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Post-Mission Data Analysis of Surveyor Mission Chemical Data

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Abstract

The prime data from the chemical analysis experiments on Surveyor 5, 6, and 7 have been critically examined and analyzed. Together with associated laboratory work, these have led to final chemical composition results for the lunar regolith at three locations on the moon. The conclusions made on the basis of the preliminary examination of the data have been confirmed and extended.

I. Introduction

The unmanned United States spacecraft, Surveyors 5, 6, and 7, landed on the moon in September, 1967, November, 1967, and January, 1968, respectively. Among the scientific equipment carried by these spacecraft were alpha particle experiments which provided the first chemical analyses of the lunar surface. Two of the landing sites of the Surveyors were in mare areas of the moon; the last was in a terra location outside the crater Tycho. On these missions data were obtained on six lunar samples. The preliminary chemical analysis results that were reported (refs. 1, 2, 3) were based on semi-real time data, limited in quantity and quality and processed by very approximate techniques. The availability of this data had been made possible only by the mission requirements to monitor the behavior of the equipment during the actual mission.

The prime data from these experiments were recorded at Goldstone, California, Robledo, Spain, and Canberra, Australia, in a format designed primarily for the engineering requirements of the Surveyor missions. The proposal being reported upon here covered the task of obtaining this prime data, processing it to put it into scientifically usable form, removal of redundancies, examination for either instrument misbehavior or transmission problems, and processing to obtain the best possible chemical analytical results. In addition, laboratory studies, using a

spare flight instrument, were performed to obtain data needed for the most precise analysis of the lunar results.

This report will summarize the accomplishments of the program under this grant. The summary will lean heavily on the numerous publications and reports which cover in quite a bit of detail the results of the program.

II. Summary of Accomplishments

A. Operational

1. Treatment of prime data

The prime data from the Surveyor chemical analyses experiments were recorded at Goldstone, California, Robledo, Spain, and Canberra, Australia. The data used for the preliminary results were those sent by teletype in semi-real time during the missions from the three receiving stations to the Jet Propulsion Laboratory. Although these preliminary chemical analyses have turned out to be more precise than expected, the errors assigned to them had to take into account the fact that the data on which they were based could not be examined in detail for possible small instrument malfunctions, errors introduced during transmission or inadequate application of instrument temperature calibration effects.

The prime data were not easily accessible. They were in a format designed primarily for the engineering objectives of the Surveyor missions and intertwined with much engineering information of little interest once the missions had proven successful. Obtaining this data from the master recording tapes, putting it into a form suitable for scientific treatment, examining it for validity, removing redundant data (for example sometimes two different stations would receive and record the same data from the moon), and correcting the data for the effects

of temperature (the instruments on the moon operated over about 100° C temperature range) was a major undertaking. A report on this aspect of the work is appended as: "Alpha Scattering Experiment Post-Mission Data Processing" by Kenneth Sowinski, May, 1970. (Report # 1).

2. Laboratory studies with spare instrument

After the missions were completed and the preliminary analyses indicated that the quality of the data was probably very high and worthy of being worked up to the fullest extent, a spare flight instrument was used in the laboratory for a whole series of studies which made possible final chemical analysis reports on the Surveyor missions. These studies included:

a. Knowing the conditions under which the instrument had actually operated on the moon during the missions, it was possible to make measurements in the laboratory that would be most appropriate to the analysis of the lunar data. For example, a new, complete, library of the responses of the instrument to different chemical elements and oxides was obtained with the spare instrument with alpha radioactive sources which were of the same quality as used during the missions, with emphasis on those chemical elements which the preliminary analysis had shown to be most important and interesting.

b. A set of analyses of rocks of known chemical composition was performed again under conditions approximating

those of the lunar missions in order to evaluate more precisely the errors of the technique. In doing these chemical analyses some improvements in the general method of treating data from the alpha scattering technique were made (see Report # 8). These studies made possible the more quantitative evaluation of the errors of the lunar analyses than had been possible heretofore.

c. Several samples examined on the lunar missions (for example, the rock studied on Surveyor 7 missions) involved geometrical relationships of sample to instrument so different from nominal as to require simulation in the laboratory to make sure that these special geometries were not affecting the results. These simulation studies made it possible to make the small corrections needed for these samples.

3. Application to lunar data

The result of the extensive work summarized above made possible publication of the final chemical analysis results from the Surveyor missions (Publications # 3,4, and 6). These final results were thus based on more data and on data that had been much more carefully evaluated than in the preliminary results. In addition, it was possible to give the chemical composition in terms of more chemical elements, and the errors assigned to each of the results were smaller and more quantitatively defined than in the earlier reports.

B. Scientific Accomplishments

1. The first result of this more complete treatment of the Surveyor chemical analysis data was the confirmation of all of the important conclusions made on the basis of the preliminary data: the lunar surface at all three sites is generally basaltic in chemical composition; the most common meteorites and tektites do not come from the surface on the moon; the basaltic composition implies strongly the occurrence of large scale chemical differentiation of the lunar surface; the terra chemical analysis is significantly different from that of the two mare analyses in having appreciably less of elements heavier than calcium; this chemical difference, if generally applicable, could explain the difference in albedo of the two areas of the moon and the difference in elevation.

2. The more precise analyses indicated a low sodium content as compared to typical terrestrial basalts at all three locations examined on the Surveyor missions. In addition, an abnormally high titanium content of the regolith at Mare Tranquillitatis (Surveyor 5) was found. The chemical composition at Mare Tranquillitatis is unique in that there are essentially no terrestrial or meteoritic materials that have the same chemical composition.

3. The more refined analyses made possible the deduction of the principal minerals present in the mare and

terra regions, and from this the density of the surface rocks. This made possible the conclusion that the moon had a crust that was significantly different both chemically and physically from the interior.

4. Most of these analytical results of the Surveyor missions have been adequately confirmed by the results of the later Apollo and Luna missions (e.g. Report # 8). They have established that the Surveyor missions correctly identified more than 99% of the atoms of the lunar surface. In particular they have confirmed the generally low content of the alkalies, the high and variable content of the titanium in lunar mare material and the principal chemical differences between the mare and terra compositions.

5. The only significant Surveyor result which has not as yet been confirmed is the reported presence of 0.3 atom percent of fluorine in the regolith of the terra outside the crater Tycho. Chemical analyses of samples brought back by Luna 20 and Apollo 16 from other terra regions of the moon show no such large amounts of fluorine. It is speculated that this apparent discrepancy may be the one case where the chemical analysis by alpha particles differs from the bulk analysis because it reflects the chemical composition of the topmost surface of the particles. There are some preliminary results which support the presence of fluorine on the surfaces of lunar particles.

6. As an additional result, detailed examination of the prime Surveyor data made possible the identification of alpha radioactivity in the lunar surface at Mare Tranquillitatis (Report # 5). Although not found in studies by other people, or on the visor of the Surveyor III camera visor (Report # 9), the presence of such radioactivity on the lunar surface has since been confirmed (ref. 4).

III. References

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2. Anthony Turkevich, J. Patterson, E. Franzgrote. "Chemical Analysis of the Moon at the Surveyor VI Landing Site: Preliminary Results," Science 160, 1108 (1968).

3. Anthony Turkevich, E. Franzgrote and J. Patterson. "Chemical Analysis of the Moon at the Surveyor VII Landing Site: Preliminary Results," Science 162, 117 (1968).

4. Paul Bjorkholm, Leon Golub, Paul Gorenstein. "Detection of a Nonuniform Distribution of Polonium-210 on the Moon with the Apollo 16 Alpha Particle Spectrometer," Science 180, 957 (1973).

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V. Publications and Reports Arising from this Grant* (copies appended)

1. Kenneth Sowinski. "Alpha Scattering Experiment Post-Mission Data Processing," May, 1970 (unpublished).

2. James H. Patterson, E. J. Franzgrote, A. L. Turkevich, W. A. Anderson, T. E. Economou, H. E. Griffin, S. L. Grotch, and K. P. Sowinski. "The Alpha Scattering Experiment on the Surveyor 7 Lunar Mission: Comparison with Surveyors 5 and 6," J. Geo. Res. 74, 6120 (1969).

3. Anthony L. Turkevich, Ernest J. Franzgrote, James H. Patterson. "Chemical Composition of the Lunar Surface in Mare Tranquillitatis," Science 165, 277-279 (1969).

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5. Anthony L. Turkevich, James H. Patterson, Ernest J. Franzgrote, Kenneth P. Sowinski, Thanasis E. Economou. "Alpha Radioactivity of the Lunar Surface at the Landing Sites of Surveyors 5, 6, and 7," Science 167, 1722-1724 (1970).

6. James H. Patterson, Anthony Turkevich, Ernest J. Franzgrote, Thanasis E. Economou, Kenneth P. Sowinski. "Chemical Composition of the Lunar Surface in a Terra Region near the Crater Tycho," Science 168, 825-828 (1970).

7. Thanasis E. Economou, Anthony L. Turkevich, Kenneth P. Sowinski, James H. Patterson and Ernest J. Franzgrote. "The Alpha-Scattering Technique of Chemical Analysis," J. Geo. Res. 75, 6514-6523 (1970).

8. Anthony L. Turkevich. "Comparison of the Analytical Results from the Surveyor, Apollo, and Luna Missions," Proc. of the Second Lunar Science Conference, Vol. 2, pp. 1209-15, M.I.T. Press (1971).

9. Thanasis E. Economou and Anthony L. Turkevich. "Examination of Returned Surveyor III Camera Visor for Alpha Radioactivity," Proc. of the Second Lunar Science Conference, Vol. 3, pp. 2699-2703, M.I.T. Press (1971).

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* Because of the essentially continuous nature of the work covered by this grant, the earlier contract NASA-JPL-951347 and the subsequent NASA grant, NASA NAS 9-7883, these publications may cover partly overlapping periods.