

TRAPPING OF CARBON DIOXIDE FROM A HOT ATMOSPHERE BY CONDENSING SILICATES.

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Planetary atmospheres are thought to be the result of release of volatiles during the bombardment of a growing planet by massive planetesimals. According to some models, the accumulation of impact-released water vapor and/or carbon dioxide can result in a dense and hot primordial atmosphere [1,2,3]. As a sink for atmospheric carbon dioxide only a post-impact formation of carbonates was considered [4]. In our experiments we show that the formation of carbonates is already possible during impact processes. In a previous set of experiments we investigated the trapping of water vapor from an atmosphere by condensing matter which originates during high-temperature pulse heating of pyroxene in a wet atmosphere, thus simulating the interaction of a wet atmosphere with ejected condensing matter during impact of a planetesimal [5,6]. An effective trapping of water vapor by condensed silicate matter was discovered, giving an amount of up to 10 wt% of trapped water. The activity of small condensing silicate particles in a spreading hot vapor cloud in a CO₂ atmosphere can also result in the formation of carbon bearing phases in the condensate leading to trapping of atmospheric carbon dioxide during an impact.

Here we present results of an experiment of interaction of a carbon dioxide atmosphere with condensing silicate matter which originated during high-temperature vaporization of clinopyroxene (Na- 1.95, Mg- 7.13, Al- 4.29, Si- 18.00, Ca- 6.05, Ti- 0.31, Fe- 2.51 atom%). As in our previous experiments [7,8,9], vaporization was achieved by a powerful neodymium laser pulse focused on a sample mounted in a hermetic cell with a volume of ~500 cm³. Parameters of the pulse are: luminous energy ~600 J, duration ~10⁻³ s, density of luminosity ~5.10⁶ W/cm². The estimated temperature of vaporization was 3000-4000 K. The cell was filled with 1 atm of carbon dioxide. A noticeable amount of condensed particles with dimensions from 50 to 1000 Å originated in a spreading hot cloud [5] which could mix and interact with CO₂ inside the cell. A part of the condensate was collected on a Ni-foil which was placed at a distance of 8 cm from the sample. Chemical analyses of the condensate were made using X-ray photoelectron spectroscopy (XPS) which provided both elemental chemical composition of the condensate and the distribution of elements between different phases. Condensed films were etched layer by layer (with a step of 200 Å) by a beam of argon ions and for every layer XPS analysis was performed providing an information of the cross-section of the film.

XPS analyses reveal the presence of a noticeable quantity of carbon which is trapped in the condensate. The main carbon-containing phases which we could distinguish in the condensate are: carbonates, carbides, amorphous carbon and chemisorbed CO₂. Carbonates are mainly formed with Ca and to lesser extent with Fe and Mg. Carbides are mainly formed with Fe. The concentration of trapped carbon-containing phases in bottom layers of the condensed film was ~1.5 wt% of CO₂ and ~0.5 wt% of carbon in amorphous and carbide phases, and in the upper layers it was ~4 wt% and ~2 wt%, respectively (Fig. 1). The bottom layers of the film represent the front part of the spreading vapor cloud which came to the Ni-foil and stuck to it first. The upper layers were formed by the last portions of evaporated matter and by sticking of condensed particles and radicals which were dispersed into the inner gas environment of the cell after the end of the laser pulse. In general the last portions of condensed films are formed at lower temperatures than front and inner parts of the film. The efficiency of CO₂ trapping is apparently higher during the last stages of condensation. The average total concentration of elemental carbon in the condensate is about 1 wt%, which is higher than in normal igneous rocks.

The same pyroxene was used in our previous experiments, where it was evaporated in an inert atmosphere of helium, and the condensed film was analysed in the same way by XPS [8]. An important difference between the experiments in helium and in CO₂ atmosphere is the presence of reduced forms of certain elements in the experiment in inert helium (~9% of silicon in the form of Si⁰ and Si²⁺, ~15% and ~7% of Al and Fe in metallic form, integrated through the volume of the film) and their absence in the experiment in CO₂. The same effect was observed after evaporation in a wet atmosphere [5], where water vapor provided for an effective oxidation of the condensate. The absence of reduced forms of elements in

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the experiment in CO_2 atmosphere also shows the oxidizing role of CO_2 molecules in the vapor cloud. The ratio $\text{Fe}^{3+}/\text{Fe}^{2+}$ for the whole condensed film in the CO_2 experiment is ~ 1.9 , that is twice as high as in the experiment in helium [8,10].

These experimental results prove the possibility of effective trapping of water vapor and of carbon dioxide from an atmosphere by dispersed hot condensing silicate matter. The trapping of gases proceeds with the formation of stable volatile-bearing phases. The concentration of trapped CO_2 can amount up to ~ 4 wt.% of the condensate. The efficiency of the trapping process suggests that it could be a feasible mechanism controlling the impact-induced formation of an atmosphere.

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Fig.1. Concentration (in wt%) of trapped carbon in the form of carbonate (left axis) and of carbide and amorphous carbon (right axis) through the depth of the condensed film from its surface to the bottom.

