IMPACT MELTING DURING THE FIRST 1.5 B.Y. OF LUNAR HISTORY; M. A. Lange[+] and T. J. Ahrens, Seismological Laboratory, California Institute of Technology, Pasadena, CA 91125; [+]Permanent address: Inst. F. Geophysik, Neue Universitaet, 2300 Kiel, W. Germany.

One large group of rocks in the lunar sample collection are the impact breccias, which demonstrate the importance of impact processes on modifying the lunar surface, and account for most of the rock types from the non-mare surfaces of the moon. Because of gravitational effects, it appears that the larger craters retain impact melted materials more readily than smaller craters. This conclusion is based on observations at terrestrial craters (1) theoretical and experimental studies; (2) and has been recognized recently by observations of lunar craters over a wide range of diameter by (3) and (4). Since crater distributions are such that small craters are always much more numerous than large craters, it is not obvious, whether the integrated effect of the small scale cratering or the single, large events dominate the modification with time of the lunar surface layer, i.e. it's chemistry, petrography, and stratigraphy e.g. (8, 10, 11). This question is addressed in terms of the amount of impact melt produced by the heavy meteoroid bombardment during the first 1.5 b.y. of lunar history. Therefore, theoretically and experimentally derived relations between impact energy and crater diameter and impact energy and the resulting impact melt were used to compute the total amount of impact melt formed on the lunar surface as a function of time. The number of craters as a function of the diameter and the time dependence of their formation was considered for two different size classes, i.e. $0.1 \leq D \leq 50$ km and $D \geq 161$ Km, on the basis of cratering studies by (7) and (9).

METHODS: The dependence of the amount of impact melt V_m [cm^3] on the kinetic energy of the impacting body KE [ergs] is given by (2):

$$V_m = 3.0 \times 10^{-12} \text{ KE} \qquad [1]$$

The numerical constant in eq. [1] includes the surface density and the bulk sound speed of the moon. Oberbeck et al. (5) used on the basis of explosion cratering data the relation:

$$D \text{ (Km)} = k \text{ KE}^{1/3.4}; \; D = \text{rim diameter} \qquad [2]$$

with $k = 2 \times 10^{-7}$ for the moon and 1.6×10^{-7} for terrestrial craters. Eq. [1] and [2] together yield:

$$V_m(\text{Km}^3) = k' \, D^{3.4}; \; k' = 2. \, 10^{-4} \qquad [3]$$

When using the above value of k' and applying Eq. [3] to terrestrial craters, the theoretical values for V_m are in good agreement with the estimated amounts of impact melt by [1] and [6] for certain Candian craters, as shown in Fig. 1. The cumulative crater-size frequency distribution as given by (7) was extended to crater diameters in the range of $0.1 \leq D \leq 50.$Km and was approximated by a linear expression:

$$\log (N) = -2.5 - 2.6 \log (D) \qquad [4]$$

where N gives the number of craters per Km^2 with diameter $\geq D$. Eq.'s [3,4] were used to compute the amount of impact melt per Km^2 of the lunar surface for diameter-intervals of 0.1 Km with D = 0.1 Km as initial value. Integration over all crater sizes yields the total amount of impact melt $V_{m,t}$ which, after multiplied by the lunar surface area, gives the total amount of melt for the whole moon. The time dependence of the meteorite flux, and hence the

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production frequency N(D,t) is given by (7) as an exponential function with a half life time of 1.4 X 10^8 yr and yields, together with eq. [3] the amount of impact melt for the first crater class on the moon's surface for the first 1.5 b.y. of its history.

As a minimum approach for the second crater class we used the diameter values and ages of 81 large craters ($D \geq 161$ Km) as given by (9), and computed the resulting amount of impact melt as a function of time according to eq. [3]. In order to compare both classes, the total impact melt volume can be expressed as the time dependent thickness of a surface melt layer Z_m.

RESULTS: The total amount and distribution of impact melt $V_{m,t}$ for $0.1 \leq D \leq 50.$Km as a function of the crater diameter and time, $V_{m,t}$, is insensitive to the choice of either the size frequency distribution of (7) or the linear approximation of eq. [4]. The contribution of certain diameters to $V_{m,t}$ is in this size class nearly independent of the crater dimension, mainly as a result of the crater size frequency distribution. Fig. 2 shows the melt layer thicknesses Z_m for both crater classes as a function of time. There is in both cases a strong increase in the amount of impact melt with time. The bending in the upper curve is mainly due to the high contribution of the Imbrium event which shows up in many highland samples and is one of the major stratigraphic features on the moon.

Impact melting (in both cases) becomes significant only for the first 0.5 b.y. of lunar history. However, this is a crucial point, since the radiometric ages of recrystallized and molten highland rocks seem to indicate that during a timespan between 3.9 and 4.1 b.y. the impact activity on the moon reached a maximum. On the other hand, there are rocks with ages >4.1 b.y. and the rapid decrease of the cratering rate has enabled an increasing number of rocks to survive the further bombardment. As was pointed out by (8), due to different temperature behaviors of certain trace elements, as affected by smaller impacts, the rock age may indicate a much younger basin age than its real excavation time. Therefore, the rock ages seem to be in accordance with the time history as proposed by (7) and (9) and as reflected in the time depence of Z_m in Fig. 2.

Regarding the petrography of highland rocks, our results imply that impact melting must have played a major role in their evolution. The melt layer reaches a maximum thickness of ≈100m for the first 10^8 y of lunar history and the total amount of impact melt for all 81 large craters is 5.3 X 10^6 Km^3 (0.02% of the lunar volume), thus accounting for the observed abundance of melt rocks on the lunar surface. However, this amount appears to be insufficient to support a large scale differentiation of the highlands as a whole, as proposed by (11).

Our results indicate that large, single events should dominate the petrography of impact breccias as proposed by (11) and that smaller impacts contribute more to the development of the regolith layer on the lunar surface.

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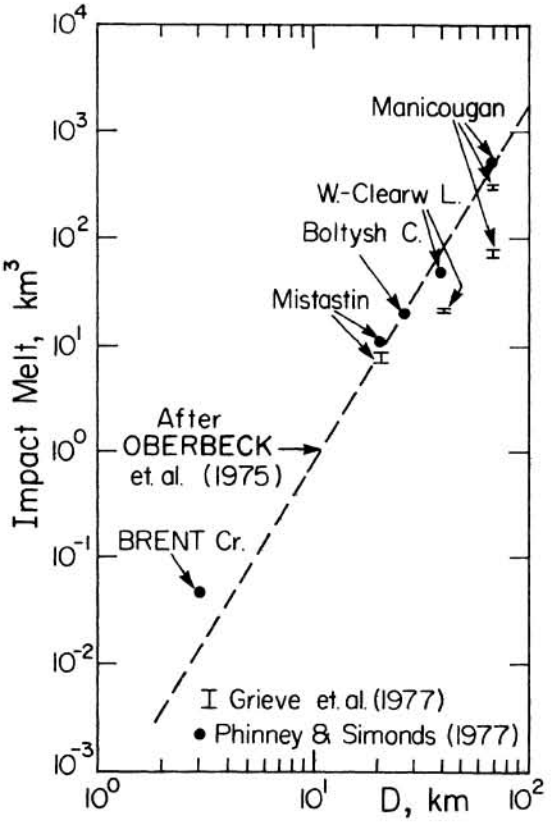

Fig. 1 Impact melt volume for different Canadian craters as given by (1) and (6) compared with theoretical values according to eq. [4].

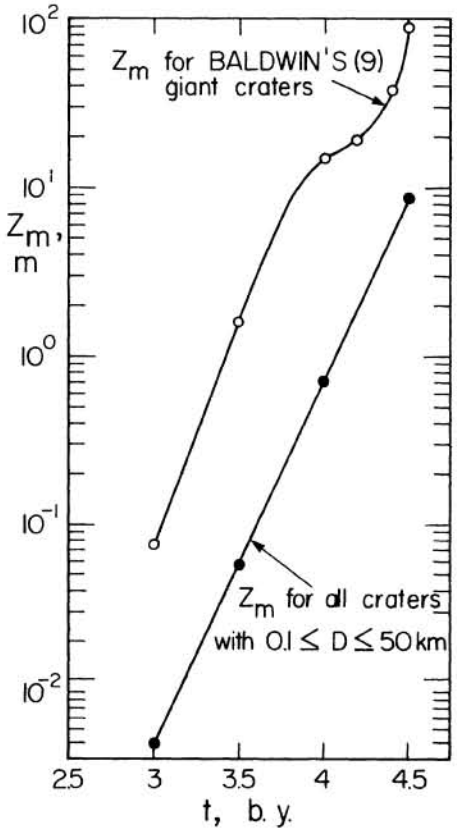

Fig. 2 Impact melt layer thickness for both crater classes as a function of time.

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