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MINERALOGY OF PYROXENE AND OLIVINE IN THE ALMAHATA SITTA UREILITE. T. Mikouchi[1], M. Zolensky[2], H. Takeda[1], K. Hagiya[3], K. Ohsumi[4], W. Satake[1], T. Kurihara[1], P. Jenniskens[6] and M. H. Shaddad[7], [1]Dept. of Earth and Planet. Science, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan (mikouchi@eps.s.u-tokyo.ac.jp), [2]NASA Johnson Space Center, Houston, TX 77058, USA, [3]Graduate School of Life Sci., University of Hyogo, Kamigori-cho, Hyogo 678-1297, Japan, [4]JASRI, Sayo-cho, Hyogo 679-5198, Japan, [5]SETI Institute, Mountain View, CA 94043, USA, [6]Physics Dept., University of Khartoum, Khartoum 11115, Sudan.

Introduction: The Almahata Sitta meteorite (hereafter "Alma") is the first example of a recovered asteroidal sample that fell to earth after detection still in the orbit (2008TC$_3$ asteroid), and thus is critical to understand the relationship between meteorites and their asteroidal parent bodies [1]. Alma is a polymict ureilite showing a fine-grained brecciated texture with variable lithologies from black, porous to denser, white stones [1]. It is an anomalous ureilite because of wide compositional ranges of silicates with abundant pores often coated by vapor-deposit crystals [1]. Nevertheless, Alma has general similarities to all ureilites because of reduction textures of silicates suggestive of rapid cooling from high temperature as well as heterogeneous oxygen isotope compositions [e.g., 1-5]. Alma is especially unique because it spans the compositional range of known ureilites [1]. In this abstract we report detailed mineralogical and crystallographic investigations of two different fragments to further constrain its thermal history with regards to the nature of the ureilite parent body.

Petrography: The analyzed fragments (#7 and #3-1) show distinct color. The #7 sample ("Alma7") is the one originally described in [1], which is dark colored. In contrast, #3-1 ("Alma3-1") is rather white partly covered with black fusion crust. In spite of the color difference, both fragments have a similar sponge-like (because of pores) fine-grained polycrystalline texture, being mainly composed of olivine and pyroxene with Fe(-Ni) metal and carbon phases. The texture is generally similar to that of mosaicized ureilites such as Haverö, Y-74154 and ALH81101 (Fig. 1) [e.g., 6]. We note that the pyroxene-rich area in Alma7 shows a similar mosaicized or mottled texture to olivine, but each minute pyroxene grain usually shows a similar extinction angle under optical microscopy unlike the olivine, probably preserving original crystal orientation. Alma3-1 is mainly composed of olivine, but small amounts of pyroxene (~5 vol.%) are present as veins with widths of up to 200 μm. Both olivine and pyroxene show granoblastic mosaic textures composed of 10-20 μm minute grains. At the boundary with the pyroxene area, pyroxene is present in the interstices of euhedral olivine grains. Pyroxene often shows twinning, probably on (100). The abundance of carbon phases and metal in Alma3-1 is smaller than that in Alma7, which would account for its whitish appearance.

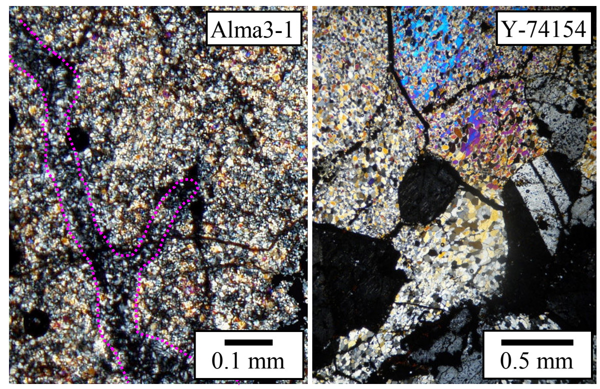

Fig. 1. Optical photomicrographs (cross polarized light) of Alma3-1 (left) and Y-74154 (right), both showing mosaicized texture. Pyroxene is present in the dashed area of Alma3-1. Note that Alma3-1 shows a finer-grained texture.

Mineral Chemistry: Electron microprobe analysis shows that pyroxenes in Alma are mostly low-Ca pyroxene with wide compositional ranges (Fig. 2). The low-Ca pyroxene in Alma7 shows chemical zoning both in Mg-Fe and Ca ($En_{90-80}Wo_{3-10}$) with the Fe-rich low-Ca pyroxene cores to the Mg-rich rims with higher Ca contents. Small amounts of augite (up to 5 μm, $En_{57}Wo_{40}$) are present associated with interstitial Si-rich phases (Fig. 3). Pyroxenes in Alma3-1 are clearly more Fe-rich ($En_{85-78}Wo_{2-6}$) than those in Alma7 (Fig. 2). In Alma3-1 pyroxene, Fe and Ca are positively correlated. Olivine in Alma3-1 is also more Fe-rich (Fa_{12-23}) than that in Alma7 (Fa_{3-18}) (Fig. 2). Both samples show small variation in Mg and Fe contents in the minute crystals, due to chemical zoning by reduction, but a millimeter scale heterogeneity is also present. Minor elements in olivine are 0.35-0.5 wt% MnO, 0.1-0.3 wt% CaO, and 0.25-0.6 wt% Cr_2O_3. The olivine mineralogy is described in more detail in [7].

Pyroxene Crystal Structure: The pyroxene crystal structure gives important information on thermal history when coupled with chemical composition. Thus we employed electron back-scatter diffraction (EBSD) on FEG-SEM and synchrotron X-ray diffraction (XRD) to study the crystallography of Alma pyroxenes. Although the Ca contents of low-Ca pyroxenes are as low as Wo_2, the obtained Kikuchi bands show that all low-Ca pyroxenes have the pigeonite ($P2_1/c$) crystal structure (Fig. 3). This is consistent with the observation that (100) twinning is common in these low-Ca pyroxenes. Alma7 pigeonites in the same pyroxene areas show generally similar orientation as suggested by optical microscopy. The Kikuchi bands from augite in Alma7 can be indexed by the $C2/c$ augite structure, but it is usually difficult to distinguish between the $P2_1/c$ and $C2/c$ pyroxene structures on EBSD patterns. SEM-EBSD was also performed on olivine, and Kikuchi bands from all grains analyzed could be indexed by the olivine structure and no high-pressure polymorph of olivine was found. The results by synchrotron XRD obtained at two Japanese synchrotron facilities (BL-4B1 at PF, KEK and BL37XU at SPring-8) will be given at the meeting.

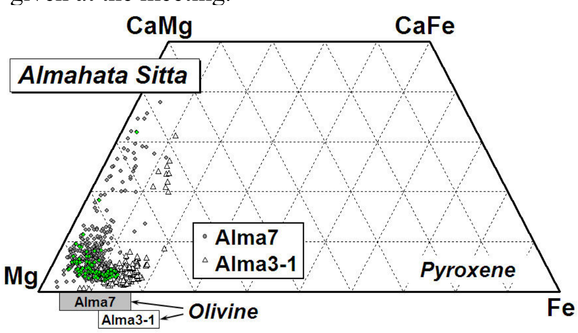

Fig. 2. Major element compositions of pyroxene (quadrilateral) and olivine (shown in two boxes under the quadrilateral) in Alma samples studied. Green circles on the pyroxene quadrilateral show compositions of pyroxenes in Fig. 3.

Discussion and Conclusion: Some ureilites are known to exhibit a mosaicized olivine texture similar to Alma, interpreted to result from shock at high temperature, possibly related to the breakup of the ureilite parent body [e.g., 4,5]. Although the abundance of diamond in Alma is small [1], Alma should have also suffered from shock metamorphism. As is observed in other mosaicized ureilites, the variation in pyroxene compositions in Alma may be due to cation migration during shock [8]. Even partial melting of silicates might occur since both olivine and pyroxene often show recrystallization textures with small amounts of interstitial Si, Al-rich phases (Fig. 3). The presence of such interstitial material is found in other ureilites [e.g., 9]. The Mg-Fe reverse zoning in Alma7 pyroxenes may suggest crystallization during reduction.

Although Alma displays high shock metamorphism textures overprinted by mosaicized olivine and deformed pigeonite, the pyroxene compositions are still useful to deduce their thermal history. The absence of orthopyroxene (*Pbca*) in Alma indicates that the pyroxene equilibration temperature was high, probably higher than 1300 ^{o}C [e.g., 9-11], which is similar to Asuka 881989 [12].

The pyroxene composition of Alma7 is similar to the most magnesian ureilites such as ALH82106 and NWA2236 [e.g., 9]. In contrast, silicate compositions of Alma3-1 are closer to the ferroan ureilites [e.g., 13]. Alma3-1 is especially similar to ALH81101 because of olivine and pyroxene polycrystalline textures and their compositions, although Alma3-1 displays a finer-grained texture [7]. They may share the same origin on the ureilite parent body. Our two samples represent clasts of two distinct ureilite members, and their coexistence of these two unique members in the same polymict ureilite indicates their genetical relationship on the same parent body [13].

References: [1] Jenniskens P. et al. (2009) *Nature, 458,* 485-488. [2] Herrin J. et al. (2009) *Meteoritics & Planet. Sci., 44,* 5444. [3] Takeda H. (1987) *Earth & Planet. Sci. Lett*., 81, 358-370. [4] Mittlefehldt D.W. (1998) *Rev. in Mineralogy, 36,* Chap. 4. [5] Goodrich C.A. (2004) *Chemie de Erde*, *64*, 283-327. [6] Berkley J. L. (1986) *Meteoritics*, *21*, 169-189. [7] Zolensky M. et al. (2010) *LPS XLI* (this volume). [8] Tribaudino M. (2006) *Meteoritics & Planet. Sci., 41,* 979-988. [9] Takeda H. et al. (1989) *Meteoritics*, *24*, 73-81. [10] Lindsley D. H. (1983) *American Mineral*., *68*, 477-93. [11] Takeda H. (1989) *Earth & Planet. Sci. Lett*., *93*, 181-194 [12] Takeda H. et al. (2009) *Meteoritics & Planet. Sci., 44,* 5117. [13] Downes H. et al. (2008) *Geochim. Cosmochim. Acta*, *72*, 4825-4844.

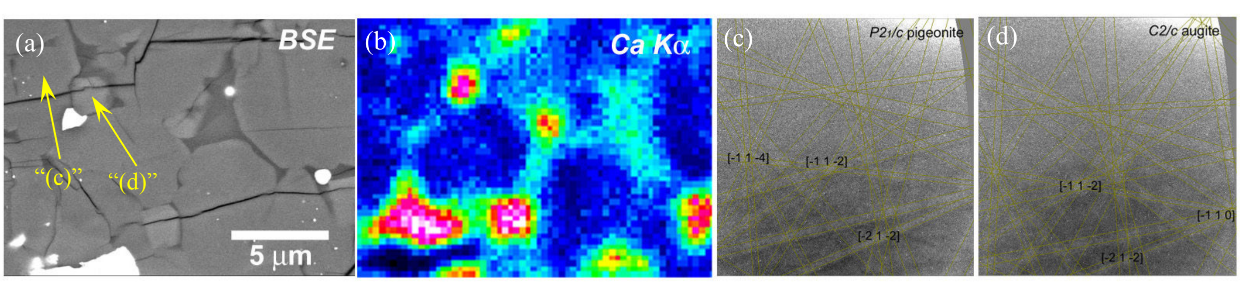

Fig. 3 (a) BSE image of pyroxene-rich area in Alma7. (b) Corresponding Ca X-ray map. Dark blue is Fe-rich low-Ca pyroxene. Bright blue is mostly Mg-rich pigeonite with high Ca content. Augite is pink to white. (c) Kikuchi bands of low-Ca pyroxene matching the pigeonite $P2_1/c$ structure. (d) Kikuchi bands of high-Ca pyroxene matching the augite $C2/c$ structure.