ALMAHATA SITTA 3005: A NEW SAMPLE OF UREILITIC CRUST AND NEW INSIGHTS INTO DIFFERENTIATION OF THE UREILITE PARENT ASTEROID.

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Introduction: Main group ureilites are ultramafic rocks that represent the mantle of a partially differentiated asteroid [1,2]. No known meteorites represent the complementary melts (crustal rocks). However, feldspathic clasts in polymict ureilites may be remnants of such rocks [3-7]. In typical polymict ureilites, these clasts are small (μm- to mm-sized), unrepresentative samples. The most abundant population has been inferred to represent a rock type ("the albitic lithology") consisting of plagioclase of An$_{0-30}$, FeO-rich pyroxenes, phosphates, Fe-Ti oxides, and Fe(Mn,K,P,Ti)-rich glass [4-7]. Another population has plagioclase of An$_{30-70}$, and appears to represent at least one distinct ("labradoritic") lithology [4,7]. Two larger clasts (up to 26 g) from the Almahata Sitta (AhS) polymict ureilite, MS-MU-011 and MS-MU-035, are trachyandesites hypothesized to be hand-sized samples of the albitic lithology [8-11]. AhS 3005 is a new clast of ureilitic crustal material that offers a different view of these melt lithologies

Sample: AhS 3005 is a 16.84 g sample from the University of Khartoum collection [12], found by A.T. Osman during a search in Dec. 2016. We studied a polished section with ~10.7 mm^2 of exposed sample. Fusion crust (100-350 μm thick) occurs on one edge.

Petrography: AhS 3005 has a microdioritic texture and consists (excluding fusion crust) of ~72% plagioclase, 4.3% olivine, 20% low-Ca pyroxenes (subequal orthopyroxene and pigeonite), 3% augite, and minor phosphates and Fe-Ti oxides (Fig. 1). However, it shows two distinct regions (referred to as labradorite-opx and oligoclase-augite) that differ in mineral abundances and compositions, with an imprecisely-defined boundary between them (Fig. 1).

Labradorite-Opx Region: Plagioclase laths range up to 1.6 mm in length and have ~150-260 μm-wide cores of An$_{50-53}$ with ~40-50 μm-wide rims zoned to An$_{25-30}$ (Fig. 1). Orthopyroxene occurs as interstitial grains (≤380 μm) with Mg# 69.7±1, Wo 3.6±0.2 and molar Fe/Mn=19.7±0.6 (110 analyses). Olivine occurs as one ~570 × 750 μm-sized cluster and a few smaller grains, with Fo 65.3±0.7, 0.21 wt.% CaO, 0.13 wt.% Cr_2O_3, molar Fe/Mn=30.8±0.5, and NiO below detection (58 analyses). The phosphates are merrillite (2.1 wt.% Na_2O) and the Fe-Ti oxides are ulvöspinel.

Oligoclase-Augite Region: Plagioclase laths range up to 950 μm in length and have 40-140 μm-wide cores of An$_{30-35}$ with ≤120 μm-wide rims zoned to An$_{10}$ (Fig. 1). Pigeonite occurs as interstitial grains (≤350 μm) with Mg# 64.9±1.2, Wo 7.3±0.4, and molar Fe/Mn=18.2±0.4 (100 analyses). Augite occurs as skeletal laths (≤100 × 950 μm) and anhedral grains, with Mg# 70.4±0.5, Wo 37.7±0.2, and molar Fe/Mn=16.4±0.4 (31 analyses). The phosphates are apatite (2.8 wt.% Cl, 0.84 wt.% F, 0.7 wt.% Na_2O) and the Fe-Ti oxides are ilmenite.

Bulk Composition: Based on modal abundances and mineral compositions, AhS 3005 is an andesite (not trachyandesite) in TAS classification.

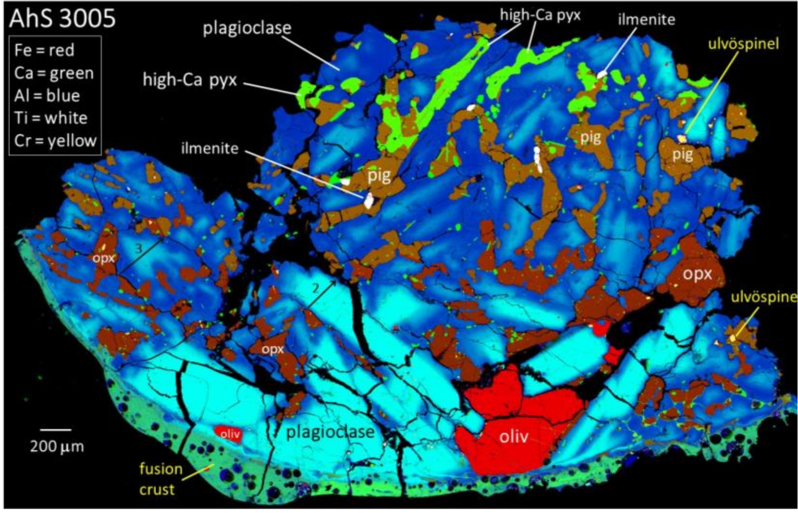
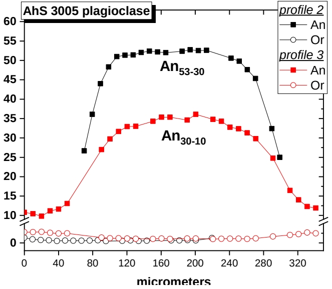


Fig. 1. Combined elemental X-ray map of AhS 3005. The sample has a microdioritic texture and shows two regions: "labradorite-opx" in the lower half, "oligoclase-augite" in the upper half. Locations of plagioclase profiles (below) are marked.



Oxygen Isotopes: Oxygen isotope compositions of hand picked separates of olivine, pyroxene, and plagioclase (Fig. 2) form a line of slope 0.533±0.02, consistent with a mass-dependent fractionation trend that passes through the bulk compositions of MS-MU-011 and MS-MU-035, as well as MS-MU-012, the only known plagioclase-bearing main group ureilite [13]. Oxygen isotope equilibration temperatures for olivine + plagioclase are ~800-1000 °C (e.g., [16]).

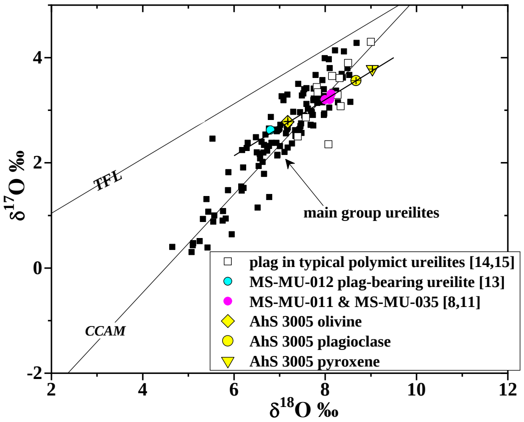


Fig. 2. Oxygen isotope compositions of mineral separates from AhS 3005 compared with main group ureilites (solid black), plagioclase clasts in typical polymict ureilites, MS-MU-011 and MS-MU-035 ureilitic trachyandesites, and MS-MU-012 plagioclase bearing main group ureilite.

Discussion: AhS 3005 appears to be closely related to MS-MU-011 and MS-MU-035, but differs in containing olivine and orthopyroxene and lacking glassy mesostasis, and in having two distinct regions. MS-MU-011 and MS-MU-035 are very similar to the oligoclase-augite region of AhS 3005 and are dominated by the An_{30-10} plagioclase zonation profile of that region. However, MS-MU-011 contains at least one occurrence of the An_{53-30} zonation profile [8]. AhS 3005 thus suggests a unifying view of the 3 samples.

We infer that the transition between the two regions in AhS 3005 is a snapshot of imperfect fractional crystallization, with the parent melt having the general crystallization sequence olivine+labradorite → orthopyroxene+labradorite → pigeonite+andesine → pigeonite+oligoclase → pigeonite+augite+albitic plagioclase. Merrillite and ulvöspinel crystallized in early stages, followed by apatite and ilmenite later. Assuming that all 3 samples share this parent melt, the sequence AhS 3005 labradorite-opx region → MS-MU-011 → AhS 3005 oligoclase-augite region → MS-MU-035 area corresponds to increasing fractionation.

The current Mg#s of the mafic phases in AhS 3005 (or MS-MU-011/035) cannot, however, represent their liquidus compositions (e.g., the olivine is too ferroan for equilibrium with ureilitic mantle). Their homogeneous compositions suggest that they have re-equilibrated (in a near-surface intrusion?). This is supported by subsolidus oxygen isotope equilibration temperatures. Preservation of zoning in plagioclase is consistent with kinetics [17].

Based on An-Fe/Mg relations (Fig. 3), the parent melt of these 3 samples is related to the magnesian labradoritic lithology [7], rather than the albitic lithology, in typical polymict ureilites. It is likely also related to MS-MU-012, which was inferred to be a cumulate from a labradoritic lithology parent melt [13]. MELTS calculations indicate that it could have originated as an intermediate-to-late degree fractional (incremental) melt on the ureilite parent body (UPB) [18]. It was too refractory to crystallize to the most fractionated compositions of the albitic lithology (e.g., An_{10-0}), consistent with origin of the latter from an earlier fractional melt [18].

Conclusions: AhS 3005 is a crucial new sample which shows that one of the dominant feldspathic lithologies in polymict ureilites was derived from an intermediate-to-late degree fractional melt on the UPB.

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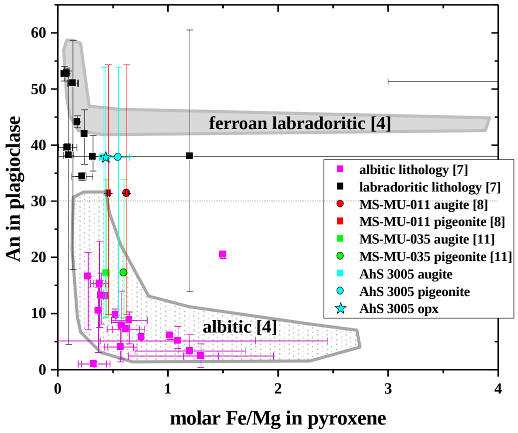

Fig. 3. In terms of An in plagioclase vs. Fe/Mg in pyroxenes, AhS 3005 and MS-MU-011/035 are consistent with the magnesian labradoritic lithology in polymict ureilites [7].