X-RAY IMAGE ANALYSIS OF CLAST SIZE AND ABUNDANCE IN ACFER 094. K. Konrad[1]. D.S Ebel[2]. S.V. McKnight[3]. [1]Queens College, City University of New York, 65-30 Kissena Blvd, Flushing, NY 11367 (kkonrad100@qc.cuny.edu). [2]Department of Earth & Planetary Sciences, American Museum of Natural History, Central Park West at 79th st, New York, NY 10024 (debel@amnh.org). [3]Mount Holyoke College, 50 College Street, South Hadley, Massachusetts, 010705 (mckni@mtholyoke.edu).

Introduction: Acfer 094 is a unique, primitive carbonaceous chondrite with little terrestrial weathering and affinities to both CM and CO chondrite groups [1-4]. The matrix contains abundant presolar grains [4,5], and no clastic materials (chondrule fragments) [6,7]. We have characterized the clast size and abundance in Acfer 094 to clarify its affinity to other chondrites, and to provide constraints on the complementary nature of clasts and matrix that might apply to larger processes in the early solar nebula. Clast size analysis can inform dynamical theories about early nebular radial drift, clast sorting, and turbulent concentration [8]. Analysis of clast type abundance can provide insight into localized heterogeneity in the solar nebula, and early time-temperature histories [9].

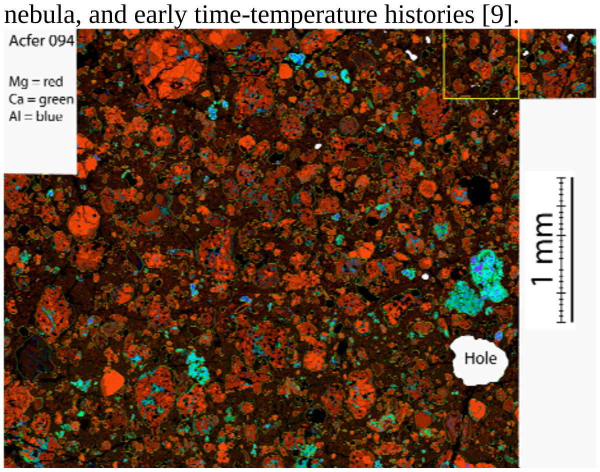

Fig 1: Mg-Ca-Al = Red-Green-Blue composite x-ray map mosaic of Acfer 094. Clasts are outlined in yellow. Each map is the size of the far upper right panel (yellow square). Image resolution is highly degraded here (each grayscale element map is 12.24MB).

Methods: Building on methods of [10], a random thin section area (Fig. 1, 10.5 mm^2) was mapped in Mg, Ni, Ti, Al, Ca (WDS); Si, S, Fe (EDS) using an electron microprobe at 1μm/pixel. Grayscale element and red-green-blue composite x-ray maps in a registered stack were used in combination to identify clast boundaries and identities: Ca-, Al-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), isolated olivine grains (IOL), six chondrule subtypes, and metal grains (Figs. 1, 2). A total 1131 clasts were outlined manually in image editing software.

Clast and matrix areas (in 1μm^2 pixels) were then counted, and the area (apparent size) of each outlined clast was measured, and corrected according to [11]. The data is entirely digital, archived, and accessible for further research (e.g., we have developed methods for pixel-by-pixel modal analysis of each separate clast using x-ray map data). We did not correct measured matrix abundance for the presence of small cracks.

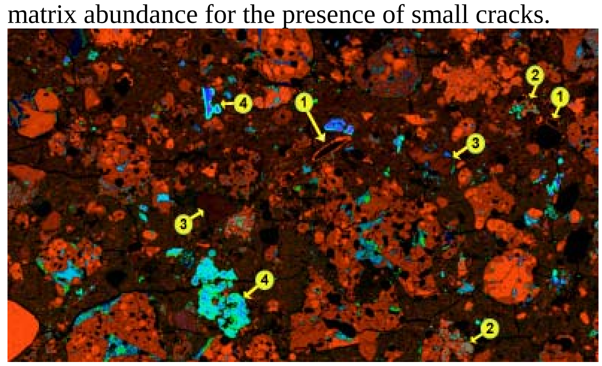

Fig 2: Detail of Fig. 1. Metal is black. 1) Olivine-rimmed metal, 2) AOA, 3) FeO-rich olivine, 4) CAI.

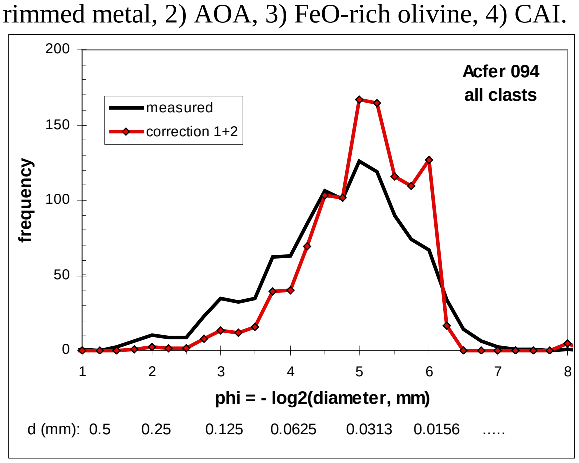

Fig 3: Size frequency distribution of all 1131 clasts. Black curve is apparent (measured) size. Red curve (diamonds) shows sizes corrected for 1) non-equatorial sectioning and 2) over-representation of large clasts, by the methods of Eisenhour [11].

Results: Area fractions directly correlate to volume fractions [11]. The volume % of clast types are: 38.9% chondrules, 2.8% CAIs, 4.0% AOAs, 2.0% metallic grains, 0.6% isolated olivine grains, and 0.1% unidentified clasts. Matrix is 51.2 volume %. Chondrules are: barred olivine 0.7, porphyritic olivine 4.2, porphyritic olivine-pyroxene 19.0, porphyritic pyroxene 9.7. Metal grains rimmed by fine olivine are ~18%

of the metal grain volume (Fig. 2). These "MO" grains resemble components of some AOAs in CR chondrites.

Size analysis of all clasts (Fig. 1) are expressed in the phi scale of sedimentary petrology (Fig. 3) where phi = - $\log_2$(diameter, mm), and diameter is calculated as the diameter of a circle with the same area as each clast, $d_m=2\cdot(A/\pi)^{0.5}$. Average apparent (uncorrected) diameters (standard deviation), and absolute number (n) of clasts are: chondrules 70.4μm (61.7), n=593; CAIs 36.7μm (32.9), n=154; AOAs 71.1μm (43.6), n=77; metal grains 29.2μm (15.4), n=246.

Discussion: Our results differ from earlier work, particularly in the abundance of refractory inclusions. Weber [6] reported less than 2 vol.% refractory inclusions in Acfer 094, ranging in size from 40 to 500 μm. Wasson [5] reports Acfer 094 has the most matrix (45vol%) of any chondrite that escaped aqueous alteration. Hezel et al. [12] report 1.21 area% CAIs with a log-normal size distribution (n=298) "with a few gaps", a mean model radius $r_m=(A/\pi)^{0.5}$ (half the d_m above) of 16 μm (min. 3, max. 59) measured in a composite x-ray map of 21.97 mm^2 at 4 μm/pixel

Comparison to Other Chondrites: Matrix is 51.2% of Acfer 094 compared to an average 33.78% among COs [13, 14]. Acfer 094 is not a CO chondrite as originally described [15]. The clast/matrix ratio is also significantly lower then CO chondrites with a value of 1.1 compared to the matrix-poor COs (1.9) [13]. Acfer 094 has a higher clast/matrix ratio then oxidized CVs (0.72) and a lower ratio than reduced CVs (2.07) [10]. CM chondrites contain on average ~70% matrix, although there is a wide range [16,17].

Acfer 094 contains upwards of 7.0 vol% AOAs and CAIs combined, while CR chondrites are reported to have only 0.5 percent AOA and CAI composition [18,19]. The average chondrule size for Acfer 094 is also much finer (0.064 mm) then the average CR chondrule (0.7 mm) [20]. CK chondrites average 10% less matrix and have coarser clast diameters (~1mm), compared to Acfer 094 [21]. The chondrule sizes in Acfer 094 are significantly smaller then any ordinary chondrites, which also contain much less matrix [22].

Clast Size Analysis: The clast sizes in Acfer 094 after using corrections [11] are slightly bimodal. The CAIs, metallic grains, and lithic fragments range in average size from 0.043 to 0.034 mm, while the chondrules and AOAs which consist of the larger overall area fall around 0.064 mm. This bimodal distribution may be interpreted as the smaller clasts being 'building blocks' for the larger chondrules and AOAs. Alternatively, the smaller clasts are expelled fragments of larger chondrules, but this would conflict with the observations of [6,7]. Overall clast sizes are small.

Preliminary measurements of CO chondrites [13] show that average clast size appears to increase with increasing metamorphic grade. It may be that the small clast size in Acfer 094 is due to its primitive unaltered state, and related to the location in time and space of the formation of its parent body in the early solar system. Preliminary results suggest that the component 'nodules' of AOAs in Acfer 094 are generally smaller than those in CV and CR chondrites. Igneously layered objects or igneous clasts with thick accretionary rims are rare.

Conclusions: Modal analysis and clast size distributions confirm that Acfer 094 should remain ungrouped or be classified separately among the carbonaceous chondrites. While apparent clast sizes obey a log-normal distribution, they display a Weibul distribution [8] when corrected according to [11; cf. 8].

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