

PETROLOGY AND OXYGEN ISOTOPE COMPOSITIONS OF REFRACTORY INCLUSIONS FROM ACFER 094. T. J. Fagan¹, A. N. Krot², and H. Yurimoto¹, ¹Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan (fagan@geo.titech.ac.jp). ²Hawaii Institute of Geophysics and Planetology, SOEST, University of Hawaii at Manoa, Honolulu, HI 96822, USA.

Introduction: The ungrouped carbonaceous chondrite Acfer 094 is among the most primitive chondrites identified on the basis of pristine mineralogy, C and N abundances and isotopic compositions, the preservation of amorphous material in the meteorite matrix, and high abundance of presolar grains [1-3]. Because of its pristine nature, Acfer 094 is well-suited for studies of pre-parent body petrogenesis.

In this study we report petrographic observations and *in situ* oxygen isotopic analyses of Ca,Al-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), and plagioclase-rich chondrules (PRCs) from Acfer 094 in an effort to understand the origin and processing of refractory materials in the nebular setting. Particularly, we address the following questions: (i) Did all CAIs originate in a ¹⁶O-rich gaseous reservoir? (ii) How and when did CAIs experience oxygen isotope exchange? (iii) Is there a continuum in oxygen isotope compositions between refractory inclusions and Al-rich chondrules?

Analytical Methods: CAIs, AOAs, and PRCs were studied in three polished thin sections of Acfer 094. Thin section scale elemental X-ray maps (Al, Mg, Ca, Si, and Ti K α) collected using a Cameca SX-50 electron microprobe were used to help identify the refractory objects. The identified objects were examined with a JEOL JSM-5900LV scanning electron microscope equipped with an energy dispersive detector. Quantitative elemental analyses of minerals were collected using JEOL JXA-8800 and Cameca SX-50 electron microprobes. *In situ* oxygen isotope analyses were collected with a TiTech Cameca 1270 SIMS ion microprobe under analytical conditions previously described [4].

Mineralogy and Textures: We identified > 300 refractory objects in Acfer 094 which can be divided into CAIs, AOAs, and PRCs. No secondary Fe- or alkali-rich phases were found in these objects. Based on mineralogy, the CAIs can be divided into (i) corundum-bearing, (ii) spinel-hibonite±melilite, (iii) grossite-rich, (iv) melilite-rich, (v) spinel-pyroxene, (vi) pyroxene-anorthite, and (vii) hibonite-pyroxene spherules. Most CAIs show no clear evidence for igneous origin and tend to have irregular shapes, concentric textures, and monomineralic or multilayered rims. The only exceptions are a pyroxene-hibonite spherule and two igneous Type C CAIs composed of anorthite, spinel and Al-diopside.

AOAs consist of forsteritic olivine (Fa_{<1}), FeNi-metal and a refractory component (CAIs and mineral intergrowths) composed of Al-diopside, spinel, anorthite, and

very minor melilite, which is typically replaced by a fine-grained mixture of spinel and diopside. One of the CAIs in AOAs has a nodular shape and consists of prismatic spinel grains in a melilite-rich groundmass partially replaced by spinel and diopside; it is surrounded by a rim of Al-diopside and forsterite (Fig. 1a). Olivine in several AOAs is replaced by low-Ca pyroxene [5].

PRCs consist of low-Ca pyroxene, forsteritic olivine, FeNi-metal, high-Ca pyroxene, anorthitic plagioclase, and crystalline mesostasis composed of plagioclase, high-Ca pyroxene and a silica phase. Several chondrules contain clusters of spinel grains enclosed by plagioclase and may represent remelted CAIs [6].

Oxygen Isotopic Results: *In situ* oxygen isotope analyses were collected from a grossite-rich CAI (RO-64, Fig. 1b), a hibonite-bearing CAI (RO-89, Fig. 1c), a melilite-rich CAI (RO-87), an AOA (RO-1), and a PRC (RO-63). Minerals from the hibonite-bearing and melilite-rich CAIs yield ¹⁶O-rich isotopic compositions ($\delta^{17}\text{O}$ from -40 to -50‰, Fig. 2a) similar to those identified in CAIs and AOAs from a variety of chondrite groups [e.g., 4, 7-10]. In contrast, the grossite-rich CAI exhibits a range in isotopic composition. Spinel from the interior of this CAI is the ¹⁶O-rich, with $\delta^{17}\text{O} \sim -40\%$; grossite is slightly depleted in ¹⁶O, with $\delta^{17}\text{O} \sim -35\%$; and diopside from the Wark-Lovering rim of this CAI is isotopically heavy, with $\delta^{17}\text{O} \sim 0\%$ (Fig. 2a).

Amoeboid olivine aggregate RO-1 also is dominated by ¹⁶O-rich phases, but with some variations in composition. Olivine and Al-diopside from typical AOAs are ¹⁶O-rich (Fig. 2b), but the igneous-textured nodule (Fig. 1a) is isotopically heterogeneous, having spinel with $\delta^{17}\text{O} \sim -40\%$ and melilite with $\delta^{17}\text{O} \sim -30\%$ (Fig. 1c).

In contrast to minerals from the CAIs and AOA, olivine, low-Ca pyroxene and anorthite from PRC RO-63 are uniformly ¹⁶O-poor (Fig. 2b).

Discussion: Our results indicate that CAIs and AOAs from Acfer 094 formed initially in a ¹⁶O-rich setting similar to most refractory objects from other chondrite groups [e.g. 4, 7-10]. Relatively ¹⁶O-depleted compositions of melilite in a melilite-spinel nodule in RO-1 could be due to isotopic exchange during incomplete melting of this CAI that was later incorporated into an AOA. This interpretation is consistent with the recently identified correlation between relatively ¹⁶O-depleted compositions and igneous textures of CAIs from CR chondrites [7]. The ¹⁶O-poor isotopic composition of the diopside rim around the grossite-rich CAI RO-64 may either reflect

formation of the rim or subsequent isotopic exchange in a ^{16}O -poor gaseous reservoir. Because Acfer 094 shows no evidence for thermal metamorphism or alteration, oxygen isotopic exchange in an asteroidal setting can be excluded. ^{16}O -poor isotopic compositions of minerals in a PRC suggest that it formed in a setting similar to typical ferromagnesian chondrules.

References: [1] Newton J. *et al.* (1995) *MAPS* 30, 47-56. [2] Greshake A. (1997) *GCA* 61, 437-452. [3] Weber D. *et al.* (1995) *GCA* 59, 803-823. [4] Yurimoto H. *et al.* (1998) *Science* 282, 1874-1877. [5] Krot A. N. *et al.* (2003) this vol. [6] Krot A. N. and Keil A. N. (2002) *MAPS* 37, 91-111. [7] Alèon J. *et al.* (2002) *MAPS* 37, 1729-1756. [8] Clayton R. N. *et al.* (1973) *Science* 182, 485-488. [9] McKeegan K. D. *et al.* (1998) *Science* 280, 414-418. [10] Krot A. N. *et al.* (2001) *MAPS* 36, 1189-1216.

Fig 1. Back-scattered electron images of an igneous nodule from AOA RO-1 (a), grossite-rich CAI RO-64 (b), and spinel-hibonite-melilite CAI RO-89 (c). Mineral abbreviations: di = Al-diopside; fo = fosterite; grs = grossite; hib = hibonite; mel = melilite; pv = perovskite; sp = spinel.

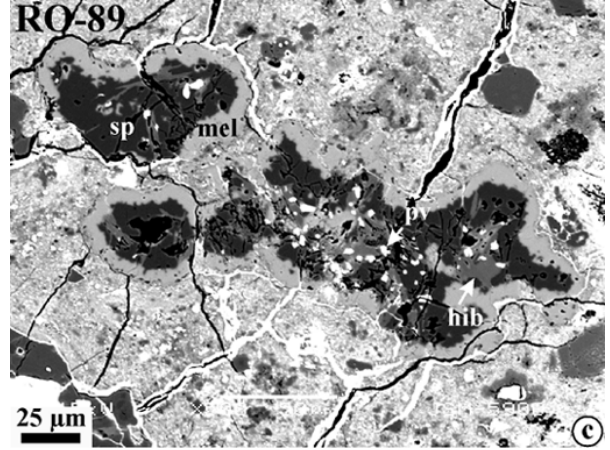
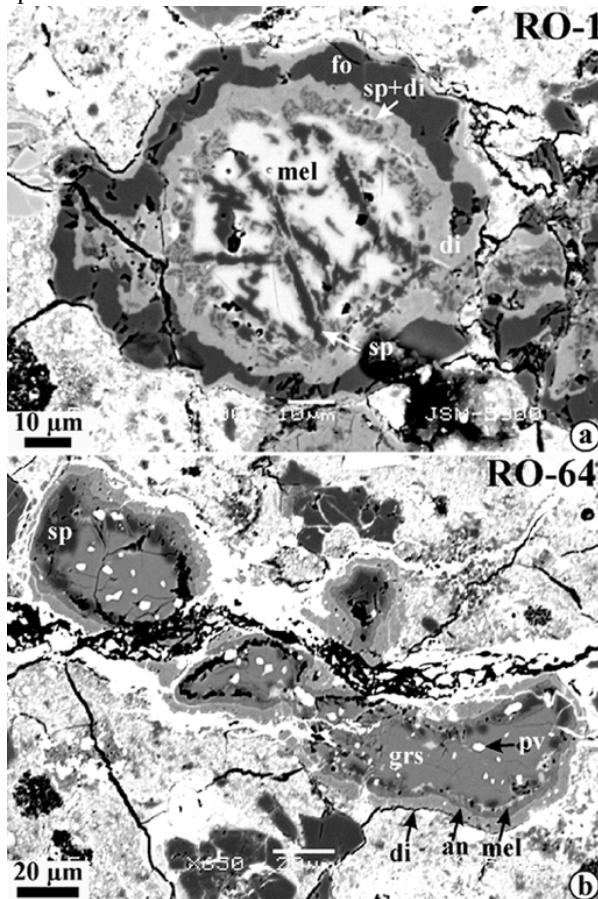


Figure 2. Oxygen isotopic compositions of minerals from Acfer 094 CAIs (a), and AOA and PRC (b). Terrestrial fractionation (TF) and carbonaceous chondrite anhydrous mineral (CCAM) lines shown for reference.

