Searching for Volatiles in Space Weathered Grains

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Space weathering alters the physical, chemical, and optical characteristics of materials on the surfaces of airless bodies. In our current understanding, solar wind ion irradiation and micrometeoroid bombardment, along with other processes, lead to the formation of thin amorphous coatings and nanophase metallic iron inclusions ($npFe^0$) that in turn are the main causes of darkening and reddening in the visible to near infrared wavelength region [1]. While we have been able to study lunar rocks and soils for the past almost 50 years and have gained an understanding of the main processes and effects of space weathering there, open questions about the rates at which alteration occurs and how various space weathering processes interact with each other remain. The return of samples from asteroid Itokawa has provided a new avenue for understanding the effects of space weathering and how the dominant processes can vary in different regions of the Solar System. Additionally, advances in scanning transmission electron microscopy (STEM) instrumentation and associated techniques have enabled new measurements and analyses of old and new samples and can provide new insights about space weathering processes and features [2,3].

Recent work on space weathered grains from the Moon and asteroid Itokawa have demonstrated that the phase of the substrate or host grain plays a significant role in how materials are altered by solar wind irradiation and micrometeoroid bombardment [2,4]. Vesicles and/or surface blisters are observed to be present in or on some phases but not others that are directly adjacent. The presence (or lack of) vesicles in some materials, as well as whether they contain hydrogen (or water) or helium provides key information about how space weathering progresses in different phases and the relative rates of alteration.

We used focused ion beam microscopy (FIB) to prepare samples for analysis using an aberration-corrected Nion STEM equipped with detectors for electron energy loss spectroscopy (EELS) and energy dispersive X-ray spectroscopy (EDS). Spectrum image data cubes were collected in order to map changes in oxidation state, presence of volatiles, and elemental composition. FIB allows for preparation of site-selected regions of grains and allows us to maintain context and spatial relationships across phase boundaries and features of interest.

Using these methods, we have identified helium in vesicles in the rims of ilmenite grains from two different lunar soils. Figure 1 shows a small ilmenite grain attached to a larger plagioclase grain. The exposed surface of the ilmenite has a well-developed space weathered rim with $npFe^0$ inclusions and small vesicles. Planar defects are seen in this rim up to 135 nm from the surface. In comparison to a rim on an ilmenite grain from sub-mature lunar soil 71501 [2], the defects in the rim have high areal density. As was noted for that grain, helium implanted by the solar wind can be identified in some vesicles using EELS. The energy of the helium K-edge measured for these vesicles, 22.8 eV, is consistent with $n_{He} \sim 40\ nm^{-3}$, similar to what was seen in [2]. Thus far, helium has been identified only in vesicles or defects in oxides, not silicates, from the Moon.

Figure 2 shows scanning electron microscope (SEM) images of the surface of a multi-phase lunar grain. As noted for some Itokawa particles [4], the two phases show different surface morphology features, including blisters present on the Mg-, Fe-rich silicate phase (either olivine or pyroxene) but not the Al-rich (plagioclase) surface. The number of small (<100 nm) adhered spherical particles is also higher on the mafic grain. FIB/STEM can be used to determine if these blisters indicate the presence of vesicles and how the rim differs between these two phases across this boundary, as well as if any volatiles remain trapped in the vesicles.

The careful work on the Itokawa particles examined to date have shown the significant scientific value in each single grain through detailed comparisons with other grains, both asteroidal and lunar. Understanding how and when hydrogen and helium implanted by the solar wind coalesce into larger defects and vesicles requires an understanding of which phases host the most vesicles, whether or not there are other features associated with these vesicles, and what other processes, such as heating, might be necessary for vesicle formation. Detailed comparisons between samples from the Moon and from Itokawa will allow for a better understanding of how location in the Solar System may affect vesicle formation and volatile trapping and how the important space weathering processes vary between those locations.

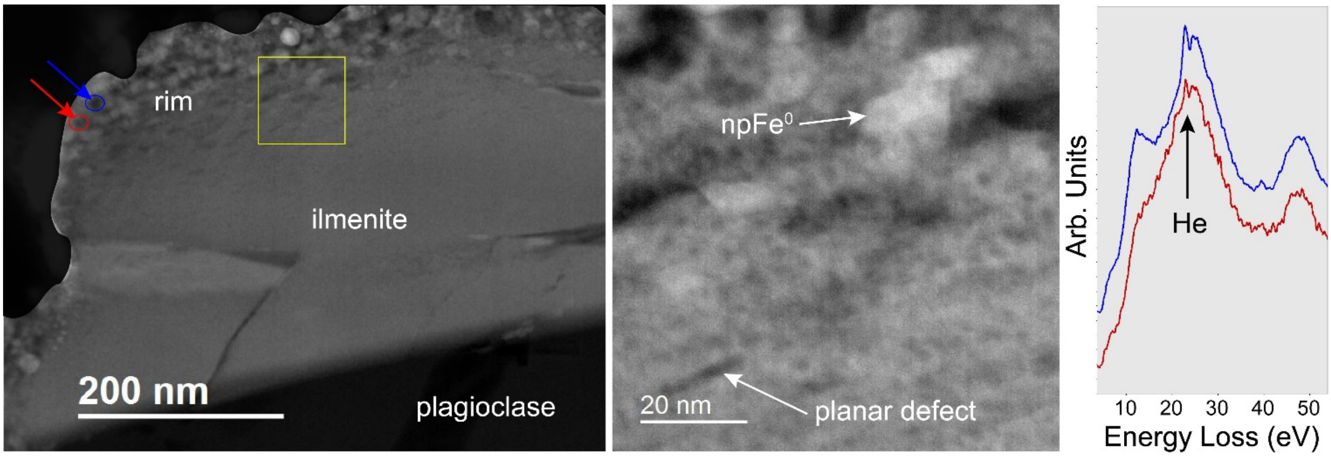

Figure 1. An ilmenite grain attached to a plagioclase grain in mature lunar soil 79221 has a well-developed space weathered rim on the exposed surface. Some of the vesicles in the rim contain trapped helium from the solar wind that can be measured using EELS.

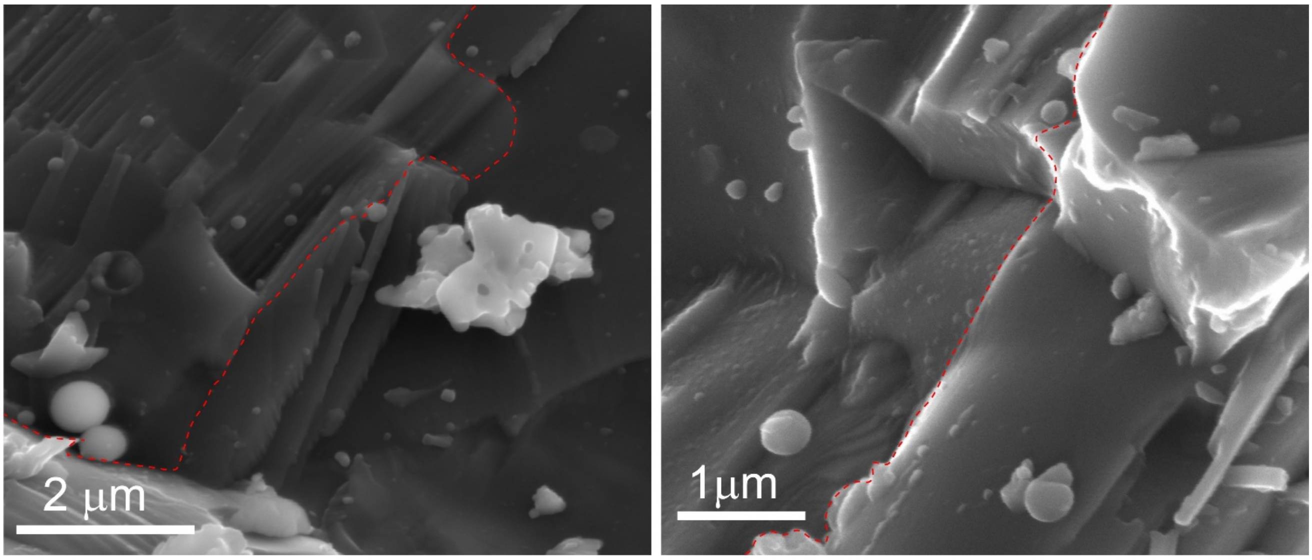

Figure 2. Different phases react very differently to the same space weathering exposure and thus are likely to have different rates of vesicle formation or have vesicles from through different mechanisms. (a) SEM secondary electron image shows the Mg-rich phase (left) is fractured in a different pattern than the Al-rich phase (right) and has more <100 nm adhered surface nanoparticles. (b) The Mg-rich silicate has numerous apparent blisters, while the Al-rich silicate lacks the blister-like features.

References

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