ALTERATION OF LUNAR ROCK SURFACES THROUGH INTERACTION WITH THE SPACE ENVIRONMENT.

A. M. Frushour[1], S. K. Noble[2], R. Christoffersen[3], and L. P. Keller[4]. [1]Department of Geology, Appalachian State University, ASU Box 32067, Boone, NC 28608 (frushouram@appstate.edu), [2]NASA GSFC, Mail Code 691, Greenbelt, MD 20771 (sarah.k.noble@nasa.gov), [3]Jacobs, NASA Johnson Space Center, MC JE23, 2101 NASA Pkwy, Houston, TX 77058, USA, roy.christoffersen-1@nasa.gov, [4]NASA Johnson Space Center, Mail Code KR, 2101 NASA Pkwy, Houston, TX 77058, USA, lindsay.p.keller@nasa.gov

Introduction: Space weathering occurs on all exposed surfaces of lunar rocks, as well as on the surfaces of smaller grains in the lunar regolith. Space weathering alters these exposed surfaces primarily through the action of solar wind ions and micrometeorite impact processes. On lunar rocks specifically, the alteration products produced by space weathering form surface coatings known as *patina* [1]. Patinas can have spectral reflectance properties different than the underlying rock. An understanding of patina composition and thickness is therefore important for interpreting remotely sensed data from airless solar system bodies. The purpose of this study is to try to understand the physical and chemical properties of patina by expanding the number of patinas known and characterized in the lunar rock sample collection.

Methods: We searched the Lunar Sample Compendium (2013) [2] to find rock samples which have been reported to have patina coatings. The search criteria included any mention of patina, micrometeorite craters, or "zap pits" in the Compendium sample descriptions. Available thin sections of these rock samples in the JSC Sample Curatorial Center were then studied with a petrographic microscope to survey samples for patina. Once patina candidates were identified, the sections were imaged using a JEOL 7600F field-emission analytical scanning electron microscope (FE-SEM). The thickness, lateral extent, microstructure and chemical composition of the patinas were measured using the FE-SEM capabilities.

Results: Relative to previous studies [1,3,4,5] we increased by six (6) the number of lunar rock samples with characterized patinas. The studied patinas were in thin sections 15485,6; 12017,23; 14301,85; 10045,39 and 60025,163.

Thin section 15485,6 is a vitrophyryic pigeonite basalt that has a discontinuous patina that is about 7 mm long and varies in thickness from about 10 µm to 350 µm (Fig. 1a,b). This patina is composed of multiple layers, each on the order of 1 to 10 µm thick. Each layer is generally defined by rounded grains of glass <1 to 10 µm in diameter with a sub-layer of glass <1 to 5 µm thick separating each layer. In some areas the glass layers are more fragmental and in others more massive; layer boundaries become indistinguishable where this occurs. The individual layers are not flat, but rather undulatory. There are areas where the patina thickness is composed of just one layer and other areas that have tens of layers. The glass grains and mineral fragments commonly fill in depressions in the outer surface of the rock. One localized region containing spherules of nanophase metallic Fe was identified. Based on energy-dispersive (EDS) compositional spectrum imaging, and spot analyses, the 15485,6 patina is fairly uniform in composition with only subtle variations in Al and Mg (Fig. 1b).

12017,23 is a pigeonite basalt that has a continuous layer of glassy patina that extends about 4.5 mm and varies from ~35 µm to ~600 µm thick. The patina consists mostly of silicate glass with entrained vesicles, mineral fragments, and spherules of nanophase Fe (Fig. 1c). The patina contains vesicles on the scale of about 10 to 100 µm. There are two areas of nanophase Fe. One area consists of a chain-like linear arrays of spherules <1 to 3 µm in size The other area is in the form of multiple thin layers 1 to 5 µm thick. There are also partially melted rock fragments near the surface of the rock. The composition of the 12017,23 patina glass is overall fairly homogeneous, with the exception of local regions of partially or wholly melted minerals, such as ilmenite.

14301,85 is a regolith breccia that has a layer of patina approximately 2 mm long which ranges from 5 to 50 µm in thickness. The patina has distinct sub layers, one composed predominantly of mineral grain and lithic fragments, the other containing partially melted mineral grains and nanophase Fe. The inner layer may or may not be patina, because it has a microstructural resemblance to types of clasts in the rock interior.

10045,39 is an ilmenite low K basalt which has a continuous patina that is about 400 µm long and varies from 1 µm to 130 µm thick. The patina is made mostly of a mix of highly vesicular glass and lithic fragments (Fig 1d). The glass is spread out along about half of the patina and contains schlieren-like layers with a high concentration of nanophase Fe. The thickest part of the patina contains lithic fragments that are angular to sub-rounded with various degrees of melting. The patina has an area ~100 µm long composed predominantly of unconsolidated mineral fragments.

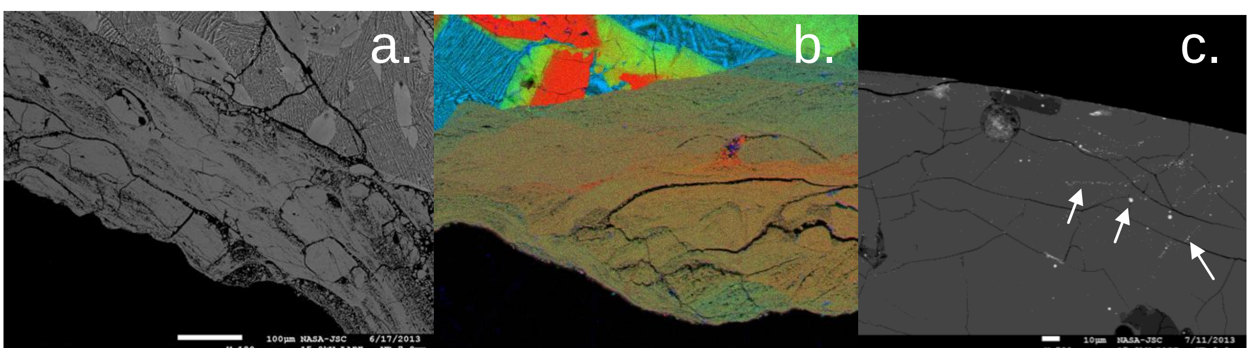
60025,163 is a ferroan anorthosite which has a continuous patina about 1 mm long that varies from 5 µm to 50 µm thick. The patina is composed of a single layer of silicate glass that is essentially identical in composition to the anorthosititc host rock such that the boundary between the patina and rock surface is compositionally indistinguishable.. The glass does, however, contain some large nanophase Fe^0 blebs in localized regions.

Discussion: Wentworth et al. [1] originally proposed a classification scheme for lunar rock patinas with three main categories. “Fragmental” patinas are composed predominantly of aggregated rounded to sub-rounded particles, well sorted in the 1-5 µm size range and held together by various degrees of melt welding. “Glazed” patinas are composed of continuous glass layers in which it is generally difficult to distinguish different small glassy constituents, i.e. the glass is microstructurally homogeneous. “Classical” patinas are also dominantly glassy, but have complex microstructures containing multiple identifiable glass units, typically referred to as “splats” or “pancakes”.

We find that some, but not all, the patinas characterized in the current study fit well with the Wentworth et al. [1] classification. 15485,6 has attributes fairly close to the fragmental type, particularly because the glassy spherules defining the layers are well sorted with respect to size. 60025,163 falls well into the “glazed” category given that it dominantly consists of continuous, homogeneous glass. 12017,23 fits somewhat into the glazed patina type, but it also contains regions with mineral fragments, making it a composite type not well covered by the Wentworth [1] scheme. Although 14301,85 clearly consists of fragmental material, the fragments are angular and poorly sorted, not consistent with Wenthworth’s fragmental designation. 14301,85 is an example of a patina type we would call heterogeneous fragmental, as an addition to the Wentworth scheme. 10045,39 is another example of a very heterogeneous patina, with complex glassy regions, and mineral fragments, that does not fit existing types and should define a new “heterogeneous” type.

Conclusions: We were successful in finding more patinas, and our results considerably expand upon the known microstructural and morphological diversity of lunar rock patinas. The variety of patinas found illustrate that they do not easily fall into the previous categories defined by Wentworth et al. [1].

References: [1] Wentworth S. et al. (1999) *Meteoritics & Planet. Sci., 34*, 593-603. [2] Meyer C. (2012) Lunar Sample Compendium. Retrieved June 2013.From:http://curator.jsc.nasa.gov/lunar/lsc/index.cfm Lunar Sample Compendium (2013). [3] Noble et al. (2007) LPSC38 Ab#1359. [4] Noble et al. (2012) LPSC43 Ab#1239 [5] Noble et al. (2013) LPSC Ab#1298.



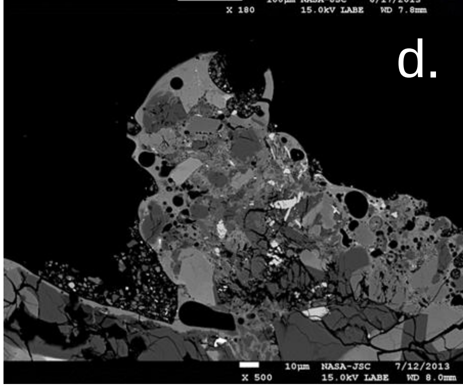


Figure 1. (a) Back-scattered electron (BSE) image showing fine-scale layering of patina in 15485, 6. (b) X-ray energy-dispersive (EDS) red-green-blue composite elemental map of 15485,6 patina showing the subtle variations in Mg (red), Ca (green), and Al (blue). Upper region of image is host rock. (c) BSE image of nanophase Fe^0 (arrows) and a partially melted mineral grain in 12017,23. (d) BSE imaging showing example of glass, mineral and lithic fragments making up the patina on 10045,39.