EPSC Abstracts,
Vol. 4, EPSC2009-675, 2009
European Planetary Science Congress,

Possible composition of the early impact-generated atmosphere and its role in the origin of life.

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Introduction.

There is general understanding that Earth's atmosphere, ocean and life emerged very early in its history. The oldest known rocks testify that all these events occur earlier than 3.8 Ga ago. A possible mechanism of early global release of volatiles can be impact-induced processing of planetesimals during accretion period. Impact-induced degassing [1, 2, 3] could be a powerful source of volatile components which provided emergence of early atmosphere, ocean and life in time of planetary growth. The paper discus possible composition of the early Earth's atmosphere and its role in the origin of life.

Chemical composition of impact-induced gases.

Low-velocity impacts decompose volatile-bearing minerals to release H_2O, CO_2 and SO_2. Hypervelocity impacts, which provide vaporization of colliding material, are characterized by complex vapor plume chemistry and result in formation of specific gases from volatile elements of the plume. Earlier we investigated chemical composition of gases which were the result of simulation of impact-generated vapor chemistry [4]. Experiments were performed using various rocks, minerals, and meteorites. It was discovered that chemical composition of released gases was qualitatively similar for all samples despite of diversity of their composition. The gas mixture was composed of oxidized and reduced components including CO, CO_2, H_2, O_2, H_2O, N_2, SO_2, H_2S, COS, CS_2, HCN, CH_3CHO, hydrocarbons from C1 to C6 [5].

Impact vaporization thermally releases oxygen as O_2 and O into the plume [4] that is the result of thermal decomposition of petrogenic oxides. Though its lifetime would have been extremely short some oxygen may have escaped into the wider atmosphere. Carbon gases are also released in this process, mainly in the form of CO and CO_2 in a ratio of about 1:1 [5]. For the sulfur-containing gases SO_2, COS, H_2S, and CS_2 also occur in impact processes (Ivanov et al., 1996, Gerasimov et al. 1994, 1997). Nitrogen is released from impacts mainly as N_2 and some oxides NO_x. Synthesis of HCN and traces of CH_3CN occurs. The amount of nitrogen in the impact-released gases is limited by its trace concentration in meteorites and surface rocks. More nitrogen can be involved in impact chemistry by interaction of a projectile or expanding plume with a nitrogen-containing atmosphere. Passage of a large asteroid through the Earth's atmosphere may in theory have produced nitrous oxides and hydrogen cyanide in an air shock wave [6, 7].

Redox state of impact-induced gases.

Gas mixtures formed after impacts are in disequilibrium compared to normal conditions. Significant quantities of oxidized and reduced components were present simultaneously in the gas mixtures (e.g. H_2 and O_2, SO_2 and H_2S, CO_2 and CH_4). The most abundant reduced gases in quenched mixtures were H_2, H_2S, CH_4, and light hydrocarbons up to C_6H_6. Coexistence of O_2 and H_2 in silicate vapors at high temperature is supported by thermodynamic calculations [8].

Iron is present as Fe^0, Fe^{+2}, and Fe^{+3} reflecting complex redox processes in the vapor. Formation of metallic iron is accompanied by the increase of the portion of Fe^{+3} compared to the starting sample. The main rock-forming element, silicon, also has complex redox behavior. We detected silicon in Si^0, Si^{+2}, and Si^{+4} states [9].

Formation of organics during an impact.

An impact of a meteorite into the Earth is generally considered as destructive process for organics because of the action of two factors: 1) extremely high temperatures, and 2) oxidizing

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conditions in the forming plume. Experimentally proven impact-generated hydrocarbons included: CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_4, C_3H_6, C_3H_8, C_4H_{2-8}, C_4H_{10}, and C_6H_6 [10]. Production of unsaturated hydrocarbons is noticeably higher than of saturated. The only experimentally proven oxygen-containing organic molecule is likely to be CH_3CHO. The output of organics in and after an impact is correlated with the total amount of C and H in the starting material of the impact. The mechanism of hydrocarbon synthesis is still unclear. The amount of formed organic species is orders of magnitude higher than gas phase thermodynamic equilibrium [8]. We claim for heterogeneous catalysis on the surface of glass nano-particles which are condensing everywhere in the spreading cloud. Possibly Fischer-Tropsch synthesis occurs [11, 12], involving reaction of carbon monoxide and molecular hydrogen (abundant in the vapor). This reaction uses surfaces of condensing particles as catalysts. The role of surface catalysis is also supported by observed synthesis of sufficient amount of complex kerogen-like organics bound to condensates, which were insoluble in solvents but detected by C-C and C-H bonding [13]. X-ray photo-electron analysis also have shown that amino- and carbonyl- groups were also present in correlation with C-H bonds in the condensate in some experiments.

Conclusions.

Impact-degassing source could provide a release of enormous quantities of various gases during accretion period. The mixture of these gases includes both oxidized and reduced components providing highly nonequilibrium source of atmospheric gases. Disequilibrium composition of evolved gases provided high potential of chemical activity in the early ecosystem with expense of the most chemically active components. The forming impact-generated atmosphere was predominantly neutral. Production of diverse organic species which are released into the forming atmosphere and ocean with various nutrients and disequilibrium environment could be a good base for the origin of life.

Acknowledgment

This research was supported by the RAS Program of Basic Research (P-15/1) and RFBR grant 07-05-01054 and 08-05-00786.

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