VAPORIZATION AND CONDENSATION TEMPERATURES OF HASP AND GASP GLASSES OF LUNAR REGOLITH

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Key words: *evaporation, condensation, Lunar, regolith*

During high velocity impact cratering events on lunar surface some masses of the impactor and target rocks are melting and vaporizing. Then an expanding cloud (or plum) of vapor, dispersed melt and solid debris occurred and this process leads to sharp cooling, quenching of the melts and partial vapor condensation. The condensation is appearing in the volume (spherule) form and in the film condensation on the mineral grain surfaces. The obvious impact vaporization proofs were discovered among glasses in ultra thin fraction (~0.4-10 µm) of lunar regolith. In the paper [1] some unusual glass compositions were presented. These glasses were from Apollo 16 regolith and they had very high Al_2O_3 (more 32 wt. %) and very low SiO_2 (less 34 wt. %) contents. It permitted to call them HASP glasses (High-Alumina-Silica-Poor). The paper's authors suggested that the HASP glasses were originated during impact process and selective vaporization of high alumina lunar basalt. This idea was confirmed by a number of authors [2-7] who discovered similar glasses practically in all lunar materials.

In the last publication, devoted to impact lunar glasses, P. Warren [7] presented much morphological and chemical data of HASP glasses as well as condensate glasses which were called GASP ones (Gas-Associated Spheroid Precipitate). The glasses were described in regolith breccia of the Apollo 14 materials. GASP glasses had spherule form (<10 µm) as the results of volume melt condensation. The Al_2O_3 contents in all GASP spherules was never more than 2.5 wt. %, and average contents was 0.4 wt. %. The chemical peculiarities of GASP glasses permitted to divide glasses into two groups: FeGASP glass condensates enriched by FeO (up to ~40 wt. %) and SiGASP glass condensates enriched by SiO_2 (up to ~90 wt. %).

Based on experimental data of the vaporization of the high alumina lunar basalt (the sample № 68415; Apollo 16) [8] and the calculated data on residual melt and complimentary vapor compositions at different temperatures and mass vaporization losses, we compared these data with the P. Warren's HASP and GASP spherule glass compositions. The aim of this comparison is to determine the vaporization and condensation temperatures and mass vaporization losses of HASP and GASP glasses which located in the Apollo 14 regolith.

The initial composition of the basalt sample № 68415 was (wt. %): SiO_2 45.5; TiO_2 0.3; Al_2O_3 28.7; FeO 4.3; MgO 4.4; CaO 16.4; Na_2O 0.4 K_2O < 0.1. The experiments on the basalt vaporization were carried out by effusive Knudsen cell method with mass-spectrometric analyses of vapor phase [8, 9]. The method permitted to measure equilibrium partial pressure of components, temperatures of the vapor-melt system in the wide range values up to ~2600^{o}C. The partial pressure interval, measured in the experiment, was 10^{-1} - 10^{-7} torr. The Knudsen cell was heated by electron bombardment technique. The temperature was measured by optical pyrometer in the cell hole, which imitated the radiation of the absolute black body. The accuracy of the temperature measurements was ± 1^o. The material of the Knudsen cell was W. For decreasing of reduction influence of the W-material the sample (15 mg) was put into Re-tube. The experiments were carried out in the step by step of heating regime. The temperature step was in average 50^o. The whole mass-spectra measurement time at the temperature step was ~15 min. Such regime permitted to keep molecular current during experiment. The total time of experiment from T~900^{o}C till full sample vaporization was ~5-7 hours.

The measurements of component partial pressure permitted to calculate the vaporization velocity of each component using Knudsen-Hertz formula. In its turn the vaporization velocity permitted to determine the composition of the residual melt and complimentary vapor at each temperature step and at each stage of mass losses [8]. The residual melt compositions were determined using measured vaporization velocity of the components at all stages (temperature and time) vaporization up to its full vapor transition. After recalculation of the component mass into oxide forms and normalization mass ratios to 100 wt. % it was obtained total composition of residual melt at each temperature step. The complimentary vapor compositions have been determined by subtraction of the component mass in residual melt from the component mass in initial sample. The final vapor compositions were determined by adding of all component masses and reducing total mass to 100 %.

The experimental results showed that at the initial vaporization stages the vapor consisted in general of alkali components (fig. 1). At the low mass losses (M, % ≈ 5%) K_2O vapor contents reached 3-5 wt. % and the Na_2O vapor contents reached ~10 wt.%. These high alkali values were usual for melt temperatures up to ~1700^{0}C. But at already vaporization melt mass losses >20% and respectably at temperature >1850^{0}C the alkali fraction in the vapor was ~1 мас.% and less.

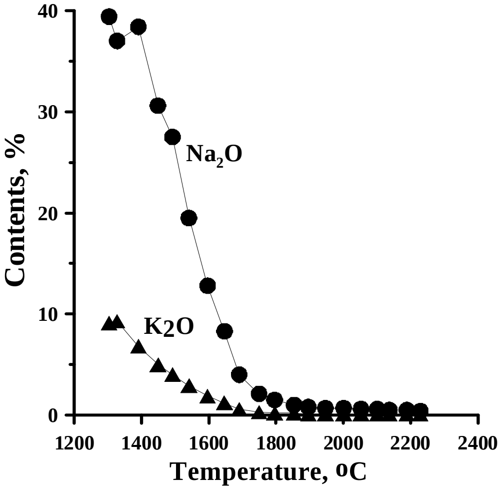

Fig.1. Concentration of alkalizes in vapor phase in dependence on temperature of basalt melt-vapor system

Figs. 2, 3 show the contents of the main components in the residual melts in dependence on the temperature and mass losses, and figs. 4, 5 show the same but for the complimentary vapor. Experimental data reveals that the main components of the residua melts were SiO_2, Al_2O_3 and CaO, and the main components of the vapor were FeO and SiO_2. The contents of these components express the temperature conditions of the vaporization. So, it permits to draw the thermometric diagram in the coordinates Al_2O_3-SiO_2 for residual melts and in the coordinates FeO-SiO_2 for vapors and its condensates. It is worth to note that the increase of SiO_2 in the vapor goes only up to T~1855^{o}C and than it steadily decreases due to its loss from the system and enrichment of the vapor with Al_2O_3 and CaO.

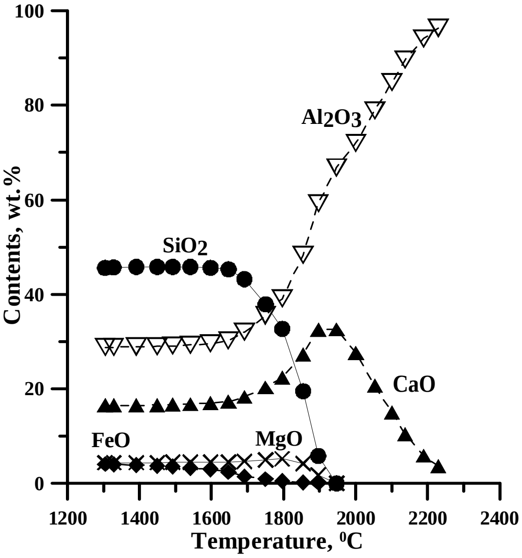

Fig.2. Concentration of main elements in the residua melt of basalt sample 68415 (Apollo 16) vs. temperature

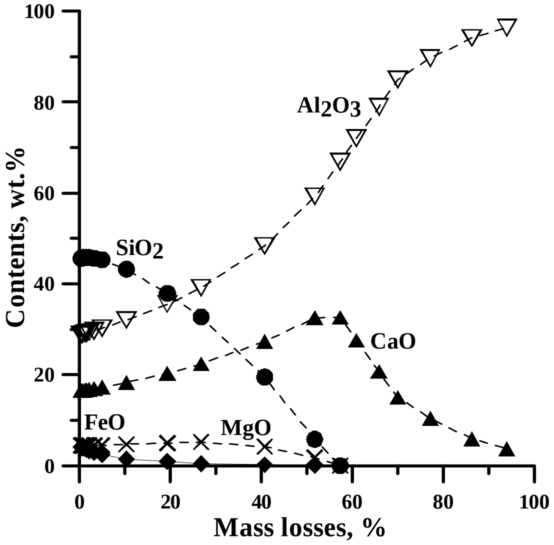

Fig.3. Concentration of main elements in the residua melt of basalt sample 68415 (Apollo 16) vs. mass losses

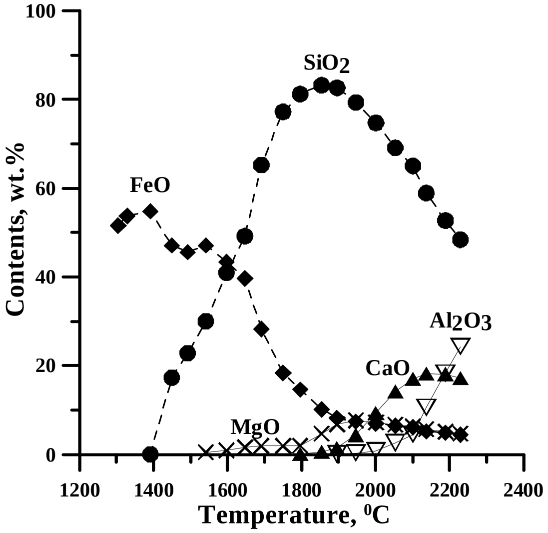

Fig.4. Concentration of main elements in the vapor phase during evaporation of basalt sample 68415 (Apollo 16) vs. temperature

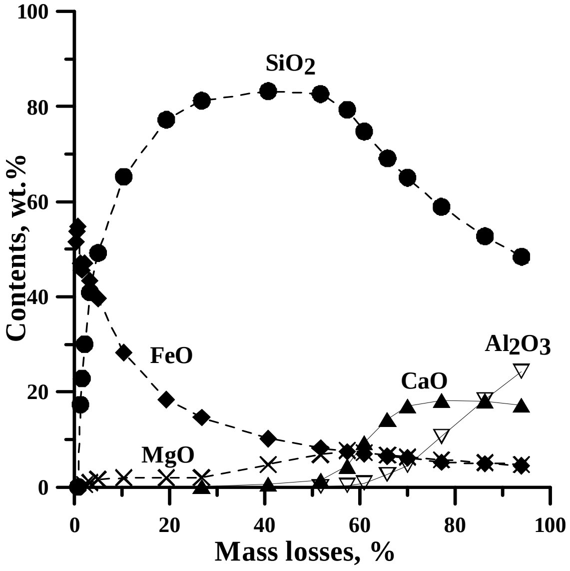

Fig.5. Concentration of main elements in the vapor phase during evaporation of basalt sample 68415 (Apollo 16) vs. mass losses

Experimental compositions of the residua melts and complementary vapor were compared with compositions of HASP glasses and GASP [7] particles, which originated during vaporization-condensation process in impact-produced plumes on the Moon. Earlier the temperature of HASP formation was evaluated as >1600^oC with respective mass loss about one forth to one third of starting mass [7]. Compositional trends of melts and vapor on Al_2O_3-SiO_2 and FeO-SiO_2 diagrams respectively are informative for more exact evaluation of temperature and mass loss of evaporating material. Figs. 6, 7 show the sequence of experimental data with defined temperature of evaporation and mass losses. Fig. 6 shows compositions of HASP glasses which have good coincidence with experimental compositional trend. All HASP glasses correspond to temperatures in the range ~1750-1870^0C and mass loss in the range ~20-50%. The dispersion in HASP glasses composition is a result of individual thermal trend of each particle caused by temporal and spatial inhomogeneity of temperature in impact-generated vapor plume.

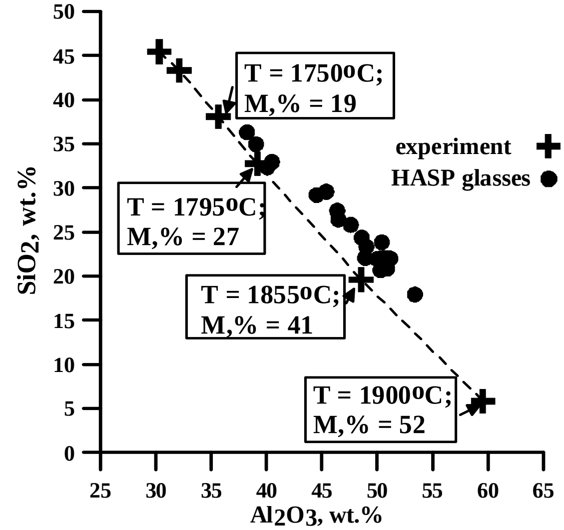

Fig.6. Compositions of HASP glasses and experimentally derived residua melts of basalt sample 68415 (Apollo 16). Labels indicate corresponding temperature and starting basalt mass loss for respective composition of the melt

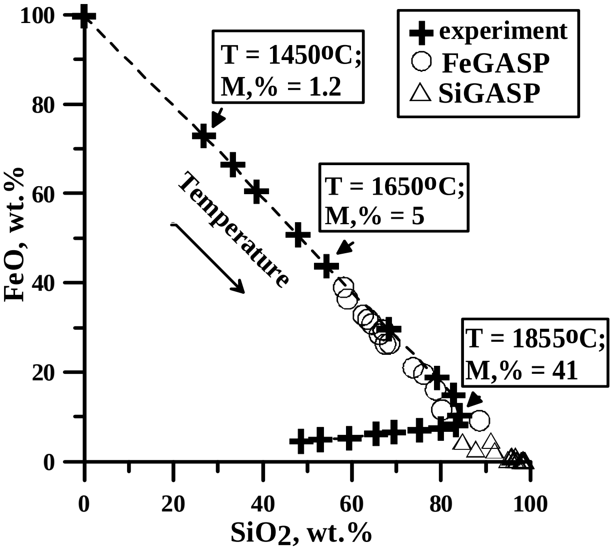

Fig.7. Compositions of FeGASP and SiGASP condensates and experimentally derived vapor compositions of basalt sample 68415 (Apollo 16). Labels indicate corresponding temperature and starting basalt mass loss for respective composition of the vapor

Fig. 7 shows composition of vapor in the experiment with related temperatures and mass losses and composition of FeGASP and SiGASP particles. Condensation from FeO and SiO_2 rich vapor was considered [7] to be the most efficient at late stages of expansion of a vapor cloud when evaporation was terminated by cooling. Condensation of FeGASP particles according to fig. 7 occurred at temperatures in the range ~1860-1650^0C. Higher enriched in iron FeGASPs were formed at lower condensation temperatures. SiGASP particles have compositions beside the experimental data, but on the same trend of enrichment of SiO_2 concentration in the vapor up to T~1855^oC (fig.7). We can admit that SiGASP particles were condensed at higher than that for FeGAS temperatures. High concentration of SiO_2 can be a result of high temperature, which is not sufficient for FeO condensation, and termination of condensation at this high-temperature stage. Dispersion of composition of SiGASP particles also is a result of individual thermal history of particles in a vapor plume.

The work was supported by RFFS Grants № 07-05-01054, № 08-05-00786 and the Program ONZ-5 of Department of Earth Science of RAS

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Electronic Scientific Information Journal “Vestnik Otdelenia nauk o Zemle RAN” № 1(27)'2009
ISSN 1819 – 6586
Informational Bulletin of the Annual Seminar of Experimental Mineralogy, Petrology and Geochemistry – 2009
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