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INTRODUCTION TO THE APOLLO COLLECTIONS:

PART I

LUNAR IGNEOUS ROCKS

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INTRODUCTION

During the past few years we have had the task of introducing scores of geoscientists to the Apollo lunar rock and regolith collection. These scientists, who represent the range of visitors to both the Planetary Geoscience Laboratories of the Johnson Space Center and the Lunar Science Institute, had petrographic skills ranging from expert to nil. Many times we felt the need for a pamphlet that contains the basic petrographic, chemical, and age data for a representative suite of lunar samples. This pamphlet is our first attempt to partially meet that requirement.

This pamphlet introduces the igneous rocks from the Moon. A second pamphlet, to be published in about a year, will introduce the impactites (breccias -- the rocks formed by meteorite impacts) from the Moon. These publications are intended as educational tools for students interested in lunar rocks and the geology of the Moon. Also, they should serve a useful role in introducing prospective lunar sample investigators to the Apollo collections and lunar science in general.

Our first task was to select a representative suite of rocks. We have chosen 62 samples: 33 igneous rocks and 29 impactites (breccias). The igneous rocks are listed in Table 1 and the impactites in Table 2. We attempted to choose a suite of rocks that covered all recognized petrographic, chemical, and isotopic groupings. We constrained our list to be more-or-less evenly distributed among the six Apollo missions. A final consideration was an attempt to include samples that have been the subject of detailed scientific investigations. We especially attempted to include rocks that have been dated by the Rb-Sr internal isochron method. The list of 62 samples in Tables 1 and 2 is the result of a detailed review of the Apollo collections and the literature that we conducted in the fall of 1974, followed by an annual review to update the list.

The igneous rocks described in this pamphlet include 27 basalts, four plutonic rocks, and two pyroclastic samples. Several workers have published classifications of the lunar basalts. The classification of Papike et al. (1976) that is based on major element chemistry appears to be the most satisfactory. The assignment of each of our 27 basalts in the Papike et al. scheme is noted in Table 1. The textural-mineralogic name that we have assigned each sample is also included in Table 1.

This pamphlet is divided into three segments: descriptions, tables of rock compositions, and a master reference list.

The description for most rocks occupies two pages. The first page contains the rock name, four sections of text, and mineral chemistry diagrams. The second page contains photographs and a table containing the rock's mode. The rock name reflects the texture of the major silicate minerals.

The first section of text gives the basic information concerning how and where the sample was collected. Reference should be made to a map of the nearside of the Moon (Figure 1) that shows the landing sites for Apollo missions and for the missions in the unmanned Ranger, Surveyor, Luna and Lunokhod series. Landing site maps for all Apollo missions except Apollo 11 are shown in Figures 2, 3, 4, 5, and 6.

The second section of text contains new petrographic descriptions that were made especially for this pamphlet. The descriptions are general and form an internally consistent picture of the lunar rocks. We have not written detailed descriptions of any phenomena of especial interest. The descriptions are intended as a guide for anyone who is attempting to learn the basic petrographic relationships in the lunar rocks.

The third section of text contains radiometric age information where such data are available. We have included crystallization ages obtained by the Rb-Sr internal isochron method and the associated initial Sr isotopic ratio. We have also included plateau ages obtained with the ^{39}Ar-^{40}Ar temperature release method. All age data is referenced to the original work.

The last section of text contains some references that we consider of potential interest to a general audience. This list is not intended to be comprehensive.

Mineral chemistry for each sample is illustrated by a series of plots. Data for pyroxenes are presented in a pyroxene quadrilateral, for olivine (when present at the level of 1 percent or more) on a Fo-Fa bar, and for plagioclase on an An-Ab bar. Data for two-thirds of the rocks were available in the literature and those plots are referenced. We collected new electron microprobe data for those rocks without adequate published data.

The second page of each description contains two photographs and a table. One photograph illustrates the nature of the hand sample for each rock. We chose the best available photograph that would show the rock's texture. Some photographs are from the Lunar Receiving Laboratory's "Mug Shot" set. Other photographs are from the set made by the Curator during the cutting and allocation of the rock.

The second photograph is a general view of a thin section. For several rocks additional photomicrographs were required to illustrate the petrographic description. These photographs are specifically mentioned in the description.

The table contains the mode of the sample. Modes are based on published values supplemented by our observations. The modes generally include a range of values to illustrate the diversity of each rock. References used to compile the ranges of values are included in the fourth section of text.

A three-part table of chemical compositions for all samples is presented after the descriptions and before the master reference list. The first part of this table contains major element analyses that are based on averages calculated from published X-ray fluorescence and gravimetric analyses. The second part of the table contains a suite of minor and trace lithophile elements. These analyses were chosen from the work of a limited set of laboratories in order to achieve internal consistency. The laboratories chosen were the neutron activation laboratory at the Johnson Space Center (L. A. Haskin and D. P. Blanchard), the mass spectrometric isotopic dilution laboratories at the Johnson Space Center (P. W. Gast and N. J. Hubbard) and at the Goddard Space Flight Center (J. A. Philpotts and C. C. Schnetzler). The data from these laboratories were supplemented with data from other laboratories only where omissions were embarrassingly large. The third part of the table contains a suite of minor and trace siderophile and chalcophile elements. Here also we limited the data to a few laboratories in order to achieve internal consistency. The laboratories we chose are the neutron activation laboratories at the University of Chicago (E. Anders) and at the University of California at Los Angeles (J. T. Wasson). All data in these tables are referenced by numbers that refer to the master reference list.

The master reference list contains the complete citation for all studies cited in the descriptions and in the chemical table.

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Table I: IGNEOUS ROCKS

Basalts

Sample Number	Rock Name	Classification after Papike
10003	porphyritic pyroxene basalt	A11 Low K
10017	intersertal basalt	A11 High K
10044	porphyritic pyroxene basalt	A11 Low K
10045	porphyritic pyroxene-olivine basalt	A11 Low K
10049	intersertal basalt	A11 High K
10072	intersertal basalt	A11 High K
12002	porphyritic olivine-pyroxene basalt	A12 olivine
12009	porphyritic olivine-pyroxene basalt	A12 olivine
12021	porphyritic pyroxene basalt	A12 pigeonite
12022	porphyritic olivine-pyroxene basalt	A12 ilmenite
12039	porphyritic pyroxene basalt	
12051	porphyritic pyroxene basalt	A12 ilmenite
12063	porphyritic olivine-pyroxene basalt	A12 ilmenite
12064	sub-ophitic basalt	A12 ilmenite
14053	porphyritic pyroxene basalt	Feldspathic basalt
14072	porphyritic pyroxene basalt	Feldspathic basalt
15016	porphyritic pyroxene-olivine basalt	A15 olivine
15076	porphyritic pyroxene basalt	A15 pigeonite
15382 15386	sub-ophitic KREEP basalt	
15475	porphyritic pyroxene basalt	A15 pigeonite
15499	porphyritic pyroxene vitrophyre	A15 pigeonite
15555	porphyritic olivine-pyroxene basalt	A15 olivine
15556	porphyritic pyroxene basalt	A15 olivine
70017	poikilitic plagioclase basalt	A17 Very High Ti
70035	poikilitic plagioclase basalt	A17 Very High Ti
70215	porphyritic olivine-pyroxene basalt	A17 Very High Ti
75055	sub-ophitic basalt	A17 Low K

Plutonic Rocks

Sample Number	Rock Name
15415	Anorthosite
60025	Cataclastic Anorthosite
76535	Troctolite
72415	Cataclastic Dunite

Pyroclastics

Sample Number	
15426	Green glass
74220	Orange glass

Table II: IMPACTITES (BRECCIAS)

10060	12013	14063	15086	60255	72315
	12034	14082	15405	61015	76215
		14301	15445	61016	76295
		14304		62235	76315
		14310		62295	77017
		14311		65015	79135
		14312		67015	79215
		14321		68415	

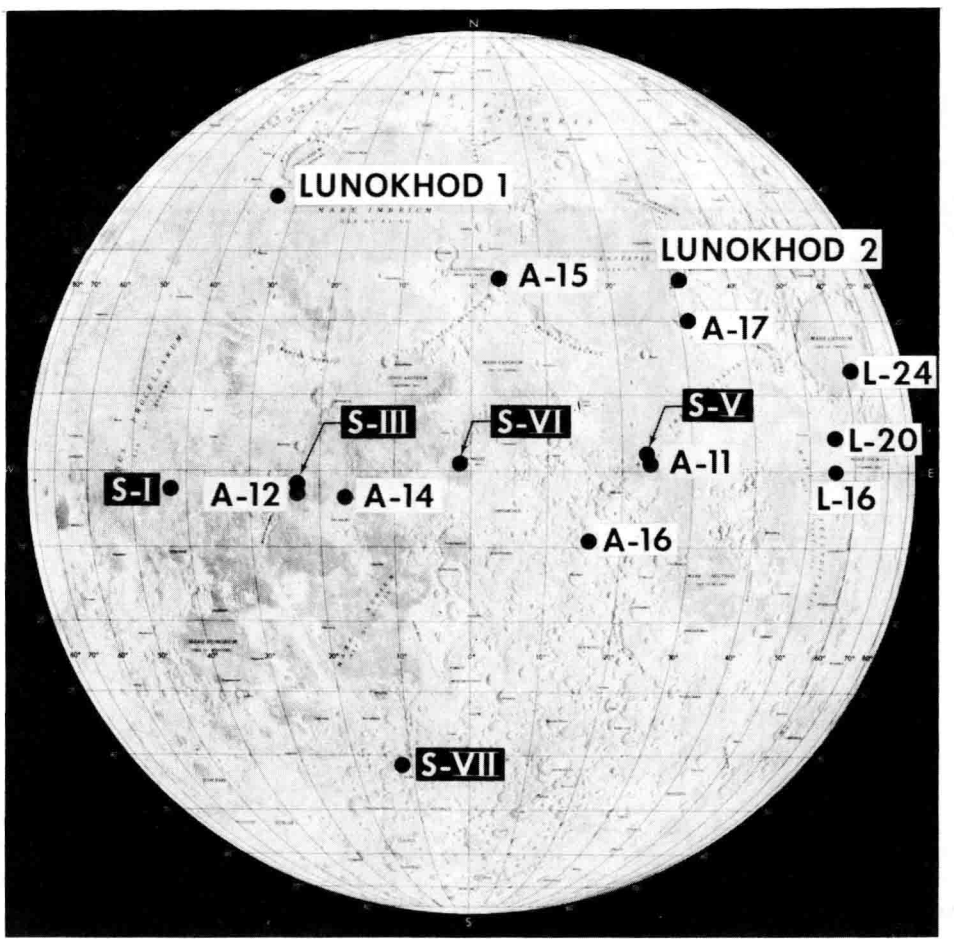


FIGURE 1 LUNAR LANDING SITES

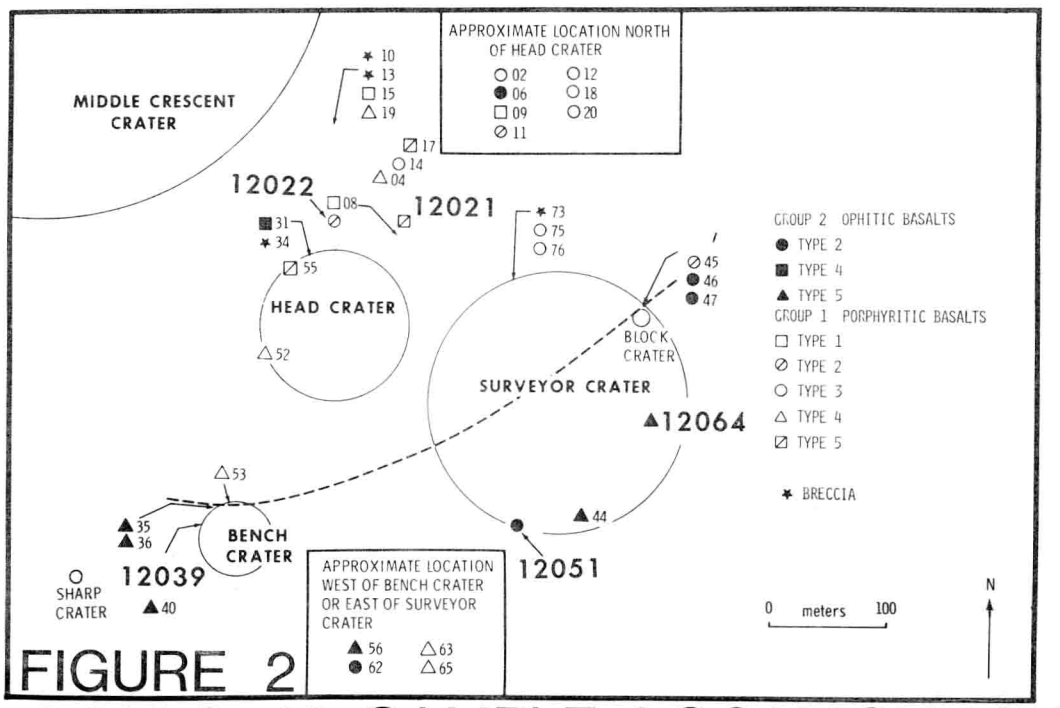


FIGURE 2
APOLLO 12 SAMPLE LOCATION MAP

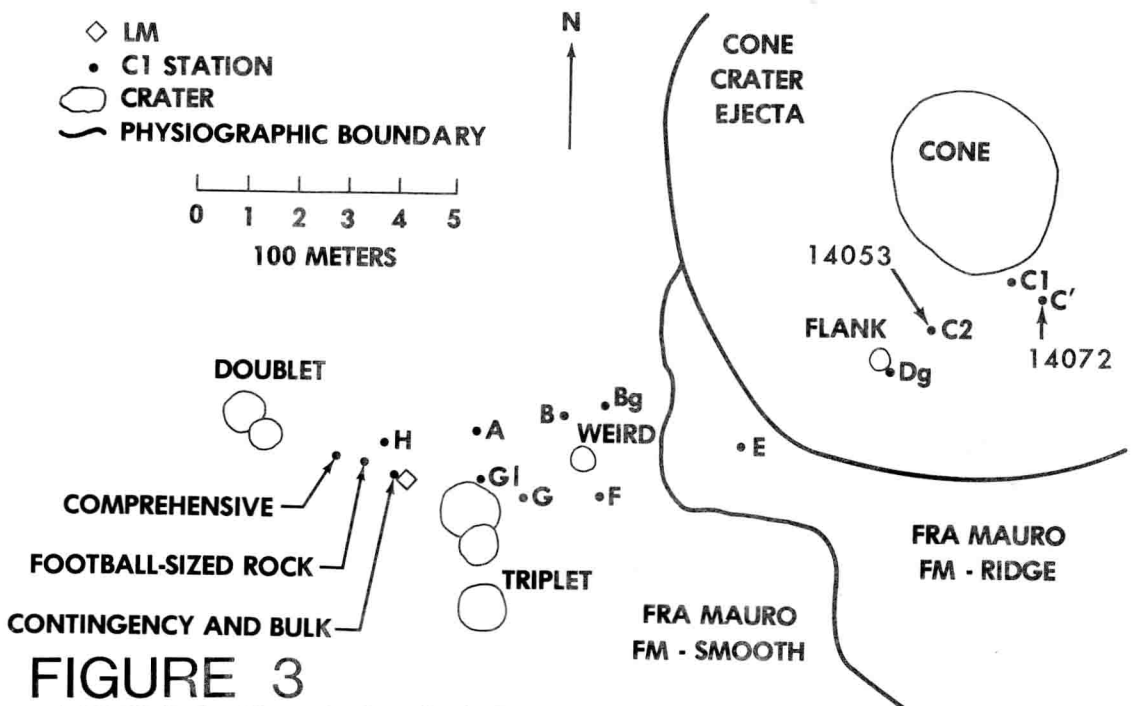


FIGURE 3
APOLLO 14 SAMPLE LOCATION MAP

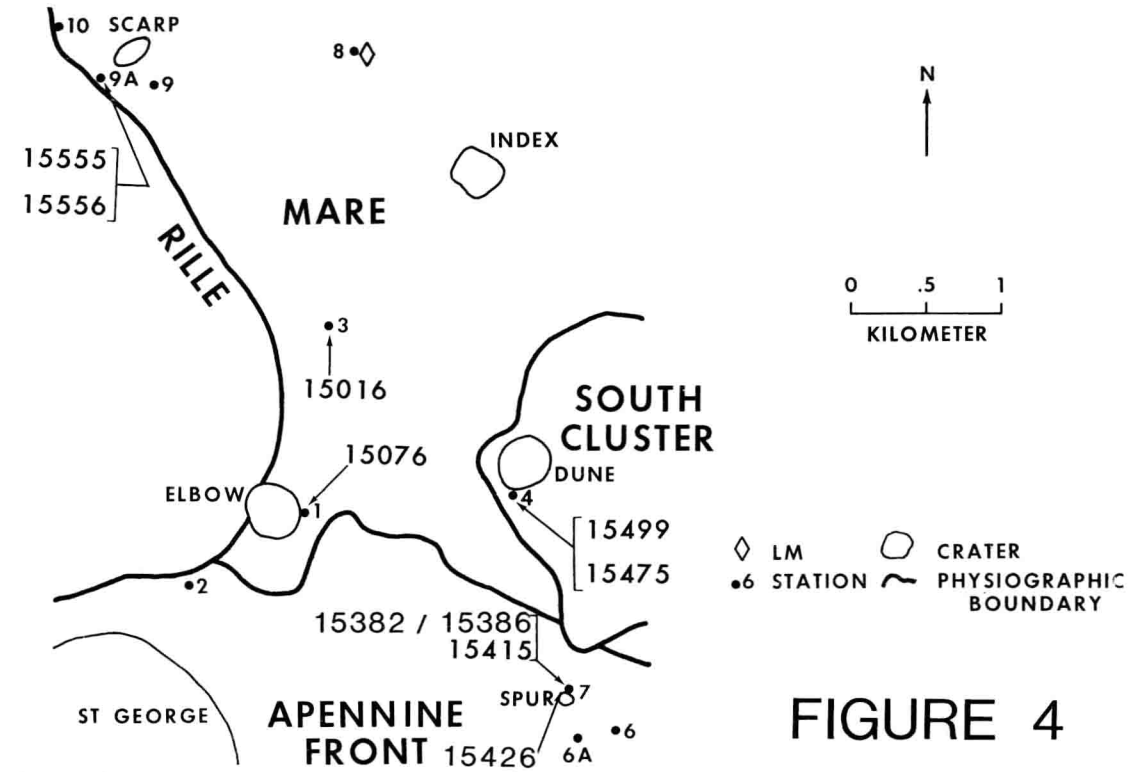
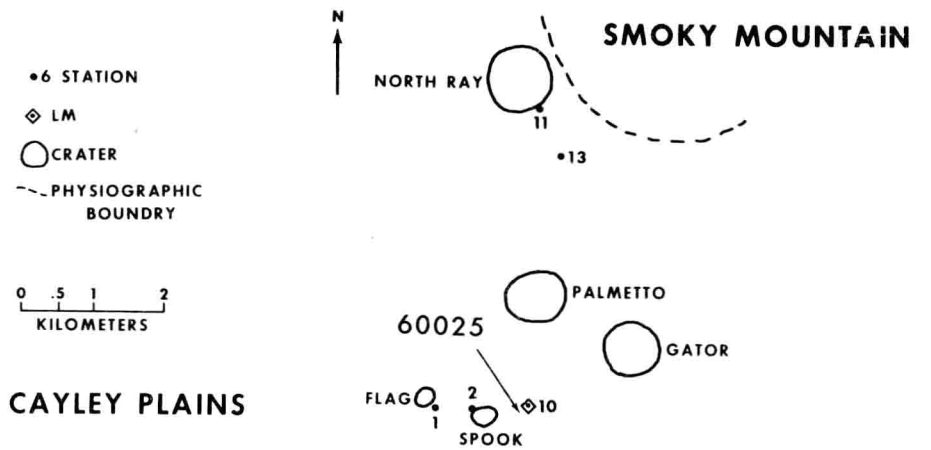


FIGURE 4

APOLLO 15 SAMPLE LOCATION MAP



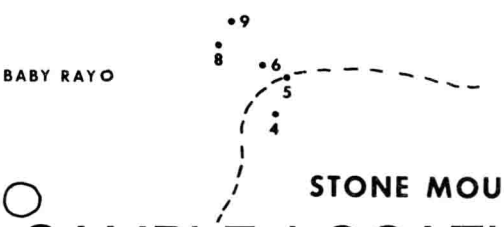


FIGURE 5

APOLLO 16 SAMPLE LOCATION MAP

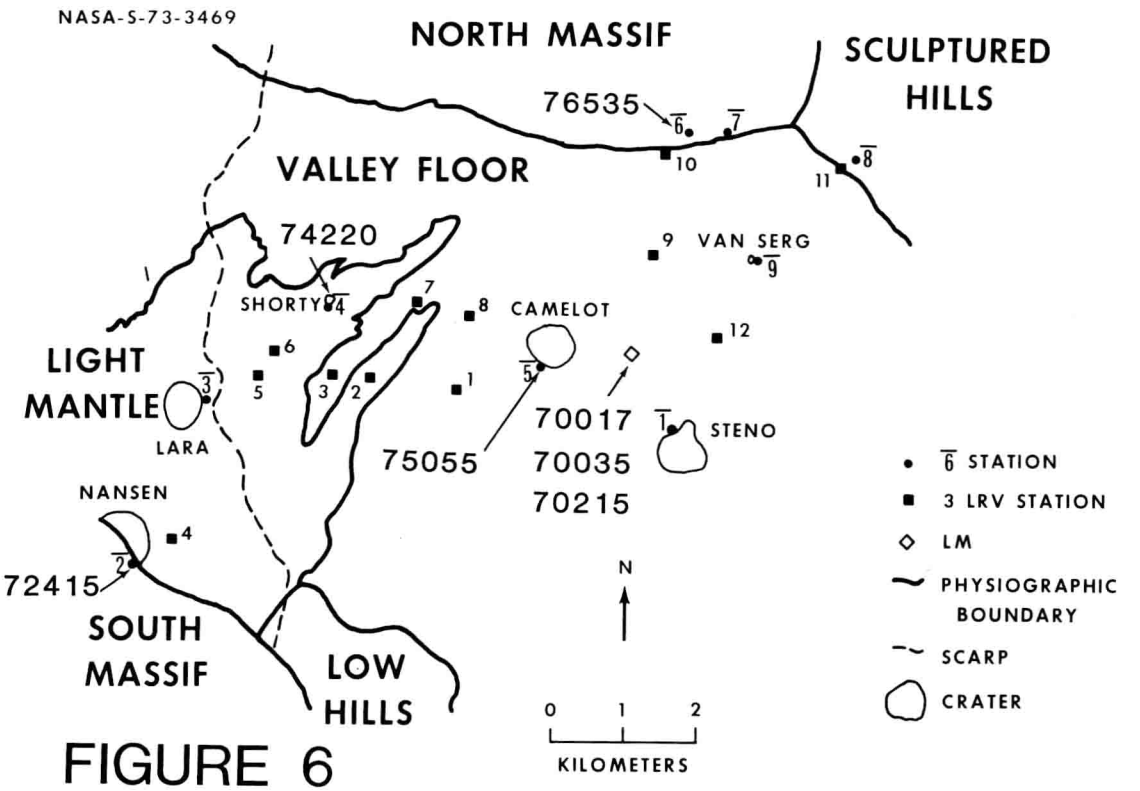


FIGURE 6
APOLLO 17 SAMPLE LOCATION MAP

ROCK DESCRIPTIONS

10003 Porphyritic Pyroxene Basalt

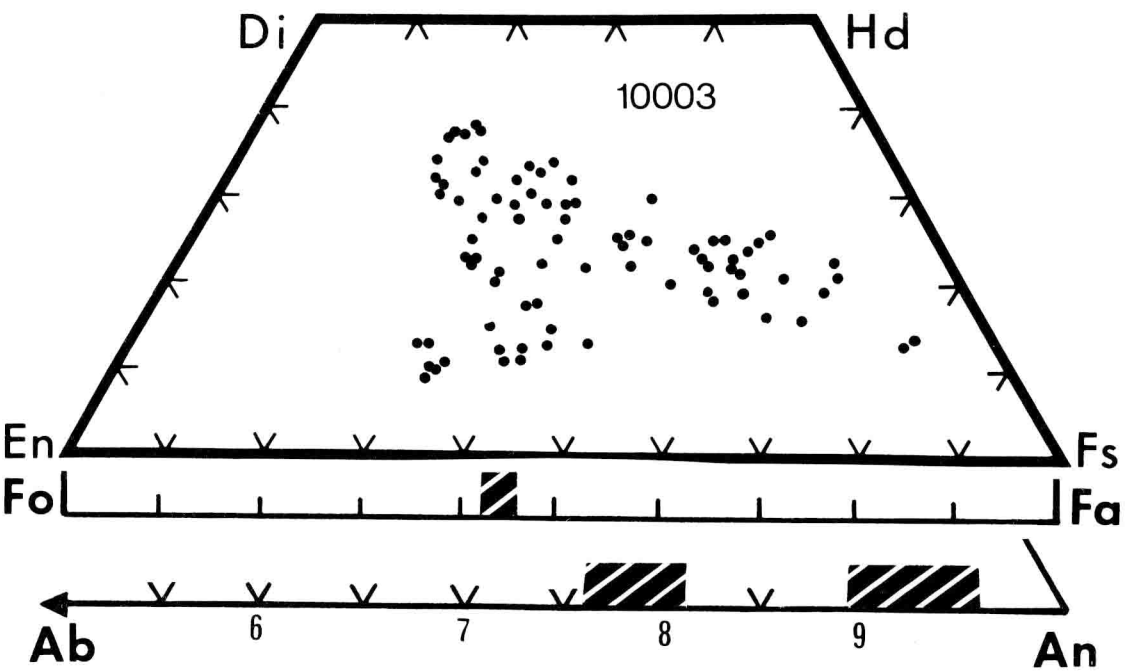
The exact collection site for sample 10003 is not documented; it is believed to have been collected in an area between the Lunar Module (LM) and the double elongate crater to the southwest of the LM.

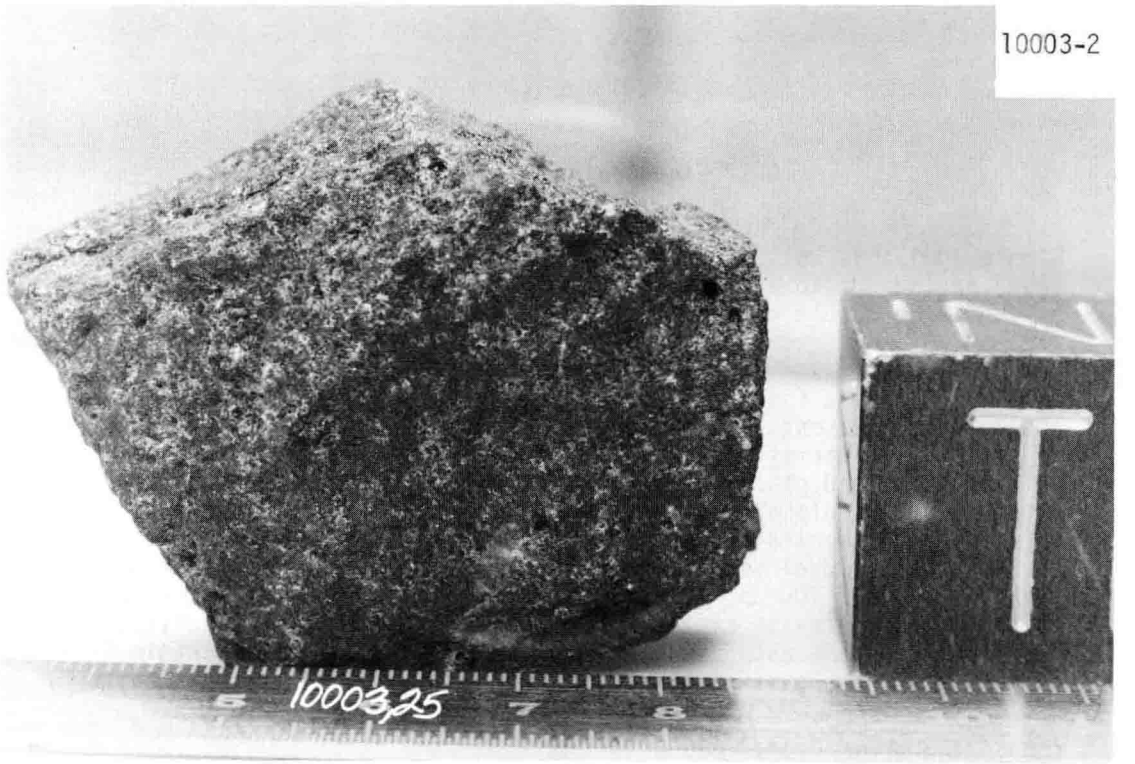
Sample 10003 is a medium grained porphyritic pyroxene basalt characterized by anhedral phenocrysts of pyroxene (1.0-2.7mm) set in a subophitic matrix of plagioclase, pyroxene, and ilmenite. Interstitial areas are filled with cristobalite, glassy mesostasis, and a small amount of irregularly shaped pore space. Plagioclase is typically tablet shaped (0.1-0.6mm), euhedral to subhedral, and occurs both subophitically intergrown with pyroxene phenocrysts and as an interstitial phase between the phenocrysts. Ilmenite is the major opaque phase, typically occurring as blocky, irregularly shaped bodies (0.5-1.0mm) intergrown with pyroxene and plagioclase, and less commonly as rounded laths (0.1-0.3mm) which are present as inclusions in pyroxene phenocrysts. Troilite, with Fe-Ni metal inclusions, is present as blebs intergrown with ilmenite or associated with the mesostasis.

AGE DATA: ^{40}Ar-^{39}Ar plateau - 3.92 ± .07 AE Turner (1970)
3.91 ± .03 AE Stettler et al. (1974)

Rb-Sr isochron - 3.84 ± .08 AE
I_{Sr} - 0.69909 ± 4
} Papanastassiou et al. (1970)

ADDITIONAL REFERENCES: Bailey et al.,(1970); Haggerty et al. (1970); James and Jackson (1970).





10003 MODAL ANALYSIS (%)	
PYROXENE	49-52
OLIVINE	0.5
PLAGIOCLASE	29-35
ILMENITE	14-18
ARMALCOLITE	——
CHROMITE	——
ULVOSPINEL	——
METAL	——
TROILITE	0.5
CRISTOBALITE	0.3-1.0
TRIDYMITE	——
MESOSTASIS	——
PORE SPACE	0.5
PHOSPHATE	0.2
OTHERS	——

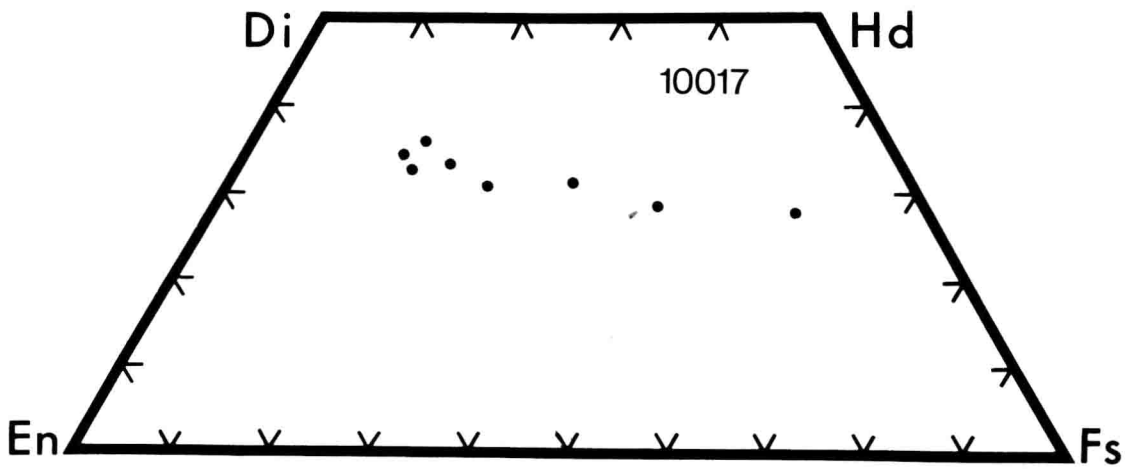
10017 Fine Grained Intersertal Basalt

Sample 10017 was collected in the final minutes of the extravehicular activity (EVA) period out to a distance of 10 to 15 meters in the area near the east rim of the large double crater.

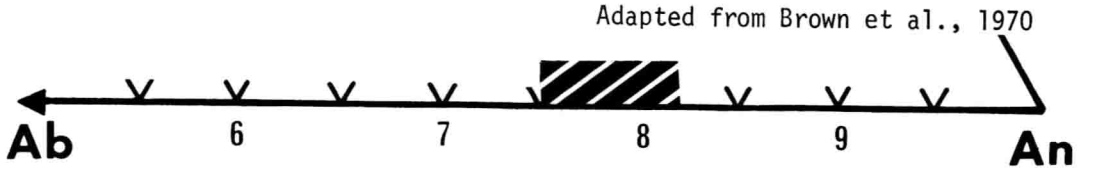
Sample 10017 is a fine grained intersertal basalt characterized by a mesh-like assemblage of essentially equal size (0.05-0.30mm) anhedral pyroxene and ilmenite crystals with interstitial plagioclase megacrysts (0.3x1.5mm), anhedral cristobalite, and glassy mesostasis. Several small vesicles (0.2-0.5mm) are present. Plagioclase megacrysts are typically poikilitic and enclose anhedral pyroxene and ilmenite crystals. Some ilmenite is present as rounded laths (0.2mm) but anhedral shapes are the typical form. Rare crystals of anhedral tranquillityite, 10μ and less, are present in the mesostasis and several plagioclase megacrysts contain rod-shaped inclusions of tranquillityite. Troilite blebs are abundant in the mesostasis and commonly contain inclusions of native iron. Fe-Ni metal also occurs in association with ilmenite.

AGE DATA: Rb-Sr isochron - 3.80 ± .11 AE Compston et al. (1970)
3.59 ± .05 AE } Papanastassiou et al. (1970)
I_{Sr} - 0.69932 ± 5 }

ADDITIONAL REFERENCES: O'Hara et al. (1970); Brown et al. (1970); Kushiro and Nakamura (1970); Housley et al. (1970); James and Jackson (1970).

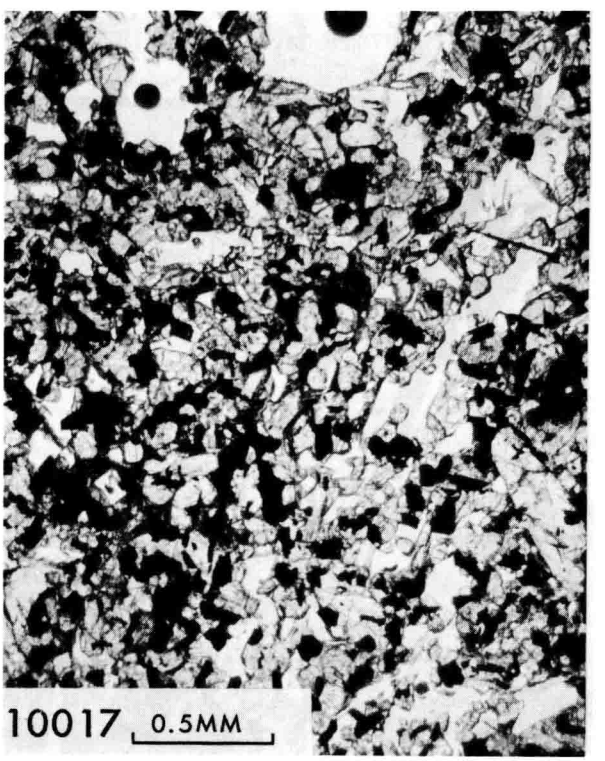


Adapted from Brown et al., 1970



Adapted from Kushiro and Nakamura, 1970

10017 MODAL ANALYSIS (%)	
PYROXENE	48-59
OLIVINE	——
PLAGIOCLASE	18-27
ILMENITE, ARMALCOLITE, CHROMITE, ULVOSPINEL	14-24
METAL	tr-0.2
TROILITE	0.3-1.0
CRISTOBALITE	1-2
TRIDYMITE	——
MESOSTASIS	6-8
PORE SPACE	——
PHOSPHATE	tr
OTHERS	——



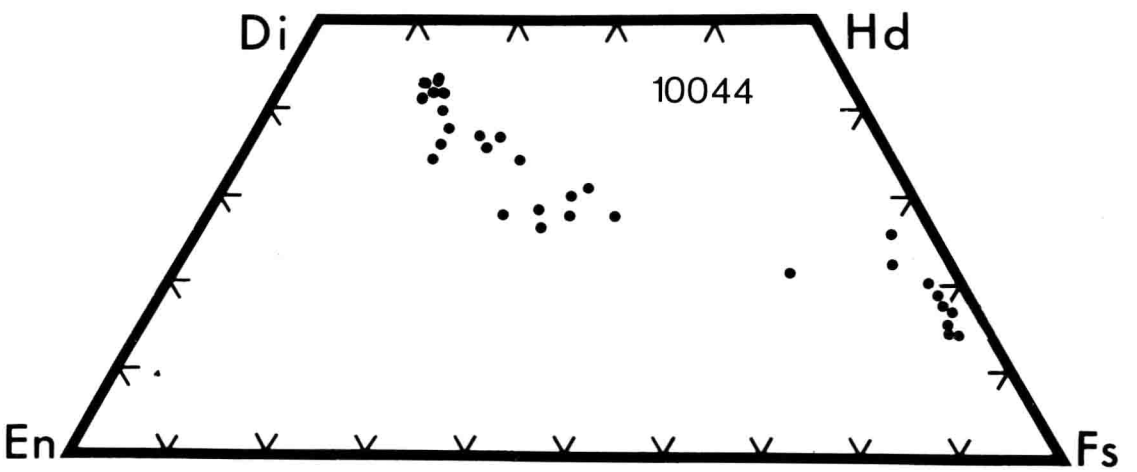
10044 Porphyritic Pyroxene Basalt

Sample 10044 was collected in the area between the LM and the double elongate crater to the southwest of the LM.

Sample 10044 is a coarse grained porphyritic basalt which consists of subhedral to anhedral phenocrysts of pyroxene (1.0-2.0mm) set in a subophitic matrix of plagioclase tablets (0.2x1.0 to 0.4x2.0mm), anhedral pyroxene grains (0.6-0.8mm), and ilmenite. Pore space is rare and occurs as irregularly shaped vugs 0.2 to 0.3mm in diameter. Interstitial areas are filled with anhedral cristobalite and glassy mesostasis, some of which is present as a clear green glass. Pyroxferroite was observed on the edges of several pyroxene grains. Several deep red, tablet-shaped minerals (0.01-0.02mm), possibly tranquillityite, occur interstitial to the larger silicate minerals. Ilmenite is present as laths (0.3-0.8mm) and as irregularly shaped bodies (0.4-1.6mm), both of which commonly contain inclusions of silicate minerals. Troilite with Fe-Ni metal inclusions is dispersed throughout the matrix.

AGE DATA: ^{40}Ar-^{39}Ar plateau - 3.73 ± .05 AE Turner (1970)
Rb-Sr isochron - 3.71 ± .11 AE } Papanastassiou et al. (1970)
I_{Sr} - 0.69909 ± 6 }

ADDITIONAL REFERENCES: Albee and Chodos (1970); Agrell et al. (1970); Bailey et al. (1970) Cameron (1970); Gay et al. (1970).



Adapted from Albee et al., 1970

Adapted from Albee et al., 1970

10044 MODAL ANALYSIS (%)	
PYROXENE	45-59
OLIVINE	—
PLAGIOCLASE	33-37
ILMENITE	6-12
ARMALCOLITE	—
CHROMITE ULVOSPINEL	0.2
METAL	tr
TROILITE	tr-0.5
CRISTOBALITE	4-6
TRIDYMITE	—
MESOSTASIS	—
PORE SPACE	1.0
PHOSPHATE	tr
OTHERS	—