Abstract. Both the Moon and Mars exhibit volcanic modification of impact craters characterized by subfloor intrusions that either lift the old crater floor or result in extrusions of lava. Endogenic modification of martian craters, however, probably has involved interactions between such intrusive bodies and permafrost, as suggested by differences between lunar and martian floor-fractured craters. Such interactions raise the interesting possibility for hydrothermally concentrating ores in a manner analogous to the Sudbury structure on the Earth that may be consistent with interpretations of Viking lander results.

Introduction

Localized crustal weaknesses created by impact craters represent primary pathways for basaltic volcanism on the Moon. Such volcanic centers are expressed by mare-filled craters with unbreached rims ranging in size from smaller than 10 km in diameter to the largest basins. In addition, over 200 lunar craters exhibit floor fractures and other tectonic modifications that provide important clues for the distribution, timing, and the style of volcanism associated with the much larger lunar basins (e.g., Pike, 1971; Schultz, 1976). Mars (Schultz et al., 1973) and perhaps Mercury (Schultz, 1977) also exhibit impact craters with endogenic modifications. Consequently, where flow termini and other indicators of endogenic processes are absent or ambiguous, floor-fractured craters may provide a record of a major stage in the thermal history of the planet.

Crater-Centered Intrusions on the Moon and Mars

The volcanic and tectonic history of Mars is considerably more complex than the volcanic history of the Moon. Nevertheless, the early stages of martian volcanism resulted in certain cratered plains resembling the lunar maria that were tentatively identified in Mariner 6 and 7 images (Schultz, 1977) also exhibit impact craters with endogenic modifications. Consequently, where flow termini and other indicators of endogenic processes are absent or ambiguous, floor-fractured craters may provide a record of a major stage in the thermal history of the planet.

Possible Sites and Implications

Martian Intrusions

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The global distribution of such channels may provide an important and sensitive record of a stage in the thermal history of Mars.

Concluding Remarks and Possible Implications

Thus there are at least three contributing processes inferred to produce martian floor-fractured craters. First, floor uplift and/or subsidence perhaps result from an intrusion of magmas most likely at the fracture/breccia interface beneath an old impact crater, in direct analogy with lunar floor-fractured craters. Evidence supporting this process is the location of martian craters similar to lunar craters adjacent to lava-flooded plains and the morphology of lava-inundated craters. Second, localization of intrusions beneath an old crater floor in a manner analogous to lunar floor-fractured craters melted and perhaps volatized trapped ices accumulated within an old impact crater. Such a process may have enhanced the development of concentric fractures around the floor. Rapid melting resulted in breaching of the crater rim and possible rafting of the crater floor; less rapid melting associated with intermittent intrusive episodes resulted in percolation through the heavily jointed and fractured region surrounding the old unbreached impact crater. In addition, percolation through the crater wall modified (filled) but not necessarily fractured the old crater floor. A third process not directly addressed above involves water (?) that undercut an endogenically inactive crater and breaks up the crater floor plate. In this case, the crater is not intruded but is nevertheless affected.

Mariner 9 and now Viking images reveal that craters in a wide range of degradation have been modified by endogenic processes (Figure 2), from...
craters with degraded rims to craters with preserved hummocky facies. The latter type of modified crater suggests that the modification process is relatively recent, possibly corresponding to the late stages of martian volcanism. The style of crater modification is also generally similar to that of lunar floor-fractured craters. Both lunar and martian floor-fractured craters rarely exhibit radial fractures beyond the crater rim, thereby indicating an intrusion localized beneath the crater floor. Polygonal patterns are much more common on Mars than on the Moon. Moreover, concentric fracture patterns are less characteristic of martian craters although the development of a concentric depression or moat encircling the floor is twice as common on Mars as on the Moon. Examples on both planetary bodies exhibit shallow crater floors with elevated and dropped central peaks, the latter expressed as a central depression. Table 1 compares the fracture patterns and postulated causes. In summary, the early crustal history of Mars seems generally similar to that of the Moon: extensive impact cratering followed by emplacement of extensive lava plains. On the Moon, pre-existing impact craters and basins played an important role in controlling vent location. The possibility that water/ice existed in the martian crust creates an interesting possibility that water/ice existed in the martian crust creates an interesting

TABLE 1. Comparison of Fracture Patterns in Lunar and Martian Craters

<table>
<thead>
<tr>
<th></th>
<th>Concentric (pattern — including combinations of patterns)</th>
<th>Radial (pattern)</th>
<th>Polygonal (pattern)</th>
<th>Concentric Depression (pattern)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOON</td>
<td>72%</td>
<td>11%</td>
<td>33%</td>
<td>(10%)</td>
</tr>
<tr>
<td>MARS</td>
<td>42%</td>
<td>7%</td>
<td>52%</td>
<td>(26%)</td>
</tr>
</tbody>
</table>

- magma withdrawal
- ring-like intrusion
- foundering of floor
- upward-directed primary stress from intrusive body
- multiple periods of uplift and subsidence
- multiple intrusions
- inhomogeneous floor (altered stress field)
- rafting of broken floor blocks due to subfloor erosion or sapping
- elevation of floor plate
- foundering of wall zone into magma reservoir
- erosion due to sapping by evaporated or melted ice at floor/wall contact

Fig. 3. Lava-filled (90 km diameter) crater south of Tharsis near 140°, 10° S. Exposed central peak, flat-topped rim profile, and rim graben resemble lunar mare-filled and modified craters. Viking Orbiter Frame 41B56.

Fig. 4. Subdued crater (85 km diameter) with wide discontinuous moat and channels (59°, 4° N). Floor exhibits little evidence of uplift, yet moat development is clear. Arrow A indicates earlier stage of moat and related channel formation; arrow B indicates later stage. Old crater floor/wall boundary without moat development is indicated by arrow C. Viking Orbiter Frames 79A62, 80A31, 80A32, 80A33, 80A34.
complication whereby these craters became release centers for such vola-
tiles and fluids during global heating. Inorganic chemical analyses from
the Viking sites suggest that the most probable constituents of the martian
soils include iron-rich smectites, carbonates, iron oxides, and sulfide
minerals that are consistent with interaction between mafic magmas and
subsuface ice as suggested by Toulmin et al. (1977). Moreover, the high
sulfur content, now interpreted as sulfates, suggests the possible existence
of hydrothermally concentrated sulfide-rich ore bodies at depth. Inter-
actions of igneous reservoirs beneath impact craters with crustal water/ice
may make the concentration of hydrothermally derived ores possible and
the existence of rich resources such as the Sudbury-type structures, as
interpreted by French (1970), commonplace. The complex albedo con-
trasts associated with several martian floor-fractured craters may indicate
hydrothermal deposits and possible sites for such ore concentrations.
Further detailed analysis from Viking Orbiter images will permit further
bracketing the time of the proposed crater modifications and their relation
to martian geologic history.

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