Examining Impact Induced Mineral Devolatilisation Using Raman Spectroscopy

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Background

Impacts played a major part in the early development of the Solar system [1]. They may also have had an equally important role in subsequent planetary evolution, including the formation and evolution of atmospheres and hydrospheres around the terrestrial planets and their satellites [1, 2]. Previous studies [3-5] have demonstrated that hypervelocity impacts can result in the release of volatiles from hydrated, carbonate and sulphate mineral targets. It is important to understand the conditions and mechanisms of impact induced devolatilisation in specific important mineral species, especially those abundant on the surfaces of planetary bodies. With this understanding, we may be able to use remote-sensing, or rover-based instruments to recognise, and quantify, any devolatilisation that may have occurred. For example, [6] has shown that Raman spectroscopy is capable of quantifying the loss of volatiles from impacts, and this instrument is beginning to be seen as a useful tool for in situ planetary surface analysis [7], evident by the inclusion of a Raman spectrometer onboard ESA's ExoMars rover [8]. Here we present results of laboratory impact experiments using two minerals believed to be relevant in the evolution of Mars: goethite and gypsum (in the form of plaster of paris (PoP)).

Experiments

Two experimental programs have so far been carried out using a two stage light gas gun (Fig. 1) [9] to simulate planetary impacts, with analysis carried out using a LabRam-HR Raman spectrometer, both instruments are based at the University of Kent.

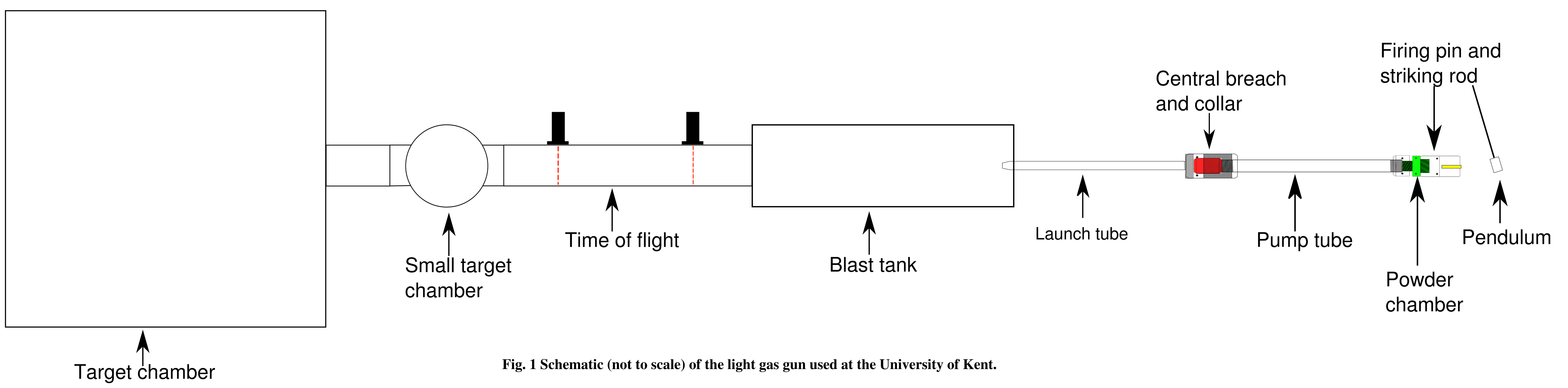

Fig. 1 Schematic (not to scale) of the light gas gun used at the University of Kent.

The first set of experiments used a cuboid projectile ($1.5 \times 1.5 \times 2$ mm) of goethite fired onto aluminium alloy plates at velocities between 1 and 5 km s^{-1}. The second set of experiments used both fully hydrated (gypsum) and semi-hydrated (bassanite) phases of PoP, either as the target or projectile material.

Results

Raman spectra taken from the impact craters (Fig 2 - 5) of these initial experiments show hypervelocity impacts induce some degree of devolatilisation of goethite and both semi-hydrous and hydrous PoP. The impacts lead to a distinctive change in the Raman signatures of these minerals. At velocities $\geq$3 km s^{-1} almost complete dehydration of goethite occurs, indicated by the change in spectra from goethite to hematite. Semi-hydrated PoP powder shows a loss of volatiles (H_2O, O and S) within the PoP as signified by a change in the spectra from the semi-hydrated phase to a phase that closely resembles that of $CaCO_3$. Whereas, a larger projectile made from semi-hydrated PoP shows the complete dehydration of PoP forming its anhydrous phase. Raman spectra taken from inside the crater of a PoP target shows some slight indication of dehydration. The appearance of a small feature at 3553 cm^{-1}, next to the H_2O features at 3405 and 3493 cm^{-1}, suggests the formation of semi-hydrated material in the crater. These initial results indicate the degree of devolatilisation is dependent on both the velocity and the size of the projectile, but further investigation is required (and is ongoing) before we are able to confidently quantify the degree of impact induced devolatilisation of minerals using Raman spectrometry.

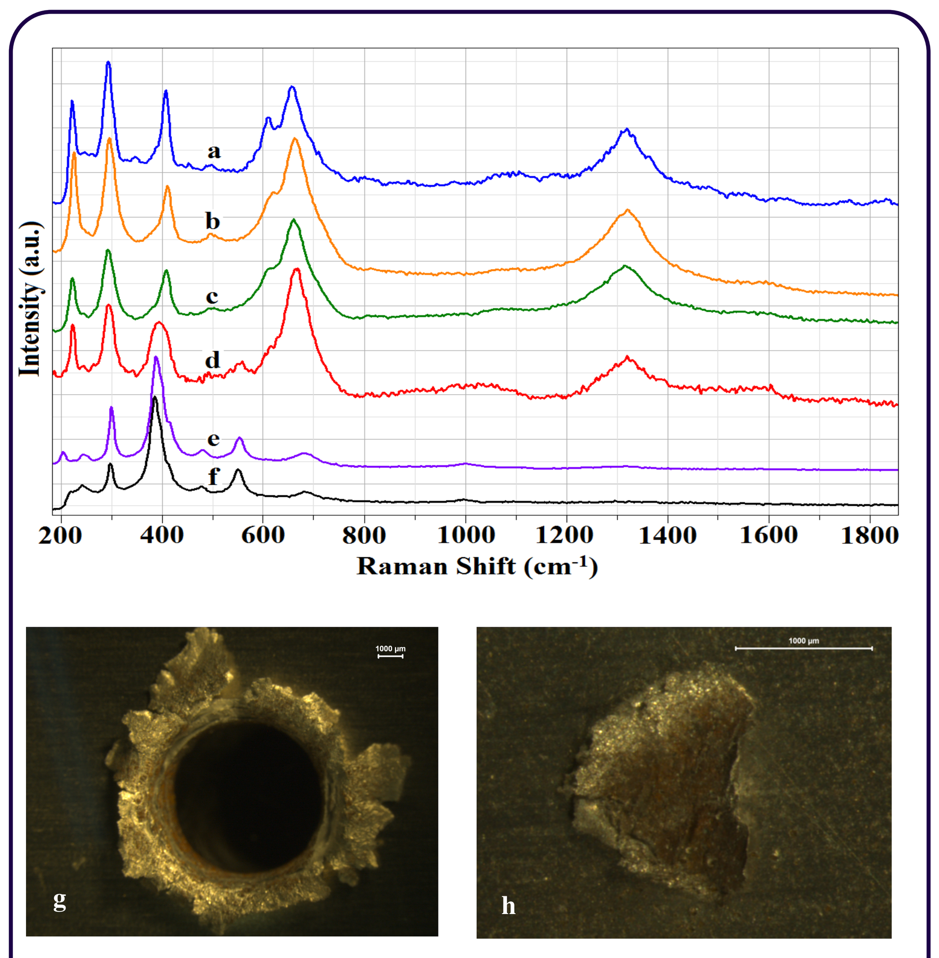

Fig. 2 a: Raman spectrum of goethite after heating to 400 °C and then cooled to 28 °C. b-e: spectra obtained from the residue within craters formed at impact velocities 5.13, 4.11, 3.72, 1.36 km s^{-1} respectively. f: Spectrum of raw goethite that has not undergone any shock or heating. Arbitrary vertical shifts have been applied for clarity. g:Image of the impact puncture created on plate 1 showing goethite material on the crater rim. h: An example of a crater fromed from a goethite projectile.

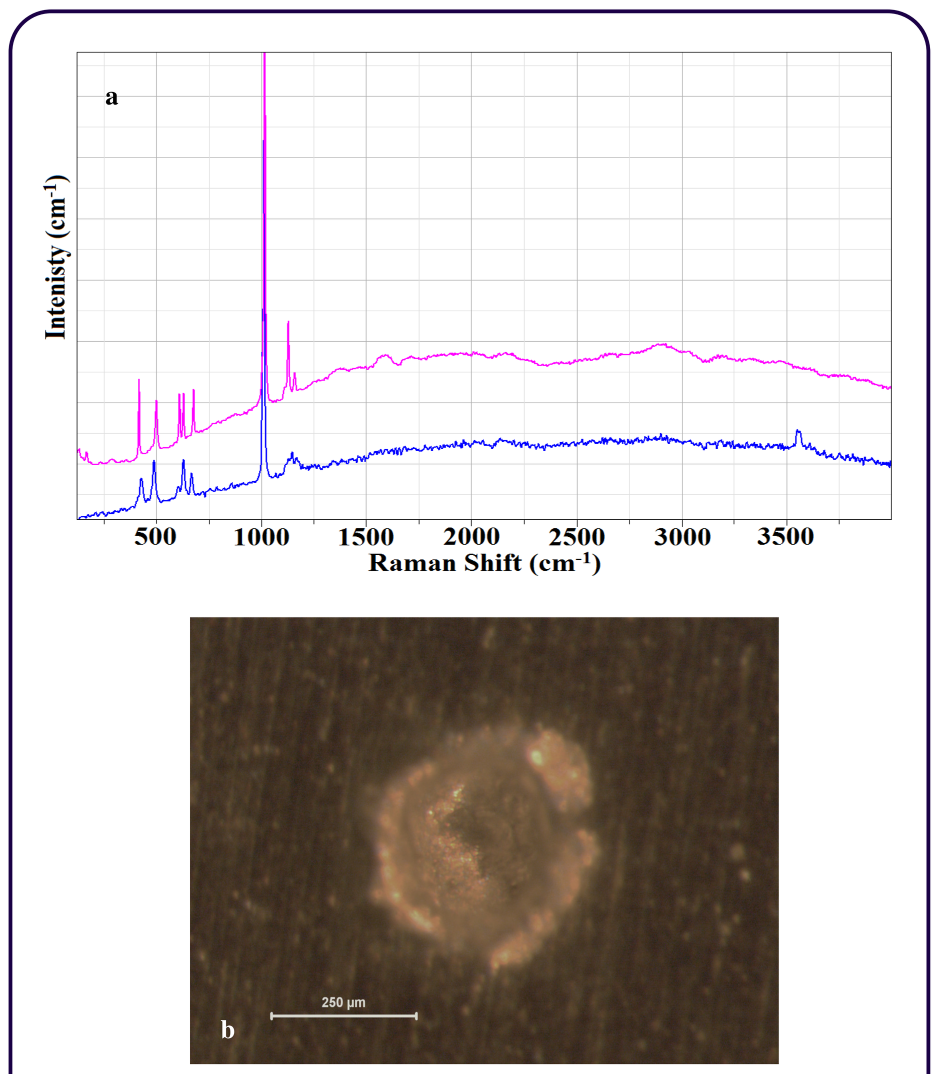

Fig. 3 a: Raman spectra of the anhydrous plaster of paris analysed in craters on the target plate (pink, top), and semi-hydrous plaster of paris (blue, below). b: An example of a crater generated from a semi-hydrated PoP projectile.

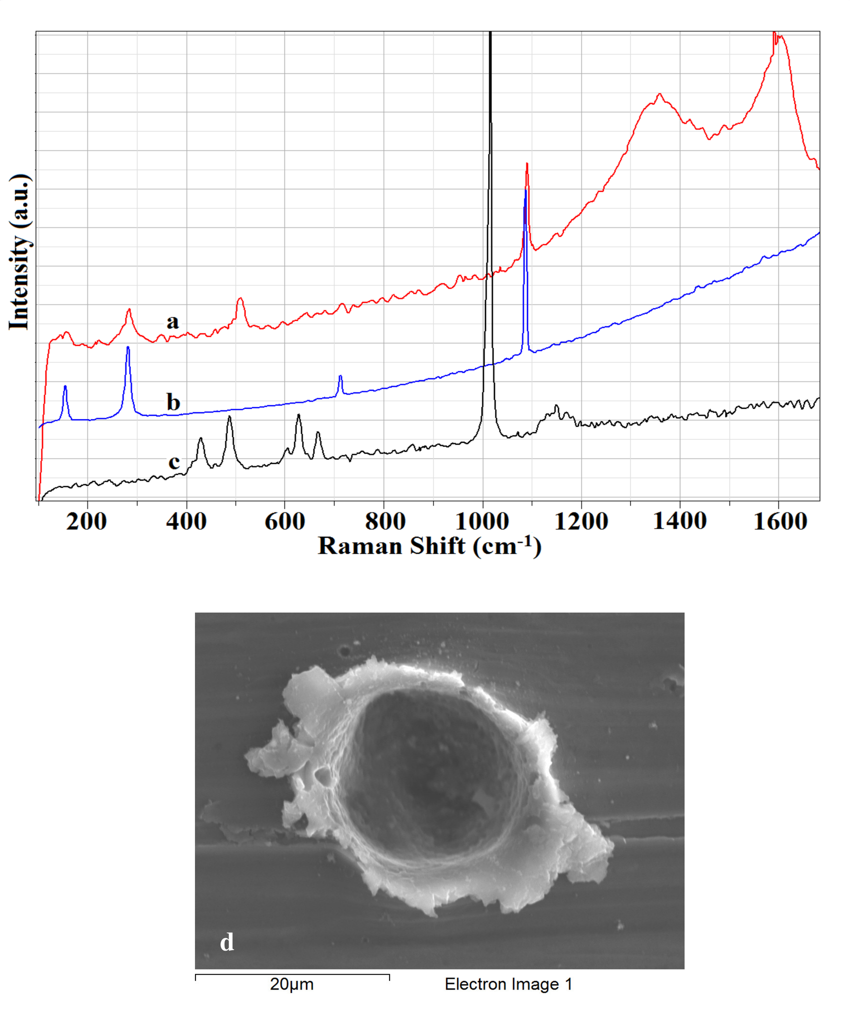

Fig. 4 (from shot G141113#2). a: Raman spectrum taken from the residue found within craters found on the aluminium plates. The broad peaks at 1350 and 1600 cm^{-1} are the 'D' and 'G' carbon peaks, probably from LGG debris. b: Pure calcite sample with peaks that match those from the target residue. c: Raman spectrum of semi-hydrous PoP. d: An SEM image of the crater sampled.

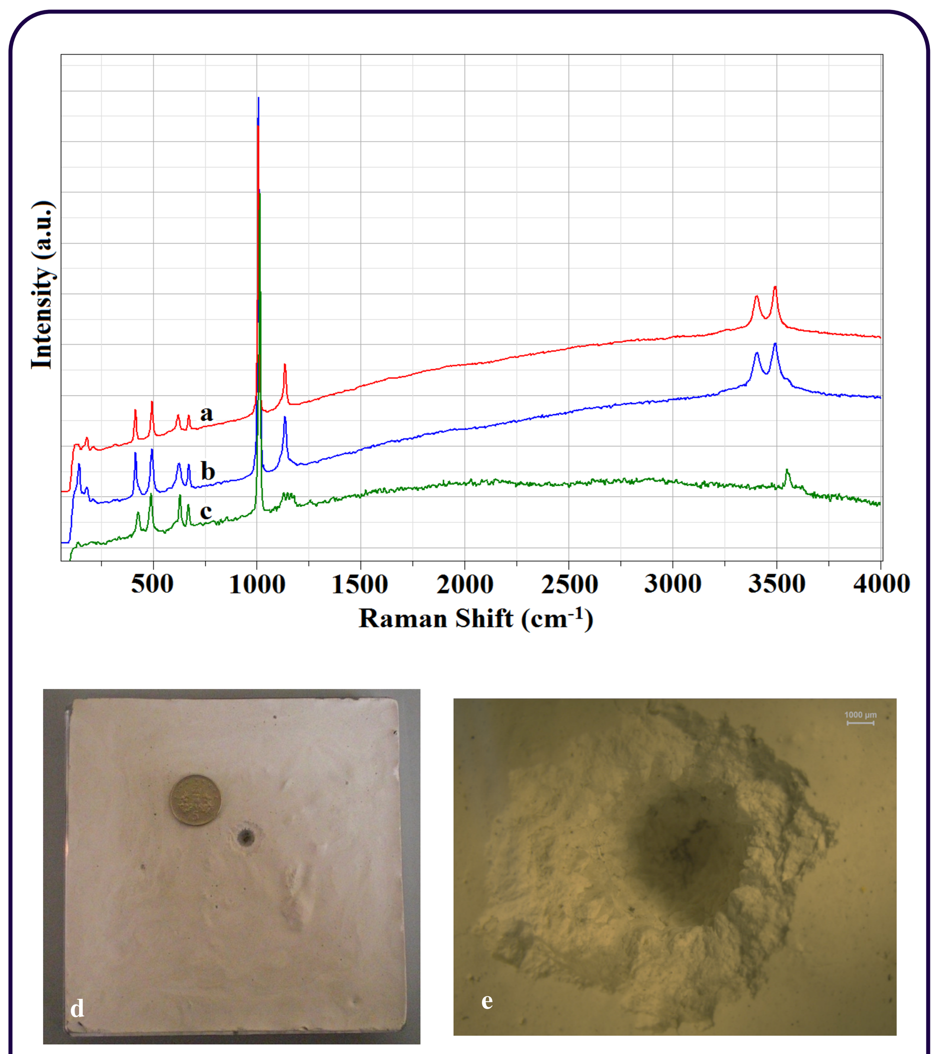

Fig. 5 (from G111013#1) a: located at the edge of the target and b: within the crater. c: semi-hydrated phase of plaster of paris. d: Impacted hydrated PoP target (with a 5p coin for scale). e: Close-up image of of the impact crater.

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References: [1] Tyburczy J. A. et al. (2001) Earth and Planet. Sci. Let, 192, 23-30. [2] Kurosawa K. et al. (2012) Earth and Planet. Sci. Let., 337-338, 68-76. [3] Lange M. A. and Aherns T. J. (1982) Jour. Geophy. Res.87, A451-A456. [4] Chen G. et al. (1994) Earth and Planet. Sci. Let, 128, 615-628. [5] Kawaragi K. et al. (2009) Earth and Planet. Sci. Let, 282, 56-64. [6] Milikocić K. et al. (2013) 44th LPSC, Abstract #1940. [7] Tercea N. et al (2008) Space Sci. Rev. 135, 281-292. [8] Perez C. et al. (2013) EPSC2013, Abstract #935. [9] Burchell M. J. et al. (1999) Meas. Sci. and Tech, 10, 41-50.