EFFECT OF PLANETARY GRAVITY AND IMPACT SIZE ON CRATER MAXIMUM PENETRATION AND EXCAVATION DEPTH; John D. O'Keefe and Thomas J. Ahrens, Seismological Laboratory, Caltech, 252-21, Pasadena, CA (91125).

Tectonic, volcanic and impact processes all bring samples of rock from the interior to the planetary surface. Tectonic and volcanic processes are multistaged. In contrast, penetration and excavation during cratering occur continuously over a relatively short period of time. These processes can be modeled in detail using finite difference simulation of impact-induced compressible flow. In this paper we address, using this technique, the issues of: 1) What is the maximum depth that the impactor penetrates the planetary surface?, and 2) What is the maximum depth that is excavated by the cratering flow? We address these issues over a broad range of gravities, material strengths, and impactor sizes (from centimeters to those that formed the multiringed basins). We examine the deformational histories of planetary material both beneath the crater and in the region forming the ejecta plumes. These results, when taken with observed deformations of exposed and deeply eroded terrestrial, and perhaps in the future, craters on other planets, will constrain the impact history of a given structure.

The computer model we have used is a two-dimensional mixed Langrangian-Eulerian numerical code. This was used to calculate the flow fields due to a fixed (10 m diameter) spherical $2.6 g/cm^3$ silicate impactor having a velocity of 12 km/s. The planetary gravities were taken to be 1, 10^2, 10^4, and 10^6g. The planetary strength was varied from normal values to zero for hydrodynamic flows. A series of massless tracer particles were used to delineate the deformations beneath the crater and the trajectories of particles in the ejecta plume.

In the hydrodynamic or gravity controlled regime, the crater depth of penetration and excavation scale as gD/U^2, where g is the planetary gravity, D is the projectile diameter and U is the impactor velocity (e.g. [1]). For terrestrial impacts at 12 km/s, the equivalent impactor diameters are 10^{-2}, 1, 10^2, and 10^4 km. In the regime of small planetary strengths (gravity dominated), the maximum relative depth of penetration is independent of impactor diameter up to diameters in the range of 10^2km. Shown in figure 1 is the flow field near the time of maximum penetration for a 10^2km diameter impactor traveling at 12 km/s. This flow field is nearly identical to those having smaller diameters. Note that in the small strength or hydrodynamic regime, the angle of ejection is nearly 90 °; this contrasts with the nominal strength cases where the ejection angle is close to 45 °. These results confirm the analytical predictions of Melosh [2] for ejection angles. At very large gravities or sizes, the relative depth of penetration decreases. Shown in figure 3 is the result for a 10^4km impactor. Here the flow is dominated by gravity, the depth of penetration is reduced, and central peak, multiringed structures form early in the flow evolution. For the above conditions, the depth of penetration was 2.1 impactor diameters for impactor diameters $\lesssim 10^2$km and was reduced to 0.75 for 10^4km impactors (see fig. 4).

The region or depth of excavation can be determined by examining the tracer particles (see fig. 1). For angles greater than around 10° relative to centerline and point of impact, the cratering flow is nearly radial and outward into the planet. In the region less than 10°, the flow is upward and it is from this region that material is excavated to produce the ejecta plume and blanket (e.g. experiments of Gault et al. [3]). Note that this region is less than a projectile diameter in depth. The deformations of the planetary material under the point of impact is complex and depends upon scale and strength of the planet. For low planetary strengths and large impactors, the region below the point of impact flows upward during the cratering flow evolution and is part of a toroidal flow field that also reverses the direction of the velocity field near the surface. This reversal of the surface velocity fields arrests the radial growth of the ejecta plume (see fig. 3).

References
[1] Holsapple, K. A. and R. M. Schmidt (1982) in *J. Geophys. Res., 87,* 1849, 1870. Schmidt, R. M. and Holsapple, K. A. (1982), in *Geol. Soc. Am., Sp. Paper #190,* 93-102. [2] H. J. Melosh, (1984) in *Icarus, 59,* 234-260. [3] Gault, D. E., W. L. Quaide, V. F. Overbeck (1968), in *Shock Metamorphism of Natural Materials,* Mono Book, 87-99.

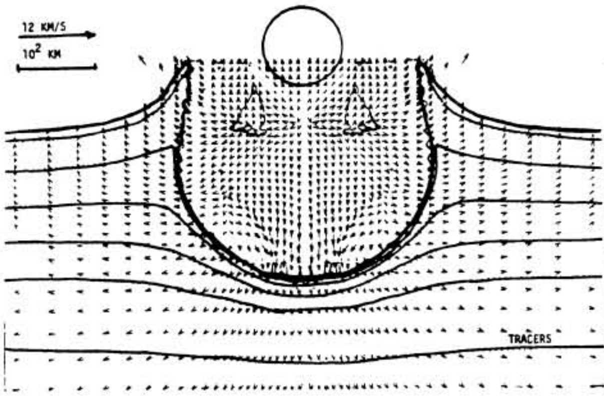

Fig. 1. Calculated cratering flow field 74 seconds after impact of a 10^2 km diameter 12 km/s silicate projectile on a planet with a gravitational acceleration of 1 g. The circle indicates the original impactor diameter and tracers the internal deformations of the planet.

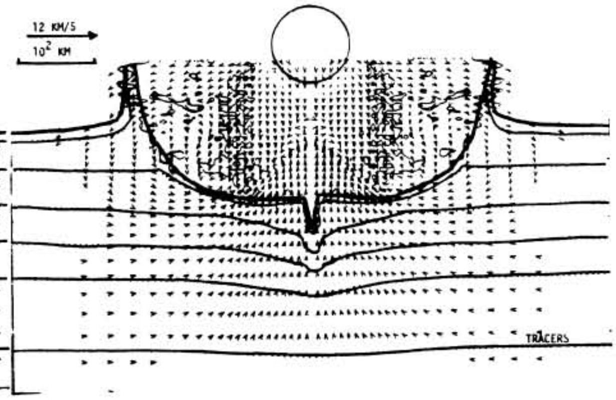

Fig. 2. Calculated cratering flow field at 2.1×10^2 seconds after impact for the same conditions as in Figure 1.

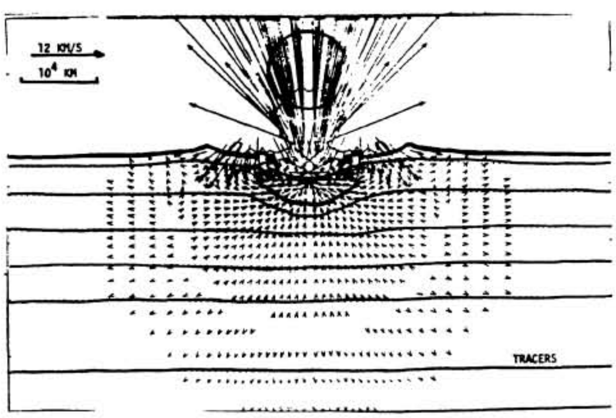

Fig. 3. Calculated cratering flow field at 2×10^3 seconds after impact of a 10^4 km diameter 12 km/s silicate projectile on a planet with a gravitational acceleration of 1 g. The circle indicates the original impactor diameter.

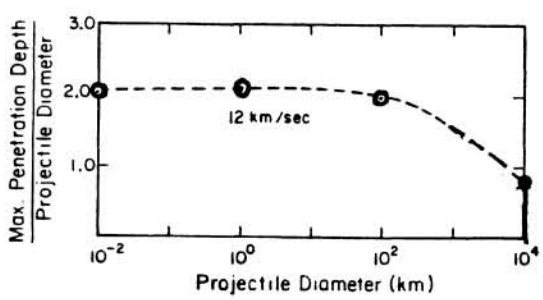

Fig. 4. Normalized maximum penetration depth versus projectile diameter for impact of silicate projectile on a silicate planet at 12 km/s and 1 g.