IMPACTS INTO COARSE GRAINED SPHERES. O.S. Barnouin-Jha[1,2], M. Cintala[3] and D.A. Crawford[4], [1]Dept. of Complexity Sci. and Engineering, U-Tokyo, Japan; [2]JHUAPL, Laurel, MD; [3]NASA JSC, Houston, TX; [4]Sandia National Labs., Albuquerque, NM.

Abstract

Several experimental studies [1,2,3] indicate that differences in the grain size of the target relative to the projectile could influence the cratering process. Impacts into coarse sand grains of size comparable to the projectile show some discrepancies with existing relationships for crater growth [e.g. 4]. Similarly, targets of fine grained, uniform in diameter glass spheres show differences in crater depth, transient crater diameter, and volume of ejecta excavated as a function of grain size [2,3]. The purpose of this work is to continue investigating how the relative grain size may influence early time coupling between a projectile and target, with implications for subsequent ejecta excavation and crater growth.

In previous efforts we used numerical techniques to focus on the propagation of shock waves in coarse, granular media emphasizing the influence of relative grain size on crater growth, ejecta production, cratering efficiency, target strength, and crater shape [5,6,7]. In this study, we use experimental techniques - in part as a reality check for the numerical studies - to report on how coarse grained targets might influence ejecta excavation and crater shape. This body of work possesses important implications for ejecta excavation and cratering efficiency on asteroids that may possess rubble pile-like structures, and on planets that may possess either pre-fractured surfaces or large-scale heterogeneities in shock impedance.

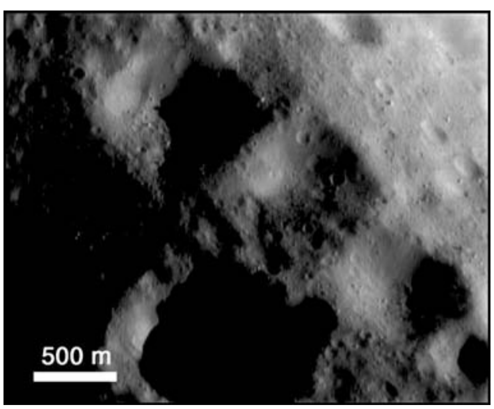


Figure 1. Square craters visible on the surface of 433 Eros formed between pre-existing tectonic ridges.

Background

The influence of pre-existing target structures during impact are well known. On Earth, for example, several authors [e.g., 8] have shown that well-developed systems of fractures often create craters that appear square in outline. One of the most dramatic examples of this is Meteor Crater, AZ [9]; another are the numerous square craters formed on 433 Eros (Fig. 1).

Typically, target strength is declared the cause for the square crater shapes mentioned [e.g., 10]. Certainly exploitation of zones of weakness provided by fractures during either crater excavation or modification generate some of the observed morphologies. However, it is also plausible that prominent target structures could significantly influence the propagation of the impact shock wave, and thereby alter ejecta excavation, crater growth and ultimately final crater shape. In fact, some impact experiments [1,11] and numerical investigations [12] suggest that the thickness of the shock front relative to the average dimension of those grains could be a controlling factor. A long pulse, encompassing a large number of grains, would result in the target behaving as a continuum. Most current scaling rules consider this type of medium [e.g., 4, 13]. However, a pulse that is short relative to the grain size, might concentrate the impact energy locally near the impact point leading to more efficient breakage or ejection of material, while causing more rapid dissipation and slower propagation of the shock wave thereafter [11, 12]. Pre-existing structures could, thus, control crater shape and the likelihood of disruption.

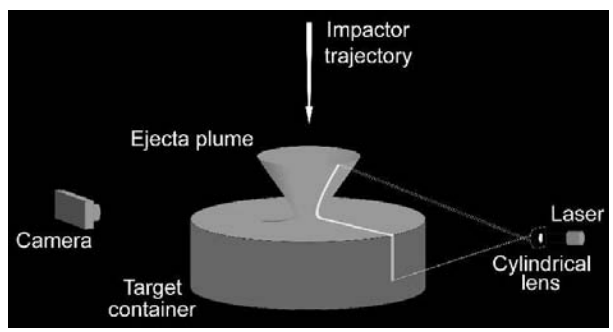
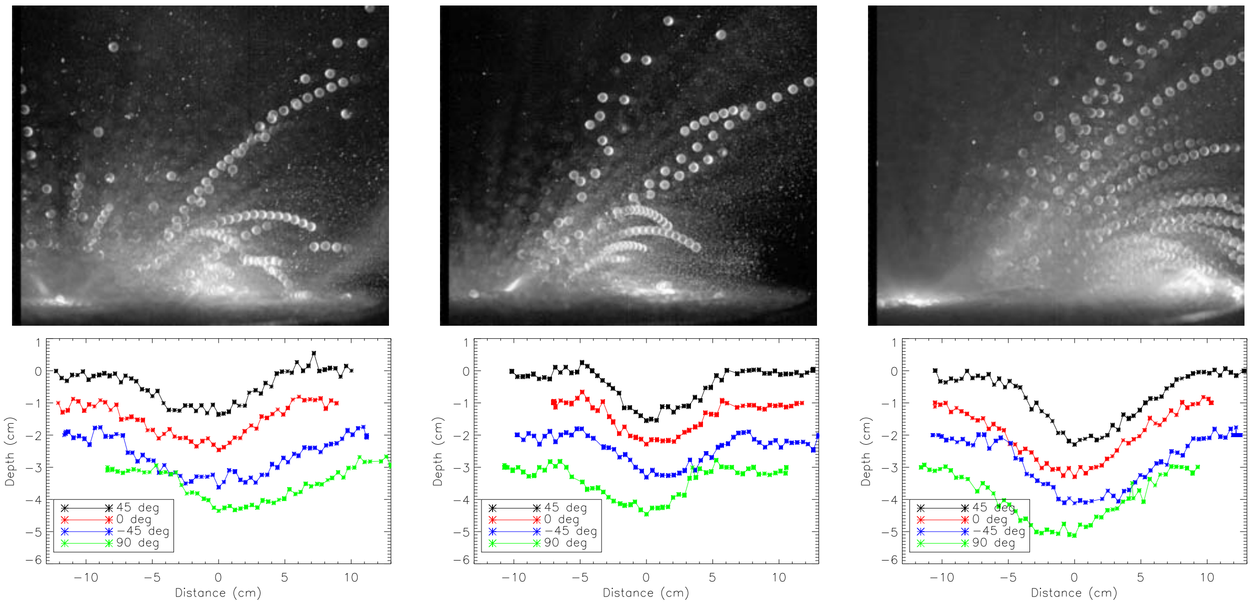


Figure 2. NASA JSC Vertical Impact Facility setup for measuring ejecta excavation velocity (from Cintala et al. [1]).

Experiments

To test this hypothesis, we undertook impact experiments at the NASA JSC Vertical Impact Facility. Glass spheres 3.5mm in diameter were launched from 1 to 2 km/s into a target of identical spheres. During each impact, we measure the excavation velocity and angle of individual ejecta as a function of distance from the impact. Figure 2 and [1] provide further details on the experimental and data processing techniques employed. We also typically measured 2-4 profiles through the crater's center using a profilometer to determine crater shape and to estimate the mass displaced by the impacts.



V = 1.06 km/s V = 1.679 km/s V = 2.026 km/s

Figure 3. Trajectories (a) and crater profiles (b) of three experiments. Angles indicate profile location relative to laser sheet used to determine trajectories.

Preliminary results

The data indicate that the thickness of the shock cannot be the only factor controlling the manner in which a crater grows. Lower speed impacts (1km/s) reveal a very complex ejecta excavation pattern: a typical inverted ejecta cone is not created (Figure 3a). The trajectories appear quite random: the ejecta move in and out of the plane of the laser with frequent collisions between particles. Furthermore, a wide range of excavation angles are observed.

As the impact velocity increases, the ejecta generate a more familiar pattern: the inverted ejecta cone begins to take form. Apparently, improvements in coupling between the projectile and the target yield a less irregular shock that traverses the target. It is possible that increased fracturing of the glass sphere near the impact point is the cause of the improved coupling. Once coupling effects no longer dominate the cratering process, the shock front's thickness relative to the size of the target spheres as described above could become the major factor influencing shock wave propagation. Frictional and collisional losses during the excavation process are probably reduced as the coupling improves, but probably never disappear, thus remaining important to overall energy dissipation.

Crater profiles (Figure 3b) show a similar pattern. The craters generated as a result of the low impact velocity are very irregular. They are frequently very shallow and quite broad. When the impact velocity increases, the crater profiles assume the more familiar, conical shape.

Results also reveal that for all the impact velocities investigated, the scaled ejection velocities in the coarse grained targets are generally slower than reported elsewhere [e.g., 1,4].

Implications

The experiments indicate that:

1. If large scale heterogeneities disrupt initial coupling between the projectile and target, then the cratering process is likely to be significantly modified. Numerical calculations [5] reveal that the influence of heterogeneities on this coupling is not just limited to the strength of the target: small differences in the location of first contact between a projectile and target comprised of spheres with no strength will change the final shape of a crater. Differences in local shock impedance could also be important if these are at scales comparable to the size of the projectile.

2. When coupling becomes less important, target heterogeneities may still play a role. For example, small scales heterogeneities can alter local strength [6], while broad scales heterogeneities may influence shock propagation.

3. Friction and collisions between grains during excavation may occur for the duration of any impact event, and thus may influence crater-scaling relations.

References: [1] Cintala et al., *Meteorit. Planet. Sci.*, 605-625, 1999; [2] Yamamoto et al., *Lun. Planet. Sci. Conf. XXXV,* 1479, 2004; [3] Yamamoto et al.,*Lun. Planet. Sci. Conf. XXXV*, 1482, 2004; [4] Housen et al., *JGR 88*, 2485-2499, 1983; [5] Barnouin-Jha, et al., *3rd Int. Conf. Large Met. Imp.*, 4106, 2003; [6] Crawford, et al., *3rd Int. Conf. Large Met. Imp.*, 4119, 2003; [7] Crawford and Barnouin-Jha, *67th Annual Meteoritical Society Meeting*, 5083, 2004. [8] Fulmer, C.V. and W. A. Roberts, *Icarus 2*, 452-465, 1963; [9] Shoemaker, E.M., In *The Moon, meteorites and comets*, p.301, 1963; [10] Melosh, H. J., Impact Cratering: A Geologic Process, Oxford Univ Press, 245 pp., 1989; [11] Martelli, G., et al., *Planet Space Sci. 42*, 1013-1026, 1994; [12] Asphaug, E., et al., *Nature 393*, 437-440, 1998; [13] Holsapple, K.A., *Ann. Rev. Earth. Planet. Sci. 21*, 333-373, 1993;