A RE-EVALUATION OF IMPACT MELT/VAPOR PRODUCTION; E. Pierazzo, A. M. Vickery, H. J. Melosh, Lunar and Planetary Lab, The University of Arizona, Tucson, AZ 85721

Impact cratering is a very important process for the evolution of planetary surfaces. Although the concept of impact cratering and its effects in planetary sciences is relatively new, it has been subjected to intensive study from many different points of view, ranging from planetary observations to laboratory-scale experiments, to computational studies and modeling of the physics of cratering [1]. One of the most complex problems is the production of melt and/or vapor during the impact event. The approach to the problem can be of two types: 1) analytical energy balance models, and 2) numerical solutions of the fundamental balance equations. Experimental approaches, while highly desirable, are still limited by the maximum impact velocities obtained in laboratory that do not reach the magnitude of real impact events. In this work numerical simulations are used to determine the amount of melt and vapor for impact events of different size and magnitude. The results of the simulations are compared to previous work [2, 3, 4, 5].

The simulations were done using the 2-D finite difference hydrocode CSQ III [6] developed at Sandia National Laboratory. Dunite, considered to be a reasonable analog for the mantle's equation of state, has been used as target material, and iron and dunite have been used for the spherical impactors of different sizes (from 0.2 to 6 km in diameter) and different velocities (10 to 100 km/sec). To compute the material's equations of state we used the ANEOS equations of state package for dunite [7], while the library ANEOS equation of state [8] has been used for iron. We used data from the JANAF Thermochemical Tables [9] for the dunite entropy of melting , and from Ahrens and O'Keefe [10] for its entropy of vaporization. The shock pressure required for complete melting and vaporization is given by the intersection of the Hugoniot with the melting/vaporization isentropes. Shock pressures corresponding to melting and vaporization are about 150 GPa and 2000 GPa respectively, for dunite.

Unlike previous work, which attempted to estimate the melt/vapor volume from material flowing through an eulerian grid, we used tracer particles, i.e. massless particles which record the conditions of material at the local tracer position, without affecting the calculations of CSQ. Rows of tracers, equally spaced, were located at constant angular intervals (15°), covering the target region close to the impact. The spacing of the tracers varies according to the size of the impact event. To determine the size of the melt/vapor region the maximum shock pressure was determined for each tracer, and the distance at which $P_{sh}=P_{melt}/P_{vap}$ was then calculated at each row. The volume of each 15° melt/vapor region was finally calculated, assuming axial symmetry.

The fundamental concept behind analytical energy balance models is that the shock pressure generated by a high-speed impact has two distinct dependencies on distance from the impact site. Near the impact site the rate of pressure decay with distance is small; this region has been called 'isobaric core' [11] or 'impedance match regime' [12]. Beyond this region is the 'pressure decay regime', a region in which pressure decay with distance from the impact is much larger The particle velocity also follows this same general trend. The general expression governing the pressure decay in this region is:

$$P(d) = P_0(d/R_0)^{-\gamma}$$

Values for γ can be measured by experiment [13] or determined by code calculation [2]. The analytical models make use of this constant for the calculation of melt and vapor production. However γ is not really a constant; its value changes with impactor velocity [12]. Fig. 1 shows the exponent γ as a function of the impact velocity keeping the impactor size constant; there is an evident increase of γ over the range of velocities spanned by the simulation (10 to 100 km/sec at an interval of 10 km/sec). This confirms the initial results of Ahrens and O'Keefe, and indicates the difficulty of choosing the right value for γ in the analytical models for melt/vapor production.

Fig. 2 is a summary of melt/vapor normalized to the volume of the impactor as function of the similarity variable: $S=(\rho_p/\rho_t)(v_i/C_p)^2$ [14], where ρ_p and ρ_t are the densities of the projectile and target respectively, v_i is the impact velocity, and C_p is the bulk sound speed (6.5 Km/sec for dunite). For comparison, the results of O'Keefe and Ahrens [2], Orphal et al. [3], and Grieve and Cintala [5] are reported as well. While the melt production results seem to agree with [2] and [5] for higher values of the similarity parameter (higher velocities), for lower values of the similarity parameter our results are in better agreement with [3]. The vapor production results are however consistently lower than [2] and [5]. This is probably due to the difference in the pressure for vaporization for the target material used in this work with respect to previous ones. While the results in [5] come from an analytical model, results in [2] come from hydrocode simulations; both groups use the same target material, anorthosite, and the Tillotson equation of state (P_{vap}=590 GPa). The same target material and equation of state is used in [3]

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for the hydrocode simulation. Our work instead relies on a completely different equation of state and uses a different target material. The difference in the pressure for melting (52 GPa for anorthosite versus 150 GPa for dunite) is instead less critical for the final results at high velocities, but clearly affects the lower speed simulations, where lower shock pressures are obtained.

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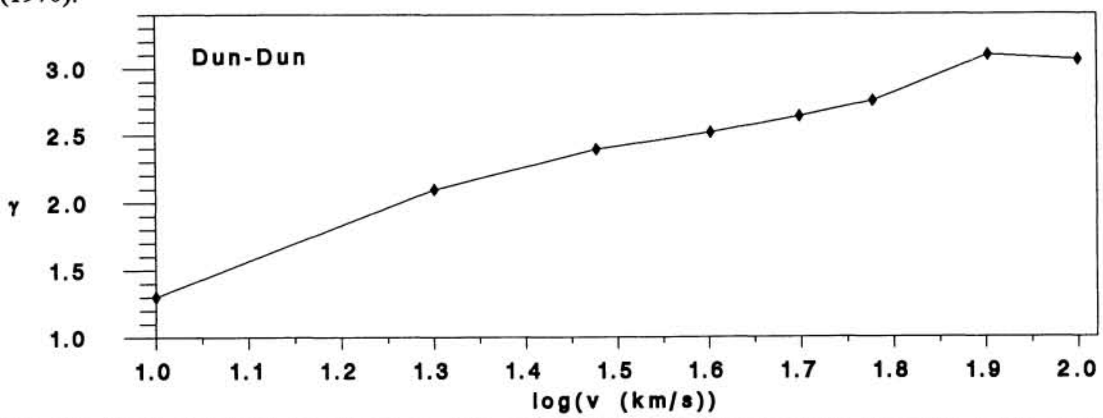

Fig. 1: Pressure decay exponent, γ, versus $\log_{10}$(impact velocity, km/sec) for a 4 km diameter dunite projectile impacting a dunite target of various velocities (ρ_{dun}=3320 kg/m^3).

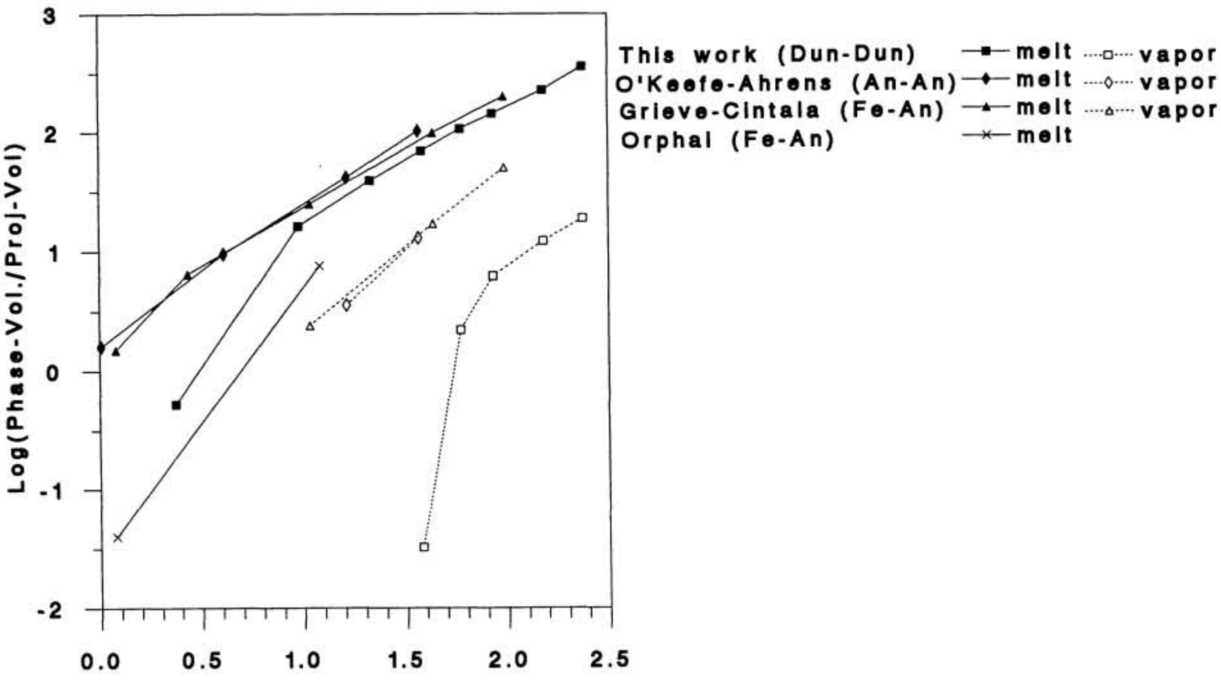

Fig. 2: Volume of melt (solid symbols, solid line) and vapor (open symbols, dotted line) normalized to the projectile volume, as a function of similarity parameter, s.