AVERAGE CHEMICAL COMPOSITION OF THE LUNAR SURFACE

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Abstract. The available data on the chemical composition of the lunar surface at eleven sites (3 Surveyor, 5 Apollo and 3 Luna) are used to estimate the amounts of principal chemical elements (those present in more than about 0.5% by atom) in average lunar surface material. The terrae of the Moon differ from the maria in having much less iron and titanium and appreciably more aluminum and calcium.

One of the principal accomplishments of lunar scientific exploration in the last six years has been the chemical analysis of the surface at various locations on the Moon. These analyses have been performed both by *in situ* measurements (Surveyor and Luna missions) and by analyses of returned samples (Apollo and Luna missions). The analytical data for the principal chemical elements at eleven sites on the Moon (eight mare and three terra) can be used to estimate the average chemical composition of the lunar surface. The principal chemical elements are those present in amounts greater than half of a percent by atom. The analyses used are those for the powdered material, on the assumption that this approximates the average surface composition at a given site. The results of this exercise are presented in Table I.

The small number of locations on the Moon that have been examined, particularly of terrae, with no detailed data available for the back side of the Moon, make this a tentative estimate of the average chemical composition of the lunar surface. However, the gross similarity in chemical composition of different maria, the general agreement in composition of three terra sites thousands of kilometers apart, and the indication from orbital X-ray measurements (Adler *et al.*, 1972) that the Al/Si ratio in many terra regions (including the backside) is enhanced over that in the maria by amounts similar to that indicated in Table I, suggest that these estimates will not be changed significantly – as, in fact, they have not since the original estimates by Turkevich (1971).

Chemically, the terrae differ from the maria in having much lower amounts of iron and titanium and enhanced amounts of aluminum and, to a smaller extent, calcium. The average density of the parent rocks in the case of the maria material is estimated from the normative mineralogy to be 3.19 g cm^{-3}; for terrae material, it is 2.97 g cm^{-3} (Turkevich, 1973). The differences in chemical composition between terrae and maria provide reasonable explanations for the major albedo and gross elevation differences on the Moon (Turkevich *et al.*, 1968a, b).

* Paper dedicated to Prof. Harold C. Urey on the occasion of his 80th birthday on 29 April 1973.

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TABLE I

Average chemical composition of the lunar surface
(Percent of atoms)

Element	Maria	Terrae				Average lunar surface	
	Average[a]	Surveyor 7[b]	Luna 20[c]	Apollo 16[d]	Average terra	Percent of atoms[e]	Weight percent of oxides[f]
O	60.6 ± 1.2	61.8 ± 1.0	(60.3)	(61.1)	61.1	61.0	
Na	0.4 ± 0.1	0.5 ± 0.2	0.4	0.29 ± 0.02	0.4	0.4	0.6
Mg	5.3 ± 1.2	3.6 ± 1.6	5.2	3.0 ± 0.4	4.0	4.3	8.0
Al	6.6 ± 0.6	9.2 ± 0.4	9.7	11.6 ± 0.4	10.2	9.5	22.3
Si	16.8 ± 1.0	16.3 ± 1.2	16.0	16.26 ± 0.06	16.2	16.3	45.0
Ca + K	4.7 ± 0.5	6.9 ± 0.6	5.9	6.1 ± 0.2	6.3	6.0	15.5
Ti	1.0 ± 0.6	0 ± 0.4	0.15	0.15 ± 0.02	0.1	0.3	1.1
Fe	4.5 ± 0.8	1.6 ± 0.4	2.1	1.6 ± 0.2	1.8	2.3	7.6

[a] The average mare chemical composition is calculated from the results of the Surveyor 5 and 7, Apollo 11, 12, 14 and 15 and Luna 16 and 17 missions, using an average value from Surveyor 5 and Apollo 11 for Mare Tranquillitatis (Turkevich, 1973). The ± represent the variability in mare composition calculated as the rms deviations from the average of the different mare results.

[b] Turkevich *et al.*, 1968a; Patterson *et al.*, 1970. The data are the averages of results on two soil samples at a location outside the crater Tycho. The ± represent estimated error limits at the 90% confidence level.

[c] Vinogradov (1972). The oxygen value is from stoichiometry.

[d] Average of eleven soil samples from Apollo 16. The ± are the rms deviations of the results of the different samples from the average. Apollo 16 Preliminary Examination Team (1973). The oxygen values are from stoichiometry.

[e] Calculated on the basis that 80% of the lunar surface is terra-type material.

[f] The oxide composition is calculated on the basis that all the iron is present as FeO.

If solar system elemental abundances (Cameron, 1968) are taken as a reference, the enrichment, relative to silicon, of the average lunar surface for the elements Al, Ca and Ti is by a factor of 6.5 ± 1.5; the depletion of the elements Na, Mg and Fe is by a factor of 4 ± 2.

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References

Adler, I., Trombka, J., Gerard, J., Lowman, P., Schmadebeck, R., Blodget, H., Eller, E., Yin, L., Lamothe, R., Gorenstein, P., and Bjorkholm, P.: 1972, *Science* **175**, 436–440.

Apollo 16 Preliminary Examination Team: 1973, *Science* **179**, 23–34.

Cameron, A. G. W.: 1968, in L. H. Ahrens (ed.), *Origin and Distribution of the Elements*, Pergamon, pp. 125–143.

Patterson, J. H., Turkevich, A., Franzgrote, E. J., Economou, T. E., and Sowinski, K. P.: 1970, *Science* **168**, 825–828.

Turkevich, A., Franzgrote, E., and Patterson, J.: 1968a, *Science* **162**, 117–118.

Turkevich, A., Patterson, J. H., and Franzgrote, E. J.: 1968b, *Am. Scientist* **56**, 312–343.

Turkevich, A.: 1971, *Proc. Second Lunar Sci. Conf.* **2**, 1209–1215.

Turkevich, A.: 1973, *Accounts of Chemical Research* **6**, 81–112.

Vinogradov, A.: 1972, *Trans. Amer. Geophys. Union* **53**, 820.