A CAI IN THE HIGHLY UNEQUILIBRATED ORDINARY CHONDRITE NORTHWEST AFRICA 8276: IMPLICATIONS FOR CAI FORMATION AND PROCESSING. S. S. Russell[1], S. Itoh[2], T. Salge[1], Y. Higashi[2], N. Kawasaki[3] and N. Sakamoto[3] [1]Natural History Museum, Cromwell Road, London SW7 5BD, UK (sarr@nhm.ac.uk), [2]Department of Earth and Planetary Sciences, Kyoto University, kitashirakawa oiwakecho, Sakyou-ku, 606-8502, Kyoto, Japan. [3] Department of Natural History Sciences, Hokkaido University, N10W8 Sapporo, 060-0810, Japan.

Introduction: CAIs are very rare in ordinary chondrites (OC) [1]. Northwest Africa (NWA) 8276 is a newly described OC that has been classified as LL3.00, perhaps paired with NWA 7731 [2]. It is a single stone, broken into 2 pieces of 394 and 395g. It has a black fusion crust with only light desert weathering (weathering grade W1)[3]. Here, we describe an unusual OC CAI that was found in this section and discuss the implications for CAI distribution and history in the early solar sytem.

Techniques: SEM-EDX spectrum images were acquired on a thin section using a ZEISS Evo 15LS SEM with Oxford Instruments XMax 80 SDD at 20 kV and at high spatial resolution using an accelerating voltage of 6 kV with an FE-SEM FEI Quanta 650 equipped with an annular BRUKER FlatQUAD SDD. Oxygen isotope measurements were undertaken by CAMECA ims-1280HR SIMS at Hokudai isotope imaging laboratory. Russian spinel standard was used to correct instrumental mass fractionation. The overall analytical errors are about 5‰. The other details of the analytical conditions are described elsewhere [4].

Results: A CAI, that we named 8276-1, was discovered by element mapping of the section. The CAI is irregular in shape, 600x400μm in size (Figs. 1,2). The interior is dominated by nodules of melilite and diopside enclosing minor spinel. This core material is surrounded by a mantle of nodules which are more spinel rich with minor corundum. Some of the nodules are composed a of Si-Al rich, Mg-poor phase. The nodules are surrounded by an Al-Si-Na rich material, possibly glass. The inclusion contains very minor amounts of secondary Na, K, F, Cl, P, S and Fe. Potassium is enriched around the outside of the inclusion. One opaque nodule is visible in the section, approximately 2 microns across enriched in refractory metals containing percent levels of Ru, Pt, Ir, Os, Rh, Fe, Ni and S.

Oxygen isotopes of the CAI fall on an array in three isotope space (Fig. 4). Spinel plots between $\delta^{17}O$= -40 to -50‰, $\delta^{18}O$ = -40 to -50‰. The analysis of altered glassy material plots at $\delta^{17}O$= 2.0±2.5‰; $\delta^{18}O$=7.4±2.8‰. Melilite and diopside are intermediate in composition, falling on an array between spinel and the alteration point. Melilite and diopside analyses may have been contaminated by alteration material.

Discussion

Comparison of CAIs in Carbonaceous Chondrite (CC) and OC meteorites: While CAIs are relatively common in many carbonaceous chondrites, and have been reported also in cometary material [4], they are rarely reported in ordinary chondrites. CAIs in OCs that have been reported in the literature have some mineralogically similarities to those in CCs [e.g. 5,6,7], however, NWA 8276-1 appears to have some differences to CC CAIs. It contains firstly, the presence of a Al-Si-rich Mg-poor phase. It contains secondly, a glassy alteration phase that has also been observed in another OC CAI [8].

Our oxygen isotope analyses of 8276-1 are similar to those reported by McKeegan et al. [5] of two OC CAIs and three OC AOAs [6] and are isotopically similar to CC CAIs [3] and enstatite chondrite CAIs [9]. Cometary CAIs also are isotopically enriched in ^{16}O compared to terrestrial values [4]. This may imply that CAIs have a common source and were scattered throughout the solar system. However the reason why some meteorite classes (and presumably, different heliocentric distances) are much richer in CAIs than others is not clear.

Alteration of OC CAIs: Although the CAI is sitting within one of the most pristine known meteorites, it shows evidence of minor alteration after its condensation formation, specifically, alkali elements and halogens which have been incorporated into the CAI. Since the host meteorite is essentially completely unmetamorphosed and unmetasomatised [1] this metasomatism is likely to be nebular in origin.

The oxygen isotopic composition of the altered region plots at the heaviest end of the CCAM line, and does not trend above the terrestrial fractionation line towards OCs [10]. This is further evidence that the alteration is not associated with parent body processes. Instead, this may represent a reaction of the CAI with water vapour in the nebula, causing mass fractionation of the resulting secondary minerals.

Similarities and Differences between CC and OC CAIs: The broad similarities in oxygen isotopes between CC and OC CAIs point to a similar original source for all CAIs. CAIs are very much rarer in OCs compared to CCs, and the OC CAIs reported in the literature also contain significant differences to CC CAI. While CC CAIs show a variety of igneous or condensate textures, typically OC CAIs are fluffy condensates and do not show evidence of melting. They also tend to lack a complex Wark-Lovering rim. This suggests that they have had a simpler thermal history of condensing from a gas to solid with limited later heating. However, evidence of metasomatism and ranges in oxygen isotopes suggest that some alteration occured. Differences between CAIs in CC and OC point to subtle differences in the pre-accretionary history of chondritic components, and suggest that some of the pre-accretionary features (such as Wark-Lovering rims) seen in CCs may have formed in a process that was not universal to CAIs.

References:

[1] Hezel et al. (2010) MAPS 43 1879, [2] Garvie et al., Meteoritical Bulletin 101 (2014). [3] Ruzicka et al. (2015) Meteoritical Bulletin 102. [4] Kawasaki et al. (2016) GCA in press. [4] Simon et al. (2008) MAPS 43 1861-1877. [5] McKeegan et al., (1998) *Science* **280** 414-418. [6] Itoh et al. (2007) MAPS 42 1241-1247. [6] Russell et al. (1996) Science 273 757. [7] Bischoff and Keil (1984) GCA 48 693 [8] Mishra et al. (2015) 78th Met Soc abtract 5139. [9] Guan et al. (2001) *Earth Planet. Sci. Lett.* 181, 271-277. [10] Clayton et al. (1991) GCA 55 2317-2337.

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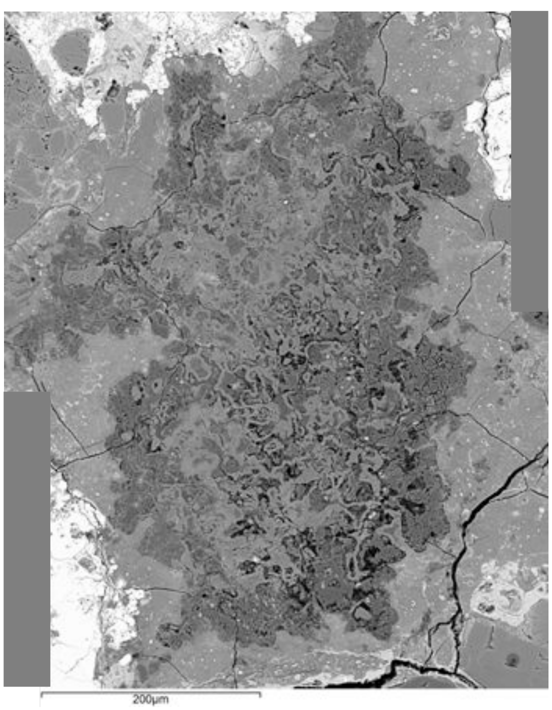

Figure 1. The CAI found in NWA 8276; 8276-1. This backscattered electron image shows that it is a highly irregular shaped inclusion approximately 600 microns in maximum dimension.

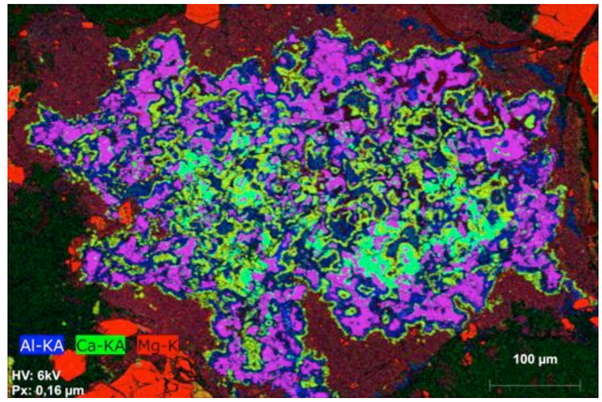

Figure 2. Composite element map of integrated peak intensities of NWA 8276-1. Mg=Red, Al=Blue, Ca=Green. Spinel appears pink/purple, Al-rich glass is dark blue, diopside green and melilite turquoise. The interior is Ca-rich and dominated by melilite and Al-rich diopside; the exterior is composed mainly of spinel nodules coated by a glass and pyroxene. 6 kV, 4096x2728 pixels, 160 nm pixel size, 190 min.

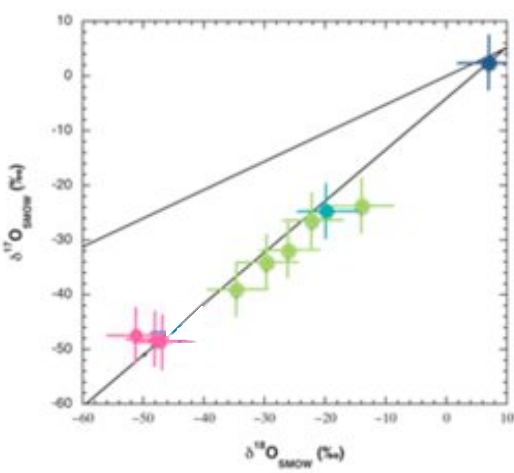

Figure 3. Oxygen isotope systematics of the CAI NWA 8276-1. Colours of symbols correspond approximately to the colour within Figure 2 above: Spinel is pink, diopside is green, melilite/glass is turquoise and glassy alteration phase is dark blue. Errors are 2σ.