DYNAMICS OF LARGE SCALE IMPACTS ON VENUS AND EARTH; John D. O'Keefe and Thomas J. Ahrens, Lindhurst Laboratory of Experimental Geophysics, Seismological Laboratory 252-21, California Institute of Technology, Pasadena, CA 91125.

Large scale impacts are a key aspect of the accretion and growth of the planets, the evolution of their atmospheres, and the viability of their life forms [1-4]. We have performed an extensive series of numerical calculations that examined the mechanics of impacts over a broad range of conditions [5] and are now extending these to account for the effects of the planetary atmosphere. We have examined the effects of large scale impacts in which the trapping and compression of an atmosphere during impact is a significant factor in the transfer of energy to the atmosphere. Shown in Figure 1 are the various energy transfer regimes and where conventional drag and trapping and subsequent compression of atmosphere between the bolide and planetary surface are significant.

Numerical simulation of the impacts on planets with substantial atmospheres is difficult because of the large differences in the densities of the impactor, planet, and the atmosphere. Since our primary purpose was to examine the interaction of the shocked atmosphere and the cratering dynamics, we analytically calculated the flow field due to the passage of the impactor through the atmosphere and the initial interaction with the planetary surface and used these results as initial conditions in the impact calculations [6]. We calculated the state conditions behind the shock wave in front of the impactor. Given these conditions, we calculated the conditions after reflection from the surface and the subsequent adiabatic compression of the entrapped atmosphere to impactor-planet Hugoniot pressure and particle velocity. These conditions represent the work done by the impactor on the encompassed atmosphere. The relative amount of energy associated with this work is shown in Figure 1 for various regimes. We placed the encompassed atmosphere and energy associated with the work done by the impactor into a ring cell just outside the impactor and used an Eulerian numerical algorithm to calculate the resulting flow fields [7]. Specifically, we calculated the impact of a 5 km radius projectile traveling at 20 km/s on models of the Earth and Venus. Since the gravitational accelerations are similar (980 vs. 887 cm/s^2), the primary differences in the initial conditions are due to the atmospheric conditions (see Figure 2).

Samples of the calculations are shown in Figure 2. The resulting flow fields are very complex and differ for the two planets. In both cases, the entrapped atmosphere drives a strong shock wave away from the impact site. In the case of Venus, the shock wave remains lower in the atmosphere as opposed to the Earth, where the larger atmospheric density gradient refracts and accelerates the shock as it propagates to higher altitudes [8]. The refraction of the shock wave upward results in the acceleration of material upward and the blowing off of the atmosphere in the case of the Earth. The atmospheric shock pressure drives a ground shock wave. This ground shock wave initially follows the atmospheric shock wave at the surface and then at later times when the atmospheric shock decays, the ground shock wave outruns it. In addition, the projectile driven shock wave also initially lags the atmospheric shock wave and finally it also outruns the atmospheric shock wave (see Figure 2). The downward propagating wake also produces a complex series of interactions. The wake impacts the surface and stagnates, and drives a shock up and around the penetrating projectile. This shock refracts around the back of the incoming projectile and intersects other downward propagating wake gases. This produces a high pressure and temperature region behind the projectile which is seen in laboratory scale experiments [9]. The crater ejecta is propelled out of the crater after the atmospheric shock has propagated away from the crater and interacts with a low density, high temperature environment. In the case of the Earth, the atmospheric flow is in the same general direction as the ejecta. On Venus where, because of the confinement of the shock wave, the ejecta plume runs into the atmosphere and produces vortices in front of the ejecta, as seen in initial laboratory experiments of Shultz et al. [9]. The angle that the ejecta is launched changes with atmospheric pressure. In the case of Earth, the ejection angle is ~60° from the horizontal and varies little with and without an atmosphere; in the case of Venus, the angle increases to ~75°. The extent of the ejecta blanket in the case of Venus, is both restricted by the increased angle of ejection, but also by the lower atmospheric scale height.

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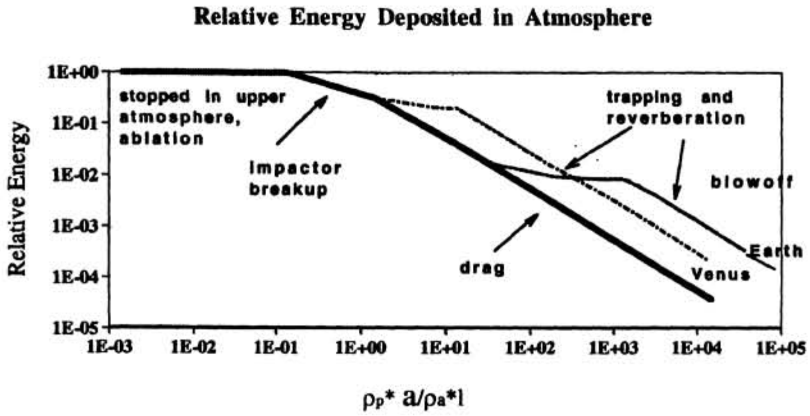

Figure 1. Regimes of relative energy deposited in atmosphere. Relative energy is given as a function of density of impactor (ρ_p) times the radius of impactor (a) divided by the product of density of atmosphere at surface (ρ_a) times scale height (ℓ). Energy is normalized to impactor kinetic energy.

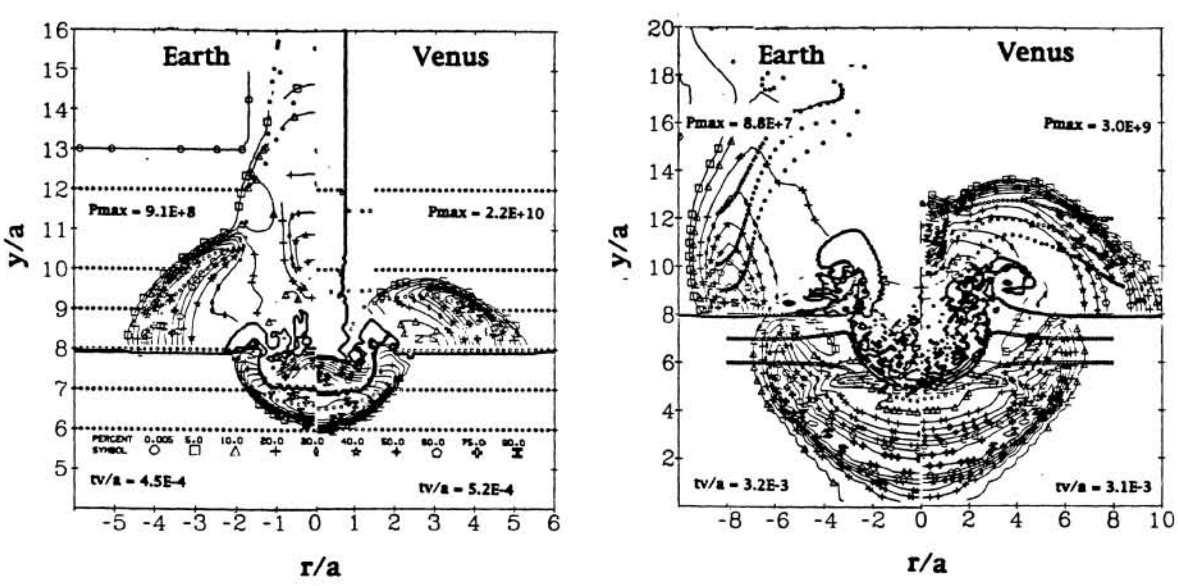

Figure 2. Impact-induced pressure fields in Earth and Venus and their atmospheres. The radius of the impactor (a) is 5 km and the velocity (v) is 20 km/s. Shown are the pressure contours for the percentages listed in Figure 2a at various dimensionless times (tv/a). The maximum atmospheric pressures are indicated for each case (dynes/cm^2).