Surveyor V: Discussion of Chemical Analysis

Abstract. *Material of basaltic composition at the Surveyor V landing site implies that differentiation has occurred in the moon, probably due to internal sources of heat. The results are consistent with the hypothesis that extensive volcanic flows have been responsible for flooding and filling the mare basins. The processes and products of lunar magmatic activity are apparently similar to those of the earth.*

The chemical analysis (*1*) of the lunar surface at the landing site of Surveyor V in southwestern Mare Tranquillitatis has opened a new era in the study of the origin and history of the moon and other planetary bodies. From preliminary results from the α-scattering experiment, the elemental abundances of the major constituents are sufficiently well defined to warrant some discussion of their significance and some tentative conclusions. We recognize, of course, that this first analysis for a single spot (10 cm in diameter) on the lunar surface may not be representative of even a small part of the mare surface. Meteoric impact or, perhaps, explosive volcanism, or both, are mechanisms for distributing and mixing lunar material so that a heterogenous mixture of many components could have been displayed for analysis under the α-scattering instrument. It seems unlikely that sufficient foreign material could be mixed with the indigenous mare material to mask the composition of the parent components totally, but it must be considered a possibility, nevertheless. The modifying effects of prolonged exposure to solar radiation must also be considered because the α-scattering technique permits a sampling of only micron-deep layers of the exposed material. However, some subsurface material shielded from direct solar radiation was ejected by the impact of the footpads against the surface into the region where the α-scattering instrument was finally deployed (*2*). Subject to such limitations and qualifications, therefore, we now offer a preliminary interpretation of the results from this experiment.

The chemical analysis by Turkevich *et al.* (*1*) is compared (Table 1) with six common rock types spanning the range in silica content from ultramafic to silicic composition. Although the composition in any given classification of rocks can vary over a fairly broad range, the magnesium and aluminum abundances in the lunar sample are inconsistent with, and cannot be related to, those of ultramafic rocks such as peridotite and chondritic meteorite. Similarly, the silicic materials represented by the averages for granite and tektite are characterized by silicon and heavy-element abundances that are also inconsistent with the α-scattering data. The analysis points to a basaltic composition, a conclusion that is consistent with the indications from the magnet experiment (*3*).

Important genetic implications arise from a basaltic composition. Basalt is derived by chemical fractionation of an ultramafic rock. Thus it seems highly probable that differentiation has occurred in the moon as a result of partial or fractional melting of lunar material.

The heat sources necessary to melt the lunar material probably originated within the moon rather than from an external source. Internal sources include decay of radioactive elements, gravitational compression, and dissipation of kinetic energy by mechanical processes. The possibility that the analyzed material is the fractionated product from a large puddle of melt produced by a monstrous collision that formed the mare basin is inconsistent with the observations that the filling of the mare basins could not have been contemporary with their formation (see *4*).

Based on the ratio of silicon to sodium in relation to oxygen content (*5*), the material analyzed by the α-scattering instrument approximates the chemistry of some of the most common terrestrial basalts. Even though the analysis of the data has not been refined to the point where the material can be categorized into a specific subgroup of basalt, the general trend is consistent with a widely acecpted hypothesis that extensive volcanic flows have been responsible for flooding and filling of the mare basins. Extensive basalt flows are widespread on earth (*6*). By far the greatest proportion is found as ocean-floor basalt, being derived from partial fusion of the underlying ultramafic mantle. The Columbia plateau or the Deccan traps are the best-known of this genre on continents.

It is both gratifying and significant that the chemical composition of the lunar material appears to be most like that of a common terrestrial rock, and this material is not composed of an unusual mixture of elements. Apparently, the geochemical processes on the earth do not differ greatly from their lunar counterparts despite environmental differences between the two bodies. Therefore, for the first time, we have some evidence for the validity of extrapolating terrestrial geochemical and geologic experience to the interpretation of the moon and of lunar processes.

If the lunar sample analyzed by the α-scattering experiment is fairly typical of the compositional type of material at the Surveyor V landing site—and this seems a reasonable assumption—then it is to be inferred that the observed composition is probably also appropriate to material in other maria because of the geologic similarities among the mare units. We have no reason to assume, however, that basaltic materials with different compositions will not be found in all maria; indeed different compositions are to be expected as the natural consequences of normal fractionation processes. Although knowledge of such differences

Table 1. Elemental abundances for some common materials, compared with preliminary chemical analysis of the moon at the Surveyor V landing site.

Element	Peridotite (*7*)	Plateau basalt (*7*)	Granite (*7*)	Moon mare (*1*)	Indo-Malayan tektite (*8*)	Basaltic achondrite (*8*)	L-type chondrite (*8*)
H	2.5	4.2	1.9		0.4	0.9	0.7
C				<3			
O	57.5	59.0	62.1	58 ± 5	63.7	59.6	54.6
Na	0.4	1.8	2.3	<2	1.0	0.6	0.8
Mg	18.7	3.6	.5	3 ± 3	1.1	5.5	14.4
Al	1.9	5.8	5.9	6.5 ± 2	5.4	5.1	1.2
Si	15.0	17.1	23.8	18.5 ± 3	25.1	18.2	15.5
P to Cu	4.1	8.6	3.5	13 ± 3	3.4	10.1	12.7
(Fe, Co, Ni)	2.4	3.9	0.9	>3	1.5	5.3	10.0

would be of great interest, the determination of the composition in the contrasting highland provinces now becomes of paramount importance for clarifying the differentiation that has occurred in the moon.

D. E. GAULT*
NASA, Ames Research Center, Moffett Field, California 94035
J. B. ADAMS
Jet Propulsion Laboratory
R. J. COLLINS
University of Minnesota
J. GREEN
Douglas Advanced Research Laboratory
G. P. KUIPER
University of Arizona
H. MAZURSKY
U.S. Geological Survey
J. A. O'KEEFE
NASA, Goddard Space Flight Center
R. A. PHINNEY
Princeton University
E. M. SHOEMAKER
U.S. Geological Survey

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* Chairman, Surveyor Working Group on Lunar Theory and Process.

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Surveyor V: Television Pictures

Abstract. *Surveyor V landed in a small crater, 8.5 meters wide and 12.5 meters long, which was probably formed by drainage of surficial fragmental debris into a subsurface fissure. The lunar surface debris layer is exposed in the walls of this crater. At depths below about 10 centimeters, the debris appears to be composed mainly of shock-compressed aggregates, ranging from a few millimeters up to 3 centimeters in diameter, set in a matrix of less-coherent finer particles. Rocky chips and fragments larger than a millimeter are dispersed as a subordinate constituent of the debris.*

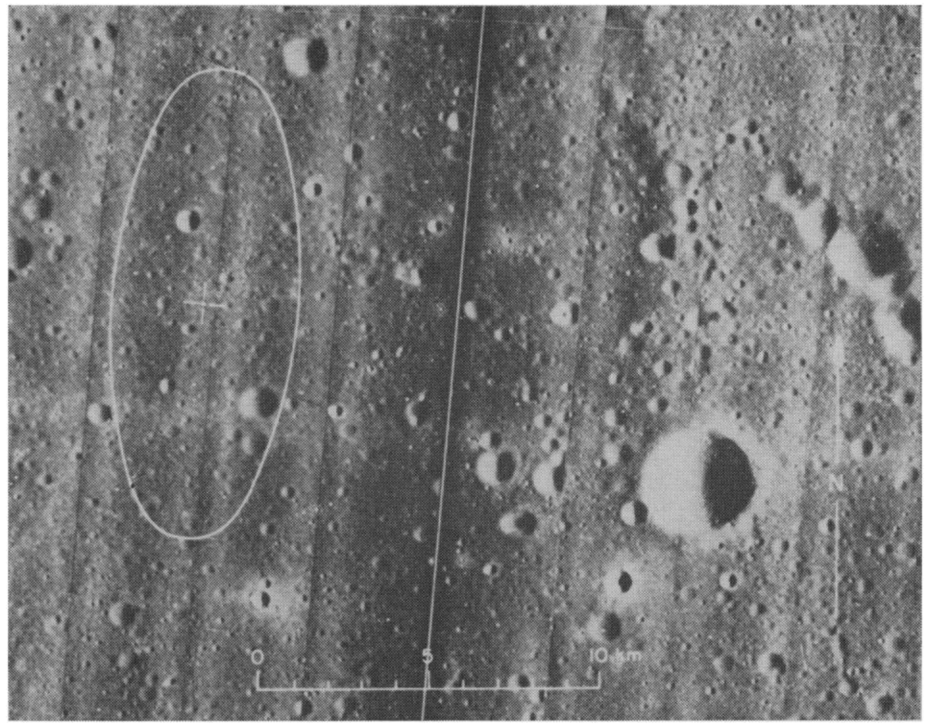

Fig. 1. Lunar Orbiter V medium resolution photograph (M-74) of an area in the southern part of Mare Tranquillitatis. The cross shows the best solution from tracking data for the location of Surveyor V, and ellipse shows 3σ-limit of error of this location. Large crater on the right side of the photograph is Sabine D. The crater in which Surveyor V landed is too small to be resolved in this photograph.

Surveyor V landed on the lunar surface at 00:47 GMT on day 254, 11 September 1967, 35 hours after local sunrise on the moon. Between the time of landing and lunar sunset, 14 days later, more than 18,000 high-quality television pictures of the lunar surface and parts of the spacecraft were acquired. The first results obtained from the television pictures on the physical features of the lunar surface immediately surrounding the spacecraft are presented in this and the foregoing reports.

Landing site of Surveyor V. The landing site of the spacecraft, as determined both from inflight and from after-landing tracking data, is at 1.50°N and 23.19°E (lunar latitudes and longitudes). The 3σ uncertainty ellipse for this solution has a semimajor axis of 6.9 km and a semiminor axis of 2.7 km (Fig. 1). This site is in the southwestern part of Mare Tranquillitatis, about 70 km north of the southern boundary of the mare and a little over 80 km east of the crater Sabine (Fig. 2). It is near the periphery of a complex system of mare ridges, but no known mare ridges occur within 10 km of the most probable position of the landing site. The region is crossed by faint rays associated with the major crater Theophilus, 350 km to the south, and the landing site may be within one of the Theophilus rays.

The highlands to the west of Mare Tranquillitatis are characterized by prominent ridges trending northwest (Fig. 2); these ridges are part of the system of Imbrian sculpture (*1*). Subordinate linear structures in the highlands, such as the Ariadaeus rille, trend about N 20°W. In the immediate vicinity of the landing site, high-resolution pictures taken by Lunar Orbiter V reveal many small craters about 10 m across which are aligned in a northwest direction. Typically, these small craters occur as pairs, with the line between the centers of the craters trending northwest; in a few instances, a single crater is markedly elongate in this same direction. This alignment follows the dominant trend on this part of the mare of the lunar patterned ground, which consists of gentle ridges and troughs of very low amplitude. Both the aligned craters and the lunar patterned ground probably reflect a subsurface system of fissures and joints related to the Imbrian sculpture.

Topography and structure of area around spacecraft. The data obtained from the television pictures (*2–4*) have