IMPACT MELT VOLUMES ASSOCIATED WITH LUNAR CRATERS. B. Ray Hawke, Institute for Astronomy, University of Hawaii, Honolulu, HI 96822 and J.W. Head, Dept. of Geological Sciences, Brown University, Providence, RI 02912.

Introduction

Recent studies of the petrography of the lunar samples[1,2] as well as photogeological investigations[3,4] have emphasized the importance of impact melts on the lunar surface. While melt deposit morphologies and distributions have been intensively studied, little is known about the relative and absolute volumes of the shock melt in and around lunar craters. Information concerning lunar impact melt volumes is important for (1) an understanding of cratering processes, (2) kinetic energy estimates and energy partitioning studies, (3) proper interpretation of melt-bearing lunar samples, and (4) comparative planetology studies. The purpose of this study was (1) determine the relative and absolute amounts of melt associated with lunar craters, (2) investigate the manner in which melt volumes vary as a function of crater size, morphology, and target chracteristics, and (3) to see if the same melt volume and distribution trends proposed for terrestrial impact structures also apply to those on the Moon.

Method

Melt deposits were identified using the criteria established by Howard and Wilshire[3] and Hawke and Head[4]. Qualitative estimates were made and trends established using a population of over 100 fresh lunar craters whose exterior melt deposits were largely described in a previous paper[4], plus additional craters for which adequate photography exists. Qualitative measurements of melt volumes were made for those craters for which high-quality topographic data are available from Lunar Topographic Orthophotomaps.

Results and Discussion

1. Melt occurrence as a function of crater size and morphology:

A. Simple craters (D <∿15 km): Impact melt is more common at fresh craters of this size than has previously been thought. The smallest extensively studied crater with interior melt was 750m in diameter but the occurrence of even smaller melt-containing craters was noted. Impact melts at these small craters (D <2 km) typically occur as narrow ponds of low albedo material on crater floors, less common dark streaks on walls, and very thin, discontinuous veneers concentrated in the vicinity of the rim crests. Simple craters of this size differ very little in form from the transient cavities that existed at the end of the excavation stage of the cratering event. Melt deposit morphologies suggest that the melt ponded on crater floors represents shock melt which originally lined the transient cavities and collected in the bottoms of the craters at the end of the impact events.

The melt deposits associated with slightly larger craters (D=2-7km) are similar but more abundant than those at smaller craters. Typical is the 5.4km crater on the rim of Gibbs. Shallow ponds occur among the small floor hummocks and veneer covers much of the floor. At least some of the melt appears to have flowed onto the floor from the lower portions of crater wall and overlies or embays clastic debris derived by mass wasting from the crater walls. Even though some minor wall failure has occurred in craters of this size, the positions of these craters on depth-diameter plots demonstrated that there has been very little reduction in depth[5,6]. While some melt may have been mixed with or buried by clastic debris mass wasted from the walls, most of the melt originally lining the upper portion of the transient cavity flowed into the lower portion of the crater, mingled with shock melt concentrated in the bottom of the cavity and ponded to form the deposits exhibited by craters of this size.

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Interior melt amounts are quite variable in fresh craters from 7-12km in diameter and range from unobserved or present in only trace amounts (thin veneer draped over floor hummocks) to quite abundant (floor largely covered with ponded material). Extensive deposits of exterior melt are first observed around craters near the upper limit of this size range. Flows are the dominant morphology in contrast to the thin hard-rock veneers and very small exterior ponds which are common at smaller sizes[4]. Wall modification has been more extensive at fresh craters of this size and at least some of the variability in interior melt abundances may be attributed to differing efficiencies of melt burial or incorporation by mass wasted clastic debris.

B. Complex craters (D >15km): Numerous workers have documented the changes in lunar crater morphology and morphometry which start at a diameter of about 15km as smaller, simple craters undergo a transition to larger, more complex craters which exhibit central peaks and walls terraces (e.g. 5,6,7,8, 9). The crater modification processes operative at craters between 15 and 30 km in diameter also seem to influence melt deposit morphologies and abundances. While most fresh primary impact craters in this diameter range for which adequate photography exists do contain at least some melt, the amounts are extremely variable. Typical of these is Dawes (D=17km), in which significant accumulations of impact melt are restricted to a small region east of the central peak[10]. Additional melt was probably present initially but was buried by scallop material slumped onto the crater floor during the modification stage of the impact cratering event. Fresh craters in this size range which exhibit no interior melt are generally characterized by the presence of extensively scalloped walls and/or swirl-textured floors, features which appear to be indicative of pervasive wall failure[7]. Analysis of the interior morphologies of these craters suggests that the interior melt was totally buried by scallop material. The variable amounts of interior melt associated with craters in this size range can best be explained by differences in the degree or style of wall failure.

Most fresh impact craters over 30-40km in diameter are extensively modified and exhibit central peaks, terraced walls, and flat floors with abundant deposits of impact melt. Wall failure has been more extensive and deep-seated at the larger terraced-wall craters and little melt appears to have been buried during the modification stage. The results of detailed mapping of interior and exterior melt distributions suggest that ponded material becomes relatively more abundant on the floors and rims of these larger craters.

2. The influence of substrate on melt generation:

Recent cratering studies have demonstrated the importance of target characteristics in determining the morphology of lunar craters[7,8]. Therefore, an attempt was made to determine the influence of substrate on the relative amounts of impact melt associated with craters in highland vs. mare terrains. A comparison of the mapped interior melt deposits in similar-sized craters (D <50km) suggests that highland craters contain melts in amounts equal to or less than mare craters. This observation should not necessarily be taken as evidence that more melt was generated by impact into mare targets. The observation could be explained by one or more of the following: (1) for a given impact energy, larger craters may be formed in the highlands relative to the mare, (2) the style of wall failure is known to be dependent on terrain and substrate[7], and (3) some evidence exists that more melt was ejected from highland craters.

3. Exterior melt volumes as a function of crater diameter:

Previous studies have emphasized the role of oblique impact and pre-existing topography in controlling the distribution and amounts of exterior

melt[3,4]. While these factors do cause variable amounts of melt to be emplaced on crater rims, a variety of evidence suggests that relatively greater quantities of melt are present on the rims of larger craters. This evidence includes: (1) the tendency for melt to occur at great relative maximum distances from the rim crest, at least at craters up to about 50km in diameter[4], (2) the dominance of larger exterior melt ponds over flows and veneer at craters over ∿50km in diameter[4], (3) the observation that exterior melt ponds are larger and more widespread at larger craters, and (4) quantitative estimates of melt volumes indicate that relatively more melt is present on the rims of larger structures. Even so, this may not imply that a greater percentage of the total melt has been ejected since the total amount of melt generated was also relatively greater at larger structures.

4. Interior melt volumes as a function of crater diameter:

There also appears to be a systematic variation in the amounts of melt in crater interiors. Since the extent and thicknesses of the ponded material on crater floors tend to increase as a function of crater size, more melt may be present in the interiors of larger craters. Support is provided by quantitative estimates of interior melt volumes for specific craters where adequate topographic data exist. A similar trend has been noted for the melt volumes associated with terrestrial impact structures[11,12]. The observation that relatively more melt is present in larger lunar craters is consistent with the proposed greater partitioning of the kinetic energy of impact into internal energy at larger impact strucutres as well as the suggestion that cavity excavation is less efficient at large hypervelocity impact events[11,12,13].

5. Comparison with melt volumes associated with terrestrial craters:

The volumes of shock melt in terrestrial craters are relatively well known because of extensive study in recent years[11,12]. A comparison of the estimated melt volumes at lunar craters with the amounts determined for similar-sized terrestrial craters demonstrates that for a given crater diameter, melt is more abundant at terrestrial impact structures. Melt volumes associated with lunar craters are only 15%-44% as great as those at terrestrial craters. This observation confirms predictions that more melt should be observed in a large terrestrial crater than in a lunar crater of comparable diameter[13,14]. This difference in melt volumes is probably related to the fact that for a given kinetic energy of impact, a larger crater will be formed on the Moon than on the Earth whereas the amounts of melt generated should be roughly the same, assuming that the properties and state of the target materials are similar.

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