IMPACT INDUCED TARGET THERMO-MECHANICAL STATES AND PARTICLE MOTION HISTORIES, John D. O'Keefe, Thomas J. Ahrens, and Lindhurst Laboratory of Experimental Geophysics, California Institute of Technology, Pasadena, CA 91125, dino@asu.com

Objectives The first objective of this effort is to determine how the post impact measurable crater features relate to the processes that take place during impact and the second is to determine from a given suite of measurements the uncertainty in estimating the impactor’s parameters.

Approach. We have taken a numerical approach using the CTH code to calculate the evolution of the near field impact process. This includes the details of the early time shock wave driven flow fields, the development and collapse of the transient cavity [2], and in a few limited cases the very late time thermal and stress histories. To quantify the impact process, we placed massless tracer particles in layers that simulate the target stratigraphy (Figs 1-4) and stored the motion and thermo-mechanical state histories (e.g., pressure, temperature, damage, peak stress/strain rate..) of these particles. We took this approach because the late time distributions are significantly different from the initial distributions. We used the ANEOS model for equation of state and a Mohr-Coulomb damage model for the strength degradation by shear strain fracture [2,3]. The key parameters for the impacts are α, the impactor radius, U, the impactor velocity, Yc, target cohesive strength, μ, internal friction, μd, damaged internal friction. We found that we could replicate the key features with values of target material parameters within the magnitudes found in laboratory measurements. We developed scaling laws for the key target metrics based upon the Mohr-Coulomb strength model. This provides a link between the measurable features and the impactor parameters. In addition it, bounds the effect of damage on the magnitude of the metrics.

Target Motion Histories and Thermo-mechanical States.

Shown in Figs 1-4 are the particle motion histories and the melted and damaged (shear fractured) regions for three representative cases: 1) simple crater –strength dominated, 2) transition crater - between strength and gravity regimes, and a 3) basin forming impact represented by the Chicxulub event[4].

The geometry of the flow in the strength dominated case (Fig. 1) is very similar to that of all cases at the time of maximum penetration. The melt has two major zones. The melt layer and melt ejecta. The melt layer is underneath the impact point and is on top the damaged region. The trajectories of the melt particles are shown and labeled at the top of the computational grid.

We found that in the strength dominated region that the depth of penetration decreases with the magnitude of the internal friction. This is due to the dynamic pressure increasing the local strength.

An example of a transition crater is shown in Fig. 2. In this case the low strength material flows over and covers part of the melt layer.

As an example of the motion histories and thermo-mechanical states in basin forming impacts, we simulated the Chicxulub event. The distribution and extent of the damaged region is critical to the crater flow and determines 1) transient cavity dimensions (e.g. depth of penetration), 2) ejecta lofting angles, 3) occurrence and number of terrace/slump faults and 4) distribution of melt. The radial extent of the damage region that replicates the Chicxulub morphology is ~ 100 km. (Fig. 4). At the time of maximum penetration, the transient cavity geometry is similar to Fig. 1. The transient cavity collapses and compresses the melt layer to a region near the center of the cavity and on top of the damaged material (e.g. Fig. 3). After the transient peak collapses, the melt flows in a thin layer over the peak ring (Fig. 4). The peak ring is formed by the collision of the downward flowing transient peak with the nearly vertically launched transient cavity flow. Note that while the transient central peak is moving upward that the ejecta curtain is still impacting the surface and that slumping is occurring in front of the ejecta curtain (Fig. 3). In addition, an asymmetric fault (diameter = 150 km) is formed that bounds the terraced zone and extends downward to the Moho. This feature has been interpreted as the crater rim [4]. On the other hand, the radius of the overturned Moho is probably a more accurate determinant of the energy of impact [5]. Further out, a 200 km diameter exterior ring is formed as a result of secondary impact of ejecta on the damaged region. The Mohr-Coulomb scaling accounts for basin forming impacts and shows the effect of internal friction on depth of penetration and quantifies the effect of overburden pressure.

Fig. 1. **Strength dominated crater.** Particle motion histories and melted and fractured regions. Time = 0.15 s, U=20 km/s, a = 5 m, Yc = 1.0e9, $\mu$ = 0.75, $\mu_d$ = 0.1, $\varepsilon_f$ = 0.05, $g$ = 0.0 m/s$^2$. Damage colors shown in Fig.3.

Fig. 2. **Transition crater.** Particle motion histories and melted and fractured regions. Time = 39 s, U=20 km/s, a = 5 km, Yc = 0.0, $\mu$ = 0.75, $\mu_d$ = 0.1, $\varepsilon_f$ = 0.05, $g$ = 9.8 m/s$^2$. Damage colors shown in Fig.3.

Fig. 3. Complex crater. Chicxulub. Time = 88 s. U=20 km/s, a = 5.0 km, Yc = 2.4e9, $\mu$ = 0.75, $\mu_d$ = 0.1, $\varepsilon_f$ = 0.05, $g$ = 9.8 m/s$^2$. Note dips in damage region indicating faulting.

Fig. 4. Complex crater. Chicxulub. Time = 568 s. U=20 km/s, a = 7.5 km, Yc = 1.0e9, $\mu$ = 0.75, $\mu_d$ = 0.2, $\varepsilon_f$ = 0.1, $g$ = 9.8 m/s$^2$. Note dips in damage region indicating faulting. Damage colors shown in Fig.3.