LARGE ENRICHMENTS IN ^{16}O AND EVIDENCE FOR MULTIPLE RESERVOIRS IN THE PROTOSOLAR ACCRETION DISK IN A CORUNDUM BEARING CAI. J.-D. Bodénan[1,2], N. A. Starkey[1], S. S. Russell[2], I. P. Wright[1], I. A. Franchi[1]. [1]Planetary and Space Sciences, The Open University, Milton Keynes, MK7 6AA, UK. E-mail: jean-david.bodenan@open.ac.uk. [2]Dept. Earth Sciences, Natural History Museum, Cromwell Road, London, SW7 5BD, UK.

Introduction: Due to its ubiquity, its 3 stable isotopes and percent level variations in solar system objects, oxygen is a powerful element to study early Solar System processes and conditions. O isotopes in Calcium-, Aluminium-rich inclusions (CAIs), believed to be the first known objects to form in the Solar System, can be enriched by ~4% relative to the Earth and can be used to study these early times. Most CAIs are surrounded by a Wark-Lovering (WL) rim made of one or more mono- or bi-mineralic layers [1]. WL rims formed after their host CAI and allow for the study of the evolution of conditions the CAI experienced.

Corundum has been predicted to be the first phase to condense from a gas of solar composition [2], and yet it is remarkably rare in meteorites, with only a handful of occurrences reported [e.g. 3, 4, 5, 6]. The study of corundum bearing CAIs is therefore a rare window to the early stages of Solar System processes.

Description of Object: A corundum-hibonite CAI (A77307-COR-1) was found in the carbonaceous chondrite ALHA 77307, belonging to the CO group. It is one of the least metamorphosed meteorites of this group and is classified as a CO3.0 [7]. This CAI is subrounded, 165 by 140 μm across, and is mainly composed of a compact, essentially silica free core of wispy corundum grains, the largest of which is 30 μm across, enclosed by hibonite (TiO_2 = 0.70 – 5.33 wt%), mantled by spinel (FeO= 0.04 wt%). A complete WL rim of diopside 6 to 10 μm thick (Al_2O_3 = 1.99 – 3.73 wt%, TiO_2= 1.42 – 2.55 wt%) encircles the CAI and is separated from the core by a void that has been formed either by the specific removal of a mineral or by mechanical separation, probably during impact.

Techniques: O isotopic ratios were measured using a Cameca NanoSIMS 50L at The Open University. A Cs^+ beam of 50 pA is used as a primary beam and is rastered on the sample on an area of 3 x 3 μm after presputtering of 5 x 5 μm. The mass resolving power (MRP) was set at >10000 (Cameca NanoSIMS definition) sufficient to resolve ^{16}OH from ^{17}O. ^{16}O was measured on a Faraday cup, with ^{17}O, ^{18}O, ^{28}Si, $^{24}Mg^{16}O$, $^{40}Ca^{16}O$ measured on electron multipliers. Pre-sputter and analysis time were 3 min and 5 min, respectively. All analyses were normalised to standards of similar mineralogy/chemical composition to correct for matrix effects and instrumental mass fractionation. Analyses of standards were performed before and after sample analyses. 2σ errors quoted include external standard deviation of standards and internal precision for each analysis.

Elemental compositions were measured on a Cameca SX100 microprobe and elemental maps were acquired on a FEI Quanta 200 3D scanning electron microscope, both at The Open University. In both cases, a 20kV electron beam was used with an analysis time of 1 minute for microprobe analysis.

Results: O isotopes in A77307-COR-1 show a bimodal distribution. Corundum, hibonite and spinel plot slightly to the right of the CCAM [8] and Young and Russell [9] lines around an average $\delta^{17}O$ = -61.6 ± 3.5 (2σ) ‰ and $\delta^{18}O$ = -55.6 ± 3.1(2σ) ‰. Rim diopside plots towards less ^{16}O-rich values with average $\delta^{17}O$ and $\delta^{18}O$ of -47.2 ± 0.3 (2σ) ‰ and -43.0 ± 1.5 (2σ) ‰, respectively. This gives an average $\Delta^{17}O_{Core}$ = -32.6 ± 3.2 (2σ) ‰ and average $\Delta^{17}O_{Rim}$= -24.8 ± 0.5 (2σ) ‰.

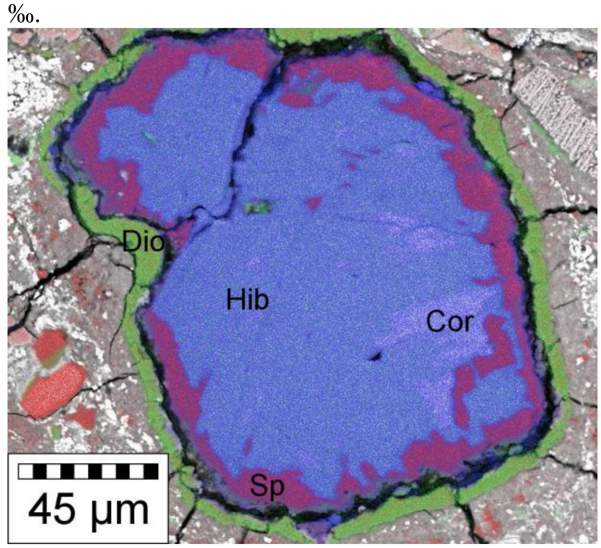

Figure 1. An elemental map of A77307-COR-1. Red = Mg, Blue=Al, and Green= Ca. Cor = corundum, Hib = hibonite, Sp = spinel and Dio = diopside.

None of the O measurements plot on the CCAM line (fig. 1). However, most of the corundum measurements, fall, within error, on the Y&R (slope=1) line. The core hibonite and mantle spinel plot approximately 4-10 ‰ to the right of the Y&R line. Careful study of analytical conditions during acquisition of these results and the match of composition between studied phases and standards suggest that the observed mass fractionation is highly unlikely to have been introduced by the instrument. Thus, this mass fractionation is most likely to record processes that the CAI went through during its history, possibly related to the processes giving FUN CAIs their composition.

Discussion: *Core***:** The core of A77307-COR-1 is one of the most ^{16}O-enriched ($\Delta^{17}O_{Core}$ = -32.6 ± 3.2 (2σ) ‰) objects measured. The O isotopic composition is slightly lighter than that of the Sun (Δ^{17}O= -28.4 ± 1.8 ‰) inferred by [10], although the uncertainties for the CAI and Sun values do overlap and therefore it maybe that the core of this CAI condensed from a gas with solar composition. More ^{16}O-rich objects have been reported [e.g. 11], and although the origins of such extreme ^{16}O-enrichments are unclear, they may be explained by formation of core minerals in a region of the protoplanetary disk close to the Sun with a high dust to gas ratio [12].

WL rim: The O isotopic composition of the rim ($\Delta^{17}O_{Rim}$= -24.8 ± 0.5 (2σ) ‰) is distinct from that of the core ($\Delta^{17}O_{Core}$ = -32.6 ± 3.2 (2σ) ‰). This difference cannot be explained by mass fractionation as core and rim compositions plot on a line of slope ~1, incompatible with mass fractionation.

The O isotopic composition measured in diopside rims found around Type A CAIs in this section and in QUE 99177 and Léoville (average $\Delta^{17}O_{Rim}$= -23.9 ± 2.5 (2σ) ‰) [13] is indistinguishable from that in A77307-COR-1. The diopside major element composition is also very similar to the compositions of diopside found in the WL rims of these other CAIs. These similarities suggest that all these rims formed in the same type of environment and under similar conditions. However, in the case of the type A CAIs, the core Δ^{17}O values are indistinguishable from the WL rim, indicating that they too formed from the same reservoir [13].

These observations suggest that the A77307-COR-1 core and rim formed in different O isotopic reservoirs. The core formed in an environment that was extremely ^{16}O-enriched, with a Δ^{17}O possibly lower than the solar value inferred from solar winds sampled by the Genesis mission [10]. Two hypotheses can be invoked to explain the discrepancy in O isotopic composition between the reservoirs in which core and rim formed. Either the CAI remained in the same location in the disk and the conditions changed to lower dust/gas ratio or the CAI moved from one reservoir in which its core minerals formed to another where the rim formed. Discriminating between these options from the limited information available is difficult. If the isotopic reservoir from which A77307-COR-1 formed evolved to heavier Δ^{17}O, some record might be expected, particularly in the mantle spinel. Such effects are not observed and therefore, as the WL rims of A77307-COR-1 and type A CAIs have a common composition, it may be that A77307-COR-1 formed in a distinct region of the protoplanetary disk and was subsequently transported to the type A CAI formation region.

Further studies of this intriguing CAI are on-going to understand better the environment in which it formed and the timescales involved.

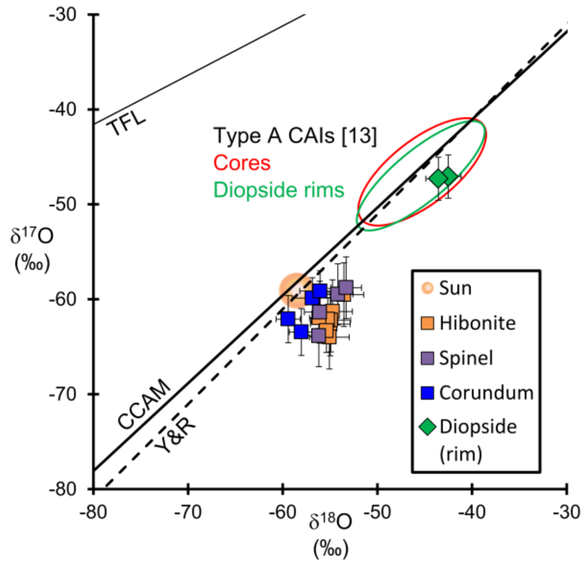

Figure 2. Three isotope diagram with the oxygen isotopic composition of core (corundum, spinel, hibonite) and rim (diopside) minerals in A77307-COR-1. Composition of the Sun [10].

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