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Possible sources of the Moon polar volatiles

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Abstract

The discovery of noticeable hydrogen concentration in the polar regions was among the most exciting events in the exploration of the Moon. Analysis of lunar samples delivered by Apollo and Lunar missions as well as of Moon meteorites showed that solid material was strongly depleted in volatiles. The amount of water in lunar samples is in the range of 64 ppb – 5 ppm [1]. Concentration of water in polar regolith is estimated at a level of 4–6 wt.% [2,3] at least in the surface meter to two meter layer. Such an increase in the water concentration is a result of migration of water molecules from hot equatorial latitudes to cold traps of the polar northern and southern regions. The question about the diversity and source of volatiles is still open. The aim of the paper is to discuss possible sources of volatiles and related differences in their pattern.

1. Sources of lunar volatiles

1.1 Degassing of the interior

Endogenous source of volatiles is provided by degassing of heated interior of planetary bodies. In this case chemical composition of released gases reflects thermodynamic equilibrium of gases over typical magmas at temperatures around 1000°C. The composition of such gas mixtures is characterized by domination of H_2O, CO_2, and SO_2 over other H, C, and S containing components. Carbon containing gases are mainly present by CO_2, CO, and hydrocarbons. CO/CO_2 ratio here is typically far below 0.1 level. Hydrocarbons are a minor part of carbon-containing gases and are mainly aromatic hydrocarbons, alkanes, and cycloalkanes. Sulfur containing gases are mainly SO_2, H_2S, and S_x with SO_2 being dominant. Isotopic ratios of volatile elements should be the same as for the bulk Moon.

1.2 Interaction of solar wind protons with surface rocks

An interesting mechanism of water production on the Moon comes from the interaction of solar wind protons with lunar surface rocks. Energetic solar wind protons with the absence of an atmospheric shield can react with oxygen of surface rocks and produce water molecules as end product. Such a mechanism provides a source of pure water on the Moon with solar hydrogen isotopes and Moon rocks oxygen isotopes.

1.3 Degassing of impacting meteorites and comets

Volatile components, which are delivered by meteorites and comets, are released during hypervelocity impacts upon lunar surface. The forming impact-generated vapor cloud is hot and dense enough to form gas mixture with a composition driven by chemistry of the cloud. It was shown experimentally [4] that despite differences in possible types of target silicates the forming compositions of gases are qualitatively similar and have the following characteristics. The portion of carbon monoxide is much higher compared to volcanic gases and the CO/CO_2 ratio is ≥ 1. Hydrocarbons are presented mainly by alkenes and PAHs and amount up to ~10% of $CO+CO_2$. Sulfur containing gases are presented by SO_2, CS_2, H_2S, and COS in decreasing sequence. CS_2 production in case of ordinary chondrites amounted to about half of SO_2 and for COS it amounted to about several percent [4]. Production of HCN was also measured. Noticeable release of water was also detected. Experimental investigation was performed for terrestrial minerals and rocks and for carbonaceous and ordinary chondrites as well. We do not expect principal difference in the chemistry of cometary impacts. Impacts of comets occur at sufficiently higher velocities than for meteorite impacts and a large portion of surface material is evaporated into the cloud providing a combination of siliceous vapor with excess of volatile components.

Criteria of discrimination between different sources of lunar polar volatiles

The aim of the work is to find principal criteria of discrimination between different sources of lunar polar volatiles. Information on the chemical composition of deposited gases and on isotopic composition of main volatile elements seams to be a key for the answer. Almost pure water in the polar depositions with solar hydrogen isotopes and surface rocks oxygen isotopes will indicate in favor of solar wind interaction mechanism. The presence of CO_2 and SO_2 components additionally to H_2O will indicate whether endogenous magmatic degassing or exogenous impact-induced degassing of meteorites and comets. CO/CO_2 ratio can be a good criterion between these two sources but there is a problem of efficiency of CO trapping since it requires sufficiently lower temperature than for trapping of CO_2. At least, CO/CO_2 ratio higher than 0.1 can be an indication in favor of impact source. Sufficient portion of CS_2 also can be an argument in favor of impact source. This argument will be supported additionally by the presence of HCN and domination of alkenes over alkanes. The cometary source of volatiles can be indicated by isotopic composition of hydrogen while impacts of meteorites as well as magmatic degassing will provide terrestrial D/H ratio.

Gas-analytic package of the Russian Lunar-Resource and Lunar-Globe missions

Lunar polar depositions of volatiles besides water can have other important species depending on their source. Hydrocarbons CO, CO_2, and other volatile components also can be a potential resource for future human activity on the Moon. There are two missions - Luna-Globe and Lunar-Resource – which are now under preparation in Russia for launch after 2015. Both missions are aimed to put landers in northern and southern polar regions of the Moon for investigation of possible depositions of water and other volatile components. The gas-analytic experiment “ALPOL” is aimed on comprehensive investigation of the inventory of volatiles in the regolith of polar regions. The Gas-Analytic Package (GAP) consists of three individual instruments: 1) Thermal Analyzer; 2) Gas Chromatograph; and 3) Neutral Gas Mass-Spectrometer. Gas Chromatograph has additionally a Tunable Diode Laser Absorption Spectrometer for spectroscopic measurements of isotopic composition of H and C in evolved gases. The main tasks of the GAP are:

1. Detailed investigation of chemical composition and abundances of volatile compounds (H_2O, CO_2, N_2, H_2, noble gases, organics, etc.) in the surface regolith material of the Moon at the landing place;
2. Investigation of forms of incorporation of volatile components into the solid surface material;
3. Investigation of organic components in the surface material;
4. Measurement of isotopic composition of CHON elements ($^{13}C/^{12}C$, D/H, $^{17}O/^{16}O$, $^{18}O/^{16}O$, $^{15}N/^{14}N$) and noble gases.
5. Measurements of the exosphere composition of the Moon.

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