

HYPERVELOCITY IMPACTS OF PLANETESIMALS AS A SOURCE OF ORGANIC MOLECULES AND OF THEIR PRECURSORS ON THE EARLY EARTH. I. M. Mukhin, M. V. Gerasimov and E. N. Safonova, Space Research Institute, U.S.S.R. Academy of Sciences, ul. Profsoyuznaya, 84/32, Moscow, 117810, U.S.S.R.

Earth's accumulation was characterized by high-temperature transformations of planetesimal matter during impact processes. During accumulation, at the final stages of the Earth's growth ($V_{\text{impact}} \sim 12 \text{ km/s}$), up to 30% of planetesimal mass and the same mass of the target were evaporated [1-3]. Impact processes may have been important during the formation of the Earth's atmosphere and hydrosphere as it was convincingly demonstrated that the Earth's atmosphere was forming simultaneously with its growth [5-7]. Melting and vaporization of planetesimal matter during impacts was very efficient for the release of volatiles from colliding matter. In our experiments the effect of a laser pulse on various (ultra-)mafic rocks and meteorite material was used to simulate high-temperature vaporization which occurs during hypervelocity impacts [7]. An important feature of vaporization processes compared with degassing from melts is thermo-dissociation of crystal silicate matrices which provide a relatively dense vapor cloud above the melt. It is important, that for laser pulse heating with density of luminosity $> 10^6 \text{ W/cm}^2$, and pulse duration $> 10^{-6} \text{ s}$, the conditions near the evaporating surface provide thermodynamic equilibrium in the silicate vapor as well as during large-scale impact evaporation [7]. Therefore, the difference of chemical compositions of the vapor phase for laser experiment and for impacts will be defined by the difference at the quenching point during expansion of the vapor cloud. The analysis [7,10] shows that during expansion of the vapor cloud, according to the saturated vapor law, the relative concentrations of major gases in the mixture are weakly temperature dependent. Thus, we will assume that gasses released by laser vaporization and impact vaporization may be correlated.

Residual gas mixtures, which we collected after evaporation of samples, are composed of both oxidized and reduced components: CO ; CO_2 ; SO_2 ; H_2O ; O_2 ; H_2 ; N_2 ; H_2S ; COS ; CS_2 ; various hydrocarbons from C_1 to C_6 ; HCN and CH_3CHO . Residual gas mixtures from different samples qualitatively resemble each other for each sample. This is because in an inert atmosphere carbon and sulphur mainly evolve as oxides— CO , CO_2 , SO_2 , irrespective of the fact that in some samples (e.g. meteorites) carbon and sulphur were present in their reduced state. Oxidation processes, which guide the chemistry of the cloud, are the result of molecular and atomic oxygen in the vapor cloud produced by thermo-dissociation of silicate minerals in our samples [8,9]. The concentration of molecular and atomic oxygen in the cloud is estimated as $\sim 30\%$ [7]. Oxygen actively interacts with condensed particles and it is almost completely absorbed during cooling [8]. Importantly, oxides of carbon, CO and CO_2 , were also the main carbon-containing compounds even during vaporization of samples in an H_2 atmosphere. Moreover for different type of meteorites and rocks the ratio CO/CO_2 differs within one order of magnitude irrespective of the nature of the atmosphere (He or H_2) in which vaporization was performed. The ratio of the sum of oxides $\text{CO} + \text{CO}_2$ to the sum of hydrocarbons and the relationship between hydrocarbons are also reproducible within one order of magnitude. While the production of carbon oxides was predominant the quantity of produced hydrocarbons was also noticeable, which amounted $\sim 5\%$ of carbon-containing gasses. The observation is that experiments in an H_2 atmosphere in comparison with those in an inert atmosphere resulted in (1) formation predominantly of carbon oxides relative to hydrocarbons and (2) comparable patterns of distribution of hydrocarbons, although a slight increase of CH_4 production was noted. This observation supports the formation of hydrocarbons by quenching in a hot inner part of a vapor cloud which is not mixed with ambient gas. By contrast, the formation of sulphur-containing gasses proceeds even in parts of a vapor cloud which are mixed with ambient gasses and resulted in formation of mainly H_2S in the hydrogen atmosphere contrary to SO_2 formation in the inert atmosphere. Laser pulses with density of luminosity $10^7 - 10^8 \text{ W/cm}^2$ produced a significant amount of hydrocarbons but with decrease of intensity of the laser pulse the output of hydrocarbons

also decreased and for laser pulses with density $<10^6$ W/cm² their abundance was below the detection limit of the instrument while release of other major gasses did not change. Thus, we suggest that hydrocarbons are indeed formed inside a hot and dense vapor cloud and not by pyrolysis of organic matter already present in the samples. Significantly, the majority of the hydrocarbons is non-saturated. It is important that together with hydrocarbons, organic compounds containing the heteroatom – HCN and acetic aldehyde – were measured.

Stable qualitative reproducibility of gas mixtures of this composition suggest that our experimental data may be used for evaluation of the chemical composition of the early Earth's atmosphere which formed during evaporation of matter due to high-velocity impacts. If one consider that impact-evaporative processes were the main source for gasses into the Earth's atmosphere in its final stages of formation, than was the input of gasses mainly as oxides, CO, CO₂, SO₂, H₂O, molecular nitrogen and a certain non-negligible quantity of reduced species. Thus, impacts of planetesimals were characterized (1) by production of organic molecules during impact-evaporative process and (2) by evolving into impact-generated atmosphere of gasses, which compositions were favorable for abiogenic synthesis of rather complex organics under the action of different inputs of energy. The occurrence in these mixtures of saturated, non-saturated and aromatic hydrocarbons, and of precursors of organic matter, such as HCN and acetic aldehyde, proves the possibility of enhanced abiogenic synthesis.

Concentrations of HCN and acetic aldehyde in our experiments are about 0.1% of the sum of major components. Yet, it is interesting to have a numerical assessment and to compare our data with the data obtained for a large meteorite passing through the Earth's primordial atmosphere [4]. In our experiment, the total amount of gasses released during evaporation of about 10 mg of the L5 ordinary chondrite Tzarev is about 0.15 cm³ STP. Thus, extrapolation of our results to an impact process predicts that about $1.5 \cdot 10^{17}$ molecules of HCN and acetic aldehyde per gram of evaporated matter may be formed during impact evaporation. Assuming a mass for the passing impactor of 10^{17} g, Fegley et.al. [4] have estimated the number of HCN molecules that will form as the result of air shock waves at 10^{33} in the atmosphere composed of CO, CO₂, N₂, H₂O. They have estimated the number of HCN molecules at 10^{37} in an atmosphere composed of CH₄, CO, N₂. The respective yield of formaldehyde in their model is 5–16 orders of magnitude lower than the yield of HCN. The number of molecular precursors of organic compounds that originated as a result of complete vaporization of a meteorite of 10^{17} g mass is about 10^{34} molecules of HCN and at least 5 times less for acetic aldehyde. These amounts are comparable to the production of HCN and noticeably larger than the production of aldehyde and hydrocarbons in comparison with the production of HCN, aldehyde and hydrocarbons by the mechanism of impact reprocessing of an atmosphere. It is clear that estimates of realistic production of organics and their precursors during large-scale impact process needs a detail account of scaling effects. Nevertheless, impact-evaporative processes must be taken into account as a new possible source for origin of organic matter and its precursors on the early Earth.

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