GHADDUWAH 001: UNIQUELY UNBRECCIATED FERROAN ANORTHOSITE LUNAR METEORITE.

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Introduction: We report here the discovery of a uniquely unbrecciated ferroan anorthosite lunar meteorite, Ghadduwah 011. This lunar meteorite is an exceptionally fresh find with spectacular pale-green, glassy fusion crust and a mineralogy consisting primarily of ~92% anorthitic plagioclase/maskelynite and ~7% ferroan olivine and pyroxene. In contrast to other lunar ferroan anorthosite meteorites and Apollo samples, which are all significantly brecciated, Ghadduwah 001 represents the first known unbrecciated rock from the lunar highlands.

History and Physical Charateristics: Ghadduwah 001 was reportedly found near Lake Gaberoun, Libya on January 7, 2020. Subsequently it was purchased by Jay Piatek from Abdelhadi Aithiba, a Moroccan meteorite dealer. The original specimen of 265 grams is a visually striking, flight-shaped stone, with a broad rollover lip, and a surface covered in shiny pale-green, translucent fusion crust. One side of the stone is broken and the interior is exposed, however this is not a recent fracture as the surface is slightly weathered and smoothed. A freshly fractured surface shows a sugary, shiny texture of white to light gray grains (figs.1&2).

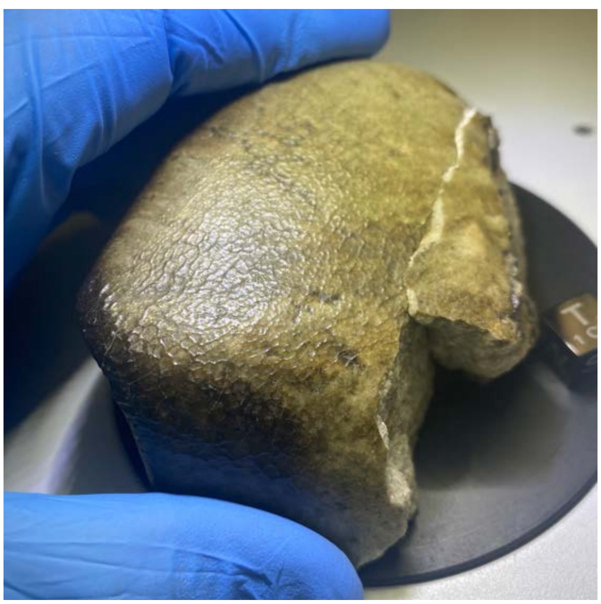

Fig. 1. Photograph of Ghadduwah 001 single stone showing the exterior fusion crusted surface.

Petrology: Electron microprobe and SEM examinations were performed on a polished probe mount taken from the classification deposit sample at the Institute of Meteoritics (fig. 3). Our analyses revealed an anorthitic plagioclase host mineralogy making up ~92% of this meteorite. Poikiolitically enclosed in the plagioclase are olivine and pyroxene grains, most in the size range 100-300 μm, making up a total of ~7% of this meteorite. Olivine grains are very homogeneous, however some exhibit resorbed rims. Pyroxene grains have exsolution lamellae with coarser bands of low-Ca pyroxene and finer bands of augite. Accessory chromite was observed throughout the polished section. Fusion crust is ~75 um thick. Petrographic microscope examination of a polished thin section under crossed polars showed that a significant fraction of the plagioclase in Ghadduwah 001 is optically isotropic, consistent with maskelynitization.

Fig. 2. Photographs of Ghadduwah 001. Photos on the left show the UNM deposit sample and a freshly broken surface. Photo on the right shows the rollover lip covered with fusion crust.

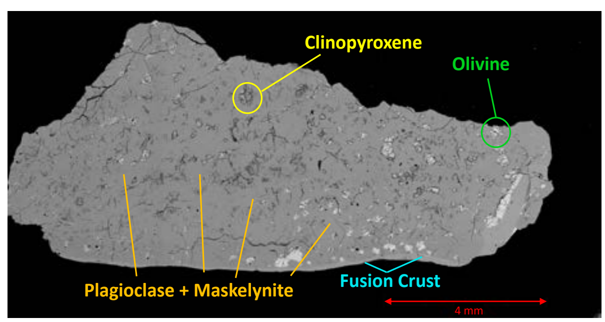

Fig. 3. Backscatter electron (BSE) image of a probe mount of Ghadduwah 001. Red scale bar is 4 mm.

Electron microprobe results: *Plagioclase (maskelynite)* An98.1±0.8Ab1.8±0.3Or0.0±0.0, n=4; *pyroxene* Fs30.5±6.2Wo12.7±11.4, Fe/Mn=52±8, n=9; *olivine* Fa40.9±0.3, Fe/Mn=88±3, n=6; *fusion crust* SiO2=43.1±0.2, Al2O3=31.0±0.1, FeO=3.7±0.2, MgO=3.3±0.1, MnO=0.05±0.03, CaO=17.0±0.1, Na2O=0.19±0.02 all wt%, n=5.

Oxygen isotope results: Oxygen isotopes were performed at UNM on 3 acid-washed fragments analyzed by laser fluorination and gave δ18O= 5.810, 6.152, 5.852; δ17O= 3.038, 3.198, 3.042; Δ17O= -0.029, -0.050, -0.047 (linearized, all per mil, TFL slope=0.528). These values are consistent with oxygen isotopes of lunar rocks.

Comparison with other Ferroan Anorthosites (FANs): Ghadduwah 001 possesses a mineralogy that is classic lunar ferroan anorthosite (FAN) as shown in. figure 4.

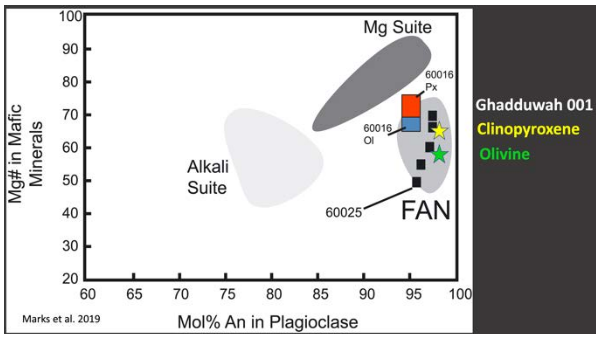

Fig. 4. Plot from Marks et al. [1] of molar anorthite content in plagioclase versus Mg# of pyroxene and olivine. Fields for ferroan anorthosites (FAN), Mg-suite, and alkali suite samples are from Shearer et al. [2]. Olivine, pyroxene, and plagioclase compositions in Ghadduwah 001 are shown as green and yellow stars.

FANs have been recognized as representative of some of the earliest crust formed subsequently to the crystallization of the lunar magma ocean. Therefore precise age dating of these samples can provide important insight into the origin of the Moon, its differentiation and the timing of the first crust formation. However interpretation of FAN ages can be challenging because of the brecciated nature of most FANs and post-crust formation impact processes that have affected the lunar regolith over geologic time [3]. For example, most FANs collected by Apollo missions are highly brecciated rocks, many of which are polymict breccias, thus age dating often requires the daunting task of extracting sufficient useful material for analysis. Figure 5 shows some Apollo 16 FANs that have been the focus radiometric age-dating studies.

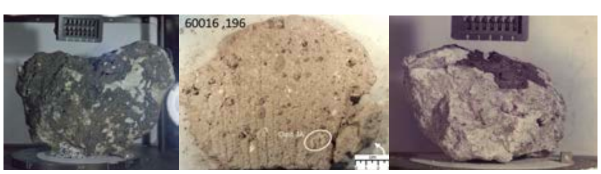

Fig. 5. Examples of ferroan anorthosites from Apollo 16, which are highly brecciated rocks. Left 60015 [4], middle 60016 [1], right 60025 [4].

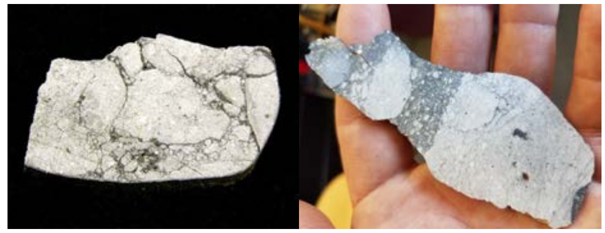

Fig. 6. Examples of ferroan anorthosite lunar meteorites which are highly brecciated rocks (photos from the UMN Meteorite Museum). Left NWA 492, right NWA 12695.

Although the lion's share of lunar meteorites are feldspathic breccias, at best, they usually possess only small, FAN-like, clasts. There are only a few examples of meteorite FANs such as NWA 492 and NWA 12695 (fig. 6), but these are also heavily brecciated in similar fashion to the Apollo FANs. Therefore the discovery of Ghadduwah 001 which is the first ever unbrecciated FAN, should offer an opportunity to enhance age dating studies of the early lunar crust. One of the drawbacks of lunar meteorites is that their place of origin on the lunar surface is unknown, thus geologic field context is absent. On the other hand, the likelihood that Ghadduwah 001 was ejected from one of the Apollo landing sites is remote (fig. 7). Therefore, future age-dating studies of Ghadduwah 001 might be a valuable complement to existing Apollo FAN data sets which sample only limited nearside field areas.

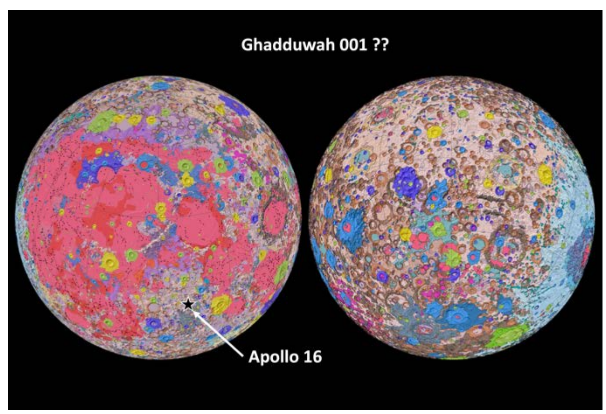

Fig. 7. Global geologic map of the Moon [5], showing the landing site of Apollo 16 where several notable FANs have been collected and the Moon-wide abundance of Nectarian and lunar highlands terrains (light pinkish-tan color) where Ghadduwah 001 could have originated.

References: [1] Marks N. E. et al. (2019) *JGR Planets,* doi.org/10.1029/2019JE005966. [2] Shearer C. K. & Papike J. J. (2005) *Geochim. Cosmochim. Acta*, 69, doi.org/10.1016/j.gca.2005.02.025. [3] Norman M. D. et al. (2003) *Meteoritics and Planetary Science*, vol 38, 645-661. [4] *Lunar Sample Compendium*, https://curator.jsc.nasa.gov/lunar/lsc/. [5] Fortezzo C. M. et al. (2020) *51st LPSC*, abstract 2760.