MAKING A REGOLITH BRECCIA

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Introduction: Regolith breccias are created when regolith is fused together by shock from nearby impacts. Some of these breccias are so friable that they crumble easily back into the soils from which they formed. Others are compacted enough to survive being launched off a parent body and landing on Earth, as evidenced by our collection of regolith breccia meteorites from both the moon and the asteroids. By comparing and contrasting de-lithified soils to their regolith counterparts, insight can be gained into the breccia forming process.

Lunar samples: Lunar regolith breccia 10068 is considered a "classic soil breccia" [1]. It is a coherent breccia of mature (I_s/Feo=84) mare soil. The soil from which it formed should have been very similar to mature mare soil 10084 (I_s/FeO=78). Breccia 10068 was de-lithified by Basu *et al*. via freeze-thaw [2]. The de-lithified soil was found to have the same size fraction characteristics of an ordinary soil, this, in addition to TEM studies [3], indicate that the breccia broke apart largely along its original grain boundaries. The de-lithified soil then provides an opportunity to directly compare the breccia to its soil counterpart, 10084.

Methods: Samples of de-lithified 10068 were prepared by placing roughly 50 grains/sample from the 90-150µm size fraction on carbon tape, this was then coated with ~50Å carbon. The 10084 samples were similarly prepared, though a different grain size was used, <20µm fraction. Both soils were analyzed by FEGSEM at Johnson Space Center. Samples of both soils were also examined via TEM. Those samples were prepared by embedding grains in epoxy and ultramicrotoming them to 70-90nm thickness. Additionally, thin sections of 10068 and several other lunar regolith breccias were examined via optical (61175, 63507) and election (15245, 60016, 79035) microscopy.

Results: As expected, both weathered soils were found to contain ubiquitous vapor/sputter deposited $npFe^0$-bearing rims (Figure 1). However, surprising differences were observed between the ordinary soil and the de-lithified soil. The biggest difference was the amount of glass present in the breccia in the form of glass splashes and coatings on grains (Figure 2). The composition of the glass rims is variable, but generally similar to that of agglutinate glass, and like agglutinates, they contain ubiquitous nanophase iron. These glass coatings are easily identified in polished thin section and are distinguished from vapor and sputter deposited rims by the presence of abundant vesicles and obvious flow features (Figure 3). The melt glass rims range in thickness from ~100 nm up to ~2 microns, compared to the 50-200 nm typical of vapor-deposited rims.

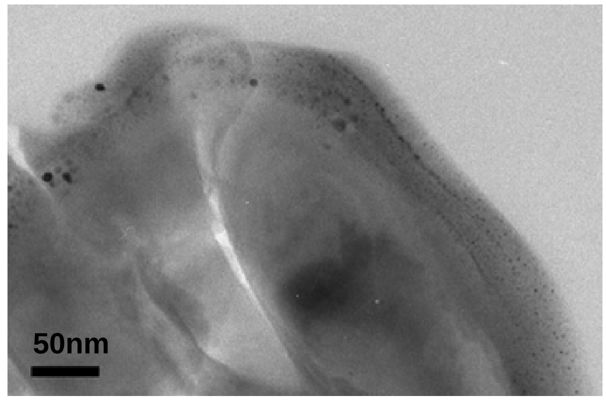

Figure 1a. TEM bright field image of a complex weathered rim on a grain from lunar soil 10084.

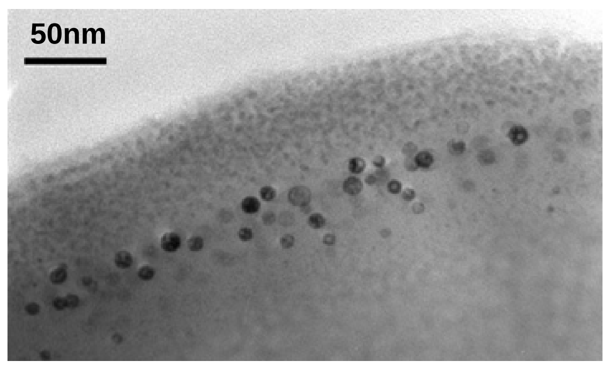

Figure 1b. TEM bright field image of a complex weathered rim on a grain from lunar regolith breccia 10068. The small dark round objects are nanophase iron grains.

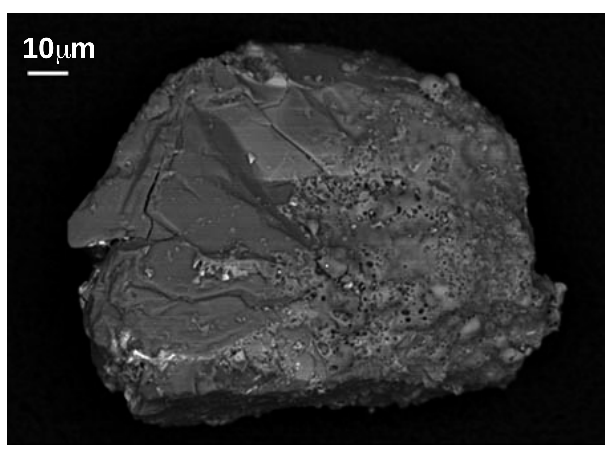

Figure 2. SEM BSE image of a grain from lunar regolith breccia 10068 with an extensive glass coating.

These glass coatings are very common among the 10068 de-lithified breccia grains with a significant percentage of observed grains partially or totally coated with glass. The 10084 soil grains are only very rarely coated with glass. This trend is also seen in other soil and breccia samples, nearly every breccia we have examined has contained melt glass coated grains, while such coatings are extremely rare or absent in all soils examined to date.

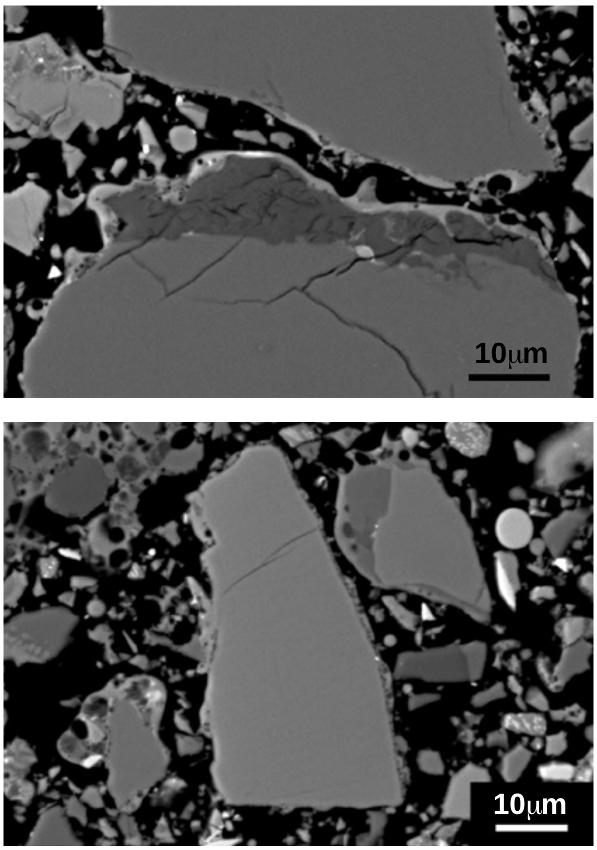

Figure 3. Examples of glass coatings in SEM BSE images from lunar regolith breccia 79035.

From the flow features and geometry, it is clear that these glass rims were acquired and solidified before the grains were incorporated into the breccia, i.e. as individual soil grains. Thus we have a conundrum: if these glass rims are a soil process, then why are they common only in breccias and not in soils? One possible explanation is that the glass coatings are a result of the breccia forming process itself; created when melt from an impact mixes with soil in an ejecta cloud. The individual grains would acquire their rims just moments before being incorporated into a breccia. In fact, pebbles coated in glass have been found at the Ries and other terrestrial impacts [4]. Additionally, glass coatings have been observed in experimental impact materials [5].

No melt glass rims have been identified during our preliminary electron microscope studies on asteroidal regolith breccias (Kapoeta, Fayetteville), suggesting that such rims are rare or absent. The observed differences between the meteorite and lunar breccias are likely due to the higher melting temperatures of asteroidal materials and the slower impact velocities in the asteroid belt compared to 1 AU.

Conclusions: A significant percentage of grains in lunar regolith breccias are coated with melt glass rims. The existence of these glass rims can give us insight into the impact and breccia forming process on the Moon.

Future Work: We are continuing to study less friable, more compacted breccias to see how well these glass coatings as well as other impact/weathering products can be preserved. By exploring how impact and weathering products change with the compaction of the breccia, we are expanding this study to include asteroidal regolith breccias to be able to compare and contrast the impact and weathering processes on asteroid regoliths.

References: [1] Fruland R. M. (1983) *JSC Publication # 66*. [2] Basu A. *et al* (2000) *LPSCXXXI*, ab# 1941. [3] Noble *et al.* (2002) *LPSCXXXIII*, ab# 1334. [4] French B. M. (1998) LPI Contribution # 954. [5] Schultz, P. H. (2002) personal communication.

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