MELT PRODUCTION IN OBLIQUE IMPACTS. E. Pierazzo and H. J. Melosh, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 87521 (betty@lpl.arizona.edu; jmelosh@lpl.arizona.edu)

***Summary*:** One of the goals of melt production studies is to find proper scaling laws to infer melt production for any impact event of interest. Previous work, however, only dealt with vertical impacts [1,2,3,4,5]. Here we report the first study of melt production in oblique impacts. We find that in the pressure-decay region the pressure-decay exponent is linearly proportional to the impact angle. Furthermore, as the impact angle decreases, the peak shock pressure (and temperature) inside the isobaric core decreases, indicating a weakening of the shock wave. Both the isobaric core and melt regions appear highly asymmetric in oblique impacts; consequently the hypothesis of hemispheric or spherical regions used in analytical models is not supported by our numerical studies.

***Introduction*:** The production of melt and vapor is an important process in impact cratering events. Because of the limited velocity in laboratory experiments, however, a detailed study of this topic has been mainly theoretical. Both analytical [6,7] and numerical [1,2,3,4,5] approaches have been used with some success for the case of vertical (axisymmetric) impacts. It is well established that melting and vaporization in impact events are governed by the thermodynamics of shock compression and release. Numerical simulations have shown that the maximum shock pressure generated by a high-speed impact is characterized by two regions. In the first region, the isobaric core, which is close to the impact point, the rate of pressure decay with distance is small. Analytical models typically assume the pressure to be constant within the isobaric core. Beyond this region the pressure as well as particle velocity decay rapidly with distance d from the impact, according to the power law: $P(d) = A (d)^{-n}$ (A is a constant). The isobaric core is usually modeled as spherical in shape, located right below the impact point. The same is true for the melt and vaporization regions, whose size, however, is proportional to the impact velocity.

The major limitation of all the previous work has been the exclusion of oblique impacts from the study. Oblique impact events are still not well understood. While the rim of the final crater is circular for all but the most oblique impacts [8], the angle of impact has a profound influence on the compression and expansion stage of an impact event [9], therefore affecting also the regions of melting and vaporization which form close to the projectile impact site.

***Model*:** A series of 3D simulations [9, 11] were carried out using the shock-physics computational hydrocode CTH [11] coupled to the SESAME equation of state package [12], developed at the Sandia National Laboratories. A spherical 10-km diameter projectile impacts the target at 15°, 30°, 45°, 60°, and 90° (vertical) from the surface, with an impact velocity of 20 km/s. The simulations were designed to model the Chicxulub impact event, therefore the target composition reflects the structure at the Chicxulub location (see [9, 10] for more details). The angle of impact θ is the only variable parameter in the simulations. One thousand tracer particles were regularly distributed in both target and projectile; the tracers move through the mesh, recording the thermodynamic history of given material points in time. As described in [9, 10] the maximum shock pressure experienced by each tracer was used to reconstruct and evaluate the amount of target material that underwent melting and vaporization.

***Results*:** The pressure decay recorded by the tracers along various directions away from the impact point indicates that while the shock wave still appears hemispherical in shape, the strength of the shock wave propagating in the target is not symmetric around the impact point (i.e., the maximum shock strength directly downward), but is stronger in the downrange region of the target. As a result, both the isobaric core and the melting regions deviate from the spherical shape typical of vertical impact simulations, and become more asymmetric as the impact angle increases.

Previous work [5,14] showed that the exponent *n* of the pressure-decay power law is proportional to impact velocity. This exponent is crucial for analytical models, which use the pressure-decay power law to estimate melt and vapor production. We looked at the influence of impact angle on the pressure-decay exponent. Values of the pressure-decay exponent are evaluated at angles between 75° and 45° from the vertical (least disturbed by surface effects), and are averaged over longitude (0° to 180° from the downrange direction; the code used bilateral symmetry). A weighted least square fit of the average n as function of the impact angle, $n=a+bq$ (θ in degrees), gives a=0.13±0.05, and b=0.0241±0.0005, with a correlation coefficient of 0.986. A comparable fit using sinθ rather than θ resulted in a comparable correlation coefficient: The scatter in the present results is too large for distinguish either a sinθ or a direct θ dependence on shock pressure decay rate.

Another effect of decreasing impact angle is the weakening of the shock wave. We determined the mean peak shock pressure inside the isobaric core for the various simulations. As shown in Figure 1, the weakening of the peak shock pressure appears to be directly proportional to sinθ. This behavior is similar to what happens inside the projectile [15]. This result has repercussions in the melting and vaporization of target material [9, 10]: as the impact angle decreases the region of melting becomes shallower, resulting in a smaller volume of target melted in oblique impacts. Figure 2 shows the volume of target material melted or vaporized (i.e., shocked at pressures higher than 46 GPa) normalized to the projectile volume, as function of angle of impact. A dependence on $\sin^2\theta$ (solid line) would appear if the hypothesis that only the vertical component of the impact velocity contributes to the shock were correct. We saw no evidence for such dependence. The volume of melt and vapor produced in the target does not seem to have a simple dependence on impact angle or its sine.

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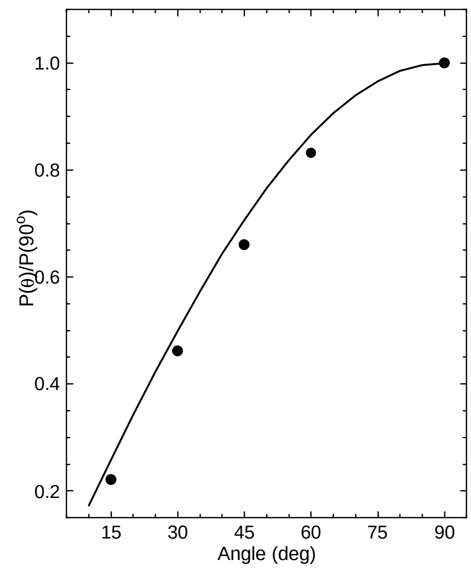

Figure 1**:** Peak Shock Pressure inside the isobaric core versus impact angle. (Solid line = sinθ)

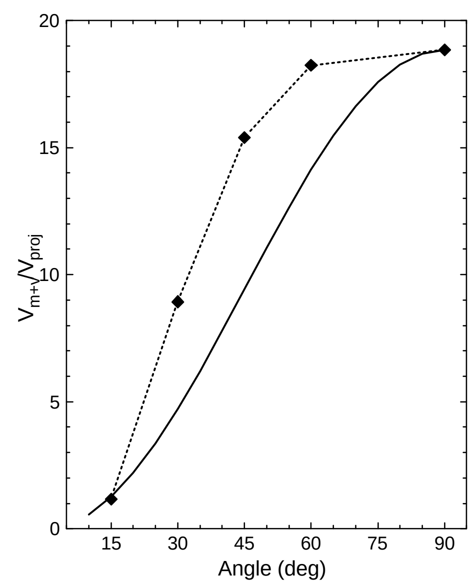

Figure 2**:** Target material melted of vaporized versus impact angle. (Solid line = $\sin^2\theta$)