EXPORING THE DISTURBANCE OF AL-MG ISOTOPES IN THE FIRST SOLAR SYSTEM ROCKS: CALCIUM-RICH, ALUMINUM-RICH INCLUSIONS.

H. C. Connolly Jr.[1,2,3], E. D. Young[4], G. R. Huss[5], K. Nagashima[5], J. R. Beckett[6]. [1]Dept. Physical Sciences, Kingsborough Community College of CUNY, Brooklyn NY 11235 & Dept. Earth & Environmental Sciences, The Graduate Center of CUNY, 365 5th Ave., New York, New York, USA (chondrule@haroldconnolly.com); [2]Dept. Earth & Planetary Sciences, AMNH, New York, NY 10024 USA; [3] LPL, University of Arizona, Tucson, AZ 85721, USA, (chondrule@haroldconnolly.com); [4] Dept. of Earth & Space Science, UCLA, Los Angeles, CA 90095 USA; [5] Hawai‘i Institute of Geophysics & Planetology, University of Hawai‘i at Mānoa, Honolulu, HI 96822 USA; [6]Division of Geological and Planetary Science, California Institute of Technology, Pasadena, CA 91125 USA.

Introduction: A key isotopic marker for constraining the evolution and processing of primitive planetary materials within the protoplanetary disk is the short-lived radionuclide ^{26}Al (mean life = 1.05 My; [1]). It's former presence in refractory inclusions (specifically, Calcium-rich, Aluminum-rich inclusions or CAIs) was confirmed by magnesium isotope ratio measurements in the 1970's [2]. Today, it is widely used as a relative chronometer for the earliest processes occurring in the protoplanetary disk such as the last melting event that igneous CAIs or chondrules experienced and the condensation of mineral grains within the disk. It is assumed that ^{26}Al was homogeneously distributed at least in the region of the protoplanetary disk where chondritic materials were formed and/or were processed.

It has been known since the 1970's that some CAIs show a disturbance in their Al-Mg isotopes, specifically within and between individual minerals of a single rock, and others do not. Furthermore, the degree of disturbance within a single CAI can be extreme, with ^{26}Al/^{27}Al ratios inferred from errorchrons ranging from 0 to 7.0 x10^{-5}.

Knowing that some CAIs are disturbed we are exploring the following major questions: (1) Why are some CAIs disturbed and others not? (2) How did they become disturbed? (3) What geological history is the disturbance recording? (4) How do we get initial ^{26}Al/^{27}Al ratios higher than canonical without invoking a supra-canonical value for the Solar System? (5) What is the initial Solar System value for ^{26}Al/^{27}Al (this must be known with confidence otherwise we cannot truly constrain the other questions)?

The disturbance of the Al-Mg isotopic system in CAIs could have occurred either in a pre-accretion environment during CAI formation (either during their initial origin or subsequent re-melting and crystallization events) or in a post-accretion environment, within an asteroid. Two *hypotheses* are proposed, which we are currently investigating, to explain the non-homogenous nature of the Al-Mg isotopic system within some CAIs: (I) Resetting occurred prior to the complete decay of ^{26}Al between inclusions and a reservoir, either pre-accretion exchange with nebular gas [3] or post-accretion exchange with matrix materials. We will term this first hypothesis the open-system hypothesis: CAIs interacted with their surroundings at various stages of their geologic history. (II) Resetting reflects self diffusion and/or elemental exchange of Mg (±Al) between minerals within a single CAI long after the decay of ^{26}Al. We will term this hypothesis the closed-system.

The only way to constrain these hypotheses is to continue to develop a data base of analyses from many CAIs. However, it is required that these rocks be analyzed in great detail through *in situ* techniques, thus maintaining and carefully documenting the petrographic context of each rock.

Results and Discussion: Our initial research has focused on comparing data from two different analytical techniques, LA-MC-ICPS and SIMS [4,5] and attempting to test the hypothesis that the initial value ^{26}Al/^{27}Al was supra-canonical. The conclusions of our investigations are clear: the two techniques produce data that are, within error, in agreement [4,5]. During our research into constraining the existence of a supra-canonical initial value ^{26}Al/^{27}Al, it became evident that we cannot separate this investigation with one that focuses on understanding the why and how Al-Mg isotopes in CAIs became disturbed.

To constrain the existence of an initial supra-canonical value for the Solar System and how and why some CAIs have disturbed Al-Mg isotopes, we have been focusing our research efforts on detailed, *in situ*, analyses of a few CAIs. Our goal is to use the data to test the closed-system hypothesis stated above. We argue that one CAI, HC-13 from Allende 3509 USNM, is especially important to exploring the disturbance of Al-Mg isotopes in these refractory rocks (Fig. 1: RGB). HC-13 is a type B inclusion that contains ~ 36% melilite, 38% anorthite, 13% fassaite, and 14% spinel (all vol%). Unlike most type B inclusions it contains abundant anorthite (An$_{99}$), up to 5 mm in section that cross cut most of the core and parts of the mantle. The overall abundance of anorthite and the crystal size are important for two major reasons: (1) To test the closed-system hypothesis stated above we need a large, internal reservoir or sink that will provide a diffusive medium for Mg (or self-diffusion), in this case, between anorthite and melilite; thus the scatter in data [4] from melilites could be the result of closed-system exchange with anorthite. (2) The anorthite grains are large enough to permit detailed elemental and isotopic abundance profile to be collected, thus testing further for evidence of diffusion. The latter is part of our ongoing investigation.

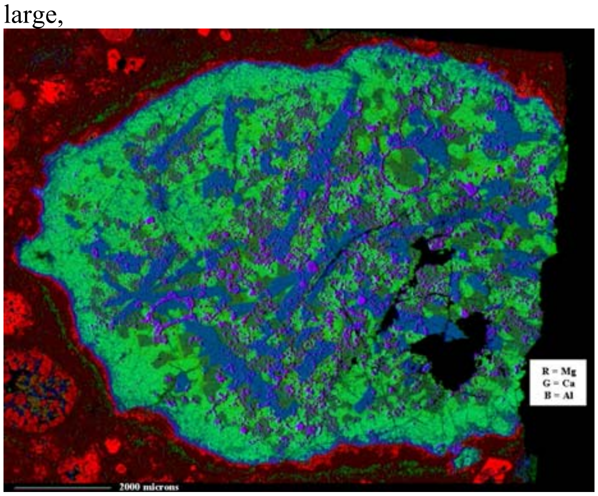

Figure 1. RGB image of HC-13, scale is 2000 µm; R = Al, G = Ca, B = Mg. Blue-colored phase is anorthite.

It is critical when evaluating resetting of the Mg isotope system in CAIs to model diffusive isotope exchange between melilite and anorthite, thus testing hypothesis 2, closed-system exchange. Figure 2 shows an example calculation portraying this exchange. For modeling purposes, we hypothesize that melilite values above the canonical evolution line in δ^{26}Mg* vs. ^{27}Al/^{24}Mg space are attributable to exchange with anorthite. We also recognize that some anorthite itself exhibits canonical initial ^{26}Al/^{27}Al [4]. We then require a combination of An/(An+Mel) and diffusive reaction progress ξ that allows for about a 0.5‰ increase in melilite at ^{27}Al/^{24}Mg = 6.0 (based on our measurements) and very little downward shift in δ^{26}Mg* for anorthite (perhaps no more than about 10‰ based on spread in data and error bars). If fits can be found that explain all the melilite values, the implication is that there is no evidence for pre-exchange supra-canonical values and that all the spread in initial ^{27}Al/^{24}Mg found in CAIs is likely the product of post-crystallization diffusion as a closed-system.

Although the melilite-anorthite exchange may be the most important mineral set to understand, the data cannot rule out a contribution of exchange (either elemental or self-diffusion) between Mg-rich and Mg-poor melilite or melilite with spinel or spinel with anorthite [6,7], and we need to explore such exchanges in more detail. If a CAI has very little anorthite (as in the case of Leoville 144A [3,5]) then testing a closed-system exchange hypothesis requires careful modeling of exchange between melilites and melilite-spinel and even melilite-fassaite and fassaite-spinel. Of course to do this effectively requires that we know the modal abundances of the different phases in three dimensions and the distribution of their elemental compositions within individual phases.

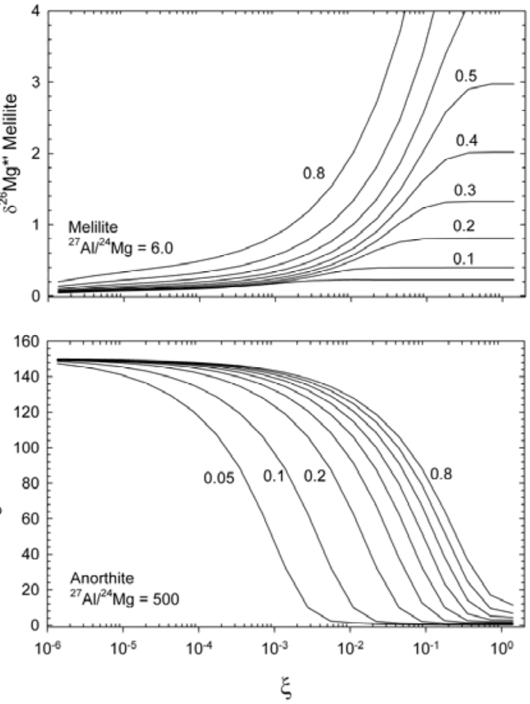

Figure 2. Plots of shifts in δ^{26}Mg*' with reaction progress ξ for diffusive exchange of Mg isotopes between melilite (^{27}Al/^{24}Mg = 6.0) and coexisting anorthite (^{27}Al/^{24}Mg = 500). Curves are labeled with abundance of anorthite relative to melilite (An/(An+Mel)). A single value for ξ is needed to explain observed shifts in δ^{26}Mg*' in both minerals if simple isotope exchange is to explain departures from canonical apparent ^{26}Al/^{27}Al.

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