OLIVINE IN ALMAHATA SITTA – CURIOUSER AND CURIOUSER. M.E. Zolensky[1], J. Herrin[2], T. Mikouchi[3], W. Satake[3], T. Kurihara[3], S.A. Sandford[4], S.N. Milam[4-5], K. Hagiya[6], K. Ohsumi[7], J.M. Friedrich[8], P. Jenniskens[9], M.H. Shaddad[10], L. Le[2], G. A. Robinson[2]. [1]ARES, NASA Johnson Space Center, Houston, TX 77058, USA. (michael.e.zolensky@nasa.gov); [2]ESCG Jacobs, Houston, TX 77058 USA; [3]Dept. of Earth and Planet. Science, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan; [4]NASA Ames Research Center, Moffett Field, CA 94035, USA.; [5]NASA Goddard Space Flight Center, Code 691, Greenbelt, MD 20771, USA; [6]Graduate School of Life Sci., University of Hyogo, Kamigori-cho, Hyogo 678-1297, Japan; [7]JASRI, Sayo-cho, Hyogo 679-5198, Japan; [8]Dept. of Chemistry, Fordham University, Bronx, NY 10458, USA (also: Dept. of Earth and Planetary Sciences, American Museum of Natural History, New York, NY 10024, USA); [9]SETI Institute, Mountain View, CA 94043, USA; [10]Physics Dept., University of Khartoum, Khartoum 11115, Sudan.

Introduction: Almahata Sitta (hereafter Alma) is an anomalous, polymict ureilite [1]. Anomalous features include low abundance of olivine, large compositional range of silicates, high abundance and large size of pores, crystalline pore wall linings, and overall fine-grained texture. Tomography suggests the presence of foliation, which is known from other ureilites. Alma pyroxenes and their interpretation are discussed in two companion abstracts [2-3]. In this abstract we discuss the composition of olivine in Alma, which is indicative of the complexity of this meteorite.

Procedure: We analyzed chips from 19 different recovered Alma stones. However, because of the brecciated nature of Alma, and the limited masses of our samples we do not claim completeness. Mineral compositions were determined using the Cameca SX100 microprobe at the Johnson Space Center, and the JEOL JXA-8900L microprobe at the University of Tokyo.

Groundmass Olivine: Olivine compositions in Alma range from Fa_2 to Fa_{18} (271 analyses), with a major peak at Fa_{13}, and a minor one at $Fa_{8\text{-}9}$. Low-calcium pyroxene (including pigeonite) ranges from $Fs_2Wo_{0.7}$ to $Fs_{29.9}$ $Wo_{12.2}$ (141 analyses) and augite from $Fs_{39.3}Wo_{37.2to}$ $Fs_{48.1}$ $Wo_{35.1}$. Olivines typically display the reverse zoning characteristic of ureilites, resulting from high-temperature reduction, with core compositions ~Fa_{13}.

There are competing classification schemes for ureilites, reflecting the complexity of these meteorites, and we will mention two. Based upon the olivine core compositions, Almahata Sitta appears to belong to Berkeley Group II [4], as redefined by Franchi et al. [5], though at the extreme upper limit Mg-rich value for this grouping. Alma olivine minor components Ca0 (0.1-0.65 wt%), MnO (0.42-0.66 wt%) and Cr2O3 (0.24-0.81 wt%) are all consistent with this grouping.

Goodrich has divided ureilites according to mineralogy [6-7]. Although augite is locally present in Alma, it is a minor phase in most (but not all) samples we have observed. Low calcium pyroxene (< 5 mole% Ca) is more abundant than compositionally-defined pigeonite (5-20 mole% calcium), however Mikouchi et al. [3] report that even the low-Ca pyroxene in Alma has the pigeonite crystal structure, and thus is properly termed pigeonite. Since the major pyroxene in Alma is pigeonite, but the abundance of pigeonite in Alma is generally greater than that of olivine, this meteorite might be called a pigeonite-olivine ureilite, rather than the conventional olivine-pigeonite ureilite group. In terms of igneous rock classification, this rock would be most similar to terrestrial wherlites.

According to Goodrich et al. [7] molar Fe/Mg vs. Fe/Mn of olivine and pyroxene in ureilites can be used to indicate critical aspects of the igneous history of an ureilite. On a plot of molar Fe/Mn vs Fe/Mg for monomict ureilites, olivine–pigeonite and olivine–orthopyroxene ureilites plot on a single trend of near constant, chondritic Mn/Mg ratio, which suggests that they are partial melt residues, and are related to one another principally by reduction rather than different degrees of melting [8]. On this plot augite-bearing ureilites lie to right of the residue fit, suggesting that they contain a melt component [7]. In Figure 2 we plot many olivine analyses from Alma on the Fe/Mn vs. Fe/Mg diagram adapted from [7]. The Alma olivines generally follow the chondritic Mn/Mg trend, with some displacements to the right, which is consistent with the presence of minor augite. However, Alma olivines lie towards the Fe-poor (lower) portion of the trend, occupied by the olivine-orthopyroene ureilites rather than the olivine-pigeonite ureilites, whereas one might have expected the reverse. Of course Alma might be more correctly termed a pigeonite-olivine ureilite, but it is not clear why it has lower than expected Fe. This is another reason to not group Alma with the typical olivine-pigeonite ureilites. The olivines in Alma mainly separate into two fields, roughly on either side of 0.1 molar Fe/Mg, a reflection of the polymict nature of Alma.

Pore Olivines: The very abundant pores in Alma have extremely irregular walls, which are lined by euhedral to subhedral olivine crystals (Figure 3), and minor metal blebs. It is difficult to obtain good microprobe analyses of these olivines, but they appear to be in the range $Fa_{12\text{-}15}$, similar to the Alma groundmass olivine core compositions. X-ray tomography reveals that the pores define thin, discontinuous "sheets" connected in three dimensions- they may outline grains that have been incompletely welded together. Thus these pores are not vesicles, and do not outline anything like vesicle cylinders. These olivines appear to be vapor deposits, but if this is true it is interesting that they are compositionally similar to the groundmass olivine.

Despite considerable work by many investigators, questions remain about this meteorite. It is clear that the diverse, fine-grained nature of Alma requires characterization of larger samples than have hitherto been available, to permit us to determine the petrography at a larger scale. However, it is clear that Alma will provide significant new information regarding the geological, especially thermal, history of the ureilite parent asteroid(s) [2-3].

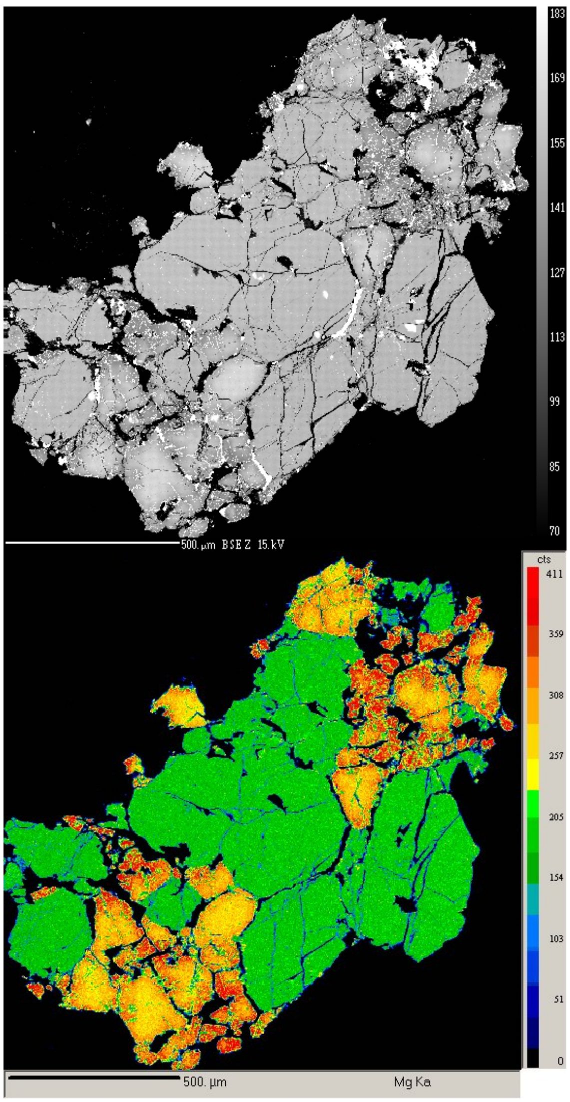

Figure 1: Top: BSE image of Alma sample 39. The majority of the white phases are metal. Pores and carbon are black. Bottom: Mg X-ray element map of Alma sample 39. Pigeonite is green, olivine is yellow (~Fa13) to red (~Fa5).

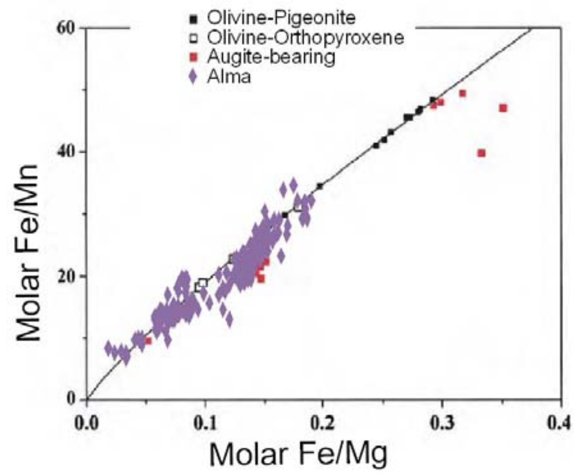

Figure 2: 271 olivine analyses from Alma (purple diamonds) plotted on a diagram of ureilite olivine molar Fe/Mn vs. Fe/Mg which has been adapted from [7]. The Alma olivines generally follow the chondritic Mn/Mg trend (the thin black line, along with ureilites that lack augite (olivine-pigeonite and olivine-orthopyroxene types as shown), with some displacements to the right of the line, which is consistent with the presence of minor augite in some samples (augite-bearing ureilites-see [7]). Alma olivines largely separate into two fields, on either side of 0.1 molar Fe/Mg, consistent with Alma's polymict nature.

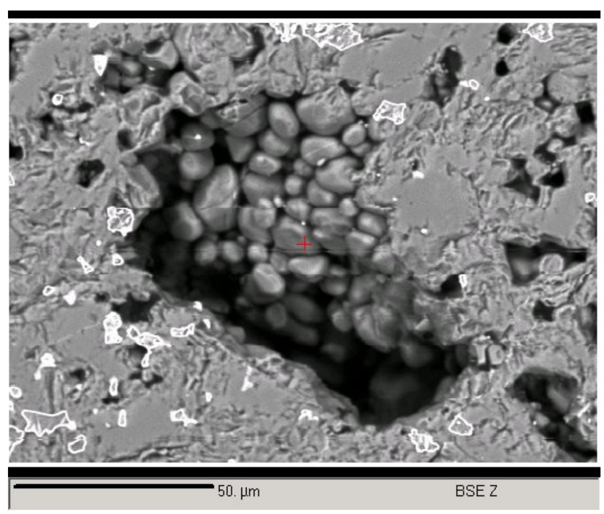

Figure 3: Olivine crystal-lined pore.

References: [1] Jenniskens et al. (2009) *Nature* **458**, 485-488; [2] Herrin et al (2010) LPSC 2010 (this volume); [3] Mikouchi et al (2010) LPSC 2010 (this volume); [4] Berkeley et al. (1980) *GCA* **44**, 1579-1597; [5] Franchi et al. (1998) *LPSC 28*, #1685; [6] Goodrich (1992) *Meteoritics* **27**, 327-352; [7] Goodrich et al. (2004) *Chemie der Erde* **64**, 283–327; [8] Goodrich (2000) *GCA* **64**, 2255–2273.