OXYGEN, MAGNESIUM, AND ALUMINUM ISOTOPES IN THE IVUNA CAI: RE-EXAMINING HIGH-TEMPERATURE FRACTIONATIONS IN CI CHONDRITES.

D. R. Frank[1], G. R. Huss[1], K. Nagashima[1], M. E. Zolensky[2], and L. Le[3], [1]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Manoa, [2]ARES, NASA Johnson Space Center, Houston, TX 77058, [3]Jacobs/JETS, Houston, TX 77058.

Introduction: CI chondrites are thought to approximate the bulk solar system composition since they closely match the composition of the solar photosphere [1]. Thus, chemical differences between a planetary object and the CI composition are interpreted to result from fractionations of a CI starting composition. This interpretation is often made despite the secondary mineralogy of CI chondrites, which resulted from low-T aqueous alteration on the parent asteroid(s) [2]. Prevalent alteration and the relatively large uncertainties in the photospheric abundances (~ ±5-10%) [3] permit chemical fractionation of CI chondrites from the bulk solar system, if primary chondrules and/or CAIs have been altered beyond recognition. Isolated olivine and pyroxene grains that range from ~5 µm to several hundred µm have been reported in CI chondrites [4-8], and acid residues of Orgueil were found to contain refractory oxides with oxygen isotopic compositions matching CAIs [9,10]. However, the only CAI found to be unambiguously preserved in a CI chondrite was identified in Ivuna by [11].

The Ivuna CAI's primary mineralogy, small size (~170 µm), and fine-grained igneous texture classify it as a compact type A [11]. Aqueous alteration infiltrated large portions of the CAI, but other regions remain pristine. The major primary phases are melilite ($Ak_{14\text{-}36}$), grossmanite (up to 20.8 wt.% TiO_2), and spinel. Both melilite and grossmanite have igneous textures and zoning patterns. An accretionary rim consists primarily of olivine ($Fa_{2\text{-}17}$) and low-Ca pyroxene ($Fs_{2\text{-}10}$), which could be either surviving CI2 material or a third lithology.

Analyses: Isotopic data were collected using the UH Cameca ims 1280 ion microprobe. Oxygen isotopes were measured using a ~1.1 nA Cs^+ primary ion beam rastered over ~7x7 µm in multi-collection mode. Two spots were measured in melilite, one in clinopyroxene, and one in spinel. Aluminum and Mg were measured using two different protocols. Both used an O^- primary beam. For melilite, a ~60 pA primary beam with a 6 x 10 µm spot size was used and Mg isotopes were sequentially collected with an electron multiplier. For spinel, the beam current was increased to 2.5 nA and Mg and Al isotopes were simultaneously collected with four Faraday cups.

Results: There is little to no resolvable difference between the four O analyses, which are consistent with ^{16}O-rich CAIs in other carbonaceous chondrites [12-16]. The $\delta^{18}O$ values have a range of (-38.3, -40.2)‰, and the range for $\delta^{17}O$ is (-44.1, -45.1)‰. Two-σ errors are ±1.0–1.3‰ for $\delta^{18}O$ and ±0.5–1.0‰ for $\delta^{17}O$. $\Delta^{17}O$ has a mean value of -24.1 ±0.7‰. Our Mg-Al isochron has a slope of $^{26}Mg^*/^{27}Al = (-1.4\pm2.4) \times 10^{-5}$.

Discussion: The small variation in $\Delta^{17}O$-values (for three phases) precludes O-isotopic exchange between our analyzed areas and CI fluids. We also consider three histories for the low $^{26}Mg^*/^{27}Al$ ratio. Assuming homogeneous distribution of ^{26}Al in the early solar system, the CAI either formed late or the Mg-Al system was disturbed by partial melting before accretion. The CAI may also have formed prior to injection of ^{26}Al in the disk [10], or in a nebula with heterogeneous distribution of ^{26}Al [17].

The serendipitous preservation of the inclusion along with its accretionary rim gives us a view of the CI precursor lithology. Circumstantial evidence for CI accretion of whole chondrules and/or CAIs is confirmed by presence of the Ivuna CAI, and therefore CI chondrites are not an exact sample of the bulk solar system. Using CI chondrites to model bulk solar system fractionations with precision better than a few percent may not be possible.

References: [1] Anders E. and Grevesse N. (1989) *GCA* 53:197-214. [2] Tomeoka K. (1990) *Nature* 345:138-140. [3] Asplund M. et al. (2009) *Ann. Rev. Astron. Astrophys.* 47:481-522. [4] Reid A. M. et al. (1970) *GCA* 34:1253-1255. [5] Kerridge J. F. and Macdougall J. D. (1976) *EPSL* 29:341-348. [6] Steele I. M. (1990) *MAPS* 25:301-307. [7] Leshin L. A. et al. (1997) *GCA* 61:835-845. [8] Frank D. R. et al. (2014) *GCA* 142:240-259. [9] Hutcheon I. D. et al. (1994) *APJ* 425:L97-L100. [10] Makide K. et al. (2011) *APJ* 733:L31. [11] Frank D. R. et al. (2011) *LPS* 42, Abstract #2785. [12] Krot A. N. et al. (2017) *GCA* 201:155-184. [13] Krot A. N. et al. (2012) *GCA* 83:159-178. [14] Sahijpal S. et al. (1999) *MAPS* 62, Abstract #5144. [15] Makide K. et al. (2009) *GCA* 73:5018-5050. [16] McKeegan K. D. et al. (1996) *MAPS* 31:A86-A87. [17] Larsen K. K. et al. (2011) *APJ* 735:L37. Supported by NASA grants NNX11AG78G & NNX14AI19G to GRH.