70135

High-Ti Mare Basalt
446.3 g, 10.5 x 6 x 3.5 cm

INTRODUCTION

70135 is a blocky, brownish-gray basalt with a few zap pits on the S and T faces and irregular vugs (1-6mm) in a 1 cm band normal to S (Fig. 1). Foliation of ilmenite and plagioclase occurs on the W face in a zone 3 cm wide. Twelve small chips returned in the sample bag with 70135 (70136-39; 70145-49; 70155-57) are from the same boulder. Some or all may have broken from 70135 after collection, but none could be remated. 70135 was collected from the "Geophone Rock", approximately 50m south of the Apollo Lunar Surface Experiment Package (ALSEP) central station. Samples 70135-39,70145-49, and 70155-57 were all taken from this boulder.

PETROGRAPHY AND MINERAL CHEMISTRY

The petrography of 70135 was described by Brown et al. (1975a,b) from thin section ,58. It classified as a Type 1B by these authors (i.e., plagioclase poikilitic). Small olivines (~0.1 mm) occur either as cores to large pyroxenes (up to 3 mm), or poikilitically enclosed in plagioclase (up to 4 mm) with no reaction rims. Rare armalcolite is found poikilitically enclosed in pyroxene. Euhedral, blocky ilmenites (1-2 mm) are the predominant opaque phase, containing small (< 0.05 mm) exsolution lamellae of rutile. Native Fe and troilite form interstitial phases. General texture indicates development in a slow-cooling regime. Brown et al. (1975b) reported the modal mineralogy of this sample as: 2.8% olivine; 21.9% opaque minerals; 28.4% plagioclase;

Figure 1; Hand specimen, photograph of 70135.

46.2% clinopyroxene; 0.3% silica; 0.4% mesostasis. Roedder and Weiblen (1975) reported the modal mineralogy of 70135 as: 51.6% pyroxene; 23.0% plagio-clase; 19.4% oxides; 0.2% native Fe and sulfides; 0.6% silica; 1.4% melt/mesostasis; and 3.8% olivine.

Olivines of approximately Fo_{70} are generally unzoned (Brown et al., 1975b). Pyroxenes zone from titan-augite towards pyroxferroite, with little evidence of pigeonite crystallization. Spinels exhibit compositions from chrome-spinel (with rutile) which is exsolved from ilmenite to late-stage ulvospinel. Plagioclase exhibits little core-to-rim zonation (<10 An units) with core compositions being $\sim An_{85}$. Roedder and Weiblen (1975) noted anomalous low-K, high-Si02 inclusions in ilmenite from 70135, but came to no satisfactory conclusion for their formation. El Goresy and Ramdohr (1975a,b,c) studied the opaque minerals of 70135 in order to determine the nature of subsolidus reduction in lunar basalts. These authors noted evidence for two reduction reactions in 70135.

WHOLE-ROCK CHEMISTRY

There !lave been numerous studies of 70135 detailing the whole-rock chemistry to various degrees. The most complete data sets can be found in Laul et al. (1974); Rose et al. (1975); Shih et al. (1975); Rhodes et al. (1976); and Duncan et al. (1976) (Table 1).

Laul et al. (1974) analyzed 70135(,35) (Table 1) by INAA in a comparison study with rocks from other Apollo missions. These authors suggested that two, possibly three different basalt lava flows were present at the Taurus Littrow site. However, on the basis of compatible, rare earth element abundances, and a re-evaluation of earlier chemical data, Laul et al. (1975) concluded that at least five different basalt flows exist at the Apollo 17 site.

Rose et al. (1975) analyzed 7013503) (Table 1) by XRF in a characterization study of rocks and soils returned by the Apollo 15, 16, and 17 missions. These authors did not specifically mention this sample in their discussion, simply stating that the "compositions of the analyzed basalts are similar to those reported earlier by Rose et al. (1974)."

Shih et al. (1975a,b) analyzed 70135,27 (Table 1) using a combination of isotope dilution and INA analytical techniques. 70135,27 contained the highest abundances of trace elements of any Apollo 17 high-Ti basalt analyzed by these authors. Shih et al. (1975 a,b) concluded that the low-K/high-Ti mare basalts were the product of extensive melting of an ilmenite-clinopyroxene cumulate followed by near-surface crystallization.

Rhodes et al. (1976) reported the major-element composition of 70135,27 analyzed by XRF (Table 1). These authors classified 70135,27 as a Class U Apollo 17 high-Ti basalt, stating that its coarse grain size precluded a representative analysis, and the available results did not conform with their A, B, C classification of finer-grained Apollo 17 basalts.

Duncan et al. (1976) reported an analysis (by XRF) of 70135,41 in a study of lunar basalt genesis. These authors concluded that variations in the ratios of the elements K, Ba, Zr, Nb, Y, and Ti could not be caused by near-surface fractionation and, therefore, provide information of basalt petrogenesis at depth. Furthermore, the results of Duncan et al. (1976) suggested that Apollo 17 low-K high-Ti basalts were generated from an ilmenite-rich cumulate, with little or no ilmenite left in the residue.

The whole-rock REE concentrations have been determined by Laul et al. (1974) and Shih et al. (1975a,b) on 70135,35 and 70135,27, resp. (Fig. 2). Both REE profiles are LREE-depleted and convex upwards, but Laul et al. (1974) reported higher REE abundances (MREE - 90 times chondritic values) than those of Shih et al. (1975) (MREE 70 times chondrite values). Both patterns contain negative Eu anomalies of approximately the same magnitude ($[Eu/Eu^*]_N$ = 0.43). The pattern of Laul et al. (1974) was determined on only 12.6 mg of sample, whereas that of Shih et al. (1975) was deter-mined on 52 mg. Therefore, considering the coarse-grained texture of this sample, it is probable that the REE profile of Laul et al. (1974) is subject to greater sampling errors than that of Shih et al., 1975a,b); the latter analysis is probably the most representative of the whole-rock composition among these two analyses.

Warner et al. (1975) used an unreferenced analysis of 70135 for comparison with 18 new analyses of Apollo 17 high-Ti basalts. These authors attempted to define three groups of Apollo 17 high-Ti basalts on the basis of Sm and $Ti0_2$

Table 1: Whole-rock analyses of 70135.

Ref.	1	2	3	4	5	6	6
Sample	,35	,33	,27		,41	,74	,74
SiO_2 (wt%)		38.60		37.85	37.68		
TiO_2	13.8	13.33		13.34	13.83		
Al_2O_3	7.0	8.88		7.34	7.83		
Cr_2O_3	0.506	0.49		0.55	0.636	0.63	0.54
FeO	21.8	18.97		19.68	19.74	14.71	16.38
MnO	0.27	0.29		0.29	0.26		
MgO	9	9.45		9.29	10.00		
CaO	8.7	9.82		10.18	9.80	11.48	10.96
Na_2O	0.40	0.36		0.34	0.40	0.28	0.31
K_2O	0.11	0.06	0.06	0.09	0.05		
P_2O_5		0.04		0.07	0.077		
S				0.15	0.191		
Nb (ppm)	<10			29.1			
Zr		230	319		319		190
Hf	14					8.9	8.6
Ta	2.6					1.4	1.8
U							
Th	0.3					1.7	0.44
W							
Y		99			118		
Sr		152	186		223		
Rb		<1	0.819		1.5		
Li		11	11.4				
Ba	210	210	105		126		86
Cs							
Be		<1					
Zn		4.1			<2		
Pb		6.4					
Cu					<2		
Ni		<1			<2		
Co	20	29	16.6		13	15	17
V	120	65			19	339	480
Sc	82	86	81.7			77	75
La	12.6	<10	8.49			3.8	7.5
Ce	52		29.4			12	25
Nd	50		31.6			32	23
Sm	18.0		13.0			6.3	11
Eu	2.84		2.30			1.3	1.8

Table 1: (Concluded).

Ref.	1	2	3	4	5	6	6
Sample	,35	,33	,27		,41	,74	,74
Gd			19.6				
Tb	4.5					1.9	3.0
Dy	29		22.6				
Er			13.2			0.59	
Yb	16	10	18.9			6.9	9.3
Lu	2.2					1.1	1.5
Ga		7.0				16	
F							
Cl							
C							
N							
H							
He							
Ir (ppb)							
Ge						1.0	2.0
Au							
Ru							
Os							

References: 1 = Laul et al. (1974); 2 = Rose et al. (1975; 3 = Shih et al. (1975); 4 = Rhodes et al. (1976); 5 = Duncan et al. (1976); 6 = Dickinson et al. (1989).

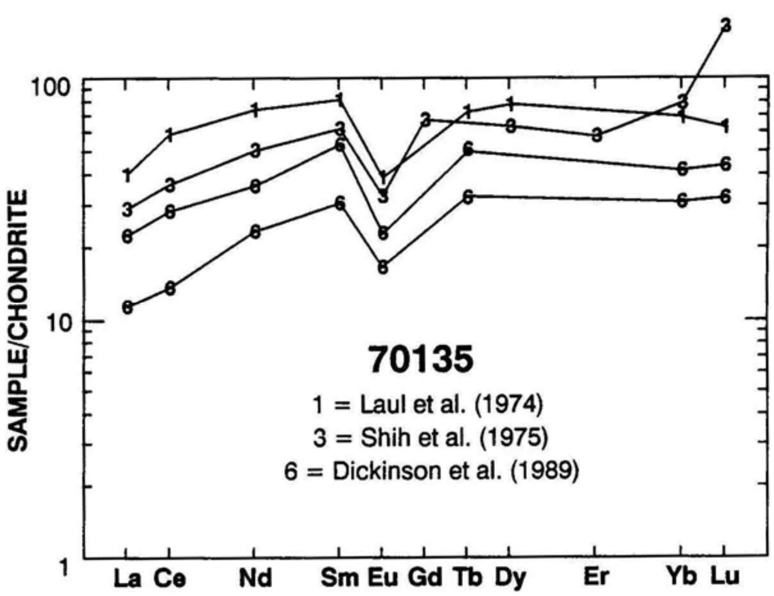

Figure 2: Chondrite-normalized rare-earth element profiles of 70135.

abundances and suggested that 70135 was not related to these Sm and TiO_2 "clusters" by partial melting of an identical cumulate (70135 possesses higher Sm and TiO_2 abundances).

Korotev and Haskin (1975) used the coarse grain size of 70135 to demonstrate the problems of getting a representative whole-rock analysis of such a sample. These authors showed the variability of trace-element abundances with different size fractions of this basalt (Table 2; Fig. 3 a-e). Korotev and Haskin (1975) suggested that these sampling errors can be minimized if an ~1 g sample is uniformly crushed to a fine powder. This study reflected on the compositions of different size fractions of lunar soil as products of comminution.

Other studies have concentrated on specific elements, such as the radio-elements (Eldridge et al. (1974), Ge (Dickinson et al., 1988,1989), and Cl, P, Re, and Os (Jovanovic and Reed, 1975a,b). Eldridge et al. (1974) reported K, Th, and U abundances of 70135 (Table 2) in a study of 13 basalt and 14 soil samples from Apollo 17. Their results for 70135 are: K = 500 ± 30 ppm; Th = 0.31 ± 0.02 ppm; U = 0.12 ± 0.01 ppm. They concluded that there is geochemical evidence for layering in the subfloor basalt flows, along with the possibility of magmatic fractionation of the K/U ratio as a function of depth.

Dickinson et al. (1988, 1989) used 70135,74 in a study of germanium abundances (analyzed by RNAA) of mare basalts in order to gain an insight into the origin and early evolution of the Moon and lunar basalts. Dickinson et al. (1988) only reported the Ge abundance, whereas Dickinson et al. (1989) reported two whole-rock analyses from splits of 70135,74. These whole-rock analyses are similar (Table 1), but variations of certain elements between these two splits are due to large errors associated with one or other of the analyses. The REE profiles are LREE-depleted (Fig. 2) and have negative Eu anomalies ($[Eu/Eu^*]_N$ = 0.44-0.54). The two REE profiles for 70135 reported by Dickinson et al. (1989) plot below those of Laul et al. (1974) and Shih et al. (1975a,b) (Fig. 2); the sample sizes analyzed were 200mg and 207mg. These relatively large sample sizes may yield compositions more representative of the actual whole-rock composition than the analyses of Laul et al.(1974) and Shih et al. (1975a,b). The reported abundance of Ge in 70135 is 1 A to 2.0 ppb. Dickinson et al. (1988, 1989) concluded that Apollo 17 basalts contain similar Ge abundances to those from the Apollo-11, 12, and 15 sites. The small variations observed are uncorrelated with other siderophile elements and cannot be explained by differences in the amount of metal segregated into the lunar core. Dickinson et al. (1988, 1989) suggested that volatile transfer of Ge by halogen-rich fluids may have generated such variations.

Gibson et al. (1976) analyzed the sulfur and metallic iron (Feo) contents of 70135 in a study of sulfur in Apollo 17 high-Ti basalts. These authors reported 1680 ± 60μgS/g and 0.163 equivalent wt% Feo for 70135. They concluded that the source regions of Apollo 17 high-Ti basalts were saturated with respect to S, whereas those of low-Ti basalts from Apollo 12 and 15 were not. Jovanovic and Reed (1975a) attempted to analyze 70135 for Cl and P_2O_5 in order to obtain a ratio of these elements, but in this paper they reported that the Cl contents were too low for reliable measurement. A P_2O_5 content of 0.04 wt% was reported here for 70135. However, Jovanovic and Reed (1975b, c) reported 0.52 ppm leachable Cl from 70135,29 with 2.2 ppm left in the residue. Furthermore, these authors also reported 13 ppb Br both in the leach and residue with 0.33 ppm I in the leach (iodine was not detected in the residue). Jovanovic and Reed (1975b) also reported a U concentration of 0.1 ppm for 70135, 29. Jovanovic and Reed (1980) again reported these earlier data, stating that 70135 falls into their second group based on Cl/P_20_5 contents. However, in light of the revealing study of Taylor and Huntert (1983), use of these data for such conclusions was not valid. In a change of emphasis, Jovanovic and Reed (1976a,b) analyzed 70135,29 for Ru and Os contents. The contents reported for 70135 are <2 ppb Ru and 0.1 ppb Os.

ISOTOPES

The isotope determinations conducted have dealt with cosmogenic radionuclides and exposure ages (Arvidson et al., 1976; O'Kelley et al., 1973, 1974a,b; Yokoyama et al., 1974; see Table 4 and radiogenic (primarily SO isotopes (Bansal et al., 1975; Murthy et al., 1976; Nyquist et al., 1975a,b, 1976a,b. See Table 5.

Table 2: Compositional variation of trace elements with size fraction analyzed.
Data from Korotev and Haskin (1975).

	Weighted Average	
	<500 µm	1-2 mm
Na_2O (wt%)	0.406	0.397
FeO	19.0	18.7
Sc (ug/g)	79.4	84.3
Cr	4515	4730
Co	22.7	19.0
La	3.64	4.94
Ce	15.1	19.2
Sm	6.48	8.16
Eu	1.72	1.72
Tb	1.94	2.46
Yb	7.02	7.92
Lu	1.04	1.06
Hf	6.7	7.4
Ta	1.66	1.56

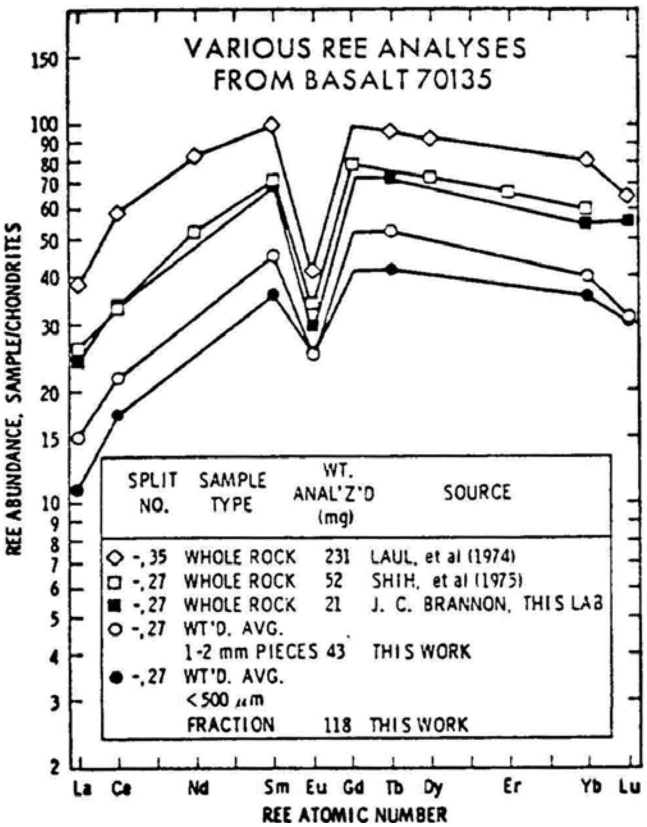

Figure 3a: REE chondrite diagram for various analyses of 70135, taken from Korotev and Haskin (1975). The samples of Shih, et al. (1975) and Brannon were taken from the same homogenized ,stock. The weighted average of seven <5001em fractions is probably a reasonable approximation to a "whole rock" analysis for the chip of 70135,27 crushed in this experiment.

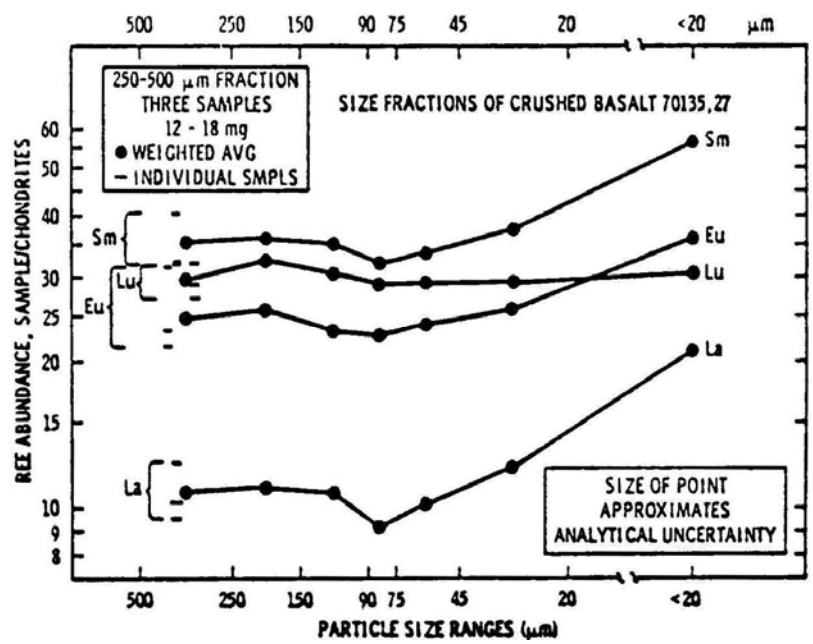

Figure 3b: Chondrite normalized REE abundances as a function of particle size. The numbers plotted on the abscissa are the sieve hole sizes

Figure 3: Chondrite-normalized REE abundances for various fractions of 70135.

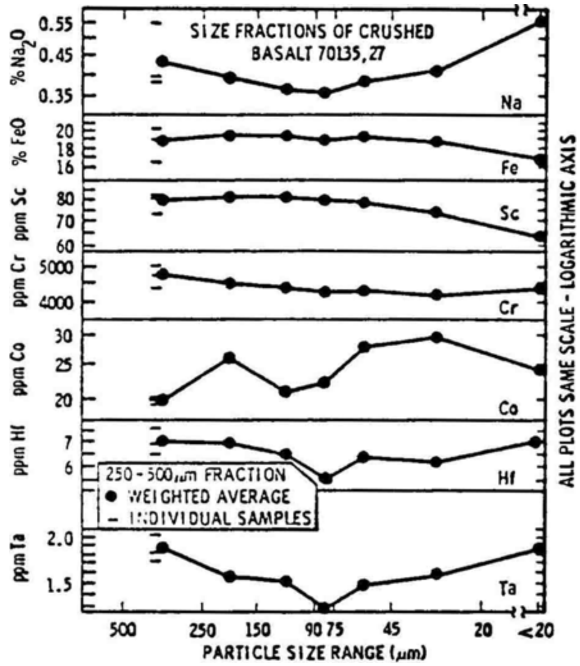

Figure 3c: Other element abundances as a function of particle size.

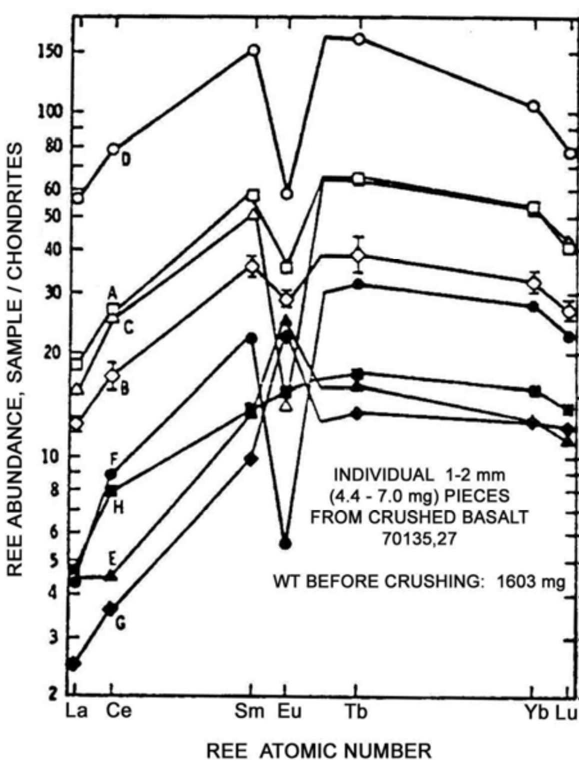

Figure 3d: REE chondrite diagram for eight individual 1-2 mm particles from 70135

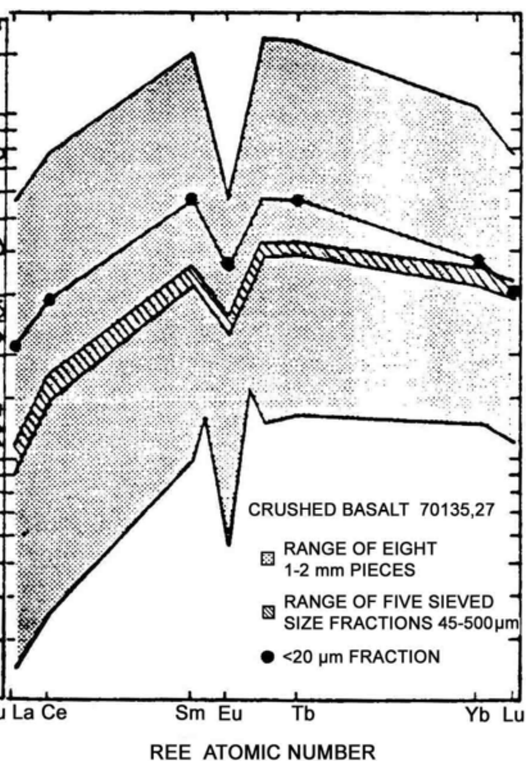

Figure 3e: Range of REE abundances in the size fractions superimposed on the range in the 1-2 mm particles.

Figure 3: Chondrite-normalized REE abundances for various fractions

O'Kelley et al. (1973, 1974) analyzed 70135 nondestructively for cosmogenic radio-nuclides using gamma-ray spectrometers with high sensitivity and low background. Abundances of ^{26}A1, ^{22}Na, ^{54}Mn, ^{56}Co, ^{46}Sc, and ^{48}V were determined for 70135 (Table 3). Yokoyama et al. (1974) analyzed 155 rocks from Apollo 11 and 17 missions for ^{22}Na and ^{26}A1. These were classified according to saturation in ^{26}A1. These authors agreed with the supposition of O'Kelley et al. (1973, 1974) that 70135 was shielded from solar flares, concluding that all ^{22}Na and ^{2}6A1 in this sample were produced by galactic cosmic rays. No tabulated data were presented by Yokoyama et al. (1974), but Figure 4 illustrates the relative proportions of ^{22}Na and ^{26}A1 in 70135.

Table 3: Abundances of cosmogenic radionuclides in 70135.
Data from O'Kelley et al. (1973, 1974).

	70135
^{26}A1	38±2
^{22}Na	33± 3
5^{4}Mn	56± 6
^{56}Co	56± 6
^{46}Sc	32± 3
^{48}V	10±5

The only exposure age reported for 70135 was by Arvidson et al. (1976). This ^{81}Kr-Kr exposure age is 106 ± 4 Ma. These authors suggested that such an age correlated with an influx of crater debris from the formation of Tycho.

Bansal et al. (1975) reported the Rb-Sr systematics of 70135, in a study of Rb-Sr ages and initial ^{87}Sr/^{86}Sr ratios of Apollo 17 mare basalts. These authors suggested a three-stage evolutionary model for 70135: 1) evolution of ^{87}Sr/^{8}6Sr in an environment with Rb/Sr greater than in the basalts; 2) production of mare basalt source regions of lower but variable Rb/Sr sometime in the interval 4.6-3.8 Ga; and 3) extraction of lavas from these sources with little or no fractionation of Rb/Sr at 3.8 Ga. Nyquist et al. (1975a,b) reported a mineral isochron for 70135,27 (Table 4) which yielded an age of 3.75 ± 0.09 Ga with an initial ^{87}Sr/^{86}Sr ratio of 0.69924 ± 0.00003 (Fig. 5). The conclusions of these authors were essentially the same as those reported by Bansal et al. (1975). Nyquist et al. (1976) reported their 1975 Rb-Sr analysis of 70135 in conjunction with others from Apollo 17 high-Ti basalts in order to demonstrate the relatively large range in Rb/Sr with initial ^{87}Sr/^{86}Sr. This observation was used in constructing the three-stage model for Sr isotopic evolution of Apollo 17 mare basalts (see above), and was used to demonstrate that the Rb/Sr of Type C Apollo 17 high-Ti basalts was increased at the time of magma generation. Murthy and Coscio (1976) used the Rb-Sr analysis of Nyquist et al. (1975) for 70135 in a comparative study of the Sr isotopic composition of Apollo 17 basalts. These authors applied a correction factor to this analysis in order to accommodate inter-laboratory bias. Therefore, the initial ^{87}Sr/^{86}Sr ratio of 70135 was quoted as 0.69912 ± 4.

No stable isotope analyses have been undertaken on 70135.

MAGNETICS

70135 has been examined in two magnetic studies to date. Brecher (1977a,b) used 70135,17 (described by Brecher as a "typical subfloor vesicular gabbroic basalt") to study the relationships between magnetization directions, magnetic fabric, and petrographic features. Her results are presented_ in Table 5 and Figure 6. 70135,17 contained vug-rich layers which could be seen nearly parallel to the "horizontal" B and T cube faces (feature B in Fig. 6) with scalloped "flow fronts" evident on cleaved faces (Brecher, 1977a). In these planes, dark and lighter-gray striations and glass-filled cracks parallel to the N-S axis could be seen (feature C in Fig. 6). A coarsely defined light-dark vertical banding was also observed, perpendicular to the vugs and crack elongation (A in Fig. 6). The NRM of 70135,17 was described by Brecher (1977a,b) as quite soft (6.14×10^{-5} emu/g), only 7% surviving cleaning to 100 Oe. The NRM and cleaned directions have high inclinations, clustering about a roughly vertical lineation axis of elongated vugs, contained in dark-light (shear-banding?) layers (Brecher, 1977a). The magnetic anisotropy is rather low (~5%) with dominant lineation, but comparable foliation. The NRM directions lie closer to the minimum susceptibility axis, paralleling trains of elongated vesicles.

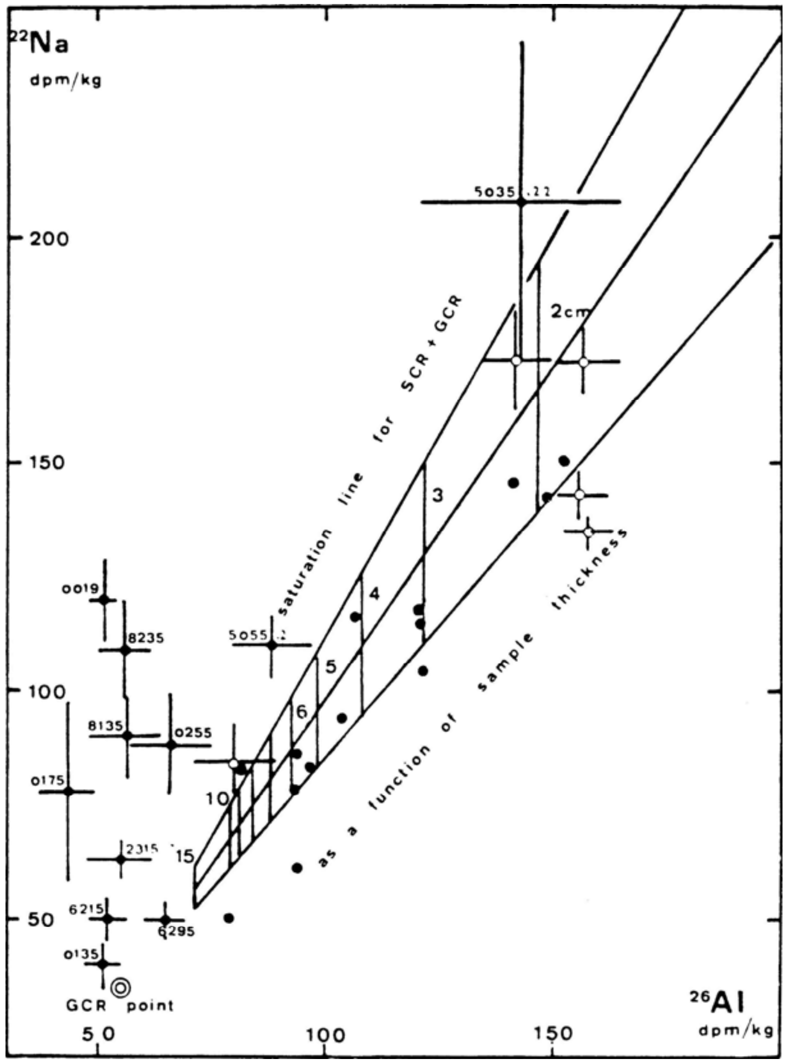

Figure 4: ^{22}Na-^{26}Al correlation diagram for Apollo 17 samples. Open circles with error bars represent soils, solid circles represent rocks saturated in ^{26}A1, and solid circles with error bars represent rocks either unsaturated in ^{26}A1 or uncertain. The first digit (7) of the LRL number of sample is omitted. Saturation lines correspond to the production of ^{22}Na and ^{26}A1 by GCR + SCR with SCR parameters of J=260 ±50 protons (E_P > 10 MeV)1 cm^2-sec-4a and R_o =100 MV for ^{22}Na and J= 70 protons (E_F,> 10 MeV)1cm^2-sec-4n with Ro =150 MV for ^{26}A1. The determination of these SCR parameters was given in the previous paper (Yokoyama et al., 1973). The approximate sample thickness corresponding to the saturated activity is also indicated along the saturation line.

Table 4: Rb-Sr data from 70135,27.
(Nyquist et al., 1975).

	Wt. (mg)	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr_a$	$^{87}Sr/^{86}Sr_b$	T_B	T_L
70135,27	51.8	0.819	186	0.0127±3	0.69995±5	7.7±0.4	5.0±0.4
plag 1	7.3	0.126	731	0.00050±1	0.69920±11		
Repeat					0.69927±3		
ilm 1	12.1	0.676	46.5	0.0421±4	0.70148±7		
px	7.7	0.39	165.7	0.0172±2	0.70010±8		
plag 2	6.2	0.124	698	0.00051±1	0.69923±7		
ilm 2	18.8	0.771	48.2	0.0463±4	0.70172±6		

Table 5: Magnetic data from 70135.
Brecher (1977a); Cisowski et al. (1983)
(all values in Gcm^2/gm).

	Sample 70135,17
Rock type	Vesicular Gabbroic Basalt
NRM	$3.6 * 10^{-5}$
NRM (200)	$4.7 * 10^{-7}$
Mass (g)	9.465
IRM_s(9 KOe)	$1.8 * 10^{-3}$
NRM ($x10^5$ emu/g)	6.14
IRM_s(200)	$2.4 * 10^{-4}$
NRM_{100}/NRM	0.068
K x 10^3 emu/Oe cc	4.9
(K_{max}-K)$x10^5$	0.49
Lineation	3
Foliation	2
Total anisotropy (%)	5.3
Petromagnetic correlation?	Strong

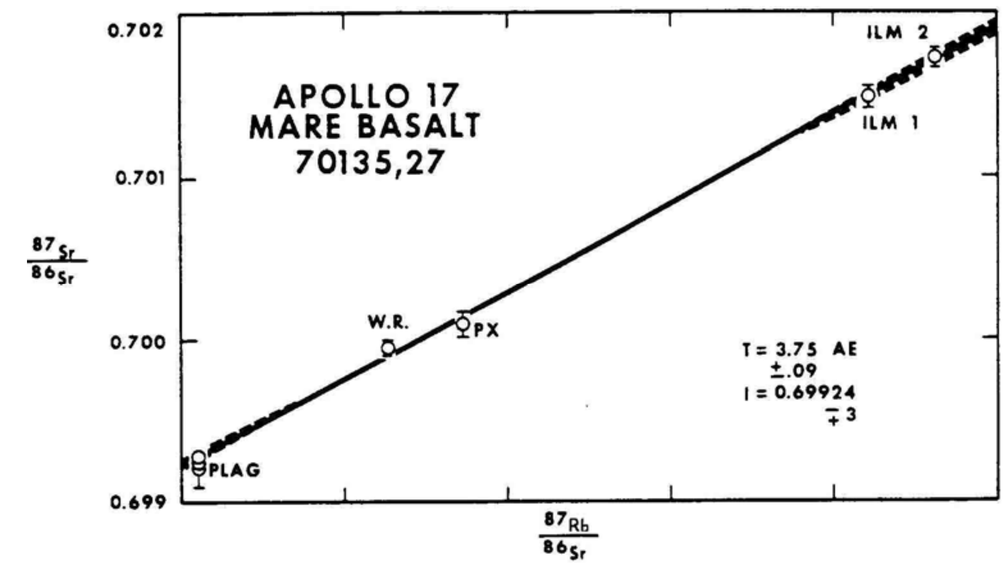

Figure 5: Isochron plot of $^{87}Sr/^{86}Sr$ versus 87Rb1^{86}Sr for 70135, 27. Taken from Nyquist et al. (1975).

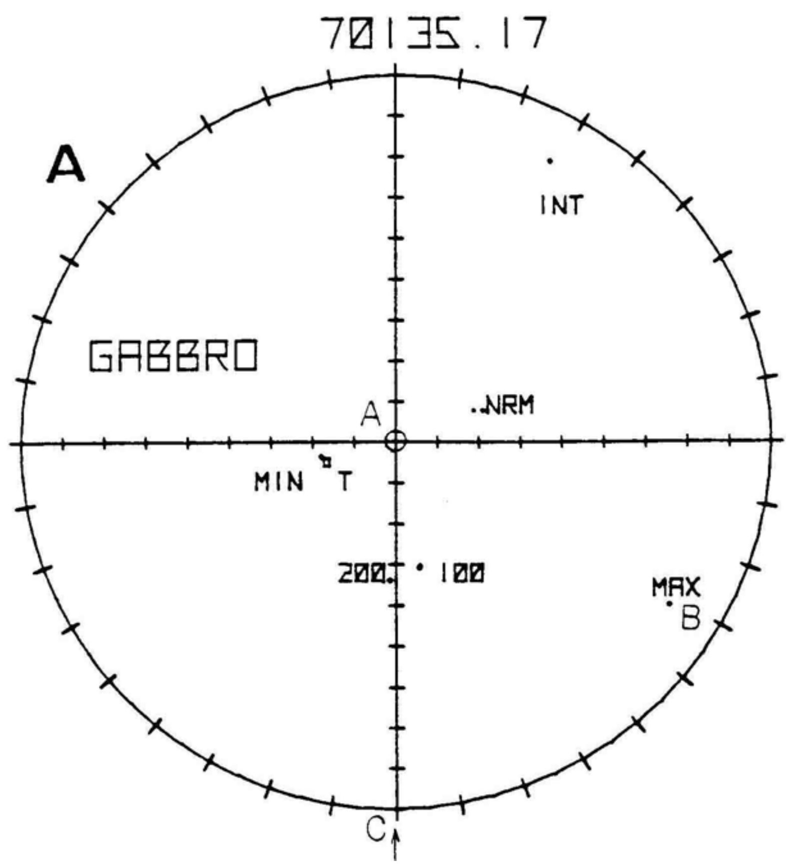

Figure 6: Magnetic data of 70135,17 taken from Brecher (1977). The high-inclination NRM and cleaned directions in basalt 70135 are grouped about the roughly vertical lineation axis of elongated Vugs (A), contained in the plane of layering (C). The magnetic fabric plane nearly coincides with vug-rich "horizontal" layers (B).

Cisowski et al. (1983) reported the magnetic intensity of 70135 in their review of paleointensity data in a study of lunar magnetism. These authors used the magnetic remanence data for 70135 (Table 5) to evaluate the origin of the lunar magnetic field. The conclusions of Cisowski et al. (1983) are somewhat vague, stating that only rocks within a certain limited age range contain magnetic intensities similar to those on Earth. They also stated that the origin of these intensities was uncertain.

EXPERIMENTAL

70135 has been used in one experimental study, that by Rutherford and Hess (1975), the experiments were designed to demonstrate the origins of lunar granites as immiscible liquids. These authors reported a major element whole-rock analysis for 70135, and the residual liquid composition after extreme (85-90%) fractional crystallization (Table 6). The fractionated residual reported by Rutherford and Hess (1975) did not experience liquid immiscibility, but did experience moderate Fe enrichment.

Osborne et al. (1978) used the major-element whole-rock analysis of 70135 reported by Rhodes et al. (1976) and the modal analysis of Roedder and Weiblen (1975) for 70135 in an experimental study of spectral reflectance for Ti determinations at room and elevated temperatures. High temperature measurements revealed that slopes of the reflectance profiles in the 0.400-0.550 pm region increased significantly up to 300°C, demonstrating a decrease in intensity at elevated temperatures as a result of metal → metal (e.g., Fe^{2+} → Ti^{4+}) charge transfer bands involving Ti. Osborne et al. (1978) concluded that techniques for mapping Ti concentrations on hot planetary surfaces should be applied cautiously if room-temperature calibration spectra are used.

PROCESSING

The major subdivisions of 70135 can be found in Figure 6 (Cutting and Chipping of Lunar Rock 70135). 70135,0 has been entirely subdivided. The largest portion of this basalt remaining is 289.1g (70135,9). Ten thin sections have been made, and the sample numbers are 70135,57-66

Table 6: Major-element analyses of 70135,34 compositions after silicate liquid immiscibility after the extreme fractional crystallization experiments of Rutherford et al. (1975).

	70135,34	
	Low-Si	High-Si
SiO_2	38.84	50.88
TiO_2	12.74	3.99
Al_2O_3	9.16	9.59
Cr_2O_3		
FeO	17.96	22.07
MnO	0.26	0.50
MgO	10.44	1.77
CaO	10.67	10.30
Na_2O	0.25	0.24
K_2O	0.02	0.18
P_2O_5	0.14	0.03
TOTAL	100.48	99.55