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Impact polymorphs of quartz: experiments and modelling.

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Abstract

We have used the light gas gun at the University of Kent to perform a series of impact experiments firing quartz projectiles onto metal, quartz and sapphire targets. The aim is to quantify the amount of any high pressure quartz polymorphs produced, and use these data to develop our hydrocode modelling to enable the prediction of the quantity of polymorphs produced during a planetary scale impact.

1. Introduction

High pressure polymorphs of quartz (such as stishovite and coesite) are generally found in association with terrestrial impact features (e.g. [1], [2]). These phases have been produced in the lab using high pressures and temperatures (e.g. [3]), and the phase diagram for quartz is thus well defined. Here we aim to couple the outputs of impact experiments to our hydrocode modelling to try and ascertain a relationship between the impact velocity (and thus peak pressure and temperature) and quantity of high pressure phases produced.

2. Experimental methodology

We have used the LGG at Kent [4] to fire polydisperse quartz powder onto high purity metal, quartz and sapphire targets. After impact the craters were imaged by SEM and mapped with a Raman spectrometer to identify any high pressure polymorphs produced. Table 1 gives details of the experiments carried out so far. Phases were identified by comparing spectra from Raman maps of impact residue to literature spectra.

Table 1: Details of shot programme. Phases (Fig. 4): ‘α’ = alpha quartz; ‘G’ = glass; ‘M’ = moganite [5]; ‘-‘ = TBD.

Shot ID	Velocity (km s^{-1})	Target materials	Phases
G100413#2	3.64	W, Al, Cu, In	α, -, -, -
G180413#2	4.85	W, Al, Cu, In	G, M, -, -
G260413#3	4.90	Quartz	α
G020513#1	7.24	W, Al, Cu, Sapphire	G, -, M, -

3. Selected results

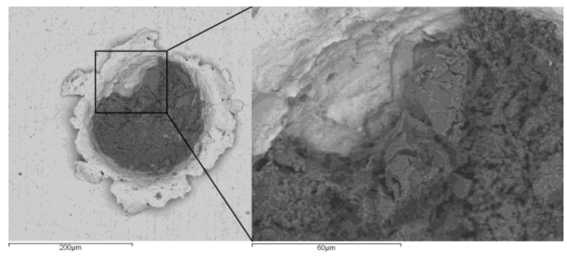

Fig. 1: Backscattered electron image (BSEI, 10kV) of an impact crater in copper from shot G100413#2. The dark residue is quartz which appears to be solid, with no signs of melt. The top left corner of the crater shows the residue partially peeled back revealing the underlying copper target material.

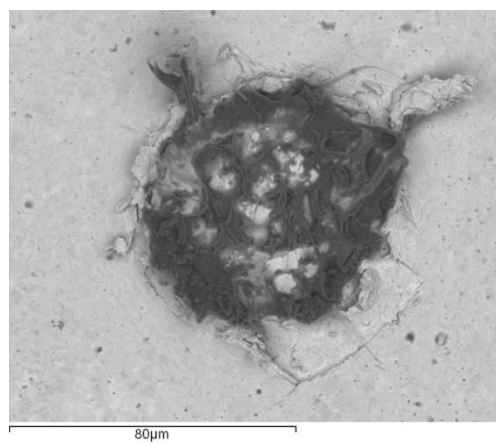

Fig. 2: BSEI (10kV) of an impact crater in tungsten from shot G180413#2. The dark residue is quartz which is extensively molten.

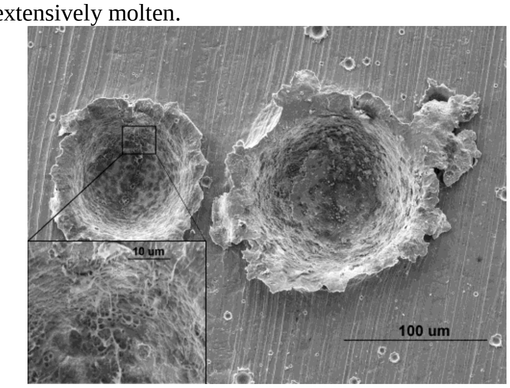

Fig. 3: Secondary electron image (20kV) of a pair of impact craters in copper from shot G020513#2. There is

evidence of a dark mottling on the interior surface of the crater, which EDX identifies as silicon rich impact melt. The left hand crater shows signs of vesiculation (inset) due to melting/boiling of either the projectile or target materials.

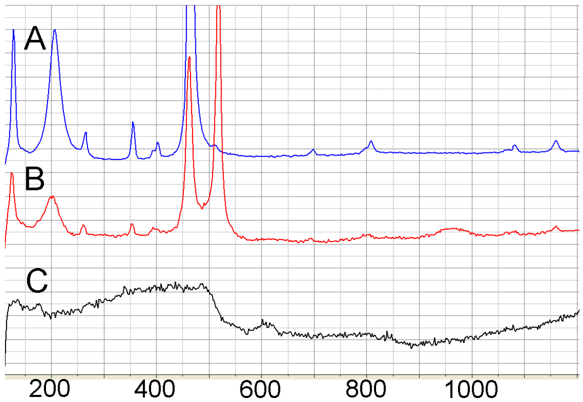

Fig. 4: Raman spectra of different states of quartz found so far. **A:** Spectrum from residue in Fig. 1 and indistinguishable from un-shot quartz (‘α’). **B:** Moganite (‘M’), a micro-crystalline phase found in aluminium and copper targets. **C:** Raman spectra of molten quartz (‘G’) found in tungsten targets. X-axis is in wavenumbers, and spectra are presented as taken with no baseline correction.

4. Hydrocode modelling

Work is underway to incorporate the results from our impact experiments, as well as published data on the equation of state for shocked quartz (e.g. [6]), into our hydrocode modelling. Here we used Ansys' AUTODYN hydrocode, incorporating a user defined equation-of-state and strength model for quartz. The results from our initial, first order, simulations are shown below. Our methodology is very simple; we track the pressure and temperature of a computational cell within the model, and assign it an appropriate phase (Fig. 5). This is a very simplistic approximation, but it has allowed us to test the user algorithm within AUTODYN. In addition, it enables us to obtain order-of-magnitude estimates of the peak pressures and temperatures generated during a hypervelocity impact and thus we can start to predict which high pressure/temperature phases we should generate. Future work is to incorporate equations-of-state for the high pressure phases so that are modelled more accurately and the results will be presented at the conference.

References: **[1]** Chao E. C, T. & Shoemaker E. P. 1960. *Science*, 132, 220. **[2]** Shoemaker E. P. & Chao E. C. T. 1961. *J. of Geo. Res.*, 66, 3371. **[3]** Tschauner O. et al. 2006. *Amer. Miner.*, 91, 1857. **[4]** Burchell M. J. et al. 1999. *Meas. Sci. & Inst.* 10, 41. **[5]** Kingma K. J & Hemley R. J. 1994. *Amer. Miner.*, 79, 269. **[6]** Panero W. R. 2003. *J. of Geo. Res.*, 108, B1, 2015.

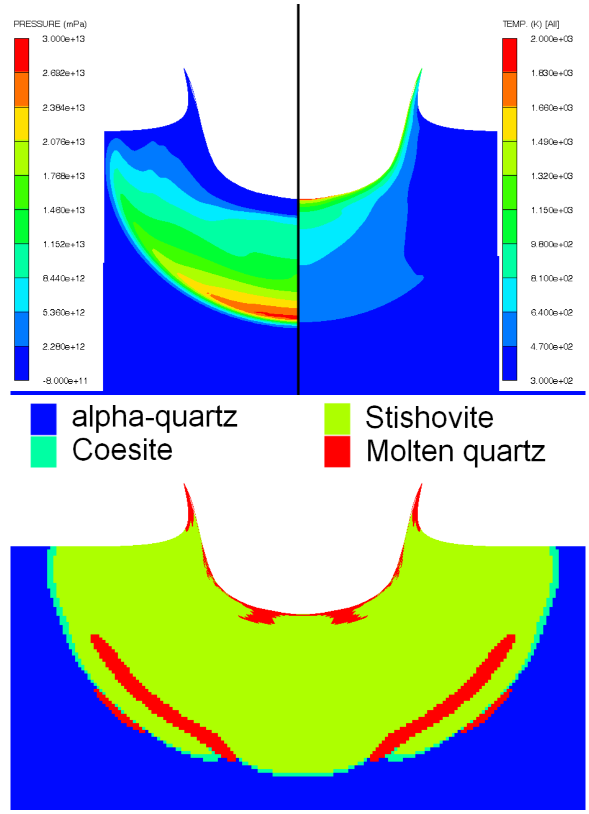

Fig. 5: AUTODYN output of simulation of a 50 micron diameter steel impactor hitting quartz at 5 km s^{-1}. **Top:** Contours of pressure (left) and temperature (right). **Bottom:** Equivalent phase if the temperature and pressure of each cell is naively mapped to the quartz phase diagram.

5. Conclusions

The results from the initial experiments show that at low speeds (3.64 km s^{-1}) the quartz projectiles shatter, but generally survive unaltered. At ~5 km s^{-1}, there is some evidence of modification of the quartz into moganite (although this is to be confirmed) in the copper and aluminium targets but for the tungsten targets the projectile material has molten completely. At the highest speed (7.24 km s^{-1}) for the copper target (the only one analysed so far) there is very little projectile residue remaining, however, small fragments are still present in the crater (Fig. 3) along with molten strings and a vesiculated texture within the crater. This vesiculated structure is possibly due to the melting and boiling of either/both the projectile or target materials resulting in a ‘honeycomb’ like texture.

Analysis is continuing as well as further shot experiments into targets of differing hardness and thermal conductivity.