EFFECTS OF TARGET PROPERTIES ON THE FORMATION OF LABORATORY SCALE IMPACT CRATERS

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Introduction – Nature shows that the shapes of large-scale craters are influenced by various target properties. For example, well-developed systems of fractures often create craters that appear square in outline [1,2], while differences in target strength may be responsible for differences in crater depth to diameter ratios seen on Mars between highland and lowland craters [3,4].

The re-discovery that target properties may play an important role during cratering at broad scales has lead to a suite of laboratory efforts using new non-intrusive measurements techniques [e.g., 5, 6, 7] to systematically assess how some of these properties may be influencing the cratering process. We compare recently acquired datasets [5,6,7,8,9,10], and attempt to assess, or at least constrain what target factors may be responsible for the various observations, always keeping in mind planetary applications.

Background – Prior to the advent of new laser based measurement techniques, where the velocity of ejecta and growth and craters could be accurately measured [e.g., 5, 6, 7], most discussion of the effects of targets on cratering during laboratory experiments primarily assessed crater efficiency [e.g., 11 and reference therein].

Based on such measurements, it was recognized by many [e.g., 11 and references therein] that different types of targets do have different crater efficiency scaling parameters: a wet sand target has lower efficiency than a dry one; an impact into a dry target will generate a smaller crater relative to one in water for the same projectile and velocity.

It was argued that scaling parameters closest to those to water should be used at broad scales because any strength effects of the target should be minor. This reasonable argument also provides the basis for the point source approximation used to justify the widely used crater scaling rules [eg., 11]. This approximation assumes that early time coupling between the projectile and target do not significantly influence the overall cratering process.

An extension of the point source approximation is that a single scaling parameter not only describe cratering efficiency, but also ejection velocities and ejecta-mass distributions [12].

New measurements – In recent years, new experiments [5,6,7,8,9,10] explore how various targets influence the cratering process, and provide new insights on the workings of the crater scaling rules and their applications at broad scales.

In this study, we review results from impacts into granular targets. We consider variations in target porosity, internal friction angle, target grain size, impact velocity and projectile properties. In all cases, we consider only vertical impacts.

Three non-intrusive measurement techniques were used to obtain the data:

(1) A laser sheet technique where the laser is strobed in order to measure the trajectory and velocity of individual ejecta [5]. Crater sizes (for efficiency measurements) are typically measured after impact using a profilometer. Projectile used are either aluminum or glass spheres. The targets used are either coarse sands (0.5-1 mm or 1-3 mm) and uniform 3 mm glass spheres. The impact velocities range from 250m/s to 2.5km/s.

(2) A particle velocity interferometry technique, where two laser sheets allow determining the trajectory and velocity of individual ejecta [6]. Data from a 6mm Al projectile launched at 1km/s in ~0.5 mm rounded sand is used. Crater sizes (for efficiency measurements) are typically measured after impact using a profilometer.

(3) A laser sheet technique where a high speed camera captures crater growth [7,10]. Changes in crater diameter and depth were investigated for impacts by a ~10mm polycarbonate projectile into uniform fine grained glass beads (80m and 220m) and non-uniform angular basaltic sand (<0.5m, 0.5-1mm and 1mm-2mm). Impact velocities considered are low between 80m/s and 350m/s.

Discussion of results

Crater efficiency - Table 1 compares crater efficiency parameters α obtained from measurements of mass displaced by impact. Results indicate that regardless of variations in the coupling between the projectile and target grains, this parameter hardly changes for similar targets. For example, slow impacts into fine grained spheres behave statistically the same as faster projectiles impacting coarse glass spheres. Likewise, all the sand impacts behave nearly the same, despite differences in projectile properties, impact velocities and grain sizes.

Differences in cratering efficiency between the sand and glass beads data can be attributed to differences in their friction angle and porosity. Which factor dominates is difficult to discern, as both typically change in tandem. The coarse sand data do suggest that friction angle effects might be small. The presence of a uniform versus non-uniform grain size distributions in the target may also be important.

Crater growth and ejection velocity – Unlike the consistency seen with crater efficiency, the new laboratory data indicate that scaling parameters describing crater growth and ejection velocities are highly variable, changing with impact velocity, and the size of the projectile and target grains. As an example, impacts by a single glass sphere in a target of comparable spheres can generate a broad range of excavation velocities from near identical launch positions within a crater. Furthermore, in most cases analyzed, the magnitude of α determined from crater growth do not equal α measured from the displaced mass from crater efficiency. Most likely, early coupling geometry between the target and projectile are responsible [5]. Other factors that could contribute include the thickness of shock pulse relative to the target grain size or void space present in the target [5], and friction angle effects [7].

Ejection angle – How ejection angle change with target properties is important for determining the distribution of ejecta emplaced after impact. The new measurements indicate ejection angles first decrease and then increase again during cratering. The cause for these changes may be due to changes in the friction environment throughout cratering, although how this process works exactly remains unclear.

Interior curtain angle – Only the last of three measurements techniques discussed can measure this interior curtain angle (measured at the interior wall of transient craters). Unlike ejection angle, it only decreases as cratering proceeds for the fine glass spheres where such data have been measured. Additional data for sand targets are currently being analyzed to gain further insights on the connection with the ejection angle results.

Crater modification – The dynamic angle of repose appears to dominate when modification ceases. Indeed, when slopes reach 20deg at the crater wall, all motion ceases for the case of the fine glass beads of Table 1. Significant crater modification is observed, with great changes in the transient crater diameter and depth significantly [7]. Additional analyzes in sand and finer glass beads are currently underway to confirm these preliminary results and will be reported.

References – [1] Fulmer, C.V. and W.A. Short, Rock Induration and crater shape, *Icarus* 2, 452, 1963. [2] Shoemaker, E.M., In *The Moon*, eds Middlehurst, B.M. and Kuiper, G.P., Univ. of Chicago Press, Chicago, 301,1963. [3] Pike, R.J., *PLPSC* 11, 2159, 1980. [4] Stewart, S.T. and Valiant, G.J. *MAPS* 41, 1509-1537, 2006. [5] Cintala M.J.,et al., *MAPS* 34, 605, 1998. [6] Anderson J.L.B., et al., *MAPS* 39, 303, 2004. [7] Barnouin-Jha O.S. et al., *Icarus*, 188, 506, 2007. [8] Barnouin-Jha O.S. et al., *LPSC, 36*, 1585, 2005. [9] Anderson J.L.B., et al., *LPSC, 38*, 2266, 2007. [10] Yamamoto S. et al., *LPSC*, 38, 1452, 2007. [11] Holsapple , K., *AREPS*, 21, 333, 1993. [12] Housen K.R., et al., *JGR* 88, 2485, 1983. [13] Yamamoto S. et al., *MAPS*, 183, 215, 2006. [14] Schmidt, R. M., *PLPSC* 11, 2099, 1980. [15] Gault, D. and C. P. Sonnet, *GSA Special Paper 190*, 69, 1982.

Table 1. Preliminary comparison of crater efficiency parameter α from mass displaced by impact.

Target type	Projectile size, *a* (cm)	Grain size, *d* (cm)	Impact Velocity, *U* (km/s)	Porosity, ϕ	Angle of repose*	Scaling parameter, α	Ref.
Coarse glass spheres	0.318 Gl	0.318	0.5-2.5	0.36	26	0.60±0.08	[8]
Fine glass spheres	0.9 Px	0.022	0.08-0.3	0.36	25	0.58±0.05	[7]
Coarse sand	0.476 Al	0.1-0.3	0.9-2.0	0.44	38	0.45±0.01	[5]
Coarse sand	0.318 Gl	0.05-0.1	0.3-1.7	0.44	34	0.45±0.01	[5]
20- 40 Sand	0.635 Al	0.0457	~1.0	0.38	32	0.46	[6]
Ottawa sand	0.318-1.22	~0.01	1.77-7.25	0.33	35	0.51	[14]
Water	0.318-1.22	NA	1.0-3.0	0	0	0.65	[14,15]

* Angle of Repose = Friction angle when cohesion is small (probably true for most of these targets)