VISCOUS RELAXATION OF THE MOHO UNDER LARGE LUNAR BASINS.

C. David Brown and Robert E. Grimm, Department of Geology, Arizona State University, Tempe, AZ 85287-1404.

Introduction. Viscously relaxed topography on the Moon is evidence of a period in lunar history of higher internal temperatures and greater surface activity. Previous work has demonstrated the viscous relaxation of the Tranquilitatis basin surface [1]. Profiles of the lunar Moho under nine basins were constructed from an inversion of lunar gravity data [2]. These profiles show a pattern of increasingly subdued relief with age, for which two explanations have been proposed [2]. First, ancient basins may have initially had extreme Moho relief like that of younger basins like Orientale, but, due to higher internal temperatures in early lunar history, this relief viscously relaxed to that observed today. Second, ductile flow in the crust immediately after basin formation resulted in an initially shallow basin and subdued mantle uplift. The intent of the work described in this paper is to test the first hypothesis.

Model and Data. The viscous relaxation model used here represents the near-surface rheology of the Moon as an isoviscous layer of viscosity η_1 over an isoviscous halfspace of viscosity η_2 [3]. The layer represents the crust, and the halfspace the mantle; thus, an important limitation of this model is that the viscosity discontinuity is imposed at the same depth as the compositional (density) boundary. The surface and Moho topography are obtained from published plots [2] and are scaled horizontally to the size of Orientale using the main ring diameter of each basin [4]. It is assumed that the main ring is the same tectonic feature for each basin, so it is representative of the basin size. Since most of the basins are within 15% of the size of Orientale, it was decided that vertical scaling of the topography was unnecessary.

Results. Tests of relaxation are carried out by using different relaxation times (t) with both Orientale and Serenitatis starting profiles. The viscosity of the layer and halfspace are also varied, but this causes no change in the shape of the final profiles. An inviscid halfspace was modeled by setting $\eta_2 = 10^{-10}\eta_1$, but for all relative viscosities up to $\eta_2 = 10^{-1}\eta_1$ the times required to achieve the same amount of relaxation are identical. Increasing or decreasing the absolute viscosity of the layer increases or decreases the relaxation time proportionally; therefore the value of t/η_1 is independent of both the relative viscosities of the layer and halfspace and the absolute viscosities of each, as long as $\eta_2 < \eta_1$. In the results described below, the viscosities of the two regions are fixed to $\eta_1 = 10^{24}$ Pa-s and $\eta_2 = 10^{21}$ Pa-s.

The Serenitatis basin profile can not be fit by a relaxed Orientale profile. The peak of the Serenitatis mantle uplift is about 70% of the maximum Orientale uplift, but the narrow Orientale profile does not relax to the broad Serenitatis contour while retaining 70% of its original relief. Nectaris is reasonably well fit by the relaxed Orientale profile with $t/\eta_1 = 6.3\times10^{-8}$ Pa^{-1} (Fig. 1). Similarly, Tranquilitatis is roughly fit by a relaxed Orientale profile, though not quite as well. The best fit value of t/η_1 is 1.3×10^{-7} Pa^{-1}, which is comparable to the result for the surface topography [1]. In general, the relaxed Serenitatis starting profile offers a better fit to many of the basins than the relaxed Orientale profile. The closest fit found in this study is the relaxed Serenitatis profile to the Nubium uplift (Fig. 2). The excellent match strongly suggests that Serenitatis and Nubium had similar initial uplift shapes. t/η_1 for this fit is 9.5×10^{-8} Pa^{-1}. Note that values of t/η_1 for the relaxed Serenitatis profile can not be compared to the Orientale results since the "initial" Serenitatis profile is presumably in a more advanced state of relaxation. The relaxed Serenitatis fit to Tranquilitatis

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is better than the fit of the Orientale starting profile. Here $t/\eta_1 = 6.3 \times 10^{-8}$ Pa^{-1}. However, the Nectaris profile can not be fit by a relaxed Serenitatis profile; as with the poor fit of the Orientale starting profile to Serenitatis, this result seems to indicate that Serenitatis is an inappropriate starting profile for Nectaris.

Discussion. In general, Orientale is an inadequate starting profile for examination of viscous relaxation. Its creation later than the other basins at the nearside-farside boundary where the crust is thicker indicates that the conditions of its formation were unique. However, the better fit of the relaxed Orientale profile to Nectaris than the relaxed Serenitatis profile does demonstrate that there was some variation in the initial mantle uplift shapes among the old basins and therefore significant heterogeneity in conditions which controlled the Moho uplift. The results of this work show that Nubium and Tranquilitatis probably had initial uplifts like that of Serenitatis, and Nectaris had a starting profile more like that of Orientale.

Orientale is commonly assigned an age of 3.8 Ga, and we assume the time of significant possible viscous relaxation on the nearside ended at this time. Since Nectaris formed at 3.92 Ga [4], t = 0.12 Ga. Using the best fit value of t/η_1 for Orientale relaxed to Nectaris, we constrain the lunar mantle viscosity at this time to be less than 10^{22} Pa-s, which agrees with the value $\eta_2 = 10^{21}$ Pa-s favored by lunar thermal evolution models [5]. If a later "freeze-in" of the Nectaris profile is assumed (3.7 Ga), the maximum mantle viscosity must be about an order of magnitude greater, thus the result of the Nectaris fit supports the assumption that at least some nearside basins had stopped relaxing by the end of the Lower Imbrian.

The near-perfect fit of the viscously relaxed Serenitatis profile to Nubium offers strong evidence for viscous relaxation over several tens or hundreds of millions of years. If the lithosphere was very thin and the viscosities were much less, the uplifts could presumably relax soon after formation. But this explanation seems to rely heavily on the contribution of heat from the impact, since thermal models of the Moon's evolution typically limit the temperature in the upper 100 km to be less than 800°C in the first 0.5 Ga [5]. It would be unlikely for viscosities to be substantially lower than 10^{21} Pa-s at such temperatures. However, if the impact heat is the primary contributor to immediate relaxation, it is difficult to explain why the Orientale uplift remains so high, 60 Ma after Serenitatis formed and relaxed.

References. [1] Solomon, S. C., R. P. Comer, and J. W. Head (1982), *JGR*, *87*, 3975. [2] Bratt, S. R., S. C. Solomon, J. W. Head, and C. H. Thurber (1985), *JGR*, *90*, 3049. [3] Drew, W. A. (1982), B. S. Thesis, MIT, unpublished. [4] Wilhelms, D. E. (1987), *The Geologic History of the Moon*, U. S. G. S. Prof. Paper 1348. [5] Cassen, P., R. T. Reynolds, F. Graziani, A. Summers, J. McNellis, and L. Blalock (1979), *Phys. Earth Planet. Inter.*, *19*, 183.

Figure 1.

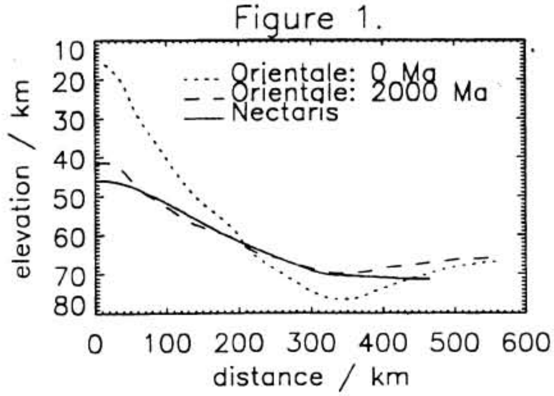

Figure 2.