Chemical Analysis of the Moon at the Surveyor VII Landing Site: Preliminary Results

Abstract. *The alpha-scattering experiment aboard Surveyor VII has provided a chemical analysis of the moon in the area of the crater Tycho. The preliminary results indicate a chemical composition similar to that already found at two mare sites, but with a lower concentration of elements of the iron group (titanium through copper).*

The preliminary results of the first direct chemical analysis of the lunar surface, by the alpha-scattering experiment on Surveyor V in Mare Tranquillitatis (*1*), were confirmed by a similar experiment on Surveyor VI at another mare site, in Sinus Medii (*2*). These results showed a similarity in chemical composition to that of basaltic types of terrestrial rocks and meteorites. Surveyor VII reached a highland region near Tycho; its soil-mechanics-surface sampler, which could move the alpha-scattering instrument from point to point, made possible the analyses of several lunar samples.

The method of chemical analysis, the instrument, and the sequence of operations have been described (*3*). The instrument aboard Suveyor VII was modified by (i) coating of the curium-242 alpha-particle sources with carbon in order to minimize transfer of radioactivity by aggregate recoil, and (ii) attachment of a knob on top of the instrument to facilitate handling by the surface sampler. The total source strength of Cm^{242} was about 70 percent higher than on previous missions.

Surveyor VII landed on 10 January 1968 at selenographic coordinates 40.95°S, 11.41°W (*4*). Local surface characteristics at the site differed visibly from those of the mare sites of earlier Surveyor missions: the local surface reflectivity was greater, and large rocks and fragments were significantly more abundant (*4*).

Operation of the alpha-scattering instrument began about 8 hours after the landing. The first two phases of operation (analysis of a sample of known composition and determination of the local radiation background) proceeded satisfactorily, and calibration with a commandable electronic pulser showed that the instrument was behaving properly. However, deployment of the instrument to the lunar surface did not follow the command; it was accomplished by the surface sampler which, in a most ingenious series of operations improvised and controlled from earth, forced the alpha-scattering sensor head down to the lunar surface (see *5*).

Analysis of the first lunar sample, a relatively undisturbed area of the surface, began at 1642 hours G.M.T. on 12 January. The intensity of scattering from this sample, as well as television pictures, indicated that the sensor-to-sample distance was somewhat greater than standard. Accumulation of data on this first sample totaled 27.4 hours over a period of 9 days; during six of these days the alpha-scattering operation had to be suspended because of excessively high temperatures.

On 21 January the surface sampler moved the sensor head to a second location over a rock measuring about 5 by 7 cm in size on its upper face. The rock had been visible before the start of any surface-sampler operations, being somewhat brighter in appearance than its surroundings. The measured rate of events in the alpha mode (about double that for the first sample), together with television pictures, indicated that the rock was well centered in the sample opening, protruding slightly inside the bottom of the sensor head. The period of accumulation of data for this sample totaled 10.3 hours.

At about 1150 hours G.M.T. on 22 January, the sensor head was moved again, this time to a trenched area previously prepared by the surface sampler. The observed rate of alpha events and television pictures showed that the sample analyzed consisted, at least partly, of subsurface material. Data were obtained from this sample for a period of only 6.7 hours before sunset ended the first lunar day's operations. Fortunately the spacecraft and most components of the alpha-scattering instrument survived the lunar night so well that more data on sample 3 were obtained during the second lunar day. Between 13 and 20 February accumulations of spectra in the alpha mode were received, equivalent to 20 hours of useful data.

These results, like earlier Surveyor reports (*1*, *2*), are based on parts of the data that were made available in "near-real time" during the mission for analysis of instrument performance and for planning of operations. The data have been corrected only approximately for nonnominal instrument behavior. The samples examined on this mission, especially the rock and material from the trench, deviate considerably from the nominal geometry in which the instrument is usually used. For these reasons larger errors are assumed than will be applicable later.

Analysis of the data from the first sample (undisturbed surface) has progressed the farthest. The higher-intensity sources used on this mission made the signal-to-background ratio even better than on previous missions. The data are of high quality; those collected during 669 minutes of operation have been subjected to preliminary certification, and corrected for background before interpretation in terms of an eight-element library of spectra, as were earlier Surveyor data (*1*, *2*). A spectrum composed of a linear combination of the contents of such a library represents the results moderately well. The chemical composition of the first sample, derived in this way, is presented in Table 1. The estimated errors are primarily systematic, and in many cases are likely to apply in the same direction in different missions. Table 1 also compares the present results with those reported previously from the mare sites of Surveyors V (*1*) and VI (*2*).

Within the errors indicated, the chemical composition at the landing site of Surveyor VII resembles those at the earlier sites except in the lower amounts of the iron-group elements (atomic weights between about 47 and 65). The reality of this difference is clearly in-

Table 1. Chemical compositions (percentages of atoms heavier than lithium) of surface material at landing sites of Surveyors V, VI, and VII (preliminary results). Surveyor V (*1*) did not provide resolution of "Ca" and "Fe," but a lower limit of 3 percent "Fe" was set in the preliminary analysis. Suveyor VII data are for the first sample. Here "Ca" denotes elements having mass numbers between about 30 and 47; included, for example, are P, S, K, and Ca; also, "Fe" denotes elements having mass numbers between about 47 and 65; included, for example, are Cr, Fe, and Ni.

Element	Surveyor V	Surveyor VI (*2*)	Surveyor VII
C	< 3	< 2	< 2
O	58 ± 5	57 ± 5	58 ± 5
Na	< 2	< 2	< 3
Mg	3 ± 3	3 ± 3	4 ± 3
Al	6.5 ± 2	6.5 ± 2	9 ± 3
Si	18.5 ± 3	22 ± 4	18 ± 4
"Ca"	13 ± 3	6 ± 2	6 ± 2
"Fe"		5 ± 2	2 ± 1

dicated in Fig. 1, which compares the spectra of scattered alpha particles observed by the three Surveyors performing chemical analyses. The spectra from Surveyors V and VI agree throughout, but that from the first sample of Surveyor VII is lower by about a factor of 2 between channels 65 and 73. The intensity in this energy region is determined by the abundance of elements with mass numbers between about 47 and 65. The differences at lower energies between the spectrum from Surveyor VII and those from the mare sites arise mostly from the differences in the amounts of these heavier elements.

The proton spectra from the three Surveyors do not differ significantly in shape. The number of protons (if the responses are normalized as indicated for the alpha spectra in Fig. 1) is about 50 percent higher from the first sample examined by Surveyor VII than from the mare samples. These differences in intensity are partially due to the different geometric relations between samples and instruments on the three missions.

The data from the other two samples of Surveyor VII, although not analyzed to the same extent, appear to be consistent with the analysis reported in Table 1. Both samples show considerable amounts of aluminum, and a lower iron-group content than do the samples examined by Surveyors V and VI.

The terrae show greater diversity in topography and optical properties than do the maria. Thus, the specific landing place of Surveyor VII may not be representative of these terrae, although it shares their most prominent characteristics of rougher topography and higher albedo than those of the maria. (Although Surveyor VII landed in the "dark halo" region just outside Tycho, the site still has a higher albedo (*4*) than most mare regions.)

Because of the gross similarity in chemical composition, many of the conclusions based on the mare results (*1*, *2*) apply at least to the terra site examined by Surveyor VII. Specifically, the chemical composition is inconsistent with that of condensed solar-atmosphere constituents, or of most meteorites that fall on the earth, or of the ultrabasic rocks that are presumed to make up the earth's mantle. The difference in composition between this terra site and terrestrial acidic rocks is less marked than in the case of the mare samples, but still significant.

The lower content of the iron group of elements at the site reached by Surveyor VII may be significant if it applies generally to the terra regions of the moon. The iron group, at the present stage of analysis of the data, comprises the elements Ti through Cu; it includes the elements which in general impart color and a lower albedo to terrestrial rocks. Thus, although there are several possible explanations (*6*) of the higher albedo of the terrae relative to that of the maria, these results suggest that a lower content of the iron group of elements may be a contributing factor (*7*).

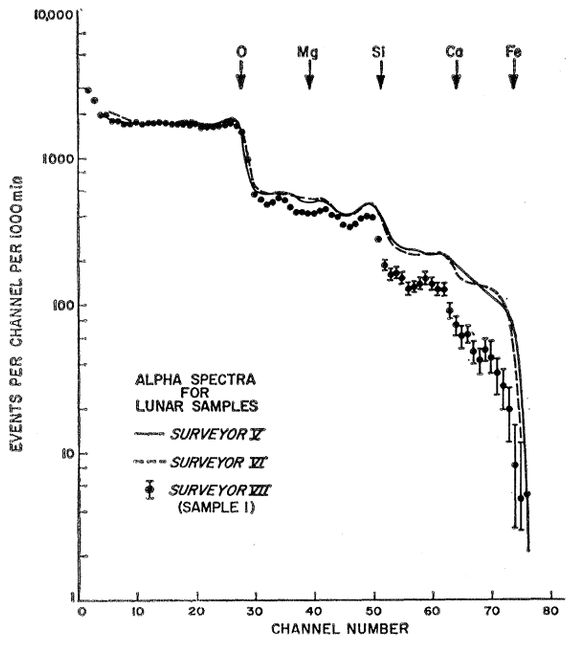

Fig. 1. Comparison of results in the alpha mode (background subtracted) from Surveyor V (solid curve), Surveyor VI (dashed curve), and Surveyor VII (points with associated error bars). The data from Surveyors VI and VII have been normalized to the Surveyor V results in the channel region 8 through 25. Positions of prominent features in some of the elemental spectra are indicated by arrows.

Similarly, the lower iron-group content of the Surveyor VII samples, if it is characteristic of the terrae in general, probably means that the bulk density of material in these regions is less than that of comparable material in the maria. In this case, the very gross topographic relations of the lunar crust would be similar to those on the earth, where in general, the continental highlands comprise material less dense than the basaltic ocean bottoms. Thus, the chemical analyses by the three Surveyors imply that the crust of the moon has a complex geochemical history that merits detailed investigation.

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References and Notes

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8. Work at the University of Chicago was supported in part by subcontract JPL NASA 951347 with the Jet Propulsion Laboratory; at the Jet Propulsion Laboratory, by NASA contract 7-1000; and at Argonne National Laboratory by AEC. The instrument used in this work was constructed mainly by the personnel of the Laboratory for Astrophysics and Space Research and other personnel of the Enrico Fermi Institute at the University of Chicago. These and many others at the Argonne National Laboratory, Jet Propulsion Laboratory, and at the Hughes Aircraft Company participated in the instrument testing, installation onto the spacecraft, and in the Surveyor VII mission operations. The success of the chemical analysis experiment on Surveyor VII was made possible by extraordinary efforts, using the surface sampler, of F. Roberson of the Jet Propulsion Laboratory and R. Scott of the California Institute of Technology in rescuing the experiment after the instrument failed to deploy normally on the moon.

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