IMPACT COMMINUTION OF GLASSES: IMPLICATIONS FOR LUNAR REGOLITH EVOLUTION. Mark J. Cintala,☆ Sheila Smith,✦ and Friedrich Hörz.☆ ☆Code SN4, NASA Johnson Space Center, Houston, TX 77058. ✦1992 LPI Summer Intern; Dept. of Physics, Baylor University, Waco, TX 76798.

Glasses are important parts of every lunar regolith sample, whether in the form of indigenous melts such as mesostasis or pyroclastics, or as quenched impact melts. The modal proportions of agglutinitic impact melts alone can exceed 50% for some mature regoliths,[1] and glasses are commonly the most dominant single component of lunar soils. They therefore participate in and possibly affect all evolutionary processes to which regoliths are subjected, such as comminution and attendant chemical fractionation as a function of grain size, the retention of solar-wind products, the production of superparamagnetic iron, and others. Because they are such an integral part of lunar regoliths, a more complete understanding of regolith evolution must include the role played by these vitreous components. This contribution examines the comminution behavior of a variety of glasses and a fine-grained basalt under conditions of repetitive impact, and compares this behavior to those of crystalline components, such as lithic fragments[2] and major rock-forming minerals.[3]

Experimental Conditions: Three distinct types of glass were used in these experiments: obsidian (a compact, dense specimen whose source is unknown); 2.29 g cm^{-3}), tephra (a frothy, pyroclastic glass from Kilauea Iki; 1.32 g cm^{-3}), and dragonite (an annealed, lead-rich, synthetic glass in the form of 3-mm spheres [Jaygo, Inc.]; 3.05 g cm^{-3}). In addition, a basalt hornfels (3.12 g cm^{-3})[4] was used as a fine-grained endmember with little or no glass. All targets were exposed to normal atmospheric conditions, and thus were subjected to the strength-modifying effects of water; direct extrapolation to dry environments (such as the lunar surface) must be made with caution,[5] although *relative* comparisons should be acceptable. As in previous experiments,[3] the starting mass of each fragmental target was 500 g, with an initial fragment size of 2-4 mm. Stainless-steel projectiles with a diameter of 3.18 mm and a mass of 0.13 g impacted each target 25 times at a nominal velocity of 1.4 km s^{-1}; actual velocities averaged 1.42 km s^{-1}. Each impact was normal to the upper surface of the target charge, and the chamber pressure was 30-mm Hg equivalent for each shot. Stainless-steel buckets were used as target containers, with a lid and baffle system employed to minimize loss of ejecta. The charges were sieved after the first and fifth shots, and after every five shots thereafter. After sieving, each fraction was weighed and all fractions were recombined and mixed for the next shot. After each 25-shot series was completed, a 0.5-g aliquot taken from the <63-μm fraction was wet sieved and the size fractions weighed; these data were used in surface-area calculations.

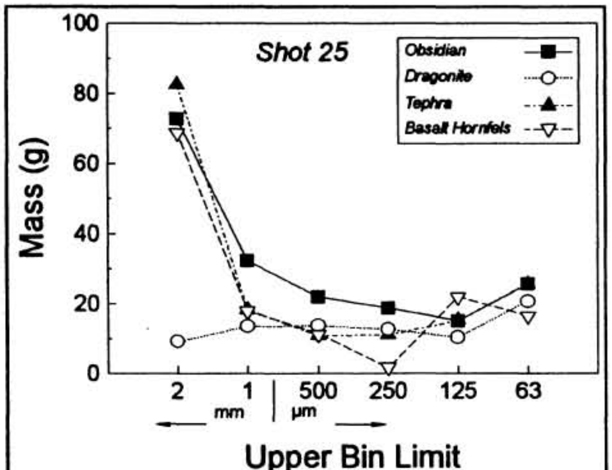

Figure 1. Size distributions for the four glass targets after the final shot in each series. Note the enhancement in the 63-125 μm bin for the cryptobasalt.

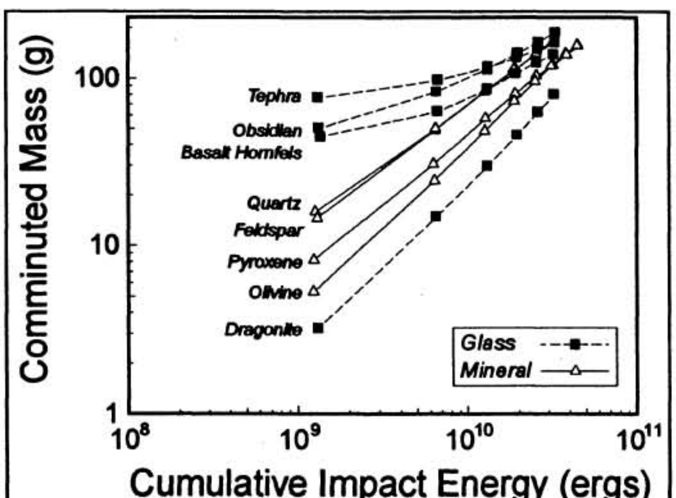

Figure 2. Comminuted masses for the four glassy targets used in this study. Also included for comparison are the results for four monomineralic targets.[3]

Data: This study considers only the comminuted fraction of the initial 500-g target — that is, that portion of the impacted target with grain sizes smaller than 2 mm. *Size Distributions* — The size distributions for the four targets after the final shot in each series are plotted in Figure 1. The tephra and obsidian follow trends common to such experiments, while the dragonite presents a very flat distribution. The distribution for the basalt hornfels is similar in shape to those of the obsidian and tephra, except for the marked lack of material in the 125-250 μm bin and the enhancement of mass in the 63-125 μm range. This relative depletion and enhancement is

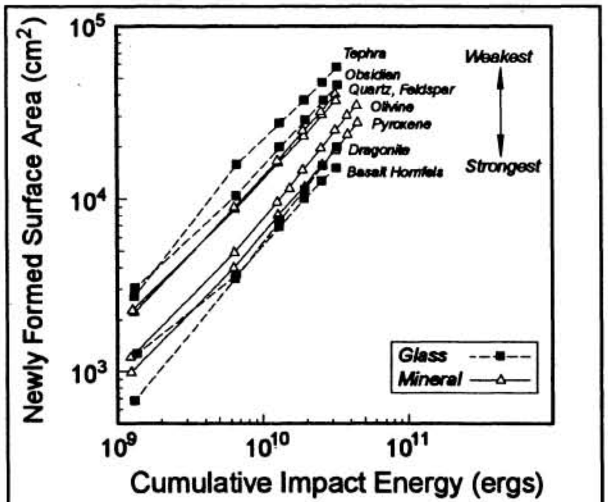

Figure 3. Newly formed surface area for the four glassy targets. Also included for comparison are the results for four monomineralic targets from a previous study.[3]

characteristic of polycrystalline targets, in which fragmentation occurs preferentially along grain boundaries.[6] On the basis of this distribution, the average crystal dimension in the basalt hornfels can be predicted to lie between 63 and 125 μm, an assessment in very good agreement with petrographic information.[4] ***Comminuted Masses*** — The comminuted masses are plotted against cumulative impact energy in Fig. 2. The dragonite is substantially different from the three natural targets, although it appears to approach them as the impacts accumulate. The distributions for the obsidian and tephra are very similar, even with their relatively large density difference. ***Surface Areas*** — The areas of the newly formed surfaces[7] for the four targets are illustrated in Fig. 3, again as a function of cumulative impact energy. The obsidian and tephra continue to exhibit similar trends, but the dragonite in this plot is very similar to the basalt hornfels.

Discussion: ***Glassy Targets*** — In terms of mass produced, the three natural targets are the easiest to fragment, and they also possess shallower slopes overall than the dragonite. Since the dragonite is intended for use as a grinding medium, its resistance to fracturing is not surprising. Because they have the highest new surface areas, the tephra and obsidian are judged to be the least resistant to comminution.[6] The dragonite generally breaks into finer fragments (Fig. 1), and thus possesses more surface area than the basalt hornfels. The relationship between these two materials is somewhat analogous to the differences observed between pyroxene and olivine in an earlier study,[3] in that the dragonite (olivine, in the earlier study) is more resistant to comminution in quantity, but breaks into finer pieces than the hornfels (pyroxene). The difference between the olivine and pyroxene was attributed to the fact that the pyroxene had to be fragmented with a hammer to generate the 2-4-mm fragments, and thus was "preconditioned" (undoubtedly including the introduction of microcracks and other flaws), while the olivine was already available as a gravel in that size range. This situation is repeated with the "pristine" dragonite and the similarly preconditioned basalt hornfels; it is probable that the polycrystalline nature of the hornfels and the spherical dragonite "grains" also contributes to the variations between the two targets. ***All Targets*** — A given mass of the three natural targets in the glass series is at least as easy if not easier to comminute than either of the two most susceptible minerals studied, feldspar and quartz. The weakest materials in terms of creating new surfaces are the tephra and obsidian, in that order, followed closely by the feldspar and quartz. Because the definition of "comminuted mass" is somewhat arbitrary, the surface area is a better measure of the ease with which a material is comminuted.[6] When considered in this light, the basalt hornfels is the strongest of all the natural materials measured. This is a somewhat surprising result, since the "matrix" of this particular basalt is plagioclase; while it is not quite as weak as the obsidian or tephra, it is barely stronger (Fig. 3). This is perhaps analogous to the case of a water-saturated frozen soil, which is significantly stronger than pure ice.[8] A simple interpretation of this phenomenon is that the silicate grains effectively impede propagation of fractures and microcracks by limiting the continuity of the ice matrix. It can then be argued that the effectively greater strength of the basalt is due to an analogous role played by the non-feldspar crystals in the rock. On this basis, we would expect that glassy basalts would behave in a similar fashion. Should this be confirmed by experiments in progress, an implication might be that the sources of the glass component in the finest fractions of regoliths are dependent on the state of the glass itself (e.g., agglutinates, glass droplets, interstitial glass in basalts or impact melts, etc.). Finally, the low resistance of the natural glasses to comminution is in keeping with experimental[2] and observational[9] evidence of enrichment of the finest grain-sizes of lunar regoliths with the most easily fragmented materials — in this case, glasses and feldspar.

References: ***1*** Morris, R.V. (1976) *PLSC 7th*, 1801. ***2*** F. Hörz *et al.* (1984) *PLPSC 15th*, in *JGR*, 89, C183. ***3*** M.J. Cintala and F. Hörz (1992) Meteoritics, **27**, 395. ***4*** P.W. Weiblen *et al.* (1990) *Engineering, Construction, and Operations in Space II* (S.W. Johnson and J.P. Wetzel, eds.) Am. Soc. Civil Engin. (New York), 98. ***5*** Blacic, J.D. (1985) *Lunar Bases and Space Activities of the 21st Century* (W.W. Mendell, ed.) Lunar and Planetary Institute (Houston), 487. ***6*** M.J. Cintala and F. Hörz. (1988) *PLPSC 18th*, 409. ***7*** M.J. Cintala and F. Hörz(1984) *LPSC 15*, The Lunar and Planetary Institute (Houston), 158. ***8*** S.K. Croft *et al.* (1979) JGR **84**, 8023. ***9*** J.M. Devine *et al.* (1982) *PLPSC 13th*, in *JGR* **87**, A260.