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Experimental study of SO_2/SO_3 ratio in impact vapor plumes using a high-speed laser gun: initial results.

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Abstract

The chemical composition of impact-generated sulfuric oxides is important to investigate the killing mechanism of the mass extinction at the Cretaceous-Paleogene boundary. In this study, we conducted hypervelocity impact experiments using a laser gun and measured the chemical compositions of the impact-generated sulfuric oxides directly. The result clearly shows that the sulfur oxides released by the Chicxulub impact was dominated by SO_3, not SO_2.

1. Introduction

A large impact is widely accepted as the cause of the mass extinction at the Cretaceous-Paleogene boundary [e.g., 7]. However, the killing mechanism caused by the impact is still controversy. Some previous studies have shown the importance of sulfuric oxide gasses which were released from the S-rich sediments at the Chicxulub impact site [e.g., 6].

SO_2/SO_3 ratio of the impact vapor plume is a key parameter to assess the environmental perturbation. The residence time of sulfuric acid aerosol in the stratosphere changes dramatically depending on the SO_2/SO_3 ratio [2]. If the released sulfur oxides were dominated by SO_3, the residence time of the released sulfur in the atmosphere is very short and intense acid rain could have acidified oceanic surface layer significantly [3]. On the other hand, if the released sulfur oxides were dominated by SO_2, the residence time was longer than that of SO_3 and sunlight blockage and cooling caused by sulfuric acid aerosol could have occurred [5].

Recently, laboratory experiments by Ohno et al. [2] suggest that the degassed sulfur have been dominated by SO_3, not SO_2. However, no previous experimental studies created and observed actual impact vapor plumes of anhydrite, because experimental difficulty. Nevertheless, some recent studies show that a combinational method of laser gun experiments and direct gas analysis is applicable for the impact-induced vaporization experiments [e.g., 4]. In this study, we experimentally created impact-induced vapor plume of sulfate and analyzed the chemical composition.

2. Experimental Methods

We accelerate flyer foils to ~15km/s using a large powered and high speed laser gun (GEKKO XII-HIPER facility of Institute of Laser Engineering of Osaka University. Detail of the facility is described by [1].). The chemical compositions of the impact-induced vapor plumes were measured directly using a quadrupole mass spectrometer. A schematic diagram of the experimental setup is shown in Fig 1.

We irradiated a YAG laser pulse (1054nm, 10-20ns, ~1 kJ) on a 50 μm-thick plastic ablator, which is set in front of a 30 μm-thick tantalum flyer. The ablator is vaporized and the generated vapor accelerates the flyer to ~15 km/s. The flyer impacts and vaporizes anhydrite ($CaSO_4$) target rock, because the peak pressure is much higher than the vaporization threshold of anhydrite. A 200 μm-thick gold spacer is set between the flyer and the anhydrite target. We introduce the released S-bearing gas to a quadrupole mass spectrometer (QMS) through a SUS inhalation tube and analyze the chemical composition. The flyer and target sample are set in a large vacuum chamber and low pressure condition ($<10^{-3}$ mbar). We use an aluminum hollow sphere in order to avoid dispersion of the released gas to the vacuum chamber and to improve the S/N ratio of the QMS analysis.

3. Results and discussion

Fig. 2 shows an example of time series data of the QMS measurements. We observed significant

amount of sulfur oxides released by the impact. The blank level is much lower than the signal. Fig. 3 shows an integrated signal of one experimental run. The ratio of mass number 49/48, 50/48, 65/64, 66/64, 81/80, and 82/80 are consistent with the isotopic ratios of sulfuric oxides and indicate that these signals are derived from the released sulfur oxides. The observed SO_3^+/SO_2^+ ratio is larger than 0.5, although the QMS sensitivity of SO_3 is much lower than that of SO_2. This indicates that the sulfur oxides generated by the anhydrite impact are dominated by SO_3.

The SO_3 rich chemical composition observed in this study signify that the sulfur oxides generated by natural planetary scale impacts are dominated by SO_3, not SO_2. First, the experimental condition in this study generates potential reducing agent such as the vapor of plastic ablator and flyer. These vapors can reduce the generated sulfur oxide and the SO_3/SO_2 ratio observed in this study can be lower than that of "pure" anhydrite impact vapor. Second, the sizes of planetary scale impact such as the Chicxulub impact are much larger than that of this study. Larger impact vapor plumes cool more slowly and have lower quenching temperature of chemical reactions. Thus, more SO_3 is formed in larger impact vapor plumes, because SO_3 is more stable at low temperatures [3]. Enormous amount of SO_3 release indicates that significant oceanic acidification could have occurred after the Chicxulub impact and caused strong environmental perturbation.

References

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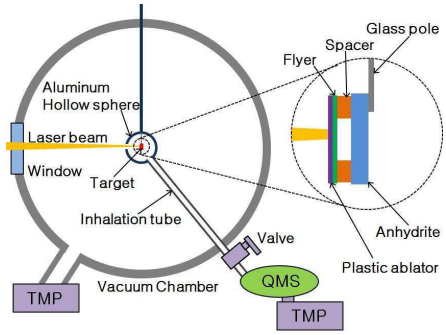

Figure 1: The experimental setup.

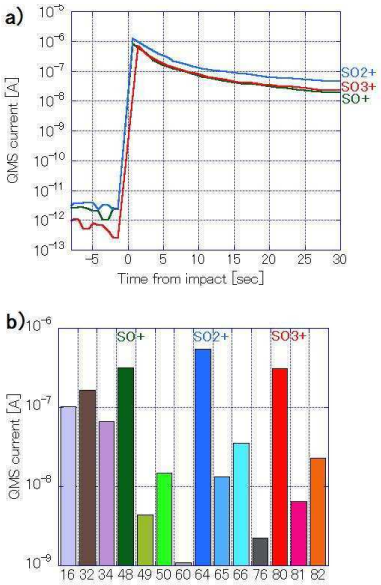

Figure 2: a) An example of the time-series data of the QMS measurements. The QMS currents of SO^+, SO_2^+, SO_3^+ are the signals of sulfuric oxides. The QMS currents increased significantly at the timing of the impact. The time-lag of SO^+, SO_2^+, and SO_3^+ is caused by a time delay of the QMS. **b)**A mass spectrum of the released gas observed in this study.