Petrogenesis and chronology of a feldspathic clast in the Almahata Sitta polymict ureilite.

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Introduction: Almahata Sitta (AhS) was derived from asteroid 2008 TC3[1] is a typical polymict ureilite[2], and contains numerous ureilitic lithologies as well as a stunning variety of exotic clasts. Of particular interest, is the sample MS-MU-011[3], an unbrecciated, feldspar-enriched clast with an oxygen isotope signature that lies within the mixing array defined by ureilites[4]. We provide further petrologic observations coupled with a possible multistage model for the formation of this unusual lithology in a partially differentiated ureilite parent body (UPB).

The MU-MS-011 assemblage is dominated by albitic feldspar with less abundant clinopyroxene and K-Si-rich glass and minor oxides[3]. The texture is unusual as phase boundaries between pyroxene-feldspar and pyroxene-glass are arcuate (Figure 1a) and even scalloped (Figure 1b) rather than the planar grain boundaries typical of volcanic rocks. This texture suggests liquid-liquid interfaces at the time of crystallization. A very minor but possibly significant 'phase' is submicron vesicles on glass-pyroxene interfaces indicating the presence of a late-stage vapor or gas phase.

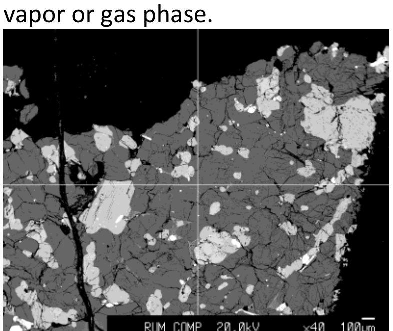

Figure 1a: Texture of Almahata Sitta (in backscattered electron image). Feldspar is middle gray, pyroxene light gray, and opaques, white.

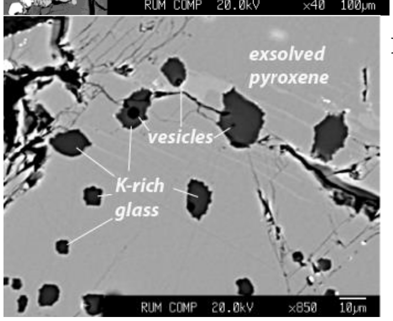

Figure 1b: Pyroxene detail with fine exsolution and scalloped K-Si-rich glass inclusions (~10% vol.) Note submicron vesicles in glass.

AhS is felsic and shares few mineralogical similarities with the ultramafic ureilites. It shares characteristics with felsic lithologies in other polymict ureilites.[5,6] The genetic link between the various lithologies, inferred from the oxygen isotope data, must involve major crystal-liquid separation, probably involving serial events. Despite this, ^{26}Al-^{26}Mg and ^{53}Mn-^{53}Cr chronometers [3] indicate very old ages within ~5-10 Ma of CAI formation for the ultimate age of this object. The chronology of the ureilite parent body will be further explored using this lithology as the abundant K in the sample makes it a premium target for precise ^{40}Ar-^{39}Ar dating of an differentiated, unbrecciated ureilitic lithology. The ^{40}Ar-^{39}Ar data may provide a more detailed chronology for the evolution of the UPB after the earliest formation ages. We explore chronological implications of the petrology.

Discussion: The texture and mineralogy of the MS-011 lithology suggest the solidification sequence was: (1) Na-Ca feldspar—(2) pyroxene— (3) glass

The modal mineralogy (vol.) of the sample studied is: fsp, 81-85%; pyx, 10-12%; K-glass, 3-5%; oxides/sulfides, 0.5-1%; vesicles <<0.5%. This sample appears to contain less feldspar than an albitite, but meets the modal criteria for a trachyte or syenite and is thus highly differentiated.

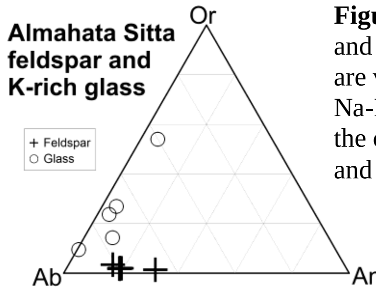

Figure 2: The feldspar and glass compositions are variable with Ca-Na-K zoning present in the coarser feldspars and in the glassy areas.

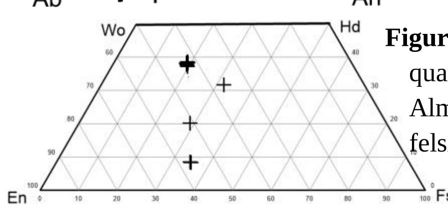

Figure 3: Pyroxene quadrilateral for Almahata Sitta felsic lithology.

The pyroxene variability reflects exsolution.

The absence of a universal Δ^{17}O value for the ureilites [4] argues strongly against a fully differentiated parent body. The formation of a trachytic/syenitic lithology is, on the other hand, ordinarily observed only in highly differentiated systems. The apparent contradiction between the isotopic and the petrographic evidence is intriguing.

The detailed solidification sequence of MS-011 is: Na-Ca feldspar — Na-feldspar + pyroxene— glass (pyroxene + K-Na-feldspar+SiO_2). This sequence and the phase compositions are compatible with a starting composition in the feldspar primary phase field (Figure 4). Despite the scalloped interfaces observed, the high modal feldspar seems unlikely to represent a liquid composition. The low density of albite (~2.6), makes feldspar flotation a possible mechanism for enriching feldspar in this lithology [7]. However, the assemblage inferred for the K-Si-rich glasses, in the interstices of the feldspar grains and as inclusions in the pyroxene, is consistent with a eutectic liquid of K-Na-feldspar$_{ss}$-SiO_2-clinopyroxene [8] remaining as the residue of an alkali rich system.

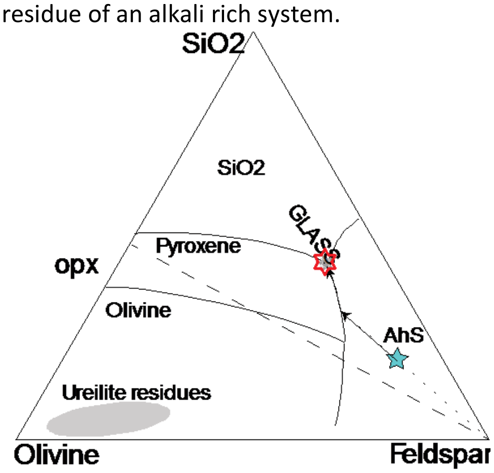

Figure 4: schematic pseudo-ternary phase diagram, olivine-feldspar-SiO2 with observed crystallization path for AhS felsic sample separated from ureilitic samples by pyx-plag alkemade line.

Typical ureilite assemblages are often interpreted to be residues of the melting of a chondritic precursor in the olivine primary phase field (Figure 4). Because of the pyx-plag alkemade, such compositions fractionate to the ol-fd-px peritectic point, not to the AhS glass eutectic composition. Unless significant fractional crystallization or changes in pressure, or the composition of the system occur, the eutectic composition is unreachable by melts from a chondritic starting composition. The required system compos-ition changes may result instead, from fO_2 controlled variation in the iron chemical state – modifying the FeO/MgO ratio of the silicate fraction and the possibility may be assessed using Fe-Mg-Mn systematics. These data [9,6] suggest that reduction of the silicates may have occurred relatively late in the evolution of the UPB (post-felsic lithology formation). Alternately, pressure changes resulting from changing depth of burial OR changes H_2O-CO_x partial pressure [10] may permit the magmatic evolution beyond the olivine phase field toward an alkali-SiO2 enriched end points. The presence of microvesicles in the AhS glass is compatible with this view. The formation of localized melt pockets with relatively high H_2O content [10] can account for the preservation of the $\Delta^{17}O$ differences between MS-011 and the majority of the ureilites while avoiding the need for large scale crustal melting that is implied by the feldspathic character of this lithology. (If the feldspathic enrichment of this lithology is treated as sampling an albitite crust analogous to the lunar highlands crust, then the $\Delta^{17}O$ of ureilites should be homogenized by the implied magma ocean event). The high alkali content of the MS-011 glasses and feldspar is also compatible with very minor volatile loss from the source magma, again compatible with a fluid rich system.

Chronology: The chondritic clast population of Almahata Sitta is dominated by samples with ^{40}Ar-^{39}Ar between 4.56n & 4.50 Ga [11]. The ^{26}Al-^{26}Mg and ^{53}Mn-^{53}Cr ages for feldspathic lithologies like MS-011 require ages of the order of 4.56 GA for their precursors, but ^{40}Ar-^{39}Ar ages may reveal events that modified them subsequently. The ^{40}Ar-^{39}Ar age of MS-011 feldspar is currently being determined.

Confirmation of a 4.56 Ga age would be consistent with the ancient assembly of the Almahata Sitta regolith (as sampled by Asteroid 2008TC3) while a younger age will require an extended regolith history on the ureilite parent body. The ability to constrain the magmatic history of MS-011 and the Almahata Sitta regolith suite opens new directions for elucidating the magmatic history of individual ureilite lithologies and the duration of high temperature processes on the partially differentiated parent body.

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