Further development of a Hugoniot for Yorkshire Sandstone

Conference or Workshop Item

FURTHER DEVELOPMENT OF A HUGONIOT FOR YORKSHIRE SANDSTONE. E. A. Taylor[1], K. Tsembelis[1, 2*], A. T. Kearsley[2] and K. Miljkovic[1], [1]Department of Physics and Astronomy, Centre for Earth Planetary Space and Astronomical Research, The Open University, Walton Hall, Milton Keynes, MK7 6AA, U. K. (e.a.taylor@open.ac.uk; kostas@tsembelis.com; k.miljkovic@open.ac.uk). [2]Physics and Chemistry of Solids, Cavendish Laboratory, Madingley Road, Cambridge CB3 0HE, U.K. [3]Department of Mineralogy, Natural History Museum, London SW7 5BD, U.K.(a.kearsley@nhm.ac.uk).

Introduction: In order to improve our understanding of the shock response of Yorkshire sandstone, particle impact tests were carried out using the Open University's All Axis Light Gas Gun [1, 2], and 1-D plate impact shock studies implemented using the University of Cambridge's Plate Impact Facility [3]. Preliminary measurements of the crater depth and diameter have been carried out, using a range of techniques. Prediction of the pressures generated on impact requires appropriate material data, preferably measured for the material (particularly relevant for geological materials where there can be material variability). This paper reports on the development of a Hugoniot for Yorkshire sandstone, building on previous work [4, 5, 6]. A range of hydrocodes and analytical techniques were used [7, 8], supported by published data on sandstones and related rocks and minerals [9, 10, 11, 12]. Techniques to estimate the shock-driven heating of the target were applied [13]. This work is a precursor to investigating the possibility of shock-driven DNA modification of microbial organisms in sandstone targets, which could occur at lower pressures than those previously established to cause extinction [14, 15]. Future studies may also look at impact-driven changes to subsurface habitats, noting that shock processing of rocks may make them more colonisable [16]. Before any conclusions can be drawn for these large structures, the different responses for the strength and gravity dominated regimes must be established.

Sandstone Properties: The measured Hugoniot values are reported in Ref. 4. The bulk density was measured to be 2.24 g/cm^3. The composition of the sandstone was established using low vacuum backscattered electron images to obtain modal mineral analyses (i.e. % of whole rock by area ~ volume) for five representative areas of a polished section taken from the edge of the target (example shown in Figure 1). All areas were very similar in their major mineral contents (quartz ca. 60%), and porosity (10-16%), but variable in the minor mineral contents. The results are reported in Table 1. Noting that the ratio of chlorite to K feldspar is estimated to be 5:1, and that the ratio of SiO_2 to albite is estimated to be 9:1, we set the composition of the Yorkshire sandstone (for the purposes of developing a "composite" synthetic Hugoniot) to be: quartz (59%), pore space (14%), chlorite (9%), kaolinite (8%), albite (7%), Fe and Ti oxides (3%) and K feldspar (2%).

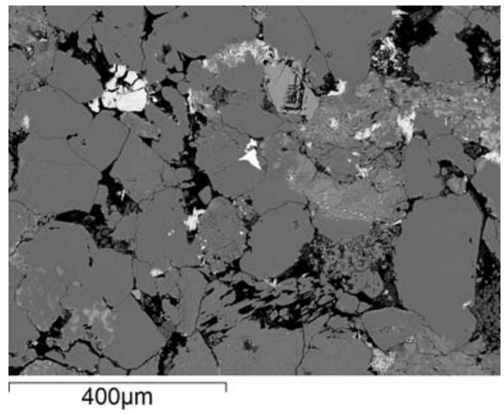

Figure 1. Backscattered electron image of the Yorkshire sandstone sample.

Table 1. Composition of Yorkshire sandstone sample

Material	*Proportion (%)*	*Error (st.dev.)*
"Bright" (metal oxides)	2.90	1.98
Chlorite and K feldspar	10.52	2.99
Silica and albite	65.28	2.85
Kaolinite	8.02	1.81
Pore space	13.60	2.18
TOTAL	100.32	N/A

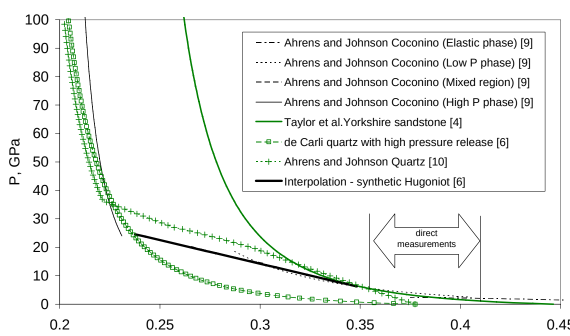

Figure 2. P-V curve for Yorkshire sandstone. A trilinear Hugoniot was derived from these data [6].

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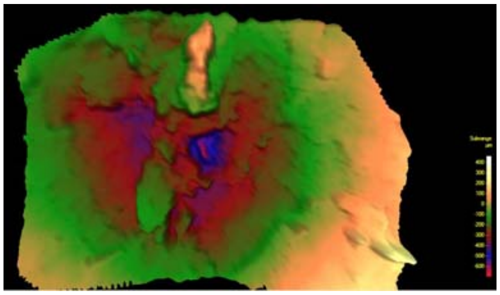

Figure 3. Profile of central region of the impact crater, produced by 1 mm spherical particle stainless steel projectile, impacting at 4.8 km/s at 30° to the horizontal.

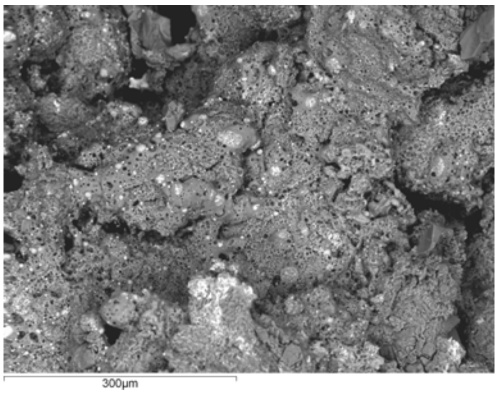

Figure 4. Distribution of impact residue

Further Development of a Sandstone Hugoniot: Based on previous work, as shown in Figure 2, where the P-V curve was based on an interpolation between experimentally measured data for Yorkshire Sandstone and a high pressure quartz data set., we now construct a "composite" synthetic Hugoniot from mineral data. Shock data for serpentine are used as the closest available analogue for K feldspar. All other data are from published experimental tests. A simple pressure-dependent crush-up model, following the approach of Ref. 13, is also developed.

Hydrocode Simulations and Analytical Calculations: A series of 1-D, 2-D and 3-D simulations are presented. The tri-linear (and a bi-linear, with a range fits reflecting the data in this intermediate regime) Hugoniot, as defined in U_s-u_p space, are used in two hydrocodes (AUTODYN and CAV_KO). A new composite Hugoniot, based on data for the constituent minerals is also used as input to the hydrocode simulations. Both sets of results are compared with analytical results based on the planar impact approximation (CAV_SHOCK).

Further Work: Strength and failure models for sandstone will be need to be implemented before a better understanding of the cratering processes. We plan to explore application of the Johnson-Holmquist 2 damage model, as previously used by the two of the authors to explore cratering and penetration in soda lime glass [17]. The objective is to characterise more fully the pressures generated on impact, and to draw broad conclusions on the pressure bounds for any changes observed in the microbial specimens. A constraint on the modeling will be provided by crater profile data, as shown in Figure 3. Plate data for water saturated sandstone are needed, noting recently reported results on survivability of microbial life differing between dry, and saturated, sandstone [18]. Modelling of larger scale impacts – a longer term aim – must consider gravity-driven effects, and other aspects, before any conclusions can be drawn about pressures experienced by any microbial life and changes in habitability driven by shock effects. The derived Hugoniot will be used to estimate release temperatures via analytical calculations of waste heat generated [13]. Initial observations suggest that material may have been emplaced downrange, possibly both from ejecta, and also down fracture systems (Figure 4). A detailed map of the impactor-bearing residue will need to be produced.

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