JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 87, NO. B5, PAGES 3975-3992, MAY 10, 1982

The Evolution of Impact Basins: Viscous Relaxation of Topographic Relief

SEAN C. SOLOMON AND ROBERT P. COMER

Department of Earth and Planetary Sciences, Massachusetts Institute of Technology Cambridge, Massachusetts 02139

JAMES W. HEAD

Department of Geological Sciences, Brown University, Providence, Rhode Island 02912

We evaluate the hypothesis that viscous relaxation has been an important process for modifying the topographic profiles of ancient large impact basins on the moon. We adopt a representative topographic profile of the Orientale basin, the youngest large impact basin on the moon, as an estimate of the initial topography of older basins of similar horizontal dimensions, and we predict the topographic profiles that would result from viscous relaxation according to a number of simple analytical representations of the rheological response of the moon to surface topography. At wavelengths greater than the thickness of a high-viscosity lithosphere, both a decrease in viscosity with depth and the partial to complete isostatic compensation of topographic relief have pronounced effects on the wavelength-dependent relaxation times and must be considered in modeling viscous relaxation for features as large as impact basins. The effect of a decrease in viscosity with depth is to enhance the rate of viscous relaxation at long wavelengths, while the rate of relaxation decreases substantially for the fraction of long-wavelength topography which is isostatically compensated as an initial condition. These models are applied to two pre-Nectarian basins on the moon, the Tranquillitatis basin on the lunar nearside and the much larger and older South Pole–Aitken basin on the farside. The topographic profile of Tranquillitatis, after correcting for the effect of mare basalt fill, is consistent with significant viscous relaxation of relief prior to the oldest episode of mare volcanism preserved as a surface unit. The large topographic relief of the larger farside basin, on the contrary, is not consistent with significant viscous relaxation and implies a mean crustal viscosity at least a factor of 10 higher than for the central nearside over the time interval during which substantial viscous relaxation of older nearside basins such as Tranquillitatis probably occurred. A difference in typical crustal temperature profiles between the farside and nearside is the most likely explanation of such a viscosity difference; such a nearside-farside asymmetry in near-surface temperature may date from the time of crust-mantle differentiation and may have persisted because of the different histories of late-stage impact basin formation and mare volcanism on the two hemispheres.

INTRODUCTION

Impact basins are large, generally circular structures exceeding about 200 km in diameter and often displaying two or more concentric rings. Impact basins formed in the first billion years of planetary history; they can be seen on the surfaces of the moon, Mars, Mercury, and the Galilean satellites [*Hartmann and Wood*, 1971; *Malin*, 1976; *Wood and Head*, 1976; *McKinnon and Melosh*, 1980], and they may have been preserved on the surface of Venus [*Schaber and Boyce*, 1977]. Their presence on these bodies makes it a virtual certainty that such impact basins also formed on the early surface of the earth, though their formation was prior to the time when stable nuclei of continental lithosphere could persist unmodified to the present, so that these early terrestrial impact basins have not been preserved. The abundances of impact basins on the solid surfaces of the solar system indicate that basin formation was an important geological process in the early, formative years of planetary crustal evolution [*Head and Solomon*, 1981].

The formation of a basin concentrates a substantial amount of heat into a small area and volume near the surface of a planet [*O'Keefe and Ahrens*, 1977]. In addition, impact basins become a focus for other planetary processes, such as volcanism and tectonic activity, long after the impact event. These volcanic and tectonic processes can modify the structure and morphology of the impact basin. The timing and character of such modification processes provide important information about the nature and evolution of the interior of a planet.

As part of an ongoing effort to understand the properties and processes that affect the formation and evolution of impact basins [*Head and Solomon*, 1981], we have identified three major processes that act to modify impact basins over geologically long time scales (millions to billions of years): (1) thermal contraction and thermal stress associated with the loss of heat from basin formation, (2) relaxation of topographic relief by viscous flow for basins formed in regions of elevated temperatures at shallow depth, and (3) volcanic filling and lithospheric loading. The last process and its effect on the volcanic and tectonic history of major impact basins on the moon and Mars have been treated at length [*Solomon and Head*, 1979, 1980; *Solomon et al.*, 1979; *Comer et al.*, 1979, 1980]. The first process and its influence on basin topography and tectonics are the topics of parallel studies [*Bratt et al.*, 1981; *Church et al.*, 1982]. The second process, viscous relaxation as a modifier of impact basin topography, is the subject of this paper.

While the rugged ring mountains of comparatively young basins are often strikingly evident on the present surfaces of

Paper number 2B0227.
0148-0227/82/002B-0227$05.00