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Multiparametric analysis of celestial bodies as sources of space resources

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Abstract. The work is devoted to the creation of a method based on data from space missions such as LRO (Lunar Reconnaissance Orbiter) and the analysis of possible impactors and meteoroid material for mapping the distribution of minerals on the Moon. In the process of surveys from the Lunar Reconnaissance Orbiter (LRO) spacecraft, the most recent generalized information on the distribution of iron and titanium in the composition of the lunar surface rocks was obtained. To obtain these data, it was necessary to compile a single map from more than 4 thousand images that the LRO spacecraft took during a month of work in a lunar orbit. The processing of the obtained data made it possible to detect areas on the lunar surface containing significant deposits of titanium. The results were calibrated using analyzes of lunar soil samples brought to Earth by the American Apollo missions and Soviet automatic vehicles of the Luna series. Concrete results obtained: Map of mineral distribution gradients depending on selenographic coordinates on the lunar sphere._

Keywords: Moon, planetary science, asteroids, space missions

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Многопараметрический анализ небесных тел как источников космических ресурсов

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Аннотация. Работа посвящена созданию метода на основе данных космических миссий, таких как LRO (Lunar Reconnaissance Orbiter), и анализу возможных ударников и метеороидного материала для картографирования распределения полезных ископаемых на Луне. В процессе съемок с космического аппарата LRO были получены самые свежие обобщенные сведения о распределении железа и титана в составе пород лунной поверхности.

Ключевые слова: Луна, планетология, астероиды, космические миссии_

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Introduction

Currently, researches of useful resources on space bodies are important [1, 2]. In our work, on the basis of the author's multi-parameter method, the simulation of dynamic characteristics was performed, and the parameters of small solar system body (SSSBs) as sources of space resources were determined. Work was carried out to estimate the content of metal atoms in the lunar exosphere. The influence of the kinetics of chemical reactions and SSSBs sizes on the chemical composition of hardened shock vapour delivered to the exosphere of the Moon during SSSBs falls was estimated. Methods were proposed for estimating the abundance of atoms of refractory elements in the exospheres of these celestial bodies, taking into account the condensation of silicates in the impact cloud and the photolysis of impact-formed molecules by solar photons. As part of this study, mapping of the content of helium-3 on the surface of the Moon was also carried out. Studies of the dynamic characteristics of SSSBs were carried out, which included: a) work on estimating the velocity distribution of the main populations of MNTs crossing the Earth's orbit [3]. Asteroids from the main belt [4] fall on the Moon at a lower speed than comets from the regions of Jupiter and the Oort [5–10]. The average impactor velocity decreases from 23 to 14 km/s as the impactor ecliptic latitude increases from 20 to 90 degrees; b) two-color diagrams of asteroid brightness maxima were constructed, the average positions (AP) of groups, root mean square distances of meteoroids from AP and maximum distances to AP were determined. The quantitative and qualitative parameters of the color characteristics of SSSBs with small perihelion distances and their spectral distribution are obtained. It was found that the spectral parameters of the SSSBs are related to the dynamics and chemical composition of celestial bodies. A relationship was also found between the color parameters and the magnitude of the SSSBs, while no dependence on the speed of the asteroid was established [11].

Materials and Methods

It is believed that the rocks that were formed in the upper regions of the mantle of the Moon and in the lower regions of its crust, went through a stage of differentiation like the terrestrial deep rocks. During the period of active lunar volcanism, these rocks came to the surface in the form of lavas, filling the depressions of the lunar seas. The time sequence of the emergence of marine basalts on the Moon with a step of 0.5 billion years is shown in Fig. 1 [12].

Mapping of the selected areas and their sequence was carried out according to geological analysis, taking into account the frequency analysis of the sizes of craters according to the Lunar Orbiter IV and Clementine spacecraft data. Model ages of basalt deposits were determined using data obtained using images from the narrow and wide-angle cameras of the Lunar Reconnaisance Orbiter (LROC NAC, WAC) and spectral data from the Moon Mineralogy Mapper (M3) [13, 14].

Areas of basalt covers were formed in the period from ~3.9 billion years ago to ~1.1 billion years ago [14]. The maximum active lunar volcanism occurred in the period from 3.8 to 3.1 billion years ago, while the largest volumes of eruptions appeared about 3.5 billion years ago [15]. Most of the basaltic lavas were erupted in the area of the Sea of Clarity approximately 3.7 billion years ago, and in the regions of the Sea of Rains and the Ocean of Storms approximately 3.6 billion years ago [16]. After these most extensive spills of basaltic lavas, the appearance of new marine areas was reduced almost to zero [17].

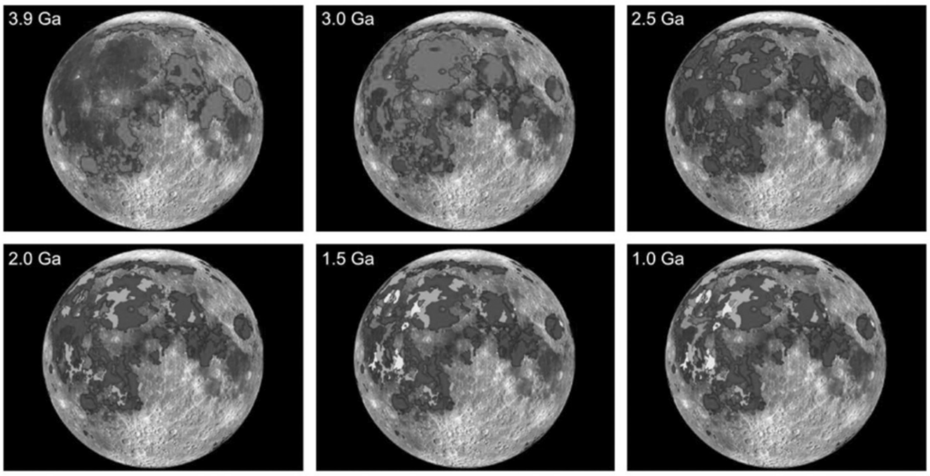

Fig. 1. Time sequence of the emergence of marine basalts on the Moon with a step of 0.5 billion years

The basalts of the lunar seas were formed in the process of crystallization that took place in basalt lavas in layers close to the lunar surface. The main minerals of marine basalts are pyroxenes, plagioclases, ilmenite, and olivines. The rocks that make up the lunar continents consist of anorthosites, norites, and troctolites.

The rocks of the continents are the most ancient and have undergone intense structural changes as a result of a very long impact of meteorite and asteroid bombardment. These rocks are dominated by such minerals as plagioclases and pyroxenes, with minor admixtures of olivine.

Fig. 2 shows distribution maps of the main elements for continental landscapes in the near side of the Moon.

The spectra of the diffuse structure of Reiner Gamma, diffuse structures in the Sea of Moscow and the Sea of Dreams, in the craters of Dufay, Hayford E and Gerasimovich and their vicinities are studied in the optical and near infrared regions according to the data of the M3 instrument.

Results and Discussion

The study of new images of the lunar regions, made by the Lunar Reconnaissance Orbiter (LRO), has revealed places quite saturated with titanium. In these areas, lava flows that have transformed into lunar stony rocks contain more titanium than the most known deposits of this metal on Earth. It is important that titanium in the future may be in demand for the creation of manned lunar bases and spacecraft.

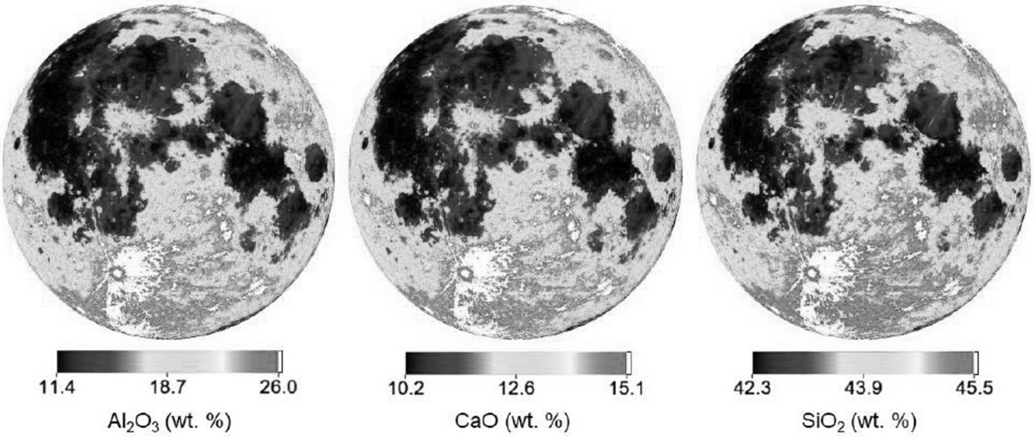

Fig. 2. Distribution maps of the main elements for continental landscapes in the visible hemisphere

According to the results of work performed at the University of Hawaii (USA), analysis of images obtained by the LRO space mission showed that the content of titanium in some "marine" areas of the Moon is 18%, which is 3% more than the content of this metal in deposits on Earth [18].

It should be noted that ilmenites are richest in titanium content on the Moon. Therefore, the areas of the lunar seas marked by the distribution of ilmenite rocks, first of all, may be of interest for obtaining industrial titanium in the future.

When using the simplest research technology, the areas of distribution of ilmenites appear on the images obtained in the process of spectrozonal survey. Such images are the result of observations of the Moon in the visible and ultraviolet ranges of the spectrum. This technique is known to astronomers and has been used more than once in the process of lunar exploration [19, 20].

Determining the frequency of collisions of impactors of various origins (comets and asteroids) with the Moon is important for estimating the influx of meteoroid matter to the Moon and the role of impactors in the formation of a layer of volatile compounds in cold traps at the Moon's poles [21]. Meteoroid matter and volatile compounds at the poles of the Moon, whose main component is water ice, are important minerals on the Moon [22, 23]. For this purpose, the spectral properties of diffuse structures on the Moon were studied using data from the M3 spectrometer of the Indian spacecraft Chandrayaan-1. To estimate the frequency of collisions of comets with the Moon from the data of studying the properties of diffuse structures, it is necessary to carefully study the physical and chemical properties of the upper layer of the lunar regolith and the hydrodynamics of the interaction of the cometary matter of comets approaching the Moon with the lunar surface [24–26]. The analysis of the density of the lunar regolith in diffuse structures was carried out using the original method of mapping the compactness significance factor (CSF) of the regolith.

To solve the problem of using space resources in the future, some projects have been proposed, including those for the utilization of the substance of near-Earth asteroids [21]. Despite the difficulties of capturing, transporting and subsequent development of such an object in space, this method of extracting useful resources seemed technologically possible and economically justified [27]. It has been shown in a number of works that the disposal of asteroidal matter falling on the lunar surface can be technologically simpler and more economically profitable [28].

Conclusions

One of the results of the work was the relevance of the development of titanium mines on the Moon. The extraction of asteroid origin on the lunar surface is more technologically justified than the capture and delivery of asteroids into the Earth's orbit. Fresh lunar craters are most important if we consider that of the increased content of asteroid origin, the location of which can be determined by analyzing LRO images and by monitoring lunar optical flares. Observable evidence in favor of the formation of a fresh 20-km crater near the craters Copernicus and Kepler after a low-velocity collision of an asteroid with the lunar surface is discussed. The content of metals such as iron, cobalt, nickel, platinum and platinoids, delivered to the lunar surface during low-velocity M and S class asteroid impacts, is estimated. An economic justification for the expediency of using lunar resources is presented. Based on the obtained data, a mapped model of mineral distribution gradients depending on selenographic coordinates on the lunar sphere was constructed.

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