

THE ORIGIN OF NONEQUILIBRIUM ATMOSPHERE AT THE STAGE OF THE EARTH'S ACCRETION

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According to modern concepts, the origin of the Earth, especially the final stage of its formation as a planet, was characterized by falling of large planetesimals on the growing embryo (1,2,3). When the radius of the growing planet reached approximately half of its present radius the velocities of the falling bodies began to exceed ~ 6 km/s. The falling of planetesimals with such velocities had to cause an intensive release of gases in shock processes (4). Probably, such a shock degassing must have resulted in the origin of the Earth's primitive atmosphere (3,5). It is obvious that the initial stages of the evolution of such an atmosphere cannot be understood without detailed information on the chemical composition of gases released in the shock processes.

The release of gases during the shock processes results from the degassing of the planetesimals matter during evaporation, melting and heating of the solid material (4). Shock evaporation, in our opinion, is the most complex and interesting mechanism of shock degassing. Matter, involved in the process of evaporation is, to a great extent, dissociated. New molecules originate at the stage of expansion and cooling of the evaporated cloud, when it lost its thermodynamic equilibrium. Such a process is highly nonequilibrium and can result in a considerable change of the composition of gases which were incorporated in the matter of planetesimals by the mechanisms of condensation in the protoplanetary cloud. This process can also result in the origination of new gas molecules from the volatile elements, which were constituents of the planetesimals matter.

We attempted to model a shock evaporation process and to analyse the gas phase released under evaporation. An analysis of the evaporation process shows that it can be modeled by reconstructing the PT-conditions at a point on a gas-melt equilibrium curve (point 2 in Fig. 1), where it is intersected by the isentrope after unloading from an impact-compressed state (point 1 in Fig. 1). The most critical is the reconstruction of temperature conditions of evaporation, because the above-mentioned effects are exponentially dependent on temperature. Temperature in point 2 (Fig. 1) can be calculated (6,7,8) and induced by an impulse laser (9,10).

In our experiment we used an impulse laser, working on neodymium glass, with the energy of an impulse ~ 800 J, a wave length $1.06 \mu\text{m}$ and duration of the impulse $\sim 10^{-3}$ sec. By means of a focusing lens the density of the energy flux of the order of $\sim 10^{17} + 10^{18}$ W/cm² was created. As an object of exploration we used natural quartz. The composition of gases contained in the bubbles incorporated in a quartz sample was measured by standard methods (11). This quartz sample was placed into a hermetic box made of stainless steel with an optical quartz window. The box was heated to reduce adsorption effects and filled with helium under the pressure of ~ 1.2 atm. After the shot, the originated gas phase was collected in a trap filled with activated coal and placed into liquid nitrogen. At the beginning of the analysis this trap was heated up to $\sim 120^\circ\text{C}$ and the gases were transmitted to the gas chromatograph and separated on two columns filled with molecular sieves A5 and Porapac Q.

A typical composition of gases released by one shot was as follows: $\sim 1 \cdot 10^{-6}$ g H₂, $\sim 12 \cdot 10^{-6}$ g O₂, $\sim 0.1 \cdot 10^{-6}$ g CH₄, $\sim 20 \cdot 10^{-6}$ g CO₂, $\sim 15 \cdot 10^{-6}$ g CO, $< 10^{-6}$ g N₂. These quantities of gases cannot be referred to any exact volume of quartz because of the complexity of a laser-produced crater which has a noticeable zone of cracks. Thus, we can only compare the relative concentrations of gases released by a laser impulse and by "cold" release. The quantities of gases released by "cold" methods per 1 g of this quartz are as follows: $17.6 \cdot 10^{-6}$ g CO₂, $2.6 \cdot 10^{-6}$ g CO, $0.9 \cdot 10^{-6}$ g CH₄, $3 \cdot 10^{-6}$ g N₂, $2.1 \cdot 10^{-4}$ g H₂O (11). O₂ and H₂ were not detected in "cold" release.

The most interesting result of the experiment, from our point of view, is the release of the molecular oxygen. It can originate as a result of thermodissociation of oxygen-containing molecules CO₂, CO, H₂O and SiO₂ as well. The energies of molecular bonds are: Si-O - 3.8 eV, C-O - 3.7 eV, H-O - 4.8 eV, C = O - 7.4 eV. The main portion of O₂, probably, was released due to thermodissociation of SiO₂. After a second shot into the same-laser produced crater a considerable reduction in the release of H₂, CO, CO₂ was observed. However, release of O₂ was at the same level as in the first shot. The fact of SiO₂ thermodissociation is very important because it means that molecular oxygen could be released into the atmosphere as a result of impact processes at the final stage of the Earth's accretion irrespective of whether O₂ or other oxygen-containing gases were incorporated into planetesimals because it could be released due to thermodissociation of crystal oxides.

The relation of gases CO/CO₂ in a "cold" release was 0.15. In our experiment this value was $0.6 + 0.8$ which means that CO originated during a laser impulse. Water was not correctly measured, probably, because of its noticeable adsorption on the box walls.

The results of our experiment cannot be directly related to the shock evaporation processes of large planetesimals because of scale factors. But the results obtained show a principal possibility of the release of gases with a nonequilibrium composition O₂, CO, H₂ and others into a primitive atmosphere in impact processes at the final stage of the Earth's formation. Because of their chemical activity these gases intensively escaped from the atmosphere being bound with the regolith. Since this escape of gases was proportional to their partial pressure in the atmosphere and the source of the gases was constant, there had to exist a residual pressure of gases O₂, CO, H₂. The quantity of gases, released during the whole period of accretion, could be considerable because about $\sim 10\%$ of the Earth's mass was subjected to evaporation (3). Due to weathering processes these gases could also affect significantly the evolution of the Earth's protocrust (12).

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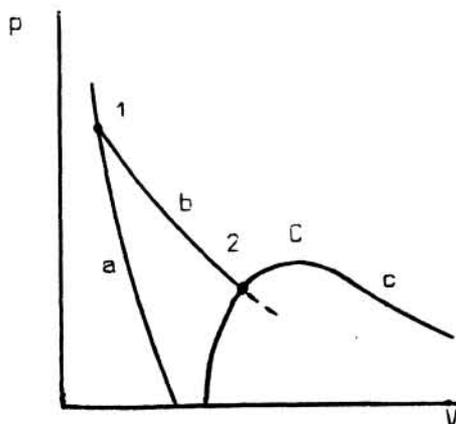


Fig. 1. a) Hugoniot adiabat,
 b) isentrope,
 c) gas-melt equilibrium curve.

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