GLOBAL INVENTORY OF LUNAR IMPACT MELT AS A FUNCTION OF PARENT CRATER SIZE

PAUL H. WARREN, Institute of Geophysics & Planetary Physics, UCLA, Los Angeles, CA 90095-1567, USA, and Mineralogical Institute, University of Tokyo, Hongo, Tokyo 113, Japan

Précis: The size-frequency distribution of lunar impact melt has been estimated by extrapolation from the crater size-frequency distribution estimates of Strom and Neukum [1]. Results indicate that the overwhelming proportion of all lunar impact melt originated during formation of a relative few large basins (most notably South Pole Aitken). This proportion is so high that among the near-surface population of lunar rocks (available as samples) impact "melt rocks" formed as basin-splash ejecta are probably more abundant than melt rocks formed as portions of large, homogeneous central sheets of impact melt.

Impact cratering was obviously the dominant process in the development of the structure and geomorphology of the Moon's upper crust. The geologic effects of small-scale cratering (mainly mass displacement and localized shock metamorphism) are fairly well understood. But the largest craters, the complex peak-ring basins and even more complicated multi-ring basins, are not well understood. One of the most important processes involved in basin origin is the formation and evolution of great volumes of impact melt. Conspicuous (fine-grained, siderophile-element-enriched, etc.) impact melt breccias represent a huge fraction (roughly half) of the available highland rock samples. At least in principle, the largest impact melts may differentiate to produce a spectrum of igneous (or igneous-seeming) cumulate rocks. In seeking to understand the origin of typical lunar nonmare rocks, and the potentially key role of pre-4.4 Ga impact melts in the genesis of the Moon's crust, it behooves us to investigate the global size distribution of impact melt. In absolute terms, this distribution is not easily constrained, but the volume of impact melt is believed to be a strong function of the energy of the impact, and thus of the diameter of the crater (or more directly, the transient, pre-collapse/modification crater), and the size distribution of craters and basins on the Moon is directly observable. Thus, the relative contributions of craters/basins of various sizes can be usefully constrained.

Until now, surprisingly little work has been done on this problem — perhaps because people interested in crater distributions and cratering physics seldom give much thought to the petrology of impact melt-produced rocks (or petrology in general), while few petrologists are depraved enough to delve into cratering numerology. The most direct, quantitative study seems to have been that of Lange and Ahrens [2]. Except for an estimation of the total volume of impact melt from all craters and basins (as a function of time), their study was limited to a simple power-law model for crater size distribution, and to craters between 0.1 and 500 km in diameter (D).

In this work, I have extended the modeling to craters with D from <1 to 1200 km, based on the more realistic (or at least far more detailed) crater size-distribution models of [1] (coauthors Strom and Neukum advocate different size distributions in a single paper); and have also included South Pole Aitken (SPA) and Procellarum (Proc, the reality of which is of course controversial) in an ad hoc fashion. The models of [1] do not address either SPA or Proc, but both do feature a large peak on the R plot at D = 800 km, which seems amply documented by lunar crater statistics. The R plots of [1] were fit with polynomials, which were incorporated into a BASIC program for translating from their inventory of crater sizes, into an inventory of impact melt volumes. Volume of melt per crater/basin is estimated as a function of D using the formula of [3], with adjustment for the effect of lunar g [4]. These methods are based on transient crater diameter (Dₜ), estimated as a function of D by standard methods [5]. Simpler models such as "methods" B and C of [6] were also tested.

Results are shown in Fig. 1. The labels for the curves are mostly self-explanatory. Since the Strom and Neukum models [1] did not include SPA or Proc, these basins (or in some models SPA alone) are inventoried as individual craters, producing the step-function aspect of the high-D ends of the curves. Possibly the observed large crater distribution is merely a subset of the total that formed late enough to survive in observable form (certainly this is true of small craters). Conceivably as many as 10x more large craters/basins might have formed over the whole course of lunar crustal evolution [7]. If so, there is little reason to assume that the earlier cratering population was any less (or more) rich in objects of basin-forming size (and velocity). However, some of the models in Fig. 1 are based on the very conservative assumption that the observed population of craters/basins smaller than 1200 km represents...
1/5 of the total (maintaining the same “production function” size distributions of [1]), but that SPA and (possibly) Proc are the only basins ever produced with $D > 1200$ km. These results (with or without Proc) indicate that the vast majority of all the volume of lunar impact melt produced on the Moon probably formed in basins with $D > 1000$ km. The reasonableness of this result can be checked by noting that the volume of impact melt in a given crater/basin is proportional to $D_{cr}^{3.85}$ [3], while the number of craters, in simple power-law models, is proportional to $D^{-b}$ where $b$ is roughly 2.3 [2, 6] (an increase in the ratio $D/D_{cr}$ as $D$ increases from 1 to 1200 km only partly offsets this effect).

I am also investigating [8] the provenance and movement of impact melted matter during individual large-scale cratering events. Fig. 2 shows an important result from that study: Despite enormous uncertainty concerning the shape of the zone of melting, it seems clear that a large proportion of the impact melt is ejected from the transient crater (TC), even during impacts with extremely high melting/displacement ratios (assuming the zone of melting is not virtually spherical — in large impacts a plausible shape is comparable to the truncated sphere shown straddling the heavy line in Fig. 2). Considering the high proportion of the total impact melt that forms in large basins, Figs. 1 and 2 together imply that most of the impact melt-produced rocks within the near-surface (megaregolith) debris layer of the Moon should be products of disseminated splashes of molten ejecta from a relative few giant basins. Petrologists often assume that Apollo/Luna impact melt-produced rocks are generally products of “the” central melt sheet of a nearby basin. A related popular notion holds that impact melt from a given basin is unlikely, except through having undergone fractional crystallization (which is obviously not the case for typically fine-grained, relict-clast-bearing impact melt breccias), to show substantial chemical heterogeneity. Chemical heterogeneity among impact melt rocks at a given locale is commonly taken as prima facie evidence for multiple parent craters [e.g., 9]. Fig. 2 suggests instead that heterogeneity may easily be inherited from the pre-impact target crust; the predominant basin-splash-ejecta form of near-surface impact melt having no opportunity to thoroughly homogenize as it blasts out of the crater, splashes down as part of a complex ejecta deposit, and rapidly cools as an isolated small mass of melt (later small impacts inevitably stir this material about, mingling compositionally dissimilar impact melt rocks from a single basin into a single sampling locale).