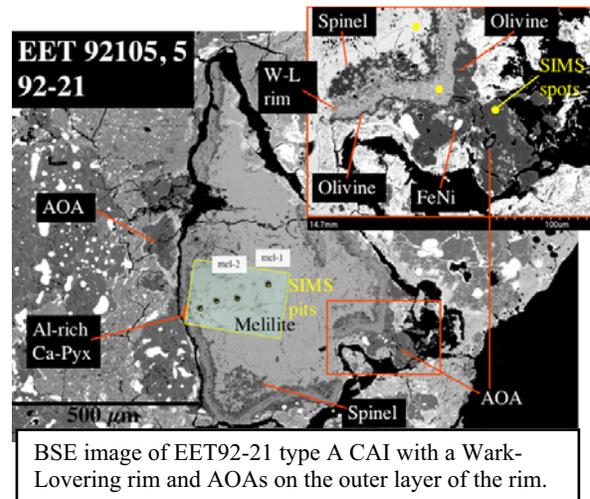# PETROLOGIC-ISOTOPIC STUDY OF AMOEBOID OLIVINE AGGREGATES IN CR CHONDRITES.

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Introduction: Amoeboid olivine aggregates (AOA) are minor but important components of chondrites [e.g., 1-7]. They are irregular-shaped, fine-grained aggregates of olivine (Ol) and refractory mineral assemblages that may include anorthite (An), Ca-pyroxene (Ca-Pyx), FeNi and less commonly melilite, spinel, and perovskite. They are important because they are related to CAIs, but contain Ol, suggesting lower condensation temperatures than CAIs and they may record processes linking CAIs and the less refractory ferromagnesian chondrules. AOAs in CR chondrites are particularly intriguing because some contain low-Fe, Mn-enriched (LIME) Ol [6] similar to that in IDPs and Comet Wild II samples [8, 9] and some are metal-rich similar to the chondrules in CRs. Here, we report O and Mg isotopic compositions, $^{25}Mg/^{24}Mg$ ratios and ^{26}Mg excesses in phases from CR AOAs. Our goal is to decipher their petrogenesis and spatial - temporal relationship to CAIs and chondrules.

Petrology: We studied three inclusions including EET92-12 (from EET 92105, 5), EET87-3 (EET 87770, 4), R317 (Renazzo AMNH 588-2) and a type A CAI (EET92-21) associated with three AOAs. These have been previously described [6] and are summarized below. In general, the AOAs in the CR chondrites are irregular-shaped aggregates of Ol and, in many cases, the Ol occurs in sinuous bands (5-20µm thick) surrounding nodules of Ca-, Al-rich phases and FeNi metal. AOAs in CR chondrites lack the spherical (melt-droplet) form and interstitial glassy mesostasis that is characteristic of chondrules and indicative of melt. The AOAs in the CRs range in size from about 70µm to 1.2mm. Larger AOAs in the CRs appear to be clusters of numerous nodules (ranging from ~10 to 100 µm in size) consisting of fine Ol or nodules of Ca-, Al-rich phases surrounded by Ol. Mineral grains in AOAs are generally very fine ranging from <1 to 7 µm in size. EET 92-12 is a 280µm AOA composed of Ol ($Fo_{99.5}$) surrounding diopside and An. EET87-3 is a 160 µm AOA and has Ol ($Fo_{99.6}$) surrounding diopside and An, and contains a large Mg-Al spinel-dominated nodule. In both of these AOAs, the Ca-Pyx appears to be an overgrowth on the Ol or occurs between Ol and An. EET87-3 also contains ~7 vol.% FeNi metal with a large metal grain (~50 µm long). R317 is a large (1 mm) AOA that has numerous nodules containing Ca-Pyx and An. EET92-21 is a compact type A inclusion

BSE image of EET92-21 type A CAI with a Wark-Lovering rim and AOAs on the outer layer of the rim.

with AOAs associated with its Wark-Lovering (W-L rim). The type A consists of zoned melilite with minor Al-Ca-Pyx, MgAl spinel, and perovskite. Surrounding the inclusion is a W-L rim containing, in sequence from inner to outer edge, spinel – melilite- Ca-Pyx - spinel and in some portions of the rim, outer Ol. The Ol in the rim is near-pure forsterite, compositionally similar to that in the AOAs. The intriguing aspect of this inclusion is that in three areas AOAs are attached to the rim. These AOAs consist of Ol surrounding An, diopside and FeNi, and they are texturally and compositionally similar to theAOAs described above.

Ion Microprobe Analyses: Isotopic analyses were performed using the CAMECA IMS-1280 ion microprobe at U. Wisconsin-Madison, with conditions similar to [10, 11]. Because of the small grain sizes in the AOAs, the primary beam was reduced to 5µm for most analyses, but a 10µm beam was used for Mg isotope analyses of the melilite and Al-Ca-Pyx in EET92-21 and a 3µm beam was used for Mg isotope analyses of An. Synthetic and natural standards of Ol, diopside, melilite, spinel and plagioclase were analyzed to correct for matrix effects. The internal and external precisions (2σ) were <1‰ for $\delta^{18}O$ and $\delta^{17}O$, and <0.5‰ for $\delta^{25}Mg$, except for An.

O isotopes: All the minerals analyzed are ^{16}O-rich. Ol grains in the AOAs have the lightest oxygen, with average values as light as $\delta^{18}O$=-46.3‰, $\delta^{17}O$=-47.4‰. Most data plot on a slope~1 or the CCAM line, consistent with previous measurements [5]. In R317, Ol data are less ^{16}O-rich compared to the other AOAs and

plot above the CCAM, but the polish on this section was relatively poor so that small differences could be attributed to analytical artifacts. For EET87-3 and EET-92-12, Ol analyses in the center of larger Ol grains plot on the CCAM line, while Ol adjacent to Ca, Al-rich minerals plot below the line. Spinel in EET-87 and melilite and Al-Ca-Pyx in EET-92-21 (type A) also plot below the CCAM. Although these differences are small, O isotopes in the Ol and the refractory minerals may be different and Ol in contact with the refractory minerals may have exchanged oxygen during AOA formation. Diopside in the W-L rim has relatively ^{16}O depleted compositions on the CCAM line.
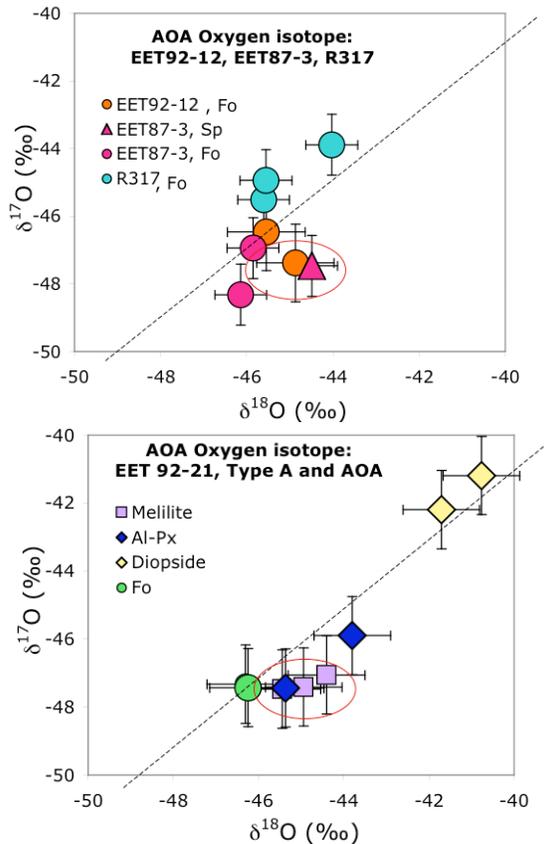
Mg isotopes and ^{26}Al chronology: Mass fractionation of Mg isotope ratio is an important indicator of evaporation in CAIs [12]. Thus, ^{25}Mg/^{24}Mg ratios were measured for Ol and some of the refractory phases in the AOAs, as well as in the EET92-21 type A inclusion. However, no significant mass fractionation effects have been detected so far. The EET92-21 type A inclusion and refractory minerals in EET92-12 and EET87-3 all show significant ^{26}Mg excesses. On an Al-Mg isochron diagram, the data for melilite, Ca-Pyx and Spinel from EET92-21 yield a well-defined line with an initial ^{26}Al/^{27}Al ratio of (4.7 ± 0.6) x 10^{-5}, within error of the canonical value reported in [13]. Another melilite (with higher Ak value) and An from

the W-L rim plot off this line. They suggest a secondary process after a significant amount of ^{26}Al had decayed, though more data are needed to evaluate this line.
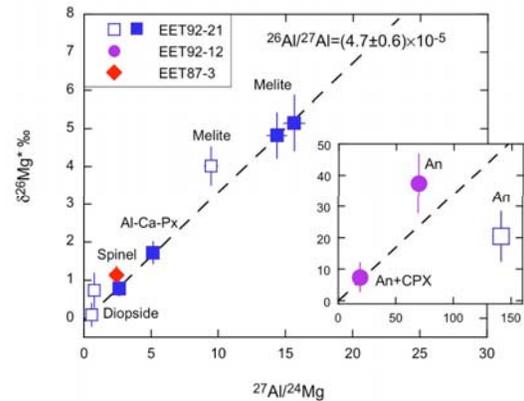
Data for An from EET92-12 and spinel from EET87-3 yield model ^{26}Al/^{27}Al ratios of $(5-7)$ x10^{-5}, suggesting greater than canonical value. More data are needed to confirm if these values are supra-canonical [e.g.,14] and the origin of An needs to be explored further.

Discussion: AOAs in CR chondrites are aggregates of materials that experienced minimal melting. The ^{16}O-rich compositions of their constituent phases are consistent with a primitive origin and suggests that AOAs and CAIs in the CR chondrites formed from the same ^{16}O-rich gaseous reservoir. The lack of O-isotopic equilibrium between Ol and refractory phases in the AOAs is consistent with interpretation of AOAs as aggregates of gas-solid condensates and minimal melting. Refractory minerals in the AOAs in CRs have ^{26}Mg excesses that indicate initial ^{26}Al values as high as those in CAIs suggesting that the refractory materials in AOAs and CAIs in CR chondrites formed contemporaneously. Refractory phases in CR AOAs clearly have ^{26}Al/^{27}Al ratios comparable to canonical values. This suggests a continuum of processes and similar environmental conditions for formation of CAIs and AOAs.

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