Introduction

Lavalike deposits that were emplaced in a fluid state occur in and around many lunar craters. Early workers considered these deposits to be volcanic but Howard and Wilshire\(^1\) have recently presented strong evidence supporting an impact-melt origin. Results of previous investigations\(^2,3,4\) support an origin by shock melting. Hawke and Head\(^3\) have recently presented the results of a study of the exterior melt deposits associated with 55 lunar craters. Major conclusions were: 1) exterior melt ponds and flows are located around craters ranging from 4 km to 300 km in diameter, 2) the morphology of these deposits changes as a function of crater size, 3) there is a tendency for melt to occur at greater relative maximum distances from the rim crest with increasing crater size, 4) relatively greater amounts of the total shock melted material appear to have been emplaced on the rims of the larger craters, 5) pre-event topography is the dominant factor controlling melt distribution on the rim but oblique impact may still play some role in causing melt deposit asymmetry, and 6) processes acting during the crater modification stage may have acted together to cause a portion of the shock melted material to be removed from the crater and emplaced on the rim. This report presents the results of an extension of the above studies to the impact melt deposits which occur on the interior of lunar craters. The present study was undertaken to 1) determine the modes of occurrence and distribution of impact melt on crater walls and floors 2) investigate the manner in which these vary as a function of crater size, 3) establish a basis for the comparison of these lunar deposits to their terrestrial analogs, and 4) determine the modes of emplacement and investigate the processes responsible. Special emphasis has been placed on the melt deposits in smaller craters because of the radical changes that occur in crater morphology between 10 and 30 km. The results should have bearing on lunar and terrestrial impact cratering processes and the provenance of the abundant melt rocks in the lunar sample collection.

Method

The criteria used in this study to identify melt deposits are similar to those described by Howard and Wilshire\(^1\) and Hawke and Head\(^3\). These include the various indications of fluid flow, material ponded to a level surface, cooling cracks in ponds, tension cracks in veneer, and gradational relationships among the various melt morphologies.

A variety of Lunar Orbiter, Apollo, and Earth-based photography was employed to locate and characterize interior melt deposits. Essentially the population studied consisted of the 55 craters whose exterior melt deposits were described in a previous paper\(^3\) plus additional craters at which only interior melt deposits could be recognized with certainty. A variety of data was collected concerning the size and location of these craters as well as the morphology and morphometry of the crater and melt deposits.

Results and Discussion

1. Modes of occurrence: Lavalike material on crater interiors exhibit a number of distinctive morphologies which are in many respects similar to those
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seen on crater rims. The bulk of the interior melt deposits are concentrated in one or more complexly fractured ponds on the crater floor. Less extensive pools can be found on crater walls. Flow lobes and channels also occur on crater walls and much less frequently, on central peaks. These flows occasionally emerge from or terminate at wall pools and in places are seen to flow onto or merge with the floor ponds. A thin, hard-rock veneer occurs on crater walls. Similar material often drapes floor hummocks and remnants can be seen on the less steep portions of central uplifts. Veneer material can often be seen to grade laterally into flows or ponds and often exhibits gradational contacts with flows and ponds.

2. Morphology of deposits as a function of crater size:

A. 1 - 10 km: Fresh impact craters in this size range are generally bowl-shaped and only rarely contain deposits of impact melt. Typical of those that do are the 4 km crater on the rim of Gibbs and the 5.5 km crater on the rim of Gagarin. These craters exhibit a narrow, flat floor composed of a low albedo material which has ponded to a level surface. Evidence of impact melt origin includes (1) a low albedo which is thought to be characteristic of thin melt ponds and veneer, (2) indications that the material behaved as a fluid, and (3) similarity of the dark material on the floor of the crater on the rim of Gibbs to deposits on the crater exterior which have been interpreted as impact melts. Craters have been located near the upper limit of this size range, which contain floor ponds and exhibit a full range of features considered diagnostic of lunar impact melts.

An important question is why melt deposits are generally not observed on the interiors of small craters. Part of the answer may lie in the fact that secondary craters are very abundant in this size range and the impact velocities commonly associated with secondary projectiles would generate very little melt. At primary craters, the molten materials were most abundant lining the bottom of the transient cavity and were buried by or mixed with debris slumped from the walls during the modification stage of the cratering event.

For those craters which do exhibit ponded floors, two alternate models can be presented. (1) Slumping from the walls was inadequate to completely cover the melt deposit. (2) Alternately, some of the melt was covered by clastic debris which was in turn overlain by melt that formed the upper portion of the lining of the transient cavity, and/or melt-rich material which had been ejected at high angles and fell back into the crater.

B. 10 - 30 km: Within this size range, profound changes occur in crater morphology and these changes seem to influence the morphology and distribution of the impact melt deposits. Most 10 km craters are bowl-shaped and lack central peaks and slump terraces whereas almost all 30 km craters are flat-floored, terraced, and exhibit central uplifts. Within this size range profound changes also occur in morphology of the molten material. Wall ponds, flows and veneer first become abundant, and thick, extensive floor ponds first appear. Abundant exterior melt deposits are first seen around craters 10-15 km in diameter and interior melt deposits are generally not observed. Dawes (D=18 km) is representative of many slightly larger craters. Melt occurs as small ponds concentrated in the area around and east of the crater center. Extensive veneer and a few flows are also seen. Similar, though more
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extensive deposits occur on the interior of Proclus (D=26 km).

The morphology and interior melt deposits of Lalande (D=30 km) are
typical of many similar craters near the upper limit of the size range. Ex-
tensive melt deposits are concentrated in the crater floor and smaller amounts
occur in various forms on the terraced walls. Lalande offers important clues
to the processes responsible for melt distribution. The crater has a small
central peak and is most extensively terraced to the SW. The most extensive
ponded flow material is found in the NE portion of the floor, adjacent to a
narrow terraced wall, a topographically lower rim crest segment, and exten-
sive exterior melt deposits. Melt appears to be draped over this NE wall and
has partly drained downward onto the crater floor. The relationships between
 crater morphology and melt distribution observed at Lalande suggest that melt
was removed from the transient cavity during the modification stage of the
 cratering event by the combined action of rebound and wall slumping. Similar
relationships have been described at other lunar craters including Necho (D=33 km) and King (D=71 km)². Differences between the morphology of Lalande
and its interior melt deposits and craters such as Dawes or Proclus can be
understood in terms of models presented by Head⁷ and Hawke and Head³ which
place emphasis on the roles of substrate characteristics and pre-event topo-
graphy. At Dawes and Proclus, central peak formation and associated rebound
helped initiate massive wall failure which formed scallops at these low dia-
ters. Some melt was removed from the transient cavity by these modification
processes but a significant quantity was buried by the scallop material. At
larger craters such as Lalande and Necho, the transient cavity was probably
more flattened but still penetrated deep beneath the megaregolith. Wall fail-
ure was more significant and extensive terraces were formed. During the
 crater modification stage, some melt was removed from the transient cavity and
can now be seen on the crater exterior adjacent to topographically low seg-
ments of the rim crest and on the crater walls. The material which was not
removed settled onto the crater floor where it formed the extensive ponds that
are observed today.

C. D>30 km: Most fresh impact craters larger than 30 km for which
adequate photography exist appear to contain abundant impact melt deposits on
their floors and walls and exhibit all of the morphologies previously discus-
sed. Typical are such large craters as King (D=71 km), Copernicus (D=95 km),
Tycho (D=85 km), and Aristarchus (D=40 km). Although interior melt deposits
appear more extensive on craters of this size, the data indicate that the same
processes described previously continued to be important.