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THE ORIGIN OF AMORPHOUS RIMS ON LUNAR PLAGIOCLASE GRAINS: SOLAR WIND DAMAGE OR VAPOR CONDENSATES?

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Introduction. A distinctive feature of µm-sized plagioclase grains from mature lunar soils is a thin (20- to 100-nm) amorphous rim surrounding the grains. These rims were originally described from high voltage electron microscope observations of lunar plagioclase grains by Dran *et al.* [1], who observed rims up to 100 nm thick on plagioclase grains from Apollo 11 and Apollo 12 soils. These rims are believed to be the product of solar wind damage [*e.g.*, 2, 3].

We studied the amorphous rims on µm-sized plagioclase grains from a mature Apollo 16 soil using a JEOL 2000FX transmission electron microscope (TEM) equiped with an energy-dispersive x-ray spectrometer. We found that the amorphous rims are compositionally distinct from the the interior plagioclase and propose that a major component of vapor condensates is present in the rims.

Experimental. We prepared TEM specimens by diamond knife ultramicrotomy of the <20 µm fraction of Apollo 16 sample 61181. The density of solar flare tracks was determined by counting the number of tracks present in 100 nm^2 areas of similar contrast in dark field TEM images and extrapolating upwards to cm^2 areas. Quantitative energy-dispersive x-ray spectroscopy (EDS) analyses were obtained using a probe ~20 nm in diameter, and a detector live time of 400 s. The accuracy for routine analyses of major elements is ~10% relative based on counting statistics and the errors associated with the determination of k-factors.

Results. We analyzed a number of µm-sized plagioclase grains with prominent amorphous rims in sample 61181. The rims are variable in thickness, from 20- to 60-nm, and share an abrupt interface with the interior plagioclase. In TEM images, the plagioclase exhibits strain contrast adjacent to the plagioclase-amorphous rim interface. We have not observed any crystalline inclusions in the rims. The interior of the plagioclase grains are characterized by high track densities (~10^{10}) as determined from dark-field TEM images.

A major result of this study is that all of the amorphous rims that we analyzed are compositionally distinct from the interior plagioclase. EDS analyses show that the rims are Si- and Fe-rich as compared to the plagioclase (Table 1). The ratio of Ca/Al in the rims is significantly different from that in the bulk plagioclase.

Discussion. The origin of amorphous rims is controversial, and two opposing models have been proposed for their formation. In the first hypothesis, originally proposed by [1] and subsequently developed by others [2, 3], it was suggested that amorphous rims are a product of solar wind damage, whereas the second hypothesis holds that the rims represent deposits of impact-generated vapor that condensed on nearby grains [*e.g.*, 4]. The latter hypothesis was disputed by [2,3] who showed that rims could be produced by exposing fresh material to a high flux of low-energy ions.

A major process affecting materials at the Moon's surface is impact vaporization, inferred from the presence of surface deposited volatiles [5-7] and from the compositions of impact glasses [*e.g.*, 8, 9]. The chemical fractionation that occurs during the vaporization process has been elucidated by experiments on lunar rocks and lunar analogs [e.g. 10, 11]. The vapors are rich in volatile elements, Si, and Fe, and are very poor in refractory elements. The same chemical trend (an enrichment in volatile elements) is observed in the rims. Thus, we believe that the composition of all the amorphous rims that we analyzed is consistent with the condensation of vapor on nearby grains as proposed by [4]. The Si- and Fe-enrichment in the rims is inconsistent with rim formation by sputtered ion deposition, which is a mass-dependent process [12].

Borg *et al* [3] noted that grains with the highest solar flare track densities also had the thickest rims and inferred that these grains had been exposed on the lunar surface for long periods of time. We propose that these grains would also tend to accumulate the greatest build-up of vapor condensates on their surfaces.

TABLE 1. EDS analyses of plagioclase and amorphous rims (average of 3 grains with rims).

	Plag.	Rim
Na_2O	1.4	0.9
MgO	0.0	0.8
Al_2O_3	34.	27.
SiO_2	47.	60.
K_2O	0.2	0.1
CaO	16.	8.4
TiO_2	0.0	0.2
FeO	0.4	2.6
Total:	100.0	100.0

Conclusions. We observed amorphous rims on µm-sized plagioclase grains that are Si- and Fe-rich compared to the interior plagioclase. We propose that rims are formed through a combination of solar wind damage and a significant accumulation of impact-generated vapor deposits.

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