Atom-Probe Tomography of Space-Weathered Lunar Ilmenite Grain Surfaces

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Airless bodies such as the moon are subject to space weathering, which alters the mineralogy and morphology of the upper tens of nanometers in mineral surfaces. Processes such as micrometeorite bombardment, irradiation by solar wind (SW), and galactic cosmic rays [1] amorphize the outermost surface, produce submicroscopic and nanophase metallic iron (SMFe and $npFe^0$), and implant SW [2]. Here, we use atom-probe tomography (APT) to characterize the composition and texture of space weathering products in ilmenite ($FeTiO_3$) from Apollo 17 sample 71501 at near-atomic resolution in three dimensions [3]. Apollo sample 71501 has been well studied due to its retentivity of space weathering products [eg. 4]. Our tomographic reconstruction exhibits the same features and zoning that have been observed in the two-dimensional TEM studies of Itokawa asteroidal regolith grains [5] and lunar soils [6]. Besides the major elements Fe, Ti, and O, we detected the minor and trace elements Mg, Si, Al, Ca, Mn and Cr enriched in the outermost edge of the grain, representing a mixture between ilmenite and bulk lunar soil [7]. These elements are not enriched in the unaltered material below a 100 nm depth. All three subsamples studied herein contain $npFe^0$ 3 to 10 nm in diameter (similar to that seen in [8]), with particles becoming less frequent with depth. We found a void space (~15 nm in diameter) which we interpret as a vesicle generated by SW irradiation. No SW noble gases, however, were detected in the APT mass spectrum, likely due to gas loss during sample preparation.

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