PLANETARY STRENGTH, CENTRAL PEAK OSCILLATION, AND FORMATION OF COMPLEX CRaters; John D. O'Keefe and Thomas J. Ahrens, Lindhurst Laboratory of Experimental Geophysics, Seismological Laboratory 252-21, California Institute of Technology, Pasadena, CA 91125.

Previous theories/models explain the formation of complex craters. These include: 1) dynamic theories [1,2,3,4] that assume rapid collapse of the transient crater, oscillation of the central peak, and the propagation and freezing of wave structures, to 2) quasi-static theories [5,6] that assume material failure and slumping of the transient cavity walls, or viscous relaxation of the transient cavity. We numerically modeled [4] the initial shock wave driven flow fields to the late-stage strength-and gravity-driven motions leading to iso-static equilibrium. Two (bounding) strength models can describe effects of deep regoliths to highly consolidated surfaces and give varying final crater depth, diameter and other features. Transition from simple to complex craters occurs for planetary strengths consistent with conventional strength models (e.g. ~10 kbs, at depth). In complex craters, the diameter of the inner ring corresponds to the diameter of the transient cavity. The calculated depth/diameter ratios for craters varies from 1/6 to 1/60, depending upon model strength and scaling regime.

Modeled [4,9] impacts on planets, for a range of strengths and gravities, give a range of crater morphologies. The gravity scaling parameter [7] $Y/pd_\text{p}$ is varied from 0 to 0.34, and the strength scaling parameter $Y/pU^2$ from 0 to 2400, where $Y$ is the impact velocity, and $Y$, g, and $p$ are planetary strength, gravity, and density. Both a thermal-degradation (T-D) strength model [4], and Mohr-Coulomb (M-C) pressure and temperature-dependent strength model [8] are used. Previous calculations [4,9] are extended to very late times to model the central peak oscillation-surface feature interaction and achieve late time, iso-static equilibrium.

The time history of the position of the top of the impactor, at the centerline, is calculated for various values of non-dimensional strength, $Y/pd_\text{p}$ (Figure 1) and non-dimensionalized, by dividing by the maximum depth of penetration ($d_p$) of the projectile, when the planet's strength is negligible. Depth is $d_p = 1.2 \cdot (ga/(U^2))^{0.22}$ [4]. Time is nondimensionalized by dividing by $(a/U)$. In Figure 1, we see that when $Y/pd_\text{p} >> 1$ (e.g. 1,200) the position of the impactor achieves, at late time, a negative value indicating a strength-dominated simple crater. When $Y/pd_\text{p} << 1$ (0.05), the impact penetrates nearly to the maximum depth under low-strength conditions, and the centerline material subsequently rebounds and several oscillations occur. Under these latter conditions, the first, and second, central-peak oscillation heights are comparable and the third is significantly lower.

From the above calculations the conditions leading to final crater morphological regimes can be quantified. Shown in Figure 2 are centerline oscillations as, non-dimensionalized maximum height versus $Y/pd_\text{p}$. Transition from simple to complex craters occurs for values of $Y/pd_\text{p}$ ~5. The T-D model results in a higher central oscillation height than the M-C model (which includes both shock heating and overburden pressure).

The differences in crater evolution between T-D and the M-C strength models are shown in Figures 3a and 3b. The M-C model assumes that the cohesive strength at the surface is zero and increases linearly with pressure with a maximum value equal to the nominal strength. Crater shapes are nearly identical up to the time of maximum penetration. Upon crater rebound, the M-C case expands laterally more than the T-G case and the centerline peak is lower (see Figure 3a). In both cases central peaks relax and the craters evolve to flat-floor morphologies. The M-C case yields a crater diameter ~ 30% larger than the T-G case and a shallower crater floor. Figure 3c and 3d media has strength 2.5 times greater than those of Figures 3a and 3b. The maximum transient crater diameter of Figure 3c corresponds to the inner ring and density decrease diameter in Figure 3d. Scaling laws (e.g. [4] and [7]) describe crater dimensions and central peak height and implications of these are presented.

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Figure 1. Time history of position of top of impactor at centerline for range of impact conditions.

Figure 2. Centerline oscillations, non-dimensionlized maximum height as a function of $Y/\rho g d_p$.

Figure 3. Differences in crater evolution between T-D (RHS) (a) and the M-C (LHS) (b) strength models for $Y/\rho g d_p = 0.48$. In 3c and 3d the strength is 2.5 times greater than in Figures 3a and 3b and $Y/\rho g d_p = 1.2$. 