The Search for Water in Lunar Soils through Coordinated Analysis of Space Weathering Characteristics in an Apollo 17 Sample

Alexander M. Kling[1*], Maizey C. Benner[1], Michelle S. Thompson[1], Jennika Greer[2,3], Rosa E. Diaz[4], and Philipp R. Heck[2,3]

[1]Department of Earth, Atmospheric and Planetary Sciences, Purdue University (klinga@purdue.edu), [2]Chicago Center for Cosmochemistry, Department of Geophysical Sciences, University of Chicago, [3]Robert A. Pritzker Center for Meteoritics and Polar Studies, The Field Museum, [4]Birck Nanotechnology Center, Purdue University

Introduction

- Water (OH and H_2O) has been proposed to form on the lunar surface due to interactions between implanted solar wind H^+ and O present in the surface minerals [1].
- Solar wind irradiation contributes to space weathering, a process which affects the microstructure and chemistry of the upper ~100 nm of lunar surface regolith grains [2].
- Solar wind irradiation is predicted to form crystal defects where hydrogen can be trapped and then react to form water [3,4].
- The relationship between space weathering and the formation and retention of water in space weathered rims is still unknown.

Sample and Methods

- Apollo 79221 is a mature lunar mare regolith sample collected from the Apollo 17 mission
- An electron-transparent cross section of a clinopyroxene grain was extracted using a focused ion beam scanning electron microscope (FIB-SEM).
- High angle annular dark field (HAADF), and energy dispersive X-ray spectroscopy (EDX) imaging were performed to characterize the chemistry and microstructure of the space weathered rim and grain interior.
- Low-loss electron energy loss spectroscopy (EELS) was performed as linescans on vesicles in the space weathered rim to identify the presence of H and water.
- Atom Probe Tomography (APT) was performed on tips extracted from the same grain in an area adjacent to the FIB section to create a 3-D reconstruction of elemental data and concentration profiles of the space weathered rim and interior of the grain.

Acknowledgements

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Results

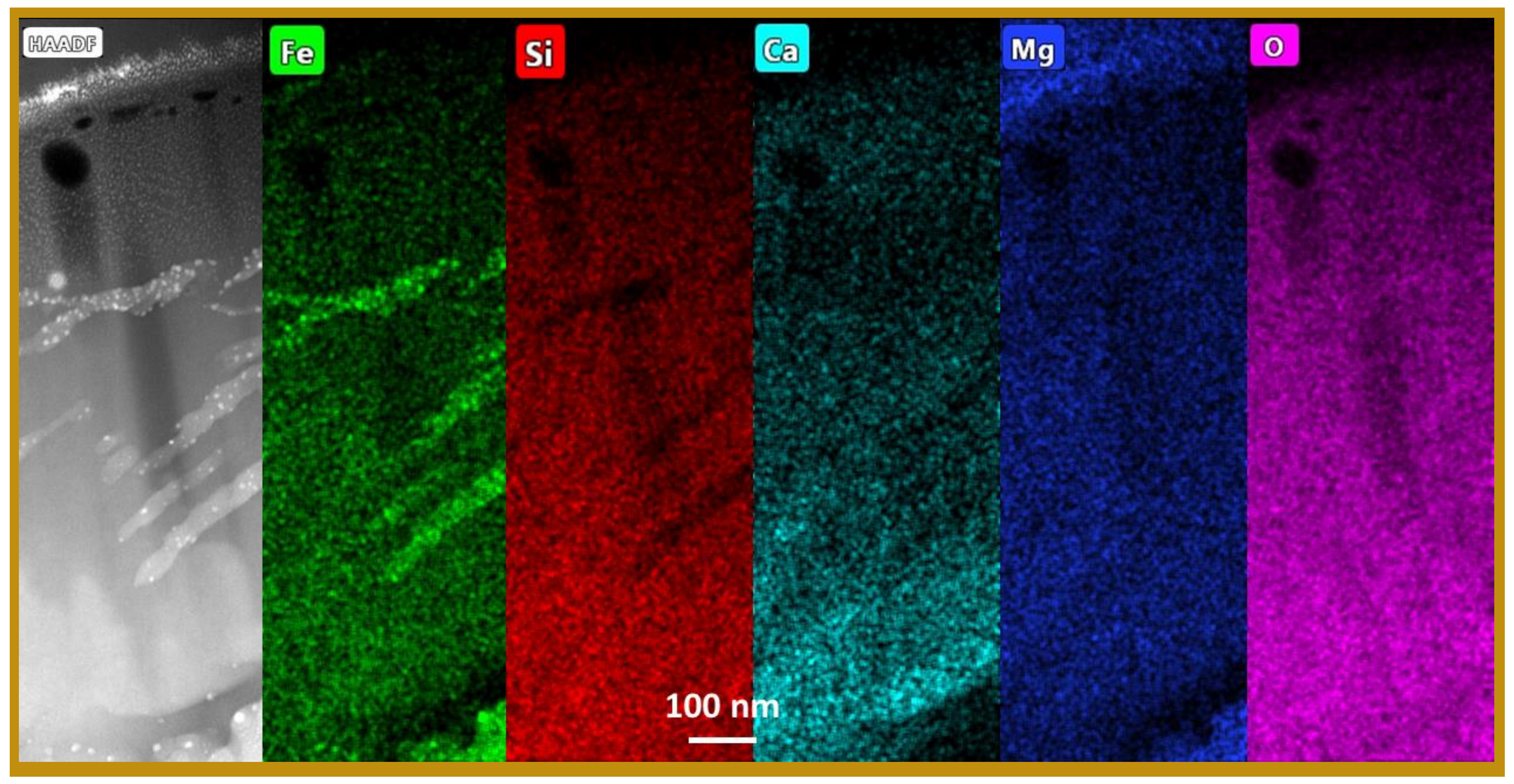

Fig. 1. HAADF image and corresponding Fe, Si, Ca, Mg, and O EDX maps showing the presence of veins running through the interior of the grain.

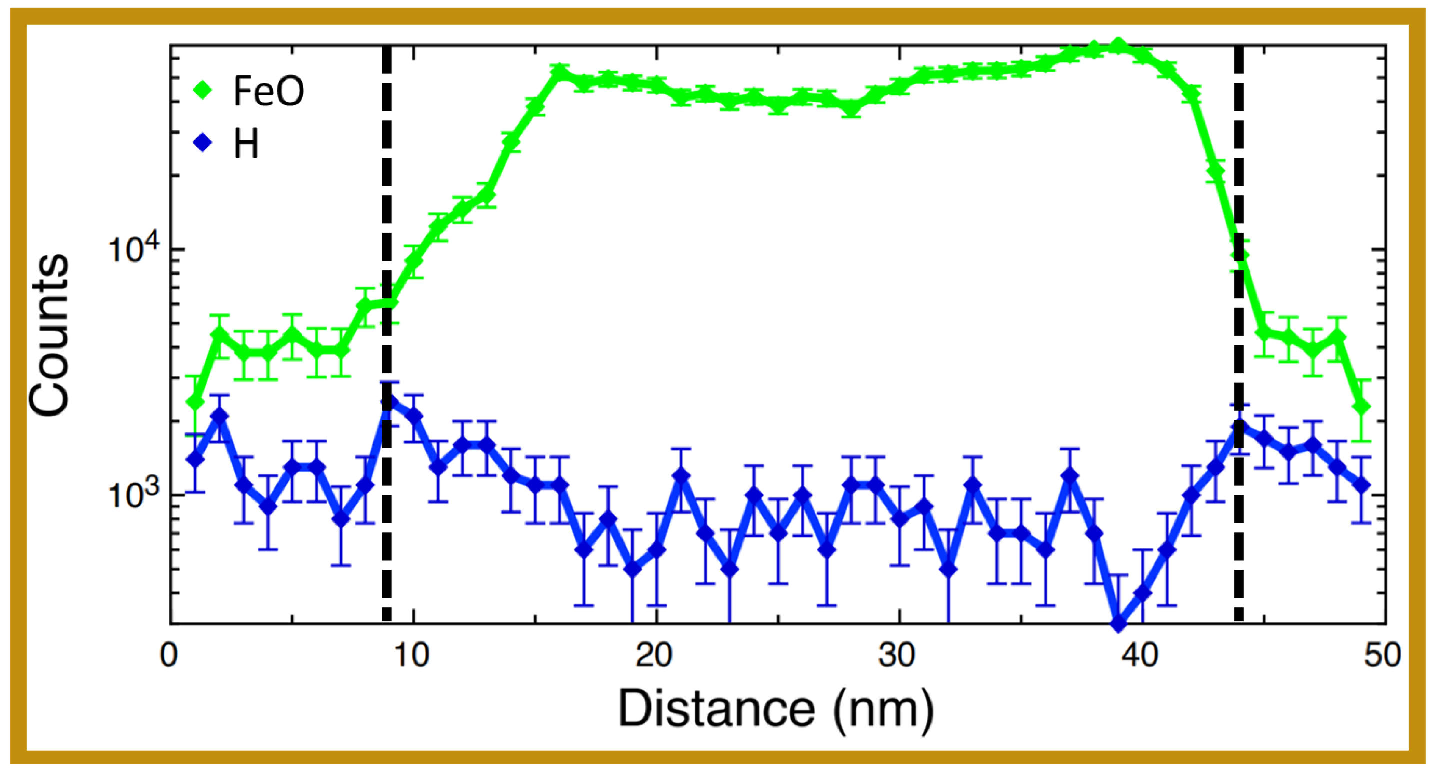

Fig. 2. Concentration profiles of FeO and H across a section of the APT tip. Dashed lines indicate the bounds of a vein like that in Figure 1.

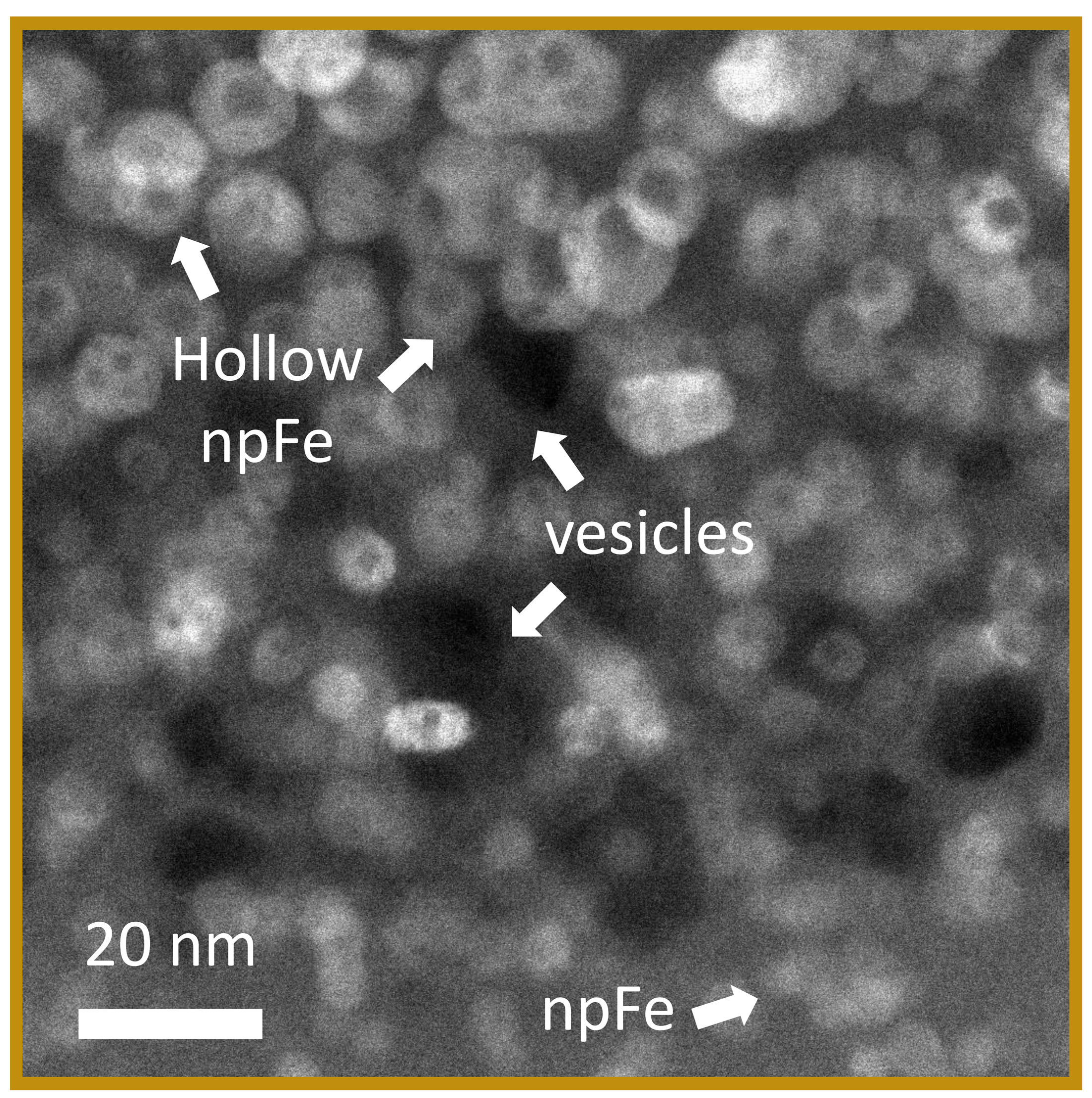

Fig. 3. HAADF image of region of space weathered rim with a high density of vesicles and hollow npFe particles.

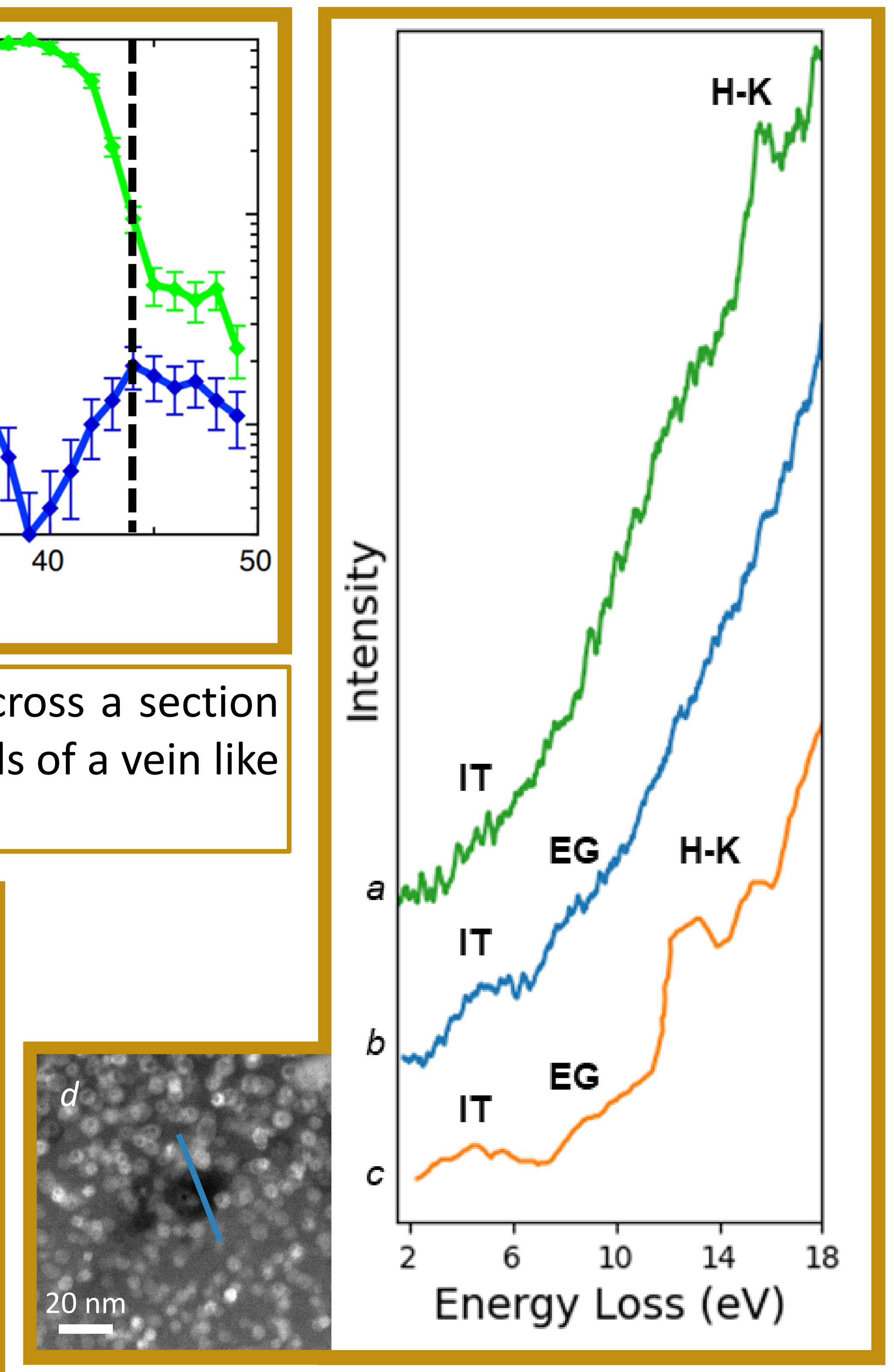

Fig. 4. Low-Loss EELS spectra of **a)** a vesicle from the space weathered rim which displays a hydrogen core scattering edge (H-K) and a weak ionizing threshold of water (IT), **b)** a vesicle (d) from the highly vesiculated region which displays an IT and energy gap of water (EG), **c)** a vesicle from the space weathered rim of an interplanetary dust particle from [5] and has H-K, IT, and EG features. **d)** shows the vesicle and EELS line scan from (b).

Discussion

- The veins in Fig. 1 contain npFe particles and are Fe-enriched and Si- and Ca-depleted relative to the grain.
- The vein identified in the reconstructed APT tip appears to be enriched in FeO and depleted in H (Fig. 2).
- Hollow npFe were only identified in regions with vesicles and measure ~6-13 nm in diameter (Fig. 3).
- The edge positions of the features in spectra a and b for Fig. 4 are IT (2.4 eV), EG (6.7 eV), and H-K (13.7 eV).

Conclusions

- The presence of npFe in the veins in Fig. 1 indicates they are likely space weathering features despite their presence below the space weathered rim.
- The anticorrelation of FeO and H across the vein may indicate a type of oxidation process.
- Hollow npFe may form when water within vesicles diffuses out, creating an oxidizing. gradient and causing the Fe to diffuse outward and leave void spaces in the centers of the particles as predicted by [6].
- The similar band shapes and edge positions of the spectral features in Fig. 4a and 4b to those in 4c from [5] lead us to believe we have identified the presence of water and hydrogen within the vesicles.
- The presence of water in the space weathered rim may provide evidence that solar wind implantation of hydrogen may be a viable mechanism to form water on the lunar surface.

References

[1] McCord, T. B. et al. (2011) *JGR: Planets, 116*, E00G05 [2] Pieters C. M. and Noble S. K. (2016) *JGR: Planets 121*(10):1865–1884. [3] Farrell, W. M. et al. (2017). *JGR: Planets*, *122*(1), 269–289. [4] Tucker, O. J. et al. (2019). *JGR: Planets, 124*(2), 278-293. [5] Bradley, J. P. et al. (2014). *PNAS*, *111*(5), 1732–1735. [6] Thompson, M. S. et al. (2016). *M&PS 51*(6):1082-1095.