7] Krot AN et al. (2017) *GCA* 201:155. [8] Dyl KA et al. (2011) *GCA* 75:937. [9] Simon SB et al. (2012) *GCA* 85:373. [10] Kawasaki N et al. (2017) *GCA* 201:83. [11] Yoshizaki T et al. (2017) *LPSC* 48:1378. [12] Yoshizaki T et al. (2017) *MAPS* 52:A400. [13] Cuzzi JN et al. (2005) *Chondrites and the PP Disk*, 732. [14] Ebel DS et al. (2012) *MAPS* 47:585. [15] Park C et al. (2012) *MAPS* 47:2070. [16] Yurimoto H et al. (1989) *GCA* 53:2387. [17] Lodders K (2003) *ApJ* 591:1220. [18] Karato S (1989) *Tectonophysics* 168:255. [19] Cuzzi JN et al. (2003) *Icarus* 166:385. [20] Van Kooten EMME et al. (2016) *PNAS* 113:2011. [21] Kruijer TS et al. (2017) *PNAS* 114:6712. [22] Desch SJ et al. (2017) arXiv:1710.03809. [23] Scott ERD et al. (2018) *ApJ* 854:164. [24] Rubin AE (2011) *Icarus* 213:547. [25] Rubin AE (2018) *LPSC* 49:1034.