AN ELECTRON MICROSCOPE AND MICROSPECTROPHOTOMETRY STUDY OF PATINA ON APOLLO 17 BRECCIA 76015. Lindsay P. Keller[1], Susan J Wentworth[2], and David S. McKay[3]. [1]MVA, Inc. 5500 Oakbrook Parkway, Norcross, GA 30093, [2]C23, Lockheed-Martin, NASA-JSC Houston, TX 77058, and [3]SN, NASA-JSC, Houston, TX 77058.

Introduction. The surfaces of lunar materials that are exposed to the space environment are modified by a number of processes which alter their chemical and physical characteristics. These surface modifications on lunar rocks result in the formation of patina. The presence of patina obscures the underlying mineralogy and can strongly affect the optical properties of the substrate. Patinas are important in the further exploration of the Moon and other airless bodies in the Solar System because of their effects on remotely-sensed data (both spectral and chemical). We present here the results of a detailed study of a small region of patina on 76015 as part of a consortium study on the nature and effects of space weathering on the lunar surface (see companion abstract [1]).

Materials and Methods. A 3 X 3-mm-sized fragment of patina from a surface of Apollo 17 breccia 76015 was analyzed using light microscopy, microspectrophotometry (for details see [2,3]), scanning electron micoscopy (SEM) and transmission electron microscopy (TEM).

Results and Discussion. Microcraters with glass-linings and spall zones are visible by light microscopy covering much of the allocated chip of 76015. Between the zap pits, the surface is brownish in color and distinctly darker than the underlying material (mostly plagioclase). Reflectance spectra of the patina were obtained from multiple regions ~0.1 mm in diameter using a microscope photometer. Typical spectra over the wavelength range of 380 to 1040 nm from both the patina and the underlying plagioclase are given in Figure 1. The patina has a much lower albedo than the plagioclase, has a slightly redder slope over the visible wavelengths, and attenuates the absorption feature at ~1.2 μm in plagioclase. SEM images of the patina surface show abundant microcraters, glass splashes, attached mineral grains, and glass spheres. The surface shows considerable roughness at the ~10 μm scale. A small fragment of the patina on plagioclase was embedded in low viscosity epoxy and TEM specimens were prepared using ultramicrotomy. The sample was oriented so that multiple cross-sections of the patina-substrate interface were obtained. Following the microtomy, the remainder of the cross-section was analyzed in the SEM, and backscattered electron images along with X-ray maps for the major elements were obtained. We observed that the patina on the fragment of 76015 has considerable porosity and is typically <10 μm thick. The X-ray maps from the analyzed fragment show that Fe and Mg are confined to the patina and are concentrated in a thin (~ 1 μm thick) glass layer (probable impact glass splash) and in regions of vesicular glass.

The analyzed patina has characteristics of both the accretionary-welded-fragmental (AWF) patina and the accretionary coalesced-type (AC) as defined by McKay *et al.* [4]. TEM analysis of the patina thin sections show that much of the thickness consists of a complex mixture of melt glass and mineral grains. The melt glass ranges from plagioclase composition glasses to silica-rich glasses with abundant Fe-metal inclusions and vesicles. The crystalline grains within the patina are predominantly plagioclase with minor ilmenite. Our preliminary data indicate that the plagioclase grains in the patina contain high solar flare track densities which range from ~1 x 10^{11} cm^{-2} near the surface to values in the low 10^{10} cm^{-2} at a depth of a few micrometers. These track densities indicate that the accreted grains have not been heated above the track annealing temperature. Furthermore, several grains in the patina show a preferred orientation of tracks normal to the patina surface.

PATINA ON 76015: Keller, L. P. *et al.*

The outermost surface of the patina is covered by an amorphous coating ~50 to 80 nm thick of silica-rich glass with numerous inclusions of fine-grained (1 to 5 nm dia.) Fe metal grains. In regions, the Fe grains occur in distinct layers within the amorphous coating (i.e. the Fe-grains are stratified). This amorphous coating is relatively uniform in composition and thickness and coats plagioclase, ilmenite, melt glass, and chromite. The amorphous coating represents material that was deposited on the rock surface either by condensation of impact-derived vapors or by sputter deposition. Adhering to the surface of the amorphous coating are submicrometer glass spheres with a wide range of compositions including a number of HASP (high-Al, Si-poor) glasses which are likely vapor-fractionated impact glasses [5].

Conclusions. Patina has a dramatic effect on the reflectance properties of exposed rock surfaces (Fig. 1). The presence of a thin amorphous coating containing abundant nanometer-sized grains of Fe metal at the uppermost surface of the patina is implicated as a major darkening agent although the contribution from glass splashes, which also contain submicroscopic Fe, has not been fully evaluated.

References. [1] Wentworth, S. J. *et al.* (1996) this volume. [2] Allen, C. C. *et al.* (1994) LPSC XXV, 21. [3] Bradley, J. P. *et al.* (1994) LPSC XXV, 159. [4] McKay, D. S. *et al.* (1995) LPSC XXVI, 943. [5] Keller, L. P. and McKay, D. S. (1992) PLPSC, 22, 137.

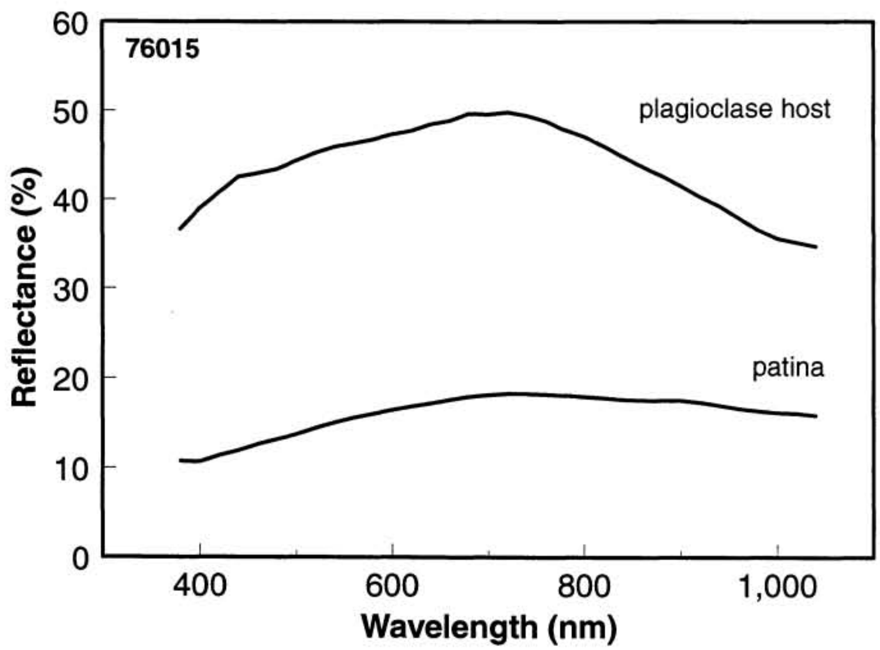

Figure 1. Typical reflectance spectra from patina on 76015 and a freshly fractured surface of the underlying plagioclase.