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# Shock alteration of geological minerals from impact cratering experiments

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## Abstract

Shock synthesis of individual geological minerals has been investigated to discover the individual effects of differing levels of impact generated shock. We find that due to the structure of the minerals olivine, enstatite and diopside, the minerals are altered at different peak shock pressures (6 – 183 GPa). This report gives the initial results from an on-going project which aims to investigate shock effects in many common geological minerals to help us further understand the composition of highly shock material we study today.

## 1. Introduction

Impact cratering has shaped the celestial bodies of the solar system to those we observe and study today. These events create a sudden and short-lived environment of high energy, temperature and shock pressure at the point of impact that the geological materials are often altered, melted or vaporized [1]. The shock effect can alter the composition and even the structure of the geological minerals as observed by [2 and 3]. By recreating these impact scenarios in a controlled laboratory environment, the effect of different shock pressures on various mineral compositions and textures can be examined to aid in the understanding of the manner in which these high peak shocked pressure events have shaped the composition of the material that dominates our solar system today. This builds upon previous work and agrees with [4] that a new shock classification system is required.

## 2. Method

Powdered and whole grains of common geological minerals found in chondrites, including orthopyroxene, clinopyroxene powders and olivine (peridot), were fired at speeds between 1 and 7 $kms^{-1}$ (see table 1 for equivalent calculated shock pressures) into Al foil (1080) and Stainless Steel (304) using the Light gas gun (LGG) at the University of Kent [5]. The residues in the resulting craters were analyzed using Raman (532 nm), SEM and FEGSEM analysis and compared to the composition and structure of the un-shot minerals. Details of the shot undertaken so far are shown in Table 1. Values used for the calculation of the peak shock pressure using the planar impact approximation were taken from [6].

Table 1: Shots undertook showing the impact speed and calculated peak shock pressure.

| Mineral | Target | Impact Speed range ($kms^{-1}$) | Peak shock Pressure (GPa) |
|---|---|---|---|
| Olivine | Steel | 2 – 5 | 30 – 108 |
| Diopside | Al | 1 – 8 | 9 – 183 |
| Enstatite | Al | 1 – 7 | 6 - 105 |

## 3. Results

The initial results show that, depending on the structure of the mineral, a significant change in the composition can occur when experiencing different shock pressures. In this report, we focus on the results of the Raman analysis

### 3.1 Enstatite

The enstatite used has a composition of $En_{86}Fs_{13}Wo_1$ and was supplied by Anton Kearsley. Post-impact the residues show very few peaks when analysed by Raman and many are lost in the background, one peak shows a broadening effect between 650 and 750 $cm^{-}1$. This feature is observed at all the shock pressured investigated. This suggests that shock affects the Raman signal of enstatite at a much lower shock pressure then olivine, i.e. at about 29 GPa.

### 3.2 Diopside

The diopside mineral investigated had a composition of $Wo_{49}En_{48}Fs_3$ from Jaipur, India supplied by M. McCanta, University of Tennessee [7]. When the residue is compared to the Raman spectrum from the un-shot material most the major peaks are identified up to 145 GPa beyond this the peaks are lost and the carbon D and G band peaks become dominant and a broadening of the peaks around 730 $cm^{-1}$. The wavenumbers do vary compared with the unshot spectra but no correlation is observed between size/direction of shift and the shock pressures, this suggests that there are no observed effects up to a shock pressure of 145 GPa.

### 3.3 Peridot

The composition of the peridot used was $Fo_{96.}$
For impact speeds of 2.0, 3.3 and 5.3 km $s^{-1}$ there was no significant change in the position of the main Raman peaks, denoted as P1 and P2 (Table 2). This implies that a pressure of 108 GPa is required before large olivine mineral grains (here typically 3 mm peridot) show significant structural changes. This differs from the result of [2] which investigated much finer powdered (typically 1 – 10 µm) olivine material in similar impacts.
Though the P1 and P2 peaks remain un-altered, other small peaks at 961 cm $^{-1}$ are lost in all of the spectra of the post shot material.

Table 2: RAMAN wave number for the olivine P1 and P2 peaks of the impacted Peridot residue

| Impact speed | P1 position | P2 position |
|---|---|---|
| 2.0 km $s^{-1}$ | 823.7 | 855.7 |
| 3.3 km $s^{-1}$ | 823.9 | 855.9 |
| 5.3 km $s^{-1}$ | 822.2 | 854.2 |
| Un-shot | 822.2 | 854.2 |

## 4. Discussion

The comparisons between the shocked and un-shocked minerals show that pyroxene minerals exhibit a different structural/composition change to that of olivine. The different mineral types appear to experience a major change in structure detected by Raman analysis which is likely linked to the structure of the minerals, such as the chain and orthorhombic structure of the pyroxene and olivine respectively.

Note that samples place in the gun can subsequently show a large D and G Raman band, which is a result of contamination from the carbon within the rifle powder used in the experiments. Therefore we do not study the D and G bands in this work.

This work is ongoing and will soon include other common minerals such as feldspar (albite and anorthite), quartz and pyrite as well as detailed FEGSEM and SEM analysis of all residues. By understanding how each mineral reacts at different shock pressures the experiments can move on to shock syntheses of whole rock facies to understand the shock interaction between the different minerals at grain boundaries and other mineral interfaces.

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