Al-Mg SYSTEMATICS OF WARK-LOVERING RIMS AROUND A REFRACTORY INCLUSION FROM THE NWA 5028 CR2 CHONDRITE.

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Introduction: Wark-Lovering (WL) rims around Calcium-Aluminum rich Inclusions (CAIs) record petrographic and geochemical signatures of the earliest events that shaped our Solar System. The WL rims are made of refractory minerals such as hibonites, spinels, perovskites, melilites, and Al-rich pyroxenes; alteration phases such as nepheline, anorthite, sodalite, grossular and wollastonite have also been reported in these rim sequences [1]. Various mechanisms have been proposed to explain the formation of WL rims including: 1) condensation and subsequent accretion on the CAI surface [2-4]; 2) crystallization from a melt produced by flash-heating in the nebula [5]; 3) formation as an evaporation residue [6]; and 4) growth of layers as a result of chemical gradients set up during alteration of the inclusion in a nebular setting [7]. Placing time constraints on the formation of WL rims is not only crucial for identifying the appropriate model for rim sequence formation, but also for providing a broader understanding of the processes and dynamics within the protoplanetary disk. Most previous chronologic investigations of WL rims have focused on CAIs from the CV3 chondrites [8-10]. The components of CR2 chondrites are among the least affected by secondary alteration processes and, therefore, CAIs and their WL rims in these primitive meteorites may provide a pristine record of their formation histories [11, 12]. We present here high spatial resolution Al-Mg chronology of a CAI from a CR2 chondrite and its WL rim using a NanoSIMS instrument.

Sample Description: The CAI analyzed here is from the CR2 chondrite Northwest Africa (NWA) 5028. It is a type B inclusion that contains melilite, perovskite, spinel, and metal grains in the core. The WL rims consist of an innermost perovskite + hibonite + spinel layer followed by an intermediate melilite layer and an outermost pyroxene layer.

Methods: The mineralogy of the CAI and its WL rim sequences was characterized using the JEOL JXA-8530F electron microprobe at Arizona State University (ASU). Magnesium isotope analyses were conducted using a Cameca Ametek NanoSIMS 50L at ASU. A 16 keV O^- primary beam with a ~50-70 pA current was rastered over 5 × 5 µm areas on the sample. Positive secondary ion signals for $^{24}Mg^+$, $^{25}Mg^+$, $^{26}Mg^+$, and $^{27}Al^+$ were collected simultaneously using electron multipliers from the central 2.5 × 2.5 µm area. Isobaric interferences such as ^{23}NaH, $^{12}C_2$, ^{24}MgH, $^{13}C_2$, and $^{12}C^{14}N$ are completely resolved using a mass resolving power of <10000. Both natural and instrumental mass fractionation were corrected using internal normalization to a $^{25}Mg/^{24}Mg$ ratio = 0.12663 [13] using an exponential law with $\beta = 0.5128$ [14]. Radiogenic ^{26}Mg excess ($\delta^{26}Mg^*$) is expressed in per mil units relative to terrestrial standards. The uncertainties reported here are 2-sigma standard deviation of bracketing terrestrial standards, which were San Carlos olivine, Madagascar hibonite, and four terrestrial melilites.

Results and Conclusions: The interior of the CAI (where the phase with the highest Al/Mg ratios is melilite) defines an Al-Mg isochron with a canonical isochron with an initial $^{26}Al/^{27}Al$ ratio of $(6.0 \pm 1.1) \times 10^{-5}$, with an initial $\delta^{26}Mg^*$ of -1.1 ± 1.3‰ (MSWD = 2.6). The rim (where the phase with the highest Al/Mg ratios is hibonite) also defines a canonical isochron, within the errors, with an initial $^{26}Al/^{27}Al$ ratio of $(5.9 \pm 3.2) \times 10^{-5}$, with initial $\delta^{26}Mg^*$ of -1.3 ± 3.4‰ (MSWD = 2.0). This suggests that the rim layer containing hibonite could not have formed any later than ~640,000 years after the CAI formation. These results are in contrast with our earlier analyses of two CAIs from a CV3 oxidized chondrite NWA 8323, and their WL rims, where Al-Mg isochrons (defined primarily by anorthites) show a formation time difference of ~2 Ma between the interior and the rims [15, 16]. Our analyses collectively suggest that rim formation either occurred during episodic events or as a continuous process that began nearly contemporaneously with, and lasted for up to ~2 Ma after, CAI formation.

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