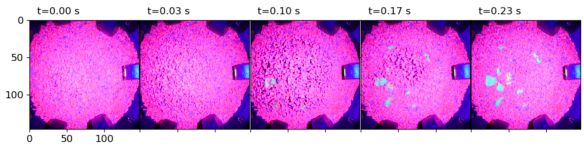
Ricochets and impulses on Asteroids. A. C. Quillen[1], J. South[1], E. Wright[1] and Randal Nelson[2] [1]Dept of Physics and Astronomy, University of Rochester, Rochester, NY, [2]Dept of Computer Science, University of Rochester, Rochester, NY

Abstract:
We describe laboratory experiment of impacts into dry polydisperse granular materials. In the first experiments we consider how an impact generated seismic pulse affects the surface distant from the impact site. In the second set of experiments we study non-round projectiles with low velocity encounters and at non-normal impact angles.

1. Experiments of impulses

Introduction:
Impact induced seismicity is important on small asteroids due to their low surface gravity and small volume which limits vibrational energy dispersal. Unfortunately, little is currently known about how impact generated seismic waves are excited, dispersed, attenuated and scattered in asteroids. The rapidly attenuated seismic pulse or 'jolt' model is consistent with strong attenuation in laboratory granular materials at kHz frequencies but qualitatively differs from the slowly attenuating seismic reverberation model that is sometimes assumed to account for large surface boulders on asteroids due to the Brazil nut effect.

Experiments of impulses from below:
We track the trajectories of particles ejected from the surface by a single strong upward propagating pressure pulse. High speed video images show that ejecta trajectories are independent of particle size, and collisions primarily take place upon landing. When they land, particles are ballistically sorted, leaving larger particles on the surface and smaller particles more widely dispersed. A single strong pulse can leave previously buried boulders stranded on the surface.



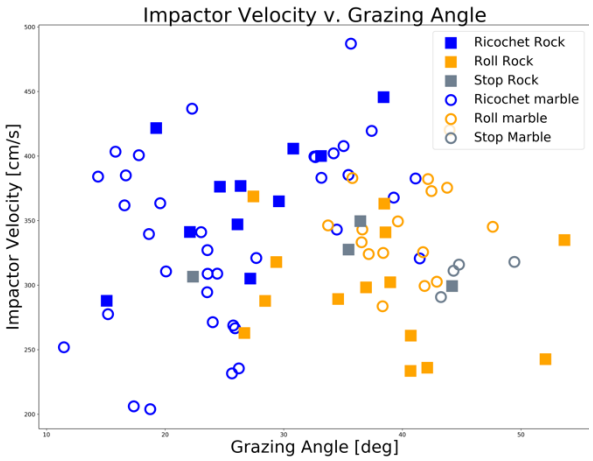
We show the surface of a bowl of gravel that is hit a single time from below. Each panel shows a different time with time from impact increasing to the right. After particles are ejected off the surface, larger particles end up on top.

Summary
Boulder stranding due to an impact excited seismic pulse is an additional mechanism that could leave large boulders present on the surface of rubble asteroids such as 162173 Ryugu, 101955 Bennu and 25143 Itokawa.

2. Experiments of non-round projectiles into sand and at non-normal impact angles:

Introduction:
Spin off events and impacts can eject boulders from an asteroid surface and rubble pile asteroids can accumulate from debris following a collision between large asteroids. These processes produce a population of gravitationally bound objects in orbit that can impact an asteroid surface at low velocity, and because they are in orbit, at low or grazing angles with respect to the surface.

Experiments non-spherical projectiles at non-normal impact angles:
We carry out laboratory experiments of low velocity non-spherical projectiles (100-400 cm/s) at different impact angles into granular media. A projectile stops within its crater or rolls or bounces out of it, depending mostly on Froude number ($v^2/(gR)$). Our impact velocities have Froude numbers, 50 to 350 and this regime is relevant for 10m rocks on asteroids 101995 Bennu or 162173 Ryugu impacting the surface at velocities below the escape velocity.



Fate of projectiles as a function of impact angle and impact velocity. There is a division between impactors that roll out of their impact crater and those that ricochet out of their crater. Very few remain in their crater after impact. Here the grazing angle is 90 degrees for a normal impact.

Summary

We find that very few low velocity projectiles stop near their site of impact. Because our lab experiments match the Froude number for 10m Boulders on Bennu, We propose that boulders perched on the surface of rubble asteroids such as Asteroid Bennu and Asteroid Ryugu could be the result of low velocity and low grazing angle impactors that ricocheted or rolled across the surface, finally coming to rest distant from their initial impact sites. The regime we study is also relevant for control of landers.