

SPALL VELOCITY MEASUREMENTS OF LABORATORY SCALE IMPACT CRATERS;  
Carol A. Polansky and Thomas J. Ahrens, California Institute of Technology,  
Pasadena, CA 91125

Evidence indicating a possible Martian origin for the Shergottite, Nakhilite, and Cassinidite meteorites has motivated interest in finding a mechanism to deliver lightly shocked samples of rock from Mars to the Earth. One possible mechanism is the recently proposed model of Melosh (1), describing the physics controlling the size and velocity of spalled ejecta. In an attempt to provide experimental data to test this spallation model, a series of experiments has been developed to determine spall velocities for impacts into competent rock.

Spallation is the dynamic tensile failure of material due to the interaction of a stress wave and a reflected rarefaction wave. According to the Melosh model, spall velocity and thickness can be calculated using simple projectile characteristics (e.g. density, diameter, and impact velocity) and the material properties of the rock (e.g. density, sound speed, and strength). The model is based on the concept of a spherical "detached shock" originating from a theoretical "depth of burst" in a manner similar to that of explosion cratering. This shock is characterized by a rise time and decay time which allow the direct stress wave and the reflected wave to interfere. This interference is such that material near the surface does not receive the full compression of the shock wave. Thus this model provides a possible mechanism for removing lightly shocked material from planetary surfaces.

Several spall velocity measurements have been made at the Caltech shock wave laboratory. The projectiles were aluminum and lead bullets fired from a 30/06 rifle at targets of San Marcos gabbro (Figure 1a). The impact velocity in these experiments was near 1 km/sec. Spall velocities were measured using flash x-ray photography to record the flight of the spall fragments 0.3 msec after impact (Figure 1b,c). At this time the spall fragments had not yet completely separated from the target rock. The resulting vertical velocities were 11 m/sec and 17 m/sec for the lead and aluminum bullets, respectively. This is approximately 2% of the impact velocity and 5-80 times lower than the vertical velocity predicted by the Melosh model. However, there are a number of reasons which could explain this discrepancy. The most obvious problem is that the Melosh model is designed for planetary scale impacts. This includes the assumption that the spall thickness is much less than any other dimension, yet in the above experiments the spall thickness was comparable to both the projectile diameter and the crater depth. Secondly, at an impact velocity of 1 km/sec the cratering process is extremely strength dominated, and the initial wave front is an elastic wave as opposed to a shock wave.

A second set of measurements were made using the light gas gun at the Ames Vertical Gun Range to obtain impact velocities from 1.4-6.5 km/sec. The projectiles were 1/8" iron and aluminum spheres fired at San Marcos gabbro and San Gabriel anorthosite. In addition, the Dynafax model 350 framing camera was used at a framing rates of 9000-35,000 frames/sec to provide a complete record of the spallation process.

Analysis of the films showed spalls traveling at a range of vertical velocities and initial angles. For one particular impact of 4.6 km/sec, velocities from 0.6 to 25 m/sec were measured. The maximum velocity of 25 m/sec was only 0.5% of the impact velocity which is even less promising than the results from the low velocity impacts. However, this measurement was made 1.2 msec after impact, and the spall had already completely separated from the

## SPALL VELOCITY MEASUREMENTS

Polansky and Ahrens

target. Once the spall is freely flying it begins to spin and tumble which decreases the net translational velocity. Some spalls were also observed fragmenting in flight which further alters the velocity.

A theoretical vertical velocity range of 2.3-15 m/sec was calculated for the above impact. This falls within the range of observed velocities. In addition, a spall thickness of 4mm was calculated from the Melosh model. This agrees with the measurements of 2-5mm for the actual spall layer. In general, there is much better agreement of the data with the model at higher impact velocities, even though the spall thickness is now greater than the projectile radius.

Although the observations show that the spall velocities evolve in a complicated manner, they are all low with respect to the impact velocity. Thus it seems that it would be difficult to remove rocks from the surface of Mars at 5 km/sec. However, the variation of spall velocity with projectile diameter at a fixed impact velocity has not yet been observed.

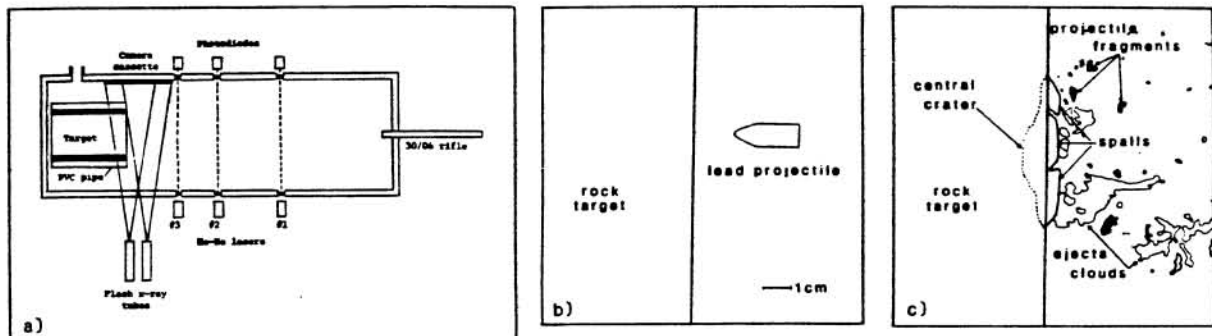


Figure 1: a) Sketch of experimental configuration for spall velocity measurements at low impact velocities. The projectile velocity is determined by a counter measuring the time intervals as the projectile breaks the laser beams. The lasers also activate other counters which in turn trigger the x-ray tubes. The first x-ray exposure, b), is taken immediately before impact and shows the projectile in flight. The second exposure, c), is taken approximately 0.3 msec later. Spall velocities can be measured directly from this exposure. In addition to the spalls, faster moving rock ejecta and projectile fragments are also visible.

### References:

- (1) Melosh, H.J., Impact ejection, spallation, and the origin of meteorites (1984) *Icarus*, 59, 234-260.