# 2. Summary of Scientific Results

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The major scientific objectives of the Apollo 15 mission were to carry out extensive geological exploration, comprehensive sampling, and photographic documentation of the Apennine Front at Hadley Delta, Hadley Rille, and the mare plain; to emplace the Apollo lunar surface experiments package (ALSEP) near the landing site; and to perform a series of survey experiments with the scientific instrument module (SIM) equipment from lunar orbit and during transearth coast. The main scientific phase of the mission began when the Apollo 15 lunar module (LM) landed as planned on the mare plain at the eastern margin of the multiringed Imbrian basin just inside the arcuate Apennine mountain range. The scientific adventure by no means ended with command module (CM) splashdown in the Pacific Ocean, however; rather, the adventure continues as the returned samples and photographs are studied and as the data transmitted daily from the ALSEP and the orbiting subsatellite are analyzed. Only the initial results of these scientific investigations are contained in the Apollo 15 Preliminary Science Report. Whenever possible, data trends from each of the experiments are indicated in this summary, and tentative interpretations based on these trends are pointed out. It should be emphasized that, because the results are preliminary, the interpretations based on the results possibly will change as more data become available and the analyses continue.

## GEOLOGIC INVESTIGATION

Because of the extended capability of the life-support equipment and the new mobility provided by the lunar roving vehicle (Rover), the Apollo 15 astronauts explored a much larger area than had been possible on previous missions. The three major geological objectives investigated during the traverses were the Apennine Front along Hadley Delta, Hadley Rille at locations west and southwest of the landing site, and the mare plain at various locations. Extensive information also was obtained about the secondary crater cluster near the Hadley Delta scarp and, although not visited, about the North Complex by photographing the south-facing exposures of this positive feature.

The Apennine Mountains, which rise above the Imbrian plain to heights of nearly 5 km, are thought to be fault blocks uplifted and segmented by the Imbrian impact. The frontal scarp of Hadley Delta, consequently, is interpreted as an exposed section of the pre-Imbrian lunar crust. For this reason, the frontal scarp of Hadley Delta was of highest priority for exploration during the mission. The mountain front was visited on both the first and second traverses; and it was sampled, photographed, and described extensively during this time. In general, the Apennine Mountains show gentle to moderate slopes and are sparsely cratered, with very subdued, rounded outlines. Large blocks are extremely scarce on the mountain flanks, which suggests a gravitationally transported, thick regolith cover on the lower portions of the mountain with a thinner cover of debris on the upper slopes. Sets of stark, sharply etched, parallel linear patterns, completely unexpected before the mission, appear on many of the mountain faces. These major lineaments may represent the expressions of sets of compositional layers or regional fractures showing through the regolith. However, the ambiguities introduced by the oblique lighting of the vertical exposures make difficult an unequivocal interpretation of these linear patterns. For example, the linear ribs clearly present in photographs of Silver Spur and vividly described in real time by the crew may be the expression of gently dipping massive rock layers, or they may reflect near-vertical geologic

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structure. The dark band observed by the crew near the base of Mt. Hadley is intermittently visible in both the surface photographs and the panoramic-camera photographs of the landing site. This feature is quite possibly the remnant of a high-lava mark left after the subsidence of the mare basalts following a partial lava drain-back or a cooling shrinkage during one episode of basin filling.

The rocks collected from the mountain front are mainly breccias; many are glass coated. The absence of clasts of older breccias within them distinguish the Apollo 15 rocks from the Apollo 14 samples. The samples from the mountain front are of three types: (1) friable breccias with clasts of nonmare-type basalt, of mare-type basalt, and of glass fragments; (2) coherent breccias with a vitreous matrix that contains clasts of nonmare-type basalt and granulated olivines and pyroxenes; and (3) well-lithified breccias with abundant granulated feldspathic clasts.

Hadley Rille, interpreted as one of the freshest sinuous rilles found on the Moon, was visited during the first and third traverses. The exposed rille walls, on both the near and far sides, were photographed in detail, and the rille rim and several massive outcrops on the near side were extensively sampled. The exposed bedrock strata visible in the photographs have thicknesses as great as 60 m, are distinctly layered, and exhibit varying surface textures and albedos. These characteristics are indicative of a number of individual flow units. All the layers are nearly horizontal. The talus deposits over the lower sections of the rille walls contain enormous blocks shed from the poorly jointed outcrops above. Unbroken blocks of the sizes seen (approaching 20 m in dimension) are uncommon on Earth. The detailed shape of the rille, the regolith cover of the rims, the lithologies of the outcrops and talus deposits, and the stratigraphy displayed in the rille walls are discussed in greater detail in sections 5 and 25.

The dark plain of the mare surface is generally smooth to gently undulating and hummocky. Rocks cover approximately 1 percent of the surface, except for the rougher ejecta blankets around the numerous subdued craters. The morphology of the craters in the surface indicates the mare age to be late Imbrian to early Eratosthenian, and the specific sampling sites visited by the crew span this age range. For example, a 15-m-diameter crater with a widespread glassy ejecta blanket probably represents the youngest surface feature (station 9) yet sampled on the Moon.

Initial study of the panoramic-camera photography of the landing site indicates a possible subdivision of the mare into four geological units characterized by differences in crater population and surface texture. The rocks collected from the mare and from the exposed outcrops at the rille edge consist mainly of basalts with abundant, coarse, yellow-green to brown pyroxene and olivine phyric basalts. In addition to the characteristics of the major geologic features, the optical properties of the surface materials, as recorded in the many photographs; a number of smaller scale features, such as the craters, fillets, and lineaments that are typical of the Hadley region; and the individual samples themselves are discussed in detail in section 5.

## PRELIMINARY EXAMINATION OF LUNAR SAMPLES

A total of 77 kg of samples was returned from the Hadley area. These samples consist of rocks that weigh from 1 g to 9.5 kg, three core tubes, a deep-drill corestem, and a variety of soil samples taken from the two distinct selenologic regions at the Hadley site (the mare plain and the base of Hadley Delta). The Lunar Sample Preliminary Examination Team has made a macroscopic study of the more than 350 individual rock samples and additional petrographic and chemical studies of a selected few of these samples. The rocks from the mare plain fit into two categories: (1) extrusive and hypabyssal basalts and (2) glass-covered breccias. The rocks from the base of Hadley Delta exhibit a variety that ranges from breccias to possible metaigneous rocks.

The mare basalts appear to be fresh igneous rocks with textures that range from dense to scoriaceous. The chemical composition of these rocks is very similar to the compositions of those basalts returned from the Apollo 11 and 12 and Luna 16 mare sites. In particular, the mare basalts are high in iron, with a correspondingly high iron-oxide-to-magnesium-oxide ratio, and low in sodium oxide, in contrast to terrestrial basalts. Thin-section examinations of 13 of these basalts reveal four different textural types: (1) porphyritic-clinopyroxene basalt with 3- to 9-mm-long prisms, (2) porphyritic-clinopyroxene-basalt vitrophyre with 1- to 7-mm-long skeletal prisms, (3) porphyritic-olivine basalt, and (4) highly vesicular basalt.

A number of rock fragments from Spur Crater and many of the clasts in breccias from the mountain front are basalts that are distinctly different from the mare basalts. Specific differences are: (1) The plagioclase-to-mafic-mineral ratio is 1, compared with a ratio of 0.5 for the mare basalts; (2) the pyroxene is light brown to tan with no zoning, compared with the cinnamon-brown, zoned pyroxene of the mare basalts; (3) the grain size of all mineral phases is less than 1 mm, compared with some grains as large as 1 cm in mare basalts; and (4) no vugs or vesicles are found in the nonmare basalts, in sharp contrast to the often highly vesiculated mare-basalt samples.

Many types of clastic and metamorphosed rocks were found along the traverse routes at the Hadley site, including several unique specimens that are discussed individually in section 6. The greatest variety of these rocks was concentrated along the base of Hadley Delta, where all the samples have undergone shock metamorphism and brecciation.

The soils returned from the Hadley-Apennine area are similar in most respects to soil samples returned from previous missions. The soil is composed primarily of the following particle types: (1) agglutinates plus brown-glass droplets, (2) basalt fragments of different textures, (3) mineral fragments, (4) microbreccias, and (5) glasses of varying color and angularity, including a particular component of green-glass spheres never before observed in lunar soils. The chemical composition of the soil samples, particularly from the mare regions, is distinctly different from the composition of the rocks from presumably the same locales. A linear correlation involving the iron oxide and aluminum oxide constituents of the soil and rocks from the Apollo sites suggests that the soil may be derived from a range of rock material, with the two end members being the iron-rich mare basalt and the aluminum-rich, iron-poor nonmare basalt.

A total of 4.6 kg of material was returned from the Hadley site in the form of core samples. A deep-drill corestem of six sections was driven to a depth of 2.4 m into the regolith near the landing site. All except part of the lowest section was returned completely full. Stereoscopic X-radiographs of this deep-drill core reveal significant variations in pebble concentration and in the density of the material along the core. These variations indicate the presence of more than 50 individual layers with thicknesses from 0.5 to 21 cm. In addition, three drive tubes with a maximum penetration as great as 70 cm were returned. As with the deep-drill core, X-radiographs of the lunar material within these tubes reveal distinct layering and a spectrum of soil textures and fragment sizes. The deep-drill core and the three drive cores all show that the lunar regolith has a substantial stratigraphic history.

The gamma-ray spectra of 19 samples have been measured to determine the concentrations of primordial radioactivity of potassium-40, uranium-238, and thorium-232 and of the cosmic-ray-induced radioactivity of aluminum-27 and sodium-22. In general, the radionuclide abundance is similar to that seen at previous sites. The potassium-to-uranium ratio of both the mare basalts and soils at the Hadley site is strikingly different from the ratio measured in terrestrial samples, which is further evidence in support of an earlier hypothesis concerning differences between Earth and Moon materials.

Concentrations of noble-gas isotopes measured in the samples from the Hadley-Apennine area are similar to the abundances previously measured in lunar materials. Variations in the argon-40 component of the soils are found at this site, as was the case for samples from previous sites, which suggests, for example, differing concentrations of argon-40 in the lunar atmosphere or differing argon-40 retention efficiencies of the soils. Concentrations of the spallation-produced isotopes, neon-21, krypton-80, and xenon-126, result in rock exposure ages in the range of 50 to $500 \times 10^6$ yr, which is similar to the range of exposure ages measured in the Apollo 11 and 12 samples.

The total carbon content for several samples has been determined. As found for the materials from previous lunar sites, the total carbon content for the soils and breccias is higher than for the igneous samples. This continued systematic difference in carbon content seems to confirm the idea that much of the carbon in the lunar soil may originate in the solar wind.

## SOIL-MECHANICS EXPERIMENT

The objectives of the soil-mechanics investigation are to examine the physical characteristics (such as particle sizes, shapes, and distributions) and the mechanical properties (such as particle density, strength, and compressibility) of the in situ lunar soil and to examine the variation of these parameters laterally over the areas traversed at the Hadley site. The longer duration of the extravehicular activities and the correspondingly larger distances covered with the Rover, the variety of the geological units found at the Hadley-Apennine site, and the quantitative measurements provided by the self-recording penetrometer (a device carried for the first time on this mission) have resulted in a number of conclusions.

The lunar surface at the Hadley site is similar in color and texture to the surfaces at the previous landing sites. Although the variability of grain-size distribution of samples from the Apollo 15 site appears to be less than the variability found at the Apollo 12 and 14 sites, considerable variety exists, both with depth and laterally, in the soil properties of strength and compressibility. For example, the compressibility ranges from soft along the mountain front to much firmer near the rim of Hadley Rille. Evidence exists of downslope movement of surficial material on the walls of Hadley Rille; however, no evidence of deep-seated slope failures along the mountain front was found.

Soil densities derived from both the core-tube and the deep-drill corestem samples exhibit considerable variability that ranges from approximately 1.3 to 2.2 $g/cm^3$. The self-recording-penetrometer data indicate an in situ density of approximately 2.0 $g/cm^3$, a high soil strength, and a low soil compressibility. When coupled with additional data from the soil-mechanics trench dug near the ALSEP site, the penetrometer information can be used to estimate the cohesion and friction angle of the lunar soil. The values for both these parameters are higher than the values that resulted from experiments conducted during previous missions.

## PASSIVE SEISMIC EXPERIMENT

The purpose of the passive seismic experiment is to study the lunar-surface vibrations, from which interpretations of the internal structure and physical state of the Moon can be determined. Sources of seismic energy may be internal (from moonquakes) or external (from impacts of both meteoroids and spent space hardware). In either case, a straightforward determination of the unambiguous source locations requires at least three vibration-sensing instruments monitoring the event of interest. The Apollo 15 passive-seismometer station represents the third of a network of seismometers now operating on the lunar surface; thus, the successful deployment of this instrument marked a vitally important step in the investigation of the Moon.

Seismic data accumulated over the first 45 days of operation have been analyzed, and the preliminary results are summarized as follows. Seismic evidence for a lunar crust and mantle has been found. The thickness of the crust is between 25 and 70 km in the region of the Apollo 12 and 14 landing sites. The velocity of compressional waves in the crustal material is between 6.0 and 7.5 km/sec, which is a range that spans the velocities expected for the feldspar-rich rocks found on the lunar surface. The transition from the crustal material to the mantle material may be gradual, starting at a depth of approximately 25 km, or rapid, with a sharp discontinuity at a depth of 45 to 70 km. In either case, the compressional-wave velocity reaches 9 km/sec in the subcrustal mantle material, and the contrast in elastic properties of the rocks comprising these two major layers is at least as great as the contrast that exists between the materials comprising the crust and mantle units of the Earth.

The major part of the natural lunar seismic energy detected by the network is in the form of periodic moonquakes that occur near times of perigee and apogee and that originate from at least 10 separate locations. However, a single focal zone at a depth of approximately 800 km, with a dimension less than 10 km and with an epicenter approximately 600 km south-southwest of the Apollo 12 and 14 sites, accounts for 80 percent of the seismic energy detected. The release of seismic energy at these depths (which are slightly greater than any known earthquake sources) suggests that the lunar interior at these depths must be rigid enough to support appreciable stress. This fact, in turn, places strong constraints on realistic thermal models of the lunar interior.

In addition to the periodic moonquakes, episodes of frequent small moonquakes have been discovered. Individual events may occur as frequently as every 2 hr for periods lasting up to several days. The source of the moonquake swarms is at present unknown, but they may well result from continuing minor adjustments to stresses in the outer shell of the Moon.

The average rate of seismic-energy release within the Moon is far below that of the Earth. Thus, the outer crust and mantle of the Moon appear to be relatively cold and stable compared with that of the Earth, and significant internal convection currents causing lunar tectonism seem to be absent; however, the discovery of moonquakes at great depths suggests the possibility of some very deep convective motion.

Seismic energy deposited at the lunar surface by an impacting meteoroid or manmade object is confined for a surprisingly long time in the near-source area by efficient scattering near the surface. Nevertheless, the energy slowly dissipates through interior propagation to more distant parts of the Moon, and, for this reason, all but the smallest of impact signals from all parts of the Moon are probably detected at the operating seismic stations.

## LUNAR-SURFACE MAGNETOMETER EXPERIMENT

The Apollo 15 magnetometer, which is the third and all-important member of the magnetometer network now on the lunar surface, was deployed to study intrinsic remanent magnetic fields and to observe the global magnetic response of the Moon to large-scale solar and terrestrial magnetic fields imposed on it. Fundamental properties of the lunar interior, such as electrical conductivity, magnetic permeability, and temperature profile, can be calculated from these magnetic measurements. The measuring and understanding of these properties are obvious requirements for meaningful theoretical descriptions of the origin and evolution of the Moon.

The three fluxgate sensors of the Apollo 15 instrument show a steady magnetic field of approximately 5 $\gamma$ at the Hadley site, which is considerably smaller than the 38-$\gamma$ field measured at the Apollo 12 site and the 103- and 43-$\gamma$ fields measured at the two locations at the Apollo 14 site. The bulk relative permeability of the Moon is calculated from the magnetometer data to be near unity. The electrical conductivity of the lunar interior is obtained from measurements of the response of the Moon to externally imposed, variable magnetic fields; and these measurements can be interpreted in terms of a spherically symmetric, three-layer model that has a thin outer crust (extending from the radius of the Moon to 0.95 the radius of the Moon) of very low conductivity, an intermediate layer (extending from 0.95 the radius of the Moon to 0.6 the radius of the Moon) with a conductivity of approximately $10^{-4}$ mho/m, and an inner core (of a diameter approximately 0.6 the radius of the Moon) of conductivity greater than $10^{-2}$ mho/m. In the case of an olivine Moon, these values correspond to a temperature profile of 440 K for the crustal layer, approximately 800 K for the intermediate layer, and greater than 1240 K for the central core.

## SOLAR-WIND SPECTROMETER EXPERIMENT

Two identical solar-wind spectrometer experiments now operate 1100 km apart at the Apollo 12 and the Apollo 15 sites. Solar-wind plasma, magnetosphere plasma, and magnetopause crossings have been observed by both instruments, which show good internal agreement of observations; for example, simultaneous (within 15 sec) changes in proton densities and velocities are detected at both sites. As first measured with the Apollo 12 instrument, the solar plasma at the lunar surface is indistinguishable from the solar plasma some distance out from the surface (monitored by orbiting instruments), when the Moon is both ahead of and behind the magnetic bow shock of the Earth.

## HEAT-FLOW EXPERIMENT

The heat-flow experiment is designed to make temperature and thermal-property measurements within the lunar subsurface in order to determine the rate at which heat is flowing out of the interior of the Moon. This heat loss is directly related to the rate of internal heat production and to the internal temperature profile; hence, the measurements result in information about the abundances of long-lived radioisotopes within the Moon and, in turn, result in an increased understanding of the thermal evolution of the body.

Emplacement of the first heat-flow experiment into the lunar surface was completed during the second period of extravehicular activity at the Hadley site. Initial measurements with this instrument show a subsurface temperature at 1.0 m below the surface of approximately 252.4 K at one probe site and 250.7 K at the other, which are temperatures that are approximately 35 K above the mean surface temperature. From 1.0 to 1.5 m below the surface, the temperature increases at the rate of 1.75 K/m (±2 percent). In situ conductivity measurements result in values between $1.4 \times 10^{-4}$ and $2.5 \times 10^{-4}$ W/cm-K at depth and are found to be greater than the conductivity values of the surface regolith by a factor of 7 to 10, which indicates that conductivity increases with depth as well.

Preliminary analysis of these results indicates that the heat flow from below the Hadley-Apennine site is $3.3 \times 10^{-6}$ W/cm$^2$ (±15 percent). This value is approximately one-half the average heat flow of the Earth. By assuming that this value is an accurate representation of the heat flow at the Hadley site (while realizing that data accumulation over a number of lunations will be required to establish this accuracy) and by further assuming that this value is representative of the moonwide heat-flow value, then consideration of the Moon as a sphere with uniform internal heat generation results in a picture of the Moon as a far more radioactive body than had been previously suspected, and a far more radioactive body than suggested by the ordinary chondrites and the type 1 carbonaceous chondrites that have been used to construct the standard models of the Earth and the Moon to date.

## SUPRATHERMAL ION DETECTOR EXPERIMENT (LUNAR-IONOSPHERE DETECTOR)

The suprathermal ion detector experiment deployed at the Apollo 15 site is identical, except for the ion mass ranges covered, to the instruments operating at the Apollo 12 and 14 sites, and the Apollo 15 experiment is the third member of this ion-monitoring network. In the first days of operation, a number of energy and mass spectra of positive ions were measured, primarily from the gas clouds vented by the spacecraft and other mission-associated equipment. At lunar lift-off, for example, a marked decrease in the magnetosheath-ion fluxes was observed. This decrease lasted approximately 8 min and is attributed to either a change in the ion flow direction (because of the exhaust-gas cloud) or to energy loss of the ions passing through the exhaust-gas cloud. Some hours later, the ascent stage impacted the lunar surface nearly 100 km west-northwest of the Hadley site, and the ions that resulted from the impact-generated cloud were monitored.

Multiple-site observations of ion events that possibly correlate with seismic events of an impact character (recorded at the seismic stations) have resulted in information about the apparent motions of the ion clouds. Typical travel velocities have been calculated to be approximately 80 m/sec. Numbers of single-site ion events have been detected, some with ions in the mass range of 16 to 20 amu/$Q$, which corresponds quite possibly to the release of water vapor from deep below the lunar surface. The 500- to 1000-eV ions streaming along the magnetosheath have been observed simultaneously by all three suprathermal ion detectors. This ion flux is strongly peaked in the down-Sun direction, which is a fact established by the different look directions of the individual instruments.

## COLD CATHODE GAGE EXPERIMENT (LUNAR-ATMOSPHERE DETECTOR)

The cold cathode gage experiment that was deployed at the Hadley site is similar to the instruments at the Apollo 12 and 14 sites and is intended to measure the density of the tenuous lunar atmosphere at the lunar surface. This anticipated thin concentration of gases is a result of the solar wind, the possible continued release of molecules from the lunar interior through the lunar crust, and certain venting and outgassing from the LM descent stage and other gear left on the Moon. The contamination, however, should decrease with time in a recognizable way.

As might be expected from cold cathode gage experiment results from the earlier missions, the gas concentrations observed during the lunar days appear to be overwhelmingly a result of contaminants released by the LM and associated equipment. However, during the lunar nights, the observed concentrations, which are typically less than $2 \times 10^5$ particles/cm$^3$, are lower even than the concentrations expected from the neon component of the solar wind alone. This fact suggests that the contaminant gases from spacecraft equipment remain adsorbed at the low nighttime temperatures and that the lunar surface itself is not saturated with neon, but rather absorbs this gas much more readily than releases it. Except for mission-associated phenomena, no easily recognizable correlations have been found between transient gas events, as seen on this instrument, and the response of the suprathermal ion detector or of the solar-wind spectrometer.

## LASER RANGING RETROREFLECTOR

The third and largest U.S. laser ranging retroreflector was delivered to the lunar surface and deployed at the Hadley site approximately 40 m from the ALSEP site. Successful range measurements to this 300-corner-cube array were made shortly after the LM lifted off several days later, and subsequent measurements indicate that no degradation of the reflective properties of the unit resulted from dust being kicked up during the extravehicular activities or by ascent-engine residue. The better signal-to-noise ratio available with this larger retroreflector will enable more frequent ranging measurements to be made and will enable measurements to be carried out by telescopes of smaller aperture than heretofore possible. Additionally, this third array now provides the important long north-south base-line separation with the Apollo 11 and the Apollo 14 retroreflectors. For the accumulation of data important to the planned astronomical, geophysical, and general relativity experiments, range measurements will be required over a period of years.

## SOLAR-WIND COMPOSITION EXPERIMENT

The solar-wind composition experiment, which is similar to the experiments conducted during the Apollo 11, 12, and 14 missions, was deployed at the end of the first extravehicular activity and exposed to the solar wind for a period of 41 hr, nearly twice the exposure time obtained during the previous mission. Initial samples of the aluminum foil have been analyzed, and isotopes of helium and neon have been detected. The helium flux during the Apollo 15 exposure is nearly four times that detected during the Apollo 14 exposure; yet, interestingly enough, the relative abundance of helium and neon and the relative isotopic abundances of these elements are very similar to the earlier abundances. A positive correlation has been found between the general level of solar activity and the helium-4 to helium-3 ratio, a correlation first suggested perhaps by the helium-to-hydrogen ratio measurements of the Explorer 34 spacecraft.

## GAMMA-RAY SPECTROMETER EXPERIMENT

The gamma-ray spectrometer experiment is designed to measure, from lunar orbit, the gamma-ray activity of the lunar-surface materials. The gamma-ray flux from the lunar surface is expected to contain two components, one resulting from naturally occurring radioisotopes (primarily of potassium, uranium, and thorium) and the other resulting from cosmic-ray-induced interactions at the lunar surface. The gamma-ray intensity from the naturally occurring radionuclides is a sensitive function of the degree of chemical differentiation undergone by the Moon; and, thus, the measured intensity relates directly to the origin and evolution of the planet.

Analysis of the very preliminary data printout (unfortunately the only data available for analysis before the preparation of this document) shows a strong contrast in gamma-ray count rates over different regions of the Moon. Specifically, the regions of highest activity are the western maria, followed by Mare Tranquillitatis and Mare Serenitatis. Considerably lower activity is found in the highlands of the far side, with the eastern portion containing nearly an order of magnitude less gamma-ray activity than that found in Oceanus Procellarum and Mare Imbrium. The preliminary data show intensity peaks that correspond to the characteristic energies of the isotopes of iron, aluminum, uranium, potassium, and thorium; however, more data than available in the preliminary printout are required to verify this identification unambiguously.

## X-RAY FLUORESCENCE EXPERIMENT

The purpose of this experiment is to map the principal elemental constitutents of the upper layer of the lunar surface by measuring the fluorescent X-rays produced by the interaction of solar X-rays with the surface material. Secondarily, the experiment is used to observe X-radiation from astronomical objects during the transearth-coast phase of the mission. The X-ray detector assembly consists of three proportional counters, two X-ray filters (and associated collimators), temperature monitors, and the necessary support electronics. Inflight energy, resolution, and efficiency calibrations are made with X-ray sources carried with the instrument.

Preliminary analysis of the initial data from this experiment is very exciting. In general, the suspected major compositional differences between the two fundamental lunar features, the maria and the highlands, are confirmed by the X-ray data, and more subtle compositional differences within both the maria and the highlands are strongly suggested. For example, the aluminum-to-silicon intensity ratio is highest over the terrae, lowest over the maria, and intermediate over the rim areas of the maria. The extremes for this ratio vary from 0.58 to 1.37, with a tendency for the value to increase from the western mare to the highlands of the eastern limb. Furthermore, a striking correlation exists between the aluminum-to-silicon intensity ratio and the values of surface albedo along the groundtrack surveyed by the X-ray experiment.

Although the data from the X-ray fluorescence experiment are still in the initial stages of analysis, a number of tentative conclusions may be drawn about the fundamental properties of the lunar surface. The sharply varying aluminum-to-silicon ratio confirms that the maria and the highlands are indeed chemically different, and the distinguishing albedo differences between these major features must be, in part, the signature of this difference. The anorthositic component of the returned lunar samples is certainly related to the high aluminum content measured in the highland regions, and the correspondingly low aluminum content of the returned mare basalts is consistent with the low measurement values over the maria. The experimental X-ray data, thus, further support the theory that the Moon, shortly after formation, developed a differentiated, aluminum-rich crust. The sharp change in the aluminum-to-silicon intensity ratio between the highland and mare areas places stringent limitations on the amount of horizontal displacement of the aluminum-rich material after the mare flooding. Indications definitely exist in the more gradual data trends that the circular maria have a lower aluminum content than the irregular maria; and within particular maria (for example, Crisium and Serenitatis), the centers have a lower aluminum content than the edges. Finally, the large ejecta blankets, such as the Fra Mauro formation, seem to be chemically different from the unmantled highlands.

During the transearth coast, X-ray data were obtained from three discrete X-ray sources and from four locations dominated by the diffuse X-ray flux. The count rate from two of the sources, Sco X-1 and Cyg X-1, did show significant changes in intensity of approximately 10 percent over time periods of several minutes; however, a final analysis of Apollo data is required to rule out completely the possibility that changes in spacecraft attitude during the counting periods might account for the counting-rate variations.

## ALPHA-PARTICLE SPECTROMETER EXPERIMENT

The alpha-particle spectrometer experiment consists of 10 totally depleted silicon surface-barrier solid-state detectors of 3 $cm^2$ area each that are particularly sensitive to alpha particles in the energy range between 5 and 12 MeV. The experiment is designed to map, from lunar orbit, possible uranium and thorium concentration differences across the surface by measuring the alpha-particle emissions from the two gaseous daughter products of uranium and thorium, radon-222 and radon-220, respectively. Because trace quantities of these radioactive gases would be included in any outgassing of, for example, water or carbon dioxide from the lunar interior, detection of radon also would provide a sensitive probe of remanent volcanic activity or of local release of common volatiles.

Preliminary analysis of the alpha-particle data indicates that the alpha-particle activity of the Moon is at most equal to the observed count rate of 0.004 count/$cm^2$-sec-sr ($\pm 1$ percent) in the energy band from 4.7 to 9.1 MeV. No significant difference in this count rate was observed between the dark and sunlit sides of the Moon. This measured alpha-particle activity is considerably less than was anticipated before the mission. For example, if the uranium and thorium concentrations measured in the samples returned from the Apollo 11 and 12 sites are typical moonwide values, then the alpha-particle counting rate that results from radon emission is at least a factor of 60 lower than the rate predicted by radon-diffusion models. Complete analysis of all the Apollo 15 alpha-particle data should result in another order of magnitude more sensitivity than reported here for the detection of alpha-particle emission from lunar sources.

## LUNAR ORBITAL MASS SPECTROMETER EXPERIMENT

The lunar orbital mass spectrometer is designed to measure the composition and density of neutral gas molecules along the flight path of the command-service module (CSM) in order to better understand the origin of the lunar atmosphere and the related transport processes in planetary exospheres in general. The instrument was mounted in the SIM on a bistem boom and was operated from the CM. The preliminary results indicate that a large number of gas molecules of many species exist near the spacecraft in lunar orbit; none, however, have an obvious lunar origin or a sufficient intensity to be detected above the background of molecules from all sources. The gas cloud apparently moves with the vehicle because the measured density is essentially independent of the angle of attack of the spectrometer entrance plenum. The spacecraft is thought to be the source of most of this cloud, even though the intensity of the apparent contamination is a strong function of the orbital parameters. For example, during the transearth coast, the detected amplitudes of all species of molecules were reduced by a factor of 5 to 10 from the amplitudes measured in lunar orbit.

## S-BAND TRANSPONDER EXPERIMENT

During the last near-side pass before transearth injection, a small scientific spacecraft was launched into lunar orbit from the SIM bay of the service module. This subsatellite is instrumented to measure plasma and energetic-particle fluxes and vector magnetic fields and is equipped with an S-band transponder to enable precision tracking of the spacecraft. The S-band transponder experiment uses the precise doppler-tracking data of this currently orbiting satellite and the tracking data of the CSM and of the LM taken during the mission to provide detailed information about the gravitational field of the near side of the Moon. The data consist of the minute changes in the spacecraft speed, as measured by the Earth-based radio tracking system (which has a resolution of 0.65 mm/sec). The initial data indicate that the subsatellite is operating normally and, because the periapsis altitudes are following closely the predicted altitudes, suggest that the spacecraft will have an orbital lifetime of at least the planned one year. The subsatellite transponder experiment should provide data for a detailed gravity map for the area between ±95° longitude and ±30° latitude.

Analyses of the low-altitude CSM data have resulted in new gravity profiles of the Serenitatis and Crisium mascons; these results are in good agreement with the Apollo 14 data analysis and strongly suggest that the mascons are near-surface features with a mass distribution per unit area of approximately 500 $kg/cm^2$. The Apennine Mountains show a local gravity high of 85 mgal but have undergone partial isostatic compensation, and the Marius Hills likewise have a gravity high of 62 mgal.

## SUBSATELLITE MEASUREMENTS OF PLASMAS AND SOLAR PARTICLES

The main objectives of the subsatellite plasma and particles experiment are to monitor the various plasma regimes in which the Moon moves, to determine how the Moon interacts with the fields and plasmas within these regimes, and to investigate certain features of the structure and dynamics of the Earth magnetosphere. The experiment consists of two solid-state particle-detector telescopes that are sensitive to electrons with energies as large as approximately 320 keV and to protons with energies as large as approximately 4 MeV, and of five electrostatic-analyzer assemblies that are sensitive to electrons in the energy range from 0.5 to 15 keV.

Detailed observations have been made of particle fluxes around the Moon as the Moon moves through interplanetary space, through the magnetosphere, and through the bow shock of the Earth. Analysis of these preliminary data leads to several tentative conclusions. Solar electrons were measured at the subsatellite following a large solar flare on September 1, 1971. In the energy range of 6 to 300 keV, the electron spectrum is reproduced by the power-law equation $dJ/dE = (3 \times 10^3)\, E^{-1.5}$ electrons/$cm^2$-sr-sec-keV. Additionally, an electron flux of 20 electrons/$cm^2$-sr-sec of energy from 25 to 30 keV is found to move predominantly in a sunward direction for several days while the Moon is upstream from the Earth. It is not known as yet whether this flux is of solar or terrestrial origin. Finally, a distinct shadow in the fast-electron component of the solar wind is formed by the Moon. For the case when the interplanetary magnetic field is nearly alined along the solar-wind flow, this electron shadow corresponds closely to the optical shadow behind the Moon. However, for the case when the interplanetary magnetic field alines more perpendicular to the solar-wind flow, the fast-electron shadow region broadens to a diameter much greater than the lunar diameter and becomes extremely complex.

## SUBSATELLITE MAGNETOMETER EXPERIMENT

The major objectives of the subsatellite magnetometer experiment are to extend the measurements of the permanent and induced components of the lunar magnetic field by systematically mapping the remanent magnetic field of the Moon and by measuring the magnetic effects of the interactions between cislunar plasmas and the lunar field. Initial data from the two subsatellite flúxgate sensors indicate that detailed mapping of the remanent magnetization, although complex, is entirely feasible with the present experiment. For example, preliminary analysis shows a fine structure in the magnetic field associated with the large craters Hertzsprung, Korolev, Gagarin, Milne, Mare Smythii I, and, in particular, Van de Graaff, which produces a 1-$\gamma$ variation in the field measured by the subsatellite passing overhead. Furthermore, magnetic fields induced within the Moon by externally imposed interplanetary magnetic fields are detectable at the subsatellite orbit. Estimated variations of lunar conductivity as a function of latitude and longitude will be possible from magnetometer data. Finally, the data show that the plasma void that forms behind the Moon when it is in the solar wind extends probably to the lunar surface, and the flow of the solar wind is itself rather strongly disturbed near the limbs of the Moon.

## BISTATIC-RADAR INVESTIGATION

The bistatic-radar experiment uses the S-band and the very high frequency (VHF) communication systems in the CSM to transmit toward the portion of the Moon that scatters the strongest echoes to Earth-based receivers. The echoes are received from an area approximately 10 km in diameter that moves across the lunar sufrace near the orbiting CSM. The characteristics of these echoes are compared to those of the directly transmitted signals in order to derive information about such lunar crustal properties as the dielectric constant, density, surface roughness, and average slope.

The VHF data obtained during this mission have approximately one order of magnitude higher signal-to-noise ratio than previously obtained, and the effects of the bulk electrical properties and slope statistics of the surface are clearly present in the data. The S-band data show the areas surveyed during the mission to be similar to those regions sampled at latitudes farther south during the Apollo 14 mission. Distinct variations in the slopes of the lunar terrain in the centimeter-to-meter range exist, and some areas contain an unusually heavy population of centimeter-size rock fragments. The bistatic-radar data are currently being combined with the CSM ephemeris data to correlate these results with orbital photography and corresponding geological interpretations in order to better distinguish between adjacent and subjacent geological units.

## APOLLO WINDOW METEOROID EXPERIMENT

The Apollo window meteoroid experiment involves a careful study of the CM heat-shield window surfaces for pits caused by meteoroid impacts. These tiny craters, when identified, are further examined to obtain information on crater morphology and possible meteoroid residence. So far, 10 possible impacts of 50 $\mu$m diameter and larger have been identified in the windows of the Apollo 7, 8, 9, 10, 12, 13, and 14 spacecraft. These findings correspond to a meteoroid flux below that expected from theoretical calculations but are in good agreement with the flux value derived by an examination of the Surveyor shroud returned by the Apollo 12 mission.

## ANCILLARY EXPERIMENTS

The numerous orbital-science and orbital-photography experiments conducted during the mission are discussed in a separate section (sec. 25) of this report. The individual experiments will not be discussed in this summary of scientific results.

Several other experiments and tests were conducted during the Apollo 15 mission that will not be discussed in detail in this report. The reader is particularly referred to the documents of the NASA Medical Research and Operations Directorate for the biomedical evaluation of the mission-related medical experiments (i.e., bone-mineral measurement, total-body gamma-ray spectrometry, and visual light-flash-phenomena experiment) and to the Apollo 15 Mission Report for a discussion of the many engineering tests conducted during the mission. Four additional experiments not reported elsewhere are discussed in the following paragraphs.

An ultraviolet (uv) photography experiment[1] was conducted primarily to obtain imagery of the Earth and Moon for comparison with similar photographs of Mars and Venus. Both of these latter planets show mysterious behavior in the uv-wavelength region; in particular, Mars exhibits a peculiar lack of detail in

[1]Private communication with T. Owen, Earth and Space Sciences Dept., State University of New York, October 1971.

this radiation region, and, in contrast, Venus exhibits major detail only in this part of the photographically accessible spectrum. Comparison of uv data for the Earth with corresponding data from the less well understood planets should aid in the understanding of these planets. The experiment equipment consisted of a Hasselblad camera fitted with a 105-mm uv lens, two filters with pass bands centered at 3400 and $3750 \times 10^{-10}$ m, and a uv cutoff filter to obtain comparison photographs in visible light. A special uv-transmitting window is used in the CM. Photographs were taken of both the Earth and the Moon from a variety of distances throughout the mission. Preliminary examination of these photographs indicates that the surface of the Earth is still clearly visible down to $3400 \times 10^{-10}$ m, and no large-scale changes in the detection of aerosols occur between 3750 and $3400 \times 10^{-10}$ m. This experiment will be extended on subsequent missions in wavelength coverage and in imagery of the Earth over more land mass.

A lunar dust detector experiment[2] has been deployed as a part of the ALSEP central station on all of the manned lunar landings to date. The experiment has three purposes: (1) to measure the accumulation of dust from the LM ascent or from slow accretion processes, (2) to measure the lunar-surface brightness temperature from reflected infrared radiation, and (3) to measure long-term high-energy-proton radiation damage to solar cells in the lunar-surface environment.

The Apollo 15 dust detector experiment is mounted on top of the ALSEP central station sunshield, with the vertically mounted infrared temperature sensor facing west. Three solar cells (2 ohm-cm, N-on-P, 1- by 2-cm corner dart cells) are mounted on a horizontal Kovar metal mounting plate. For the purpose of determining radiation damage, one cell is bare; the other two cells each have 6-mil cover glasses attached. Solar-cell temperature is monitored by a thermistor on the cell mounting plate.

Results from the dust detectors deployed so far have shown (1) no measurable dust accumulation as a result of the LM ascent during the Apollo 11, 12, 14, and 15 missions; (2) a rapid surface-temperature drop of approximately 185 K during the August 6, 1971, lunar eclipse; and (3) no long-term radiation damage thus far to any of the dust detectors. However, a difference of approximately 8.5 percent in the amount of solar-radiation energy received at the lunar surface has been measured by the Apollo 12 dust detector; this variation is a result of the change of the Moon from lunar aphelion to perihelion.

During the time between spacecraft touchdown and the powerdown of the primary guidance, navigation, and control system of the LM, nearly 19 min of data[3] were obtained from the pulsed integrating pendulous accelerometers, which are instruments normally used with the inertial measurement unit for operational guidance and navigation of the LM. In this case, however, these data provide a direct measurement of the acceleration of gravity ($g$) at the Hadley site. The mean of the accelerometer data results in a value for $g$ of 162 706 mgal, with a standard deviation of 12 mgal. If a spherical mass distribution is assumed for the Moon, this same quantity can be calculated from the familiar equation $g = GM/R^2$, where $GM$ is the product of the universal gravitational constant and the lunar mass, and $R$ is the lunar radius at the Hadley site, as determined from a combination of doppler-shift tracking of the spacecraft around the lunar center of mass and optical tracking of the landing site from the orbiting spacecraft. If the values $GM = 4902.78$ km$^3$/sec$^2$ and $R = 1735.64$ km are used in the equation, then a value for $g$ of 162 752 mgal is obtained, which is in good agreement with the directly measured value of acceleration at the Hadley site.

During the final minutes of the third extravehicular activity, a short demonstration experiment was conducted. A heavy object (a 1.32-kg aluminum geological hammer) and a light object (a 0.03-kg falcon feather) were released simultaneously from approximately the same height (approximately 1.6 m) and were allowed to fall to the surface. Within the accuracy of the simultaneous release, the objects were observed to undergo the same acceleration and strike the lunar surface simultaneously, which was a result predicted by well-established theory, but a result nonetheless reassuring considering both the number of viewers that witnessed the experiment and the fact that the homeward journey was based critically on the validity of the particular theory being tested.

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[2]Private communication with James R. Bates, NASA Manned Spacecraft Center, October 1971.

[3]Private communication with R.L. Nance, NASA Manned Spacecraft Center, October 1971.