CRATERING EFFICIENCY IN ROCKS AS A FUNCTION OF ROCK TEMPERATURE.

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Introduction: Impact cratering is a ubiquitous process throughout the Solar System. It is a significant geological process in terms of the evolution of bodies and their surfaces. Rocky bodies are usually considered as a group wherein variations in composition etc. can alter the resulting crater morphology. However, ambient conditions also vary. For example, the temperature of rocky surfaces alters across the inner Solar System. It is therefore appropriate to consider how this may influence the outcome of impact cratering events.

Method: The issue of target rock temperature in impact events is considered herein via experimentation using a two-stage light gas gun [1]. To ensure a wide temperature range, the target holder was designed to hold both cooled and heated targets. Cold targets were frozen in a suite of freezers (domestic, CO_2 and LN_2). These were located within metres of the target chamber and cold targets could be rapidly transferred to the gun which was then pumped down to low pressure (typically 0.5 mbar) and fired. Temperature sensors were placed on the targets and read out at the moment of the impact. Hot targets were heated in place in a holder with built in heater units. Again, target temperature at the moment of impact was measured.

The targets were a variety of rocks: limestone, sandstone and hematite. They were cut into a variety of shapes, some were rectangular blocks, others cylindrical blocks. A total of 15 shots were done and are summarized in Table 1. In each case the projectile was a 1 mm dia. stainless steel sphere. The craters were imaged after each shot using a stereo microscope. The craters were measured by hand using depth gauges to map out profiles across the craters and obtain crater diameter and depth. The craters were in-filled with glass microspheres to obtain measure of their volume. In addition, fake stereo images were obtained and reconstructed using stereo reconstruction software (Alicona's *Mex* software package) which then generated crater dimensions automatically. The various methods gave results in good agreement with each other.

Results: The data show considerable scatter and very few clear trends. In Fig. 2 a variety of graphs are shown for crater depth, diameter and depth/ diameter. The errors on the crater depth are of order 10 µm, those on crater diameter are from the spread in individual profile measurements inside each crater (typically 6 measurements were averaged) and the errors on crater volume are of order 10%.

Table 1: Details of shots.

Rock	Temp. (K)	Speed (km s^{-1})
Limestone	191	4.97
Limestone	291	5.14
Limestone	291	5.10
Limestone	499	5.23
Limestone	500	5.01
Sandstone	156	5.01
Sandstone	161	4.95
Sandstone	160	4.97
Sandstone	291	5.14
Sandstone	291	4.92
Sandstone	291	5.05
Sandstone	500	5.01
Hematite	172	5.16
Hematite	291	4.92
Hematite	499	5.00

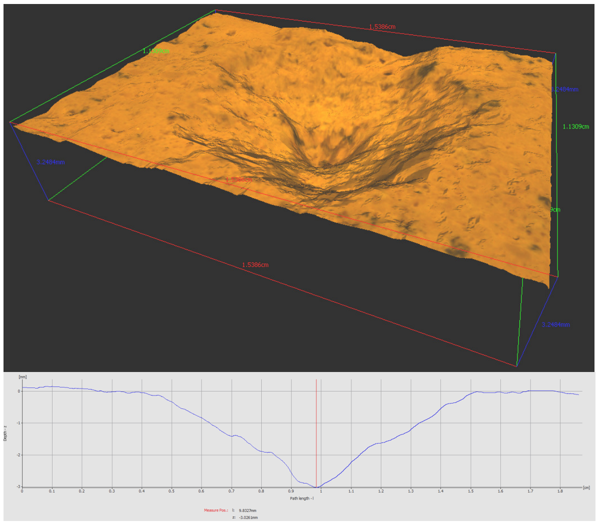

Fig. 1. Stereo view of the crater in limestone at 191 K. The upper panel shows the crater, the lower panel is an automatically generated profile across the crater.

Discussion: There are very few clear trends in the results. There is variability at the level of ±20% in the worse case in crater diameter at a given temperature. This probably reflects the brittle nature of the targets, but precludes observing any trends of less than this magnitude without a much more extensive shot programme. Crater depth might have been held to be less susceptible to variation due to the brittle nature of the targets, but still shows a worst case variation of ±16%, again masking trends of similar magnitude. The depth

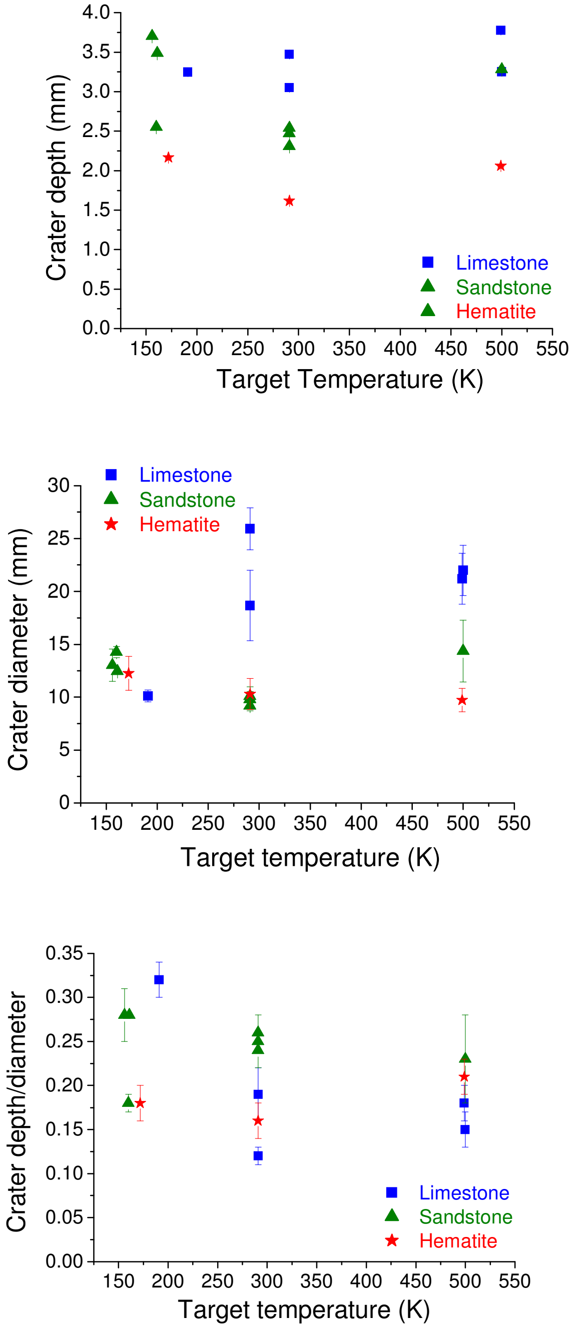

Fig. 2. Crater depth, diameter and depth/diameter results vs. target temperature.

to diameter ratio is typical of that found for rock targets in light gas gun experiments at these speeds, e.g. [2]. The only data set which appears to show a clear strong trend is that for the crater volume in limestone, which increases by a factor of 3 over the temperature range here (150 – 500 K). However, at the lowest temperature there is currently only 1 datum, so this awaits confirmation. Overall, there is a general trend by rock sample, with hematite giving the smallest craters and limestone the largest.

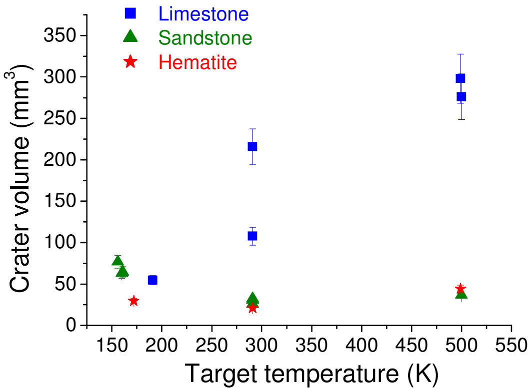

Fig. 3. Crater volume vs. target temperature.

Conclusions: A preliminary study of the effect of target temperature on laboratory scale impact cratering in rock has been carried out. A wide temperature range has been used, ~150 – 500 K. The craters show the classic broad appearance due to spallation of the brittle target materials. Given the magnitude of the spread in data from shot to shot even at equal temperature, trends in crater depth and diameter would only be apparent if significantly greater than 20 and 40% respectively. There may be a trend in one material (limestone) for crater volume to grow with temperature, but this relies on a single crater at low temperature (whose diameter is much smaller than expected, significantly lowering its volume). We can however conclude that no gross effects due to the change in material properties with temperature are occurring.

For future work we intend a more extensive shot programme. The rock samples will be characterized in more details, and tested for uniformity. Data will be collected at more values of the target temperature in the range here (150 – 500 K), and the range itself will be extended to cover 100 – 700 K. Static strength measurements of the rocks used will also be taken over this range. It is planned to use X-ray tomography to measure and characterize the sub-surface damage beneath the craters. The data will then be modeled in a hydrocode.

References: [1] Burchell M. J., et al., (1999) *Meas. Sci Tech., 10*, 41-50. [2] Burchell and Whitehorn (2004) *Monthly Notice of the Royal Astronomical Society*, *341*, 192 – 198.