Table 3. Trace elements in three Apollo 11 moon samples. ES, emission spectra.

Element	Sample 10017 (ppm)	Sample 10072 (ppm)	Sample 10084 (ppm)	Methods used
Sc	77	77	59	ES
V	70	82	71	ES
Co	30	30	32	ES; NA
Ni	<5	<5	200	ES; NA; AA
Cu	20	21	13	ES
Zn	47	24	36	AA
Y	160	175	120	ES
Zr	430	460	380	ES
Sm	25	21	18	NA
Eu	2.1	2.0	1.8	NA
Tb	4	3	3	NA
Lu	5	5	3	NA
Yb	19	19	12	NA
Hf	12	12	8	NA
Ta	5	5	3	NA
Th	4.6	4	3	NA

As is apparent from the tables, there is hardly any resemblance with any known rock from the earth or with any meteorite. The almost complete lack of nickel in the rocks is especially peculiar. With 15 percent iron and also the other transition elements of the fourth period well represented, there should be some trace of nickel if the lunar material and the material from which the earth and the meteorites were formed had a common origin. How has the differentiation worked, if the lunar rocks are products of a differentiation, which of course is not proven at all? In any case, the rocks at the Apollo 11 site have neither a basaltic nor a eucritic composition.

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Note

1. The authors themselves performed the gravimetric, colorimetric, titrimetric, flame photometric, and atomic absorption determinations. We thank the following specialists who contributed to the work: A. Löfgren and A. Savola, who did the emission spectroscopy; P. Kauranen, P. Puumalainen, E. Häsänen, and R. Rosenberg, who did the neutron activation.

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Quantitative Chemical Analysis of Lunar Samples

Abstract. *In three lunar samples the high titanium contents previously reported were confirmed. Water and ferric oxide were absent.*

Three moon samples were analyzed by classical methods (Table 1) (*1*). Determinations for sulfur and chromium were made because of their possible petrologic significance (*2*).

We did not determine metallic iron because we doubt the reliability of published methods and therefore held this determination in abeyance pending discussion with other investigators. Material might be better used in the application of other techniques (for example Mössbauer) to the separated magnetics.

Silica. The procedure was modified to eliminate complications caused by the high concentration of titanium; too much titanium remained with the silica. The procedure (*1*, p. 62) was followed through step 13, the filtrate set aside, 3 g of sodium carbonate added to the silica, and the procedure repeated from step 3 through step 13. The combined filtrates were used in determination of the ammonium hydroxide group which follows.

Table 1. Analyses of moon samples. Values are percentages.

Compound	Olivine basalt 10020-23	Vesicular basalt 10072-32	Lunar fines 10084-131
SiO_2	39.95	40.53	42.20
Al_2O_3	10.19	8.52	14.07
Fe_2O_3	.03	.00*	.00†
FeO	19.14	19.76	15.81
MgO	7.87	7.68	7.93
CaO	11.31	10.42	12.01
Na_2O	.39	.54	.46
K_2O	.05	.27	.12
H_2O^+	.00	.00	.05
H_2O^-	.00	.00	.00
TiO_2	10.52	11.74	7.32
P_2O_5	.07	.14	.08
MnO	.27	.24	.21
S	.18	.24	.14
Cr_2O_3	.38	.35	.28
Subtotal	100.35	100.43	100.68
Less O	.09	.12	.07
Total	100.26	100.31	100.61

*Actual value obtained minus 0.14. †Actual value obtained minus 0.12.

Ferrous oxide. The presence of troilite (FeS) and metallic iron makes results for ferrous oxide uncertain (*1*, pp. 39–42). Hydrogen sulfide should not interfere greatly, because no reducible element is present and most of the hydrogen sulfide is expelled during solution of the sample. Metallic iron is counted as ferrous oxide in the analysis.

Ferric oxide. Ferric oxide is determined by difference after separate determinations of total iron oxide and ferrous oxide. The cumulative errors in both of these determinations are therefore reflected in the value for ferric oxide. The small negative and positive amounts found are probably due to such errors. Within accuracy limits of the method, the samples do not contain ferric oxide.

Combined water. The H_2O^+ reported in sample 10084-131 is probably water adsorbed after the sample reached earth; strongly adsorbed water is not expelled when a silicate is heated at 105°C.

Titanium oxide. Titanium oxide was determined colorimetrically (*1*, p. 70). The precision of the method is probably no better than ±0.1 percent absolute.

Chromium oxide. It is likely that most of the chromium oxide is present in mafic minerals. Sample 10084-131 contained a little black material that might be chromite, but there was no evidence of its presence in the other two samples.

The summation on sample 10084-31 is unacceptably high. The presence of metallic iron, in amounts of about 3 percent, could account for the high total. (Metallic iron is reported as ferrous oxide.) Data from others, however, indicate that 1 percent or less of iron is present. Other factors may contribute to the high total. For example, powder segregation is troublesome in samples containing particles of high density.

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References and Notes

1. Except where otherwise noted, procedures described in *U.S. Geol. Surv. Bull. 1170* were used.
2. Methods used are described in I. M. Kolthoff and E. B. Sandell, *Textbook of Quantitative Inorganic Analysis* (Macmillan, New York, ed. 3, 1952), p. 724.

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