TSUNAMIS FROM GIANT IMPACTS ON SOLID PLANETS; John D. O'Keefe and Thomas J. Ahrens, Lindhurst Laboratory of Experimental Geophysics, Seismological Laboratory 252-21, California Institute of Technology, Pasadena CA 91125

Baldwin (1) and Van Dorn (2), (3), suggested that the rings around lunar craters formed as the result of the arresting of giant fluid surface waves driven by impact events. They based their arguments on an analogy to droplet impacts in water and the train of concentric ring shaped waves that are produced. While these papers were provocative, they did not provide a quantitative description of the threshold for wave production nor the description of the arresting mechanism(s). We have modelled large scale impacts and found that tsunami-like waves are produced as a result of the collapse and propagation of the transient crater lip. In addition, we determined the physics underlying the onset for such wave propagation and the mechanisms for their arrestment. We have modelled the impact of silicate projectiles on a silicate planetary surface under a wide range of conditions using numerical techniques (4). In our calculations, we varied the dimensionless impact parameter, ga/U^2 of Holsapple and Schmidt (5) from 0 to 0.034. For a U (impact velocity) = 12 km/sec, g (gravity) = 980 cm/sec^2, we varied, a, the projectile radius from 5 to 5000 m. The evolution of the crater diameter (d) and depth (D) normalized by projectile radius (a) was calculated as a function of normalized time, Ut/a. There are three major regimes of cratering flow induced by impact: (1) penetration, (2) inertial, and (3) gravitational collapse. The penetration regime for d extends from the initial impact time to penetration of the projectile radius beneath the planetary surface. At this point, Ut/a = 1 and the projectile does no longer do work in radially displacing the target . Next, the inertial regime begins. The cratering flow is driven primarily by the energy and momentum that was transferred to the target. The diameter grows as $d/a = 2.2\,(Ut/a)^{0.37}$. The inertial regime for crater depth, D, begins later, at Ut/a = 5.1, and is described by $D/a = 1.2\,(Ut/a)^{0.37}$. Because the projectile must do additional work in displacing the target downward, the inertial regime for D starts at a later time. The occurrence of the gravitational collapse regime depends upon the ratio of strength to gravitational forces. For weak planets and/or large scale impacts, the transition time from the inertial flow to the gravitational collapse regime occurs at $Ut/a = 1.8\,(ga/U^2)^{-0.61}$. Shown in Figure 2a is the flow field of a large scale impact near the maximum time of penetration. The crater lip has just grown to its maximum height. The collapse of the lip results in an outwardly propagating surface wave (Figure 2b) which rapidly increases the diameter of the crater. The velocity of the lip wave is, $c = 25\,(ga)^{0.5}\,(ga/U^2)^{-0.11}$. Simultaneously, the crater floor moves upward and an inner crater lip forms. Note that neither the outer ring nor the inner ring correspond to the diameter of the transient crater.

The above results for diameter (d) scaling have been combined with those for depth (D) scaling for crater geometries at various times. For $1 < (Ut/a) < 5$, D increases faster than d because D is still in the penetration regime while d is evolving inertially. The diameter-depth ratio scales as $(d/D) = 4.4\,(Ut/a)^{-0.63}$. For times when both D and d are evolving inertially $(5.1 < (Ut/a) < 0.92\,(ga/U^2)^{-0.61})$ prior to gravitational collapse or arrest, the crater geometry is nearly constant with, $d/D \cong 1.6$. The launching of the tsunami-like wave form from the collapse of the crater lip occurs at almost twice the time interval required for the crater to rebound.

REFERENCES: 1. Baldwin R. B. (1949) *The Face of the Moon* Univ. Chicago Press, Chicago, IL 2. Van Dorn W. G. (1968) *Nature* , 220, 1102-1107. 3. Van Dorn W. G. (1969) *Science* , 165, 693-695. 4. O'Keefe J. D. and Ahrens T. J. (1990) in *Lunar and Planetary Science XXI* Lunar and Planetary Institute, Houston. 5. Holsapple K. A. and Schmidt R. M. (1987) *J. Geophys. Res.* , 92, 6350-6376.

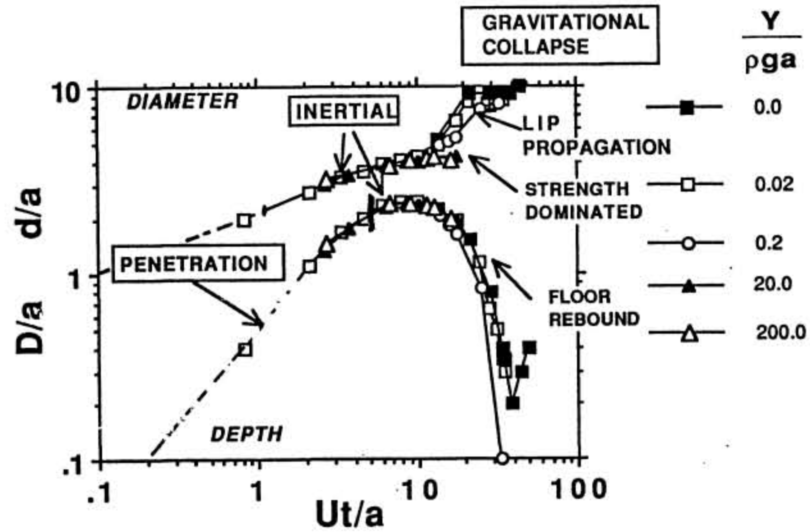

Figure 1. Normalized crater diameter (d/a), upper, and normalized crater depth (D/a), lower, versus normalized time for impact parameter, $ga/U^2 = 0.034$. Symbols indicated on right are for normalized strength. Different regimes are labeled, whereas floor rebounds for all strengths, (Y), lip wave propagation is only observed for weak planetary crusts $Y/\rho ga < 0.2$.

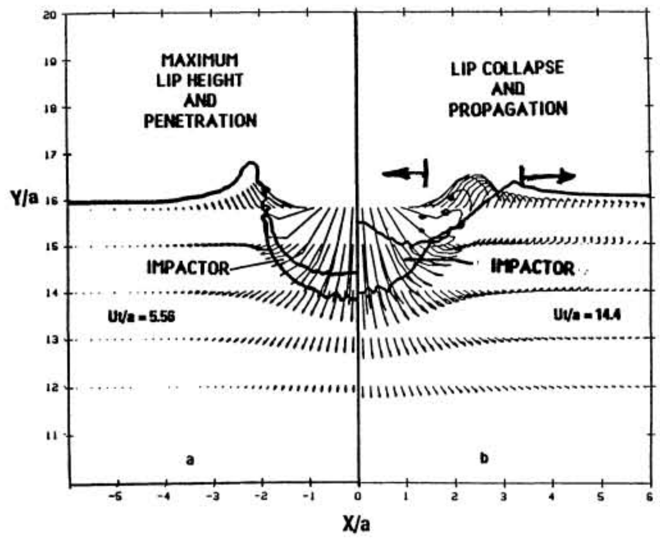

Figure 2. Crater profile, units are projectile radii (a) left, light lines indicate particle paths. Heavy lines outline maximum impactor penetration and transient crater lip height, Ut/a = 5.56, (b) right, Ut/a = 14.4, uplift of crater and movement of deeper part of crater toward center-line. Tsunami-like lip collapse and outward growth of crater via lip wave occurs.

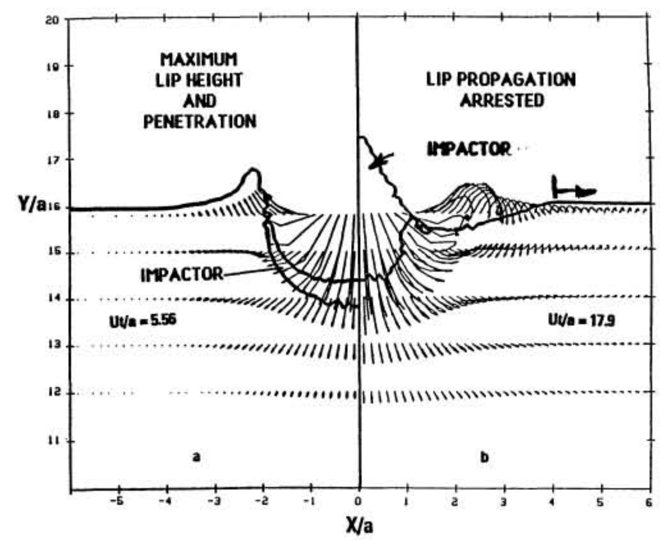

Figure 3. (a) left, same as in Fig. 2. (b) right, Ut/a = 14.4, deformed impactor thrown upward into central peak, growth of crater diameter via tsunami-lip wave is arrested.