NANOSCALE ANALYSES OF SPACE WEATHERED MATURE LUNAR SOIL 79221

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Introduction and Methods: The alteration of the outer surfaces of grains on airless bodies by space weathering processes results in the production of new nanoscale features. Samples that have been exposed to this environment for a long time are termed mature. Apollo 17 sample Soil 79221 is classified as mature and has previously been used to study space weathering on the Moon, e.g. [1], and herein we present atom-probe tomography (APT) analyses of this soil to compare with our previously published data on submature soil 71501 [2]. In APT, atoms on a sample nanotip are field evaporated using a pulsed picosecond laser and their mass-to-charge-state ratio is measured via a position-sensitive detector, permitting a 3D reconstruction of the outermost ~100s of nanometers of space weathered material, e.g., [2,3]. Lift-outs were performed with a TESCAN LYRA3 FIB-SEM the University of Chicago close to the location of lamellae extracted for TEM for correlative analyses [4]. Prepared nanotips were analyzed with the CAMECA LEAP 5000XS tomograph at Northwestern University.

Results: A total of 16 nanotips from agglutinate, plagioclase, olivine, and ilmenite were analyzed for their space weathering features, with nine providing useful data. Of particular interest are the olivine (Fig. 1) and ilmenite nanotips, as they exhibit zones of decreased atomic density which we interpret as vesicles and irregularly shaped defects. These features are prominent in our samples, and are also observed in TEM analyses [5]. The agglutinate nanotips are instead dominated by Fe-rich structures, including whisps of increased oxidation and a microphase Fe particle which are depleted in H relative to the rest of the sample [4]. The ilmenite nanotips contained some nanophase Fe particles, but heterogeneous Fe structures were not observed in the (Mg-rich) olivine nanotips. None of the analyzed samples preserved or included redeposition rims.

Discussion: The olivine displays evidence of a complex structure of voids (Fig. 1). There is a fine-scale network of spaces that are much smaller than that of the round vesicles detected in the ilmenite nanotips. Like the vesicles, these void spaces are are filled with H species. Our previous APT study [2] identified a vesicle in submature lunar ilmenite with a small amount of ^{4}He detected. This previously analyzed vesicle was similar in size to one of the vesicles we found in the mature lunar ilmenite, which also included a small ^{4}He signal (5±2 atoms, 1σ). Both analyses are missing at least three orders of magnitude of He atoms when compared to data from bulk analyses [6]. A burst of H detections at the top of vesicles indicates the opening and degassing of vesicles as the top of the nanotip field-evaporated during analysis. This suggests that the volatiles in the vesicle largely escaped into the vacuum without being analyzed, with only a small fraction ionized and detected. The number density of vesicles is much greater in the nanotips from the mature soils than the submature soil sample.

Where the vesicle comprised a significant volume of the nanotip, the nanotips fractured before an analysis reached the lower half of the vesicle. Vesiculated textures present challenges to APT analysis. Interior voids cannot be filled with coating methods. The resulting non-hemispherical topography from vesicles alters the local electric field-evaporation dynamics in ways that can lead to instabilities and nanotip failure. Mature space-weathered samples are more challenging for APT than submature ones.

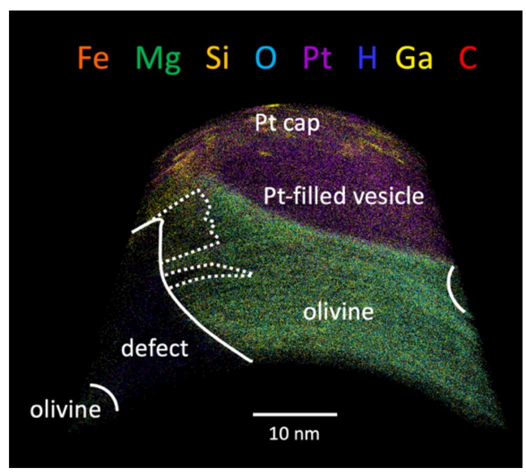

Fig 1. A cross-section through an APT reconstruction of an olivine grain from lunar soil 79221, with individual, color-coded ions shown as labeled. Dotted lines indicate areas of decreased density attached to a defect, suggesting very fine-scale features of a network.

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