
A number of rocks in the lunar sample collection have surface patinas which formed as a result of exposure to the space weathering environment on the surface of the moon. It is important to understand patinas and their relationships to the rocks on which they formed because it is likely that patinas on surface-exposed rocks on the moon and other planetary bodies would affect data obtained by either remote sensing or unmanned landers. We have undertaken a multidisciplinary study of patinas on selected Apollo samples using a wide range of techniques including scanning electron microscopy (SEM), backscattered electron imaging (BEI), energy dispersive X-ray analysis (EDX), transmission electron microscopy (TEM), backscatter Mossbauer spectrometry (BaMS), spectral reflectance spectroscopy, ferromagnetic resonance (FMR) analysis, and wavelength dispersive spectrometry (WDS). SEM/EDX results for patina on high-Ti mare basalt 75075 were reported in [1]. Our current focus is on the patina on crystalline matrix breccia 76015 (see companion abstract [2]). Our initial results show that the 76015 patina is very complex with characteristics that vary widely over a short distance. The 76015 patina is a good example of classic patina with typical lunar surface exposure features such as microcraters and glass pancakes, and is defined here as accretionary microcratered pancake-bearing (AMP) patina.

Sample 76015 is a crystalline matrix breccia that was taken as a loose rock from the top of the boulder at Station 6 on the North Massif at the Apollo 17 site. The sample has a known lunar orientation and a simple exposure history. Its exposure age is ~22 Ma based on cosmic ray tracks, Kr isotopes, and noble gases; solar flare track data indicate it was split from the Station 6 boulder ~1 Ma ago [3]. Some SEM petrography for 76015 patina was described previously [4].

For our study, flat chips several millimeters across (186) containing a macroscopically visible patina were taken from the weathered surface of 76015. Two petrographic polished thin sections, [196 and 197], oriented normal to the patina surface, were made from one chip for use in SEM, BEI, and WDS. One patina chip was carbon-coated for SEM petrography. Another patina surface was used for BaMS, and a crushed chip of unweathered 76015 was used for transmission Mossbauer spectrometry for comparison to patina data.

In the SEM, the space-exposed surface of 76015 shows a wide range of weathering effects. Some areas are very fresh while others have been extensively modified. The patina, which includes both accretionary and erosional features, ranges from 0-10 micrometers (μm) in thickness. Erosional features include fractures and microcraters formed by the impact of hypervelocity micrometeorites. Hypervelocity microcraters are common (Fig. 1), and are distributed heterogeneously. Spall zones around the bigger (>5 μm) microcraters are generally weathered themselves and contain smaller microcraters along with accretionary material. Accretionary features on 76015 are more common than erosional ones as noted by [4], and include glass pancakes, spherules, and stringers, ranging in size from <1 to a few μm (Fig. 1). Submicrometer particles are very well sorted, as noted for 75075 patina particles [1].

We previously defined two types of patina for mare basalt 75075 [1]. Accretionary coalesced (AC) patina is a thin scaly layer or layers of glassy material, while accretionary welded fragmental (AWF) patina consists of fine-grained fragmental material welded to the rock surface. Some areas of the 76015 patina fall into the AC category. Other areas are similar to the 75075 AWF patina but there are distinct differences; i.e., the surfaces of welded fine-grained particles on 76015 are smoother than those on 75075, and it is more obvious that most of the 76015 particles are impact glass spherules (Fig. 1). The biggest difference between the patinas on the two rocks, however, is that microcraters and glass pancakes are nearly ubiquitous on 76015 but completely absent from 75075. As noted by previous workers (e.g., [4]), the presence of microcraters and glass pancakes clearly demonstrates that a lunar rock surface has been exposed to the space weathering
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environment. These classic patina features are so distinctive that we use them to define a third patina type, accretionary microcratered pancake-bearing (AMP) patina. Our work thus far demonstrates that two or more of the three types of patinas we have defined can be present on a single rock.

Figure 2 shows the transmission Mossbauer spectrum for a powder of 76015 bulk rock and the backscatter Mossbauer spectrum for the patina surface. Within counting statistics, these two spectra indicate the same proportions of iron in ilmenite, pyroxene, and olivine. These results suggest either that the iron mineralogy of the patina is nearly equivalent to that of the bulk rock or that the sampling depth in the backscatter experiments is significantly larger than that of the patina (<10 μm) although we need to improve the counting statistics.

Figure 1. Scanning electron image of AMP (accretionary microcratered pancake-bearing) patina on plagioclase in 76015,186, showing classic lunar patina features (microcraters and glass pancakes) along with other impact glasses.

Figure 2. Transmission Mossbauer spectrum of bulk 76015 powder and backscatter Mossbauer spectrum of 76015 patina surface.