Surveyor V: Magnet Experiment

Abstract. *During the Surveyor V landing, a footpad with an attached permanent magnet assembly slid for about a meter through lunar surface material at a depth of about 10 centimeters. Subsequent pictures showed material adhering to the magnetic pole edges, where the magnetic field strength is greatest. Comparison of these pictures with those made under simulated laboratory conditions permits three conclusions. (i) Iron is present on the lunar surface in one of the forms attracted to a 500-gauss magnet. (ii) A 1-percent addition by volume of powdered free iron to a powdered terrestrial rock represents an upper limit for the lunar results. (iii) The lunar results are most similar to a terrestrial plateau basalt with no addition of free iron.*

A magnet experiment was conducted on Surveyor V to determine the presence and an indication of the amount of magnetic material on the lunar surface. The magnet assembly, attached to footpad 2 (Fig. 1), consisted of a magnetic bar of Alnico V and a nonmagnetic bar of Inconel X-750; the dimensions of both bars were 5 by 1.27 by 0.32 cm. The strength of the magnetic field along the pole faces ranges from 440 to 680 gauss. (See Fig. 2 for the gauss contours of the Surveyor V magnet.)

The Surveyor V landing mode caused footpad 2 to slide a distance of about a meter at about 0.7 to 1 m/sec after initial contact, leaving a path approximately 10 cm deep in the lunar surface material (Fig. 3). After the landing, soil was observed on the top surface of the footpad, in the honeycomb structure behind the magnet assembly, on the lower right portion of the nonmagnetic bar, on the bracket, and covering the magnetic bar. We infer that the magnet assembly contacted and "plowed through" the lunar surface material. As seen in the television pictures, the very fine coating of lunar surface material which appeared to cover most of the magnet assembly was probably due to vacuum cohesion. The magnet assembly after landing, prior to the firing of the vernier engines, may be seen in Fig. 4.

After the 0.55-second firing of the vernier engines, which caused an estimated dynamic force of 14 dyne/cm^2 on the magnet assembly, several changes were observed: the nonmagnetic control bar and bracket appeared completely free of material. Some changes in the appearance of the top of the footpad and in the honeycomb structure were also noted. From laboratory studies of jet exhausts in vacuum, little (if any) material would be added to the magnet by the firing of the vernier engines. However, ma-

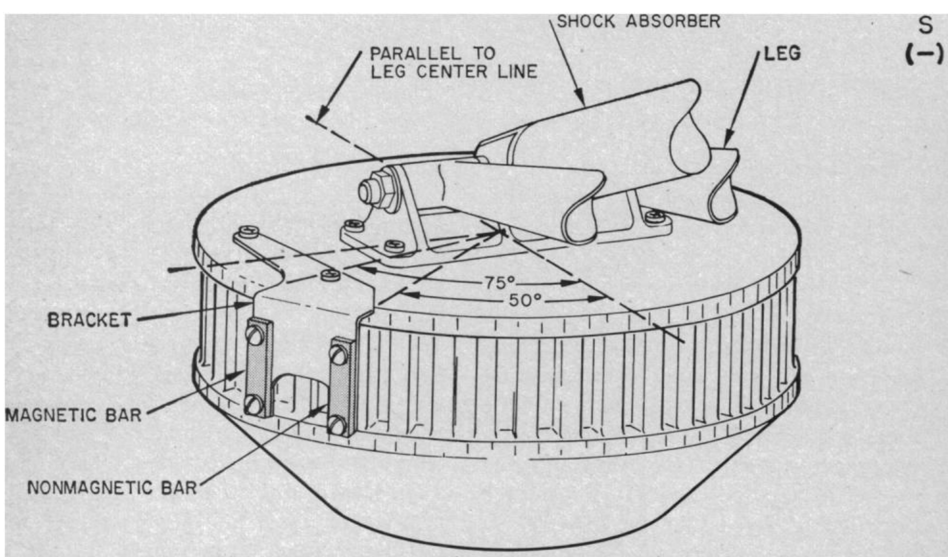
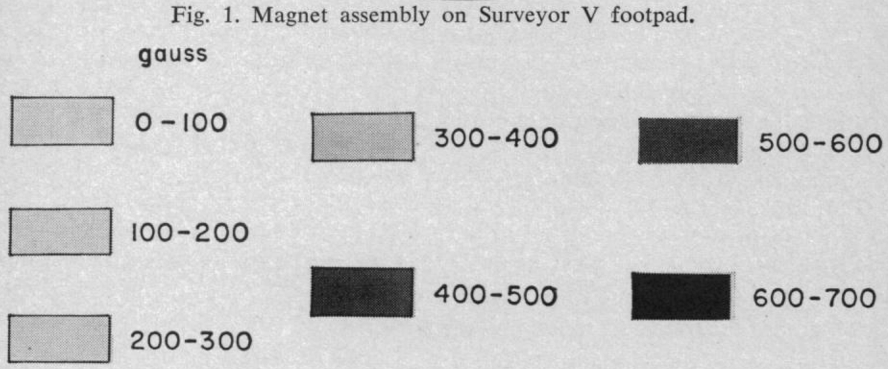


Fig. 1. Magnet assembly on Surveyor V footpad.



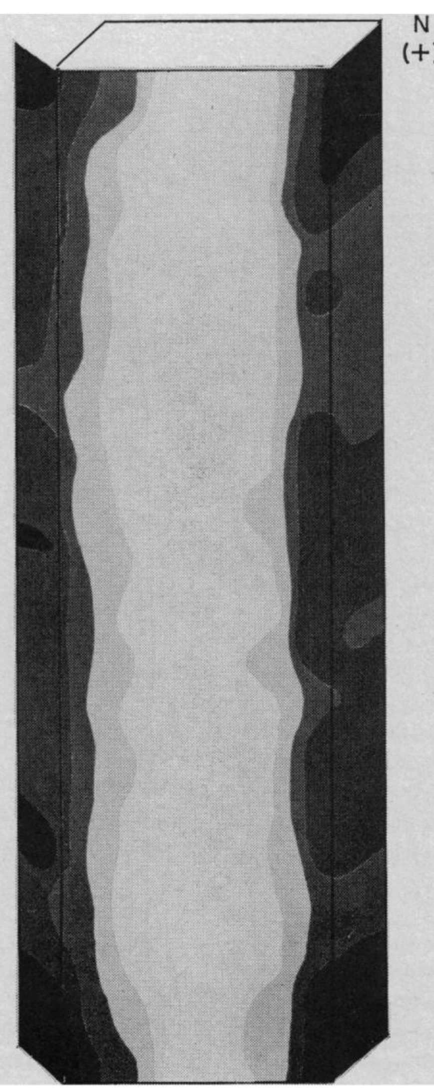


Fig. 2 (above and right). Gauss contours of magnet on Surveyor V indicating the magnetic strength at the surface of the magnet. Note areas of lesser or higher strength along poles, which may be compared to results in Fig. 5. South pole extends down entire left side, north pole down the right. The same orientation exists on the magnet assembly.

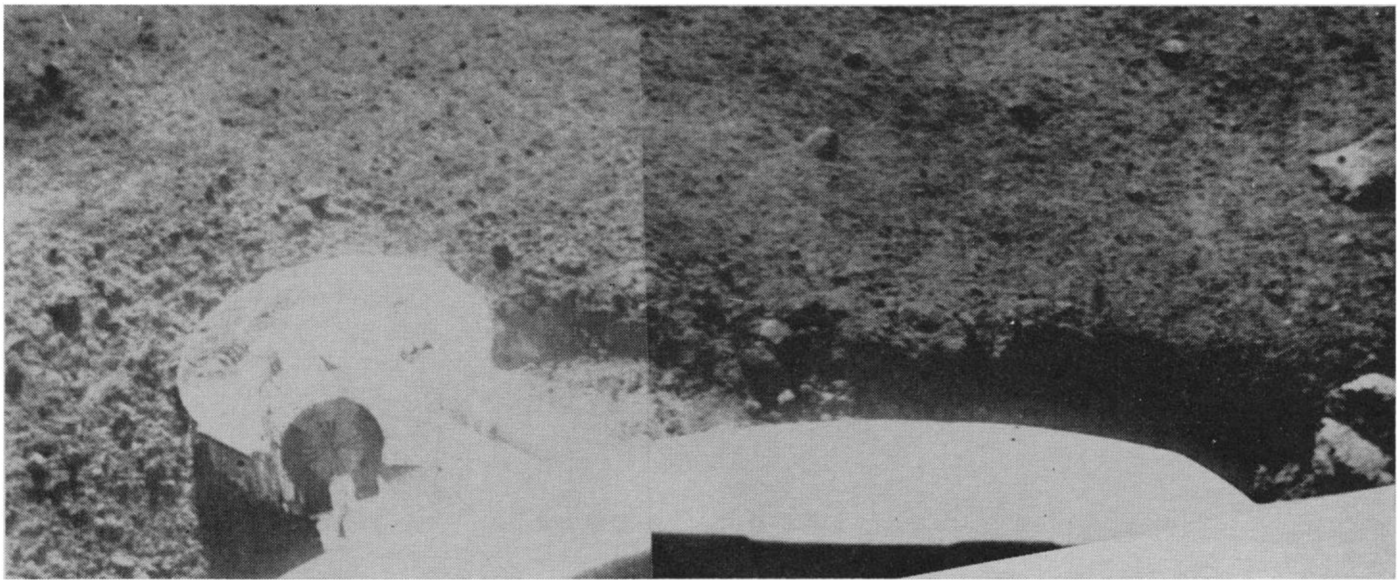


Fig. 3. Mosaic of trench dug by footpad 2. The footpad impacted the surface at the right end of the trench and scoured the meter-long trench down the crater's 20-degree slope. Note material spewed up over the front of the footpad. The Sun is from the upper right (east); (day 255, 00:18:35; day 254, 23:38:23).

terial adhering by vacuum cohesion would be blown off. In sunset lighting, the coating of dark material adhering to the pole faces of the magnet and particles forming bridges across the area of lower strength down the center of the magnet could be seen distinctly (Fig. 5, after firing of vernier). The shape of the particles has not been determined; however, they appear to be smaller than the camera resolution (1 millimeter). The major part of the lunar surface material through which footpad 2 traveled consists of particles less than 1 millimeter, similar to the material observed in pictures from Surveyors I and III.

Laboratory studies included samples of Little Lake basalt, a terrestrial plateau basalt which was powdered to 37 to 50 μ, to which varying percent-

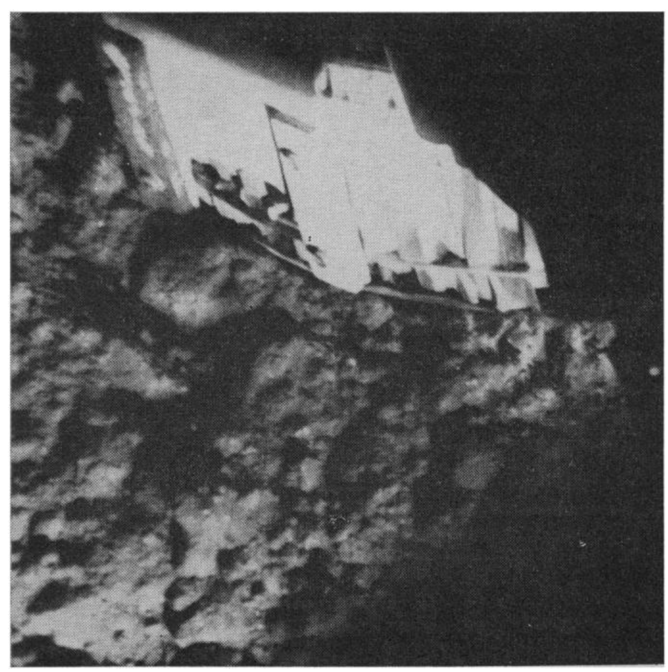


Fig. 4 (left). Computer-processed picture of magnet assembly on footpad 2 immediately after landing. This is an enlargement of a part of a frame taken early in the lunar day. The Sun is to the east (upper right), low on the lunar horizon, casting a deep shadow over the entire magnet assembly. Note the material on lower portion of the nonmagnetic bar, bracket, top of footpad, and in the honeycomb; also note the completely dark magnet. For comparison, note the light patches due to blue paint (day 255, 00 : 33 : 33). Fig. 5 (right). Sunset on Surveyor V magnet assembly, showing magnetic material on the pole edges and bridging the 0-gauss area down the center of the magnet. Note areas on the north pole face (right edge) where the light blue paint patches may be seen. These patches correspond to the areas in which the gauss strength dips slightly as seen in Fig. 2. Direct sunlighting of the entire magnet assembly lasted only 1.5 hours during the entire lunar day (14 Earth days), just prior to sunset on footpad 2 (day 266, 09:52:49).

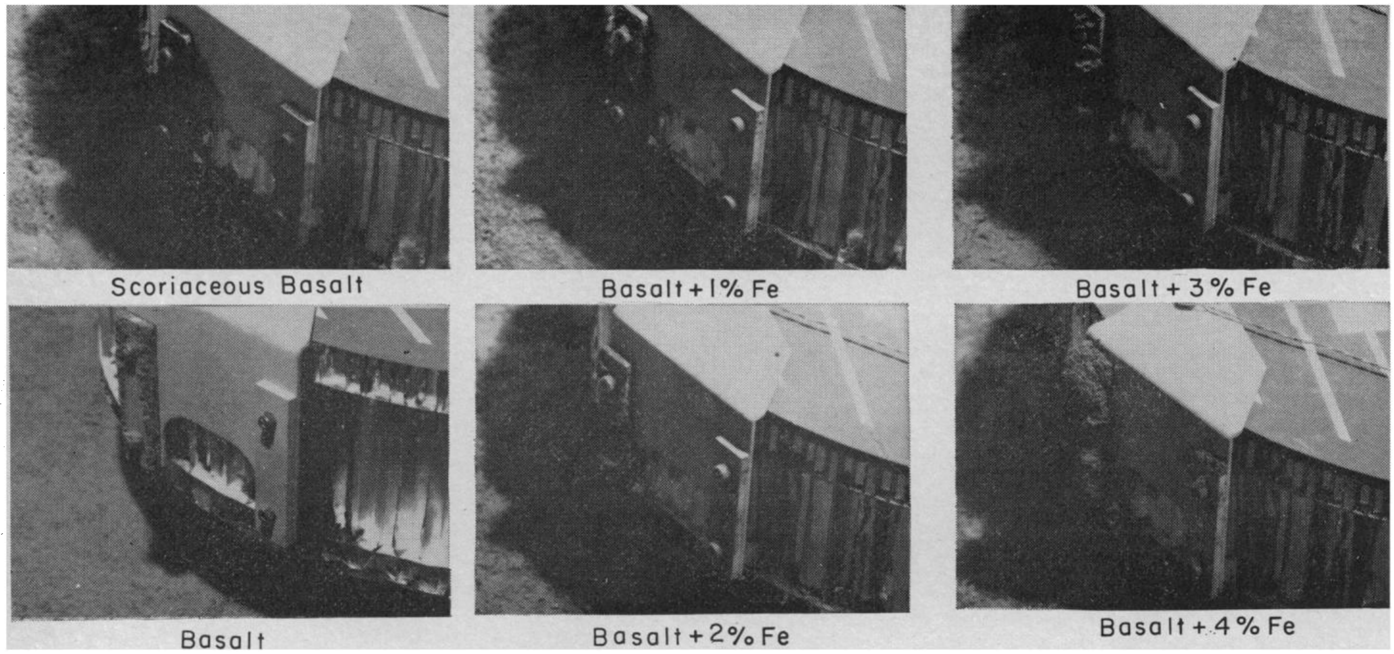


Fig. 6. Laboratory studies in atmosphere of impact in powdered basalt with percentages of iron added as indicated. Vacuum cohesion of a very fine coating on the bracket and nonmagnetic bar was the only difference in the vacuum studies.

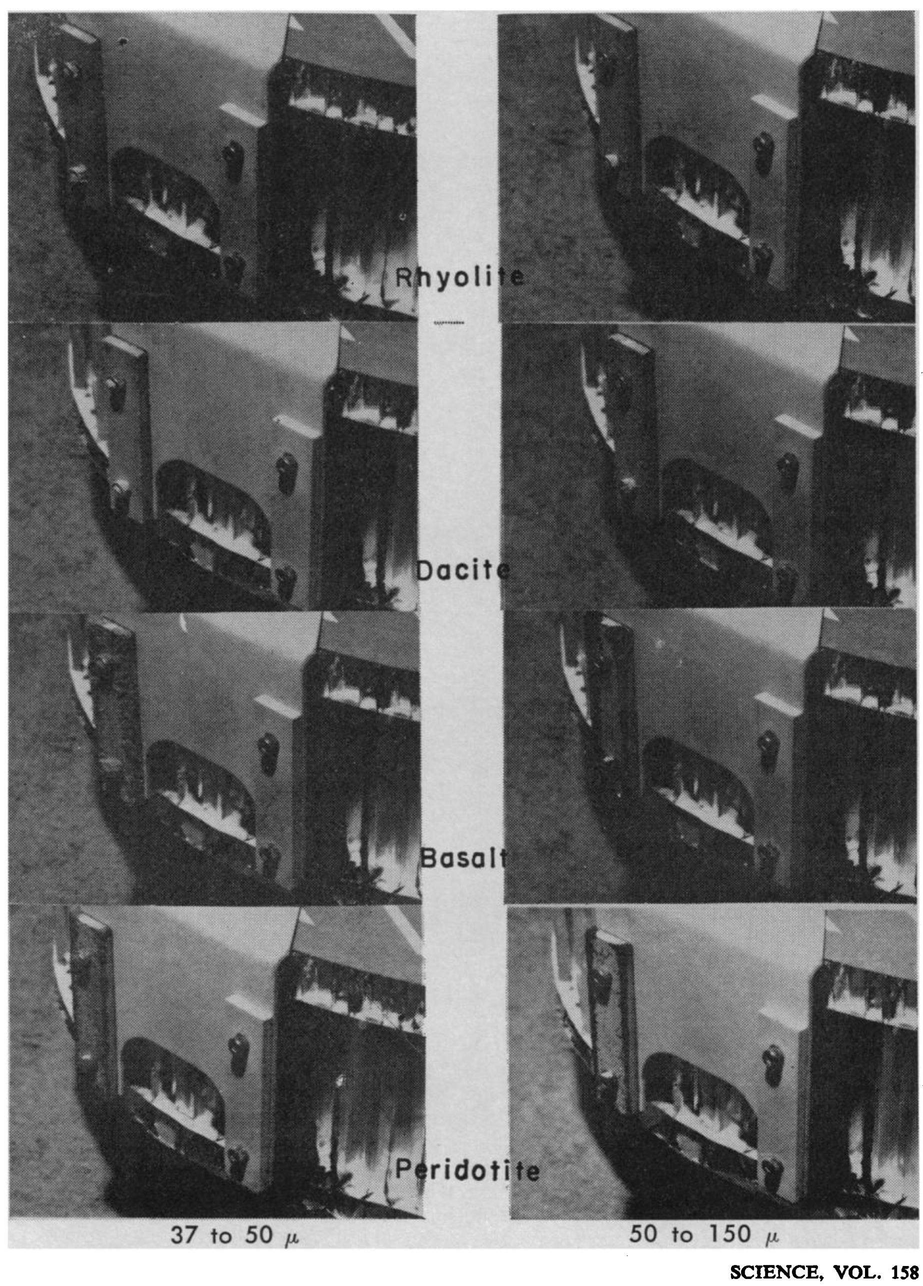


Fig. 7. Laboratory studies in atmosphere of impact in powdered rock. Note difference in results from impact in fine (37 to 50 μ) and coarse fraction (50 to 150 μ) of the same rock type. The lunar results are most similar to impact in basalt. In each case, the magnetic bar is on the left and the nonmagnetic bar is on the right.

ages (0 to 20 percent by volume) of powdered iron were added. The indigenous iron in the basalt occurs primarily as magnetite (10 to 15 μ) finely disseminated throughout the rock. Impacts, jet exhausts, and the landing mode of footpad 2 were simulated. Tests in atmosphere and in a vacuum (10^{-6} torr) were conducted. In the sequence showing the addition of iron, a definite change was discernible with each additional percent of powdered iron (Fig. 6).

Studies of impact in rock types ranging from acidic to ultrabasic were conducted with two powder sizes: 37 to 50 μ and 50 to 150 μ. (See Fig. 7 for results in rhyolite, dacite, basalt, and peridotite.)

It is possible to estimate the percentage of iron (occurring in one of the forms attracted to a 500-gauss magnet) on the lunar surface from a visual comparison of the Surveyor V pictures of the lunar-landed magnet with the pictures of a similar magnet after laboratory-simulated tests of impact and splash phenomena.

Preliminary conclusions. (i) Iron appears to be present on the lunar surface in the area of the Surveyor V landing site in one of the forms that is attracted by a 500-gauss magnet, that is, magnetite, meteoritic nickel-iron, or free iron. (ii) An addition of 1 percent (by volume) of free iron to a basic terrestrial rock represents an upper limit for the lunar results, by comparison to laboratory studies. (iii) Surveyor V magnet results are most similar to those obtained in laboratory impact studies with 37- to 50-μ powdered plateau basalt with no addition of free iron.

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Note

1. This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract No. NAS 7-100, sponsored by NASA.

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Chemical Analysis of the Moon at the Surveyor V Landing Site

Abstract. *The chemical composition of the lunar surface material at a maria landing site has been determined by the alpha-scattering technique. Oxygen, silicon, and aluminum have been identified in the preliminary evaluation of the data. The general chemical composition is similar to that of a silicate of a basaltic type.*

A remarkable amount of information about the moon has been obtained by earth-based measurements. Together with theoretical arguments, these provide clues as to the origin and history of this earth satellite. In the last decade, such earth-based observations have been supplemented by results from the United States and Russian space programs, which have provided high-resolution photographs, data on the physical properties of the lunar surface, and radiation measurements.

Some of the basic questions about the moon, however, can best be answered by a knowledge of the chemical composition of lunar material; until now, observations and measurements have provided only indirect information about this important property. The alpha-scattering experiment of the NASA Surveyor Program is designed to measure directly the abundances of the major elements of the lunar surface. We now report preliminary results of such an experiment at the Surveyor V landing site in Mare Tranquillitatis (23°E, 1°N) on 11 and 12 September 1967.

The α-scattering method of chemical analysis, the instrument used on the Surveyor mission, and the nominal mission operation have been described (*1*, *2*). This technique is especially suitable for instrumented missions in space because of compactness and relative simplicity of operation. It involves the measurement of the energy spectra of α-particles scattered backward from the atomic nuclei of the sample, and of protons obtained from the nuclear reactions of α-particles with some of the lighter elements. These spectra contain quantitative information on all major elements in the sample except hydrogen, helium, and lithium. The method can readily distinguish among the lighter elements, but the atomic weight of heavier constituents can only be approximated.

The alpha-scattering instrument consists of a sensor head, which is deployed directly to the lunar surface, and a digital electronics package located in a compartment on the spacecraft. A collimated stream of alpha particles from approximately 100 mc of curium-242 strikes the sample through an opening (10 cm in diameter) in the bottom of the sensor head. Semiconductor detectors and pulse-height analysis electronics are used to obtain the energy spectra of the scattered alpha particles and of the protons from the lunar surface. Analyses of rocks performed with instruments of the type used on Surveyor V have given results on the major constituents with an accuracy and sensitivity of about 1 atomic percent (*2*).

In the Surveyor V soft-landing mission to the moon (*3*), the sequence of operations of the α-scattering instrument included three distinct stages. In the first stage, the instrument, in its stowed position on the spacecraft, obtained data on a sample of known composition. The first operation of this type was conducted for 1 hour during transit to the moon. The data showed that the instrument had survived the launching, and that radiation-background rates would probably be low enough for useful measurements on the moon. Two hours after landing, the instrument was again turned on by command from the earth; engineering data, including voltages and temperatures, were received and found to be normal. Spectra of the known sample were taken again for about 1 hour, and they agreed very well with spectra obtained before launch.

The sensor head was then released to the background position, suspended about 0.5 m above the lunar surface. During this second stage of operation, the sensor head was far enough from the lunar surface to respond primarily to cosmic rays, solar protons, and possible surface radioactivity. Approximately 3 hours of background spectra were obtained.

The instrument was lowered from the background position to the lunar surface (stage 3) at 15:36 GMT on 11 September 1967. About 20 minutes later, the first spectra from a lunar sample were received at the control center at the Jet Propulsion Laboratory in Pasadena, California, from a tracking station in Robledo, Spain. Television pictures, obtained some time later, confirmed that the instrument had come to rest in a proper manner on the lunar surface. Data were received for a total of 17 hours during the next 2 days.

On 13 September, three liquid-propellant rocket engines (verniers) near the

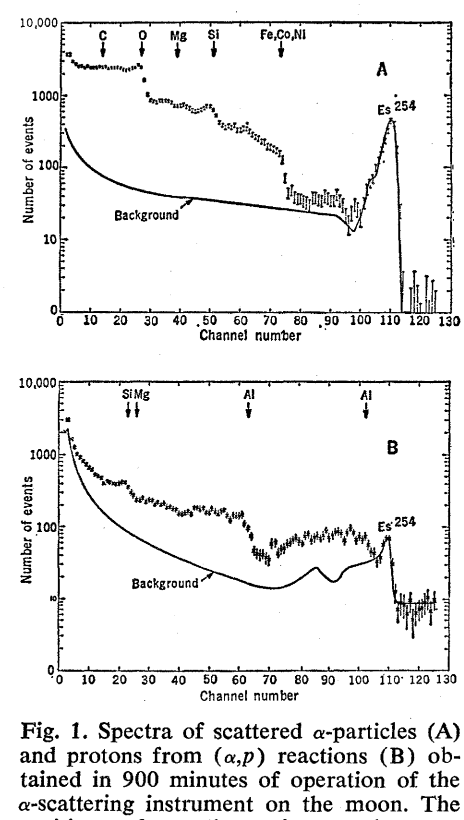

Fig. 1. Spectra of scattered α-particles (A) and protons from (α,p) reactions (B) obtained in 900 minutes of operation of the α-scattering instrument on the moon. The positions of prominent features in some of the elemental spectra are indicated by arrows with chemical symbols.