ON THE QUESTION OF ANALYZING THE CHEMICAL COMPOSITION OF THE LUNAR SURFACE BY DIRECT METHODS

PHYSICS

1968

SovietRxiv

Abstract

Full Text

UDC 523.044+543.422.8:523.30

PHYSICS

Academician B. P. KONSTANTINOV, M. M. BREDOV, S. V. VIKTOROV, G. V. KIRYAN, G. E. KOCHAROV, V. O. NAIDENOV

ON THE QUESTION OF ANALYZING THE CHEMICAL COMPOSITION OF THE LUNAR SURFACE BY DIRECT METHODS

The chemical composition of a planetary body is among the most essential characteristics of the history of its origin and evolution. In the general program for studying the chemical composition of the surfaces of planetary bodies of the Solar System, the Moon is, naturally, the primary object of investigation.

In studying the chemical composition of the lunar surface, it is first of all necessary to establish the general correspondence between the distribution of chemical elements on its surface and their distribution on the Earth. This problem has been partially solved by Soviet scientists in indirect experiments on the study of the gamma activity (^1) and X-ray radiation (^2) of the Moon, carried out from orbital stations, and by the efforts of American scientists who performed elemental analysis of a small area of the lunar surface at the landing site of the spacecraft "Surveyor-5" (^3). From Table 1 (^3) it is evident that the soil they studied contains the most oxygen, followed by silicon and aluminum, which corresponds to the character of the distribution of oxygen, silicon, and aluminum in the Earth' s lithosphere. At present it is difficult to draw a more categorical conclusion about the adequacy of the chemical composition of the Earth and the Moon because of the absence of sufficiently definite data on the content of other chemical elements in the surface layer of lunar material.

The next task is to determine whether the chemical composition of the lunar surface corresponds to one or another type of terrestrial rocks or to meteoritic material. Investigations of this kind, carried out on various areas of the visible and invisible parts of the lunar surface—in regions of maria and continents, craters of various sizes, "rays," etc.—will provide experimental material for further fruitful discussion of hypotheses concerning the origin and evolution of the Moon. It should be noted that chemical analysis of the surface layer must be supplemented by analysis of the soil at different depths.

Table 2 presents data on the average content of the most widespread chemical elements in the rocks composing the Earth' s lithosphere and in stony meteorites.*

Let us consider which of the elements are the most representative from the standpoint of an attempt to distinguish, by means of them, different categories of rocks. The elements most widespread on the Earth and in stony meteorites—oxygen and silicon—are, in our opinion, not the most convenient in this respect, since their content is sufficiently constant in all categories of rocks. By sodium content, ultrabasic (0.57%) and sedimentary (0.66%) rocks can be distinguished from the remaining rocks. It is possible to distinguish intermediate

* The data given in Table 2 reflect only the average concentrations of elements in certain large categories of rocks. Therefore, in interpreting experimental results one should take into account deviations from the values given here. It is also possible that the measured content of elements in individual areas of the lunar surface will not correspond to any of the categories considered.

(3.0%) from acidic rocks (2.77%), apparently, cannot be done. A somewhat more favorable ratio is found for the sodium content in basic (1.94%) and intermediate (3%) rocks.

Analysis for magnesium makes it possible at once to determine that a rock belongs to the ultrabasic type (25.9%), since its content in them is 6–46 times higher than in other rocks. The magnesium concentrations in the other rocks also differ sufficiently from one another. Thus, magnesium is very convenient in determining whether a sample belongs to one or another rock type.

By the very low aluminum content a rock can immediately be assigned to the ultrabasic type (0.45%). However, distinguishing by aluminum basic rocks (8.76%) from intermediate (8.85%), acidic (7.7%), and even sedimentary (10.45%) rocks appears difficult.

Table 1

Chemical composition of the investigated region of the lunar surface

Elements*	O	Si	Al	Mg	C	Na	28<A<65	Fe, Co, Ni	A>65
Atomic %	58$±5|18.5±3|6.5±2|3±3| < 3| < 2|13±$3								

* The method used makes it possible to determine only the concentrations of elements with the given mass number **A**.

Table 2

Content of the most widespread elements (wt. %) in the major types of rocks of the Earth' s lithosphere and of stony meteorites

Rock element	Ultrabasic	Basic	Intermediate	Acidic	Sedimentary	Stony meteorites (chondrites)
Oxygen	42.5	43.5	46.0	48.7	52.8	35.0
Sodium	0.57	1.94	3.0	2.77	0.66	0.7
Magnesium	25.9	4.5	2.18	0.56	1.34	14.0
Aluminum	0.45	8.76	8.85	7.7	10.45	1.30
Silicon	19.0	24.0	26.0	32.3	23.8	18.0
Sulfur	0.01	0.03	0.02	0.04	0.3	2.0*
Potassium	0.03	0.83	2.3	3.34	2.28	0.085
Calcium	0.7	6.72	4.65	1.58	2.53	1.40
Titanium	0.03	0.9	0.8	0.23	0.45	0.05
Iron	9.85	8.56	5.85	2.7	3.33	25.0*

* Together with the iron phase of chondrites.

From the potassium content, apparently, one may judge whether a sample belongs to ultrabasic (0.03%), basic (0.83%), or other rocks. A low calcium concentration indicates membership in ultrabasic rocks (0.7%), a considerably higher one (6.72 and 4.65%)—in basic or intermediate rocks, and an intermediate one (2.53 and 1.58%)—in sedimentary or acidic rocks. The concentrations of sulfur and titanium differ markedly in different types of rocks, but their overall content is small (except for the case of the anomalously high sulfur content in chondrites).

Finally, from the iron content one may judge whether a sample belongs to ultrabasic and basic rocks (9.85 and 8.56%), to intermediate rocks (5.85%), or to acidic or sedimentary rocks (2.7 and 3.33%). Thus, the most **representative** elements include magnesium, potassium, calcium, sulfur, and iron (for more detail see (4)).

The method* of (α, α)- and (α, p)-reactions (5), used in the work of the American group, in its present form does not make it possible to determine the concentrations of each of the most representative elements in complex mixtures of unknown composition (such as the surfaces of planetary bodies). This circumstance deprived the authors (3) of the possibility, with greater certainty —

* See (6) for details.

with certainty assign the rock of the investigated site to a definite category: although their data correspond most fully to the composition of basic rocks, the results of the analysis partially correspond to intermediate, sedimentary, and acidic rocks, while the concentrations of groups of intermediate and heavy elements indicate the possibility of the presence of introduced meteoritic material.

Let us note that, according to the results of interpretation of gamma spectra of lunar rocks obtained from the orbital station "Luna-10" ([1]), acidic rocks were rejected.

An analysis ([4], [7]) of the comparative characteristics of modern methods for determining the chemical composition of matter as applied to the study of the surfaces of the Moon and planets showed that exceptional possibilities in terms of informativeness and rapidity are inherent in the X-ray spectrochemical method of analysis. At the A. F. Ioffe Physico-Technical Institute of the USSR Academy of Sciences, an X-ray isotope fluorescent method has been developed for the analysis of unprepared surfaces for the main rock-forming chemical elements (see, in particular, ([8], [9])).

In the apparatus developed for exciting the characteristic X-ray radiation of chemical elements present in the soil, radioactive sources are used. Soldered proportional counters for soft X-rays serve for detecting the characteristic radiation. The use of proportional counters in combination with characteristic filters (potassium, silicon, magnesium, etc.) makes it possible to determine the concentrations of various elements, including the most representative chemical elements: magnesium, potassium, calcium, sulfur, and iron.

The developed method and apparatus can be used for express analysis of the chemical composition of the surfaces of the Moon, Mars, Venus, and other planetary bodies of the Solar System.

In conclusion, we consider it our pleasant duty to thank V. V. Petrov and Yu. N. Starbunov for fruitful discussions and consideration of the questions touched upon in the present work.

Physico-Technical Institute named after A. F. Ioffe
Academy of Sciences of the USSR

Received
5 V 1968

CITED LITERATURE

[1] A. P. Vinogradov, Yu. A. Surkov et al., *Kosmicheskie issledovaniya*, **5**, No. 6, 874 (1967). [2] S. L. Mandelshtam, I. P. Tindo et al., *Kosmicheskie issledovaniya*, **6**, No. 1, 119 (1968). [3] A. L. Turkevich, E. J. Franzgrote, J. H. Patterson, *Science*, **158**, 635 (1967). [4] S. V. Viktorov, G. V. Kiryan, G. E. Kocharov, On the presumed chemical composition of the lunar surface and possible methods for its investigation, Report of the A. F. Ioffe Physico-Technical Institute, USSR Academy of Sciences, No. 0–189 (1967). [5] J. H. Patterson, A. L. Turkevich, E. Franzgrote, *J. Geophys. Res.*, **70**, No. 6, 1311 (1965). [6] S. V. Viktorov, G. V. Kiryan, G. E. Kocharov, Some problems in the study of the chemical composition of lunar soil according to the Surveyor program, Lecture at the V annual winter school on cosmophysics, Apatity, 1968. [7] S. V. Viktorov, G. V. Kiryan, G. E. Kocharov, The present state of the problem of investigating the

chemical composition of the lunar surface by direct methods, Lecture at the V annual winter school on cosmophysics, Apatity, 1968. [8] S. V. Viktorov, G. V. Kiryan, G. E. Kocharov, X-ray spectrochemical analysis, Report of the A. F. Ioffe Physico-Technical Institute, USSR Academy of Sciences, No. 0–190, 1967. [9] S. V. Viktorov, G. V. Kiryan et al., Use of the filter method in nondispersive X-ray spectrochemical analysis of the main rock-forming elements, Report of the A. F. Ioffe Physico-Technical Institute, USSR Academy of Sciences, No. 0–191, 1967.

Note: Figure translations are in progress. See original paper for figures.