Radiolytic solar wind water in rims on an Itokawa regolith grain

John P. Bradley[1] and Hope A. Ishii[1]
[1]*Hawaii Institute of Geophysics and Planetology, University of Hawai'i, Honolulu, HI 96922, USA*

Introduction: The detection using electron energy-loss spectroscopy (EELS) of OH/H_2O *in-situ* in vesicles within sputtered rims on interplanetary exposed to the solar wind for ~10^4-10^5 years provided the first direct evidence that the interaction of the solar wind with oxygen-rich silicates produces water; additional confirmation was provided by detection of water using EELS in the sputtered rims on silicate mineral standards following proton irradiation at solar wind fluences [1]. The results are consistent with OH/H_2O signatures on the surface of airless bodies observed by remote spectroscopy, e.g. [2]. Regolith from the S-type asteroid Itokawa returned by the Hayabusa mission enables us to further explore the effects of solar wind irradiation on airless bodies. Enrichments in water and hydroxyl in the solar wind-irradiated rim of an Itokawa olivine grain and a lab-irradiated olivine standard have been detected using atom probe tomography [3]. Here we describe detection of OH/H_2O in the surface of another Itokawa olivine grain using electron energy loss spectroscopy (EELS).

Experimental procedure: Hayabusa regolith particle RA-QD02-0332 was carbon-coated for imaging and element-mapping in a focused ion beam-scanning electron microscope (FIB-SEM: FEI Helios 660 with Oxford Instruments EDS), and FIB sections of selected regions were extracted at Univ. Hawai'i using Pt protective straps. These were further analyzed on (scanning) transmission electron microscopes at the Molecular Foundry (S/TEM: FEI Titan ChemiSTEM with EDS, TEAM 1.0 with Gatan Continuum GIF for EELS).

Results: RA-QD02-0332 is a ~48µm grain that consists of olivine, pyroxene, plagioclase and, likely, K-feldspar. In SEM imaging, glassy melt splashes with degassing vesicles are visible in multiple locations on the surface. Fractures are observed as well as significant fine-grained adhering material, including angular fragments and spheroidal particles with melt droplet appearance. Two FIB sections crossing fine-grained material contain small mineral crystals of albitic plagioclase and fayalitic olivine with lesser amounts of high-Ca pyroxene and iron-sulfide. Fine grain sizes range from ~100 nm to several microns across, and grain shapes range from angular to euhedral to rounded, consistent with some brecciation on the parent body. Another FIB section contains a ~4 µm plagioclase grain with fracture and defects in the interior consistent with shock, an amorphized rim on one face that has lost most of its Na and some Ca relative to the underlying crystal, and surficial lacy Fe-rich material that is likely remnants of the impactor.

A FIB section through an olivine crystal shows melt splash glass and a ~40 nm in thick vesiculated amorphous rim on the surface (Figure 1a). Energy dispersive spectral mapping shows that the amorphous rim has a composition similar to the underlying olivine but with minor additional Al and Ca present. An EELS spectrum from one of the vesicles shows features at ~8 and ~13.5 eV features. These features correspond to the energy gap and H-K core scattering edge from hydroxyl and/or molecular water, like those we previously observed in rims on IDPs, water in a liquid cell, proton irradiated silicate standards and electron beam-damaged talc and brucite [1,4]. Weaker features are observed in the amorphous rim off the vesicle.

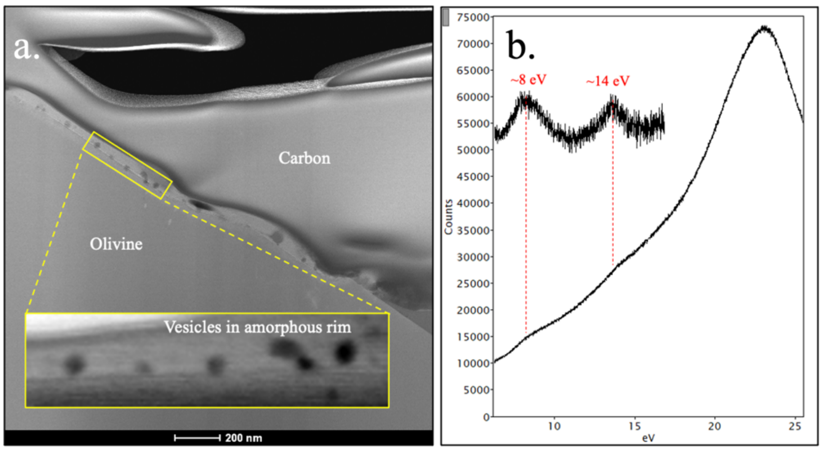

***Figure 1:** (a) Darkfield image and higher-magnification inset show vesicles in amorphous rim on Itokawa olivine,.(b) EELS low-loss spectrum shows ~8 eV and ~13 eV features from one of the vesicles superimposed on the amorphous rim volume plasmon.*

Discussion: The vesiculated amorphous rim on the olivine crystal in Itokawa grain RA-QD02-0332 establishes that it was exposed to the solar wind on the surface Itokawa. Detection of water by EELS confirms the prior atom probe tomography detection of water in another solar wind-irradiated rim on an Itokawa olivine [3]. The relatively low intensity of the features observed here from the vesicle in the amorphous rim on Itokawa olivine compared to those observed in some vesicles in IDPs (Fig 1c), may be a consequence of a shorter (solar wind) exposure ages of Itokawa regolith grains relative to IDP orbital exposure ages.

References: [1] Bradley J.P. et al. (2014) *Proceedings of the National Academy of Sciences* 111:1732. [2] Li S. and Milliken R.E. (2017) *Science Advances* 3:e1701471. [3] Daly L. et al. (2021) *Nature Astronomy* 5:1275. [4] Zhu C. et al. (2019) *Proceedings of the National Academy of Sciences* 116:11165-11170.