Preliminary Scientific Results of Apollo 15
(As of September 24, 1971)

INTRODUCTION

The preliminary scientific results of Apollo 15 are set forth herein. An attempt is made to describe these results in the framework of results from previous Apollo missions.

It should be understood that analysis of Apollo 15 data has barely begun. Hence, the conclusions drawn are necessarily only tentative and far from being complete. Study of the Apollo data will continue for years to come with many revisions expected to our understanding of the Moon.

LUNAR SURFACE SCIENCE

Science data is being recorded continuously from all three ALSEPs during the 45-day real time support period at the MCC-H. The Apollo 12 ALSEP has been functioning on the lunar surface for 23 lunations (674 days). The Apollo 14 ALSEP has been functioning for seven lunations (231 days). Signal strength and power supply are both satisfactory. The Apollo 15 ALSEP has now been in operation for 55 days. Again signal strength and power supply are both satisfactory.

There are now three Passive Seismometers operating simultaneously on the lunar surface. This network of three instruments allows determinations to be made of the distance to meteoroid impacts, and, in the case of moonquakes, the depth as well. During the first lunar perigee after deployment a large moonquake occurred that was determined by triangulation to be approximately 700-800 km beneath the surface and 600 km west of the crater Tycho. This event has been correlated by the P.I. with the most active seismic zone observed during previous perigees. Preliminary analysis of the seismic data give new insights into the nature of the lunar interior. There appears to be a gradual increase in velocity with depth to approximately 25 km at which point there is a sharp velocity increase. This sharp increase in velocity suggests a change in the composition of the lunar material that may be equivalent to the base of a primitive lunar crust. At a depth of 60 km the velocity is estimated to be as high as 9.0 km/sec. This high velocity at such a shallow depth, i.e., at low pressure, raises basic questions about the nature of the lunar material. Equivalent velocities do not occur in the earth until depths of 400 to 500 km. None of the rocks examined thus far exhibit the required mineralogical composition which, under suitable pressure, would transmit seismic impulses at this velocity. Utilizing a new data analysis technique the P.I. has been able to observe "swarms" of small moonquakes not associated with previously observed perigee events. One swarm, which occurred last April, culminated with the largest event yet recorded on the Moon. Analyses of the swarms will continue to determine their source and significance to lunar seismology.

The Heat Flow Experiment now has results from one complete lunation which included six conductivity measurements. The uncorrected diurnal temperature variation at the surface is about 271°C (from -185°C to +86°C), but three feet below the surface the variation is on the order of a few thousandths of a degree. Preliminary results indicate that the heat flow from the interior of the moon outward is about one-fifth that of the earth. This is consistent with preliminary estimates based upon relative volumes and surface areas of the two bodies. From this it can be deduced that the total relative amounts of lunar heat-producing elements U, Th, K, are about the same as that of the earth although the vertical distribution may differ. Although the temperature sensors were not deployed to their full planned depth, the low thermal conductivity of the lunar regolith permits a successful heat flow measurement to be made. The low conductivity results in a high thermal gradient (1.7°C/meter or 1°F/foot) in the regolith. However, since it is likely that conductivity increases rapidly with depth, with a resultant decrease in thermal gradient, prediction of lunar interior temperatures by extrapolation of the observed gradient must be qualified until more data are available.

The Lunar Surface Magnetometer is recording data during both lunar day and might. The magnetic field at the surface at this site is very small and appears to be in the range of 0 to 10 gamma. The Apollo 12 instrument shows a remnant field of 38 gammas. The magnetic field of the moon induced by the magnetic field from the sun is being recorded by both the Apollo 12 and 15 instruments. These data are now being analyzed. Due to the increased sensitivity of the Apollo 15 instrument, the Principal Investigator anticipates that he will be able to deduce a temperature profile from the surface to the center of the moon.

For the first time scientists are beginning to correlate data from three surface experiments to formulate a consistent model of the moon. The seismometer, magnetometer and heat flow data, plus sample analyses, all point to a layered or differentiated moon. As is to be expected at this early date, agreement has not been reached as to the depth or thickness of the differentiated zone.

The Apollo 15 Solar Wind Spectrometer is now recording data simultaneously with the Apollo 12 instrument. The use of two instruments will now permit analysis of both temporal and spacial variations in the solar wind.

The Suprathermal Ion Detector Experiment (SIDE) and Cold Cathode Gauge Experiment (CCGE) both operate throughout lunar night, just prior to sunset, and for short periods after sunrise. With each lunation, their time of operation will be increased until they record data during the entire day and night. The CCGE records an atmospheric pressure of 10^{-12} torr at night from both the Apollo 14 and 15 sites. This increases to 10^{-11} torr during lunar day at the 14 site and increased to 10^{-10} torr at the 15 site. The Apollo 14 instrument has seen occasional pressures even higher, indicating that transient gas clouds are present near the lunar surface from time to time.

The Solar Wind Composition Experiment, which was exposed on Apollo 15 for more than 41 hours, has been delivered to the Principal Investigator for analysis. This is about twice as long as any previous exposure and is expected to enable the P.I. to obtain precise abundances of ^{21}Ne and ^{38}Ar and to define further the acceleration and fractionation processes in the solar atmosphere.

The Laser Ranging Retroreflector (LR^3) at the Apollo 15 site is made up of 300 corner prisms. The Apollo 11 and 14 LR^3 have 100 corners each. The McDonald Observatory is now ranging successfully on all three arrays. The Apollo 15 array is now the key array in the network and is ranged to first at each session since it is more easily acquired and permits a quick calibration of the ground-based instrumentation, thus simplifying ranging to the other arrays. We have recently acquired our strongest returns from the Apollo 11 array indicating that there has been no measurable degradation to the reflector since its emplacement.

Apollo 15 completed our plans for emplacing this experiment and an excellent equilateral network is now in place. With three widely spaced arrays the measurements, when integrated and analyzed, will be utilized to define the earth's wobble and rotation variations, to describe terrestrial, continental drift and differential movements within tectonic plates; to describe the orbit of the moon and its oscillations due to its shape, mass distribution and attraction to the earth; and to test gravitational theories.

A preliminary report on the geology and field petrology at the Apollo 15 landing site was issued by the Apollo Lunar Geology Investigation Team August 5, 1971. The Team has also completed a comprehensive report, "Preliminary Documentation of the Apollo 15 Samples," which will be used by the Preliminary Examination Team and the Lunar Sample Analysis Planning Team. Major highlights of the report are that 57 of the 59 rock samples weighing more than 25 grams can be definitely located on the lunar surface and approximately 45 of the total samples may be precisely oriented when the necessary study of the photography is completed. Documentation of the drive tube locations and the comprehensive and trench samples was also confirmed. The team has updated the traverse map prepared during the mission on the basis of surface photography by both 70 mm and 16 mm cameras, TV video tapes, LRV navigation system data, and recollections of the astronauts. The LM landing position, finally agreed upon at the end of the mission, about halfway between the crater Quark and the planned landing point, has been confirmed by the panoramic photography.

LUNAR ORBITAL SCIENCE

The Principal Investigator for the Service Module experiments have now received the first 30 hours of data tapes, and are proceeding with detailed analysis. Results thus far have been derived from analysis of preliminary data obtained in real time during mission operations. Delivery of data tapes will continue on a weekly basis.

After examining the preliminary data on hand, the Principal Investigator for the Gamma Ray Spectrometer believes that he can define general areas of radioactivity. With the data in five-minute sums, he can see variations of radioactivity as the spacecraft passed over different kinds of terrain. The western mare areas (i.e., Mare Imbrium and Oceanus Procellarum) are generally the highest in radioactivity, with the eastern maria (Crisium, Serenitatis) being somewhat lower. The highlands are the lowest in activity with a slightly lower level in the farside highlands.

The X-Ray Spectrometer Principal Investigator has looked at results from preliminary data for eight orbital tracks. His data are good, and gives consistent information from one pass to the next. The data indicate, from aluminum and silicon intensitites, that the eastern highlands are two to three times higher in aluminum content than are the mare basins. The Al-Si ratios east of the Sea of Fertility correspond to the Al-Si ratios for an anorthosite or gabbroic anorthosite. The lunar farside highlands are very high in aluminum content, and the Apennine highlands are lower in aluminum than eastern frontside highlands.

Further analysis of the X-ray astronomy observations made enroute back to the earth has shown an intensity variation in x-ray output of Sco X-1 and Cygnus X-1 which varies on a time scale of minutes. Concurrent radio astronomy observations were made by the Westbork Observatory in Holland. The Principal Investigator has also received data from concurrent visual observations made by the Crimean Observatory.

The Alpha Particle Spectrometer did not detect any local areas of radon enhancement. The general radon evolution rate of the moon is three orders of magnitude less than that of earth. A refinement of the data, in which summation of counts from successive orbital passes over the same area is made, will be required to make more definitive statements about the lunar distribution of radon isotopes. This detailed analysis effort will be conducted when the Principal Investigator receives his magnetic tapes from the mission.

The Mass Spectrometer measured an unexpectedly large amount of gas at orbital altitude around the moon. This amount was an order of magnitude greater than that seen while the spacecraft was on its way back to earth. Many gases were detected, including water vapor, carbon dioxide, and a variety of hydrocarbons. In the preliminary data two transient events were detected consisting of sudden increases in carbon dioxide measured without increases in water vapor and hydrocarbon enhancements, normally associated with spacecraft dumps and purges. The source of these carbon dioxide events cannot be identified without careful analysis of all the final data.

The Mapping Camera film has been processed, and distribution to the users is underway. The exposure of the film is as anticipated, and image quality is excellent throughout the entire sequence of 3400 frames. The entire portion of the lunar surface which was overflown by Apollo 15 in daylight has been covered by excellent stereoscopic photography which is as well suited to detailed analysis and geologic interpretation as it is to mapping. Indexing of the photography is near completion, and plots of the coverage are being provided to the DoD agencies for use in their mensuration activities.

Panoramic Camera film has been processed and examined. The quality of exposure was as anticipated, and within the limits of visual examination, all the imagery appears to be of very high quality. A copy of the film from the first camera operation on revolution four has been sent to the camera vendor for careful analysis of the effects of the V/H sensor malfunction. Preliminary examination of the film shows that less than one per cent of the total film exposed was seriously degraded by this malfunction. The film is being duplicated for distribution to the user agencies. Plans are underway to start the first mapping activities of the Hadley Apennine area, using Panoramic photography to produce a topographic orthophoto map at a scale of 1:25,000.

The results of Laser Altimetry on the early orbits have been correlated with S-band transponder data for the frontside pass, and show the shape of the gravity anomalies as related to Mare Basins. The complete, circumlunar altimetry data show that, relative to the mean lunar radius, the average lunar farside is about two kilometers high and the average frontside is about two kilometers low.

Among the Command Module pilot's many responsibilities, was the requirement to conduct photographic investigations and tasks using handheld and bracket mounted cameras in the Command Module. Many hitherto unknown remarkable surface features were photographed, as well as assigned targets of special interest. Existence of these unusual features reinforces earlier observations that the moon has undergone a complex history.

The Principal Investigator for the Ultraviolet photography has a second generation positive transparency and prints of the UV film. His preliminary examination shows that exposures, crew performance, etc. were excellent. He will continue working with the duplicates to establish his working plans before starting detailed densitometric and spectrometric studies with the original negative. He expects to be able to draw significant conclusions, based on his preliminary examination.

The performance of Gegenschein photography on Apollo 15 was unsuccessful, due to incorrect spacecraft attitude information for acquisition of the Gegenschein. Analysis of the Apollo 14 original photography, after isodensitometry of the original negative to remove lens vignetting and other known noise sources reveals that the exposure level is not adequate to confirm Gegenschein at the Moulton point. This effort will continue with an attempt to sum the imagery from two photos simultaneously, one photo being laid on top of another. The Apollo 15 images, which acquired the Milky Way, will be analyzed in the same manner to improve the isodensitometry techniques.

Based on preliminary examination of the Dim Light photographic tasks, it appears that excellent quality imagery was obtained of the Solar Corona Zodiacal light, and the lunar surface in earthshine.

A checkout tape of the final data for the CSM S-Band Transponder has been validated by the Principal Investigator. The data are very good; the final tape will be formatted and sent to him for detailed analysis this week.

Dual frequency (S-band and VHF) bistatic radar experiments were conducted on Revolutions 17 and 28. The S-band portion of the Revolution 17 was not successful due to incorrect spacecraft attitude information. The data from the VHF portion of Revolution 17 appears to be of high quality. Since the attitude error was discovered and corrected in time for Revolution 28, all the data for that revolution are of excellent quality. The VHF experiment conducted during the entire sleep cycle of August 2 provided high quality data. All the data have been digitized, and computer processing is underway to determine dielectric constant, surface roughness and slopes.

The data from the subsatellite experiments have been reaching the Principal Investigators according to plan.

The subsatellite S-band transponder is working well, and is now being operated every twelfth lunar revolution. The tracking data shows that the perilune variation is following pre-flight predictions, and in about 60 days will verify the predicted spacecraft orbital lifetime of greater than one year. The subsatellite transponder has shown at least one new mascon in the region of the crater Humboldt on the eastern lunar nearside.

The Subsatellite Magnetometer is returning better than expected information in relation to detecting surface anomalies. The Principal Investigator is carrying out hand calculations on farside data that indicates excellent repetitive information over the craters Gagarin, Korolev and Van de Graaff. While in the solar wind the magnetometer is mapping the signature of the diamagnetic cavity behind the moon. As the subsatellite passes behind the moon, variations in the solar wind by factors of two to three are detected by the magnetometer. These may be caused by interaction of the solar wind with local magnetic regions near the limb. More careful long term analysis is required to confirm this preliminary finding.

All the particle detectors of the Particle Shadows/Boundary Layer experiment are working properly. When the moon is not in the Earth's tail, the effect of the moon's shadow on the solar wind electrons is clearly detected. The variation in the shadow shape is rather large. With the moon in the Earth's tail, a very tenuous plasma is seen outside the plasma sheath. Within the plasma sheath intensities increase, with some flow of plasma from the Earth's direction.

A solar flare event last week permitted observation of the effect of the lunar shadow. In addition, last week the Principal Investigator launched two sounding rockets from the arctic region at the time of full moon, to record different points in the same field lines observed by the subsatellite.

LUNAR SAMPLES

The Apollo 15 mission returned a total of about 76 kg (168 lbs.) of lunar material (the total will be slightly higher when the amounts remaining in bags and boxes are inventoried). This represents a little more than three-quarters of the combined weight of all the material returned by the three previous missions. The total sample weight includes 2.7 kg for the five drive tubes and 1.3 kg for the deep drill core. The collection is quite diverse and contains the most documented samples yet returned by any lunar mission. The attached tabulation gives a very generalized comparison between the lunar samples returned by Apollos 11, 12, 14 and 15.

The Apollo 15 rocks can be broadly grouped into two main types in about equal proportion: basalts and breccias. For rocks greater than 25 grams, basalts predominate at the rille collection sites, whereas breccias overwhelmingly predominate at the Apennine Front and LM sites.

The basalts vary considerably in grain size and texture; some have the greatest development of cavities yet observed for lunar rocks and consequently have a "spongy" appearance. The largest single lunar sample returned to date is a basalt (15555, the so-called "Great Scott") that weighs 9.6 kg (about 21 lbs.). Preliminary chemical data indicate that the "Great Scott" basalt has the highest iron content observed thus far for lunar samples (23.1% FeO). A few of the basalts are characterized by yellowish or blackish coatings that may represent some sort of alteration processes not previously observed for other lunar samples. Preliminary examination indicates that the basalts also have different populations of phenocryst minerals (i.e., those larger crystals that develop first from a melt); such differences will provide valuable clues on the crystallization histories of the basalts.

The breccias as a group are varied. Most are more coherent than the Apollo 14 fragmental rocks, although a few are rather fragile (e.g., the "green" rocks). The so-called "black and white" rocks appear to be complex breccias, rather than rocks showing a contact between basalt and white rock as previously suggested. The "green" rocks collected by the astronauts acquire their color from an unusually high concentration of green glassy spherules that probably represent droplets of (impact generated?) melt. The fact that similar green glassy spherules can be recognized in all the soil samples suggests that the event that produced them was not merely a local phenomenon. These green spherules have a high refractive index (1.65) and are high in magnesium.

Much has already been said about the anorthosite of the so-called "genesis rock" (15415). This important sample (269 grams) appears to be a fragment of a previously much larger rock, the remains of which served as a "pedestal" for the "genesis rock". The so-called "pedestal rock" (15430-) appears to be a poorly consolidated breccia (i.e., a "clod"). The "genesis rock" is indeed anorthosite from mineralogic and chemical evidence; it is composed almost entirely of plagioclase (Ca-Na-Al-silicate) and its content of radioactive elements is very low: 0.012%K, 0.030 ppm Th, and 0.0024 ppm U. These values give Th/U and K/U ratios which are quite different from those of other terrestrial or lunar rocks, and so are of considerable geochemical interest. Although the anorthosite may represent a chunk of the original lunar crust, as some scientists believe, it may be difficult (or impossible) to date by Rb-Sr or Th-U-Pb methods. An $^{39}Ar/^{40}Ar$ date of 4.15 ± 0.2 billion years has been reported for the "genesis rock" which makes it the oldest whole rock so far returned from the moon. The "Great Scott" basalt has an age of 3.27 ± 0.06 billion years. In general, the radioactivity of the Apollo 15 samples is comparable to the lower end of the levels noted for the Apollo 12 samples, and accordingly, much lower than the Apollo 14 materials.

The Apollo 15 soils vary according to their sampling sites: the soils in the LM area appear to be derived from both reworked basaltic material and debris from the Front; the soils from the rille area are composed primarily of reworked mare basaltic material; and the soils from the Apennine Front appear to be reworked debris from bedded deposits upslope with only a very small component of mare material.

The soils with high content of green glass spherules are similar in composition to the "green" rocks (i.e., high in MgO). Preliminary data do not indicate any great amount of the KREEP material (high potassium, rare earths, and phosphorus) commonly found in the Apollo 14 soils.

Drive tubes and the deep drill core show distinct layering as deduced from x-ray examination. For example, 58 distinct layers have been identified in the deep drill core taken to a total depth of almost eight feet. The excellent stratigraphy observed in the deep drill core and in the drive tubes should give much information to help understand lunar surface processes.

In summary, the limited data obtained by the Preliminary Examination Team indicate that the Apollo 15 samples differ in many ways from the previously sampled lunar material and that the samples should provide good collections for well-designed experiment. When more information is available from detailed investigations by Principal Investigators, more interpretation will be possible. In a significant departure from previous practice, material from the "genesis rock" (15415), the "Great Scott" basalt (15555), and the contingency fines (15021) distributed to Principal Investigators prior to completion of the Preliminary Examination. This action has already provided important data, especially age determinations, on a short-time basis that can be utilized in site selection and mission planning for Apollo 17.

GENERALIZED COMPARISON OF LUNAR MATERIALS

	Apollo-11	Apollo-12	Apollo-14	Apollo-15
tal weight of returned material	22 kg (48 lbs.)	34 kg (75 lbs.)	42 kg (92 lbs.)	76 kg (168 lbs.)
neral color of returned material	Rocks variable but mainly dark; soil dark	Rocks variable but mainly dark; soil dark	Rocks variable but light-colored not uncommon; soil distinctly lighter than Apollo-11 and -12 soils	Rocks variable but mainly dark; some rocks and fragments in breccias are distinctly lighter; soils variable, and locally greenish.
es of rocks	Predominantly basalts; fragmental rocks rare; angular and coherent	Predominantly basalts; fragmental rocks uncommon but more abundant than in Apollo-11; angular and coherent	Predominantly fragmental; crystalline and basalt rocks rare; most fragmental rocks fragile, not very coherent (e.g., the "clods")	About half crystalline and half fragmental; one anorthosite ("genesis rock"); most rocks are coherent, but some fragmental rocks are "cloddish" (e.g., the green rocks)
ls	- - -	- - -	Finer grained and lighter in color than Apollo-11 and -12 soils	More variable in character relative to Apollo-11, -12, and -14 soils; character depends on sampling site (e.g., Apennine Front vs. mare)
	Glass particles common	Glass particles less than in Apollo-11	Glass particles scarce (i.e., less than in Apollo-11 and-12)	Glass particles variable; green glassy spheres present in nearly all samples but abundant in samples near Spur Crater
	Cohesive	Cohesive	Less cohesive (e.g., sloughing of trench wall; material falling out of core tube)	Cohesive; locally extremely cohesive
oactivity (from U, Th, of rocks	Not unusual for basaltic rocks	Not unusual for basaltic rocks (except for a few samples, e.g., 12013)	Significantly higher than Apollo-11 and -12 (2 samples 10 times higher)	Generally comparable to Apollo-1[illegible] but some samples have lowest radioactivity yet observed for lunar samples

GENERALIZED COMPARISON OF LUNAR MATERIALS
(Cont)

	Apollo-11	Apollo-12	Apollo-14	Apollo-15
ılogy	Principal minerals feldspar, pyroxene, olivine; ilmenite (high Ti) abundant	Similar to Apollo-11, but less ilmenite	Similar to Apollo-12 but significantly higher in feldspar	Similar to Apollo-12 but more variable; locally higher in pyroxene and olivine; locally extremely high in feldspar (e.g., anorthosite)
ːal composition of l	High in titanium	Normal in titanium	Because of more feldspar, higher in Si, Al, Ca, Na, and K; proportionately lower in Fe, Mg, and Mn	Variable; some samples are iron-rich (at rille edge), and others are magnesium-rich (Spur Crater)

Allenby

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: MAL

SEP 28 1971

MEMORANDUM

TO: Distribution

FROM: MA/Apollo Program Director

SUBJECT: Report of Preliminary Scientific Results of Apollo 15

Enclosed is a summary of preliminary scientific results of the Apollo 15 mission as of September 24, 1971. This is a first progress report of analyses being conducted by the Principal Investigators. A much more detailed preliminary report will be published late in February or early March 1972.

Rocco A. Petrone
Rocco A. Petrone

Enclosure

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