E. PETROLOGY AND DISTRIBUTION OF RETURNED SAMPLES, APOLLO 16

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INTRODUCTION

Apollo 16 returned about 96 kg of samples, collected by astronauts Young and Duke over a distance of about 20 km during the three traverses. About 75 percent of the total by weight are rock fragments larger than 1 cm. The station locations are known for all rocks; 47 rocks heavier than 20 g (excluding rake samples) have been identified and oriented using lunar surface photographs (Sutton, this volume).

Apollo 16 rocks, like the samples returned by Apollo 14 and nonmare samples returned by Apollos 15 and

17, are predominantly fragmental: they consist of clasts (larger than 1 mm) and microclasts (0.1-1 mm) of glass, minerals, and lithic fragments in generally fine-grained matrices. Homogeneous crystalline rocks constitute a small proportion of the samples and have their counterparts as clasts in or matrix components of the breccias; a number of such rocks were collected directly from breccias or were dislodged from breccia samples in transit. It is therefore likely that all the crystalline rocks are either breccia clasts or pieces of breccia matrix.

MEGASCOPIC STRUCTURES

Reports by the Field Geology Team (Muelhberger and others, 1972) briefly describe fractures and discontinuous color bands in some large breccia boulders photographed by the astronauts. The fractures are multiple sets of irregular to planar joints. Irregular discontinuous light-colored lenses occur in Shadow rock at station 13 (Ulrich, this volume, fig. 9); study of samples suggests that this type of layering results from cataclastic flow of relict feldspathic clasts as a consequence of multiple brecciation.

In addition to planar fractures, hand specimens reveal two structures not visible in most surface photographs: glass coatings and thin light-colored veins. The glass in breccias occurs in three ways in addition to clasts: (1) exterior veneers that have sharp contacts with the coated rock; (2) selvages that have gradational boundaries with the coated rock; (3) veins that commonly form complex anastomosing networks. Thin glass was injected as impact melt into fractures or formed by fusion along fractures beneath a transient impact crater (Wilshire and Moore, 1974). As the crater grew, the glass was excavated by disaggregation along the same fracture systems. The light-colored veins appear to be largely unannealed mineral debris derived from feldspathic clasts and injected into cracks in the breccia matrices. These cracks and the mobilization of crushed feldspathic material apparently result from multiple impact events (Wilshire and others, 1973).

HAND-SPECIMEN PETROLOGY

The hand-specimen petrology of Apollo 16 rocks was described by Wilshire and others (1973) and will not be repeated in detail. Subsequent examination of thin sections, however, has led to revision of sample classification (table 1) and pointed up the gradational character of the class boundaries. All sources of information available to us were used to compile table 1: our own extensive examination of the samples as members of the Preliminary Examination Team, the Apollo 16 sample information catalog (LRL, 1972), rake sample catalogs (Keil and others, 1972; Phinney and Lofgren, 1973); and other published sources cited in table 2.

The 468 samples heavier than 2 g are placed in three major groups, crystalline rocks, glasses, and breccias, and these are further subdivided into nine categories (table 1, fig. 1): two (C_1 and C_2) are subdivisions of the crystalline rocks; one (G) consists of glass; five (B,-B5) are subdivisions of the breccias; and one (U) consists of unclassified samples. The class boundaries are not rigid, and ambiguities arise in classifying certain rocks. In hand specimen, the finest grained crystalline rocks can be subdivided as "igneous" (C_1) or "metaclastic" (C_2) only on the basis of crystallinity and occurrence of angular mineral debris; some thin sections show that even rocks containing comparatively large amounts of mineral debris may have a predominantly igneous texture or a texture that is not easily classified as either igneous or metamorphic. The distinction between fine-grained crystalline rocks and dark-matrix breccias is somewhat arbitrary. The crystalline rocks are generally lighter in color because of coarser grain size and the absence of conspicuous lithic clasts. The matrices of dark-matrix breccias, however, have finer grained igneous or metamorphic textures of the same types as the crystalline rocks. Breccias may be assigned to the B_2 class (light matrix, dark clasts) rather than B_1 (light matrix, light clasts) on the basis of a few dark clasts seen in hand specimens that may not have been thin sectioned. The B_3 group is intermediate in color mainly because of the development of matrix glass. Many of these rocks are the so-called soil breccias, but they may have originated in the same way as some multiply brecciated but little-melted rocks classed as B_2 breccias or some multiply brecciated and extensively melted rocks classed as B_4 or B_5 breccias. As certain samples (designated (F) in table 1) are known to be nonrepresentative parts of larger rocks, the classification should be used in conjunction with the sample documentation report (ALGIT, 1972b, and Sutton, this volume). And a number of rocks classified as B_4 breccias have light-colored fragmental material adhering to one or more surfaces, suggesting that they are clasts from breccias. Despite these practical and conceptual difficulties, classification on the basis of megascopic properties, with subdivision based on available data from microscopy, has the advantage of describing the sample as a whole, whereas many thin sections are known to be quite unrepresentative of the sample. Representative sampling by thin section is generally difficult because of the great complexity

TABLE 1.-*Megascopic classification of Apollo 16 rock samples greater than 2 grams*

[Sample number in parentheses, tentative identification based on cursory laboratory description. (F), sample nonrepresentative piece from a larger rock. Letter and class number in parentheses, possible alternative classification. (B), possible exotic mare basalt sample]

Crystalline		Glass	Unclassified	Breccia				
				Light matrix		Medium matrix	Dark matrix	
Igneous	Metaclastic			Light clasts	Dark clasts	Light and dark clasts	Light clasts	Dark clasts
C_1	C_2	G	U	B_1	B_2	B_3	B_4	B_5
60335	60235	60095	60617	60015	60016(B_3)	60535	60017(B_5)	60019
60615	60315	60528		60025	60075(B_1)	60637	60018	(63335)
60635	60525(B_4)	60646	61017	60035	60115(B_5)	60639	60255	67735 (B_3)
(61576)	60526	60665	61245	60055	60659(B_4)	(60648)	60275	68115
62295	(60527)	60666	61246	60056	61015	60655	60645	68815
(63506)	60616	60668	61247	60057	61155(B_4)	60656	(60657)	
65055	60619	60669	62285	60058	(61516)	61135	(60658)	
65785	60625	60677	62286	60135	62255	61175	60667	
65795	60626	60679	62287	60215	62275	61295	60676	
67936 (F)	60627	61157	64505	60515	63509	(61525)	61016	
67956 (F)	60636	61158	64506	60516	(63588)(B_3)	(61526)	61568	
68415	61156	(61195)	64507	60618	(64425)	(61536)	61569	
68416	61225	61546	64508	60628	64435	(61537)	(61575)	
69955 (F)	62235	61547	64509	60629	64475	(61538)	63355	
	(62245)	61548	64515	62236	64476	(61539)	(63505)	
	(63537)	61549	64516	62237	64477 (B_4)	(61545)	(63525)	
	(63538)	61555	65908	62246	64535	(62247)	(63526)	
	(63545)	61556	65909	64589	64536	63507	(63527)	
	(63547)	61558	65915	64819	64537	63508	(63528)	
	(63549)	(63559)	66085	(65588)	64538	(63578)	(63529)	
	(63556)	(63566)	66086	(65759)	(64539)	(63579)	(63535)	
	(63558)	(63567)	67215	65789	(64545)	(63587)	(63546)	
	(63585)	(63568)	67235	67075	(64546)	(63589)(B_2)	(63555)	
	64455	(63575)	67557	67415	(64547)	(63595)	(63557)	
	64576	65016	67558	(67486)	(64548)	(63596)	(63577)(C,)	
	64815 (B)	65056	67647	67635	(64549)	(63597)	64478(%)	
	64817	65348	67706	67636	(64555)	(63598)	(64565)	
	65015	65349	68825	67637	(64556)	(64559)	(64566)	
	65357	(65355)	68845	67955	(64557)	(64588)	(64567)	
	65358	(65356)	68846		(64558)	64825	(64568)	
	65365	65366	68847		(64587)	64826	(64569)	
	65777	65585			65035	64827	(64575)	
	65778	65586			65075(B,)	64829	(64577)	
	65779	65587			65095(B,)	64835	(64578)	
	(65905)	(65767)			65315	64837	(64579)	
	(65906)	(65768)			65325(B,)	(65337)	(64585)	
	(67485)	(65769)			65326	(65338)	(64586)	
	(67487)	(65775)			65327 (B,)	(65515)	64816(C,)	
	(67488)	(65776)			(65359)	(65516)	64818(C,)	
	(67489)	67095			(65719)	(65517)	66095	
	(67559)	67567			65757	(65518)	(67435)	
	67565	67568			(65758)	(65519)	67475 (F)	
	67566	67569			65907(%)	(65525)	67715	
	67615	67575			66055	(65526)	67716	
	67616	67576			67025(%)	(65527)	67717	
	67617	67626			67035	(65528)	67719	
	67618	67627			67055(%)	(65529)	67725	
	67619	67628			67455	(65535)	67726	
	67625	67629			67515	(65537)	67737	
	67667 (B)	(67705)			67516(B,)	(65538)	67738	
	67668	67728			67517(B,)	(65539)	67739	
	67676	67729			67518(B,)	(65548)	67745	
	67736	(68529)			67519(B,)	(65549)	67915	
	67746				67525(B,)	(65555)	67937 (F)	
	67747				67526 (B,)	(65715)	67945	
	67748				67527(B,)	(65716)	(67946)	
	(67935)(F)				67539 (B,)	(65717)	(67947)	
	(68525)				67549	(65718)(B,)	(68516)	
	(68526)				67555	(65725)(B,)	(68518)	
	(68527)				67556	(65726)	69935	
	(68535)				67605	(65727)		
	69945				67638	(65728)		
					67639	(65729)		
					67646	(65735)		
					67648	(65736)		
					67655	(65745)		
					67666	(65746)		
					67749	65786		
					67755	(65787) (C,)		
					67756	(65788)(C,)		
					67757	(65925)		
					67758	(65926)		
					67759	66035		
					67766	66036		
					67769	66037		
					67776	67015 (%)		
					67975	67016 (B,)		
					68035	(67115)		
					68515	(67665)		
					(68517)	(67669)		
					(68519)	(67718)		

TABLE 2.-*Microscopic textures of the crystalline rocks and of the matrices of the least-modified breccias*

[Parentheses enclose station numbers]

Igneous	Pokiloblastic	Granoblastic fragmental	Glassy or
			60017 (13)
60016 (LM-ALSEP)	60255 (LM-ALSEP)	60115 (LM-ALSEP)	60535 (LM-ALSEP)
60018 (LM-ALSEP)	60275 (LM-ALSEP)	61155 (LM-ALSEP)	60655 (LM-ALSEP)
60019 (LM-ALSEP)	60315 (LM-ALSEP)	65338 (5)	60656 (LM-ALSEP)
60335 (LM-ALSEP)	60526 (LM-ALSEP)	67946 (11)	61135 (1)
60615 (LM-ALSEP)	60616 (LM-ALSEP)	67955 (11)	61175 (1)
60618 (LM-ALSEP)	60625 (LM-ALSEP)	67975 (11)	61295 (1)
60635 (LM-ALSEP)	60645 (LM-ALSEP)		63507 (13)
60667 (LM-ALSEP)	61156 (1)		63335 (13)
61015 (1)	63505 (13)		66036 (6)
61016 (1)	64435 (4)		67015 (11)
62295 (2)	64478 (4)		67016 (11)
63506 (13)	65015 (5)		67035 (11)
64476 (4)	65055 (5)		67075 (11)
64477 (4)	65356 (5)		67445 (11)
65035 (5)	65357 (5)		67475 (11)
65075 (5)	65778 (5)		67735 (11)
65095 (5)	67435 (11)		67915 (11)
65359 (5)	67945 (11)		68815 (8)
65719 (5)	68035 (8)		69935 (9)
65785 (5)			
65795 (5)			
66055 (6)			
66095 (6)			
67025 (11)			
67936 (11)			
67937 (11)			
67956 (11)			
68415 (8)			
68416 (8)			

imposed by small-scale changes in degree of granulation and lithologic mixing, degree of melting and thermal metamorphism, and degree of admixture from the projectiles that caused brecciation. Moreover, fewer than 25 percent of the samples have been thin-sectioned at this time (1974).

MEGASCOPIC ROCK TYPES

The three rock groups and the number to which samples are assigned are defined by their principal characteristics.

CRYSTALLINE ROCKS

Of the 76 samples classified as crystalline (table 1), 14 (group C_1) appear to be fine- to coarse-grained igneous rocks. They are highly feldspathic, containing irregular plagioclase inclusions up to 10 mm across and irregularly scattered crystal-lined vugs. Sixty-two crystalline rocks (group C_2) appear to be metaclastic rocks containing variable amounts of fine angular mineral and lithic debris. The matrix of some is so fine grained that igneous and metamorphic textures cannot be distinguished in hand specimen.

The few rocks that have been thin sectioned are classified in table 2. Two samples of this group, 64815 and 67667, appear in hand specimen to be crushed and annealed mare basalts with ilmenite in about the same proportion given for Apollo 12 and 15 mare basalts.

GLASS

Of the 53 glass samples, two are spheres, the rest irregular glass fragments and coarse agglutinates containing small amounts of mineral and lithic debris.

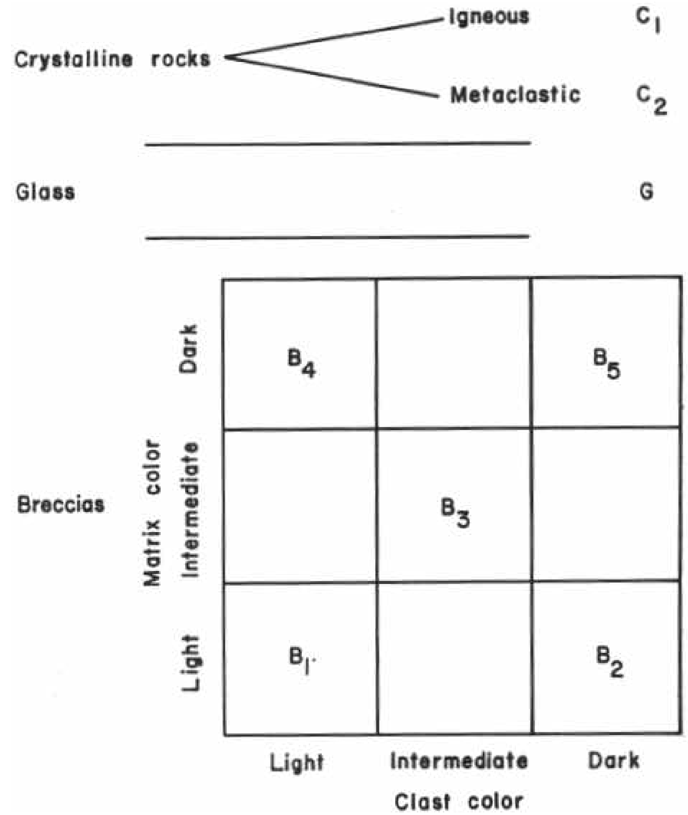

FIGURE 1.-Scheme used for classification of Apollo 16 rocks. From Wilshire and others (1973).

Many of these samples may have spalled from melt veneered ejecta while the veneer was still molten.

BRECCIAS

The fragmental rocks are divided into five groups according to proportions of light- and dark-gray clasts and matrix color (fig. 1). Although there are clasts of all shades of gray and of varying crystallinity, two types are clearly dominant: (1) dark-gray aphanitic to finely crystalline hard lithic fragments and (2) white to light-gray partly crushed to powdered feldspathic fragments. Matrices are of mainly three types: light and medium-gray matrices, generally friable and not visibly altered by thermal events; dark matrices that are made coherent by fusion and thermal metamorphism.

On the basis of clasts and matrices, the 263 samples of breccia are classified into five types, in order of abundance: (1) light matrix breccias with dark clasts (B_2-85 samples); (2) breccias with medium-gray matrices and roughly equal proportions of light and dark clasts (B_3-83 samples); (3) dark-matrix breccias with light clasts (B_4-60 samples); (4) light-matrix breccias with light clasts (B_1-30 samples); and (5) dark-matrix breccias with dark clasts (B_5-5 samples). Because clasts of the same color as the matrix are harder to identify, the B_1 and B_5 breccias may be more abundant than indicated. Thirty samples (table 1) remain unclassified for lack of adequate catalog descriptions and photographs. All are small, and none appear in any way unusual.

THIN-SECTION PETROLOGY

Thin sections have been studied of 77 samples examined in hand specimen. Although statistics on the clasts in breccias have not yet been compiled, textural characteristics and qualitative data on rock-type distribution allow preliminary subdivision of the mega scopic classification.

CRYSTALLINE ROCKS

IGNEOUS GROUPS (C_1)

Of the 14 samples of igneous group C_1, only two (61576 and 69955) appear to be coarse-grained plutonic rocks; one (65785) is composite coarse- and fine-grained rock. Sample 61576, a 6-g rock, may be a single large grain of plagioclase with a glass coating (Phinney and Lofgren, 1973); 69955, coarse-grained polycrystalline rock, probably is more than 95 percent plagioclase (see Rose and others, 1973), making it one of the few true lunar. anorthosites (Wilshire and Jackson, 1972b; Jackson and others, 1975). Sample 65785 (Dowty and others, 1974a) consists of a small fragment of spinel troctolite in a fine-grained feldspathic igneous matrix having essentially the same minerals and bulk composition as the troctolite.

The remaining 11 samples in group C, are fine grained rocks, consisting of approximately 60 percent or more very calcic plagioclase, magnesian olivine and pyroxenes, and metallic Fe-Ni with or without magnesian spinel and a variety of minor phases (Dowty and others 1974a; LSPET, 1973; Agrell and others, 1973; Hodges and Kushiro, 1973; Gancarz and others, 1972; Helz and Appleman, 1973; Brown and others, 1973). Textures of these rocks range from intersertal, subherulitic ("radiate") through fine-grained ophitic to intergranular. All are characterized by abrupt variaons in crystallinity and texture (fig. 2A), due partly to incomplete melting of inclusions (60335, 60615, 60635, 65796, 68415, 68416) and partly to proximity to vugs, were the grain size is typically coarser (especially 68415, 65055). In some rocks (65055, 68415, 68416) a few large plagioclase grains appear to be euhedral enocrysts (fig. 2B), but similar grains in sample 60618 (Dowty and others, 1974a) are almost certainly derived by disaggregation and incomplete melting of a coarse-grained spinel-olivine anorthosite into which the fine-grained igneous-textured rock grades. The portion of unmelted mineral debris is extremely variable, ranging from negligible in 60635 to probably more than 25 percent in samples 60335 and 65795.

Textural similarity of these fine-grained feldspathic igneous rocks to terrestrial impact melts (Grieve and others; 1974) suggests that they are products of wholerock impact melting. This interpretation, supported by a number of workers (among them, Agrell and others, 1973; Wilshire and others, 1973; Dowty and others, 1974a; Walker and others, 1973; Helz and Appleman, 1973), is substantiated by common occurrence of unmelted relics derived from coarse-grained rocks. This class of rocks has a bulk composition spread like that of cataclastic plutonic clasts in breccias (essentially troctolitic, 62295 and 60335, to anorthositic, 65795); gradations from melt texture through disaggregated fragments of plutonic rock with interstitial melt texture to plutonic rock of essentially the same bulk composition further support an origin of the fine-grained igneous rocks by impact melting of plutonic rocks. Textures of breccia matrices formed by melting of plutonic feldspathic rocks differ from those of group C_1 melt rock only by being finer grained and more variable.

Departures in bulk composition of the melt rocks from single plutonic rock types are to be expected and may result from melting of soils or mixed breccias (Dowty and others, 1974a), homogenization of lithologically layered rocks (see Grieve and others, 1974), and contributions from the projectile that caused melting (see Moore, 1969). Partial melting (Warner and others, 1974) has been postulated as a cause of variation in melt rocks but does not seem likely to be a critical consequence of impact melting (Grieve and others, 1974).

METACLASTIC GROUPS (C2)

The 11 metaclastic rocks examined in thin section, all have poikiloblastic texture except 60619, which has a medium-grained granoblastic texture that resembles the textures formed by local recrystallization within plutonic igneous rocks (Wilshire, 1974).

The remaining 10 samples consist of variable proportions of angular mineral and lithic debris and small euhedral plagioclase crystals partly to wholly enclosed in larger anhedral mafic mineral grains (oikocrysts) and interstitial "diabasic" material. This constitutes what is termed a poikilitic texture by those favoring an igneous origin of the texture (Simonds and others, 1973; Warner and others, 1973; Crawford, 1974), a poikiloblastic texture by those favoring a metamorphic origin (Wilshire and others, 1973; Bence and others, 1973; Albee and-others, 1973b; Hodges and Kushiro, 1973). Angular mineral debris, which occurs either as inclusions in, or interstitial to, mafic oikocrysts, is predominantly plagioclase and olivine, both commonly

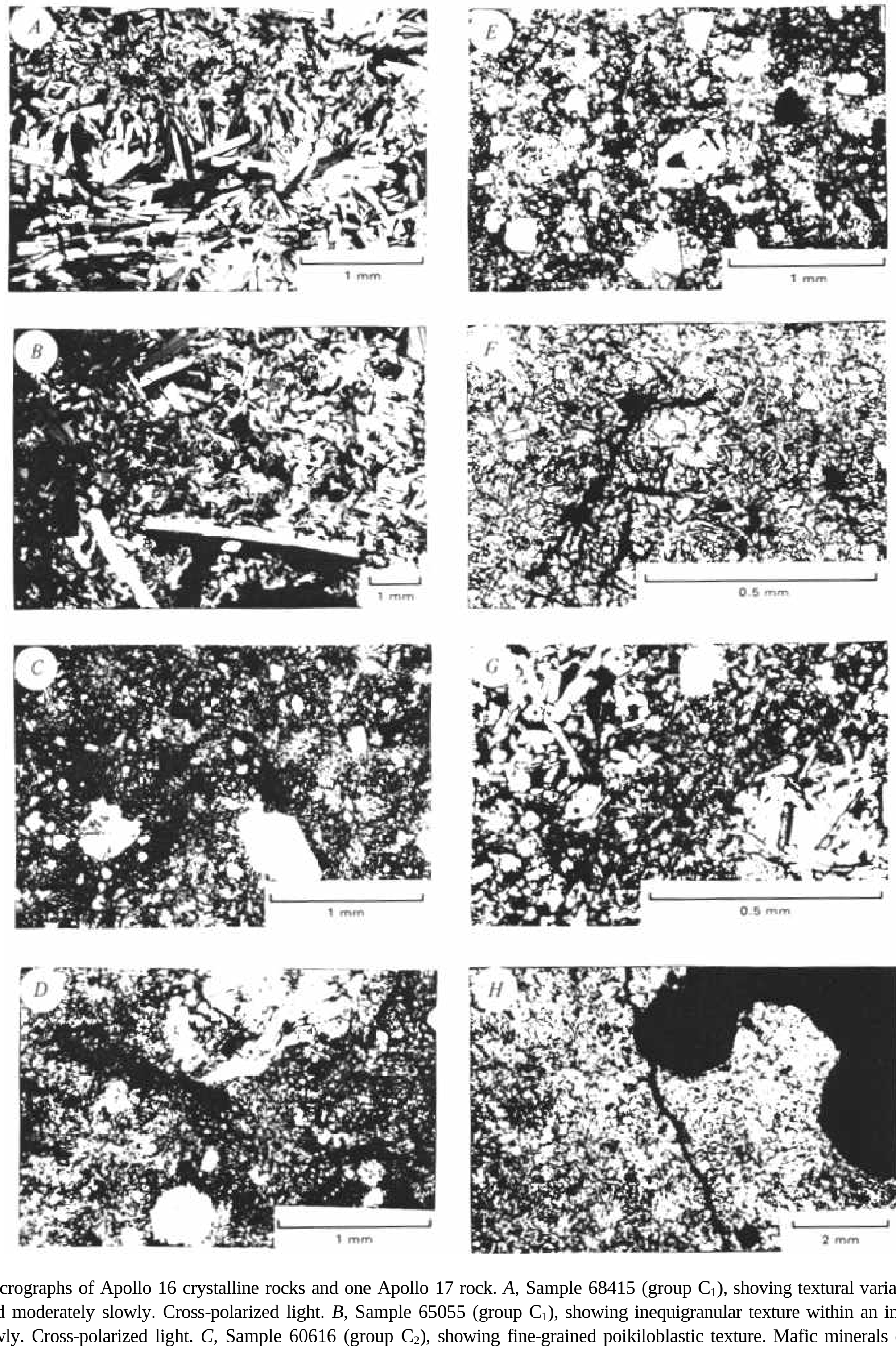

FIGURE 2.-Photomicrographs of Apollo 16 crystalline rocks and one Apollo 17 rock. *A*, Sample 68415 (group C_1), shoving textural variations within an impact melt that cooled moderately slowly. Cross-polarized light. *B*, Sample 65055 (group C_1), showing inequigranular texture within an impact melt that cooled moderately slowly. Cross-polarized light. *C*, Sample 60616 (group C_2), showing fine-grained poikiloblastic texture. Mafic minerals do not interlock; areas between them have granoblastic texture. Cross-polarized light. *D*, Sample 60625. (group C_2), medium-grained poikilobastic texture. Mafic minerals interlock; enclosed minerals dominantly very fine grained, anhedral. Cross-polarized light. *E*, Sample 65778 (group C_2), showing coarse-grained poikiloblastic texture. Mafic minerals interlock; note unusual amount of mineral debris (light color). Cross-polarized light. *F*, Sample 60315 (group C_2), showing interstitial igneous texture between large poikiloblastic orthopyroxene grains. Plane-polarized light. *G*, Sample 60315 (group C_2), showing spherical droplets with intersertal to intergranular igneous texture in coarse-grained poikiloblastic rocks. Plane-polarized light. *H*, Apollo 17 sample 76215. showing transition from poikiloblastic texture (left) in which orthopyroxene oikocrysts enclose abundant mineral debris to ophitic texture with polkilitic clinopyroxene and less mineral debris. Vesicles occur only in the ophitic area. Cross-polarized light.

zoned. Lithic debris is predominantly medium-grained hornfels derived from troctolitic or gabbroic rocks. Various proportions of euhedral plagioclases, occuring both as inclusions in mafic oikocrysts and interstitially between them, range from equant to lath shaped. and appear optically to be zoned. Oikocrysts are most commonly slightly zoned pigeonite or orthopyroxene, but in some rocks are olivine (Simonds and others, 1973).

The degree of development of the poikiloblastic texture varies from incipient, spotty, very fine grained oikocrysts (moderately common in matrices of B_4 and B_5 breccias and dark clasts in B_2 and B_3 breccias) to coarse grains easily visible in hand specimen (fig. 2*C*-*E*). In the much better examples of this lithologic type returned by Apollo 17 (for example, 76215), a systematic increase in grain size with proximity to cavities can be observed, but thin-section study of Apollo 16 and 17 samples reveals rapid lateral variations from the fine-grained poikiloblastic texture to granoblastic texture and from coarser poikiloblastic textures to those with unequivocal igneous textures (fig. *2H*). Interstitial material with igneous texture (fig. *2F*) has been noted by a number of authors (Delano and others, 1973; Bence and others, 1973; Walker and others, 1973; Hodges and Kushiro, 1973), and spherical blebs with igneous texture (fig. 2*G*) are widespread.

The origin of the poikiloblastic texture is still uncertain; some workers favoring crystallization from a melt, others recrystallization in the solid state. Most workers agree that interstitial material with intersertal to intergranular texture ("diabasic" material) indicates the presence of some melt, and the common occurrence of cavities indicates the presence of a vapor phase. There is little doubt that most of these rocks contained at least a small proportion of melt. Moreover, as one attempts to classify these rocks and the fine-grained breccias, the rather subtle and gradational character of the differences between poikiloblasitic texture and ophitic texture are often apparent (for example, the rock classified by Simonds and others (1973) as poikilitic in their figure 9, we would probably classify as ophitic and place in group C_1). We believe, however, that the distinctive textural differences in he coarser grained poikiloblastic rocks between those parts that most workers consider igneous (interstitial diabasic" material) and the main body of the rock suggest a metamorphic origin of the coarse pyroxene oikocrysts (see Bence and others, 1973). This appears be substantiated in rock 76215 (fig. 2*H*) by the gradation from a coarse-grained poikiloblastic texture in which orthopyroxenes enclose abundant undigested mineral debris to a well-developed ophitic texture with poikocrysts of clinopyroxene and much less mineral debris. It is highly unlikely that both parts of the rock crystallized from a liquid.

The suggestion by Simonds and others (1973) and Warner and others (1973) that gas cavities and flow structures are evidence of igneous origin is equivocal, as cataclastic flow structures in solids are well known and vesiculation of powdered material lacking a liquid phase seems at least possible. In many lunar rocks, gas cavities commonly are locally surrounded by unequivocal melt textures; a good example is the well known Apollo 15 rock 15418; another is Apollo 17 rock 76215 (fig. 2*H*), in which spherical cavities are concentrated in the ophitic part of the rock. Lowering of melting temperature by the presence of a gas phase may locally induce melting. The suggestion of Albee and others (1973b) and of Bence and others (1973) that the cavities were present in a glassy precursor of the poikiloblastic rocks seems implausible, especially in view of the shapes and distribution of cavities described by Simonds and others (1973) and concentration of cavities in more extensively melted parts of poikiloblastic rocks.

The nature of the precursor of poikiloblastic rocks remains a critical problem (see Duncan and others, 1973). The statement of Bence and others (1973) that there is little disagreement that the precursor to these rocks was either a polymict highlands breccia or a clast-laden glass is not supported by any facts known to us. While statistical information on relics may aid in solution of this problem, a subjective view of the dominant types of mineral and lithic debris suggests that partly metamorphosed troctolitic rocks were important contributors. Several Apollo 17 poikiloblastic rocks, however, contain scattered mineral debris (plagioclases spongy with inclusions; brown clinopyroxenes) derived from distinctive vug and vein fillings in the blue-gray breccias with which the poikiloblastic rocks are associated. Some mixing of lithologic types is evident.

BRECCIAS

GROUP B, (LIGHT MA TRIX, LIGHT CLASTS)

The 30 samples in group B_1 range from cataclastic plutonic feldspathic rocks to cataclastic hornfels to polymict breccias. Study in hand specimen indicates that many of the coarse-grained feldspathic components of B_1 breccias were partly metamorphosed to medium-grained hornfels before cataclasis; the hornfelsed parts appear to survive crushing better than the coarse igneous rocks from which they were derived and may be represented disproportionately in thin section. Of the 10 rocks thin sectioned so far (1974), all are cataclastic plutonic feldspathic rocks except 67075, which may be a polymict breccia, and 67955, a cataclastic coarsely hornfelsed olivine gabbro. In the eight anorthositic rocks, the matrix is unannealed or weakly annealed crushed anorthosite and the clasts are relics that survived the crushing. Sample 67075 contains medium-grained hornfels fragments that apparently were derived from different kinds of anorthositic rocks, as their mineral assemblages are highly varied; mineral debris shows major variations in constituent proportions from thin section to thin section. This rock, as well as some others not yet thin sectioned, may therefore represent mixed lithologies rather than a single rock that has been crushed.

The cataclastic plutonic rocks range from norite through noritic anorthosite to anorthosite. Some noritic anorthosites are olivine bearing (for example, 60025), and some anorthosites contain both olivine and spinel (for example, 60618, Dowty and others, 1974a, b). Most of the cataclasites have not undergone severe cataclastic mixing (fig. 3*A*, *B*); the original coarse to very coarse grain size is evident from the size of relict mineral debris (table 3). Because of this, individual thin sections may be misleading with respect to the modal composition of the original rock and the textural relations between plagioclase and mafic minerals. In a few of these rocks and similar ones occurring as clasts in other breccia types, textural relations suggest that mafic minerals in the most feldspar-rich rocks are interstitial postcumulus phases (fig.- 3*C*) but form cumulus phases with or without cumulus plagioclase in the more mafic rocks (fig. 3*D*).

GROUP B_2 (LIGHT MATRIX, DARK CLASTS)

The B_2 breccias are extremely variable, ranging from breccias that have been little modified since the first impact event (for example 64435, 61015) to multicycle breccias, some of which are ploymict (for example, 60016, 67075) (Wilshire and others, 1973). In the 19 thin sections examined, even the simplest, least modified breccias show mild rebrecciation of a firstcycle breccia that consisted of highly feldspathic clasts in a fine-grained dark matrix (some relics of which are visible in the lower left part of the rock in fig. 3*E).* Rebrecciation resulted in a large-scale fracturing and dilation of the brittle, fine-grained original matrix and injection of the friable feldspathic clast material into the fractures. The injected plagioclase debris remained unannealed (fig. 3*F*). The texture of the dark finegrained clasts generally remains unchanged in this brecciation. In these clasts, very fine grained intersertal textures predominate but grade to fine-grained poikiloblastic and granoblastic textures on the one hand and to fine-grained ophitic textures on the other (table 2). Somewhat more severe second-generation brecciation resulted in local fusion of the original dark matrix along fractures (fig. 3*G*) (Wilshire and Moore, 1974). Small droplets of melt, many with unmelted cores, spalled from the glass selvages during emplacement of the unmelted feldspathic debris (fig. 3*H*). Severe brecciation accompanied by local fusion adds to the complexity of a second-cycle breccias but involves the same number of impacts. Later impacts tend to break down the friable feldspathic material to smallsize particles and concentrate the tough dark clasts in the coarser size fractions. It is clear from the extraordinary variety of lithologic types (fig. 4*A*) in some of these breccias (for example, 67455, 60115) that mixing of fragments of diverse origin has occurred as well as disaggregation of originally simple breccias.

GROUP B_3 (INTERMEDIATE MATRIX COLOR, LIGHT AND DARK CLASTS)

Of the 83 samples in group B_3 only 7 have .been examined in thin section. These are polymict breccias with a wide range of mostly fine grained lithic clasts, glass, and mineral debris in a friable, glassy to very weakly annealed matrix (fig. 4*B*). The thin-sectioned rocks are loosely aggregated regolith material that clearly corresponds to the "soil breccias" returned from other missions. Although their origin has not been determined,. they appear to differ little from some polymict breccias of group B_2 except for the presence of glass.

GROUP B_4 (DARK MATRIX, LIGHT CLASTS)

A wide variety of lithologic types is represented in the 14 rocks of group B_4 studied in thin section. The clasts vary from metaclastic fragments with poikiloblastic textures to annealed cataclastic feldspar-rich fragments to rare fine-grained feldspathic igneous fragments (fig. 4*C*). The matrices are tough and fine grained with igneous or granoblastic textures. Some of the B_4 breccias (table 3) are little-modified fragments of first-cycle breccias, but the polymict character of many shows repeated impact events, each severe enough to anneal the pulverized rock.

GROUP B_5 (DARK MATRIX, DARK CLASTS)

The four samples in group B_5 that have been thin sectioned are lithologically very complex, consisting of a variety of dark fine-grained metaclastic rock fragments and mineral debris in a tough, annealed clastic matrix. There is some evidence of derivation by multiple impact of simpler types of breccia. In thin section (fig. 4*D*), characteristics of B_2 breccias can be discerned; net veins of broken feldspathic debris in dark finegrained igneous-textured rock have survived multiple impacts.

INTERPRE TATION OF THE BRECCIAS

Wilshire and others (1973) attempted to reconstruct the sequence of brecciation leading to diversification of the breccias. Even though no unbrecciated outcrops were found at the Apollo 16 site, the sequence can be established by comparison with products of single im-

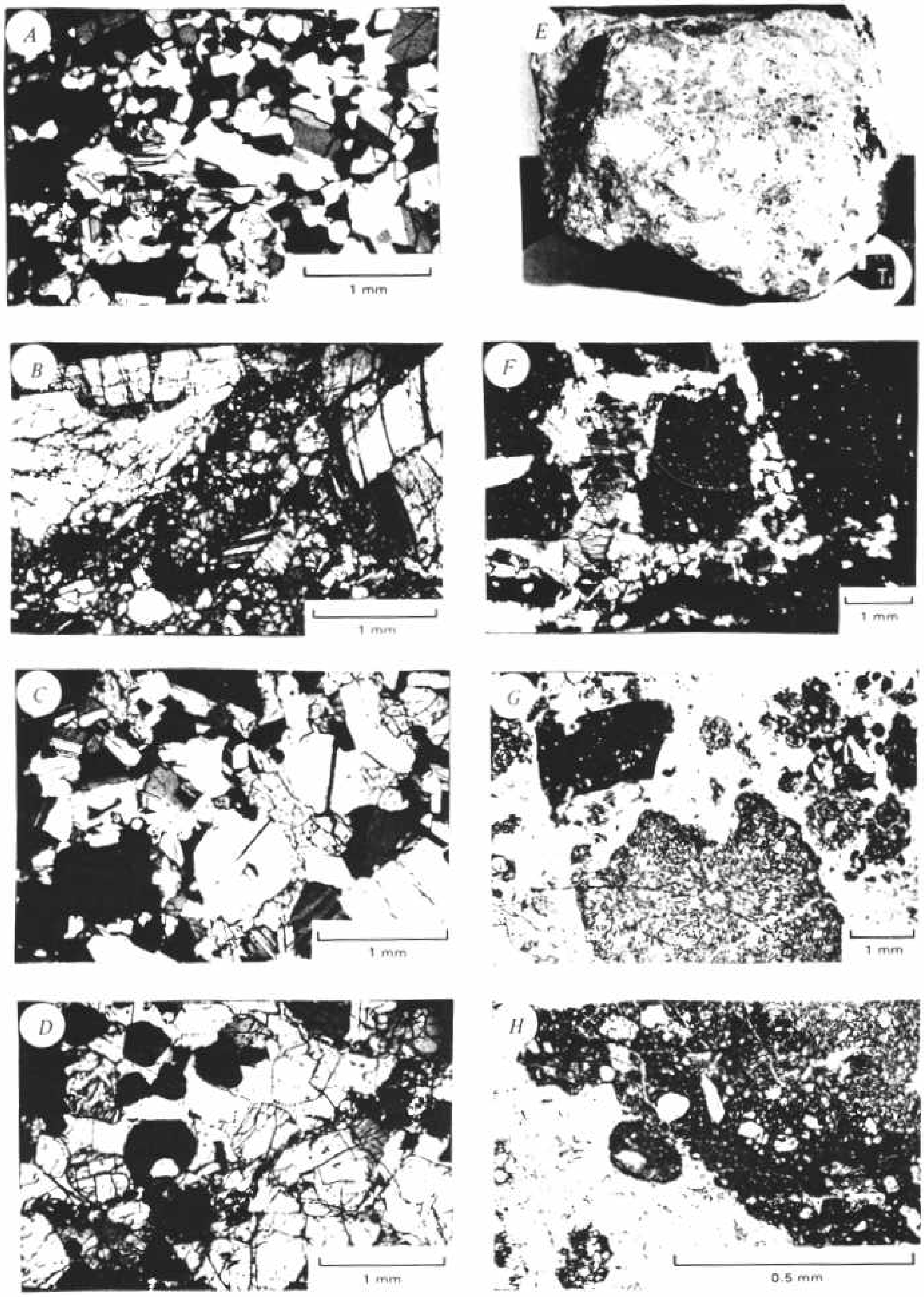

FIGURE 3 -- Photomicrograph of Apollo 16 metaclastic rock and breccias and photograph of breccia 61015 . *A*. Sample 60619 group C_2). showing coarse hornfels texture in metaanorthosite. Cross-polarized light. *B*, Sample 62237 (B_1 breccia), showing coarse mineral relics and cataclastic flow structure in troctolite. Cross-polarized light. *C*, Sample 65785 (group C_2), a lithic relic in cataclasite, having postcumulus olivine (high relief) separating cumulus plagioclase grains twinned. Cross-polarized light. *D*. Sample 67435 (B_4 breccia). showing lithic clast in breccia with postcumulus plagioclase (low relief, white) separating cumulus olivine (high relief) and spinel (in extinction) grains. Cross-polarized light. *E*, Sample 61015 (NASA photograph S-72-40585B), showing net-veining of original dark matrix by clastic material derived from the white clasts *F*. Sample 61015 (B_2 breccia), showing weakly annealed, coarse mineral debris in fractures in original matrix (dark). Cross-polarized light. *G*. Sample 66055 (B_2 breccia), showing glass selvage (dark gray) on lighter gray fragment of original matrix. Note surrounding fragments of spalled selvage in feldspathic debris derived from original clasts. Plane polarized light *H*. Sample 66055 (B_2 breccia), showing incompletely spalled ellipsoid of glass selvage. Plane-polarized light.

TABLE 3.-*Degree of modification of selected Apollo 16 rocks*

Sample	Classification	Glass[1]			Lithic relics[2]	Mineral relics[2] (maximum size in mm; pc, plagioclase; px, pyroxene ol, olivine	Major events Preserved[3]			Notes (Numbers give references to additional petrologic, chemical, and age data. Standard catalog and classification references not given)
		Veneer	Selvage	Venns			Initial crystallization of target rock	Preexcavation metamorphism	Excavation	
60015	B_1	x		x	Medium-grained hornfels.	pc 12 possibly 15				Major modification by multiple impact[6]. (1,2,3,4,5,6)
60016	$B_2(B_3)$[5]				Medium-grained hornfels.	pc 1				Major modification by multiple impact and mixing[7].(7,8)
60017	$B_4(B_5)$		x							Major modification by multiple impact. (2,9,10)
60018	B_4	x	x	x	Medium-grained hornfels. Cataclastic anorthosite, troctolite	pc 7 x 10				Major modification by multple impact. Some clasts probably represent first-cycle breccia matrix.
60019	B_5	x		?						Major modification by multiple impact.
60025	B_1	x			Noritic anorthosite	pc 15	x			Cataclastic noritic anorthosite. No first-cycle matrix present (2,4,10,11,12,13)
60215	B_1	x				pc 6	x			Mafic minerals severly modified. Cataclastic noritic anorthosite. No first-cycle matrix present.
60235	C_2					pc 10	?		?	Insufficient data[8].
60255	B_4		x			pc 4				Major modification by multiple impact. (14)
60275	B_4	x		x						Major modification by multiple impact.
60315	C_2					pc 4	?		?	Poikiloblastic texture[8] (10,11,13,15,16,17)
60335	C_2					pc 5,px, ol 3	?		?	Ophitic-poikiloblastic texture. (10,13,18)
60516	B_1					pc 4, possibly 5	x			Cataclastic anorthosite. No first-cycle matrix present. (19)
60526	C_2					pc 0.1	?		?	Poikiloblastic texture. Very scarce mineral debris.
60615	C_1					pc 0.75	?		?	Medium-grained ophitic texture. (2,20)
60616	C_2				Medium-grained hornfels.	pc 0.7, ol 0.1	?		?	Poikiloblastic texture.
60618	B_1					pc greater than 5	x?		x	Cataclastic spinel, olivine-bearing anorthosite. First-cycle matrix subspherulitic. (19,20)
60619	C_2							x		Medium-grained hornfels. No first-cycle matrix present. (19)
60625	C_2			x					?	Poikiloblastic texture.
60629	B_1	x				pc 3.5	x			Cataclastic anorthosite. No first-cycle matrix present. (19)
60635	C_1					pc 2.5	?		?	Medium-grained ophitic texture. (20)
60645	B_4		?			pc 1.1, px 0.3	?		?	Cataclastic anorthosite. First-cycle matrix weakly poikiloblastic
60658	B_4	x				pc 1.0				Insufficient data.
60659	$B_2(B_4)$					pc 0.75				Major modfication by multiple impact. (19)
60667	B_4				Medium-grained hornfels.	pc 0.6			?	First-cycle matrix? Intersertal texture.
60676	B_4					pc 1.6				
61015	B_2	x				pc 3			?	
61016	B_4	x		x		pc 15				Major modfication by multiple impact. (1,2,10,12,24,25,26,27,28)
62235	C_2					pc 2	?		?	Poikiloblastic-ophitic texture. (25,29)
62236	B_1					pc 4	x			Cataclastic anorthosite. No first-cycle matrix present.
62237	B_1			?	Norite	pc 3	x			Cataclastic olivine-bearing norite or noritic anorthosite. No first-cycle matrix present.
62246	B_1		x							Insufficient data
62255	B_2		x	x	Gabbro(?)	pc 1, px 5	x			Cataclastic clinopyroxene-bearing anorthosite. (8)
62295	C_1					pc 2				Subspherulitic quench texture. (10,11,13,18,30,31,32,33)
63335	(B_5)					pc 1				Major modfication by multiple impact. (9,34)
63505	B_4					pc 1			?	First-cycle (?) matrix? poikiloblastic texture.
63506	(C_2)								?	First-cycle (?) matrix? Poikiloblastic to intergranular texture.
64435	B_2	x		x		pc 1.5	x		x	Cataclastic two-pyroxene, olivine-bearing anorthosite First-cycle matrix present weakly poikilitic. (3.8.34)
64455	C_2	x		x	Medium-grained Hornfels(?)	pc 1				Insufficient data

TABLE 3. *Degree of modification of selected Apollo* 16 *rocks* -Continued.

Sample	Classification	Glass[1]			Lithic relics[2]	Mineral relics[2] (maximum size in mm; pc, plagioclase; px, pyroxene ol, olivine	Major events Preserved[3]			Notes
		Veneer	Selvage	Venns			Initial crystallization of target rock	Preexcavation metamorphism	Excavation	(Numbers give references to additional petrologic, chemical, and age data. Standard catalog and classification references not given)
64476	B_2	x				pc 1.5	x	x	x	Partly metamorphosed (medium-grained hornfels) cataclastic two-pyroxene anorthosite in intersertal to weakly poikilitic matrix.
64477	$B_2(B_4)$						?		x	Cataclastic gabbro; first-cycle matrix very fine-grained intersertal to subspherulitic.
64478	$B_4(B_3)$		?						?	Poikiloblastic texture, grading to feldspathic material with recrystallized mafic minerals.
64535	B_2	x					?	?	?	Insufficient data.
65015	C_2					pc 2			?	Medium-grained poikiloblastic textures. (17,27,36,37)
65035	B_2	x			Medium-grained hornfels.		x		x	Cataclastic noritic anorthosite clasts in intersertal matrix.
65055	C_1									Medium-grained ophitic textures.
65075	$B_2(B_4)$	x		x	Anorthosite (?); gabbroid; medium-grained hornfels.	pc 10	x	x	x	Partly metamorphosed gabbroic anorthosite; first cycle matrix ophitic. (35)
65095	$B_2(B_1)$		?			pc 6.5	?		?	Cataclastic olivine-bearing noritic anorthosite and other clasts in intersertal matrix grading to ophitic.
65315	B_2	x				pc 6	x		?	Cataclastic anorthosite; first-cycle matrix component not in thin section. (38)
65326	B_2					pc 2+	x		?	Cataclastic anorthosite; first-cycle matrix forms very small proportion of sample. (19)
65357	C_2					pc 0.45, ol 0.15				Medium-grained poikiloblastic texture.
65359	B_2	x					x		x	Cataclastic troctolite, anorthosite; first-cycle matrix intersertal grading to ophitic.
65365	C_2					pc 0.75			?	Medium-grained poikiloblastic ophitic texture.
65719	(B_2)					pc 1	?		?	Feldspathic mineral debris; first-cycle matrix intersertal-ophitic
65757	B_2	x				pc 1.3	x		?	Cataclastic anorthosite. No first-cycle matrix. (19)
65778	C_2					pc 0.45, ol 0.3			?	Medium-grained poikiloblastic texture.
65785	C_2					ol 5+, pc 2.5, spinel 1.5	x		x	Spinel troctolite. No first-cycle matrix in thin section. (20)
65789	B_1	x				pc 0.5	x			Cataclastic anorthosite. No first-cycle matrix present.
65795	C_1					pc 1.25			?	Medium-grained ophitic texture. (20)
66055	B_2					pc 3; mafics 3	x	x	x	Cataclastic anorthosite and coarsely hornsfelsed troctolite; first -cycle matrix intersertal to weakly poikilitic. (39)
66095	B_4			x		pc 3.5, poss. 5			?	First-cycle matrix ophitic. Very few clasts in rocks. (12,24,25,27,37,40)
67015	$B_3(B_2)$					pc 6, px 1				Major modfication by multiple impact. (1)
67016	$B_3(B_2)$					pc 4				Major modfication by multiple impact. (8,27)
67025	$B_2(B_3)$	x		x						Major modfication by multiple impact.
67035	B_2					pc 1				Major modfication by multiple impact. (2)
67055	$B_2(B_3)$				Medium-grained hornfels.	pc 3				Major modfication by multiple impact.
67075	B_1			?	Medium-grained hornfels.	pc 6, px 2		?		Possible major modfication by multiple impact and mixing. (14,18,28,37,41)
67415	B_1				Medium-grained hornfels.	pc 2		?		Possible major modfication by multiple impact and mixing.
67435	B_4	x			Spinel troctolite.	pc 1, ol 2	?		?	Possible major modfication by multiple impact and mixing. (42)
67455	B_2			x						Possible major modfication by multiple impact and mixing. (10,37)
67605	B_2					pc 3				Insufficient data
67915	B_4			x		Mafic 2, pc 2				Major modfication by multiple impact (12,27,33,43)
67936	(C_2)			x		pc 1			?	First-cycle (?) matrix with granoblastic texture grading to intersertal and ophitic. No clasts.
67937	B_4									Moderate modification of first- cycle (?) matrix with intersertal to ophitic texture. Clasts of metaclastic rock.

Sample	Classification	Glass[1] Veneer	Glass[1] Selvage	Glass[1] Venns	Lithic relics[2]	Mineral relics[2] (maximum size in mm; pc, plagioclase; px, pyroxene ol, olivine	Major events Preserved[3] Initial crystalliza-tion of target rock	Major events Preserved[3] Preexcavation meta-morphism	Major events Preserved[3] Excavation	Notes (Numbers give references to additional petrologic, chemical, an age data. Standard catalog and classification references not given)
67945	B_4	x				pc 5			?	First-cycle matrix, poikiloblastic texture.
67946	(B_4)		?							Major modification by multiple impact.
67947	(B_4)		?			pc 2				Do.
67955	B_1			x	Medium-grained hornfels.			?		Cataclastic olivine gabbro hornfels No first-cycle matrix present. (44)
67975	B_2					pc 4				Major modification by multiple impact.
68035	B_2	x				pc 3				Insufficient data.
68115	B_5					pc 2				Major modification by multiple impact. (8,21)
68415	C_1					pc 3				Medium-grained ophitic texture. Few clasts. (10,15,18,22,23,24)
68416	C_1					pc 8				Medium-grained ophitic texture. Clasts moderately abundant. (10,11,18,22)
68515	B_2	x	x	x						Insufficient data.
69955	C_1					pc 7	?			Cataclastic anorthosite clasts in intersertal matrix.

[1]Glass occurs in three modes (Wilshire and Moore, 1974) other than as clasts: (1) veneer-sharply bounded exterior coatings; (2) selvages-coatings with gradational boundaries with the coated rock, (3) veins commonly occurring in complex, anastomosing patterns Theglass is thought to have formed during comparatively small impact events following initial excavation.

[2]Llithic and mineral relics are considered to be impact target materials that escaped major damage resulting from impact; the matrices of breccias containing these relics were derived by comminution, melting, and thermal meta-morphism of the same types of rock represented by the relics.

[3]This column represents a qualitative attempt to give petrologic guidance in interpreting major events in Apollo 16 rocks. Most Apollo 16 rocks have been multiply brecciated so that their ages are not specifically meaningful. However, some have undergone little reworking since their initial excavation (see Wilshire and others, 1973); the clasts (relics) in these breccias represent original target material, which consists of plutonic igneous and metamorphic rocks (Wilshire, 1974), and thoroughly metamorphosed or melted material forming their matrix. From such rocks it may be possibe to date the three types of events listed in this column, as well as specify the petrologic consequences of those events.

[4]Medium-grained hornfels (Wilshire, 1974) may represent preexcavation metamorphism in a plutonic environment. These parts of plutonic rocks survive crushing more consistently than the coarse-grained igneous rocks from which they are derived.

[5]Parentheses following letter and class number indicate alternative classification. Parentheses unaccompanied enclose tentative classification.

[6]Textures formed at time of initial excavation of the rock have undergone major modification by subsequent impact(s); age not meaningful with respect to primary excavating event or crystallization age of source rock.

[7]Multiple impacts have resulted in mixing diverse lithologies that may or may not have been significantly modified by postexcavation impacts. Difficult or impossible to determine the significance of ages with respect to primary excavating event or cryatallization age of source rock(s).

[8]Metaclastic rocks have relict lithic and mineral debris in thoroughly recrystallized (granoblastic to poikiloblastic textures) to partly or wholly (intersertal, intergranular, subspherulitic, ophitic textures) melted matrices. Isotopic data (table 4) indicate that relict material may yield minimum ages of target material, whereas whole-rock data yield age of metamorphism. The significance of these data with respect to initial excavating event or crystallization age of the source rock(s) is not known.

References:
(1) Juan and others, 1974
(2) Lual and Schmitt, 1973
(3) Nunes and others, 1974
(4) Schaeffer and Husain, 1974
(5) Sclar and others, 1973
(6) Sclar and Bauer, 1974
(7) Johan and Christophe, 1974
(8) S. R. Taylor and others, 1974
(9) Kridelbaugh and others, 1973
(10) Rose and others, 1973
(11) Hodges and Kushiro, 1973
(12) Nakamura and others, 1973
(13) Walker and others, 173
(14) Scoon, 1974
(15) Bence and others, 1973
(16) Delano and others, 1973
(17) Simonds and others, 1973
(18) Brown and others, 1973
(19) Dowty and others, 1974b
(20) Dowty and others, 1974a
(21) Grieve and others, 1974
(22) Gancarz and others, 1972
(23) Helz and Appleman, 1973
(24) Nava, 1974
(25) Brunfelt and others, 1973a
(26) Drake, 1974
(27) Duncan and others, 1973
(28) Steele and Smith, 1973
(29) Crawford, 1974
(30) Agrell and others, 1973
(31) Mark and others, 1974
(32) Roedder and Weiblen, 1974b
(33) Weiblen and Roedder, 1973
(34) Laul and others, 1974
(35) Grieve and Plant, 1973
(36) Albee and others, 1973a, b
(37) El Gorsey and others, 1973
(38) Stettler and others, 1974
(39) Fruchter and others, 1974
(40) Friedman and others, 1974
(41) Peckett and Brown, 1973
(42) Prinz and others, 1973a
(43) Roedder and Weiblen, 1974a
(44) Hollister, 1973

pacts on terrestrial crystalline targets-the Vredefort Ring, South Africa (fig. 4*E*) and Sudbury Crater, Canada-impacts that produced a breccia consisting of relics of the target material encased in a dark finegrained annealed (fig 4*F*) to partly melted (fig. 4*G*) matrix of the same composition. Several Apollo 16 samples approach this simplicity (table 3, footnote 2 and notes on 60018, 60616, 67936), but none has survived untouched. At least slight rebrecciation has affected all, resulting in fracturing of the original matrix and injection of broken feldspathic debris derived from original clasts (forming B_2-type breccias from a B_4-type parent). Continued brecciation gradually destroyed the remnants of the original target material, although pieces of the tough first-cycle matrix apparently survived Beyond a certain stage, however, it is not possible to determine whether the different parts of a breccia were originally related or were derived from different sources.

The source rocks from which the Apollo 16 breccias were derived are represented at least in part by the clasts in the simplest, least-reworked breccias. These clasts are consistently of two lithologic types: (1) cataclastic plutonic feldspathic rocks of a troctolite-noriteanorthosite suite; relics show coarse to very coarse grain sizes and pyroxenes with coarse exsolution lamellae (fig. 4*H*); (2) cataclastic feldspathic hornfelses with medium-grained granoblastic textures, commonly modifications of the plutonic rocks (Wilshire and others, 1972). The hornfelses are far coarser grained

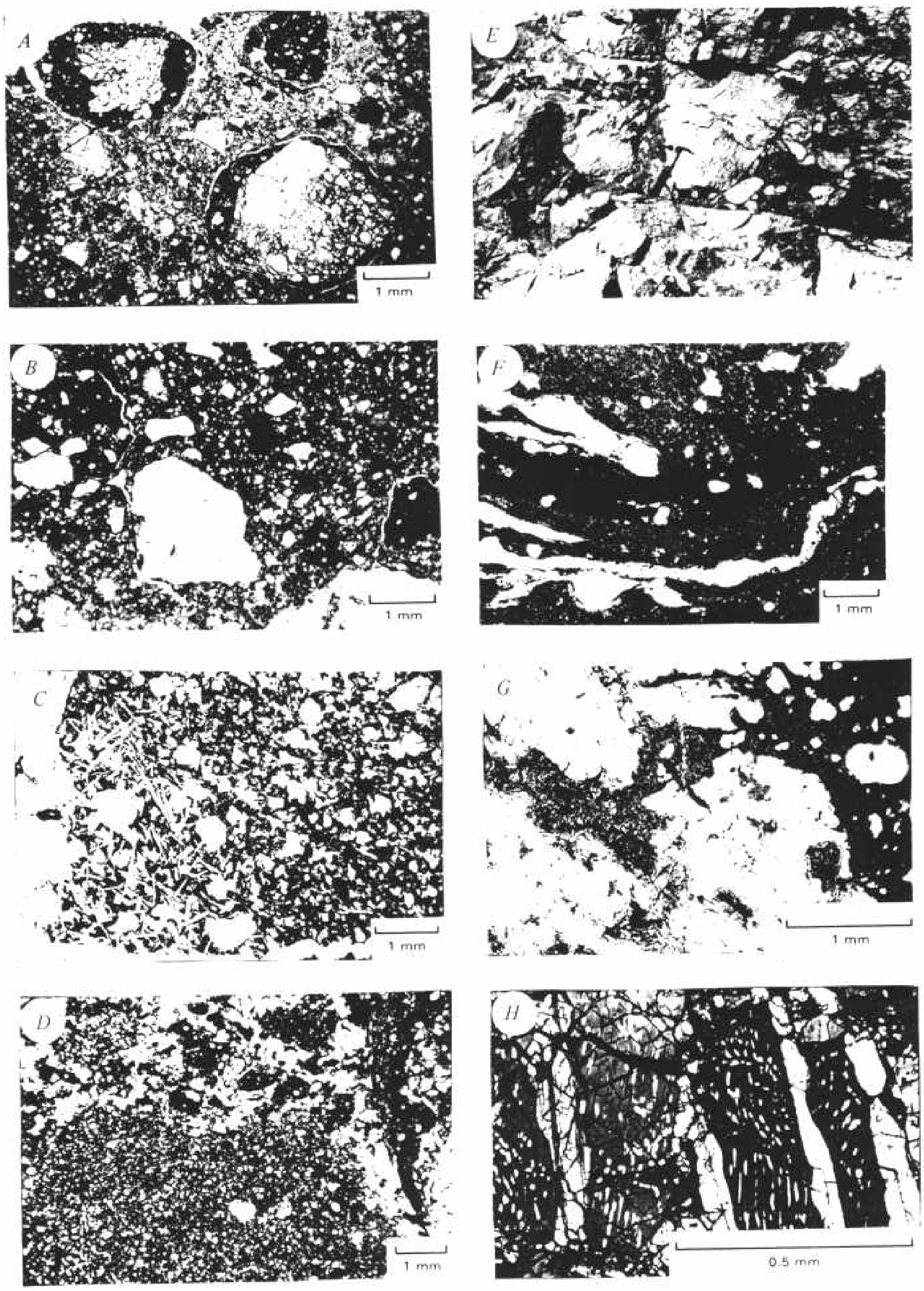

FIGURE 4.-Photomicrographs of Apollo 16 breccia photograph and photo micrographs of pseudotachvlites of Vredefort structure. South Africa, *E-G*. .*A*, Sample 67035 (B_2 breccia), showing clasts with selvages embedded in a friable light-gray matrix containing a variety of lithic and mineral microclasts Phone-polarized light *B*. Sample 61295 (B_3 breccia), showing a variety of clasts, including glass, in a fine-grained glassy matrix. Plane-polarized light. *C*. Sample 60018 B_4 breccia). showing a cataclastic anorthositic clast at one edge grading into an impact melt zone with ophitic texture. and this into intersertal texture. Plane-polarized light *D*, Sample 68815 (B_5 breccia). showing a small area in a rock dominated by dark clasts in dark matrix This area shows a remnant of B_2 breccia with feldspathic debris in fractures in the fine-grained dark original matrix Plane-polarized light. *E*, Pseudotachylite, Vredefort structure. South Africa, showing breccia composed of clasts of crystalline rock in finely comminuted and locally fused material of the same chemical composition as the clasts. Photograph by Warren Hamilton. *F*, Pseudotachylite in alkali granite. Vredefort structure. South Africa, showing cataclastic flow structures in comminuted alkali granite, metamorphosed to very fine grained granoblastic texture. Crosspolarized light *G*. Pseudotachylite in OId Granite. Vredefort structure. South Africa; local fused zone showing newly crystallized feldspar laths and flow structure. Cross-polarized light. *H*, Sample 62236 (B_4 breccia), showing coarse irregular and finer regular clinopyroxene exsolution lamellae (white) in orthopyroxene (dark). Cross-polarized light.

than those forming the matrices of intensely deformed impact breccias. The hornfelsic breccia clasts have the same textures and compositions as B_1 group breccias and therefore could have a common origin.

The most common type of crystalline igneous rock, ophitic feldspathic rock, is not present as clasts in the simplest, least-reworked breccias, nor is the coarsely poikiloblastic lithology. Both of these rock types appear in the Apollo 16 samples only as clasts in complex breccias. The balance of evidence indicates that these rocks result from solidification of impact melts.

It seems apparent, then, that the target material for the first major impact event shown in Apollo 16 rocks was a plutonic suite composed of troctolite, norite, and anorthosite that had undergone partial thermal metamorphism prior to impact. These rocks constitute the "ANT" suite of Prinz and others (1973b), whose existence they inferred largely from the chemical compositions of fine-grained, impact-generated

CHRONOLOGY OF APOLLO 16 ROCKS

Relics of the coarse-grained target materials and of the finely pulverized, partly to wholly melted rock produced in the first major excavation are sufficient to allow us to specify the nature of the products and perhaps to date three significant events: crystallization and differentiation; metamorphism that produced the coarse hornfels; and primary excavation and brecciation. Table 3 presents a qualitative guide to the samples that might yield this information.

Isotope data gathered on Apollo 16 rocks have not generally been systematically directed by the petrology of the collection as a whole. A number of ages (table 4) have been determined on complex rocks with no indication of what part or parts of the rock were measured. Other ages date unknown events that took place after initial excavation and deposition of the Apollo 16 breccias. The problem of terminology (see Wilshire and Jackson, 1972b; Jackson and others, 1975) adds considerably to confusion about the meaning of the ages.

TABLE 4.-*Isotope. data on Apollo 16 samples*

Sample	Rock Type	Part of rock dated	Age (109) (b.y.)	Method and source	Notes
60015	B_1	Whole rock	3.55+/-0.55	Ar^{40}-Ar^{39} (1)	Age probably time of shock deformation.
60015		-------do -------	3.6-3.8	U-Pb (2)	
60025	B_1	-------do -------	4.18+/-0.06	Ar^{40}-Ar^{39} (1)	Age of excavation or minimum age of crystallization.
60315	C_2	-------do -------	3.94+/-0.05	Ar^{40}-Ar^{39} (3)	Maximum age of metamorphism?
60315		-------do -------	4.03+/-0.03	Ar^{40}-Ar^{39} (4)	
60315		-------do -------	About 3.99	U-Pb (2)	Age of metamorphism?
61016	B_4	?	(3.65+/-0.04)	Ar^{40}-Ar^{39} (5)	Poorly defined plateau. Rock very in-homogeneous
62242,3	Anorthosite	Whole rock	4.5+/-0.3	Ar^{40}-Ar^{39} (4)	Total Ar age. May ave excess Ar.

TABLE 4.-*Isotope data on Apollo 16 samples*-Continued

Sample	Rock Type	Part of rock dated	Age (b.y.)	Method and source	Notes
62295	C_1	-------do -------	4.00+/-0.06	Rb-Sr (6)	Age of crystalliza-tion of melt rock.
62295		-------do -------	3.89+/-0.05	Ar^{40}-Ar^{39} (7)	
63502,17a	B_1?	?	3.89+/-0.01	Ar^{40}-Ar^{39} (4)	"Monomict anor-thositic breccia."
63502,17b	?	Whole rock?	(3.8+/-0.3)	Ar^{40}-Ar^{39} (4)	"Aphanitic dark fragment." No well defined plateau.
63502,17c2	Anorthosite	Whole rock	(4.1+/-0.1)	Ar^{40}-Ar^{39} (4)	"Unshocked anor-thositic particle."
63502,17d	Plagioclase	----------------	(3.9+/-0.3)	Ar^{40}-Ar^{39} (4)	"Clear plagioclase crystals." No well-defined plateau
63503,13,2	Anorthosite	Whole rock?	3.98+/-0.07	Ar^{40}-Ar^{39} (8)	
63503,13,7	G	Whole rock	4.00+/-0.06	Ar^{40}-Ar^{39} (8)	
63503,15,3	C_1	-------do -------	3.95+/-0.06	Ar^{40}-Ar^{39} (8)	Possible excavation age
63503,17	?	?	4.19+/-0.06	Ar^{40}-Ar^{39} (9)	No description.
63503,17	?	?	3.98+/-0.04	Ar^{40}-Ar^{39} (9)	Do.
63503,17	?	?	3.99+/-0.03	Ar^{40}-Ar^{39} (9)	Do.
63503,17	?	?	3.99+/-0.02	Ar^{40}-Ar^{39} (9)	Do.
65015	C_2	Whole rock? Plagioiclase	3.98+/-3.93 About 4.5; 4.42	Ar^{40}-Ar^{39} and Rb-Sr (10,11)	Whole rock age of metamorphism; plagioclase, minimum age of precusor.
65015		Whole rock	4.0	U-Pb (2)	
65015		-------do -------	3.92+/-0.04	Ar^{40}-Ar^{39} (4)	
65315	B_2	?	4.30+/-0.26 3-4	Ar^{40}-Ar^{39} (9)	Interpreted as two-stage evolution, old age = time of crystallization of time of excavation
66043,1,9	G	Whole rock	>1.6	Ar^{40}-Ar^{39} (8)	
66043,2,4	C_1	-------do -------	4.13+/-0.05	Ar^{40}-Ar^{39} (8)	Possible excavation age.
66403,2,5	C_1	-------do -------	4.01+/-0.05	Ar^{40}-Ar^{39} (8)	Do.
66095	B_4	Whole rock?	About 3.6	Ar^{40}-Ar^{39} (7)	Complex release pattern.
66095		Whole rock	About 4.0	U-Pb (1+E32)	
67015	$B_3(B_2)$	Black clast Matrix	~4.42 3.99	U-Pb (2)	Clast = original matrix?Model age.
67075	B_1	?	4.04+/-0.05	Ar^{40}-Ar^{39} (7)	
67455,8a	B_2	Dark clast	(4.15+/-0.1)	Ar^{40}-Ar^{39} (4)	No well definned plateau.
67455,8b	B_2	Light clast	3.91+/-0.12	Ar^{40}-Ar^{39} (4)	
67483,13,6	B_1,B_2?	?	$\geq$4.2	Ar^{40}-Ar^{39} (8)	Matrix partly melted.
67483,13,8	B_1,B_2?	?	4.26+/-0.05	Ar^{40}-Ar^{39} (8)	
67483,14,2	B_1,B_2?	?	4.24+/-0.05	Ar^{40}-Ar^{39} (8)	Do.
67483,14,6	B_1,B_2?	?	4.05+/-0.05	Ar^{40}-Ar^{39} (8)	Do.
67483,14,7	B_1,B_2?	?	4.1+/-0.1	Ar^{40}-Ar^{39} (8)	
67483,15,2	?	?	3.93+/-0.04	Ar^{40}-Ar^{39} (13)	
67483,14,18	Anorthosite	Whole rock	4.04+/-0.07	Ar^{40}-Ar^{39} (8)	
67915,41b	B_4	Light clast?	(4.3+/-0.1)	Ar^{40}-Ar^{39} (4)	No well defined plateau.
67915,41c		First matrix	3.91+/-0.05	Ar^{40}-Ar^{39} (4)	May be original matrix component
67915,41d			3.99+/-0.05	Ar^{40}-Ar^{39} (4)	"Friable Matrix"
68415	C_1	Whole rock	3.84+/-0.01	Rb-Sr (17)	Internal isochron.
68415		-------do ------- Plagioclase	3.82+/-0.04 4.09;4.51	Ar^{40}-Ar^{39} (14,15)	Whole rock = age of crystallization of melt; plagioclase = age of precusor.
68415		Whole rock	3.80+/-0.04	Ar^{40}-Ar^{39} (5)	
68415		-------do -------	4.47	U-Pb (2, 16)	
68415		-------do -------	3.85+/-0.06	Ar^{40}-Ar^{39} (4)	
68415		-------do -------	3.94	U-Pb (16)	Whole rock-plagioclase internal isochron.
68416		-------do -------	4.00+/-0.05	Ar^{40}-Ar^{39} (4)	
68593,13,5	B_1,B_2?	?	4.04+/-0.05	Ar^{40}-Ar^{39} (8)	
68503,13,6	G	Whole rock	3.98+/-0.06	Ar^{40}-Ar^{39} (8)	
68503,13,7	Anorthosite	Whole rock?	4.06+/-0.05	Ar^{40}-Ar^{39} (8)	
68503,16,1	G	Whole rock	4.00+/-0.04	Ar^{40}-Ar^{39} (8)	
68503,16,12	Troctolite	Whole rock?	3.79+/-0.05	Ar^{40}-Ar^{39} (8)	
68503,16,31	C_1	-------do -------	3.86+/-0.07	Ar^{40}-Ar^{39} (8)	Possible excavation age.
68503,16,33	C_1		3.95+/-0.06	Ar^{40}-Ar^{39} (8)	Do.
68503,16,34	G	Whole rock	> 2.3	Ar^{40}-Ar^{39} (8)	

Scources:

1. Schaeffer and Husain, 1974
2. Nunes and others, 1973
3. Husain and Schaeffer, 1973
4. Kirsten and others, 1973
5. Stettler and others, 1973
6. Mark and others, 1974
7. Turner and others, 1973
8. Schaeffer and others, 1974
9. Stettler and others, 1974
10. Jessberger and others, 1974
11. Papanastassiou and Wasserburg, 1972b
12. Nunes and Tatsumoto, 1973
13. Albee and others, 1973b
14. Hueneke and others, 1973a
15. Hueneke and others, 1973b
16. Tera and others, 1973
17. Papanastassiou and Wasserburg, 1972a

effort is made here to point out some of these problems respect to specific samples and to interpret the data where possible. The discussion is based, as is table 3, on the assumption that the plutonic rocks, wether clasts in breccias or isolated fragments, were excavated from the deep lunar interior by basing impacts (Wilshire, 1974). The significance of their ages, as well as those of rocks that were melted or metamorphosed as a consequence of this excavation, depends on their subsequent history. The petrology of the sample shows that impact events following the initial excavation of Apollo 16 rocks produced effects ranging from minor to effects so profound as to have completely reset radiogenic clocks. Moreover, extreme effects can be registered in small areas of rocks that have not otherwise been much changed since excavation.

Breccias that have been little modified since excavation can be recognized by large areas of unmixed cataclastic feldspathic rock with coarse mineral and lithic relics and large areas of the dark fine grained original matrix; the first-cycle matrix is generally broken, but thre pieces commonly are not much rotated. A magnificant number of Apollo 16 rocks have these characteristics (table 3), but few of them have been dated and none has had all of its components (matrix and plutonic igneous and metamorphic clasts) dated separately. The ages of samples such as soils and the C_1 and C_2 crystalline rocks are ambiguous because their history since excavation has not been determined.

Age data (table 4) have been determined on eight samples called "anorthosite." Three of these are documented rocks (60015, 60025, 67075); five are samples 2 to 4 mm coarse fines (62242, 3; 63503, 13, 2; 63502, 17, c2; 67483, 14, 18; 68503, 13, 7). Ages range from 3.55 b.y. to 4.5±0.3 b.y. Sample 60015, dated at 3.55 b.y. by ^{40}Ar-^{39}Ar, is considered to be the "youngest anorthosite" yet found on the Moon (Schaeffer and Husain, 1974). The hand specimen, however, clearly reveals heavy shock damage that resulted in extensive pulverization, melting, and maskelynitization of the anorthosite. Moreover, some areas have a coarsely sugary texture typical of preexcavation (?) metamorphic textures (Wilshire, 1974). Where information is, insufficient to determine the exact nature of the part of the sample dated, the age may be interpreted to represent the age of crystallization of the anorthosite as implied Schaffer and Husain (1974), the age of preexcavation (?) thermal metamorphism, age(s) of shock deformations or some averaged combination of these. If the age represents shock deformation, as seems likely the extensive shock damage and from its primitive initial ^{86}Sr (Nunes and others, 1974), it has no significance with respect to basin chronology. Sample 61016, which is texturally similar to 60015, is a breccia that has undergone extreme shock damage following its excavation and following crystallization of the melt rock matrix that encloses the anorthositic clasts (see references, table 3). These events may have no relation at all to the initial excavation of rocks and conceivably are the more extreme results of minor impacts. Moreover, Nunes and others (1974) documented loss of lead from 60015 glass less than 1.3 b.y. ago, indicating further modification by a still more recent event. Sample 60025, dated by ^{40}Ar-^{39}Ar at 4.18 b.y., is intensely pulverized and locally partly melted. It is not as badly damaged as 60015, and the age may represent a minimum crystallization age, although no description of the piece analyzed is given. The presence of substantial amounts of olivine and orthopyroxene in the cataclastic parts of the rock as well as unpulverized relics of the original rock suggest that more meaningful ages could be obtained by dating these relics (table 3). Sample 67075, dated by ^{40}Ar-^{39}Ar at 4.04 b.y., is a complex B_1 breccia in which a variety of coarse hornfels clasts (preexcavation metamorphism?) are the dominant lithic relic. As the grain size of much of the mineral debris is too coarse grained to have been derived from the hornfelses, the breccia as a whole may be derived from one or more partly metamorphosed plutonic rocks. The whole-rock age of the rock could represent an average of several metamorphic and crystallization ages.

"Anorthosite" samples from the 2- to 4-mm fines dated are accompanied by meager descriptions. As material called "anorthosite" in the literature is commonly hornfels, sometimes glass, and rarely anorthosite, one does not know whether the ages represent time of crystallization of the parent rock, time(s) of thermal metamorphism, or time(s) of melting in a regolith environment.

Two samples called "troctolite," one (62295) a documented rock, and one (68503,16,12) from 2 to 4 mm coarse fines, have been dated (table 4). Sample 62295 is probably an impact melt (see references, table 3), and its age that of crystallization of the melt. The rock does contain a small amount of unmelted relics that could affect the age, producing the spread of ages determined by Rb-Sr (4.00±0.06 b.y.) and ^{40}Ar-^{39}Ar (3.89±0.05 b.y.) methods. Whether 68503,16,12 is an impact melt, a plutonic igneous rock, or a hornfels is not known from the description given, and the significance of the age is therefore unknown.

Other dated samples of apparent impact melt rocks other than glass include documented rocks 68415 and 68416 and 2-4 mm coarse fines samples 63503,15,3; 66043,2,4; 66043,2,5; 68503,16,31; and 68503,16,33. Many dates are available for the ophitic rock 68415 (table 4); they show a range from 3.80±0.04 to 4.47 b.y., with a Rb-Sr internal isochron registering 3.84±0.01 b.y. A plagioclase separate from 68415 analyzed by Huneke and others (1973a) has a distinctly higher (4.09 b.y.) ^{40}Ar-^{39}Ar plateau age than the whole rock and a high-temperature release age of about 4.5 b.y. The plagioclase separate may include unmelted relics of the precursor of the rock. Sample 68416, taken from the same boulder as 68415 (ALGIT, 1972b) and having an essentially identical bulk composition (Rose and others, 1973), yielded a ^{40}Ar-^{39}Ar whole-rock age of 4.00±0.05 b.y. Our descriptions of this sample in hand specimen indicate a higher abundance of relict plagioclase than in 68415, which may account for the older apparent age of the whole rock. Rocks like 68415 and 62295 are not abundant in the Apollo 16 collection, but the evidence seems good (see Dowty and others, 1974a) that they represent impact melts derived from older, highly feldspathic rocks. Their relatively coarse grain sizes compared with other Apollo 16 impact melt rocks indicate slower cooling, but they did not cool so slowly that isotopic equilibrium was achieved. The ages of these rocks, exclusive of unmelted residual material, may be significant in basic chronology, but are nevertheless ambiguous, as direct ties to plutonic source rocks have not been made.

The 2-4-mm samples that are probable impact melt rocks are identified as "fine-grained intersertal igneous rocks" (Schaffer and Husain, 1973) in the terminology of Delano and others (1973). Such rocks form significant amounts of the matrices of many simple breccias (table 2), but also survive as clasts through multiple impacts. The histories of such materials in 2-4-mm coarse fines are therefore impossible to decipher, and their ^{40}Ar-^{39}Ar ages cannot be meaningfully interpreted.

Two documented samples (60315, 65015) of C_2 metaclastic rocks have been dated. Sample 60315 yielded ^{40}Ar-^{39}Ar ages of 3.94±0.5 b.y. and 4.03±0.03 b.y. and a U-Pb whole-rock age of 3.99 b.y.; 65015 yielded a Rb-Sr whole-rock age of 3.93±0.02 b.y., ^{40}Ar-^{39}Ar whole-rock ages of 3.92±0.04 b.y. and 3.98 b.y., and a U-Pb whole-rock age of 3.99 b.y. These rocks have moderately coarse grained poikiloblastic textures with variable amounts of unrecrystallized mineral and lithic debris. Both dating methods indicate that unrecrystallized plagioclase in 65015 is not in isotopic equilibrium and is much older (4.40-4.5 b.y.) than wholerock ages. Angular plagioclase relics in 60315 are zoned; this chemical disequilibrium suggests that isotopic equilibrium may not have. been achieved in this rock either. Differences in whole-rock ages may reflect differences in amount of unrecrvstallized debris in the particular parts of the rock analyzed. The whole-rock ^{40}Ar-^{39}Ar ages are of course older, by an unknown amount, than the age of metamorphism because plagioclase that yields a greater age was present in the rock measured. As lithologic mixing may have occurred during formation of these rocks (see Bence and others, 1973; Albee and others, 1973b), the wholerock Rb-Sr and unrecrystallized plagioclase ages may also average rock materials of different ages. The lack of direct ties between these rocks and plutonic rocks makes their times of metamorphism ambiguous with respect to basin chronology.

Of 17 breccias dated (table 4), 10 are parts of six documented rocks (61016, 65315, 66095, 67015, 67455, and 67915); the rest are samples taken from coarse fines (63502,17a; 67483,13,6; 67483,13,8; 67483,14,2; 67483,14,6; 67483,14,7; 68503,13,5). Our criteria (table 3) indicate that of the analyzed group, only documented samples 65315 and 66095 are likely to yield unambiguous information on basin chronology. Sample 65315 yielded an ^{40}Ar-^{39}Ar age. of 4.30±0.26 b.y., interpreted (Stettler and others, 1974) as possibly reflecting the crystallization age of the anorthositic component, with indications of excavation between 3 and 4 b.y., and rebrecciation (converting the rock to a B_2 breccia) at about 2 b.y. We believe that the excavation age could be determined precisely from the original matrix component of this breccia, but we do not know what component of the rock was dated by Stettler and others (1973). Sample 66095 is dated by U-Pb at about 4.0 b.y. (Nunes and Tatsumoto, 1973); this may represent an excavation age, but its relation to excavation ages of little-modified breccias remains unknown.

Sample 61016 is a complex breccia consisting of extensively shattered, partly maskelynitized, and partly coarsely metamorphosed anorthositic clasts in a finegrained intersertal matrix. Maskelynitization of the plagioclase laths in the matrix indicates that the entire rock was severely shocked after consolidation of the iritersertal matrix. The poorly defined ^{40}Ar-^{39}Ar age of about 3.65 b.y. (table 4) has no significance with respect to basin chronology or crustal formation. Sample 67015, which may be a complex soil breccia, and 67455 are so thoroughly reworked by multiple impacts that the postexcavation histories of their components are extremely difficult to decipher. Sample 67915 is another very complex rock of which three components have been analyzed. Our classification of the rock as a B_4 breccia disregards the extensive glass net-veining as the event that produced the glass may have altered significant portions of the rock, we regard the ages as ambiguous. Furthermore, the component dated a 3.99±0.05 b.y. (67015, 41d) is called "friable matrix" of the breccia by Kirsten and others (1973). The rock as a hole, viewed either as including or excluding the lass veins, does not have a friable matrix; we do not know what was actually dated nor its relation to the rest of the rock.

The seven breccia samples taken from coarse fines (table 4) could have been derived from virtually any source among the breccias; therefore, their significance in basin chronology and crustal formation is unknown.

Five samples of glass (63503,13,7; 66043,1,9; 68503,13,6; 68503,16,1; 68503,16,34) and one of plagioclase (63503,17d) from coarse fines were analyzed (table 4). In many of the documented samples, it is clear that glass formation is among the youngest events in the history of the rocks and presumably is the consequence of comparatively small impacts that do not produce thick ejecta deposits in which the melt could crystallize. The glass ages have no obvious significance with respect to basic chronology or crustal formation.

Five analyzed samples (63503,17, four samples from 2 to 4 mm coarse fines and 67483,15,2) were not well enough described for us to interpret their ages.

Of the 47 samples of Apollo 16 rocks dated, only one appears to have a reasonably unambiguous age: the age of 60025, 4.18 b.y., may represent the minimum

crystallization age of this rock, or, if Turner and others (1973) are correct in assuming that degassing in the lunar interior occurs continuously to the time of excavation, the age may represent the minimum age of excavation. However, the ^{40}Ar-^{39}Ar ages obtained on plagioclase separates from 65015, which are older than those obtained from the whole rock, and the results obtained by Stettler and others (1974) on 65315 suggest that crustal anorthositic rocks were not degassed prior to excavation. Hence, the ages of the least damaged anorthositic components of breccias more likely represent minimum ages of crystallization than time of excavation (Stettler and others, 1974), but both ages could probably be made more reliable by more selective sampling of the hand specimen (see table 3). Four other samples that ambiguously date basin-forming events are 62295, 4.00 b.y., 3.89 b.y.; 68415, 3.80-3.85 b.y.; 60315, 3.94 b.y., 4.03 b.y.; and 65015, 3.93 b.y., 3.98 b.y. The only criterion by which these rocks are identified as possible derivatives of very large pact events is their comparatively coarse grain size. Two of these samples (68415, 4.09-4.5 b.y.; 65015, 4.40-4.5 b.y.) yield possible ages of their precursors that may be significant with respect to crustal formation. These results do not appear to us to provide a sound basis for speculating on the chronology of basin-forming events or crustal formation. It seems clear however, that useful information can be obtained from the least-damaged breccias, as detailed in table 3, if they are selected and dated systematically with regard to their petrology.

AREAL DISTRIBUTION OF CLASSIFIED SAMPLES

The field distribution of all samples classified in table 1 is plotted in histogram (fig. 5). Samples from stations 4, 5, and 13 are heavily weighted by rake samples collected from a small area. The LM-ALSEP and station 11 areas are much better represented by documented samples than the other stations. Samples of all eight rock groups described were found at these two stations, suggesting that more extensive sampling at other stations would have expanded the range of rock types at each station.

The stations can be divided into two groups (1) Cayley plains stations are LM-ALSEP, 1, 2, 6, 8, and 9; LM-ALSEP and station 6 may be mantled by a thin discontinuous veneer of material from the Descartes mountains. (2) Descartes mountains stations are 4 and 5, located on Stone mountain but possibly partly mantled by ejecta from South Ray crater; and 11 and 13, on the North Ray crater ejecta blanket, which may sample the Descartes mountains.

Although proportions of rock types vary from station to station, depending on thoroughness of documented sampling, there are no distinctive differences in rock populations between the two groups of stations (fig. 5). When all data within the two station groups are combined (fig. 6), some differences appear: Cayley stations have higher proportions of C_1 and C_2 crystalline rocks and a lower proportion of B_2 breccia. According to our view of the breccias, both B_1 and B_2 breccias are derivatives of B_4 types, the B_1's differing from B_2's only by having none of the first matrix component attached. If these close relations are considered, there do not appear to be significant differences in rock populations between sample sites on the Descartes mountains and those on the Cayley plains.

The comparatively small number of samples thin sectioned to date does not allow final conclusions on possible petrographic differences between rocks from the Descartes mountains and the Cayley plains, but the data available (table 2) indicate that differences are not significant. In figure 7, the textures of crystalline rocks and unmodified breccia matrices are placed in the two station groups. The histograms are virtually identical.

Studies of soils from the Apollo 16 site (Delano and others, 1973; G. J. Taylor and others, 1973) suggest that, in general, materials derived from the Cayley plains are comparatively rich in fine-grained igneous

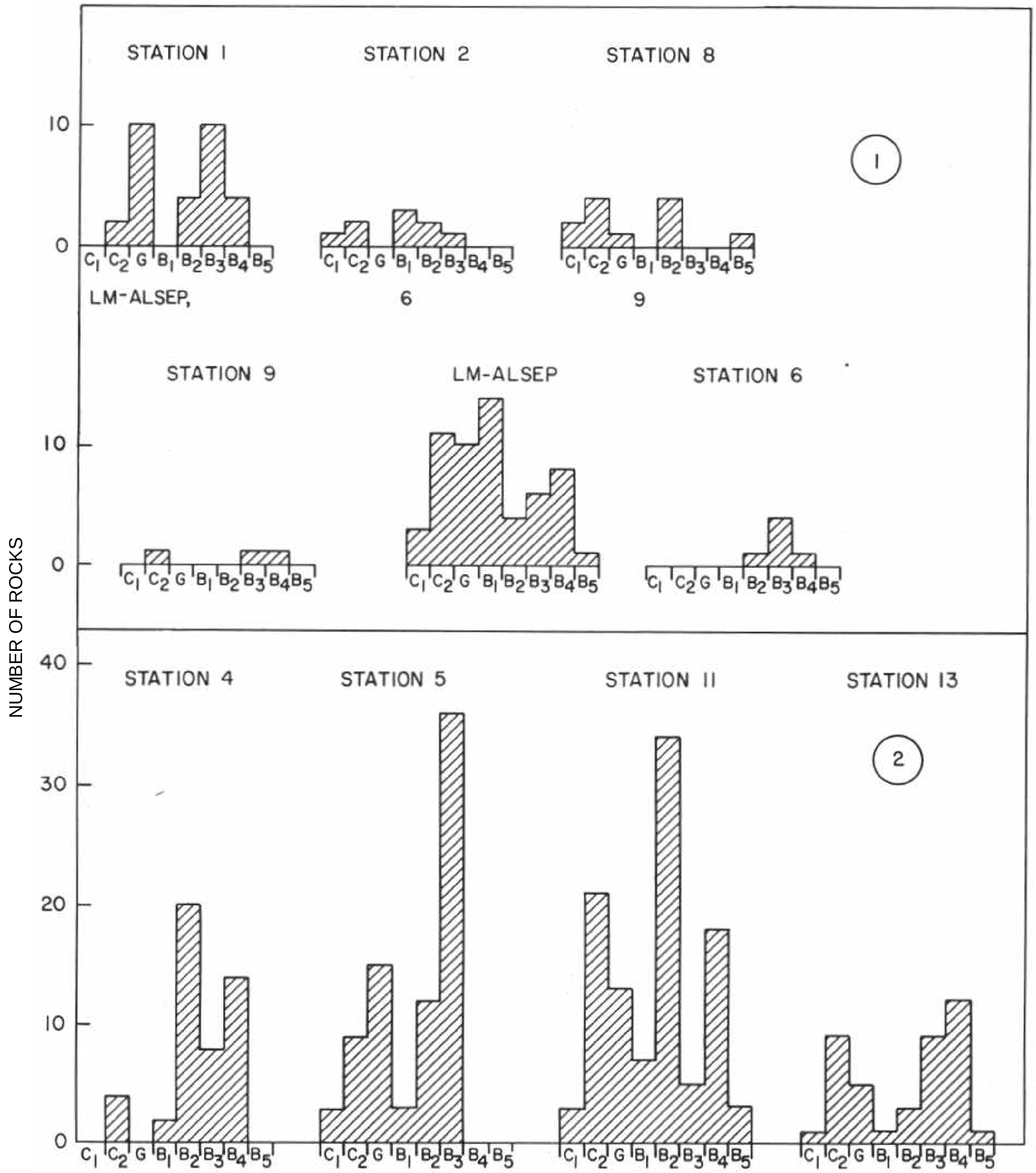

FIGURE 5.-Histograms showing distribution of rock types at each sampling station. Rocks in group 1 are from Cayley plains, those in group 2 from Descartes mountains and the ejecta blanket of North Ray crater.

and poikiloblastic lithic fragments whereas materials derived from the Descartes mountains are comparatively rich in what is termed "ANT" (anorthosite, norite-ite, troctolite) lithic fragments. Heiken and others (1973), who studied a wider size range of particles; found the reverse situation at station 4 on the Des-

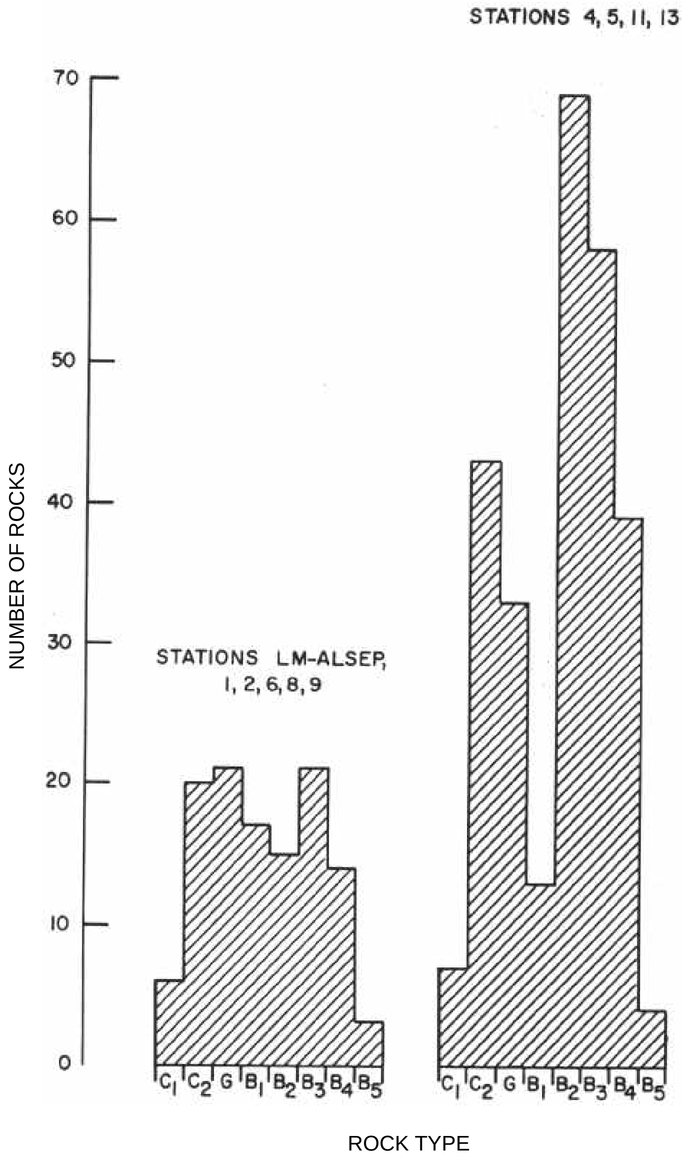

FIGURE 6.-Composite histograms of the two groups of stations.

cartes highlands, where samples had a higher proportion of "medium- and high-grade" metamorphic fragments (poikiloblastic and sheaf-textured rocks) than soils from the Cayley plains or North Ray crater stations. Such differences in the soil components may reflect differences in proportions of clasts and matrix of parent breccias; Cayley soils might be taken as derived from breccias with a larger matrix component than Descartes soils. This type of information is not included with the distribution of the larger rock samples shown by the histograms (figs. 5 and 6).

While the bulk chemical composition of soils (LSPET, 1973; Rose and others, 1973) shows little variation, Duncan and others (1973) noted subtle differences between Descartes and Cayley materials that

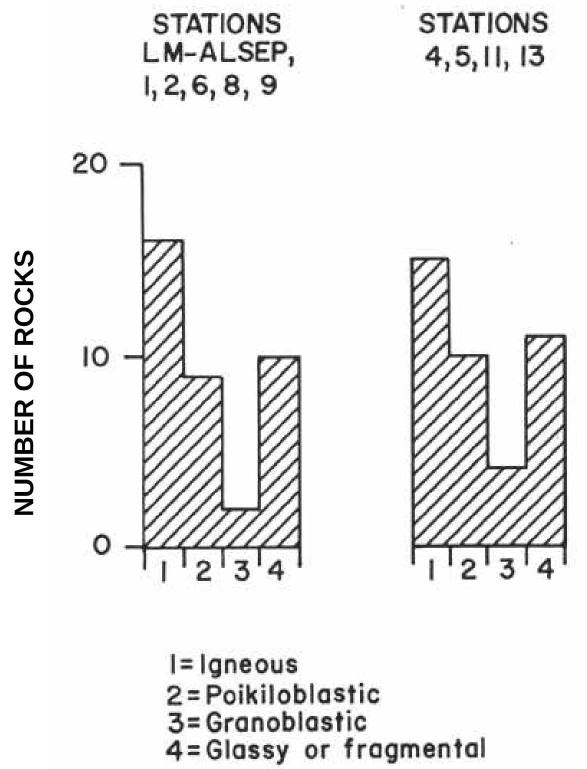

FIGURE 7.- Histograms showing distribution of micro scopic textures at each of the two groups of stations.

could be accounted for by Descartes materials enriched in "anorthosite" and depleted in "KREEP," "granite," "high-Mg basalt," and the meteoritic component relative to Cayley materials. These differences may reflect compositional differences between matrix and clast components of the first-cycle breccias, perhaps in part a consequence of partial melting (Warner and others, 1974); the statistics on coarse fines and compositional variations indicate a larger proportion of first-cycle breccia matrix in soils of the Cayley Formation.

These results are consistent with the concept of Hodges and Muehlberger (this volume) that the Cayley Formation and Descartes mountains units are lateral facies of the same ejecta deposit. In this view, the Descartes material is the comparatively "dry," clast-rich part of the ejecta, the Cayley Formation the comparatively "wet," matrix-rich part. Ulrich (1973) suggested that at the Apollo 16 site, dark "melt-rich" breccias are relatively abundant at lower elevations, "dry," lightmatrix breccias at higher elevations, concluding that the stratigraphic section consists of light-matrix breccias overlying dark-matrix melt-rich breccias. The soils data are less in accord with this view, unless South Ray crater distributed a considerable amount of debris from the hypothetical dark breccia layer over the southern and central Cayley stations.

Delano and others (1973) utilized the same hypothet ical stratigraphic section but identified the dark layer as either a brecciated volcanic flow or a regolith containing abundant volcanic material ("FIIR"=fine-grained intersertal igneous rock). The enrichment of Cayley soils in poikiloblastic and fine-grained intersertal rocks raises the same problem with their hypothesis as with Ulrich's. Moreover, the fine-grained intersertal texture is well developed as impact melt matrix in many breccias, much likelier sources of the "F11R" than a volcanic flow. The significance of the FIIR ages (Schaffer and Husain, 1973) is unknown, but the range of values from 3.86±0.07 b.y. to 4.13±0.05 b.y. is much too great for one lava flow.

There seems to be little basis for the supposition (G. J. Taylor and others, 1973) that soil components from the Cayley indicate stratigraphic layering in which the Cayley Formation is composed predominantly of poikiloblastic rocks underlain by a regolith of lightmatrix breccias. The documented rock collection clearly shows that all components of those soils could have been derived from a section composed of a single breccia parent with no vertical lithologic variations. There is even less basis for the postulated bedrock of anorthosite-norite-troctolite (ANT) on which the light-matrix-breccia regolith is thought to have formed (Taylor and others, 1973). The sample data seem rather to support derivation of the soils from ejecta deposits in which an original matrix component (powdered and partly melted rock) was present in somewhat higher proportion than anorthositic clasts in the areas underlain by Cayley Formation than in areas underlain by Descartes materials. Whether these ejecta deposits overlie still older ejecta is not known but seems likely.

SUMMARY AND CONCLUSIONS

Apollo 16 samples heavier than 2 g are classified by a descriptive scheme of three groups: (1) crystalline rocks, subdivided as igneous or metamorphic; (2) glass; and (3) breccias, subdivided on the basis of color of clast and matrix and proportions of these components.

The crystalline igneous rocks consist of one certain and one possible anorthosite, 11 fine-grained ophiticto-intersertal rocks of troctolitic to anorthositic composition, and one troctolite enclosed in fine-grained melt rock of the same composition. Derivation of the finegrained igneous rocks by impact melting of feldspathic plutonic source rocks is indicated by common occurrence in the fine-grained rocks of unmelted relics derived from coarse-grained plutonic rocks, a bulk compositional spread like that of the plutonic clasts in breccias, and gradations from fine-grained melt textures to plutonic rocks of essentially the same composition.

Metamorphic crystalline rocks studied consist of one medium-grained granoblastic rock, considered to be a product of metamorphism in a plutonic environment prior to excavation, and ten poikiloblastic rocks. We conclude that gradation from poikiloblastic to unequivocal igneous textures in these rocks is evidence of metamorphic origin with minor melting.

The five breccia types have been derived by rebrecciation of a first-cycle breccia that consisted of anorthositic clasts in a fine-grained matrix that varied from melt texture to metamorphic texture. The first-cycle breccia is considered to be multiring basic ejecta, as it contains clasts of plutonic rock derived from deep in the lunar crust. These breccias have been modified in varying degrees by subsequent smaller impacts.

Rocks reflecting modification of first-cycle breccias are sufficiently well represented in the Apollo 16 collection that least-damaged samples can be identified. From such samples, it may be possible to date the crystallization of the original crustal rocks, the preexcavation local metamorphism of those rocks, and the time of excavation. A review of age data shows that most samples selected for isotopic measurement are so severely modified by subsequent impacts that the ages are ambiguous. The samples petrologically most favorable for dating significant and identifiable events in the histories of the rocks are tabulated with the hope that they will help in obtaining unambiguous dates, now so scarce that speculation on basin chronology is at present unwarranted.

The distribution of classified samples shows no significant differences among Cayley and Descartes sample sites. Statistical and compositional data on soils support the view that the Cayley plains and materials of the Descartes mountains are facies of the same ejecta deposit and that a somewhat higher proportion of matrix, melt and powdered rock, was segregated to form the Cayley Formation.

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