O, SI AND MG ISOTOPIC COMPOSITIONS OF FUN INCLUSION VIGARANO 1623-5.
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Introduction: Among CAIs, some are characterized by large mass-dependant isotopic fractionation of major elements (Mg, Si, O) accompanied by large nonradiogenic nuclear anomalies in various minor and trace elements [1]. The origin of the isotopic fractionations and the compositions of the precursors of these so-called FUN inclusions are still unknown. Vigarano 1623-5 has strong isotopic affinities to the Allende FUN inclusion C1 and is still available in thin section and so can be studied by in situ methods [2]. This object, which shows the first unequivocal correlated petrologic and isotopic evidence for volatilization [2,3], has an interior composed of forsterite and minor spinel poikilitically enclosed in åkermanitic melilite or calcic pyroxene. The distribution of melilite and pyroxene are quite heterogeneous. A discontinuous 200 µm thick gehlenitic melilite mantle surrounds these cores [2]. The inclusion has a large vesicle and is surrounded by a hibonite-rich fine grained matrix separating the coarse grained interior portions from meteorite matrix. Here, we use in situ SIMS measurements to investigate in detail the correlations between O, Mg and Si isotopic compositions within each part and compare the two parts of this unique inclusion. The goal of this study is to better understand the relationship between the mantle and the two cores of this inclusion and to constrain its origin and environment of formation.

The analyses were done on a Cameca ims-1270 at UCLA at high mass resolution in multicollection modes. Olivine, pyroxene, and melilite standards were used to correct for instrumental mass fractionation. The matrix effect due to variation of Åk content [4] was also corrected for by analyzing synthetic zoned melilite.

Results: Individual minerals show a large range of mass fractionation in $\delta^{18}O$, $\delta^{30}Si$ and $\delta^{26}Mg$; this CAI has little or no radiogenic ^{26}Mg, so $\delta^{26}Mg$ variations reflect mass fractionation effects. Olivine grains from both cores show $\delta^{18}O$ from -23.8 ‰ to -8.84 ‰, $\delta^{30}Si$ from +6.9 ‰ to +23.2 ‰ and $\delta^{26}Mg$ from +43.7 ‰ to +82.7 ‰. One pyroxene grain has been measured and shows a $\delta^{18}O$ value = -8.4 ‰, a $\delta^{26}Mg$ value = +60.0‰ and a $\delta^{30}Si$ value = +21.8 ‰. Melilite from the core has been measured only for Mg and Si and shows a $\delta^{26}Mg$ variations from +56.4 ‰ to +66.2 ‰ and $\delta^{30}Si$ from +6.7 ‰ to + 17.6 ‰ Olivines show less mass-dependent fractionation for Mg than do pyroxene and melilite, but the same range of fractionation for Si is present in all of these minerals. There are no large isotopic differences between the pyroxene-rich core and the melilite-rich core, although olivines from the melilite-rich core are slightly less fractionated (1-2‰). The melilite-rich core shows a relationship between the Mg and Si isotopic compositions and the location of the olivines. The olivines of the melilite-rich core close to the matrix are more fractionated (~ 12 ‰ for Mg and ~ 6 ‰ for Si) than the olivines from the inside of the core. The pyroxene-rich core does not show any discernable relationship between mass fractionation and spatial position.

Unlike olivine and pyroxene, melilite has ^{16}O deficient compositions and shows a range of $\delta^{18}O$ variations from +4.6 ‰ to -8.9 ‰. Melilite from the mantle is also mass fractionated with $\delta^{30}Si$ ranging from +13.2‰ to +30.5‰ and $\delta^{26}Mg$ ranging from +54.9‰ to +66.3‰.

Discussion: The olivines from the core show mass fractionated compositions both in Mg and Si, which follow Rayleigh fractionation curve with a mass fractionation exponent close to the value measured for free evaporation of synthetic CAIs [4-7]. The range of Mg and O isotopes in core olivine indicates that this phase crystallized from the melt while the CAI was still evaporating. However, the fraction evaporated (as determined from the Rayleigh curve) is not consistent between Mg and Si. This implies that the evaporation event can not be explained by any simple, single-stage Rayleigh distillation event.

Isotopic compositions of O, Si and Mg of the melilite of the mantle have been measured along several profiles. The melilite mantle is characterized by a chemical variation of the åkermanite content, from Åk 75 in the olivine edge to Åk39 close to the matrix edge. Figure 1a shows that the $\delta^{18}O$ value of the melilite decreases with the distance from the edge of the pyroxene-rich core and increases with the åkermanite content. This trend is not due to a matrix effect, because the matrix effect of Al content on instrumental mass fractionation of oxygen isotope analyses is small (average of 1- 3‰). Contrary to the $\delta^{18}O$ profile, the $\Delta^{17}O$ of the melilite is independent of Åk content. Thus, it appears that the oxygen isotopic composition of the melilite was exchanged with an external reservoir during or after the last evaporation event. In con-

trast, the δ^{30}Si (Fig 1b) of the melilite increases by ~15-20‰ with the distance from the olivine edge and correlates with åkermanite content. The Mg of melilite is highly mass fractionated, consistent with an evaporation event but also show no correlation with Åk content (Fig 1c). These profiles reveal a complex history of several heating events as recorded in the inclusion mantle. Indeed, during an evaporation event, Mg and Si isotope fractionation should be correlated, but that is not the case. This discrepancy can be explained by a later homogenization of Mg, possibly produced by Mg self diffusion in melilite [9].
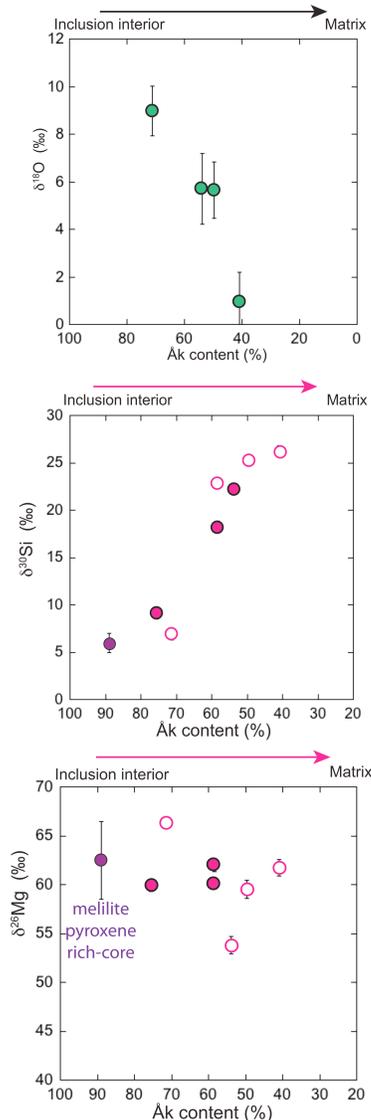

Figure 1: Profiles performed in the melilite mantle for δ^{18}O, δ^{30}Si, and δ^{26}Mg, respectively. The melilite from the inside of the pyroxene-rich core is represented in purple. The two profiles are shown by the filled and the empty pink symbols.

The average δ^{30}Si and δ^{26}Mg values increase from olivine to melilite to pyroxene (Fig 2), which is consis-

tent with the crystallization sequence already inferred by Davis et al. [2]. In principle, such a correlation can permit determination of a relationship between the amount of evaporation and the crystallization temperature. We are pursuing comparison with experimental data to provide such constraints on the temperature evolution of this inclusion.
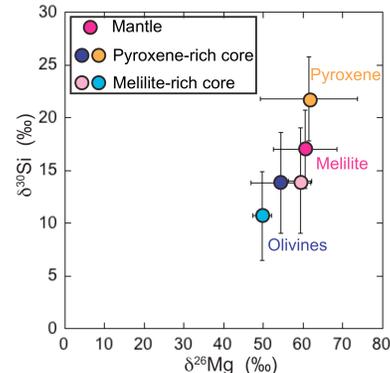

Figure 2 : Average δ^{30}Si versus δ^{26}Mg of different minerals of the FUN inclusion. The dark color is for the pyroxene-rich core, the light color for the melilite-rich core and pink is for the mantle. The heavy isotopes of Mg and Si increase with crystallization sequence, indicating crystallization during progressive evaporation

Conclusions : Vigarano 1623-5 is a complex object reflecting a complex history. The core ic chemically and mineralogically heterogeneous but shows very similar isotopic compositions. We found that the inclusion has experienced more than one evaporation event and the composition cannot be explained by a simple Rayleigh distillation process. The mantle surrounding the core has undergone the highest degree of evaporation (~ 80 %). This evaporation event was followed by an isotopic exhange of O. Several heating events are required to understand the isotopic compositions recorded in this CAI. With a more complete set of experimental data on evaporation material with starting compositions similar to that of 1623-5, we hope to better understand the history of this inclusion and thereby constrain the conditions of its formation.

References: [1] Loss, R.D. et al., (1994) *Astrophysical Journal.* 436 193-196. [2] Davis A.M. et al., (1991) *Geochimica et Cosmochimica Acta, 55,* 621–637. [3] McKeegan K.D. et al., (2005) *Lunar & Planetary Science* 36, *#2077.* [4] Knight K.B. et al. (2009) *Geochimica et Cosmochimica Acta, 73*, 6390-6401. [5] Davis A.M. et al. (2005) *Lunar and Planetary Science XXXVI.* # 2334 [6] Mendybaev R.A et al. (2009) *Lunar & Plan etary Science* 40, *#2461.* [7] Richter et al. (2007) *Geochimica et Cosmochimica Acta,* 71(22): 5544 5564. [8] Kita N. et al. (2007) *Lunar and Planetary Sciences XXXVIII, #1338* [9] LaTourrette, T., Wasserburg, G.J., (1998) *EPSL* 158 91-108.