THE EARLY MOON: IMPLICATIONS OF A LARGE IMPACT INTO A HOT TARGET.

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INTRODUCTION. After a decade of intensive study, many aspects of lunar highland and basin geology remain obscure. Among the unresolved problems are the abundant impact melts and thermally processed rocks found in the lunar terrae. Some workers [e.g., 1] have suggested that the evidence from terrestrial impact structures indicates that ejecta from large impacts are deposited at more or less ambient temperatures. This result, if applied directly to the Moon, would require an extensive multiple-impact history to explain the high degree of thermal processing seen in lunar rocks [2]. A closely related problem is the question of a lunar "cataclysm". On the basis of the large population of lunar rocks with an apparent radiometric age of 3.9 AE, [3] proposed that the Moon experienced a large increase in cratering rate at that time [3]. Alternatively, [4] held that this evidence merely reflects the "trail-off" of accretional processes.

Many workers [e.g., 5] have employed numerical models to simulate and study thermal effects associated with impact events. Yet, no modelling work to date has addressed the problem of initial lunar temperature during the epoch of basin formation. Several workers [6-8] have commented on the possible effects produced by an impact into a hot Moon, but only qualitatively. In this study, we report on results of calculations involving impact into hot target media. These results may provide some insight into the complex processes operating during the epoch of lunar-basin formation.

APPROACH. Our computer impact-cratering model is described in detail elsewhere [9]. A constant projectile type and size and a constant target type are assumed; the projectile used was a "chondrite" (basalt of density 3.58 g/cm$^3$) and the target consisted of Tahawus anorthosite [10]. Impact velocity was varied from 2.5 to 20 km/s, and target temperature from 273° to 1600° K. As we are interested in the thermal effects associated with this type of impact, melt volumes (pure liquid) normalized to projectile volume were examined in relation to impact velocity. From these results, plots were made of the increase in melt volume produced as a function of increasing impact velocity for different target temperatures (Fig. 1).

RESULTS. The data of Fig. 1 demonstrate that initial target temperature does effect the volume of melt produced. The magnitude of the hot target effect is variable and velocity dependent. At 5 km/s, relative melt volumes at 1400° K are almost 7 times the volume produced in a cold target; for a 20 km/s impact, this factor is about 2.5. Absolute melt volumes increase dramatically with increasing impact velocity (projectile mass and volume constant): at 1200° K, 31 projectile volumes are melted at 20 km/s whereas only 3.5 projectile volumes of melt are produced at 5 km/s. These values are consistent with those of previous work [5] on the effects of impact velocity on melt generation.

These results suggest that initial target temperature is an important, yet generally overlooked, variable in the cratering process. Previous attempts to model numerically impact melting during lunar-basin formation have assumed an initially cold target [11]. Is this a realistic assumption for the early Moon?

LUNAR THERMAL STRUCTURE AT THE TIME OF BASIN FORMATION. There is general agreement that the Moon was considerably hotter early in its history [12]. Evidence from photogeology [13], global geochemistry [14] and lunar petrology [15] indicate that extensive mare and KREEP volcanism may have been active on the Moon prior to 3.9 AE, the time of basin formation [12]. These observations are complemented by several thermal models [16-18] that indicate very high lunar internal temperatures at this time. The most conservative of these models suggests that at the time of basin formation, temperature of the lunar interior was in the range of 1000° to 1400° K at the 50-km depth [16] affected by basin impact. Even if these values are only approximately correct, they suggest that for a large impact event, melt volumes would be considerably larger (by a factor of 2 or more; Fig.1) than those calculated by assuming an initially cold lunar-basin target [11].

**GEOLOGIC IMPLICATIONS OF IMPACT INTO HOT TARGETS.** Large-body impact into a hot Moon may have several consequences for models of multi-ring basin-formation and early lunar geologic history. Large quantities of melt rocks of noritic-KREEP composition are found at highland landing sites (Apollo 15-17); their occurrence at Apollo 16, not located within a large basin, is particularly perplexing because the upper crust in this region is anorthositic, and these melts must be derived from a noritic target [19]. Previous studies [1,11] suggested that basin events do not produce enough impact melt to account for the amounts of melt seen in the highlands. This discrepancy has been cited as evidence for derivation of mafic melt rocks at Apollo 16 from north of the site by a secondary cratering debris surge uprange to Imbrium [1]. However, in addition to the effects of high lunar internal temperature in generating a larger volume of melt (Fig. 1) in a basin-forming impact, more of this melt may actually be ejected during excavation [5]. Thus, an alternative possibility now arises: noritic-KREEP impact melts in the lunar highlands may be basin related, rather than derived from small, local cratering.

Our results raise further questions about an increase in the lunar cratering rate at 3.9 AE. Because of high lunar internal temperatures, a relatively small amount of shock energy would be required to re-set a rock age; moreover, the lunar radiometric clock may have not even started until excavation by a large basin event [8]. Thus, the "cataclysm" may simply reflect thermal conditions within the Moon at 3.9 AE, not an increase in the cratering rate.

Finally, the increased plasticity of the Moon at 3.9 AE would have had important effects on the modification style of basin morphology [20-22]. Therefore, the use of Orientale as an archetypal lunar multi-ring basin may be unwarranted [21,22]; much of the "degraded" morphology of the older basins (e.g., Crisium, Nectaris) may actually be little modified from the pristine form of those basins.

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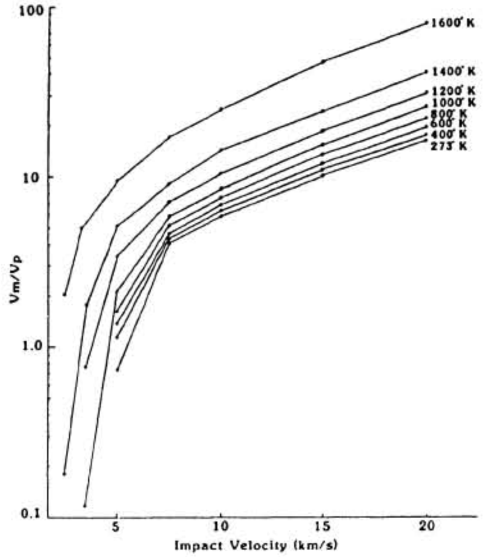

Figure 1. Semi-log plots of volumes of impact melt (Vm) relative to projectile volume (Vp) as a function of impact velocity at different initial target temperatures.