STABILITY OF VOLATILE SPECIES AT THE POLES OF THE MOON. A. A. Berezhnoy, E. A. Kozlova, and V. V. Shevchenko, Sternberg Astronomical Institute, Moscow State University, Universitetskij pr., 13, Moscow, Russia, Email: ber@sai.msu.ru

Temperature regime at the north pole of the Moon: For study of the temperature regime in the north polar regions (φ>80°) of the Moon we used altimetry data from LOLA (LRO) .The data were taken with step of 0.1° for latitude and with step of 1° for longitude. The investigated part of the Moon's surface was divided into areas and for each area we have determined on the basis of LOLA altimeter data the height, the slope angle and the orientation of the area with respect to other areas. To investigate the illumination regime for each area we determined the azimuths and the angular heights of all the surrounding areas in order to get the real picture of horizon. The temperature of any element of the surface was calculated in accordance with approach [2].

Thermal stability of volatiles at the poles of the Moon: 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. Majority of these species are delivered to the poles of the Moon by impacts of comets [4].

Species are stable on the surface against thermal evaporation if the vapor pressure is less than 10^{-16} bar. The evaporation rates of volatile species as a function of temperature and the depth under the surface were calculated according to approach of [6]. Dependence of vapor pressure on temperature for $CH_4{\cdot}5.75H_2O$ and $CO{\cdot}5.75H_2O$ was taken from [7], for Mg – from [8], 1965), for Ca – from [9], for Hg – from [10], for Na – from [11], for H_2O, Ar, Kr, Xe, CO, CH_4, C_2H_4, H_2S, NO, N_2, O_2, and CH_3OH – from [12]. Based on dependence of pressure on temperature surface deposits of N_2, CO, Ar, O_2, CH_4, Kr, $CO{\cdot}5.75H_2O$, NO, Xe, $CH_4{\cdot}5.75H_2O$, C_2H_4, H_2S, NH_3, CH_3OH, Hg, Na, Mg, and Ca are stable at temperatures less than 18, 20, 20, 22, 24, 28, 37, 38, 40, 43, 45, 57, 71, 100, 173, 255, 350, and 447 K, respectively. Areas of thermal stability of Ca, Mg, and Na deposits at the north pole (80-90 N) are estimated as 335 000, 332 000, and 263 000 km^2, respectively. Thermal stability of more volatile species in the north cold traps can be studied when more detailed temperature maps will be available.

Meteoroid bombardment of the cold traps: Detection of Mg, Ca, and Hg atoms at the LCROSS impact-produced cloud can be explained that these species like Na and K atoms can migrate toward the lunar poles. Mg, Ca, and Hg atoms may be released from the lunar surface by high-energetic processes such as micrometeoroid bombardment. Production of Mg atoms in the exosphere during low-energetic processes is also possible [13]. Absence of hot photolysis-generated Mg and Ca atoms in the LCROSS impact-produced cloud can be explained by delivery of Mg and Ca to the cold traps mainly in the form of atoms. It is possible if photolysis lifetimes of Mg- and Ca- bearing molecules are less than typical ballistic flight time, about 10^3 s. Our estimate agrees with upper limit of photolysis lifetimes of Mg-bearing molecules, about 10^3 s [13]. Detection of Hg atoms at the cold traps is in doubt because the Hg content in CI chondrites and the equatorial regions of the Moon is very low, just about 300 and 0.3 ppb, respectively [14]. Assuming that Hg-to-water mass ratio in the cold traps is the same as in CI chondrites Hg content in the cold traps can be estimates as 100 ppb, in 10^5 times lower than this value according to [3].

Let us consider survival of lunar polar volatiles during meteoroid bombardment. Elemental composition of cold traps is assuming to be the same as that of the LCROSS impact-produced cloud. Based on previously developed model of collisions between meteoroids and the Moon [15] we assume that quenching of chemical reactions in the impact-produced clouds occurs at about 3 000 K and 10 bar for the case of 10^{-3} – 10^{-2} cm impactors. The main species during adiabatical cooling of the impact-produced cloud are H_2O, H_2, CO, CO_2, HSOH, SO, SO_2, H_2S, and N_2 (see Fig. 1 and 2) while the equilibrium content of NH_3, C_2H_4, CH_3OH, and CH_4 at typical quenching temperatures and pressures is too low, less than 10^{-6}, in comparison with the observed values at the LCROSS impact site. The main Na-, Ca- and Mg-bearing impact-produced species are Na, NaOH, $Ca(OH)_2$, CaOH, Mg, and MgOH (see Fig. 3). Among H-, C-, N-, S- bearing species still undetected at the poles of the Moon the maximal content in the impact-produced cloud at the time of quenching is reached for HSOH (10^{-2}), SO (10^{-2}), N_2 (5×10^{-3}), SH (3×10^{-3}), S (2×10^{-3}), O_2 (6×10^{-4}), NO (2×10^{-4}), and H_2SO (2×10^{-4}).

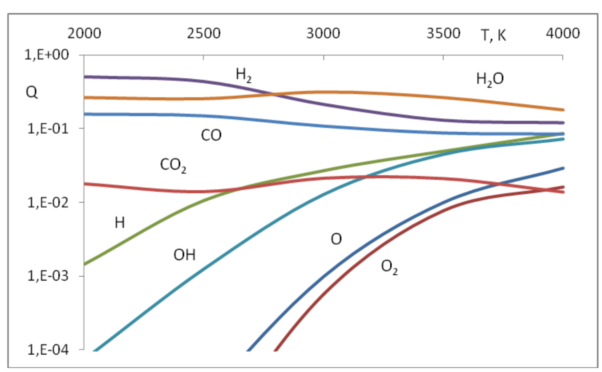

Fig. 1. Equilibrium content of H- and C-bearing volatile species during adiabatic cooling of the impact-produced vapor cloud formed during impacts of sporadic CI meteoroids in a lunar polar crater. Initial temperature is 10 000 K, initial pressure is 10 000 bar, γ = 1.2. The elemental composition of lunar rocks, volatiles species, and impactors are assumed to be that of ferroan anorthosites [14], the LCROSS impact-produced cloud [3, 4, 5], and CI meteoroids [14], respectively. The target-to-impactor mass ratio in the cloud is equal to 6.

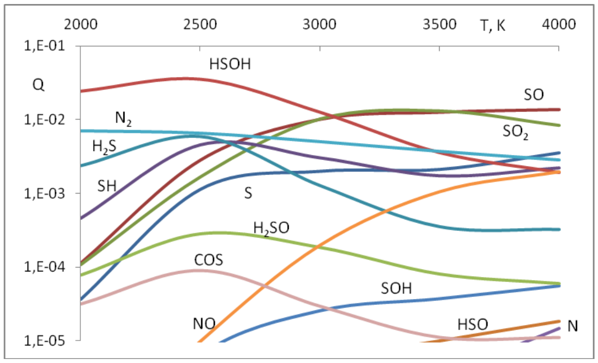

Fig. 2. Equilibrium content of S- and N-bearing volatile species during adiabatic cooling of the impact-produced vapor cloud formed during impacts of sporadic CI meteoroids in a lunar polar crater. The parameters of calculations are the same as for Fig. 1.

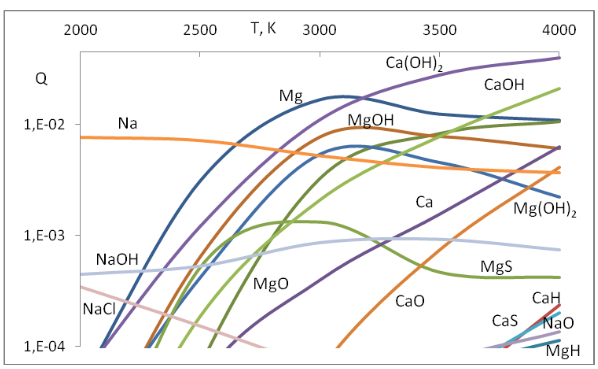

Fig. 3. Equilibrium content of Ca-, Mg-, and Na-bearing volatile species during adiabatic cooling of the impact-produced vapor cloud formed during impacts of sporadic CI meteoroids in a lunar polar crater. The parameters of calculations are the same as for Fig. 1.

For estimation of probabilities of re-capture of impact-produced volatile species to the cold traps during meteoroid bombardment the simple ballistic model [16] was applied. Probabilities of re-capture of Na, Mg, and Ca impact-produced atoms are close to unity at typical temperatures of impact-produced cloud of about 3 000 K. Let us assume that photolysis of $Ca(OH)_2$, CaOH, and MgOH leads to formation of photolysis-generated Ca and Mg atoms with excess energies equal to that during photolysis of CaO and MgO molecules (namely, 0.45 and 0.6 eV [15]). In this case majority of photolysis-generated Ca and Mg atoms will leave the Moon.

Conclusions: Temperature regime at the north pole of the Moon is studied. Areas of thermal stability of Ca, Mg, and Na deposits are estimated. Complex species such as NH_3, H_2S, C_2H_4, CH_3OH, and CH_4 can be destroyed during meteoroid bombardment of cold traps. The list of still undetected polar species (HSOH, SO, N_2, SH, S, O_2, NO, and H_2SO) with maximal content in the impact-produced cloud is proposed. Probabilities of re-capture of Na, Mg, and Ca atoms by north cold traps during meteoroid bombardment are estimated. Photolysis of Ca- and Mg-bearing molecules leads to escape of photolysis-generated Ca and Mg atoms from the Moon.

Acknowledgments: This research is supported by RFBR grant 11-02-90440-Ukr_f_a.

References: [1] http://wwwpds.wustl.edu/ [2] Kozlova E. A. (2004) *Solar System Research*, *38*, 335–346. [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) *GRL*, *37*, CiteID L23201. [6] Schorghofer N. and Taylor G. J. (2007) *JGR*, *112*, E02010. [7] Lunine J. I. and Stevenson D. J. (1985) *Astrophys. J. Suppl. Ser.*, *58*, 493-531. [8] Gilbreath W. P. (1965) *NASA Technical Note*, NASA TN D-2723, 11 p. [9] Douglas P. E. (1954) *Proc. Phys. Soc.. Sect. B*, *67*, 783. [10] Huber M. L. et al. (2009) *NIST*, NISTIR 6643, 59 p. [11] Makansi M. M. et al. (1955) *J. Phys. Chem.*, *59*, 40–42 [12] Fray N. and Schmitt B. (2009) *Planet. Space Sci.*, *57*, 2053-2080. [13] Sarantos M. et al. (2011) *Planet. Sp. Sci.*, *59*, 1992-2003. [14] Lodders K. and Fegley Br. (1998) *The Planetary Scientist Companion*, Oxford Univ. Press, NY, 1998. [15] Berezhnoy A. A. (2010) *Adv. Sp. Res.*, *45*, 70-76. [16] Berezhnoy A. A. et al. (2003) *PASJ*, 55, 859-870.