ON THE PROBLEM OF LUNAR IMPACT-VAPOR CONDENSATE. V. V. Svetsov[1] and V. V. Shuvalov, Institute for Dynamics of Geospheres, Russian Academy of Sciences, Leninskiy Prospekt 38-1, Moscow, 119334, Russia, [1]svetsov@idg.chph.ras.ru.

Introduction: Investigation of a sample 14076 from Apollo 14 [1] has shown that the regolith breccias contain, along with high alumina silica-poor (HASP) material of evaporation-residue origin, some small amount of complementary condensates, named GASP (gas-associated spheroidal precipitates). SiO_2-rich GASP material is depleted in the same refractory major oxides that are in excess in HASP. GASP constitution is incompatible both with igneous and impact-melt origins, and, as has been shown in [1], GASP undoubtedly originates from molten condensate droplets. Submicrometer-sized spheroidal condensates, about an order of magnitude smaller in diameters than the GASP spherules, have been detected in lunar regoliths earlier [2]. This type of material was called VRAP (volatile-rich alumina-poor) because of high concentrations of K_2O and Na_2O. Distinctive composition of GASP permits it to be easily identified, however most lunar samples contain very little traces of this material.

It has been estimated in [3] from lunar sample observations that lunar condensates are less than 0.0001 times as abundant as impact melt breccia. Scarcity of VRAP and GASP spherules remains unclear because impact-melt breccia is a typical element of the moon crust and regolith. Current impact velocities on the Moon, with the average value 17.5 km/s [4], seem to be sufficient to vaporize an appreciable amount of lunar rocks. The authors of [1, 2], assuming that the impacts generally produce vapor along with melt in a roughly 1:9 mass ratio, considered this discrepancy as an enigmatic characteristic of the sampled lunar regolith. The observed abundance of lunar condensate appears lower by at least 2 orders of magnitude. Indeed, the estimates based on numerical simulations of impacts at 15-30 km/s showed that the mass ratio of impact-vapor to impact-melt is in the range 0.01 – 0.1 [5-7]. However the authors calculated the mass of vapor rather than the mass of condensate. After the impacts on the Earth the vapor plume expands to the atmosphere but on the Moon the vapor or two-phase material expand into vacuum to very low pressures. The purpose of our study was calculation of the masses of condensates after the impacts on the Moon.

Release adiabats: Using the ANEOS equation of state [8] with the input data from [9] for quartz, we have calculated parameters behind shock wave fronts for particle velocities behind the front from 4.5 km/s to 15 km/s. These particle velocities correspond to impact velocities from 9 to 30 km/s if the target and impactor have the same density and equation of state. Then we have calculated release adiabats from some points on the Hugoniot curve to very low pressures, assuming that after the impacts on the Moon the shock-compressed material expands into vacuum. The results are shown in Fig. 1.

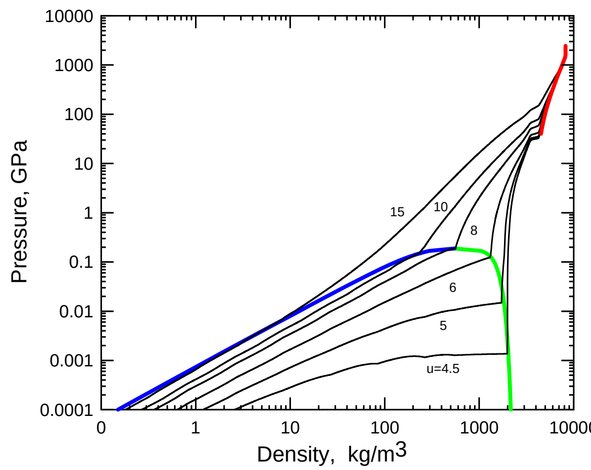

Fig. 1. The P-ρ plot of Hugoniot curve (red) and release adiabats (black) beginning from various points on the Hugoniot curve. The thick solid line bounds the two-phase region, the green brunch of the two-phase curve represents liquid (melt) and the blue branch represents vapor. The numbers at the curves show particle velocities behind shock fronts in the frame of reference where the uncompressed material is at rest.

For particle velocities from 4.5 km/s and lower up to 8 km/s (impact velocities 9–16 km/s for equal densities of the impactor and target) the release adiabats come to the liquid branch of the two-phase curve and, during the following expansion of two-phase mixture, the shock-compressed material vaporizes and not condenses. Only if the impact velocities are higher than 16 km/s, the material turns into vapor, when it reaches the state at the two-phase curve, and then, during the expansion, condenses. The mass concentration of vapor in the expanding two-phase mixture varies only slightly when the pressure drops below 10 Pa.

Fig. 2 shows mass concentrations of vapor and condensate in the two-phase mixture, which can be produced when quartz compressed in the shock wave to some pressure expands to the pressure of 10 Pa. Vaporization of quartz begins if the pressure behind the shock wave is 70-80 GPa, this pressure corresponds to particle velocities behind the shock front about 4 km/s (or the impact velocity of 8 km/s). The condensate appears at much higher pressures about 270 GPa. Complete vaporization occurs if the shock pressure is about 400 GPa when the release adiabat comes to the vapor branch of the two-phase curve.

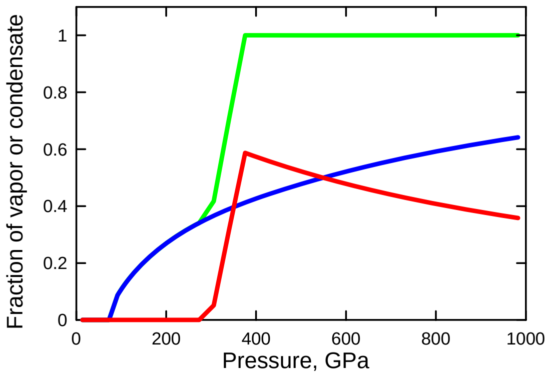

Fig. 2. The mass concentration of quartz vapor after release to a pressure of 10 Pa (blue), the maximum vapor concentration which can be achieved after expansion of shocked material (green) and the concentration of condensate (red) as functions of initial pressures on the Hugoniot curve.

Impact simulations: The pressure dependence of condensate concentration (the red curve in Fig. 2) allows us to estimate the mass of condensate produced after the impact if we know the mass of material compressed in the shock wave as a function of the shock pressure. Using the hydrocode SOVA [10], we have made numerical simulations of the vertical impacts of quartz and dunite spherical impactors on the targets made up of the same materials. For dunite we also used the ANEOS equation of state. The impact velocities were 15, 20 and 25 km/s. The maximum pressures experienced by the projectile and target materials in the shock wave were determined through the use of passive markers in the code.

Along with the masses of condensates we calculated the masses of melted material assuming that melting begins when quartz is shock-compressed to a pressure of 53 GPa and dunite – to a pressure of 120 GPa (then, after release, these materials reach the melting temperatures). In the case of quartz the melted masses (both of the impactor and target) are equal to 27*M* (*M* is the impactor mass), 17*M*, and 10*M* for impact velocities 25, 20 and 15 km/s respectively. In the case of dunite the melted masses are 16*M*, 10*M*, and 5*M* for impact velocities 25, 20 and 15 km/s. The results of simulations are shown in Fig. 3.

The calculated ratio of vaporized mass to the melted mass is really high – of the order of 0.1. Had the entire vapor condensed the deficit of silicate condensate in lunar samples would be enigmatic as was said in [3]. But we obtain that at the velocities below 20 km/s the condensate is only a small fraction of melt and the vapor must disperse in the form of separate molecules.

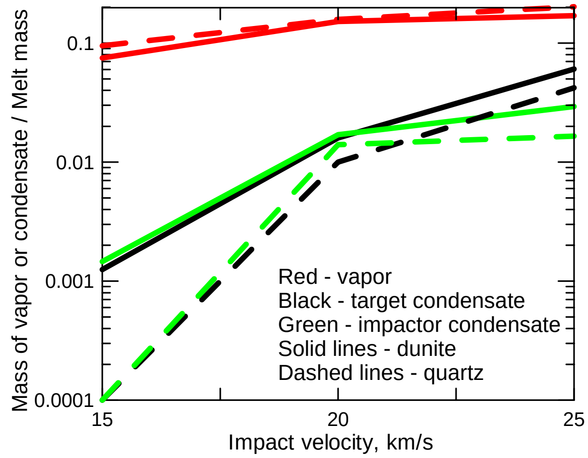

Fig. 3. The relative masses of vapor (red) and condensate (black and green) as functions of impact velocities for the impacts of a quartz impactor on a quartz target and a dunite impactor on a dunite target.

Conclusions: At impact velocity 15 km/s the relative abundance of silicate condensates is 0.001 – 0.0001 in accordance with the studies of lunar samples. For the observed condensate abundances the velocities of major impacts on the Moon could not substantially exceed 20 km/s. However, a part of the condensed spheroids had to be destroyed during the numerous impacts after the formation of the major lunar impact basins.

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