STABILITY AND ORIGIN OF LUNAR POLAR VOLATILES. A.A. Berezhnoy, E. A. Kozlova, and A.A. Shangaraev, Sternberg Astronomical Institute, Moscow State University, Universitetskij pr., 13, Moscow, Russia, Email: ber@sai.msu.ru

Temperature regime at the LCROSS impact site: We used data from the LOLA altimeter [1] on board the LRO spacecraft to study the illumination conditions and to define the temperature regime in the vicinity of the LCROSS impact site in Cabeus crater (85.5 S, 45 W) (Fig. 1). Permanently shadowed area, where the surface temperature is below 110 K, is located at the north part of the crater and has an area of 3230 km^2. Fig. 1 shows the distribution of the mean and maximal surface temperatures in Cabeus crater with latitude step of 0.05° and longitude step of 0.5°. Daytime temperature at LCROSS impact site is about 40 K, this value is in agreement with observations [2].

Stability of volatiles at the LCROSS impact site: Several volatile compounds such as H_2O, CO, H_2, Ca, Hg, Mg [3], H_2O, H_2S, NH_3, SO_2, C_2H_4, CO_2, CH_3OH, CH_4, OH [4], and Na [5] were detected during LCROSS impact experiment in Cabeus crater. We need to improve the model of the temperature regime of the cold traps by adding of other volatile species into the standard regolith – water ice model used for calculations of thermal conductivity.

Surface deposits of H_2O, SO_2, NH_3, CO_2 are stable at temperatures less than 112, 78, 71, and 59 K, respectively [6]. It means that in Cabeus crater all detected species less volatile than CO_2 (it is Ca, Mg, Na, Hg, H_2O, CH_3OH, SO_2, NH_3, C_2H_4, H_2S) are stable at the surface. However, H_2, CO, and CH_4 are more volatile than CO_2. At 40 K 1 m deposit layers of CH_4, CO, and H_2 are evaporating for about 10 years, 10 days, and 0.01 s, respectively. It is therefore reasonable to consider the possibility of the existence of such volatile species as H_2, CO, and CH_4 as not pure solids, but as chemisorbed at the surface of the regolith particles or in the form of clathrate hydrates. Based on vapor pressures of clathrates [7] $CH_4 \cdot 5.75H_2O$ and $CO \cdot 5.75H_2O$ are stable at the surface (see Fig. 2).

Fig. 2 shows the evaporation rate of CH_4, $CH_4 \cdot 5.75H_2O$ and $CO \cdot 5.75H_2O$ during the lunar day at the LCROSS impact site. Species are stable if the evaporation rate is less than 10^{-7} cm/years. It has been discovered that in the impact cloud which was generated by the LCROSS fall the content of water molecules in the regolith of Cabeus crater reaches 5.6 ± 2.9 % [3], which is consistent with LEND data, according to which the water content in the regolith is estimated as 0.5 – 4 % [8]. In our calculations we assumed that the water ice content in the regolith of Cabeus crater is equal to 4%. Under such conditions CH_4 and CO clathrates are stable at the surface.

Origin of lunar polar volatiles: Detection of Mg, Ca, and Hg can be explained that these species like Na and K can migrate toward the lunar poles. Atoms of Mg, Ca, and Hg may be released from the lunar surface by high-energetic processes such as micrometeoroid bombardment.

Based on previously developed model of collisions between comets and the Moon [9] we found that other species such as H_2O, CO, H_2, H_2S, SO_2, and CO_2 can be impact-produced during collisions between O-rich comets and the Moon (see Fig. 3 and 4). However, the equilibrium content of NH_3, C_2H_4, CH_3OH, and CH_4 at typical quenching temperatures and pressures during collisions of O-rich comets is too low in comparison with the observed values at LCROSS impact site (see Fig. 3 and 4). These species can be delivered to the poles by 10-15 km/s low-speed impacts of comets with the Moon. During such impacts the temperature can be not higher than 2000–3000 K and complex species originally presented in the impactor's material will not be fully destroyed. Big amounts of H_2 and CO can be delivered to the lunar poles also by impacts of C-rich inactive comets (see Fig. 3).

Solar wind is responsible for delivery of hydrogen-containing species such as H_2, OH, and H_2O [10]. Outgassing of lunar interiors is just a minor source of lunar polar volatiles because the composition of lunar volcanic gases (mainly, CO, CO_2, COS) [11] is different from that of lunar polar ices.

Conclusions: Temperature regime at the LCROSS impact site is studied. All detected species in Cabeus crater as well as CH_4 and CO clathrate hydrates except H_2, CO, and CH_4 are stable against evaporation at the LCROSS impact site. H_2, CO, and CH_4 can be chemisorbed at the surface of the regolith particles. Comet hypothesis of delivery of volatile species into the permanently shadowed regions is considered. H_2O, CO, H_2, H_2S, SO_2, and CO_2 can be impact-produced during collisions between O-rich comets and the Moon while cometary NH_3, C_2H_4, CH_3OH, and CH_4 can survive during low-speed impacts and then can be delivered to the lunar poles.

References: [1] http://wwwpds.wustl.edu/ [2] Hayne P.O. et al. (2010) *Science*, 330, 477–479. [3] Gladstone G.R. et al. (2010) *Science*, 330, 472–476. [4] Colaprete A. et al. (2010) *Science*, 330, 463–468. [5] Killen R.M. et al. (2010)

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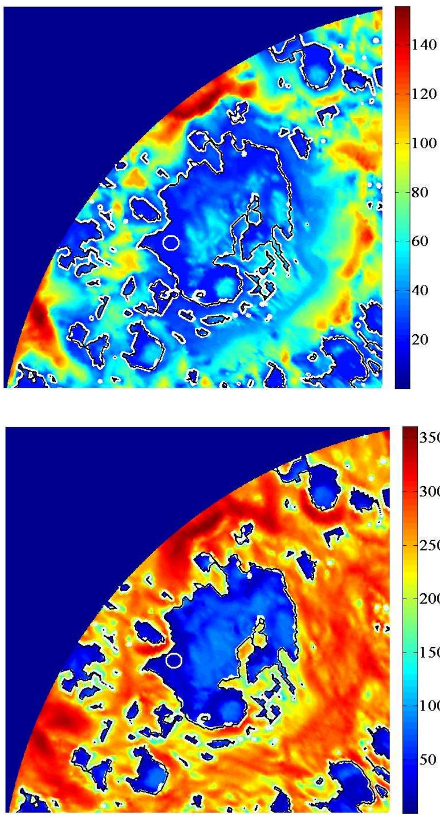

Fig. 1. Mean (up) and maximal temperature (down) in Cabeus crater. White circle shows the LCROSS impact region. The boundaries of permanently shadowed area are shown by black line, the boundaries of the cold traps are shown by white line.

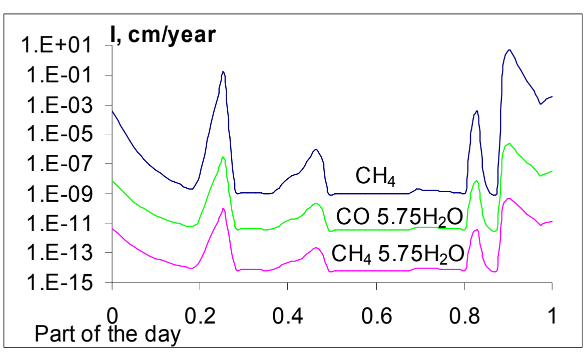

Fig. 2. Evaporation rate of CH_4, CH_4 and CO clathrates at the LCROSS impact site during the lunar day.

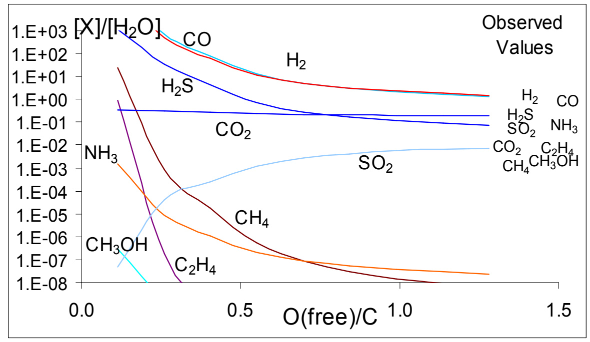

Fig. 3. Equilibrium content of species detected at the LCROSS impact site normalized to H_2O content at 2000 K and 0.64 bar versus O(free)/C ratio in comets. Observed values are given according to papers [3] and [4]. O(free) is the amount of oxygen atoms do not connected with Mg, Si, Al, Fe, Ca, Na atoms. Comet composition is assumed to be that of the comet Halley [12]. C/O ratio in the comet Halley is 1.3. Decreasing of O/C ratio is performed by removing of H_2O molecules from the elemental composition of the comet Halley.

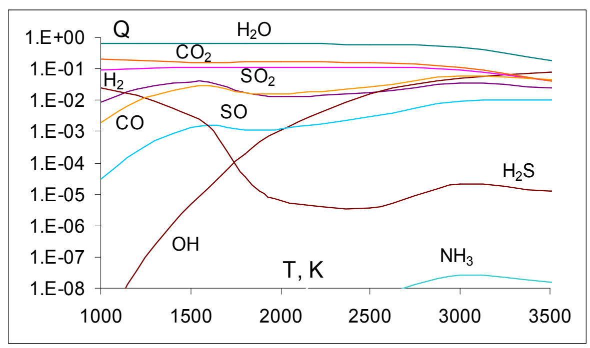

Fig. 4. Equilibrium content of species detected in crater Cabeus during adiabatic cooling of impact-produced vapor cloud. Initial temperature is 10 000 K, initial pressure is 10 000 bar, $\gamma = 1.2$. The elemental composition of the impactor is assumed to be that of the comet Halley [12].