JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 90, NO. B14, PAGES 12,415–12,433, DECEMBER 10, 1985

The Evolution of Impact Basins: Cooling, Subsidence, and Thermal Stress

STEVEN R. BRATT[1] AND SEAN C. SOLOMON

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

JAMES W. HEAD

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

Potentially important contributors to the topography and tectonics of multi-ring impact basins are the thermal contraction and thermal stress that accompany the loss of heat emplaced during basin formation. Heat converted from impact kinetic energy and contributed from the uplift of isotherms during cavity collapse are important components in the energy budget of a newly-formed basin. That the subsequent cooling may have been an important factor in the tectonic evolution of the Orientale basin is suggested by the deep central depression and by a surrounding region of extensive fissuring. To test these concepts, we develop models for the anomalous temperature distribution immediately following basin formation, and we calculate the resulting elastic displacement and stress fields that then would accompany cooling of the basin region. All models predict subsidence of the basin floor and a near-surface stress field consistent with fissuring. In addition, the rates of cooling and of accumulation of thermal stress are in agreement with the inferred timing of fissure formation in Orientale. The sensitivity of the predicted displacements and stresses to the initial temperature field allows us to place bounds on the quantity and distribution of impact heat emplaced during basin formation. In order to be consistent with the observed topography and the distribution of fissures in the Orientale basin, the buried heat deposited during the basin-forming event was between 10^{32} and 10^{33} erg. It is likely that most of this heat was concentrated within a distance of 100–200 km from the point of impact.

INTRODUCTION

Multi-ring impact basins on the Moon exhibit wide variations in their present geometry and structure [*Hartmann and Wood*, 1971; *Wilhelms*, 1973; *Wood and Head*, 1976]. Some of the variations may be related to differences in the properties of the lithosphere or impacting projectile at the time of basin formation [e.g., *Melosh and McKinnon*, 1978; *Holsapple and Schmidt*, 1982]. Many of the observed variations likely reflect different degrees of modification of initial basin geometry and structure on time scales long compared to those for cavity excavation and ring formation. The subdued topographic relief of basins formed early in lunar history when the lithosphere was relatively warm is probably a consequence of lateral flow of crustal material over times scales ranging up to millions of years [*Solomon et al.*, 1982; *Bratt et al.*, 1985*a*]. The infilling of impact basins with mare basalt, on a somewhat greater time scale, led to loading of the lunar lithosphere and consequent subsidence and flexurally-induced tectonic activity [*Solomon and Head*, 1979, 1980; *Comer et al.*, 1979].

Thermal contraction and thermal stress accompanying the loss of heat emplaced during basin formation are two additional and potentially important contributors to the long-term modification of an impact basin [*Bratt et al.*, 1981]. During impact a significant fraction of the projectile kinetic energy is converted to buried heat [*O'Keefe and Ahrens*, 1976, 1977]. Further, the uplift of lower crustal and upper mantle material during collapse of the excavated cavity and formation of the multi-ring basin [*Melosh and McKinnon*, 1978] results in a corresponding uplift of the crustal and mantle isotherms, an additional source of heat beneath newly formed basins. Conduction of this anomalous heat to the surface gives rise to lithospheric thermal contraction and stress.

In this paper we assess the contribution of thermal contraction and thermal stress to the topography and tectonics of large lunar impact basins. Exploratory models are developed for the temperature structure following basin formation, for the subsequent cooling of the basin region, and for the resulting thermal displacements and stresses as functions of time. The subsidence and stress at the surface are compared with topography and tectonic features in the comparatively well-preserved Orientale basin [*Head*, 1974; *Church et al.*, 1982]. On the basis of these comparisons we derive approximate constraints on the quantity and distribution of heat implanted during the basin-formation process.

GEOLOGICAL OBSERVATIONS: THE ORIENTALE BASIN

The Orientale basin (Figure 1), the youngest and best preserved of all lunar impact basins [*Head*, 1974; *Moore et al.*, 1974], is an important source of information about the formation and modification of impact basins on all the terrestrial planets. Only the centralmost 220 km of the 900-km-diameter topographic depression is extensively covered by mare basalt [*Head*, 1974], leaving exposed many geologic units and tectonic features that are presumably hidden beneath mare units in other nearside basins. Because Orientale is the youngest major basin on the Moon [*Wilhelms*, 1979], it has been left relatively undisturbed by ejecta deposits from other large impact events. Orientale is thus a nearly ideal location to look for tectonic and topographic expressions of basin cooling.

A careful documentation of the principal structural features and morphological units within the Orientale basin has been made by *Church et al.* [1982]; see Figure 2. The plains and

[1]Now at Science Applications International Corporation, San Diego, California.

Paper number 5B5451.
0148-0227/85/005B-5451$05.00