Patinas on Lunar Rocks: The Unusual Surface of Apollo 17 Basalt 75075

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Introduction Space weathering of lunar rocks includes any process which changes their surface properties from those of fresh unaltered material. If the surface is notably different in appearance, the rock is said to have a patina. Patinas on lunar rocks (and also on rocks on asteroids and other small or planetary bodies) may be extremely important because they may modify or even dominate remote sensing data from such rocks. Furthermore, unless patinas are removed, they can also influence data from landers which contain or deploy spectral and chemical analyzers. Rock surfaces are modified by a number of processes. Both erosion and accretion occur because of micrometeorite (and larger) impacts as well as solar wind and flares [1, 2, 3]. Effects of these processes include microcraters, splash glass, vapor-deposited material, implanted noble gases, radiation damage, adhering soil particles, and even loose dust. We are beginning systematic studies of rock and soil grain patinas, and we are classifying them and trying to understand their processes of formation and their effect on surface properties.

Although patinas have been studied in the past by a variety of methods (e.g., [1, 2]), their detailed characteristics and mechanisms of formation are still not well understood. Many questions need to be answered. What are the most common characteristics of patinas? Are there different types? How did they form? Are there differences between glass coatings and patinas? What are they? Do different types of rocks develop different types of patinas? Are patinas on big rocks and boulders similar to patinas on individual small soil grains or are they fundamentally different? Can rock types be identified based on their patina characteristics? It is clearly very important to understand patinas in view of possible future robotic missions to the moon and other planetary bodies so that we can plan studies and sampling techniques appropriately. The multidisciplinary studies of patinas that we have begun are part of our long-term studies of lunar regolith formation processes and space weathering. We plan to study specific Apollo samples with a variety of techniques, such as optical microscopy, reflectance Mossbauer spectroscopy, scanning electron microscopy (SEM), ferromagnetic resonance (FMR) analysis, electron microprobe analysis, and transmission electron microscopy (TEM).

We surveyed photos and catalog descriptions of the Apollo samples, and requested samples with distinct patinas from a range of rock types. These samples were recently allocated to us, and include mare basalt 75075, crystalline matrix breccia 76015, and dilithologic (anorthosite and impact melt) breccia 62255 [4, 5, 6]. We received two samples each for 62255 (which has a distinct glass coating in addition to the patina) and 75075 (which has brownish material on the surface distinct from a gray patina). We have begun reconnaissance studies of one of the 75075 samples, the other samples remain in their curator-sealed bags. Here we report on initial results for 75075.

Description Rock 75075 was collected from the fracture zone of a large (3 m) boulder which appeared to be partly or mostly buried in the regolith near the rim of Camelot crater. It is not clear whether it is part of the big boulder, but the crew believed that it was. This rock is a relatively coarse-grained basalt dominated by plagioclase, ilmenite, and pyroxene [7]. The upper surface of this rock is mostly covered with a quite pronounced dark gray patina. Under the binocular microscope, the patina is a thin, coherent coating of dark gray to black material resembling semi-gloss black paint. During chipping of the rock, the coating flaked off in places, exposing fresh underlying basalt having distinctly different texture and color. Patina flakes retain some coherence. The coating closely follows the contours of the underlying minerals and pre-existing fracture surfaces, causing rounding of grain edges. Pitting of the surface reflects the vugginess of the basalt. In some places, the slightly glossy, dark gray luster is replaced or covered by a dull matte finish which has a slightly reddish brown cast. These matte areas are concentrated in depressions and pits and are lacking on ridges.

We carbon-coated one representative cm-size rock chip of 75075,166 for SEM studies. Examination of this chip has revealed three basic surface types. First is fresh basalt consisting of clean grains of pyroxene, plagioclase, ilmenite, and minor minerals. Vugs are common on these freshly broken surfaces. None of the surfaces display microcraters. The fresh surfaces are mostly the result of the laboratory chipping. The remaining two surfaces are basically two types of patina. The first type (Fig. 1) consists of a thin layer of glass-like material which on closer examination appears to be made of coalesced fragmental material which is mostly melted and welded together in a somewhat lumpy layer. This layer closely reflects underlying mineral fractures but effectively rounds sharp edges. This material is clearly an accretionary addition to the original rock surface. We term this Accretionary Coalesced (AC) patina. The second surface consists of fine-grained fragmental material which has
been welded to the surface (Fig. 2). This fragmental material is relatively well-sorted and is mostly between 1 and 5 μm in diameter, with only a very small fraction of grains 10 μm or larger. Many of the grains are partly rounded or even subspherical. Treatment of the chip in ultrasonic bath of Freon 113 did not dislodge these grains; they are firmly attached. We term this Accretionary Welded Fragmental (AWF) patina. Where edges of the patinas are visible we have estimated that the thickness of either patina may reach up to about 50 micrometers. The AWF patina covers the AC patina at many locations and is concentrated in depressions and on flat areas. Backscatter data and preliminary x-ray data indicate that a variety of mineral types are present in individual fragments of AWF patina. AC patina is most obvious on protrusions and bumpy areas. In some regions it appears that one type may grade into the other, but additional work with thin sections is necessary to verify this relationship.

Discussion: It is clear that the patina on rock 75075 has significantly different optical properties from the underlying rock. Exposure age based on range from 119 to 143 Ma based on Ar and Kr isotopes [5]. However, the lack of obvious microcraters on these patina surfaces suggests that this rock has not been directly exposed at the lunar surface for very long, unless the patinas somehow cover the microcraters. The accretionary welded and coalesced nature of these patinas implies that they were formed by impact processes, possibly larger impacts which created, heated, and partially melted large amounts of fragmental material which was then plastered onto rocks and boulders on the surface or thrown up by the impact. In the simplest version of this hypothesis, the Camelot impact would create the partly melted fragmental material, eject the boulders and rocks, plaster them with gas-sorted fragmental material in the impact plume, and deposit them near the rim. While these patinas may not be strictly considered space weathering because, if our hypothesis is correct, they do not build up over time, they clearly qualify as important surface features of 75075 and possibly the entire boulder from which it came. They clearly influence data from the surface and outer tens of micrometers of the rock.