THE UNIQUE CROWDFUNDED OUED AWLITIS 001 LUNAR METEORITE – A CONSORTIUM OVERVIEW.

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Introduction: Oued Awlitis (OA) 001 is a very fresh lunar meteorite that was found in 2014 in Western Sahara. The main fragment, originally 382 g, is largely covered with a green to brownish fusion crust showing features of orientation. Another fragment, 50.5 g, fitting the larger one, was found a few weeks later; ~60% of it is covered with a crackled fusion crust and shows a rollover lip on one side. Two other fragments, 497 mg and 148 mg, were also found. OA 001 was classified as a crystallized anorthositic (clast-rich) impact melt rock with poikilitic texture [1,2]. The classification and investigations reported thus far are based on a 20.1 g piece that was cut from the main fragment.

Petrographic studies on one thin section and bulk rock chemical data, based on instrumental neutron activation (INAA) and electron microprobe (EMP) analysis on fused beads, as well as cosmogenic radionuclides, were previously conducted by [1,2] and [3], respectively. The reported minerals in OA 001 include: olivine, pyroxene, plagioclase, silica, kamacite, taenite, troilite, and rare ilmenite and Ti–Fe-rich spinel. It shows evidences of impact metamorphism, including melt veins and pockets as well as plagioclase clasts with planar deformation features [1,2]. Previous studies suggest that it was formed in a lunar impact crater >50 km Ø and excavated during an impact event forming a >0.5 km Ø crater [2].

Here we report on the first results from a consortium study that was set up during the crowdfunding campaign initiated by L.F. in 2014 to acquire the full mass of OA 001 for the Natural History Museum Vienna (NHMV) collection. Although the main mass (now 362.13 g) was acquired by a private collector, the three other fragments, including the 50.5 g one, are now in the NHMV's collection.

Samples and Methods: Several thin and thick sections were prepared. These as well as some chips and powders were distributed for investigations to consortium members.

Petrology: Transmitted and reflected light microscopy, BSE images, and X-ray maps were obtained on different sections, with a JEOL JSM-6610 SEM at the NHMV, a JEOL JXA-8500F Field Emission Gun EMP at the Museum für Naturkunde, and a Cameca SX-100 EMP at the Univ. of Arizona. Raman measurements were conducted with a Witec Alpha 300 at the DLR and micro-XRF measurements were obtained with a M4 Tornado at Bruker, both in Berlin.

Major & trace elements: Major and trace element abundances were acquired using a ICP-AES Ultima 2 and an HR-ICP-MS Thermo Element 2 in Plouzané and an Agilent 7900x ICP-MS in Prague. In addition, the concentration of 27 major and trace elements in 8 subsamples (total mass ~236 mg) were obtained by INAA at the Washington University [4].

Li & Li isotope systematics: Two separate bulk-rock powder fractions were analyzed using a Neptune MC-ICPMS at the Czech Geological Survey (Prague).

Organic spectroscopy: The organic analysis was performed with ultrahigh resolution mass spectrometry (FT-ICR-MS (12 Tesla)) in negative electrospray ionization mode after methanol extraction during crushing in an agate mortar (after intensive cleaning to avoid terrestrial biological contaminations).

Bulk Noble Gas analysis: Two fusion crust-free fragments (OA-1, 23.7 mg; OA-2, 62.0 mg) were wrapped in Al foil and analyzed at ETH-Zurich with a single heating step to ~1700°C. He, Ne, and Ar isotope ratios and concentrations were analyzed based on the protocol described by [5]. Blank contributions were <0.2%, <2%, and <6% for all He, Ne, and Ar isotopes, respectively.

^{40}Ar–^{39}Ar dating: A Thermo Scientific Argus VI mass spectrometer was used at the University of Manchester for ^{40}Ar–^{39}Ar age determination via the IR-laser step-heating technique; 32 incremental heating steps were applied to a bulk sample of 5.5 mg [6]. All data were corrected for blank, discrimination, and decay of the short-lived nucleogenic nuclides (^{37}Ar and ^{39}Ar).

Results & Discussion: *Petrology*: Our observations are generally consistent with [1,2] but new minerals were identified, including apatite, zircon, baddeleyite (which could potentially be used as targets for chronology), and cristobalite. Several anorthositic clasts (up to ~5 mm) were also identified. OA 001 suffered at least two shock events as the (fully crystallized) impact melt rock later developed shock effects in plagioclase and cristobalite, as well as small melt veins and pockets.

Major & trace elements: A comparison of subsamples of OA 001 to those of NWA meteorites of similar composition in a Sc-Cr/Sc diagram shows that OA 001 overlaps only with NWA 8222 and pairs. However, there is little to no overlap for Ba and Ni, thus there is no compositional evidence to suggest that OA 001 is paired with any other known lunar NWA meteorite.

Li & Li isotope systematics: The low mean [Li] = 2.3 ppm is consistent with earlier results for Apollo anorthosites and is distinctively different from values reported for lunar maria basalts [7]. The preliminary cumulative mean $\delta^7Li_{L\text{-}SVEC}$ = 17.4±0.5‰ is significantly higher than the value reported for pristine FAN 62255 [7]. At present, no major lunar silicate reservoir other than anorthositic crust has similar Li systematics [7,8]. The high δ^7Li must be related to early segregation of anorthositic magmas, likely coupled with kinetic fractionation effects in plagioclase.

Organic spectroscopy: The analysis of the methanol soluble fraction revealed a high diverse compositional space with an elevated abundance of nitrogen containing compounds and organomagnesium in the higher molecular mass range. The regular structural patterns observed reflect a abbiotic chemosynthesis of the organic compounds.

Noble Gases: The He, Ne, and Ar isotopic systematics in OA 001 are exclusively cosmogenic and radiogenic; this result is consistent with its classification as an anorthositic impact melt rock. In contrast, many lunar samples are solar-wind-rich regolith breccias (e.g., [9]). The terrestrial atmospheric contribution to ^{40}Ar is negligible (<1.8%, assuming $^{36}Ar_{trapped}$ = $^{36}Ar_{atm}$). The U, Th abundances of 80 and 214 ppb, respectively, can be used to calculate a U,Th-He retention age of ~50 Ma.

^{40}Ar/^{39}Ar apparent age spectrum shows at low-temperature steps that the ^{39}Ar-release is affected by partial resetting due to a thermal event, e.g., an impact, at ≤938 Ma. The high-temperature steps, covering ~36% of the ^{39}Ar release, suggest an age of ≥3555±34 Ma, likely dating the formation of this impact melt rock. We note that the lunar granulitic meteorite NWA 4881 has a similar Ar–Ar age [10].

We calculate cosmic-ray exposure ages using the elemental production rates for Galactic Cosmic Rays (GCR) and Solar Cosmic Rays (SCR) from [11]. The cosmogenic ^{21}Ne/^{22}Ne ratio of 0.775 is compatible with GCR-produced Ne which suggests that SCR contributions are at most minor. From the chemical composition of the sample, and the concentrations of stable cosmogenic ^{21}Ne and ^{38}Ar, a (2π) GCR age of ca. 30 Ma is obtained for low shielding, and of ca. 50 Ma for high shielding (200 g/cm^2). The 2π CRE age derived from ^{38}Ar measured by the ^{40}Ar–^{39}Ar analysis, 45 Ma, is within this range. The CRE age of OA 001 is a factor of >100x higher than the 0.30±0.02 Ma the meteorite spent as a cm-sized object in interplanetary space (= 4π), determined by [3] from cosmogenic radionuclides (^{10}Be, ^{26}Al, ^{36}Cl, and ^{14}C). The cosmic-ray exposure history of OA 001 is thus complex (multi-stage) with the majority (~99%) of $^{21}Ne_{cosm}$ acquired during at least one previous episode of GCR exposure within about a meter of the lunar surface. The $(^3He/^{21}Ne)_{cosm}$ ratio is very low at ca. 0.38, indicating a strong He-loss event some time during its exposure history near the lunar surface. It is tempting to associate this loss of cosmogenic He with the event that reset the U,Th-He clock at <50 Ma. It is unclear whether this is the same loss event (<938 Ma) recorded by the low-temperature Ar steps, or whether these represent two separate events. The low activities of cosmogenic radionuclides suggest that OA 001 spent the last few Ma before its ejection in a shielded position. A possible exposure history scenario (among others) is that OA 001 was excavated from a shielded position at <938 Ma, and subsequently (perhaps repeatedly) exposed to GCR within a meter of the lunar surface, until an impact at ca. 50 Ma reset the U,Th-He system, without affecting the K–Ar system. Another impact at ca. 0.3 Ma finally ejected OA 001 from the Moon.

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