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Sequence and Mechanisms of Deformation Around the Hellas and Isidis Impact Basins on Mars

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The distribution and age of early volcanic and tectonic features surrounding the Hellas and Isidis impact basins are shown to fit a four-stage sequence. First, concentric "canyons" form outside the basin boundary scarp at or near the time of basin formation, followed shortly thereafter by radial troughs extending beyond the boundary scarp. After a hiatus, concentric graben develop inside the basin within the massif ring. Finally, soon after graben formation, widespread volcanic plains are emplaced between the massif ring and the boundary scarp to one side of the basin. Three models of basin-centered deformation are compared to these observed deformation events: elastic flexure due to loading, elastic flexure due to uplift, and impact fracture. A central load of basin fill can account for concentric fractures by elastic flexure around the load. Formation of the distant concentric canyons, however, requires lithospheric thicknesses a factor of 5 greater than those indicated by planetary thermal history models and an increase in feature width by an order of magnitude relative to flexural graben identified elsewhere on Mars and the Moon. Although inclusion of loading by basin ejecta reduces the required lithospheric thickness to acceptable values, flexure still fails to account for the large canyon widths observed. Impact fracture from a rapid inward flow of asthenosphere during transient cavity collapse, however, is consistent with the three key observational constraints for the distant canyons: their age, width, and distance from the basin. As the basin then undergoes isostatic uplift soon after impact, elastic flexure induces a radial pattern of failure consistent with the observed extent and timing of the radial troughs. Later, after a long period of basin infilling, elastic failure due to loading of the central basin region can account for the ring grabens in the massif ring. The localization of volcanism into a single ridged plains unit on the basin rim indicates a thermal source offset from the basin which is not included in these models and perhaps reflects an additional mechanism unique to Mars.

INTRODUCTION

Multiring basins and large craters are the dominant features of the most ancient preserved surfaces in the solar system. On the Moon, these basins apparently controlled both subsequent mare volcanism (see *Head* [1976] and *Wilhelms* [1987] for reviews) and many of the observed tectonic features through flexure under the resulting mare loads [*Solomon and Head*, 1980]. On Mars, however, surface degradation has obscured the oldest volcanic and tectonic features. Multiring basins are subdued in expression and harder to identify than on the Moon, even though the areal densities are similar [*Schultz et al.*, 1982]. Further, the more recent and extensive volcanic and tectonic activity in the Tharsis and Elysium regions obscures the early geologic record of nearly half the planet's surface. The combination of these two modifying processes (degradation and recent massive volcanism) largely masks the obvious role of basins on the volcanic and tectonic history of Mars that is so evident for the Moon.

The cratered highlands of Mars preserve numerous ancient volcanic and tectonic features reflecting regional deformation despite pervasive surface modification. Tharsis loading stresses apparently played a negligible role in the formation of many ancient highland scarps, ridges, graben and channel wall scarps [*R.A. Schultz*, 1985], thereby leaving an early signature of stresses of an uncertain origin outside the Tharsis and Elysium volcanic provinces. The possible role of impact basins in this early structural and volcanic history of Mars, however, has been addressed in only a few studies. Flexural deformation under a basin-filling load has been modeled only for the Isidis basin on Mars [*Solomon et al.*, 1979] as a means to estimate the thickness of the early Martian lithosphere. *Chicarro et al.* [1985] correlated both the orientation and location of wrinkle ridges in the highlands with ancient impact basins and also examined the residual, non-basin-related trends for possible global patterns. *Peterson* [1978] associated volcanic centers with ring structures around the Hellas basin. *Schultz* [1984] subsequently proposed preferred sites for volcanism occurred where concentric zones of weakness around one basin were reinforced by extension radial to a nearby basin. Less obvious volcanic and tectonic modification may be expressed by chaotic terrains localized along deep-seated, basin-concentric zones of weakness [*Schultz et al.*, 1982; *Schultz*, 1984]. Thus several styles of significant regional modification on Mars appear to be influenced by ancient basin structures.

Although such studies have documented basin control of volcanic and tectonic structures in the Martian uplands, the nature and evolution of the controlling processes as a function of time remain only broadly characterized around any given basin. Thus, in the present study we first focus on the ex-

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