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Data User's Note

Apollo Seismological Investigations

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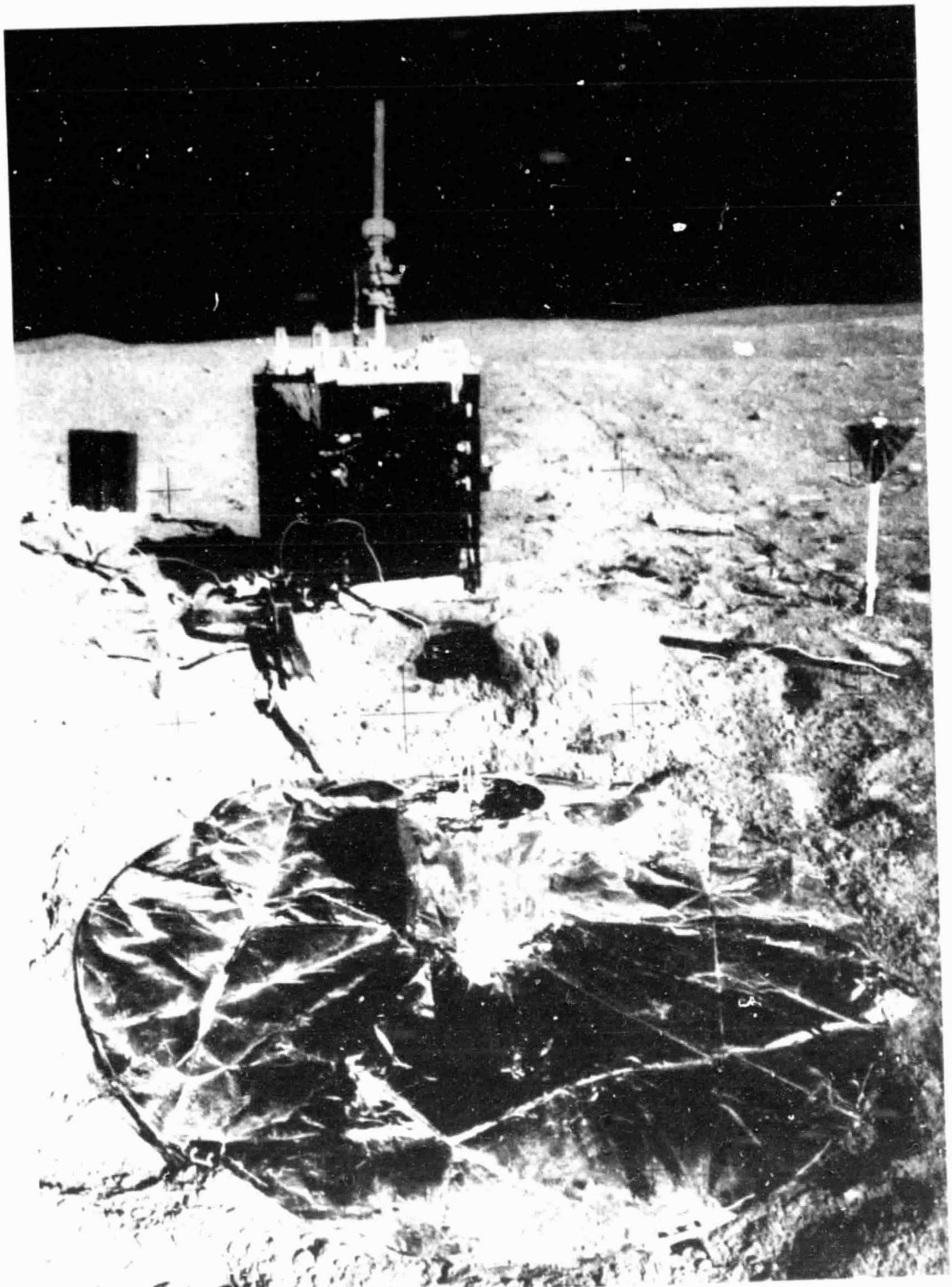

Apollo 16 Passive Seismic Experiment emplaced at Descartes Highlands
(AS16-113-18347)

NSSDC/WDC-A-R&S 80-11

DATA USER'S NOTE

APOLLO SEISMOLOGICAL INVESTIGATIONS

by

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October 1980

National Space Science Data Center (NSSDC)/
World Data Center A for Rockets and Satellites (WDC-A-R&S)
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This document utilizes international metric units according to the Systeme International d'Unites (SI). In certain cases, conventional units reported are stated in parentheses following the computed SI equivalents.

PREFACE

This Apollo Data User's Note (DUN) was prepared by the National Space Science Data Center (NSSDC). Important contributions were provided by the staff of NSSDC and by the principal investigators and their co-workers. The purposes of this DUN are to announce the availability of Apollo seismological data and to aid investigators in the selection of data for additional studies beyond those carried out by the principal investigators. NSSDC will provide data and information upon request directly to individuals or organizations resident in the United States and, through the World Data Center A for Rockets and Satellites (WDC-A-R&S), to researchers outside the United States.

NSSDC strives to serve the scientific community in a useful manner so that the data deposited can be disseminated for continued and further analysis. Scientists are invited to submit comments or recommendations regarding the format of this DUN, the data described herein, and the services provided by NSSDC. Recipients are urged to inform others of its availability.

Robert W. Vostreys

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INTRODUCTION

The manned lunar landing missions flown by the National Aeronautics and Space Administration (NASA) included Apollo 11, 12, 14, 15, 16, and 17. Apollo 13, originally planned as a landing mission, was reassigned as a lunar orbiting mission when a malfunction prevented lunar landing. Each mission consisted of a command module (CM), a service module (SM), and a lunar module (LM). The CM and SM, when referred to together, are identified as the command service module (CSM).

The first three landing missions were Apollo 11, 12, and 14. On these missions, two astronauts landed on the Moon in the LM while the third astronaut performed investigations in the orbiting CSM. With each mission, life support facilities and time spent on the surface were considerably extended. The mobility of the astronauts was limited to within 100 m of the LM on Apollo 11, and to within 1.5 km on Apollo 12 and 14.

The complexity of experiments and tasks to be performed on the surface and in the CSM also increased with each mission. An experiment package powered by a radioisotope thermoelectric generator was carried to the lunar surface. The package was known as the early Apollo surface experiments package (EASEP) on Apollo 11 and as the Apollo lunar surface experiments package (ALSEP) on later missions. Some of the surface investigations, such as sample collection, soil mechanics, and solar wind, were conducted on the surface and returned to Earth, while other instrumented experiments were left on the surface and continued to acquire data.

The final Apollo spacecraft, Apollo 15, 16, and 17, were twice as heavy as the Apollo 11, 12, and 14 spacecraft and carried more equipment. In addition to the ALSEP, the lunar roving vehicle (LRV) was carried on the LM and enabled the astronauts to drive on the lunar surface, extending their range of activity to within a 3.5-km radius of the LM. The time spent on the surface was also extended, and the number of experiments deployed was increased. On Apollo 15 and 16, subsatellites (SS's) were carried in the scientific instrument module (SIM) and released to orbit the Moon.

For all of the landing missions, the LM lifted off the lunar surface and rendezvoused with the CSM. After docking, the astronauts reentered the CM, and the samples and equipment were transferred. The LM (except for Apollo 16) was jettisoned and crashed on the lunar surface prior to transearth coast. The CSM returned to the vicinity of the Earth, the SM was jettisoned, and then the CM reentered the Earth's atmosphere and splashed down. A summary of the manned lunar landing missions is given in Table 1.

The Apollo seismological experiments are discussed in the Description of Seismological Objectives and Equipment section. The passive seismic experiment (PSE), active seismic experiment (ASE), lunar seismic profiling experiment (LSPE), and lunar surface gravimeter (LSG) are covered here. Figure 1 shows the Apollo 11 EASEP on the lunar surface with the PSE seismometer. The Apollo 16 ALSEP is shown in Figure 2 with the ASE seismometer in the foreground.

Table 1. Manned Lunar Landing Missions

Spacecraft	No. of Experiments	Total Mission Time Period	Landing Site Coordinates (mean spherical)	Lunar Surface Time
Apollo 11		7/16/69	23.49°E, 0.67°N	7/20/69
Command Service		to	(Mare Tranquil-	to
Module	7	7/24/69	litatis)	7/21/69
Lunar Module	5			
Apollo 12				
Command Service		11/14/69	23.45°W, 2.94°S	11/19/69
Module	12	to	(Oceanus Procellarum,	to
Lunar Module	10	11/24/69	near Surveyor 3)	11/20/69
Apollo 14				
Command Service		1/31/71	17.46°W, 3.67°S	2/5/71
Module	7	to	(near Fra Mauro)	to
Lunar Module	12	2/9/71		2/6/71
Apollo 15				
Command Service		7/26/71	3.66°E, 26.11°N	7/30/71
Module	14	to	(Apennine Mts. &	to
Lunar Module	12	8/7/71	Hadley Rille)	8/2/71
Subsatellite	3			
Apollo 16				
Command Service				
Module	15	4/16/72	15.51°E, 8.97°S	4/21/72
Lunar Module	11	to	(Descartes region)	to
Subsatellite	3	4/27/72		4/24/72
Apollo 17				
Command Service		12/7/72	30.80°E, 20.17°N	12/11/72
Module	11	to	(near Littrow &	to
Lunar Module	14	12/19/72	Taurus Mts.)	12/14/72

NSSDC can provide data and supporting information as described in the Section on Available Data. Appendix 1, ordering of Apollo Seismic Data, contains information on NSSDC/WDC-A-R&S policies concerning dissemination of data, specific instructions for ordering data, and an order form. Appendix 2, Investigators for the Apollo Seismic Experiments, lists the principal investigators (PI's) and other investigators (OI's) for the experiments covered. Appendix 3 contains a list of acronyms and abbreviations used throughout the document. The Index to Available Data lists the individual data sets along with the corresponding NSSDC ID's (identification numbers used for ordering purposes). A full description of all the Apollo investigations is contained in the *Apollo Scientific Experiments Data Handbook* (NASA TMX-58131). Copies of this document may be obtained from NSSDC.

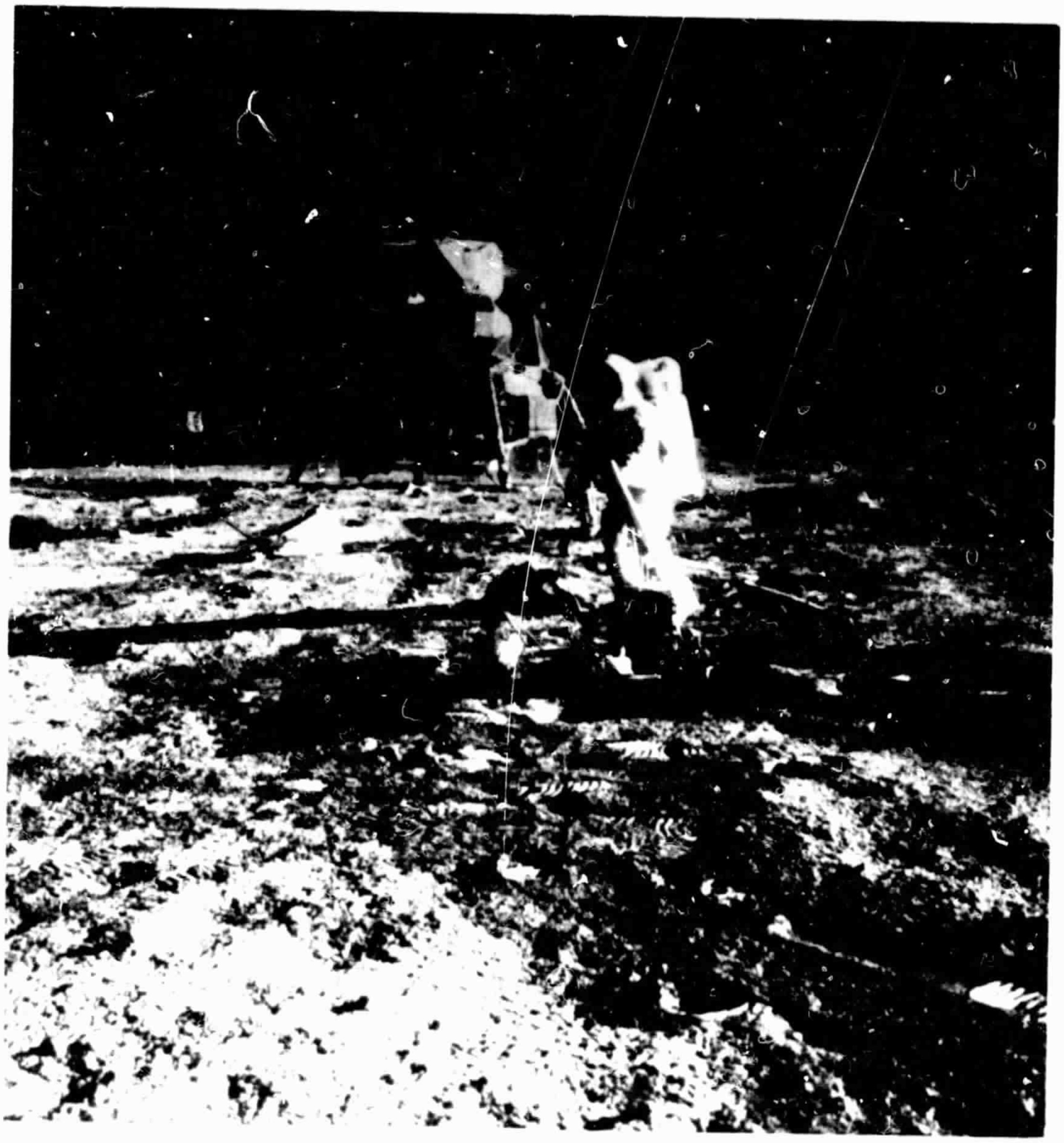

Figure 1. Apollo 11 EASEP on the Lunar Surface
with the PSE in the Foreground

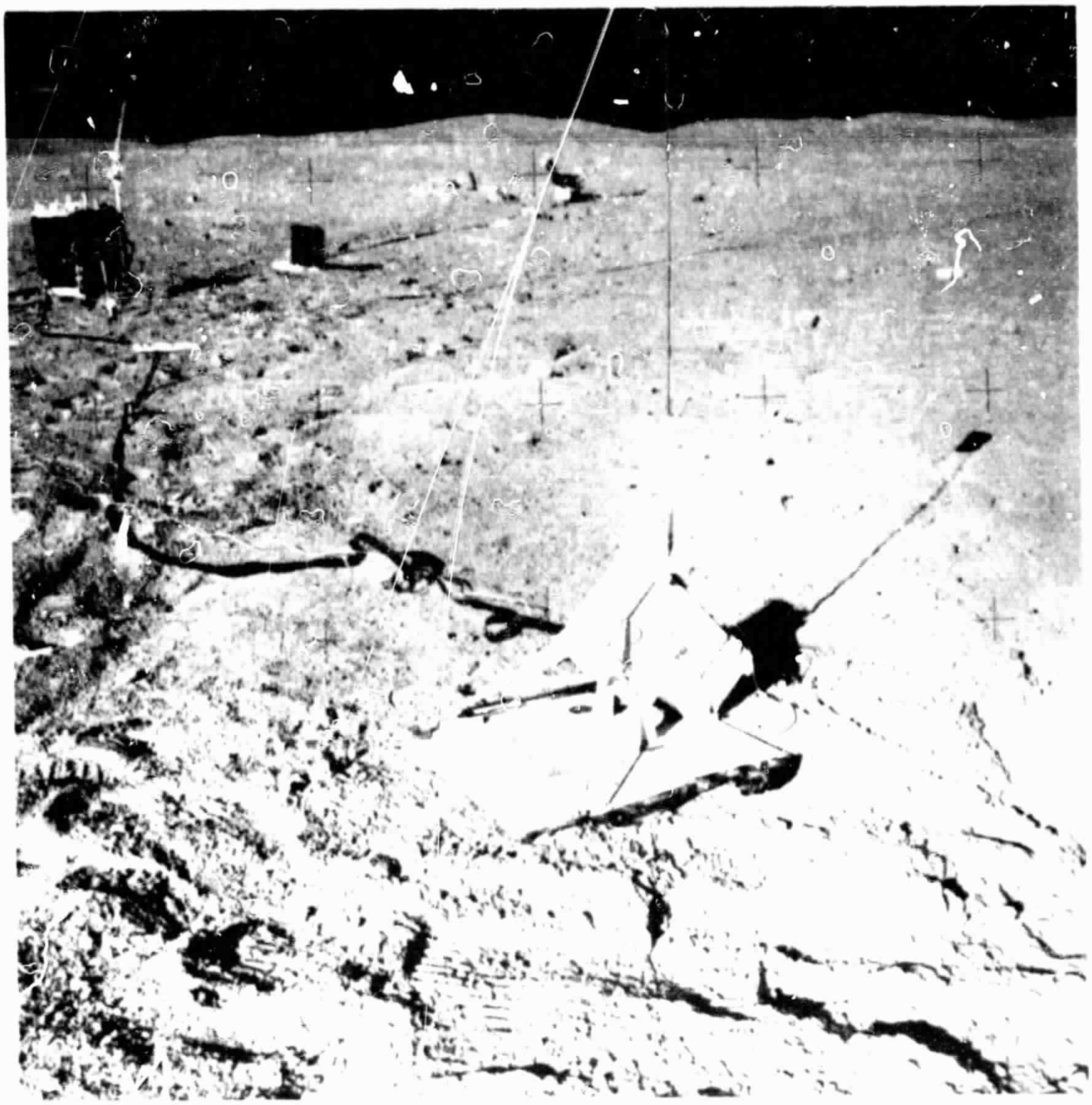

Figure 2. Apollo 16 ALSEP on the Lunar Surface with the ASE

DESCRIPTION OF SEISMOLOGICAL OBJECTIVES AND EQUIPMENT

The Apollo seismological investigations provide the only extensive source of information on the internal structure of an extraterrestrial body. Data from the seismometers can be used to determine the velocity parameters of the lunar interior, the seismicity of the Moon caused by internal and external processes, and the physical and chemical properties of the lunar interior.

Seismometers were emplaced at six sites on the lunar surface during the Apollo program. Passive seismometers were left at the Apollo 11, 12, 14, 15, and 16 landing sites. Active seismometers were operated at the Apollo 14, 16, and 17 landing sites. For the active seismometers, the detonations of explosive charges were used as sources of seismic energy to facilitate studies of the shallow structure of the lunar crust. The LSG at the Apollo 17 landing site also operated in a seismic mode with reduced sensitivity.

The Apollo 12, 14, 15, and 16 PSE's comprised a lunar seismic network. These stations are compared in Table 2. Data on artificial impacts and the May 1972 meteoroid impact are listed in Table 3. A loss of the attitude control system left the Apollo 16 LM ascent stage in a lunar orbit with a predicted life of 1 yr before expected decay onto the lunar surface. The actual date of decay is unknown because the impact was not detected by the lunar seismic network.

Active Seismic Experiment (ASE)

The ASE was emplaced at the Apollo 14 and 16 landing sites. The LSPE at the Apollo 17 site also acted in an active seismic mode. In this section, the active seismometers at the Apollo 14 and 16 sites will be discussed.

The purpose of the ASE was to generate and detect seismic waves to study the shallow structure of the Moon. The ASE consisted of an astronaut-activated thumper, a mortar package, geophones, connecting cables to the ALSEP's, and electronics in the ALSEP central station. The thumper was a short staff used to detonate compressive explosive charges that produced seismic waves detectable by the geophones. The geophones acted as miniature seismometers of the moving coil magnet type. There were three identical geophones at each ALSEP station. Figures 3, 4, and 5 illustrate the ASE equipment.

Apollo 14 Geophones

Three Apollo 14 geophones were deployed in a southerly direction from the ALSEP central station. Operations began with thumper shot 1 at geophone 3 and continued at 4.6-m intervals along the geophone line until shot 21 at geophone 1, which was closest to the ALSEP. The thumper failed to fire at several intiator positions, and some firing postions were skipped to gain extravehicular activity time. Successful thumper shots were recorded at positions 1 (located at geophone 3), 2, 3, 4, 7, 11 (located at geophone 2), 12, 13 17, 18, 19, 20, and 21 (located at geophone 1). Geophone 2 was found to have pulled out of the ground just before shot 11 was fired. It was replaced, and the series of shots was continued. Even though geophone 2 was resting on its side during the first five shots, usable seismic data were obtained for those shots. The ASE was also capable of operating in a passive mode. While functioning in this mode, it detected seismic events.

The mortar package was positioned to fire four grenades in a northerly direction in alignment with the geophone line. It was planned that the grenades would be fired at distances of 150, 300, 900, and 1500 m. Because of possible damage to the other experi-

Table 2. Lunar Seismic Network Statistics

	Apollo 12 (PSE)	Apollo 14 (PSE)	Apollo 15 (PSE)	Apollo 16 (PSE)
Deployment Date	Nov. 19, 1969	Feb. 5, 1971	July 31, 1971	Apr. 21, 1972
Position*	3.04°S 23.42°W	3.65°S 17.48°W	26.08°N 3.66°E	8.97°S 15.51°E
Lunar Module Distance	130 m	178 m	110 m	95 m
Horizontal Component Azimuth +X	180°	0°	0°	334.5°
+Y	270°	90°	90°	64.5°
Distance to Other Stations				
12	--	181 km	1188 km	1187 km
14	181 km	--	1095 km	1007 km
15	1188 km	1095 km	--	1007 km
16	1187 km	1007 km	1119 km	--
Azimuth to Other Stations				
12	--	276°	226°	276°
14	96°	--	218°	277°
15	40°	33°	--	342°
16	100°	101°	160°	--

*Mean spherical surface coordinates.

ments in the vicinity, however, they were not fired.

Apollo 16 Geophones

The three geophones emplaced at the Descartes site were located on the Cayley Formation, at a bearing 287° clockwise from north of the ALSEP central station. Geophone 3 was deployed 90 m from geophone 1. Thumper operations started at geophone 3, and shots were fired at 4.75-m intervals proceeding toward geophone 1. The distance between shots 11 and 12 and between shots 18 and 19 was increased to 9.5 m. All 19 thumper shots were successful.

The mortar package was located 14 m from geophone 1 and was pointed to fire parallel and downrange of the geophone line. The four grenades of the mortar package assembly were similar in construction, but differed in the amount of propellant and high explosive carried. The square cross-section cas-

Table 3. Lunar Impact Coordinate Statistics

Event	Date	Position*	Lunar Seismic Network Station									
			Apollo 12		Apollo 14		Apollo 15		Apollo 16		Apollo 17	
			Dist.**	Azim.†	Dist.	Azim.	Dist.	Azim.	Dist.	Azim.	Dist.	Azim.
Apollo 12 LM Ascent Stage	11/21/69	3.94°S 21.20°W	73	112	-	-	-	-	-	-	-	-
Apollo 13 SIVB	4/15/70	2.75°S 27.86°W	135	274	-	-	-	-	-	-	-	-
Apollo 14 SIVB	2/4/71	8.09°S 26.02°W	172	207	-	-	-	-	-	-	-	-
Apollo 14 LM Ascent Stage	2/7/71	3.42°S 19.67°W	114	96	67	276	-	-	-	-	-	-
Apollo 15 SIVB	7/29/71	1.51°S 11.81°W	355	83	184	69	-	-	-	-	-	-
Apollo 15 LM Ascent Stage	8/3/71	26.36°N 0.25°E	1130	36	1048	29	93	276	-	-	-	-
Apollo 16 SIVB	4/19/72	~1.3°N ~23.8°W	132	355	243	308	1099	231	-	-	-	-
Large meteoroid Impact	5/13/72	~1.1°N ~16.9°W	234	58	145	7	967	222	1026	286	-	-
Apollo 17 SIVB	12/10/72	~4.5°S	~348	~97	~155	~97	~1020	~206	~815	~280	~1420	~240
Apollo 17 LM	12/15/72	20.51°N	~1650	~67	~1510	~63	~790	~105	~972	~27	8.7	283

*Mean spherical surface coordinates.
**Kilometers.
†Degrees.

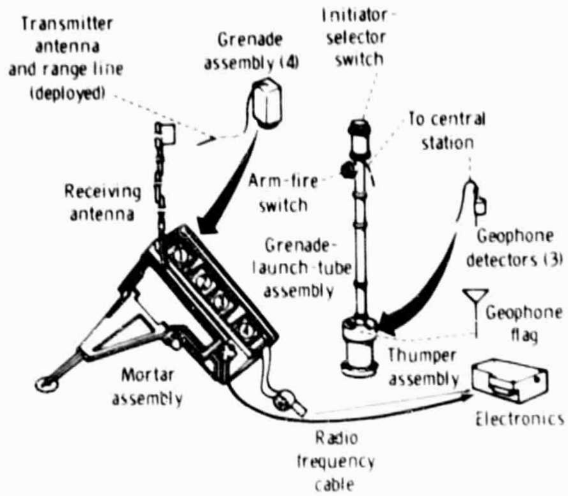

Figure 3. Schematic Diagram of the ASE Seismometer

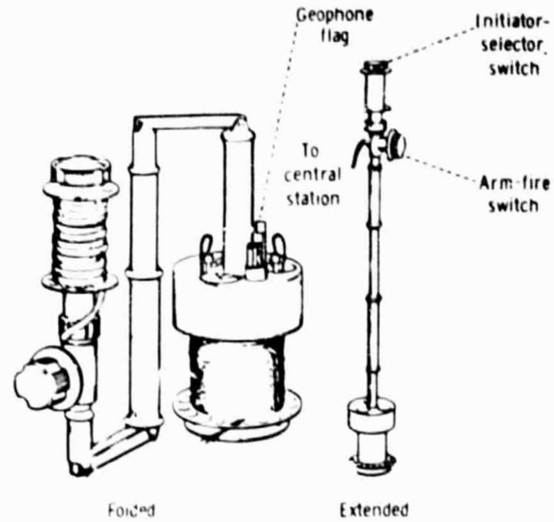

Figure 4. Schematic Diagram of the ASE Thumper

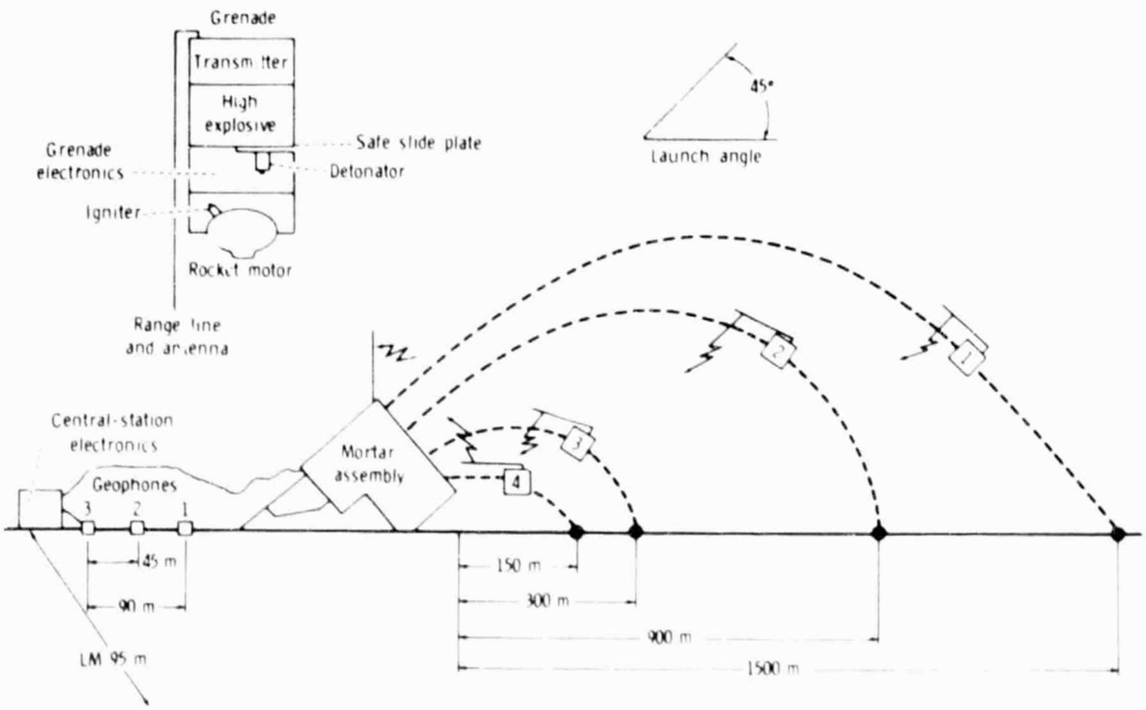

Figure 5. Mortar Mode of the ASE Operation

ing contained the rocket motor, safe slide plate, high-explosive charge, ignition and detonation device, thermal battery, and 30-MHz transmitter. Three of the four grenades were fired. On May 23, 1972, the Apollo 16 ALSEP was commanded to a high bit rate between 05:20:00 and 06:44:00 UT for the mortar mode of operation. Grenade 2 (1024 g) was launched a distance of 900 m; grenade 4 (695 g) was launched a distance of 150 m; and grenade 3 (775 g) was launched a distance of 300 m. Grenade 1 (1261 g) was not launched because the mortar package pitch-angle sensor indicated an off-scale reading after grenade 3 was fired.

The Apollo 16 ASE was commanded to a high bit-rate mode on April 24, 1972, and successfully recorded the seismic signal generated by the ascent of the LM. The ASE also operated periodically in the high bit-rate mode for passive detection of seismic signals and to verify experiment operation capability. While in this passive listening mode, the ASE detected seismic events.

Lunar Seismic Profiling Experiment (LSPE)

The purpose of the Apollo 17 LSPE was to record the seismicity of the lunar subsurface induced by explosive charges, the thrust of the LM ascent engine, and the impact of the LM ascent stage on the lunar surface. Another objective of the LSPE was to monitor lunar seismic activity during periodic listening intervals.

Eight explosive packages (EP's) were armed and placed on the lunar surface. These were deployed by the Apollo 17 astronauts during their extravehicular traverses at various points to a maximum distance of 2.7 km from the ALSEP. The eight EP's were identical except for the amount of high explosive and the preset runout time of the mechanical timers. The LSPE transmitter was located within the ALSEP central station. It transmitted a repetitive pulsed carrier signal. A series of three pulses properly spaced in time was used to elicit a signal to fire from the signal processor within the EP and to detonate the explosive train.

Four identical geophones were used in a triangular array as shown in Figure 6. The geophones were miniature seismometers of the moving coil magnet type. Above the natural resonant frequency of the geophones (7.5 Hz), the output was proportional to ground velocity. The array was deployed northwest of the LM at a distance of about 148 m.

All eight EP's were successfully detonated. Table 4 shows EP explosive masses and times of detonation.

Table 4. Detonation Masses and Times of EP's

Charge Number	Explosive Mass (g)	Date (1972)	Time (UT)
EP-6	454	12/15	23:48:14.56
EP-7	227	12/16	02:17:57.11
EP-4	57	12/16	19:08:34.67
EP-1	2722	12/17	00:42:36.79
EP-8	113	12/17	03:45:46.08
EP-5	1361	12/17	23:16:41.08
EP-2	113	12/18	00:44:56.82
EP-3	57	12/18	03:07:22.28

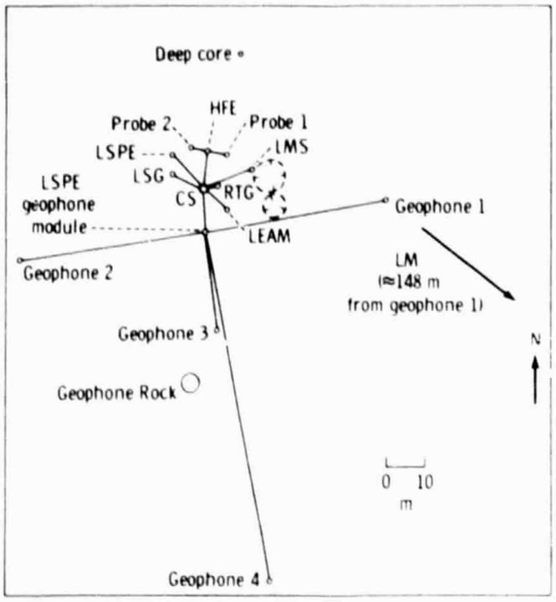

Figure 6. LSPE Nominal Deployment

The LSPE detected the seismic signals generated by the Apollo 17 LM ascent and the impact of the ascent stage on the lunar surface. It was used to detect lunar seismic energy over one complete lunation while operating in a passive mode. The LSPE operated in a passive mode as part of seismic network with the PSE instruments.

Lunar Surface Gravimeter (LSG)

The LSG was part of the ALSEP emplaced on the lunar surface by the Apollo 17 astronauts. The LSG consisted of a sensitive balance with a mass, spring, and lever system, and associated electronics. It is illustrated in Figures 7 and 8. The purpose of the LSG was to measure acceleration in the frequency range of 0 to 16 Hz. It was designed to detect gravity waves (if any), to act as a one-axis seismometer, and to measure tidal effects on the

Figure 7. Lunar Surface Gravimeter

Moon. It had a nominal sensitivity of approximately 1 part in 10^{11} of lunar gravity.

When the LSG instrument was deployed and activated, the movable beam could not be balanced when commands were sent to add or subtract weights. As a result, the LSG could not function as designed. Attempts were made to use the LSG as a low-sensitivity seismometer.

Passive Seismic Experiment (PSE)

The PSE was deployed on the lunar surface as part of the Apollo 11, 12, 14, 15, and 16 experiment packages. The seismometers consisted of two main subsystems: the sensor unit and the electronics module.

The sensor unit contained four seismometers. Three long-period (LP) seismometers formed a triaxial set. One was sensitive to vertical motion (the LPZ component), and the other two

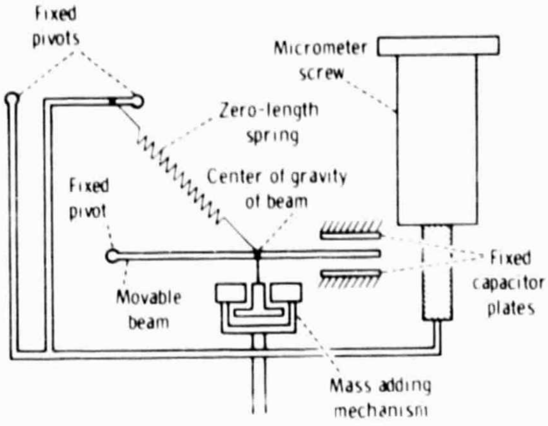

Figure 8. Schematic Diagram of the Lunar Gravity Sensor

were sensitive to horizontal motion (the LPX and LPY components). The fourth seismometer in the sensor unit was a short-period (SP) instrument sensitive to vertical motion with a peak sensitivity at 8 Hz and a frequency response range of 0.05 to 20 Hz. The seismometers could detect vibrations on the lunar surface as small as 0.05 nm (0.5 A) at maximum sensitivity.

The unit was constructed principally of beryllium and had a mass of 11.5 kg, including the electronics module and thermal insulation. It was 23 cm in diameter and 29 cm in height without the insulation. The PSE is shown schematically in Figure 9.

Temperature was regulated using a 6-W heater, a proportional controller, and (except for the Apollo 11 PSE) aluminized Mylar insulation spread over the surface to reduce temperature variations.

The LP seismometers could function in a flat-response mode and in a peaked-response mode. In the flat-response mode, the LP seismometers had a natural period of 15 s. In the peaked-response mode, they acted as underdamped pendulums with a natural period of 2.2 s. Sensitivity to ground motion peaked sharply at 0.45 Hz (peaked-response mode) with a useful frequency range of 0.004 to 2 Hz. Maximum sensitivity was enhanced by a factor of 5.6 in the peaked-response mode, but sensitivity to low-frequency signals was reduced. Figure 10 diagrams the LP seismometers, and Figure 11 shows the LP and SP response curves. In Figure 11, the ordinate scale is in digital units (DU) per centimeter of ground motion amplitude. A DU is the signal variation that corresponds to a change in the least significant bit of the 10-bit data word.

At tidal frequencies, gravitational acceleration was measured by monitoring the feedback current used to center the seismometer mass. The sensitivity of the instruments was 8 x 10^{-8} m/s^2 (8 x 10^{-3} mgal) per DU recorded.

The seismometers were operated at reduced gain while the astronauts were on the lunar surface. Subsequently, they were operated primarily at maximum sensitivity with the LP seismometers in the peaked-response mode.

The PSE detected signals from natural sources (moonquakes and meteoroid impacts) and signals from nine manmade impacts (LM ascent stages and SIVB Saturn booster stages). The most intense seismic disturbances, detected near sunrise and sunset, are believed to have been caused by thermal contraction and expansion of the Mylar insulation and/or the cable connecting it to the central station.

Apollo 11 Seismometers

The Apollo 11 seismometers functioned for 20 Earth days before the loss of command uplink capability terminated operations. During the operational period, all four seismometers of the PSE functioned nominally. Some transient signals of instrument origin were detected. While no body waves

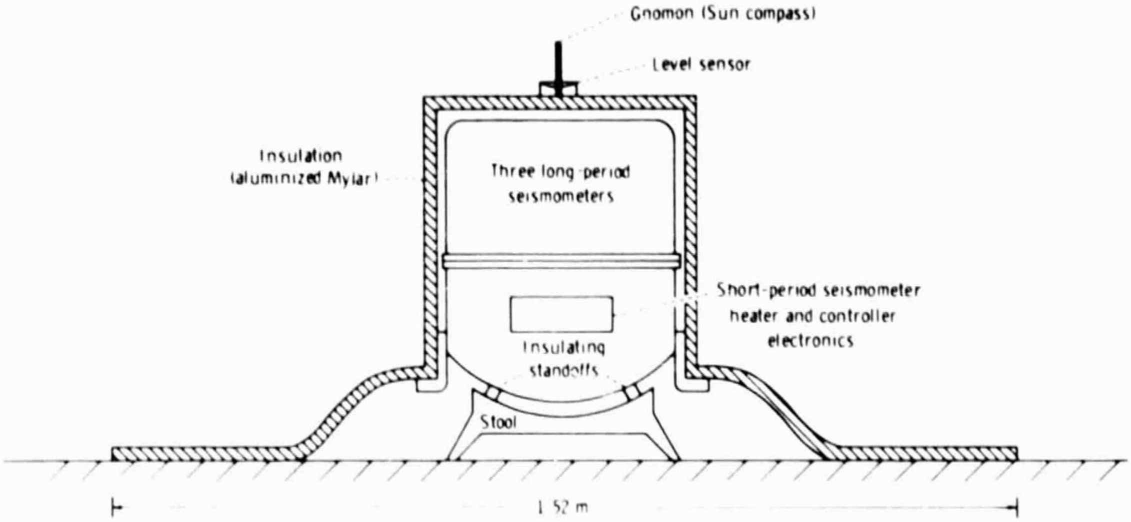

Figure 9. Schematic Diagram of the PSE

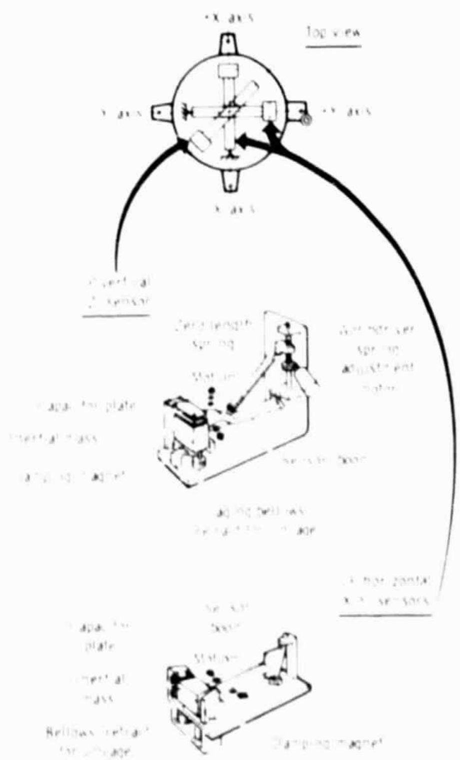

Figure 10. Schematic Diagrams of the Elements of the LP Seismometers

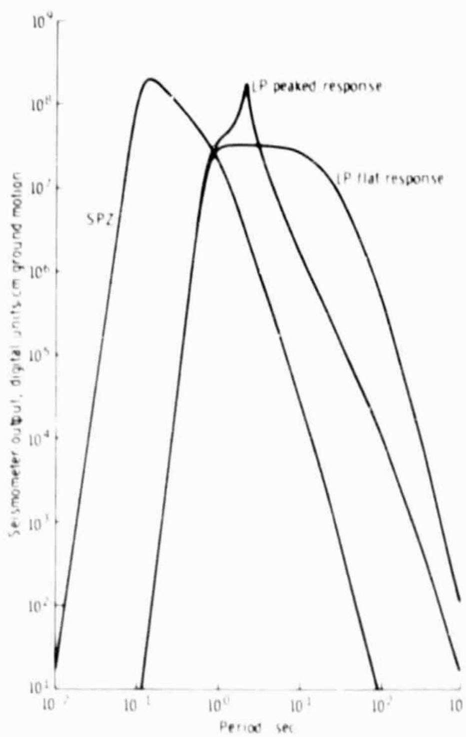

Figure 11. Response Curve for the LP and SP Vertical-Component Seismometers

were detected, about 30 surface waves were recorded. Three categories of signals were detected: (1) those produced by astronaut activities, (2) those with impulsive onset and short duration, and (3) those with emergent onset and long duration.

Apollo 12 Seismometers

The Apollo 12 LPX and LPY components functioned normally from deployment. The LPZ component originally produced abnormal responses, but this problem was corrected 3 Earth days after deployment. Intermittently, between December 1973 and March 1974, the LPZ component showed sporadic loss of data during the lunar night. It functioned nominally, however, from March 1974 until ALSEP operations terminated on September 30, 1977. The SPZ component (short-period vertical motion) failed to respond to calibration pulses and operated at a much reduced gain, obtaining little or no valid data.

Apollo 14 Seismometers

Since initial activation of the Apollo 14 PSE, all elements operated as planned with two exceptions. The LPZ seismometer was unstable in the flat-response mode from deployment until November 17, 1976, when the problem was rectified. The Y-axis of the gimbal leveling system responded to commands only intermittently.

The Apollo 14 ALSEP suffered several periods of loss of signal (LOS), and because there was no data storage capability in the PSE, these periods represent total data loss. The cause for the LOS is unknown. Periods of LOS are listed in Table 5. The periods listed do not include short intervals, when higher priorities or receiving station technical problems prevented reception of data from the ALSEP.

Table 5. Apollo 14 ALSEP Operational History

Loss of Signal (LOS)	Acquisition of Signal (AOS)
	Feb. 5, 1971
Mar. 1, 1975	Mar. 5, 1975
Jan. 18, 1976	Feb. 19, 1976
Mar. 17, 1976	May 20, 1976
June 8, 1976	June 10, 1976
Oct. 9, 1976	Nov. 12, 1976

In addition to naturally caused events, the Apollo 14 PSE detected impacts of manmade objects on the lunar surface. The impact signal of the Apollo 14 LM ascent stage was the first event of precisely known location and time recorded by two instruments (Apollo 12 and 14 PSE's).

Apollo 15 Seismometers

With the establishment of the Apollo 15 PSE and the continued operation of the Apollo 12 and 14 PSE's, the Apollo program achieved a network of seismic stations on the lunar surface. Since the initial activation of the Apollo 15 PSE, all elements operated as planned. The one exception was that the sensor thermal control system did not maintain designed temperature ranges. This is believed to have been caused by uneven deployment of the thermal shroud. Despite this, data return was nominal.

Apollo 16 Seismometers

The Apollo 16 PSE was the most sensitive seismological instrument emplaced on the Moon during the Apollo program. The instrument continued the observations made by the earlier missions and served to expand the lunar seismic network. A large meteoroid impact that occurred on May 13, 1972, shortly after the emplacement of the Apollo 16 PSE, was recorded by all four operational stations. This impact took place approximately 145 km north of the Apollo 14 site, and it was determined that the meteoroid had a mass of about 1100 kg, making it the largest natural object to impact on the Moon during the existence of the network.

The only problems encountered in the instrument were with the sensor thermal control system and excessive noise from the SPZ seismometer. This noise occurred at intervals that appear to have correlated with the temperature fluctuation cycle.

AVAILABLE DATA

The ALSEP's transmitted experiment and engineering telemetry to the tracking stations on Earth. The tracking stations recorded the telemetered data on analog range tapes. The analog range tapes were made into digital 24-h working tapes containing all the data received from each ALSEP over a 24-h period by the various tracking stations. The 24-h work tapes were processed at the Johnson Space Center (JSC), and data from each experiment were stripped off. New tapes were generated and supplied to each experimenter for data reduction and anlysis. To request any of the following data, refer to the Index of Available Data at the end of this document for the appropriate NSSDC ID. The NSSDC ID is necessary for the efficient processing of orders for data.

Active Seismic Event Data

Data from the Apollo 14 and 16 ASE's and the active mode of the Apollo 17 LSPE are available on magnetic tape. For ASE's, the data are also available on microfilm in log-compressed, digital form with the appearance of seismogram plots. The ASE tapes are odd-parity, 7-track, 800-bpi, binary tapes with standard IBM end-of-file markers. The data are 36-bit words in 228-word logical records. Each logical record contains 10 frames of 32 seismic data words each, 10 timing words, and day, date, and identification information. The 10 timing words give the time in milliseconds from the start of the previous frame for the start of each of the 10 corresponding data frames. Each 32-word data frame covers 0.060377 s. The occurrence of a seismic event (either thumper or mortar) is indicated by a frame mark in word 29 of each frame. If the frame mark in word 29 is 4 (00100), an event was recorded; if it is 0, no event occurred. The base time for the event is the start time of the previous frame. The exact time is marked by recording the word count and bit count portions of words 30 and 31, respectively, of the frame in which the event mark is set. In the case of the LM ascent, no frame mark is present. These data must be located using the known time of firing.

To achieve the maximum dynamic range, the seismic data were logarithmically compressed into 32 binary levels. The binary data for the three geophones must be decompressed to obtain the actual seismic signal data output from the seismometers. For information on the appropriate expansion formula to recover true input voltages, see the ASE section of the *Apollo Scientific Experiment Data Handbook*. This section is supplied by NSSDC as supporting documentation when active seismic data are ordered.

Lunar Seismic Profiling Experiment (LSPE) Active Mode

Data from the active mode of the LSPE collected during the detonation of the EP's are available on magnetic tape. The format is a data frame consisting of three subframes. Each subframe consists of 20 30-bit words. The first word of each subframe consists of a 10-bit synchronous word and a 5-bit seismic data signal from each of the four seismic data channels. Words 2 - 20 of each subframe are 7-bit signals from each of the four channels. Engineering data are interleaved and subcommutated, using the remaining 2 bits to form 30-bit words. In words 2 - 19, the geophone signals are sampled on the bit preceding the word on which they are read out. The most significant bit is read out first. In the first word of each subframe, the timing of the data signal is the same as in words 2 - 19 except that the signals are stored and read out in the last 20 bits with one 5-bit word per channel.

Seismograms

Seismograms for the Apollo 11 PSE were created at the Lamont-Doherty Geological Observatory from the experiment data tapes (EDT's). The orginal seismograms were 90 cm in width and approximately 25 cm in height. The hardcopy was microfilmed by NSSDC after receipt from JSC. Each seismogram contains approximately 6 h of data. On the microfilm, minute marks appear approximately 12 cm apart. The records were calibrated by using the width of the seismograms as an exact scale and a full scale amplitude deviation of ± 3 cm equal to ± 512 DU (a signal variation that corresponds to a change in the least significant bit of the 10-bit data word recorded on the experimenter tapes) at a 1x recorder magnification. Accompanying documentation indicates changes in SP seismometer gain, and the seismometer magnification curve is in DU/cm of ground displacement. The seismograms are numbered in chronological order, starting with emplacement of the instrument on the lunar surface. The first lunar day is numbered from 1 to 52, and the second lunar day is numbered from 53 to 78. Time is indicated in UT. Occasional data dropouts visible on the seismograms were present in the original digital tapes. There has been no filtering performed on the data.

Compressed Scale Playouts

In the first stage of data reduction, the experimenter took the raw data tapes and generated playouts from the data synchronously in compressed form. This was done to aid in identifying seismic events recorded as part of the data. Figure 12 is an example of a compressed scale playout.

A different method is used to enhance the signal-to-noise ratio for higher-frequency events. The absolute value of the difference between consecutive data points is summed over 40 points for LP data and 320 points for SP data. This value is plotted, yielding one value for each 6 s of data. Consecutive points are plotted with opposite polarity to yield a line with the appearance of a seismogram. A horizontal scale of 7.87 min/cm (20 min/in.) is used on the original plots. The vertical scale values are 157 DU/cm (400 DU/in.) for LP data and 1260 DU/cm (3200 DU/in.) for SP data. Components at each station are arranged from top to bottom LPX, LPY, LPZ, and SPZ. The plots are labeled with time tick marks at 10-min intervals, and each hour (UT) is identified. The year and day are identified every 6 h. These times are not corrected for any clock-rate errors created when a computer internal clock was substituted for unreadable times on the 24-h work tapes derived from the range tapes.

The experimenter-supplied hardcopy compressed scale playouts were filmed on 16- or 35-mm microfilm by NSSDC. The microfilmed playouts contain the data from each operational seismometer displayed simultaneously for the appropriate time period. Some playouts also contain error messages that were included for ease of filming, but these are not necessary for use in interpreting the data. The playouts provide infor-

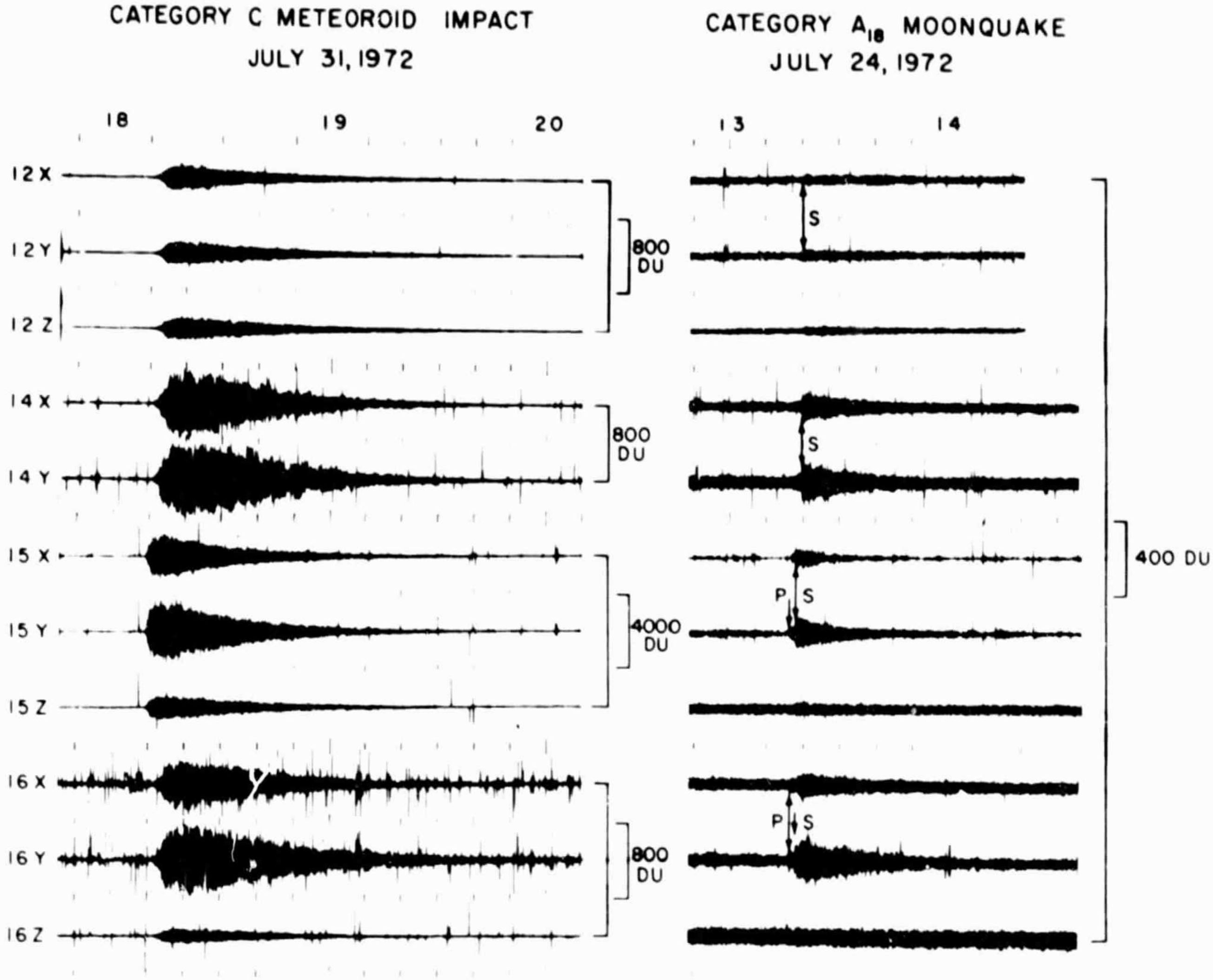

Figure 12. Sample of a Compressed Scale Playout

mation for selecting interesting events and may be used for determining start and stop times of the events. Playouts are available only for the Apollo 12, 14, 15, and 16 passive seismometers. Table 6 contains a listing of compressed scale playout availability. Note that the dates given indicate the overall range of the data collected; there may or may not be a playout available for a given time. The event catalog described next includes this information.

Event Catalog

The event catalog was compiled by the experimenter from the LP events observed on the compressed scale playouts. The events included are those of apparent or probable seismic origin. Events believed to have been caused by tilting and thermal effects of the instrument and those observed only on the SP components are not included.

The event catalog contains the following parameters: year; day of year; start and stop times; amplitude at station 12 Z-axis; amplitudes and stations 14, 15, and 16 Y-axes; indication if expanded scale playout exists; quality factor; event type; and moonquake class. The times are in UT. The amplitudes, in millimeters, are picked from compressed scale playout records plotted at a scale of 157 DU/cm (400 DU/in.). A stop time of 9999 indicates that the event overlaps the next event. If an expanded scale playout is available, the playout log equals 1. Quality factors are: blank, no data; 1, no data; 2, internal computer clock error; 3, noisy record; and 4, masked record. The quality factor with the lowest number is indicated where applicable under each station. Seismic event type codes are given in Table 8.

The event catalog is available on 35-mm microfilm and also as card images on 556-bpi, BCD, 7-track magnetic tape.

Event Tapes

Seismic event data, obtained by the experimenter through a manual search of compressed scale playout LP components, were copied from the EDT's onto event tapes containing only the time periods when seismic events were observed. These do not include events with amplitudes less than 10 DU, which were observed only at station 16 where the instrument was more sensitive than the others.

Each event tape contains data from only one station. The same time periods were copied onto separate tapes for each station. Thus, intervals that do not contain a detectable signal at a station may be on the event tapes because an event was detected at another station.

Event tapes are numbered serially and are in chronological order. The tapes are labeled with the event tape number, station number, tape number, and total time interval covered. The tapes are 7-track, binary, 800-bpi, odd parity, with standard IBM end-of-file markers.

Data from the ALSEP's were transmitted in 64-word frames, 1 frame every 0.60375 s. The words assigned to the PSE are as follows: even words in the frame (except 2, 46, and 56) are SP vertical data. For Apollo 15, word 24 was also not used for SP data. Missing words in the SP data should be replaced to obtain equal spacing of the data points. Words 9, 25, 41, and 57, and words 11, 27, 43, and 59 are the LP horizontal components (LPX and LPY, respectively); words 13, 29, 45, and 61 are the LP vertical component (LPZ). X-axis tidal data are on word 35, even frames; Z-axis tidal data are on word 35, odd frames; and Y-axis tidal data are on word 37, even frames. Instrument temperature data are on word 37, odd frames.

Each ALSEP word is 10 bits, or a range from 0 to 1023 DU. Sensor equilibrium data values are near 500 DU. Each frame of data is a logical record consisting of 18 36-bit words (format A) or 9 36-bit words (format B).

Format A was used for all tapes except those for Apollo 12 after day 288 of 1971. Format B was used for data from Apollo 12 because of the failure in the SP component of the seismometer. In format B, the data are compressed by a factor of 2. The first three words in each format are identical.

Word 1 contains the time of the start of the frame in milliseconds from the start of the year plus 8.64×10^7 ms, so that the year starts on day 1 rather than on day 0. It starts in bit 1 and ends in bit 35, right-justified in binary.

Word 2 contains a range station

Table 6. Compressed Scale Playout Data Availability

Spacecraft		Apollo 12	Apollo 14	Apollo 15	Apollo 16
Time Period		Nov. 19, 1969 to Mar. 1, 1975	Feb. 5, 1971 to Oct. 3, 1975	Sept. 2, 1971 to Mar. 1, 1975	Apr. 21, 1972 to Mar. 1, 1975
Number of Reels	16-mm	5	5	5	5
	35-mm	3	3	--	--

identification code in bits 0 - 3 throughout, a bit error rate in bits 4 - 9, and a time source indicator in bit 35 starting on day 183 of 1973. If bit 35 is set, it indicates that computer internal clock time was used for updating the time code rather than absolute time.

Word 3 contains synchronization codes and a frame counter. Bits 0 - 9, 12 - 21, and 24 - 25 contain the synchronization codes. Bits 26 - 32 contain the frame counter that stops once per frame and resets to 0 after 89 frames. Up to event tape 124, each tape starts with two identical BCD label records of four words each. Word 1 is the experiment identification. Word 2 is the ALSEP station where Apollo 12 is indicated by A, Apollo 14 by B, Apollo 15 by C, and Apollo 16 by D. Word 3 is a unique mission identifier where A/S507 corresponds to Apollo 12, A/S509 to Apollo 14, A/S510 to Apollo 15, and A/S511 to Apollo 16. Word 4 is either blank or the year.

Commencing with event 125, the label record format was changed. Word 1 is EVENT in BCD. Word 2 is the event tape number and the station number in binary. Word 3 is the year of the first event in binary and the format of the data (A = 0, B = 1). Word 4 is the time in milliseconds at the beginning of the PSE tape from which the first event on the tape was retrieved.

The event tapes contain some of the following irregularities, which should be noted when using them.

(1) Small data gaps of a few seconds in duration occur several to many times per day.

(2) Earlier tapes may contain data overlap, which is represented by a time and frame number decrement from one logical record to the next.

(3) When range stations are switched from one station to another, a time offset of less than 20 ms is observed.

(4) Synchronization errors that are followed by a data gap of a few frames occur for cases in which the data from the Moon were not correctly translated onto the tapes. These synchronization errors are indicated on the Barker code included in each logical record.

(5) Some logical records contain all zeros. These may be accompanied by a data gap.

(6) When the computer internal clock is substituted for UT because of inability to read time from the range tapes, a clock-rate error can occur. Occasionally these clock-rate errors can last as long as 8 h.

(7) Simultaneous discontinuities in time and frame count that do not agree with each other occur frequently without an abnormal clock rate.

For further information on these possible event tape irregularities, the experimenter should be contacted. Event tapes are available from NSSDC commencing with the deployment of the Apollo 12, 14, 15, and 16 PSE's. Event tape data from the Apollo 17 seismic profiling experiment are currently available for the time periods listed in Table 7. These data cover one complete lunation with overlap.

Table 7. LSPE Coverage for One Lunation

Date	Sun Angle
Oct. 22 - 25, 1974	22.5° - 60.2°
Mar. 3 - 7, 1974	59.5° - 102.2°
July 13 - 17, 1973	100.4° - 147.8°
Apr. 29 - May 1, 1975	6.6° - 180.3°
Nov. 1 - 5, 1974	145.0° - 193.9°
Sept. 6 - 10, 1974	181.4° - 235.1°
Aug. 12 - 16, 1974	233.7° - 285.6°
Dec. 12 - 16, 1974	283.7° - 330.0°
[illegible] 12 - 16, 1975	322.2° - 10.3°
Apr. 13 - 18, 1975	327.6° - 28.7°
May 25, 1974	Solar Eclipse

Event Tape Compressed Scale Playouts

Each of the event tapes previously described is plotted in a compressed scale to provide a visual display of the data. The playouts are similar to the compressed scale playouts generated from the experimenter data tapes, except that time is not continuous, and an amplitude scale twice as great is used. These data are available on 12 reels of microfilm. For further information on playout format and content, see the section on Compressed Scale Playouts.

Continuous Data

Experimenter tapes for a 1-month period of continuous operation are available for the period July 14 to August 13, 1973. These tapes contain all the data collected by the Apollo 12, 14, 15, and 16 passive seismometers for that time period.

The format of the tapes is the same as the event tapes described previously. Because these tapes contain all data received for the time period, they may be used in determining background noise and calibration for interpreting events.

Expanded Scale Playouts

Expanded time-scale playouts were made from the passive seismic event tape data. These playouts are expanded so that 1 min of data is shown on 10 cm of the original playout. The hardcopy playouts were then microfilmed by NSSDC on 35-mm microfilm. Events selected for expanded scale playouts are the artificial impacts, largest natural impacts, selected deep-focus moonquakes, and high-frequency teleseismic events. They were taken directly from the event tapes, so there was no processing of the data such as filtering, smoothing, signal coverage, etc. Some of the seismograms contain notations that are experimenter-interpreted, such as phase picks (P or S) and event classification. These should be recognized as not being primary data. Time marks on the playouts were not corrected for possible clock errors. Each expanded event playout contains simultaneously displayed data from the Apollo 12, 14, 15, and 16 passive seismometers with the recorded traces from the three LP axes of each seismometer. Figure 13 is an example of an expanded scale playout.

Selected Event Data

Special event data tapes are available in the same format as the passive seismic event tapes. The data are also available as compressed and expanded scale playouts. There are special event data for all the artificial impacts (type L and S events), meteoroid impacts with a compressed scale amplitude of 10 mm or larger on at least two stations (type C events), selected moonquakes with matching signal characteristics (type A events), and distant high-frequency, teleseismic events. These events are listed in the event catalog, and also, using the same format, in a separate special event catalog. The data are from the Apollo 12, 14, 15, and 16 seismometers. The event classification scheme used is shown in Table 8.

Table 8. Experimenter-Interpreted Event Types

Event Type	Event
A	Moonquake
C	Meteoroid impact
H	High-frequency teleseism
L	LM impact
M	Suspected moonquake
S	SIVB impact
T	Thermal event (Apollo 16 only)
X	Unusual event
Z	Short period, primarily

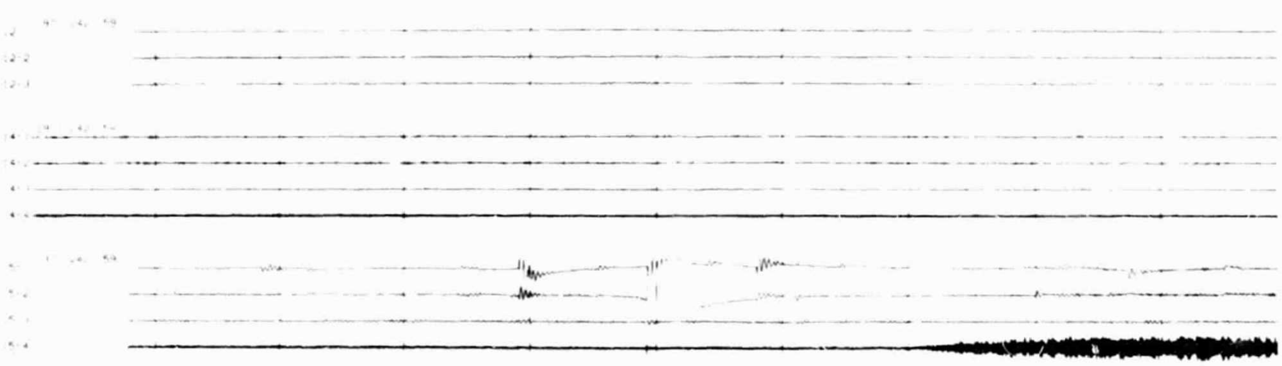

Figure 13. Sample of an Expanded Scale Playout

INDEX TO AVAILABLE DATA

EXPERIMENT	NSSDC ID*
ACTIVE SEISMIC EXPERIMENT	
Active Seismic Event Data (magnetic tape)	
Apollo 14	71-008C-05A
Apollo 16	72-031C-02A
Active Seismic Events Plots (microfilm)	
Apollo 16	72-031C-02B
LUNAR SEISMIC PROFILING EXPERIMENT	
Seismic Profile - Active Mode (magnetic tape)	
Apollo 17	72-096C-06B
Seismic Profiling Tapes (magnetic tape)	
Apollo 17	72-096C-06A
PASSIVE SEISMIC EXPERIMENT	
Passive Seismograms (microfilm)	
Apollo 11	69-059C-03A
Passive Seismic Event Data (magnetic tape)	
Apollo 12	69-099C-03A
Apollo 14	71-008C-04B
Apollo 15	71-063C-01B
Apollo 16	72-031C-01B
Passive Seismic Continuous Data (magnetic tape)	
Apollo 12	69-099C-03E
Apollo 14	71-008C-04A
Apollo 15	71-063V-01A
Apollo 16	72-031C-01A
Compressed Scale Playouts (microfilm)	
Apollo 12	69-099C-03B
Apollo 14	71-008C-04C
Apollo 15	71-063C-01D
Apollo 16	72-031V-01D
Compressed Scale Event Playouts (microfilm)	
Apollo 12	69-099C-03C
Apollo 14	71-008C-04E
Apollo 15	71-063C-01F
Apollo 16	72-031C-01F
Expanded Scale Event Playouts (microfilm)	
Apollo 12	69-009C-03D
Apollo 14	71-008C-04D
Apollo 15	71-063C-01C
Apollo 16	72-031C-01C

*This number refers to the NSSDC data set identification and must be used when requesting data.

EXPERIMENT	NSSDC ID*
Artificial Lunar Impact Data	
Apollo 12 (magnetic tape)	69-099C-03F
(microfilm)	69-099C-03O
Apollo 14 (magnetic tape)	71-008C-04F
(microfilm)	71-088C-04O
Apollo 15 (magnetic tape)	71-063C-01E
(microfilm)	71-063C-01O
Apollo 16 (magnetic tape)	72-031C-01E
(microfilm)	72-031C-01O
Selected Seismic Event Catalog (microfiche)	
Apollo 12	69-099C-03Q
Apollo 14	71-008C-04Q
Apollo 15	71-063C-01Q
Apollo 16	72-031C-01Q
Selected Seismic Event Data (magnetic tape)	
Apollo 12 (meteoroids)	69-099C-03R
(teleseismic)	69-099C-03S
(moonquakes)	69-099C-03T
Apollo 14 (meteoroids)	71-008C-04R
(teleseismic)	71-008C-04S
(moonquakes)	71-008C-04T
Apollo 15 (meteoroids)	71-063C-01R
(teleseismic)	71-063C-01S
(moonquakes)	71-063C-01T
Apollo 16 (meteoroids)	72-031C-01R
(teleseismic)	72-031C-01S
(moonquakes)	72-031C-01T
Seismic Event Catalog (microfiche)	
Apollo 12	69-099C-03H
Apollo 14	71-008C-04H
Apollo 15	71-063C-01H
Apollo 16	72-031C-01H
Compressed Scale Playouts of Selected Events (microfilm)	
Apollo 12 (meteoroids)	69-099C-03I
(teleseismic)	69-099C-03L
(moonquakes)	69-099C-03M
(artificial)	69-099C-03P
Apollo 14 (meteoroids)	71-008C-04I
(teleseismic)	71-008C-04L
(moonquakes)	71-008C-04M
(artificial)	71-008C-04P
Apollo 15 (meteoroids)	71-063C-01I
(teleseismic)	71-063C-01L
(moonquakes)	71-063C-01M
(artificial)	71-063C-01P

*This number refers to the NSSDC data set identification and must be used when requesting data.

EXPERIMENT	NSSDC ID*
Apollo 16 (meteoroids)	72-031C-01I
(teleseismic)	72-031C-01L
(moonquakes)	72-031C-01M
(artificial)	72-031C-01P
Expanded Scale Playouts of Selected Events (microfilm)	
Apollo 12 (meteoroids)	69-099C-03J
(teleseismic)	69-099C-03K
(moonquakes)	69-099C-03N
(artificial)	69-099C-03O
Apollo 14 (meteoroids)	71-008C-04J
(teleseismic)	71-008C-04K
(moonquakes)	71-008C-04N
(artificial)	71-008C-04O
Apollo 15 (meteoroids)	71-063C-01J
(teleseismic)	71-063C-01K
(moonquakes)	71-063C-01N
(artificial)	71-063C-01O
Apollo 16 (meteoroids)	72-031C-01J
(teleseismic)	72-031C-01K
(moonquakes)	72-031C-01N
(artificial)	72-031C-01O

*This number refers to the NSSDC data set identification and must be used when requesting data.

APPENDIXES

APPENDIX 1 - ORDERING OF APOLLO SEISMIC DATA

ORDERING PROCEDURES

The Apollo seismic data order form enclosed with this DUN is provided for the requester's convenience. All parts of the form must be completed to assure satisfactory request fulfillment. All required items should be identified in a single order to expedite the processing of the request. A copy of the "NSSDC Charge and Service Policy" for dissemination of data is included for the requester's guidance.

NSSDC requires knowledge of the scientific purpose for which the data provided will be used; therefore, a statement to this effect should be included in each request. NSSDC would also appreciate receiving copies of all publications resulting from studies in which data supplied by NSSDC were used. It is further requested that NSSDC be acknowledged as the source of the data in all publications resulting from use of the data provided.

Researchers within the United States should address inquiries about or requests for data to:

National Space Science Data Center
Code 601.4
Goddard Space Flight Center
Greenbelt, Maryland 20771
Telephone: (301) 344-6695

Researchers outside the United States should direct requests to:

World Data Center A for Rockets and Satellites
Code 601
Goddard Space Flight Center
Greenbelt, Maryland 20771 U.S.A.
Telephone: (301) 344-6695

APPENDIX 2 - INVESTIGATORS FOR THE APOLLO SEISMIC EXPERIMENTS

ACTIVE SEISMIC EXPERIMENT (ASE)

PI - Dr. Robert L. Kovach, Stanford University, Palo Alto, California
OI - Prof. Joel S. Watkins, University of Texas at Galveston

LUNAR SEISMIC PROFILING EXPERIMENT (LSPE)

PI - Dr. Robert L. Kovach, Stanford University, Palo Alto, California
OI - Prof. Joel S. Watkins, University of Texas at Galveston

LUNAR SURFACE GRAVIMETER (LSG)

PI - Prof. Joseph Weber, University of Maryland, College Park
OI - Mr. J. V. Larson, University of Maryland, College Park

PASSIVE SEISMIC EXPERIMENT (PSE)

PI - Dr. Gary V. Latham, University of Texas at Galveston
OI - Mr. Frank Press, Massachusetts Institute of Technology, Cambridge
OI - Dr. George H. Sutton, Hawaii Institute of Geophysics, Honolulu

APPENDIX 3 - ACRONYMS AND ABBREVIATIONS

A	angstrom; moonquake (event type)
ALSEP	Apollo lunar surface experiments package
ASE	active seismic experiment
BCD	binary coded decimal
bpi	bits per inch
c	meteoroid impact (event type)
cm	centimeter
CM	command module
CS	central station
CSM	command service module
deg	degree
DU	digital unit
DUN	Data Users Note
EASEP	early Apollo surface experiments package
EDT	experimenter data tapes
EP	explosive package
g	gram
H	high-frequency teleseism (event type)
h	hour
HFE	heat flow experiment
Hz	hertz
IBM	International Business Machines (Corp.)
ID	identification number
in.	inch
JSC	Johnson Space Center (NASA)
kg	kilogram
km	kilometer
L	LM impact (event type)
LEAM	lunar ejecta and meteorites experiment
LM	lunar module
LMS	lunar mass spectrometer
LOS	loss of signal
LP	long period
LPX	long-period seismometer X component of motion
LPY	long-period seismometer Y component of motion
LPZ	long-period seismometer Z component of motion
LRV	lunar roving vehicle
LSG	lunar surface gravimeter
LSPE	lunar seismic profiling experiment
M	suspected moonquake (event type)
m	meter
mgal	milligalileo
MHz	megahertz
min	minute
mm	millimeter
ms	millisecond

NASA	National Aeronautics and Space Administration
nm	r_nometer
NSSDC/WDC-A-R&S	National Space Science Data Center/World Data Center A for Rockets and Satellites
OI	other investigator
PI	principal investigator
PSE	passive seismic experiment
RTG	radioisotope thermoelectric generator
S	SIVB impact (event type)
s	second
SIM	scientific instrument module
SIVB	Saturn IVB booster
SM	service module
SP	short period
SPZ	short-period Z component of motion
SS	subsatellite
T	terminal event, Apollo 16 only (event type)
UT	universal time
W	watt
X	unusual event (event type)
yr	year
Z	short period, primarily (event type)