CATALOG OF APOLLO 15 ROCKS

Part 3. 15475—15698

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15475 PORPHYRITIC SUBOPHITIC QUARTZ-NORMATIVE ST. 4 406.8 g
MARE BASALT

INTRODUCTION: 15475 is a coarse-grained pigeonite-porphyritic mare basalt (Fig. 1) with a radiate to subophitic groundmass. It is an average- composition member of the quartz-normative mare basalt suite. It is light brown with green to brown prismatic pyroxene phenocrysts, white to translucent plagioclase laths and plates, and conspicuous small vugs. It is tough, blocky with subangular corners, and has zap pits on some surfaces.

15475 was collected about 28 m south-southeast of the rim crest of Dune Crater, a few centimeters from rocks 15476 and 15495. The immediate surface had a moderate cover of fragments. 15475 was dust-covered but not filleted or buried. Its orientation was documented.

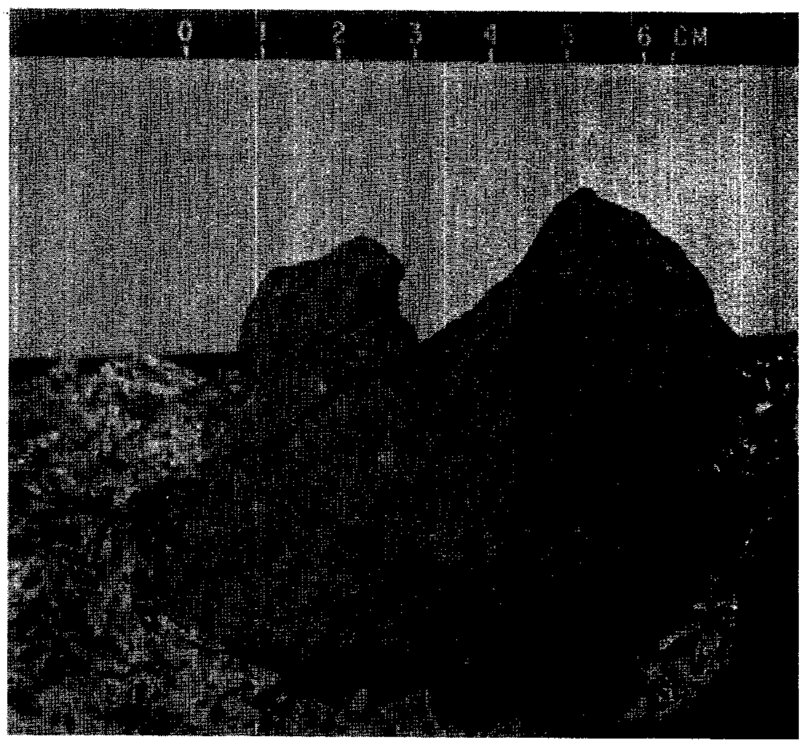


Fig. 1a

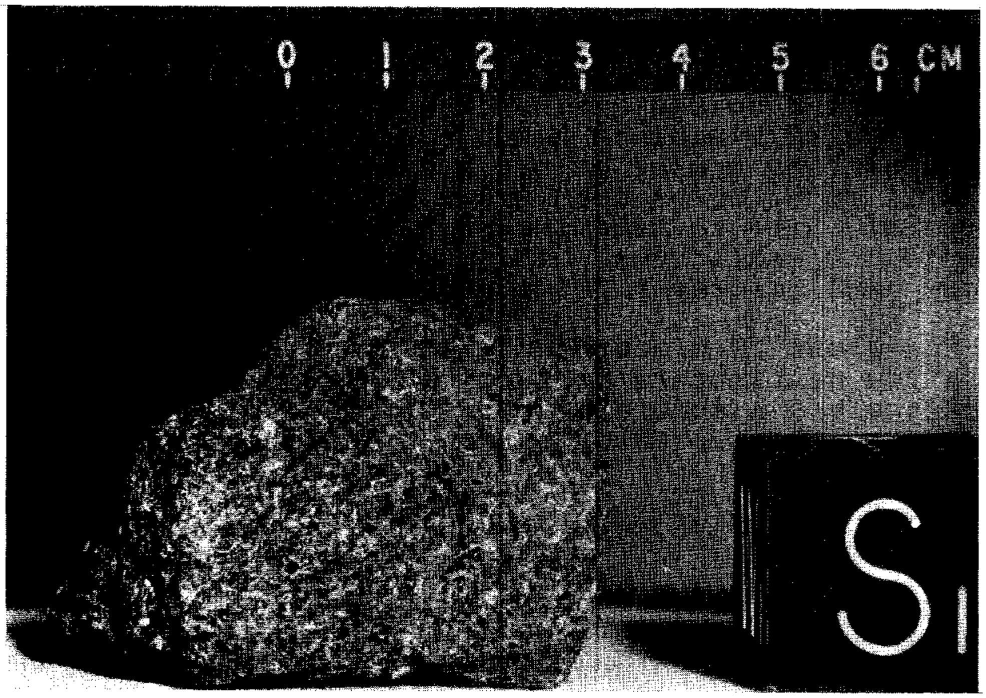


Fig. 1b

Fig. 1c

Figure 1. a) Macroscopic view of original pieces of 15475, fitted together. S-71-47935
b) Piece ,1, showing vuggy character. S-71-47021
c) Main saw pieces, prior to splitting the slab. S-72-33024

Fig. 2a

Fig. 2b

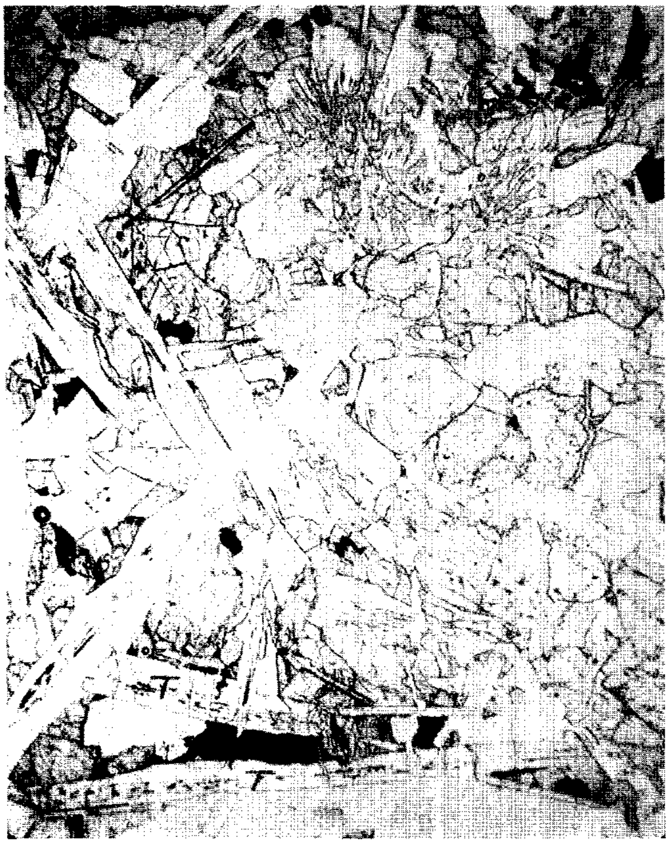


Fig. 2c

Figure 2. Photomicrographs of 15475. a,b, widths about 6 mm. c, width about 3 mm. a,c transmitted light. b, crossed polarizer. a,b, pigeonite phenocrysts, showing twinning, zoning, and inclusionrich rims; and groundmass, with plagioclase laths, opaque phases, and tridymite (T). c) groundmass, showing radiate clusters and subophitic areas. Laths at bottom (T) are tridymite.

PETROLOGY: 15475 is a coarse-grained porphyritic basalt (Figs. 1, 2). Pigeonite phenocrysts are twinned and zoned to augite; plagioclase is the second most conspicuous mineral. A sequence of oxides from chromite to ulvospinel to ilmenite is present, and the groundmass contains tridymite, cristobalite, pyroxferroite, and minor brown residual glass. Fe-metal and troilite are sparse. The pigeonites are as much as 1.5 cm long; most are about 5 mm. They are not evenly distributed, some thin sections containing perhaps 75% pyroxene, others as little as 55%. Modes are listed in Table 1 and show some variations. The groundmass texture is radiate but transitional to subophitic, according to Lofgren et al. (1975).

TABLE 15475-1. Published modes

	(1)	(2)	(3)
Cpx	75	64	--
Plag	20	24	--
Ilm	4	1.2	--
Ulvo	<1	1.2	--
Trid	0.5	0.6	0.5
Crist	tr.	--	--
Glass	tr.	1.7	--
Fe-Ni	<0.1	tr.	--
Troil	<0.1	tr.	--
Vugs	--	6.4	--
Chromite	--	0.5	--
Olivine	--	0	--

(1) Lunar Sample Information Catalog Apollo 15 (1971)
(2) Rhodes and Hubbard (1973)
(3) Mason (1972)

Brown et al. (1972, 1973) tabulated the compositions of two evolved pyroxenes. They found pyroxene compositions to be similar to those in 15076 except for a greater volume of pigeonite cores. They noted the presence of whitlockite and tranquillityite, with analyses; the whitlockite has high SrO (1.01%) but Eu is below detection. They reported a titanochromite analysis, and noted the absence of olivine. Takeda et al. (1975) reported on a study of pyroxenes using optical and x-ray diffraction (single crystal) techniques. They tabulated three pyroxene analyses ($En_{68.4}Wo_{5.3}$ to $En_{31.2}Wo_{28.5}$), and provided cell dimensions, relative orientations, and space group data. No exsolution was visible optically, but an augite grain had exsolved about 40% pigeonite ($\Delta\beta = 2.87°$).

Weeks (1972) produced electron magnetic response spectra for two pyroxene and a "plag + pyroxene" separates. Neither Fe^{3+} nor Ti^{3+} was found in the pyroxenes but Fe^{3+} was observed in the plagioclases. Plagioclases 1 cm from the top of the rock and 8 cm from the top had the same Fe^{3+} concentration, hence Fe^{3+} is not a result of radiation damage. Bell and Mao (1972, 1973) also found evidence for Fe^{3+} in plagioclase and reported total iron oxide (as FeO) of 0.66%, with no systematic zoning. They suggested that the Fe^{3+} was an alteration product.

El Goresy et al. (1976) reported on spinel textures and chemistry, without tabulating or diagramming specific data. 15475 contains corroded and rounded chromite cores to Cr-ulvospinel (as do other coarse basalts), indicating considerable reaction. The zoning trends (their "third" trend) from low FeO/(FeO + MgO) cores (0.80 to 0.85) to more iron-rich rims, with slightly increasing Ti/(Ti + Cr + Al) and a decrease in V, is indicative of crystallization from a liquid with continuously increasing FeO. Roedder and Weiblen (1972) tabulated analyses of high-SiO_2 melt inclusions (interstitial, in plagioclase, and in ilmenite), with compositions ranging from 72.8 to 76.8% SiO_2 and 6.3 to 7.8% K_2O. The pigeonite cores are inclusion-free, their mantles are inclusion-rich. Engelhardt (1979) noted that ilmenite started crystallizing after plagioclase started, and ended crystallizing before pyroxene ended. Mason (1972) reported that the refractive indices for tridymite and cristobalite in 15475 were identical with the corresponding phases in 15085. Mason et al. (1972) found 0.5% tridymite in the mode.

Cooling Rates: L. Taylor and co-workers (L. Taylor and McCallister 1972a, b; L. Taylor et al., 1973) used the partitioning of Zr between ilmenite and ulvospinel to estimate cooling rates, based on experimental determination of variation of the coefficient with temperature. The low ratio (Zr in ilmenite/Zr in ulvospinel) of 1.5 to 2 (Fig. 3) suggests subsolidus re-equilibration to about 850°C, like some other slowly-cooled basalts. Such slow cooling is correlated with a greater amount of reduction of ulvospinel, which is hence cooling-rate dependent rather than oxidation-state dependent.

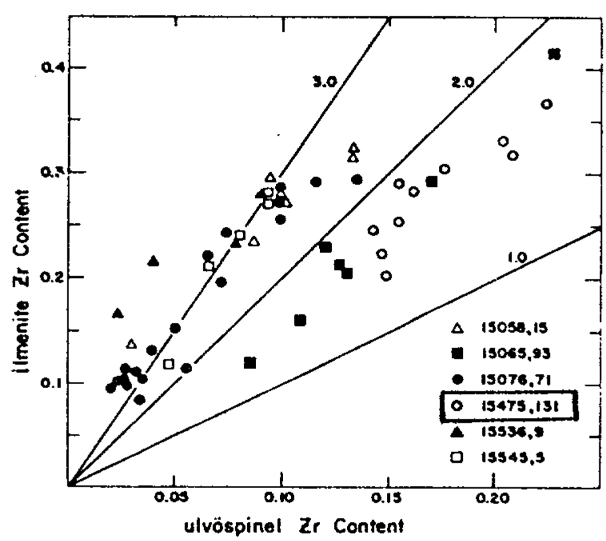


Figure 3. Zr partitioning between ilmenite and ulvospinel (L. Taylor and McCallister, 1972a).

Lofgren et al. (1975), in a comparison of the texture of 15475 with the products of dynamic experimental products (known, linear cooling rates) inferred a crystallization rate of less than 1°C/hr for both the phenocrysts and the groundmass, but a little faster than 15058, 15075, 15076, etc. Grove and Walker (1977), in a similar but more quantitative study, inferred an early cooling rate of 0.05°C/hr from the pyroxene nucleation density (0.3/mm^2), and a late stage cooling rate of 0.1°C/hr from plagioclase sizes. The integrated rate from pyroxene phenocryst size is less than 0.5°C/hr. The final position of 15475 from a conductive boundary is estimated to be 263 cm. The sample appears to have undergone a slow, near-linear cooling rate throughout its crystallization.

On the basis of the augite exsolution, Takeda et al. (1975) inferred that 15475 was the slowest-cooled quartz-normative mare basalt of those they studied, because the $\Delta\beta$ of 2.87° was the largest. They inferred a faster cooling rate early in crystallization than later. Brett (1975), on the basis of limited data, inferred that 15475 cooled within a 2 m thick flow.

EXPERIMENTAL PETROLOGY: Muan et al. (1974) mentioned equilibrium, liquid-solid phase equilibria on a representative sample (data pack information) of 15475, using Fe-equilibria. Olivine or spinel is the liquidus phase, but no specific data was presented.

CHEMISTRY: Bulk rock chemical analyses are listed in Table 2, and the rare-earths are plotted in Figure 4. The analyses are quite consistent considering the grain-size of the rock and demonstrate that 15475 is a rather average-composition Apollo 15 quartz-normative mare basalt. The largest variation is in TiO2 content. Compston et al. (1972) noted that their x-ray fluorescence Rb data are consistently lower and not as reliable as their isotope dilution Rb data. Drozd et al. (1974) reported a total Kr abundance of 43.9 x 10^{-11} g/cm^3.

Gros et al. (1976) and Hertogen et al. (1977) erroneously refer to 15475 as a non-mare basalt in their discussions and tabulations. In fact, all their elements have abundances quite typical of mare basalts.

RADIOGENIC ISOTOPES: No age of crystallization has been determined for 15475, but Compston et al. (1972), and Nyquist et al. (1972, 1973) and Wiesmann and Hubbard (1975) reported whole-rock Rb-Sr isotopic data (Table 3). They are consistent (adjusting for interlaboratory bias) with dispersion along a 3.3 b.y. isochron. Calculated initial $^{87}Sr/^{86}Sr$ for ages of about 3.3 to 3.4 are within the range of other Apollo 15 mare basalts.

TABLE 15475-2. Bulk rock chemical analyses

		,33	,35	,35	,35	,35	,0	,34	,34	,152	,4	?
Wt %	SiO2	48.32	47.82					48.32		49.0		
	TiO2	1.57	1.96	1.90	1.66			1.77		1.75		
	Al2O3	9.23	9.52					9.59		9.77		
	FeO	20.17	19.95					19.83		19.9		
	MgO	9.54	8.28		8.31			8.72		8.42		
	CaO	10.33	10.65					10.77		10.77		
	Na2O	0.27	0.24		0.33			0.31		0.305		
	K2O	0.05	0.04	0.0498	0.0416		0.0425	0.05		0.048		
	P2O5	0.05	0.07					0.06		0.052		
(ppm)	Sc									47.7		
	V	130										
	Cr	4520		3092				4180		3630		
	Mn	2400	2250					2325		1900		
	Co	56								44.6		
	Ni	50	9								35	
	Rb	<5	1.2	0.514	0.696	0.688		0.58	0.73		0.89	
	Sr	96	117		111	110.7		106.8	105.0			
	Y	37	29					22				
	Zr	65	89	107	84			75				
	Nb		5.9					6				
	Hf			3.0	2.7					2.37		
	Ba	47		61.2	45.2					49		
	Th						0.40					
	U			0.153	0.108		0.12				0.135	0.19
	Pb	<2										
	La			5.76	4.01					5.47		
	Ce			15.5	13.1					15.0		
	Pr											
	Nd			11.5	8.87					11		
	Sm			3.66	2.93					3.45		
	Eu			0.961	0.481					0.92		
	Gd											
	Tb									0.79		
	Dy			5.45	4.59					4.72		
	Ho											
	Er			3.2	2.70							
	Tm											
	Yb			2.6	2.35					2.45		
	Lu				0.35					0.38		
	Li	8		6.3	15.3					7.0		
	Be											
	B	4000										
	C											
	N											
	S		700					400		590		
	F									43		
	Cl									5.9		
	Br									0.034	0.008	
	Cu	6										
	Zn										1.1	
(ppb)	I											
	At											
	Ga	3000						2900				
	Ge										5.2	
	As											
	Se										9.2	
	Mo											
	Tc											
	Ru											
	Rh											
	Pd										<0.4	
	Ag										0.72	
	Cd										2.0	
	In										0.46	
	Sn											
	Sb										0.34	
	Te										2.5	
	Cs										37.5	
	Ta									340		
	W											
	Re										0.0026	
	Os										0.010	
	Ir										0.0146	
	Pt											
	Au									7	0.0094	
	Hg											
	Tl										0.38	
	Bi										0.08	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

References and Methods: **Table 15475-2.**

(1) Mason et al. (1972); general silicate, gravimetric, flame photometry, colorimetry, emission spec.
(2) Rhodes and Hubbard (1973); XRF.
(3) Rhodes and Hubbard (1973); Wiesmann and Hubbard (1975); ID/MS.
(4) Hubbard et al. (1973); Church et al. (1972); Wiesmann and Hubbard (1975); ID/MS, colorimetry, AA.
(5) Nyquist et al. (1972, 1973); ID/MS.
(6) O'Kelley et al. (1972a, b)
(7) Chappell and Green (1973); Compston et al. (1972); XRF.
(8) Compston et al. (1972); ID/MS.
(9) Wanke et al. (1975); XRF, INAA, RNAA.
(10) Gros et al. (1976); RNAA.
(11) Drozd et al. (1974); ?

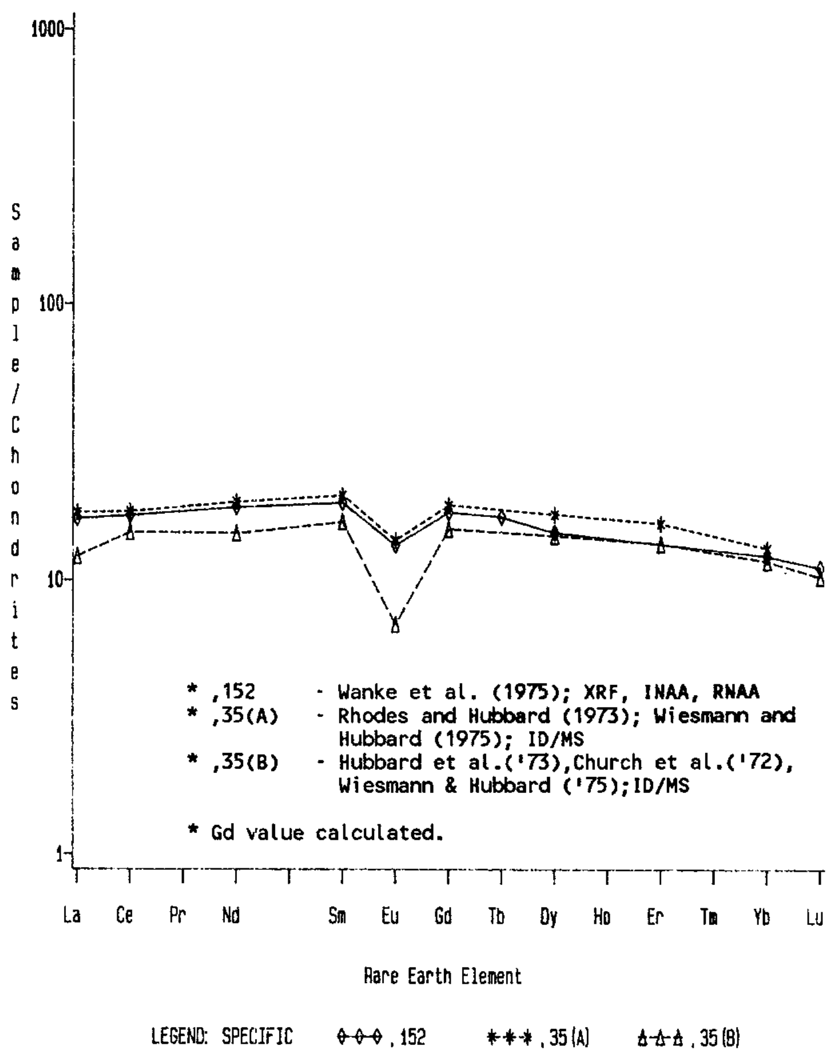


Figure 4. Rare earths in 15475.

TABLE 15475-3. Rb-Sr isotopic data for whole-rock samples (as reported)

Reference	Split	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	T_{BABI}
Compston et al., (1972)	,34 (ID)	0.73	105.0	0.0201	0.70039±10	4.54
Compston et al., (1972)	,34 (XRF)	0.58	106.8	--	0.70029±10(a)	--
Nyquist et al., (1972, 1973)	,35 chip	0.688	110.7	0.0180	0.70037±6	4.90
Wiesmann & Hubbard (1975)	,35 pwdr	0.514	110	--	0.70041±5	--

(a) unspiked

RARE GAS AND EXPOSURE: Drozd et al. (1974) reported Kr isotopic data, and calculated spallation ages of: ^{81}Kr-Kr, 473 ± 9 m.y.; ^{21}Ne, 336 ± 79 m.y.; ^{38}Ar, 543 ± 183 m.y., without specific discussion. Pepin et al. (1974) used this data to calculate exposure ages from an effective production rate and some depth expressions (see their text): T^{21}(d) of 529 ± 88 m.y. and T^{38}(d) of 529 ± 72 m.y. They concluded that 15475 appeared to have resided at an effective depth of about 100g/cm^2 for more than 500 m.y.

Eldridge et al. (1972) and O'Kelley et al. (1972) reported disintegration count data for ^{22}Na, ^{26}Al, ^{46}Sc, ^{54}Mn, and ^{56}Co. ^{26}Al is below saturation, and indicates an exposure age of 0.7 to 1.1 m.y. The unsaturation was confirmed by Yokoyama et al. (1974).

PROCESSING AND SUBDIVISIONS: Two large pieces had broken from the main mass (,1 and ,2; Fig. 1) and were originally numbered 15477 and 15478 respectively. Chipping of ,2 produced daughters ,3 to ,9 for early allocations, including potted butt ,3 which was used to produce thin sections ,11 and ,13 to ,19. Other small chips were removed from ,0 for further allocations (,20 to ,30). ,20 was made into a potted butt and produced thin sections ,127 and ,147 to ,150. A small chip from ,1 was also made into a potted butt (,36) and produced thin sections ,125 and ,126. ,0 was sawn to produce two end pieces (N ,134 and S ,132) and a thin slab (,133 and ,135) (Fig. 1c). ,133 was split to produce several daughters. End piece ,132 (106.6 g) is in remote storage at Brooks. ,134 is 117.8 g, and ,1 is 75.00 g. All other pieces are smaller than 6 g.

15476 PORPHYRITIC RADIATE QUARTZ-NORMATIVE MARE BASALT ST. 4 266.3 g

INTRODUCTION: 15476 is a pigeonite-porphyritic mare basalt with large phenocrysts, a radiate, finer-grained groundmass, and a distinct foliation or lineation (Fig. 1). It is an average-composition member of the quartz-normative mare basalt suite. It is light brown with green to brown zoned prismatic pyroxene phenocrysts and a few per cent vugs. It is coherent, slabby or tabular, and has a few zap pits on all faces.

15476 was collected about 28 m south-southeast of the rim crest of Dune Crater, a few centimeters from rocks 15475 and 15495. The immediate surface had a moderate cover of fragments. 15476 was dust-covered but not filleted or buried. Its orientation was documented.

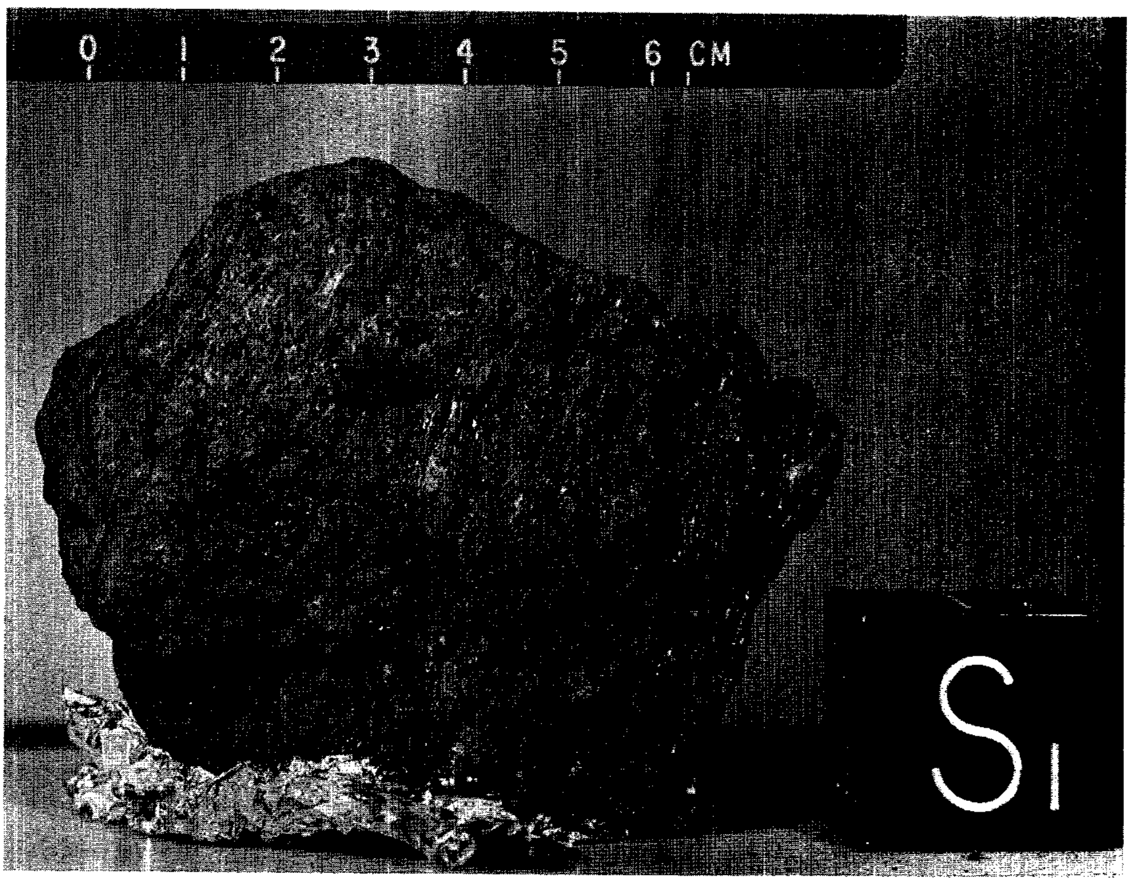


Figure 1. Pre-split view of 15476, showing foliation and small vugs. S-71-46905

Fig. 2a

Fig. 2b

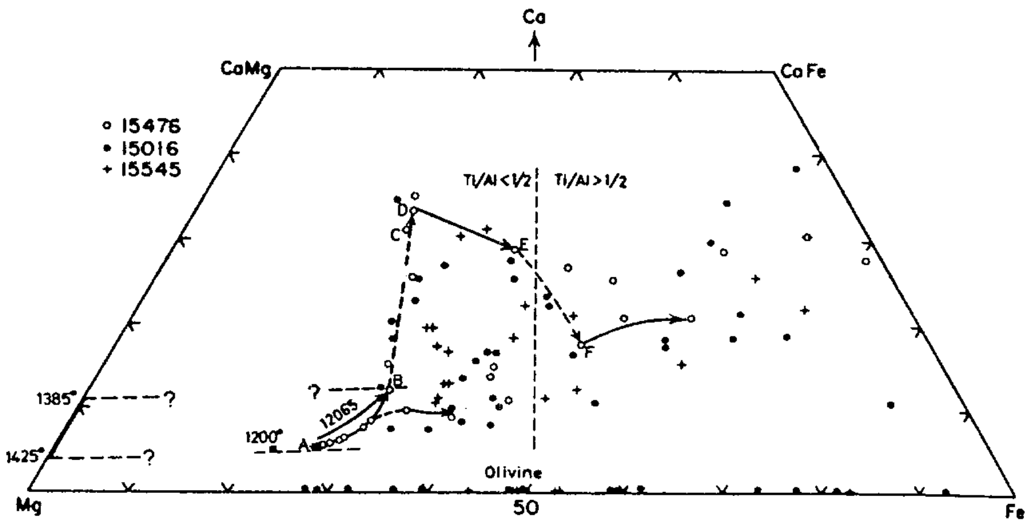
<u>Figure 2</u>. Photomicrographs of 15476,32. Widths about 3 mm. a)d) transmitted light; b)c) crossed polarizers. a) Radiate or variolitic portions of groundmass; b) irregularly-grown pigeonite phenocrysts, with hollows filled with crystallized groundmass; c)d) common phenocryst, with filled hollow core and sharply bounded augite rim; groundmass is coarser than variolitic portion shown in a).

Fig. 2c

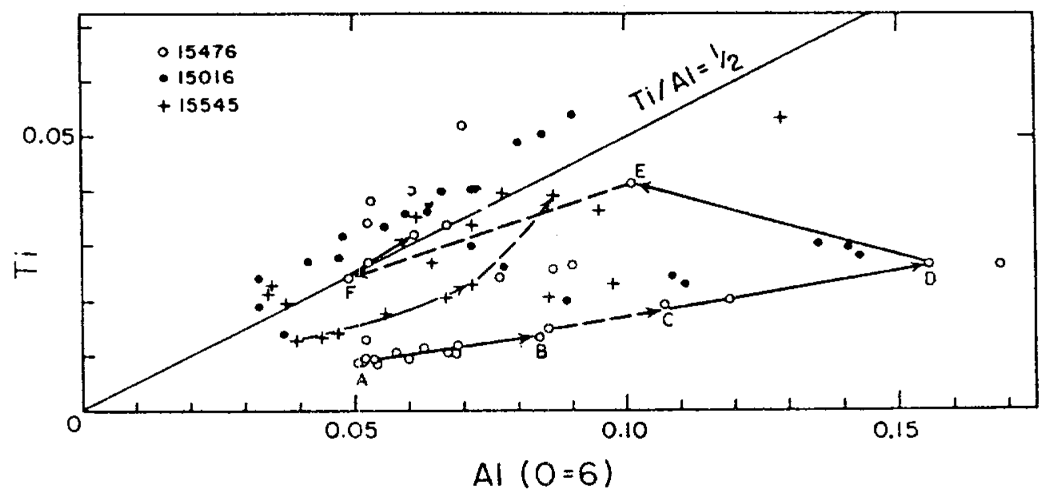
Fig. 2d

PETROLOGY: 15476 is a porphyritic basalt in which long (up to 3 x 15 mm) pigeonite crystals lie in a much finer-grained, radiate groundmass (Fig. 2). Although the pyroxenes are as big as in some other coarse-grained rocks, they are not so abundant, only 20 to 30%. The groundmass consists of a frequently radiate mass of plagioclase (An_{93} to An_{87}; Kushiro, 1972, 1973), augite, cristobalite, opaque phases, and a sparse mesostasis. The texture is not the same everywhere, varying from radiate masses (Fig. 2a) to more subophitic patches. The plagioclases are lathy, rarely up to 4 mm long, and both they and the pigeonite phenocrysts are very roughly foliated. Opaque phases range from euhedral chromite in pigeonite cores, through ulvospinel, to ilmenite. Fe-metal and troilite are also present. Tridymite appears to be absent. Mason et al. (1972) reported 0.70% cristobalite. The sample has a density of 2.8 g/cm^3 (O'Kelley et al., 1972).

The pigeonite phenocrysts, although large, are different from those in other coarse-grained quartz-normative basalts in that, although some have homogeneous cores, several are irregular and appear to have grown as hollow crystals in which groundmass later crystallized (Figs. 2b-d). The pigeonite phenocrysts also lack the twinning common in basalts with a coarser groundmass. They have sharply-banded rims of augitic pyroxene. Kushiro (1972, 1973) reported pyroxene compositions (Figs. 3, 4). Brunfelt et al. (1973) also reported a few pyroxene analyses. The variation observed is similar to that in other Apollo 15 mare basalts. Kushiro (1972, 1973) noted that the pigeonite cores are overgrown discontinuously with subcalcic augite; ferroaugite and subcalcic ferroaugite are intergrown with anhedral plagioclase crystals, with which they must have crystallized rapidly. The sharp break at the rim, corresponding also with the sharp change in Ti/Al ratios, he believes to result from plagioclase crystallization, and the Ti/Al ratios less than half to reflect Ti^{3+} and very reducing conditions. Kushiro (1972a,b) interprets the textures and mineral chemistry as resulting from the subsurface crystallization of pigeonite and then extrusion and rapid crystal-



<u>Figure 3</u>. Compositions of pyroxenes in 15476 (open circles) and two other Apollo 15 mare basalts. Solid lines show continuous, dashed lines show discontinuous, zoning in a single crystal (Kushiro, 1973).



<u>Figure 4</u>. Ti-Al variations in pyroxenes in 15476 (open circles) and two other Apollo 15 mare basalts (Kushiro, 1973).

lization of the remaining liquid. Virgo (1972, 1973) studied the separated phenocryst fragments ($En_{65.5}Wo_{6.5}$ average) with x-ray diffraction and Mossbauer techniques. X-ray diffraction single crystal precession pictures had no visible exsolved augite spots along the expected planes after 90 hours exposure. The Mossbauer studies showed no evidence for Fe^{3+}; site occupancies for Fe^{2+}-Mg and calculated distribution coefficients were tabulated. The K values (0.08) show the Fe^{2+} and Mg to be somewhat ordered, indicating equilibration temperatures (520°C) significantly less than the critical temperature for ordering (600°-810°C) and suggests slow cooling over the range T critical - T annealing, i.e., about 600 to 480°C. Hence Virgo (1972) suggested that crystallization was characterized by an initially fast growth of pigeonite crystals, then at lower temperatures a rapid and heterogeneous crystallization of rims and groundmass. The lack of augite exsolution indicates rapid cooling in the 1200°C to 950°C range. In the 1000°C to 950°C range, pigeonite undergoes a transition from C_2/c to P_{21}/c space group; the x-ray diffraction reflections indicate small P_{21}/c domains. The domain size, absence of unmixing, and the low temperature Fe-Mg ordering appear to be incompatible with a single cooling cycle, and suggest a post-crystallization heating event, such as from superimposed lava flows.

Lofgren et al. (1975), in a comparison of natural textures with those produced in dynamic crystallization experiments, inferred a cooling rate of less than 1°C/hr (but near 1°C to 2-5°C/hr limit) for the phenocrysts, and 1 to 5°C/hr for the radiate groundmass.

CHEMISTRY: Bulk rock analyses are listed in Table 1 and the rare earths are shown in Figure 5. The analyses are generally fairly consistent and demonstrate that 15476 is a rather average-composition Apollo 15 quartz-normative basalt. The Rb analysis of 6.0 ppm of Brunfelt et al. (1972) is very high and apparently in error; their CaO is also higher than normally found for Apollo 15 quartz-normative basalts.

RADIOGENIC ISOTOPES: Tatsumoto et al. (1972) reported U, Th-Pb isotopic data for a whole-rock sample. 15476 lies on a 3.5 to 4.65 b.y. discordia line with samples from Elbow Crater but has a distinctly higher $^{207}Pb/^{206}Pb$ ratio. Rosholt (1974) compared the expected Th^{232}/Th^{230} ratio with the measured ratio, discussing possible and probably reasons why the expected/measured (=1.13) is high, like other Apollo 15 mare basalts.

EXPOSURE, TRACKS, (AND RARE GAS): Eldrige et al. (1972) reported disintegration count data for ^{22}Na, ^{26}Al, ^{46}Sc, ^{54}Mn, and ^{56}Co. The ^{26}Al is unsaturated (confirmed by Yokoyama et al., 1974), and indicates a surface residence age of 0.8 to 1.5 m.y. Bhattacharya et al. (1975) briefly reported track data, with a density in the general range of 6 to 20 x 10^6 tracks/cm^2, and an exposure age of 10 to 30 m.y. Schaeffer et al. (1976) erroneously referred to 15476 in a discussion of argon in sample 15465; they never were allocated any of 15476.

TABLE 15476-1. Bulk rock chemical analyses

		,5	,11	,9	,0	
Wt %	SiO2	48.46		47.84		
	TiO2	1.75	1.90	1.82		
	Al2O3	9.54	9.17	10.02		
	FeO	20.76	19.5	19.79		
	MgO	8.69	8.3	8.35		
	CaO	10.50	13.9	10.74		
	Na2O	0.28	0.35	0.35		
	K2O	0.07		0.043	0.049	
	P2O5	0.05		0.081		
(ppm)	Sc		40.6			
	V	90	220	160		
	Cr	2945/3600	3280	3200		
	Mn	2170	2180	2020		
	Co	37	34.4	38		
	Ni	27	20	15		
	Rb	<5	6.0	1.5		
	Sr	98	114	115		
	Y	42		31.4		
	Zr	105		110		
	Nb			5.6		
	Hf		3.6			
	Ba	63	54	75		
	Th		0.52		0.51	0.7334
	U		0.21		0.14	0.1919
	Pb	<2				0.354
	La		5.9			
	Ce					
	Pr					
	Nd					
	Sm		4.3			
	Eu		1.13			
	Gd					
	Tb		0.88			
	Dy		3.5			
	Ho					
	Er					
	Tm					
	Yb		3.4			
	Lu					
	Li	8				
	Be					
	B	2				
	C					
	N					
	S			670		
	F					
	Cl					
	Br					
	Cu	7		4		
	Zn			<1.5		
(ppb)	I					
	At					
	Ga	3000				
	Ge					
	As					
	Se					
	Mo					
	Tc					
	Ru					
	Rh					
	Pd					
	Ag					
	Cd					
	In					
	Sn					
	Sb					
	Te					
	Cs		310			
	Ta		4100			
	W					
	Re					
	Os					
	Ir					
	Pt					
	Au					
	Hg					
	Tl					
	Bi					
		(1)	(2)	(3)	(4)	(5)

References and methods:

(1) Mason et al. (1972); general silicate, gravimetric, flame photometry, colorimetry, emission spec.
(2) Brunfelt et al. (1972); INAA
(3) Duncan et al. (1975); XRF
(4) O'Kelley et al. (1972); gamma ray spectroscopy
(5) Tatsumoto et al. (1972); ID/MS

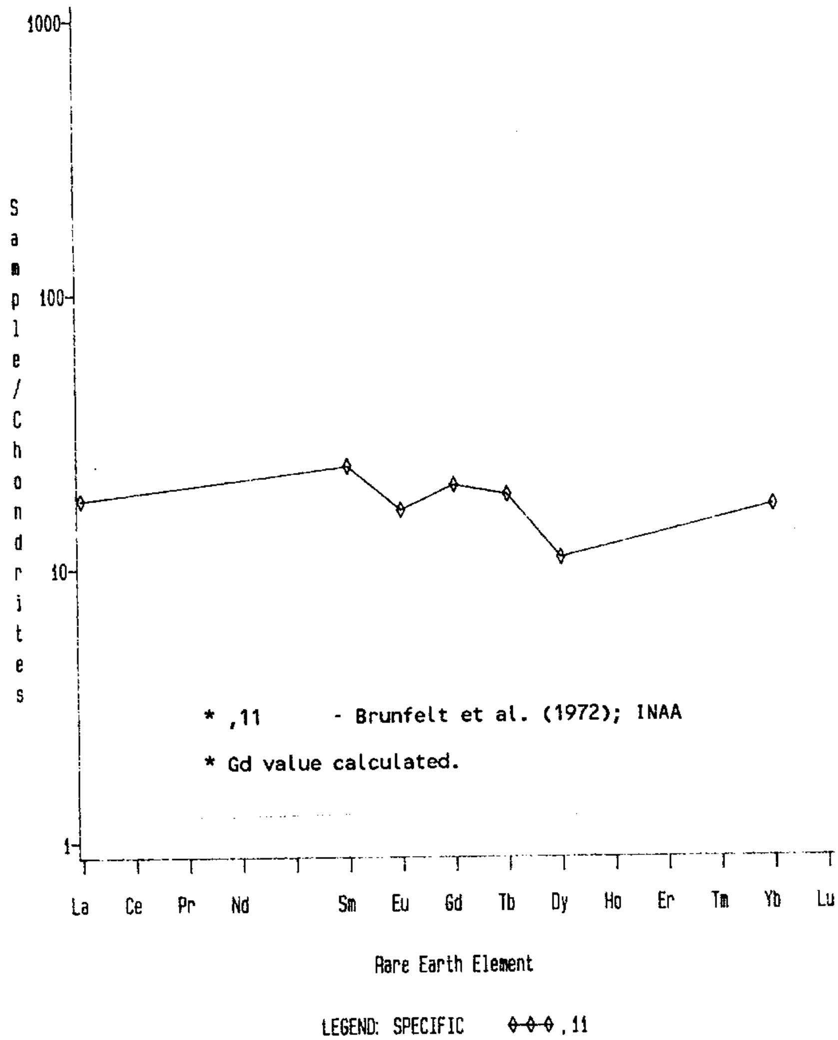


Figure 5. Rare earths in 15476.

PROCESSING AND SUBDIVISIONS: Samples were removed from 15476 by chipping (Fig. 6), and most allocations made by subdivisions of those (exterior) chips. ,3 was made into a potted butt and produced all the thin sections (,32 and ,33 to ,38). ,0 is now 206.91 g, and no other single piece is as large as 5 g except for the remains of ,3.

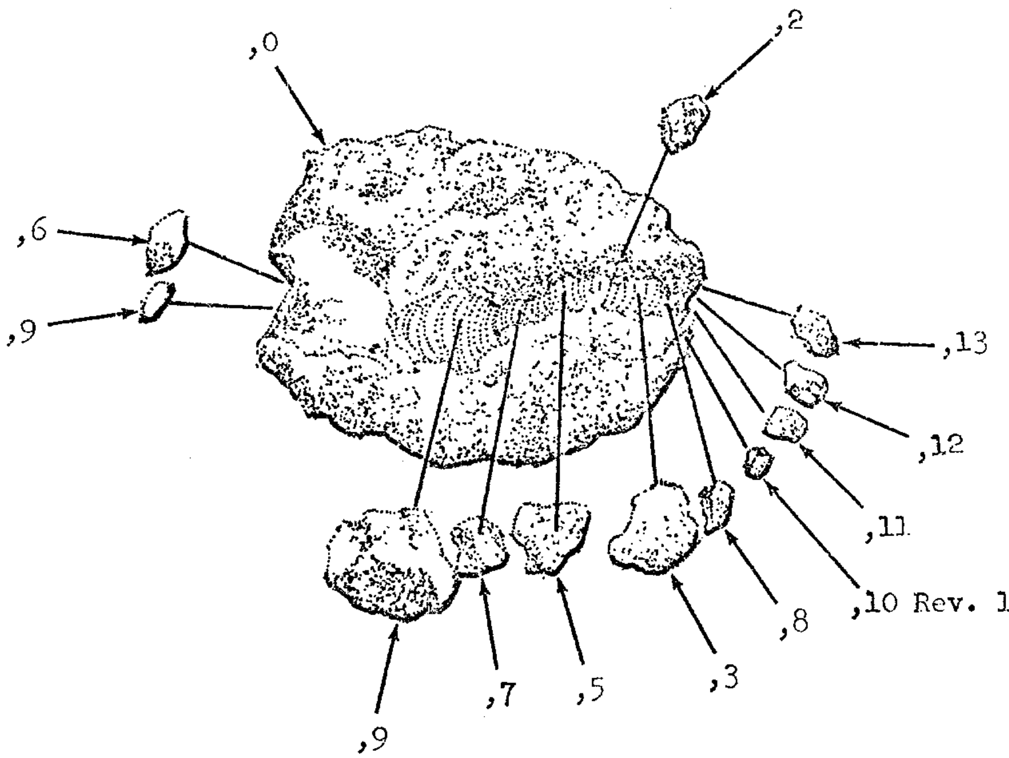


Figure 6. Chipping of 15476.

15485 VITROPHYRIC QUARTZ-NORMATIVE MARE BASALT ST. 4 104.9 g

INTRODUCTION: 15485 is a vitrophyric pigeonite basalt collected from the same vesicular boulder as the similar samples 15486 and 15499 (see Fig. 15499-1) on the south rim of Dune Crater. It is one of the most rapidly cooled of the quartz-normative basalts.

15485 is a vesicular basalt with a porphyritic, diktytaxitic texture (Figs. 1, 2). It is medium-gray, angular, and tough. One surface (laboratory N) is fresh where it was broken from the boulder. There are a few zap pits on B. A greenish yellow powdery material seeped in along a fracture, similar to that which is more abundant on 15486.

PETROLOGY: 15485 contains abundant elongated pyroxene phenocrysts (Figs. 1 to 3) up to 1 cm long in a fine-grained, dark-colored matrix. The pyroxenes are yellow-gray. A general description of thin section ,3 was given in the Apollo 15 Lunar Sample Information Catalog (1972), with a mode of 64% skeletal clinopyroxene phenocrysts, 33% groundmass of plumose intergrowths of pyroxene and plagioclase laths, and 0.1% each of ilmenite, Fe-metal, Cr-spinel, ulvospinel, and troilite. Brown *et al.* (1972) reported 53% phenocrysts in a glassy groundmass, which is a greater abundance of phenocrysts than slower-cooled quartz-normative basalts. The phenocrysts are 1-6 mm prisms, originally with hollow cores, zoned from Mg-pigeonite cores, to sharp discontinuties against narrow augite mantles. Al/Ti is greater in the cores (7 to 10) than in the rims (5 to 7). Spinels also show a sharp discontinuity from a chromite core (in pyroxene) to ulvospinel mantles (in groundmass). The groundmass contains abundant occult plagioclase. Engelhardt (1979) tabulated ilmenite paragenesis.

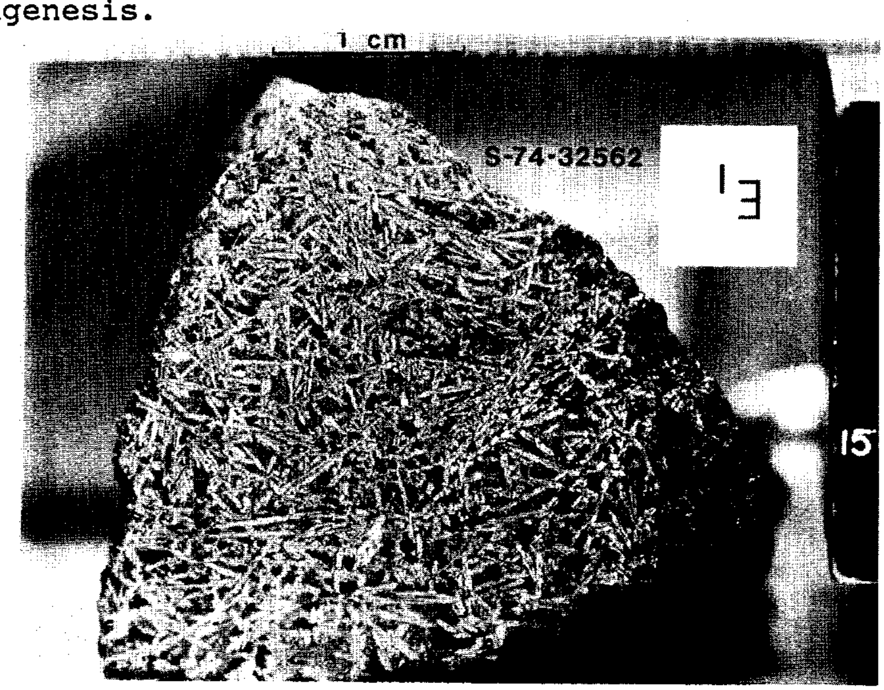
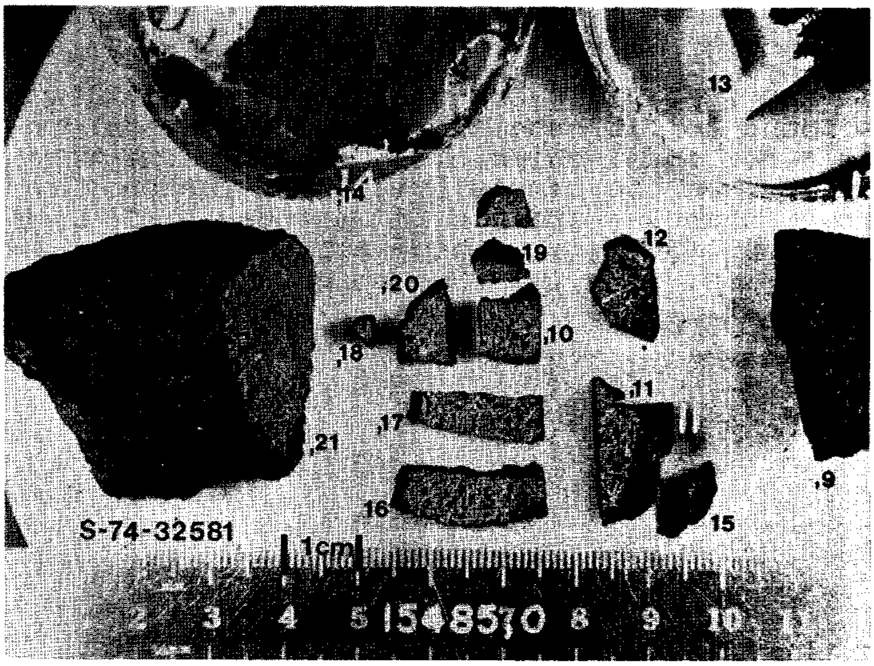


Figure 1. Sawn face of W end piece ,21, showing pigeonite phenocrysts.

Figure 2. Slab subdivisions of 15485.



Cooling history: Lofgren et al. (1975) in a comparison of natural rocks with the products of linear cooling rate experiments on a similar composition (15597) found 15485 to be one of the fastest cooled of the quartz-normative basalts, with phenocryst shapes indicating 5-20°C/hr, and the matrix >30°C/hr. Grove and Walker (1977) made a similar but more sophisticated study, again on comparison of natural rocks with the products of dynamic crystallization experiments. Pyroxene nucleation density indicated a cooling rate at nucleation of ~3.75°C/hr, and pyroxene "size" indicated an integrated rate during pyroxene growth of between 3.75°C and 10°C/hr. The late-stage cooling, from plagioclase "size" indicated 85°C to 250°C/hr. Thus two-stage cooling is most consistent with the rock characteristics. Grove and Walker (1977) suggested a final cooling history 6-9 cm from a conductive boundary.

The fracture filling is represented in thin sections ,5 and ,6. It is a pale-green material, isotropic but fine-grained and not glassy. The particles are mainly submicroscopic (Fig. 4) but some bands are made up of grains almost 10 μm across (e.g., Fig. 4a) which are rounded. Flow structures including current bedding are present, and where the flow-stream was interrupted by cavities, the cavities tend to have accumulated coarser grains and material plucked from the basalt (Figs. 4c, d).

<u>CHEMISTRY</u>: Duncan <u>et al.</u> (1976) presented the only chemical data for 15485 (Table 1), without discussion. The chemistry is fairly typical of A15 quartz-normative basalts.

<u>PROCESSING AND SUBDIVISIONS</u>: One sample originally numbered 15487 was found to fit onto 15485, and was renumbered 15485,1. Apart from a few small chips, most subdivisions were made by sawing a slab from the sample (Fig. 2). The only remaining pieces larger than 3 g are the end pieces ,9 (28.1 g) in remote storage, and ,21 (57.1 g). Thin sections ,3 to ,6 were made from chip ,2 which came from ,1. One other thin section ,31 was made from part of ,20.

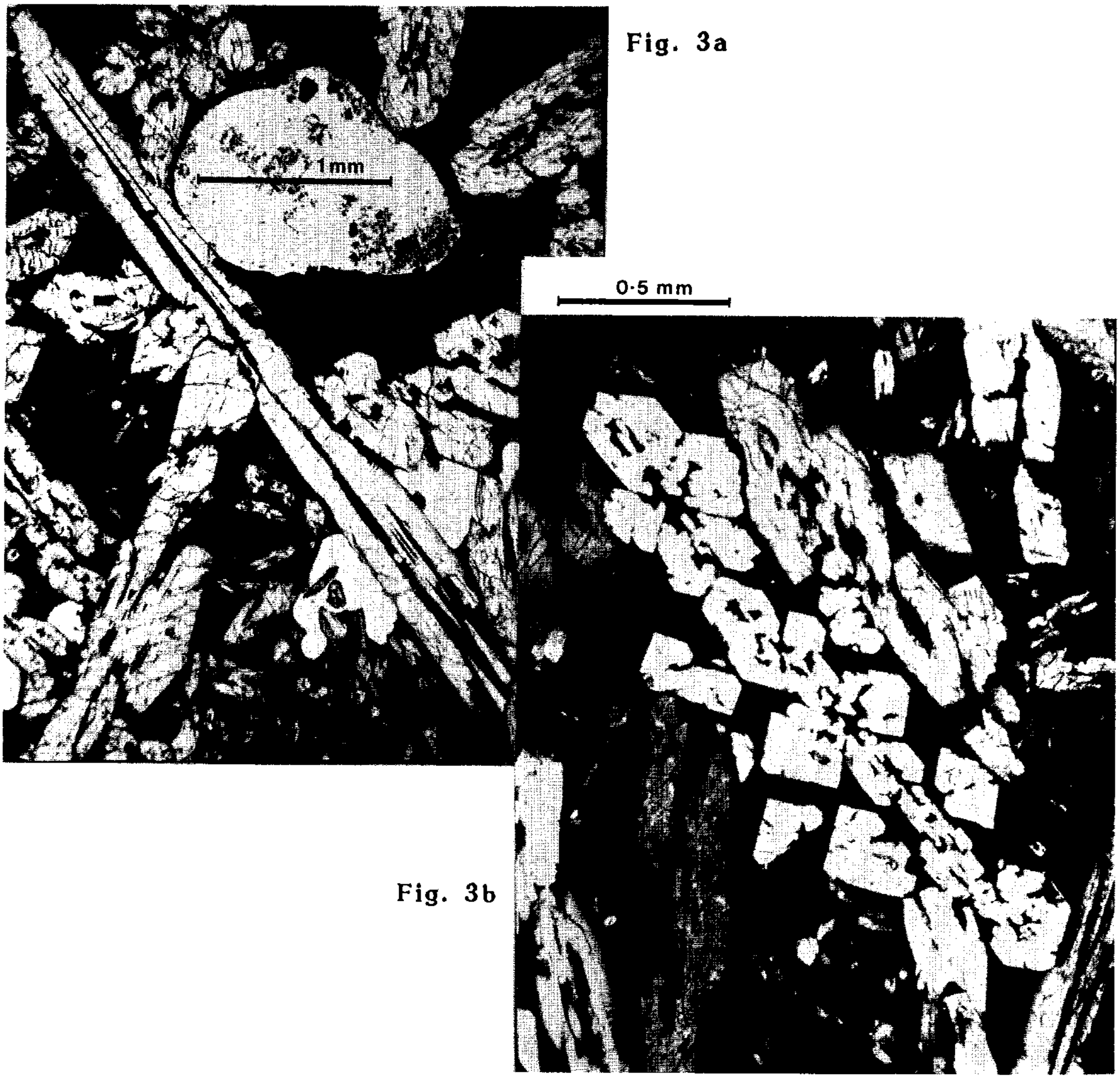


Fig. 3a

Fig. 3b

<u>Figure 3</u>. Photomicrographs of 15485,5 (a) transmitted light, showing skeletal pigeonite phenocrysts, opaque matrix, and vesicles; (b) crossed polarizers, showing single skeletal pyroxene (top left to bottom right).

TABLE 15485-1

		,17
Wt %	SiO2	47.39
	TiO2	1.77
	Al2O3	9.14
	FeO	19.82
	MgO	9.48
	CaO	10.21
	Na2O	0.28
	K2O	0.031
	P2O5	0.084
(ppm)	Sc	
	V	177
	Cr	4000
	Mn	2100
	Co	42
	Ni	22
	Rb	<1.4
	Sr	104
	Y	32.2
	Zr	113
	Nb	5.5
	Hf	
	Ba	71
	Th	
	U	
	Pb	
	La	
	Ce	
	Pr	
	Nd	
	Sm	
	Eu	
	Gd	
	Tb	
	Dy	
	Ho	
	Er	
	Tm	
	Yb	
	Lu	
	Li	
	Be	
	B	
	C	
	N	
	S	640
	F	
	Cl	
	Br	
	Cu	4
	Zn	<2
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

Reference and method:

(1) Duncan et al. (1976); XRF

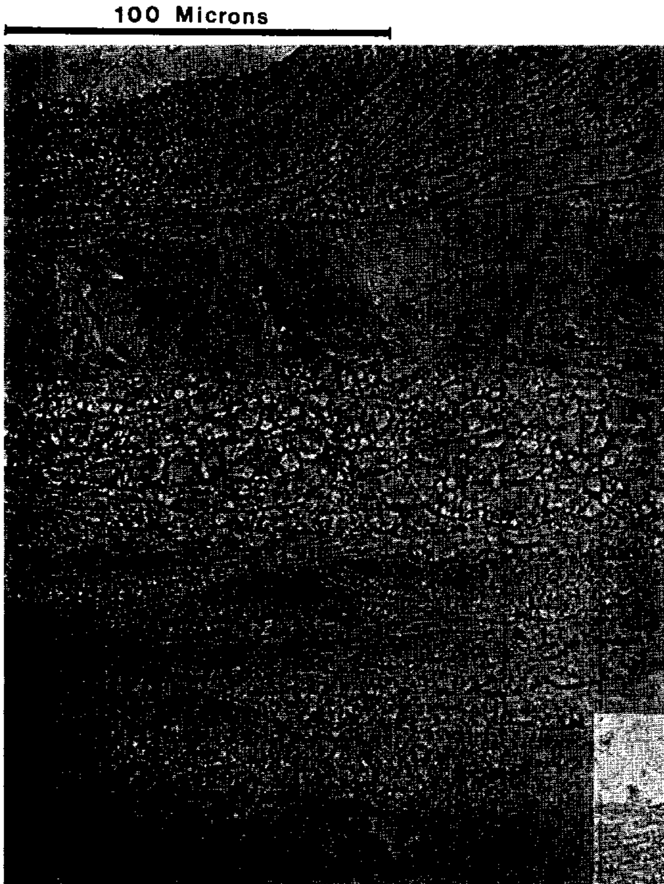


Fig. 4a

Fig. 4b

Figure 4. Photomicrographs of powdery fissure fill in 15485, transmitted light, all to same scale (a)(b)(c) 15485,5 general "sedimentary" structures; (d) coarser grains and debris trapped behind an obstacle in 15485,6.

Fig. 4c

Fig. 4d

15486 VITROPHYRIC QUARTZ-NORMATIVE MARE BASALT ST. 4 46.8 g

INTRODUCTION: 15486 is a vitrophyric pigeonite basalt collected from the same vesicular boulder as the similar samples 15485 and 15499 (see Fig. 15499-1) on the south rim of Dune Crater. It is one of the most rapidly cooled of the quartz-normative basalts.

15486 is a vesicular basalt with a porphyritic, diktytaxitic texture. It is medium dark gray (surface), blocky and angular (Fig. 1) and tough. One surface is fresh where it was broken from the boulder; there are a few zap pits on other surfaces. A light olive gray "coat" on the "N" side (Fig. 1) is related to a fracture and is similar to the one on 15485.

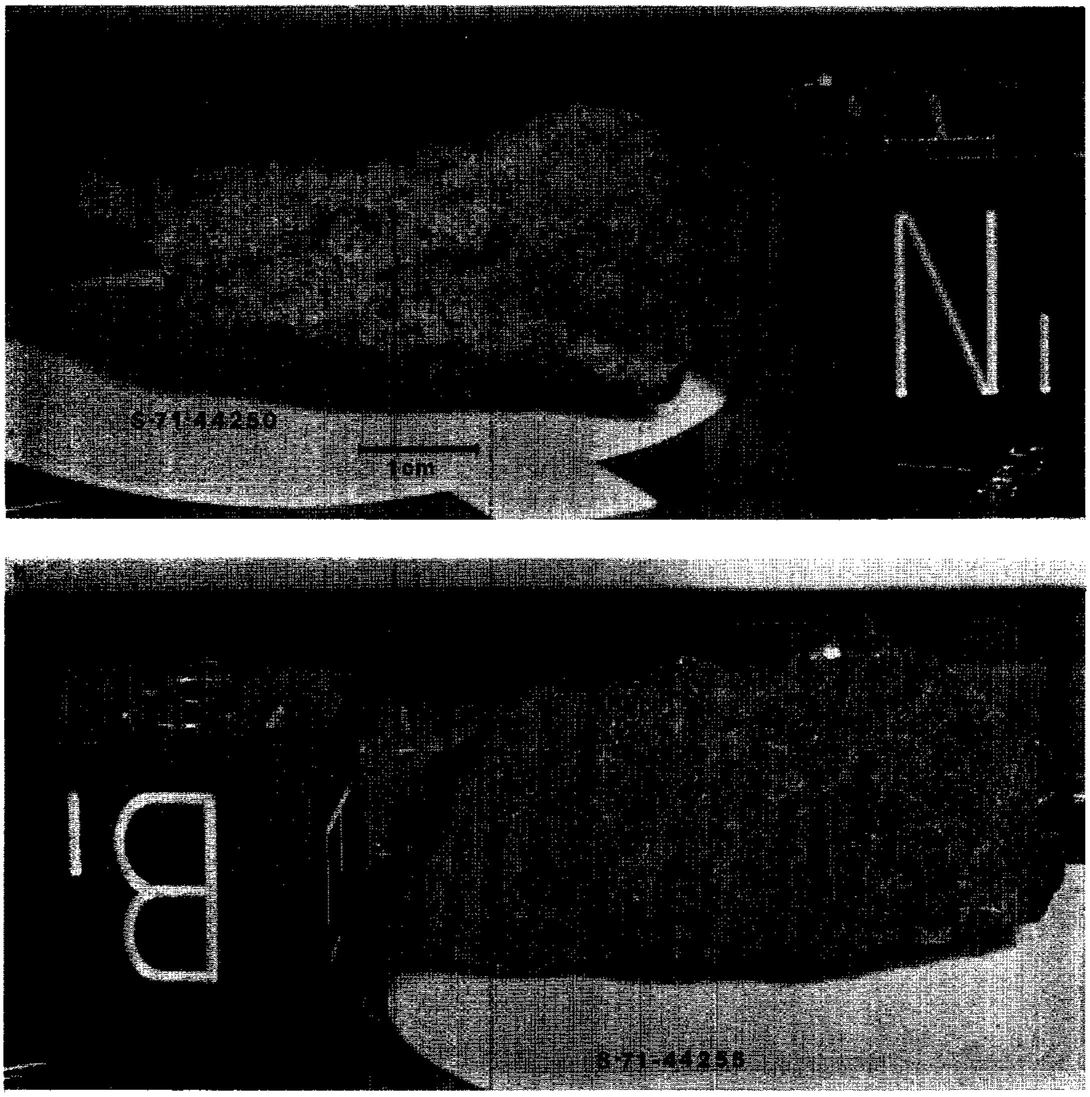


Figure 1. Macroscopic views of original sample, showing the pale-colored coat on "N" side.

PETROLOGY: 15486 contains abundant elongated pyroxene phenocrysts (Fig. 2) which are pale-brown and up to 7 mm long. The groundmass is fine-grained and dark-colored. It was described by Albee et al. (1972) as a clinopyroxene vitrophyre, with (thin section ,20) 53% elongated pyroxene prisms, 44% groundmass of opaque devitrified glass, 3% globulose vugs, and 0.1% each of spinel and metal. No olivine was identified. The groundmass has extremely fine-grained segregations of crystallites, and is predominantly opaque, but a "fingerprint" pattern, consisting of alternating 1 m wide segregations of (pyroxene) and (plagioclase + opaques). 20 m diameter microprobe analyses show the matrix to be homogeneous at that scale, with (normative) 53% feldspar, 35% pyroxene, 7% silica, and 4% opaques. The pyroxenes have cores of low-Ca clinopyroxene enclosed by high-Ca pyroxene (compositions in Fig. 3). Minor element variation is similar to 15499. Spinel and Fe-metal is minor; ilmenite and troilite are "not present as phenocrysts". The spinels (Fig. 4) are euhedral and 20 to 100 m across, and are rimmed with Fe-rich ulvospinel; the ulvospinel rims are broader on groundmass spinels than on those enclosed in pyroxenes. The metals are spherical blebs or aggregates of equidimensional blebs; an average of 8 analyses has 6.28% Ni and 1.42% Co. Engelhardt (1979) tabulated ilmenite paragenesis.

Figure 2. Photomicrograph of 15486,22, transmitted light, showing prismatic pyroxene phenocrysts, opaque groundmass, and vesicles.

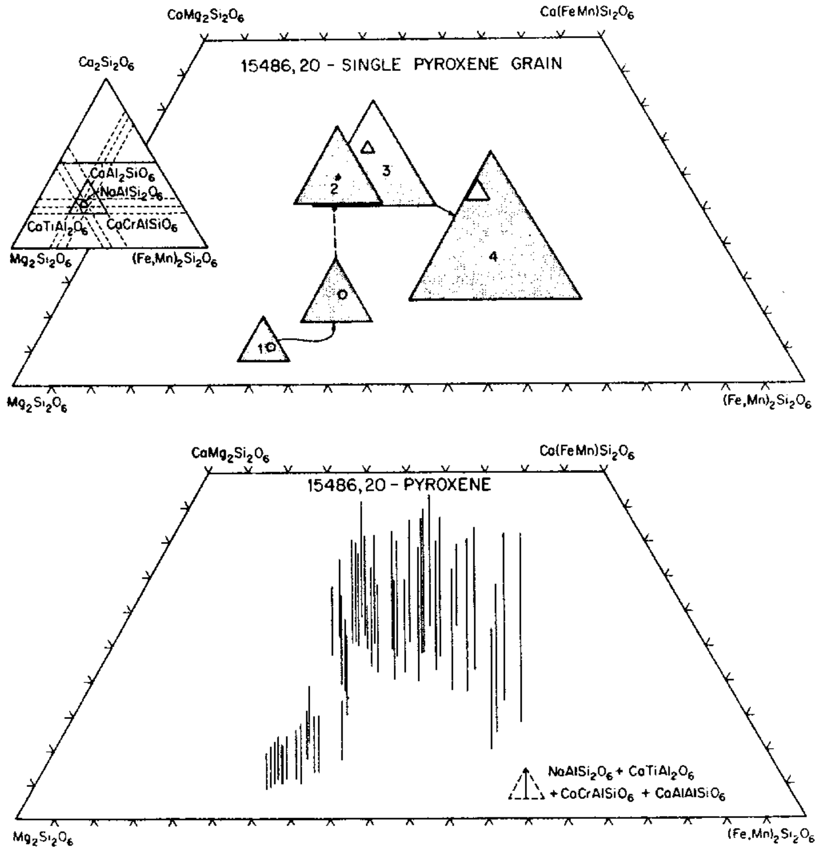


Figure 3. Compositions of pyroxenes in 15486,20 (Albee *et al.* 1972).

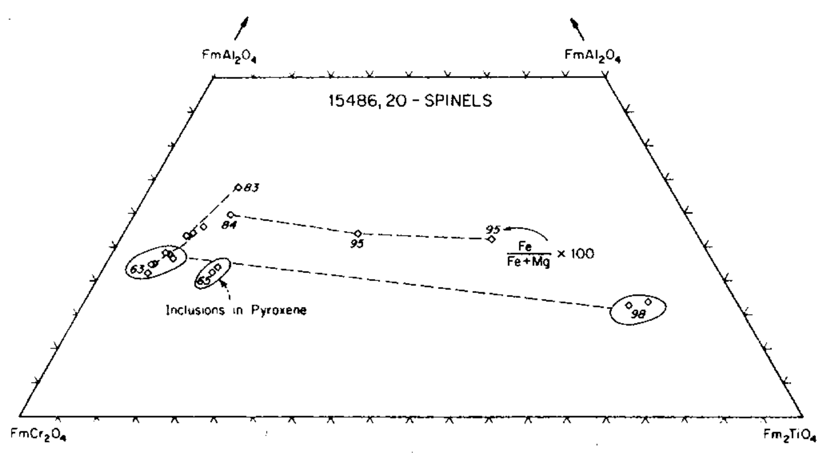


Figure 4. Compositions of spinels in 15486,20 (Albee *et al.* 1972).

Cooling history: Lofgren et al. (1975) in a comparison of natural rock samples with the products of linear cooling rate experiments found 15486 to be one of the most rapidly cooled quartz-normative basalts. From pyroxene shapes a cooling rate of 5°C-20°C/hr was deduced; the matrix suggests >30°C/hr. Grove and Walker (1977) in a similar but more detailed study found a cooling rate during pyroxene nucleation of between 1.75°C and 3.75°C/hr from the nucleation density. An integrated rate during all phenocryst crystallization of 3.75°C/hr from pyroxene "size" and a late-stage rate of 85°C to 250°C/hr from plagioclase "size" were also estimated. They also estimated that this final cooling took place 6-9 cm from a conductive boundary.

Grove and Bence (1977) used the same experiments as Grove and Walker (1977) to compare minor element chemical data from rocks and experiments to establish cooling rates. The minor element chemistry of cores in 15486 is closest to those in 150°C/hr cooling rate experiments, suggesting rapid cooling throughout the crystallization, not just at late stage (this conflict with the result of Grove and Walker, 1977, might result from an inability to analyze actual cores). They suggested that 15486 was totally liquid 4 to 6 cms from the contact of the flow.

CHEMISTRY: Published chemical data are presented in Table 1 and Figure 5. Helmke et al. (1973) suggested that the high Sm/Eu (4.7) of 15486 (and some other samples) makes it different from other quartz-normative basalts (e.g., 15597, 15604, Sm/Eu 3.7) because a difference in this ratio cannot result from pyroxene accumulation.

EXPOSURE: Eldridge et al. (1972) provided cosmogenic radionuclide data, and stated that the sample was apparently shielded. Equilibrium values of ^{22}Na and ^{26}Al show that exposure was too long to determine by the ^{22}Na/^{26}Al method i.e., more than 2 m.y.

PROCESSING AND SUBDIVISIONS: Only a few chips have been separated from the sample. ,0 is 34.7 g, and ,23 is 1.78 g, and no other pieces larger than 1 gram exist. Thin sections ,20 to ,22 were made from chip ,9.

TABLE 15486-1

		,10A	,10	,0
Wt %	SiO2	48.25		
	TiO2	1.81		
	Al2O3	10.00		
	FeO	19.85		
	MgO	8.80		
	CaO	10.25		
	Na2O	0.37		
	K2O	0.08		0.061
	P2O5	0.13		
(ppm)	Sc	54	44.2	
	V			
	Cr	3400		
	Mn	2250		
	Co	100	47	
	Ni	62		
	Rb	1.3		
	Sr	135		
	Y	36		
	Zr	127		
	Nb	10		
	Hf		3.0	
	Ba	74		
	Th			0.64
	U			0.15
	Pb			
	La		7.09	
	Ce		18	
	Pr			
	Nd		1.4a	
	Sm		4.57	
	Eu		0.977	
	Gd		5.5	
	Tb		0.92	
	Dy		5.96	
	Ho		1.2	
	Er		3.0	
	Tm			
	Yb	4.4	2.79	
	Lu		0.44	
	Li	8.8		
	Be	<1		
	B			
	C			
	N			
	S			
	F			
	Cl			
	Br			
	Cu	10		
	Zn			
(ppb)	I			
	At			
	Ga	7800		
	Ge			
	As			
	Se			
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag			
	Cd			
	In			
	Sn			
	Sb			
	Te			
	Cs			
	Ta			
	W			
	Re			
	Os			
	Ir			
	Pt			
	Au			
	Hg			
	Tl			
	Bi			
		(1)	(2)	(3)

References for Table 15486-1

References and methods:

(1) Cuttitta et al. (1973); XRF, OES
(2) Helmke et al. (1973); INAA, RNAA
(3) O'Kelley et al. (1972); Gamma ray spectroscopy

Notes:

(a) evident typographical error; probably should be 14.0

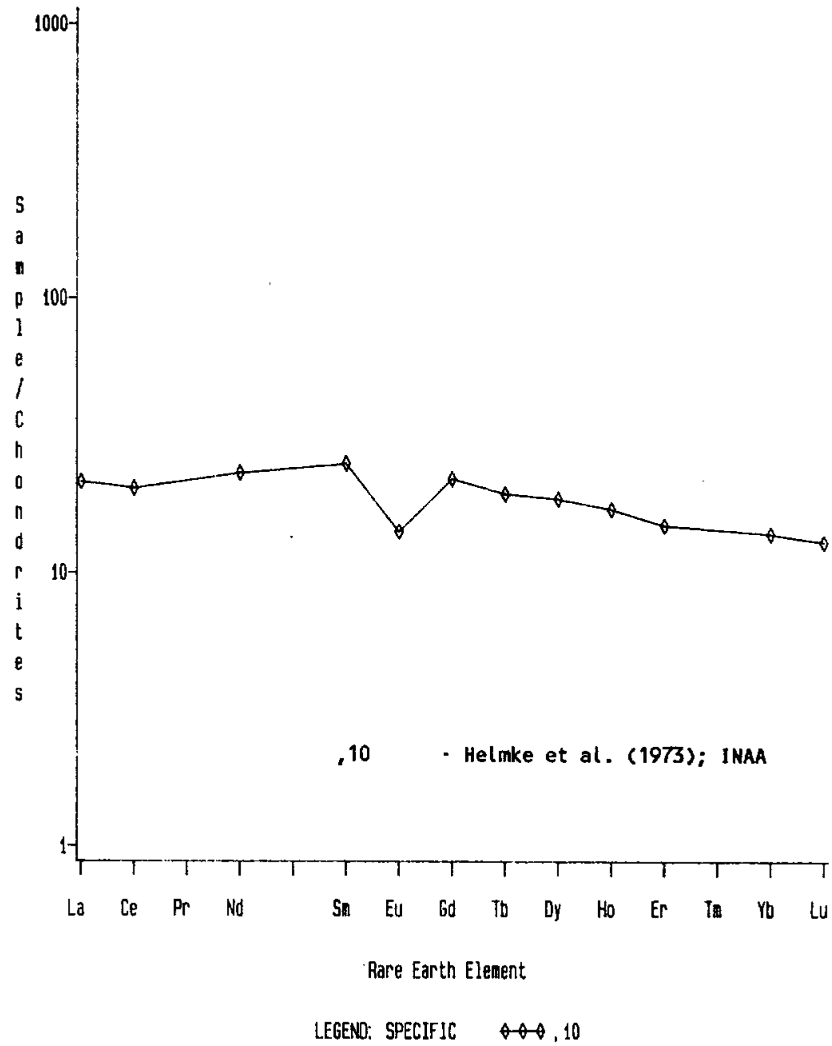


Figure 5. Rare earth elements in 15486. Nd value is 10 x that actually reported.

15495 PORPHYRITIC RADIATE QUARTZ-NORMATIVE MARE BASALT 908.9 g

INTRODUCTION: 15495 is a coarse porphyritic mare basalt, containing zoned phenocrysts of pigeonite up to 2.5 cm long. Its crystallization age has not been determined. It contains 5-10% prominent vugs partly bounded by euhedral pyroxene prisms (Fig. 1). The sample is brownish gray, subangular, and tough. A few zap pits are present on "S", "T", "E", and "B".

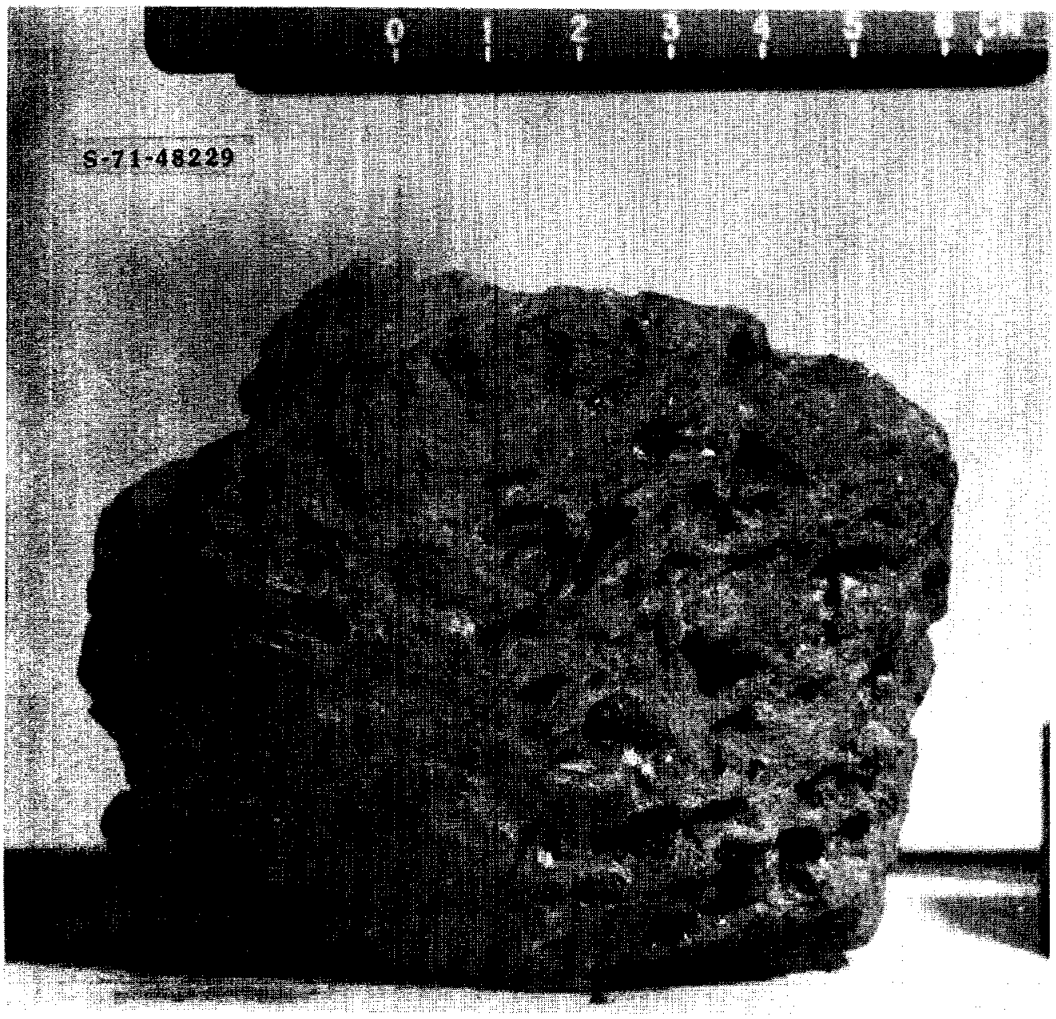


Figure 1. Macroscopic view of "N" face of 15495.

The sample was collected about 28 m south-southeast of the rim crest of Dune Crater, from an area with moderate fragment cover and sparse small craters, and near to rocks 15475 and 15476. Its orientation is known.

PETROLOGY: No comprehensive description of 15495 has been published, but it is clearly a quartz-normative or pigeonite basalt. It consists of coarse (up to 2.5 cm long) complex phenocrysts of pigeonite, radially oriented, embedded in a fine-grained groundmass of pyroxene, plagioclase, opaque phases, and silica glass (Fig. 2). Takeda et al. (1975) made a study of the pyroxenes using single crystal x-ray diffraction and microprobe methods, providing pyroxene analyses and crystallographic parameters. The pyroxenes have pigeonite cores and augite rims. Exsolution is not visible under the microscope, but is shown by x-ray diffraction. Roedder and Weiblen (1972) reported the presence of late-stage immiscible high-silica and high-iron melts in 15495. Huffmann et al. (1972, 1974) in a Mossbauer and magnetic study found that 98% of the iron was in silicates and 1.5% in ilmenite, with 0.076% metallic iron. Humphries et al. (1972) briefly diagrammed results of crystallization experiments (1 atmosphere, equilibrium, fO_2 buffered at iron-wustite) for a sample of 15495. Spinel crystallized just before olivine (about 1240°C) with pigeonite entering at about 1220°C. Olivine reacted out just before plagioclase entry at about 1145°C. The entire was solid somewhere below 1100°C.

Figure 2. Photomicrograph of part of 15495,14 (crossed polarizers). Field of view is about 3 mm.

Cooling history: Cooling rate estimates were made by L. Taylor et al. (1973), Lofgren et al. (1975), and Grove and Walker (1977). L. Taylor et al. (1973) plotted Zr in ilmenite against Zr in ulvospinel, with the results indicating re-equilibration of these phases to below 900°C. The subsolidus Zr in ilmenite/Zr in ulvospinel is a little higher than in 15475 and 15065 (coarser-grained basalts), hence cooled a little faster. This interpretation is consistent with the slightly smaller degree of ulvospinel reduction in 15495 than in 15475 and 15065. Brett (1975) used these data to estimate a minimum flow thickness of 2 meters. Lofgren et al. (1975) compared phenocryst morphologies with those in charges from dynamic (cooling rate) experiments on a quartz-normative basalt composition. The small differences in cooling rate estimated for pyroxene phenocrysts (less than 1°C/hr) and matrix (1 to 5°C/hr) are not interpreted as indicating a two-stage origin but to result from crystallization of a 2 to 3 meter thick flow extruded without phenocrysts. Grove and Walker (1977) also did controlled cooling rate experimental studies of a quartz-normative basalt. By comparison, the phenocryst nucleation density in 15495 suggests an early crystallization rate of 0.05°C/hr, while the integrated rate from the total phenocryst size is slower than 0.5°C/hour. A late stage rate of 0.5°C/hr was derived from plagioclase sizes. They interpreted the data to give results similar to Lofgren et al. (1975) and Brett (1975): final cooling at 133 cm from a conductive boundary, and slow, nearly linear cooling throughout its entire cooling history. Takeda et al. (1975) also discussed cooling rates obtained from their pyroxene data.

CHEMISTRY: Bulk rock chemical analyses are listed in Table 1 and the rare earths plotted in Figure 3. Laul and Schmitt (1973) also analyzed separates of pyroxene, plagioclase, and ilmenite. Christian et al. (1972) and Cuttitta et al. (1973) reported an "excess reducing capacity" of +0.11. Wanke et al. (1975) reported an analysis for oxygen. Flory et al. (1972) reported organogenic compound data from acidolysis and volatilization for different temperature releases, giving abundances of N_2, CO, CH_4, CO_2, and H_2O.

Few of the authors have made specific comment on their data. Laul and Schmitt (1973) noted that the Sm/Eu of 5.4 was higher than that in both 15016 and 15659 (which are both olivine-normative basalts) and all their rake samples. However this high Sm/Eu does not show up in the analysis of Wanke et al. (1975) and is not a usual feature of Apollo 15 basalts. O'Kelley et al. (1972a,b,c) noted that the K abundances are similar to Apollo 11 and 12 samples but that K/U is a little higher. The nitrogen abundance reported by Becker and Clayton (1975) is much lower than in soils and breccias, as would be expected.

TABLE 15495-1. Chemical Analyses of 15495

		,23	,24	,58	,52	,0	,59	,10	,60
Wt %	SiO2	47.98		48.00	49.0				
	TiO2	2.00	1.6	1.80	1.52				
	Al2O3	8.97	8.4	9.57	9.28				
	FeO	20.74	22.0	20.07	19.4				
	MgO	8.96	8	8.42	9.68				
	CaO	10.26	10.6	10.43	10.4				
	Na2O	0.31	0.271		0.327				
	K2O	0.07	0.062	0.062	0.047	0.059			
	P2O5	0.08		0.090	0.062				
(ppm)	Sc	36	46		46.0				
	V	152	240		179.4				
	Cr	2000	3980	3500	3880				
	Mn	2250	2100	2020	2050				
	Co	44	46		44.5				
	Ni	26			47				
	Rb	1.3		<2	0.77		1.032		
	Sr	105		114	108		108.42		
	Y	33		32.2	25				
	Zr	100		126	85				
	Nb	10		7.7	4.7				
	Hf		3.2		2.31				
	Ba	92	<140		68				
	Th				0.43	0.60	0.6331		
	U				0.136	0.16	0.1720		
	Pb						0.4100		
	La	10	8.1		6.03				
	Ce		22		14				
	Pr				2.4				
	Nd								
	Sm		5.4		3.71				
	Eu		1.1		0.87				
	Gd				5.1				
	Tb		0.90		0.91				
	Dy		5.8		5.50				
	Ho				1.2				
	Er				3.1				
	Tm								
	Yb	4.6	3.3		2.46				
	Lu		0.49		0.35				
	Li	6.4			6.2				
	Be	<1							
	B								
	C								
	N							3.5	
	S				654				569
	F				27				
	Cl				6.0				
	Br				0.024				
	Cu	12			27.2				
	Zn				1.3				
(ppb)	I								
	At								
	Ga	4200			3270				
	Ge				<50				
	As				5.5				
	Se				<60				
	Mo								
	Tc								
	Ru								
	Rh								
	Pd				<10				
	Ag								
	Cd								
	In								
	Sn								
	Sb								
	Te								
	Cs				32				
	Ta		500		310				
	W				168				
	Re				1.8				
	Os								
	Ir								
	Pt								
	Au				0.26				
	Hg								
	Tl								
	Bi								
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)

References for Table 15495-1

References and methods:

(1) Christian et al. (1972); XRF, chemical, optical emission spec.
(2) Laul and Schmitt (1973); INAA.
(3) Willis et al. (1972); XRF
(4) Wanke et al. (1975, 1977); XRF, INAA, RNAA.
(5) O'Kelley et al. (1972a, c); gamma ray
(6) Barnes et al. (1973); isotope dilution, electro-deposition, mass spec.
(7) Becker and Clayton (1975); pyrolysis.
(8) Thode and Rees (1972);

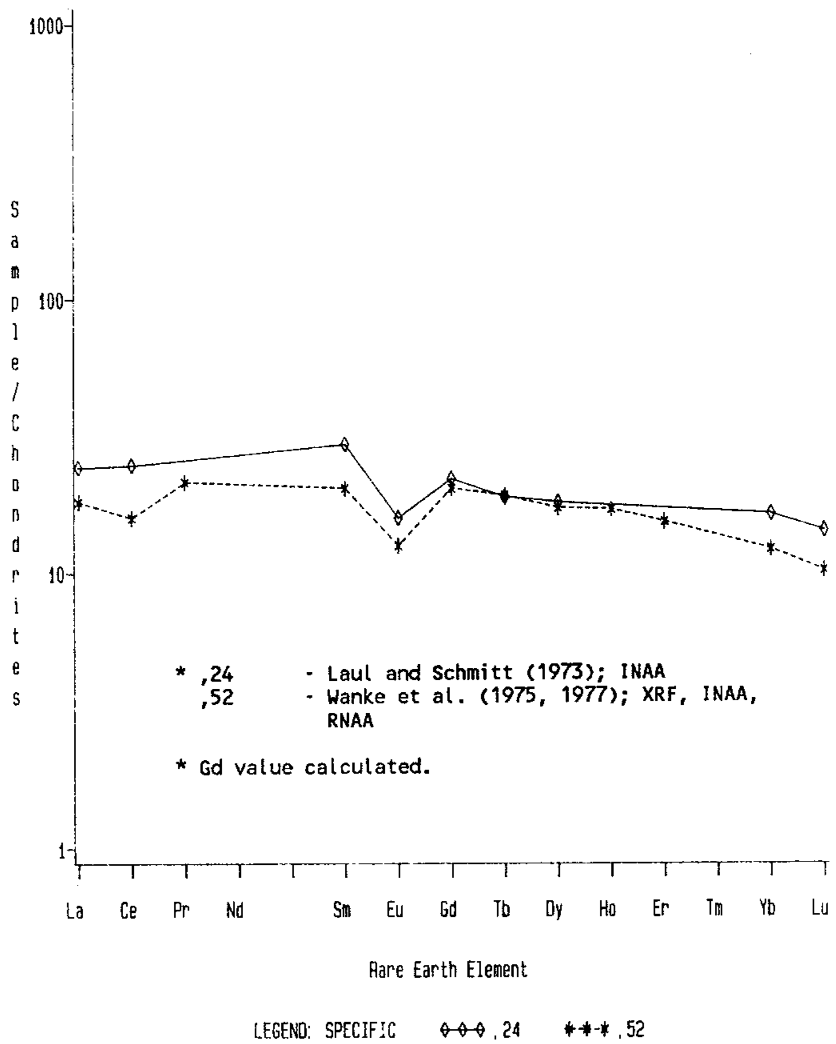


Figure 3. Rare earth abundances for 15495.

STABLE ISOTOPES: Becker and Clayton (1975) reported $\delta^{15}N$ °/oo as +89 (±5%) which differs from 12063, another mare basalt analysed, by 100%. They suggested that even in basalts, spallation must be considered, otherwise nitrogen should be isotopically homogeneous. Thode and Rees (1972) reported $\delta^{34}S$ °/oo of +0.24, similar to other basalts and lower than soils (+5 to +10). Barnes et al. (1973) reported K isotopic data: 39/41 of 14.004 and 13.999; and 40/41 of 0.001855 and 0.001859.

RADIOGENIC ISOTOPES: Barnes et al. (1973) reported Pb and Sr isotopic data for whole rock samples. They calculated the model ages listed in Table 2.

TABLE 15495-2. Pb and Sr model ages for 15495 (Barnes et al., 1973)

ISOTOPE SYSTEM	MODEL AGE (m.y.)
207/206	4500
206/238	4423
207/235	4476
208/232	4533
87/86*	4509

* λ : ± 1.39 x 10^{-11} yr^{-1}

EXPOSURE AGES: O'Kelley et al. (1972b,c) and Eldridge et al. (1972) reported cosmogenic nuclide disintegration data (gamma ray spectrometry) for ^{22}Na, ^{26}Al, ^{46}Sc, ^{48}V, ^{54}Mn, and ^{56}Co. The Co, Mn, and Na isotopes are close to saturation from exposure to solar and galactic rays; the exposure may be low, i.e., about 2 m.y. Yokoyama et al. (1974) stated that ^{26}Al is unsaturated, an agreement with a 2 m.y. or less exposure.

PHYSICAL PROPERTIES: Nagata et al. (1972, 1973) listed basic magnetic properties for split ,52 (Table 3). A thermomagnetic curve is similar to that for other basalts; iron metal is the ferromagnetic constituent. Banerjee and Mellema (1973) obtained a paleofield of 2200 (±~ 15%) gammas using the ARM method, while Murthy and Banerjee (1973) quoted stable magnetism less than 0.3 x 10^{-6} emu/g. Collinson et al. (1975) noted that the Banerjee and Mellema (1973) interpretation must be treated with caution because the method is actually only valid for single domain grains whereas lunar samples usually contain multidomain particles.

TABLE 15495-3. Magnetic properties of 15495 (Nagata et al., 1973)

Property	Value	Units
spec. paramag. susc Xa	3.8×10^{-5}	emu/g
saturation mag. 4.2°K I_s	0.98	emu/g
saturation mag. 300°K I_s	0.165	emu/g
saturation rem. mag. 4.2°K I_s	0.078	emu/g
saturation rem. mag. 300°K I_s	0.00075	emu/g
coercive force 4.2°K H_c	87	Oersteds
coercive force 300°K H_c	10	Oersteds
T at which H_c and Ir sharply change	120	°K

PROCESSING AND SUBDIVISIONS: 15495 has been substantially dissected and allocated. Originally one end was sawn off, chips removed, and the end piece substantially dissected by sawing into three strips (Fig. 4). Most original allocations were from this end-piece. A second piece at right angles (,61; 94.0 g) was subsequently sawn off and is a display sample. A second cut parallel to the first was made in 1979 and sawn into small pieces (Fig. 5), several of which were allocated. ,0 is now 574.0 g.

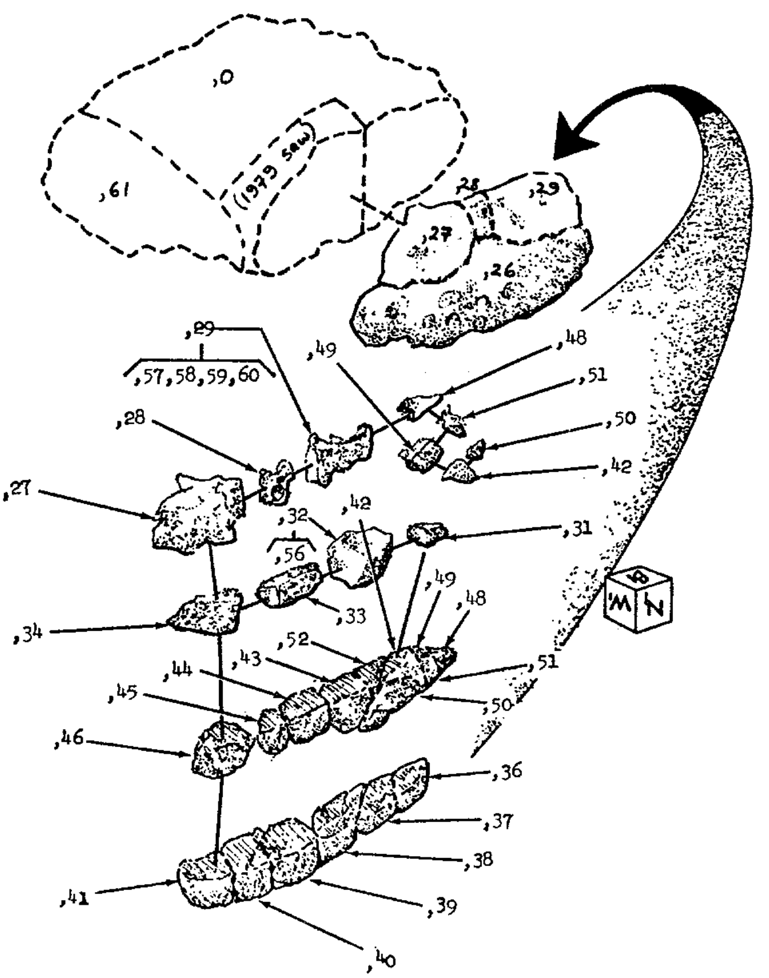


Figure 4. Dissection of 15495.

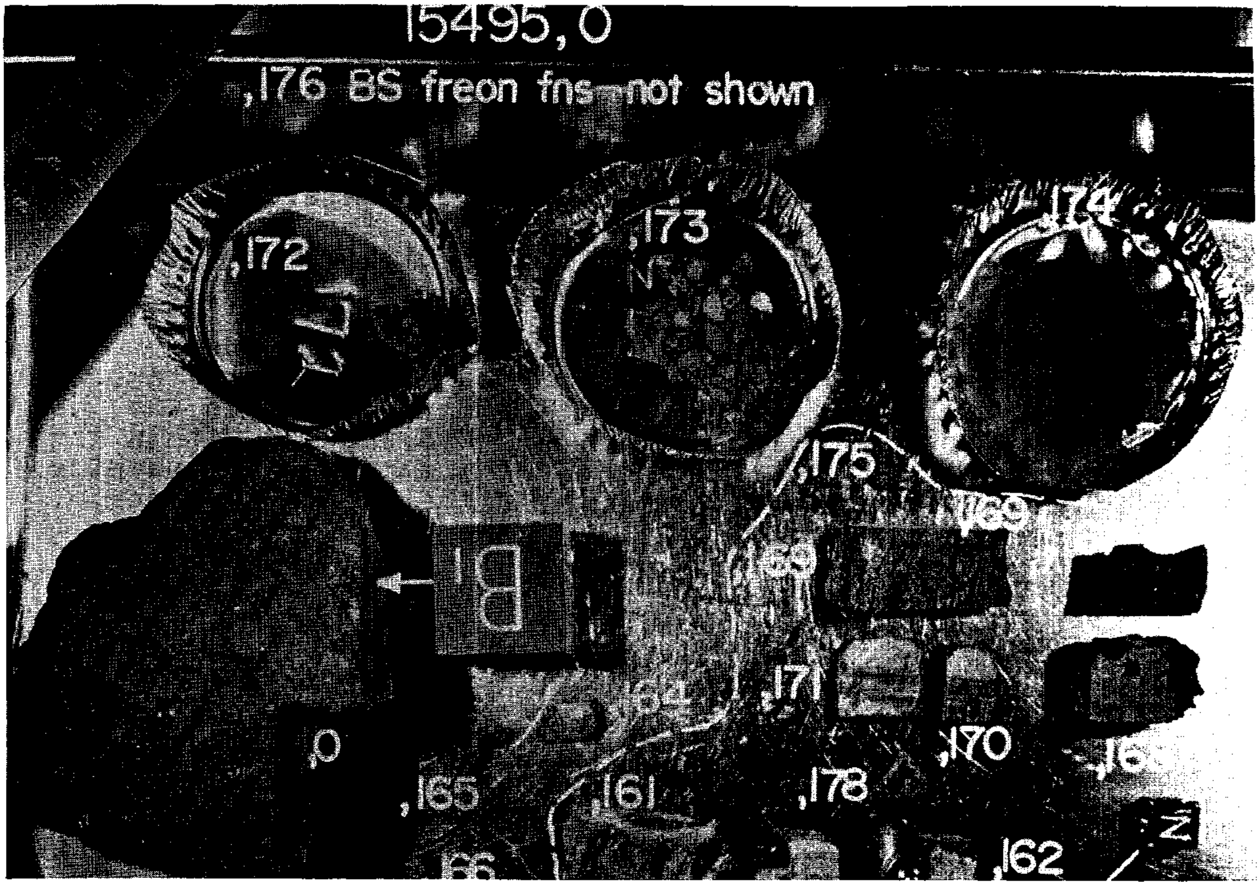


Figure 5. Subsplits of 1979 saw cut and remainder of ,0.

15498 REGOLITH BRECCIA, GLASS-COATED ST. 4 2339.8 g

INTRODUCTION: 15498 is a coherent, glassy matrix breccia (Figs. 1, 2) with components mainly of mare derivation, including basalt fragments and glass. It is partly covered with vesicular black glass and has fissures filled with glass. It was originally described (Apollo 15 Lunar Sample Information Catalog, 1971) as recrystallized, but subsequent work has shown that interpretation to be in error. Its composition is rather similar to that of regolith collected at Station 4.

15498 was collected at the south rim of Dune Crater, near the boulder from which samples 15485, 15486, and 15499 were taken (Fig. 15485-1). It was one-third to one-half buried in the fillet on that boulder. It is dark gray and angular with a thin, partial glass coat (Fig. 1). It has a few zap pits on one side. It was originally studied in a consortium headed by B. Mason.

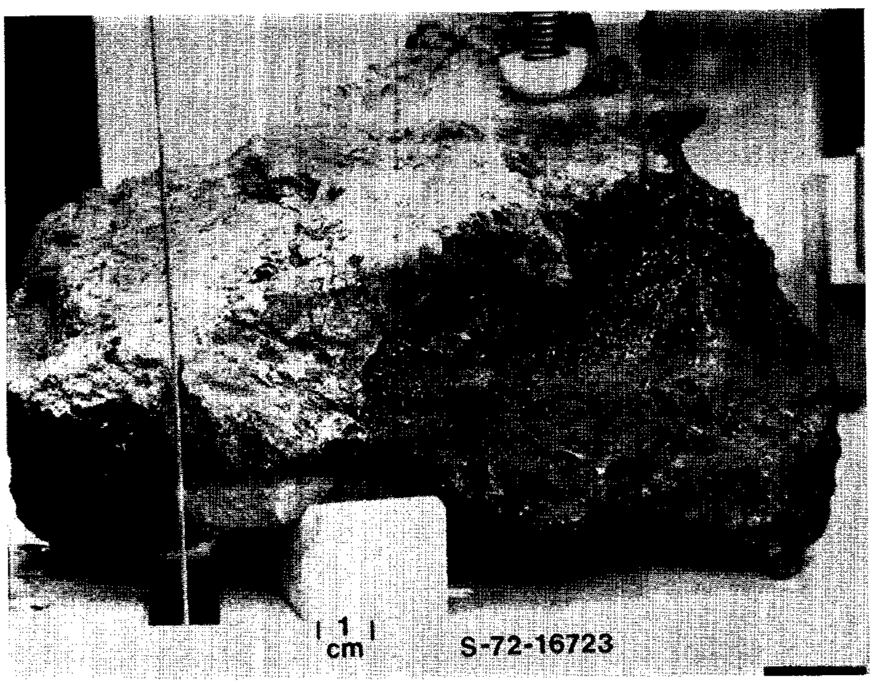


Figure 1. 15498 prior to sawing, showing angular nature and vesicular glass.

PETROLOGY: 15498 is medium to dark gray with a brown tint. Clasts larger than ~0.2 mm compose ~85% of the rock; the rest is a glassy matrix (Figs. 2, 3). Glass cuts (veinlets) and surrounds (selvages) clasts, and occurs as a partial coat. Most of the components are of mare origin: basalt fragments, pyroxene fragments, opaque fragments, and mare glasses. McKay and Wentworth (1983) found it to be compact, with intermediate fracture porosity, and to have rare agglutinates, minor spheres, and abundant shock features. Wentworth and McKay (1984) found it to have a bulk density of 2.43 g/cm^3, with a calculated porosity of 23.8%. Its I_s/FeO of 19-29 (McKay et al., 1984) or 18 (Korotev, 1984 unpublished) is immature.

Figure 2. Sawn face of 15498,0, showing pale-colored, cm-sized clasts.

<u>Figure 3</u>. Photomicrographs (transmitted light) of 15498 matrix.

Mason (1972) described the general petrography of the sample. Numerous irregularly-shaped clasts, all lighter in color than the matrix and up to 1 cm across, are prominent. The breccia is well-indurated and tends to break through clasts. It consists of rock, mineral, and glass fragments, with glass spherules and fissures, the whole welded together with interstitial glass. Rock fragments are mainly mare basalts, similar to those from Dune Crater; some show shock effects. One 0.6 mm fragment is an Apollo 15 KREEP basalt; other plagioclase-rich fragments are not uncommon, particularly among the larger clasts. Mineral fragments compose about half the rock: pyroxenes are almost entirely pigeonites or subcalcic augites with a wide range in composition. The compositions and proportions of minerals are similar to local soils. Glass forms 10% of the non-matrix material. Spheres are rare and small, and most glass occurs as shards. The fissure fillings are vesicular, gray-green glass, whose composition is similar to the bulk rock and to local fines (Table 2). The mineralogy and petrology suggest strongly that 15498 is a local regolith, lithified largely by welding of interstitial glass.

Pearce et al. (1976) described one thin section, ,8, of which 20% is a single olivine gabbro (mare) clast. The rest is glassy matrix (53%) and lithic and mineral clasts (46%), with abundant maskelynite. Metal is estimated to compose 0.01% of the volume (less than that determined by other methods) and is observable in sizes less than 1 μm to 45x18 μm. The iron-nickel metal occurs as single phase particles in glass, in pyroxene, and between fragments. Even the metal grains in the matrix have Co higher than the "meteoritic" range (Fig. 4).

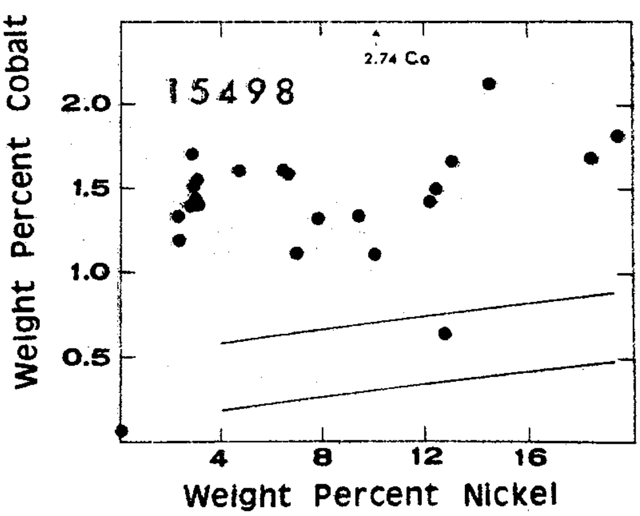


Figure 4. Compositions of metals in 15498 (Pearce et al., 1976).

Christie et al. (1973) studied 15498 with optical and high-voltage electron microscopy techniques. They found low porosity, no evidence for recrystallization, and 50% glass matrix. Most clasts show extensive evidence of deformation, and none show no deformation; Christie et al. (1973) interpreted this observation to mean that deformation took place in situ. There is no evidence for clast annealing as in some higher-grade rocks. They concluded that 15498 formed from unconsolidated regolith by the passage of shock waves of a few tens of kilobars.

Steele et al. (1980) made ion-probe analyses of the plagioclase in the basalt clast in ,8, finding 7.4 ppm Li, 10.8 Wt % Ab, 1690 ppm Mg, 465 ppm K, 435 ppm Ti, 350 ppm Sr, and 25 ppm Ba.

Uhlmann's group (Uhlmann and Klein, 1976; Uhlmann and Onorato, 1979; Yinnon et al., 1980; and Uhlmann, 1981) studied the viscous flow and crystallization behaviour of a glass purportedly of 15498 composition in order to constrain the thermal history of 15498. The data are used in models of varying complexity to determine cooling rates. However, the composition used is unlike any published analysis of 15498, being much higher in Al_2O3 (19.8%) and lower in FeO (8.4%) than data in Table 1, hence the results are not of direct application. In a study on 15498 glass itself, Uhlmann and Klein (1976) found that annealing increased its density, a characteristic which suggests that it formed by cooling from a molten state, not from shock which would already have given it a high density. They thus suggested that the shock features observed by Christie et al. (1973) are unrelated to lithification itself.

CHEMISTRY: Published analyses of 15498 are listed in Tables 1 and 2, with rare earths plotted on Figure 5. The identities of the two splits analyzed by Laul and Schmitt (1973) are not precisely known: they were listed as breccia "clasts" but the samples from which they were taken were general matrix. The similarity of their K, U, and Th with the determinations on the bulk rock (,0; O'Kelley et al., 1972) suggest that they are general matrix samples. The matrix is similar to local soil compositions and 15498 was thus presumed by Laul et al. (1972) and others to be lithified soil. The glass fissure analysis is similar to the Laul and Schmitt (1972) "clast" analyses. The abundant mare component is conspicuous. The analysis of Wanke et al. (1976) is of a light gray clast, and it is clearly a mare basalt. The Si, Fe, Sc, and Th abundances strongly suggest that it is a quartz-normative basalt.

Modzeleski et al. (1972) reported data for compounds of carbon i.e., CO, CO_2, and CH_4; and Kaplan et al. (1976) also reported CH_4 data (as C = 12.6 ppm). Wanke et al. (1977) reported an oxygen analysis for the mare basalt clast. Kaplan et al. (1976) used an acid hydrolysis method to determine an Fe-metal abundance of 0.53%.

TABLE 15498-1. Bulk analyses of 15498

		,45A	,46A	,0	,32	,31	,126
Wt %	SiO2						
	TiO2	1.6	1.6				1.93
	Al2O3	12.9	13.7				11.2
	FeO	17.3	16.7				17.9
	MgO	10	11				9.7
	CaO	10.8	11.1				8.5
	Na2O	0.385	0.395				0.36
	K2O	0.13	0.13	0.1374			
	P2O5						
(ppm)	Sc	34	31				34.1
	V	160	150				117
	Cr	3150	3100				3090
	Mn	1700	1600				1175
	Co	43	44				45.7
	Ni						169
	Rb						
	Sr						120
	Y						
	Zr						250
	Nb						
	Hf	5.7	5.3				6.7
	Ba	140	150				149
	Th	1.9	2.1	2.5			2.4
	U	0.7	0.7	0.65			0.68
	Pb						
	La	15	16				15.4
	Ce	42	43				43
	Pr						
	Nd						25
	Sm	7.8	7.8				7.92
	Eu	1.2	1.2				1.24
	Gd						
	Tb	1.6	1.6				1.66
	Dy	9.6	10				
	Ho						
	Er						
	Tm						
	Yb	5.5	5.8				5.6
	Lu	0.79	0.85				0.75
	Li						
	Be						
	B						
	C				16.4	62	
	N					55	
	S					660,680	
	F						
	Cl						
	Br						
	Cu						
	Zn						
(ppb)	I						
	At						
	Ga						
	Ge						
	As						
	Se						
	Mo						
	Tc						
	Ru						
	Rh						
	Pd						
	Ag						
	Cd						
	In						
	Sn						
	Sb						
	Te						
	Cs						150
	Ta	800	800				830
	W						
	Re						
	Os						
	Ir						7.1
	Pt						
	Au						1.6
	Hg						
	Tl						
	Bi						
		(1)	(1)	(2)	(3)	(4)	(5)

References and methods:

(1) Laul and Schmitt (1973); INAA
(2) O'Kelley et al. (1972); Gamma ray spectroscopy
(3) Modzeleski et al. (1972); Vacuum pyrolysis/MS
(4) Kaplan et al. (1976); Pyrolysis/hydrolysis
(5) Korotev (1984 unpublished); INAA

TABLE 15498-2

		,52 CLAST	GLASS FISSURE
Wt %	SiO2	47.1	47.4
	TiO2	1.97	1.9
	Al2O3	9.8	12.8
	FeO	19.19	16.8
	MgO	9.1	10.5
	CaO	10.1	9.8
	Na2O	0.255	0.41
	K2O	0.041	0.11
	P2O5	0.087	
(ppm)	Sc	45.9	
	V	182	
	Cr	4020	
	Mn	2070	
	Co	44.9	
	Ni	90	
	Rb	0.80	
	Sr	75,83	
	Y	35	
	Zr	94	
	Nb	10	
	Hf	2.49	
	Ba	60	
	Th	1.08	
	U	0.18	
	Pb		
	La	5.93	
	Ce	18.0	
	Pr	2.40	
	Nd	12	
	Sm	3.58	
	Eu	0.76	
	Gd	4.91	
	Tb	0.79	
	Dy	5.35	
	Ho	1.09	
	Er	3.19	
	Tm		
	Yb	2.62	
	Lu	0.37	
	Li	7.7	
	Be	1.12	
	B		
	C		
	N		
	S	670	
	F	31	
	Cl	4.2	
	Br	0.034	
	Cu	7.73	
	Zn	15	
(ppb)	I		
	At		
	Ga	3000	
	Ge	<250	
	As	1.5	
	Se	*30	
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd		
	In		
	Sn		
	Sb		
	Te		
	Cs	40	
	Ta	390	
	W	96	
	Re		
	Os		
	Ir		
	Pt		
	Au	0.13	
	Hg		
	Tl		
	Bi		
		(1)	(2)

References and methods:

(1) Wanke et al. (1977); Combined XRF, INAA, etc.
(2) Mason (1972); Microprobe

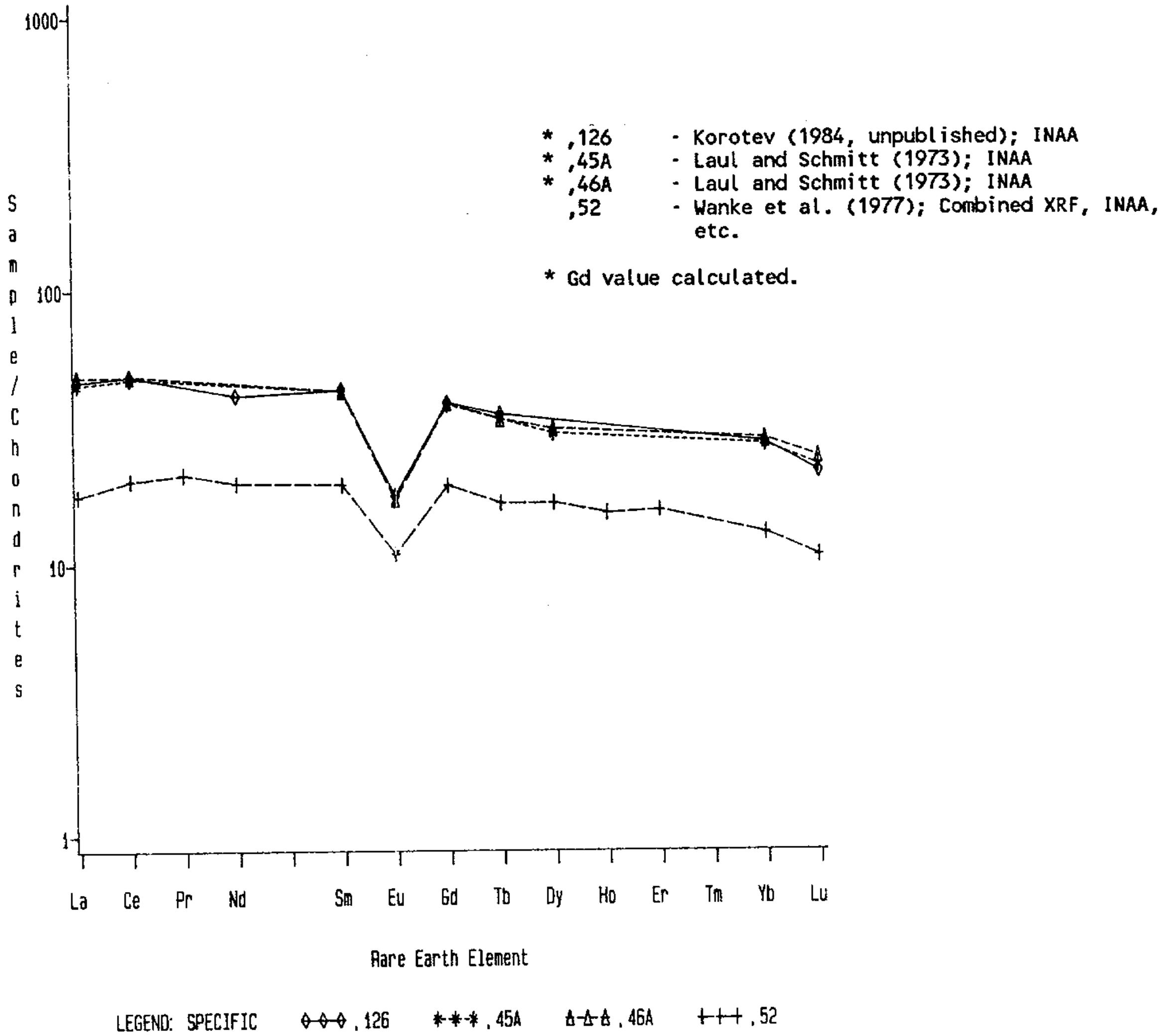


Figure 5. Rare-earths in materials from 15498.

STABLE ISOTOPES: Kaplan et al. (1976) reported isotopic ratios for light elements: $\delta C^{13} = -19.9$, $\delta^{15}N = -41$, $\delta^{34}S$ (from combustion) = +8.0, and $\delta^{34}S$ (from hydrolysis) = +5.1. The nitrogen and carbon isotopes are quite dissimilar from typical soils, even though the absolute abundances are similar to soils.

RARE GASES AND EXPOSURE: Bogard and Nyquist (1972) and PET (1972) tabulated noble gas contents and isotopic abundances. Kaplan et al. (1976) reported He abundances, which are lower than soils. Megrue (1972, 1973) reported noble gas isotopic abundance for four splits (laser probe, mass spectrometry methods). The essential gas component is a highly fractionated solar wind, with cosmogenic gases primarily within a light-colored lithic fragment and the fine-grained matrix in one sample. Glass from sample ,55 requires a source separate from the others. The data suggest that 15498 is a consolidated lunar soil.

The data of Eldridge et al. (1972) suggest that ^{26}Al is saturated, thus 15498 has been exposed at least 2 m.y.

PHYSICAL PROPERTIES: Gose et al. (1972, 1973a) and Pearce et al. (1973) found a paleomagnetic intensity of 2100 ± 85 gammas using the Thellier-Thellier method, one of the few intensities considered at all reliable (however, Collinson et al. (1975) stated that this intensity is uncertain because of the way the slope of the data is constrained on a plot of NRM lost vs. pTRM gained, and they suggested a revised intensity of at least 7,000 gammas). Gose et al. (1972) also tabulated basic magnetic data derived from hysteresis loops. They found 0.34% metallic iron, like soils, which is not meteoritic but from subsolidus reduction of Fe^{2+}. 15498 is very unusual under demagnetization in having an extremely stable intensity which does not change in direction (Fig. 6). At the same time it shows a strong viscous remanent magnetization acquisition (see also Gose et al., 1973b), with a classical Richter-type effect similar to Apollo 14 low-grade breccias and typical of rocks containing metal grains of a few hundred angstroms size. The high stability is undoubtedly due to the presence of single domain grains.

Pearce et al. (1976) reported magnetic data from heating and thermal demagnetization of ,36 and found no reason to doubt their previous 2100 gammas paleointensity determination. Hale et al. (1978) studied a small clast, too small to permit analysis of hysteresis characteristics, using microwave heating (in an attempt to determine its usefulness) and conventional heating techniques; they depicted demagnetization curves for NRM, ARM, and IRMs. The paleointensity determined following microwave heating was 27000 gammas, significantly higher than that of Gose et al. (1972, 1973a).

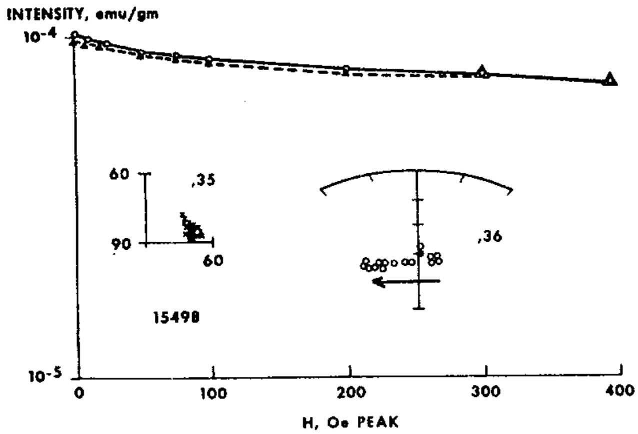


Figure 6. Change in intensity and direction upon AF demagnetization of 15498,35 and ,36 (Pearce et al., 1973).

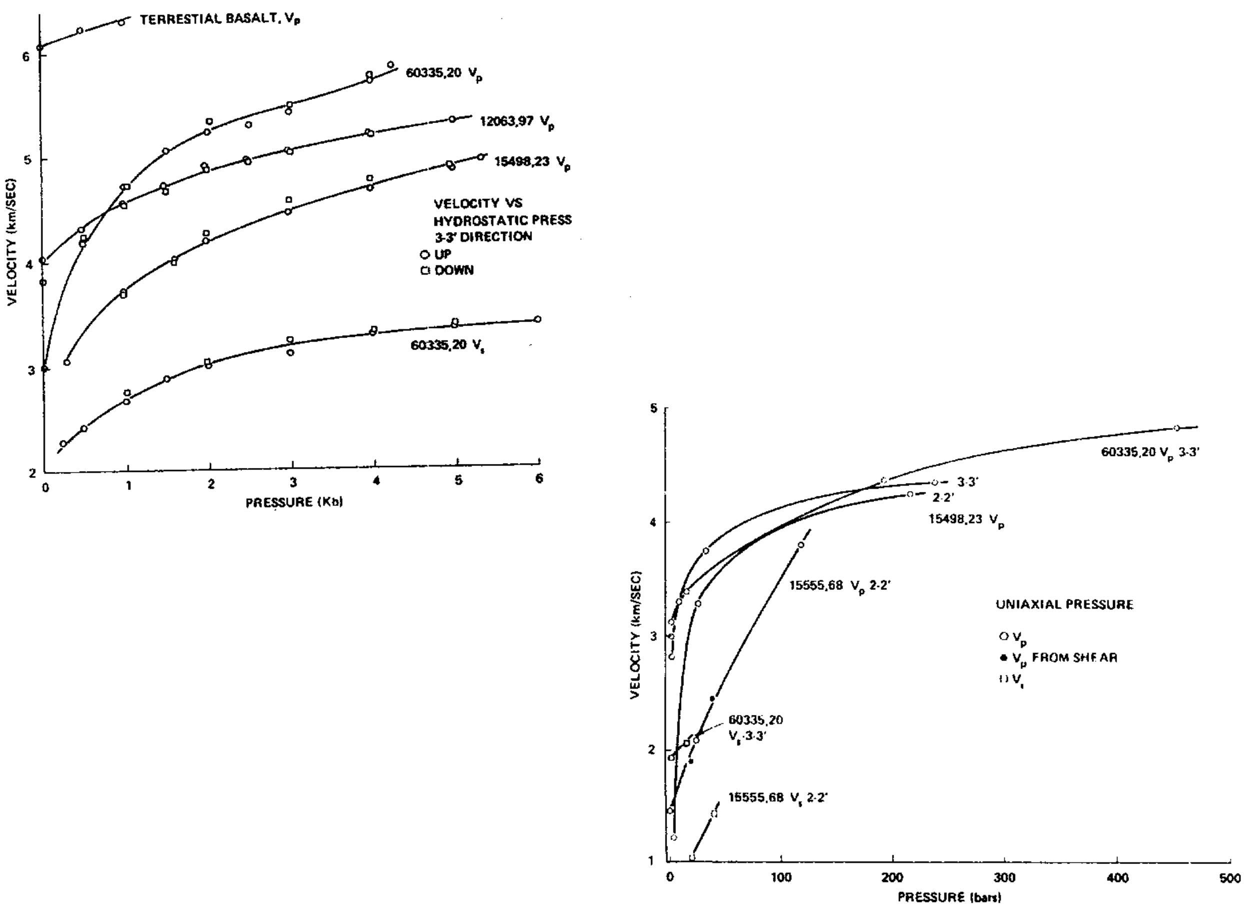


Figure 7. Velocity profile for 15498 (a) hydrostatic pressure (b) uniaxial loading (Warren et al., 1973).

Brecher (1975, 1976) listed 15498 as an example showing magnetic "textural remanence" on account of its stable direction of NRM under AF-demagnetization. Housley et al. (1976) presented ferromagnetic resonance (FMR) spectra for 15498, listing the response as strong, and similar to lunar fines.

Warren et al. (1973) depicted the variation of Vp with pressure, both hydrostatic and under uniaxial loading (Fig. 7). They also plotted strain vs. pressure (Fig. 8); at high pressure strains become homogeneous and independent of orientation. Trice et al. (1974) depicted linear strain measurements made up to 5 Kb hydrostatic pressure (Fig. 9).

Alvarez (1975) used 15498 to study the effect of solar radiation on electrical properties (which are normally measured in the dark). His photoconductivity studies showed a 5-fold increase in surface conductivity when the sample was illuminated for 22 minutes with infrared and ultraviolet sources. Since this was far from reaching equilibrium, real values are probably more than 5-fold increases.

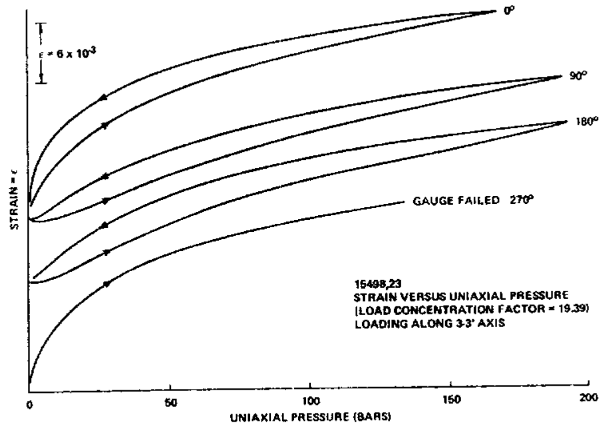


Figure 8. Strain results under axial loading for 15498,23 (Warren et al., 1973).

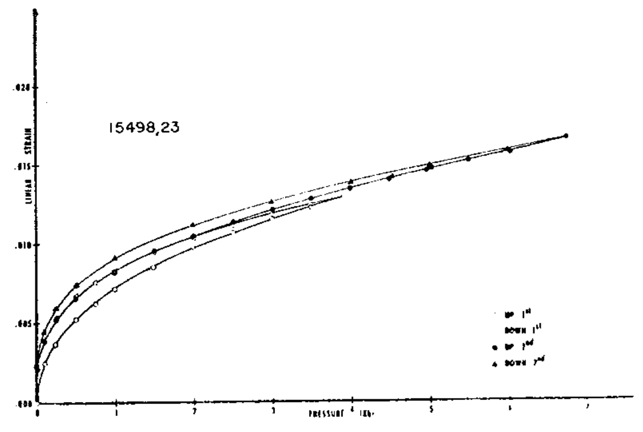


Figure 9. Linear strain vs. pressure for 15498,23 (Trice et al., 1974).

PROCESSING AND SUBDIVISIONS: A slab ,17 was cut through the sample, leaving ,0 (1708 g) as one end and several pieces as the other (Fig. 10). Pieces ,0, ,14 (62 g) and ,16 (213 g) remain almost intact, the latter in remote storage. The slab was substantially divided (Fig. 10), and ,20 (38 g) is in remote storage. All the thin sections (,5; ,6; ,8; ,9; ,99; ,100; and ,101) were made from a single small piece ,3 chipped off prior to sawing, with the exception of several grain mounts made from pieces of the slab.

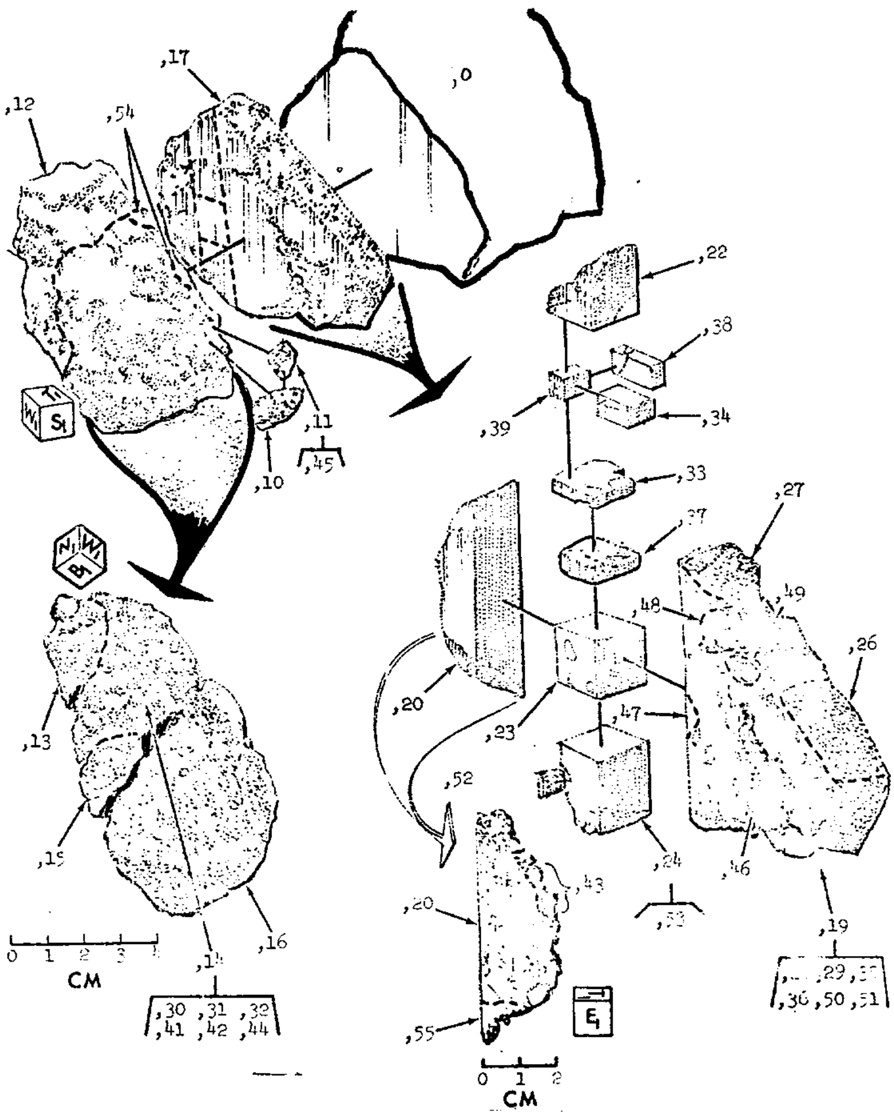


Figure 10. Cutting diagram for 15498, showing splits following sawcutting and slab dissection.

15499 VITROPHYRIC QUARTZ-NORMATIVE MARE BASALT ST. 4 2024 g

INTRODUCTION: 15499 is a vitrophyric pigeonite basalt collected from the top of the same vesicular boulder on the south rim of Dune Crater as the similar samples 15485 and 15486 (Fig. 1). It is one of the most-rapidly cooled of the quartz-normative basalts and has an age of ~3.3 b.y.

15499 is a vesicular basalt with a porphyritic, diktytaxitic texture (Fig. 2). It is medium-dark gray, blocky and angular, and tough. It was broken from the boulder, hence has a fresh surface, and the other side has zap pits.

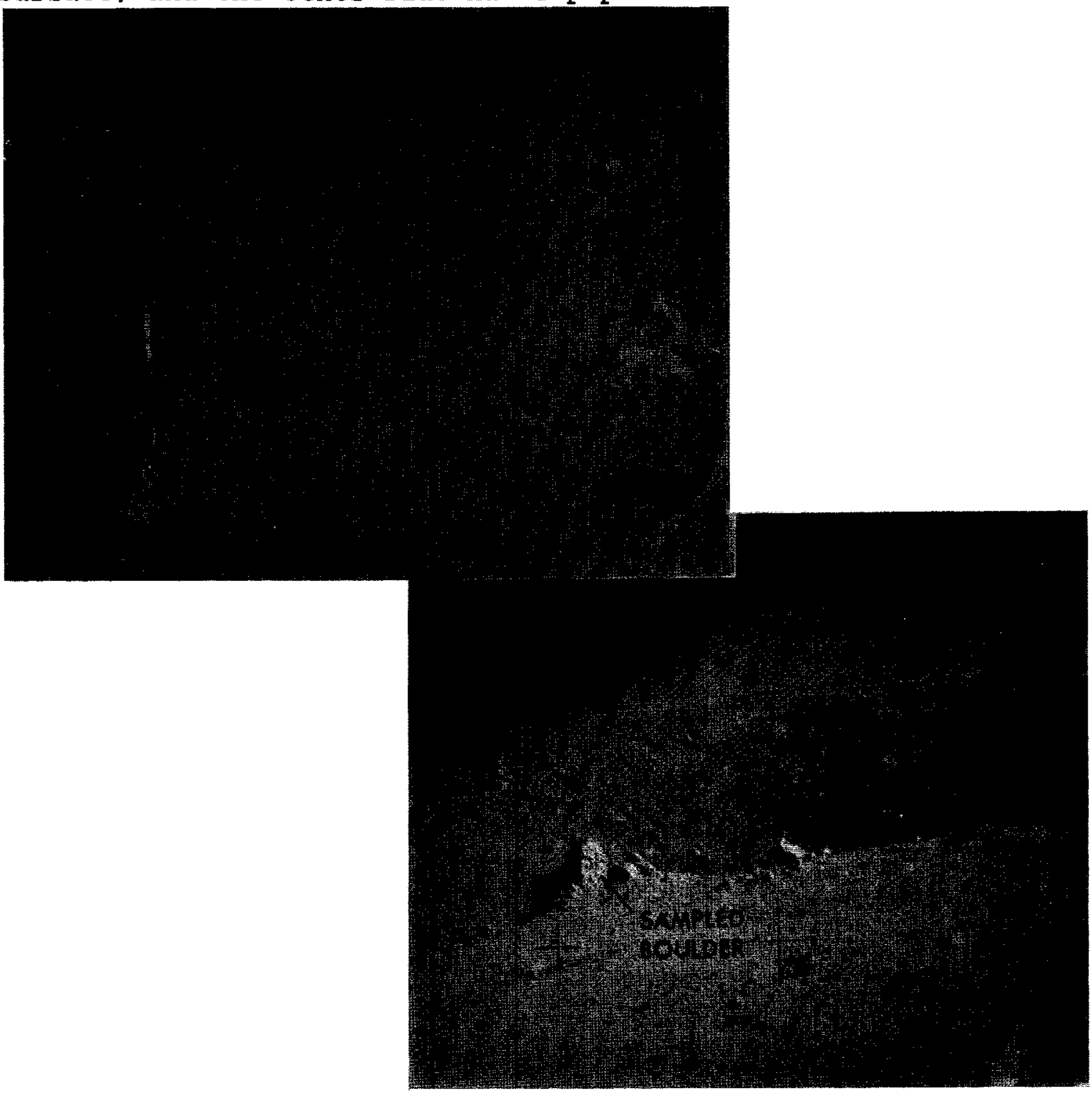


Figure 1. Sampling locations for 15485, 15486, and 15499 from a boulder on the south rim of Dune Crater.

Fig. 2a

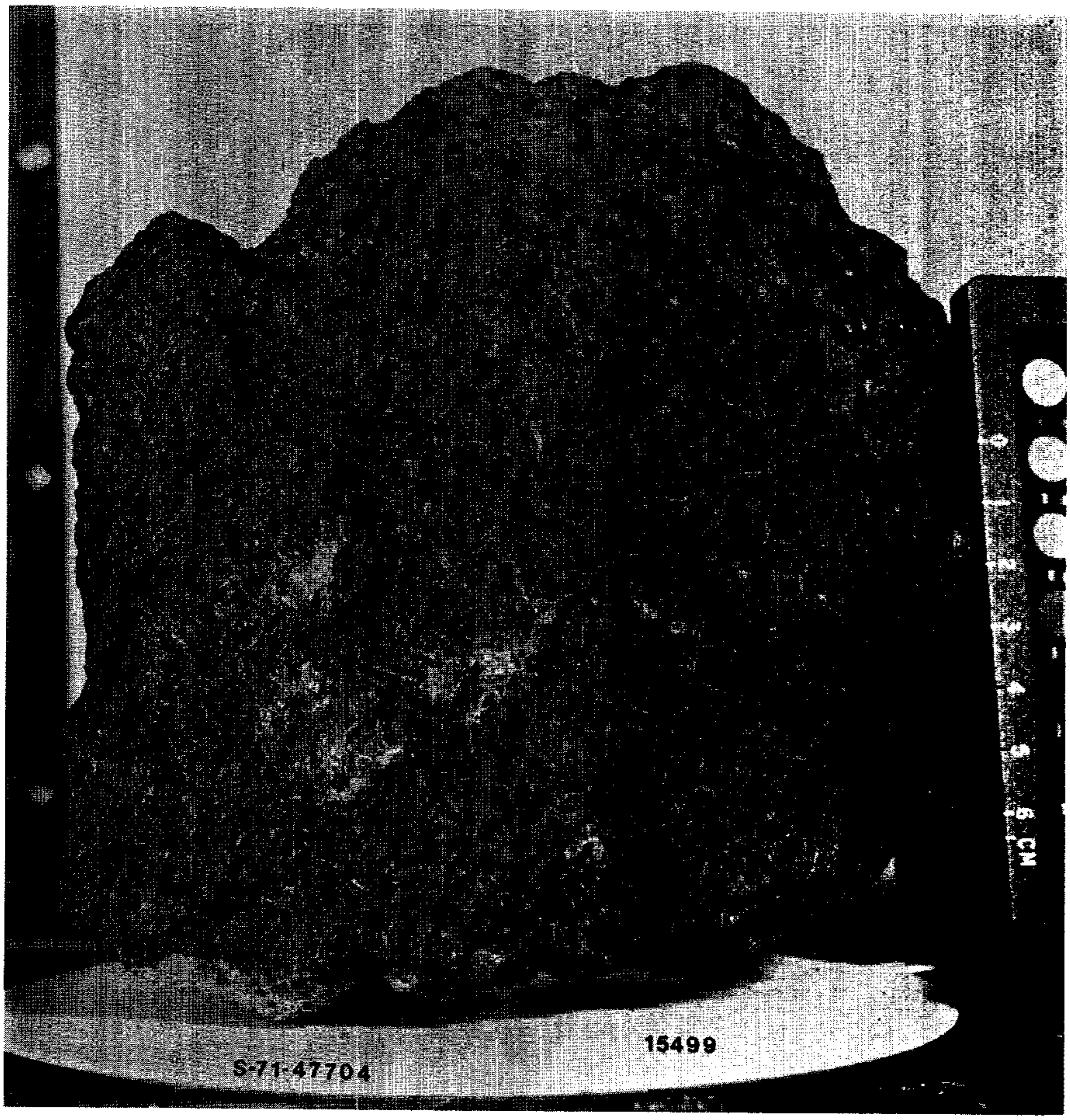


Figure 2. Macroscopic views of 15499 prior to any chipping, showing angular, tabular nature, and diktytaxitic texture.

Fig. 2b

<u>PETROLOGY</u>: 15499 contains abundant euhedral pyroxene phenocrysts, with yellowish cores and brown rims, up to 1 cm long, set in a dark brownish gray groundmass (Fig. 3). A general description of thin section ,4 was given in the Apollo 15 Lunar Sample Information Catalog, which stateD that the sample is porphyritic (42%) with a fine-grained groundmass (>57%). The groundmass contains clinopyroxene (52% of rock), 5% ilmenite, and minor Fe-Ni metal, Cr-spinel, troilite, and ulvospinel. Rhodes and Hubbard (1973) reported a similar mode for ,7: 41.8% pyroxene, 0.8% olivine, and 57.3% groundmass, with the same identified trace minerals. Bence and Papike (1972) also noted the single large skeletal olivine phenocryst: it is extremely zoned from an Fo_{88} core to an Fo_{33} rim. Brief general descriptions of the rock are also given by Papike <u>et al.</u> (1972) and Bence and Papike (1972). The crystallization sequence of olivine→olivine + pigeonite→pigeonite + augite→augite + plagioclase (Bence and Papike 1972) is an agreement with the experimental results (below). Very little olivine developed. The pyroxenes are composite with pigeonite core and augite rims. The groundmass is a variolitic aggregate of coprecipitating plagioclase, augite, and glass. Oxide phases occur only in the groundmass. Several studies have focussed on determining the cooling history of 15499.

Fig. 3a

Fig. 3b

Figure 3. Photomicrographs of 15499,95. All transmitted light except (c), crossed polarizers. (b) and (c) are the same field. All same scale.

Fig. 3c

The pyroxenes are described by Papike et al. (1972), Bence and Papike (1972), Bence and Autier (1972), and Grove and Walker (1977). Compositional variations are shown in Figure 4. Papike et al. (1972) studied exsolution relationships using single crystal x-ray diffraction and microprobe techniques, and found virtually no exsolution. They noted that the phenocrysts are well developed with little evidence for resorption, consistent with a rapid, late-stage quench. The phenocrysts show a continuous buildup of Al to nearly 10% Al_2O_3 in augite rims (Bence and Papike 1972), and there is no Ca-discontinuity, consistent with the interpretation that plagioclase did not precipitate until the phenocrysts to all intents and purposes stopped growing. The phenocrysts show two crystallization trends, according to growing direction. Pyroxene analyses are tabulated by Bence and Papike (1972) (Table 1). Bence and Autier (1972) used secondary ion mass analysis and the electron microprobe to analyze for several minor elements along traverses (Fig. 5). Abu-Eid et al. (1973) studied electronic absorption and Mossbauer spectra for a hand-picked pyroxene, finding significant Ti^{3+} in the rims of pyroxenes, and that Fe^{3+} was below their 1% detectability limit.

Figure 4. Pyroxene major and minor element plots (Bence and Papike, 1972).

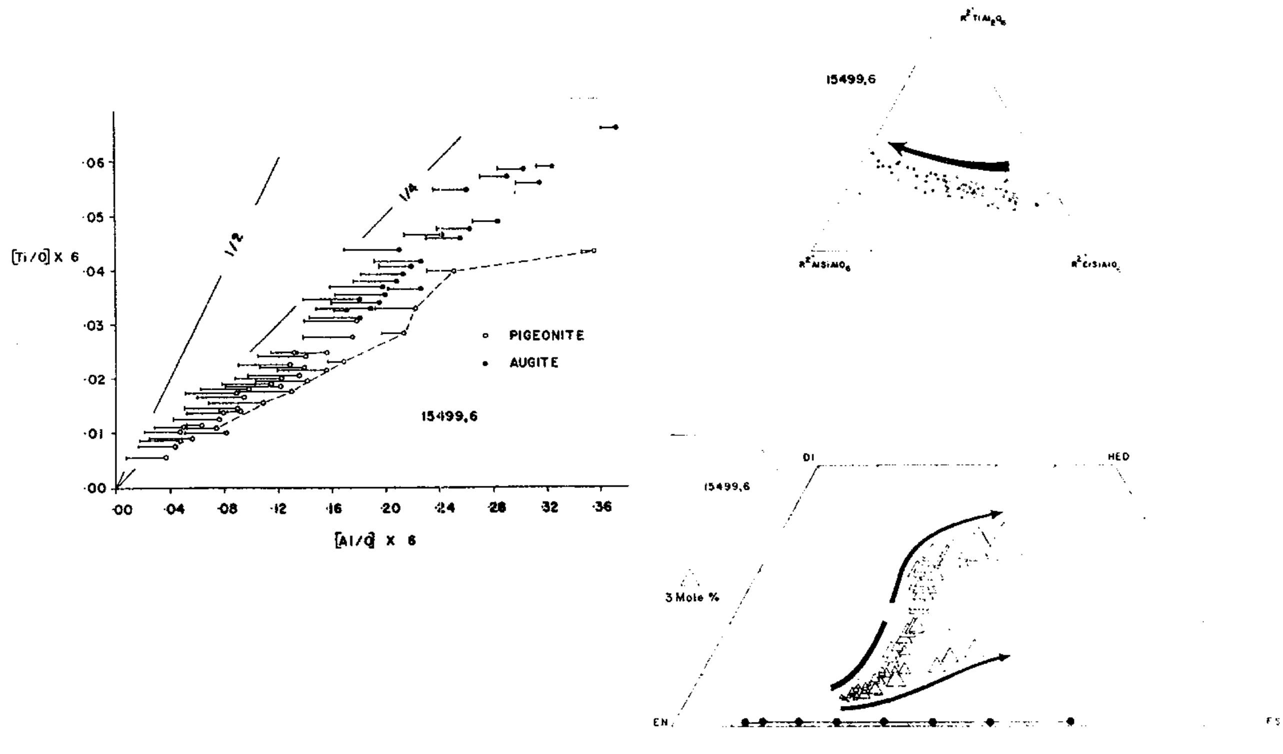
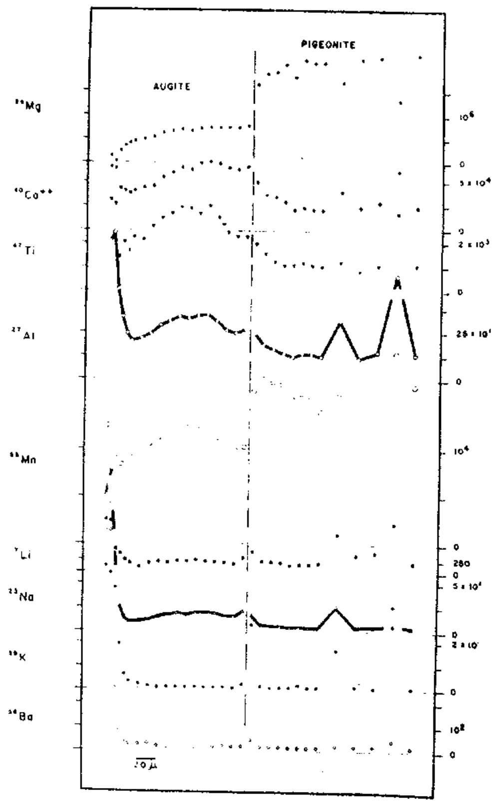


TABLE 15499-1. Representative electron microprobe analyses of pyroxenes from 15499 (Bence and Papike, 1972).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	52.4	52.9	52.1	50.1	50.1	49.4	49.4	49.3	48.5	46.7	43.2	47.8	53.2	52.9	53.2
Al_2O_3	1.89	1.73	1.96	3.55	3.96	4.25	4.35	4.59	5.05	6.67	9.66	4.52	1.75	1.97	1.46
TiO_2	0.36	0.39	0.41	0.88	0.98	1.16	1.30	1.32	1.45	2.01	3.99	0.98	0.43	0.37	0.37
FeO	16.9	17.4	17.5	18.1	18.6	17.5	16.2	16.5	17.4	19.7	20.1	25.0	18.0	16.4	16.5
MgO	23.9	22.6	22.6	18.9	16.5	15.2	14.4	13.1	11.9	9.43	8.58	13.3	21.4	23.1	23.0
CaO	2.62	3.40	3.71	6.51	8.52	10.6	12.2	13.3	14.2	14.3	13.8	6.20	2.96	2.46	2.37
Na_2O	0.03	0.00	0.00	0.00	0.02	0.01	0.05	0.04	0.03	0.02	0.05	0.02	0.00	0.03	0.00
Cr_2O_3	1.04	1.09	1.15	1.18	1.26	1.39	1.45	1.36	1.11	0.71	0.66	0.27	1.08	1.15	1.05
	99.1	99.5	99.4	99.2	99.9	99.5	99.4	99.5	99.6	99.5	100.0	98.1	98.8	98.4	98.0
Si	1.934	1.952	1.932	1.884	1.887	1.872	1.872	1.873	1.854	1.809	1.676	1.884	1.997	1.973	1.995
Al^{IV}	0.076	0.048	0.068	0.116	0.113	0.128	0.128	0.127	0.146	0.191	0.324	0.110	0.003	0.027	0.005
Al^{VI}	0.006	0.027	0.018	0.041	0.063	0.062	0.066	0.079	0.081	0.113	0.118	0.100	0.074	0.060	0.059
Ti	0.010	0.011	0.011	0.025	0.028	0.033	0.037	0.038	0.042	0.059	0.117	0.029	0.012	0.010	0.010
Fe	0.523	0.536	0.541	0.571	0.584	0.555	0.513	0.525	0.557	0.639	0.653	0.824	0.565	0.512	0.518
Mg	1.316	1.244	1.246	1.061	0.923	0.859	0.814	0.742	0.677	0.543	0.496	0.781	1.197	1.284	1.286
Ca	0.104	0.134	0.147	0.262	0.343	0.430	0.495	0.542	0.582	0.594	0.572	0.262	0.119	0.098	0.095
Na	0.002	0.0	0.0	0.0	0.001	0.000	0.004	0.003	0.002	0.002	0.004	0.002	0.0	0.002	0.0
Cr	0.030	0.032	0.034	0.035	0.038	0.042	0.044	0.041	0.034	0.022	0.020	0.008	0.032	0.034	0.031

Figure 5. Variation of trace elements across pyroxene in 15499 (Bence and Autier, 1972).

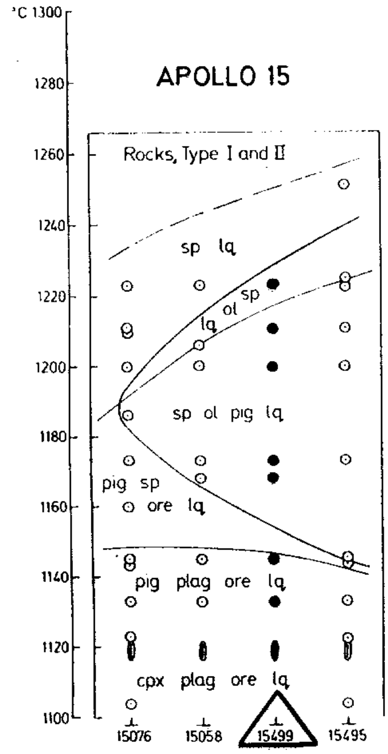


El Goresy et al. (1976) studied zoning in the spinels, noting that 15499 and other fine-grained quartz-normative basalts have spinels with chromite cores which display idiomorphic sharp boundaries to an ulvospinel rim, without a sign of reaction prior to ulvospinel precipitation (in contrast with the corroded cores in coarse basalts). No details are presented for 15499 specifically, although the authors state that a number of spinels in 15499 were analyzed. Engelhardt (1977) tabulates ilmenite paragenesis.

Cooling history: Several petrological studies have been directed at establishing the cooling history of 15499, mainly from a comparison of the rock with products of dynamic crystallization experiments on a similar composition. Lofgren et al. (1974) found that the morphology and zoning of 15499 phenocrysts resembled those in experiments conducted with linear cooling rates of 1.2°C to 30°C/hr, and a comparison of the core compositions suggests that the nucleation was at 1190°C i.e., supercooled 30°C. The results do not require a two-stage cooling history. A further study (Lofgren et al., 1975) of phenocryst shapes and matrix textures indicated 5-20°C/hr and 10-30°C/hr respectively, and 15499 to be one of the fastest-cooled quartz-normative basalts. Grove and Walker (1977) made a more detailed study, again using comparisons with dynamic experiments. The pyroxene nucleation density suggests 1.75°C to 3.75°C/hr at nucleation, the phenocrysts size suggests an integrated phenocryst cooling rate of 1.75°C/hr, and the plagioclase sizes suggest a late-stage cooling rate of 30°C/hr. i.e., initial slow cooling and late rapid cooling. A cooling experiment (1°C/hr for 4 days, 30°C/hr for 12 hrs) duplicating these inferred conditions resulted in a very close match with 15499. Both the products of this experiment and 15499 contain skeletal pyroxenes smaller than the phenocrysts but bigger than the groundmass pyroxenes; these are not found in linear cooling rate experiments. Grove and Walker (1977) further concluded that 15499 crystallized ~15 cm from a conductive boundary. In comparison with 15485 and 15486 from the same boulder, 15499 has a similar nucleation density but both pyroxene and plagioclase are coarser. Grove (1982) studied pyroxenes exsolution with TEM for comparison with experimental analogs. Tweed modulation and heterogeneously-nucleated (001) lamellae are present. On (001) the mean wavelength is 186 Å. Spinodal decomposition is also present on (100). $\Delta\beta$ is 2.67°. The integrated cooling rate estimated from the (001) lamellae wavelength is about 80°C/hr. Brett (1975), using available kinetic data, concluded that 15499 was from a cooling unit ~0.5 m thick. Uhlmann (1981), using a 15499-like composition, studied the characteristics of glass to evaluate the cooling rate, finding that a rate of 14°C/second (much faster than the natural sample) would be required to form a glass.

EXPERIMENTAL PETROLOGY: Humphries et al. (1972) determined the equilibrium, low pressure crystallization of a 15499 sample, finding results similar to other quartz-normative basalts (Fig. 6): some olivine crystallizes before pyroxene; all olivine reacts out before anorthite entry. They prefer the interpretation that 15499 is a mixture of liquid and accumulated pyroxenes, not a liquid composition.

Figure 6. Experimental equilibrium crystallization data for 15499 and other quartz-normative basalts (Humphries et al., 1972).



CHEMISTRY: A few analyses have been published (Table 2) but not including rare-earth data. There has been little specific descussion of the 15499 composition, other than to note that the sample is in the quartz-normative basalt group. Gibson et al. (1975) presented data for CO, CO_2, H_2, H_2S, and Fe°, and Kaplan et al.(1976) also presented an Fe° abundance.

STABLE ISOTOPES: Gibson et al. (1975) reported $\delta^{34}S$ determinations of +0.2 (,20) and -0.9 (,20), and Kaplan et al. (1977) reported sulfur isotopic determinations which are similar, $\delta^{34}S$ = 1.2 (from combustion sulfur) and +0.6 (from hydrolysis sulfur).

TABLE 15499-2

			,9	,2		,20	,22	,11	,72	,104	,18	,19	,12
Wt %	SiO_2	47.89		47.62					47.93				
	TiO_2	1.81		1.81					1.73				
	Al_2O_3	9.19		9.27					8.88				
	FeO	20.47		20.26					19.84				
	MgO	9.11		8.94					9.93				
	CaO	10.41		10.40					10.23				7.3
	Na_2O	0.38		0.29					0.29				
	K_2O	0.06	0.058	0.06					0.028				0.054
	P_2O_5	0.08		0.08					0.083				
(ppm)	Sc												
	V								189				
	Cr	3600							4200				
	Mn	2300		2200					2100				
	Co								44				
	Ni								19	51			
	Rb	0.90							1.4	1.2	0.96d	1.08	
	Sr	109.4							100		108.7d	114.3	
	Y	28							31.1				
	Zr	111							109				
	Nb	8							5.4				
	Hf												
	Ba								69				
	Th		0.59										
	U		0.16							0.173			
	Pb												
	La												
	Ce												
	Pr												
	Nd												
	Sm												
	Eu												
	Gd												
	Tb												
	Dy												
	Ho												
	Er												
	Tm												
	Yb												
	Lu												
	Li												
	Be												
	B												
	C				12	27.8b	9.9b	12					
	N							<2					
	S	600a		700		805c	855c	640c	660				
	F												
	Cl												
	Br												
	Cu								3				
	Zn								<2	1.07			
(ppb)	I												
	At												
	Ga	3000											
	Ge									4.28			
	As												
	Se									115			
	Mo												
	Tc												
	Ru												
	Rh												
	Pd									<0.61			
	Ag									0.99			
	Cd									3.37			
	In									0.90			
	Sn									23			
	Sb									1.42			
	Te									3.2			
	Cs									49.1			
	Ta												
	W												
	Re									0.007			
	Os									<0.06			
	Ir									0.0043			
	Pt												
	Au									0.013			
	Hg												
	Tl									0.32			
	Bi									<0.16			
		(1)	(2)	(3)	(4)	(5)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

References to Table 15499-2

References and methods:

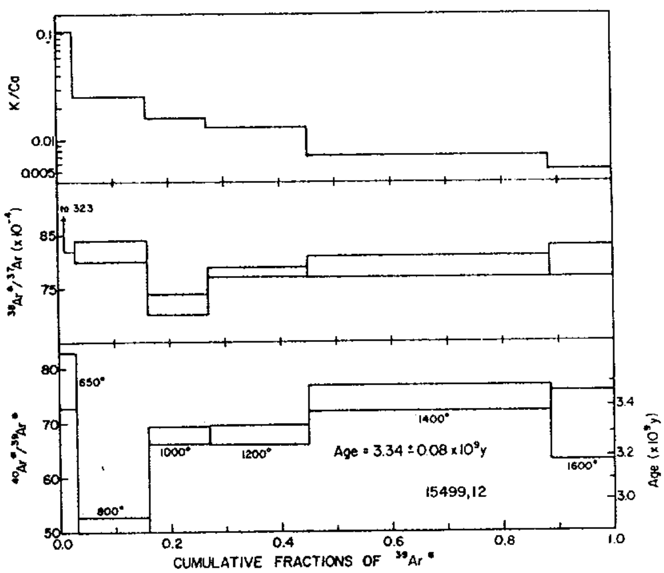
(1) Chappell and Green (1973); XRF
(2) O'Kelley et al. (1972); Gamma ray spectroscopy
(3) Rhodes and Hubbard (1973); XRF
(4) Moore et al. (1973)
(5) Gibson et al. (1975); Combustion, hydrolysis
(6) Kaplan et al. (1976)
(7) Duncan et al. (1976); XRF
(8) Wolf et al. (1979); RNAA
(9) Compston et al. (1972); XRF, IDMS
(10) Papanastassiou and Wasserburg (1973)
(11) Husain (1974); MS

Notes:

(a) quoted as 590 ppm by Gibson et al. (1975) from a Moore 1974 checklist.
(b) from CO, CO_2 abundances.
(c) lower abundances were derived from acid hydrolysis.
(d) average of three determinations.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: According to Albee et al. (1972), Huneke, Podosek, and Wasserburg determined a ^{40}Ar-^{39}Ar age of 3.40 b.y. for 15499; this data has not otherwise been published. Husain (1974) found that the $^{40}Ar^*/^{39}Ar^*$ release pattern was somewhat perplexing, but derived an age of 3.34 ± 0.08 b.y. from the 1000°C, 1200°C, and 1400°C releases (Fig. 7). Although tabulated as "no radiogenic Ar loss" the K-Ar age is slightly lower, 3.328 ± 0.036 b.y., and Husain (1972) previously reported a small (0.8%) radiogenic argon loss.

Compston et al. (1972) and Papanastassiou et al. (1973) presented whole-rock Rb-Sr isotopic data (Table 3). Compston et al. (1972) found the difference between subsplits to be consistent with dispersion along a 3.3 b.y. isochron. Assuming this age, the initial $^{87}Sr/^{86}Sr$ ratios for two splits would have been 0.69945 and 0.6996 ± 3 (sic).



Thermal release study of the $^{40}Ar^*/^{39}Ar^*$, $^{39}Ar^*/^{37}Ar$, and K/Ca ratios of 15499,12. See text

Figure 7. Ar release diagram (Husain, 1974).

TABLE 15499-3. Rb-Sr isotopic data for 15499 whole rock sample

Reference	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	T_{BABI}*
Compston et al. (1972)	0.0248	0.70062 ± 10	4.33
Compston et al. (1972)	0.0280	0.70092 ± 25	4.22
Compston et al. (1972)	--	0.70077 ± 10	--
Papanastassiou and Wasserburg (1973)	0.02740 ± 11	0.70064 ± 11	4.28

*from Nyquist (1977)

EXPOSURE: Husain (1974) determined an Ar exposure age of 114 m.y. Eldridge et al. (1972) provide cosmogenic radionuclide data; evidently the sample was without much exposed surface area. The equilibrium concentrations of ^{26}Al and ^{22}Na mean that the exposure has been too long to allow an estimate using the $^{26}Al/^{22}Na$ method.

TRACKS: Hutcheon et al. (1972) studied crystals at the bottom of two vugs from the surface of 15499. They observed no micro-craters. The largest crystals were pigeonite prisms without resolvable edge rounding but with a matte finish as if they were rough on a submicroscopic scale. Polished vertical sections were made through the vugs. One vug, ellipsoidal with only a narrow neck to the exterior, had a track density which dropped off very rapidly with depth in the outer few microns of crystals, but the high background track density (~1 x 10^8 cm^{-2}) precluded measuring the gradient at a depth of a few microns. The background was probably accumulated before the vug was exposed, the steep gradient when some chip above the vug was removed. A second vug has a track profile steeper than seen in any other lunar rock or meteorite, >5 x 10^{10} cm^{-2} near surface to ~10^8 cm^{-2} a few tens of microns below (Fig. 8). This profile is as steep as that on the Surveyor spacecraft, and much steeper than on an eroded surface. An exposure time of ~10^5 years was estimated for the vug. Price et al. (1973) discussed this data, noting that the vug interior escaped erosion.

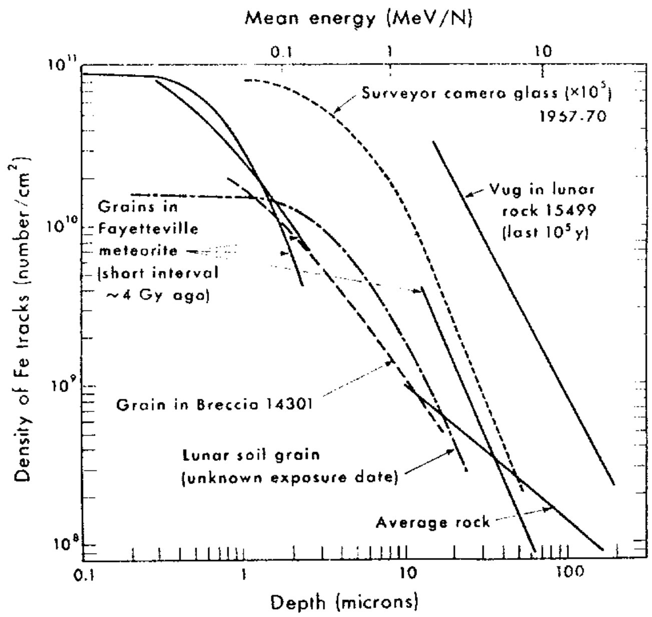
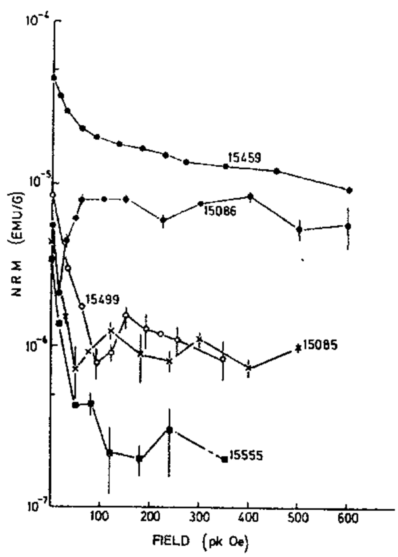


Figure 8. Track density profile of Hutcheon et al. (1972) (from Price et al., 1973).



Alternating field demagnetization of Apollo 15 samples. Vertical bars indicate range of intensities obtained after repeated demagnetization.

Figure 9. Magnetic data (Collinson et al., 1973).

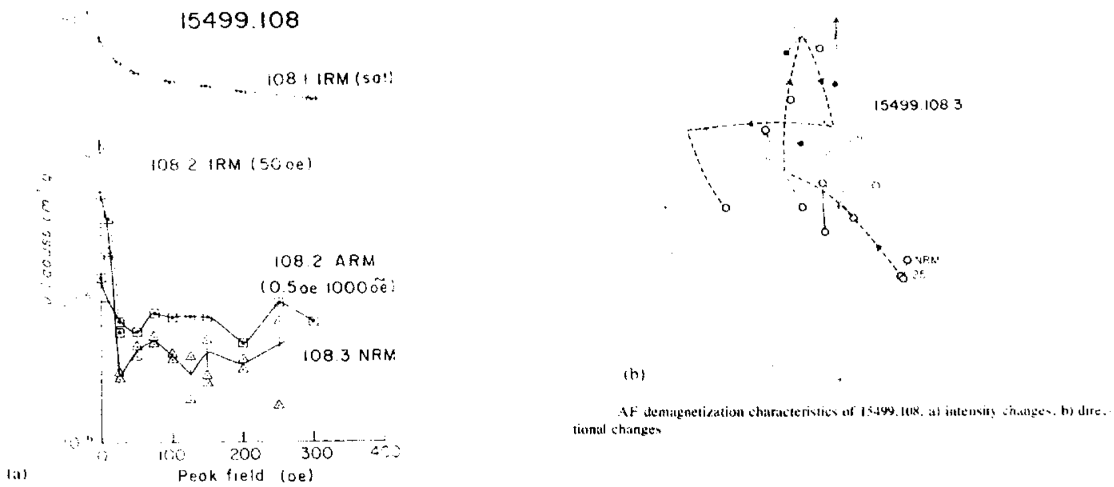
PHYSICAL PROPERTIES: Collinson et al. (1972, 1973) presented basic magnetic and NRM data (Fig. 9). Split ,21 shows a steady movement of the NRM direction up to the maximum demagnetizing field used of 350 Oe. Split ,27, undergoing stepwise thermal demagnetization up to 810°C, showed no change in the initial susceptibility at each stage, and this is typical of basalts. The NRM persists up to the Curie point of iron, its apparent carrier. Split ,27 also shows a steady migration of NRM direction up to the iron Curie point, i.e. no stable direction is revealed up to ~750°C. Split ,21 has a low viscosity coefficient. Artifical thermoremanence gives a TRM proportional to the applied field; an ambient field of 1000 gammas is derived using some assumptions. The results are not easy to interpret in a single magnetization history of a single thermoremanence event in a linear field.

Fuller et al. (1979) also studied the NRM (Fig. 10) finding a large soft component, and a poor directional stability under AF-demagnetization.

Adams and McCord (1972), using diffuse reflectance spectra (0.35 to 2.5 μm) to determine the wavelength positions of the two crystal-field absorption bands contributed by pyroxene, found 15499 to be one of the most augitic Apollo 15 rocks. Charette and Adams (1975) presented spectral reflectance data on a powdered sample: the vitrophyric texture produces a shallower 0.5 to 0.75 μm slope than coarser rocks.

PROCESSING AND SUBDIVISIONS: 15499 was broken into three large pieces ,0; ,9; and ,10. (The only sawing was on ,26). Only a few pieces were taken from ,0 (now 1128 g). ,9 was totally subdivided, with the two largest pieces being ,67 (177 g) and ,76 (377 g); the latter is in remote storage. The largest remaining piece of ,10 became a PAO display (163 g). A chip ,1 was made into thin sections ,4 to ,8, and two pieces of ,10 were made into potted butts ,14 and ,25, producing thin sections ,40; ,42; ,62; ,95; and ,43 and ,44 respectively.

Figure 10. Magnetic data (Fuller et al., 1979).



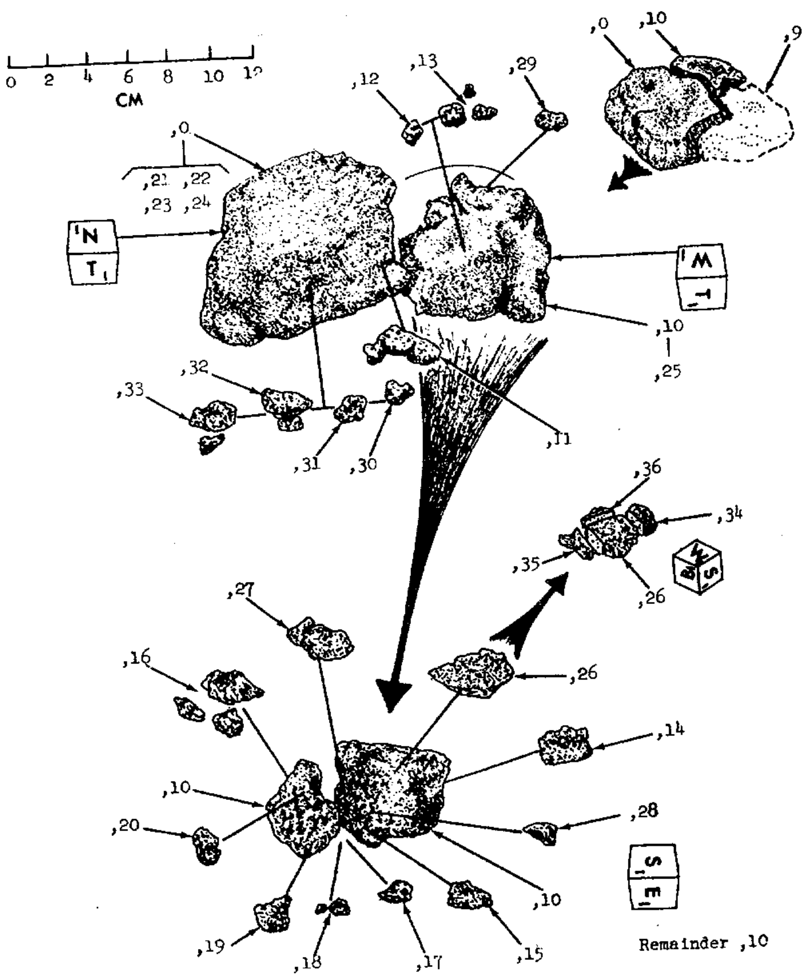


Figure 11. Dissection of 15499.

15505 REGOLITH BRECCIA, GLASS COATED ST. 9 1147.0 g

INTRODUCTION: 15505 is a regolith breccia derived mainly from mare materials and almost entirely coated with glass (Fig. 1). The composition of the glass is similar to that of the breccia. The sample is irregularly shaped. The glass coat is black; the interior breccia is coherent and medium dark gray. The sample was less than one-half buried and lacks zap pits; its lunar orientation is known.

15505 was collected 15 m west of the rim of a small crater and is probably part of the ejecta blanket. Samples 15506 and 15508 probably broke off 15505 in transit.

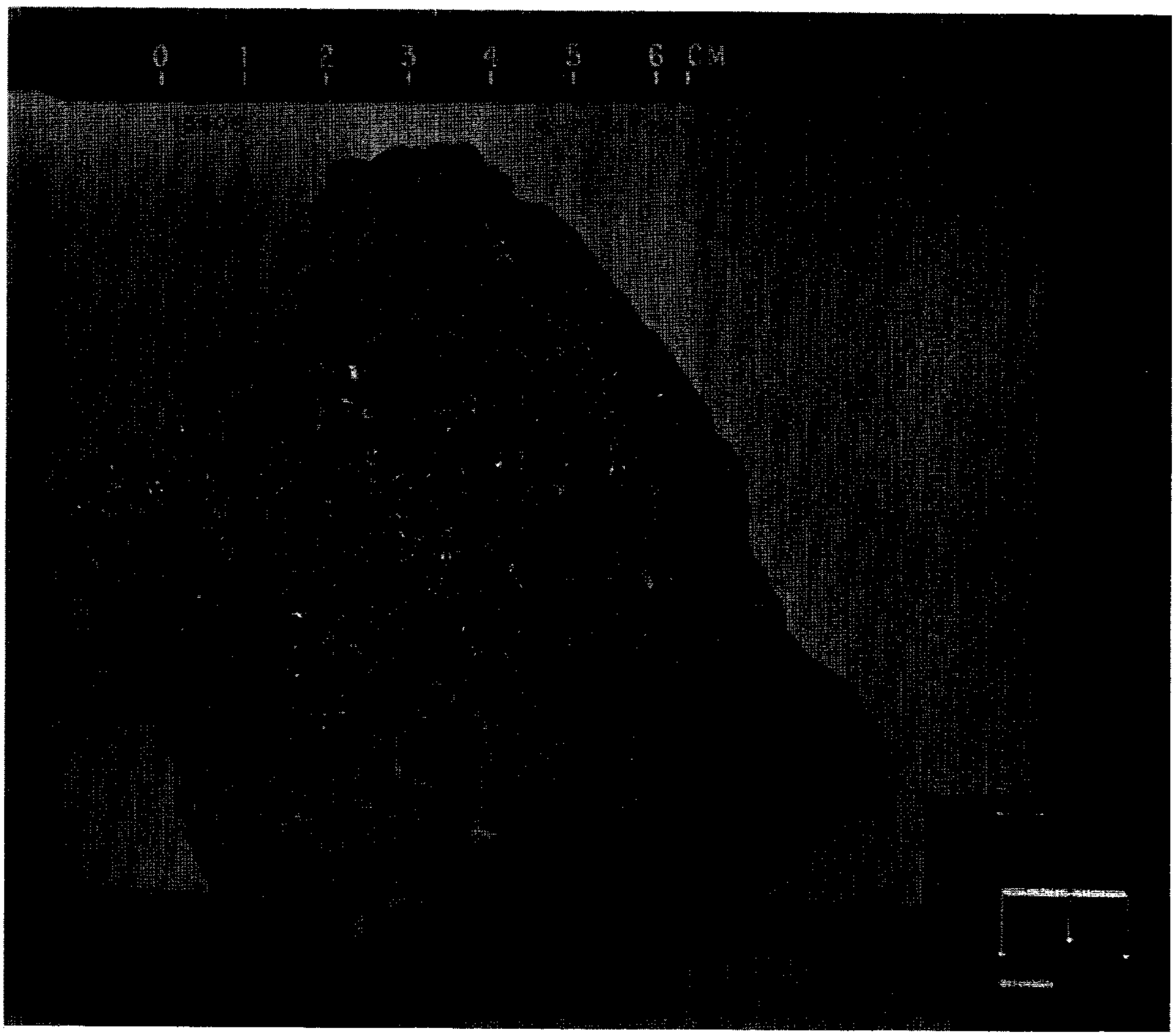


Figure 1. Pre-split showing abundant vesicular glass, with breccia matrix in lower left.

PETROLOGY: 15505 is a regolith breccia (Fig. 2) which is derived principally from the bedrock quartz-normative mare basalts at St. 9 (Engelhardt et al., 1972, 1973) and is similar to soils collected at that site in its fragment population. Both Engelhardt et al. (1972, 1973) and Michel-Levy and Jahann (1973) agreed that the matrix is rich in comminuted debris including abundant glass particles and spheres and welded with glass. Engelhardt et al. (1973) analyzed glass fragments but reported no specific data. Pyroxene mineral fragments are more abundant than plagioclase. Gleadow et al. (1974) noted a group of mafic meta-basalts in the sample, and defocussed beam, energy-dispersive microprobe analyses of these and other components are given in Sewell et al. (1974).

Wilshire and Moore (1974) noted that the glass does not mask the sharply angular character of the rock, and concluded that the glass is exposed veins which had developed along conjugate fracture surfaces. Michel-Levy and Jahann (1973) agreed that the glass cannot be a "splash" glass because it covers the entire sample, and interpreted it as an "exudation" glass derived from the matrix. Winzer et al. (1978) reported a composition for the glass coat (Table 2). Griscom and Marquardt (1972) and Tsay et al. (1976) reported brief electron spin resonance data for surface glass samples.

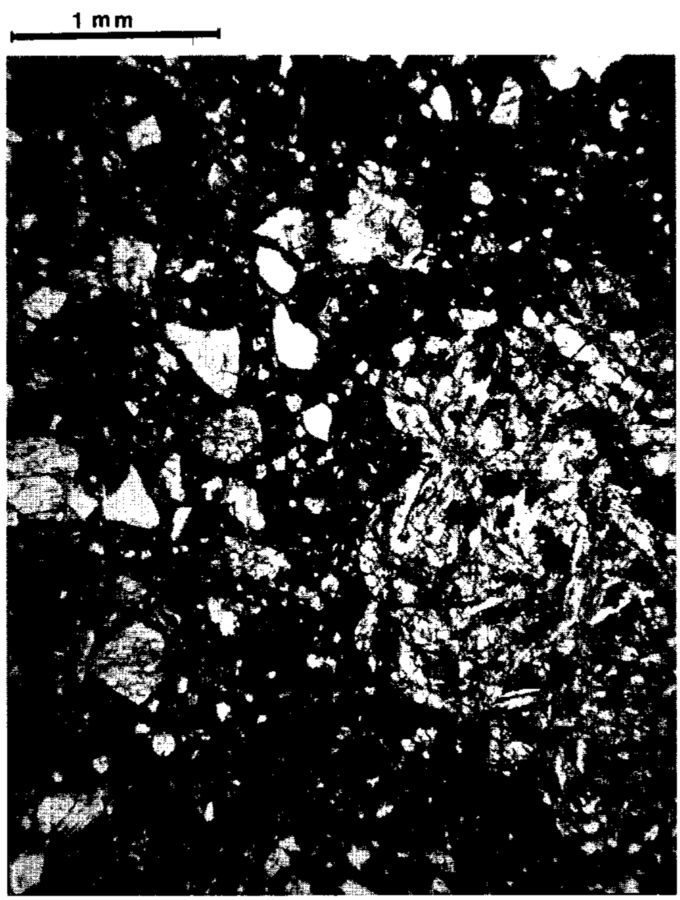


Figure 2. Photomicrograph of matrix of 15505,48, transmitted light.

TABLE 15505-1. Chemical analysis of bulk rock

		,29	,22	,26	,17	,17a	,17	,24	,8	,8M	,72	,0	,91
Wt %	SiO2												
	TiO2	1.6											
	Al2O3	12.4											
	FeO	17.2											17.4
	MgO	9											
	CaO	10.9									14.4		9.9
	Na2O	0.365											0.40
	K2O	0.16									0.1873	0.1868	
	P2O5				0.18	0.2							
(ppm)	Sc	32											33.1
	V	150											
	Cr	3030											3310
	Mn	1640											
	Co	53											49.6
	Ni												205
	Rb												
	Sr												100
	Y												
	Zr	570											290
	Nb												
	Hf	9.0											7.9
	Ba	150											210
	Th	2.8							3.685	3.570		3.64	3.5
	U	0.9			0.87	1.1			1.039	0.984		0.94	0.87
	Pb								2.116	2.032			
	La	21											20.8
	Ce	57											55
	Pr												
	Nd												32
	Sm	10.0											10.1
	Eu	1.2											1.25
	Gd												
	Tb	1.7											1.99
	Dy	6.4											
	Ho												
	Er												
	Tm												
	Yb	7.5											6.9
	Lu	1.1											0.97
	Li				17	19							
	Be												
	B												
	C		47.6	104									
	N												
	S							1100					
	F												
	Cl				15.5	17.3							
	Br				0.193	0.050							
	Cu												
	Zn						11.33						
(ppb)	I				1400	1900							
	At												
	Ga												
	Ge												
	As												
	Se							280					
	Mo												
	Tc												
	Ru												
	Rh												
	Pd												
	Ag							7.8					
	Cd												
	In												
	Sn												
	Sb												
	Te												
	Cs												210
	Ta	900											1040
	W												
	Re							0.59					
	Os							6.5					
	Ir							5.5					7.1
	Pt												
	Au							2.7					3.8
	Hg							2.2					
	Tl						0.89						
	Bi						<7.7	0.56					
		(1)	(2)	(3)	(4)	(4)	(5)	(6)	(7)	(7)	(9)	(10)	(11)

References to Table 15505-1

References and methods:

(1) Laul and Schmitt (1973); INAA
(2) Modzeleski et al. (1972); Vacuum pyrolysis/MS
(3) Moore et al. (1973)
(4) Jovanovic and Reed (1975); RNAA, etc.
(5) Reed et al. (1977)
(6) Hughes et al. (1973); RNAA
(7) Silver (1973); ID/MS
(8) Winzer et al. (1978); Microprobe
(9) Schaeffer and Schaeffer (1977); MS
(10) Rancitelli et al. (1972); Gamma ray spectroscopy
(11) Korotev (1984 unpublished); INAA

Notes:

(a) ~50% glass, ~50% matrix

TABLE 15505-2. Glass

		,80	,8
Wt %	SiO2	49.65	
	TiO2	1.72	
	Al2O3	11.63	
	FeO	14.99	
	MgO	11.22	
	CaO	9.63	
	Na2O	0.45	
	K2O	0.21	
	P2O5		
(ppm)	Sc		
	V		
	Cr	3300	
	Mn		
	Co		
	Ni		
	Rb		
	Sr		
	Y		
	Zr		
	Nb		
	Hf		
	Ba		
	Th		3.565
	U		0.975
	Pb		1.998
	La		
	Ce		
	Pr		
	Nd		
	Sm		
	Eu		
	Gd		
	Tb		
	Dy		
	Ho		
	Er		
	Tm		
	Yb		
	Lu		
	Li		
	Be		
	B		
	C		
	N		
	S		
	F		
	Cl		
	Br		
	Cu		
	Zn		
(ppb)	I		
	At		
	Ga		
	Ge		
	As		
	Se		
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd		
	In		
	Sn		
	Sb		
	Te		
	Cs		
	Ta		
	W		
	Re		
	Os		
	Ir		
	Pt		
	Au		
	Hg		
	Tl		
	Bi		
		(8)	(7)

References and methods:

(8) Winzer et al. (1978); Microprobe
(7) Silver (1973); IDMS

CHEMISTRY: Chemical analyses of the matrix are listed in Table 1 and of the glass "coat" in Table 2, with rare earths for the matrix shown as Figure 3. There is a distinct similarity between glass, breccia, and local soils. Modzeleski et al. (1972) reported CO, CO_2, and CH_4 determinations from which their bulk carbon abundance is derived.

STABLE ISOTOPES: Garner et al. (1975) reported Li, K, and Rb isotopic determinations; they could not distinguish whether their samples were breccia, glass, or a mixture. They found the sample to be depleted in ^{39}K, the first rock so found. Reed et al. (1977) reported ^{204}Pb data.

RADIOGENIC ISOTOPES: Silver (1973) reported Pb isotopic data and found that bulk rock, matrix, and glass are all similar. and similar to local soils. Schaeffer and Schaeffer (1977) found that Ar gas release gave little information, with increases and decreases with temperature increase, ranging from 3.33 to 6.83 b.y. The total K-Ar "age" is 5.18 $\pm$ 0.05 b.y. The sample has a large trapped Ar component.

Rosholt (1975) and Rosholt and Tatsumoto (1973) reported Th isotopic data in a discussion of the sources of the radioactivity in the sample.

EXPOSURE AND TRACKS: Rancitelli et al. (1972) reported cosmogenic radionuclide data: ^{26}Al is extremely undersaturated, indicating exposure for only a few hundred thousand years. The Ar data of Schaeffer and Schaeffer (1977) give an exposure of 604 m.y. averaged over the entire release, but the range is 1 to 3800 m.y. Ar is too complexly distributed for meaningful interpretations.

Fleischer et al. (1973) found a minimum track density in pyroxene of 2 x 10^6 cm^{-2}, at 1.5 mm depth, indicating an exposure of <600,000 yrs. According to Crozaz et al. (1974) the exposure is multistage.

PROCESSING AND SUBDIVISIONS: A slab was cut from 15505 and substantially dissected (Fig. 4). End piece ,3 (92.4 g) is in remote storage, and ,0 has a mass of 862.1 g. Thin sections were made from a chip ,42 which was taken from exterior pieces ,11 (TS ,48; ,53; ,54; ,55; ,56; ,57), except for TS ,68 (from ,7) and ,80 (from ,78).

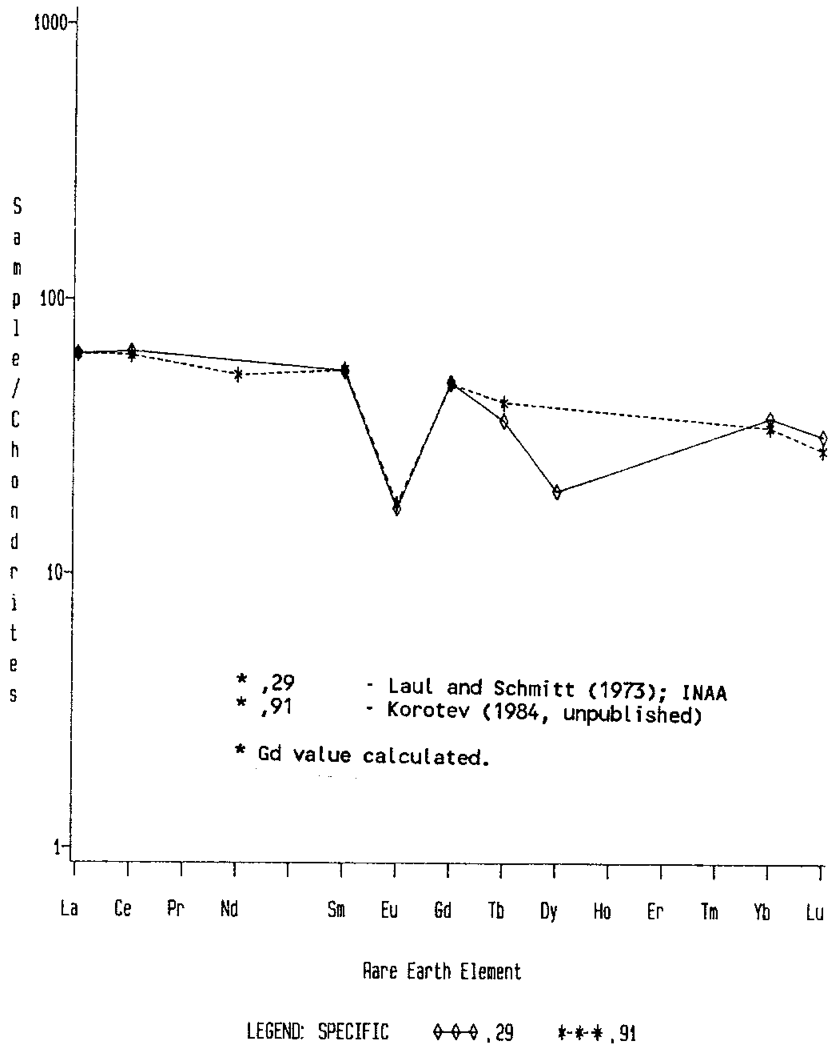


Figure 3. Rare earths in matrix.

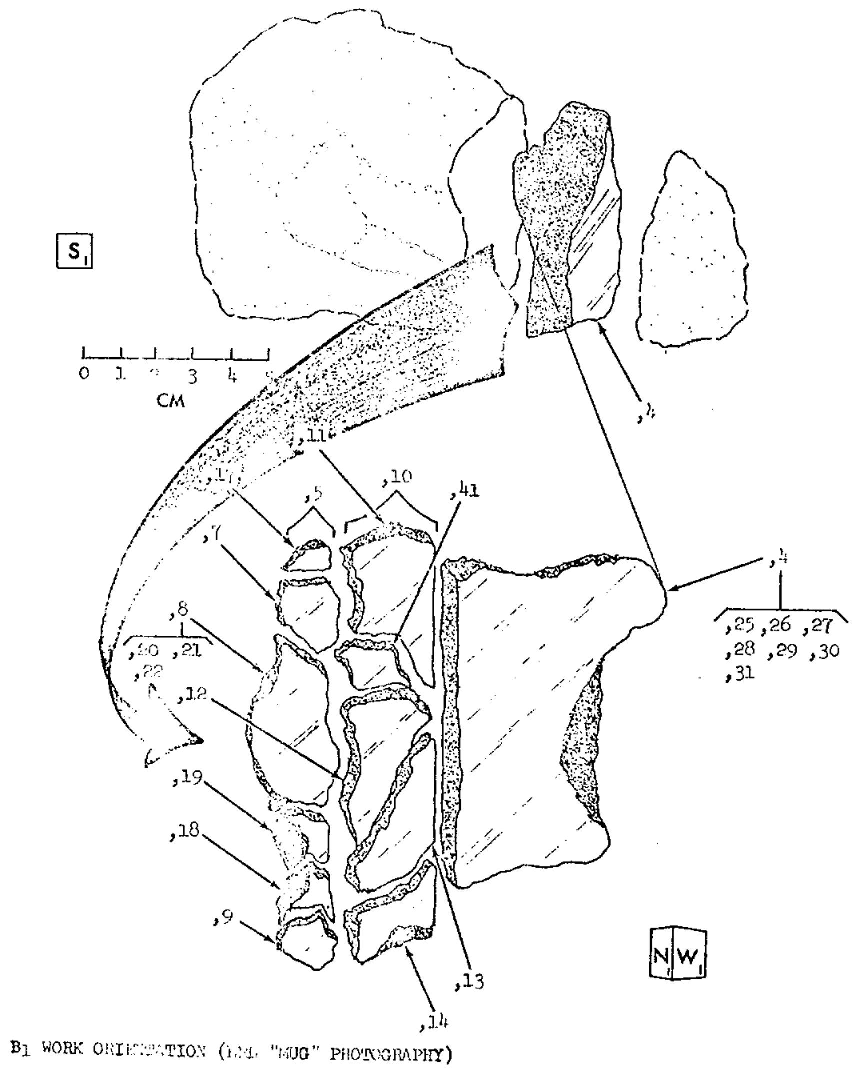


Figure 4. Main splitting of 15505.

15506 REGOLITH BRECCIA, GLASS-COATED ST. 9 22.9 g

INTRODUCTION: 15506 is a moderately friable regolith breccia with some surface glass coating (Fig. 1). The breccia itself is medium dark gray and subangular, and contains small fragments of lithic and mineral material. The glass is olive black and partly dust-covered. A few zap pits are present on some surfaces. 15506 is probably a piece broken off 15505 (with 15508), which was collected about half way out from the rim of the 15 m crater at Station 9, on its ejecta blanket which is about 25 m across. 15506 has never been subdivided or allocated.

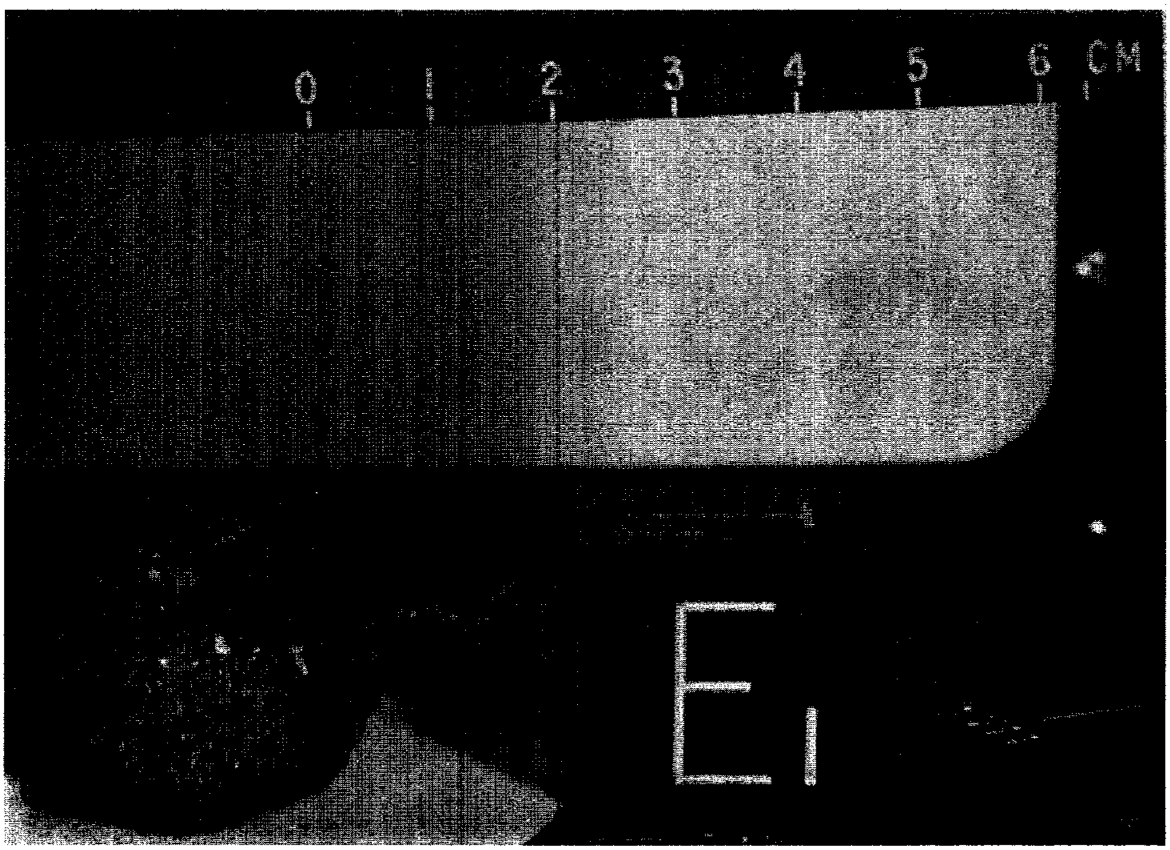


Figure 1: Sample 15506. S-71-44528

15507 GLASS, VESICULAR ELLIPSOID ST. 9 3.9 g

INTRODUCTION: 15507 consists of three fragments which combine to form an egg-shaped object (Fig. 1). The fragments are olivine brown to grayish brown glass, which has 40 to 50% vesicules up to 1 mm across. The glass is tough. Some surfaces have adhering dust. The fragment appears to have been broken prior to collection because an interior vesicle lining has a zap pit. The glass contains a few soil clasts and metallic swirls. The sample was collected near to 15505, which was collected about halfway out from the rim of the 15 m crater at Station 9, on its ejecta blanket which is about 25 m across. 15507 was recognized by the astronauts as a glassy ball distinct from most nearby fragments. It has not been recognized on photographs. It has never been subdivided or allocated.

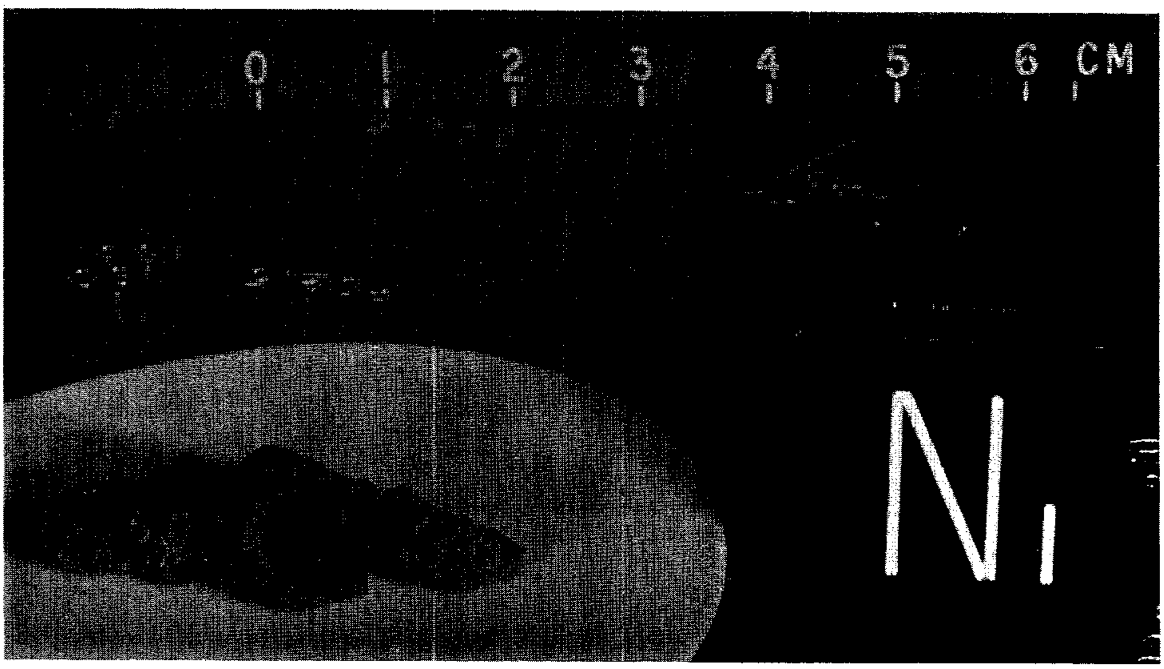


Figure 1: Sample 15507. S-71-44521

15508 REGOLITH BRECCIA, GLASS-COATED ST. 9 1.4 g

INTRODUCTION: 15508 is a small coherent regolith breccia fragment with a substantial vesicular glass coating (Fig. 1). The breccia is medium gray and irregular in shape. The glass is black and its vesicles are up to 2 mm across. Zap pits are absent from most of the surface. 15508 is probably a piece broken off 15505 (with 15506), which was collected about halfway out from the rim of the 15 m crater at Station 9, on its ejecta blanket which is about 25 m across. 15508 has never been subdivided or allocated.

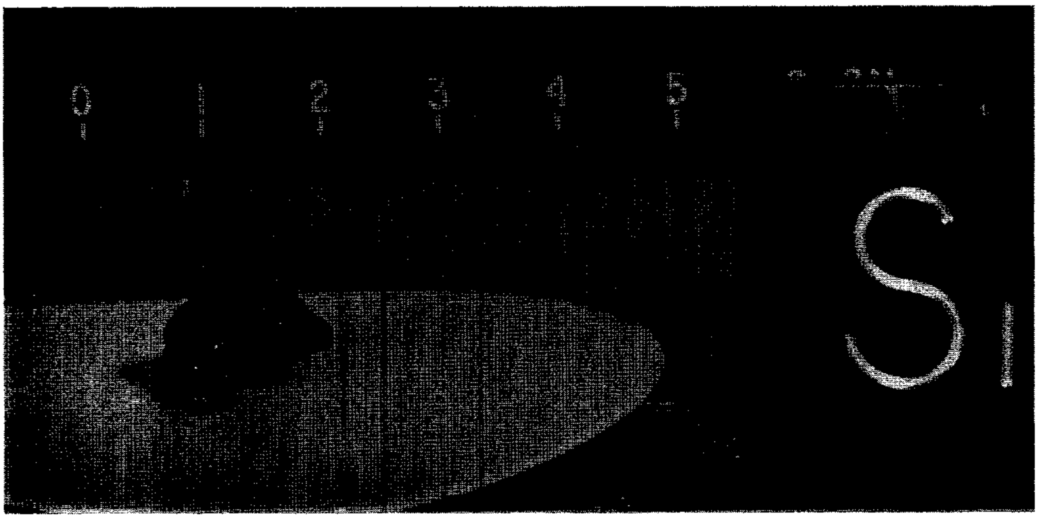


Figure 1: Sample 15508. S-71-44808

15515 REGOLITH CLODS ST. 9 144.7 g

INTRODUCTION: 15515 consists of 48 extremely friable clods which were the greater-than-1 cm fraction of two clods which were individually collected but disintegrated. The samples are caked clods which "look like a piece of mud". They consist of porous, glassy, non-annealed regolith components, including glass, mineral, and mare basaltic fragments. Most have disintegrated to fines. The bulk chemistry is very similiar to that of the local regolith.

15515 and its fines (15510 and 15514) were collected as two clods from the northwest rim crest of the 15 m, cloddy crater at Station 9. The clods appeared to be typical of local material.

PETROLOGY: The clods consist of glassy, fine-grained, non-annealed breccia with predominantly mare basalt clasts. They also contain varied glass and mineral fragments. Only ,18 was made into grain size fractions and thin sections. A mode from PET (Lunar Sample Information Catalog Apollo 15, 1972) is given as Table 1. Reed et al. (1977) found a clod to contain 0.57% metal iron (chemical methods). Tsay et al. (1976) used electron spin resonance techniques to determine a total Fe-metal content of 0.62 wt %. The weight % (SP+SD) Fe° was 0.39.

TABLE 15515-1. Petrographic components of 15515 (Lunar Sample Information Catalog Apollo 15, 1972)

COMPONENTS	NOTE	PERCENT OF GRAINS 0.5-1.0mm	0.25-0.5mm	0.125-0.25mm
Agglutinate	1	22	33.5	53
Clinopyroxene	2	-	20.0	19.5
Plagioclase	3	-	2.5	5.0
Glass spheres, green	4	27.5	6.5	4.5
Glass spheres, colorless	5	-	3.5	3.0
Basalt, ophitic	6	-	10.5	3.5
Basalt, hyalocrystalline	7	11	6.0	2.5
Microbreccia, vitric	8	11	5.0	4.0
Microbreccia, recrystallized	9	5.5	5.0	1.5
Glass frags, brown	10	5.5	3.0	1.5
Basalt, equigranular	11	11	2.0	1.0
Anortho ite	12	-	1.0	-
Glass droplets	13	5.5	2.0	-
Grains counted	-	18	200	200
Section number		58,63,64	75,62	56,61

NOTES TO TABLE:

1. Glass and mineral (feldspar, pyroxene) detritus bound together in welded droplets of very dark brown to black glass.
2. Colorless, broken, anhedral to subhedral crystals of augite. Some are zoned from pigeonite to augite. The pigeonite has a very pale brown color. Also there are some unzoned pigeonite.
3. Fractured and shocked.
4. Clear and free of detritus or schlieren; some are devitrified.
5. Devitrified; sheaves of thin feldspar crystals.
6. Clinopyroxene > plagioclase > opaques. Some grains have feldspar with parallel orientations.
7. Feldspar cloths and opaque minerals in a clear brown glassy matrix.
8. About 50% small clinopyroxene crystals in a clear brown glass matrix.
9. Detritus in a finely crystalline feldspar matrix.
10. Angular, 5-8% debris in clear brown glass with some schlieren.
11. Equigranular basalt - clinopyroxene > feldspar > opaques.
12. Equigranular, 5% pyroxene, 95% feldspar.
13. Spheres both vesiculated and non-vesiculated contain up to 20% detritus.

CHEMISTRY: Chemical analyses of different clod pieces (designated by split numbers) are given in Table 2 and the rare earths are shown in Figure 1. The clod pieces all seem to be similar to one another and to local regolith in all respects.

Jovanovic and Reed (1975) listed leached and residue data for Cl and Br separately, and noted that the leach Cl/Br ratio was different from that of nearby materials 15501 and 15505. Reed et al. (1977) tabulated separate leach and residue data for ^{204}Pb, Bi, Te, and Zn.

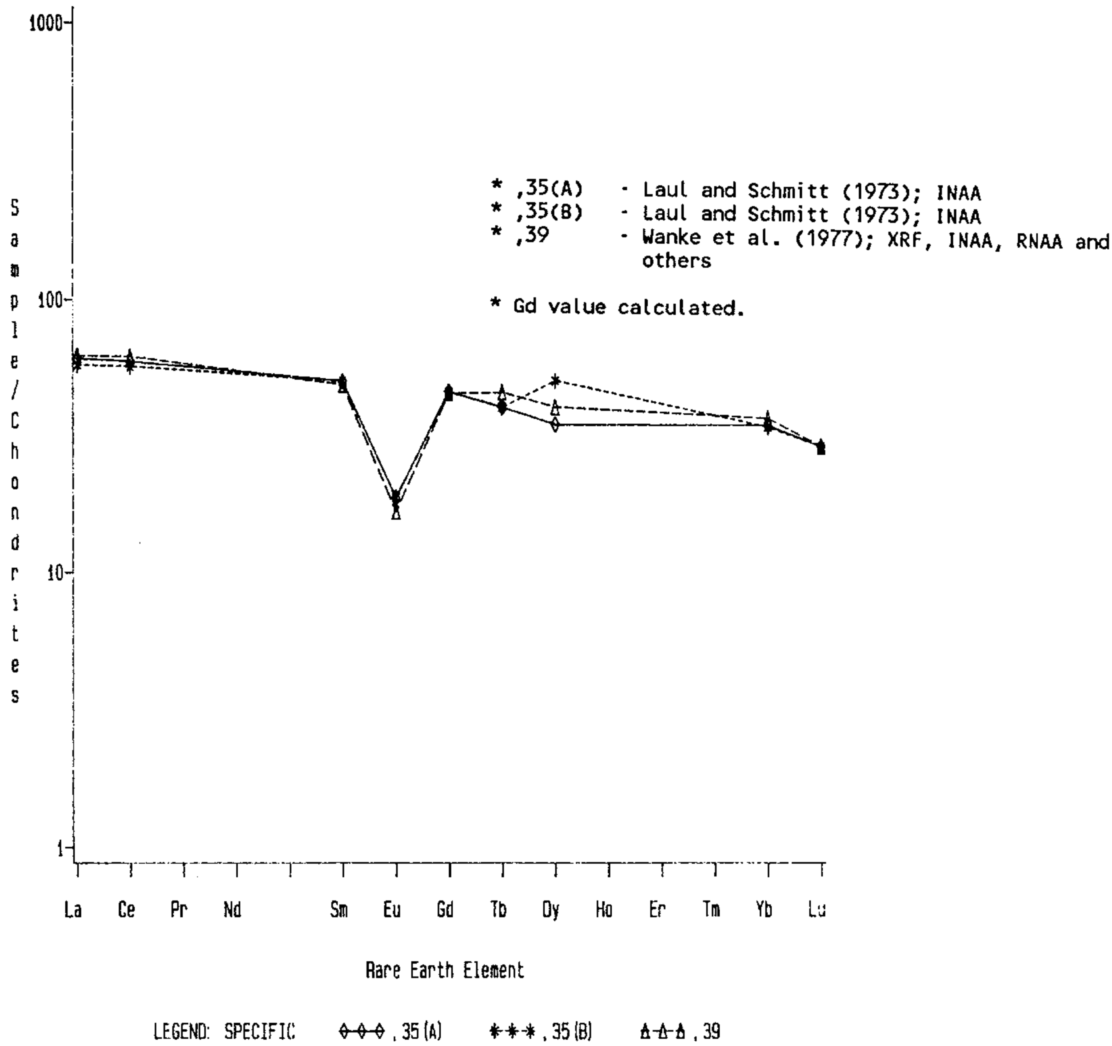


Figure 1. Rare earths in 15515.

TABLE 15515-2. Chemical analyses of 15515 clods

		,9	,35	,35	,39	,15	,15	,23	,97(,4)	,13
Wt %	SiO2				46.1					
	TiO2		1.9	1.7						
	Al2O3		12.4	12.2	11.7					
	FeO		17.4	17.0	17.0					
	MgO		12	11	10.8					
	CaO		10.0	10.9	10.4					
	Na2O		0.369	0.364	0.381					
	K2O		0.14	0.14	0.167					
	P2O5				0.199	0.19				
(ppm)	Sc		32	32	35.3					
	V		149	150						
	Cr		3110	2980	3260					
	Mn		1670	1680	1775					
	Co		48	48	49.4					
	Ni				230					
	Rb									
	Sr				114					
	Y				76					
	Zr		630(a)	470(a)	306					
	Nb				23					
	Hf		6.4	6.9	7.50					
	Ba		220	180	200					
	Th		3.0	4.1	3.2				3.49	3.619
	U		0.7	0.9		0.61			0.85	0.974
	Pb								1.99	
	La		20	19	20.5					
	Ce		52	50	54.2					
	Pr									
	Nd									
	Sm		9.1	9.1	8.80					
	Eu		1.3	1.3	1.15					
	Gd									
	Tb		1.9	1.9	2.14					
	Dy		11	16	12.8					
	Ho									
	Er									
	Tm									
	Yb		6.9	6.8	7.28					
	Lu		0.98	0.98	0.98					
	Li					17(b)				
	Be									
	B									
	C							110		
	N							98		
	S	1140			530			750		
	F									
	Cl					17.2				
	Br					0.179				
	Cu									
	Zn						11.77			
(ppb)	I					2300				
	At									
	Ga									
	Ge									
	As									
	Se	270								
	Mo									
	Tc									
	Ru									
	Rh									
	Pd									
	Ag	6.5								
	Cd									
	In									
	Sn									
	Sb									
	Te									
	Cs									
	Ta		1200	1000	920					
	W									
	Re	0.59								
	Os	5.8								
	Ir	5.7								
	Pt									
	Au	2.4								
	Hg									
	Tl	1.4					0.61			
	Bi	0.61								
		(1)	(2)	(2)	(30	(4)	(5)	(6)	(7)	(8)

References and methods:

(1) Hughes et al. (1973); RNAA
(2) Laul and Schmitt (1973); INAA
(3) Wanke et al. (1977); XRF, INAA, RNAA and others
(4) Jovanovic and Reed (1975); INAA
(5) Reed et al. (1972); INAA
(6) Cripe and Moore (1975), Moore and Lewis (1976); combustion-titration, gas chromatography
(7) Silver (1972); ID/MS
(8) Rosholt (1974)

Notes:

(a) uncertainties about 30%
(c) conc. based on average specific activity of monitors from other irradiations.

STABLE ISOTOPES: Reed et al. (1977) tabulated data for residue and leach ^{204}Pb. Garner et al. (1975) reported Li and K isotopic data (Table 3), finding values similar to 15511, the fines from the same sample.

TABLE 15515-3. Isotopic analyses (Garner et al., 1975)

$^{6}Li/^{7}Li$ sample / $^{6}Li/^{7}Li$ std. (a)	$^{39}K/^{41}K$	$^{41}K/^{40}K$
1.007	13.743	573.6

(a) standard = NBS reference standard 9A.

RADIOGENIC ISOTOPES: Silver (1972) reported Pb isotopic data for clod ,4 (Table 4). The isotopes are slightly discordant and within the region occupied by the upper part of the ALSEP drill core sample, with higher $^{207}Pb/^{235}U$ and higher $^{206}Pb/^{238}U$ than mare basalts. Rosholt and Tatsumoto (1973) and Rosholt (1974) reported a $^{232}Th/^{230}Th$ ratio slightly less than expected from the $^{232}Th/^{238}U$ ratio (expected ratio/measured ratio = 1.02), but much closer to the expected than are the mare basalts. Garner et al. (1975) determined a $^{85}Rb/^{87}Rb$ ratio of 2.5914.

PROCESSING AND SUBDIVISIONS: Clods were originally individually numbered from ,1 to ,48; several became largely fines on sample handling. ,8 was used for thin sections and for grain-size separates. Most clod pieces have not been allocated.

TABLE 15515-4. Pb isotopic data (Silver, 1972)

Pb ppm	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
1.99	314.3	193.7	313.6

15528 REGOLITH BRECCIA ST. 9A 4.7 g

INTRODUCTION: 15528 is a friable regolith breccia with a composition apparently quite different from local regolith. It is brownish gray and subrounded (Fig. 1) and has a smooth surface with few to no zap pits. 15528 was collected approximately 60 m northeast of the rim of Hadley Rille, near 15529, but it has not been identified on photographs.

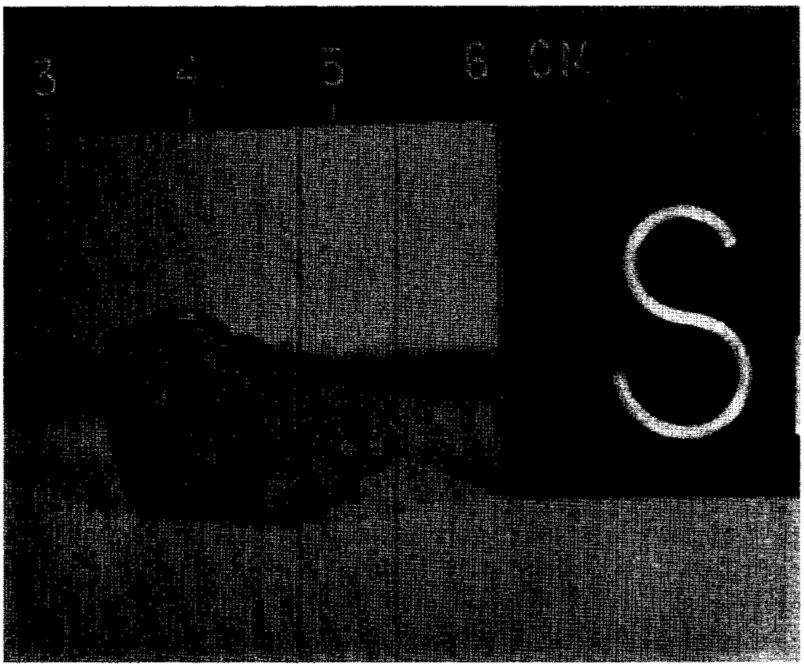


Figure 1. Macroscopic, pre-chip view of 15528. S-71-43647

PETROLOGY: 15528 is a friable regolith breccia containing a few prominent basalt clasts (Figs. 1, 2). The large basaltic fragment in Figure 2 appears to be a KREEP basalt. Diverse glass and mineral fragments are common. McKay et al. (1984) measured an I_s/FeO of 16-25 (21 in Korotev, 1984, unpublished), an immature index.

Figure 2. Photomicrograph of 15528,4. Width about 3 mm. Transmitted light.

CHEMISTRY: A bulk analysis of a small (45 mg) sample was made by Korotev (1984, unpublished) (Table 1, Fig. 3). The composition is unlike local regolith or any other regolith at the Apollo 15 site, being very high in incompatible elements. It appears to be rich in an Apollo 15 KREEP basalt component. Either the analyzed sample was unrepresentative or the sample is exotic, at least to Station 9A.

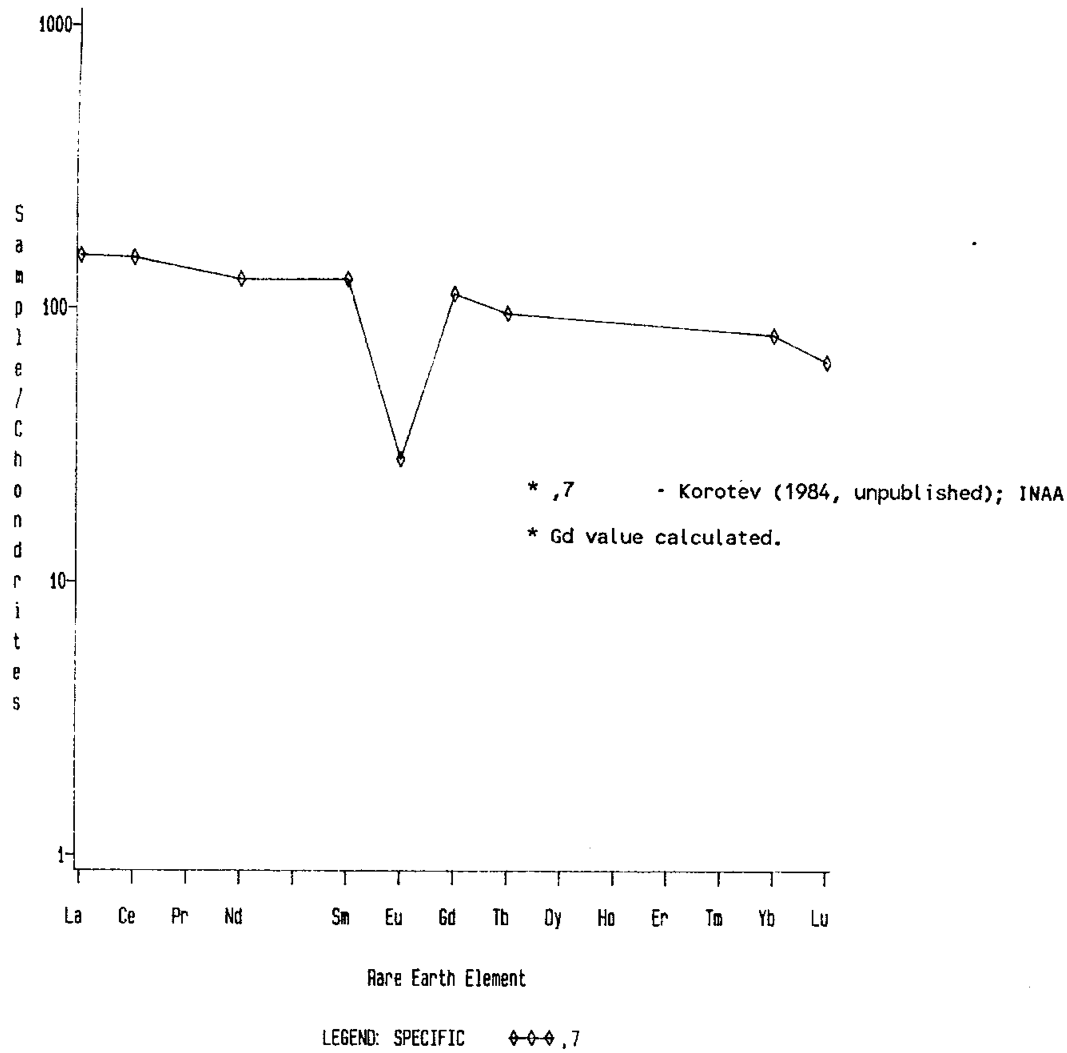


Figure 3. Rare earths in 15528,7 (bulk rock).

PROCESSING AND SUBDIVISIONS: Chipping produced ,1, from which thin sections ,5 and ,6 were made. During this chipping, several other chips were produced. These appear to have partly disintegrated in storage. ,7 was picked from one of these small fragments in 1984 for petrographic and chemical study.

TABLE 15528-1. Bulk rock chemical analysis

		,7
Wt%	SiO2	
	TiO2	2.03
	Al2O3	13.8
	FeO	13.0
	MgO	9.3
	CaO	10.1
	Na2O	0.62
	K2O	
	P2O5	
(ppm)	Sc	26.4
	V	78
	Cr	2410
	Mn	1375
	Co	29.0
	Ni	75
	Rb	
	Sr	130
	Y	
	Zr	740
	Nb	
	Hf	19.3
	Ba	521
	Th	8.7
	U	2.3
	Pb	
	La	51.2
	Ce	134
	Pr	
	Nd	76
	Sm	23.0
	Eu	1.95
	Gd	
	Tb	4.52
	Dy	
	Ho	
	Er	
	Tm	
	Yb	16.1
	Lu	2.20
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	480
	Ta	2170
	W	
	Re	
	Os	
	Ir	<3
	Pt	
	Au	<5
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Korotev (1984, unpublished); INAA

15529 MEDIUM-GRAINED OLIVINE-NORMATIVE(?) BASALT ST. 9 1531.0 g

INTRODUCTION: 15529 is a very vesicular basalt with an appearance similar to olivine-normative basalts 15016 and 15556. The sample is light olive gray, rounded, tough, and very vesicular (Fig. 1). It had a 3-cm high fillet, but has no zap pits.

15529 was collected about 60 m northeast of the rim of Hadley Rille, in an area in which rock fragments with sizes up to 20 cm are fairly abundant.

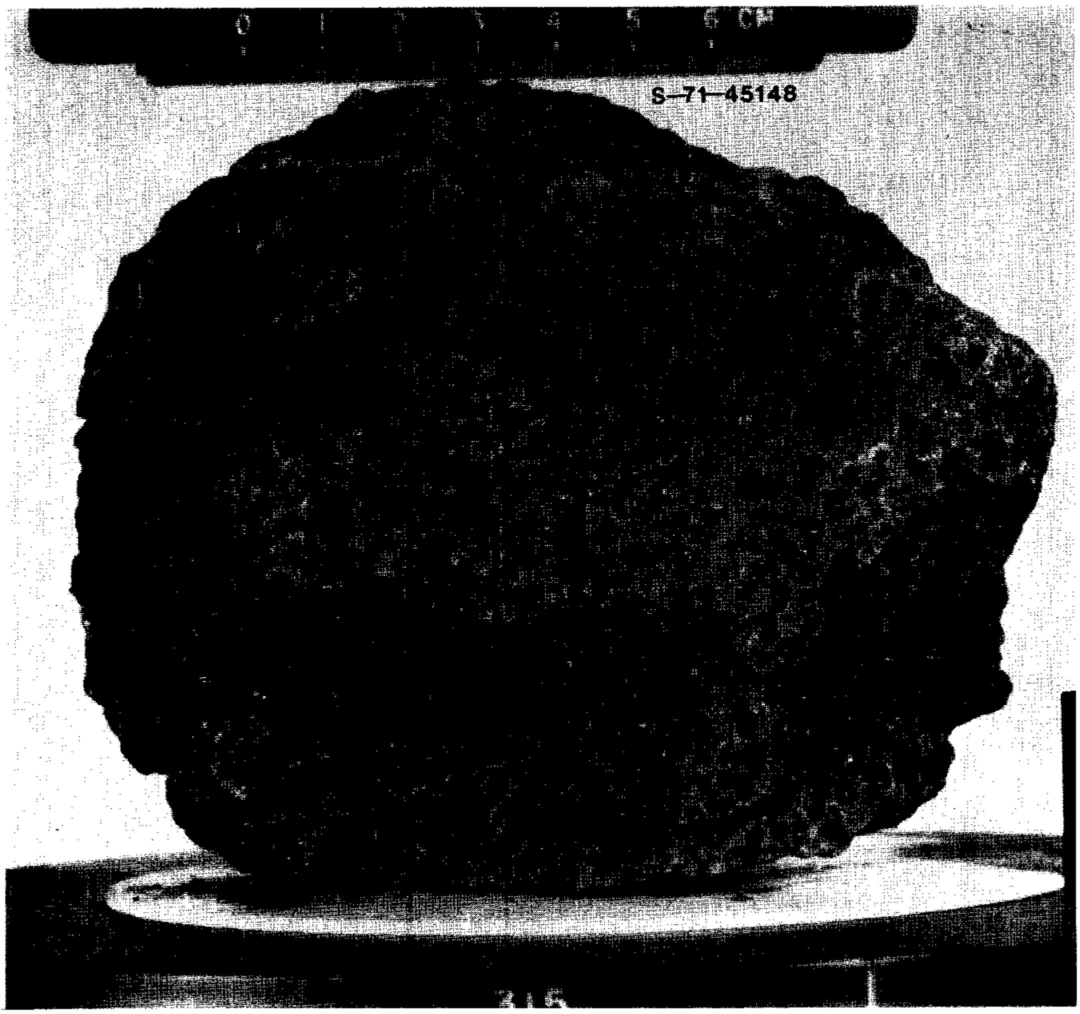


Figure 1. Sample 15529.

PETROLOGY: Macroscopically the sample is equigranular with conspicuous glass-lined vesicles lacking any preferred orientation (Fig. 1). In the absence of any thin sections, the only published study is that of Garvin et al. (1982) who studied vesicle size distributions. Vesicle diameters average 2.4 mm. Calculations indicate that the sizes and distribution of vesicles is consistent with a magma having 80 to 400 ppm dissolved CO ascending at 0.20 m/sec. This calculated amount depends not only on the ascent rate but also, to a lesser extent, on viscosity.

PROCESSING AND SUBDIVISIONS: Only a few chips have been removed, leaving ,0 at 1509.4 g. One split was allocated for chemical analysis.

15535 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 404.4 g

INTRODUCTION: 15535 is a fine-grained, olivine-bearing mare basalt (Fig. 1) in which fine-grained pyroxenes are enclosed in poikilitic plagioclases and olivine phenocrysts are scattered. It is finer-grained than 15536, chipped from the same boulder. Chemically it is an average member of the Apollo 15 olivine-normative mare basalt group. The sample is medium dark to brownish to olive gray, and is tough, slabby, and subangular to angular. Its surface is irregular and somewhat hackly, with zap pits irregularly distributed. It has 3 to 5% vugs, into which crystals project.

15535 was chipped with 15536 from a 0.75 m boulder about 20 m east of the rim of Hadley Rille, from the north rim of a moderately fresh, blocky, 3 m diameter young crater. The boulders are probably bedrock excavated by the impact event. The orientation of 15535 was documented.

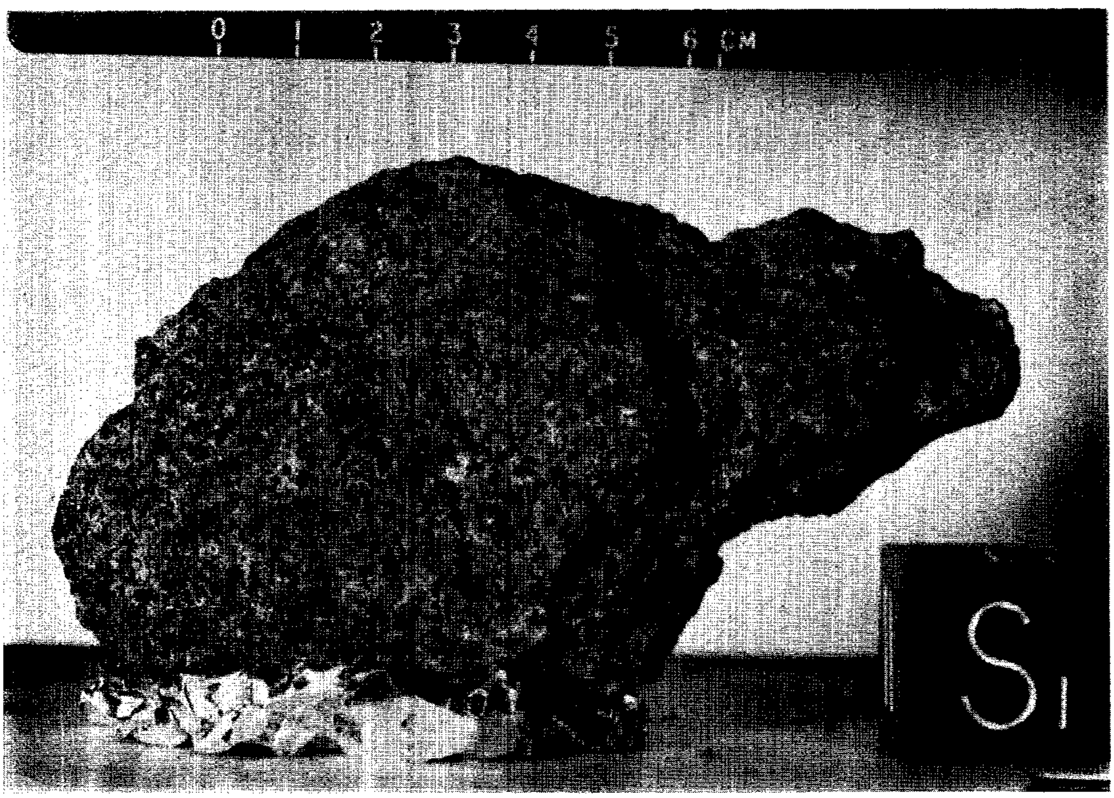


Figure 1. Pre-split view of 15535. The top surface is that broken from the parent boulder. S-71-46850

PETROLOGY: 15535 is a plagioclase-poikilitic mare basalt with scattered olivine phenocrysts (Fig. 2). The mass of the rock consists of clustered, granular clinopyroxenes and some olivines a few hundred microns across. The poikilitic plagioclases are up to 3 mm across, and the scattered, corroded, olivine phenocrysts are rarely as large as 2 mm. The opaques cluster with the mafic clusters, and are dominantly ulvospinel and some late-stage ilmenite. Chromite is rare. Cristobalites up to about 200 microns, fayalite, troilite, rare Fe-metal and residual glass are present. Many olivines and pyroxenes are optically zoned, and feldspars have curved twin planes. 2-mm sized vugs are scattered. Two published modes are listed in Table 1 and are reasonably consistent.

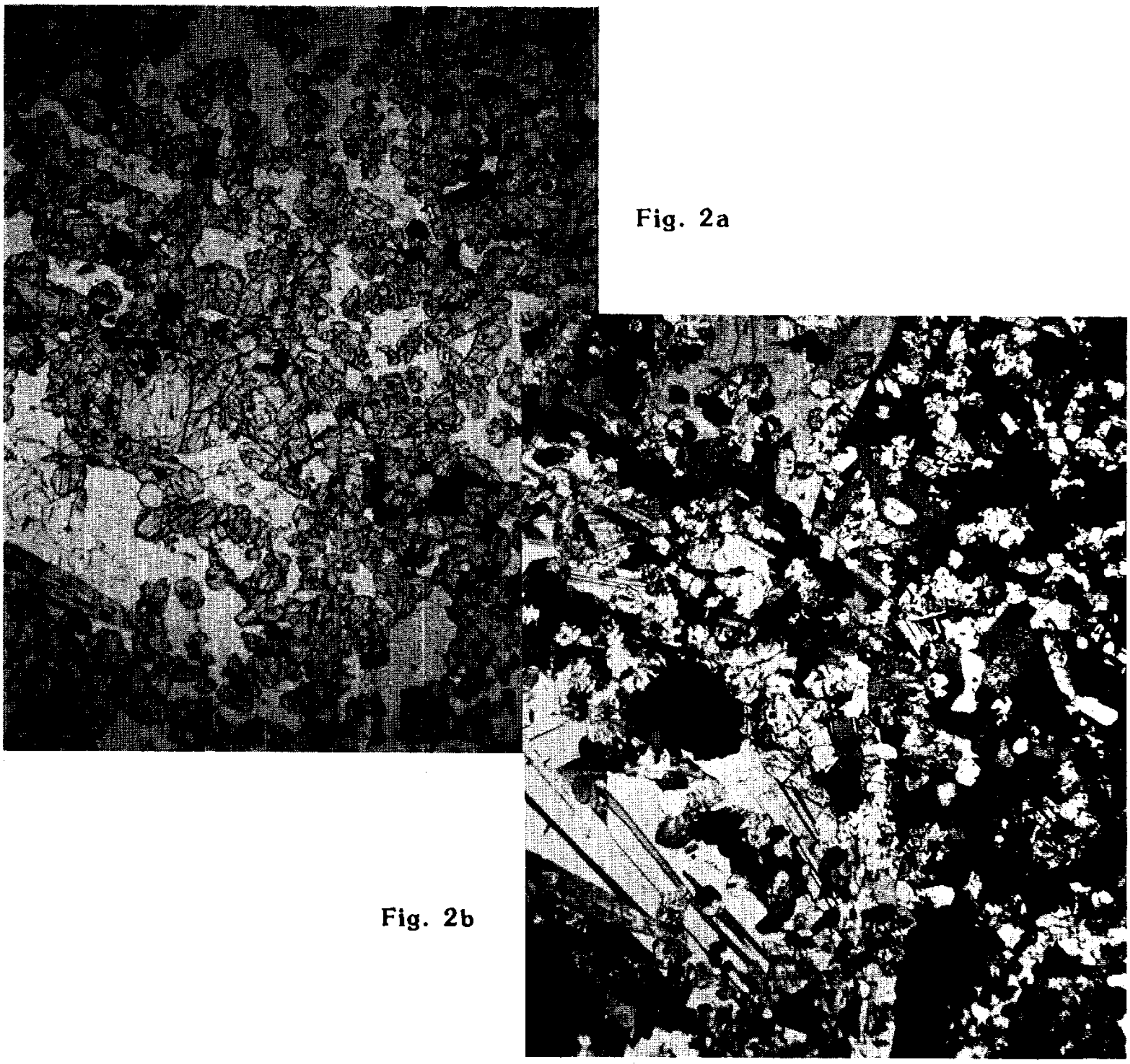


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15535,9 showing clustering of small, granular mafic grains and opaque minerals; poikilitic plagioclases; and a small olivine phenocryst (left center). Width about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15535-1. Modes of 15535

Phase	%	%
Ol	10	10
Cpx	53	60
Plag	32	25
Ulvo	2	
Ilm	1	4
Troil	<0.1	
Fe-Ni	<0.1	
Crist	0.5	
Glass	1	<1
Zircon	-	
	(1)	(2)

(1) Lunar Sample Information Catalog Apollo 15 (1971)
(2) Juan et al. (1972a)

Juan et al. (1972a) noted that the clinopyroxene was commonly twinned with (100) as the twin plane, and was zoned from a pigeonite core to a subcalcic augite rim. Fernandez-Moran et al. (1973) studied 16 mg of zoned small grains ($En_{50\pm10}Wo_{15.6\pm6.5}$) using electron optical techniques. The grains were crushed and impurities removed. Electron micrographs showed exsolution lamellae in 20% of the grains. Dense bands were 25-555 Å wide (av. 250 Å), the interbands were 50-900 Å wide (av. 330 Å). Virgo (1973a) used the same pyroxenes for x-ray diffraction and Mossbauer studies. The pigeonite cores (Ti/Al about 1/4) zoned towards Ca, Fe-rich rims (Ti/Al<1/2), and their patterns showed deviations from Lorentzian line-slopes and broader line widths consistent with their chemical heterogeneity. The Mossbauer study showed a high degree of disorder of the Fe^{2+}-Mg distributions; the interpretation is difficult because of the chemical heterogeneity and the mixture of structural states.

Juan et al. (1972a) reported that the olivines had a composition of Fo_{76}, (and that some had inclusions of clinopyroxene and ilmenite) and that plagioclases are An_{83}. They attributed fracture, wavy extinction, and bent twin lamellae for plagioclases to a shock event. They interpreted the crystallization sequence as cpx-->ol-->plag.

Haggerty (1972a,c,d) reported spinel compositional data (Fig. 3). The data display a typical bimodal ulvospinel-rich and a chromite-rich distribution, but there are also a few spinels of intermediate composition. Engelhardt (1979) tabulated 15535 as showing ilmenite crystallization as starting with plagioclase crystallization, and ending before the end of pyroxene crystallization.

Muan et al. (1974) reported that they had conducted equilibrium liquid-solid experiments (Fe-metal equilibria) on a representative powder of 15535, but apart from its having olivine or spinel on the liquidus, gave no specific data.

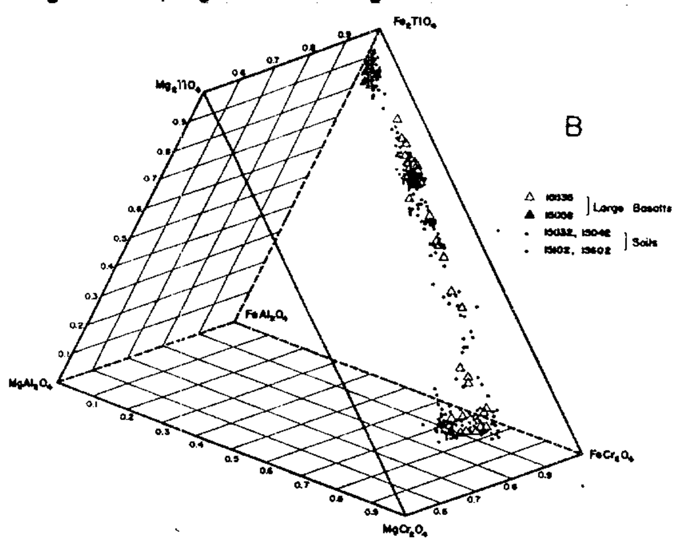


Figure 3. Compositions of spinel group minerals in 15535 (open triangles) and other Apollo 15 samples (Haggerty, 1972c).

TABLE 15535-2. Bulk rock chemical analyses

		,2	,4	,6	,5	,32	,31	,30	,0
Wt %	SiO_2	45.50	44.73	45.3		44.46			
	TiO_2	2.51	2.83	2.15		2.19			
	Al_2O_3	9.70	9.55	8.37		8.68			
	FeO	21.70	22.15	22.9		23.80			
	MgO	10.34	10.34	11.2		11.27			
	CaO	9.30	8.92	9.68		9.20			
	Na_2O	0.195	0.195	0.267		0.28			
	K_2O	0.041	0.046	0.044		0.04			0.059
	P_2O_5					0.06			
(ppm)	Sc								
	V					140			
	Cr	4120	3910			3900/4800			
	Mn	2250	2210		2190	2560			
	Co	77	59			52			
	Ni	92	76		46	70		75	
	Rb	3.8	3.8			<5			
	Sr	201	184		87	83			
	Y					42			
	Zr					85			
	Nb								
	Hf								
	Ba				45	38			
	Th								0.45
	U						0.11		0.104
	Pb					<2			
	La				3.49				
	Ce				9.7				
	Pr								
	Nd				6.7				
	Sm				2.60				
	Eu				0.69				
	Gd				3.6				
	Tb				0.59				
	Dy				4.07				
	Ho				0.73				
	Er								
	Tm								
	Yb				1.69				
	Lu				0.236				
	Li	8	7			7	7.1		
	Be								
	B					4			
	C								
	N								
	S								
	F								
	Cl						2.79		
	Br						0.017		
	Cu	3	7			8			
	Zn	12	17					1.4	
(ppb)	I						2.0		
	At								
	Ga	<10,000	<10,000			3000		3100	
	Ge							19	
	As								
	Se								
	Mo								
	Tc								
	Ru								
	Rh								
	Pd								
	Ag	32	26						
	Cd							1.4	
	In							0.34	
	Sn								
	Sb								
	Te						1.4		
	Cs								
	Ta								
	W								
	Re								
	Os								
	Ir							0.059	
	Pt								
	Au	4	2					0.060	
	Hg								
	Tl								
	Bi								
		(1)	(1)	(2)	(3)	(4)	(5)	(6)	

References and methods:

(1) Juan et al. (1972a, b); AAS, colorimetry
(2) Helmke et al. (1973); INAA, AAS
(3) Helmke and Haskin (1972), Helmke et al. (1973); RNAA
(4) Mason et al. (1972); general silicate analysis, gravimetry, flame photometry, colorimetry
(5) Reed and Jovanovic (1972); INAA
(6) Baedecker et al. (1973); RNAA

CHEMISTRY: Chemical analyses are listed in Table 2 and the rare earths shown in Figure 4. The data are fairly consistent except for TiO_2 (whose variation is probably a reflection of the localized distribution of ulvospinel and ilmenite) and show 15535 to be an average member of the Apollo 15 olivine-normative basalt suite. However, the rare earths are slightly lower than is typical, again probably a sampling problem. Mason et al. (1972) suggested caution because of the small sample sizes used.

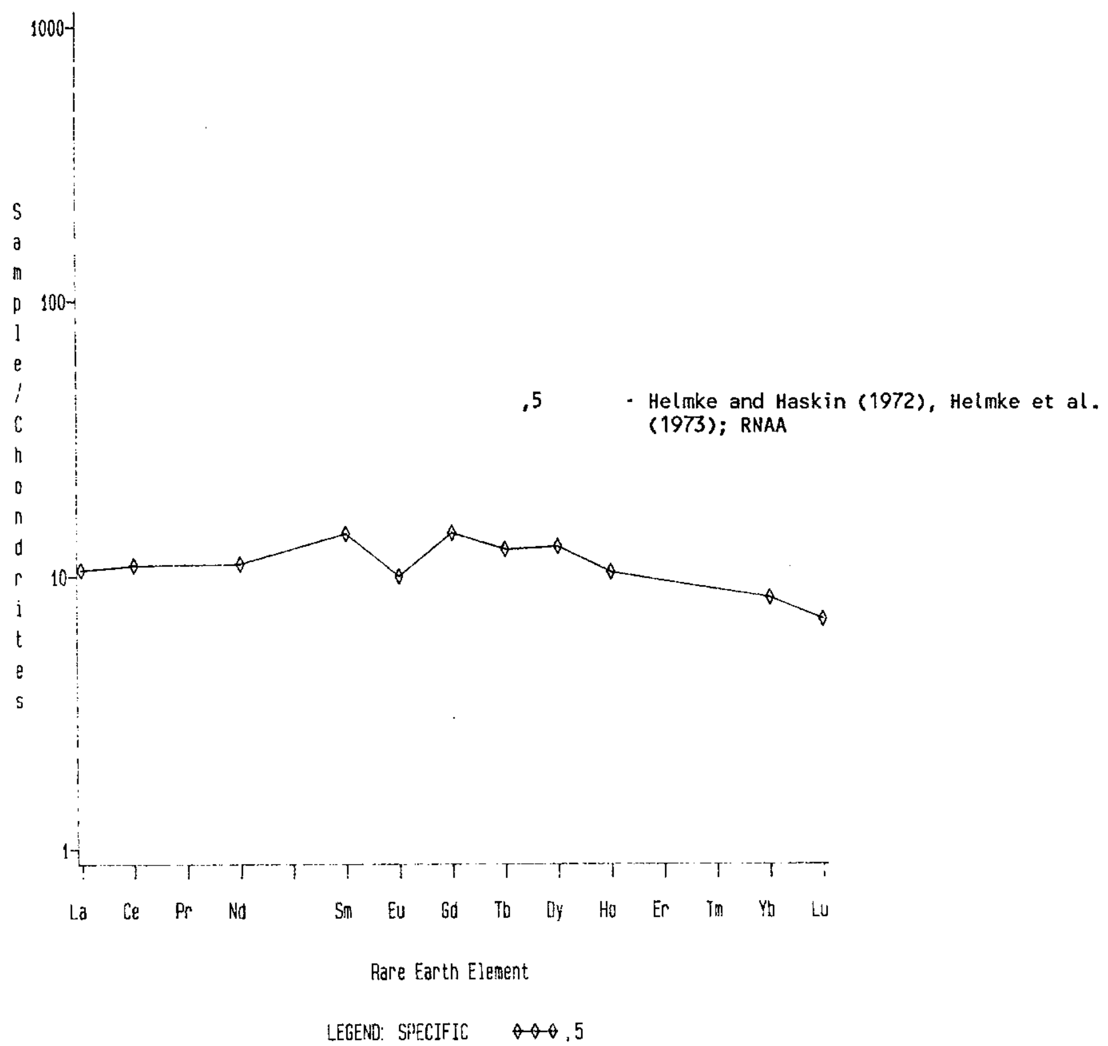


Figure 4. Rare earths in 15535.

EXPOSURE, TRACKS, AND RARE GAS: Rancitelli et al. (1972) tabulated disintegration count data for cosmogenic radionuclides, and stated that ^{26}Al was saturated, indicating a long exposure in comparison with the ^{26}Al half-life. However, Yokoymama et al. (1974) found the Rancitelli et al. (1972) data to indicate that the ^{26}Al was not saturated (^{22}Na-^{26}Al method).

Bhandari et al. (1972, 1973) diagrammed track density with depth (Fig. 5) showing a very shallow slope. The track density was 5 x $10^6/cm^2$. They tabulated a "sun-tan" exposure age of less than 1 m.y. and a "subdecimeter" exposure age of 10 m.y. (1973 report) or less than 10 m.y. (1972 report).

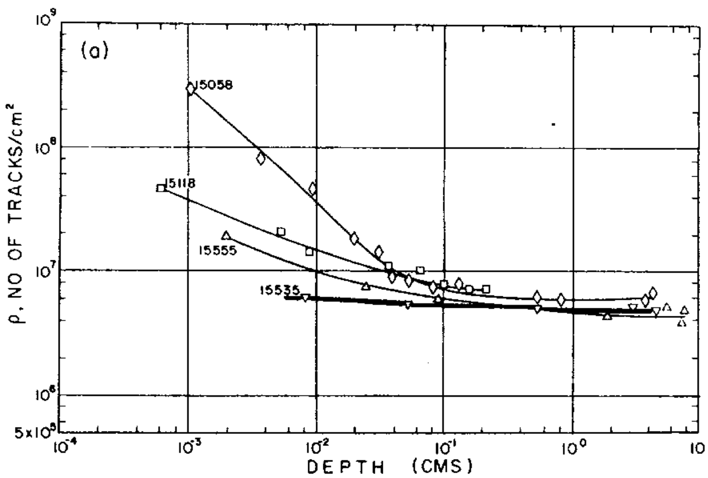


Figure 5. Track density profile for 15535 and other Apollo 15 rocks (Bhandari et al., 1975).

PHYSICAL PROPERTIES: Banerjee et al. (1972) and Hoffmann and Banerjee (1975) measured the natural remanent magnetization of 15535, in particular alternating field demagnetization. The sample showed extreme "zig-zag" behaviour, i.e., changes of intensity and direction (Fig. 6). The behaviour is characterized by nonreproducible remanent magnetization values upon demagnetization at a given peak AF. The direction is roughly confined in a plane. The behaviour is attributed to the presence of a few, planar, multidomain grains representing a local mineral fabric. These "super-grains" do not demagnetize, and if present in any given sample could easily render any paleointensity determination of little value. Hoffmann and Banerjee (1975) also conducted experiments of viscous acquisition and decay on their sample, with results consistent with the "super-grains" responsible for the zig-zag NRM behaviour.

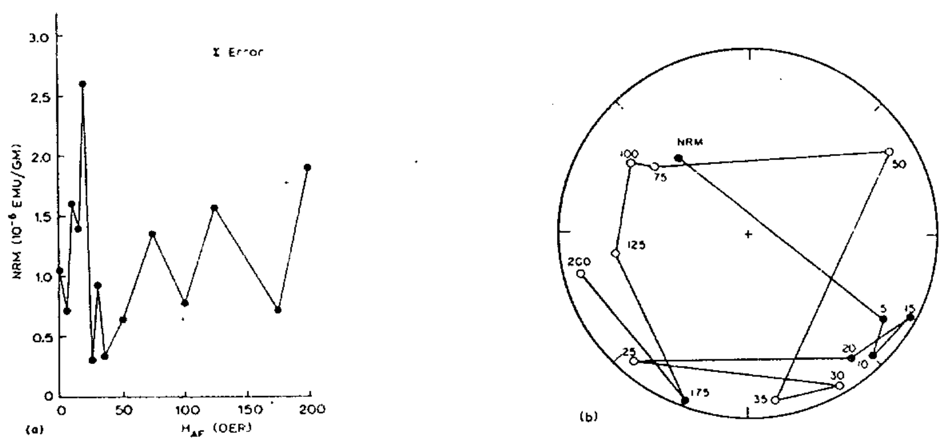


Figure 6. a) AF-demagnetization curve of NRM for 15535,28; b) stereographic projection of NRM directions after stepwise demagnetization of the indicated peak AF values. Solid and open circles refer to the upper and lower hemispheres respectively (Hoffman and Banerjee, 1975).

PROCESSING AND SUBDIVISIONS: A chip was removed from the sample (,1) and subdivided to produce ,2 to ,8 (total about 8 g). ,3 was made into a potted butt and produced all the thin sections from 15535, i.e., ,9 and ,11 to ,15. Subsequently the sample was sawn to make a slab which was dissected (Fig. 7). Most allocations were made from those pieces. About 10 g of the slab piece was homogenized as a fine material (,34 and daughters) and part of it allocated for experimental studies. ,0 is now 230.0 g, and end piece ,18 (61.28 g) is in remote storage in Brooks.

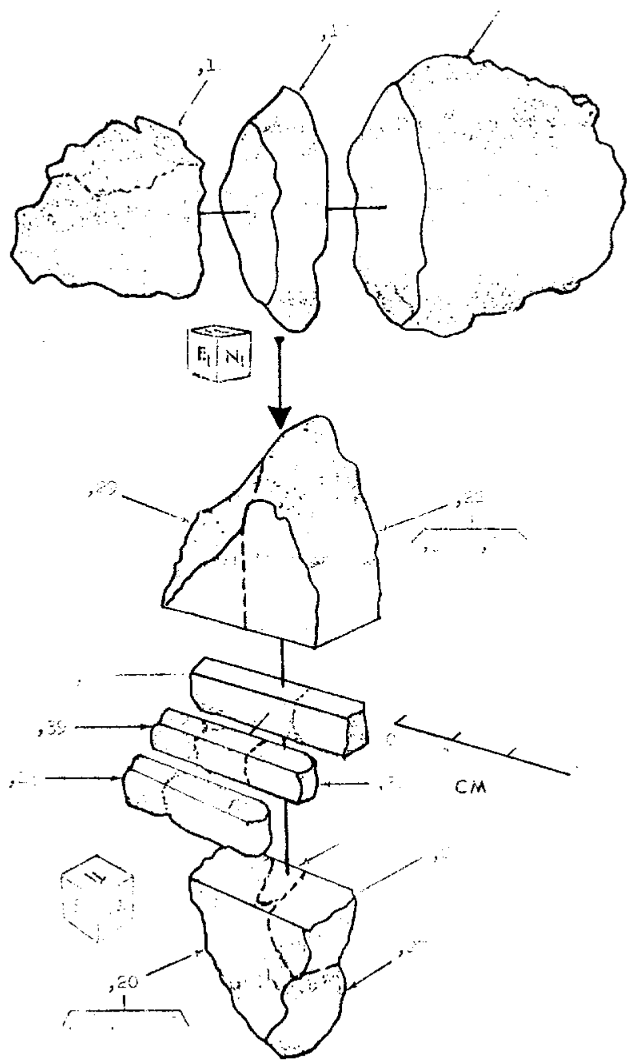


Figure 7. Basic splitting of 15535.

15536 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 317.2 g

INTRODUCTION: 15536 is a medium-grained, olivine-bearing mare basalt (Fig. 1) in which small pyroxenes are enclosed in poikilitic plagioclases and olivine phenocrysts are common. The mafic grains show clear clustering, macroscopically observed as pyroxene-rich and plagioclase-rich narrow bands (Fig. 1). The sample is coarser-grained than 15535, chipped from the same boulder. Chemically it is an average member of the Apollo 15 olivine-normative mare basalt group. The sample is light olive gray, and is tough, slabby, and angular to subangular. The non-broken surface had a light soil cover and a few zap pits. Small vugs occupy about 5% of the sample.

15536 was chipped with 15535 from a 0.75 m boulder about 20 m east of the rim of Hadley Rille, from the north rim of a moderately fresh, blocky, 3 m-diameter young crater. The boulders are probably bedrock excavated by the crater-forming impact event. The orientation of 15536 was documented.

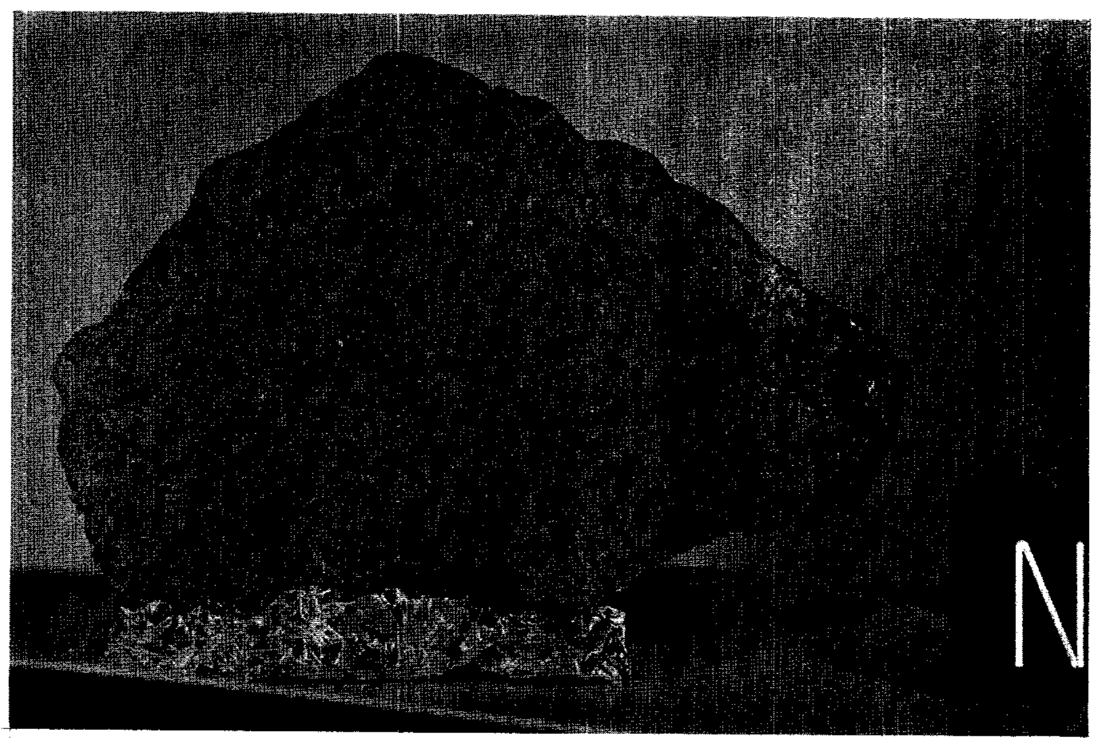


Figure 1. Broken face of 15536, pre-chipping. S-71-47277

15536

PETROLOGY: 15536 is a plagioclase-poikilitic mare basalt with olivine phenocrysts (Fig. 2). It is similar to 15535 except that the olivines and pyroxenes are larger and there is a distinct tendency for pyroxene-rich bands and plagioclase-rich bands to segregate. Some areas are quite densely packed with pyroxene (and some olivine) and with little plagioclase. These mafic-rich zones contain olivine (including "sieved" fayalite), conspicuous cristobalite, troilite, and opaque minerals. Chromite is not as common as ulvospinel and most is in olivine phenocrysts, which are zoned and up to 2 mm across. The olivine phenocrysts commonly contain silicate inclusions. Ilmenite is a late-stage mineral with fayalite. The pyroxenes are granular, zoned, and many are twinned. The plagioclase-rich areas contain poikilitic plagioclase 1 to 2 mm across enclosing granular pyroxenes and some olivines, but only rarely opaque minerals, cristobalite, or fayalite.

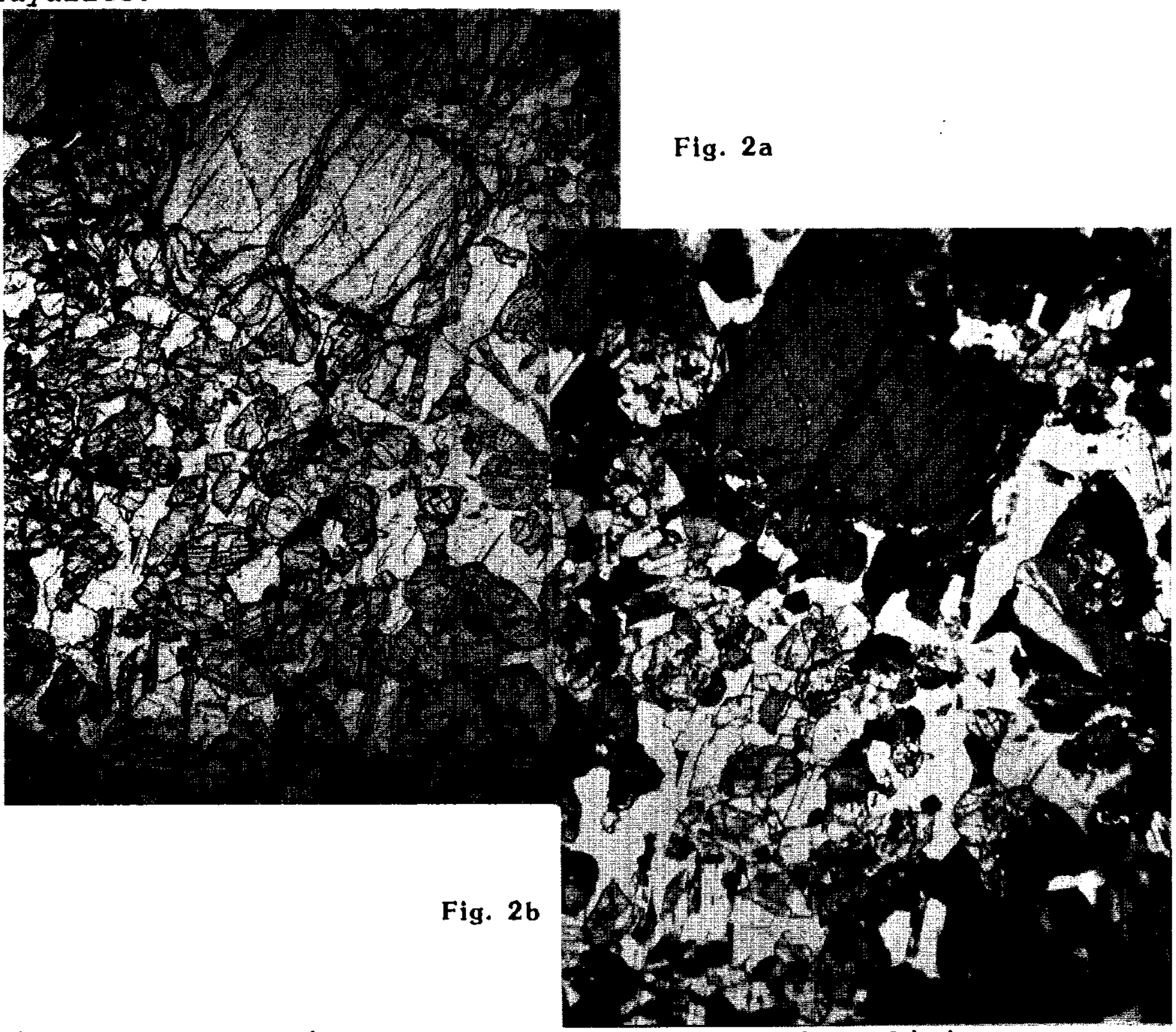


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15536,7, showing olivine phenocryst, plagioclase-poikilitic area (right, lower), and mafic-cluster area (top, left). Widths about 3 mm. a) Transmitted light; b) crossed polarizers.

Very little has been published on 15536. Brown et al. (1972a) noted it as being an olivine-normative mare basalt (PET Type III) with a fine grain size, granular texture, and the mineral chemical characteristics of that basalt type, but gave no specific data. Taylor and McCallister (1972a,b) and Taylor et al. (1973) studied the partitioning of Zr between ilmenite and ulvospinel (Fig. 3). The ratios suggest a quenching-in at high temperatures (about 1225°C or more), from a comparison with experimental data. The cooling rate was fast enough that ulvospinel was not reduced to Fe-metal and ilmenite. Taylor et al. (1972b) and Taylor et al. (1973) measured the chromium content of Fe-metal in various associations (Fig. 4). 15536 was the only sample of those studied which showed a correlation of the Cr in metal with its association: metal in association with chromite had higher Cr. Experiments in the temperature range 800-1000°C of Fe-metal and chromite coexistence showed the metal

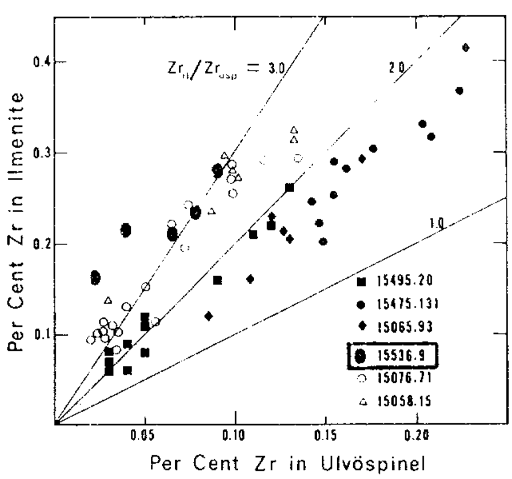


Figure 3. Zirconium contents of coexisting ilmenite and ulvospinel in 15536,9 and other Apollo 15 samples (Taylor et al., 1973).

to have 2.5 ± 0.3% Cr, higher than the natural samples (the amount depends perhaps also on the Ni content of metal and the Cr activity of the chromite). There is not sufficient chromium-content dependency for the Cr-in-metal to be used as a geothermometer; there is perhaps also an fO_2 dependency.

CHEMISTRY: Rhodes and Blanchard (1983) reported that they had made an analysis of 15536 for major and trace elements (XRF, INAA). This analysis was similar to those of 15529 and 15598 and showed the sample to be an Apollo 15 olivine-normative mare basalt.

PROCESSING AND SUBDIVISIONS: Chips ,1 and ,2 were taken from the E-N end. ,1 was partly used for thin sections ,5 and ,7 to ,9. ,2 was used for chemical analyses. In 1982, further chipping from the E-N end produced several chips, including the 2 g piece used by Rhodes and Blanchard (1983). ,0 is now 293.79 g.

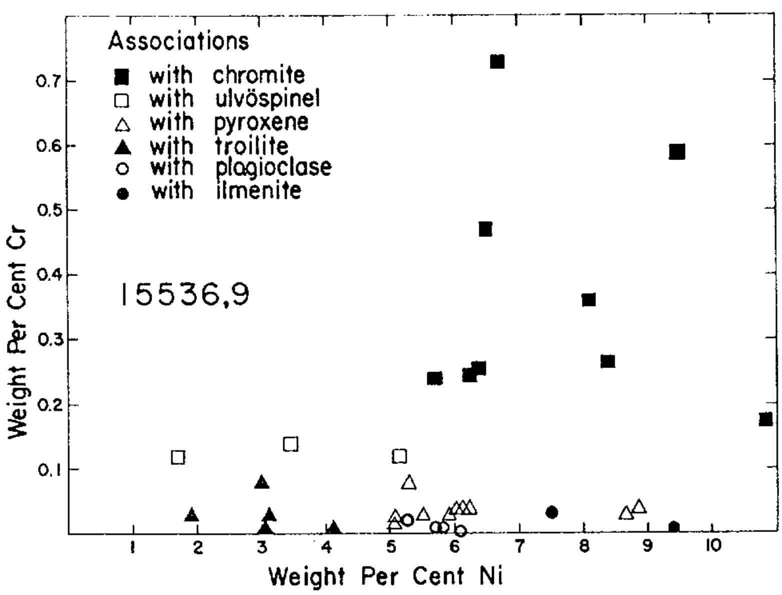


Figure 4. Cr and Ni contents of metal grains in 15536,9 (Taylor et al., 1973).

15537 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 1.90 g

INTRODUCTION: 15537 is a medium-grained olivine-bearing basalt. It is neither plagioclase-poikilitic nor olivine-phyric. It is a medium dark to brownish gray, angular, blocky, coherent, and vesicular fragment. The pyroxenes are brown, the olivines are yellow green. The vesicles are about 10% of the rock and average about 1 mm but some are as big as 3 mm. Zap pits are absent from one fresh face.

15537 was collected from the north rim of a moderately fresh, blocky 3 m-diameter young crater, about 20 m east of the rim of Hadley Rille. It has not been identified on photographs.

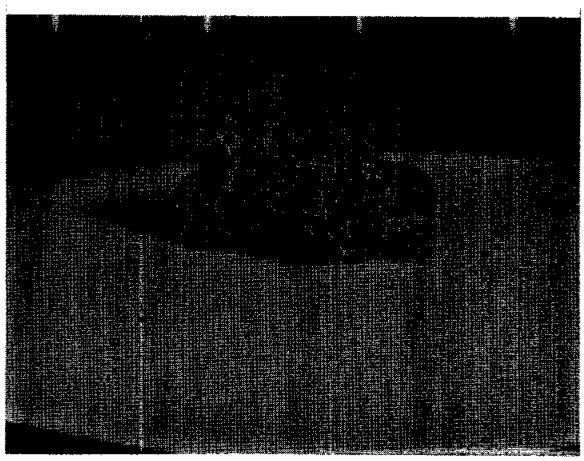


Figure 1. Pre-chip view of 15537. S-71-44523

PETROLOGY: 15537 is a medium-grained, olivine-bearing mare basalt (Fig. 2). The dominant phase is pyroxene, which occurs in grains up to 2 mm long. The olivines are not phenocrysts, most being less than 400 microns across and embedded in larger pyroxenes (Fig. 2c). The olivines are corroded, and several are polygonal aggregates. Some have silicate liquid inclusions. The plagioclases form laths, and are not poikilitic; most are less than 1 mm long. Chromite, ulvospinel, and ilmenite are present, but chromite is rare. Minor amounts of residual phases (glass, phosphate, troilite, fayalite) are present, but only one small grain of cristobalite is present in the thin section.

PROCESSING AND SUBDIVISIONS: A small chip ,1 was removed, and partly used to make thin section ,4. ,0 (1.53 g) consists of one main chip, a small piece, and fines.

Fig. 2a

Fig. 2b

Fig. 2c

Figure 2. Photomicrographs of 15537,4. a) transmitted light; b) and c) crossed polarizers. a) and b) general view, showing mafic nature and lathy plagioclases. Width about 3 mm. c) olivines (dark) embedded in pyroxene (white). Width about 750 microns.

15538 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 2.60 g

INTRODUCTION: 15538 is a medium-grained olivine-bearing basalt with a texture and grain-size very similar to 15536, i.e., plagioclase-poikilitic and olivine-phyric. The sample is light or medium-gray, blocky, angular, and tough, with plagioclase-rich and pyroxene-rich bands like 15536. Only one side has zap pits, and the sample is probably a spall (perhaps from 15536 itself). The sample has 2% vugs, confined to the mafic bands. The pyroxenes are brown, the olivines yellow-green.

15538 was collected from the north rim of a moderately fresh, blocky, 3 m-diameter young crater, about 20 m east of the rim of Hadley Rille. It has not been identified on photographs.

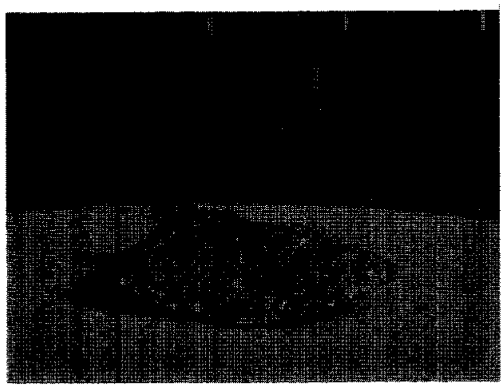


Figure 1. Pre-split view of 15538. S-71-44810

PETROLOGY: 15538 is a medium-grained, plagioclase-poikilitic mare basalt (Fig. 2) with olivine phenocrysts and is petrographically indistinguishable from 15536. It has the same grain-sizes, textures, and segregation into plagioclase-rich and plagioclase-poor areas. The olivine phenocrysts are not present in the (small) thin sections. Cristobalite and fayalite are conspicuous in the mafic-rich clusters. Sewell et al. (1974) tabulated five clinopyroxene and four plagioclase microprobe analyses. Wark et al. (1973) tabulated a comprehensive microprobe analysis of a zirconolite grain.

PROCESSING AND SUBDIVISIONS: A small chip ,1 was removed and entirely used to make thin sections ,4 and ,5. ,0 is now 2.40 g.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15538,4 showing plagioclase-rich zone (bottom) and mafic-rich zone (upper). Widths about 3 mm. a) transmitted light; b) crossed polarizers.

15545 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 746.6 g

INTRODUCTION: 15545 is a plagioclase-poikilitic, olivine-bearing mare basalt. It is a member of the olivine-normative group of basalts, and is very similar to 15535, chipped from a nearby boulder. The olivines include scattered phenocrysts. Chemically 15545 is an average member of the Apollo 15 olivine-normative mare basalt group. It is a light brownish gray, blocky, and coherent sample (Fig. 1). It contains a few vugs (2%) and a few zap pits on all faces.

15545 was collected in the region of several other rocks and soils on the rim of a 3 m fresh crater, 20 m east of the rim of Hadley Rille. It has not been identified on photographs, hence its orientation is unknown.

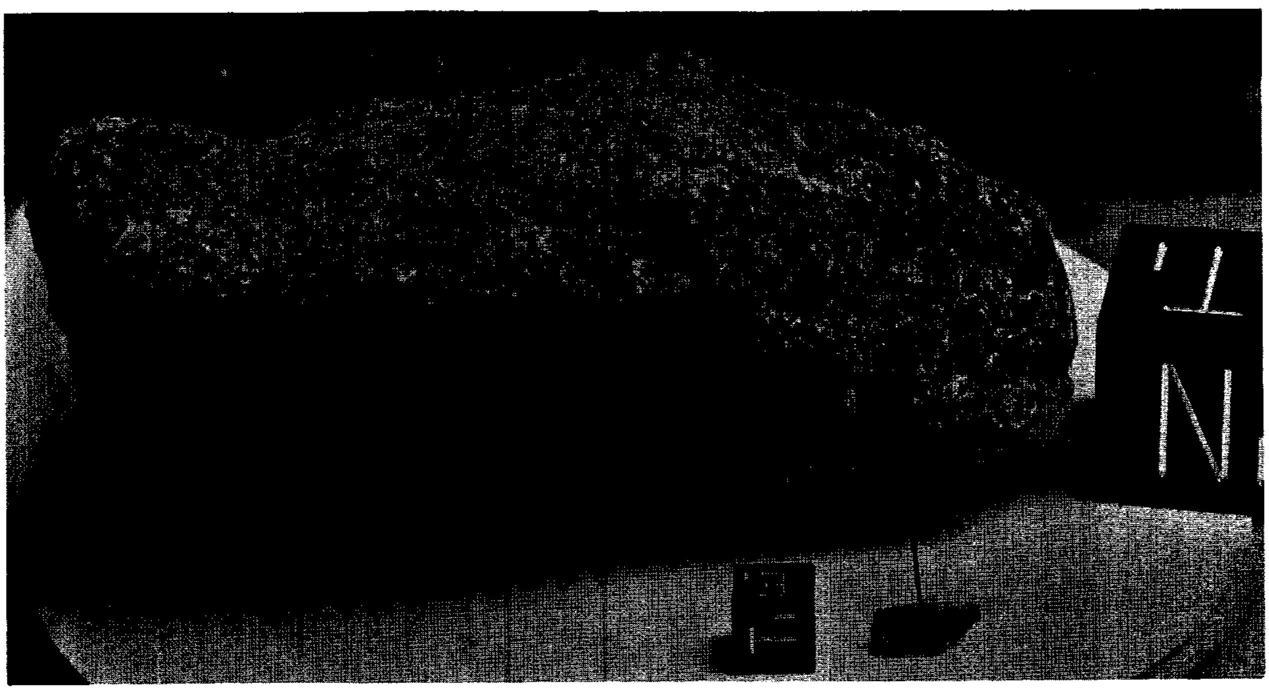


Figure 1. View of 15545,0 following separation of ,1 (S-71-48362).

PETROLOGY: No comprehensive description of 15545 has been published. It is a plagioclase-poikilitic mare basalt, containing small granular pyroxenes, and small, scattered olivine phenocrysts (Fig. 2), with some vesicles. The olivines are up to 1.5 mm, the plagioclase up to 2 mm. Modes listed in Table 1 are in reasonable agreement and show only small amounts of residual glass and silica phases.

Kushiro (1972, 1973) provided microprobe mineral analyses. The olivines are zoned from Fo_{56} to Fo_{17} (1972) or Fo_7 (1973, although only Fo_{17} is shown on the diagram); plagioclases from $An_{91}Ab_{8.5}Or_{0.5}$ to $An_{79}Ab_{18}Or_3$. The pyroxenes have extensive zoning and grain-to-grain variation (Fig. 3) starting with pigeonite ($Mg_{54}Ca_{11}$) and extending to subcalcic ferroaugite. The most iron-rich pyroxenes have Ti/Al >1/2 (Fig. 4) indicating the presence of Ti^{3+} and very reducing conditions. Taylor and McAllister (1972a, b) plotted Zr in ilmenite against Zr in ulvospinel, finding a ratio of approximately 3.0, among the higher values for Apollo 15 mare basalts. By comparison with experiments, the data indicate an equilibration temperature of about 1225°C, i.e., near-liquidus or quenched-in equilibria, in contrast with the lower temperatures derived for other coarser-grained, more slowly-cooled rocks. Engelhardt (1979) tabulated ilmenite paragenesis.

Roedder and Weiblen (1977) analyzed inclusions in olivine and ilmenite, but did not specifically discuss the 15545 data, which is archived. Both El Goresy et al. (1976) and Gleadow et al. (1974) listed 15545 as among their studied samples but reported no data.

CHEMISTRY: Chemical analyses for bulk 15545 are listed in Table 2 and the rare earths plotted in Figure 5. An energy-dispersive defocussed beam analysis by Sewell et al. (1974) is in general agreement except for lower TiO_2 and FeO. The data show that 15545 is a member of the olivine-normative mare basalt group. Compston et al. (1972) noted that their XRF determination for Rb is systematically low by 0.2 ppm. Maxwell et al. (1972) also analyzed for, and found no, Fe_2O_3, H_2O^+, and H_2O^-. Rhodes (1972) included his analysis in a general average and discussion of Apollo 15 olivine-normative basalts.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15545,58 a) plane light; b) crossed polarizers. Width of view 2 mm.

TABLE 15545-1. Modes of 15545

	,2	,58	,?
Ol	11	3.7	8.6
Cpx	50	67.3	61.4
Plag	30	24	23.5
Ulvo	3	1.6	
Ilm	3	1.7	
CrSp	0.1	tr	6.0
Fe-Ni	0.1	tr	
Troil	0.1	0.5	
Crist	1.5	tr	0.5
Glass	0.5	0.3	

,2 from Lunar Sample Information Catalog Apollo 15 (1971).
,58 from Rhodes and Hubbard (1973).
,? from Papike *et al*. (1976).

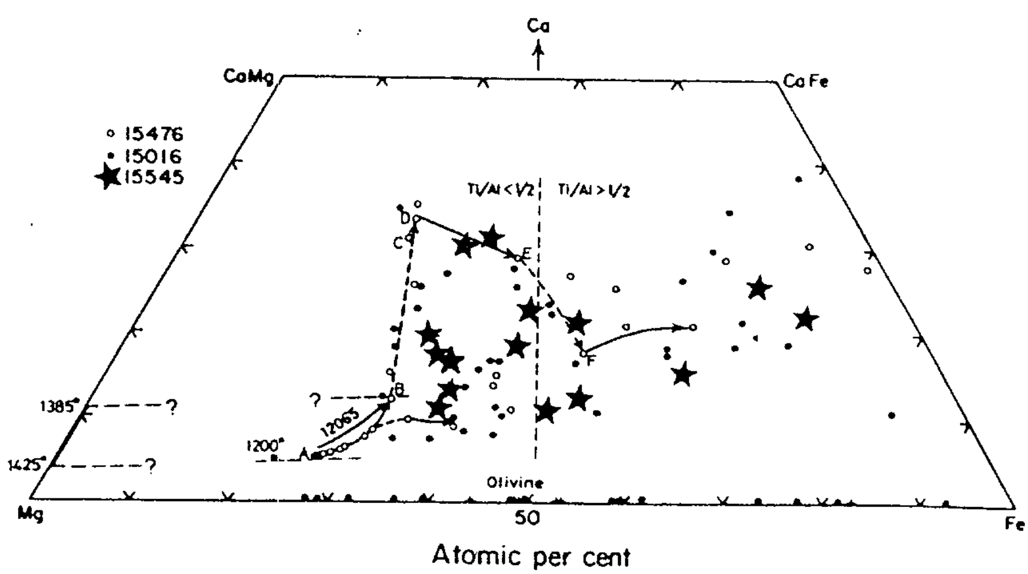


Figure 3. Pyroxene compositions in 15545 and other samples (Kushiro, 1973).

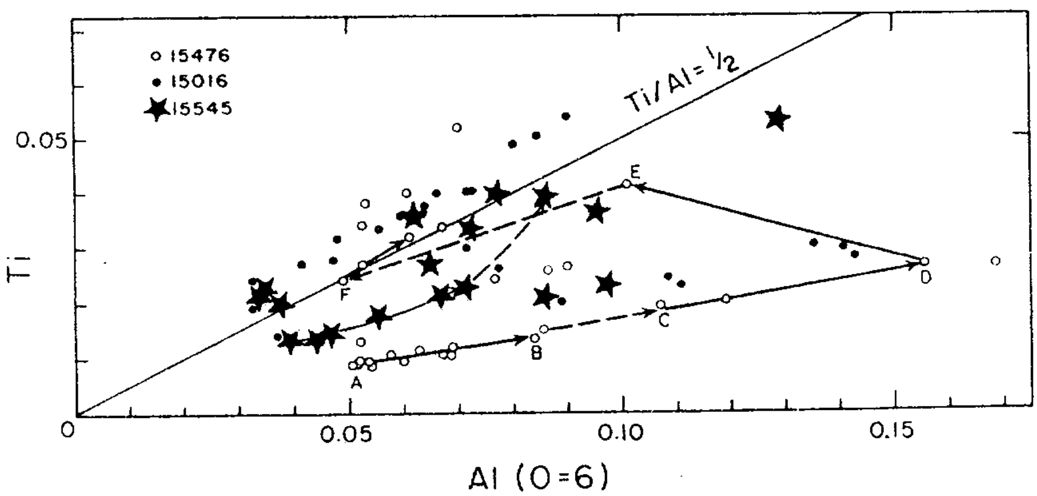


Figure 4. Ti vs. Al for pyroxenes in 15545 and other samples (Kushiro, 1973).

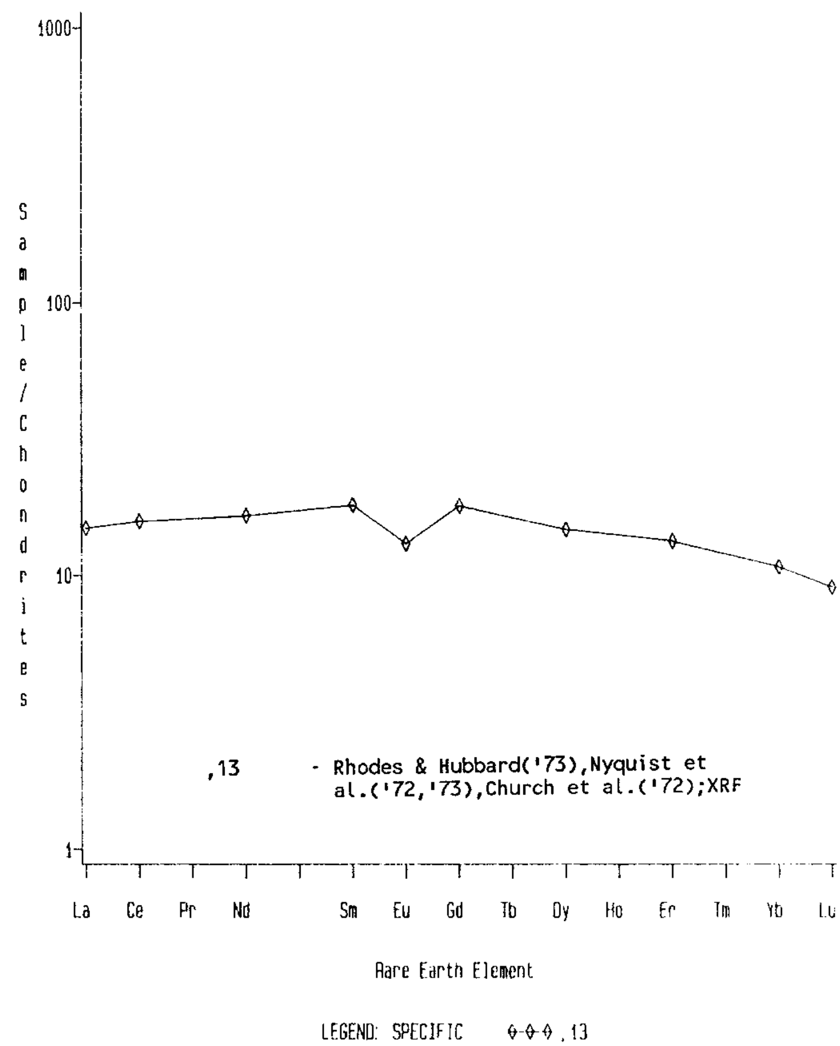


Figure 5. Rare earths in 15545.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Compston et al. (1972) and Nyquist et al. (1972, 1973) reported Rb-Sr isotopic data for bulk rock samples (Table 3). 15545 falls isotopically into the same tight grouping as other Apollo 15 olivine-and quartz-normative basalts. The data of Compston et al. (1972) show sampling effects consistent with dispersion along a 3.3 b.y. isochron.

EXPOSURE: Eldridge et al. (1972) reported cosmogenic nuclide disintegration data for ^{22}Na, ^{26}Al, and ^{54}Mn for the bulk rock. Yokoyama et al. (1974) found that ^{26}Al was saturated, indicating an exposure greater than about 2 m.y.

PHYSICAL PROPERTIES: Mizutani and Newbigging (1973) determined elastic wave velocities (Vp) at 27°C for a range of pressures up to 9 Kb (Table 4 and Fig. 6) for split ,24. At any given pressure, Vp is higher than for basalts 14053 or 15058.

PROCESSING AND SUBDIVISIONS: A small piece (,1) was pried off and made into thin sections (Fig. 1). Subsequently the "E" end was sawn off and substantially dissected by more sawing (Fig. 7). To obtain interior and unsawn pieces, splits were made from the other ("W") end around the fracture from which ,1 was taken. A large piece from that action, ,36 (96.75 g) is stored at Brooks. ,0 now has a mass of 565.8 g.

TABLE 15545-3. Rb-Sr isotopic data for 15545

Split	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	T_{BABI} *
,15	0.84	96.9	0.0250	0.70074 ± 10	4.62
,15	0.73	96.1	0.0219	0.70051 ± 10	4.55
,13	0.750	103.9	0.0209 ± 6	0.70041 ± 4	4.37 ± 0.26

* adjusted for interlaboratory bias with BABI = 0.69898.
,15 from Compston et al. (1972) (T_{BABI} from Nyquist, 1977).
,13 from Nyquist et al. (1972, 1973).

TABLE 15545-4. Elastic wave velocities, Vp. (Mizutani and Newbigging, 1973)

Pressure (Kb)	0.0	0.5	1.0	2.0	3.0	5.0	7.0	9.0
Vp (Km/sec)	5.60	6.10	6.37	6.63	6.76	6.90	6.98	7.02

Figure 6. Elastic wave velocities in 15545 and other basalt samples (Mizutani and Newbigging, 1973).

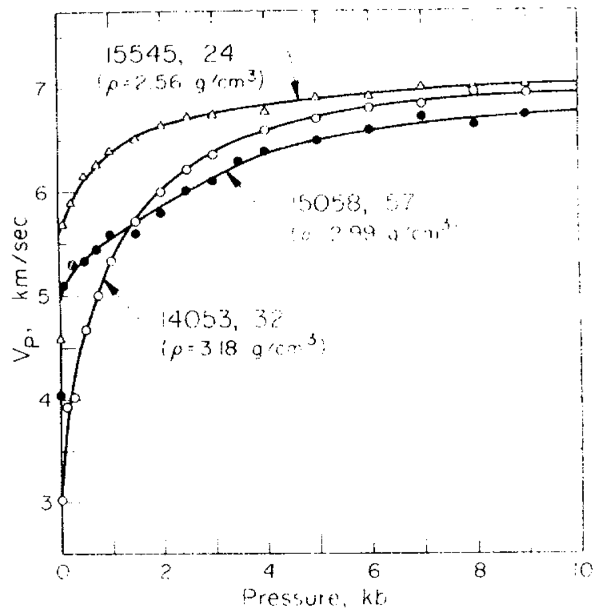


Figure 7. General subdivision of 15545.

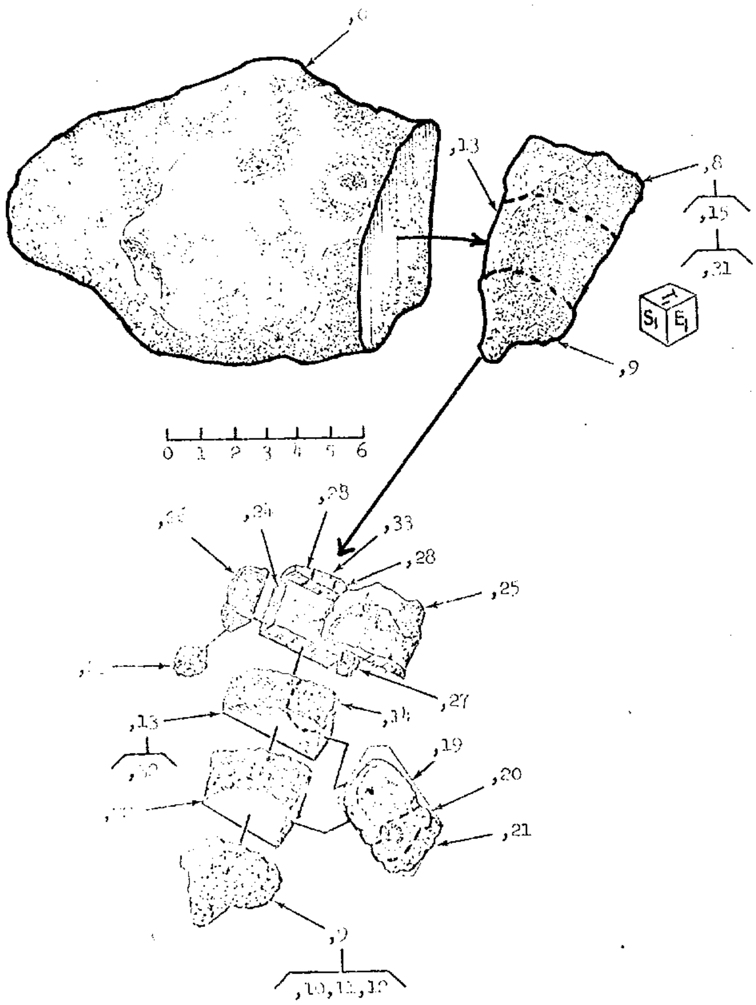


TABLE 15545-2. Chemical analyses

		,13	,13	,15	,15	,15	,12	,12	,45	,35	,0
Wt %	SiO2	45.02				44.89				45.72	
	TiO2	2.33	2.35			2.49				2.40	
	Al2O3	8.77				8.71				8.30	
	FeO	22.02	22.0			22.43				21.99	
	MgO	10.36	9.45			10.08				10.39	
	CaO	9.89				9.95				9.62	
	Na2O	0.21	0.283			0.45				0.28	
	K2O	0.032				0.04				0.04	0.028
	P2O5	0.05				0.07				0.11	
(ppm)	Sc										
	V										
	Cr					3700				4300	
	Mn	2300				2400				2300	
	Co										
	Ni								51		
	Rb	0.750		0.84	0.73	0.57			0.909		
	Sr	104		96.9	96.1	97.6					
	Y										
	Zr										
	Nb										
	Hf										
	Ba	46.7									
	Th										0.43
	U	0.132							0.144		0.13
	Pb										
	La	4.93									
	Ce	13.9									
	Pr										
	Nd	9.92									
	Sm	3.29									
	Eu	0.895									
	Gd	4.48									
	Tb										
	Dy	4.68									
	Ho										
	Er	2.67									
	Tm										
	Yb	2.16									
	Lu	0.308									
	Li										
	Be										
	B										
	C										
	N										
	S	700				500	750	780		700	
	F										
	Cl										
	Br										
	Cu										
	Zn								0.99		
(ppb)	I										
	At										
	Ga					3000					
	Ge								3.76		
	As										
	Se						160	190	117		
	Mo										
	Tc										
	Ru										
	Rh										
	Pd								≤0.43		
	Ag						1.6	1.5	2.85		
	Cd								1.8		
	In								1.45		
	Sn								≤40		
	Sb								1.31		
	Te								2.8		
	Cs								34.8		
	Ta										
	W										
	Re						0.011	0.014	0.0009		
	Os						0.12	0.19	≤0.02		
	Ir						0.12	0.056	0.015		
	Pt										
	Au						0.019	0.028	0.005		
	Hg										
	Tl						0.73	1.4	0.31		
	Bi						0.22	0.25	0.21		
		(1)	(2)	(3)	(3)	(3,4)	(5)	(5)	(6)	(7)	(8)

References and methods:

(1) Rhodes and Hubbard (1973), Nyquist et al. (1972, 1973), Church et al. (1972, Wiesmann and Hubbard (1973); XRF, isotope dilution/mass spec.
(2) Hubbard et al. (1973), only discrepancies with references (1) noted (same split); Na_2O, FeO, and MgO are atomic absorption.
(3) Compston et al. (1972); isotope dilution/mass spec.
(4) Chappell and Green (1973); XRF.
(5) Hughes et al. (1973); neutron activation.
(6) Wolf et al. (1979); RNAA.
(7) Maxwell et al. (1972); conventional.
(8) O'Kelley et al. (1972) gamma ray spectroscopy.

15546 COARSE-GRAINED OLIVINE-NORMATIVE ST. 9A 27.8 g
MARE BASALT

INTRODUCTION: 15546 is a coarse to medium-grained granular olivine-normative mare basalt (Fig. 1). It contains olivine, most of which is not phenocrystic. Its small yellow-green olivines are not abundant macroscopically. The sample is blocky, angular, and tough, with a few vugs. There are a few zap pits on all surfaces and some glass on one surface. 15546 was collected in the vicinity of the moderately fresh, blocky, 3 m-diameter crater from which 15535 and 15536 were sampled, but it has not been identified in photographs.

PETROLOGY: 15546 is a coarse- or medium-grained olivine-normative mare basalt consisting of generally large, anhedral crystals (Fig. 2), i.e., it is granular rather than diabasic. The dominant phase is pigeonite which is zoned, and some crystals are twinned. They are generally less than 2 mm long, and many contain small olivine inclusions. Some olivines are discrete grains, most irregularly-shaped, and most less than 1 mm across. Small euhedral olivines are enclosed within the plagioclases, which like the pyroxenes are about 1 to 2 mm across; the plagioclases are irregularly-twinned. Cristobalite is ubiquitous, and opaque minerals (chromite, ulvospinel, ilmenite) are common. Fayalite occurs as a residual phase with sulfide, ilmenite, and rare glass. 15546 has a texture similar to 15547 but is a little finer-grained.

PROCESSING AND SUBDIVISIONS: ,1 was chipped from one corner and partly used to make thin sections ,5 through ,8.

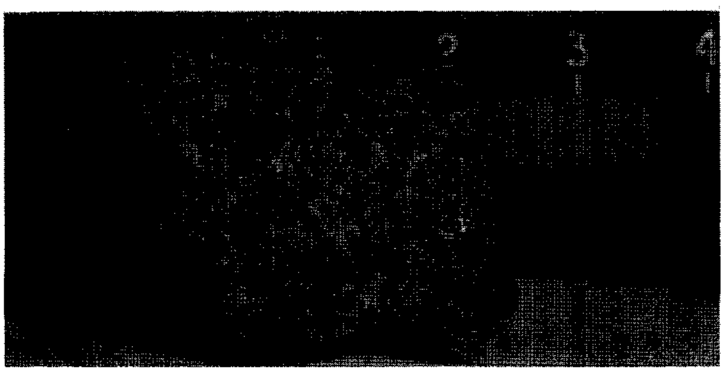


Figure 1. Pre-chip, macroscopic view of 15546. S-71-44926

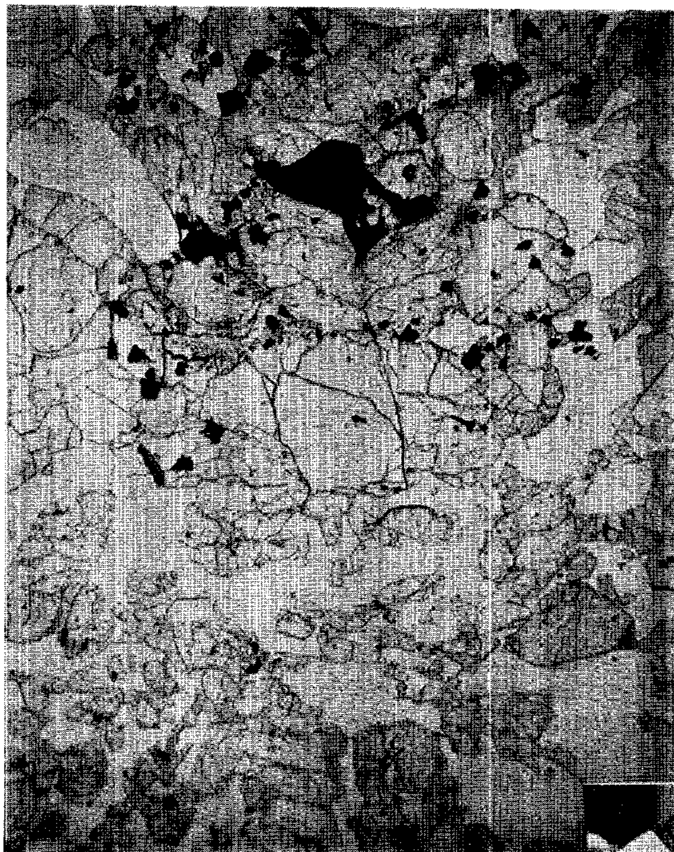


Fig. 2a

Fig. 2b

Figure 2. Photomicrograph of 15546,5. Grain in center is olivine. Width of field about 3 mm. a) transmitted light; b) crossed polarizers.

15547 COARSE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 20.1 g

INTRODUCTION: 15547 is a coarse-grained, granular olivine-normative mare basalt (Fig. 1). It contains olivine, most of which is not phenocrystic. The yellow-green olivines are conspicuous macroscopically. The sample is angular and tough. Slickensides occur on one face. A few zap pits occur on two sides, and vugs are present. 15547 was collected in the vicinity of the moderately fresh, blocky, 3 m-diameter crater from which 15535 and 15536 were sampled, but it has not been identified on photographs.

PETROLOGY: 15546 is a coarse-grained olivine-normative mare basalt consisting of generally large, anhedral crystals (Fig. 2), i.e., it is granular, not diabasic. Olivines are sparce, irregular, most less than 1 mm across, and form cores to or inclusions in the dominant pigeonite. A few olivines have silicate liquid inclusions. Small, euhedral olivines are enclosed ophitically in plagioclase, which are about 2 mm across and have irregular twinning. Several pyroxenes are either irregularly zoned or shocked; some are twinned. Cristobalite is ubiquitous, and fayalite, sulfate, ilmenite, and rare glass form a residuum. Opaque phases include chromite, ulvospinel, ilmenite, and rare Fe-metal. The texture of 15547 is very similar to that of 15546 but it is a little coarser-grained.

PROCESSING AND SUBDIVISIONS: Several chips were removed from 15547, and ,0 is now only 12.51 g. ,1 (4.65 g) consists of several chips from different parts of the rock. ,2 was a single chip, partly used to make thin sections ,6 to ,8.

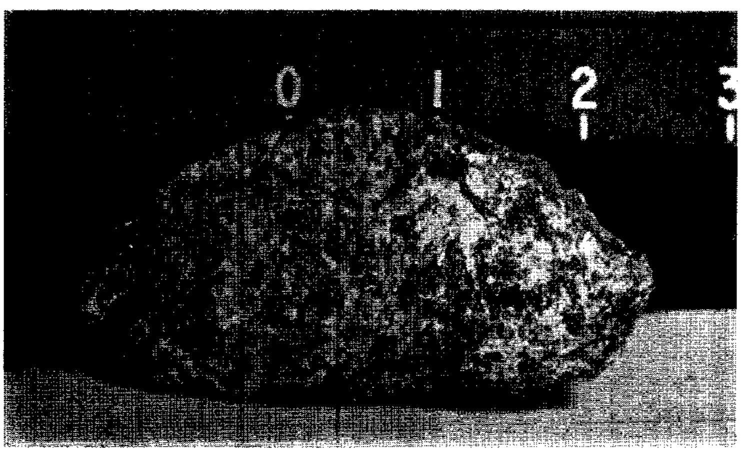


Figure 1. Pre-chip, macroscopic view of 15547. S-71-44969

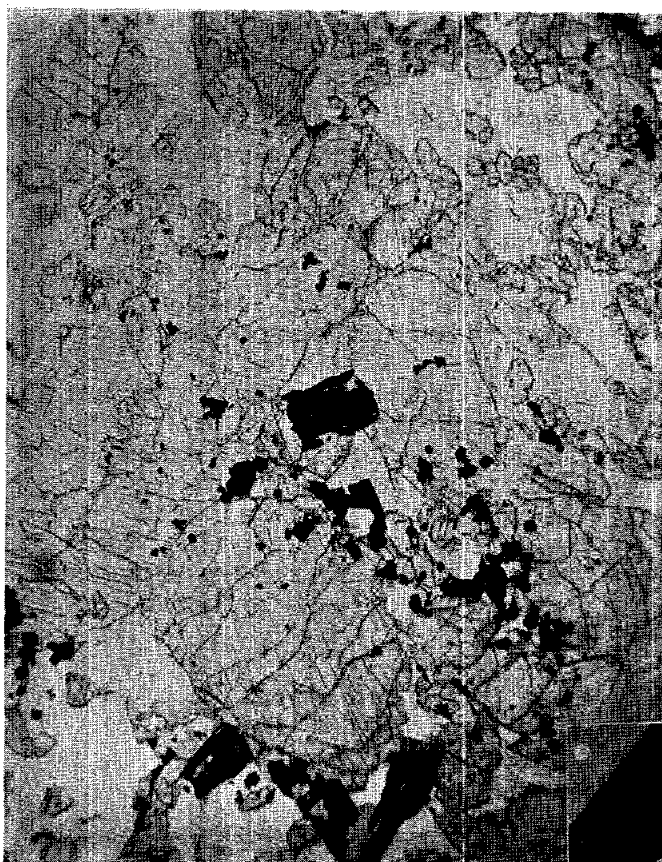


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15547,7. Widths about 5 mm. To left and upper right are euhedral olivines and some pyroxenes enclosed in plagioclase. Lower center is an anhedral, larger (about 0.5 mm) olivine. a) transmitted light; b) crossed polarizers.

15548 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 3.3 g

INTRODUCTION: 15548 is a fine-grained, microporphyritic olivine-normative mare basalt, with a few per cent spherical vesicles (Fig. 1). It is one of the finest-grained of the olivine-normative basalt group. The sample is light brown-gray, blocky, angular, and tough. Only one zap pit appears to be present. 15546 was collected in the vicinity of the moderately fresh, blocky, 3-m diameter crater from which 15535 and 15536 were sampled, but it has not been identified in photographs.

PETROLOGY: 15548 is a very-fine-grained olivine-normative mare basalt, with scattered microphenocrysts of olivine in a groundmass of tiny granular pyroxenes and ragged plagioclases (Fig. 2). The olivines enclose subhedral chromites and ulvospinels; the dominant opaque phases are ulvospinel and ilmenite. On a fine-scale, some plagioclases ophitically enclose pyroxenes. Some cristobalites are present but they are not common. There are small patches of residual glass and troilite. Fe-metal is rare.

PROCESSING AND SUBDIVISIONS: Chipping produced several small pieces, all remaining with ,0 except ,1 which was made into a potted butt and partly used to make thin section ,4.

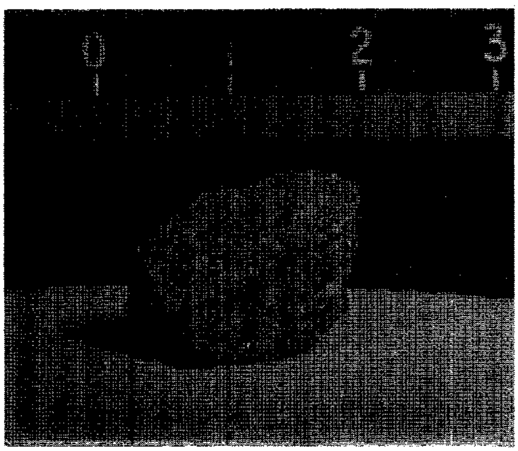
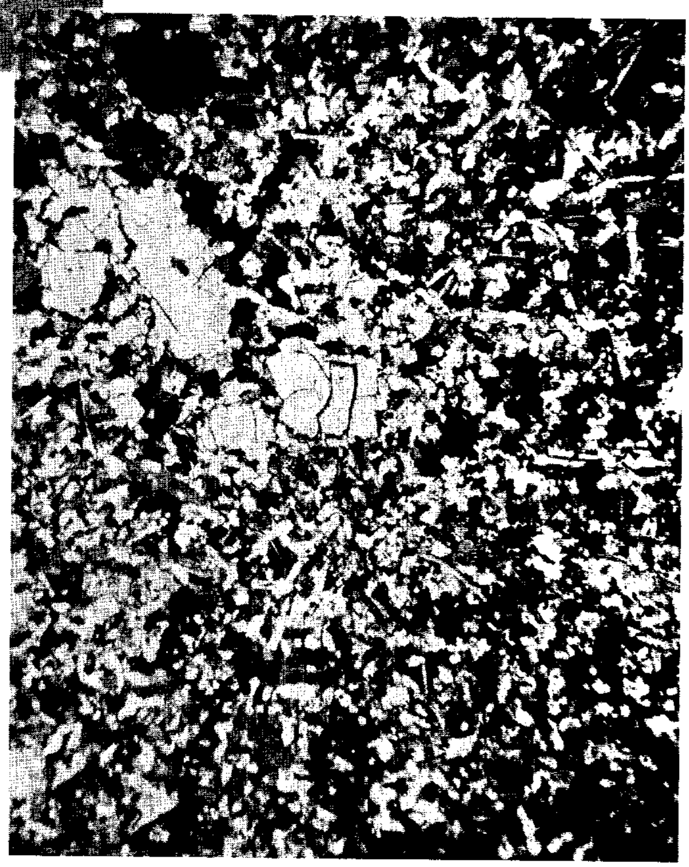


Figure 1. Pre-chip, macroscopic view of 15548. S-71-44919

Fig. 2a

Fig. 2b



<u>Figure 2</u>. Photomicrograph of 15548,4. Width about 3 mm. a) transmitted light; b) crossed polarizers.

15555 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST.9A 9614.0 g

INTRODUCTION: 15555 ("Great Scott") is both the largest and the most intensively studied of the Apollo 15 rocks. It is a medium-grained olivine basalt, with a few percent small vugs (Fig. 1). It is probably very close to a liquid composition, i.e., it contains few, if any, accumulated crystals. It crystallized ~3.3 b.y. ago. Unlike other nearby rocks, 15555 was not dust-coated. It is generally tough, but many exterior chips fell off during earth transit and many of these pieces are friable. It is sub-rounded and blocky (Figs. 1,2), with many zap pits.

15555 was collected about 12 metres north of the rim of Hadley Rille, with no fresh craters in its immediate vicinity, and from an area with fewer rocks exposed than at the Rille edge.

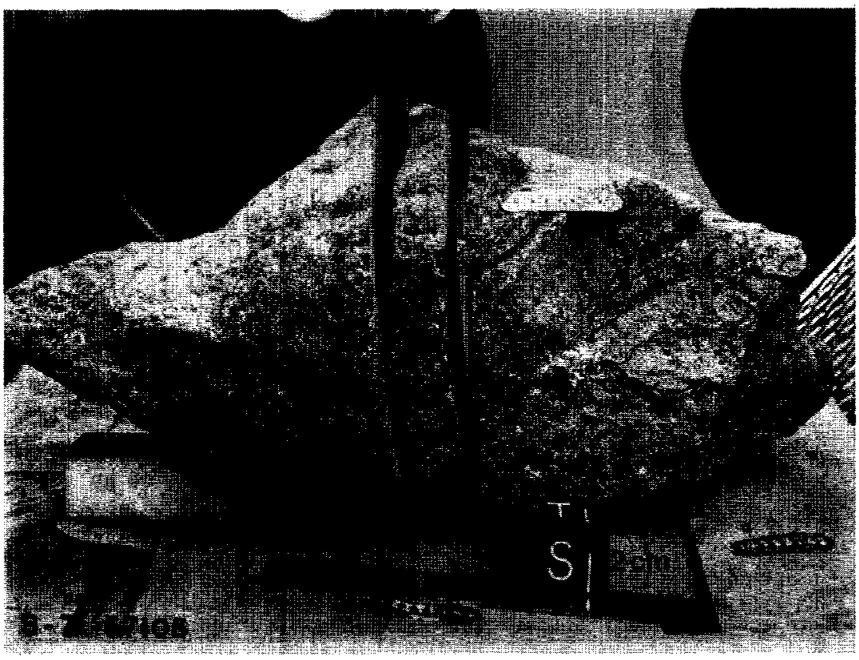


Figure 1. Saw cutting of 15555,0.

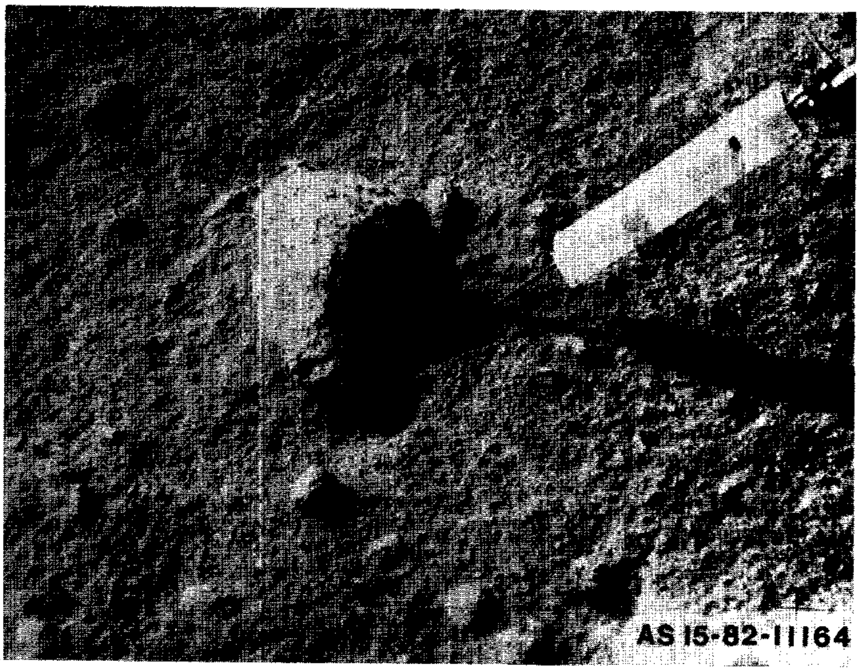


Figure 2. Presampling photograph.

PETROLOGY: 15555 is among the coarsest of the olivine basalts. Macroscopically it is dark brownish gray, with red-brown and honey-brown pyroxenes, translucent plagioclases, and yellowish olivines clearly visible. Vugs are conspicuous and evenly distributed (Fig. 3); they contain euhedral crystals. The thin sections are generally equigranular but pigeonite and olivine have frequently been described as phenocrysts. The plagioclases ophitically enclose smaller olivines and augite (Fig. 4). Plagioclases are up to ~4 mm long, pigeonites commonly 2 mm or more long and twinned, and olivines commonly about 1 mm. All these minerals, and the opaque oxides, are zoned. There is very little mesostasis.

Descriptions of the petrography and silicate mineralogy and chemistry (microprobe data) were given by Heuer et al. (1972), Longhi et al. (1972), Papike et al. (1972), Bence and Papike (1972), Brown et al. (1972a,b), Chappell et al. (1972), Mason et al. (1972), Boyd (1972), Bell and Mao (1972a,b), Michel-Levy and Johann (1973), Nord et al. (1973), Crawford (1973), Dalton and Hollister (1974), Walker et al. (1977), and L. Taylor et al. (1977). These reports differ more in emphasis than substance. Published modes (Table 1) are reasonably consistent given the coarse grain size.

TABLE 15555-1. Published modes of 15555 thin sections

OL	PX	PL	GL+SIL	OPQ	REFERENCE
12.1	52.4	30.4	2.3	2.7	Longhi et al. (1972)
20	40	35	5		Heuer et al. (1972) Nord et al. (1973)
15	55	26	1.5	3	A15 Lunar Sample Information Catalog (1971)

Figure 3. Close-up showing vuggy nature.

According to Bell and Mao (1972a,b) olivines are of two varieties. One has large grains (0.5-1.55 mm) with rounded edges, and includes several complex and reversely zoned specimens (Fo_{40} cores to Fo_{60} rims), although others are quite uniform. The second variety is of smaller grains (10-100 m) which are euhedral, less strongly zoned (Fo_{60-50}), and ophitically included in plagioclases. Other reports have similar or consistent descriptions (Longhi et al. 1972, Bence and Papike 1972, Mason et al. 1972, Heuer et al. 1972, Chappell et al. 1972, and Dalton and Hollister 1974) but with slightly different compositional ranges. Chappell et al. (1972) stated that the most magnesian olivine is Fo_{61}; Longhi et al. (1972) reported a range of Fo_{71-59}; Walker et al. (1977) showed zoning profiles extending that range down to Fo_{40}. Dalton and Hollister (1974) reported a wide range from Fo_{67-29} for the larger olivines, and divide the small olivines into two textural types: euhedral/subhedral in plagioclases are Fo_{49-16}; anhedral in pyroxenes are Fo_{63-48}. L. Taylor et al. (1977) showed a compositional zoning profile from Fo_{62-15} over a distance of 300 μm. Brown et al. (1972b) reported one olivine zoned continuously from Fo_{50} to Fo_{8}. Heuer et al. (1972) found the olivines to be devoid of substructure other than a moderate density of dislocations produced during cooling. Olivines are significant for the estimation of cooling rates for 15555 (below).

1 Cm

Fig. 4a

Fig. 4b

Fig. 4c

Fig. 4d

Figure 4. Photomicrographs of 15555. (a) Whole thin section ,257, partly crossed polarizers; (b) 15555,257, crossed polarizers, width 3mm, showing zoned pyroxene; (c) as (b) transmitted light, and showing euhedral spinels; (d) interstitial area of 15555,170, transmitted light. M = mesostasis, F = feldspar, C = cristobalite.

Pyroxenes are composite and described by Heuer et al. (1972), Longhi et al. (1972), Papike et al. (1972), Brown et al. (1972b), Bence and Papike (1972), Mason et al. (1972), Nord et al. (1972), Dalton and Hollister (1974), Boyd (1972), Walker et al. (1977), Michel-Levy and Johann (1973), and Chappell et al. (1972). Quadrilateral diagrams are shown in Figure 5. Boyd (1972) described the zoning in most detail: pigeonite cores have sector-zoned mantles of more Ca-rich pyroxene (see Fig. 5). Pyroxferroite did not form; instead ferroaugite with fayalite + cristobalite appears. Mason et al. (1972) described some complex and in some places oscillatory zoning in pyroxenes (Fig. 6). Bence and Papike also showed and tabulated detailed analytical profiles. The most iron-rich pyroxenes are the ferroaugites which occur as small, euhedral grains enclosed in plagioclases. The trends in pyroxene minor element chemistry, in particular discussed by Bence and Papike (1972), Dalton and Hollister (1974) and Walker et al. (1972), are of significance in establishing the crystallization sequence of minerals in 15555 (below).

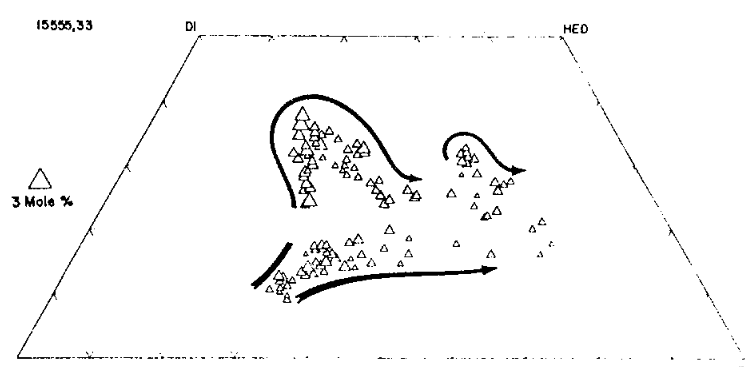


Fig. 5a

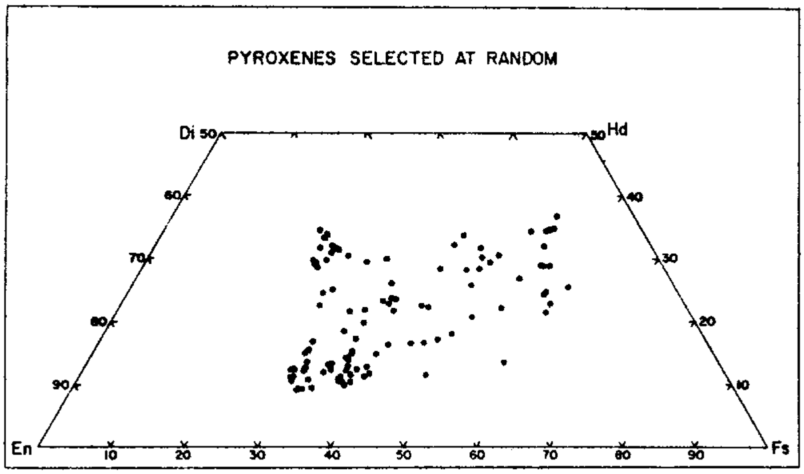
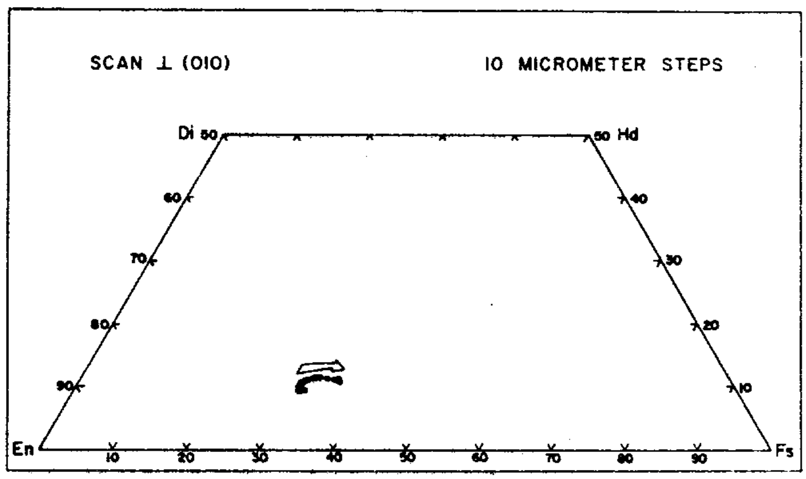


Fig. 5b

Fig. 5c



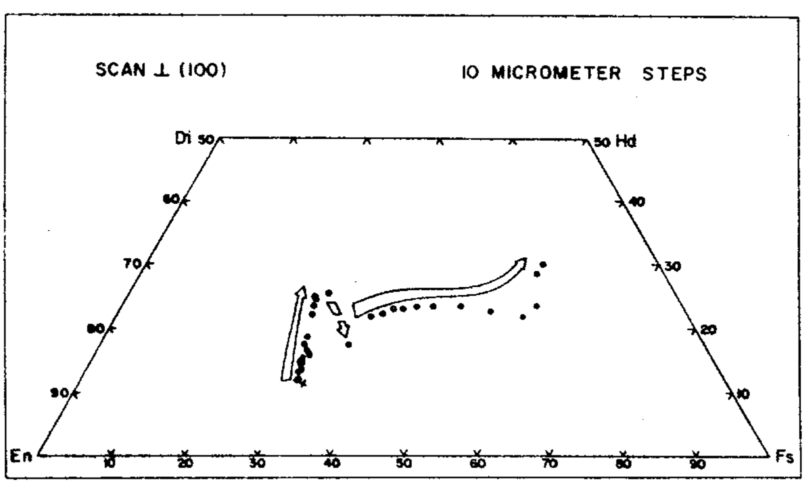


Fig. 5d

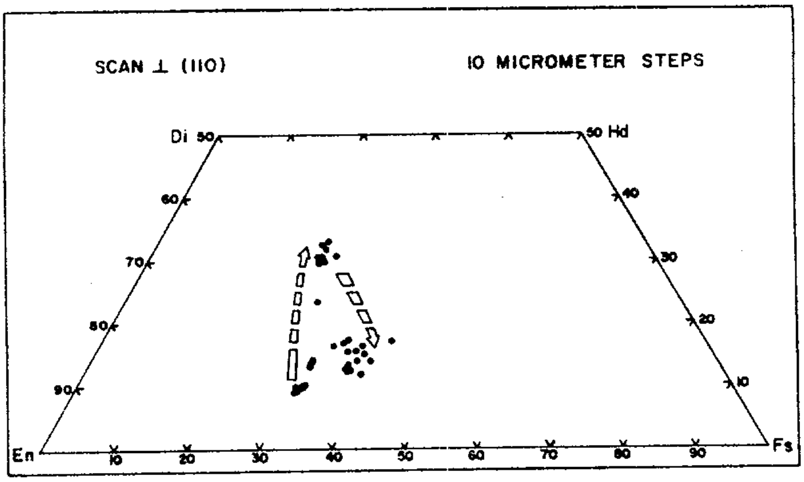


Fig. 5e

Fig. 5f

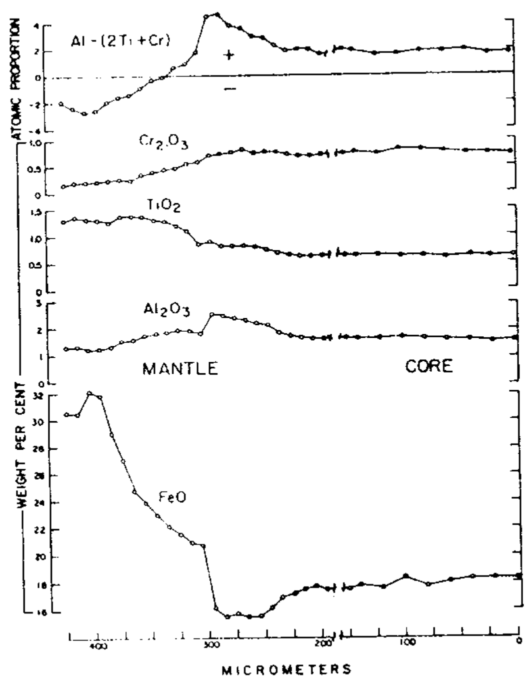


Figure 5. Pyroxene quadrilaterals and zoning profiles. (a) Bence and Papike (1972); (b) to (f) Boyd (1972).

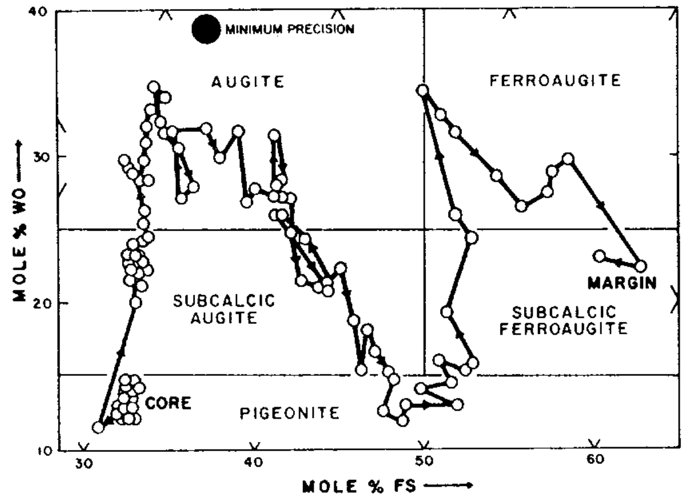


Figure 6. Pyroxene zoning profile (Mason, 1972).

Heuer et al. (1972) and Nord et al. (1973) described exsolution features (revealed with HVTEM techniques) as well as anti-phase domains. In the cores, the pyroxene consists of 300 A pigeonites and 80 A augite plates; away from the core the augite lamellae are coarser and have a different orientation. Papike et al. (1972) reported some x-ray diffraction data for pyroxenes, and concluded that 15555 cooled a little more slowly than the isochemical sample 15016.

Plagioclases, which ophitically enclose small olivines and augites, are more or less anhedral and are zoned normally. Longhi et al. (1972) reported a range of An_{94-78}, with homogeneous cores (An_{94-91}; Fe/Mg = 0.5). The rims have the strong zoning, An_{91-78}; Fe/Mg = 0.6 to 0.9. Longhi et al. (1976) plotted Fe/Fe+Mg v. Ca/Ca+Na+K for natural cores, mantles, and rims, and noted that iron increases as calcium decreases. Crawford (1973) reported microprobe scans and analyses: the early plagioclase is a lath, zoned but not hollow, which grows into a more irregular shape. FeO/FeO+MgO of the core is 0.62, of the margins 0.88. The plagioclases deviate from ideal compositions in the manner common for lunar plagioclases. Meyer et al. (1974) made ion-probe traverses across plagioclase for the analyses of Mg, Ca, Sr, K, and Ba. Sr, Ba, and K concentrations increase towards the grain boundaries. Czank et al. (1973) found weak, diffuse c-reflections in plagioclases, and Wenk and Wild (1973) briefly reported on optical properties derived from universal stage work. Heuer et al. (1972) reported on small (900 A) b-type domains in plagioclase, and found no unambiguous evidence of plagioclase exsolution. Wenk et al. (1973) also reported small b-type anti-phase domains, and Nord et al. (1973) found that the anti-phase domains have morphologies correlated with composition. They also reported weak exsolution.

Detailed studies of the oxide phases, with microprobe analyses, were presented by Haggerty (1971, 1972a,b,c,d), Dalton and Hollister (1974), and El Goresy et al. (1976). The oxides are spinels (chromite-ulvospinel series) and ilmenites. 15555 is among the few basalts which have spinels whose compositions span the entire normal-inverse series (Fig. 7, 8). However, intermediate compositions are not as common as others, and discontinuous mantling does occur. Corroded and rounded chromite cores as inclusions in later members of the series suggests a reaction relationship between Ti-chromite and liquid (El Goresy et al. (1976). Idiomorphic Ti-chromites, optically unzoned but chemically zoned, are included in olivines. Haggerty (1972c) concluded that Ti^{3+} and Cr^{2+} can be present in only very small abundances, if at all. Ilmenite occurs as discrete grains and as lamellae in reduced spinel; Haggerty (1971, 1972a) in particular discussed subsolidus reduction of chromite to intergrowths of ulvospinel, ilmenite, and Fe-metal. About 10% of the chromite has been so reduced. Blank et al. (1982) analyzed opaque oxides for the trace elements Zr and Nb using a proton microprobe. These elements are of very low abundance in primary chromite (<5 ppm) but higher in chromian ulvospinels (Zr 250-2000 ppm; Nb 20-300 ppm). The oxide compositional changes have been considered important indicators of changing liquid compositions resulting from crystallization of silicate phases, hence of value in assessing the crystallization sequence of 15555 (below) (see especially Dalton and Hollister 1974, and El Goresy et al. (1976).

Fig. 7a

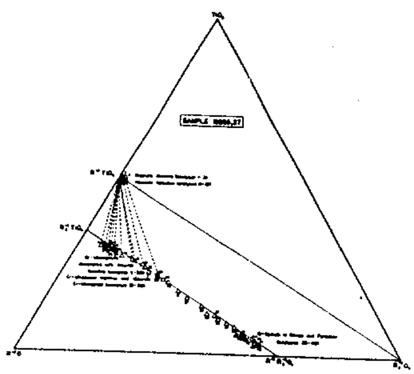


Fig. 7b

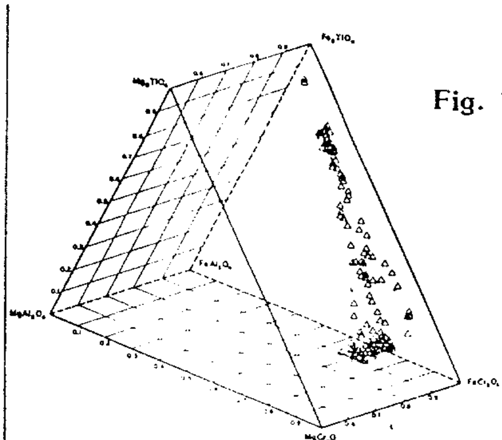


Fig. 7c

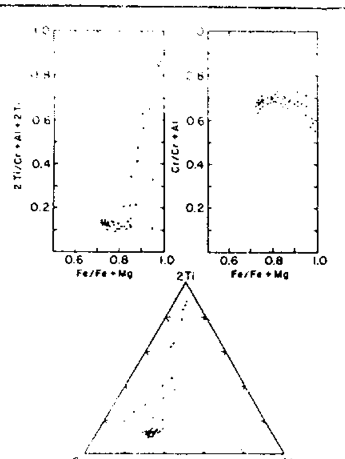
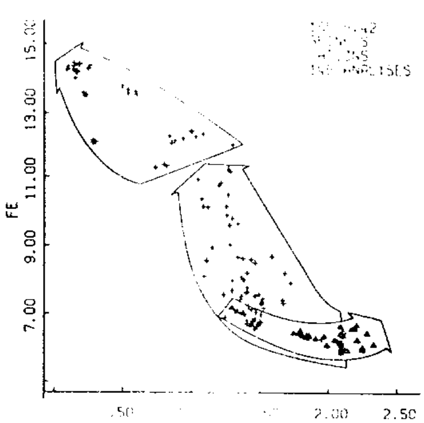


Fig. 7d



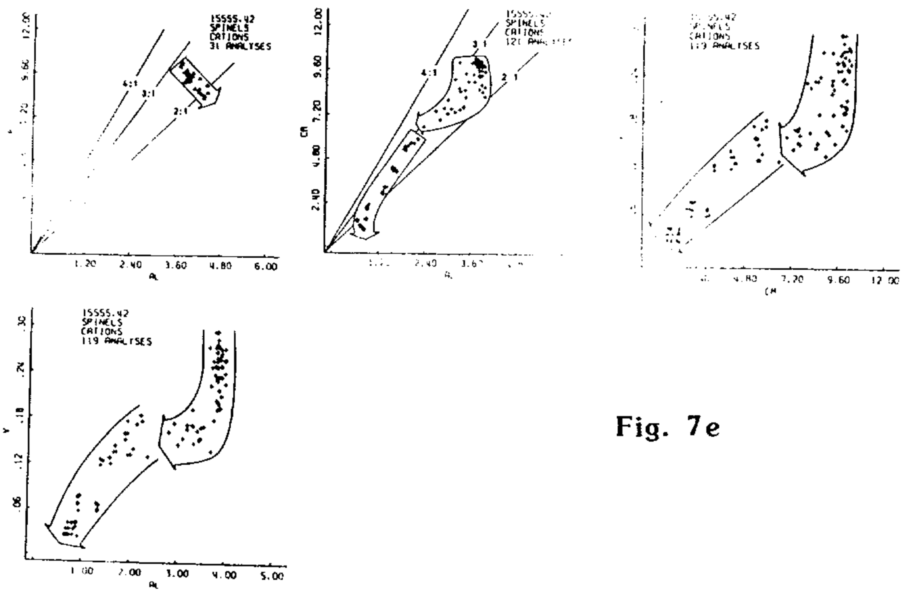
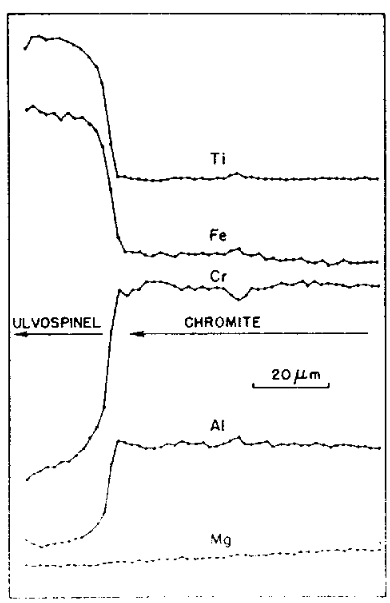


Fig. 7*e*

<u>Figure 7</u>. Spinel compositions. (a) Haggerty (1971); (b) Haggerty (1972c); (c) Dalton and Hollister (1974); (d) and (e) El Goresy <u>et al.</u> (1976).



<u>Figure 8</u>. Spinel zoning profile (Dalton and Hollister, 1974).

Brown et al. (1972b) and Peckett et al. (1972) reported the discovery of a Zr-Ti-Fe mineral with high concentrations of Y and REEs ("Phase Y") in the 15555 mesostasis, and provided a microprobe analysis. Roedder and Weiblen (1972) reported on inclusions, including melt inclusions, in mineral phases, particularly olivine and ilmenite, with microprobe analyses. The olivines contain numerous tiny silicate "melt" inclusions, now assemblages of ilmenite, glass, immiscible sulfide, and shrinkage bubbles. Roedder and Weiblen (1972) also reported on high-Fe and high-Si immiscible melt inclusions in plagioclase and cristobalite.

Crystallization sequence: The textural, mineral chemical and zoning, and experimental (see EXPERIMENTAL PETROLOGY, below) data have been utilized to infer details of the crystallization sequence of 15555. From Ti/Al zoning in pyroxenes, Longhi et al. (1972) suggested that 45% crystallization had taken place before plagioclase started to crystallize, 90% before ilmenite. The low-pressure experimental sequence of ol->px->plag matches that inferred for the rock itself. Dalton and Hollister (1974) used the microprobe analyses of host and inclusion mineral pairs to deduce the crystallization sequence. The reversal from increasing to decreasing Ca and Al in pyroxenes is interpreted by these authors to coincide with the incoming of plagioclase under supersaturation, in agreement with Longhi et al. (1972) and others. They could not find evidence to indicate whether olivine, chromite, or pigeonite crystallized first, but all precede plagioclase. They did conclude that there was no significant settling of mineral phases, with the possible exception of chromite. El Goresy et al. (1976) concluded that the chromites probably preceeded pigeonite, either during or preceding olivine. Walker et al. (1977), using experimental data extensively to deduce the relationship between the rock composition and the original liquid from which it crystallized, inferred, like Dalton and Hollister (1977) that there was little, if any, accumulation.

Apart from cooling history studies, other mineralogical studies are dominated by those elucidating valence states of cations, e.g., Mossbauer studies. Weeks (1972) found the intensity of Fe^{3+} spectra from plagioclase to be greater than in Apollo 14 rocks, and believed the Fe^{3+} not to result from radiation damage; the study did not detect Ti^{3+}. Burns et al. (1972) measured polarized absorption spectra on single crystals of pyroxene to identify Fe and Ti valences; Ti^{3+} bands were not observed. A spectra taken for olivine (Burns et al., 1973) found the expected Cr^{3+} bands, but lead to the conclusion that the inference of Cr^{2+} which had been made for lunar olivines was not convincing. Bell and Mao (1972c) analyzed an olivine (Fo_{50}) and found polarized bands attributable to Fe^{3+}. Huffman et al. (1972, 1974, 1975) made Mossbauer analyses and magnetic studies: 98.5% of Fe is in silicates (77.6% in px, 20.9% in ol) with 1.3% in ilmenite. Fe metal (0.055 wt.%) was not detected in the Mossbauer study. Virtually all of the Fe is Fe^{2+}, and totals 18.7%. Abu-Eid et al. (1973) found Fe^{3+} to be less than the detectability level of 1%.

Simmons et al. (1975) illustrated a possible natural stress-induced crack of tectonic rather than shock origin, as well as radial cracks most probably resulting from thermal expansion. A healed crack is marked by a bubble chain (glass inclusions).

Cooling history: Estimates of the cooling rate(s) for 15555 have been made utilizing mineral compositional data and experimental data. 15555 is too coarse-grained for direct analog with the products of dynamic crystallization experiments (Walker et al. 1977), other than to give maximum rates. Pyroxene cores in the experimental products are similar to natural ones, and implies that there was little supercooling at pyroxene entry (Walker et al., 1977); pyroxenes maintained surface equilibrium (cores not erased), but rims depart from equilibrium trends. Ti/Al in experimental samples approaches 1/2 rather than 1/4 as in natural samples, thus 15555 had delayed nucleation of plagioclase followed by its rapid growth. Olivine natural cores are Fo_{71}, cf. Fo_{73} in equilibrium experiments, hence olivine is not accumulative and was reequilibrated during cooling (however, O'Hara and Humphries, 1977, cautioned against "over-interpretation" of small differences of Mg/Fe in experiments because of iron-loss problems). Olivine major-element zoning profiles, compared with modelled diffusion and equilibration, suggest ~4°C/day cooling during early olivine crystallization (Walker et al., 1977), thus 15555 is from a location a few meters from the edge of a flow which took a few months to cool. Taylor et al. (1977), modelling Fe-Mg diffusion and olivine zoning profiles, deduced ~5°C/day (minimum rate), and Onorato et al. (1978) improved on these diffusion models by including diffusion in the liquid. Bianco and Taylor (1977) found that olivines in 2°C/hr. cooling experiments had morphologies similar to those in 15555 except that they were internally skeletal. From the olivine nucleation density they estimated a cooling rate of 0.5 to 1.0°C/hr. at the beginning of olivine crystallization (assuming that the erupted melt was olivine-free). Cukierman et al. (1973) reported data on the kinetics of crystallization of a glass of 15555 composition, noting that it does not form glass easily.

EXPERIMENTAL PETROLOGY: Several equilibrium experimental crystallization studies have been conducted on a 15555 composition, at low and high pressures (Humphries et al., 1972; Longhi et al., 1972; Kesson, 1975, 1977; and Walker et al., 1977). Longhi et al. (1978) included 15555 (natural rock powder) in experiments specifically to determine the distribution of Fe and Mg between olivine and basaltic liquids, and Bianco and Taylor (1977) used a Ca-depleted 15555-like composition for isothermal and constant cooling rate experiments. The problems of iron-loss to the containers are widely recognized and discussed in detail by O'Hara and Humphries (1977) and Walker et al. (1977).

The experimental data are depicted in Figure 9. Some of the differences result from iron-loss according to the capsules and conditions used, as discussed by Walker et al. (1977) and O'Hara and Humphries (1977). The data are similar except that spinel appears earlier in the Humphries et al. (1972) diagram, and except for the Mg/Fe of mafic phases. Walker et al. (1972) noted that the olivine and pyroxene natural core compositions are close to those in the equilibrium experiments, so that little crystal accumulation took place and 15555 is close to a liquid composition. This is in disagreement with O'Hara et al. (1975), and the evidence is discussed extensively by Walker et al. (1977). The high pressure experiments show similar multiple saturation points with olivine and low-Ca pyroxene without spinel. The difference of several kilobars between the Kesson (1975, 1977) and the Longhi et al. (1972) and Walker et al. (1977) multiple saturation points may be a calibration difference as much as a result of different conditions and capsules. Assuming multiple saturation, twelve kb indicates a 240 km depth for the source liquid of 15555, deeper if olivine separation took place during ascent (Kesson, 1975).

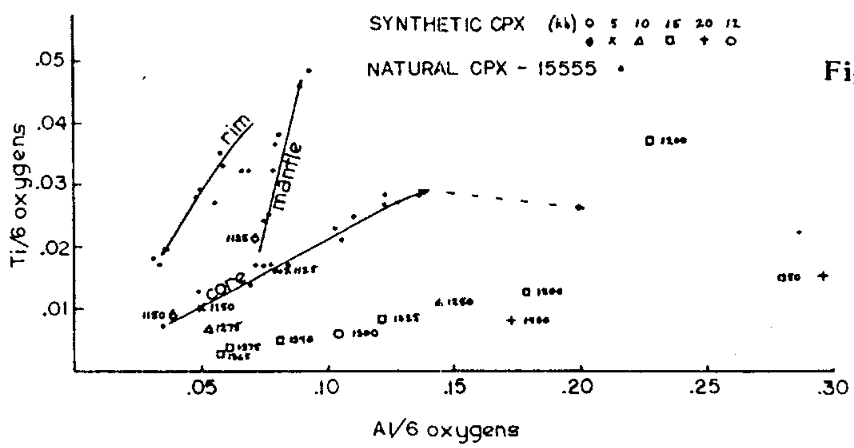


Fig. 9a

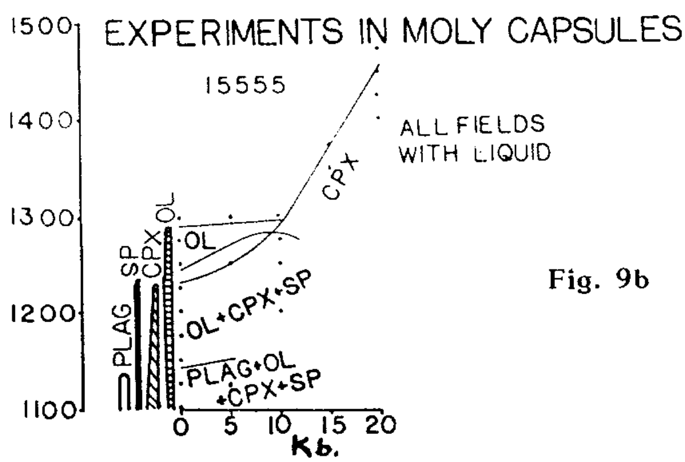


Fig. 9b

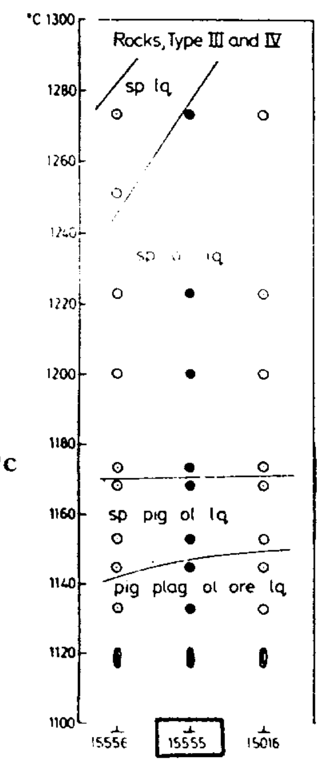


Fig. 9c

Figure 9. Experimental phase petrology. (a) and (b) Longhi et al. (1972); (c) Humphries et al. (1972).

TABLE 15555-2. Bulk rock chemical analyses

		,225	,157	,149	,59	,27	,25	,148	,134	,153	,8
Wt %	SiO2	45.86	44.75			45.21		43.0	45.2	44.22	44.24
	TiO2	2.40	2.07	2.04	2.05	1.73		2.8	2.3	2.36	2.26
	Al2O3	8.29	8.67	8.41	9.24	10.32		8.5	9.3	7.54	8.48
	FeO	23.45	23.40	22.2	21.4	20.16		21.8;22.4;23.0	21.0	24.24	22.47
	MgO	11.55	11.48			11.20		10.2	11.9	11.11	11.19
	CaO	9.24	9.14	10.4	9.9	9.96				9.18	9.45
	Na2O	0.34	0.24	0.28	0.28	0.35		0.39	0.39	0.29	0.24
	K2O	0.09	0.05			0.05				0.04	0.03
	P2O5		0.05			0.05				0.06	0.06
(ppm)	Sc			38.4	43.1	40		38;38;38			
	V		145	244	266	240					
	Cr	4700	4200;4500	4820	4720	4500		3620;3530;3570		5200	
	Mn		2300	2300	2310	1900		2100	2000	2250	2250
	Co		66	61.8	50.3	87		54;58;52			
	Ni		70	90	50	96					42
	Rb		<5	0.75	0.84	1.1	0.65				0.6
	Sr		83	84	88	93					92
	Y		47			23					23
	Zr		60			58		124;130;124			76
	Nb					17					4.3
	Hf			2.1	3.1	<20		3.12;3.20;3.26			
	Ba		30	47	59	30					
	Th			0.30	0.40	<100					
	U			0.14	0.21	<500					
	Pb			<2							
	La			3.5	4.8						
	Ce			10	18	<100					
	Pr										
	Nd					<100					
	Sm			3.2	4.0						
	Eu			0.75	1.00			0.93;1.1;1.3			
	Gd										
	Tb			0.51	0.77			0.92;0.93;—			
	Dy			3.2	4.4						
	Ho			0.78	0.91						
	Er			2.7	3.3						
	Tm										
	Yb			1.64	1.59	4.2					
	Lu			0.43	0.39						
	Li		7			5.5					
	Be										
	B		3								
	C										
	N										
	S										700
	F										
	Cl										
	Br						6000				
	Cu		17	6.6	7.1	13a					
	Zn			1.3	1.2		0.78				
(ppb)	I										
	At										
	Ga		3000	2900	3700	4600					
	Ge						8.5				
	As			<50	<50						
	Se			85	106		156				
	Mo										
	Tc										
	Ru										
	Rh										
	Pd										
	Ag			<7	<7	200	1.0				
	Cd						2.1				
	In			2	<2		0.55				
	Sn										
	Sb						0.067				
	Te						3.4				
	Cs			26	32		30				
	Ta			290	400			1500;1400;1400			
	W			1200	430						
	Re						0.0013				
	Os										
	Ir			<0.1	<0.1		0.006				
	Pt										
	Au			0.48	0.85		0.139c				
	Hg										
	Tl						0.20				
	Bi						0.089				
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

TABLE 15555-2 Continued

		,20	,18	,13	,16	,13	,33	A	B			,15
Wt %	SiO2		45.0	44.75	43.82							
	TiO2	2.25	1.60	2.05	2.63							
	Al2O3	8.5	9.37	9.01	7.45							
	FeO	23.2	21.18	21.68	24.58							
	MgO		12.22	11.39	10.96							
	CaO		9.25	9.62	9.22		8.4h					
	Na2O	0.2655	0.26	0.27	0.24							
	K2O		0.03;0.0276	0.04	0.04		0.0421			0.0646		
	P2O5		0.007;0.066	0.06	0.07							
(ppm)	Sc	40										
	V											
	Cr	4100	3300	4100	4200							
	Mn		2000	2300	2500							
	Co	50										
	Ni											
	Rb		0.445	0.54	0.76	0.63				0.874		0.700
	Sr		84.4	92.2	90.7	89.9				92.0		85.32
	Y			18								
	Zr		57.3	69								
	Nb			5								
	Hf	2.2										
	Ba		32.2									41.61
	Th							0.4596	0.4296		0.3095	
	U							0.1264	0.1173		0.0850	
	Pb							0.209	0.191		0.1388	
	La	5.4										
	Ce		8.06									
	Pr											
	Nd		6.26									
	Sm	3.5	2.09									
	Eu	1.18	0.688									
	Gd		2.90									
	Tb	0.7										
	Dy		3.27									
	Ho											
	Er		1.70									
	Tm											
	Yb	2.1	1.45									
	Lu	0.37										
	Li		6.36									
	Be											
	B											
	C											
	N											
	S			400	600							
	F											
	Cl											
	Br											
	Cu											
	Zn											
	I											
	At											
	Ga			2700								
	Ge											
	As											
	Se											
	Mo											
	Tc											
	Ru											
	Rh											
	Pd											
	Ag											
	Cd											
	In											
	Sn											
	Sb											
	Te											
	Cs											
	Ta											
	W											
	Re											
	Os											
	Ir											
	Pt											
	Au											
	Hg											
	Tl											
	Bi											
		(11)	(12)	(13)	(14)	(15)	(16)	(17)	(17)	(17)	(18)	(19)

TABLE 15555-2 Continued

		(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)
		,12			,144	,144	,143				,135	,135	,479	,81	,195
Wt %	SiO2														
	TiO2														
	Al2O3														
	FeO														
	MgO														
	CaO														
	Na2O														
	K2O		0.0376	0.0390											
	P2O5														
(ppm)	Sc														
	V														
	Cr						3540;3830;4390								
	Mn														
	Co														
	Ni														
	Rb	0.538	0.675	0.62k											
	Sr	74.11	86.9j	91.0j											
	Y														
	Zr														
	Nb														
	Hf														2.001/1.962
	Ba														
	Th														
	U														
	Pb														
	La														
	Ce														
	Pr														
	Nd						11.85m								7.518
	Sm							3.784							2.520
	Eu														
	Gd														
	Tb														
	Dy														
	Ho														
	Er														
	Tm														
	Yb														
	Lu														.255/.250
	Li														
	Be						0.28								
	B														
	C				7.3	7.7					12		7.7n		
	N										<2		<0.8		
	S							855	726		650	580	>12.9		
	F														
	Cl														
	Br														
	Cu														
	Zn													980	
(ppb)	I														
	At														
	Ga														
	Ge														
	As														
	Se														
	Mo														
	Tc														
	Ru														
	Rh														
	Pd														
	Ag														
	Cd														
	In														
	Sn														
	Sb														
	Te														
	Cs														
	Ta														
	W														
	Re														
	Os														
	Ir														
	Pt														
	Au														
	Hg														
	Tl														
	Bi													0.25	

References Table 15555-2.

References and methods:

(1) Longhi et al. (1972); EMP/FB
(2) Mason et al. (1972); Gen. sil.
(3)(4) Brunfelt et al. (1972); INAA
(5) Christian et al. (1972), Cuttitta et al. (1973b); Combined, XRF, etc.
(6) Morgan et al. (1972d), Ganapathy et al. (1973); RNAA
(7) Janghorbani et al. (1973), except Zr, Hf from Chyi and Ehmann (1973); RNAA
(8) Janghorbani et al. (1973); RNAA
(9) Maxwell et al. (1972); Combined
(10) Rhodes and Hubbard (1973), PET (1972); XRF
(11) Fruchter et al. (1973); INAA
(12) Schnetzler et al. (1972), Nava (1974e); AAS, Col, ID
(13) Chappell and Green (1973), Compston et al. (1972f); XRF
(14) Chappell and Green (1973), Chappell et al. (1972); XRF, ID
(15) Compston et al. (1972); ID
(16) Husain et al. (1972a), Husain (1974); MS
(17) Tatsumoto et al. (1972); ID, MS
(18) Tera and Wasserburg (1974); ID, MS
(19) Murthy et al. (1972); ID, MS
(20) Mark et al. (1973); ID, MS
(21) Birck et al. (1975); ID, MS
(22) Friedman et al. (19721); Combustion
(23) Friedman et al. (19721); Pyrolysis
(24) Eisentraut et al. (1972); GC
(25) Lugmair (1975); ID, MS
(26) Gibson et al. (1975); Combustion
(27) Gibson et al. (1975); Hydrolysis
(28) Kaplan et al. (1976); Combustion
(29) Kaplan et al. (1976); Hydrolysis
(30) Desmarais et al. (1978); Combustion
(31) Allen et al. (1973); INAA
(32) Unruh et al. (1984); ID/MS

Other Notes:

(a) Listed erroneously as 0.13 ppm in Cuttitta et al. (1972).
(b) Also list very high upper limits for several trace elements.
(c) Listed by Ganapathy et al. (1973) as "doubtful value": contamination.
(d) Units not stated, but ppb except Zn, Rb ppm. Te not listed.
(e) Majors only.
(f) Rb, Sr only.
(g) K only.
(h) From 39Ar abundance.
(i) From 37Ar abundance.
(j) Calc. from 86Sr and isotopic ratios.
(k) Calc. from 87Rb and isotopic ratios.
(l) Also provide H abundances.
(m) Calc. from 144Nd and isotopic ratios.
(n) 5.6 indigenous, 2.1 terrestrial contamination.

References 15555-3.

References and methods:

(1) Brunfelt et al. (1973a); INAA
(2) Schnetzler et al. (1972); AAS, Col, ID

TABLE 15555-3. Chemical analyses of mineral separates

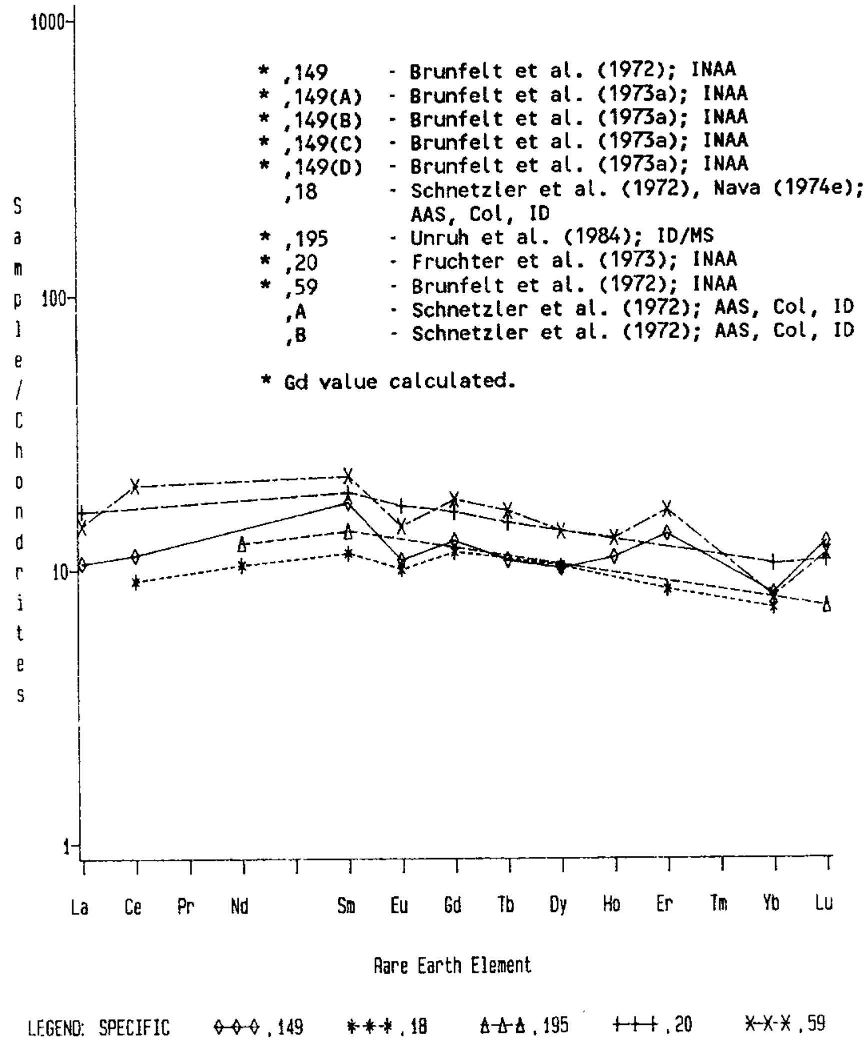
		,149 Plag	,149 Lt.Cpx	,149 Dk.Cpx	,149 Oliv	Plag	Px
Wt %	SiO2						
	TiO2	0.20	1.19	1.27	<0.17		
	Al2O3	33.09	4.61	2.31	1.06		
	FeO	0.6	13.8	27.9	39.3		
	MgO	<1.7	13.1	6.8	24.9		
	CaO	25.5	8.5	14.4	1.7		
	Na2O	0.97	0.15	0.03	0.12		
	K2O					0.0433	0.0126
	P2O5						
(ppm)	Sc	0.5	65.9	71.0	10.0		
	V	53	212	115	82		
	Cr	8	531	196	192		
	Mn	7.5	2169	3024	2842		
	Co	1.2	32.0	42.2	103.5		
	Ni	<10	148	<10	54		
	Rb	<0.9	5.1	<0.9	1.3	0.131	0.204
	Sr	310	<10	16	<10	282	26.1
	Y						
	Zr						45
	Nb						
	Hf	<0.9	0.1	3.2	<0.9		
	Ba	18	<15	60	25	27.1	12.2
	Th	<0.20	<0.20	0.29	<0.20		
	U	<0.10	<0.10	<0.10	<0.10		
	Pb						
	La	<0.5	1.0	6.3	1.8		
	Ce					1.25	3.14
	Pr						
	Nd					0.87	2.99
	Sm	0.21	1.84	6.12	0.82	0.27	1.19
	Eu	1.80	<0.40	0.86	<0.50	1.84	0.27
	Gd					0.34	1.88
	Tb	0.02	0.55	1.20	0.19		
	Dy	0.1	3.1	6.2	1.1	0.39	2.29
	Ho						
	Er						1.27
	Tm						
	Yb	0.1	1.6	3.6	0.53	0.14	1.04
	Lu						
	Li					11.3	4.97
	Be						
	B						
	C						
	N						
	S						
	F						
	Cl						
	Br						
	Cu						
	Zn						
(ppb)	I						
	At						
	Ga						
	Ge						
	As						
	Se						
	Mo						
	Tc						
	Ru						
	Rh						
	Pd						
	Ag						
	Cd						
	In						
	Sn						
	Sb						
	Te						
	Cs	100	490	<100	1050		
	Ta	<100	<100	130	<100		
	W						
	Re						
	Os						
	Ir						
	Pt						
	Au						
	Hg						
	Tl						
	Bi						
		(1)	(1)	(1)	(1)	(2)	(2)

CHEMISTRY: 15555 has been widely allocated for chemical analyses, with resulting duplicate data for many elements (Table 2). There is also data on mineral separates (Table 3). Apart from noting the conformity with other Apollo 15 olivine basalts, most papers do not specifically discuss the chemistry other than to relate discrepancies between analyses to the coarse grain size of the sample. Most of the data suggest that 15555 is a fairly average A15 olivine-normative mare basalt. Christian et al. (1972) analyzed for ferric iron but found none, reporting 0.00%. Rare-earth element data are illustrated in Figure 10 and indicate probable sampling biases and systematic errors.

STABLE ISOTOPES: Published data are listed in Table 4. Data for ^{204}Pb (generally considered stable on account of its long half-life) published by Allen et al. (1973b) are lower from those previously reported by them (Allen et al., 1973a), but the change is not noted or discussed. In general the stable isotope data received no specific discussion. The isotopic compositions distinguish 15555 from regolith, as expected. According to Friedman et al. (1972), the hydrogen is probably a mixture of spallationogenic hydrogen with that left over after melting and partial outgassing.

GEOCHRONOLOGY AND RADIOGENIC ISOTOPES: Several different groups have reported Rb-Sr isotopic data and results (Table 5; Figure 11). Two analytically significant discrepancies are the old age determined by Chappell et al. (1972), and the low initial $^{87}Sr/^{86}Sr$ determined by Murthy et al. (1972a, b). These discrepancies are discussed by Papanastassiou and Wasserburg (1973) whose opinion is that the Chappell et al. (1972) data is affected by serious analytical difficulties. They also measured $^{87}Sr/^{86}Sr$ in four plagioclase separates to test the suggestion of Murthy et al. (1972a) that differences in initial $^{87}Sr/^{86}Sr$ result from original variations within the rock, but concluded that the rock had uniform initial ratios throughout its volume. Thus 15555 has a Rb-Sr age close to 3.32 b.y. and an initial $^{87}Sr/^{86}Sr$ ratio similar to other Apollo 15 olivine basalts. T_{BABI} model ages calculated by Nyquist (1977) for much of the data are quite varied.

^{40}Ar-^{39}Ar age determinations are consistent with those of Rb-Sr data (Table 6; Figure 12), averaging about 3.32 b.y., as is a K-Ar age of 3.31 $\pm$ 0.07 b.y. determined by Murthy et al. (1972b). However, Husain et al. (1972b) determined a lower K-Ar age of 2.87 b.y. (uncertainty not stated), and Lightner and Marti (1972) also determined a K-Ar age of 2.8 b.y. Analysts tend to agree that 15555 has lost about 20% of its radiogenic ^{40}Ar, leading to K-Ar ages lower than Ar-Ar ages. Podosek et al. (1972) concluded that 60% of the potassium is in minor phases, in quintescence, making quantitative evaluation difficult; the "real" age is best given by the plagioclase determination which in any case gives the best plateau. The Podosek et al. (1972) release data were also presented and discussed by Turner et al. (1972).



* ,149 - Brunfelt et al. (1972); INAA
* ,149(A) - Brunfelt et al. (1973a); INAA
* ,149(B) - Brunfelt et al. (1973a); INAA
* ,149(C) - Brunfelt et al. (1973a); INAA
* ,149(D) - Brunfelt et al. (1973a); INAA
,18 - Schnetzler et al. (1972), Nava (1974e); AAS, Col, ID
* ,195 - Unruh et al. (1984); ID/MS
* ,20 - Fruchter et al. (1973); INAA
* ,59 - Brunfelt et al. (1972); INAA
,A - Schnetzler et al. (1972); AAS, Col, ID
,B - Schnetzler et al. (1972); AAS, Col, ID
* Gd value calculated.
Sample/Chondrites
1000
100
10
1
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Rare Earth Element
LEGEND: SPECIFIC ◊-◊-◊ ,149 *-*-* ,18 Δ-Δ-Δ ,195 +-+-+ ,20 X-X-X ,59

Fig. 10a

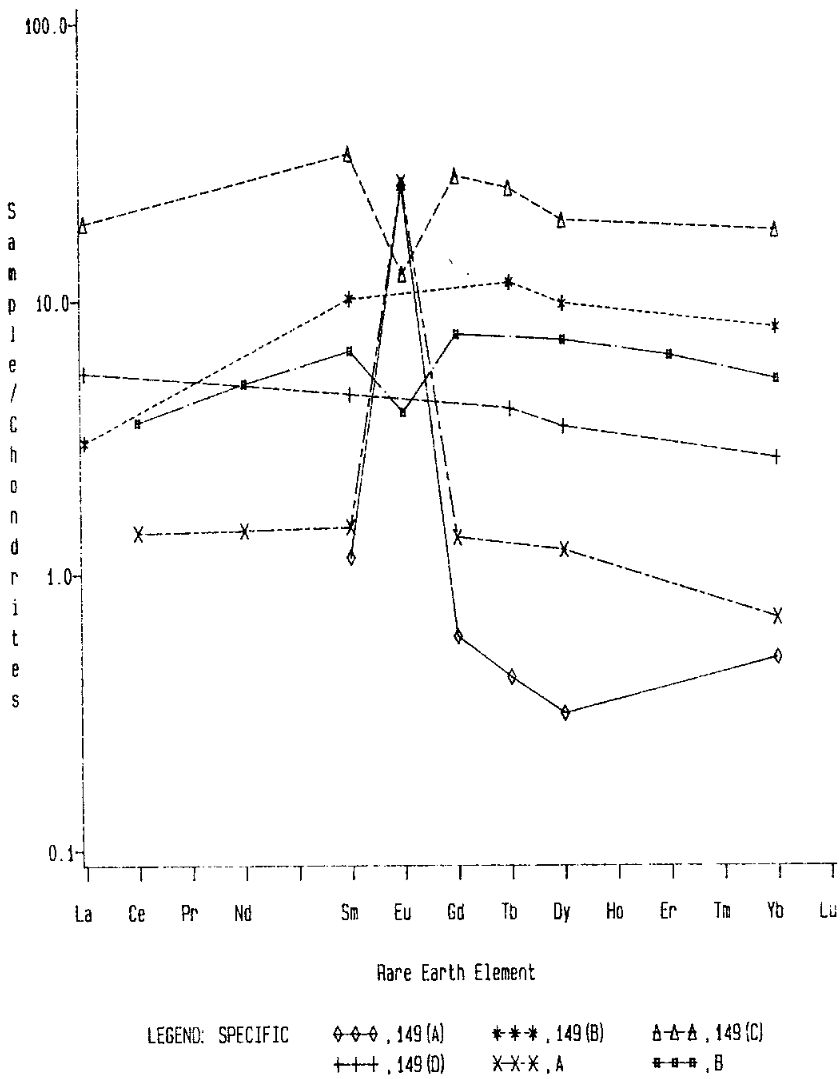


Fig. 10b

Figure 10. (a) Rare earths in bulk rock 15555; (b) rare earths in mineral separates from 15555.

TABLE 15555-4. Stable isotopic data for 15555

D	^{13}C	^{34}S	^{204}Pb	EXTRACTION	REFERENCE
-90	-24			Pyrolysis	Friedman et al. (1972)
	-27.5			Combustion	Friedman et al. (1972)
	-14			Combustion	Kaplan et al. (1976)
		+0.7		Combustion	Kaplan et al. (1976)
		+0.8		Hydrolysis	Kaplan et al. (1976)
	-27.8			Combustion	DesMarais (1978)
			<0.2ppb	Leach, Leach residues	Allen et al. (1973b)

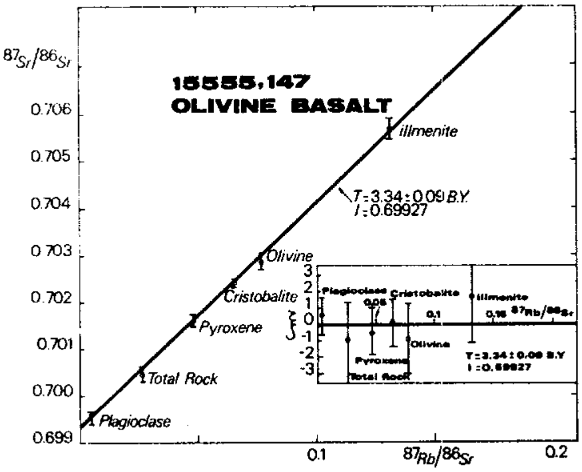
TABLE 15555-5. Summary of Rb-Sr isotopic results for 15555 whole rock

REFERENCE	INT. ISOCH. AGE (b.y.)	INITIAL $^{82}Sr/^{86}Sr$	MEASURED $^{87}Sr/^{86}Sr$	MEASURED $^{87}Rb/^{86}Sr$
Compston et al. (1972)			0.70051±10	0.0203
Tatsumoto et al. (1972)			0.70062	
Chappell et al. (1972)	3.54±0.13	0.69936±8	0.70042±5 0.70062±10	0.0220 0.0226
Murthy et al. (1972a,b)	3.30±0.08	0.69906±4	0.70009±6 0.70005±5	0.02375 0.02102
Mark et al. (1973)			0.70032±8	0.0218a
Wasserburg and Papanastassiou (1971)	3.32±0.06[b]	0.69934[c]±5		
Cliff et al. (1972)	3.34d			
Birck et al. (1975)	3.34±0.09	0.69927	0.70046±15	0.0262

Notes:

(a) erroneously reported as 0.218
(b) uncertainty revised down to 0.04 by Papanastassiou and Wasserburg (1973) from recalculations using different tracer $^{87}Sr/^{84}Sr$
(c) value reported as 0.69930 in Papanastassiou and Wasserburg (1973)
(d) no isotopic data reported

Fig. 11a



$^{87}Sr/^{86}Sr$, $^{87}Rb/^{86}Sr$ diagram for Apollo 15555,147 rock. The inset corresponds to ξ, $^{87}Rb/^{87}Sr$ diagram.

$$\xi = \left\{ \frac{(^{87}Sr/^{86}Sr) \text{ measured} - (^{87}Sr/^{86}Sr) \text{ best fit line}}{(^{87}Sr/^{86}Sr) \text{ best fit line}} \right\} \times 1000$$

I is the ($^{87}Sr/^{86}Sr$) initial ratio.

Fig. 11b

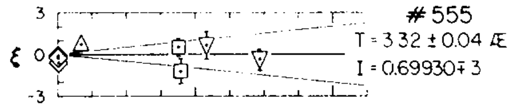
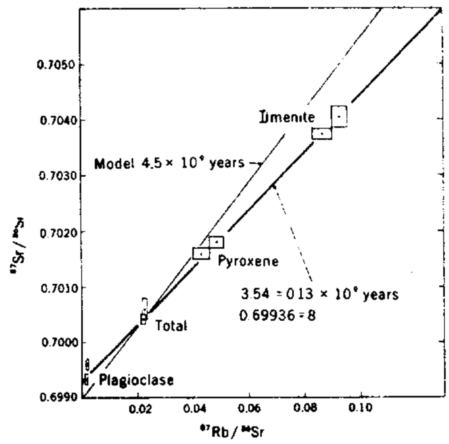


Fig. 11c



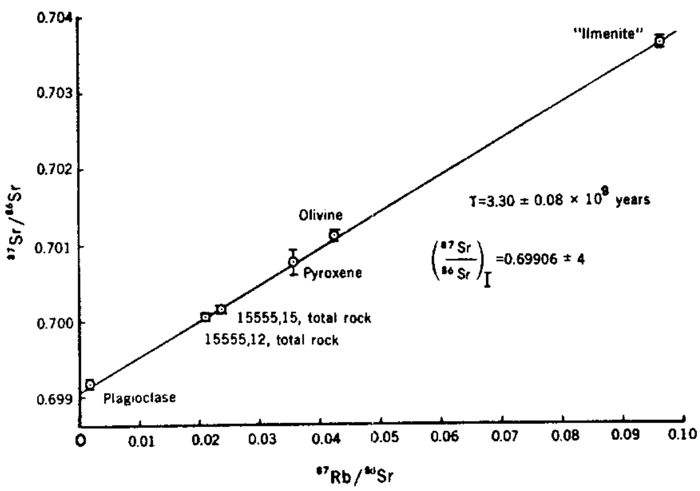


Fig. 11d

Figure 11. Rb-Sr internal isochrons. (a) Birck *et al.* (1975); (b) Papanastassiou and Wasserburg (1973); (c) Chappell *et al.* (1972); (d) Murthy *et al.* (1972a).

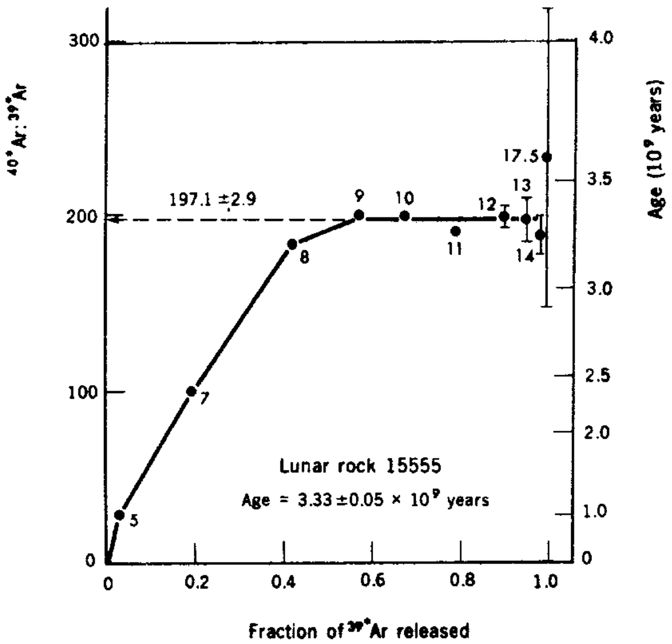
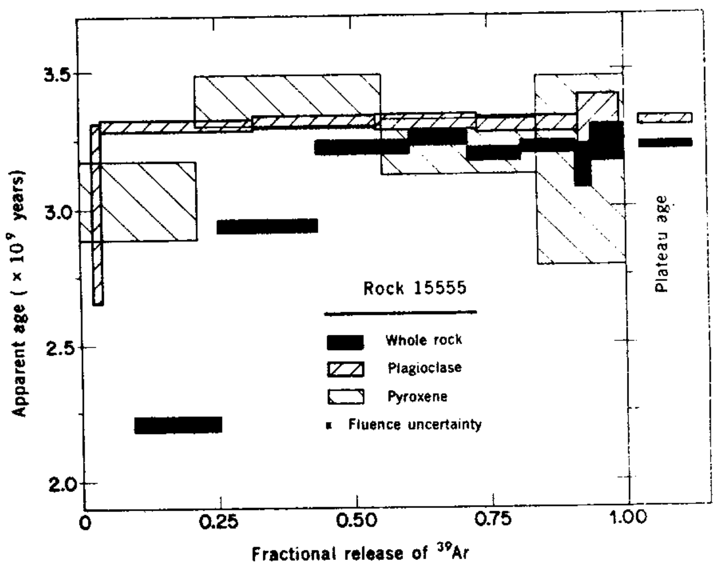


Fig. 12a

Fig. 12b



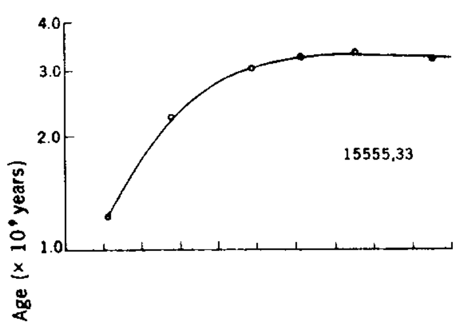


Fig. 12c

Figure 12. Ar release diagrams. (a) Alexander et al. (1972); (b) Podosek et al. (1972); (c) Husain et al. (1972a).

TABLE 15555-6. Summary of ^{40}Ar-^{39}Ar gas retention ages for 15555

REFERENCE	MATERIAL	AGE (b.y.)
Podosek et al. (1972)	WR	3.219 ± .025
Podosek et al. (1972)	PL.	3.308 ± .025
Podosek et al. (1972)	PL.	3.32 ± .05
Podosek et al. (1972)	PX.	3.328 ± .09
Alexander et al. (1972)	WR	3.33 ± .05
York et al. (1972a)	WR, 2 dups.	3.31 ± .06
Husain et al. (1972a)	WR	3.28 ± .06

TABLE 15555-7a. Sm/Nd whole rock isotopic data for 15555,82 (Lugmair, 1975)

$^{147}Sm/^{144}Nd$	$(^{143}Nd/^{144}Nd)$s	$(^{143}Nd/^{144}Nd)$
0.1991 ± 2	0.512887 ± 34	0.512863 ± 13

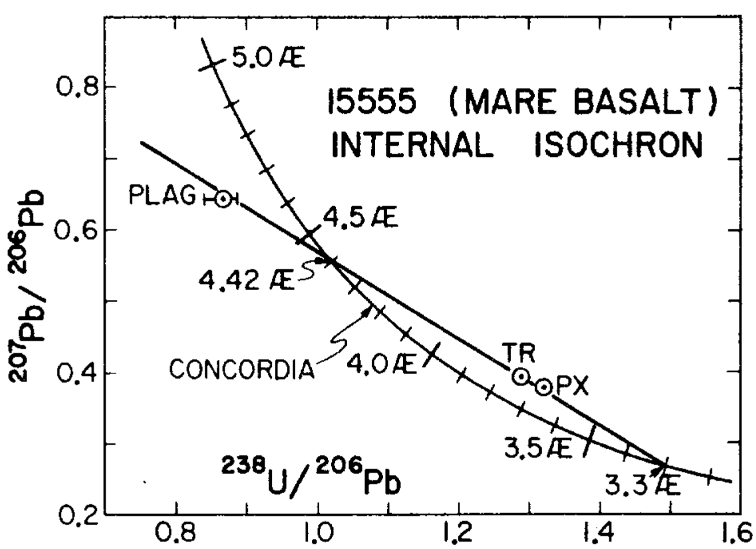
s = from spiked sample

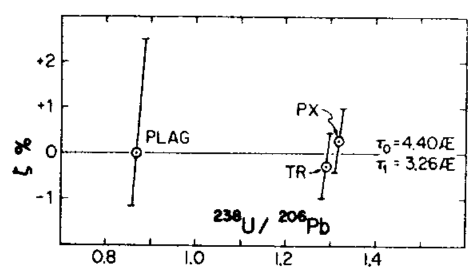
TABLE 15555-7b. Sm/Nd and Lu/Hf whole-rock isotopic data for 15555,195 (Unruh et al., 1984)

$^{147}Sm/^{144}Nd$	$(^{143}Nd/^{144}Nd)_o$	ϵNd_o	$(^{143}Nd/^{144}Nd)_I$	ϵNd_I	$^{176}Lu/^{177}Hf$	$(^{176}Hf/^{177}Hf)_o$	ϵHf_o	$(^{176}Hf/^{177}Hf)_I$	ϵHf_I
0.2026 ± 1	0.512883 ± 40	+4.8 ± 0.8	0.50853 ± 4	+2.4 ± 0.8	0.01806 ± 2	0.282247 ± 43	-21.7 ± 1.5	0.28107 ± 4	+13
					0.01803 ± 4	0.182217 ± 41	-22.8 ± 1.5	0.28104 ± 4	+12.7 ± 1.4

o = at present day; I = at time of crystallization

Data on isotopes in the U, Th-Pb system were presented by Tatsumoto et al. (1972), and Tera and Wasserburg (1974, 1975). The data lie on a discordia: Tatsumoto et al. (1972) determined intersections at 3.3 and 4.65 b.y., but Tera and Wasserburg (1974) preferred 4.42 b.y. with an upper limit of 4.55 b.y. They noted some disagreement with the Tatsumoto et al. (1972) data, especially μ (= $^{238}U/^{204}Pb$), and discussed their study to determine the effects of leaching during the analytical procedure. Tera and Wasserburg (1974) concluded that 15555 definitely contained radiogenic initial Pb but the data cannot distinguish whether this Pb is from the source of 15555 or a crustal contaminant. The upper discordia intersection may indicate that 15555 was produced from undifferentiated lunar mantle or from one which differentiated rapidly at ~4.42 b.y. This study was expanded by Tera and Wasserburg (1975) in obtaining an internal U-Pb isochron on 15555. The most critical errors result from ^{204}Pb terrestrial contamination, and isochrons including ^{204}Pb data are not fully convincing. They concluded that 15555 does have an internal isochron in reasonable accord with Rb-Sr and Ar-Ar ages; the ages determined from intersections (cf. slope) are 4.36-4.43 b.y. and 3.19-3.33 b.y. (Fig. 13). Again, the simplest interpretation is of a two-stage development with the source forming at ~4.42 b.y. Nunes et al. (1975) have the opinion that considering the possibilities of 3-stage Pb evolution, a 4.42 b.y. source age is merely conjecture.





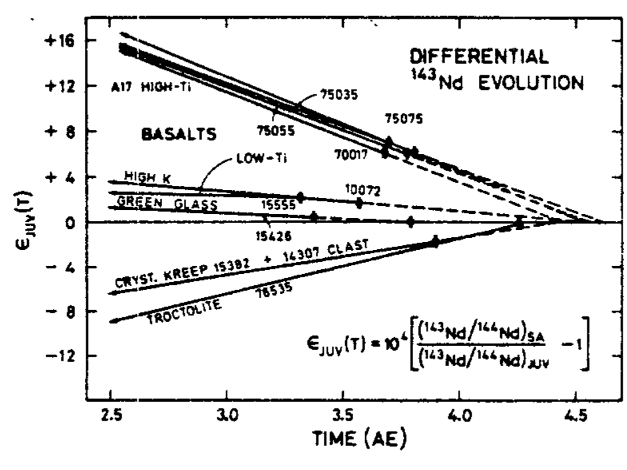
Zeta diagram for 15555 showing deviations (in percent) of the data points from a best fit isochron. $\zeta = 100 [(X_m-X_c)/X_c]$ where m = measured and c = calculated. X_c is a point on the line at the same $^{207}Pb/^{206}Pb$ value as the measured point. This representation is necessary for the evaluation of errors in the more precise U-Pb data presented.

U-Pb internal isochron for 15555. If, on the basis of Rb-Sr data a lower intersection at 3.3 AE is chosen then the isochron (passing through the center of total rock point) yields an upper intersection at the magic point 4.42 AE. A best fit line yields 3.26 AE and 4.40 AE respectively for lower and upper intersections.

Figure 13. U-Pb internal isochron (Tera and Wasserburg, 1975).

Lightner and Marti (1972) determined a U, Th-He age of 2.8 b.y. (with an assumed U abundance), again suggesting some rare gas loss. Anderson and Hinthorne (1973) determined $^{207}Pb/^{206}Pb$ ages of 3.36 ± 0.06 b.y. and 3.46 ± 0.09 b.y. from ion microprobe analyses of an Y-Zr phase in 15555, and gave other Pb isotopic data. Rosholt (1974) provided data on the $^{232}Th/^{230}Th$ activity in a discussion of radioactivity and its sources.

Whole rock Sm-Nd isotopic data were presented by Lugmair (1975) (Table 7a) and discussed by Lugmair and Marti (1977, 1978). 15555 lies on a 4.40 ± 0.06 b.y. isochron with 75075 and 75055, and this was the last time that the sources of these samples had the common parameter of a chondritic Sm/Nd ratio. (Not all mare basalts fall on this isochron.) The source region for 15555 evolved with positive epsilon until eruption at 3.3 b.y. when light REEs were enriched, reducing Sm/Nd ~3.5% to the present near-chondritic ratio (Lugmair and Marti, 1977, 1978) (Fig. 14). T_{ICE} is very imprecise at 6.18 ± 0.54 b.y. because of this ratio. Whole rock Sm-Nd isotopic data was also presented by Unruh et al. (1984), in addition to whole-rock Lu-Hf data (Table 7b). The whole-rock ϵNd (ϵ Ndo in Table 7b) is higher than the quartz-normative basalts 15065 and 15076. The Lu/Hf ratio is less than chondritic, like all mare basalts, thus ϵHf has been falling since crystallization.



The differential ^{143}Nd evolution $\epsilon_{JUV}(T)$ relative to Juvinas is shown for four Apollo 17 basalts, one each Apollo 11 and 15 basalt, green glass 15426, one each KREEP basalt and clast and troctolite 76535.

Figure 14. Sm evolution (Lugmair and Marti, 1978).

RARE GASES AND EXPOSURE AGES: Exposure ages calculated from rare gas isotopic data are listed in Table 8, and are consistent. Podosek et al. (1972) stated that their 90 m.y. age is an upper limit for excavation from a depth greater than the equivalent of 1000 g/cm^2 burial, and excavation could be more recent from shallower depths. Exposure ages determined from cosmic ray tracks are lower: 34 m.y. (Behrmann et al., 1972); 1 m.y. (suntan) and 26 m.y. (subdecimeter) (Bhandari et al., 1972); maximum 26 ± 5 m.y. (Poupeau et al., 1972); less than 5 m.y. (Fleischer et al., 1973), and presumably indicate that rare gas exposure was at shallow depth rather than actually at the surface.

Apart from the studies listed in Table 8, which present considerable rare gas isotopic data, He, Ne, and Ar isotopes were studied by Megrue (1973) using laser probe mass spectrometry in a search for primordial lunar gases. No unequivocal evidence for such gases exist: Megrue (1973) concluded that He, Ne, and Ar are mainly of solar wind origin (similar to Apollo 12 foil experiment) with some cosmogenic contribution. Data collected from a vug on the surface indicate that vugs may be very efficient collectors of solar wind irradiations. Fireman (1972) investigated ^{37}Ar and ^{39}Ar produced from flares and rays, and attributed the ^{37}Ar/Ca to solar flares in the few years before the mission. Fireman et al. (1972) tabulated information on ^{3}H, ^{37}Ar, and ^{39}Ar at several depths in 15555, again correlated with solar flare activity. Marti and Lightner (1972) found that Ne, ^{36}Ar, and ^{38}Ar are almost purely spallation products; in contrast Kr and Xe have sizeable trapped componee been made to determine exposure ages (above), exposure history, and erosion rates. Behrmann et al. (1972) noted that the depth dependence of track intensity is flatter than would be expected of a simple exposure history, and that the sample was buried under a few centimeters of soil until recently; solar flare tracks are not observed on the outer part. An upper limit of 1.3 ± 0.1 mm/yr mass wastage erosion is calculated from a comparison of the 26 m.y. track age with the ~85 m.y. rare gas age. Bhandari et al. (1972, 1973) diagrammed the track profile (density/depth) (Fig. 15). Poupeau et al. (1972) determined track densities at the center, midway, and surface of the sample. The latter are more dense and result from solar flares. Fleischer et al. (1973) also determined track densities at various locations within the sample. The study of Fireman (1972) on rare gases was to elucidate the exposure of 15555 to the solar wind.

TABLE 15555-8. Rare gas exposure ages (m.y.) for 15555

REFERENCE	Ar	He	Ne	Kr
Husain (1974) Husain *et al.* (1972)	80 ± 10 81[a]	77[a]	73[a]	
York *et al.* (1972a)	79[b],72			
Podosek *et al.* (1972)	90[c] ± 10			
Marti and Lightner (1972)		62		81^{+17}_{-7}

Notes:

(a) unirradiated
(b) given as 81 in York *et al.* (1972b)
(c) plagioclase

Surface irradiation and evolution of the lunar regolith

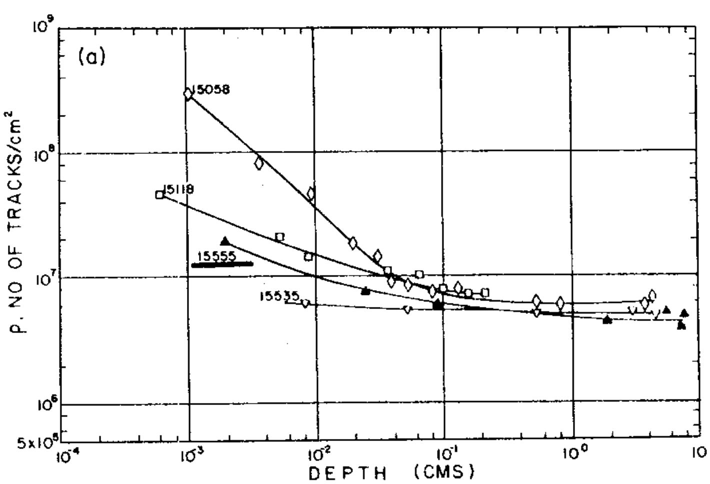


Figure 15. Track density profile (Bhandari *et al.*, 1973).

<u>PHYSICAL PROPERTIES</u>: Basic magnetic measurements and NRM determinations are presented by Collinson <u>et al.</u> (1972, 1973), Pearce <u>et al.</u> (1972, 1973), and Dunn and Fuller (1972). Nagata <u>et al.</u> (1972, 1973) presented basic magnetic data and Hargraves <u>et al.</u> (1972) presented NRM results. The results are in general agreement that 15555 contains little iron; that present is predominantly multidomain and exhibits a very small NRM. Demagnetization curves from different laboratories (Fig. 16) are in good agreement, except that Pearce <u>et al.</u> (1973) found that demagnetization did not yield meaningful data (attributed to multidomain iron grains dominating the sample). The hard NRM is fairly stable, but weaker than other samples of similar age, and scatter probably results from the high noise levels for such weak fields. The direction is roughly constant (Collinson <u>et al.</u>, 1972). Nagata <u>et al.</u> (1973) presented a thermomagnetic curve (intensity vs. temperature) (Fig. 17) without specific discussion.

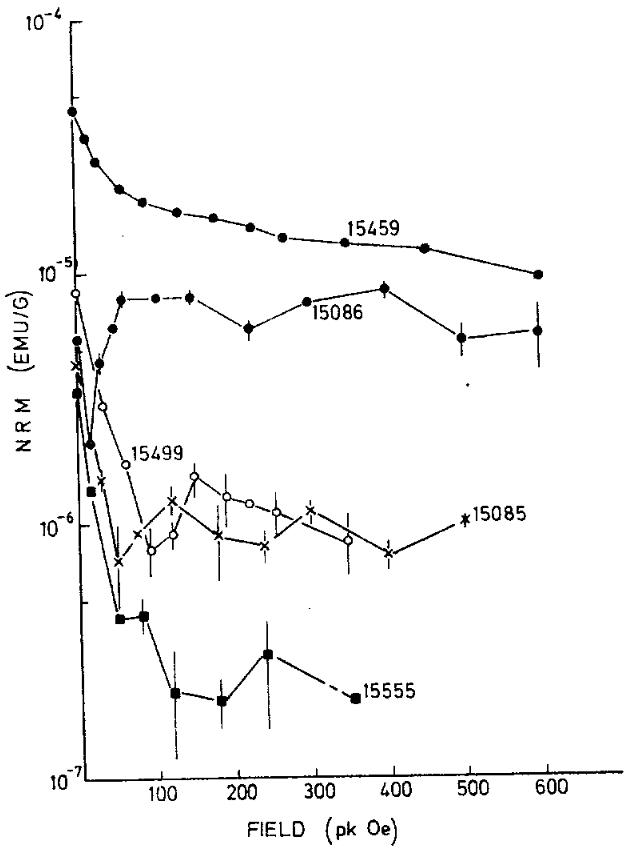
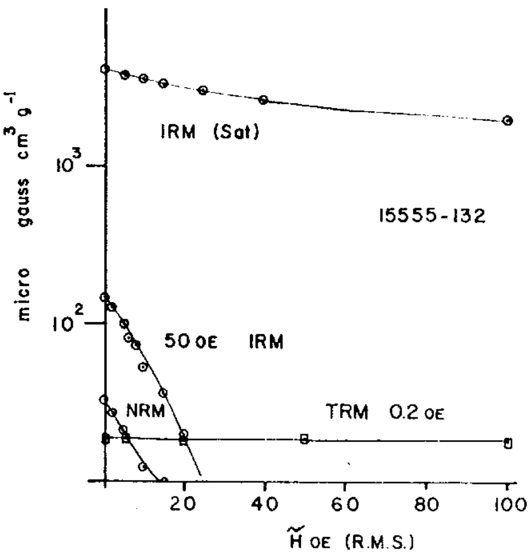


Fig. 16a

Alternating field demagnetization of Apollo 15 samples. Vertical bars indicate range of intensities obtained after repeated demagnetization.

Fig. 16b



AF demagnetization characteristics of 15555,132.

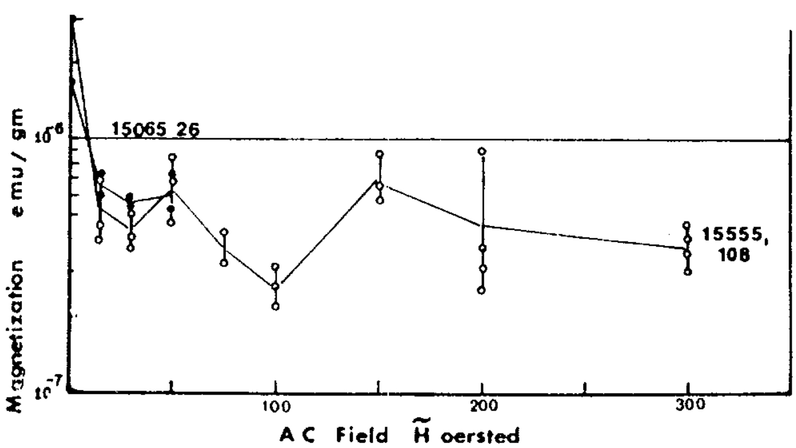


Fig. 16c

Figure 16. AF demagnetization. (a) Collinson et al. (1973); (b) Dunn and Fuller (1972); (c) Hargraves and Dorety (1972).

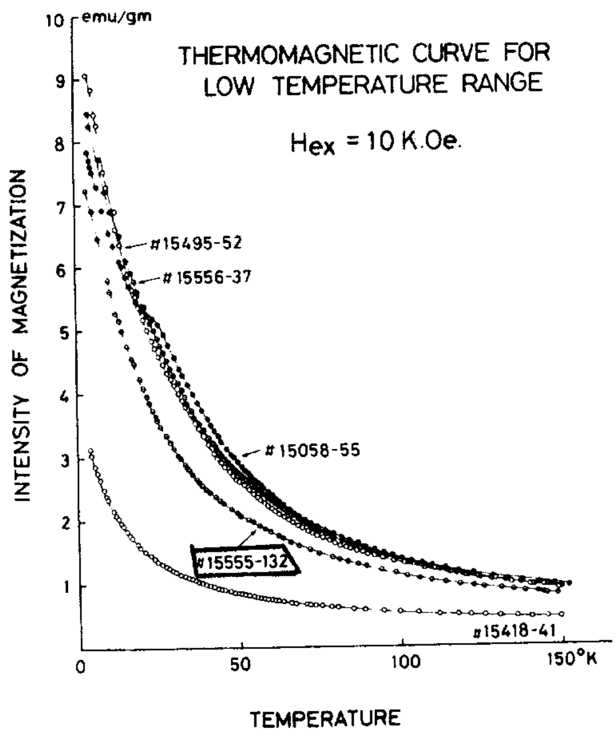
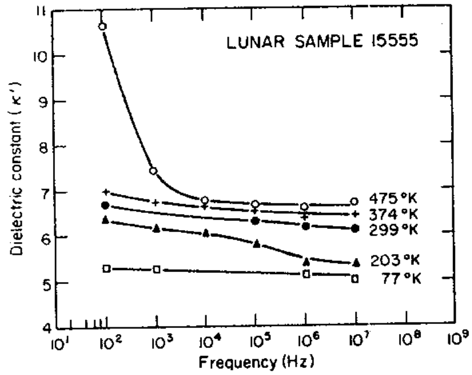


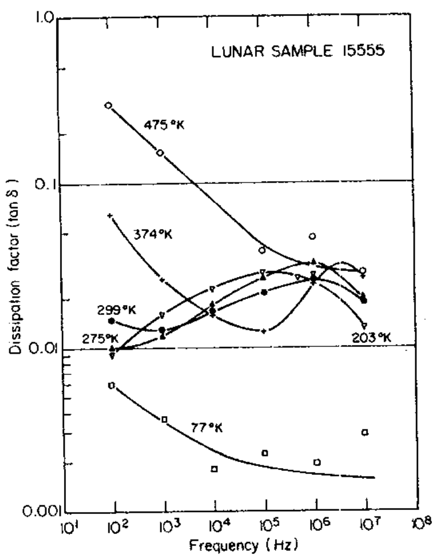
Figure 17. Thermomagnetic curve (Nagata et al., 1973).

Schwerer and Nagata (1976) applied a technique of magnetic granulometry to previously reported data for the temperature dependence of isothermal remanent magnetization. They arrived at the conclusion that, while igneous rocks generally have a larger fraction of metallic iron as fine particles, 15555 is an extreme case in which particles with mean diameters less than 100 A account for about 88% of the total metallic iron.

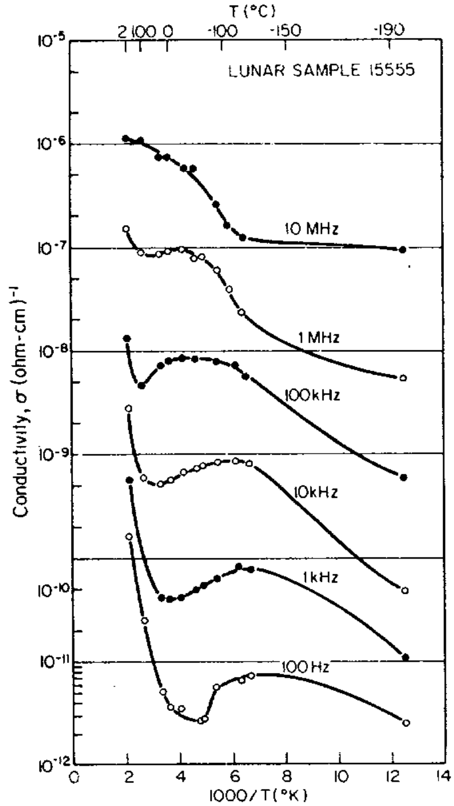
Chung and Westphal (1973) tabulated and plotted (Fig. 18) dielectric data without specific discussion, and other electrical conductivity measurements were presented by Schwerer et al. (1973, 1974) for different oxidation-reduction conditions (Fig. 19). Schwerer et al. (1973) also presented Mossbauer spectra for an interior portion and surface scrapings taken under oxidising conditions following a reduction process.



Dielectric constant of sample 15555,88 as a function of frequency and temperature.



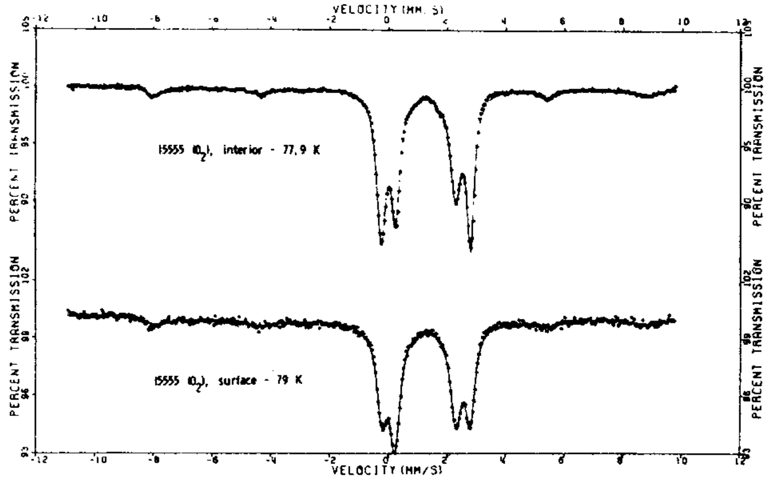
Dielectric losses in sample 15555,88 as a function of frequency and temperature.



Electrical conductivity of sample 15555,88 as a function of frequency and temperature.

Figure 18. Dielectric spectra (Chung and Westphal, 1973).

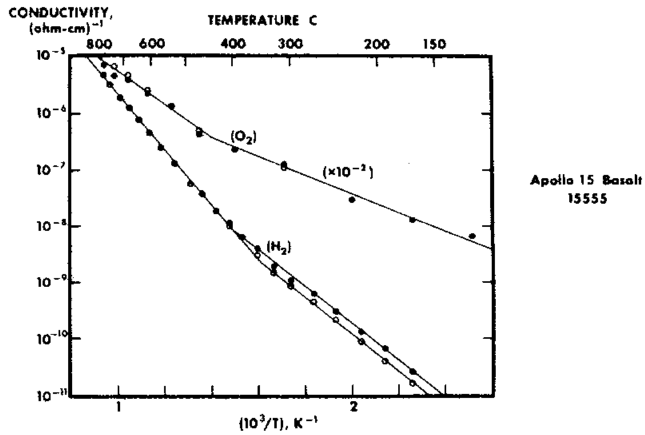
Tittmann et al. (1972a,b) found unusually low elastic velocities for 15555: Rayleigh wave (velocity (V_R) of 0.28-0.33 km/sec; bulk longitudinal wave velocity (V_P) 0.70-0.95 km/sec. These low velocities result from microfractures, illustrated on an SEM photograph in Tittmann et al. (1972a). Warren et al. (1973) also measured acoustic velocities under uniaxial loading (Fig. 20), also demonstrating low values. They also measured the internal friction (Q) on a glass of 15555 composition. Chung (1973) determined elastic wave velocities under confining pressures from 0.5 to 7 kb (Fig. 21, Table 9), under which pressures the acoustic velocities are similar to those of other rocks.



Mössbauer spectra of an interior portion and surface scrapings of Apollo sample 15555 after annealing at 800°C first in He–H_2, then in He–O_2.

Fig. 19a

Fig. 19b



Electrical conductivity (dc, full symbols; ac, open symbols) for lunar basalt (Apollo 15555) in reducing and oxidizing atmospheres (lower and upper sets of curves, respectively). Solid lines are results of least-squares fit to Equation 1. (For purposes of presentation, data for the oxidizing environment have been reduced by a factor of 100.)

Figure 19. (a) Mossbauer spectra and (b) electrical conductivity (Schwerer et al., 1974).

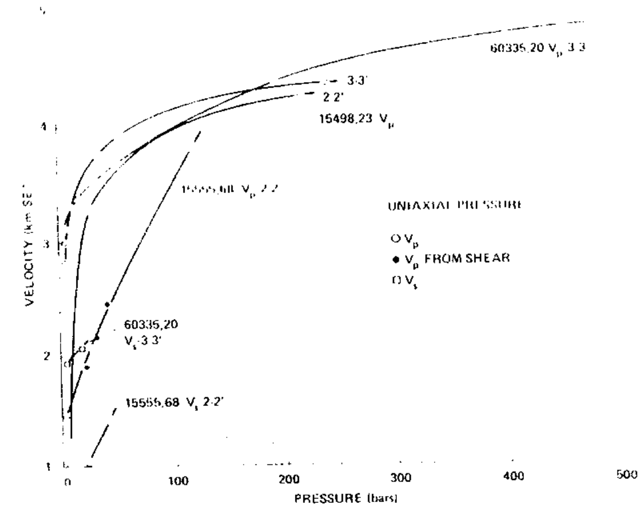


Figure 20. Seismic velocity as a function of pressure (Warren et al., 1973).

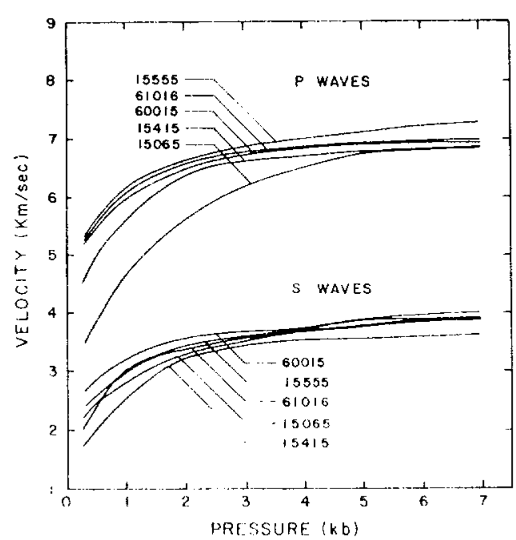


Figure 21. Seismic velocity as a function of pressure (Chung, 1973).

TABLE 15555-9. Elastic wave velocities for 15555 (Chung, 1973)

	Pressure, kb								
	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0
P (km/sec)	5.6	6.1	6.45	6.66	6.90	7.02	7.14	7.25	7.30
S (km/sec)	2.6	3.0	3.24	3.45	3.66	3.76	3.87	3.94	4.01

Hemingway et al. (1973) tabulated and plotted specific heat determinations over a temperature range of 83.56°K to 363.53°K (Table 10). The data are similar to those for other lunar rocks and soils.

TABLE 15555-10. Specific heat measurements for 15555 (Hemingway et al., 1973).

Temperature °K	Specific heat J/(gram · K)	Temperature °K	Specific heat J/(gram · K)	Temperature °K	Specific heat J/(gram · K)
83.56	0.2088	187.06	0.5180	293.09	0.7556
94.05	0.2414	197.83	0.5456	303.77	0.7703
103.71	0.2715	208.68	0.5736	313.96	0.7895
113.58	0.3038	218.95	0.5983	323.97	0.8071
124.82	0.3389	230.05	0.6230	333.68	0.8222
136.51	0.3749	240.98	0.6481	343.36	0.8397
143.07	0.3946	249.20	0.6648	353.28	0.8565
154.35	0.4276	260.22	0.6874	363.53	0.8728
165.24	0.4586	271.21	0.7084		
176.18	0.4879	281.80	0.7330		

Adams and McCord (1972) and Charrette and Adams (1975) presented reflection spectra for 15555, and Brito et al. (1973) made thermo-luminescence studies on six samples from the center to the outside.

Cukiermann and Uhlmann (1974) studied the viscous flow behavior of a 15555-like composition glass at 620° to 700°C and 1215° to 1400°C under mildly reducing conditions. They also studied the effect of oxidation state on viscosity, finding that a decrease in Fe^{2+}/Fe^{3+} produced a dramatic increase in viscosity.

Cukiermann et al. (1973) also reported data on the viscosity of a similar glass sample, as well as on the crystallization kinetics; 15555 does not easily form a glass.

PROCESSING AND SUBDIVISIONS: 15555 has been widely split, including the production of sawn slabs, resulting in about 800 subsamples. Several allocations were made from undocumented chips loose in the sample container. The basic subdivisions are shown in Figure 22. Nearly all the thin sections are from subdivisions of slab ,57, with the exceptions of several made from ,14, an undocumented loose fragment (Fig. 23). The large pieces ,47 (3654 g) and ,56 (2226 g) are still intact. ,58 has been subdivided into numerous subsamples, many of which are 100-300 g. A large proportion of these are now PAO samples.

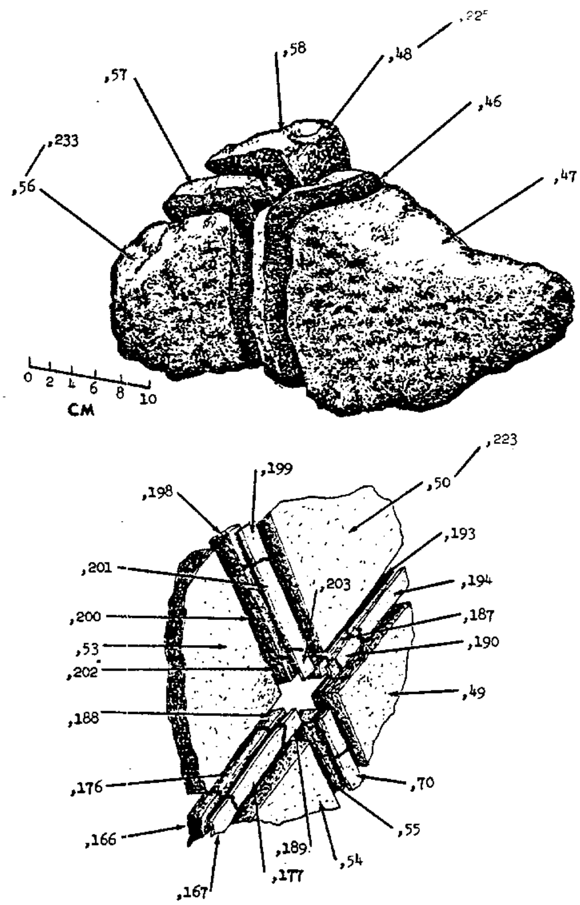


Figure 22. Main subdivision of 15555.

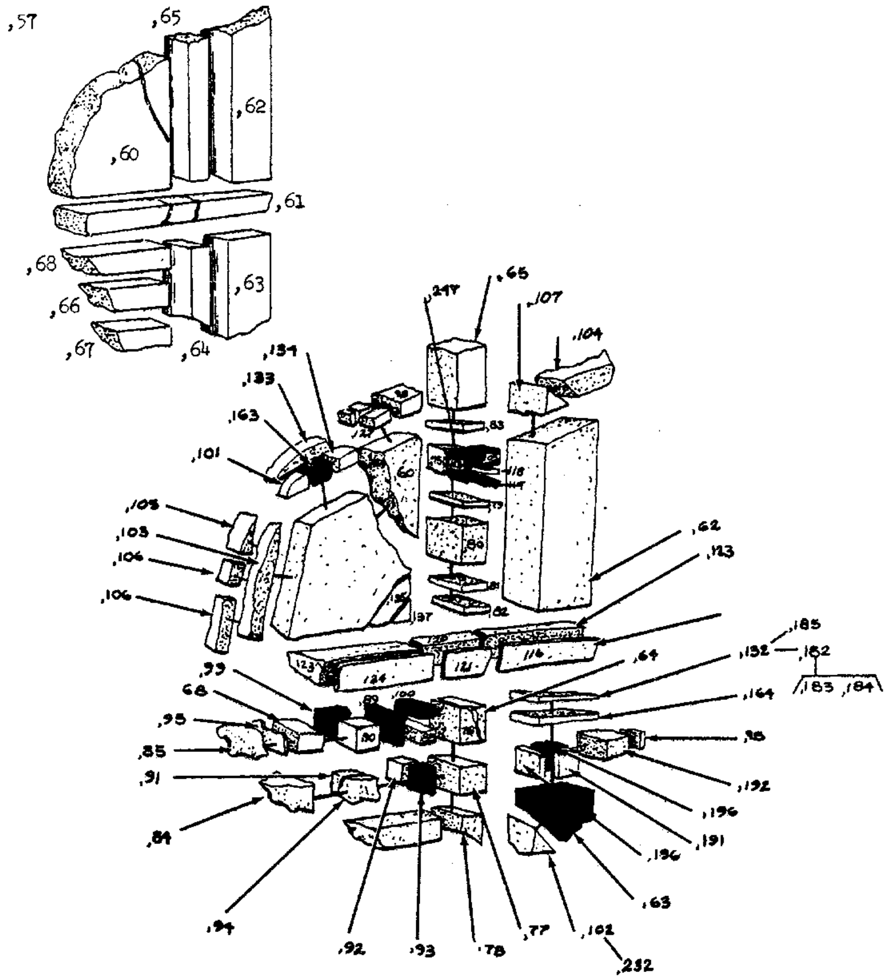


Figure 23. Subdivision of slab 15555,57.

15556 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 1542.0 g

INTRODUCTION: 15556 is a medium-grained, extremely vesicular olivine-normative basalt containing small olivine phenocrysts. It is ~3.4 b.y. old. According to the Apollo 15 Lunar Sample Information Catalog (1972), a 1-cm xenolith occurs on one face. A few percent yellow-green olivine phenocrysts are visible. The basalt is medium gray, subrounded (Fig. 1), and tough. The sample was barely in the soil, lacking fillets or much dust coating, and has zap pits on all surfaces.

15556 was collected approximately 60 m northeast of the rim of Hadley Rille, from an area in which rocks as large as 20 cm are common. Its orientation was documented.

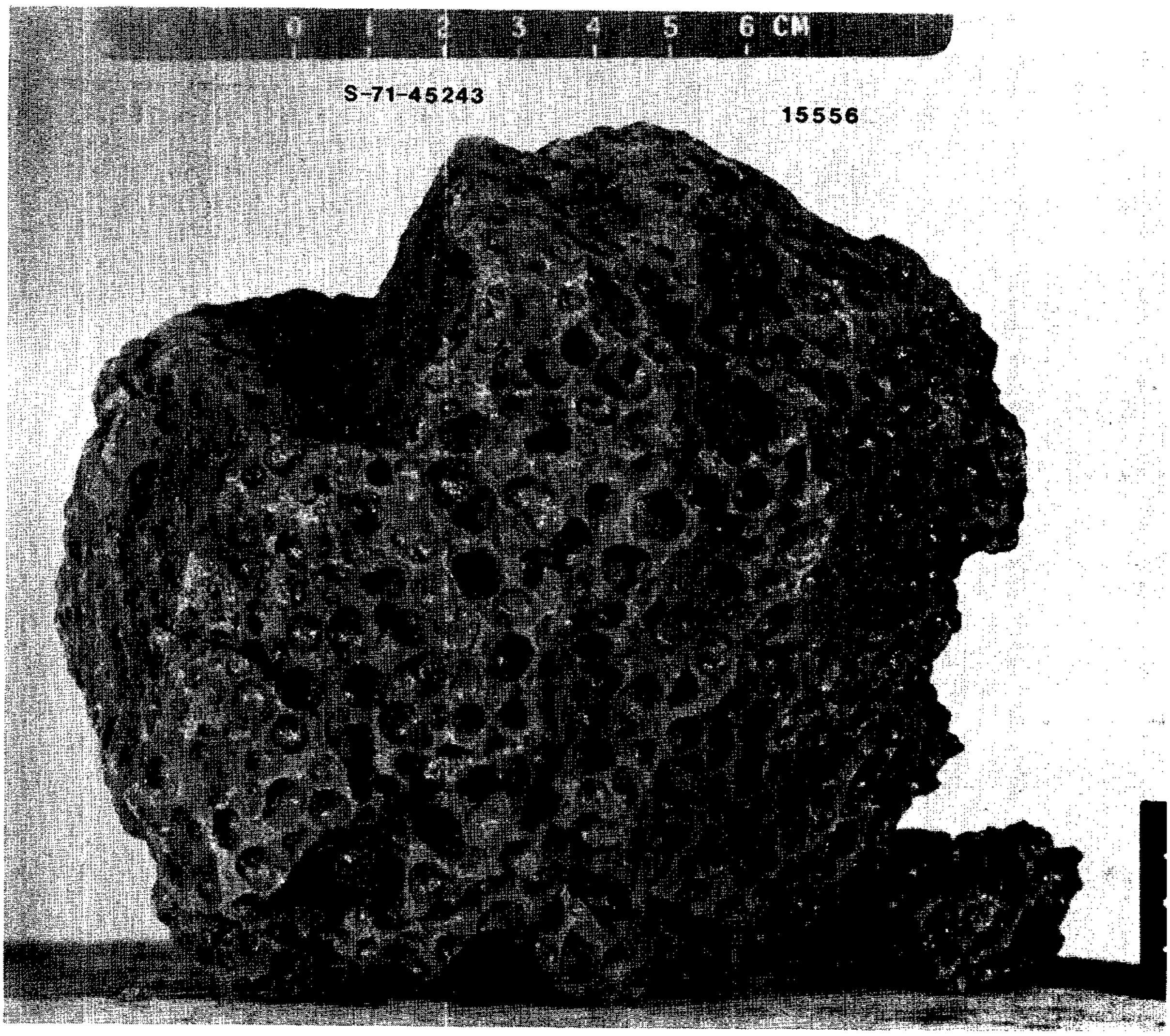


Figure 1. Macroscopic view of 15556, showing large vesicles on "B" side.

PETROLOGY: The sample is conspicuous because of its vesicles. They show a continuous change from one side of the rock to the other in both size and abundance, which both increase as the rock's apparent grain size decreases. However, thin sections reveal no conspicuous change in grain size across the rock (Fig. 2) although they do in vesicularity. There appear to be fewer and smaller olivine phenocrysts in those thin sections with more vesicles than in those with fewer vesicles. The largest vesicles are almost a centimeter across.

Little on the petrology of 15556 has been published. The Apollo 15 Sample Information Catalog (1972) gave a mode for thin section ,15 of 50% clinopyroxene, 30% plagioclase, 5% olivine, 5% cristobalite, 3% ilmenite, 3% ulvospinel, 2% chromite, 1% mesostasis, and traces of Fe-Ni metal and troilite. Rhodes and Hubbard (1973) reported a mode with 57% pyroxene, 38% plagioclase, and only 0.1% olivine.

Inspection of thin sections shows ragged, corroded olivines, and ragged laths of plagioclase which partly enclose generally granular, small clinopyroxenes (Fig. 2). Except for the size of vesicles, this texture is common across the sample. Brunfelt et al. (1973) made microprobe analyses of pyroxenes (Fig. 3) in conjunction with their chemical analyses of mineral separates. El Goresy et al. (1976) made analyses of spinels. The spinels occur as corroded and rounded chromite cores (inclusions) in Cr-ulvospinel; analyses are diagrammed in Figure 4. El Goresy et al. (1976) discussed the compositional zoning and substitutional trends. Engelhardt (1979) tabulated ilmenite paragenesis. Huffman et al. (1972, 1974, 1975) made Mossbauer and magnetic studies of 15556, finding clear evidence for olivine, and analyzing the distribution of Fe among phases. Huffman et al. (1975) interpreted the spectra as requiring subsolidus reheating of the sample for a long time at moderate temperatures.

Garvin et al. (1982) studied the physical properties (length, width, distance to nearest neighbor, etc.) of the vesicles, finding an average diameter of 4.1 mm. Calculations of the vesicle distribution are consistent with a magma ascending at 0.20 m/sec with 80 to 400 ppm dissolved CO. The magma rise rate is more influential in these calculations than is viscosity. These authors do not discuss the variation of vesicles across the sample.

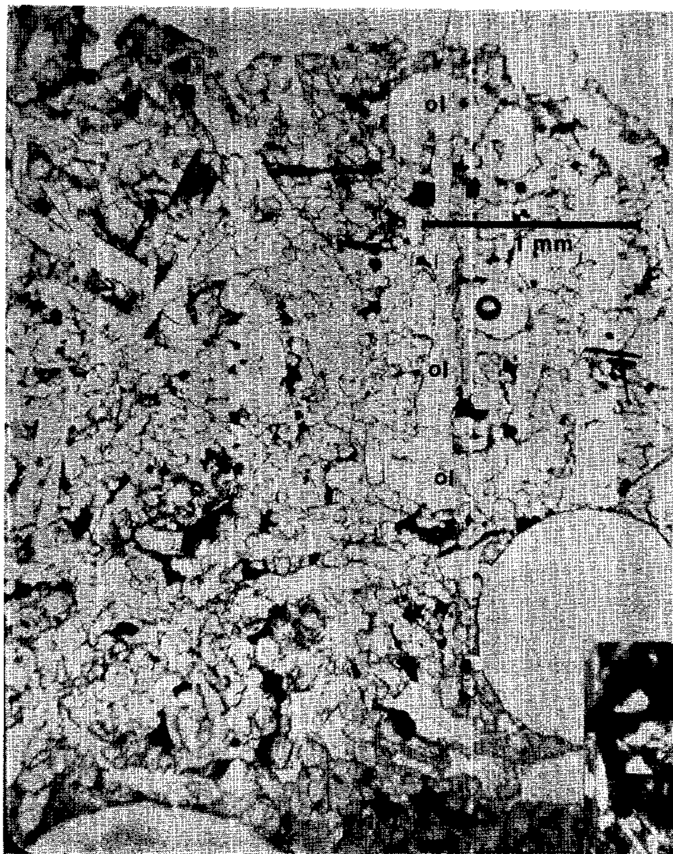


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of thin sections, all to same scale (a) 15556,132 from one end with small vesicles, transmitted light; (b) as (a) crossed polarizers. "ol" is a single, corroded olivine grain; (c) 15556,130, from other end, with large vesicles (not shown), transmitted light; (d) as (c) crossed polarizers.

Fig. 2c

Fig. 2d

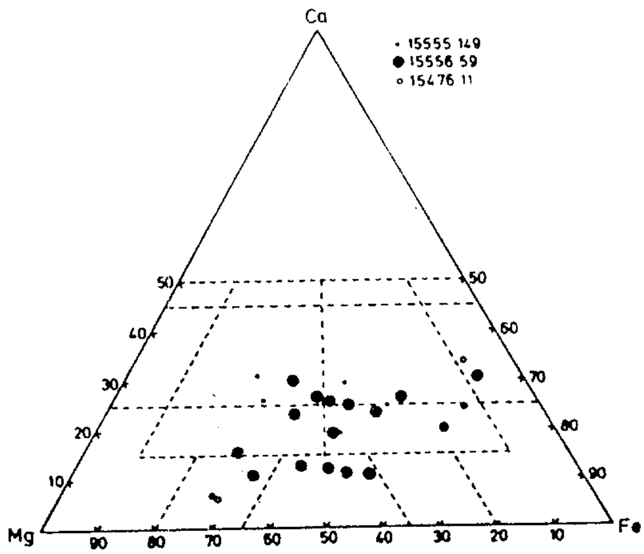


Figure 3. Pyroxene compositions (Brunfelt et al., 1973).

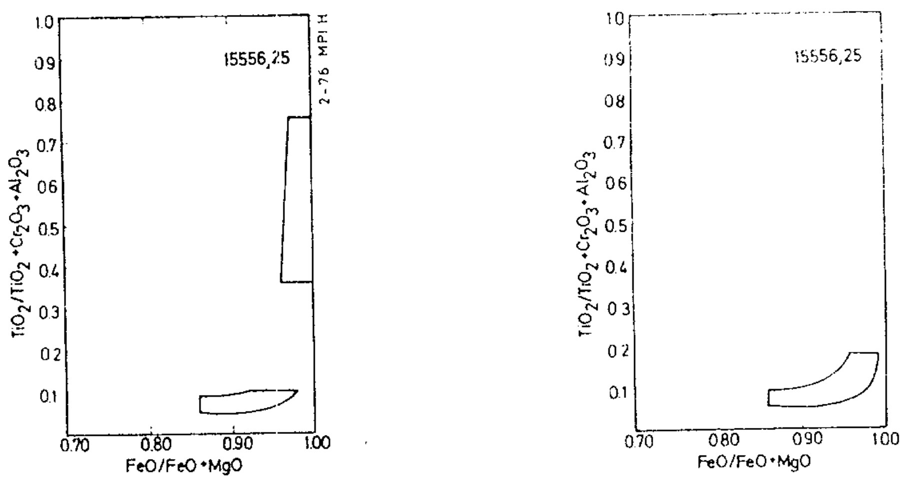


Figure 4. Compositions of spinels (El Goresy et al., 1976).

EXPERIMENTAL PETROLOGY: Humphries et al. (1972) conducted low-pressure crystallization experiments on 15556 (Fig. 5). It has a high-temperature olivine liquidus, with pigeonite the second silicate phase to crystallize. The sample is substantially crystalline at anorthite crystallization. They prefer the interpretation that the sample is not a liquid composition, but a mafic cumulate.

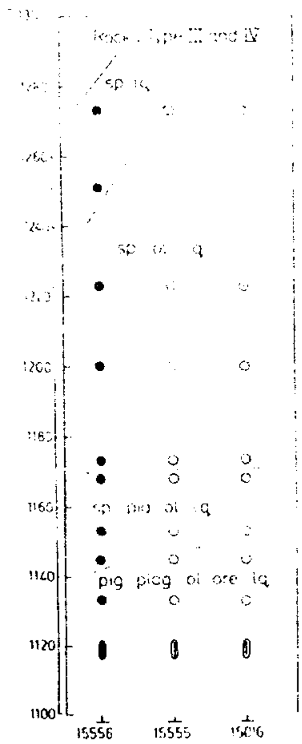
CHEMISTRY: Chemical analyses are listed in Table 1, with rare earths shown in Figure 6. The analyses, which generally are not specifically discussed by their authors, are quite consistent with each other and have the high iron and titanium of Apollo 15 olivine-normative basalts. According to the low MgO, it is a fairly evolved member of the group. Rhodes (1972) analyzed split ,5 but did not publish the analysis, using it only in an average of olivine-normative basalts. Brunfelt et al. (1973) also reported mineral separates data for plagioclase, pyroxene, and olivine.

Ganapathy et al. (1973) noted a strong enrichment in Cd (~10x) over other Apollo 15 mare basalt samples, and suggested that Cd was in the gas phase which gave the rock its vesicularity. They also profess doubt on their Rb analysis, but only because it differs from that reported by other laboratories. Muller (1976) cited the disparity between his nitrogen analyses as a probable result of sample heterogeneity, although both sets were on the same split ,25.

Desmarais et al. (1974) found a H concentration of 4 micro-moles/gm (pyrolysis), much lower than soils. The H is even lower than other mare basalts, consistent with outgassing manifested in the vesicularity. Gibson et al. (1975) analyzed for CO, CO_2, H_2, H_2S, and metallic iron. Gibson and Andrawes (1978) analyzed gas released on crushing the sample, finding no active gases, e.g. nitrogen less than 10 ppm.

Goldberg et al. (1976) analyzed for F in the surfaces of vesicle and inter-vesicle areas, in a study aimed at determing the composition of the gas which formed the vesicles. They found more F in the vesicles than in intervesicle areas for fresh-sawn samples. The vesicle F abundance is still ~10x less than on Apollo 15 Green Glass, a result of either different gas compositions or more efficient condensation on the faster-cooled glass. Neither F or S would have enough total pressure to have formed the vesicles, the gas for which they believe to have been mainly CO.

Figure 5. Low-pressure crystallization, black dots (Humphries et al., 1972).



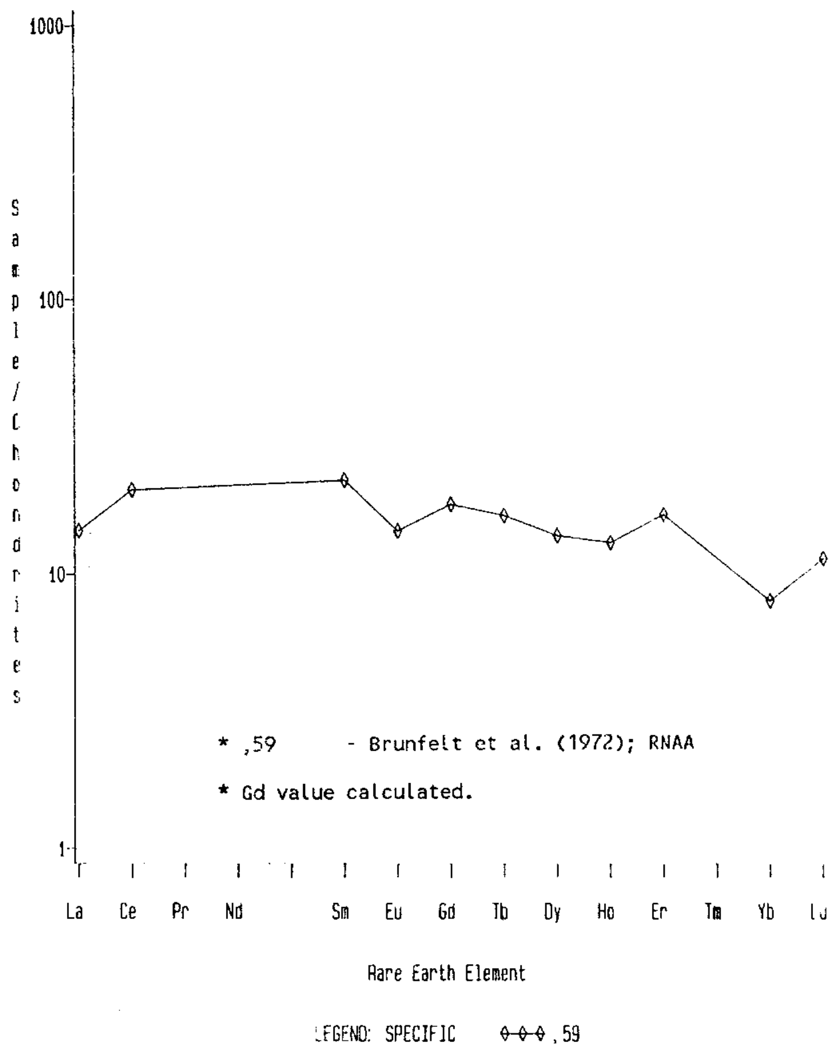


Figure 6. Rare earths in bulk rock.

TABLE 15556-1. Chemical analyses of bulk rock

		,26	,59	,25	,25	,12	,4	,9	,159	,125	,0
Wt. %	SiO2	46.18				46.2					
	TiO2	2.64	2.04			2.68					
	Al2O3	9.85	9.24			9.44					
	FeO	21.70	21.41			21.62					
	MgO	8.03		8.2		8.09					
	CaO	10.72	9.94	11.3		10.54					
	Na2O	0.30	0.28	0.279c		0.22					
	K2O	0.09		0.0470		0.06					0.053
	P2O5	0.07				0.08					
(ppm)	Sc		43.1								
	V	165	266			255					
	Cr	5200	3200			4300					
	Mn	2500	1800			2000					
	Co	46	50.3			49		51			
	Ni	65	50			57					
	Rb	<5	0.84	0.85		3		0.10a			
	Sr	102	88	103		96					
	Y	50				32					
	Zr	100				85					
	Nb					8					
	Hf		3.1								
	Ba	50	59	53		85					
	Th		0.40								0.56
	U		0.21	0.15				0.145			0.15
	Pb	<2									
	La		4.8	5.5							
	Ce		18								
	Pr										
	Nd										
	Sm		4.0								
	Eu		1.00								
	Ge										
	Tb		0.77								
	Dy		4.4								
	Ho		0.91								
	Er		3.3								
	Tm										
	Yb		1.59								
	Lu		0.39								
	Li	9		8.0							
	Be										
	B	3									
	C						16				
	N				<10					126	
	S								965b		
	F										
	Cl										
	Br							13			
	Cu	10	7.1			9					
	Zn		1.2					2.1			
(ppb)	I										
	At										
	Ga	5000	3700								
	Ge							9.8			
	As		<50								
	Se		106					142			
	Mo										
	Tc										
	Ru										
	Rh										
	Pd										
	Ag		<7					0.85			
	Cd							28			
	In		<2					0.56			
	Sn										
	Sb							0.13			
	Te							2.7			
	Cs		<32	30				32			
	Ta		400								
	W		430								
	Re							0.00413			
	Os										
	Ir		<0.1					0.039			
	Pt										
	Au		0.85					0.026			
	Hg										
	Tl							0.32			
	Bi							0.18			
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

References and methods:

(1) Mason et al. (1972); varied
(2) Brunfelt et al. (1972); RNAA
(3) Muller (1972a, 1975); AAS, RNAA
(4) Muller (1972b); Kjeldahl method, "conventional"
(5) Strasheim (1972); Varied
(6) Moore et al. (1972, 1973)
(7) Ganapathy et al. (1973); RNAA
(8) Gibson et al. (1975); Combustion
(9) Muller et al. (1976); Kjeldahl method, "optimized"
(10) Rancitelli et al. (1972); Gamma ray spectroscopy

Notes:

(a) Quoted by authors as probable analytical error (also Wolf et al., 1979).
(b) A lower value was obtained from hydrolysis
(c) Revised from (1972a) value.

STABLE ISOTOPES: Clayton et al. (1974) reported oxygen isotope analyses for mineral separates (Table 2). The data is consistent with fractionation at temperatures of ~1100°C.

Gibson et al. (1975) reported typically magmatic sulfur isotopes ($\delta^{34}S$) of +0.9. Lipschutz et al. (1973) reported a $^{50}V/^{51}V$ isotopic ratio, in part of a search for early, energetic charged particle radiations. Strasheim et al. (1972) reported a $^{7}Li/^{6}Li$ ratio of 12.2.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Kirsten et al. (1972) analyzed Ar isotopes and found a total K-Ar age of 3.4 ± 0.1 b.y. Temperature releases were not reported. [Strasheim et al. (1972) stated that the $^{7}Li/^{6}Li$ relation leads to an age of 3.05 b.y., but no details of the "method" were given.]

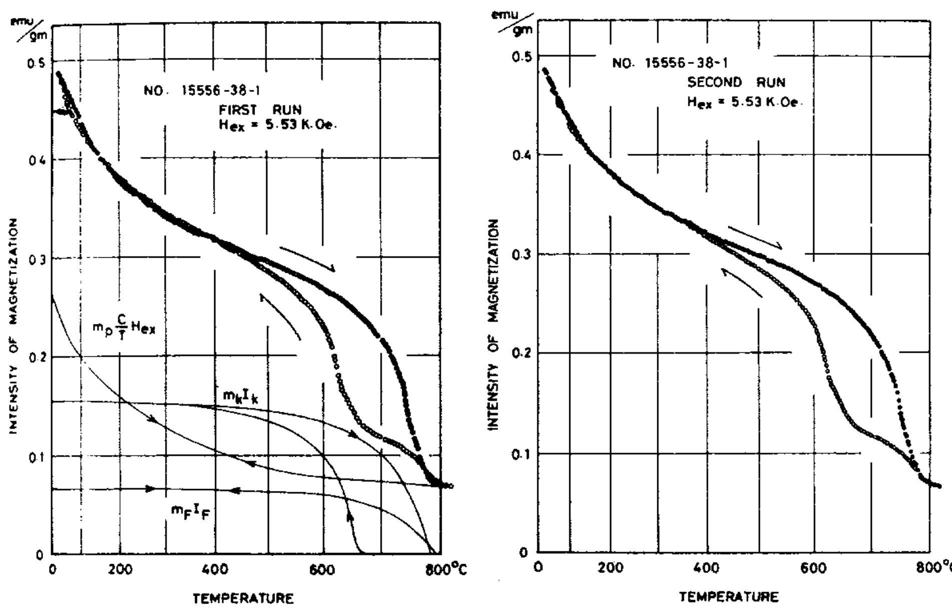
RARE GASES AND EXPOSURE: Kirsten et al. (1972) reported rare gas isotopic data and found consistent exposure ages from three methods: ^{3}He 490 ± 50 m.y., ^{21}Ne 525 ± 40 m.y., ^{38}Ar 490 ± 50 m.y. Rancitelli et al. (1972) measured cosmogenic radionuclides, finding a long exposure relative to the ^{26}Al halflife. The sample has a high $^{26}Al/^{22}Na$ ratio in comparison with other mare basalts, perhaps because it had been barely buried in the lunar regolith.

PHYSICAL PROPERTIES: Nagata et al. (1972a,b, 1973, 1974) reported basic magnetic and NRM data for ,37 and ,38 (Figs. 7-9). Unlike most other basalts, kamacite with a few per cent nickel rather than metal almost lacking Ni appears to be the major ferromagnetic phase. ,38 was split into two parts, one black, the other gray. The black has a strong NRM, and the gray a weak NRM similar to ,37, also gray. The NRM has a hard component ~1×10^{-6} emu/gm, with a direction reasonably invariant for AF demagnetizing fields greater than 100 Oe.rms (Figs. 8, 9). Partial thermo-remanent magnetization increases steadily with temperature to 800°C, and if the stable component of NRM can be attributed to PTRM, an ambient lunar field of 3400 gammas (Nagata et al. 1973) or ~2000 gammas (Nagata et al. 1972b) is implied. Schwerer and Nagata (1976) applied the technique of magnetic granulometry to the published magnetic data, tabulating distribution parameters for fine-grained (30-150 Å) metallic iron. Brecher (1975, 1976) listed 15556 under two sections of her lists of samples which show "textural remanence."

Gold et al. (1974, 1975, 1976) made Auger spectra of pulverized rock, finding that pulverized rock has a higher albedo than soils because the soil grains have more iron in their surfaces. Solar wind simulation experiments, with α-particles in the case of 15556, caused an increase in Fe/O and Ca/O in surfaces (shown by Auger analysis). The experiments strongly support the model that selective sputtering of oxygen and other light elements by solar wind irradiation is the cause of lower albedo in soils.

TABLE 15556-2. Oxygen isotopes (δ^{18} O/oo SMOW)
(Clayton et al. 1972)

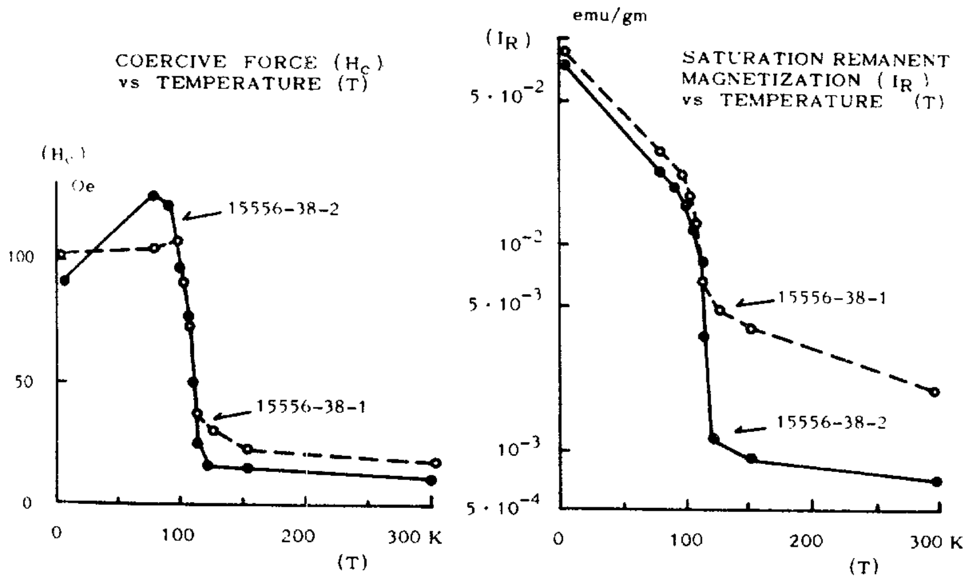
	Plag	Px	Ol	Ilm
,63	5.88	5.68	4.99	4.01



Thermomagnetic curve of Apollo 15 basalt No. 15556-38 in temperature range from 20 to 820 °C.

Figure 7. Magnetic hysteresis loops (Nagata et al., 1974).

Figure 8. Dependence of the coercive force (left) and the saturation remanent magnetization (right) upon temperature (Nagata et al., 1974).



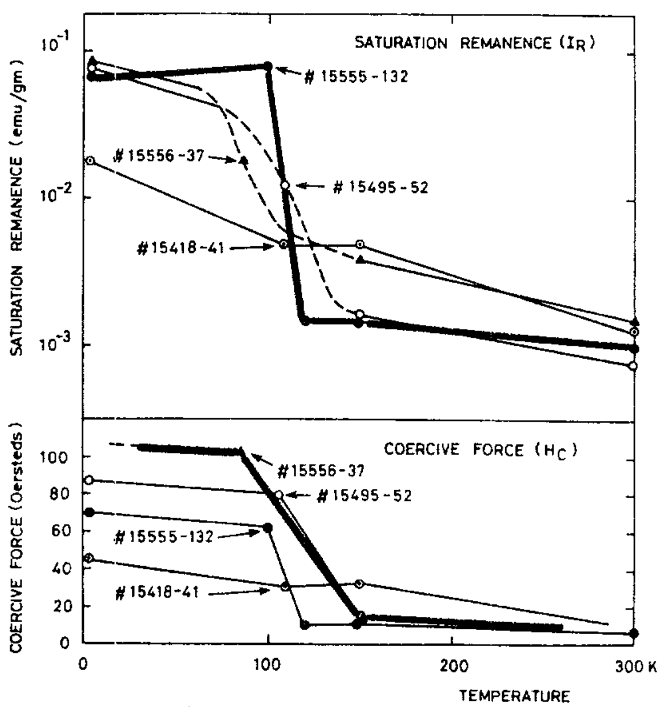
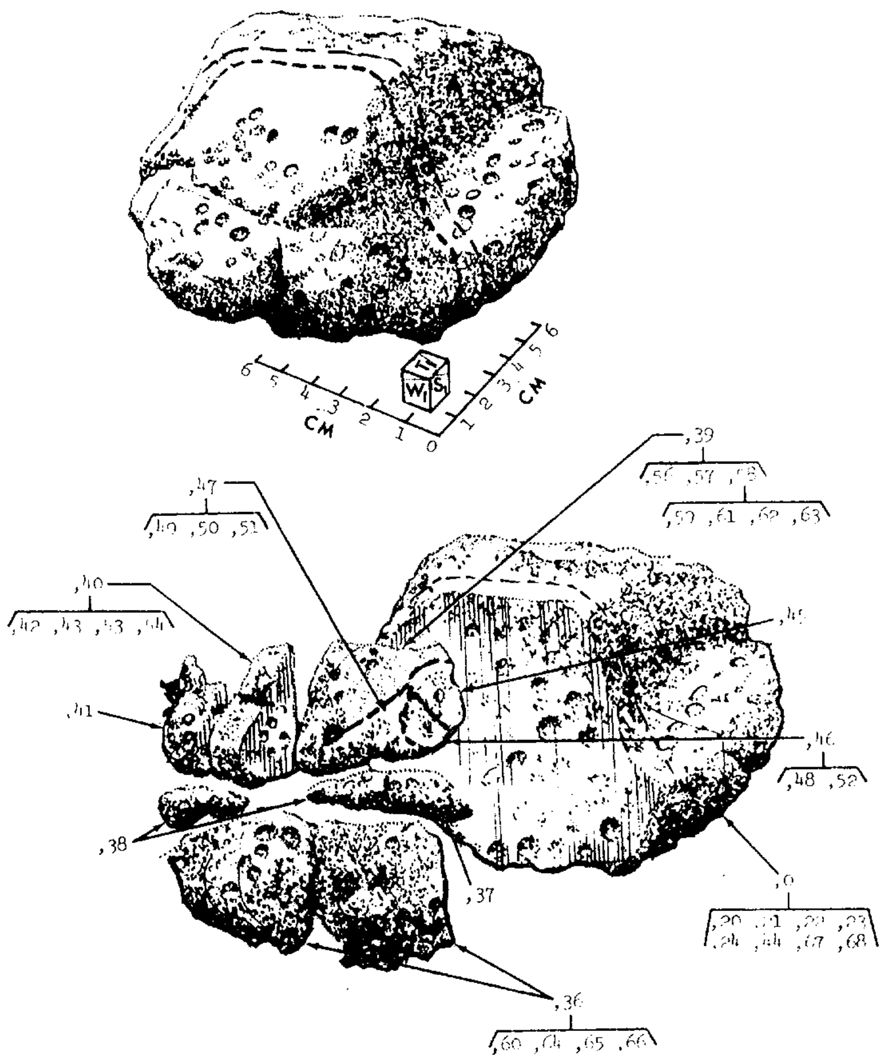


Figure 9. Dependence of the saturation remanent magnetization (top) and the coercive force (bottom) for 15556 (heavy line) and other Apollo 15 samples (Nagata et al., 1974).

<u>PROCESSING AND SUBDIVISIONS</u>: Two chips ,1 (18.0 g) and ,2 (6.1 g) (which were loose in the bag with 15556 but fitted onto broken surfaces i.e. documented) provided the first allocations. Two potted butts ,3 and ,10, from ,2 and ,1 respectively, provided all the thin sections until a new slab was cut in 1981 (below). A saw cut was made through 15556 and the end piece dissected for allocation (Fig. 10). The remainder of ,36 is in remote storage. A few pieces were incorporated into educational disks. In 1981 a new saw cut (Fig. 10) was made from ,0 (now 1184.1 g) to produce thin sections directly relatable to the vesicularity variation (Table 3) and other sub-samples.



<u>Figure 10</u>. Sawing of 15556. The slab produced in the 1981 sawing is roughly indicated with a dashed line.

TABLE 15556-3 Thin sections of 15556

POTTED BUTT	RELATION TO VESICLES	THIN SECTIONS
,3	Middle ?	,15,18,19,32,34,35,136,137,138
,10	Middle ?	,16,28,29,30,31
,112	Middle	,129,131
,113	Bottom, large vesicle	,130
,116	Top, small vesicles	,132
,128	Middle	,133

15557 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 2518.0 g

INTRODUCTION: 15557 is a fairly fine-grained olivine-normative basalt containing small (~1.5 mm) olivine phenocrysts. It is well-rounded (Fig. 1), light to medium gray, and tough. It had a well-developed fillet and has a few zap pits.

15557 was collected about 40 m north of the rim of Hadley Rille from an area with few large fragments. Its orientation was documented.

PETROLOGY: The sample is a microporphyritic olivine-normative basalt with an intergranular groundmass (Figs. 2, 3A), and with irregularly distributed small cavities. The olivines are macroscopically visible as small yellow green subhedral crystals, none larger than 3 mm.

Heuer et al. (1972) and Nord et al. (1973) made optical and high voltage electron microscopy studies on thin section ,36, describing the sample as a finer-grained olivine basalt with an intergranular texture. The olivines occur as ~1.5 mm, anhedral crystals (10 to 15%) which are slightly zoned and rimmed with pyroxene. Augite and pigeonite (~50%) occur as discrete grains, but with some pigeonite mantled with augite. Pyroxenes show some apparent fine exsolution microscopically. Most are granular grains poikilitically included in large (~0.5-1.5 mm) plagioclases which form about 35% of the rock. The remaining 5% consists of cristobalite, ilmenite, ulvospinel, troilite, and Fe-metal. High voltage electron microscopy studies showed that the plagioclase was zoned, with a marked variation in size of b-domains with position in the crystal, with the smallest domains in central, Ca-rich areas (as previously observed in other samples). They suggest a potential for using b-domain size to establish cooling rates. Pyroxene microstructures are similar to those in 15555.

Bell et al. (1975), in a general study of symplectites in olivines in lunar samples, described olivines in 15557 which have two zones of symplectites. One is in the core (Fo_{71}), another near the outer edge (Fo_{69}), with symplectite-free zones between and at the crystal edge. These symplectites are "rosettes". Bell et al. (1975) presented three microprobe analyses of olivines and an average of two similar symplectites (bulk 18.4% Cr_2O_3), and noted that there is not much symplectite present.

CHEMISTRY: Published analyses are presented in Table 1, and rare-earths shown in Figure 4. The original papers presented little specific discussion, generally noting a similarity with other olivine-normative basalts. The MgO and TiO_2 contents suggest a fairly evolved member of the group. In addition to the data tabulated, Fe_2O_3 was analyzed for, but not found, by Christian et al. (1972)/Cuttitta et al. (1973) and Maxwell et al. (1973); the latter also found a lack of H_2O. Cuttitta et al. (1973) erroneously listed SiO_2 as 25.74% instead of 45.74%. The

Figure 1. Whole rock sample prior to sawing.

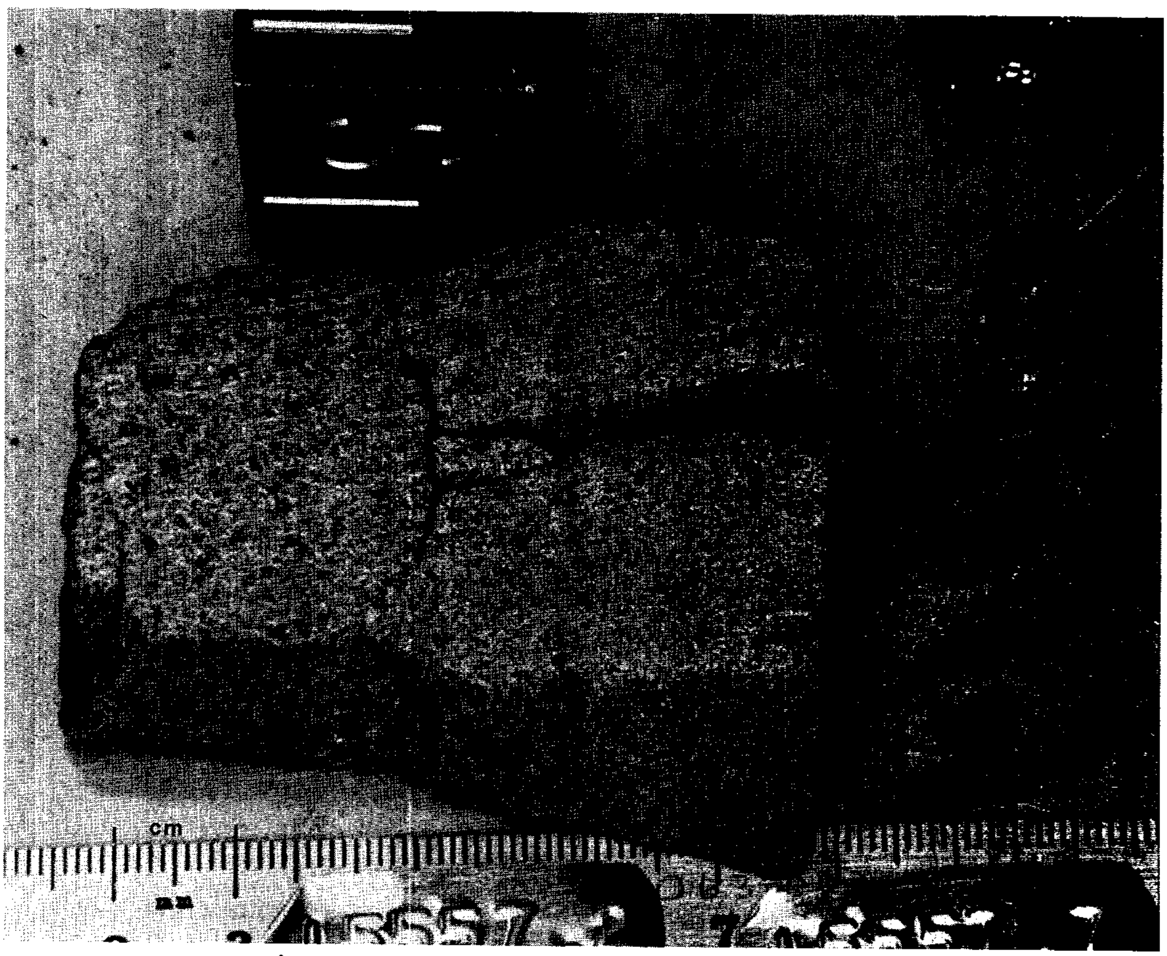


Figure 2. Part of sawn slab.

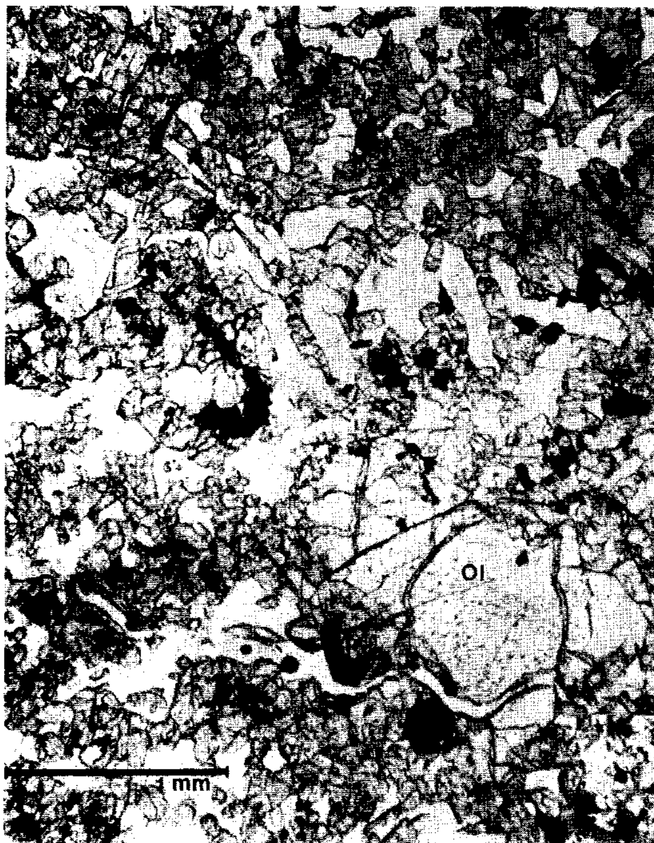


Fig. 3a

Fig. 3b

Figure 3. Photomicrographs of 15557,96 (a) transmitted light, general view showing olivine phenocrysts, granular pyroxenes ,and plagioclase; (b) same view as (a), crossed polarizers; (c) radial plagioclase growth; (d) same view as (c), crossed polarizers.

Fig. 3c

Fig. 3d

TABLE 15557-1

		,27	,40	,29	,42	,0	,41	,24	,24	,65	,66	,67	,47	,1
Wt. %	SiO2	45.74	45.06	45.01										
	TiO2	2.55	2.43	2.53										
	Al2O3	8.88	8.82	8.84										
	FeO	22.35	22.50	22.68										
	MgO	9.43	9.52	9.38										
	CaO	10.29	10.05	9.99										
	Na2O	0.27	0.34	0.25										
	K2O	0.05	0.04	0.045		0.0410								0.041
	P2O5	0.07	0.07	0.071										
(ppm)	Sc	37			43.5									
	V	185												
	Cr	3100	4600	4000	4700									
	Mn	2200	2250	2200										
	Co	60			50									
	Ni	49										56		
	Rb	<1		<2										
	Sr	105		96.4										
	Y	37		24.2										
	Zr	63		88.4										
	Nb	12		6.1										
	Hf				2.3									
	Ba	40		55										
	Th					0.45								0.44
	U					0.14		0.045	≤0.18	≤0.14	≤0.25			0.131
	Pb													
	La	22			5.77									
	Ce				16.1									
	Pr													
	Nd				12.1									
	Sm				4.36									
	Eu				1.10									
	Gd				5.8									
	Tb				0.98									
	Dy				6.43									
	Ho				1.3									
	Er				3.6									
	Tm													
	Yb	4.4			2.64									
	Lu				0.39									
	Li	6.9						5.6						
	Be													
	B													
	C						18c							
	N													
	S		650	900									673	
	F													
	Cl							8.4a						
	Br							0.041a						
	Cu	14												
	Zn				<4							1.3		
(ppb)	I							1.8						
	At													
	Ga	4900			3600							4000		
	Ge											14		
	As													
	Se													
	Mo													
	Tc													
	Ru													
	Rh													
	Pd													
	Ag	2200												
	Cd											2.0		
	In											0.50		
	Sn													
	Sb													
	Te							7.5						
	Cs				35									
	Ta													
	W													
	Re													
	Os								≥0.24	1.4	0.21			
	Ir											0.061		
	Pt													
	Au											0.084		
	Hg								5.4b	0.98b	1.4b			
	Tl													
	Bi													
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(7)	(7)	(7)	(8)	(9)	(10)

References for Table 15557-1

References and methods:

(1) Christian et al. (1972), Cuttitta et al. (1973); XRF and others
(2) Maxwell et al. (1972); Several
(3) Willis et al. (1972); XRF
(4) Helmke et al. (1973); INAA, RNAA
(5) O'Kelley et al. (1972); Gamma ray spectroscopy
(6) Kothari and Goel (1972, 1973) INAA
(7) Reed and Jovanovic (1972); NAA
(8) Baedecker et al. (1973); RNAA
(9) Thode and Rees (1972)
(10) Rancitelli et al. (1972); Gamma ray spectroscopy

Notes:

(a) Combined leach and residue.
(b) Data for <130° removal also tabulated.
(c) Weighted mean of four analyses: 17,17,21,19 ppm.

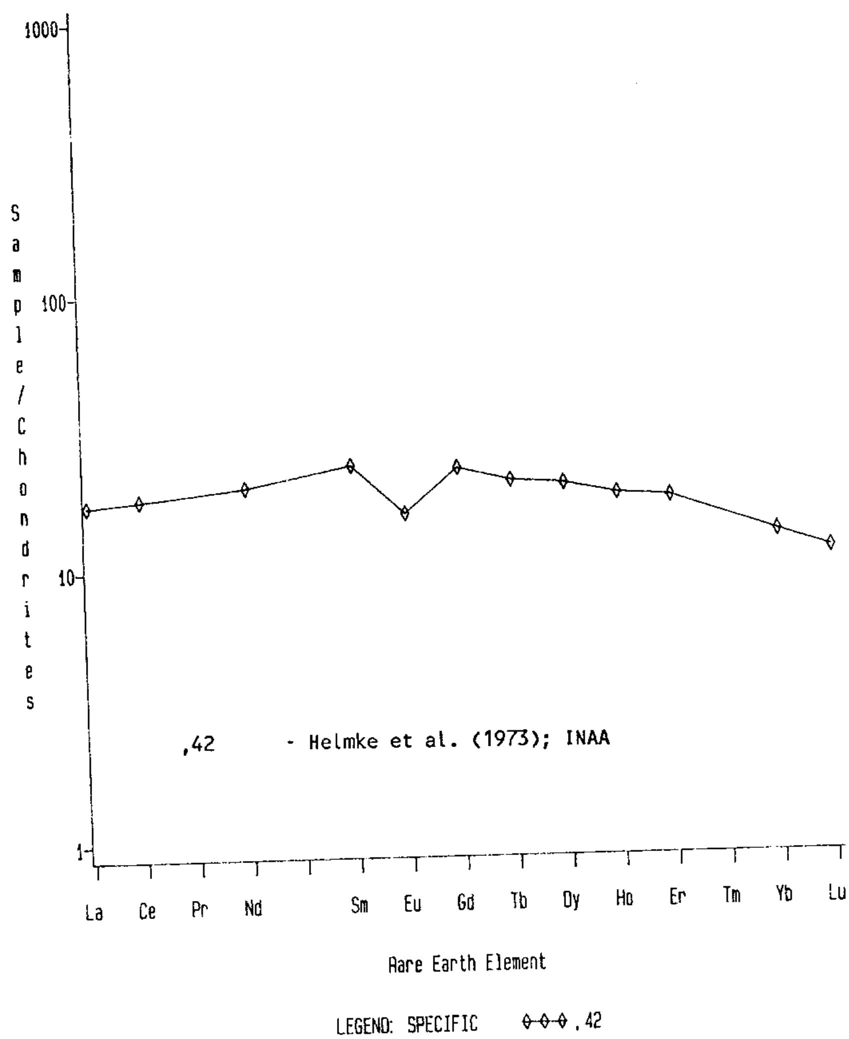


Figure 4. Rare earths in 15557.

data of Baedecker et al. (1973) is the average of two replicates, individually tabulated by those authors.

STABLE ISOTOPES: Thode and Rees (1972) found $\delta^{34}S$ of +0.39, similar to other basalts and different from regoliths.

EXPOSURE AND TRACKS: Eldridge et al. (1972) and Rancitelli et al. (1973) presented cosmogenic nuclide data, with similar results indicating a long surface age compared with the ^{26}Al half-life (Yokoyama et al. 1974). Bhandari et al. (1972, 1973) studied tracks in an interior and an exterior chip, finding track densities of 9 to 14 x 10^6 cm^{-2}. The data produce a "suntan" age of less than 1 m.y.

PROCESSING AND SUBDIVISIONS: A slab was cut from the sample and substantially dissected (Fig. 5). The two end pieces ,0 (1838 g) and ,1 (406 g) remain intact, the latter in remote storage. Of the other slab pieces, only ,4 (10.4 g); ,8 (26.4 g); and ,17 (32.5 g) are now more than 10 grams. A few small chips went into educational disks. All thin sections (,90 to ,96) were made from ,55, except ,76 which was made from ,36.

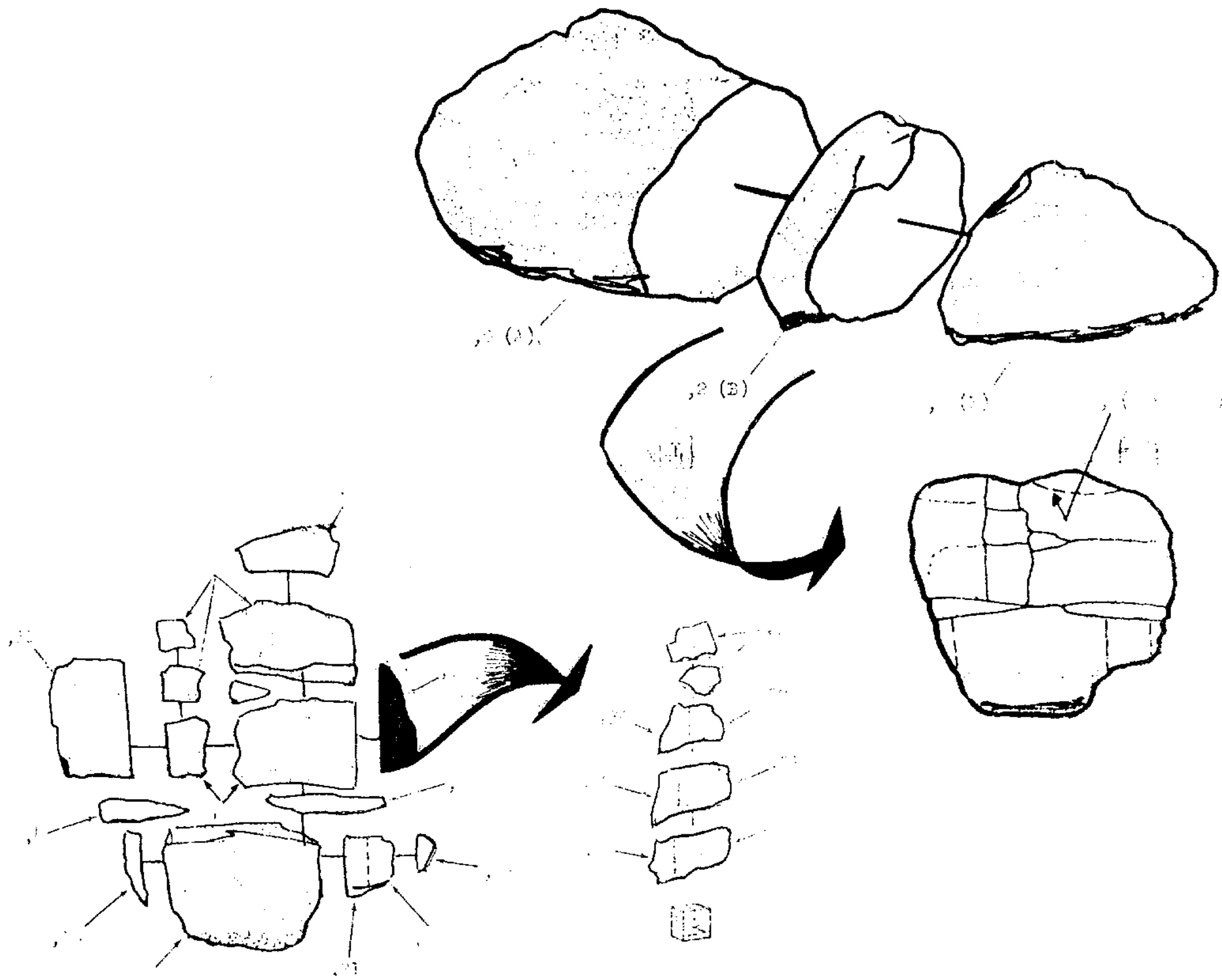


Figure 5. Subdivisions of 15557.

<u>15558 REGOLITH BRECCIA, GLASS-COATED ST. 9? 1333.0 g</u>

<u>INTRODUCTION</u>: 15558 is a regolith breccia derived mainly from mare components. It is gray, subangular, and has several large fractures (Fig. 1) and small areas of vesicular glass. A few zap pits occur on all surfaces. Its collection site is uncertain and its collection was not photographed, but it was probably collected at Station 9 (Baileyand Ulrich, 1975).

<u>PETROLOGY AND EXPERIMENTAL PETROLOGY</u>: 15558 contains mineral, lithic, and glass fragments and balls, set in a brown, glassy matrix (Fig. 2). Most of the lithic fragments are mare basalts with a range of textures, with a few Apollo 15 KREEP basalt fragments and only rare breccia fragments. Brown or colorless spheres are the predominant glass type.

Humphries <u>et al.</u> (1972) performed crystallization experiments on a synthetic 15558 composition ("Rille breccia" in Fig. 3). They found that plagioclase crystallized earlier than pigeonite and at a higher temperature than in the basalts: compared with bed-rock basalts, the breccia (and soil) is enriched in an Mg-norite or pyroxene-anorthosite component.

<u>CHEMISTRY</u>: Chemical analyses are listed in Table 1, and demonstrate similarities with Station 9 and 9A soils. According to Schonfeld (1975) the composition can be generated by a mixture of 33% brown breccia (other soil breccias), 45% olivine-normative basalt, 15% Apollo 15 KREEP, and 1.0% meteoritic and 0.4% granite components.

<u>RARE GASES</u>: Bogard and Nyquist (1972) reported Xe and Kr isotopic analyses for an interior chip, without specific discussion.

<u>PROCESSING AND SUBDIVISIONS</u>: Very little has been removed from 15558. A few small pieces, including ,4 and ,11 from which all the thin sections were made, were chipped. Subsequently the rock split along one of its fractures to produce ,21 (328 g), now in remote storage, and ,22 (944.2 g).

Figure 1. Macroscopic views of original sample showing fractures, glass patch, basaltic clasts, and zap pits.

Figure 2. Photomicrograph of breccia matrix of 15558,9, transmitted light.

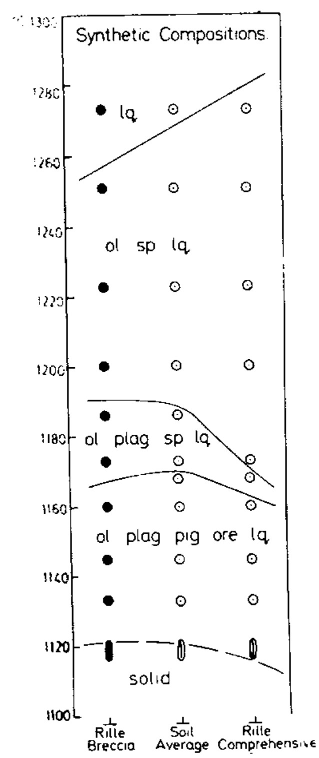


Figure 3. Experimental results of crystallization of a synthetic 15558 composition (black dots) and basalt and soil samples for comparison (Humphries et al., 1972).

TABLE 15558-1. Chemical analyses of bulk breccia

		,2	,2	
Wt. %	SiO2	46.31		
	TiO2	1.89		
	Al2O3	12.40		
	FeO	16.54		
	MgO	10.51		
	CaO	10.18		
	Na2O	0.42		
	K2O	0.19		0.205
	P2O5	0.21		
(ppm)	Sc			
	V			
	Cr	3500		
	Mn	1700		
	Co			
	Ni			
	Rb	5.3		
	Sr	123		
	Y	78		
	Zr	356		
	Nb	22		
	Hf			
	Ba			
	Th	3.6		3.42
	U			1.01
	Pb			
	La			
	Ce			
	Pr			
	Nd			
	Sm			
	Eu			
	Gd			
	Tb			
	Dy			
	Ho			
	Er			
	Tm			
	Yb			
	Lu			
	Li			
	Be			
	B			
	C		110	
	N			
	S	900		
	F			
	Cl			
	Br			
	Cu			
	Zn			
(ppb)	I			
	At			
	Ga			
	Ge			
	As			
	Se			
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag			
	Cd			
	In			
	Sn			
	Sb			
	Te			
	Cs			
	Ta			
	W			
	Re			
	Os			
	Ir			
	Pt			
	Au			
	Hg			
	Tl			
	Bi			
		(1)	(2)	(3)

References and methods:

(1) PET (1972)
(2) Moore et al. (1972, 1973)
(3) Keith et al. (1972)

15565 REGOLITH BRECCIA FRAGMENTS ST. 9A-LM 822.6 g

INTRODUCTION: 15565 is a collection of regolith breccia fragments which are the residue from Sample Collection Bag 2, which also contained three other loose rocks (15556-15558). Some of the fragments could have been part of 15558, which is also a regolith breccia. The Lunar Sample Information Catalog Apollo 15 (1972) states that there are 38 pieces. The pieces range from friable to coherent. Those studied contain mare basalt, non-mare (KREEP) basalt, breccia, and mineral fragments, and glasses, all in a glassy matrix. Only one piece has a surface glass.

The sampling location of 15565 has not been identified but appears to have been somewhere between 9 and LM inclusive, collected on EVA 3 (Sutton et al., 1972). The reason for this uncertainty is that at the end of EVA 3 grab samples were placed into the bag, including samples from under the seat of the rover.

PETROLOGY: No comprehensive description has been made, and individual pieces may not be closely related. However, all seem to be regolith breccias ranging from friable to coherent, with brown glassy matrices and containing mare basalt, KREEP basalt and other types of clastic materials (Fig. 1).

Piece ,1 was studied by Michel-Levy and Johann (1973) who found that it contained basaltic, vitrophyric, noritic, and glassy clasts (including green glass). They also found that it had a striated glassy coating in which the results of several events are superimposed, from original splashing to zap pits. Sewell et al. (1974) and Gleadow et al. (1974) also studied ,1, with the former reporting defocussed beam (energy dispersive) microprobe analyses of a feldspathic basalt clast, feldspathic recrystallized breccia, and several types of glasses, as well as analyses of mineral fragments and minerals in lithic clasts. These analyses demonstrate the diversity of materials in ,1 but emphasize the dominance of mare and KREEP materials.

Juan et al. (1972) found that piece ,7 was a welded breccia with 50% glassy matrix enclosing 20% lithic clasts (mare, non-mare, and older breccias), 19% mineral clasts (bytownite, pigeonite, olivine, ilmenite, and ulvospinel), 10% glass fragments, and 10% glass spherules. Engelhardt et al. (1972, 1973) found that piece ,8, consisted of soil components in a fragmental, perhaps partly glassy matrix. It contains both mare basalt and material described as "Apennine Front material." The dominant crystalline materials are, in order of abundance, intersertal noritic basalts (presumably KREEP basalts), ophitic basalts, noritic cumulates, and fragmental rocks. Glass and mineral fragments and glass spheres are present. McKay and Wentworth (1983) and McKay et al. (1984) found that piece ,11 was subporous with a low fracture porosity, had common agglutinates, common glass spheres, minor shock features, and an immature FMR index (I_s/FeO = 14; reported as 19 in Korotev, 1984 unpublished). Warren et al. (1981) analyzed minerals in the matrix of ,11; An_{78-92}, $Ol_{61.5-64.5}$, and disperse pyroxenes. They also studied an 8 x 7 mm anorthositic norite clast which is a pristine highlands lithology (see CHEMISTRY). It has grain sizes (cataclasized zones) up to 2 mm, with a uniform and uncomplicated mineralogy: An_{93-95}, $En_{78}Wo_3$, with about 25% pyroxene. Fe-metal grains contain 2.8 to 3.0% Co and less than 1% Ni. Housley et al. (1976) show an absorption spectrum for ,21 which strongly resembles lunar fines.

CHEMISTRY: Analyses of breccia samples were made by Blanchard (1973 unpublished) and Korotev (1984 unpublished) (Table 1). The analyses indicate that the two fragments (,3 and ,11) are similar to each other. However, their high incompatible element levels and low iron make them more similar to a few high-KREEP breccias scattered around the site than to either 15558 (from the same bag) or LM-ALSEP area regoliths. They are certainly not like Station 9 or 9A regoliths.

Cadenhead and Buergel (1973), Cadenhead et al. (1973), and Cadenhead and Stetter (1974) studied the outgassing properties of the piece ,3 (which they refer to as a "typical complex breccia"), with emphasis on the production of water vapor and planetary atmospheres. They concluded that water vapor could be produced by the interaction of solar wind hydrogen and sample oxygen.

Warren et al. (1981) analyzed a small anorthositic norite clast for major and trace elements (Table 2, Fig. 2). The low abundances of siderophile elements, as well as the metal composition (above) indicate that this is a pristine fragment, derived from a lunar highlands igneous cumulate.

PROCESSING AND SUBDIVISIONS: Sample processing documentation is complicated by some sample number changes from a collection of separate numbers to the unified group 15565, and by erroneous numbering on the documentation of sample splitting diagrams. The individual pieces appear to be ,1 to ,15 and ,19 to ,43, i.e., 40 pieces. More than half of the sample mass is taken up with ,1 (80.6 g); ,2 (121.3 g); ,3 (126.8 g); ,4 (137.7 g); and ,5 (23.1 g). A list of thin section derivations is given in Table 3.

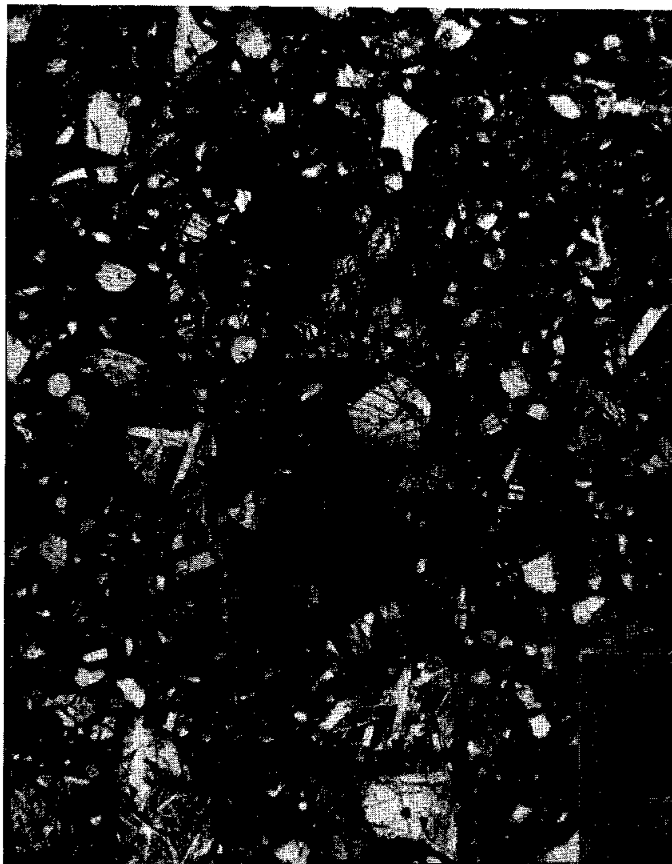


Fig. 1a

Fig. 1b

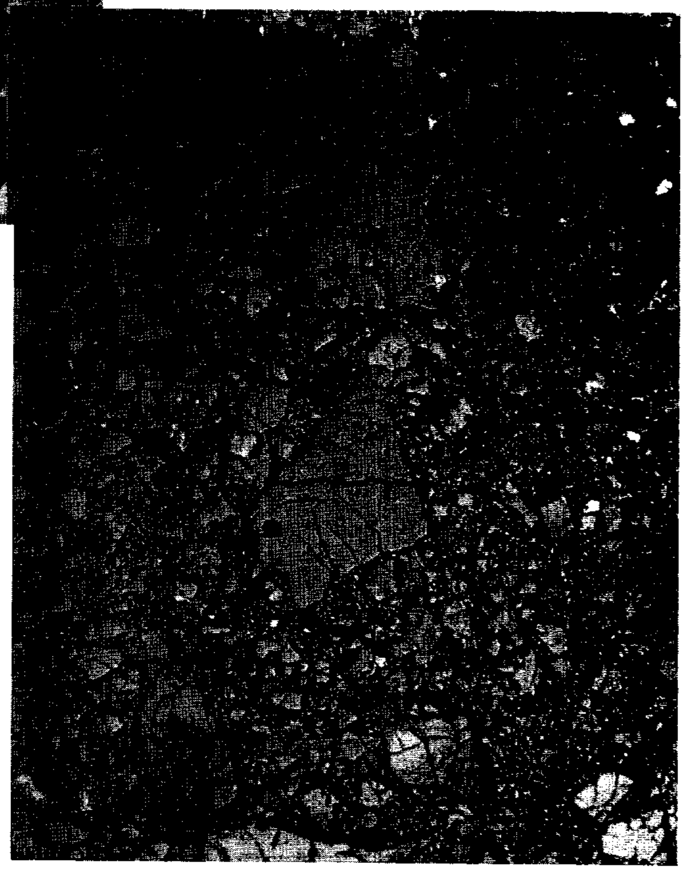


Figure 1. A,B, General matrix of 15565,87, a piece of ,1. A) plane light B) same view, reflected light, showing porosity. Clasts include KREEP basalts (bottom), pyroxene vitrophyre (top center), and glass (center). Width 2 mm. C,D, clasts in 15565,86, pieces of ,10. C) pyroxene porphyritic mare basalt, plane light. D) KREEP basalt, plane light. Widths 2 mm.

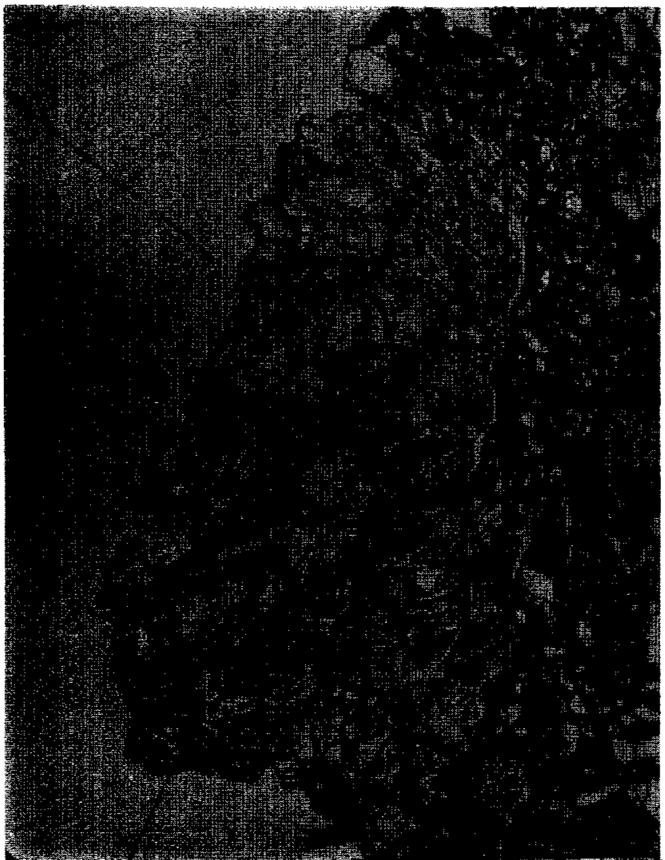


Fig. 1c

Fig. 1d

TABLE 15565-1. Chemical analyses of breccia fragments

		,3	,117
Wt %	SiO2		
	TiO2	1.91	
	Al2O3	13.3	14.1
	FeO	13.5	
	MgO	9.2	
	CaO	10.5	9.6
	Na2O	0.58	0.58
	K2O		
	P2O5		
(ppm)	Sc	28.1	29.0
	V		
	Cr	2890	2600
	Mn	1400	
	Co	32.7	33.2
	Ni	95	111
	Rb		
	Sr	100	150
	Y		
	Zr		620
	Nb		
	Hf	17.8	14.6
	Ba	760	385
	Th		6.6
	U		1.72
	Pb		
	La	42.9	40.6
	Ce	103	105
	Pr		
	Nd	68	61
	Sm	20.1	18.4
	Eu	1.85	1.74
	Gd		
	Tb	4.08	3.63
	Dy		
	Ho		
	Er		
	Tm		
	Yb	14.4	13.5
	Lu	1.99	1.72
	Li		
	Be		
	B		
	C		
	N		
	S		
	F		
	Cl		
	Br		
	Cu		
	Zn		
(ppb)	I		
	At		
	Ga		
	Ge		
	As		
	Se		
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd		
	In		
	Sn		
	Sb		
	Te		
	Cs	430	360
	Ta		1790
	W		
	Re		
	Os		
	Ir		<3
	Pt		
	Au		<4
	Hg		
	Tl		
	Bi		
		(1)	(2)

References and methods:

(1) Blanchard (1973 unpublished); INAA
(2) Korotev (1984 unpublished); INAA

Figure 2. Rare earths.

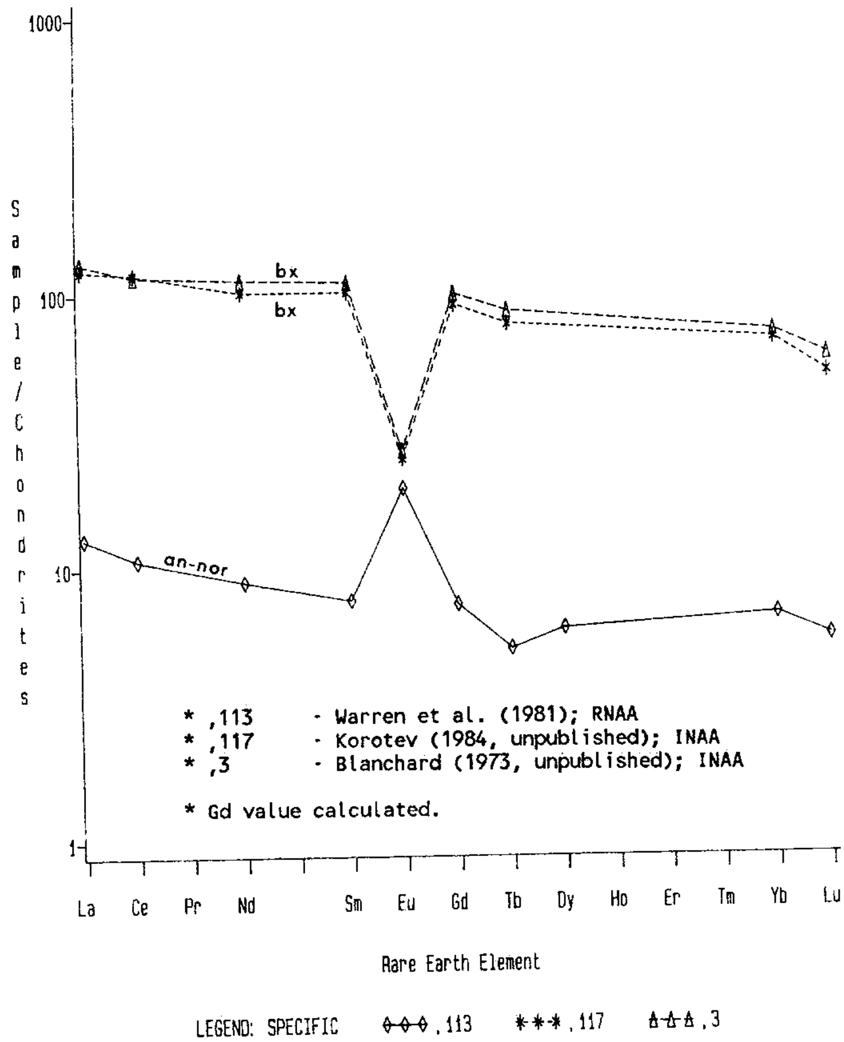


TABLE 15565-2. Chemical analysis of a pristine highlands clast

		,113
Wt %	SiO2	48.15
	TiO2	0.10
	Al2O3	24.9
	FeO	4.1
	MgO	8.8
	CaO	13.3
	Na2O	0.425
	K2O	0.060
	P2O5	
(ppm)	Sc	6.7
	V	
	Cr	1510
	Mn	573
	Co	20
	Ni	8.8
	Rb	
	Sr	
	Y	
	Zr	<260
	Nb	
	Hf	0.69
	Ba	68
	Th	0.43
	U	0.31
	Pb	
	La	4.25
	Ce	9.5
	Pr	
	Nd	5.4
	Sm	1.38
	Eu	1.36
	Gd	
	Tb	0.24
	Dy	1.9
	Ho	
	Er	
	Tm	
	Yb	1.35
	Lu	0.19
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	1.68
(ppb)	I	
	At	
	Ga	
	Ge	18.1
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	
	W	
	Re	0.0071
	Os	
	Ir	<0.03
	Pt	
	Au	0.069
	Hg	
	Tl	
	Bi	
		(1)

TABLE 15565-3. Thin section derivations

Ultimate Parent Piece	Potted Butt	Thin Sections or Probe Mount
,1	,52	,83; ,87; ,92; ,95; ,96; ,98
,7	,59	,84; ,93
,8	,65	,85; ,94
,10	,75	,82; ,86
,11	,56	,57
,15	(,15)	,16; ,17; ,18; ,44; ,45; ,46; ,47; ,48; ,80; ,81

Reference and method:

(1) Warren et al. (1981); RNAA, fused bead.

15595 PORPHYRITIC SPHERULITIC QUARTZ-NORMATIVE MARE BASALT ST. 9A 237.6 g

INTRODUCTION: 15595 is fine-grained, porphyritic mare basalt with conspicuously irregularly distributed vugs (Fig. 1). Pigeonite phenocrysts are set in a spherulitic, almost vitrophyric groundmass. Both phenocrysts and groundmass are finer-grained than in 15596, chipped from the same boulder. Its chemistry is typical of Apollo 15 quartz-normative mare basalts. The sample is olive gray to olive black, angular, and tough. The broken surface is hackly, the others are smoothed to irregular and have zap pits. The vugs make up 30% of the fresh surface.

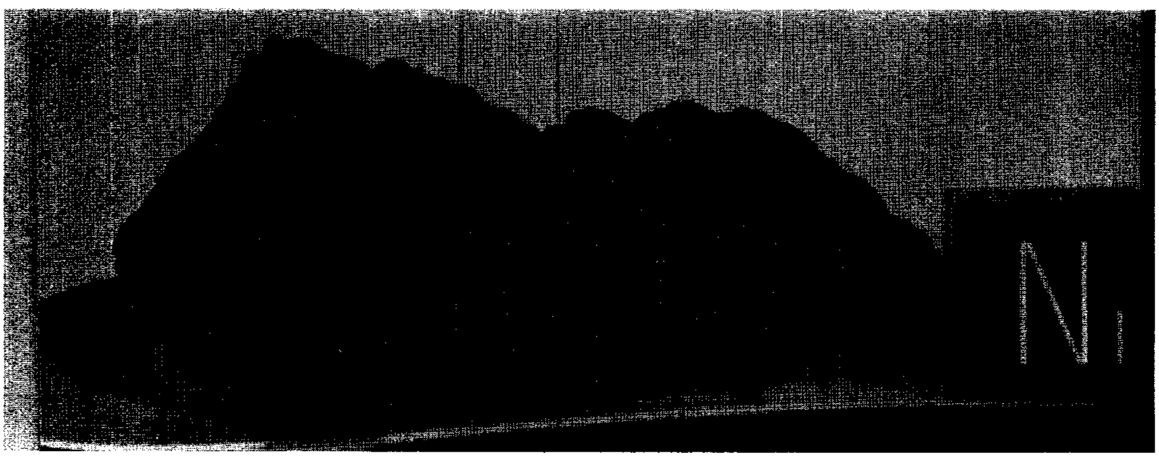


Figure 1. Broken-off face of 15595. S-71-46706

15595 was chipped from a 2 m x 50 cm boulder about 8 m east of the rim of Hadley Rille (Fig. 2). 15596 was chipped from the same boulder. The boulder appeared to be typical of those in the vicinity, which is strewn with boulders, cobbles, and pebbles. The boulder was described as bedrock by the astronauts; the boulder is probably not in situ bedrock, but is also probably very nearly in place.

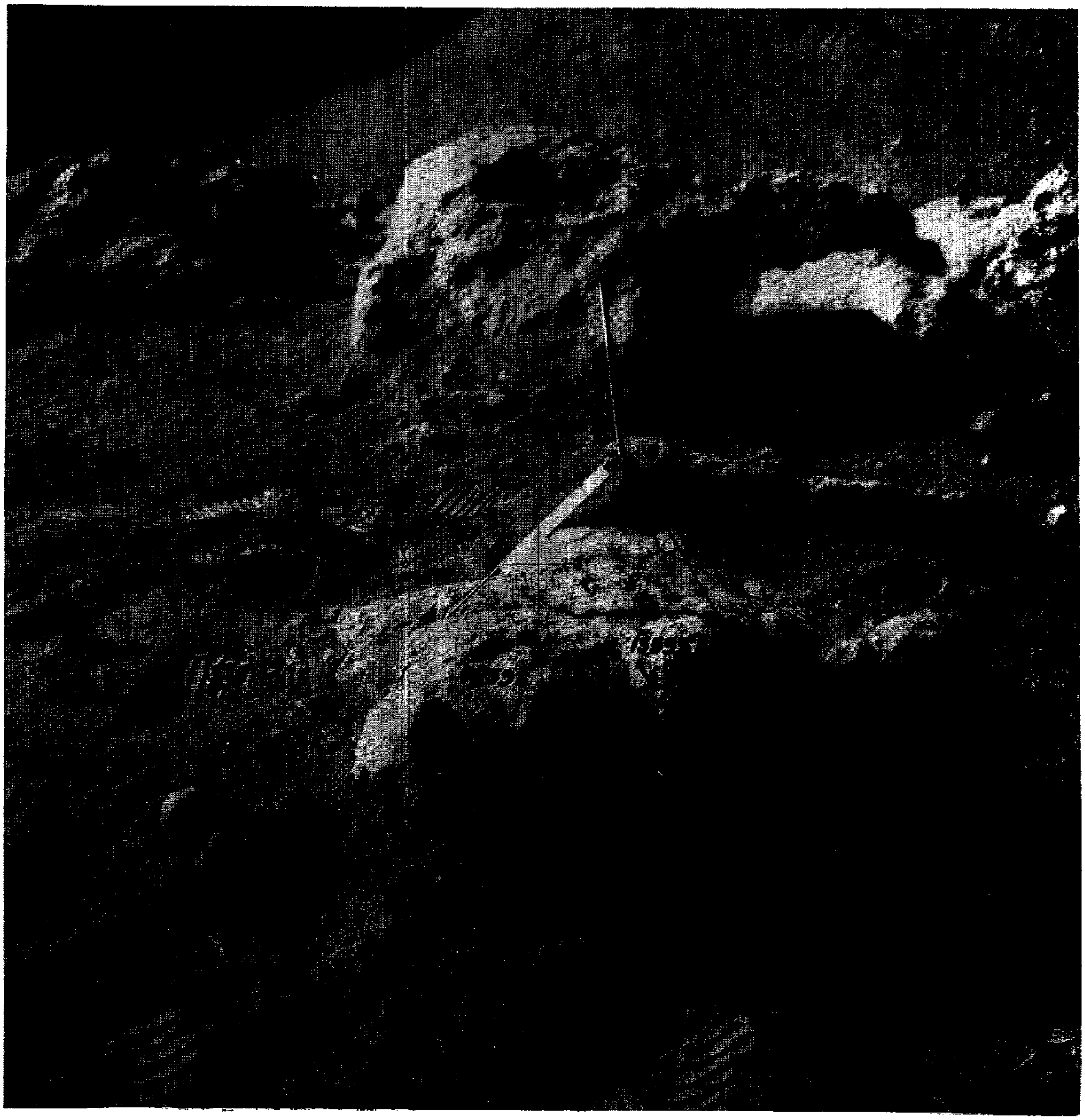


Figure 2. Sampling of 15595 and 15596. AS15-82-11143

PETROLOGY: 15595 consists of small pigeonite phenocrysts in a spherulitic groundmass of plagioclase, pyroxene, and glass (Fig. 3). Most of the pigeonite phenocrysts are less than 2 mm long in thin section, but a few reach about 5 mm. They are zoned, with sharply banded rims of augite. Many are hollow (groundmass-filled) and a few have simple twins. Irregularly-shaped vugs are present, and the euhedral phenocrysts project into them. The groundmass consists of fan spherulites of pyroxene (mainly augite), and plagioclase laths. Grove and Walker (1977) gave a mode with 52% phenocrysts and 48% groundmass, Papike et al. (1976) one with 48.1% pyroxenes, 51.6% groundmass, and 0.3% opaque minerals. The sample has more phenocryst volume than the isochemical but more slowly-cooled 15596.

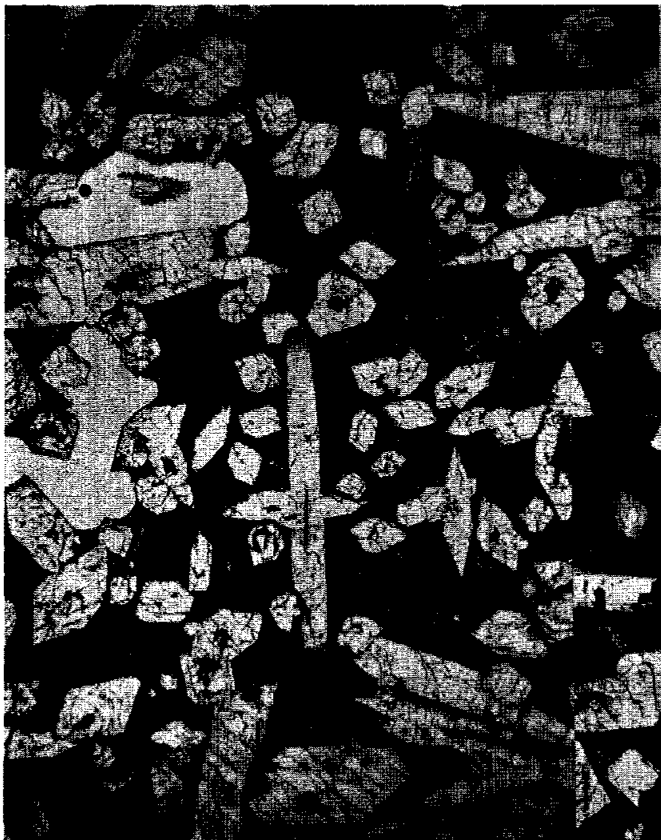


Fig. 3a

Fig. 3b

Figure 3. Photomicrographs of 15595,31. Width about 3 mm. a) transmitted light; b) crossed polarizers.

Sato (1973) measured fO_2 with temperature variation (1000°C to 1200°C) for a sample of 15595 (Fig. 4). The data form a smooth curve similar to that for Apollo 12 basalts.

Cooling history: Lofgren *et al*. (1975), in a comparison of natural textures with those produced in dynamic crystallization experiments (known linear cooling rates) deduced a cooling rate of 2 to 5°C/hr for the phenocrysts and about 30°C/hr for the groundmass, i.e., slower than 15597, and faster than 15596. They depicted a cross-section of a pyroxene phenocryst, similar to one grown in the 2.5°C/hr cooling rate experiment. Grove and Walker (1977), in a similar but more sophisticated study, inferred an early cooling rate of about 10°C/hr from the pyroxene nucleation density, an integrated rate of about 3.75°C/hr from pyroxene sizes, and a late-stage cooling rate of about 60°C/hr from the plagioclase sizes. They inferred final crystallization about 12 cm from a conductive boundary. Essentially slow initial cooling was followed by rapid cooling.

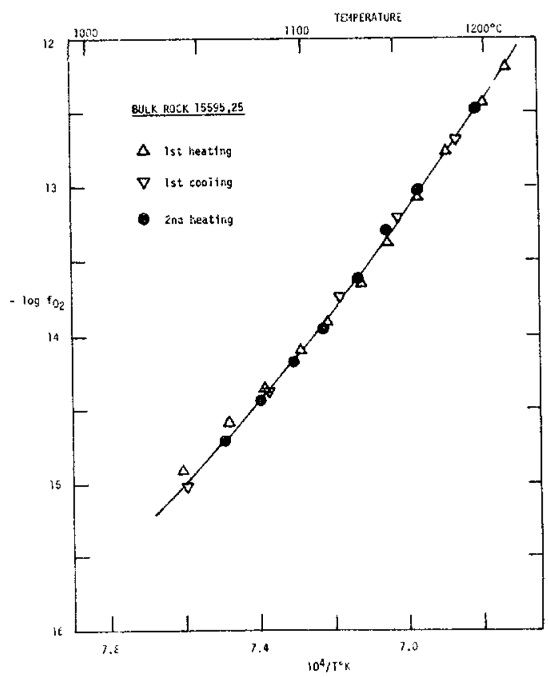


Figure 4. Measured fO_2 as a function of temperature (Sato *et al*., 1973).

CHEMISTRY: Chemical analyses are listed in Table 1, and the rare earths plotted in Figure 5. The analyses are of a typical Apollo 15 quartz-normative basalt, very similar to 15597, and are reasonably consistent. Compston et al. (1972) noted a systematic difference between their Rb abundances determined by x-ray fluorescence and the more reliable isotope dilution method.

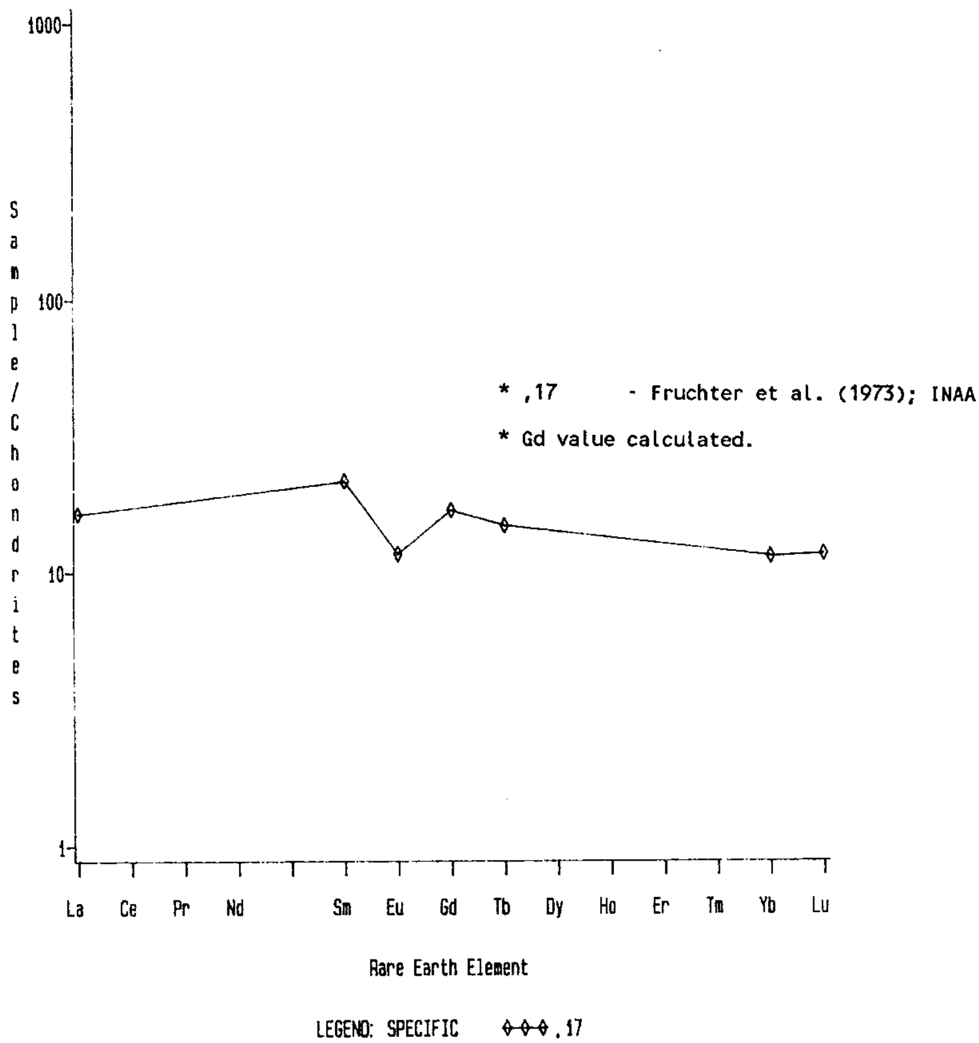


Figure 5. Rare earths in 15595.

TABLE 15595-1. Bulk rock chemical analyses

		,17		,15		,16	,5
Wt %	SiO2		48.07				
	TiO2	1.62	1.77				
	Al2O3	9.1	9.06				
	FeO	18.96	20.23				
	MgO		9.21				
	CaO		10.52				
	Na2O	0.286	0.35				
	K2O		0.05				
	P2O5		0.07				
(ppm)	Sc	45					
	V						
	Cr	3450	3560				
	Mn		2330				
	Co	42					
	Ni						
	Rb		0.72			0.90	
	Sr		103.8			99.4	
	Y		26				
	Zr		94				
	Nb		8				
	Hf	2.0					
	Ba						
	Th						
	U				0.196		0.208
	Pb						
	La	5.4					
	Ce						
	Pr						
	Nd						
	Sm	3.9					
	Eu	0.81					
	Gd						
	Tb	0.7					
	Dy						
	Ho						
	Er						
	Tm						
	Yb	2.3					
	Lu	0.40					
	Li						
	Be						
	B						
	C			18			
	N						
	S		500				
	F						
	Cl						
	Br						
	Cu						
	Zn						
(ppb)	I						
	At						
	Ga		2800				
	Ge						
	As						
	Se						
	Mo						
	Tc						
	Ru						
	Rh						
	Pd						
	Ag						
	Cd						
	In						
	Sn						
	Sb						
	Te						
	Cs						
	Ta	350					
	W						
	Re						
	Os						
	Ir						
	Pt						
	Au						
	Hg						
	Tl						
	Bi						
		(1)	(2)	(3)	(4)	(5)	(6)

References and methods:

(1) Fruchter et al. (1973); INAA
(2) Chappell and Green (1973); XRF
(3) Moore et al. (1973); combustion, gas chromatography
(4) Graf et al. (1973); tracks
(5) Compston et al. (1972); ID/MS
(6) Drozd et al. (1974), Behrmann et al. (1972);

RADIOGENIC ISOTOPES: Compston et al. (1972) presented Rb-Sr isotopic data for a whole-rock sample (Table 2). Assuming an age of 3.3 b.y. gives an initial $^{87}Sr/^{86}Sr$ of 0.69951 ($\lambda = 1.39 \times 10^{-11}$ yr^{-1}), indistinguishable from other Apollo 15 mare basalts.

TABLE 15595-2. Rb-Sr isotopic data (Compston et al., 1972)

Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
0.9 (ID)	99.4 (ID)	0.0261	0.70074 ± 10
0.72 (XRF)	103.8 (XRF)		0.70055 ± 10*

* unspiked sample

RARE GASES, TRACKS, AND EXPOSURE: Behrmann et al. (1972) reported abundances of ^{3}He, ^{21}Ne, ^{38}Ar, and spallation Kr and Xe data. The ^{2}Ne, ^{38}Ar, and ^{81}Kr-Kr exposure ages are similar (112, 105, and 110 ± 17 m.y. respectively) and indicate a simple exposure history. ^{3}He gives a much lower exposure age of 6.5 m.y. Spallation Kr and Xe show a fairly hard cosmic ray isotopic spectrum, suggesting a single-step transition from a well-shielded to an unshielded position, such as might occur in a major rock slide. Fission ^{132}Xe is about the amount expected for a 3.5 ± 0.3 b.y. old rock with its U abundance. Drozd et al. (1974) reported Kr isotopic data, and total Kr at 1100°C. They gave uncertanties for the Behrmann et al. (1972) exposure ages of 26(^{21}Ne), 34(^{38}Ar), and 9(^{81}Kr-Kr) m.y. Pepin et al. (1974) noted that 15595 was the only sample which gave concordant exposure ages using the Bogard et al. (1972) production rates and discordant ages using the production rate derived from the drill core, raising questions about such production rates.

Behrmann et al. (1972) found that track densities in large pyroxene crystals in a surface chip are highly zoned and anonamously low considering the 100 m.y. rare gas exposure age and inferred simple exposure history. The tracks suggest that the boulder was recently chipped on the centimeter scale or that the thermal stability of tracks in pyroxene is low.

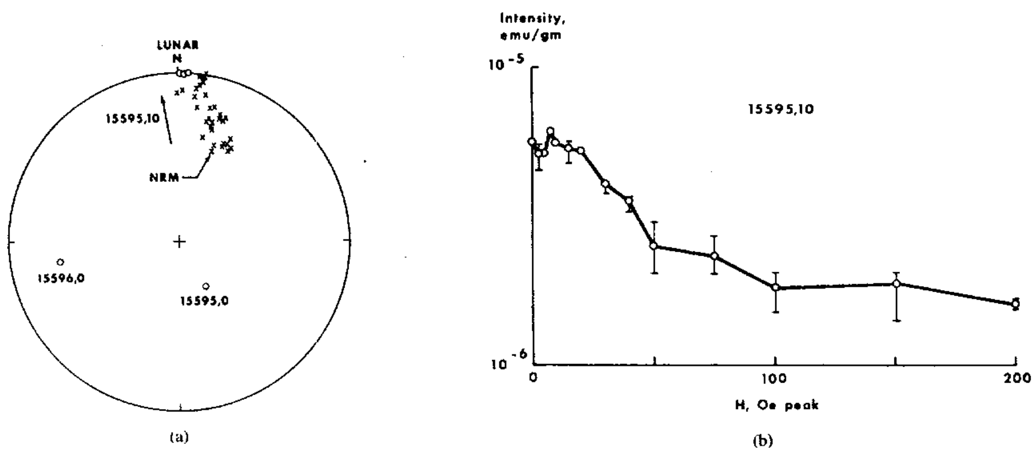


Figure 6. a) Direction of magnetization in lunar coordinates of three samples from the same boulder. Only 15595,10 was allowed to be demagnetized--the arrow shows change in direction. b) change in intensity during AF demagnetization of 15595,10.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) measured the natural remanent magnetism (NRM) and magnetic properties of two chips of 15595, and also the NRM of bulk sample 15596, from the same boulder (Fig. 6). One chip of 15595 was oriented, the other was not. The NRM of one chip was 1.7×10^{-6}, of the other about 1×10^{-5} emu/g. The directions are random and thus unlikely to be of lunar origin. On demagnetization a stable direction was found, and should be the direction of lunar magnetism if the boulder was actually bedrock, i.e., the direction was almost due north and horizontal. An inflection (Curie point) in the hysteresis loops at about 200°C indicates a metal with 30-40% Ni, and one at about 750°C indicates normal, low-Ni iron metal (Fig. 7). The magnetic properties indicate 0.060 of Fe° equivalent and 17.2% of Fe^{2+} equivalent. The magnetic properties are listed in Table 3. Brecher (1975, 1976) noted the inhomogeneity of direction of NRM in 15595 in her study proposing textural remanent magnetization of lunar samples.

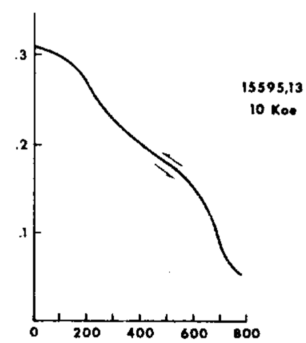


Figure 7. Magnetization as a function of temperature. Horizontal axis in °C, vertical axis in emu/g.

PROCESSING AND SUBDIVISIONS: 15595 was sawn to produce a slab through the interior (Fig. 8). ,1 broke off before its cut was completed, and the remainder which was cut was labelled ,2 (17.3 g). ,1 had only 0.16 g of its "W" end (,11) chipped off; it is now 76.63 g and is in remote storage in Brooks. ,0 has not been further subdivided and is now 98.37 g. The slab piece ,3 was extensively subdivided and allocated (Fig. 8). All the thin sections, ,30 to ,39, were made from chip ,21.

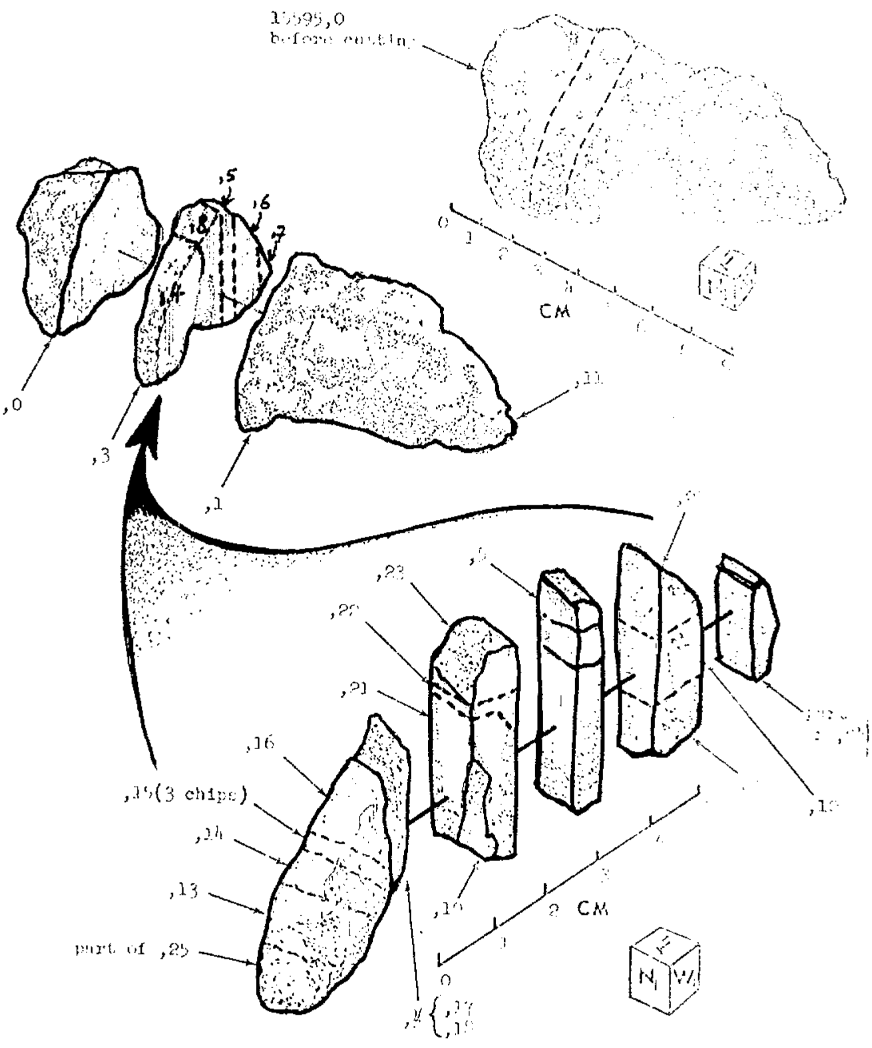


Figure 8. Cutting of 15595.

TABLE 15595-3. Magnetic properties (Pearce et al., 1973)

Js emu/g	Xp emu/g Oe	Xo emu/g Oe	Jrs/Js --	Hc Oe	Js/Xo K Oe
0.13	37.4	0.48	0.006	33.0	2.7

15596 PORPHYRITIC SPHERULITIC QUARTZ-NORMATIVE MARE BASALT ST. 9A 224.8 g

INTRODUCTION: 15596 is a porphyritic mare basalt with conspicuously irregularly distributed vugs (Fig. 1). Large pigeonite phenocrysts are set in a spherulitic groundmass. Both phenocrysts and groundmass are coarser-grained than in 15595, chipped from the same boulder. Its chemistry is typical of Apollo 15 quartz-normative mare basalts. The sample is medium olive gray, blocky, angular, and tough. The broken surface is rough, the others irregular with many zap pits. The vugs make up about 15% of the fresh surface. The pigeonites have yellow-green cores and dark brown rims.

15596 was chipped, with 15595, from a 2 m x 50 cm boulder about 8 m east of the rim of Hadley Rille (See Fig. 15595-2).

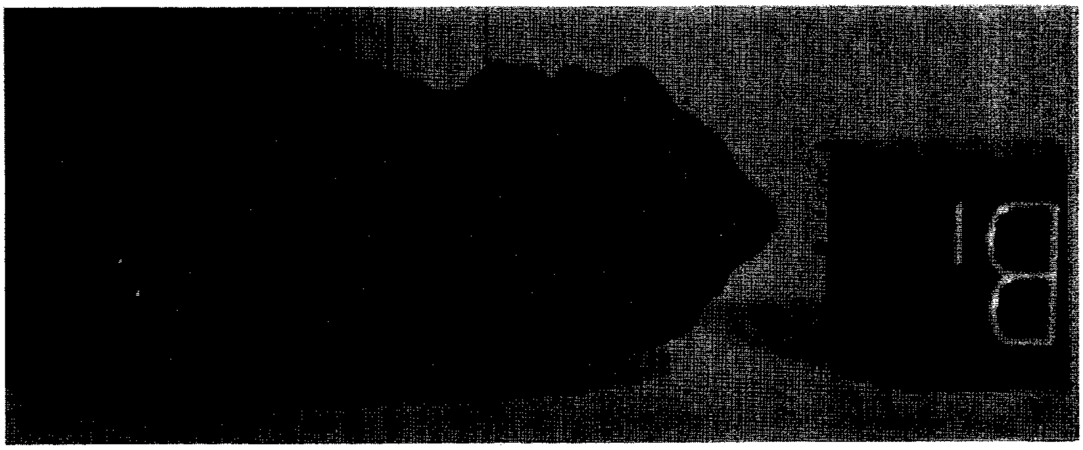


Figure 1. Broken face of 15596. S-71-46811

PETROLOGY: 15596 consists of large pigeonite phenocrysts in a fan spherulitic groundmass of plagioclase, pyroxene, and opaque minerals (Fig. 2). The pigeonites are commonly 6 or 7 mm long in thin sections. Some are twinned, and several are hollow (filled with spherulitic groundmass). They are zoned, with sharply bounded rims of augite. The groundmass contains opaque minerals and vugs. Brown et al. (1972) gave a mode with 41% phenocrysts, and a groundmass comprising 32% clinopyroxene, 20% plagioclase (An_{83-87}), and 6% opaque minerals. They also observed rare zoned olivines (Fo_{66-37}), and Cr-spinel microphenocrysts. Grove and Walker (1977) reported a mode of 40.9% phenocrysts, 58.9% groundmass, and 0.2% opaques (not including those in the groundmass). Brown et al. (1972) reported that the zoned Mg-pigeonite cores have Al:Ti of 7 to 10 and the augite mantles have Al:Ti of 5 to 7. The groundmass pyroxenes have a chemistry discontinuous with the mantles and approach pyroxferroite in composition. Engelhardt (1979) noted that ilmenite crystallization started after plagioclase crystallization started, and ended before pyroxene crystallization ended.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15596,12, showing pigeonite phenocrysts with their augite rims, hollow cross-sections, vug, and spherulitic groundmass containing opaques. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

Cooling history: Lofgren et al. (1975), in a comparison of natural textures with those produced in dynamic crystallization experiments (known linear cooling rates) deduced a cooling rate of 2 to 5°C/hr for the phenocrysts, within the same range as 15595 but actually slower, and 10 to 30°C/hr for the groundmass, and also slower than 15595. In a similar but more sophisticated study, Grove and Walker (1977) inferred an early crystallization rate of 3.75°C/hr from the pyroxene nucleation density, a integrated rate of 1.75°C/hr from the total pyroxene phenocryst size, and a late-stage rate of 13°C/hr from the plagioclase sizes. They inferred final crystallization about 24 cm from a conductive boundary.

CHEMISTRY: Rhodes and Blanchard (1983) reported that they had made a major and trace element analysis of a 2 g sample of bulk rock which is similar to that of average Apollo 15 quartz-normative mare basalts.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) reported on natural remanent magnetic intensity and direction for the bulk rock. The intensity was 6.4×10^{-6} emu/g, and the direction differs from those of 15595 splits, chips from the same boulder (see Fig. 15595-6). Hence the NRM is probably not of lunar origin.

PROCESSING AND SUBDIVISIONS: Chip ,1 was taken from the "S-B" edge, made into a potted butt, and partly used to make thin sections ,12 through ,16. A small chip ,2 was removed at the same time. In 1982, further chipping produced samples for the chemical analysis. ,0 is now 213.9 g.

15597 VITROPHYRIC QUARTZ-NORMATIVE MARE BASALT ST. 9A 145.7 g

INTRODUCTION: 15597 is a fine-grained, pyroxene vitrophyric mare basalt with conspicuous small phenocrysts and vugs (Fig. 1). It is the most rapidly cooled of the larger samples of this basalt type and is widely believed to be unaffected by surface fractionation. Its chemistry is that of an average A15 quartz-normative basalt and has been used in crystallization experiments because it better represents a melt composition than other samples. The sample is medium dark gray, slabby with two flat faces, angular, and tough. It appears to be homogeneous, with yellow-green prismatic phenocrysts (weathering white) and a black groundmass. PET (Lunar Sample Information Catalog Apollo 15, 1972) recognized a lamination of some phenocrysts which has not been recognized in thin section. The vugs are small and about 1% of the total volume. Zap pits occur on most faces but are not dense.

15597 was collected in the vicinity of the boulder from which 15595 and 15596 were chipped, but has not been recognized in surface photographs. Its orientation is therefore unknown.

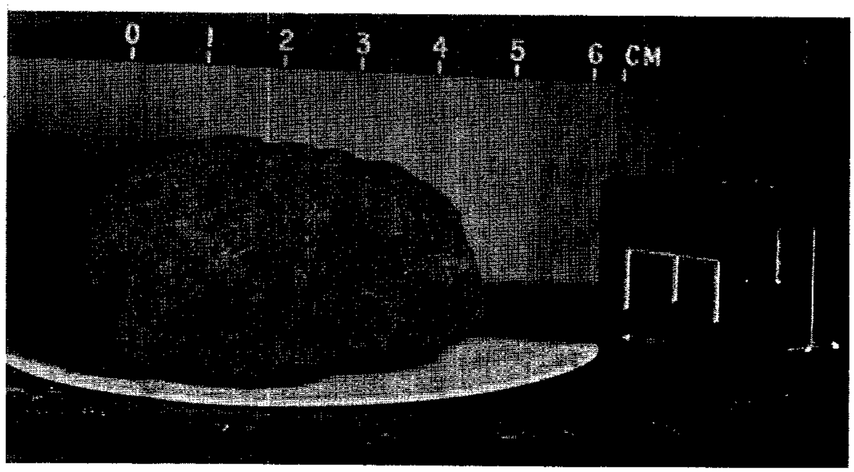


Figure 1. Macroscopic view of 15597. Sparse pigeonite phenocrysts and small vugs are visible. S-71-49940

PETROLOGY: 15597 consists of numerous, tiny pigeonite phenocrysts, commonly hollow, in a groundmass of opaque glass. Small vesicles are ubiquitous and pigeonite megacrysts are rare (Fig. 2). Published modes (Table 1) have high total phenocryst percentages. Drever et al. (1973) found no preferred orientation except an example of a radial arrangement of acicular phenocrysts. Donaldson et al. (1977) noted extreme discordancies in the sizes of phenocrysts and their uniform distribution indicating that they are not aggregations.

A comprehensive petrographic and microprobe study was given by Weigand (1972) and Weigand and Hollister (1973), with tabulated microprobe analyses. They noted that acicular pyroxene phenocrysts are 0.5 to 1.5 mm x 0.04 to 0.15 mm. Cross sections show prominent (100) faces and subordinate (010) faces. Simple twinning is common, parallel to (100). Phenocrysts commonly have a glass core, and some length sections exhibit a "swallow-tail." Both cores and the sharply bounded rims have extreme chemical zonation (Fig. 3) as also shown by the data of Grove and Bence (1977) and Drever et al. (1972) (also shown in Fig. 3). The first pyroxene to crystallize was $En_{70}Wo_4$, identified as pigeonite on low 2V values (less than 20°). The composition falls well within the range of lunar orthopyroxenes, and the pigeonite is probably metastable. This "inner" pigeonite zones out to about $En_{52}Wo_{15}$ ("outer" pigeonite), then is epitaxially grown with "inner" augite, $En_{40}Wo_{30}$, which is zoned extremely to $En_{10}Wo_{32}$ ("outer" augite). Minor sector-zoning was observed. Ti and Al are partitioned into inner augites relative to outer pigeonites (Fig. 3). Al_2O_3 and TiO_2 rise to extreme values at the augite rim (13.8% and 3.5% respectively), and Cr_2O_3 falls to very low abundances (~0.03%). A single large megacryst is remarkably homogeneous with only the outer 5% of the pigeonite zoned. Chemical evidence suggests however that it was not the first to nucleate and grow. Groundmass crystals are various skeletal ferroaugites with compositions similar to edges of augite rims. The pyroxene zoning patterns are explained by the crystallization of pyroxene in the absence of co-crystallizing plagioclase or Ti-rich minerals. Chromite is minor and has an irregular distribution. It has a bimodal size distribution. The larger (about 100 microns) are typically clustered, euhedral, and commonly partially enclosed in phenocrysts. The smaller (about 25 microns) are in phenocrysts or in groundmass. The chromites are Al-Mg-chromites grading into Ti-Mg-aluminian chromites (Fig. 4). In contact with glass matrix they are rimmed (1 to 2 microns) by ulvospinel. Weigand and Hollister (1973) tabulated chromite analyses and discussed the zoning trends. Nickel-iron grains are ubiquitous but of minor abundance. Ni varies from 4 to 7%, and Co from 1 to 3%. At least the large chromites appear to have completed crystallization prior to pyroxene nucleation, and metal grains to have at least nucleated before pyroxene nucleation. The glass groundmass of 15597 has an unusual composition (Table 2), with extremely low MgO. Gradients adjacent to crystals suggest that the rate of crystal growth exceeded diffusion rates in the melt. The overall sequence of crystallization for 15597 as inferred by Weigand and Hollister (1973) is shown in Figure 5.

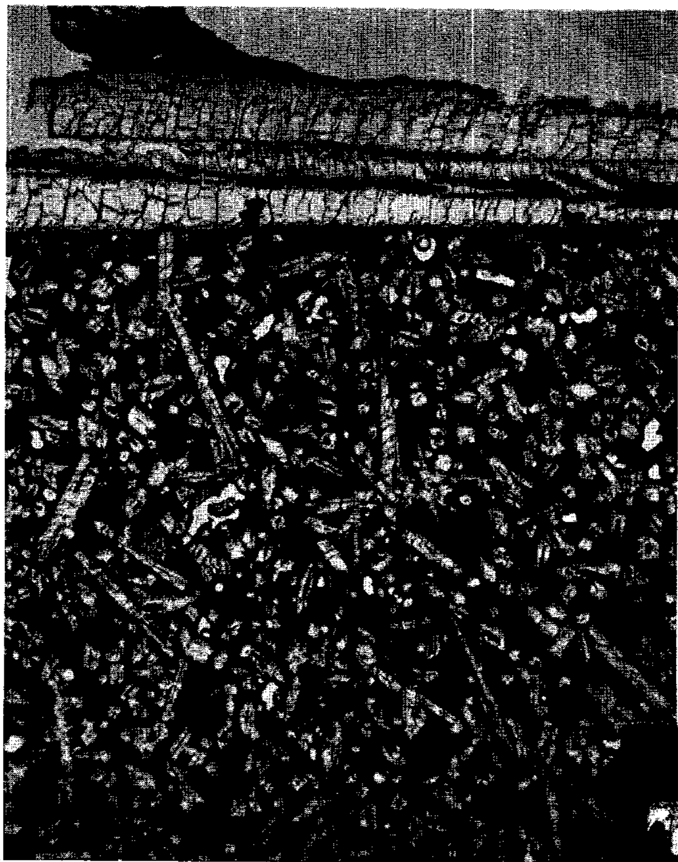


Fig. 2a

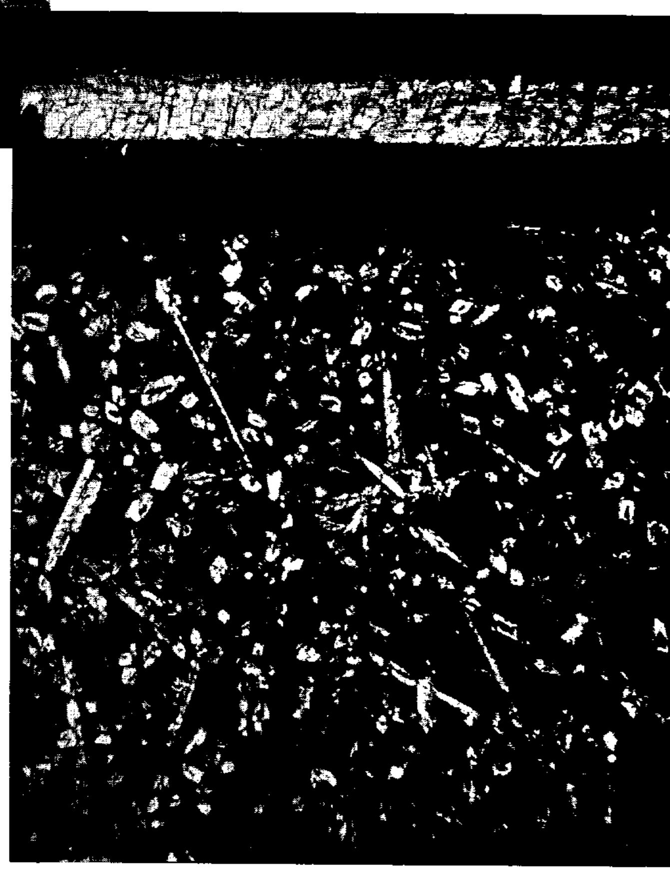


Fig. 2b

Figure 2. Photomicrographs of 15597,12, showing small acicular phenocrysts, opaque glassy groundmass, small vesicles, and part of a twinned megacryst. a) transmitted light; b) crossed polarizers.

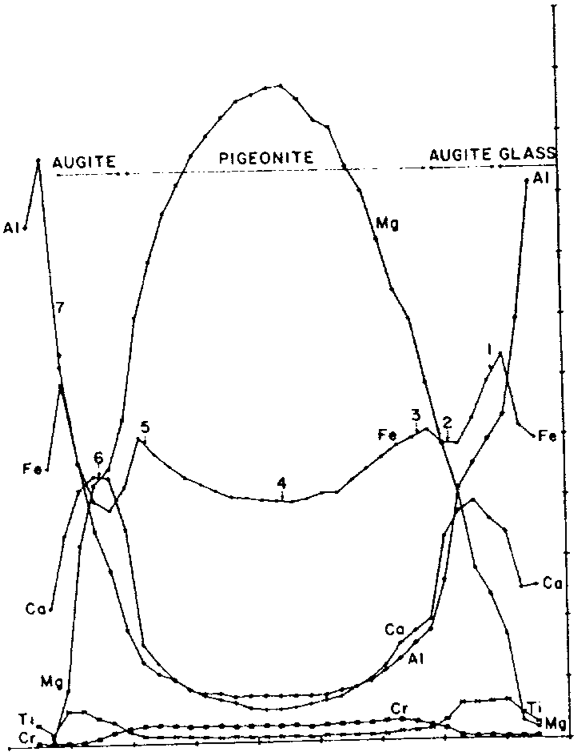


Fig. 3a

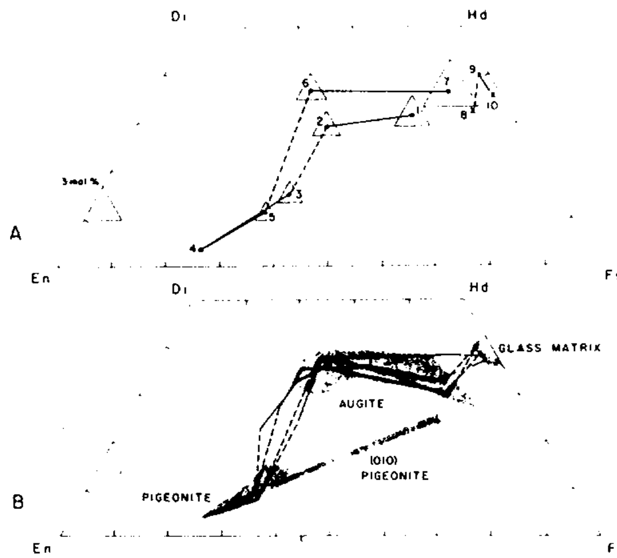


Fig. 3b

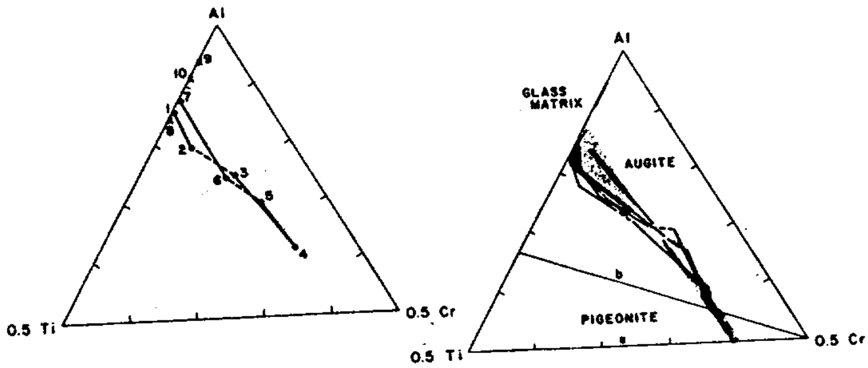


Fig. 3c

Figure 3. Compositions of pyroxenes in 15597. a) typical elemental profile across a phenocryst. Vertical scale is raw intensity, analysis interval is 2 microns. b) compositional zoning in the quadrilateral. Triangle size is proportional to "others" components. c) Ti-Cr-Al trends. a)-c) from Weigand and Hollister (1973). d) sketch and analyses of radiate clino-pyroxene (Drever et al., 1972). e) major and minor element analyses. f) minor element analyses of 15597 and other Apollo 15 quartz-normative basalt pigeonite cores, and experimental cooling rate products. e)f) from Grove and Bence (1977).

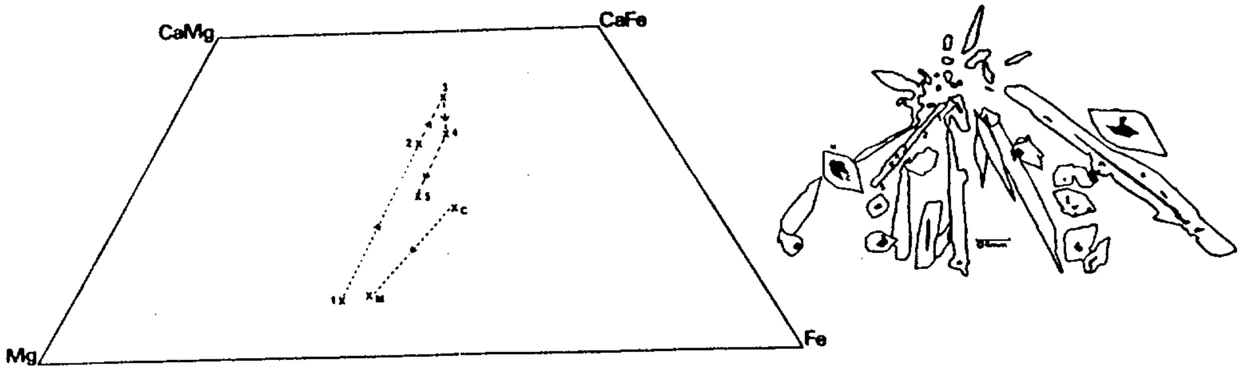


Fig. 3d

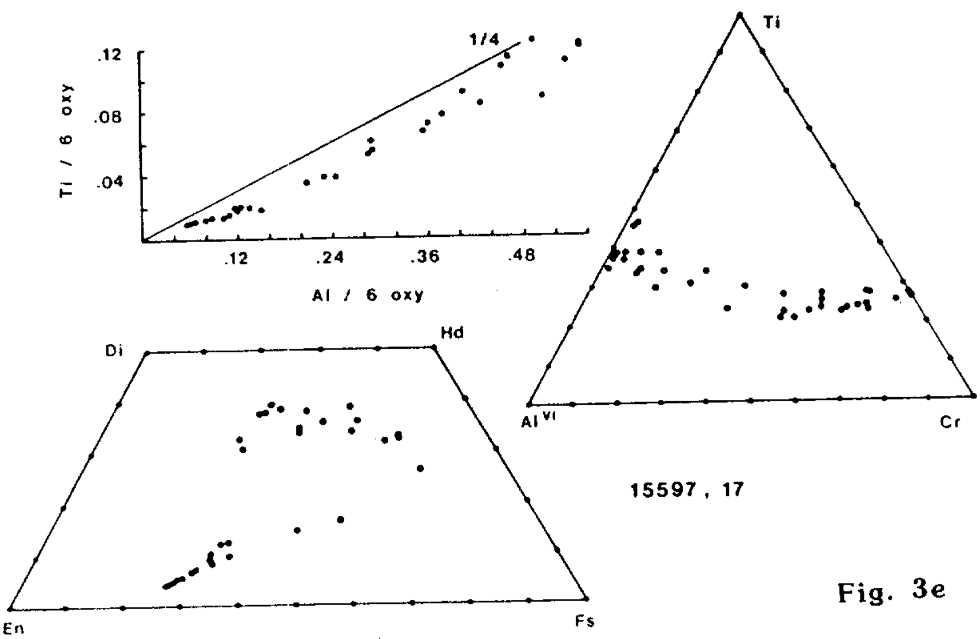


Fig. 3e

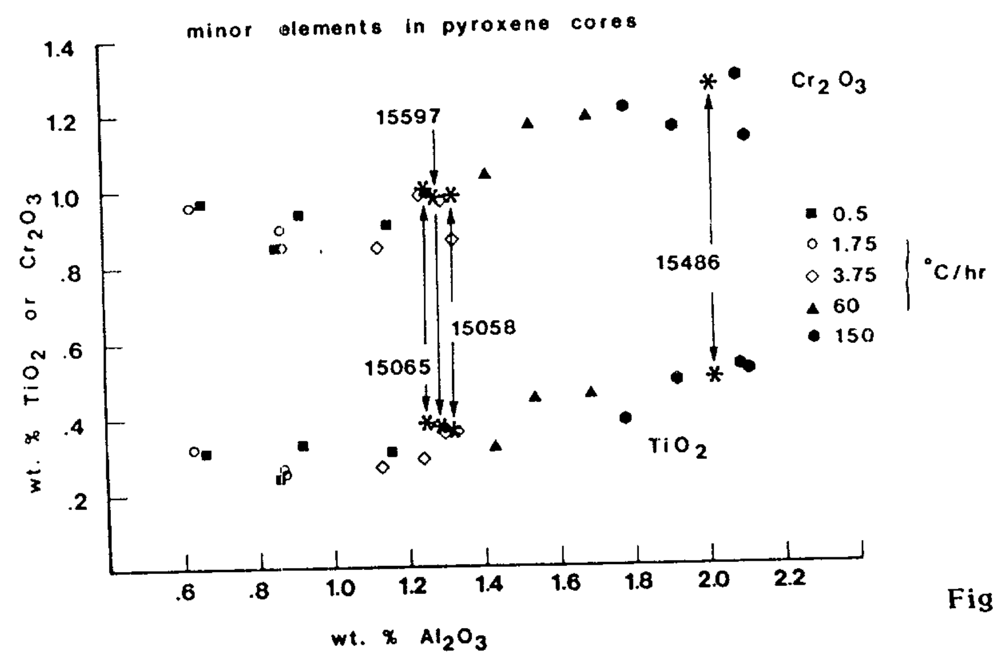


Fig. 3f

TABLE 15597-1. Modes of 15597

	(1)	(2)	(3)	(4)
Pig	42	59	55.8	50.1
Aug	17			
Glass	37	41	43.9	49.9
Opaques	<1	<0.3	0.3	<0.1
Vesicles	3	--	--	--

(1) Weigand and Hollister (1973)
(2) PET (Lunar Sample Information Catalog, 1972)
(3) Grove and Walker (1977)
(4) Papike et al. (1976)

TABLE 15597-2. Analysis of groundmass glass

		(1)	(2)
Wt %	SiO_2	47.9	48.63
	TiO_2	2.30	2.33
	Al_2O_3	15.13	16.05
	FeO	22.24	21.26
	MgO	1.40	0.43
	CaO	9.62	9.29
	Na_2O	0.66	0.75
	K_2O	0.111	0.13
	P_2O_5	0.151	0.14
ppm	Cr	<35	~70
	Mn	1740	~1500
	S	--	1600

(1) Nava (1974); AAS, colorimetry
(2) Weigand and Hollister (1973); microprobe

Figure 4. Cr-Al and Fe-Mg relationships in 15597 chromites. Filled dots = large chromites, open dots = small chromites (Weigand and Hollister, 1973).

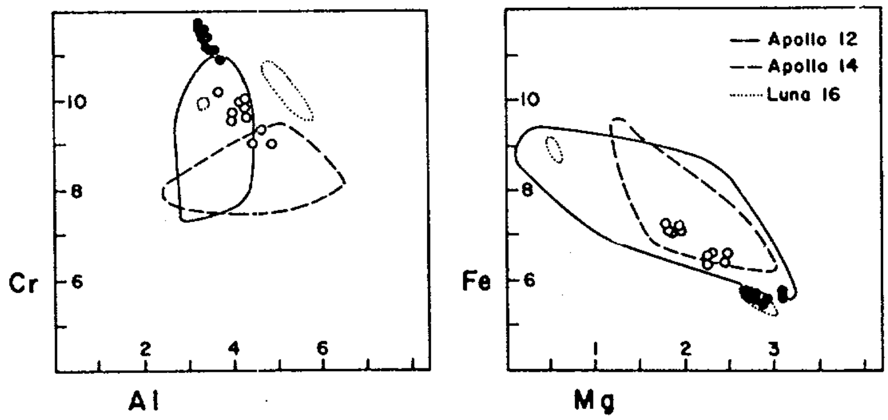
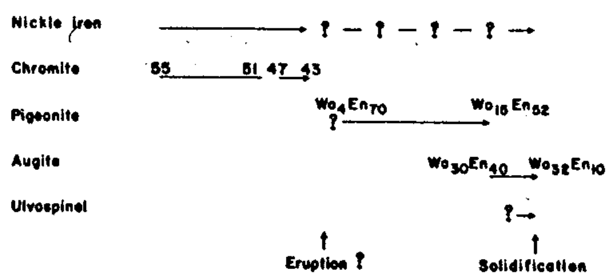


Figure 5. Inferred crystallization sequence for 15597 (Weigand and Hollister, 1973). Numbers on chromite arrow are wt% Cr_2O_3.



Brown and Wechsler (1973) and Brown et al. (1973) used a precession camera, x-ray diffraction, and microprobe techniques to study pyroxenes. They found no augite exsolution (i.e., no (001) augite), suggesting very rapid crystallization from 1200°C to 950°C. Augite overgrows pigeonite epitaxially on (100). The pigeonite shows fine-scale polysynthetic twinning which could be from inversion from orthopyroxene (although no core orthopyroxene was observed, the compositions, $En_{70}Wo_4$, are well within the range of lunar orthopyroxenes). Coarse, simple growth twins are also not uncommon. Brown and Wechsler (1973) tabulated fractional atomic coordinates, bond lengths and angles, and other crystallographic data. There appear to be significant difference between class b peak diffusenes in 15597 and Mull pigeonites (contrary to the conclusion in Brown et al., 1973) indicating that 15597 cooled through the C-->P transition (about 950°C) more slowly than the Mull pigeonite. The Fe-Mg distribution coefficient (Kd) of 0.12 for $En_{65}Wo_6$ is one of the most disordered reported and indicates equilibration at about 650°C. (The Brown et al., 1973, calculated Kd (0.18) is reported by Brown and Wechsler, 1973, as being in error.) Brown and Wechsler (1973) suggested that reheating could cause the discrepancy between the Fe-Mg equilibration tempeature and the P-->C phase transition, but the heating must not be enough to cause exsolution. However, in such reheating the groundmass glass might have devitrified. An alternative explanation is that reheating was a result of the heat of crystallization.

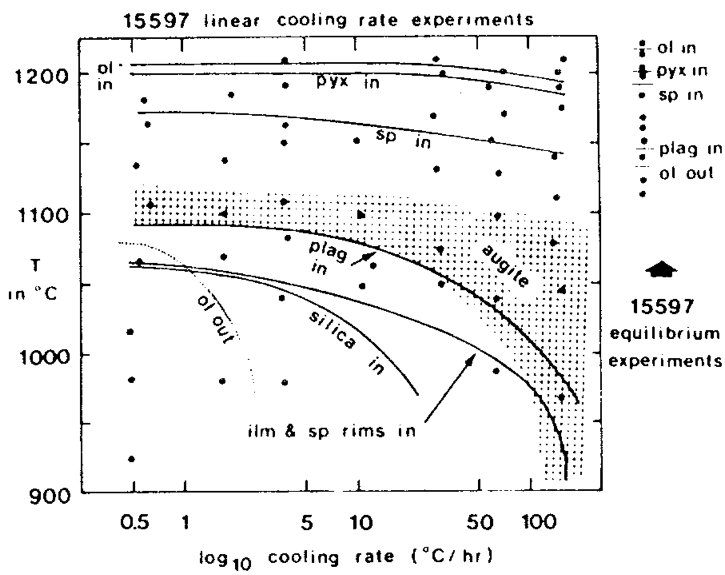
Cooling rate studies: Apart from the studies above, several experimental studies have been made to elucidate the cooling rate of 15597. Lofgren et al. (1974, 1975) found that the crystal morphologies and zoning trends of the phenocrysts resemble those produced in dynamic crystallization experiments with linear cooling rates of 5 to 20°C/hr. The groundmass is inferred similarly to have cooled at more than 30°C/hr. The groundmass is the most rapidly cooled of all those studied, but the phenocrysts (despite their smaller size and greater nucleation density) are inferred to have crystallized more slowly than those in vitrophyres 15485 and 15486. In a similar but more sophisticated study, Grove and Walker (1977) inferred an early cooling rate of 300° to 500°C/hr from the phenocryst nucleation density, an integrated rate of 10°to 150°C/hr from the pyroxene sizes, and a late-stage rate of 300° to 500°C/hr from plagioclase sizes. A megacryst was inferred to have grown during cooling at 3.75°C/hr. They inferred the final crystallizing position of 15597 from a conductive boundary to be 4 cm. They noted the variety of early-stage cooling rates to be inferred, depending on which technique is used. They suggested that the megacrysts grew in a more slowly cooled environment for possibly a day or two. The nucleation density recorded by the smaller pyroxenes may have been biased by a concentration of nucleii during the event which increased the cooling rate.

Grove and Bence (1977) performed the experiments on which the Grove and Walker (1977) analysis is based. The summarized phase results are shown in Figure 6. They also used pyroxene compositions to assess cooling rates. The general zoning trends for 15597 are closest to these produced in 150°C/hr cooling rate experiments. The cores of phenocrysts have minor elements similar to these in much coarser rocks 15065 and 15058 (Fig. 3f) and most similar to those in 3.75°C/hr cooling rate experiments. Thus all these cores formed under similar conditions probably fairly close to equilibrium. The results confirm the complex cooling history and suggest nucleii formed in the interior of the flow. Lofgren et al. (1979) performed experiments to compare the differing results of experiments on the 15597 compostion which was used in the cooling rate studies. Grove (1982) used TEM techniques to study micro-exsolution textures in experimentally-produces pyroxenes and in 15597, to assess cooling rates. Fine-scale tweed (001) and (100) modulations were found in 15597 with spinodal decomposition showing lamellar wavelenghts of 165 and 170Å (001) and being present on (100). Heterogeneous nucleation had a lamellar wavelength of 576Å (001) and absent on (100). The data indicate cooling at 20°C/hr, similar to but a littler slower than other estimations.

Other Experimental Studies: Muan et al. (1974, and quoted pers. comm. in Brown and Wechsler, 1973) conducted equilibrium crystallization experiments, in contact with metallic iron, on a powdered, representative piece of 15597. The liquidus phases were olivine and chromite at 1230°C, with pyroxene entry at 1170°C, and anorthite at 1140°C. The solidus was 1060°C. Grove and Bence (1977) reported similar equilibrium experiments in iron capsules in evacuated silica glass tubes with a realistic imposed fO_2. They had no iron loss from or gain to the charge. They found olivine (Fo_{68-70}) to be the liquidus phase, at 1215°C, and it reacted out by 1130°C (Fo_{56}). Pigeonite $En_{68}Wo_5$ entered at 1197°C and became more Ca, Fe-rich with decreasing temperatures. Spinel entered at 1185°C (a lower temperature than the Muan et al., 1974, experiments, a result of either higher chromium or higher oxidation state in the latter study). Plagioclase entered at 1143°C. Tabulated analyses of the run products were given.

Grove and Raudsapp (1978) conducted experiments on a 15597 synthetic composition to study the kinetic effects on pyroxene chemistry and the liquid line of descent, documenting the departures of dynamic liquid lines of descent from ideal fractional crystallization. Diffusion at the interface and the suppression of late phases during rapid cooling are important factors governing pyroxene and liquid chemistries. Residual liquids metastably penetrated the plagioclase primary phase volume.

Figure 6. Summary of linear controlled cooling rate and equilibrium experiments on synthetic glass with the bulk composition of 15597 (Grove and Bence, 1977).



Grove and Lindsley (1979a) conducted an experimental study on a late-stage liquid compostion for 15597 at a cooling rate of 0.5°C/hr in an attempt to produce pyroxferroite and understand why pyroxferroite or alternatively fayalite and silica crystallize. If pyroxferroite was produced in the experiments, it was not as large or abundant as those in coarse-grained quartz-normative basalts, and the controlling factors for this (metastable) pyroxferroite production remain unknown. Grove and Lindsley (1979b) conducted experiments on synthetic compositions of 15597 and its residual liquids in a study of the partitioning of Fe, Mg, and Ca between pigeonite and liquids in basaltic liquids.

CHEMISTRY: Bulk rock chemical analyses are listed in Table 3 and the rare earths shown in Figure 7. The analyses are generally consistent, as might be expected of such a fine-grained, glassy rock, and are clearly of an average Apollo 15 quartz-normative basalt. It is a little lower in MgO and higher in FeO than some coarser members of the group, such as 15065. Helmke et al. (1973) placed 15597 in a low Sm/Eu group of quartz-normative mare basalts. Compston et al. (1972) noted that their Rb determinations by XRF were systematically lower than their more reliable isotope dilution analyses.

Nava (1974) reported an analysis of the groundmass glass separated from ground bulk rock powder by heavy liquid methods.

STABLE ISOTOPES: Clayton et al. (1972) reported $\delta^{18}O$ values of 5.60 for glass and 5.41 for pigeonite, without specific discussion. They are typical lunar values.

TABLE 15597-3. Bulk rock chemical analyses

		,21	,8	,19	,0	,21	,27	,6
wt %	SiO2	47.98	48.0	48.1				
	TiO2	1.80	1.84	1.87				
	Al2O3	9.44	9.55	9.27				
	FeO	20.23	20.6	20.17				
	MgO	8.74	9.06	9.18				
	CaO	10.43	10.4	9.69			9.5	
	Na2O	0.32	0.317	0.32				
	K2O	0.06	0.078	0.056	0.053		0.053	
	P2O5	0.07		0.107				
(ppm)	Sc							
	V							
	Cr	3290		3356				
	Mn	2320	2160	1970				
	Co							40
	Ni		30					
	Rb	0.90				1.13		0.72
	Sr	109.4	91			111.0		
	Y	27						
	Zr	101						
	Nb	6						
	Hf							
	Ba		52					
	Th				0.53			
	U				0.14			
	Pb							
	La		4.86					
	Ce		13.0					
	Pr							
	Nd		9.3					
	Sm		3.09					
	Eu		0.84					
	Gd		4.4					
	Tb		0.69					
	Dy		4.51					
	Ho		0.86					
	Er		1.9					
	Tm							
	Yb		2.13					
	Lu		0.301					
	Li							
	Be							
	B							
	C							
	N							
	S	600						
	F							
	Cl							
	Br							0.024
	Cu							
	Zn							1.2
(ppb)	I							
	At							
	Ga	2600						
	Ge							
	As							
	Se							117
	Mo							
	Tc							
	Ru							
	Rh							
	Pd							
	Ag							0.90
	Cd							1.7
	In							0.59
	Sn							
	Sb							1.49(a)
	Te							1.9
	Cs							37
	Ta							
	W							
	Re							.0081
	Os							
	Ir							.0072
	Pt							
	Au							.045
	Hg							
	Tl							0.32
	Bi							0.21
		(1)	(2)	(3)	(4)	(5)	(6)	(7)

References to Table 15597-3

References and methods:

(1) Chappell and Green (1973), Compston et al. (1972); XRF
(2) Helmke et al. (1973); INAA, AAS, RNAA
(3) Nava (1974); semi-micro, AAS, colorimetry
(4) O'Kelley et al. (1972); gamma ray spec
(5) Compston et al. (1972); ID/MS
(6) Kirsten et al. (1973); argon, irradiation
(7) Ganapathy et al. (1973); RNAA

Notes:

(a) doubtful -- contamination or analytical error--in authors' own judgement.

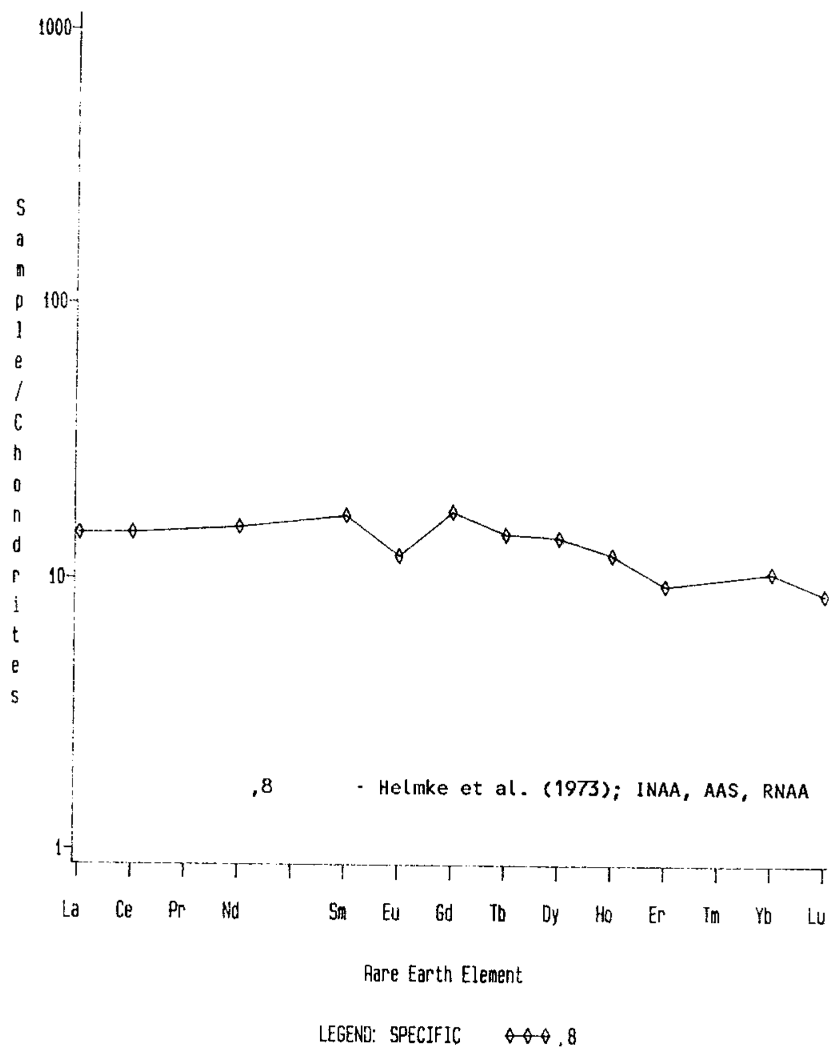


Figure 7. Rare earths in 15597.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Kirsten et al. (1973) reported a ^{40}Ar-^{39}Ar plateau age of between 3.1 and 3.5 b.y., an imprecise age but covering the known age of other Apollo 15 quartz-normative mare basalts. The sample contains large amounts of excess argon, released between 580°C and 880°C, which Kirsten et al. (1973) suggest was probably incorporated while the magma was upwelling through older crust and then frozen in.

Compston et al. (1972) reported Rb-Sr isotopic data for a whole-rock sample. The $^{87}Rb/^{86}Sr$ (0.0294) and $^{87}Sr/^{86}Sr$ (0.70091 ± 10) give an initial $^{87}Sr/^{86}Sr$ of 0.69953 for an assumed age of 3.35 b.y., an initial value indistinguishable from other Apollo 15 mare basalts.

RARE GASES, RADIONUCLIDES AND EXPOSURE: Kirsten et al. (1973) reported a ^{38}Ar exposure age of 210 m.y., without comment. Eldridge et al. (1972) reported disintegration count data for ^{22}Na, ^{26}Al, and ^{54}Mn without discussion. The ^{26}Al is saturated (Yokoyama et al., 1974) indicating exposure of a million years or more.

PHYSICAL PROPERTIES: Hargraves and Dorety (1972) measured the intensity of the natural remanent magentization, saturated IRM, and their variation with AF demagnetization (Fig. 8). They found that their sample had a stronger intensity of remanence than many of the other samples they analyzed, even higher than the older Apollo 11 basalts. Fuller et al. (1979) made a comprehensive study of the magnetism of 15597 and some other fine-grained basalts. They found that two subsamples of ,20, whose mutual orientations are not known, gave different AF demagnetization curves but that both had good directional stability (Fig. 9). Thermal demagnetization to 100°C had no significant effect on the NRM. The magnitude of the NRM in the two subsamples differed by almost an order of magnitude. The stability of the NRM is less than the anhysteric remanent magnetization (ARM) and saturated IRM, so is unlikely to be a thermoremanent magnetization; the NRM was acquired by a single process which activated hard and soft microscopic coercivities. Fuller et al. (1979) believed that the NRM was too soft to be of thermal origin and too hard to be simply isothermal contamination. The explanation they considered to be least unacceptable was that the NRM was a shock remanent magnetization. Paleointensity field derivations hence must be virtually impossible. Fuller et al. (1979) also tabulated many of the magnetic properties derived from hysteresis loops. The saturated magnetization (Js) and the Jr/Js are so small that a mixture of single domain with either multidomain or superparamagnetic grains is suggested. Heating experiments showed little change in the saturated magnetization but the saturated IRM increased by an order of magnitude.

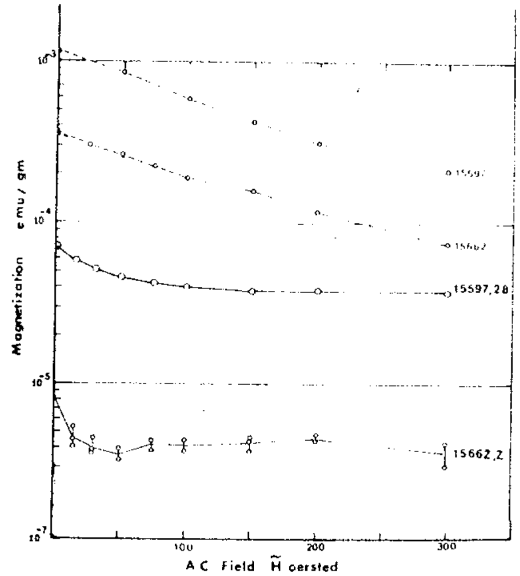


Figure 8. NRM intensity (solid line) and saturated IRM (dashed line) for 15597 and 15662 (Apollo 15 olivine-normative mare basalt). (Hargraves and Dorety, 1972).

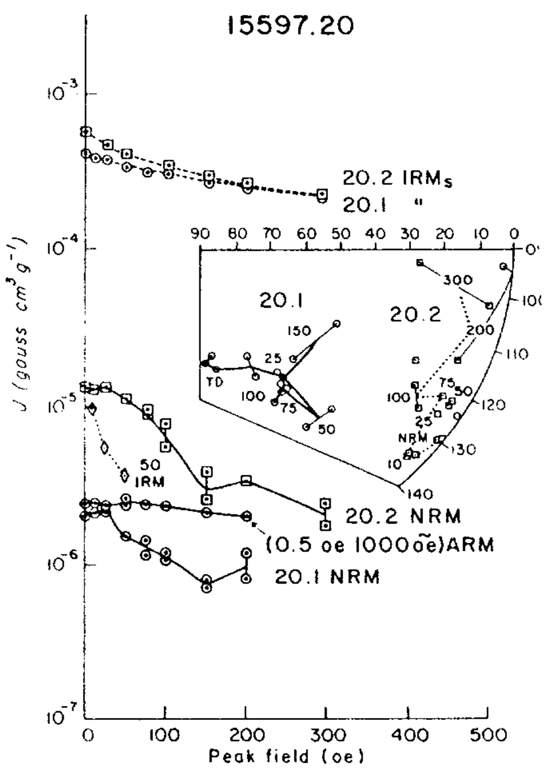


Figure 9. AF demagnetization of 15597,20. Inset is directional changes. (Fuller et al., 1979).

Cisowski et al. (1983) (of which Fuller is a co-author) contested the NRM data of Hargraves and Dorety (1972), suggesting that the chip used was small and its high NRM was magnetically contaminated. Cisowski et al. (1983) made new measurements and, with the data from Fuller et al. (1979) noted that the NRM's were an order of magnitude lower. In contrast with Fuller et al. (1979), Cisowski et al. (1983) believed that paleointensity data were obtainable and that the NRM was not a shock remanent magnetization.

PROCESSING AND SUBDIVISIONS: A single, nearly 20 g piece (,1) was chipped from the "W" end and entirely subdivided for the initial allocations. Subsamples included ,7, made into a potted butt and partly used to make thin sections ,7; ,16; ,18; and ,23; potted butt ,22 (thin sections ,24 to ,26); thin sections were also made from pieces of ,2 (thin sections ,11; ,12; ,14; ,15; and ,17). Further chippings were made from the same area to fulfill chemistry allocations, and, in 1979, magnetism allocations.

15598 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 135.7 g

INTRODUCTION: 15598 is an olivine-normative mare basalt with small olivine phenocrysts and a texture and grain-size very similar to 15535 (which was chipped from a boulder 20 m away). Its chemistry is that of an average Apollo 15 olivine-normative mare basalt. The sample is light brownish gray, blocky, subrounded, and tough (Fig. 1). It has a few smallvugs, and many zap pits on most surfaces. It was collected in the vicinity of the boulder from which 15595 and 15596 were taken, but it has not been identified in surface photographs.

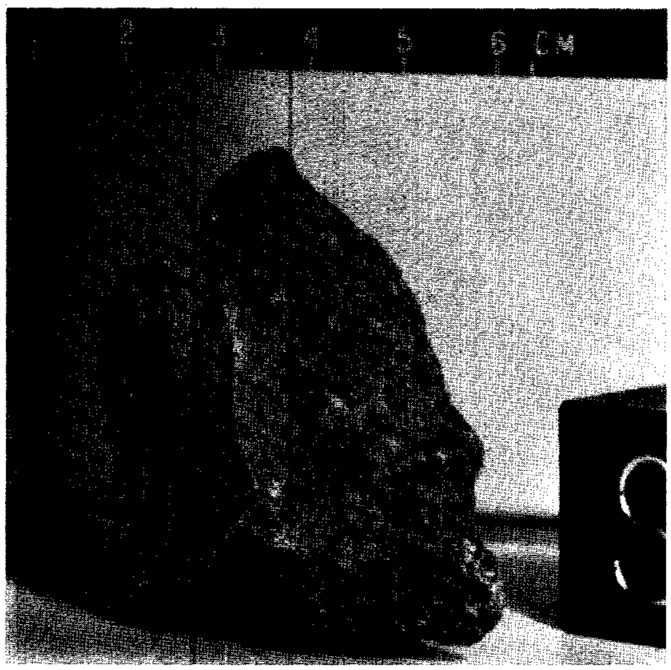


Figure 1. Macroscopic pre-split view of 15598. S-71-46697

PETROLOGY: 15598 consists mainly of small olivine phenocrysts, granular clustered pyroxenes, and plagioclases (Fig. 2). It has residual patches of glass, fayalite, sulfides, and cristobalite. Opaques range from chromite to ulvospinel and ilmenite. The sample is very similar to 15535 but is perhaps slightly finer in grain size and has less cristobalite.

Brown et al. (1972) noted that 15598 was an olivine-normative mare basalt (i.e., PET, Type III) but gave no specific data. Weiblen and Roedder (1973) studied melt inclusions in olivine as well as other features. Two analyzed melt inclusions (archived data) contained 57.2% SiO_2 and 60.2% SiO_2, in hosts of $Fo_{50.2}$ and $Fo_{62.2}$ respectively. The olivine phenocrysts are reported as zoned over the same range. One olivine encloses Mg-Al chromite and Fe metal with 34% Ni (analyses archived).There are also late-stage high-silica melts in ilmenite and as melts interstitial and adjacent to ilmenite,pyroxferroite(?), and sodic plagioclase ($An_{85.4}$). Roedder and Weiblen (1977) made many more analyses of melt-inclusions in olivine and ilmenite, and archived the data. Bell et al. (1975) reported the presence of Type A symplectites (disseminated rosettes) in olivines.

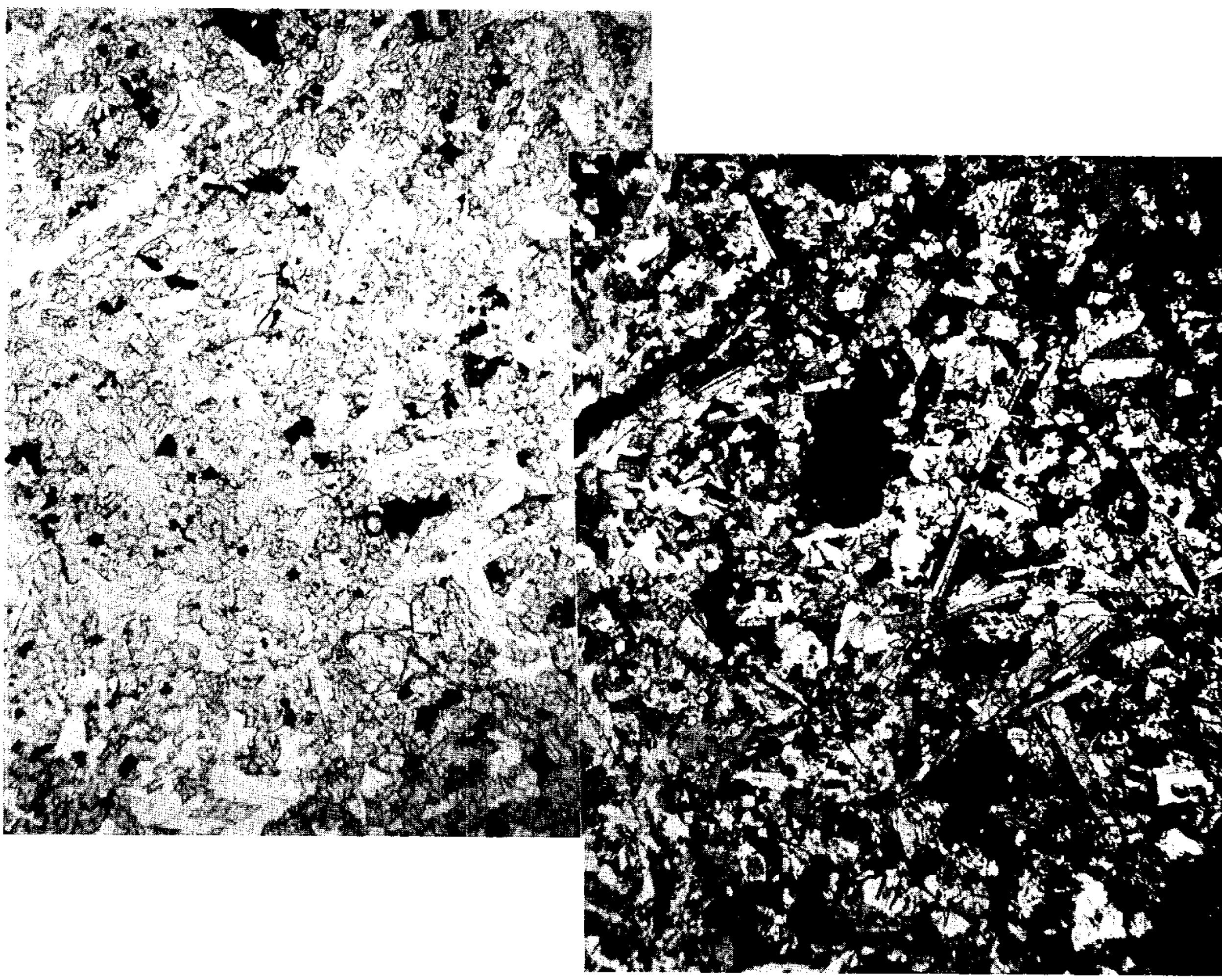


Figure 2. Photomicrographs of 15598,10. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: Rhodes and Blanchard (1983) reported a major and trace element analysis of a 2 gram split of 15598. The sample is an average olivine-normative mare basalt.

PROCESSING AND SUBDIVISIONS: 15598 was chipped to produce ,5 (apparently without photo documentation) which was made into a potted butt and partly used to make thin sections ,10 to ,12. Other small chips and fines (,6; ,7) were produced at the same time. In 1982, further chipping from the "T" end produced the splits for chemical analysis. ,0 is now 126.5 g.

15605 COARSE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 6.1 g

INTRODUCTION: 15605 is a coarse-grained, olivine-bearing mare basalt which is very vesicular (Fig. 1). The olivine only rarely forms phenocrysts. In chemistry the sample is an average member of the Apollo 15 olivine-normative mare basalt group. The sample is brownish gray, stubby, angular, and tough, with the sparse yellow-green olivines visible macroscopically. The large (1 to 4 mm) vesicles compose about 15% of the rock. No zap pits were observed. 15605 was collected as part of the rake sample at Station 9A.

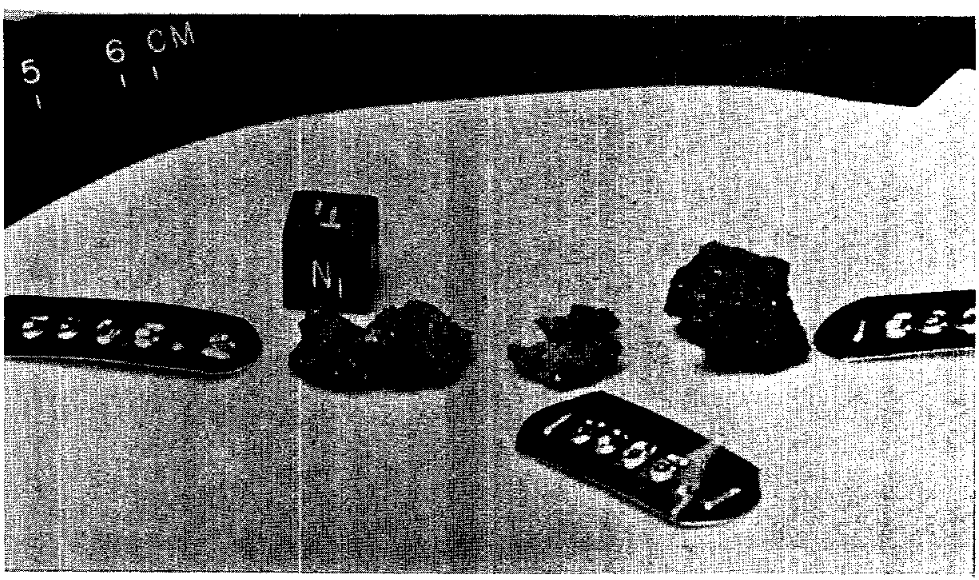


Figure 1. Post-split view of 15605. S-72-19842

PETROLOGY: 15605 is a coarse-grained, olivine-bearing mare basalt (Fig. 2). The olivines are anhedral and do not generally form phenocrysts, being only 1 mm or less in diameter. One olivine in thin section is an elongated, hollow, ragged phenocryst 3 mm long (Fig. 2). Generally the texture is gabbroic. The dominant phase is pigeonite which is commonly twinned and zoned outward to augite. Some contain small olivine cores or inclusions. Stubby plagioclase laths are generally interstitial but enclose some small pyroxenes and olivines; most plagioclases are about 1 mm long. Cristobalite and fayalite are present.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15605,5. Widths about 3 mm. a) transmitted light; b) crossed polarizers. Grain crossing center from left to right is a hollow, anhedral olivine phenocryst.

CHEMISTRY: A bulk rock chemical analysis (Table 1, Fig. 3) shows 15605 to be a member of the Apollo 15 olivine-normative mare basalt group. The critical element Mg is imprecisely measured with the technique used, hence its apparent average nature is uncertain.

PROCESSING AND SUBDIVISIONS: 15605 was substantially chipped (Fig. 1), and ,0 is now 3.11 g. ,1 was made into a potted butt and partly used to make thin sections ,5 and ,6.

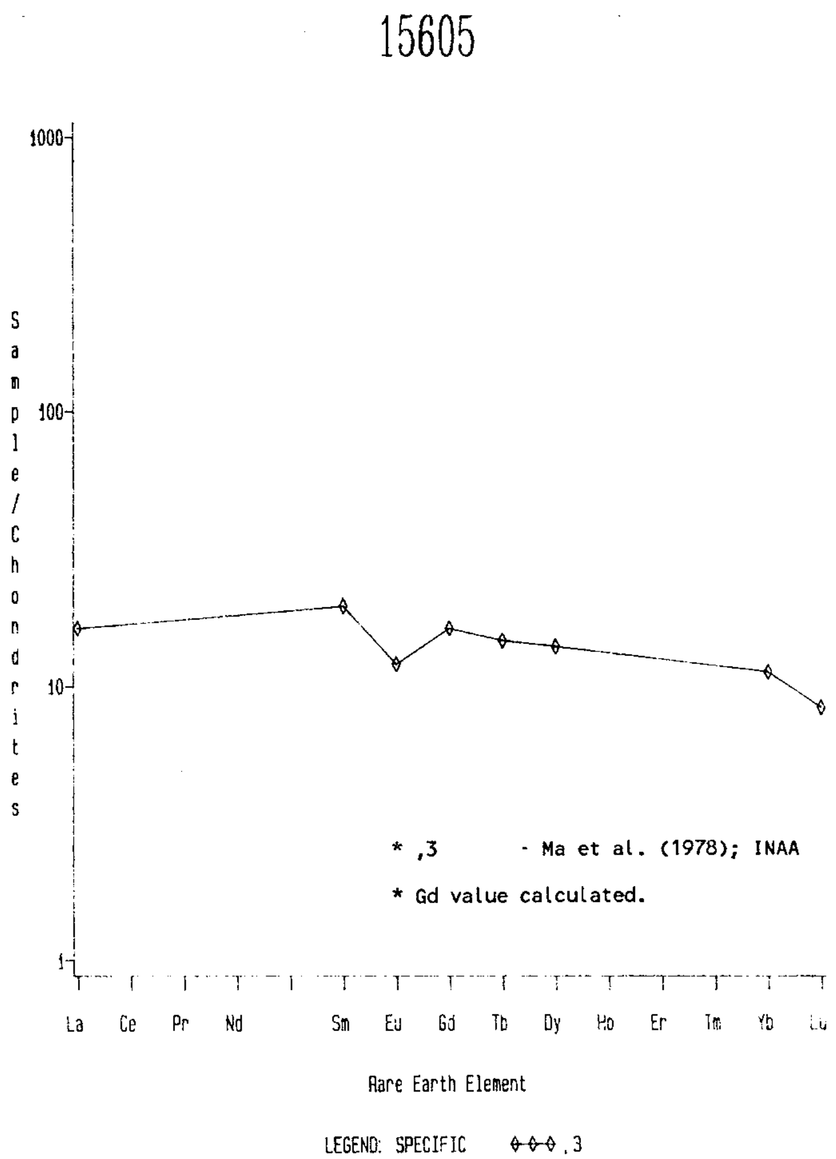


Figure 3. Rare earths in 15605.

TABLE 15605-1. Bulk rock chemical analysis

		,3
Wt %	SiO2	
	TiO2	2.1
	Al2O3	9.1
	FeO	22.3
	MgO	11
	CaO	10.1
	Na2O	0.257
	K2O	0.051
	P2O5	
(ppm)	Sc	42
	V	232
	Cr	4150
	Mn	1300
	Co	51
	Ni	40(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.5
	Ba	45(b)
	Th	
	U	
	Pb	
	La	5.4
	Ce	
	Pr	
	Nd	
	Sm	3.6
	Eu	0.84
	Gd	
	Tb	0.7
	Dy	4.5
	Ho	
	Er	
	Tm	
	Yb	2.3
	Lu	0.29
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	450
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma *et al.* (1978); INAA

Notes:

(a) ±20 ppm
(b) ±25 ppm

15606 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 10.10 g

INTRODUCTION: 15606 is a medium-grained olivine-bearing and very vesicular mare basalt (Fig. 1). The olivine only rarely forms phenocrysts. In chemistry, the sample is a fairly average member of the Apollo 15 olivine-normative mare basalt group. The sample is brownish gray with the few small yellow-green olivines visible, and is blocky, subangular, and tough. The large (up to 5 mm) spherical vesicles compose 45% of the volume. No zap pits were observed. 15606 was collected as part of the rake sample at Station 9A.

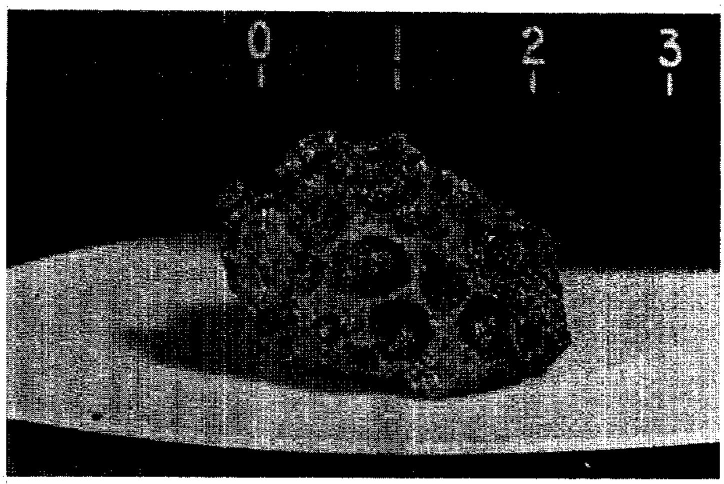


Figure 1. Pre-split view of 15606. S-71-44940

PETROLOGY: 15606 is an olivine-bearing basalt with a gabbroic texture of medium grain size (Fig. 2). The dominant phase is pigeonite which is anhedral and smaller ones are granular. Larger ones have small olivine inclusions. The plagioclases form laths less than 1 mm long; a few are up to 2 mm and ophitically enclose small olivines and pyroxenes. Most olivines are less than 1 mm across. Opaque phases range from chromite to ulvospinel to ilmenite. Residual phases include fayalite, cristobalite, glass, ilmenite, ulvospinel, and troilite. Fe-metal is scarce.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15606,5. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: A bulk rock analysis is presented in Table 1 with rare earths shown in Figure 3. The sample is an average member of the Apollo 15 olivine-normative mare basalt group.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) measured a natural magnetic intensity of 7.0×10^{-6} emu/g for the bulk sample, an intensity typical of Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: A single chip (,1) was removed and subdivided to give ,1 through ,4. ,2 was potted and partly used to make thin sections ,5 and ,6. ,0 is now 7.13 g.

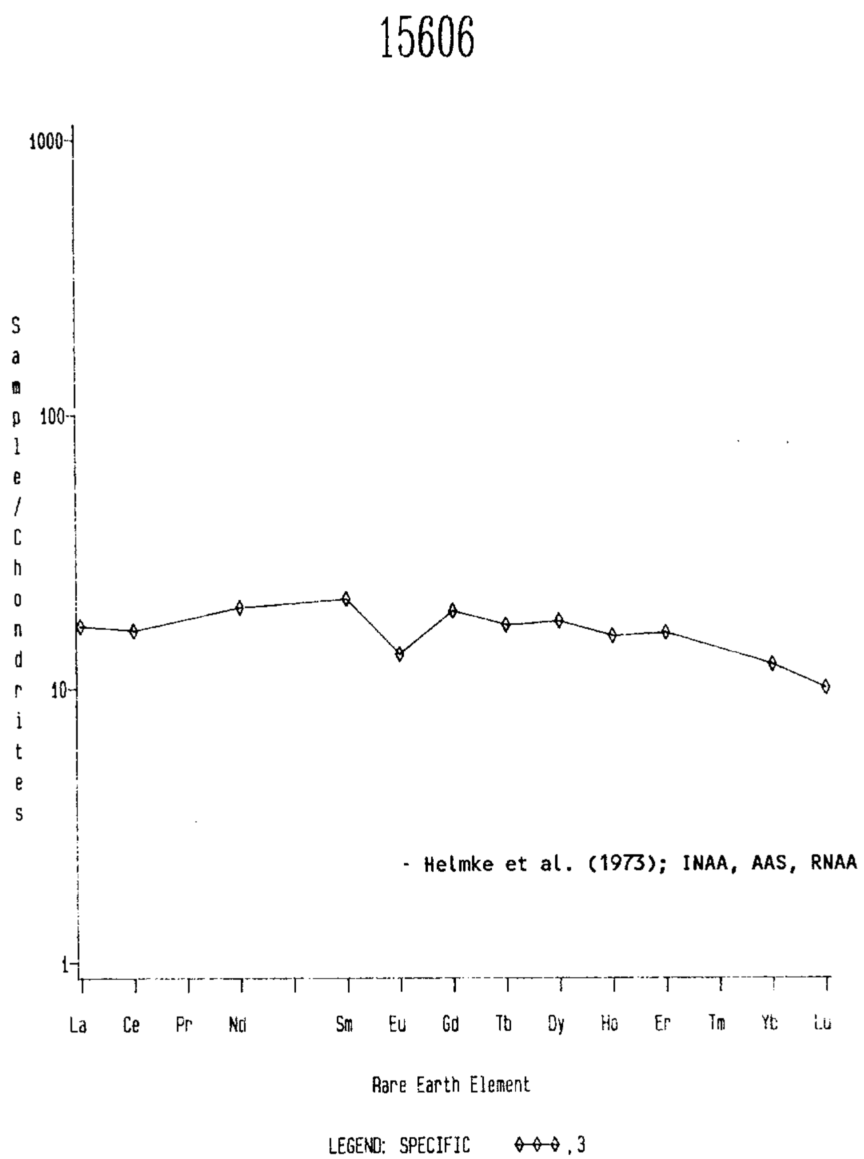


Figure 3. Rare earths in 15606.

TABLE 15606-1. Bulk rock chemical analysis

		,3
Wt %	SiO2	47.7
	TiO2	2.51
	Al2O3	8.72
	FeO	22.0
	MgO	10.0
	CaO	9.56
	Na2O	0.257
	K2O	0.053
	P2O5	
(ppm)	Sc	41.8
	V	
	Cr	4610
	Mn	2130
	Co	49
	Ni	
	Rb	0.71
	Sr	
	Y	
	Zr	
	Nb	
	Hf	3.4
	Ba	
	Th	
	U	
	Pb	
	La	5.56
	Ce	14.3
	Pr	
	Nd	11.9
	Sm	3.84
	Eu	0.92
	Gd	4.8
	Tb	0.80
	Dy	5.60
	Ho	1.09
	Er	3.2
	Tm	
	Yb	2.45
	Lu	0.340
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	<2
(ppb)	I	
	At	
	Ga	3700
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	44
	Ta	
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Helmke et al. (1973); INAA, AAS, RNAA

15607 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 14.8 g

INTRODUCTION: 15607 is a fine-grained, olivine-bearing mare basalt (Fig. 1) in which olivine forms small phenocrysts. In chemistry the sample is an average member of the Apollo 15 olivine-normative mare basalt group. A ^{40}Ar-^{39}Ar plateau age of 3.27 ± 0.12 b.y. (Husain, 1974) is only slightly lower than other such basalts and the sample has suffered considerable gas loss. The sample is gray brown with yellow-green olivines visible. It is irregularly-shaped and is coherent. Small vugs are common; no zap pits were observed. 15607 was collected as part of the rake sample at Station 9A.

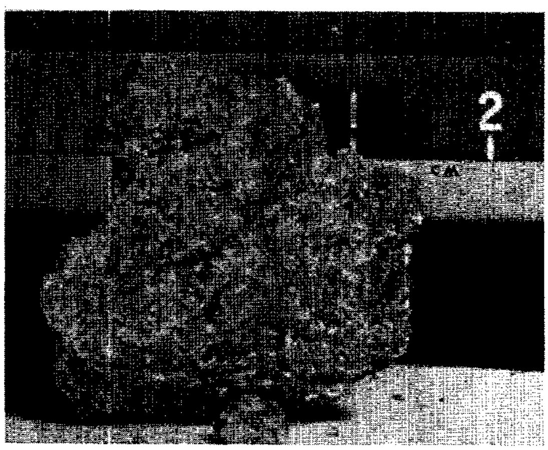


Figure 1. Pre-chip view of 15607. S-71-44933

PETROLOGY: 15607 is a fine-grained olivine-bearing mare basalt. The texture is dominated by small granular pyroxenes and olivines embedded or partly embedded in plagioclases up to 2 mm long (Fig. 2). Olivines form sparse anhedral phenocrysts. Dowty et al. (1973a,b) reported a mode with 56% pyroxene, 30% plagioclase, 8% olivine, 5% opaques, and 1% silica (which is actually cristobalite). Microprobe analyses of pyroxenes, plagioclases, olivines, potash feldspar, Si-K glass, and Fe-metals were reported by Dowty et al. (1973b,c) with the opaque phases tabulated in Nehru et al. (1973). Nehru et al. (1974) included 15607 in their general discussion and tabulated a chromite analysis. Some of the mineral chemistries are diagrammed in Figure 3. The metal contains 1.4 to 1.8% Co and 4.3 to 7.7% Ni; the ilmenite contains 0.5 to 0.91% MgO.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15607,8. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

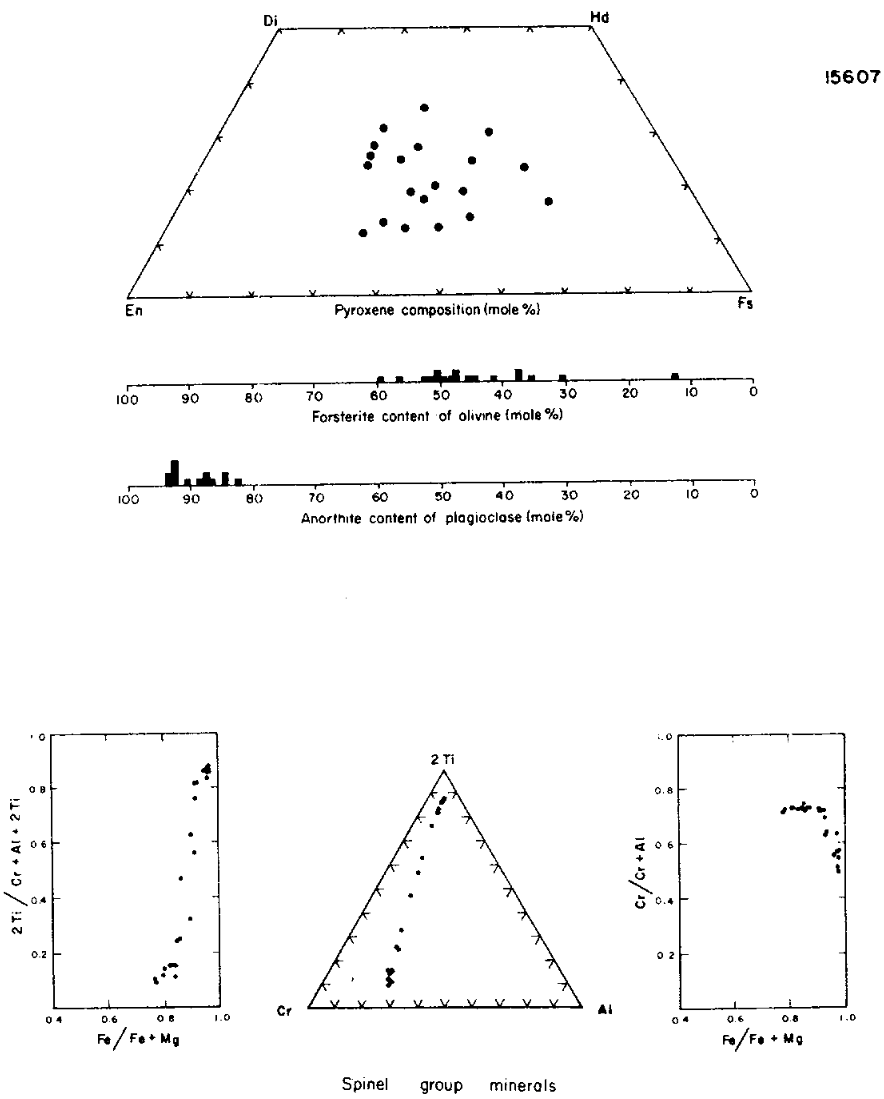


Figure 3. Chemistry of minerals in 15607 (Dowty et al., 1973b).

CHEMISTRY: Chemical analyses are listed in Table 1 with the rare earths shown in Figure 4. A bulk analysis using the microprobe defocussed-beam method is listed as Table 2 and is very consistent with the conventional chemical analyses. The analyses show 15607 to be a fairly average Apollo 15 olivine-normative mare basalt. Ma et al. (1976) found a high Sm/Eu and suggested that it belonged to a group different from some other such basalts, but the analysis of Laul and Schmitt (1973) has a low Sm/Eu and suggests that Sm/Eu is either too subject to sampling errors or too imprecisely determined to be a group discriminator in this case.

Christian et al. (1972) and Cuttitta et al. (1973) analyzed for Fe_2O_3 and found none, and reported an "excess reducing capacity" (over FeO) of +0.17. Their rare earth data is (systematically) higher than other group's analyses and are unreliable.

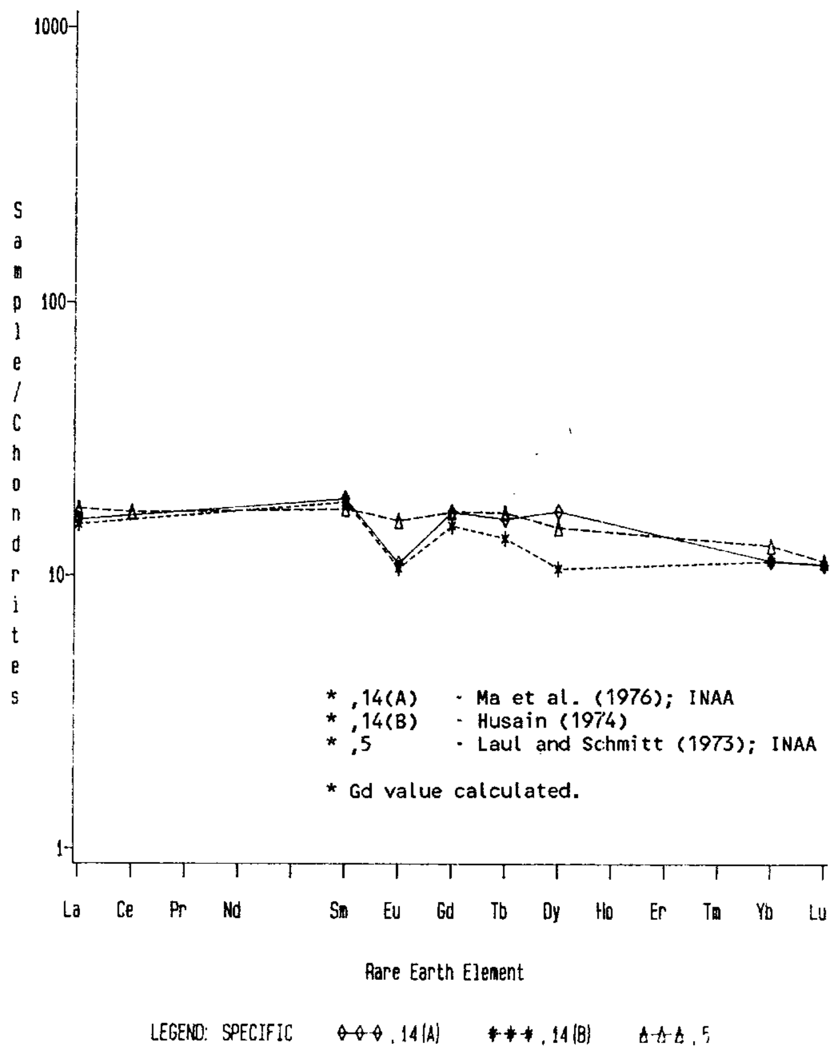


Figure 4. Rare earths in 15607.

TABLE 15607-1. Bulk rock chemical analyses

		,3	,5	,14A	,14B	,4
Wt %	SiO2	45.55				
	TiO2	2.51	2.4	2.4	2.6	
	Al2O3	8.55	8.9	9.0	9.0	
	FeO	22.33	23.7	23.3	23.1	
	MgO	9.96	10	9.9	9.9	
	CaO	10.10	10.2	8.9	8.9	7.0
	Na2O	0.35	0.251	0.263	0.274	
	K2O	0.05	0.044	0.048	0.046	0.0476
	P2O5	0.08				
(ppm)	Sc	44	38	40	40	
	V	185	200	194	213	
	Cr	3425	3725	3990	3900	
	Mn	2250	2100	2125	2125	
	Co	60	50	48	46	
	Ni	51		37	73	
	Rb	<1				
	Sr	125				
	Y	44				
	Zr	75				
	Nb	<10				
	Hf		3.3	2.9	2.7	
	Ba	50	50	38(a)	55(b)	
	Th					
	U					
	Pb					
	La	15	5.8	5.3	5.1	
	Ce		15			
	Pr					
	Nd					
	Sm		3.2	3.5	3.4	
	Eu		1.1	0.77	0.74	
	Gd					
	Tb		0.8	0.76	0.65	
	Dy		4.8	5.5	3.4	
	Ho					
	Er					
	Tm					
	Yb	4.6	2.6	2.3	2.3	
	Lu		0.39	0.38	0.38	
	Li	6.3				
	Be					
	B					
	C					
	N					
	S					
	F					
	Cl					
	Br					
	Cu	20				
	Zn					
(ppb)	I					
	At					
	Ga	4700				
	Ge					
	As					
	Se					
	Mo					
	Tc					
	Ru					
	Rh					
	Pd					
	Ag					
	Cd					
	In					
	Sn					
	Sb					
	Te					
	Cs					
	Ta		700	470	430	
	W					
	Re					
	Os					
	Ir					
	Pt					
	Au					
	Hg					
	Tl					
	Bi					
		(1)	(2)	(3)	(4)	

References and methods:

(1) Christian et al. (1972); Cuttitta et al. (1973); XRF, semi-micro chem., opt. emmiss. spec.
(2) Laul and Schmitt (1973); INAA
(3) Ma et al. (1976); INAA
(4) Husain (1974); Ar-isotopes, irradiation

Notes:

(a) ± 18 ppm
(b) ± 25 ppm

TABLE 15607-2. Defocussed beam bulk analysis (Dowty _et al_., 1973 a,b)

Wt %	SiO_2	44.6
	TiO_2	2.58
	Al_2O_3	8.8
	FeO	22.3
	MgO	9.7
	CaO	9.8
	Na_2O	0.33
	K_2O	0.02
	P_2O_5	0.09
ppm	Cr	3010
	Mn	1860

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Husain (1974) reported Ar isotopic data for step-wise heating. He found that 39.4% of the ^{40}Ar had been lost, resulting in a K-Ar age of 2.52 ± 0.02 b.y. However, a ^{40}Ar-^{39}Ar plateau age (high temperature releases) was 3.27 ± 0.12 b.y., slightly lower than but within error of the ages of other Apollo 15 mare basalts. Plieninger and Schaeffer (1976) tabulated laser-probe-released argon isotopic analyses for individual phases. The interiors of plagioclase gave an average age of 3.55 ± 0.20 b.y., imprecise but within error of the usual age of such basalts. The pyroxenes and the K-rich mesostasis showed abundant gas loss giving substantially lower ages (Fig. 5), with the K-rich mesostasis giving an age (2.56 ± 0.05 b.y.) similar to the K-Ar age.

EXPOSURE: Husain (1974) reported a ^{38}Ar spallation age of 300 ± 12 m.y. for 15607.

PROCESSING AND SUBDIVISIONS: Small chips were removed from ,0, which is now 11.66 g. ,2 was potted and partly used to make thin sections ,6 to ,8. In 1975 further chipping produced ,14 for chemical analysis.

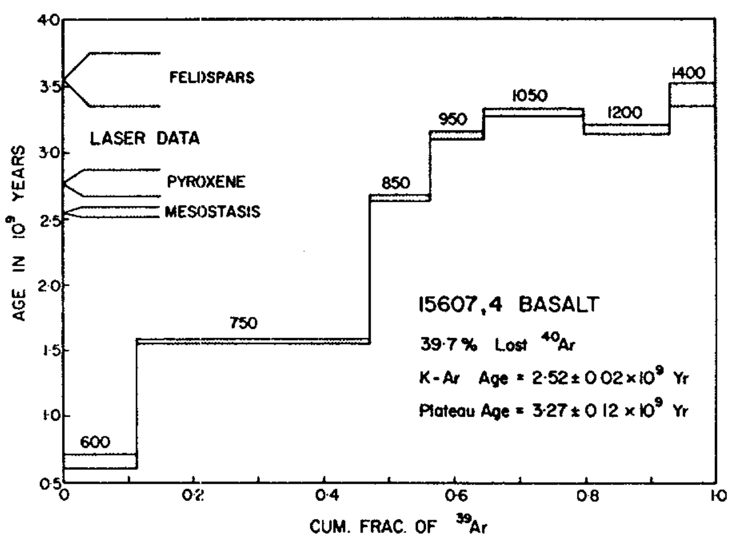


Figure 5. Laser-probe ages (left) and argon-release ages for 15607 (Plieninger and Schaeffer, 1976, and Husain, 1974).

15608 PORPHYRITIC SPHERULITIC QUARTZ-NORMATIVE ST. 9A 1.2 g
MARE BASALT

INTRODUCTION: 15608 is a fine-grained, slightly vesicular quartz-normative mare basalt (Fig. 1). It is microporphyritic, and has a textural gradation across it which suggests it is a chilled margin sample. It is gray, angular with subrounded corners, and tough. It has a few per cent tiny vugs and many zap pits on most faces. 15608 was collected as part of the rake sample at Station 9A.

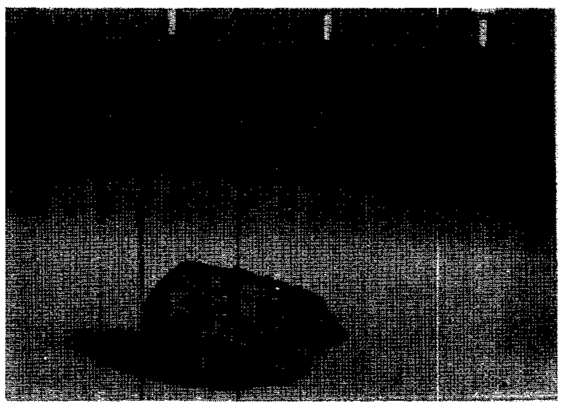


Figure 1. Pre-split view of 15608. S-71-44966

PETROLOGY: 15608 consists dominantly of skeletal pigeonite microphenocrysts in a finer-grained, variolitic groundmass (Fig. 2). The groundmass consists of pyroxene, plagioclase, and opaque minerals (chromite, ulvospinel mainly). Glass is minor. Rarely, aggregates of small olivine phenocrysts are present. The pyroxene commonly form radial structures. A unique feature of this sample is that one edge is much finer-grained and consists of parallel pyroxene blades (Fig. 2) and a groundmass arrangement of plagioclase, pyroxene, and opaque minerals perpendicular to them. This edge would appear to be a chilled margin; even so, it contains very little glass. Steele et al. (1972) reported that the skeletal pyroxenes were Mg-rich and the groundmass pyroxenes were more Fe-rich. They suggested that the textures indicated devitrification but did not mention the strong textural grade.

PROCESSING AND SUBDIVISIONS: The sample was sawn to produce two pieces. ,0 is now only 0.370 g and has a sawn face. ,1 was potted and partly used to make thin sections ,5; ,6; and ,7.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15608,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers. Top are the finer-grained parallel blades of pigeonite which probably are a chilled margin. Center is a cluster of equant olivine microphenocrysts.

15609 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT — ST. 9A — 1.10 g

INTRODUCTION: 15609 is a fine-grained ophitic olivine-bearing mare basalt (Fig. 1) which is presumably a fine-grained member of the Apollo 15 olivine-normative mare basalt group. It is a blocky, subangular, tough fragment which was originally too dust-covered for surface features to be inspected. The yellow-green olivines are visible macroscopically. 15609 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15609 is a fine-grained olivine-bearing mare basalt (Fig. 2). Small, sparse, anhedral olivine phenocrysts and small, granular olivines and pyroxenes are embedded in plagioclases which are less than 1 mm long. Opaque phases cluster with the granular mafic grains and range from chromite through ulvospinel to ilmenite.

PROCESSING AND SUBDIVISIONS: A small piece was chipped to make potted butt ,1 which was partly used to make thin sections ,5 and ,6. ,0 is now 0.76 g.

Figure 1. Pre-chip, dust-covered view of 15609. S-71-44962

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15609,5. Width about 3 mm. a) transmitted light; b) crossed polarizers.

15610 COARSE-GRAINED OLIVINE-NORMATIVE ST. 9A 1.50 g
MARE BASALT

INTRODUCTION: 15610 is a coarse-grained, olivine-bearing mare basalt with a hackly appearance (Fig. 1). The olivine does not form phenocrysts. The sample is brownish gray, blocky and angular, and tough. It contains 10 to 15% cavities with pyroxene prisms crossing them. The yellow-green olivines are visible but not conspicuous macroscopically. A few zap pits occur on one face. 15610 was collected as part of the rake sample at Station 9A.

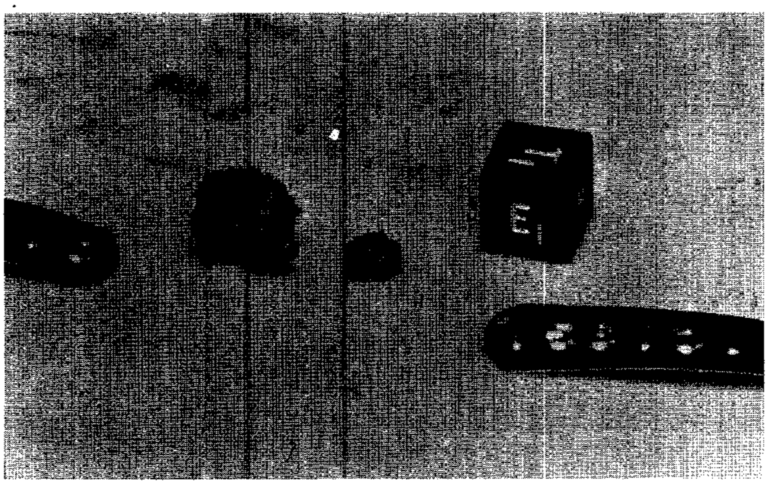


Figure 1. Post-chip view of 15610. S-72-20378

PETROLOGY: 15610 is a very coarse, gabbroic-textured olivine-bearing basalt. Plagioclases 1 to 2 mm across enclose small pyroxenes and olivines. Some pyroxenes larger than 1 mm across are twinned, and sparse olivines up to 2 mm across contain silicate liquid inclusions. Dowty et al. (1973a,b) gave a mode of 51% pyroxene, 25% plagioclase, 13% olivine, 8% opaque minerals, 0.6% silica (actually cristobalite) and 2.4% mesostasis. The residual phases include glass, cristobalite, troilite, and sieved fayalite. Microprobe analyses of pyroxene, olivine, plagioclase, Si-K-rich glass, and metal were tabulated by Dowty et al. (1973c) and spinel group and ilmenite analyses were tabulated by Nehru et al. (1973). Nehru et al. (1974) tabulated a chromite analysis and included 15610 in their general discussion. The mineral chemistries (Fig. 3) are typical of Apollo 15 olivine-normative mare basalts. The metal contains 1.0 to 2.3% Co and 0.8 to 12.5% Ni, and the ilmenite contains 0.13 to 1.21% MgO.

Fig. 2a

Fig. 2b

Figure 2. Photomicrograph of 15610,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

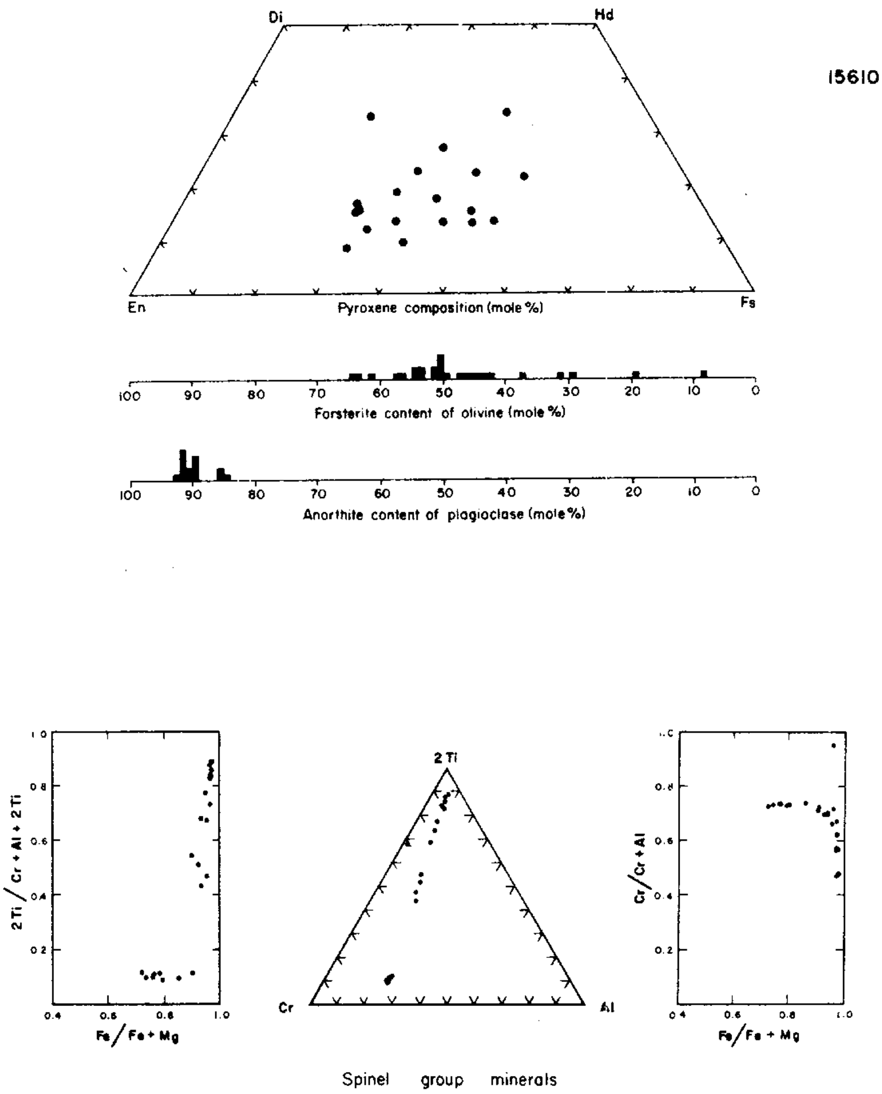


Figure 3. Chemistry of minerals in 15610 (Dowty et al., 1973b).

CHEMISTRY: The only bulk analysis is the microprobe defocussed-beam analysis of Dowty *et al*. (1973a,b) (Table 1). The analysis shows a fairly average Apollo 15 olivine-normative mare basalt.

PROCESSING AND SUBDIVISIONS: A single piece was chipped off (,1) (Fig. 1), potted and partly used to make thin sections ,5 and ,6. ,0 is now 1.23 g.

TABLE 15610-1. Defocussed beam bulk analysis (Dowty *et al*., 1973a,b)

Wt %	SiO_2	44.8
	TiO_2	2.86
	Al_2O_3	7.8
	FeO	22.9
	MgO	10.7
	CaO	9.6
	Na_2O	0.28
	K_2O	0.06
	P_2O_5	0.18
ppm	Cr	3425
	Mn	1940

15612 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 5.90 g

INTRODUCTION: 15612 is a medium-grained olivine-bearing mare basalt which is very vesicular (Fig. 1). A few olivines form phenocrysts. In chemistry the sample appears to be an Mg-rich member of the Apollo 15 olivine-normative mare basalt group. It is tough with the porphyritic olivines macroscopically visible. 15612 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15612 is a medium-grained olivine-bearing mare basalt (Fig. 2) with some of the olivine forming anhedral phenocrysts up to 2 mm long. Plagioclase laths project into their exteriors in a peculiar multiple needle-like fashion. The dominant phase is pyroxene in large and small grains. Residual phases include fayalite (sieved and unsieved), cristobalite, glass, ulvospinel and ilmenite, and troilite. The sample is very vesicular, and many of the vesicles are lined with opaque minerals, mainly ulvospinel.

CHEMISTRY: A bulk chemical analysis, listed in Table 1 and with rare earths shown in Figure 3, shows the sample to be a member of the Apollo 15 olivine-normative mare basalt group. The low TiO_2 and the (imprecisely measured) high MgO suggest that the sample is not average but an Mg-enriched sample.

PROCESSING AND SUBDIVISIONS: Original chipping produced some small chips (,1), and a larger chip (,2). The latter was partly used to make thin sections ,6 and ,13. In 1976 three of the larger chips composing ,1 were allocated for chemistry and a third thin section (,10) also made from them. ,0 is now 4.60 g.

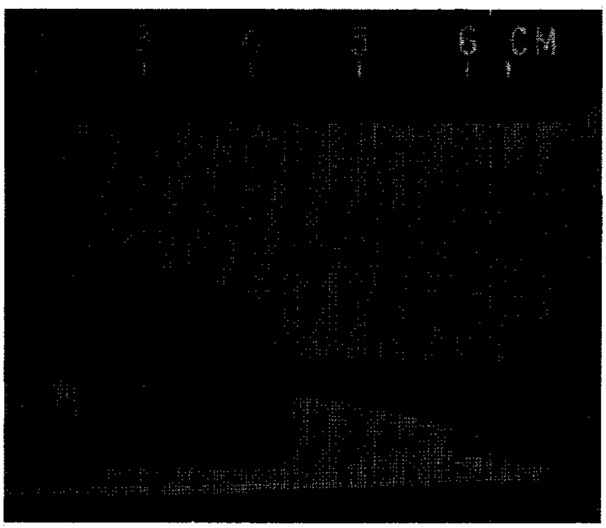


Figure 1. Pre-chip view of 15612. S-71-49066

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15612,13. Widths about 3 mm. At bottom is opaque-lined vesicle. Center is an olivine phenocryst with plagioclase projecting into it. a) transmitted light; b) crossed polarizers.

TABLE 15612-1. Bulk rock chemical analysis

		,3
Wt %	SiO2	
	TiO2	2.2
	Al2O3	8.5
	FeO	22.2
	MgO	12
	CaO	9.2
	Na2O	0.244
	K2O	0.037
	P2O5	
(ppm)	Sc	37
	V	208
	Cr	5500
	Mn	2015
	Co	52
	Ni	65(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.7
	Ba	50(b)
	Th	
	U	
	Pb	
	La	5.5
	Ce	
	Pr	
	Nd	
	Sm	3.6
	Eu	0.84
	Gd	
	Tb	0.7
	Dy	4.2
	Ho	
	Er	
	Tm	
	Yb	2.2
	Lu	0.31
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	460
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

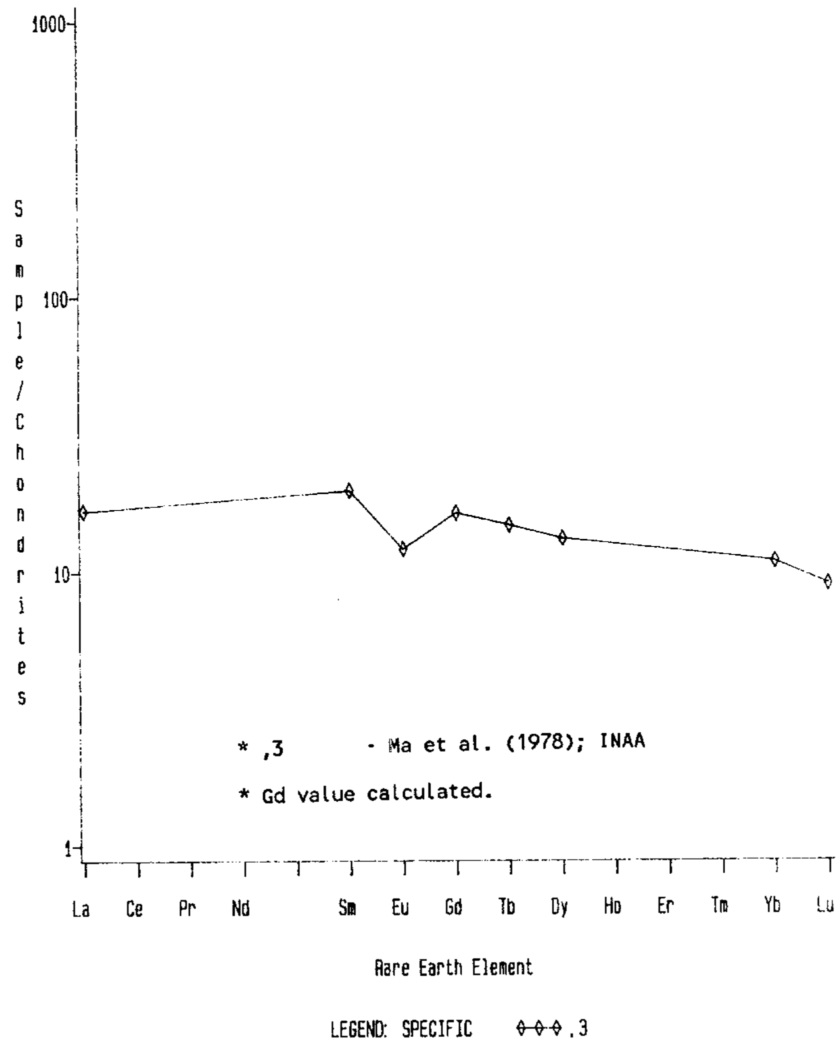


Figure 3. Rare earths in 15612.

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ± 30 ppm
(b) ± 40 ppm

15613 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 1.00 g

INTRODUCTION: 15613 is a medium-grained olivine-bearing mare basalt which is vesicular (Fig. 1). A few olivines form phenocrysts. It is tough with porphyritic olivine macroscopically visible. 15613 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15613 is a medium-to fine-grained olivine-bearing mare basalt (Fig. 2) with olivines largely phenocrystic. Most pyroxenes are small, but a few are up to 2 mm long. The plagioclases form lathy to stubby hollow crystals which in places form a radiate structure. Dowty et al. (1973a,b) described 15613 as a vesicular olivine microgabbro with small olivines and some variolitic-fasciculate intergrowths of feldspar and pyroxene. They reported a mode of 55% pyroxene, 29% plagioclase, 10% olivine, 4% opaques, 0.6% silica phase (actually cristobalite) and 1.4% miscellaneous. Microprobe analyses of pyroxene, olivine, plagioclase, Si-K glass, and Fe-metal were tabulated by Dowty et al. (1973c), and spinel group and ilmenite analyses were tabulated by Nehru et al. (1973). The latter were included in the discussion but no data specified in Nehru et al. (1974). The metal grains contain 1.5 to 2.4% Co and 6.7 to 8.5% Ni, although one grain had 1.0% Co and 1.9% Ni. Ilmenite contains 0.3 to 1.95% MgO. The mineral compositions (Fig. 3) are typical of Apollo 15 olivine-normative mare basalts.

CHEMISTRY: The only bulk analysis is the microprobe defocussed-beam analysis of Dowty et al. (1973a,b) (Table 1). The analysis shows a fairly average Apollo 15 olivine-normative mare basalt.

PROCESSING AND SUBDIVISIONS: Chipping produced two small pieces, the smallest of which remains as part of ,0 (now 0.80 g). The other, ,1 was partly consumed in producing thin sections ,2 and ,3.

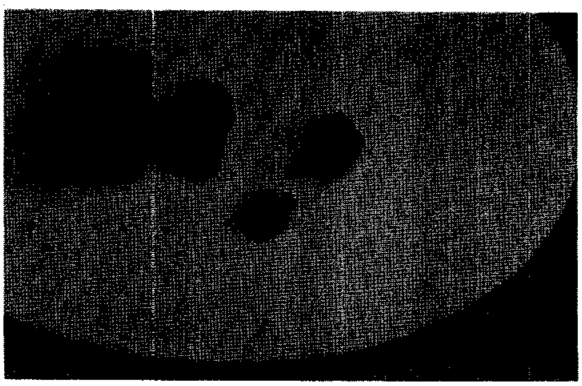


Figure 1. Post-chip view of 15613. Medium-sized chip is ,1.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15613,2. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

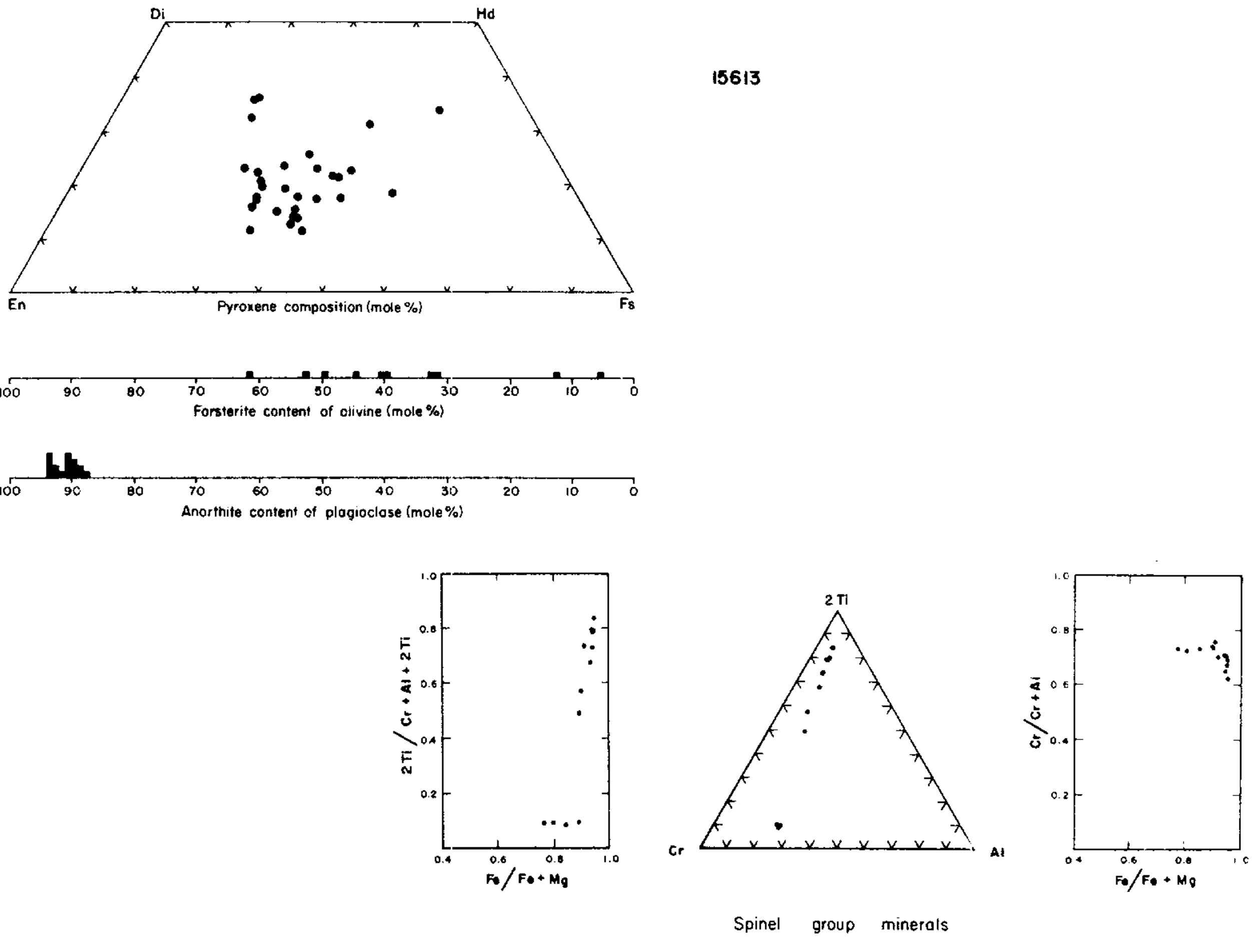


Figure 3. Chemistry of minerals in 15613 (Dowty *et al.*, 1973b).

TABLE 15613-1. Defocussed beam bulk analysis (Dowty *et al.*, 1973a, b)

Wt %	SiO2	44.1
	TiO2	2.66
	Al2O3	9.2
	FeO	22.9
	MgO	10.4
	CaO	9.4
	Na2O	0.34
	K2O	0.04
	P2O5	0.06
ppm	Cr	3015
	Mn	1860

15614 COARSE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 9.70 g

INTRODUCTION: 15614 is an olivine-bearing mare basalt which is very vesicular (Fig. 1). In chemistry it is an average to magnesian Apollo 15 olivine-normative mare basalt. It was collected as part of the rake sample at Station 9A.

PETROLOGY: 15614 is a vesicular, olivine-bearing mare basalt with a coarse gabbroic texture (Fig. 2).

CHEMISTRY: A bulk chemical analysis is listed in Table 1 and the rare earths shown in Figure 3. The sample is an Apollo 15 olivine-normative mare basalt. On the basis of TiO_2 and MgO it would appear to be an Mg-rich member of the group, but the MgO is imprecisely determined.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) measured a natural magnetic intensity of 5.4×10^{-6} emu/g, a value typical for Apollo 15 mare basalts.

PROCESSING AND SUVDIVISIONS: Chipping produced several chips numbered ,1 and one chip numbered ,2 (Fig. 1). ,2 was used for chemical analysis and to make thin section ,5. ,0 is now 7.40 g.

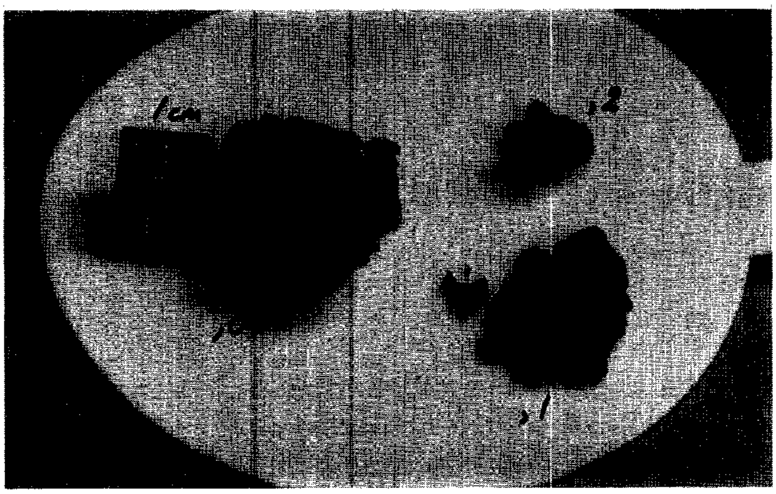


Figure 1. Post-chip view of 15614. S-71-56156

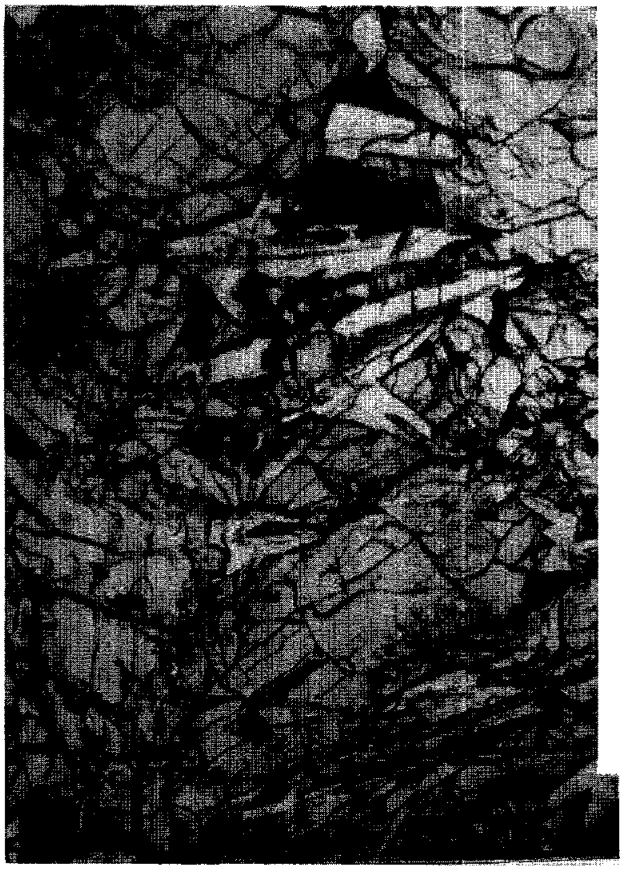


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15614,5. a) Transmitted light; b) crossed polarizers. Widths about 2 mm.

TABLE 15614-1. Bulk rock chemical analysis

		,2
Wt. %	SiO2	
	TiO2	2.0
	Al2O3	8.8
	FeO	21.3
	MgO	11
	CaO	8.9
	Na2O	0.250
	K2O	0.034
	P2O5	
(ppm)	Sc	38
	V	218
	Cr	4685
	Mn	2070
	Co	52
	Ni	70(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.4
	Ba	55(b)
	Th	
	U	
	Pb	
	La	5.2
	Ce	
	Pr	
	Nd	
	Sm	3.4
	Eu	0.76
	Gd	
	Tb	0.6
	Dy	4.0
	Ho	
	Er	
	Tm	
	Yb	2.0
	Lu	0.27
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	390
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

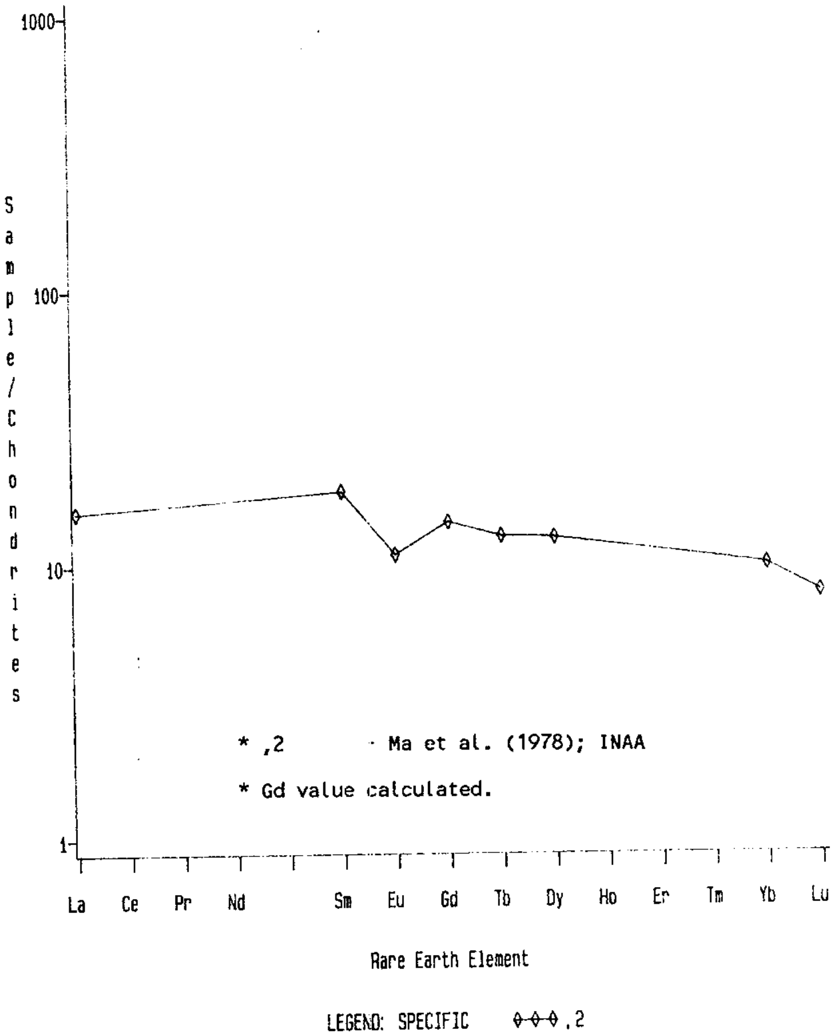


Figure 3. Rare earths in 15614.

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ± 30 ppm
(b) ± 25 ppm

15615 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 1.70 g

INTRODUCTION: 15615 is a medium-grained olivine-bearing mare basalt which is very vesicular (Fig. 1). A few olivines form phenocrysts. It is tough with the porphyritic olivines macroscopically visible. 15615 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15615 is a vesicular, olivine-bearing mare basalt (Fig. 2). It has a generally gabbroic texture, but some olivines form phenocrysts. The plagioclases are stubby to lathy. The dominant phase, pyroxene, is almost invariably smaller than 1 mm; larger areas contain small olivine inclusions. Dowty et al. (1973a,b) reported a mode of 59% pyroxene, 22% plagioclase, 13% olivine, 4% opaques, 0.5% silica (actually cristobalite), and 1.5% miscellaneous. They noted that the later growth stages were dominated by variolitic-fasciculate pyroxene and plagioclase. Microprobe analyses of pyroxene, olivine, plagioclase, Si-K glass, and Fe-metal were tabulated in Dowty et al. (1973c), and spinel group and ilmenite analyses were tabulated in Nehru et al. (1973). Nehru et al. (1974) included 15615 in their general discussion but gave no specific data or discussion. The metal grains contain 1.4 to 2.1% Co and 6.2 to 8.8% Ni generally, but some grains have 2.5 to 2.7% Co and 14 to 18% Ni. Ilmenite contains 0.08 to 2.2% MgO. The mineral compositions (Fig. 3) are typical for Apollo 15 olivine-normative mare basalts.

CHEMISTRY: The only bulk analysis is the microprobe defocussed-beam analysis of Dowty et al. (1973a,b) (Table 1). The analysis shows an average or MgO-enriched olivine-normative mare basalt.

PROCESSING AND SUBDIVISIONS: A single chip was removed (Fig. 1), and was partly used to make thin sections ,2 and ,3. ,0 is now 1.50 g.

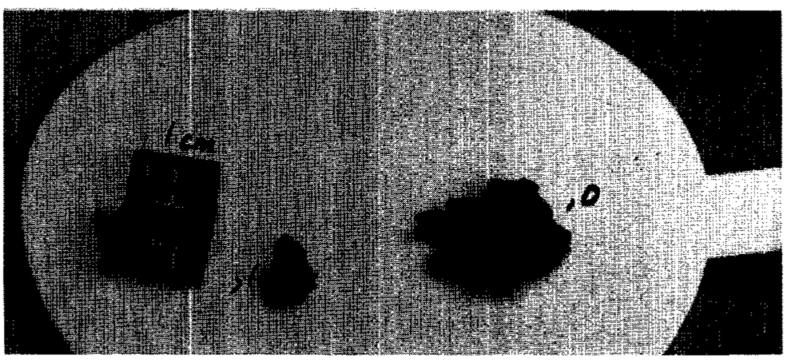


Figure 1. Post-chip view of 15615. S-71-56171

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15615,2. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

Figure 3. Chemistry of minerals in 15615 (Dowty et al., 1973b).

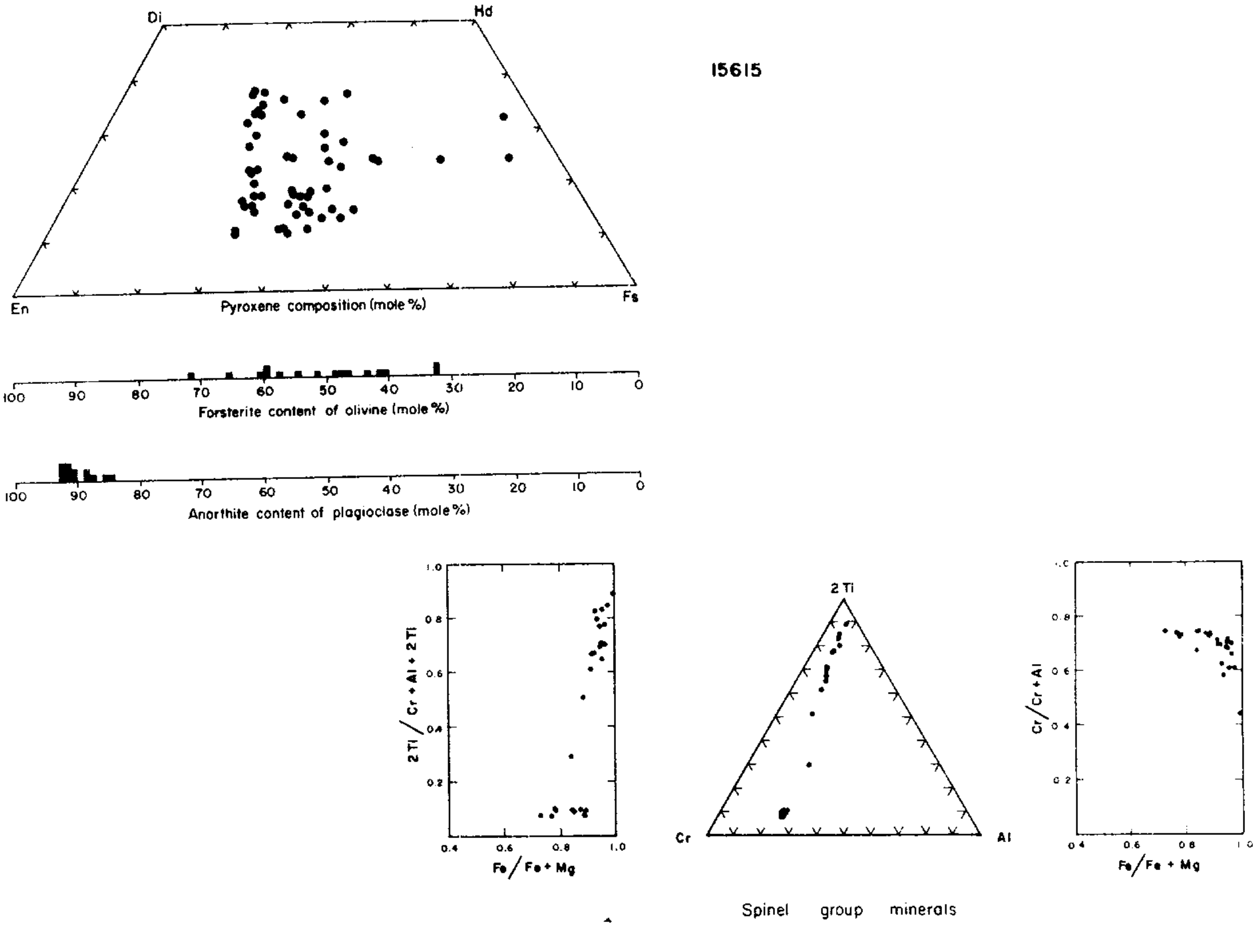


TABLE 15615-1. Defocussed beam bulk analysis (Dowty et al., 1973a,b)

Wt %	SiO_2	43.8
	TiO_2	2.37
	Al_2O_3	9.2
	FeO	23.4
	MgO	11.3
	CaO	9.0
	Na_2O	0.32
	K_2O	0.03
	P_2O_5	0.05
ppm	Cr	3425
	Mn	2015

15616 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 8.00 g

INTRODUCTION: 15616 is an olivine-bearing mare basalt which is very vesicular (Fig. 1). The olivines form microphenocrysts. Chemically the sample appears to be a magnesian member of the Apollo 15 olivine-normative mare basalt group. It is tough with porphyritic olivine macroscopically visible. It was collected as part of the rake sample at Station 9A.

PETROLOGY: 15616 is a medium-grained, olivine-bearing mare basalt (Fig. 2). It is vesicular. Some olivines form small anhedral phenocrysts (less than 1 mm). Some pyroxenes are as large as 2 mm and twinned, but most are smaller and granular. Plagioclases are up to 1 mm long laths, or hollow stubby sections.

CHEMISTRY: A bulk rock analysis is listed in Table 1 and the rare earths shown in Figure 3. The sample is an Apollo 15 olivine-normative mare basalt. On the basis of TiO_2 and MgO it would appear to be an Mg-rich member of the group, but the MgO is imprecisely determined.

PROCESSING AND SUBDIVISIONS: Several chips were numbered as ,2, and a single chip as ,1. ,1 was partly consumed in making thin sections ,6 and ,11. In 1977 the largest chip from ,2 was numbered ,4 and allocated for chemistry and a third section, ,14. ,0 is now 6.40 g.

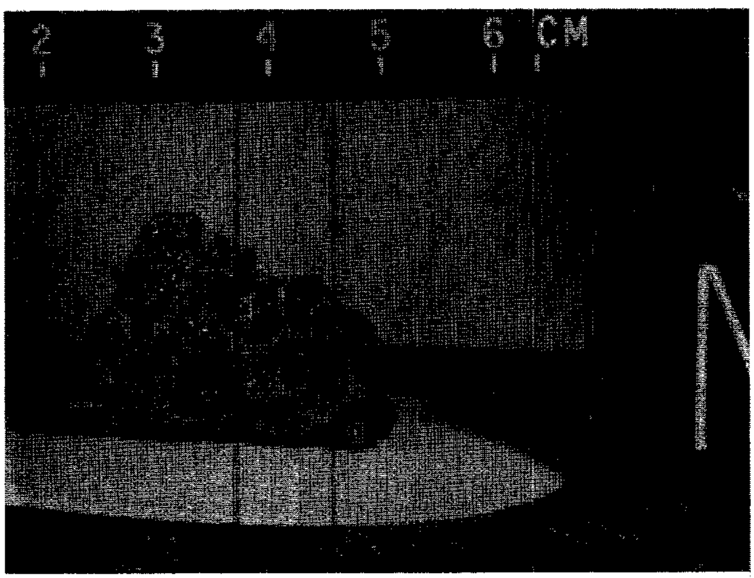


Figure 1. Pre-chip view of 15616. S-71-49120

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15616,11. Widths about 2 mm. a) transmitted light; b) crossed polarizers.

TABLE 15616-1. Bulk rock chemical analyses

		,4
Wt %	SiO2	
	TiO2	2.0
	Al2O3	8.7
	FeO	21.8
	MgO	12
	CaO	8.3
	Na2O	0.238
	K2O	0.043
	P2O5	
(ppm)	Sc	38
	V	248
	Cr	6230
	Mn	2045
	Co	57
	Ni	90
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.4
	Ba	60
	Th	
	U	
	Pb	
	La	5.3
	Ce	
	Pr	
	Nd	
	Sm	3.5
	Eu	0.77
	Gd	
	Tb	0.7
	Dy	3.8
	Ho	
	Er	
	Tm	
	Yb	2.2
	Lu	0.34
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	470
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

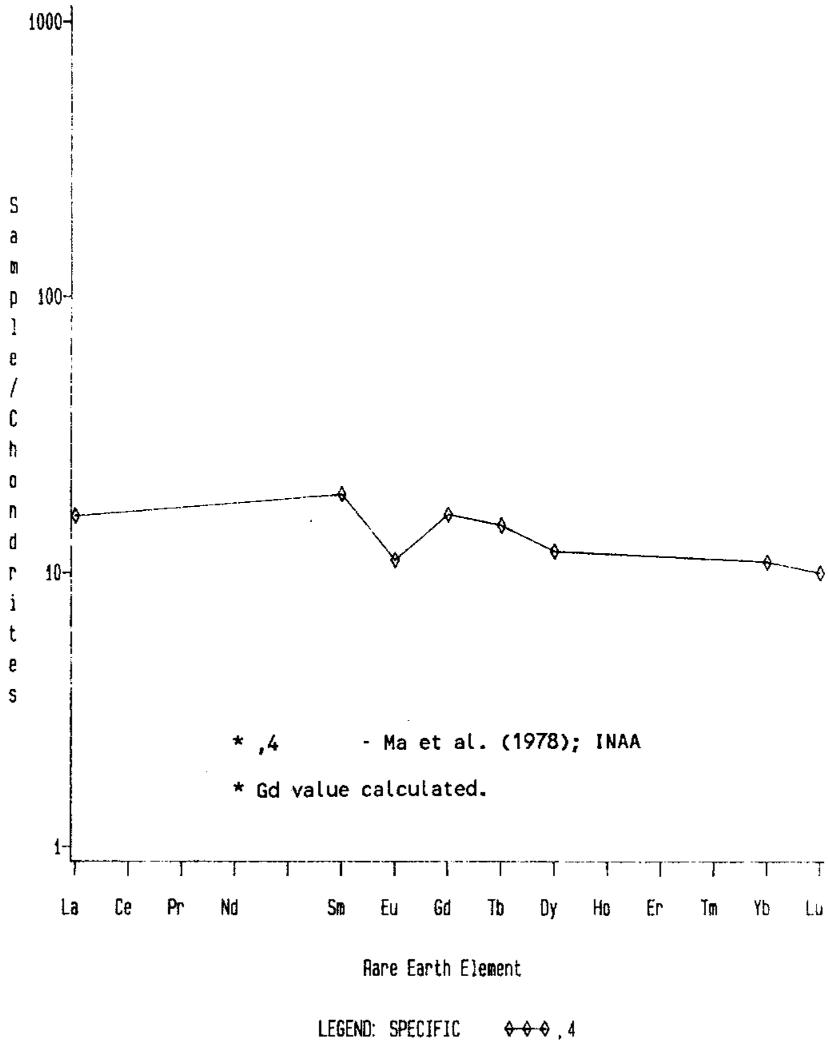


Figure 3. Rare earths in 15616.

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) +45 ppm
(b) ∓30 ppm

15617 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 3.10 g

INTRODUCTION: 15617 is a medium-grained, olivine-bearing mare basalt which is very vesicular (Fig. 1). The olivine includes some microphenocrysts. In chemistry the sample appears to be a magnesian member of the Apollo 15 olivine-normative mare basalt group. It is tough with porphyritic olivine macroscopically visible. 15617 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15617 is an olivine-bearing, medium-grained, vesicular mare basalt (Fig. 2). Olivines are present as microphenocrysts, as small grains or inclusions in pyroxenes, and as small discrete grains. Some larger pyroxenes are twinned and zoned. Dowty et al. (1973b) described 15617 as an olivine-microgabbro "similar to 15613". They reported a mode of 56% pyroxene, 24% plagioclase, 11% olivine, 6% opaques, no silica, and 2% miscellaneous. They noted it to have subradiating intergrowths of elongated pyroxene and plagioclase crystals. Microprobe analyses of pyroxene, olivine, plagioclase, Si-K glass, and Fe-metal were tabulated by Dowty et al. (1973c), and spinel group and ilmenite analyses were tabulated by Nehru et al. (1973). Nehru et al. (1974) included 15617 in their general discussion but gave no specific data or discussion. The mineral chemistry (Fig. 3) is typical of Apollo 15 olivine-normative mare basalts.

CHEMISTRY: A bulk rock analysis is listed in Table 1 and the rare earths are shown in Figure 4. A defocussed beam microprobe analysis (Table 2) is consistent, and the low TiO_2 and high MgO suggest that this sample is an Mg-rich member of the Apollo 15 olivine-normative mare basalt group.

PROCESSING AND SUBDIVISIONS: A single chip ,1 was originally removed (Fig. 1) and partly used to make thin sections ,2 and ,6. In 1977, ,0 was rechipped to produce ,3 which was used for chemical analysis and to make thin section ,7. During this operation, ,0 also split into two pieces; these two pieces have a total mass of 2.28 g.

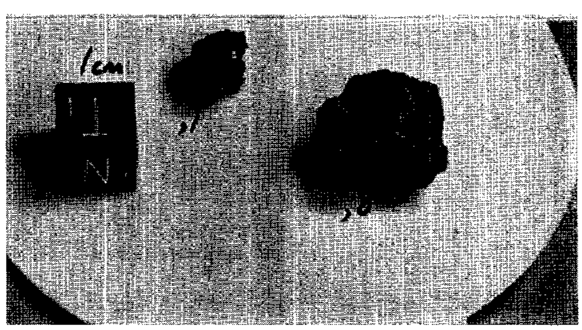


Figure 1. Post-original-chipping of 15617. S-71-56283

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15617,2. Widths about 2 mm. a) transmitted light; b) crossed polarizers.

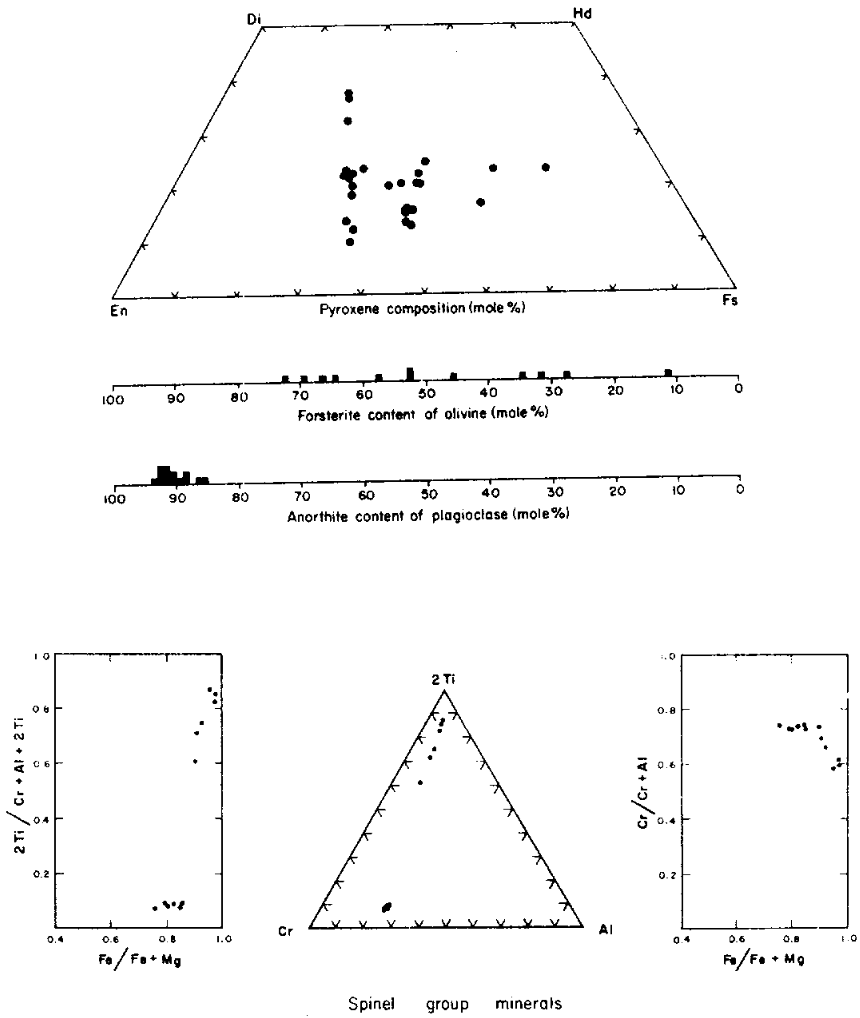


Figure 3. Chemistry of minerals in 15617 (Dowty et al., 1973b).

TABLE 15617-1. Bulk rock chemical analyses

		,3
Wt %	SiO2	
	TiO2	2.1
	Al2O3	8.8
	FeO	21.8
	MgO	12
	CaO	8.5
	Na2O	0.256
	K2O	0.041
	P2O5	
(ppm)	Sc	36
	V	208
	Cr	4945
	Mn	2080
	Co	49
	Ni	65
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.5
	Ba	70
	Th	
	U	
	Pb	
	La	5.2
	Ce	
	Pr	
	Nd	
	Sm	3.4
	Eu	0.80
	Gd	
	Tb	0.7
	Dy	4.4
	Ho	
	Er	
	Tm	
	Yb	2.1
	Lu	0.31
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	370
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ±25 ppm
(b) ±35 ppm

TABLE 15617-2. Defocussed beam bulk analysis (Dowty et al., 1973a,b)

Wt %	SiO2	45.7
	TiO2	2.03
	Al2O3	8.0
	FeO	22.6
	MgO	11.8
	CaO	9.2
	Na2O	0.28
	K2O	0.01
ppm	Cr	2875
	Mn	1935

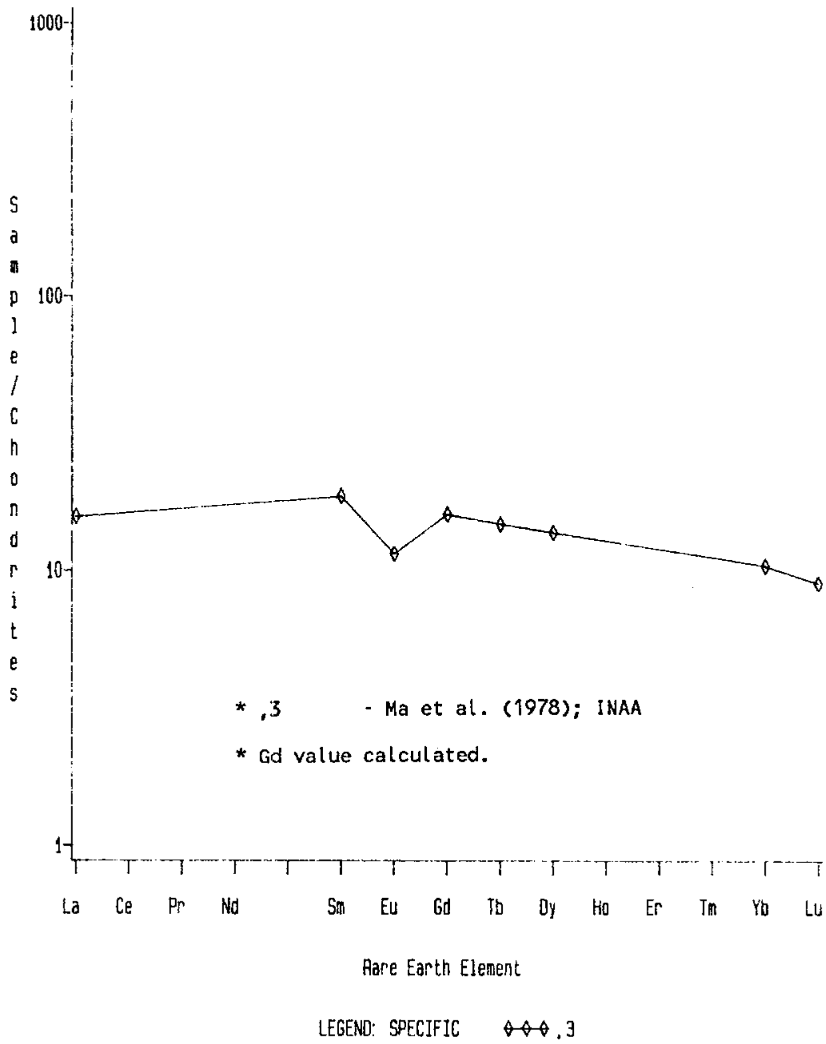


Figure 4. Rare earths in 15617.

15618 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.80 g

INTRODUCTION: 15618 is a very vesicular mare basalt fragment (Fig. 1), macroscopically very similar to 15612, 15615, etc. Small yellow-green olivines are visible. The sample has never been allocated or subdivided.

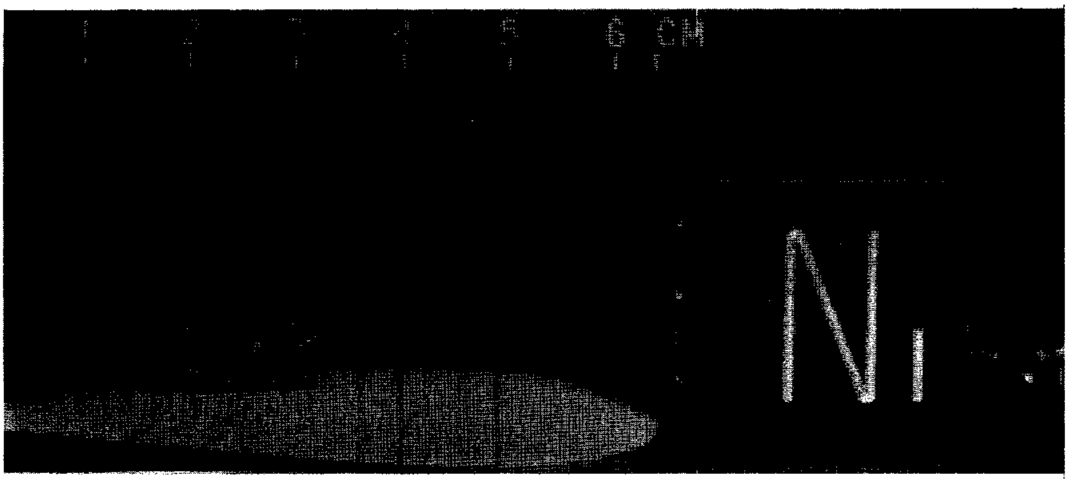


Figure 1. Sample 15618. S-71-49112

15619 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.60 g

INTRODUCTION: 15619 is a very vesicular mare basalt fragment (Fig. 1), macroscopically very similar to 15612, 15615, etc. Small yellow-green olivines are visible. The sample has never been allocated or subdivided.

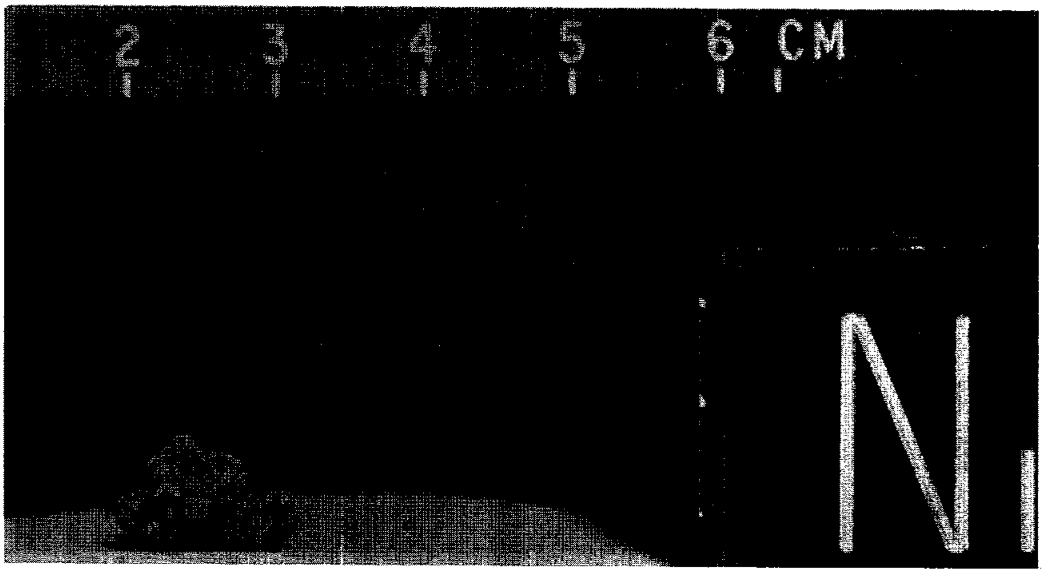


Figure 1. Sample 15619. S-71-49108

15620 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 6.60 g

INTRODUCTION: 15620 is a medium-grained, olivine-bearing mare basalt which is very vesicular (Fig. 1). The yellow-green olivines are visible macroscopically but are rarely phenocrysts. In chemistry, the sample is a fairly average Apollo 15 olivine-normative mare basalt. It is tough. 15620 was collected as part of the rake sample at Station 9A.

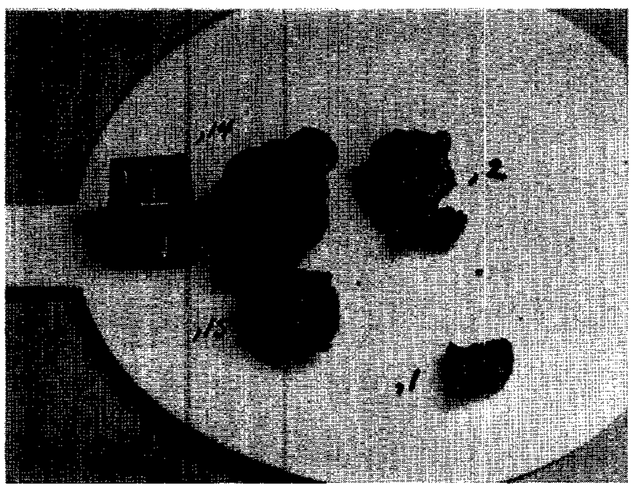


Figure 1. Post-chip view of 15620. S-71-56281

PETROLOGY: 15620 is a medium-grained, olivine-bearing, vesicular mare basalt (Fig. 2). The texture is gabbroic, with the olivines forming fairly small (less than 1 mm) anhedral crystals which only rarely are large enough to be considered phenocrystic. The pyroxenes, generally no more than 1 mm long, have mosaic extinction and the larger ones contain small olivine inclusions. Plagioclases are less than 1 mm long and either lathy or hollow, stubby cross-sections. Dowty et al. (1973c,b) reported a mode of 63% pyroxene, 24% plagioclase, 8% olivine, 4% opaque minerals, 0.2% silica (actually cristobalite) and 0.8% miscellaneous. Microprobe analyses of pyroxene, plagioclase, olivine, si-k glass, and fe-metal were tabulated by Dowty et al. (1973c), and spinel group and ilmenite analyses were tabulated by Nehru et al. (1973). 15620 was included in the general discussion of Nehru et al. (1974) but no specific data or discussion were presented. The metal grains generally contain 1.3 to 1.8% Co and 4.9 to 6.8% Ni, but grains contain up to 4.2% Co and 28% Ni. The ilmenite contains 0.11 to 1.03% MgO. The mineral chemistry (Fig. 3) is typical of the Apollo 15 olivine-normative mare basalts.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15620,3. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

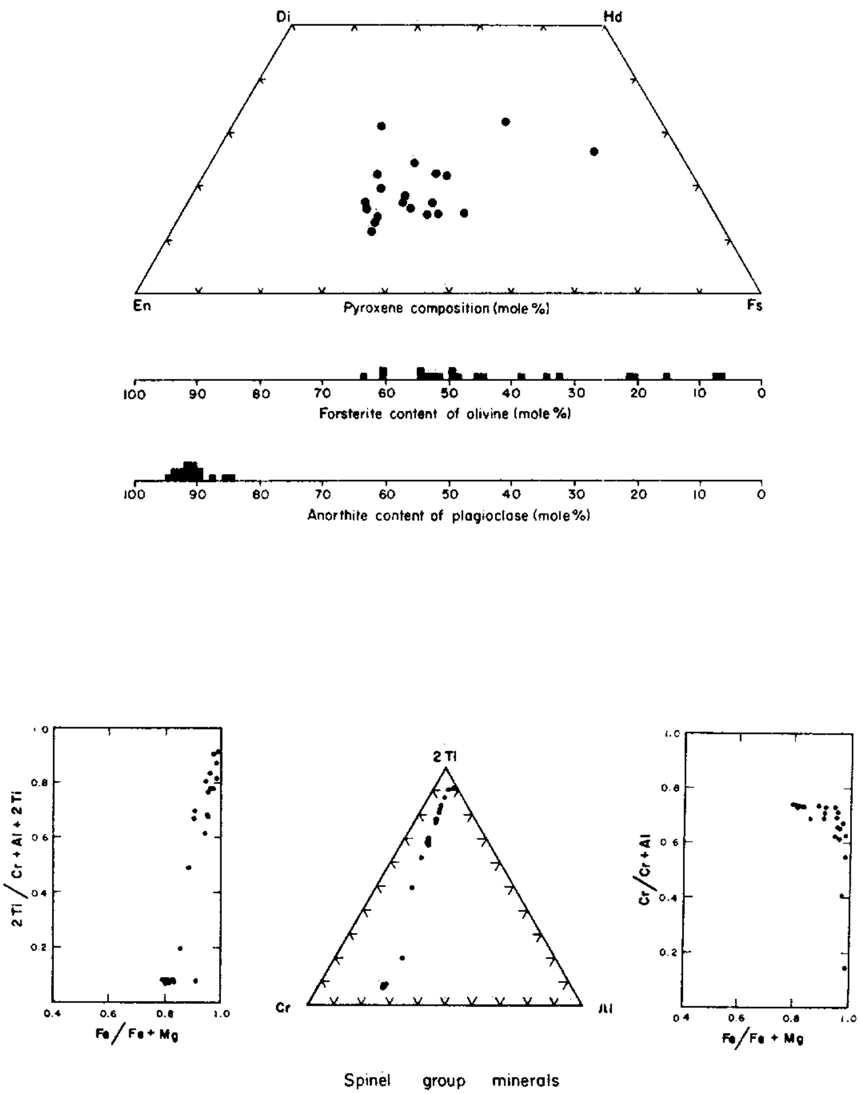


Figure 3. Chemistry of minerals in 15620 (Dowty et al., 1973b).

CHEMISTRY: A bulk rock analysis is listed in Table 1 and the rare earths shown in Figure 4. A defocussed beam microprobe analysis (Table 2) is generally consistent. The analyses show that 15620 is an average to slightly Mg-enriched Apollo 15 olivine-normative mare basalt.

PROCESSING AND SUBDIVISIONS: 15620 was chipped up (Fig. 1), with ,1 being potted and partly used to make thin sections ,3; ,10; and ,11. In 1975 the two chips constituting ,0 were numbered separately as ,14 and ,15 and small chips were taken from ,2 for chemical analysis. ,14 and ,15 have masses of 3.23 g and 1.56 g respectively.

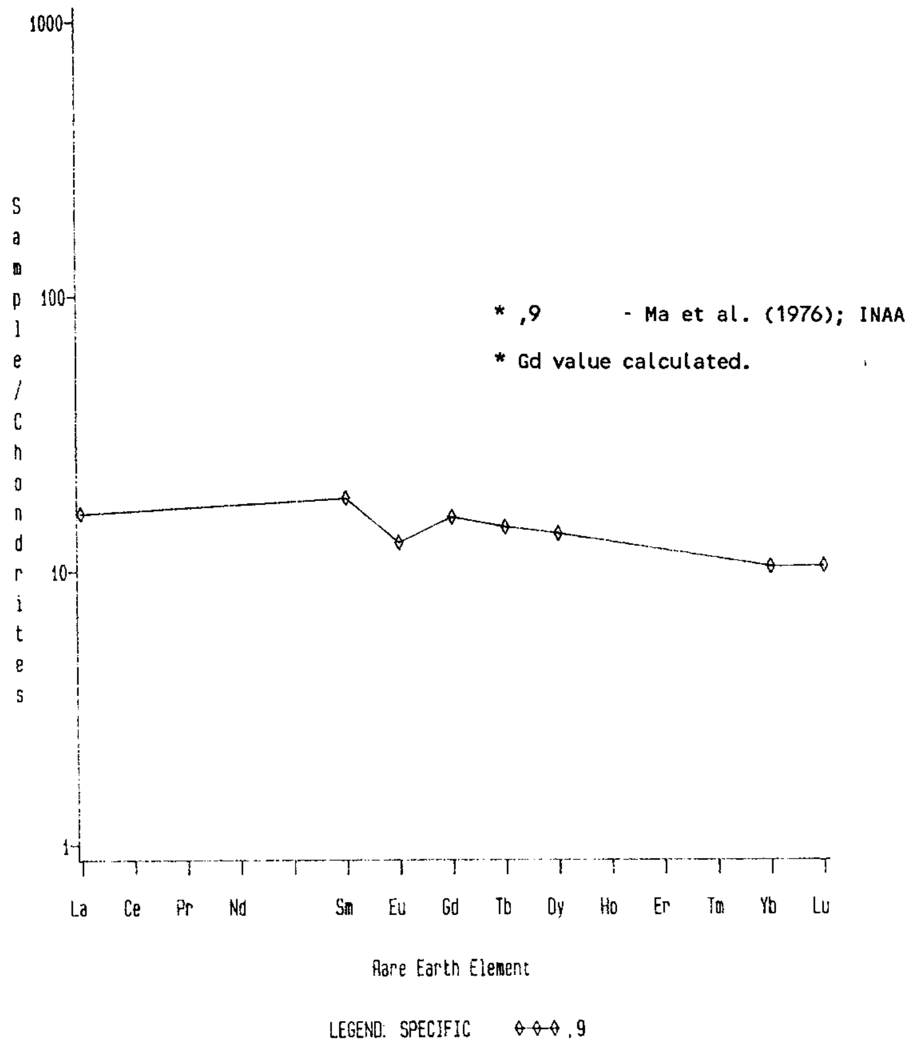


Figure 4. Rare earths in 15620.

TABLE 15620-1. Bulk rock chemical analysis

		,9
Wt%	SiO2	
	TiO2	2.3
	Al2O3	8.8
	FeO	23.5
	MgO	11.1
	CaO	8.9
	Na2O	0.259
	K2O	0.044
	P2O5	
(ppm)	Sc	41
	V	225
	Cr	4420
	Mn	2000
	Co	48
	Ni	95
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.7
	Ba	54(a)
	Th	
	U	
	Pb	
	La	5.4
	Ce	
	Pr	
	Nd	
	Sm	3.4
	Eu	0.88
	Gd	
	Tb	0.69
	Dy	4.4
	Ho	
	Er	
	Tm	
	Yb	2.1
	Lu	0.36
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	440
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

TABLE 15620-2. Defocussed beam bulk analysis (Dowty et al., 1973a,b)

Wt%	SiO2	44.9
	TiO2	2.63
	Al2O3	9.7
	FeO	21.9
	MgO	10.9
	CaO	9.6
	Na2O	0.36
	K2O	0.04
	P2O5	0.13
ppm	Cr	2740
	Mn	2170

References and methods:

(1) Ma et al. (1976); INAA

Notes:

(a) $\pm$15 ppm

15621 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 1.60 g

INTRODUCTION: 15621 is a medium-grained, olivine-bearing mare basalt which is very vesicular (Fig. 1). The yellow-green olivines are visible macroscopically and some form phenocrysts. 15621 is tough and was collected as part of the rake sample at Station 9A.

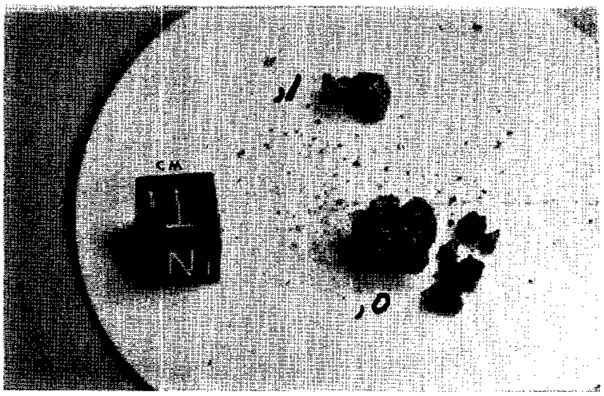


Figure 1. Post-chip view of 15621. S-71-56293

PETROLOGY: 15621 is a medium-grained, very vesicular, olivine-bearing mare basalt (Fig. 2). Some of the olivines form phenocrysts, generally less than 1 mm across and anhedral. The plagioclases are irregular laths up to 1 mm long, and hollow. Steele et al. (1980) reported ion-microprobe analyses of plagioclase for Li (21 ppm), Mg (2970 ppm), K (490 ppm), Ti (635 ppm), Sr (350 ppm), and Ba (30 ppm), for plagioclase of 14.3 mol% Ab. The Mg in plagioclase is high as in other mare basalt types.

PROCESSING AND SUBDIVISIONS: Several chips were taken from ,0, and only the largest, ,1 was numbered separately (Fig. 1). It was partly used to make thin sections ,1 and ,6. ,0 consists of one larger chip and several small chips totalling 1.30 g.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15621,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

15622 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 29.5 g

INTRODUCTION: 15622 is a highly vesicular basalt with red-brown pyroxene and porphyritic olivine (Fig. 1). It appears to be a magnesian member of the olivine-normative mare basalt group. It was collected as part of the rake sample at Station 9A.

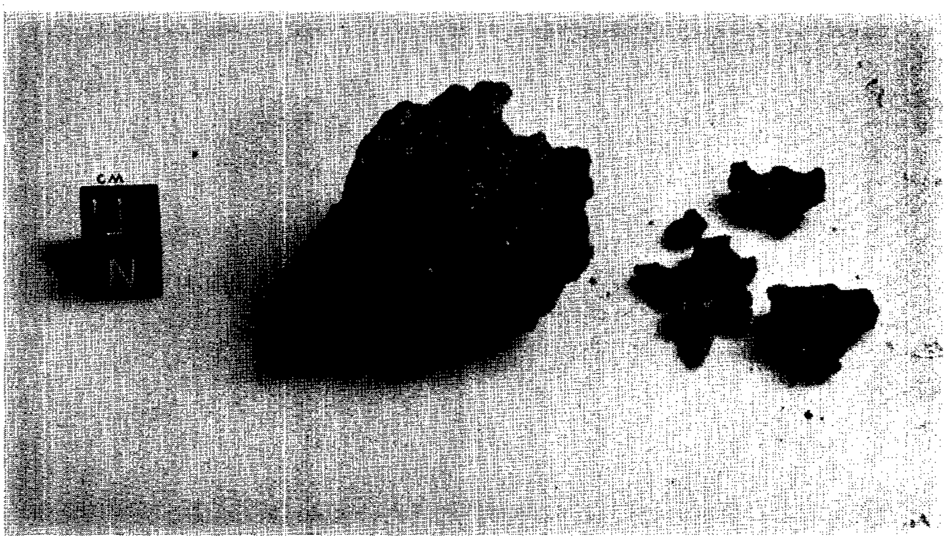


Figure 1. Post chip view of 15622. S-71-56278

CHEMISTRY: Chemical analyses are listed in Table 1 and the rare-earths shown in Figure 2. Chappell and Green (1973) found it to be one of the most magnesian members of the olivine-normative mare basalt suite, but did not have the evidence to decide whether it was a primitive magma composition or a cumulate. They suggested it was the same rock as 15636, but that rock is much less vesicular and has a coarser grain size. The partial analysis of Fruchter et al. (1973) contains higher TiO_2, and has anomalously low Al_2O_3.

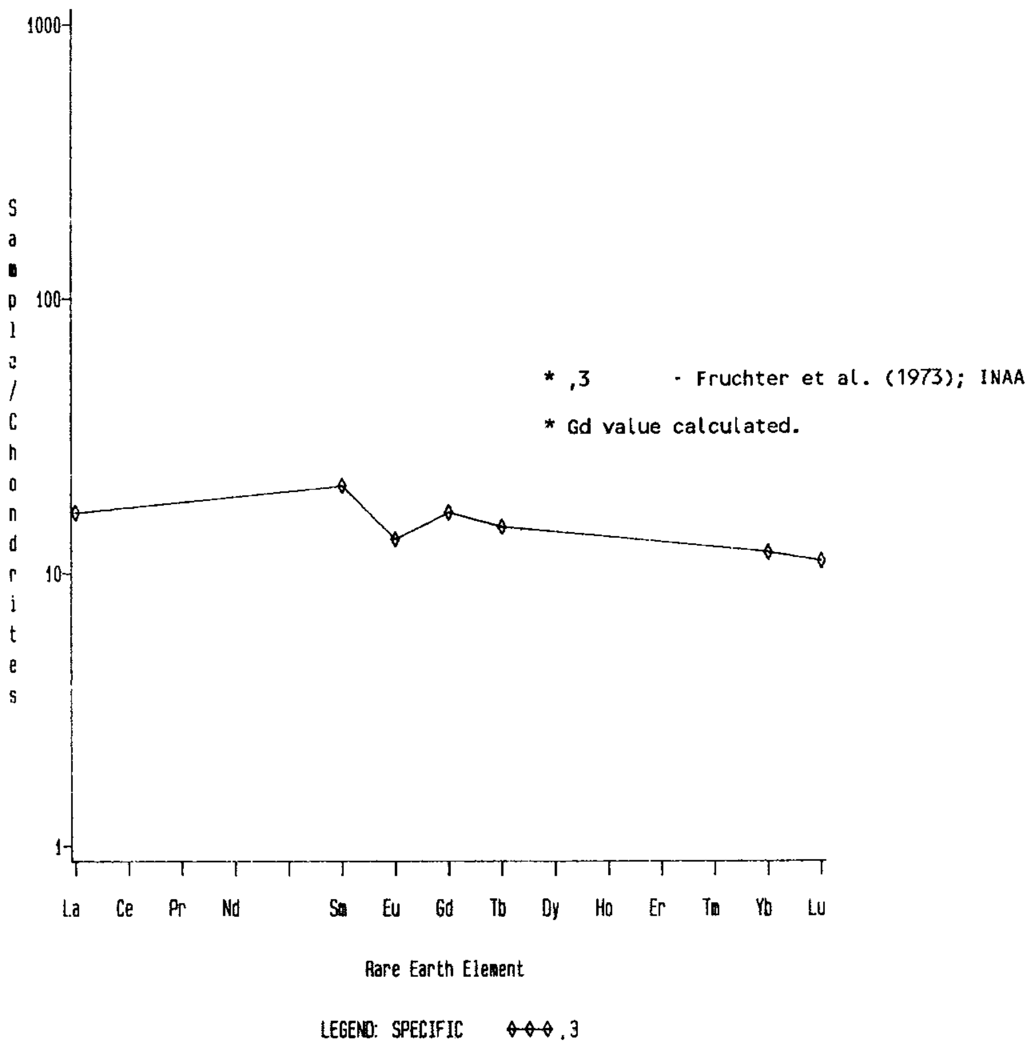


Figure 2. Rare earths in 15622,3.

TABLE 15622-1. Bulk rock chemical analyses

		,3	,5	,5
wt %	SiO_2		43.98	
	TiO_2	2.94	2.29	
	Al_2O_3	7.84	8.46	
	FeO	21.8	22.73	
	MgO		11.64	
	CaO		9.19	
	Na_2O	0.257	0.29	
	K_2O		0.05	
	P_2O_5		0.08	
(ppm)	Sc	40		
	V			
	Cr	6060	5550	
	Mn		2400	
	Co	56		
	Ni			
	Rb			0.89
	Sr			93.8
	Y			
	Zr			
	Nb			
	Hf	2.6		
	Ba			
	Th			
	U			
	Pb			
	La	5.5		
	Ce			
	Pr			
	Nd			
	Sm	3.8		
	Eu	0.92		
	Gd			
	Tb	0.7		
	Dy			
	Ho			
	Er			
	Tm			
	Yb	2.4		
	Lu	0.38		
	Li			
	Be			
	B			
	C			
	N			
	S		500	
	F			
	Cl			
	Br			
	Cu			
	Zn			
(ppb)	I			
	At			
	Ga			
	Ge			
	As			
	Se			
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag			
	Cd			
	In			
	Sn			
	Sb			
	Te			
	Cs			
	Ta	430		
	W			
	Re			
	Os			
	Ir			
	Pt			
	Au			
	Hg			
	Tl			
	Bi			
		(1)	(2)	(3)

References and methods:

(1) Fruchter et al. (1973); INAA
(2) Chappell and Green (1973); XRF
(3) Compston et al. (1972); ID/MS

RADIOGENIC ISOTOPES: Compston et al. (1972) reported Rb and Sr isotopic data for a whole-rock sample. The $^{87}Rb/^{86}Sr$ (0.0274) and $^{87}Sr/^{86}Sr$ (0.70074 ± 15) extrapolate back to an initial $^{87}Sr/^{86}Sr$ of 0.69945 at 3.3 b.y., indistinguishable from other Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: Several small pieces were chipped from ,0 (now 27.0 g), and were partly used in varied allocations (Fig. 1).

15623 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 3.00 g

INTRODUCTION: 15623 is a medium-grained, olivine-bearing mare basalt which is very vesicular (Fig. 1). Small yellow-green olivines are visible but are not phenocrysts. In chemistry, 15623 is a fairly magnesian member of the Apollo 15 olivine-normative mare basalt group. It is tough and was collected as part of the rake sample from Station 9A.

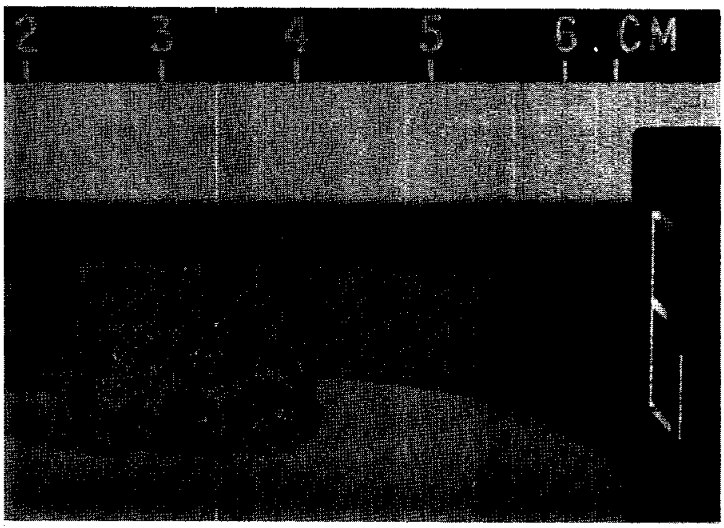


Figure 1. Pre-chip view of 15623. S-71-49313

PETROLOGY: 15623 is a medium-grained, olivine-bearing mare basalt (Fig. 2). Most of the olivines are small (less than 1 mm across) and not phenocrysts, and many occur as inclusions or cores in pyroxenes. Most pyroxenes and plagioclases are also less than 1 mm. The pyroxenes are mosaic-zoned. Dowty et al. (1973b) described 15623 as an olivine microgabbro. They reported a mode of 61% pyroxene, 24% plagioclase, 9% olivine, 6% opaques, and no miscellaneous or silica phases. They noted the presence of many small chromites, but ulvospinel and ilmenite are actually the dominant opaque phases. Dowty et al. (1973a) modified the mode slightly to 63% pyroxene, 26% plagioclase, 7% olivine, and 4% opaques. Dowty et al. (1973c) tabulated microprobe analyses of pyroxene, olivine, plagioclase, Si-K glass, and Fe-metal, and Nehru et al. (1973) tabulated spinel group and ilmenite analyses. Nehru et al. (1974) noted that the boundary between chromite cores and ulvospinel mantles is sharp. The metal contains 1.2 to 1.8% Co and 8.0 to 9.4% Ni in general, though some have Ni contents as low as 2.1 to 4.7%. The ilmenite contains 0.38 to 1.65% MgO. The mineral chemistry (Fig. 3) is typical of Apollo 15 olivine-normative mare basalts.

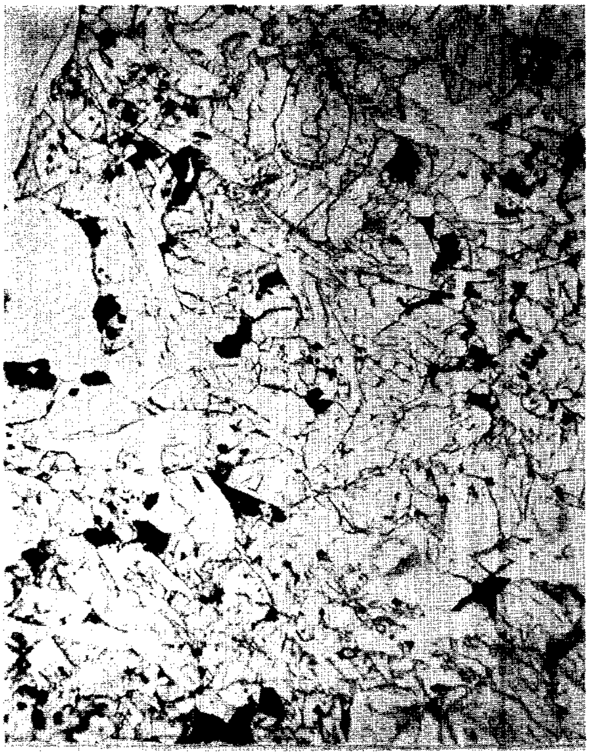


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15623,3. Width about 3 mm. a) transmitted light; b) crossed polarizers.

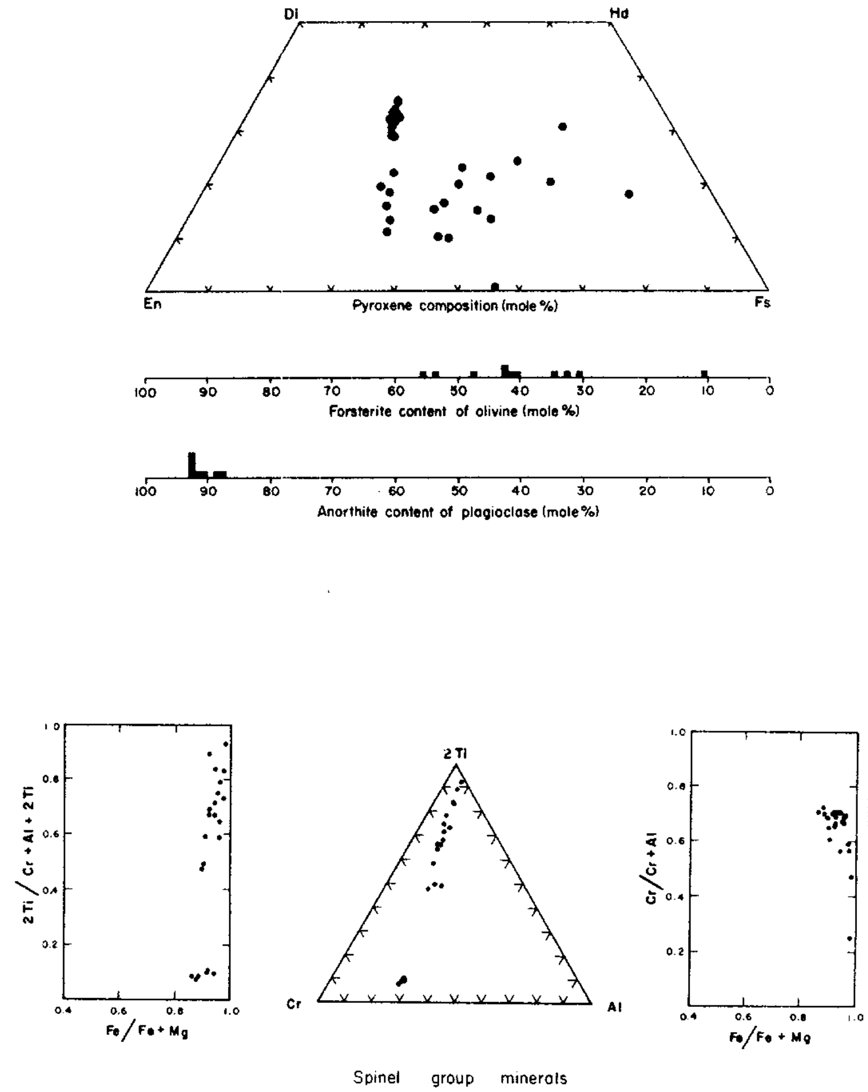


Figure 3. Chemistry of minerals in 15623 (Dowty et al., 1973b).

TABLE 15623-1. Bulk rock chemical analysis

		,4
Wt%	SiO2	
	TiO2	2.0
	Al2O3	8.6
	FeO	23.2
	MgO	13
	CaO	9.2
	Na2O	0.241
	K2O	0.043
	P2O5	
(ppm)	Sc	38
	V	217
	Cr	5850
	Mn	2060
	Co	54
	Ni	45(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.6
	Ba	55(b)
	Th	
	U	
	Pb	
	La	5.2
	Ce	
	Pr	
	Nd	
	Sm	3.5
	Eu	0.85
	Gd	
	Tb	0.8
	Dy	4.2
	Ho	
	Er	
	Tm	
	Yb	2.2
	Lu	0.35
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	530
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ±25 ppm
(b) ±35 ppm

CHEMISTRY: A bulk rock analysis is listed in Table 1 and the rare earths shown in Figure 4. This analysis shows 15623 to be a low-TiO_2, high-MgO member of the Apollo 15 olivine-normative mare basalt group, although MgO is imprecisely determined. A defocussed beam microprobe analysis (Table 2) has even lower TiO_2, probably subject to a large sampling error, but MgO closer to the average for this basalt group.

PROCESSING AND SUBDIVISIONS: Original chipping produced several small chips, most labelled ,1. The largest, ,2, was potted and produced thin sections ,3 and ,9. In 1977, more chipping produced ,4 which was used for chemical analysis and to make thin section ,8. ,0 is now 2.05 g.

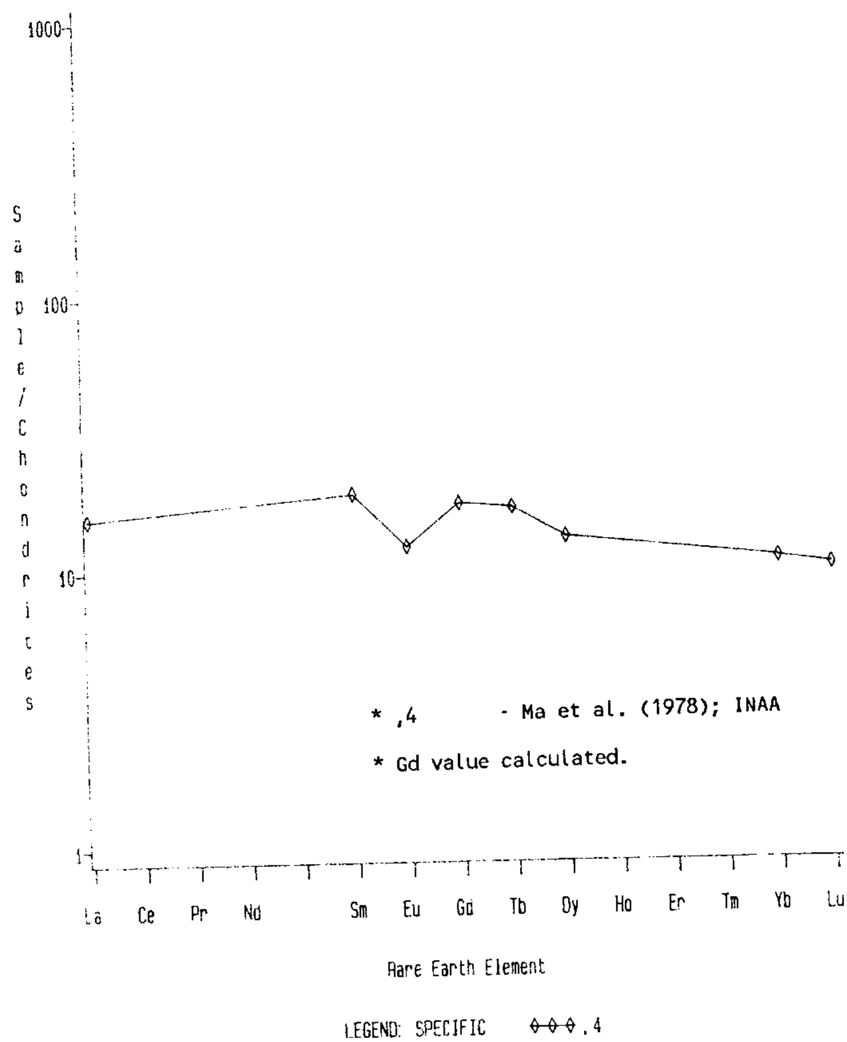


Figure 4. Rare earths in 15623.

TABLE 15623-2. Defocussed beam bulk analysis (Dowty et al., 1973a,b)

Wt%	SiO2	45.1
	TiO2	1.46
	Al2O3	8.6
	FeO	23.1
	MgO	11.4
	CaO	9.5
	Na2O	0.30
	K2O	0.02
	P2O5	0.17
ppm	Cr	4110
	Mn	1705

15624 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 0.20 g

INTRODUCTION: 15624 is a medium-grained, olivine-bearing mare basalt which is vesicular (Fig. 1). It is tough and was collected as part of the rake sample at Station 9A.

PETROLOGY: 15624 is an olivine microgabbro (Fig. 2). Zoned pyroxenes and hollow, lathy plagioclases less than 1 mm long form the bulk of the sample. Small olivines (less than 1/2 mm) form a few per cent of the sample. Some portions are extremely mafic, suggesting mafic accumulation.

PROCESSING AND SUBDIVISIONS: 15624 has been entirely consumed in making thin sections ,0 and ,6, except for two tiny potted butts which remain.

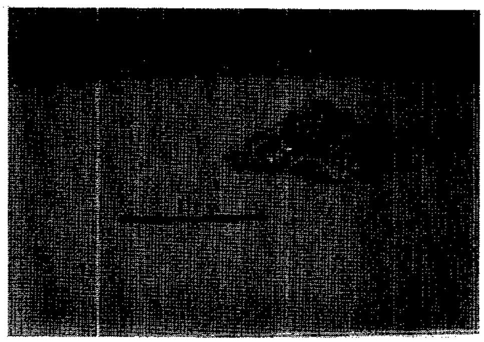


Figure 1. Pre-chip view of 15624. S-71-49325

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15624,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

15625 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.50 g

INTRODUCTION: 15625 is a vesicular, olivine-bearing sample macroscopically similar to 15606, 15612, etc. It has never been subdivided or allocated.

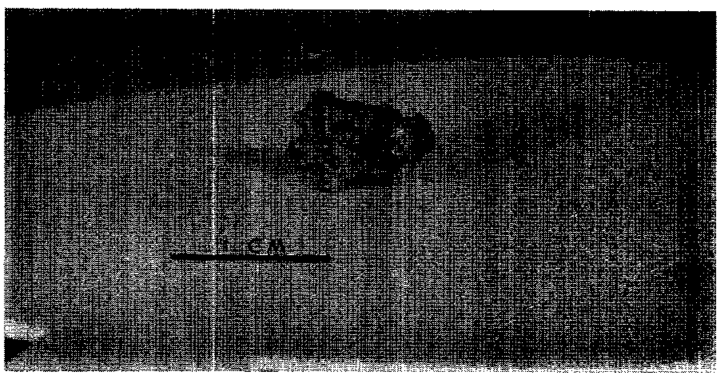


Figure 1. Sample 15625. S-71-49317

15626 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.60 g

INTRODUCTION: 15626 is a vesicular, olivine-bearing sample macroscopically similar to 15606, 15612, etc. It has never been subdivided or allocated.

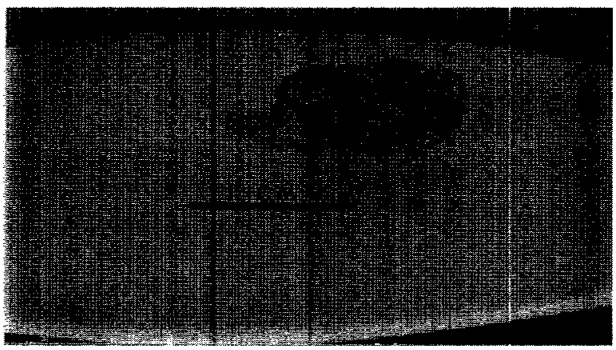


Figure 1. Sample 15626. S-71-49309

15627 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.40 g

INTRODUCTION: 15627 is a vesicular, olivine-bearing sample macroscopically similar to 15606, 15612, etc. It has never been subdivided or allocated.

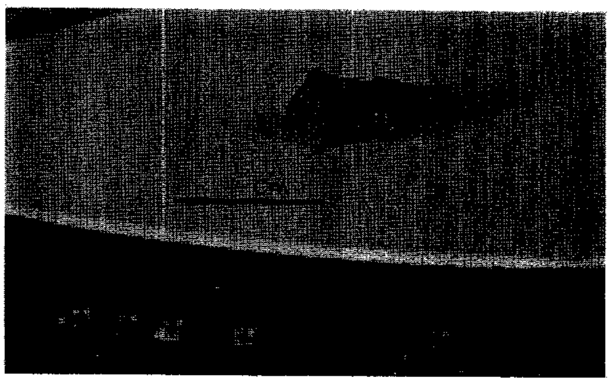


Figure 1. Sample 15627. S-71-49273

<u>15628 MEDIUM-GRAINED OLIVINE-NORMATIVE ST. 9A 0.40 g</u>
<u>MARE BASALT(?)</u>

<u>INTRODUCTION</u>: 15628 is a vesicular, olivine-bearing sample macroscopically similar to 15606, 15612, etc. It has never been subdivided or allocated.

<u>Figure 1</u>. Sample 15625. S-71-49280

15629 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.40 g

INTRODUCTION: 15629 is a vesicular, olivine-bearing sample macroscopically similar to 15606, 15612, etc. It has never been subdivided or allocated.

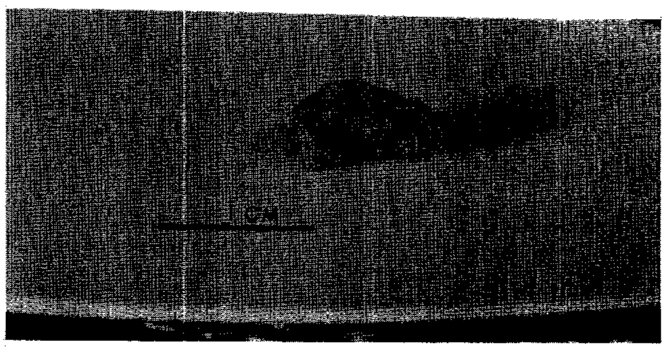


Figure 1. Sample 15629. S-71-49277

15630 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 23.2 g

INTRODUCTION: 15630 is a medium-grained, olivine-bearing mare basalt which is very vesicular (Fig. 1). The olivines do not form conspicuous phenocrysts. In chemistry, it is an average olivine-normative mare basalt. It is tough, angular, and lacks zap pits. 15630 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15630 is an olivine microgabbro similar to 15606, 15612, etc. (Fig. 2). The olivine is not conspicuously phenocrystic.

CHEMISTRY: A bulk rock chemical analysis is listed in Table 1 and the rare earths shown in Figure 3. Apart from the low TiO_2, the sample is a fairly average Apollo 15 olivine-normative mare basalt.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) reported a natural magnetic intensity (NRM) of 3.3×10^{-6} emu/g for the bulk sample. This value is typical for Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: In 1977, chipping produced two chips, one of which remains with ,0. The other (,1) was used for chemical analysis and also produced the thin section ,4. ,0 is now 22.46 g.

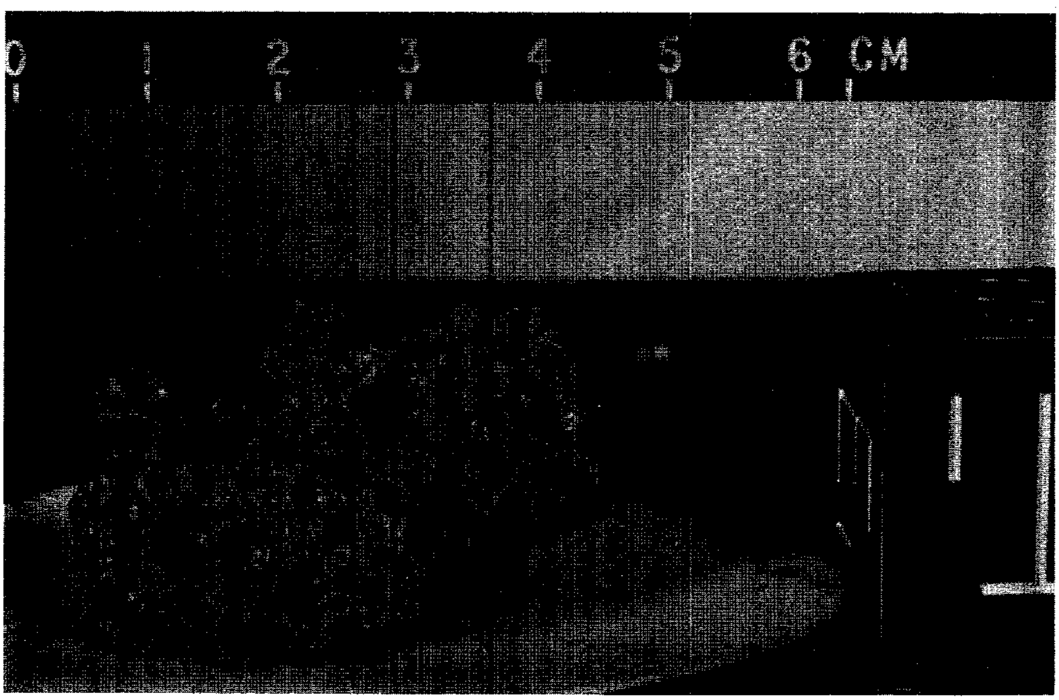


Figure 1. Macroscopic, pre-split view of 15630. S-71-49269

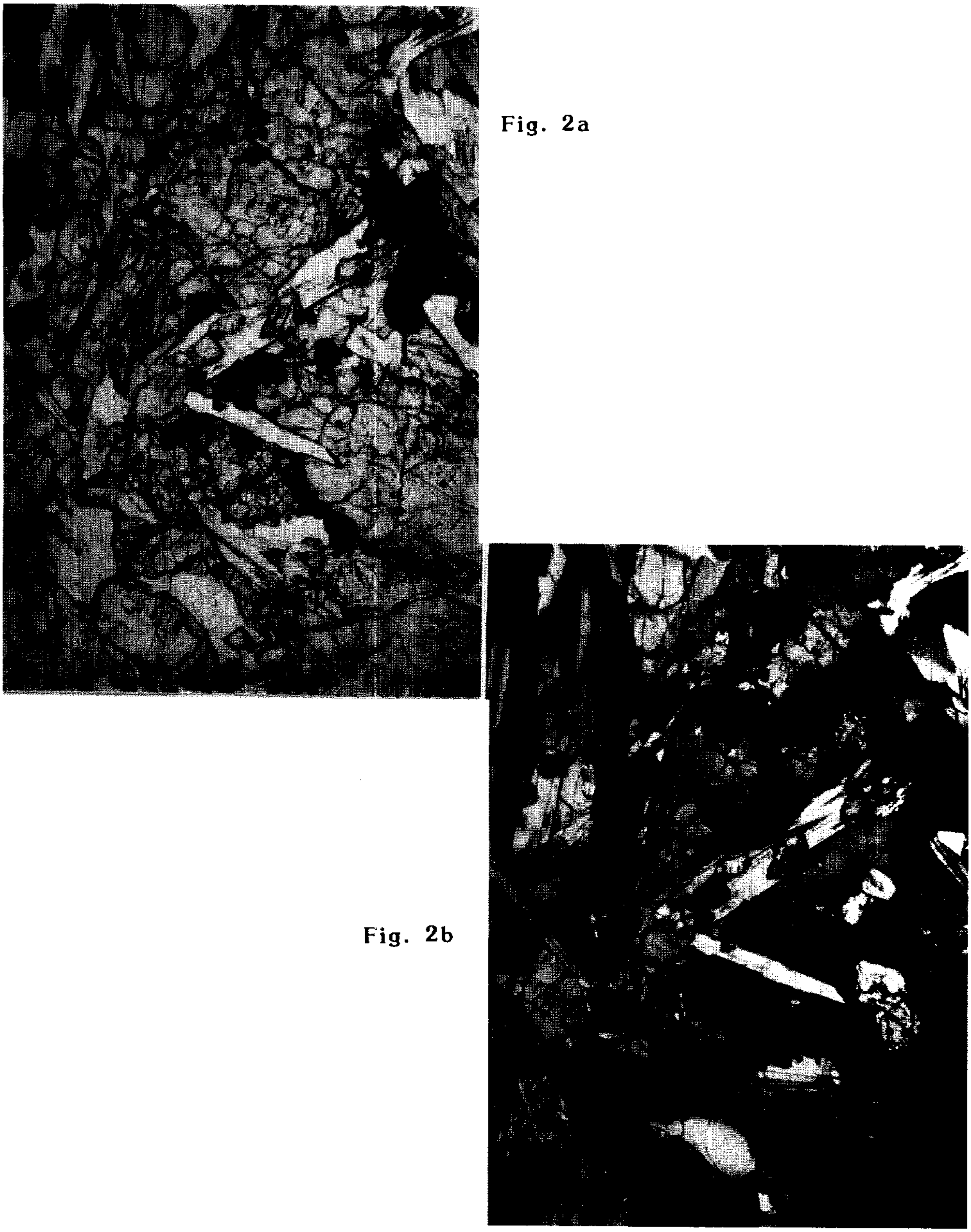


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15630,4. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15630-1. Bulk rock chemical analysis

		,1
Wt %	SiO2	
	TiO2	2.0
	Al2O3	8.9
	FeO	20.8
	MgO	11
	CaO	8.8
	Na2O	0.252
	K2O	0.044
	P2O5	
(ppm)	Sc	39
	V	225
	Cr	5355
	Mn	2080
	Co	53
	Ni	70(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.4
	Ba	80(b)
	Th	
	U	
	Pb	
	La	5.4
	Ce	
	Pr	
	Nd	
	Sm	3.5
	Eu	0.79
	Gd	
	Tb	0.7
	Dy	4.3
	Ho	
	Er	
	Tm	
	Yb	2.1
	Lu	0.27
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	470
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

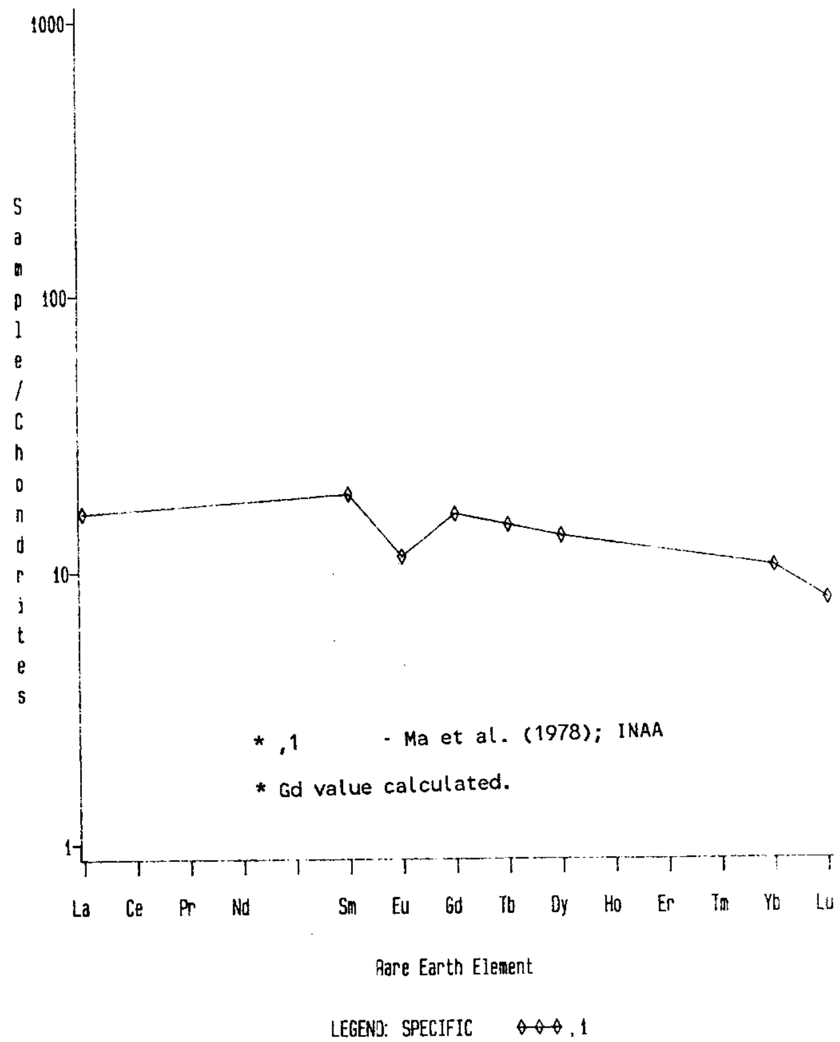


Figure 3. Rare earths in 15630.

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ±30 ppm
(b) ±55 ppm

15632 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 2.30 g

INTRODUCTION: 15632 is a medium-grained, olivine-bearing mare basalt which is vuggy but not vesicular (Fig. 1). Olivines do not form phenocrysts. It is tough. 15632 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15632 is medium-grained and similar to other medium-grained Apollo 15 olivine-normative mare basalts (Fig. 2). The dominant phase is pigeonite (1 to 2 mm) which is frequently twinned and zoned to augite. The plagioclase is ophitic, enclosing small olivines and pyroxenes. A few olivines are as large as 1 mm and anhedral but can scarcely be considered phenocrysts.

PROCESSING AND SUBDIVISIONS: Chipping produced ,1 (Fig. 1) which was almost entirely used in producing thin sections ,1 and ,6. ,0 is now 2.05 g.

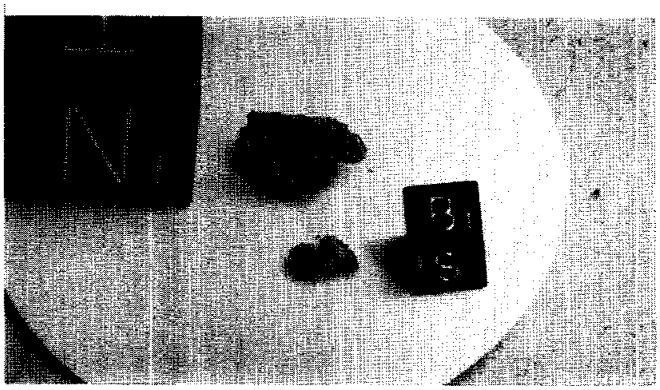


Figure 1. Post chip view of 15632. S-71-56308

Fig. 2a

Fig. 2b

Figure 2. Photomicrograph of 15632,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

15633 COARSE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 7.40 g

INTRODUCTION: 15633 is a coarse-grained, olivine-bearing mare basalt which is vuggy but not vesicular (Fig. 1). The olivines do not form phenocrysts. In chemistry, the sample is a member of the Apollo 15 olivine-normative group. It has a crystallization age of 3.26 ± 0.05 b.y. (Husain, 1974). 15633 is tough and has no zap pits, although there is some welded dust on the surface. It was collected as part of the rake sample at Station 9A.

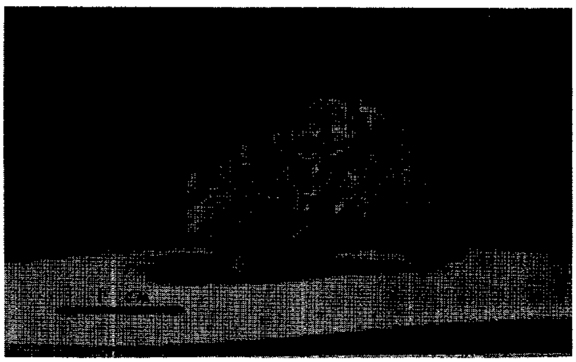


Figure 1. Pre-chip view of 15633. S-71-49294

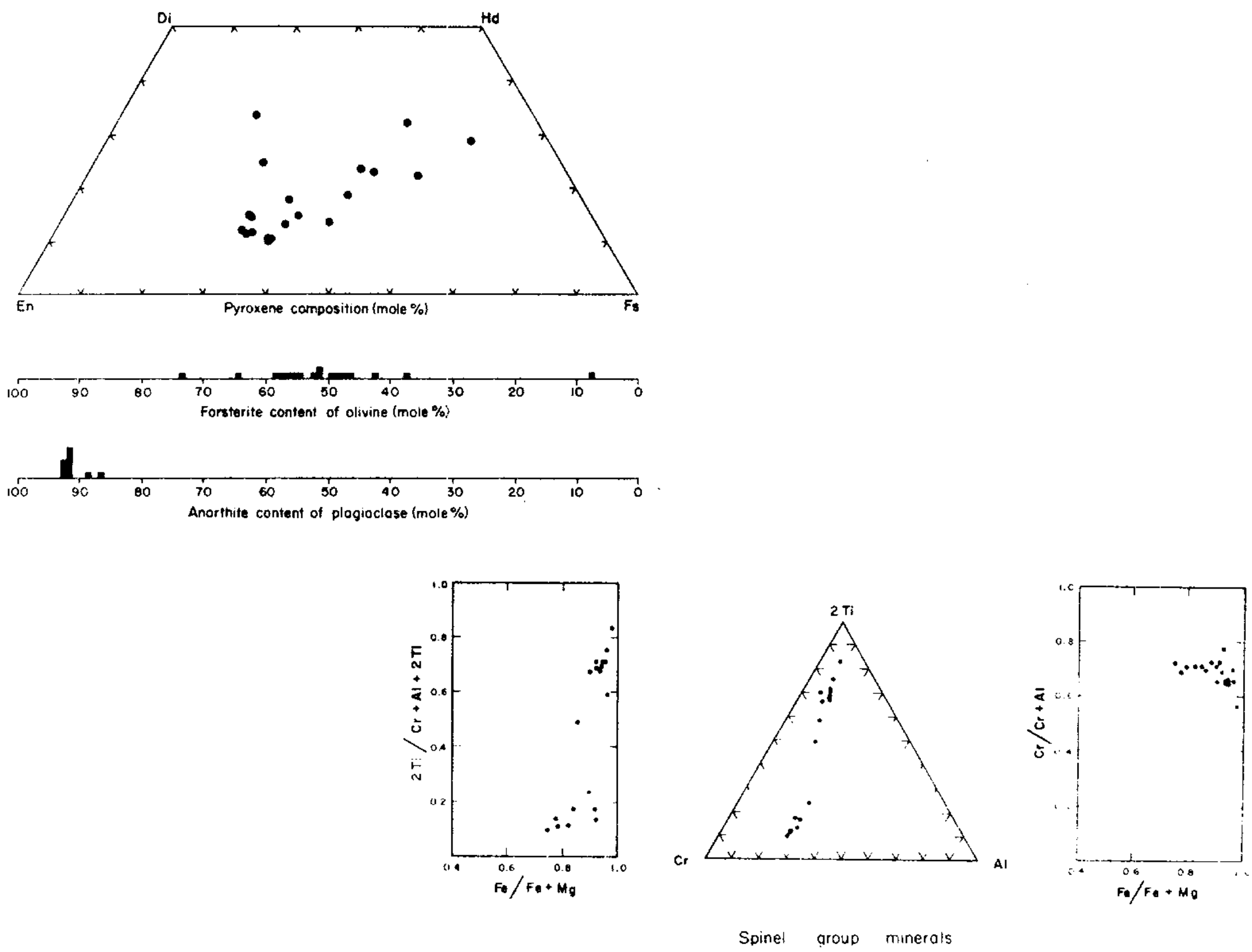
PETROLOGY: 15633 is a coarse-grained basalt with pigeonites up to 2 mm long and commonly twinned, zoned, and containing olivine inclusions (Fig. 2). Plagioclases are ophitic, enclosing small pyroxenes and olivines, and are up to about 1.5 mm. Most olivines are small and anhedral, but a few are about 1 mm with silicate liquid inclusions. Dowty et al. (1973b) noted such large olivines as amoedoid and zoned. Dowty et al. (1973a,b) reported a mode of 52% pyroxene, 21% plagioclase, 18% olivines, 6% opaque minerals, 1% silica (actually cristobalite), and 2% miscellaneous. Dowty et al. (1973c) tabulated microprobe analyses of pyroxene, olivine, plagioclase, Si-K glass, and Fe-metal, and Nehru et al. (1973) tabulated spinel group and ilmenite analyses. Nehru et al. (1974) noted that there was a sharp break from chromite cores to ulvospinel mantles. The Fe-metal contains 1.5 to 1.6% Co and 5.6 to 7.1% Ni, and the ilmenite contains 0.52 to 4.6% MgO. The mineral chemistry (Fig. 3) is typical for Apollo 15 olivine-normative mare basalts.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15633,15. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

Figure 3. Chemistry of minerals in 15633 (Dowty et al., 1973b).



CHEMISTRY: The bulk rock analyses (Table 1, Fig. 4) and the defocussed beam microprobe analysis (Table 2) all show 15633 to be an Apollo 15 olivine-normative mare basalt, but there are considerable differences among them. These differences are probably a result of the coarse grain size of the sample. The analysis of Helmke et al. (1973) is particularly high in TiO_2 and FeO and low in Al_2O_3. On average, the sample appears to be fairly magnesian. The Ca analysis of Husain (1974) is probably spuriously high.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: In an Ar-Ar study, Husain (1974) found that 20.3% of the $^{40}Ar^*$ had been lost, giving a low K-Ar age of 2.95 ± 0.08 b.y. The plateau age (from the 950°C to 1250°C releases) of 3.26 ± 0.05 b.y. is within error of the age of other Apollo 15 mare basalts.

RARE GASES AND EXPOSURE: Husain (1974) tabulated Ar isotopic temperature release data for 15633. He reported a ^{38}Ar-Ca exposure age of 66 ± 4 m.y.

PROCESSING AND SUBDIVISIONS: Chipping produced ,1 (single chip); ,2 (two chips); and ,3; ,4; and ,5 (several small chips and fines). ,1 was partly used to produce thin sections ,15 and ,16. ,0 is now 4.60 g.

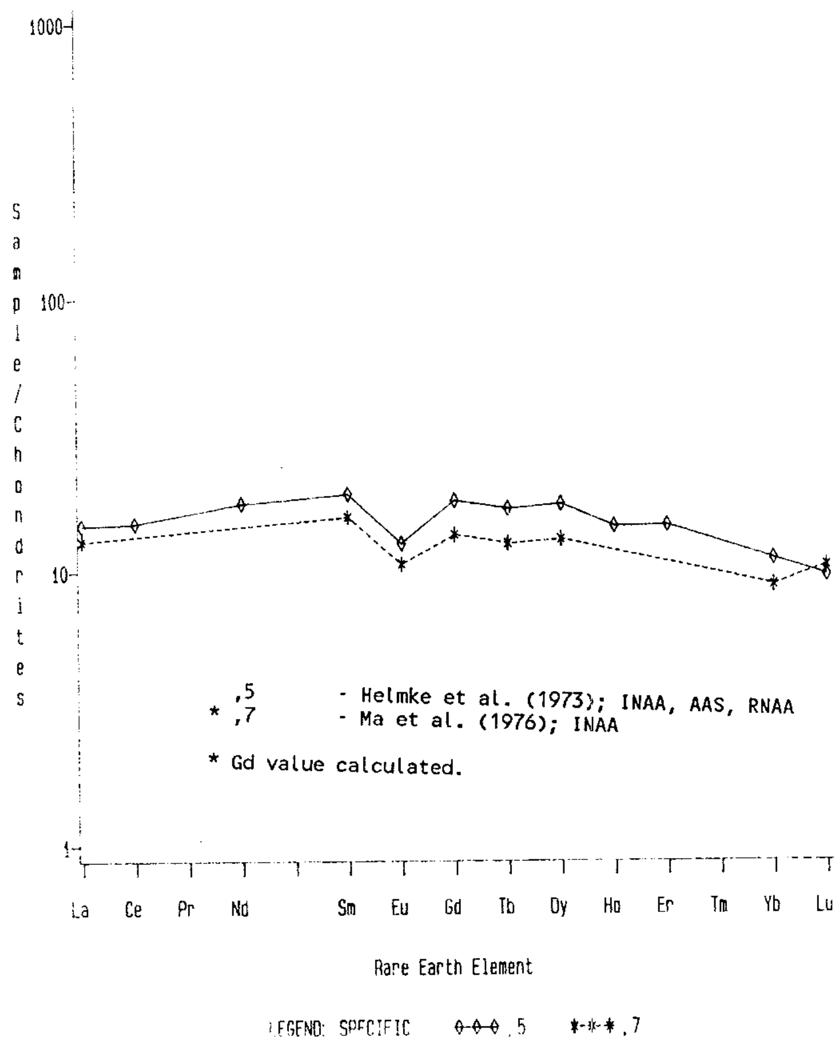


Figure 4. Rare earths in 15633.

TABLE 15633-1. Bulk rock chemical analyses

		,7	,5	,3
Wt. %	SiO_2		44.1	
	TiO_2	2.2	3.04	
	Al_2O_3	8.8	7.20	
	FeO	23.0	25.0	
	MgO	11.1	10.7	
	CaO	9.3	9.09	13.6
	Na_2O	0.247	0.305	
	K_2O	0.033	0.056	0.034
	P_2O_5			
(ppm)	Sc	41	47.0	
	V	225		
	Cr	4080	3930	
	Mn	2085	2330	
	Co	50	56	
	Ni	101		
	Rb		0.5	
	Sr			
	Y			
	Zr			
	Nb			
	Hf	2.3	2.5	
	Ba	45		
	Th			
	U			
	Pb			
	La	4.3	4.93	
	Ce		13.4	
	Pr			
	Nd		10.8	
	Sm	2.9	3.54	
	Eu	0.74	0.88	
	Gd		4.6	
	Tb	0.60	0.81	
	Dy	4.2	5.7	
	Ho		1.04	
	Er		3.0	
	Tm			
	Yb	1.8	2.26	
	Lu	0.36	0.328	
	Li			
	Be			
	B			
	C			
	N			
	S			
	F			
	Cl			
	Br			
	Cu			
	Zn		<3	
(ppb)	I			
	At			
	Ga		2900	
	Ge			
	As			
	Se			
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag			
	Cd			
	In			
	Sn			
	Sb			
	Te			
	Cs		17	
	Ta	380		
	W			
	Re			
	Os			
	Ir			
	Pt			
	Au			
	Hg			
	Tl			
	Bi			
		(1)	(2)	(3)

TABLE 15633-2. Defocussed beam bulk rock analysis (Dowty *et al.*, 1973a,b)

Wt%	SiO_2	46.4
	TiO_2	1.28
	Al_2O_3	8.5
	FeO	22.2
	MgO	12.7
	CaO	8.6
	Na_2O	0.27
	K_2O	0.02
	P_2O_5	0.05
ppm	Cr	2535
	Mn	2170

References and methods:

(1) Ma *et al.* (1976); INAA
(2) Helmke *et al.* (1973); INAA, AAS, RNAA
(3) Husain (1974); Ar isotopes, irradiation

Notes:

(a) ±19 ppm

15634 COARSE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 5.20 g

INTRODUCTION: 15634 is a coarse-grained, olivine-bearing mare basalt which contains some vugs but is not vesicular (Fig. 1). The yellow-green olivines are conspicuous macroscopically. In chemistry, the sample is a member (perhaps Mg-rich) of the Apollo 15 olivine-normative mare basalt group. It is tough and has no zap pits. 15634 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15634 is a coarse-grained, olivine-bearing mare basalt, similar to the other coarse-grained members of the group (Fig. 2).

CHEMISTRY: A bulk rock chemical analysis is listed in Table 1 and the rare earths shown in Figure 3. The major element chemistry shows the sample to be an Apollo 15 olivine-normative mare basalt, and the low TiO_2 and (imprecisely-determined) MgO suggest it is an Mg-rich member. The rare earths are 2 to 3 times lower than other members of the group, and on the basis of low values of La/Sm and Sm/Eu, Ma et al. (1978) suggested it was from a flow different from the others.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) reported a natural magnetic intensity (NRM) of 4.1 x 10^{-6} emu/g for the entire rock (erroneously listed as 15664 in Pearce et al., 1973). This value is typical for Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: In 1977, chipping produced ,1 (3 chips) which was used for chemical analysis and to make thin section ,4. ,0 is now 5.20 g.

Figure 1. Pre-split view of 15634. S-71-49287

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15634,4. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15634-1. Bulk rock chemical analysis

		,1
Wt %	SiO2	
	TiO2	1.5
	Al2O3	9.8
	FeO	19.9
	MgO	13
	CaO	9.1
	Na2O	0.269
	K2O	0.020
	P2O5	
(ppm)	Sc	38
	V	223
	Cr	4365
	Mn	1155
	Co	55
	Ni	100(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	1.1
	Ba	20(b)
	Th	
	U	
	Pb	
	La	2.4
	Ce	
	Pr	
	Nd	
	Sm	1.8
	Eu	0.58
	Gd	
	Tb	0.4
	Dy	2.6
	Ho	
	Er	
	Tm	
	Yb	1.2
	Lu	0.15
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	150
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

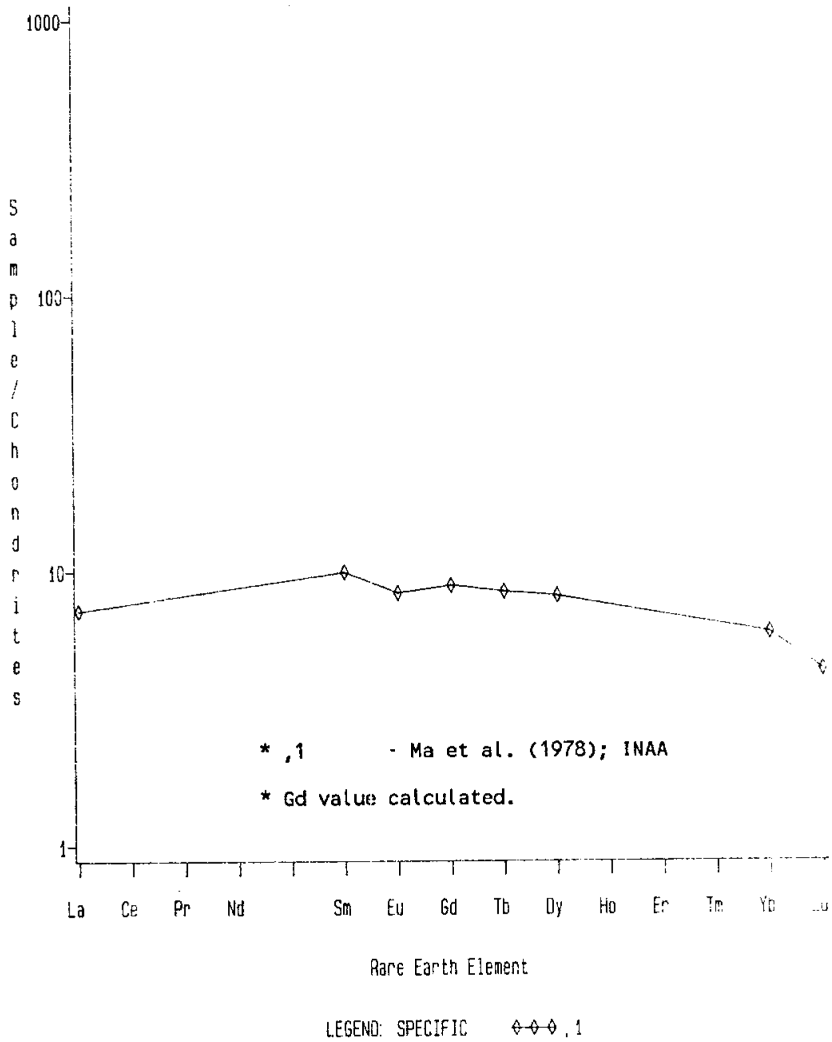


Figure 3. Rare earths in 15634.

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) +50 ppm
(b) ±20 ppm

15635 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.50 g

INTRODUCTION: 15635 is a small fragment of a medium-grained mare basalt with yellow-green olivines (Fig. 1) and small vugs. The grain size is 1 to 2 mm and the sample is macroscopically very similar to other coarse-to medium-grained Apollo 15 olivine-normative mare basalts. 15635 was collected as part of the rake sample at Station 9A. It has never been subdivided or allocated.

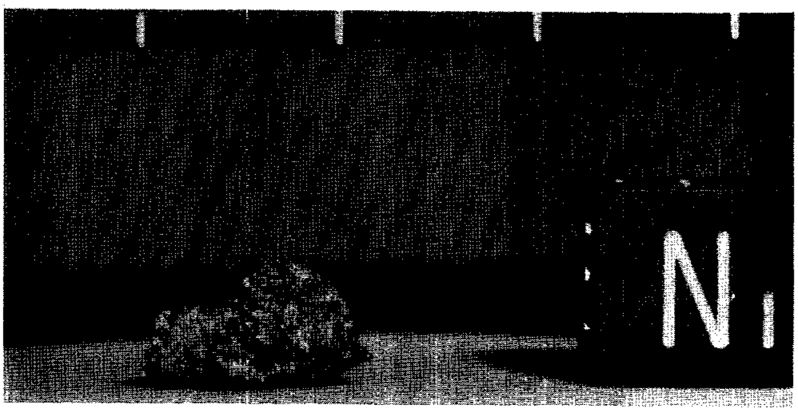


Figure 1. Macroscopic view of 15635. S-71-49283

15636	COARSE-GRAINED OLIVINE-NORMATIVE MARE BASALT	ST. 9A	336.7 g

INTRODUCTION: 15636 is a coarse-grained olivine-bearing mare basalt (Fig. 1). The olivines do not form phenocrysts but are visible as yellow-green crystals macroscopically. The sample is a magnesian member of the Apollo 15 olivine-normative mare basalt group. The sample has several fresh surfaces but one end is rounded. It was collected as part of the rake sample at Station 9A.

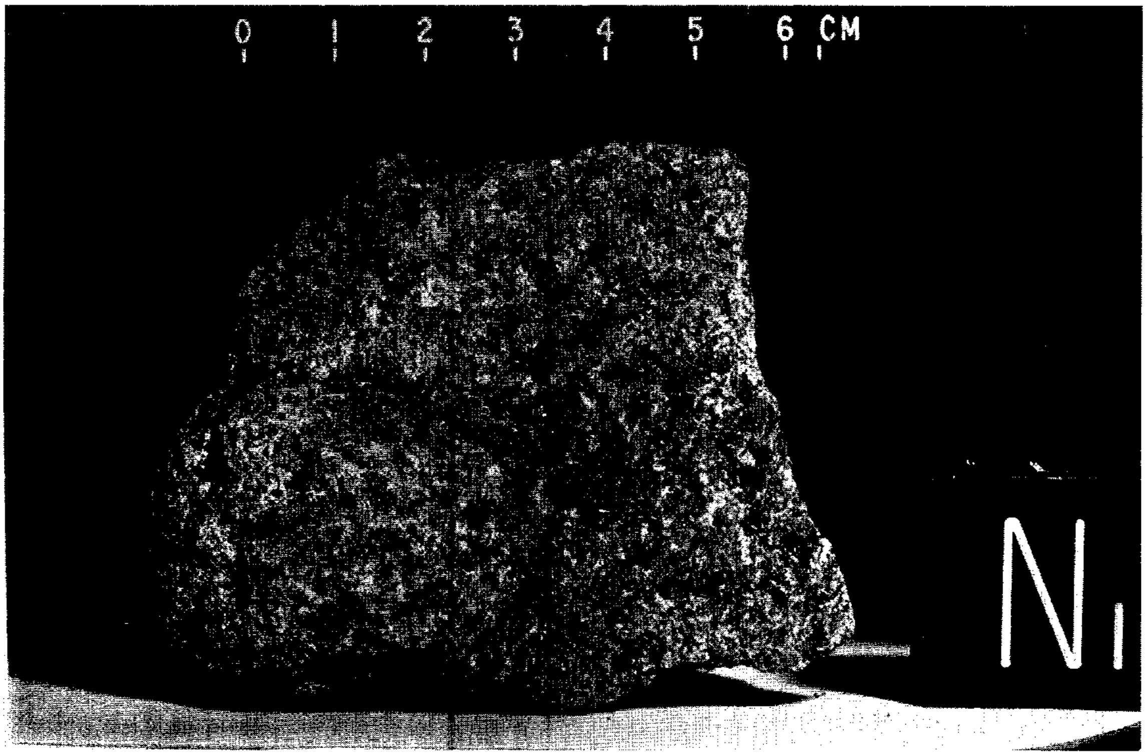


Figure 1. Pre-split view of 15636. S-71-52023

PETROLOGY: 15636 consists of anhedral, embayed olivines, and large pyroxenes and plagioclases (Fig. 2). The pyroxenes are anhedral pigeonites, zoned to augite, and are twinned; they are generally about 1 mm across but rarely reach 3 mm. The rims are browner than the interiors and are inclusion-rich. The plagioclases are anhedral and 1 or 2 mm across. The larger olivines are scattered, embayed, and about 1 mm or less across; some smaller (less than 200 microns) olivines are euhedral and embedded in the plagioclases. Some of the phenocrysts embedded in plagioclase have sharp crystal faces (e.g., Fig. 2). Several olivine crystals contain silicate liquid inclusions. Residual phases include cristobalite, Fe-olivine, sulfide, and glass. Chromite occurs in olivine and pyroxene, and ulvospinel is common. Ilmenite, and some ulvospinel, tends to be associated with the residual fayalite and cristobalite.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15636,8. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: Chemical analyses are listed in Table 1 and rare-earths shown in Figure 3. The major element analyses differ, and the rare earths of the Fruchter et al. (1973) analyses are much lower than is normal for Apollo 15 mare basalts; this analysis is perhaps much less reliable and subject to some sampling problems resulting from the coarse grain size. The analysis of Chappell and Green (1973) is almost identical with their analysis of 15622 and they suggested it was the same rock, broken up. However, 15622 is much more vesicular and probably much finer grained. The analysis is one of the most magnesian of the Apollo 15 olivine-normative basalts, but Chappell and Green did not have enough evidence to distinguish a primitive magma from a cumulate origin for the rock. Compston et al. (1972) noted the systematically lower Rb derived from their XRF analysis (reported in Chappell and Green, 1973), and the more-reliable ID/MS data.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) measured a magnetic intensity of 3.2×10^{-6} emu/g for the whole rock, an intensity about average for Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: Several small pieces were chipped off ,0 (now 325.8 g) to make the allocations. The thin sections (,8 and ,9) were made from an unused returned chip (,4).

TABLE 15636-1. Bulk rock chemical analysis

			,6	,5
Wt %	SiO_2	44.58		
	TiO_2	2.22		
	Al_2O_3	8.55	9.8	
	FeO	22.67	19.61	
	MgO	11.32		
	CaO	9.58		
	Na_2O	0.26	0.247	
	K_2O	0.04		
	P_2O_5	0.07		
(ppm)	Sc		35	
	V			
	Cr	3840	3540	
	Mn	2400		
	Co		52	
	Ni			
	Rb	0.52		0.72
	Sr	94.6		90.9
	Y	21		
	Zr	77		
	Nb	6		
	Hf		1.3	
	Ba			
	Th			
	U			
	Pb			
	La		2.6	
	Ce			
	Pr			
	Nd			
	Sm		1.9	
	Eu		0.66	
	Gd			
	Tb			
	Dy			
	Ho			
	Er			
	Tm			
	Yb		1.3	
	Lu		0.22	
	Li			
	Be			
	B			
	C			
	N			
	S	500		
	F			
	Cl			
	Br			
	Cu			
	Zn			
(ppb)	I			
	At			
	Ga	2900		
	Ge			
	As			
	Se			
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag			
	Cd			
	In			
	Sn			
	Sb			
	Te			
	Cs			
	Ta			
	W			
	Re			
	Os			
	Ir			
	Pt			
	Au			
	Hg			
	Tl			
	Bi			
		(1)	(2)	(3)

References and methods:

(1) Chappell and Green (1973), Compston et al. (1972); XRF
(2) Fruchter et al. (1973); INAA
(3) Compston et al. (1972); ID/MS

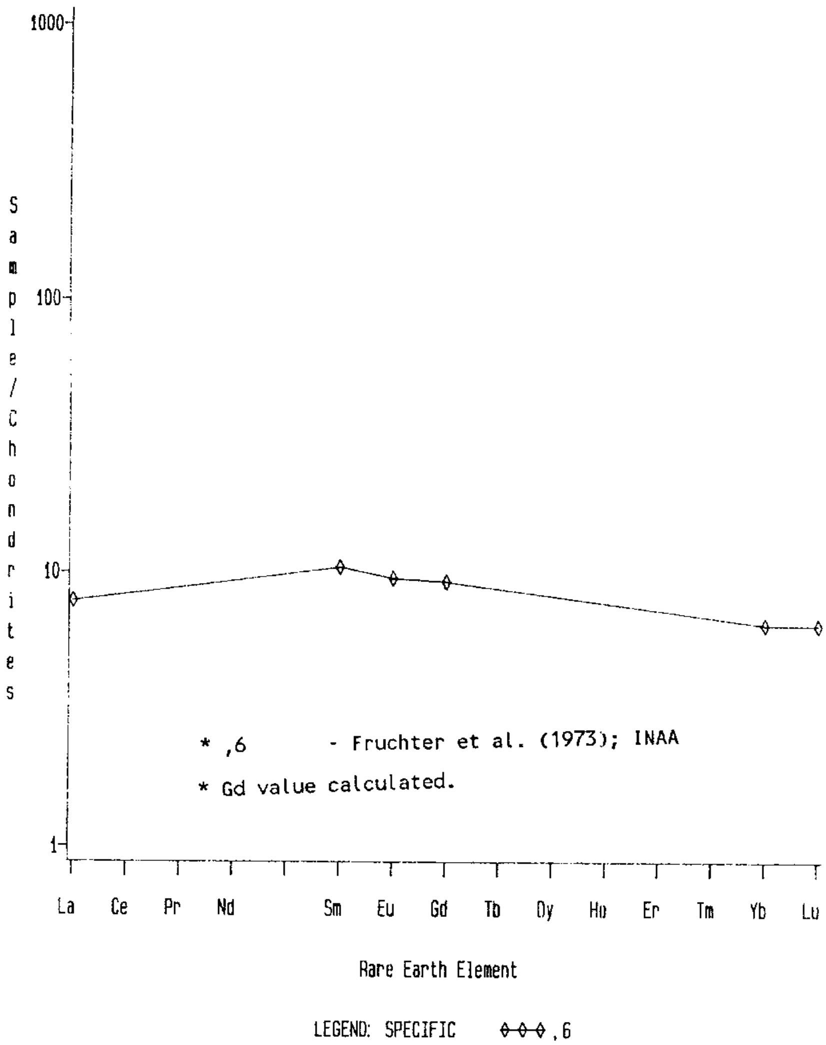


Figure 3. Rare earths in a split of 15636.

15637 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.90 g

INTRODUCTION: 15637 is a small fragment of a medium-grained mare basalt with yellow-green olivines (Fig. 1) and small vugs. The grain size is 1 to 2 mm and the sample is macroscopically very similar to other coarse-to medium-grained Apollo 15 olivine-normative mare basalts. 15637 was collected as part of the rake sample at Station 9A. It has never been subdivided or allocated.

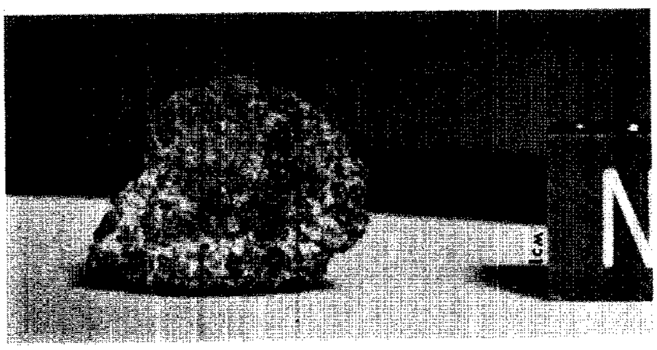
Figure 1. Macroscopic view of 15637. S-71-49307

<u>15638 MEDIUM-GRAINED OLIVINE-NORMATIVE ST. 9A 3.60 g</u>
<u>MARE BASALT</u>

<u>INTRODUCTION</u>: 15638 is a medium-grained, olivine-bearing mare basalt which contains some vugs but is not vesicular (Fig. 1). Yellow-green olivines are conspicuous macroscopically. The sample is tough and was collected as part of the rake sample at Station 9A.

<u>PETROLOGY</u>: 15638 is a medium-grained mare basalt (Fig. 2). Mg-olivine appears to be absent from the tiny thin sections although it is visible macroscopically; fayalite is present with cristobalite, troilite, glass, ulvospinel and ilmenite as a residual phase. Steele <u>et al</u>. (1972) noted the absence of olivine. The dominant phase is pigeonite, up to 2 mm and zoned to augite. Plagioclase forms an interstitial phase.

<u>PROCESSING AND SUBDIVISIONS</u>: A small piece was sawn off the "E" end (left tip in Figure 1) and entirely used up in making the two tiny thin sections ,9 and ,10. Five very tiny chips (,2) were taken in the same processing. ,0 is now 3.45 g.



<u>Figure 1</u>. Pre-saw view of 15638. S-71-49559

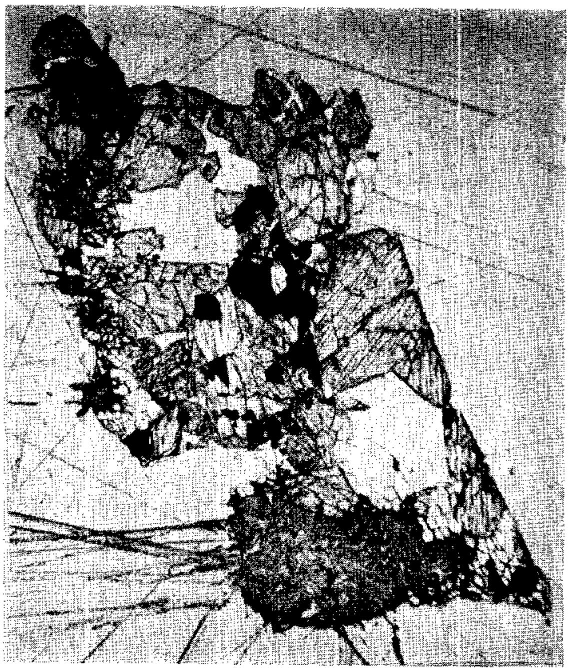


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of entire thin section 15638,10 (about 1x2 mm) a) transmitted light; b) crossed polarizers.

15639 COARSE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 7.00 g

INTRODUCTION: 15639 is a coarse-grained olivine-bearing mare basalt which is vuggy but not vesicular (Fig. 1). Yellow-green olivines and lathy plagioclases are conspicuous macroscopically. In chemistry, the sample is a member of the Apollo 15 olivine-normative mare basalt group. The sample is tough and has some small glass splashes and possibly zap pits. 15639 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15639 is an olivine microgabbro (Fig. 2) with a moderately diabasic texture. The olivine does not form phenocrysts.

CHEMISTRY: A bulk rock analysis (Table 1, Fig. 3) shows the sample to be a member of the Apollo 15 olivine-normative mare basalt group, and on the basis of the low TiO_2 and (imprecisely-determined) high MgO, probably one of the least-evolved.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) measured a natural magnetic intensity (NRM) of 6.7×10^{-6} emu/g for the entire rock. This value is typical of Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: In 1977, chipping produced two chips (,1) and a separate chip which remains part of ,0 (now 6.56 g). ,1 was used for chemical analysis and to make thin section ,4.

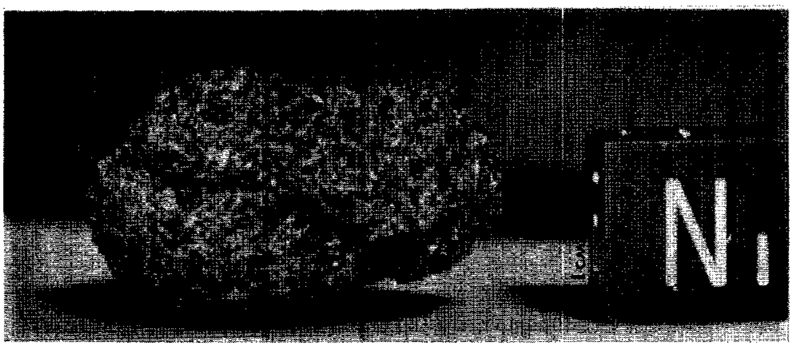


Figure 1. Pre-chip view of 15639. S-71-49551

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15639,4. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15639-1. Bulk rock chemical analysis

		,1
Wt. %	SiO2	
	TiO2	1.8
	Al2O3	9.4
	FeO	21.9
	MgO	12
	CaO	8.9
	Na2O	0.280
	K2O	0.038
	P2O5	
(ppm)	Sc	39
	V	194
	Cr	4130
	Mn	2030
	Co	54
	Ni	
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.1
	Ba	
	Th	
	U	
	Pb	
	La	4.1
	Ce	
	Pr	
	Nd	
	Sm	2.8
	Eu	0.76
	Gd	
	Tb	0.5
	Dy	3.3
	Ho	
	Er	
	Tm	
	Yb	1.8
	Lu	0.21
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	350
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

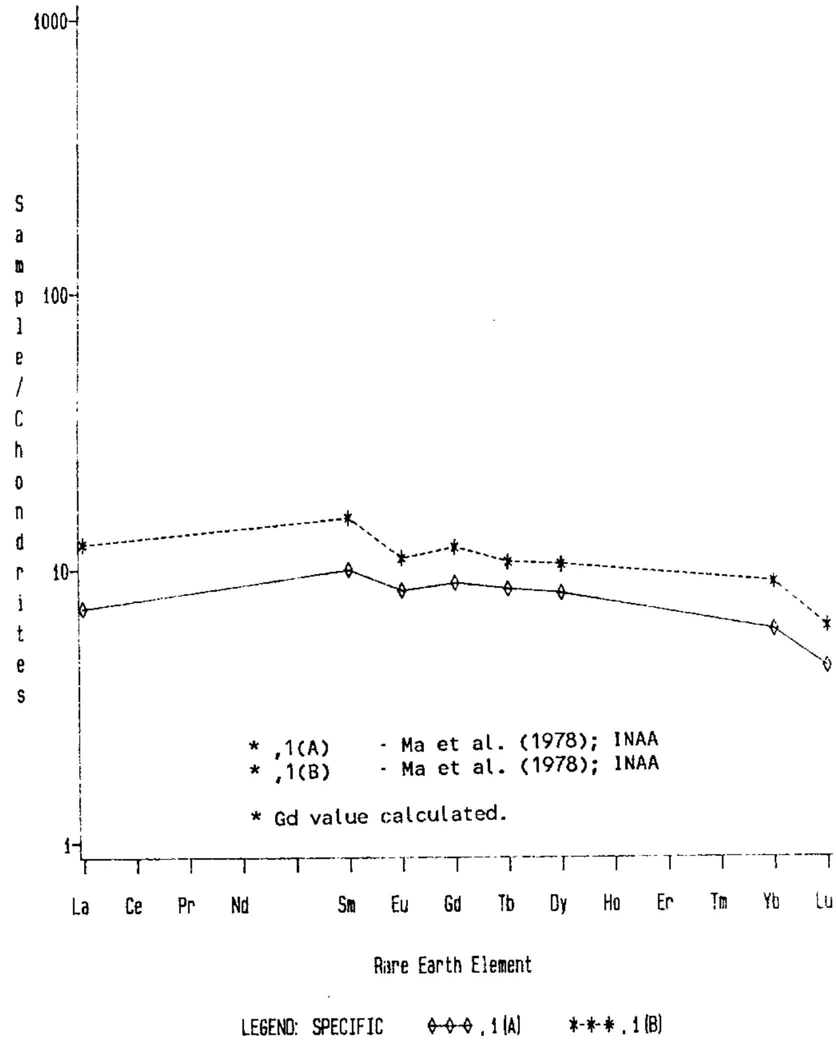


Figure 3. Rare earths in 15639.

References and methods:

(1) Ma *et al.* (1978); INAA

Notes:

(a) ± 30 ppm
(b) ± 40 ppm

15640 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.50 g

INTRODUCTION: 15640 is a medium-grained, olivine-bearing mare basalt which is vuggy but not vesicular (Fig. 1). The olivines are visible as small (less than 1 mm) yellow-green crystals. Macroscopically the sample is similar to many medium-grained Apollo 15 olivine-normative mare basalts. It was collected as part of the rake sample at Station 9A.

PROCESSING AND SUBDIVISIONS: 15640 was allocated *in toto* and part of it (,1) consumed. ,0 was returned to the Returned Sample Vault and has a mass of 0.482 g.

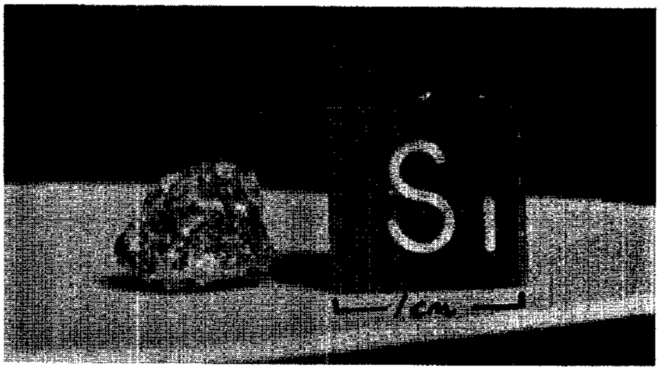


Figure 1. Macroscopic, pre-allocation view of 15640. S-71-49565

15641 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 6.90 g

INTRODUCTION: 15641 is a medium-grained, olivine-bearing mare basalt which is vuggy but not vesicular (Fig. 1). Yellow-green olivines are conspicuous macroscopically; they do not generally form phenocrysts. In chemistry, the sample is a fairly average member of the Apollo 15 olivine-normative mare basalt group. Most of the surface is fresh, but there is one patch of about 1 cm^2 which is pitted with glassy patches. 15641 was collected as part of the rake sample at Station 9A.

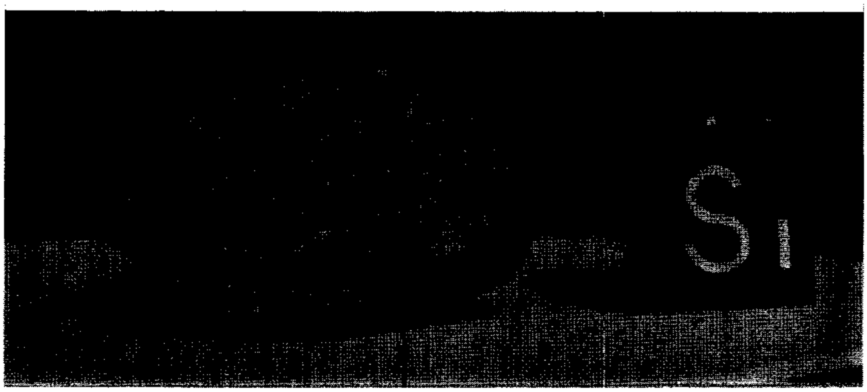


Figure 1. Pre-chip view of 15641. S-71-49557

PETROLOGY: 15641 is a medium-grained, olivine-bearing mare basalt (Fig. 2). Most olivines and pyroxenes are less than 1 mm across but a few anhedral olivines, containing silicate liquid inclusions, are up to 2 mm. The pyroxenes enclose small olivines. Plagioclases are ophitic to lathy and enclose small pyroxenes and olivines. A residue includes glass, fayalite, cristobalite, and troilite. According to Dowty et al. (1973b) the sample is like 15610 but has less residue. They reported a mode of 51% pyroxene, 26% plagioclase, 17% olivine, 4% opaques, 0.3% silica (actually cristobalite), and 0.7% miscellaneous. The mode in Dowty et al. (1973a) is slightly different: 0.2% silica and 0.8% miscellaneous. Dowty et al. (1973c) tabulated microprobe analyses of pyroxene, olivine, plagioclase, and Fe-metal, and Nehru et al. (1973) tabulated analyses of spinel group minerals and ilmenite. Nehru et al. (1974) noted that boundaries between chromites and their ulvospinel mantles included both sharp and gradual varieties. The metal grains contain 1.4 to 1.6% Co and 6.2 to 9.1% Ni (but up to 33% Ni in some cases). The ilmenites contain 0.33 to 1.07% MgO. The chemistry of minerals (Fig. 3) is typical for Apollo 15 olivine-normative mare basalts.

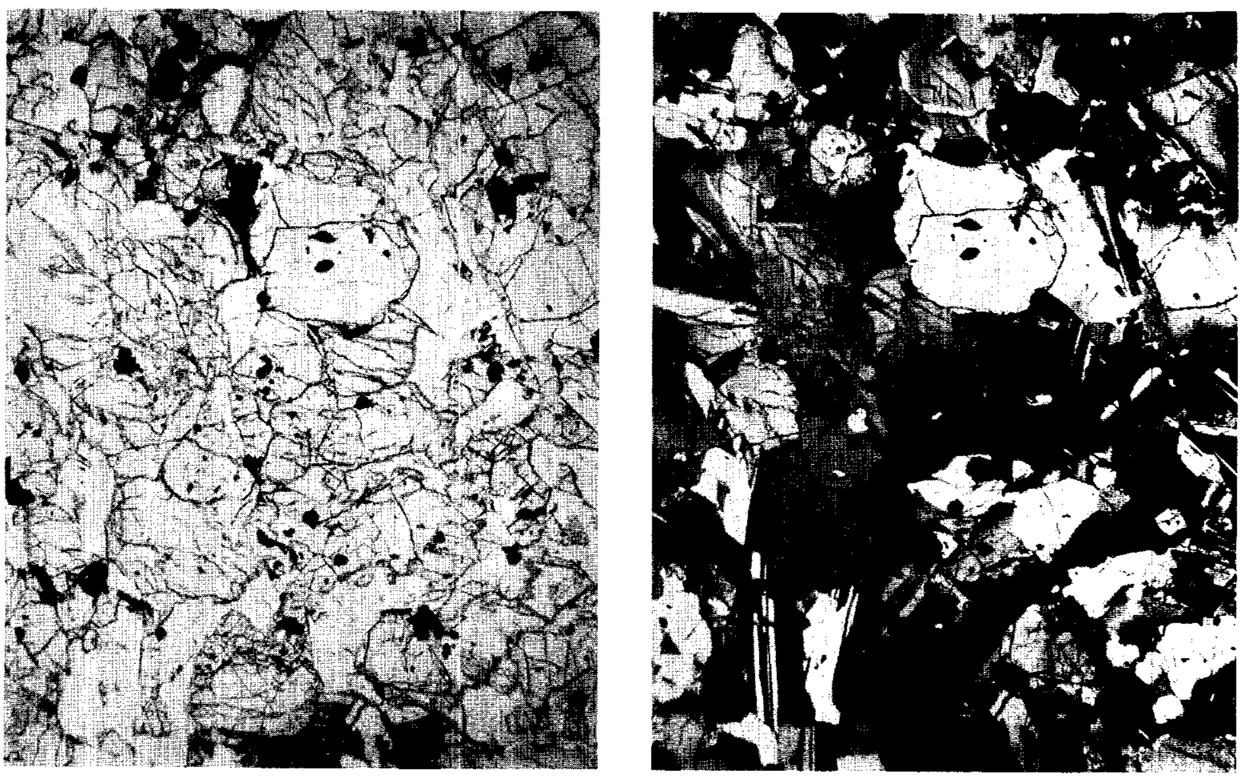
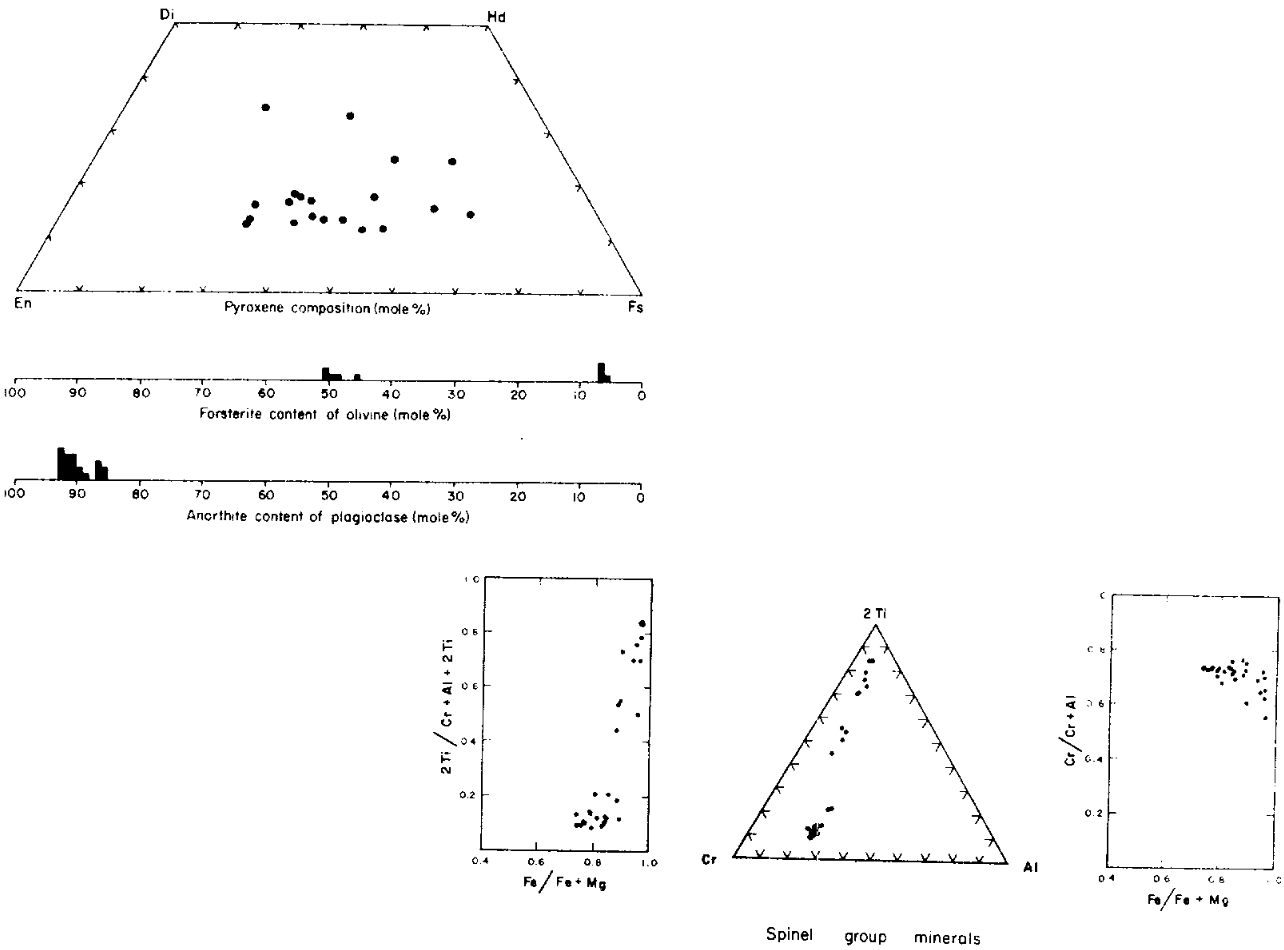


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15641,3. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

Figure 3. Chemistry of minerals in 15641 (Dowty et al., 1973b).



CHEMISTRY: A bulk rock analysis (Table 1, Fig. 4) shows 15641 to be a member of the Apollo 15 olivine-normative mare basalt group, perhaps an Mg-rich one. A defocussed beam microprobe bulk analysis is reasonably consistent but suggests that the sample is a fairly average member of the group.

TRACKS: Poupeau et al. (1972) measured solar flare tracks in feldspars from 25 surface locations. Solar flare irradiation is correlated with the rounded, dust-coated, pitted surface. Track densities range from 0.7 to more than 20 x $10^7/cm^2$. A sectioned surface has a density of 10 to 3.5 x $10^7/cm^2$ tracks in the outer millimeter, and 0.7 x $10^7/cm^2$ at 5.8 mm depth.

PROCESSING AND SUBDIVISIONS: Chipping produced ,1 (3 chips) and ,2 (1 chip). ,2 was partly used to produce thin sections ,3 and ,8. ,0 was allocated in toto for the track work and was returned, the largest piece being numbered ,9. In 1977, ,9 was further chipped to produce ,13 for chemical analyses and to make thin section ,19. ,9 at 3.98 g is the largest piece.

TABLE 15641-1. Bulk rock chemical analyses

		,13
Wt %	SiO2	
	TiO2	1.9
	Al2O3	8.8
	FeO	21.9
	MgO	12
	CaO	9.2
	Na2O	0.252
	K2O	0.034
	P2O5	
(ppm)	Sc	37
	V	212
	Cr	4110
	Mn	2080
	Co	52
	Ni	75(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.3
	Ba	55(b)
	Th	
	U	
	Pb	
	La	4.4
	Ce	
	Pr	
	Nd	
	Sm	3.1
	Eu	0.77
	Gd	
	Tb	0.6
	Dy	3.5
	Ho	
	Er	
	Tm	
	Yb	1.9
	Lu	0.26
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	390
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ±20 ppm
(b) ±35 ppm

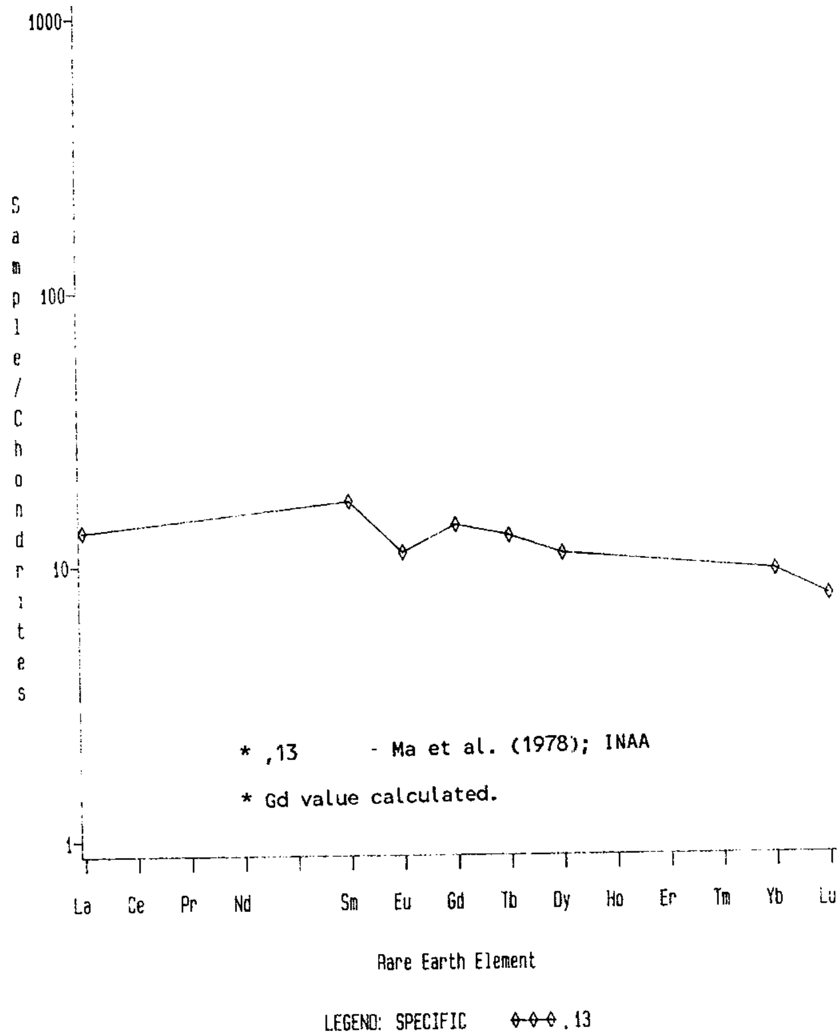


Figure 4. Rare earths in 15641.

TABLE 15641-2. Defocussed beam bulk analysis (Dowty et al., 1973a,b)

Wt%	SiO2	44.4
	TiO2	2.18
	Al2O3	10.1
	FeO	21.3
	MgO	10.2
	CaO	9.7
	Na2O	0.37
	K2O	0.06
	P2O5	0.07
ppm	Cr	3015
	Mn	1860

15642 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 1.90 g

INTRODUCTION: 15642 is a medium-grained, olivine-bearing basalt which is vuggy but not vesicular (Fig. 1). The yellow-green olivines are conspicuous macroscopically. 15642 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15642 is a medium-grained, olivine-bearing mare basalt in which the pyroxenes are up to 2 mm long, zoned, and twinned (Fig. 2). Olivines are anhedral and most are less than 1 mm across. Larger ones contain crystallized silicate-liquid inclusions. Plagioclases include some with hollow, square sections. There is some residual glass, but fayalite and cristobalite appear to be rare.

PROCESSING AND SUBDIVISIONS: ,1 was chipped off and largely used to make thin sections ,1 and ,6. ,0 is now 1.60 g.

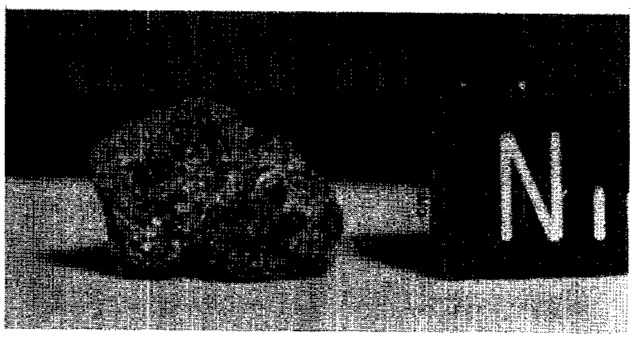


Figure 1. Pre-chip view of 15642. S-71-49575

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15642,1. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

15643 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 17.90 g

INTRODUCTION: 15643 is a medium-grained, olivine-bearing mare basalt which is vuggy but not vesicular (Fig. 1). Yellow-green olivines are conspicuous macroscopically but do not form vesicles. In chemistry, the sample is a magnesian member of the Apollo 15 olivine-normative mare basalt group. The sample is very dusty on one side and showed a possible soil line. It had no zap pits. 15643 was collected as part of the rake sample at Station 9A.

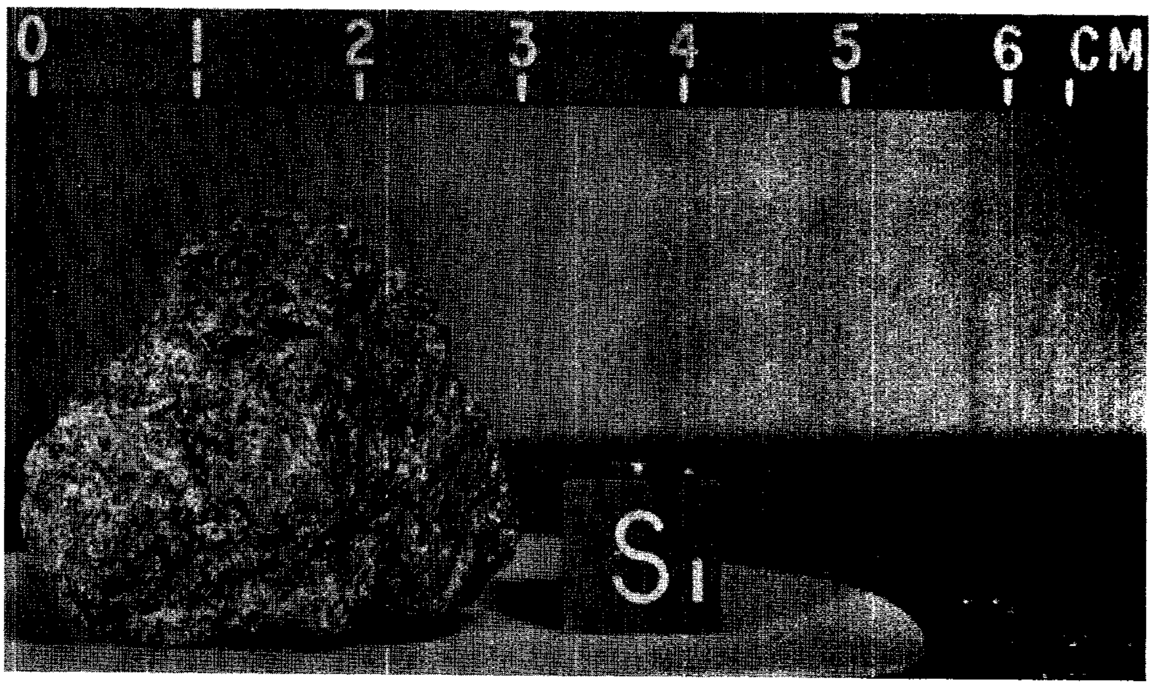


Figure 1. Pre-chip view of 15643. S-71-49783

PETROLOGY: 15643 is a medium-grained, olivine-bearing mare basalt (Fig. 2). Many grains are about 1 mm across, but a few pigeonites are bigger, and some plagioclases which ophitically enclose small pyroxenes and olivines are almost 2 mm across. Some of the larger olivines contain crystallized silicate liquid inclusions. According to Dowty et al. (1973b), the sample is similar to 15641, and has some variolitic areas. Dowty et al. (1973a,b) reported a mode of 60% pyroxene, 21% plagioclase, 13% olivine, 4% opaques, 0.5% silica (actually cristobalite) and 1.5% miscellaneous. Dowty et al. (1973c) tabulated microprobe analyses of pyroxenes, olivines, plagioclases, Si-K glass, and Fe-metal, and Nehru et al. (1973) tabulated analyses of spinel group minerals and ilmenite. Nehru et al. (1974) included 15643 in their general discussion but provided no specific data or comment. The metal grains contain 1.3 to 4.2% Co and 2.4 to 2.8% Ni. The ilmenites contain 0.64 to 0.99% MgO. The chemistry of minerals (Fig. 3) is typical of Apollo 15 olivine-normative mare basalts.

Fig. 2a

Fig. 2b

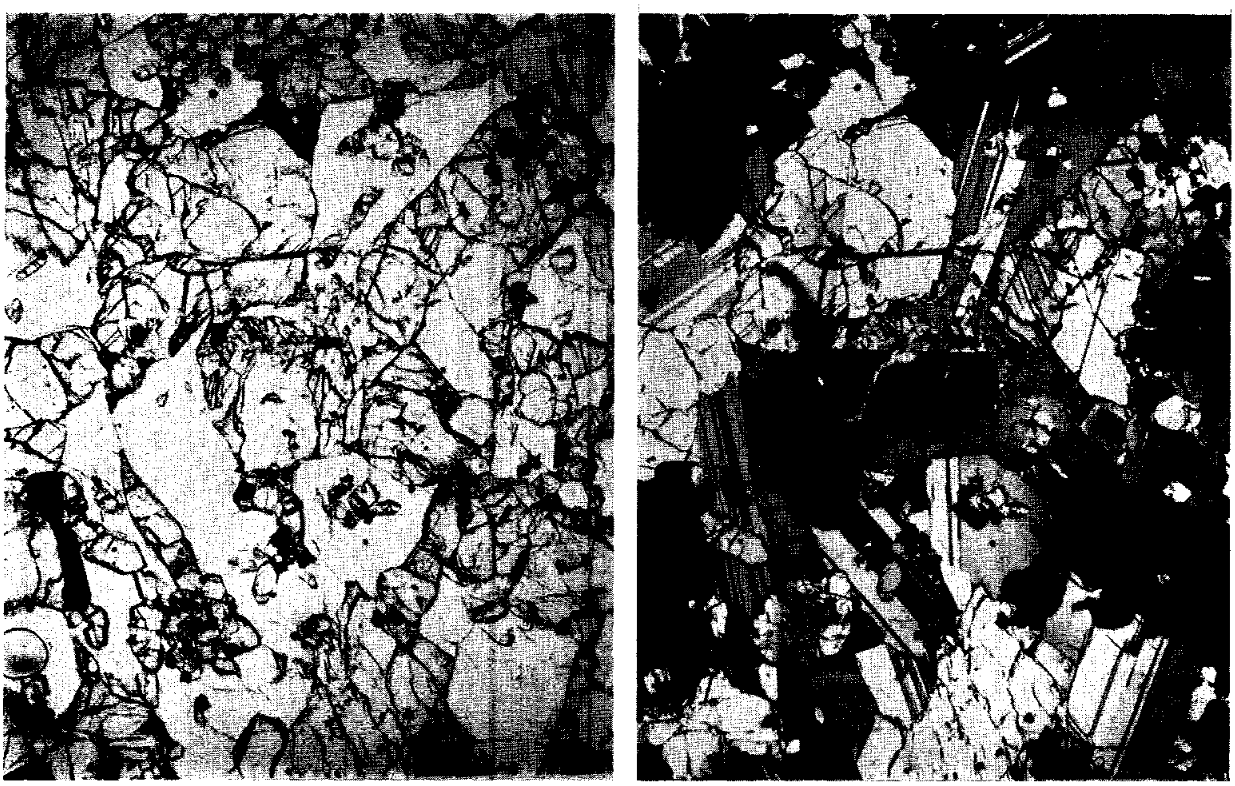
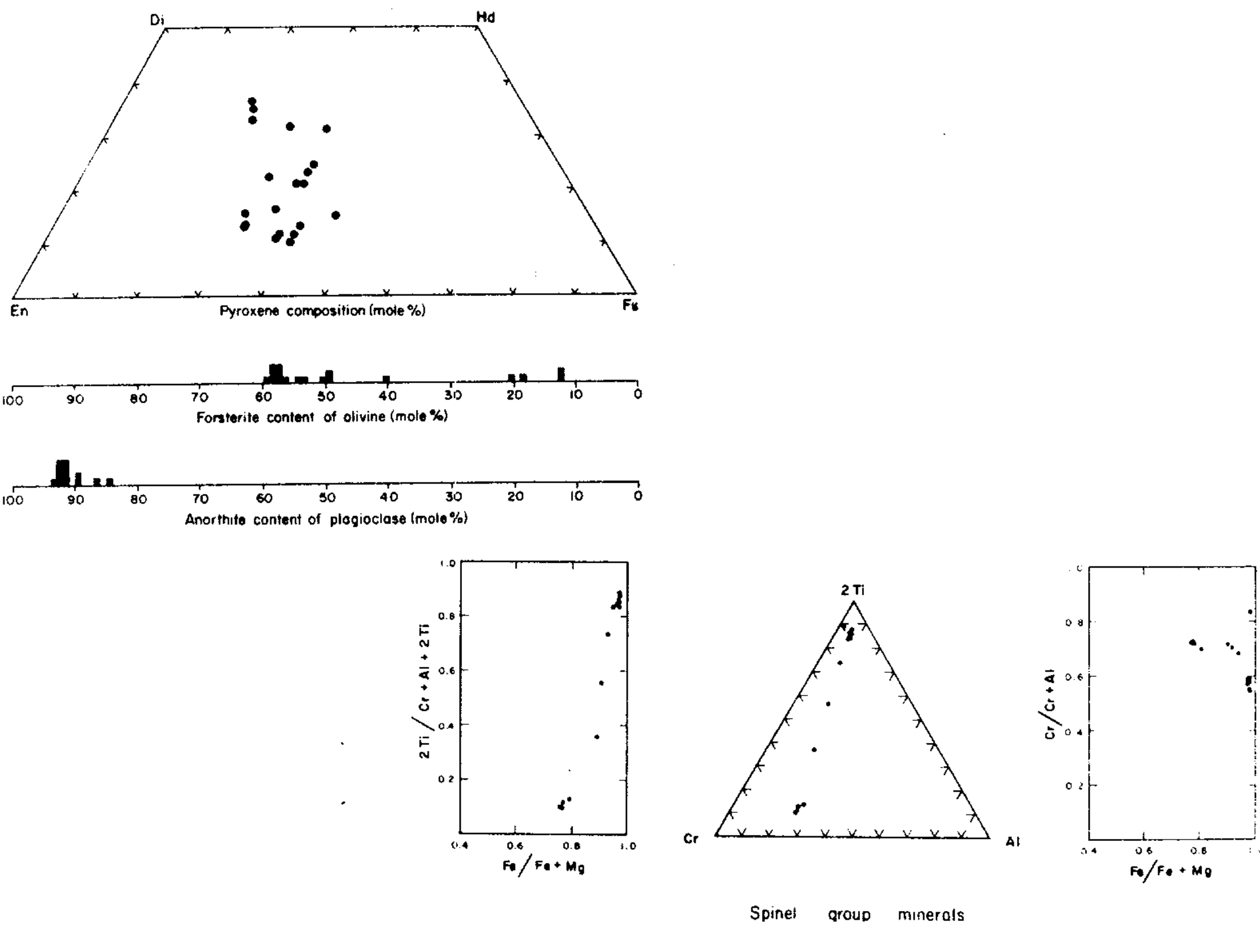


Figure 2. Photomicrographs of 15643,14. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

Figure 3. Chemistry of minerals in 15643 (Dowty et al., 1973b).



CHEMISTRY: Bulk rock chemical analyses are listed in Table 1 and the rare earths shown in Figure 4. A defocussed beam microprobe analysis listed in Table 2 is consistent. The sample appears to be a member, and an Mg-rich one, of the Apollo 15 olivine-normative mare basalt suite. Laul et al. (1972a) noted the positive Eu anomaly, low Sm/Eu, and low rare-earths and stated that 15643 was probably derived by a higher degree of partial melting, involving larger degrees of plagioclase melting in the source, than other samples such as 15555. This concept cannot be considered tenable. Laul and Schmitt (1973), using the same data, suggested that the sample occluded very little, if any, late magma. Such would be consistent with the very low TiO_2. (Dowty et al., 1973a, referring to this feature erroneously ascribed it to 15641 instead of 15643.) Of note is the very small sample size (49 mg) used by Laul and Schmitt (1973) in this analysis. Ma et al. (1978) also referred to the Laul and Schmitt (1973) data and stated that 15643 was not related to other olivine-normative mare basalts by fractionation or filter-pressing.

Cuttitta et al. (1973) and Christian et al. (1972) also analyzed for, and found no, Fe_2O_3, and found an "excess reducing capacity" (ΔRC) of +0.12.

PROCESSING AND SUBDIVISIONS: Early chipping produced sets of chips ,1 through ,6. ,2 and ,3 were reprocessed in 1977 to produce thin sections ,14 and ,15 from ,2 and chemical analysis of ,3. ,0 is not 15.60 g.

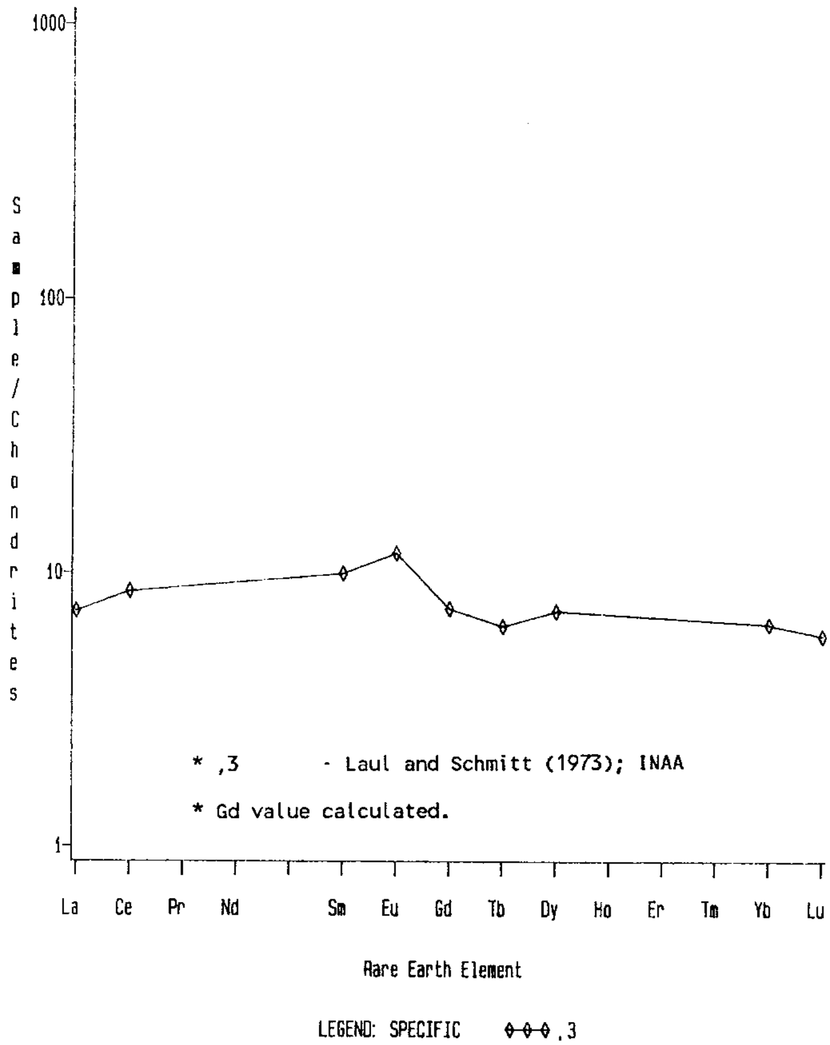


Figure 4. Rare earths in 15643.

TABLE 15643-1. Bulk rock chemical analyses

		,5	,3
Wt%	SiO2	44.80	
	TiO2	2.01	1.1
	Al2O3	9.08	10.0
	FeO	21.28	23.1
	MgO	12.20	13
	CaO	9.48	9.0
	Na2O	0.27	0.271
	K2O	0.05	0.018
	P2O5	0.09	
(ppm)	Sc	32	30
	V	15	150
	Cr	3355	3040
	Mn	2170	1990
	Co	74	57
	Ni	145	
	Rb	<1	
	Sr	140	
	Y	23	
	Zr	59	<170
	Nb	<10	
	Hf		1.1
	Ba	43	60
	Th		
	U		
	Pb		
	La	<10	2.4
	Ce		7.6
	Pr		
	Nd		
	Sm		1.8
	Eu		0.82
	Gd		
	Tb		0.3
	Dy		2.3
	Ho		
	Er		
	Tm		
	Yb	3.9	1.3
	Lu		0.20
	Li	4.7	
	Be	<1	
	B		
	C		
	N		
	S		
	F		
	Cl		
	Br		
	Cu	8.6	
	Zn		
(ppb)	I		
	At		
	Ga	4100	
	Ge		
	As		
	Se		
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd		
	In		
	Sn		
	Sb		
	Te		
	Cs		
	Ta		200
	W		
	Re		
	Os		
	Ir		
	Pt		
	Au		
	Hg		
	Tl		
	Bi		
		(1)	(2)

TABLE 15643-2. Defocussed beam bulk chemical analysis (Dowty et al., 1973a,b)

Wt%	SiO2	45.4
	TiO2	1.87
	Al2O3	7.2
	FeO	23.7
	MgO	12.5
	CaO	8.6
	Na2O	0.25
	K2O	0.03
	P2O5	0.07
ppm	Cr	3150
	Mn	2095

References and methods:

(1) Christian et al. (1972), Cuttitta et al. (1973); XRF, chemical, optical emiss. spec.
(2) Laul and Schmitt (1973); INAA

15644 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.40 g

INTRODUCTION: 15644 is a small fragment contining yellow-green olivines, brown pyroxene, and white plagioclase (Fig. 1). It is similar in appearance to non-vesicular, medium-grained Apollo 15 olivine-normative mare basalts. It was collected as part of the rake sample at Station 9A. 15644 has never been subdivided or allocated.

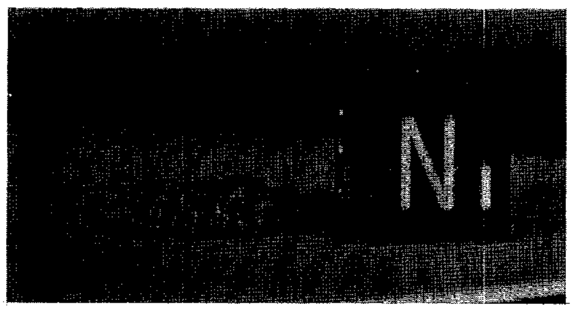


Figure 1. Sample 15644. S-71-49777

15645 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.50 g

INTRODUCTION: 15645 is a small fragment contining yellow-green olivines, brown pyroxene, and white plagioclase (Fig. 1). It is similar in appearance to non-vesicular, medium-grained Apollo 15 olivine-normative mare basalts. It was collected as part of the rake sample at Station 9A. 15645 has never been subdivided or allocated.

Figure 1. Sample 15645. S-71-49569

15647 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT — ST. 9A — 58.2 g

INTRODUCTION: 15647 is a fine-grained, olivine-bearing mare basalt (Fig. 1). The olivines form small phenocrysts. In chemistry, the basalt appears to be an average member of the Apollo 15 olivine-normative mare basalt group. It is a coherent, rounded sample with numerous zap pits. It was collected as part of the rake sample at Station 9A.

PETROLOGY: 15647 consists of anhedral, small (less than 1 mm) olivines, small granular pyroxenes and some granular olivine, and plagioclases (Fig. 2). The plagioclases, up to 2 mm long, are ragged and poikilitically enclose the small mafic phases. In places they grow in a radial arrangement. The olivine phenocrysts appear optically unzoned generally, and a few contain quenched silicate liquid inclusions. Chromite is present in the olivines, but ulvospinel is the dominant opaque phase. Ilmenite, cristobalite, glass, fayalite, and troilite form the residuum. Dowty et al. (1973a,b) described 15647 as the coarsest (by far) of the olivine-phyric basalts they studied; coarser rocks have a gabbroic, non-porphyritic texture. They reported a mode of 51% pyroxene, 29% plagioclase, 11% olivine, 6% opaques, and 3% miscellaneous. Microprobe analyses of pyroxenes, olivines, plagioclases, and residual glass were listed in Dowty et al. (1973c) (Fig. 3), and Nehru et al. (1973, 1974) reported and generally discussed spinel group and ilmenite analyses. Metal grains contain 1.3 to 1.8% Co and 2.2 to 7.7% Ni (some up to 23% Ni), and the ilmenite has 0.6 to 1.11% MgO. The residual silicic glass contains up to 7.9% K_2O.

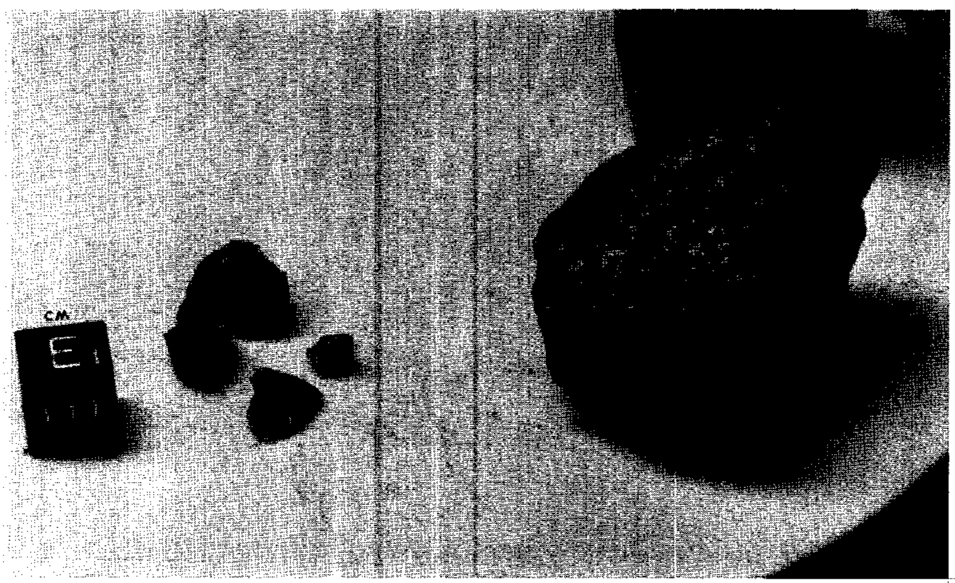


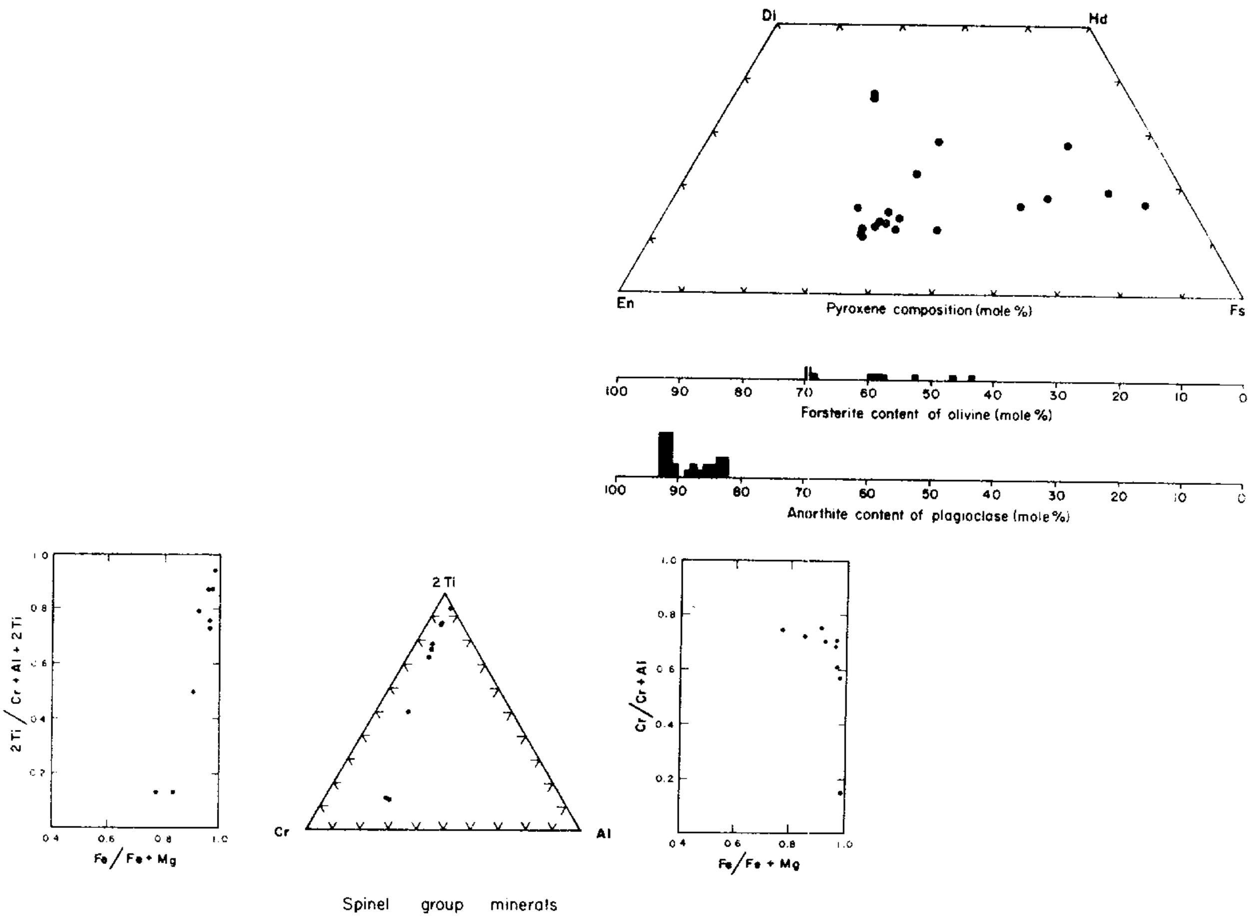
Figure 1. Post chip view of 15647. S-71-56353

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15647,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers. Olivine phenocryst (center) has a quenched silicate liquid inclusion, and euhedral crystal faces against plagioclase, anhedral against mafic phases.

Figure 3. Compositions of mineral phases in 15647 (Dowty et al., 1973b).



CHEMISTRY: A major and trace element analysis reported by Helmke and Haskin (1972) and Helmke et al. (1973) is listed in Table 1, with the rare earths plotted in Figure 4. Although Helmke and Haskin (1972) stated that 15647 is representative of most of the olivine-normative basalts (for trace elements), it has higher TiO_2 and FeO, and lower Al_2O_3. The defocussed beam analysis of Dowty et al. (1973a,b) (erroneously listed under 15697 in 1973a) is similar to the Helmke et al. (1973) analysis except for more "normal" TiO_2 and Al_2O_3 abundances. The sample would thus appear to be a fairly average member of the Apollo 15 olivine-normative mare basalt group. The Hf abundance for 15647 (and all other samples analyzed) reported by Helmke et al. (1973) is a revision downwards of the Helmke and Haskin (1972) data.

PROCESSING AND SUBDIVISIONS: A few small pieces were chipped from 15647 (,0 now 55.39 g) for allocations (Fig. 1). Thin sections were made from two pieces: ,1 produced ,6 and ,7; and ,2 produced ,12 and ,13.

TABLE 15647-1. Bulk rock chemical analysis

		,4
Wt%	SiO2	46.2
	TiO2	3.01
	Al2O3	7.86
	FeO	23.9
	MgO	10.4
	CaO	9.67
	Na2O	0.275
	K2O	0.047
	P2O5	
(ppm)	Sc	46.1
	V	
	Cr	4000
	Mn	2290
	Co	53
	Ni	
	Rb	1.7
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.6(a)
	Ba	
	Th	
	U	
	Pb	
	La	4.83
	Ce	13.3
	Pr	
	Nd	10.6
	Sm	3.54
	Eu	0.92
	Gd	5.0
	Tb	0.83
	Dy	5.64
	Ho	0.93
	Er	3.0
	Tm	
	Yb	2.27
	Lu	0.327
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	3500
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	41
	Ta	
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Helmke and Haskin (1972), Helmke *et al.*, (1973); INAA, AAS, RNAA

Notes:

(a) listed as 6.5 ppm in Helmke and Haskin (1972)

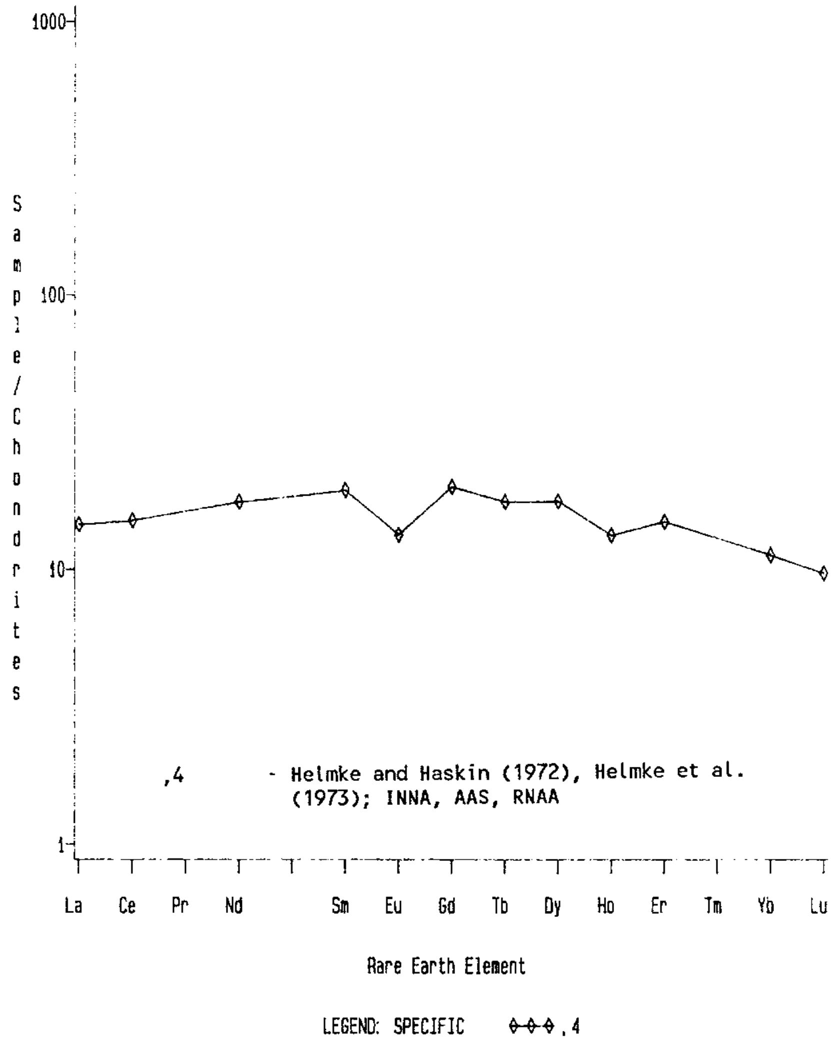


Figure 4. Rare earths in 15647,4.

TABLE 15647-2. Defocussed beam bulk rock analysis (Dowty et al., 1973a,b)

Wt %	SiO2	44.8
	TiO2	2.35
	Al2O3	9.0
	FeO	23.6
	MgO	10.5
	CaO	8.8
	Na2O	0.33
	K2O	0.04
	P2O5	0.07
ppm	Cr	3015
	Mn	2015

15648 BRECCIATED/MELTED MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 9.10 g

INTRODUCTION: 15648 is an olivine-bearing, medium-grained mare basalt which has been brecciated and partly melted. It is not vesicular and has few vugs (Fig. 1). In chemistry, it is an average member of the Apollo 15 olivine-normative mare basalt group. The sample is moderately friable and fractured, and pale-colored with chalky (shocked) feldspars. The surfaces tend to be rounded but zap pits are not obvious. One side is dusty and there are some possible welded-dust/glassy patches. 15648 was collected as part of the rake sample from Station 9A.

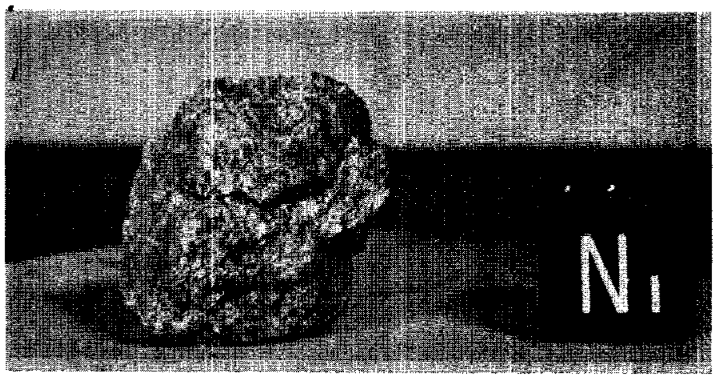


Figure 1. Pre-chip view of 15648. S-71-49773

PETROLOGY: 15648 is a brecciated basalt (Fig. 2). A brief description was given by Ma et al. (1978). The sample has been partly melted. Most has been severely deformed and consists of crushed mineral debris surrounded by dark-brown glassy mesostasis. Larger, relatively undeformed crystals (mainly pyroxene) are interspersed in the matrix. Other parts are less severely deformed and retain the original microgabboroic texture.

CHEMISTRY: A bulk chemical analysis (Table 1, Fig. 3) shows 15648 to be a fairly average member of the Apollo 15 olivine-normative mare basalt group, although the FeO is low. Neither Ni nor Co appear to have been increased by any meteoritic contamination.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) measured a natural magnetic intensity (NRM) of 2.5 x 10^{-6} emu/g for the total sample. This value is typical for Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: In 1977, a single chip (,1) was taken and used for chemical analysis and to make thin section ,5. ,0 is now 8.40 g.

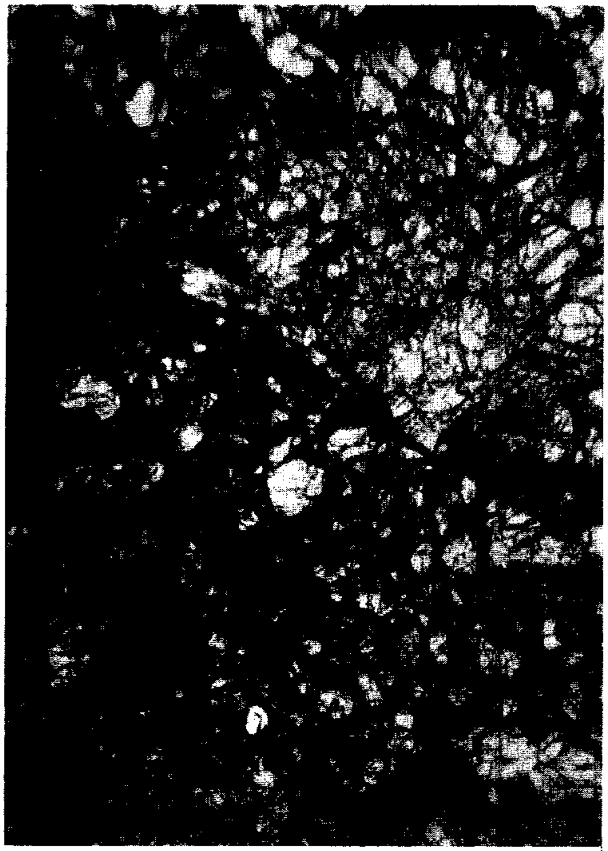


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15648,5. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15648-1. Bulk rock chemical analysis

		,1
Wt%	SiO2	
	TiO2	2.2
	Al2O3	9.9
	FeO	20.1
	MgO	11
	CaO	9.7
	Na2O	0.284
	K2O	0.041
	P2O5	
(ppm)	Sc	44
	V	196
	Cr	3480
	Mn	2000
	Co	43
	Ni	20(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.1
	Ba	
	Th	
	U	
	Pb	
	La	4.7
	Ce	
	Pr	
	Nd	
	Sm	3.2
	Eu	0.82
	Gd	
	Tb	0.7
	Dy	4.5
	Ho	
	Er	
	Tm	
	Yb	2.2
	Lu	0.26
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	390
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:
(1) Ma *et al.* (1978); INAA

Notes:

(a) ±15 ppm

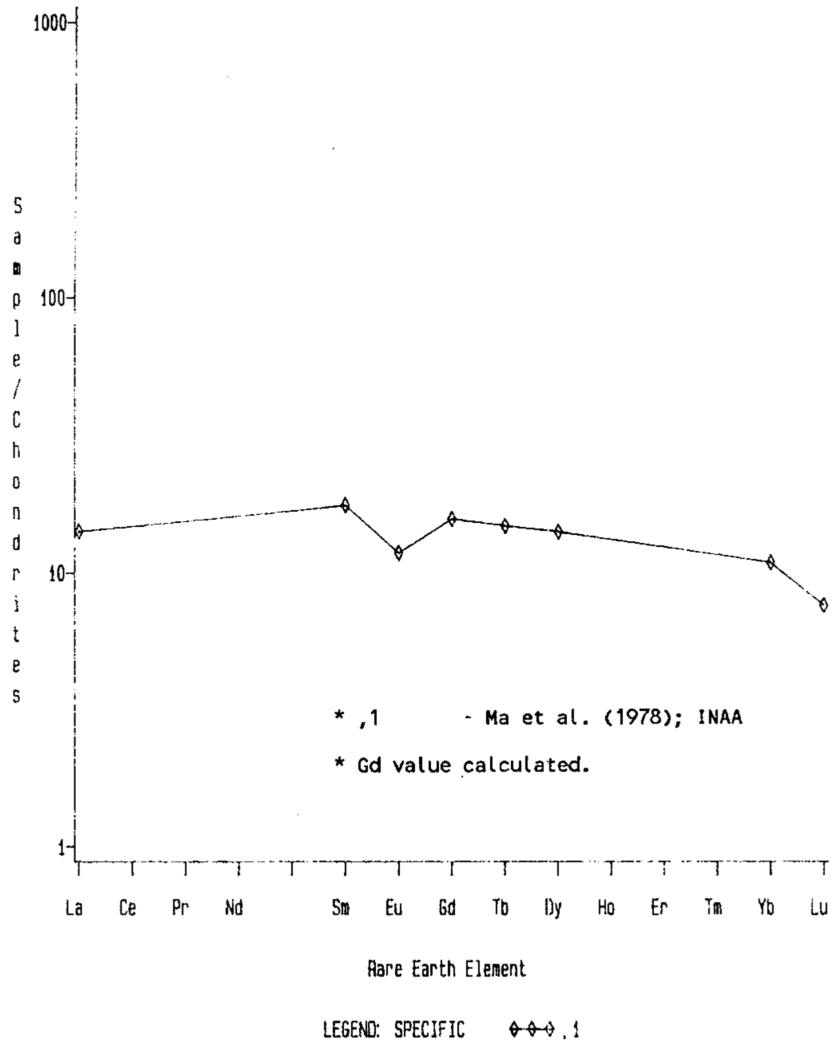


Figure 3. Rare earths in 15648.

15649 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 6.20 g

INTRODUCTION: 15649 is a fine-grained, olivine-bearing mare basalt which is not vesicular and has few vugs (Fig. 1). Like 15648 it is pale-colored, but is not brecciated or melted; it does appear to be shocked-fractured. Small yellow-green olivines are visible macroscopically. In chemistry the sample is an average member of the Apollo 15 olivine-normative mare basalt group. 15649 was collected as part of the rake sample at Station 9A.

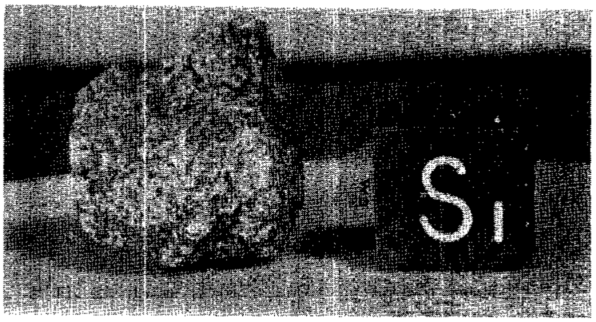


Figure 1. Pre-chip view of 15649. S-71-49587

PETROLOGY: 15649 is a moderately fine-grained, subophitic, olivine-bearing mare basalt (Fig. 2). It appears to be shock-fractured. Pyroxenes and plagioclases are generally less than half a millimeter long; the plagioclases form stubby crystals. The olivines are up to about 1 mm and some are zoned and phenocrystic, but many are smaller. Fayalite is present but cristobalite is rare to absent. Opaque phases include chromite, ulvospinel, ilmenite, Fe-metal (rare), and troilite. Ma et al. (1978) referred to 15649 as an olivine microgabbro. Steele et al. (1972a) plotted the compositions of plagioclases: An_{93-89} and Fe of 0.4 to 0.6%, similar to Apollo 12 and other Apollo 15 mare basalt plagioclases.

CHEMISTRY: A bulk chemical analysis (Table 1, Fig. 3) shows 15649 to be a fairly average member of the Apollo 15 olivine-normative mare basalt group, perhaps Mg-enriched but the Mg is imprecisely determined. The composition is very similar to 15648.

PROCESSING AND SUBDIVISIONS: In 1971, chipping produced ,1 (several chips) and ,2 (single chip). ,2 was used to make thin sections ,4 and ,6. In 1977, two chips (,10) were removed from ,1 (leaving it mainly as small chips and fines) and used for chemical analysis and to make thin section ,12. ,0 is now 4.42 g.

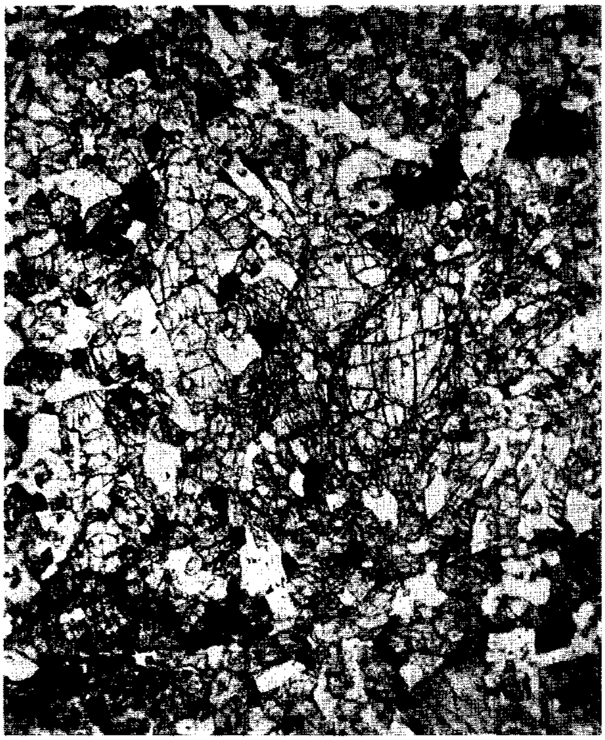


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15649,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15649-1. Bulk rock chemical analysis

		,10
Wt %	SiO2	
	TiO2	2.2
	Al2O3	9.1
	FeO	21.7
	MgO	12
	CaO	9.1
	Na2O	0.255
	K2O	0.042
	P2O5	
(ppm)	Sc	38
	V	174
	Cr	3590
	Mn	2015
	Co	46
	Ni	20(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.8
	Ba	70(b)
	Th	
	U	
	Pb	
	La	6.1
	Ce	
	Pr	
	Nd	
	Sm	4.1
	Eu	0.87
	Gd	
	Tb	0.8
	Dy	5.1
	Ho	
	Er	
	Tm	
	Yb	2.5
	Lu	0.37
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	480
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ±20 ppm
(b) ±5 ppm

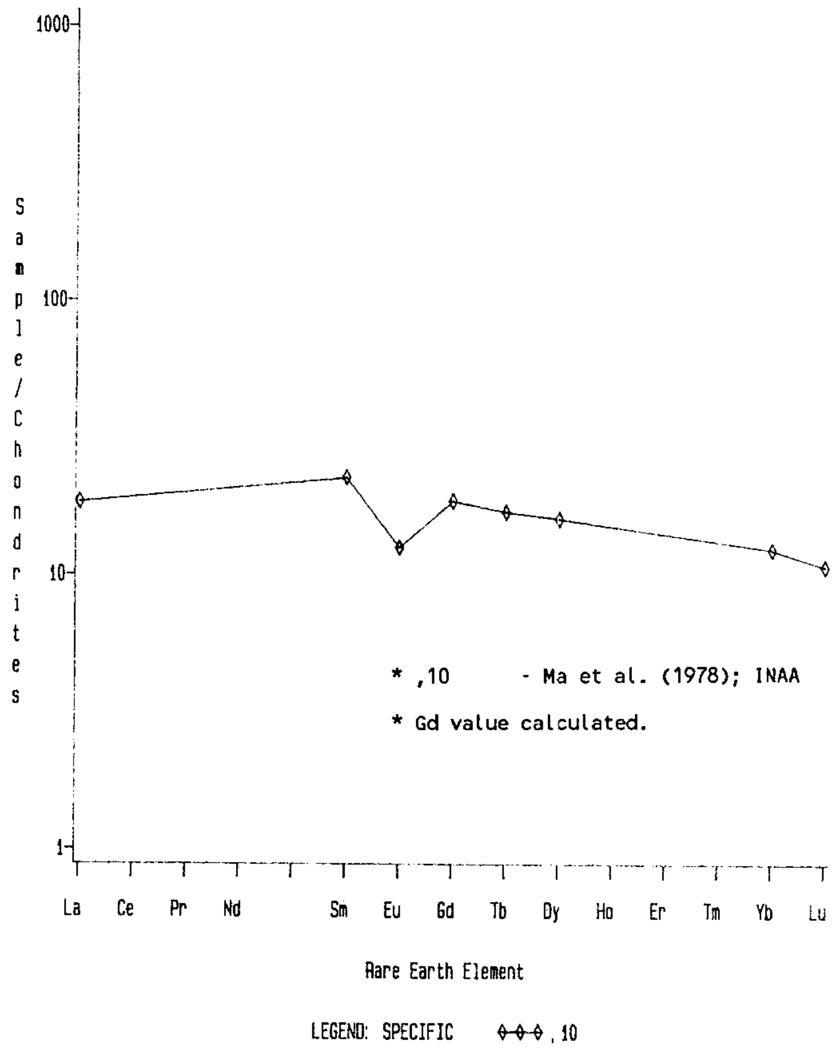


Figure 3. Rare earths in 15649.

15650 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 3.40 g

INTRODUCTION: 15650 is a fine-grained, pale-colored, non-vesicular fragment (Fig. 1). Small yellow-green olivines are visible and the sample is probably an Apollo 15 olivine-normative mare basaslt. It was collected as part of the rake sample at Station 9A.

Figure 1. Pre-chip view of 15650. S-71-49547

PROCESSING AND SUBDIVISIONS: Chipping produced several small chips (,1) of which the largest was numbered ,2 and allocated. It was partly used in making small grain mounts (,7 to ,14). ,0 is now 2.48 g.

15651 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 1.60 g

INTRODUCTION: 15651 is a fine-grained, pale-colored, non-vesicular, olivine-bearing mare basalt (Fig. 1). It has been moderately shocked. The olivines do not appear to form phenocrysts and are visible but not conspicuous macroscopically. The sample appears to be a member of the Apollo 15 olivine-normative mare basalt group. It is angular and friable. 15651 was collected as part of the rake sample at Station 9A.

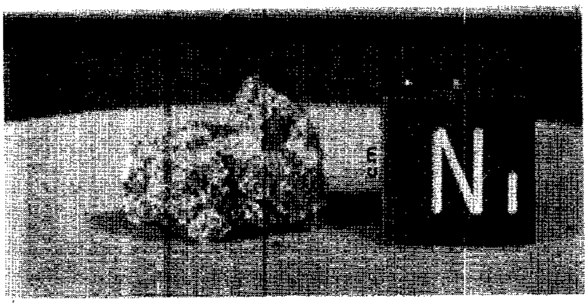


Figure 1. Pre-chip view of 15651. S-71-49769

PETROLOGY: 15651 is a moderately fine-grained, olivine-bearing mare basalt with a subophitic or gabbroic texture; it has been somewhat cataclasized by shock (Fig. 2). Dowty et al. (1973a,b) found it to be finer-grained than most olivine microgabbros and that it might be olivine phyric. They reported a mode of 62% pyroxene, 28% plagioclase, 3% olivine, 0.3% silica, 5% opaques, and 1.7% miscellaneous. Dowty et al. (1973c) tabulated microprobe analyses of pyroxene, olivine, plagioclase, and Fe-metal; and Nehru et al. (1973) tabulated analyses of spinel group and ilmenite minerals. Nehru et al. (1974) included 15651 in their general discussion of opaque minerals but reported no specific data or comment. The mineral chemistry (Fig. 3) is typical for Apollo 15 olivine-normative mare basalts.

CHEMISTRY: The only chemical data is a microprobe defocussed beam bulk rock analysis (Table 1). This analysis is consistent with 15651 being a member of the Apollo 15 olivine-normative mare basalt group. The measured TiO_2 is high and K_2O low, suggesting some sampling problems.

PROCESSING AND SUBDIVISIONS: Chipping produced ,1 which was mostly used to make thin sections ,6 to ,8. ,0 is now 1.45 g.

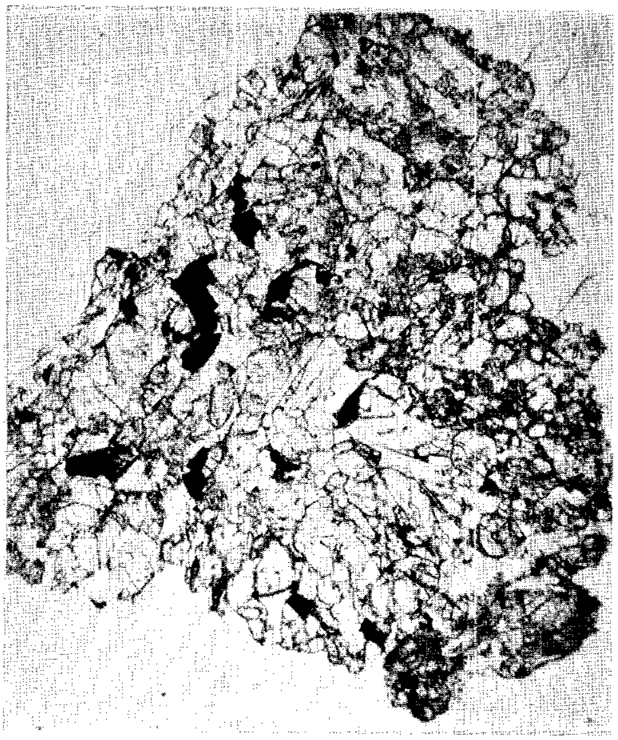


Fig. 2a

Fig. 2b

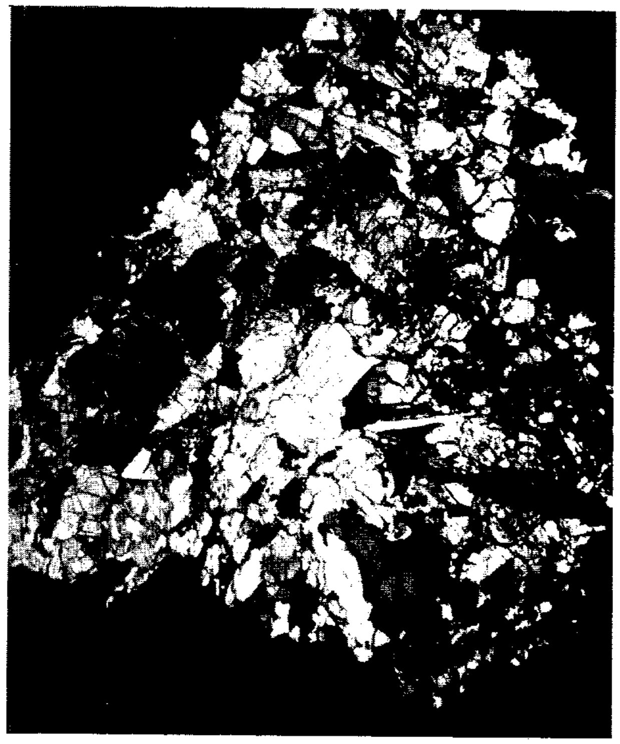


Figure 2. Photomicrographs of entire thin section 15651,6, about 3 mm across. a) transmitted light; b) crossed polarizers.

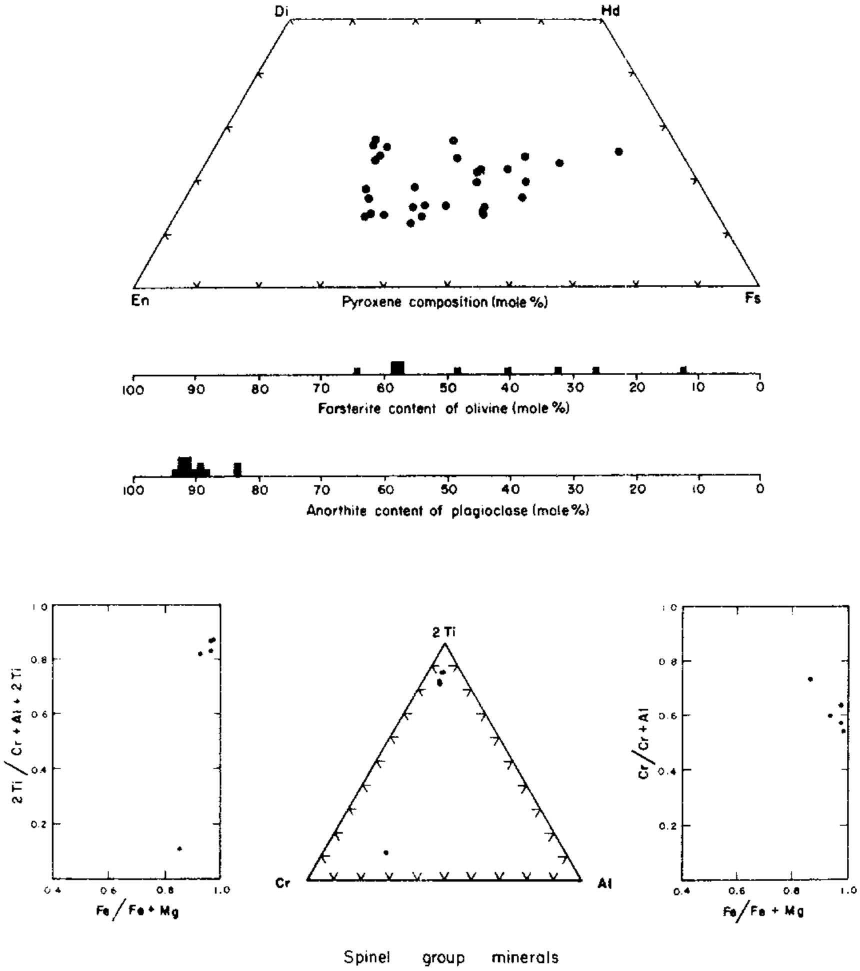


Figure 3. Chemistry of minerals in 15651 (Dowty et al., 1973b).

TABLE 15651-1. Defocussed beam bulk analysis (Dowty et al., 1973a,b)

Wt %	SiO2	43.7
	TiO3	3.1
	Al2O3	8.9
	FeO	23.9
	MgO	10.9
	CaO	9.0
	Na2O	0.25
	K2O	<0.01
	P2O5	0.04
ppm	Cr	2330
	Mn	1940

15652 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.70 g

INTRODUCTION: 15652 is a fine-grained, pale-colored, non-vesicular fragment (Fig. 1). Small yellow-green olivines are visible and the sample is probably an Apollo 15 olivine-normative mare basalt. It was collected as part of the rake sample at Station 9A. It has never been subdivided or allocated.

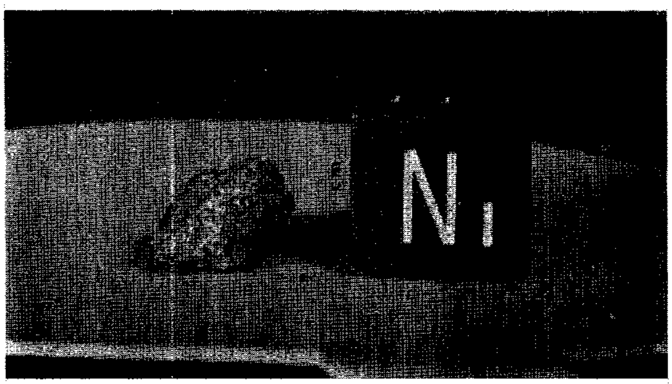


Figure 1. Sample 15652. S-71-49787

15653 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.40 g

INTRODUCTION: 15653 is a fine-grained, pale-colored, non-vesicular fragment (Fig. 1). Small yellow-green olivines are visible and the sample is probably an Apollo 15 olivine-normative mare basalt. It was collected as part of the rake sample at Station 9A. It has never been subdivided or allocated.

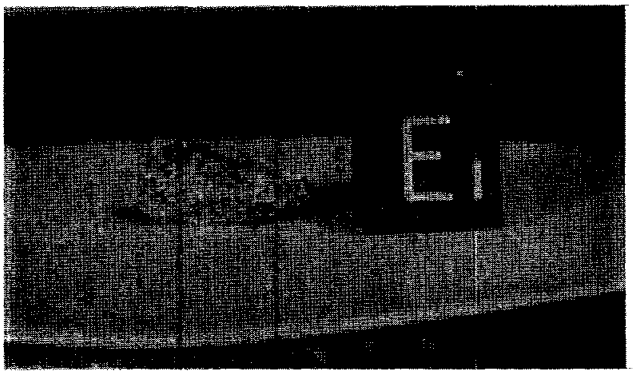


Figure 1. Sample 15653. S-71-49572

15654	FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?)	ST. 9A	0.20 g

INTRODUCTION: 15654 is a fine-grained, pale-colored, non-vesicular fragment (Fig. 1). Small yellow-green olivines are visible and the sample is probably an Apollo 15 olivine-normative mare basalt. It was collected as part of the rake sample at Station 9A. It has never been subdivided or allocated.

Figure 1. Sample 15654. S-71-49765

15655 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.40 g

INTRODUCTION: 15655 is a fine-grained, pale-colored, non-vesicular fragment (Fig. 1). Small yellow-green olivines are visible and the sample is probably an Apollo 15 olivine-normative mare basalt. It was collected as part of the rake sample at Station 9A. It has never been subdivided or allocated.

Figure 1. Sample 15655. S-71-49746

15656 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.20 g

INTRODUCTION: 15656 is a fine-grained, pale-colored, non-vesicular fragment (Fig. 1). Small yellow-green olivines are visible and the sample is probably an Apollo 15 olivine-normative mare basalt. It was collected as part of the rake sample at Station 9A. It has never been subdivided or allocated.

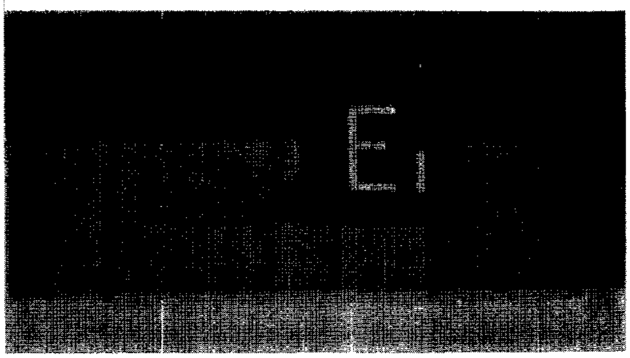


Figure 1. Sample 15656. S-71-49736

15658 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 11.60 g

INTRODUCTION: 15658 is an olivine-bearing, medium-grained, vesicular and vuggy mare basalt (Fig. 1). In chemistry, it is an average member of the Apollo 15 olivine-normative mare basalt group. The sample is rounded and one side has a moderate density of zap pits. It appears that the sample occupied only one position on the lunar surface. One side is a fresh fracture surface. 15658 was collected as part of the rake sample at Station 9A.

PETROLOGY: 15658 is a medium-grained, olivine-bearing basalt (Fig. 2). Pigeonites range from 1 to 2 mm long and are twinned and zoned. Most plagioclases form stubby crystals up to about 1 mm, some of which are hollow. Some radial growth of plagioclase and pyroxene is present. Olivine forms scattered anhedral phenocrysts, and smaller grains are present, many as inclusions in pigeonite. Cristobalite, fayalite, and a range of opaque phases including chromite, ulvospinel, and ilmenite are present.

CHEMISTRY: Bulk chemical analyses (Table 1) are consistent with each other and demonstrate that 15658 is a fairly average member of the Apollo 15 olivine-normative mare basalt group. It has a typical rare earth pattern (Fig. 3). The consistency is perhaps surprising considering the grain-size and the small sample size (60 mg) used by Helmke et al. (1973). Chappell et al. (1973) on the basis of the similar chemistry suggested that 15658, 15668, and 15674 were chips of the same original rock, and for purposes of discussion averaged their analyses. However, both 15668 and 15674 are much finer-grained than 15658.

PHYSICAL PROPERTIES: Gose et al. (1972) and Pearce et al. (1973) measured a natural magnetic intensity (NRM) of 0.7×10^{-6} emu/g for the bulk sample. This is on the low end of the range for Apollo 15 mare basalts and more like anorthosite 15415.

PROCESSING AND SUBDIVISIONS: Chipping produced ,1 (two chips) and ,2 (one chip). ,2 was used to make thin sections ,2 and ,10. One of the chips of ,1 was split to make ,3 and ,4, used for chemical analyses. ,0 is now 6.51 g.

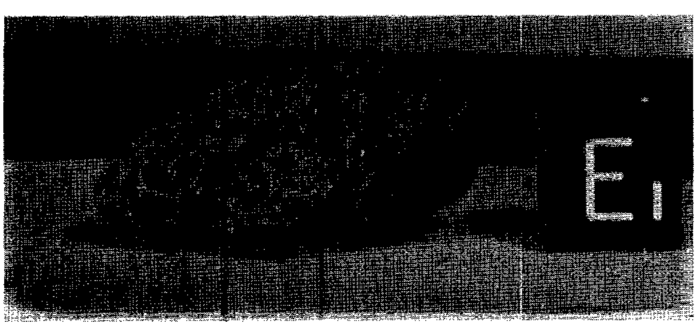


Figure 1. Pre-chip view of 15658. S-71-49532

Fig. 2a

Fig. 2b

<u>Figure 2</u>. Photomicrographs of 15658,2. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15658-1. Bulk rock chemical analyses

		,3	,4
Wt%	SiO2	45.09	46.5
	TiO2	2.50	2.69
	Al2O3	9.02	9.11
	FeO	22.59	22.5
	MgO	9.73	10.0
	CaO	10.11	10.0
	Na2O	0.28	0.257
	K2O	0.04	0.049
	P2O5	0.07	
(ppm)	Sc		47.1
	V		
	Cr	3630	
	Mn	2405	2150
	Co		50
	Ni		
	Rb		
	Sr		
	Y		
	Zr		
	Nb		
	Hf		2.0
	Ba		
	Th		
	U		
	Pb		
	La		4.5
	Ce		14.0
	Pr		
	Nd		9.9
	Sm		3.09
	Eu		0.81
	Gd		
	Tb		0.77
	Dy		5.1
	Ho		
	Er		3.0
	Tm		
	Yb		2.24
	Lu		0.30
	Li		
	Be		
	B		
	C		
	N		
	S	500	
	F		
	Cl		
	Br		
	Cu		
	Zn		
(ppb)	I		
	At		
	Ga		
	Ge		
	As		
	Se		
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd		
	In		
	Sn		
	Sb		
	Te		
	Cs		
	Ta		
	W		
	Re		
	Os		
	Ir		
	Pt		
	Au		
	Hg		
	Tl		
	Bi		
		(1)	(2)

References and methods:

(1) Chappell and Green (1973); XRF
(2) Helmke et al. (1973); INAA, AAS

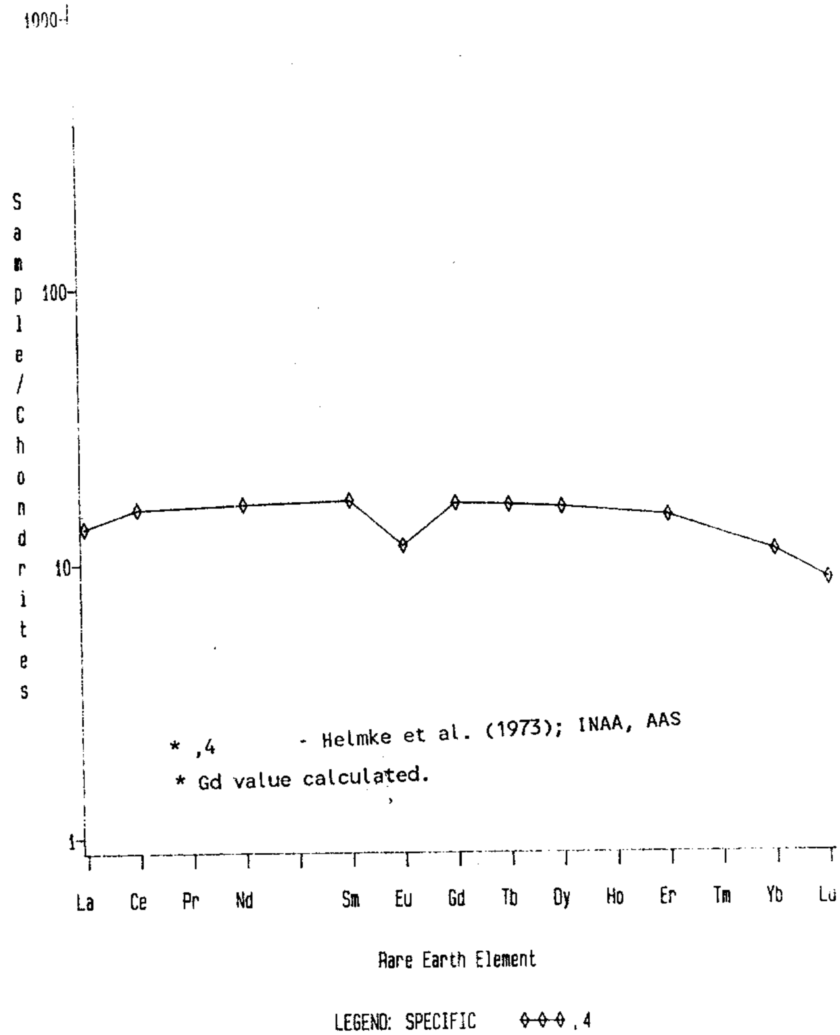


Figure 3. Rare earths in 15658.

15659 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 12.60 g

INTRODUCTION: 15659 is a medium-grained, olivine-bearing, vesicular and vuggy mare basalt (Fig. 1). Small yellow-green olivines are visible macroscopically but are neither conspicuous nor phenocrystic. In chemistry, the sample is a magnesian member of the Apollo 15 olivine-normative mare basalt group. The sample has no zap pits but one surface is somewhat rounded, indicating possible exposure at some time. 15659 was collected as part of the rake sample at Station 9A.

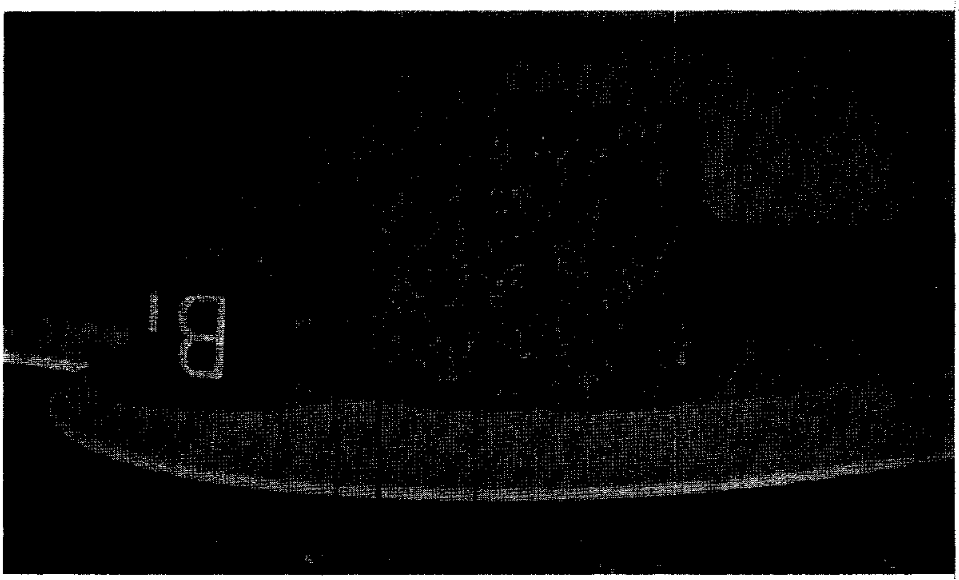


Figure 1. Pre-saw view of 15659. S-71-49756

PETROLOGY: 15659 is a vesicular, medium- to fine-grained, olivine-bearing mare basalt (Fig. 2). The pyroxenes are generally less than 1 mm long; they commonly enclose small olivines. Plagioclases tend to be lathy and interstitial. The small thin section lacks large olivines (all are less than half-millimeter). Opaques include chromite, ulvospinel, and ilmenite. The residue occurs in local pockets and consists of glass, cristobalite, fayalite, troilite, ulvospinel, and ilmenite. Steele et al. (1972a) plotted plagioclase compositional data: An_{93-90} with Fe of 0.4 to 0.65 wt%, similar to Apollo 12 and other Apollo 15 mare basalts.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15659,10. Widths about 2 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: Bulk rock analyses are shown in Table 1 and the rare earths are plotted in Figure 3. The chemistry is that of a fairly magnesian member of the Apollo 15 olivine-normative mare basalt group (e.g., Laul et al., 1972a). The La abundance of Christian et al. (1972) and Cuttitta et al. (1973) appears to be high and grossly unreliable, the Zr of Laul and Schmitt (1973) too high, and the Ca of Husain (1974) too low, even allowing for sampling errors. Cu was reported erroneously (as 0.32 ppm) in Cuttitta et al. (1973).

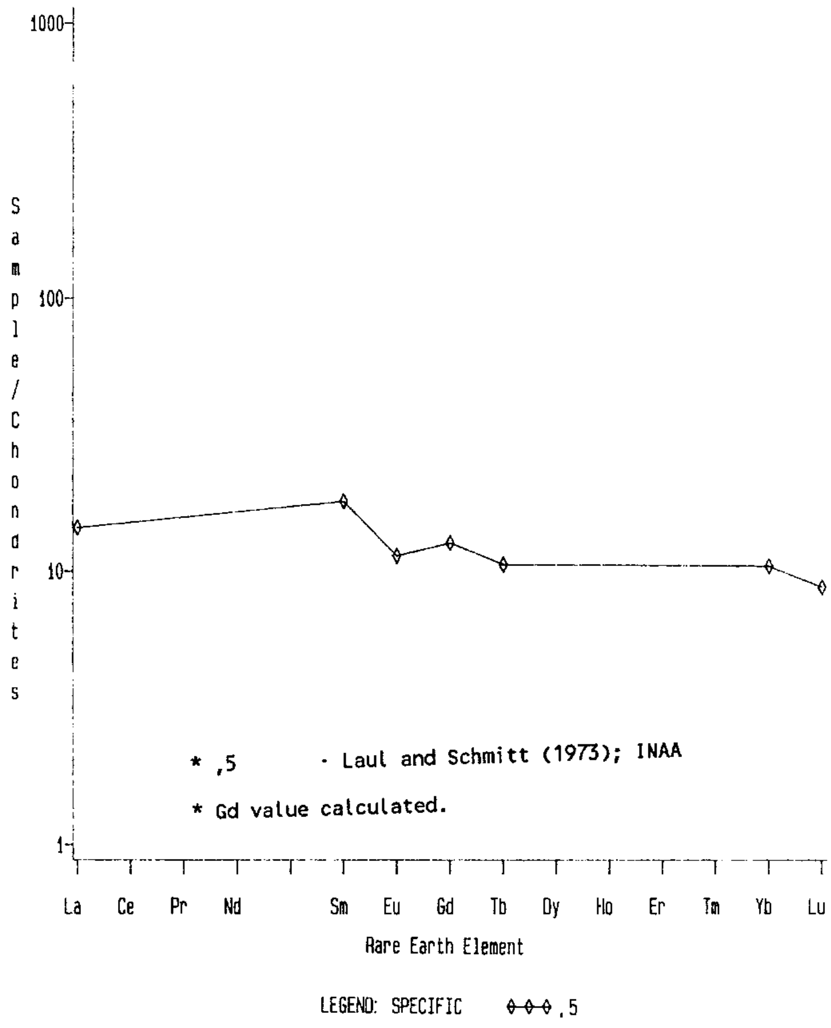


Figure 3. Rare earths in 15659.

TABLE 15659-1. Bulk rock chemical analyses

		,4	,5	,3
Wt %	SiO2	45.33		
	TiO2	2.25	2.4	
	Al2O3	8.17	8.0	
	FeO	22.17	22.0	
	MgO	12.27	13	
	CaO	8.98	9.1	7.1
	Na2O	0.27	0.232	
	K2O	0.06	0.042	0.038
	P2O5	0.12		
(ppm)	Sc	37	37	
	V	215	260	
	Cr	3425	5820	
	Mn	2015	2170	
	Co	66	55	
	Ni	87		
	Rb	1.0		
	Sr	130		
	Y	25		
	Zr	67	200	
	Nb	<10		
	Hf		2.5	
	Ba	62	<120	
	Th			
	U			
	Pb			
	La	38	4.8	
	Ce			
	Pr			
	Nd			
	Sm		3.3	
	Eu		0.79	
	Gd			
	Tb		0.50	
	Dy			
	Ho			
	Er			
	Tm			
	Yb	3.7	2.1	
	Lu		0.30	
	Li	5.4		
	Be			
	B			
	C			
	N			
	S			
	F			
	Cl			
	Br			
	Cu	32		
	Zn			
(ppb)	I			
	At			
	Ga	3800		
	Ge			
	As			
	Se			
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag			
	Cd			
	In			
	Sn			
	Sb			
	Te			
	Cs			
	Ta		400	
	W			
	Re			
	Os			
	Ir			
	Pt			
	Au			
	Hg			
	Tl			
	Bi			
		(1)	(2)	(3)

References and methods:

(1) Christian et al. (1972), Cuttitta et al. (1973); XRF, chemical, optical emiss. spec.
(2) Laul and Schmitt (1973); INAA
(3) Husain (1974); Ar isotopes, irradiation

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Husain (1974) reported Ar isotopic data for temperature releases and found a ^{40}Ar-^{39}Ar high temperature (850° to 1400°C releases) plateau age of 3.34 ± 0.04 b.y. (Fig. 4), identical with the crystallization age of other Apollo 15 mare basalts.

RARE GASES AND EXPOSURE: Husain reported Ar isotopic data and an exposure age of 394 ± 20 m.y.

PROCESSING AND SUBDIVISIONS: 15659 was sawn to produce a slab (,2), and a tiny end (,1), leaving ,0 as 9.81 g. ,1 was used to make thin section ,10. ,2 was subdivided and partly used for the chemical and isotopic analyses (,3 to ,5).

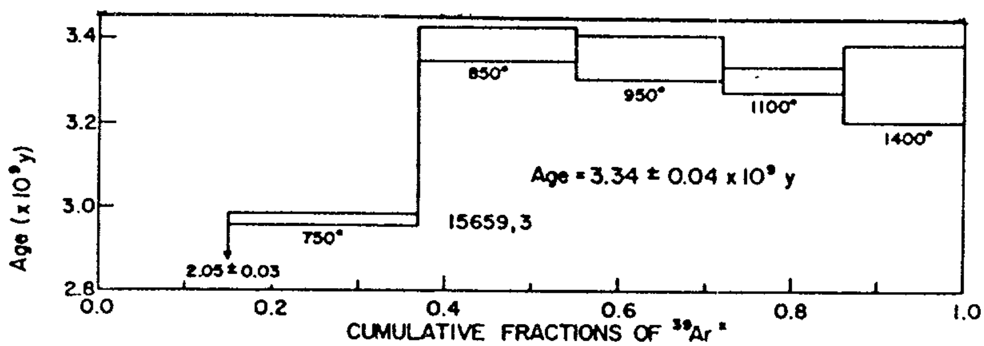


Figure 4. Ar plateau age for 15659 (Hasain; 1974).

15660 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 8.90 g

INTRODUCTION: 15660 is a vuggy, medium-grained, mare basalt (Fig. 1). It is macroscopically similar to 15658 and 15659 but not so vesicular, with zoned green to red-brown pyroxenes and small olivines visible. The texture appears to be equigranular or subophitic. Several faces are rounded and one is pitted and rounded. 15660 was collected as part of the rake sample from Station 9A. It has never been subdivided.

PHYSICAL PROPERTIES: Gose *et al*. (1972) and Pearce *et al*. (1973) measured a natural magnetic intensity (NRM) of 2.7 x 10^{-6} emu/g for the entire sample. This value is typical for Apollo 15 mare basalts.

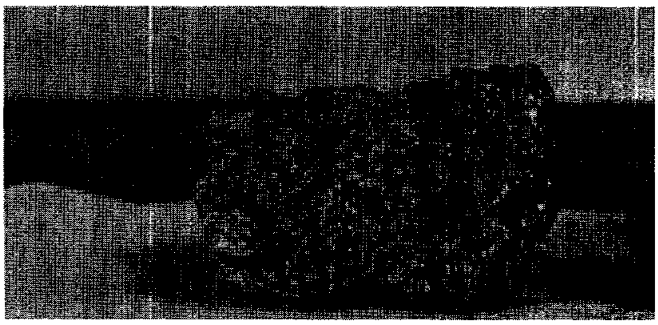


Figure 1. Sample 15660. S-71-49537

15661 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 5.90 g

INTRODUCTION: 15661 is a fine- to medium-grained olivine-bearing mare basalt which is vesicular and vuggy (Fig. 1). Small olivines are visible macroscopically. In chemistry, the sample is an average member of the Apollo 15 olivine-normative mare basalt group. The sample is rather rounded. 15661 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15661 is a fine- to medium-grained microgabbroic mare basalt (Fig. 2) with about 60% pyroxene. Rare olivine phenocrysts reach about 1.5 mm, are anhedral, and contain crystallized silicate melt inclusions. Most pyroxenes, plagioclases, and olivines are less than 0.5 mm across. The pyroxenes and olivines tend to be granular and the plagioclases to be hollow laths which are not euhedral. A few variolitic areas are present. Chromite forms cores to some ulvospinel. Cristobalite, (sieved) fayalite, ilmenite, sulfide, and some glass are present. Steele et al. (1972a) showed Ti/Al ratios for pyroxenes ranging from 1/2 to 1/4. They also reported plagioclases of An_{92-87}, containing 0.5 to 0.65% Fe, similar to Apollo 12 and other Apollo 15 mare basalt plagioclases.

CHEMISTRY: Ma et al. (1978) reported a bulk rock analysis (Table 1; Fig 3). The composition is rather average for Apollo 15 olivine-normative mare basalts. The MgO is an imprecisely determined abundance.

PROCESSING AND SUBDIVISIONS: 15661 was sawn to produce pieces ,1 (several small pieces) and ,2 (one piece) from its "S" end. ,2 was partly used to make thin sections ,6 to ,8. In 1977, the north end was chipped to produce interior, and saw-blade free, pieces (,9; ,10). ,10 was used for chemical and petrographic studies, including the making of thin section ,13. ,0 is now 3.21 g.

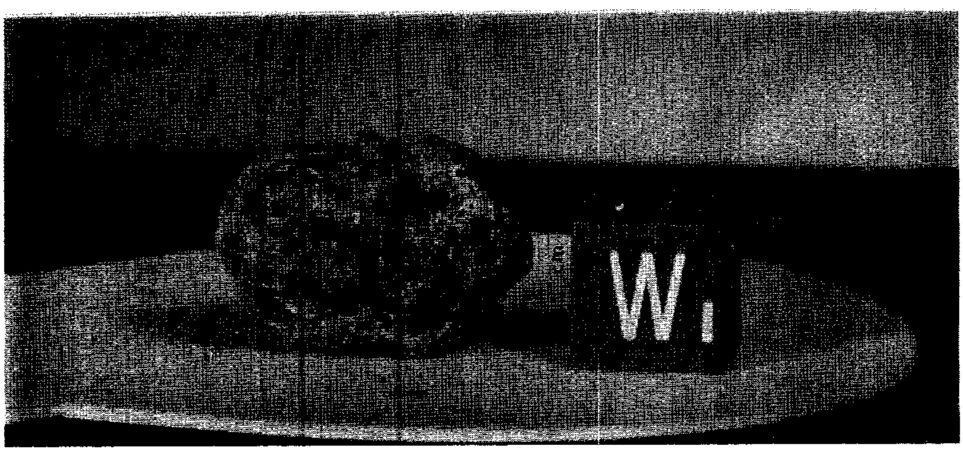


Figure 1. Pre-saw view of 15661. S-71-49530

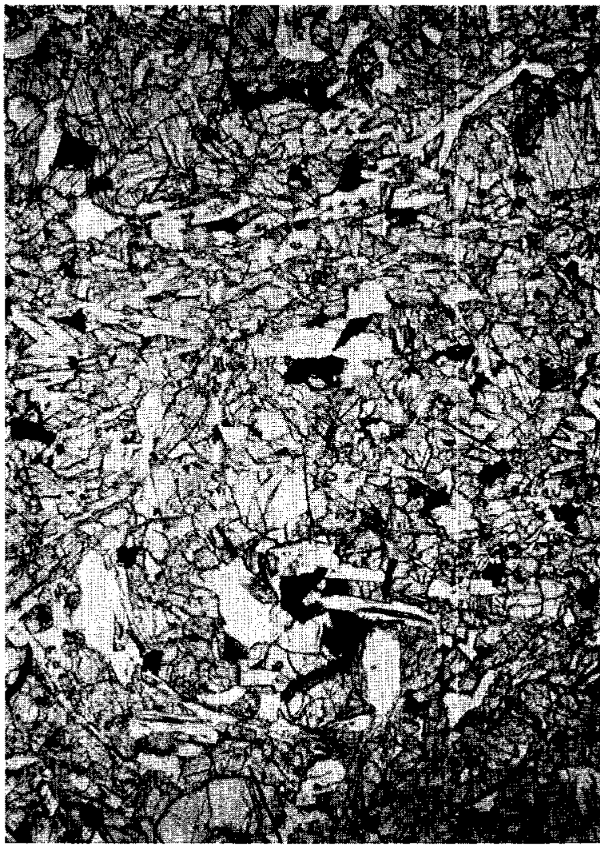


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15661,7. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15661-1. Bulk rock chemical analysis

		,10
Wt %	SiO2	
	TiO2	1.9
	Al2O3	8.7
	FeO	21.9
	MgO	12
	CaO	8.6
	Na2O	0.250
	K2O	0.036
	P2O5	
(ppm)	Sc	35
	V	186
	Cr	4470
	Mn	1990
	Co	51
	Ni	80(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.5
	Ba	70(b)
	Th	
	U	
	Pb	
	La	5.1
	Ce	
	Pr	
	Nd	
	Sm	3.3
	Eu	0.78
	Gd	
	Tb	0.7
	Dy	4.3
	Ho	
	Er	
	Tm	
	Yb	2.0
	Lu	0.25
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	410
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

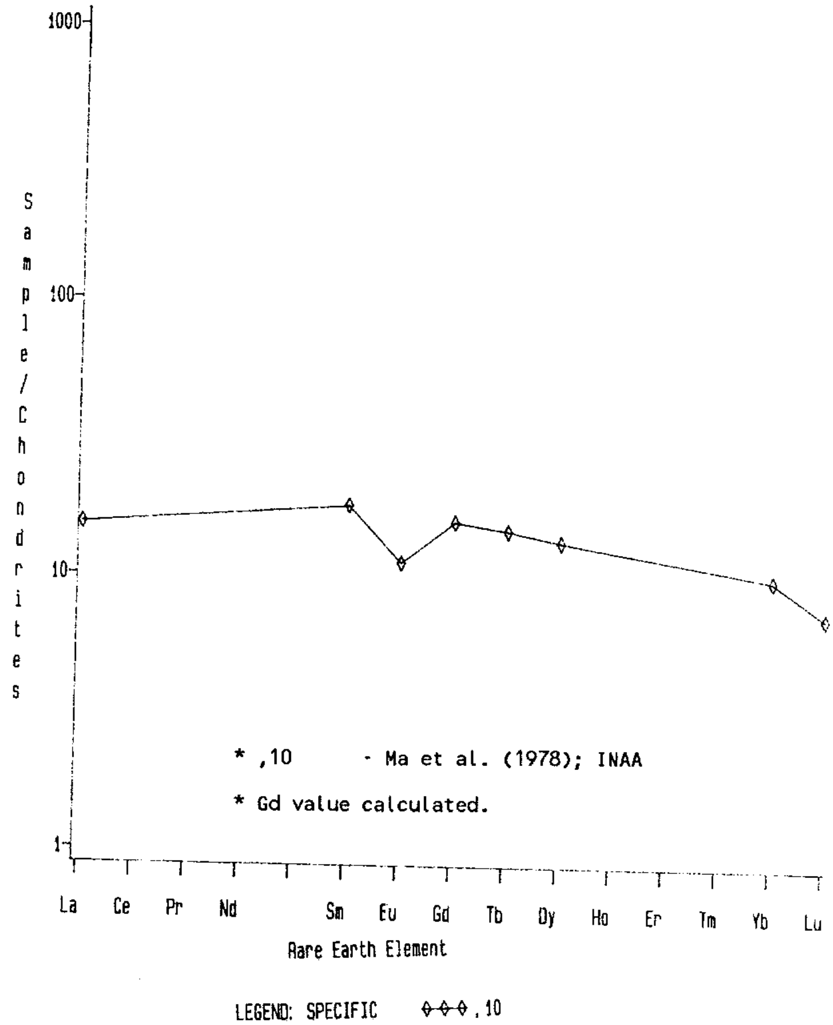


Figure 3. Rare earths in 15661.

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ±25 ppm
(b) ±40 ppm

15662 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 4.90 g

INTRODUCTION: 15662 is a medium-grained, olivine-bearing mare basalt which is vuggy and vesicular (Fig. 1). Pyroxenes are conspicuous macroscopically but olivine is not. In chemistry, the sample is a fairly average member of the Apollo 15 olivine-normative mare basalt group. 15662 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15662 is an olivine microgabbro (Fig. 2; Ma et al., 1978), consisting dominantly of pyroxene (pigeonite cores, augite rims), plagioclase, and a few per cent olivines. Its texture is similar to many other medium-grained Apollo 15 olivine-normative mare basalts.

CHEMISTRY: Ma et al. (1978) reported a bulk rock chemical analysis (Table 1, Fig. 3). The sample is a fairly average member of the Apollo 15 olivine-normative mare basalt group.

PHYSICAL PROPERTIES: Hargraves and Dorety (1972) reported measurements of natural magnetic intensity (NRM) and saturated IRM (H = 8 kiloauss) and their variation with AF-demagnetization (Fig. 4), for a small chip. The intensities are higher than for 15555, a coarser-grained rock of the same basalt chemical group.

PROCESSING AND SUBDIVISIONS: Chipping produced a single piece (,2) and two pieces (,1). ,2 was used for the magnetic study and mainly returned. ,1 was further chipped in 1976 to produce ,4 which was used for chemical studies and to produce the thin section ,7. ,0 is now 3.29 g.

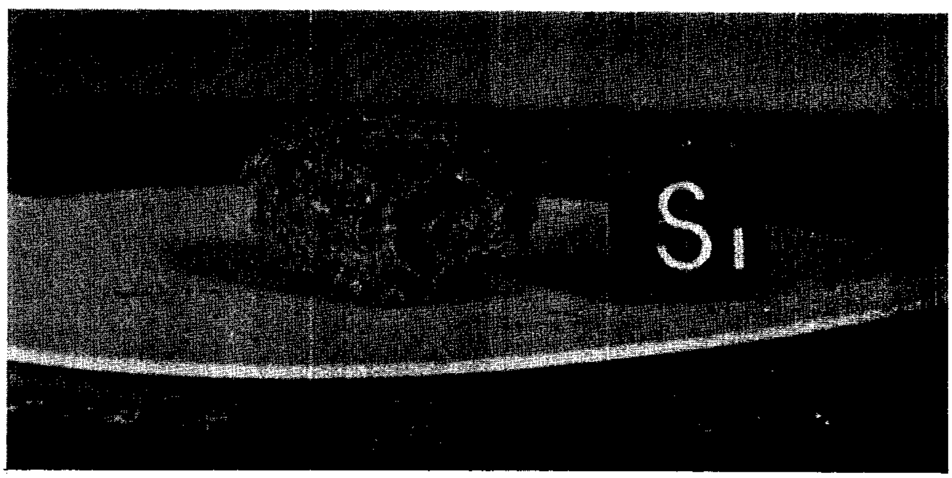


Figure 1. Pre-chip view of 15662. S-71-49733

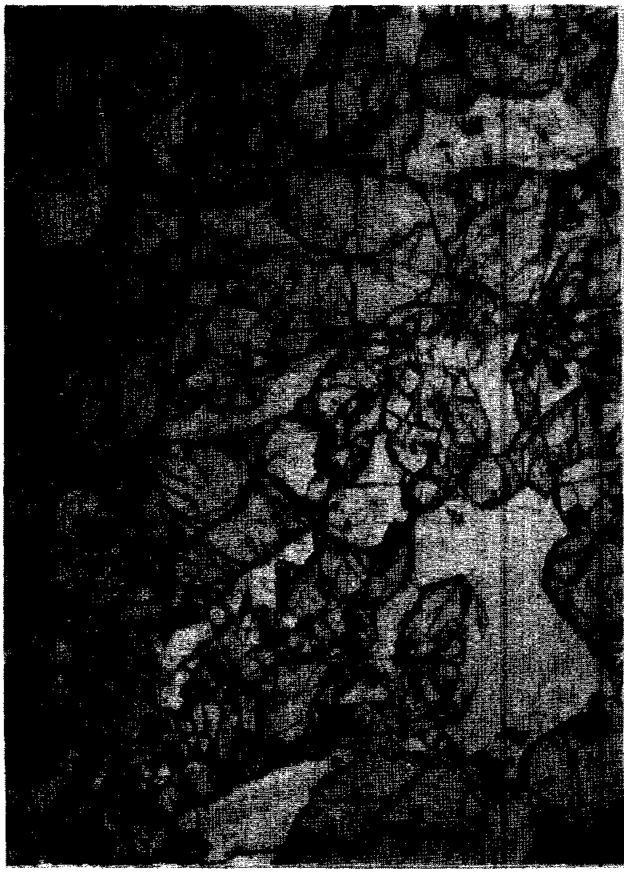


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15662,7. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15662-1. Bulk rock chemical analysis

		,4
Wt %	SiO2	
	TiO2	2.3
	Al2O3	9.5
	FeO	22.5
	MgO	10
	CaO	9.4
	Na2O	0.271
	K2O	0.040
	P2O5	
(ppm)	Sc	41
	V	237
	Cr	4430
	Mn	2115
	Co	52
	Ni	75(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.5
	Ba	65(b)
	Th	
	U	
	Pb	
	La	5.0
	Ce	
	Pr	
	Nd	
	Sm	3.4
	Eu	0.82
	Gd	
	Tb	0.7
	Dy	3.8
	Ho	
	Er	
	Tm	
	Yb	2.1
	Lu	0.27
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	600
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

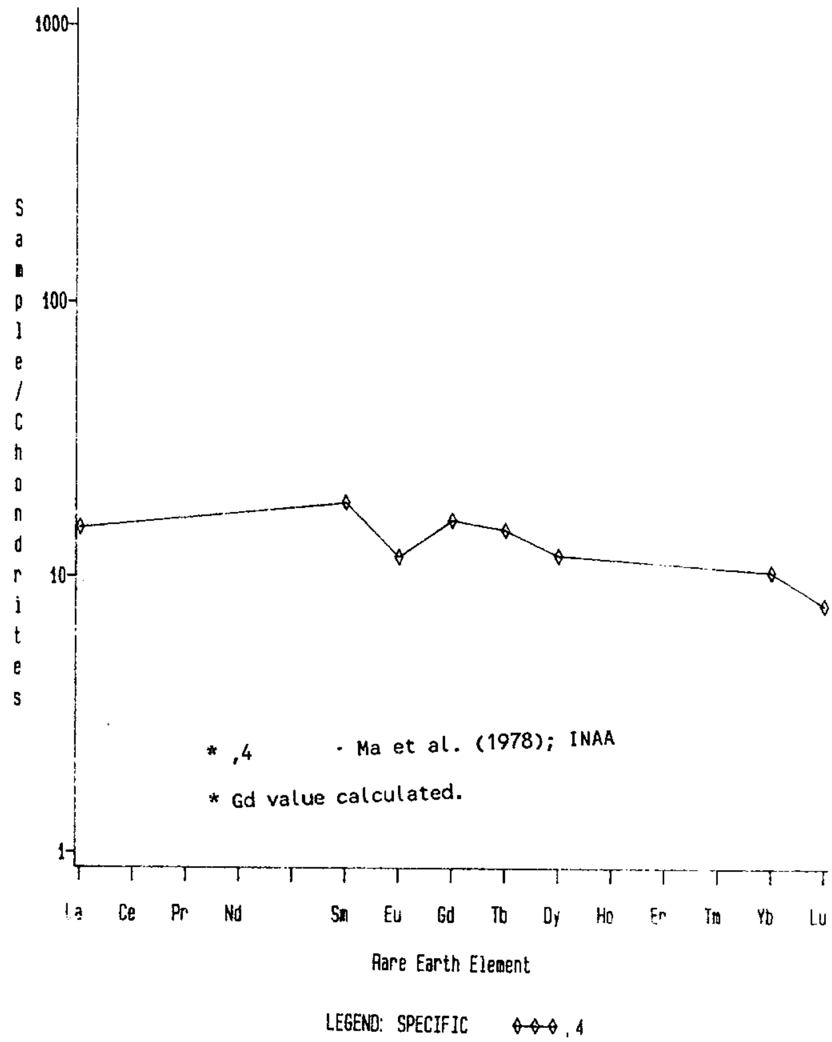


Figure 3. Rare earths in 15662.

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ± 30 ppm
(b) ± 35 ppm

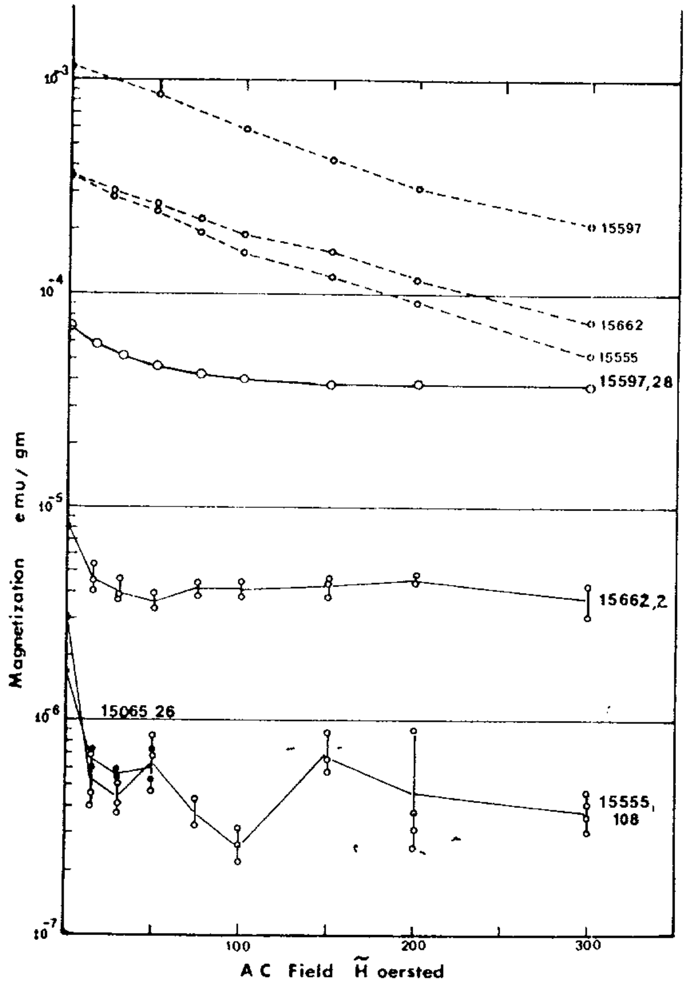


Figure 4. Demagnetization results of 15662 and two other mare basalts (15555, coarse olivine-normative; 15597, pyroxene vitrophyre). NRM = solid line curve. Saturated IRM = broken line. (Hargraves and Dorety, 1972).

15663 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 10.30 g

INTRODUCTION: 15663 is a medium-grained, olivine-bearing mare basalt which is vuggy and vesicular (Fig. 1). Pyroxenes are conspicuous and olivines are visible macroscopically. In chemistry, it is an average member of the Apollo 15 olivine-normative mare basalt group. It is rounded and has several (apparent) zap pits visible to the naked eye. All sides except for a few small fresh patches appear to be pitted. 15663 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15663 is a medium-grained, olivine-bearing mare basalt (Fig. 2). Most olivines are less than 1 mm across; the larger ones contain crystallized silicate melt inclusions. Pyroxenes are up to about 1.5 mm and somewhat elongated; they are pigeonites zoned to augite. The plagioclases are irregular laths, generally less than 1 mm long and some are hollow. A few poikilitically enclose small pyroxenes. Chromite, ulvospinel, ilmenite, fayalite, sulfide, and cristobalite are present; cristobalite is locally conspicuous. Dowty et al. (1973a, b) reported a mode of 58% pyroxene, 27% plagioclase, 8% olivine, 6% opaques, 1% silica (cristobalite); no miscellaneous fraction was reported. Dowty et al. (1973c) reported microprobe analyses of pyroxenes, plagioclases, and olivines, and Nehru et al. (1973) reported one ilmenite analysis and several spinel group mineral analyses. The opaque phases were included in the general discussion of Nehru et al. (1974) without specific additional data or comment. Ilmenites contain 0.27% MgO. The limited mineral data (Fig. 3) are similar to those of other olivine-normative mare basalts.

CHEMISTRY: Helmke et al. (1973) reported a bulk rock analysis (Table 1, Fig. 4). (Their trace element data was tabulated erroneously as 15563,2.) The analysis shows 15663 to be a fairly average Apollo 15 olivine-normative mare basalt. Dowty et al. (1973a, b) reported two separate defocussed beam bulk analyses. That of Dowty et al. (1973a) is fairly consistent with the Helmke et al. (1973) analysis except for the higher TiO_2.

PROCESSING AND SUBDIVISIONS: 15663 was sawn to produce an end (,1) which was chipped to produce ,1 through ,4. ,2 was used for chemical analysis and ,4 was mainly used to produce thin sections ,10 through ,13. ,0 is now 6.95 g.

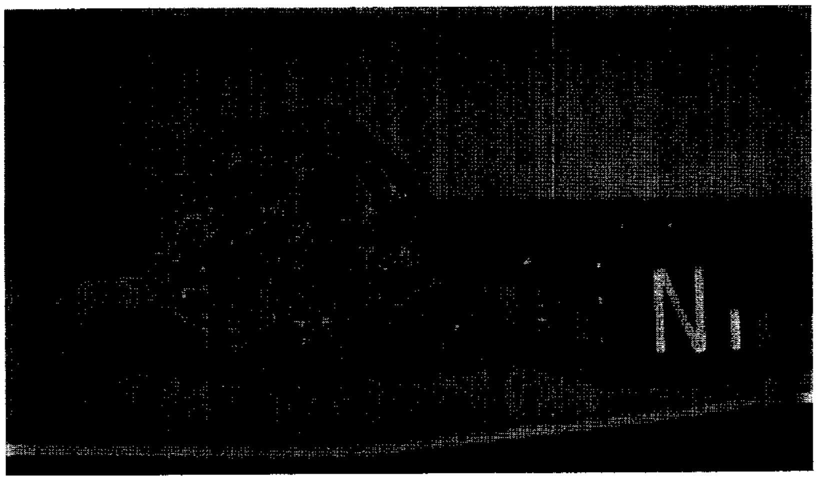
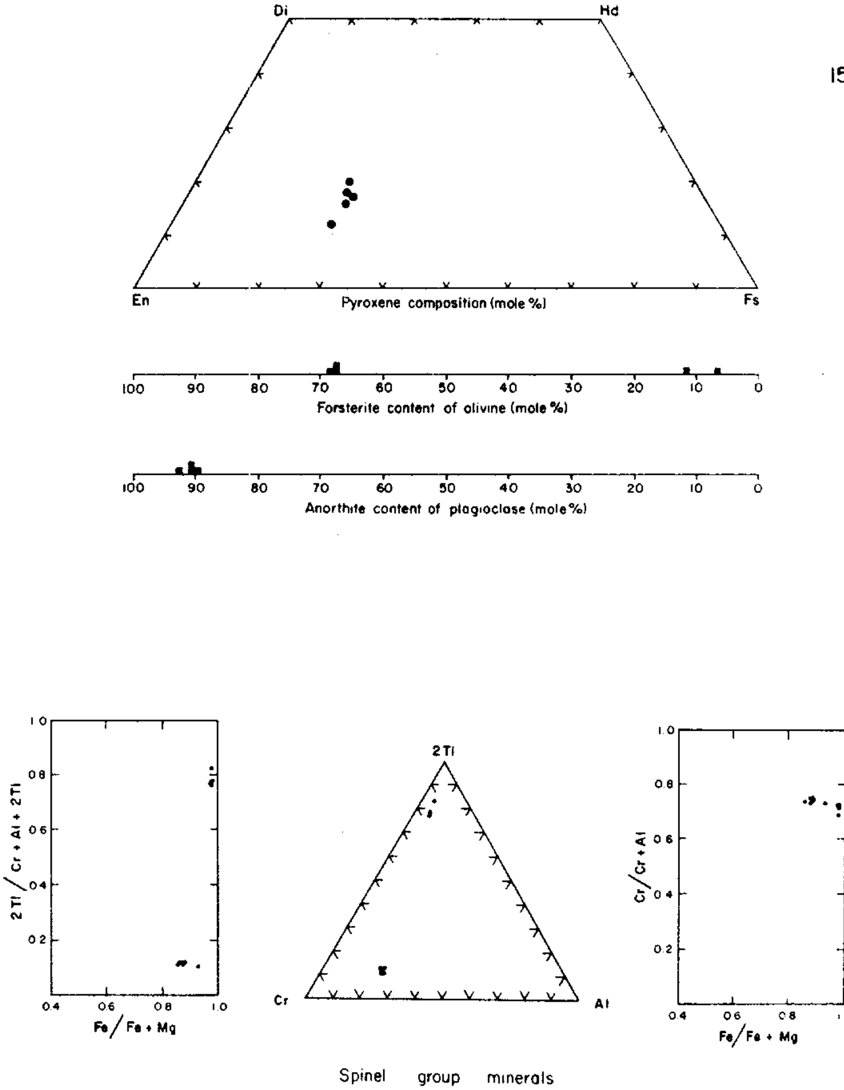


Figure 1. Pre-saw view of 15663. S-71-49717

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15663,11. Widths about 3 mm. a) transmitted light; b) crossed polarizers.



15663

Figure 3. Chemistry of minerals in 15663 (Dowty et al., 1973b).

TABLE 15663-1. Bulk rock chemical analysis

		,2
Wt %	SiO2	46.5
	TiO2	2.39
	Al2O3	8.73
	FeO	21.8
	MgO	10.4
	CaO	10.6
	Na2O	0.261
	K2O	0.046
	P2O5	
(ppm)	Sc	47
	V	
	Cr	3930
	Mn	2150
	Co	56
	Ni	
	Rb	0.5
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.5
	Ba	
	Th	
	U	
	Pb	
	La	4.93
	Ce	13.4
	Pr	
	Nd	10.8
	Sm	3.54
	Eu	0.88
	Gd	4.6
	Tb	0.81
	Dy	5.7
	Ho	1.04
	Er	3
	Tm	
	Yb	2.26
	Lu	0.328
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	<3
(ppb)	I	
	At	
	Ga	2900
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	17
	Ta	
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

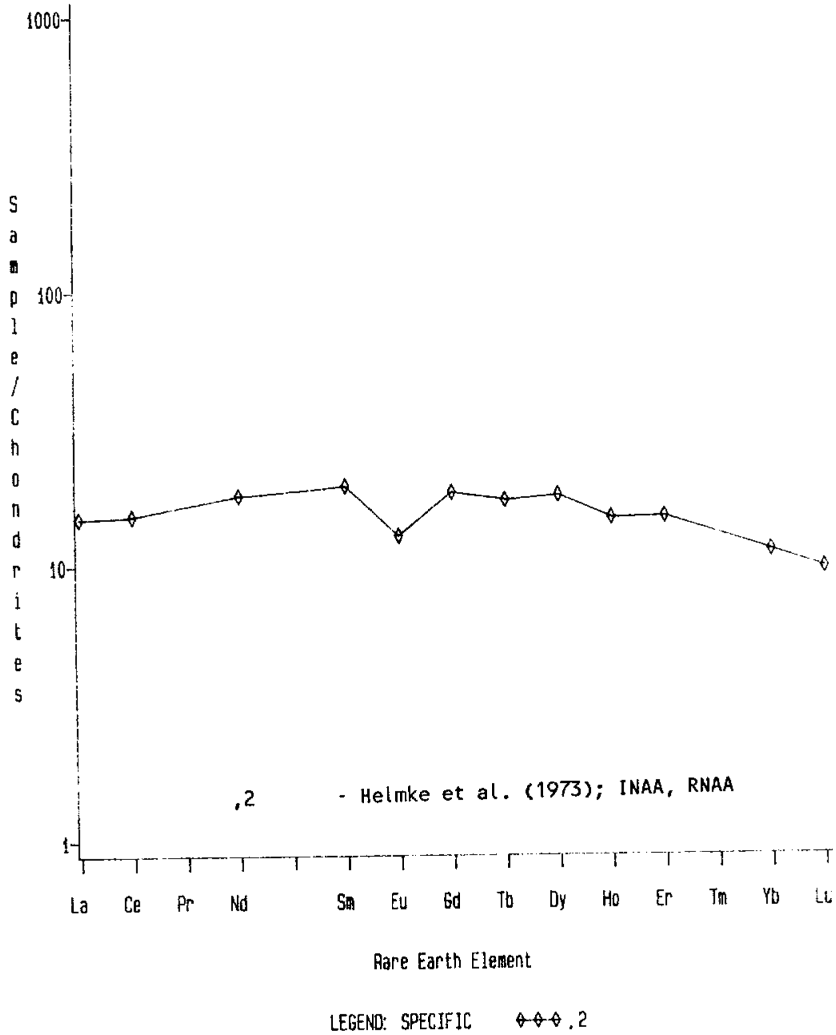


Figure 4. Rare earths in 15663.

References and methods:

(1) Helmke et al. (1973); INAA, RNAA, AAS

TABLE 15663-2. Defocussed beam microprobe bulk rock analyses

Wt %	SiO2	42.3	44.5
	TiO2	2.66	2.89
	Al2O3	7.7	8.4
	FeO	22.5	22.2
	MgO	13.0	10.3
	CaO	10.2	10.1
	Na2O	0.49	0.37
	K2O	0.05	0.08
	P2O5	0.06	0.07
ppm	Cr	4040	4040
	Mn	1940	2015
		100.0	99.06
		(1)	(2)

(1) Dowty et al. (1973b), normalized to 100%
(2) Dowty et al. (1973a)

15664 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT — ST. 9A — 7.40 g

INTRODUCTION: 15664 is a medium-grained, olivine-bearing mare basalt which is vuggy and somewhat vesicular (Fig. 1). Pyroxene and small olivines are visible macroscopically. In chemistry, the sample is a magnesian Apollo 15 olivine-normative mare basalt. 15664 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15664 is a medium-grained, olivine-bearing mare basalt (Fig. 2). Pyroxene, the dominant phase, occurs in grains up to 2 mm long, and some are twinned. Plagioclases are lathy to irregular poikilitic, most less than 1 mm long, and nearly all the olivines are less than 1 mm anhedral crystals. Several contain crystallized silicate melt inclusions.

CHEMISTRY: Ma et al. (1978) reported a bulk rock chemical analysis (Table 1, Fig. 3). The analysis is of an Apollo 15 olivine-normative mare basalt. The high MgO (imprecisely determined), low Ti, and slightly low rare earths suggest that the sample is a less-evolved member than most.

PHYSICAL PROPERTIES: 15664 was erroneously listed (instead of 15634) in a table of natural remanent magnetic intensity by Pearce et al. (1973). No magnetic data exist for 15664.

PROCESSING AND SUBDIVISIONS: The "N-T" end was chipped off to give several small chips (,1) and a single chip (,2). The latter was mainly consumed in producing thin sections ,4 and ,6. In 1976, ,1 was rechipped to give ,10, used for chemistry and to produce thin section ,13. ,0 is now 5.97 g.

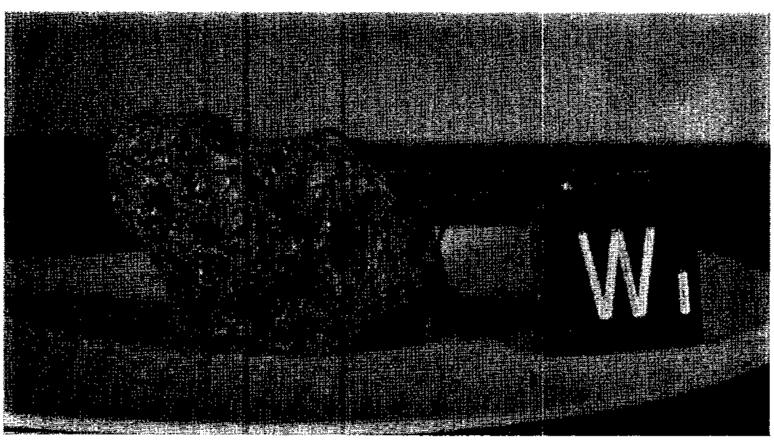


Figure 1. Pre-chip view of 15664. S-71-49542

Fig. 2a

Fig. 2b

<u>Figure 2</u>. Photomicrographs of 15664,4. Widths about 2 mm. a) transmitted light; b) crossed polarizers.

TABLE 15664-1. Bulk rock chemical analysis

		,10
Wt %	SiO2	
	TiO2	2.1
	Al2O3	8.5
	FeO	22.6
	MgO	13
	CaO	9.2
	Na2O	0.238
	K2O	0.040
	P2O5	
(ppm)	Sc	38
	V	204
	Cr	4340
	Mn	2140
	Co	54
	Ni	55(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.5
	Ba	
	Th	
	U	
	Pb	
	La	4.5
	Ce	
	Pr	
	Nd	
	Sm	3.3
	Eu	0.76
	Gd	
	Tb	0.7
	Dy	4.0
	Ho	
	Er	
	Tm	
	Yb	2.0
	Lu	0.30
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	400
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

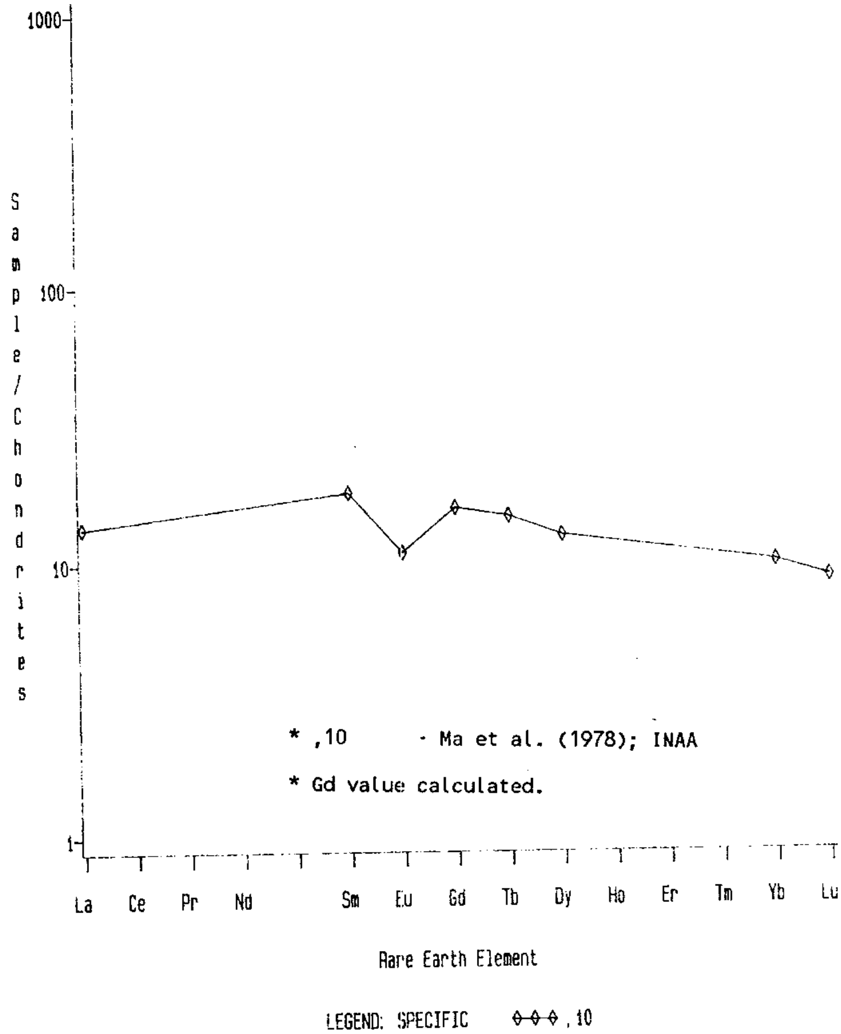


Figure 3. Rare earths in 15664.

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ± 25 ppm

15665 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 10.20 g

INTRODUCTION: 15665 is a fine-grained, olivine-porphyritic mare basalt which is vesicular (Fig. 1). The olivines are small but visible macroscopically. In chemistry, the sample is an average Apollo 15 olivine-normative mare basalt. Vesicles total about 15% of the sample; crystals do not project into them. A few vugs do have projecting crystals. Most surfaces have no zap pits but a few are present. 15665 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15665 is a fine-grained, vesicular basalt which is olivine phyric (Fig. 2). The texture, grain size, mode, and mineral chemistry are very similar to 15669. The olivines are up to about 1 mm in maximum dimension and show intense resorption and corrosion. The groundmass consists of small, granular pyroxenes and small plagioclase laths which are less than 0.5 mm long. Many chromites occur, some up to a few hundred microns across and euhedral, and sharp boundaries to thin rims of ulvospinel are common. Residues are very fine-grained and cristobalite appears to be rare. Dowty et al. (1973b) noted that most of the ilmenite is platy and skeletal. Dowty et al. (1973a, b) reported a mode of 56% pyroxene, 25% plagioclase, 8% olivine, 8% opaque minerals, 3% miscellaneous, and no silica. Dowty et al. (1973c) tabulated microprobe analyses of pyroxenes, olivines, plagioclases, and metal grains; and Nehru et al. (1973) tabulated microprobe analyses of spinel group minerals and ilmenites. Nehru et al. (1974) remarked on the sharp chromite-ulvospinel boundaries. The metal grains contain 1.4 to 1.7% Co and 4.0 to 5.9% Ni; residual glass contains 2% K_2O and 60% SiO_2; and ilmenite contains 0.16% to 0.88% MgO. The mineral chemistry (Fig. 3) is typical of Apollo 15 olivine-normative mare basalts except that the rapid cooling has prevented the crystallization of fayalite.

CHEMISTRY: Helmke et al. (1973) reported a bulk rock chemical analysis (Table 1, Fig. 4). The analysis shows 15665 to be an average member of the Apollo 15 olivine-normative mare basalt group. The defocussed beam microprobe bulk analysis of Dowty et al. (1973a, b) is low in MgO and is (abnormally) only slightly olivine-normative; probably the sporadic distribution of olivine phenocrysts has led to their under representation in the microprobe analysis.

PROCESSING AND SUBDIVISIONS: A large chip (,1) was removed and subdivided into ,1 through ,4. ,2 was largely used to make thin sections ,13 and ,14, and ,3 was used for chemistry. In 1975, ,0 was rechipped to produce ,6, which was partly used to make thin sections ,8 and ,12. ,0 is now 7.84 g.

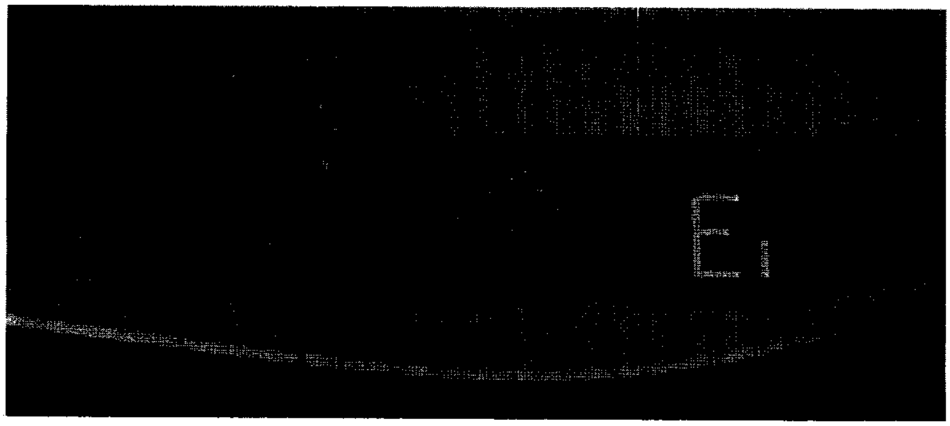


Figure 1. Pre-chip view of 15665. S-71-49740

Fig. 2a

Fig. 2b

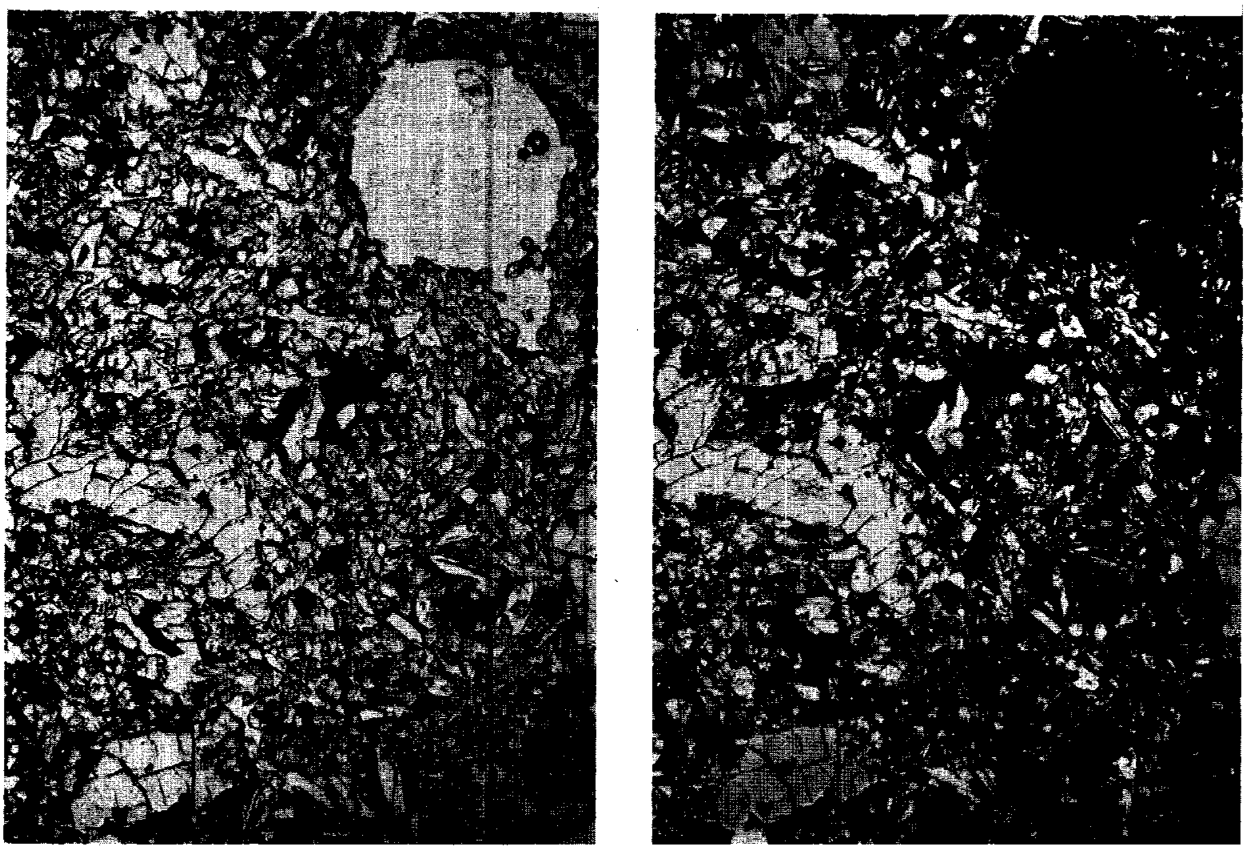


Figure 2. Photomicrographs of 15665,8. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

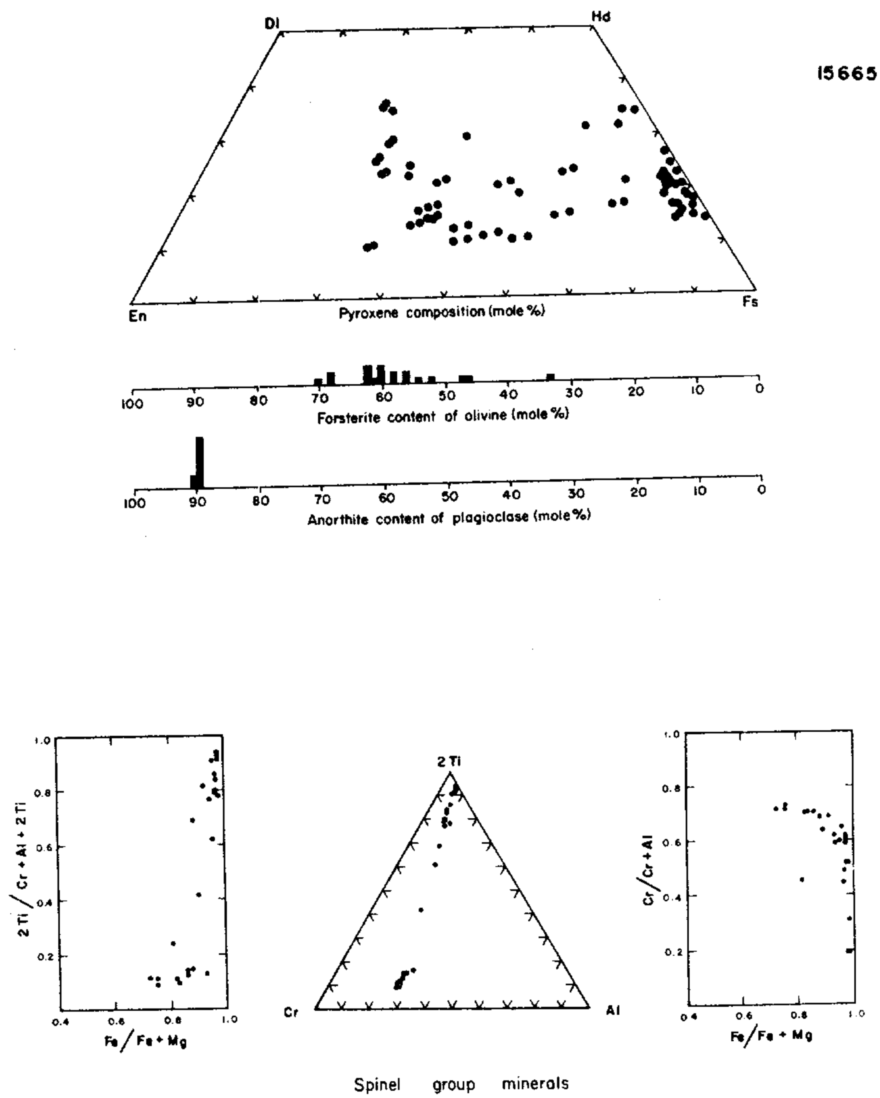


Figure 3. Compositions of minerals in 15665 (Dowty *et al.*, 1973b).

TABLE 15665-1. Bulk rock chemical analysis

		,3
Wt %	SiO2	44.4
	TiO2	2.64
	Al2O3	8.25
	FeO	23.4
	MgO	10.3
	CaO	9.42
	Na2O	0.298
	K2O	0.046
	P2O5	
(ppm)	Sc	43.2
	V	
	Cr	3950
	Mn	2210
	Co	54
	Ni	
	Rb	1.1
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.2
	Ba	
	Th	
	U	
	Pb	
	La	4.87
	Ce	12.6
	Pr	
	Nd	10.2
	Sm	3.39
	Eu	0.84
	Gd	4.7
	Tb	0.75
	Dy	5.5
	Ho	1.0
	Er	3.1
	Tm	
	Yb	2.23
	Lu	0.309
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	<2.5
(ppb)	I	
	At	
	Ga	3100
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	21
	Ta	
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Helmke et al. (1973); INAA, RNAA, AAS

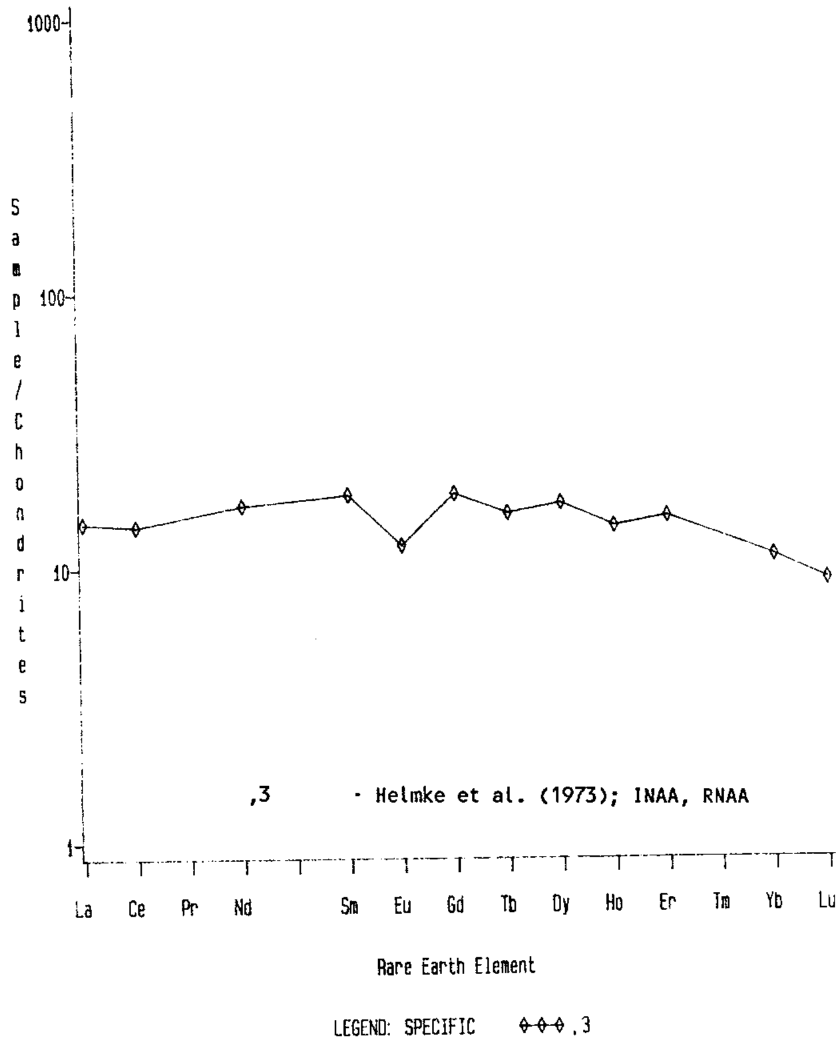


Figure 4. Rare earths in 15665.

TABLE 15665-2. Defocussed beam microprobe bulk analysis (Dowty et al., 1973a, b)

Wt %	SiO2	46.7
	TiO2	2.94
	Al2O3	10.2
	FeO	21.7
	MgO	7.7
	CaO	10.6
	Na2O	0.39
	K2O	0.06
	P2O5	0.09
ppm	Cr	4450
	Mn	2170

15666 PORPHYRITIC VARIOLITIC QUARTZ-NORMATIVE MARE BASALT ST. 9A 3.90 g

INTRODUCTION: 15666 is a pyroxene-phyric basalt with a variolitic groundmass and is vuggy (Fig. 1). The large (2 to 5 mm) zoned green to brown pyroxenes are conspicuous macroscopically. In chemistry, the sample is an average member of the Apollo 15 quartz-normative basalt group. Crystals extend into the vugs. The rounded surface appears to be pitted to saturation with small recent fractures making local fresh areas. 15666 was collected as part of the rake sample for Station 9A.

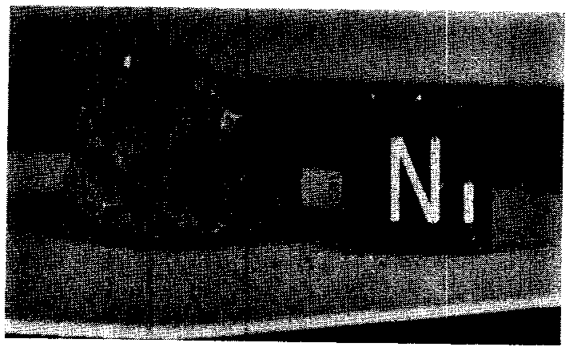


Figure 1. Pre-chip view of 15666. S-71-49757

PETROLOGY: 15666 consists of pigeonite-augite phenocrysts in a variolitic groundmass (Fig. 2) which consists of pyroxene and plagioclase laths, and some glass and opaque minerals. The pyroxenes are up to 5 mm long at least. Dowty et al. (1973b) reported a mode of 40% pyroxene phenocrysts, plus 2% olivine, 5% opaques, and 53% matrix. The olivine consists of highly skeletal phenocrysts which are the same size as the pyroxene phenocrysts (Dowty et al., 1973a). Dowty et al. (1974) found the pyroxenes too long to measure in the small thin sections; the widths averaged about 0.55 mm. Groundmass grains are 0.1 to 0.2 x 0.005 to 0.010 mm. Zoning trends are similar to those in 15125, with a conspicuous break from pigeonite to augite. Al and Ti increase up to the edge of the phenocrysts, whereas Cr decreases. Dowty et al. (1974) also reported cell parameters derived from x-ray diffraction, and reported $\Delta\beta$ of 1.70 and 1.61, i.e., very low; the relationship is an overgrowth of augite on pigeonite and there is little or no exsolution. Thus 15666 was rapidly cooled. Dowty et al. (1973c) tabulated microprobe analyses of pyroxenes, olivines, plagioclases, and metals; and Nehru et al. (1973) tabulated spinel group mineral and ilmenite analyses. Nehru et al. (1974) noted the restricted range of Fe/(Fe+Mg) in chromites and their high Al. The chromite-ulvospinel compositional gap is very wide in 15666. Metal grains generally contain 1.4 to 1.8% Co and 2.9 to 4.0% Ni; one grain contains 6.5 to 37% Ni. Ilmenite contains 0.20 to 0.53% MgO. The mineral analyses (Fig. 3) are generally similar to those from other rapidly-cooled Apollo 15 quartz-normative mare basalts.

Cooling history: Lofgren et al. (1974) compared the crystal morphologies and zoning trends in pyroxene phenocrysts to those grown in dynamic crystallization experiments (linear cooling rates) on an Apollo 15 quartz-normative mare basalt composition. The comparison suggested cooling rates between 1.2°C/hr and 30°C/hr for 15666. In a continuation of the same study, Lofgren et al. (1975) inferred cooling rates of 2 to 5°C/hr for the phenocrysts and 10 to 30°C/hr for the matrix. In a similar but more sophisticated study, Grove and Walker (1977) used the pyroxene nucleation density (1.1/mm²) to infer an early cooling rate of 0.5°C/hr, pyroxene size to infer a similar intergrated cooling rate, and the plagioclase size to infer a late cooling rate of 34°C/hr. They concluded that final solidification took place 15 cm from a conductive boundary.

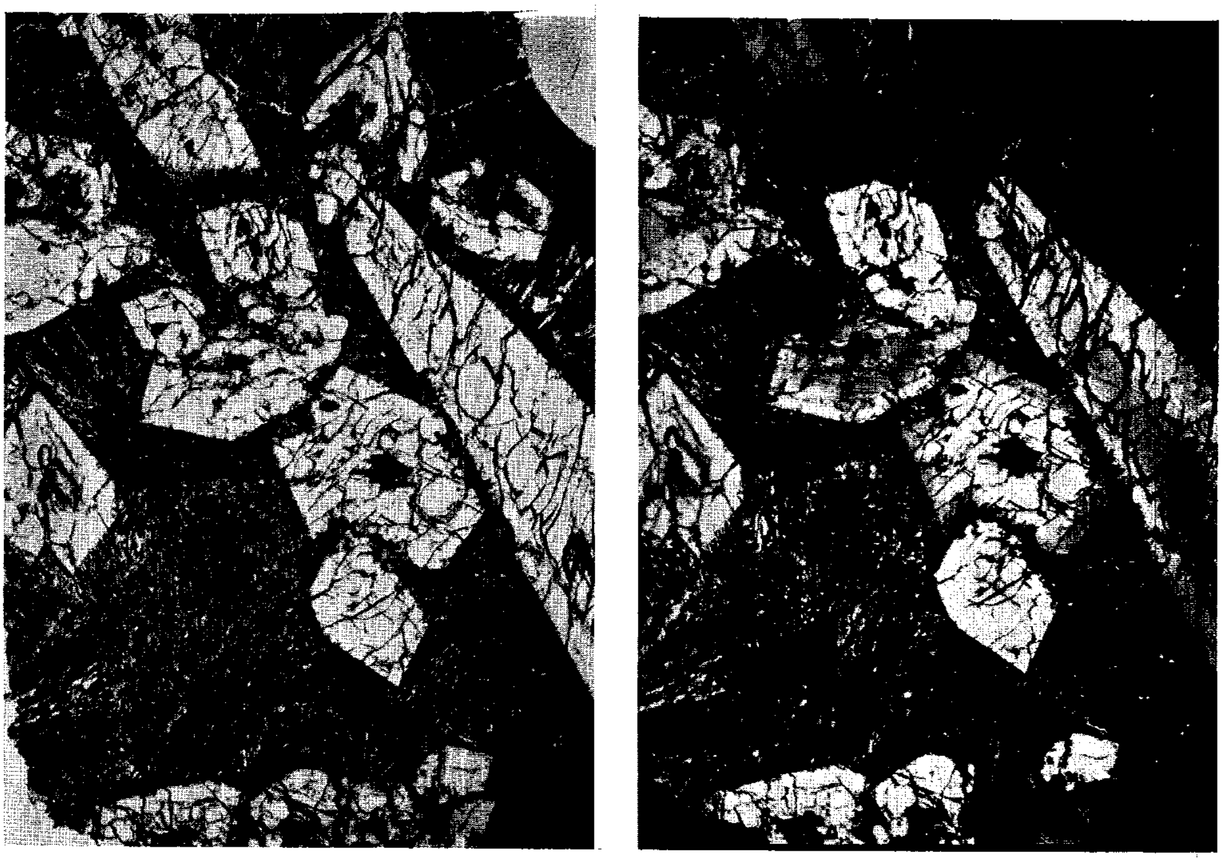
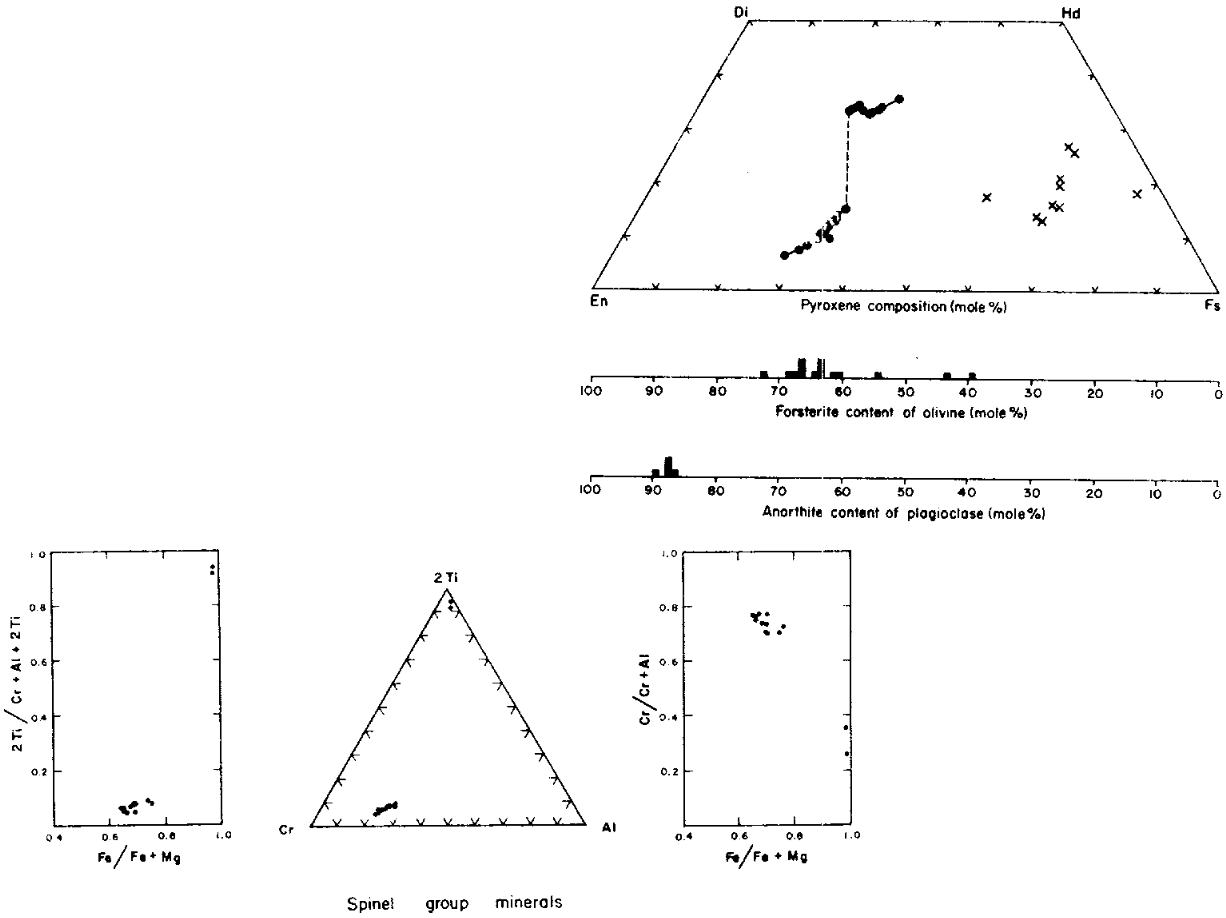


Fig. 2a Fig. 2b

Figure 2. Photomicrographs of 15666,8. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

Figure 3. Compositions of minerals in 15666. On pyroxene plot, dots are for a phenocryst, x's are groundmass (Dowty et al., 1973b).



CHEMISTRY: A bulk rock chemical analysis by Ma et al. (1976) (Table 1; Fig. 4) shows that 15666 is a fairly average Apollo 15 quartz-normative mare basalt, clearly distinguished from the olivine-normative group. A defocussed beam microprobe bulk analysis (Table 2) has more MgO but is generally consistent.

PROCESSING AND SUBDIVISIONS: Chipping produced ,1 (two pieces) and ,2 (one piece). ,2 was used to produce thin sections ,6 and ,8. In 1975, ,1 was further chipped to provide material for the chemical analysis. ,0 is now 3.03 g.

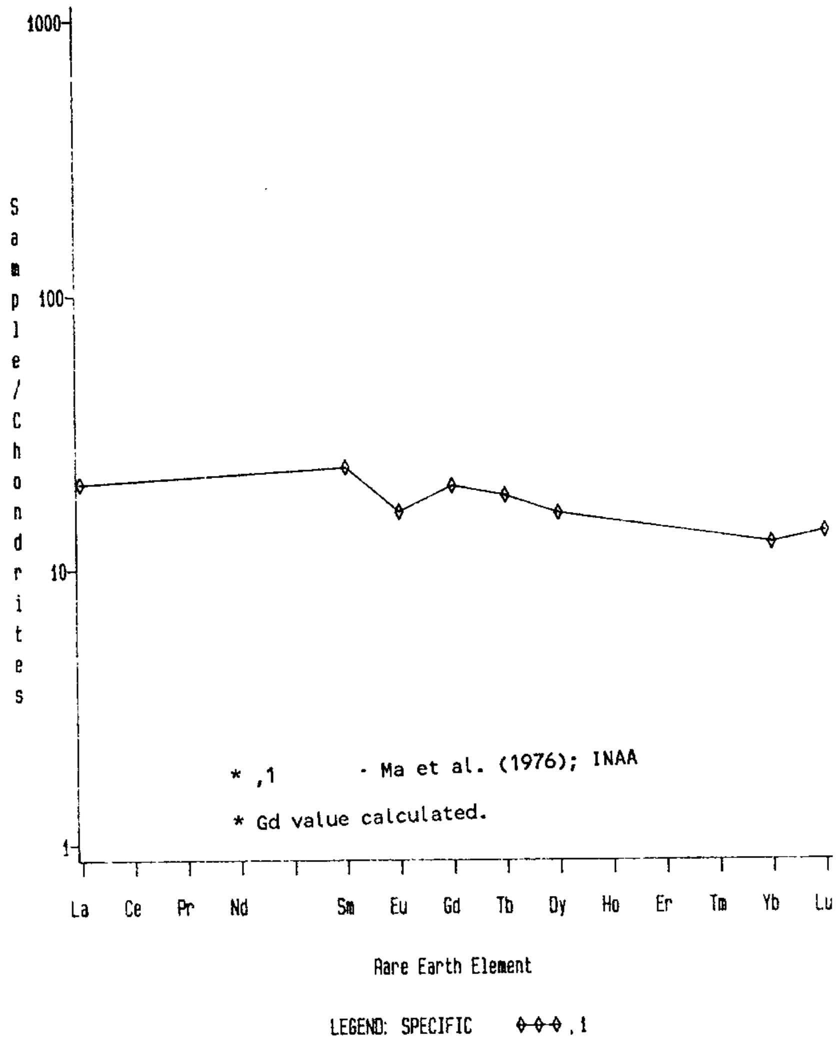


Figure 4. Rare earths in 15666.

TABLE 15666-1. Bulk rock chemical analysis

		,1
Wt %	SiO2	
	TiO2	2.3
	Al2O3	10.3
	FeO	21.3
	MgO	7.2
	CaO	10.2
	Na2O	0.372
	K2O	0.063
	P2O5	
(ppm)	Sc	42
	V	176
	Cr	3320
	Mn	2055
	Co	37
	Ni	49
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	3.2
	Ba	40(a)
	Th	
	U	
	Pb	
	La	6.8
	Ce	
	Pr	
	Nd	
	Sm	4.3
	Eu	1.12
	Gd	
	Tb	0.88
	Dy	5.1
	Ho	
	Er	
	Tm	
	Yb	2.5
	Lu	0.47
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	410
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma et al. (1976); INAA

Notes:

(a) ± 25 ppm

TABLE 15666-2. Defocussed beam microprobe bulk analysis (Dowty et al., 1973a,b)

Wt%	SiO2	46.9
	TiO2	1.97
	Al2O3	9.2
	FeO	21.3
	MgO	9.5
	CaO	9.7
	Na2O	0.37
	K2O	0.02
	P2O5	0.08
ppm	Cr	3015
	Mn	1940

15667 PORPHYRITIC VARIOLITIC QUARTZ-NORMATIVE MARE BASALT ST. 9A 1.10 g

INTRODUCTION: 15667 is a pyroxene-phyric basalt with a variolitic groundmass and which is not vesicular (Fig. 1); it has one vug. It is very similar to 15666. The large (3 to 5 mm) zoned green to brown pyroxenes are conspicuous macroscopically. The texture macroscopically appears (pseudo) ophitic to subophitic and is inequigranular. One surface is a fresh fracture; the others are rounded and pitted. 15667 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15667 consists of pigeonite-augite phenocrysts in a variolitic groundmass (Fig. 2). It is very similar to 15666 although the phenocrysts may be a little smaller on average. The groundmass consists of pyroxene and plagioclase laths, and some glass and opaque minerals. Steele et al. (1972a) reported that 15667 contained no olivine. They showed the zoning trend across pyroxene phenocrysts (Fig. 3) in which pigeonite cores are sharply overgrown with augite rims. They also reported a plagioclase compositional range of An_{93-87}; plagioclases containing 0.4 to 0.6% Fe. The pyroxene compositions were also diagrammed in Steele et al. (1972b).

PROCESSING AND SUBDIVISIONS: Chipping produced two pieces, one labelled ,1 and the other remaining part of ,0 (total mass now 0.930 g). ,1 was largely consumed producing thin sections ,1 and ,6.

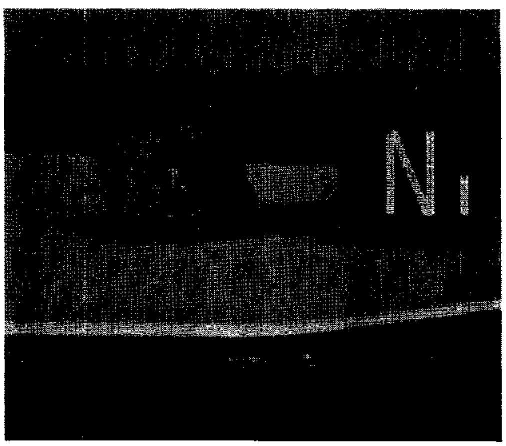


Figure 1. Pre-chip view of 15667.

Figure 2. Photomicrograph of 15667,6. Width about 3 mm. Transmitted light. Most pyroxenes in thin sections seem to have been cut perpendicular to their long axes (indicating a lineation?) and no laths are seen.

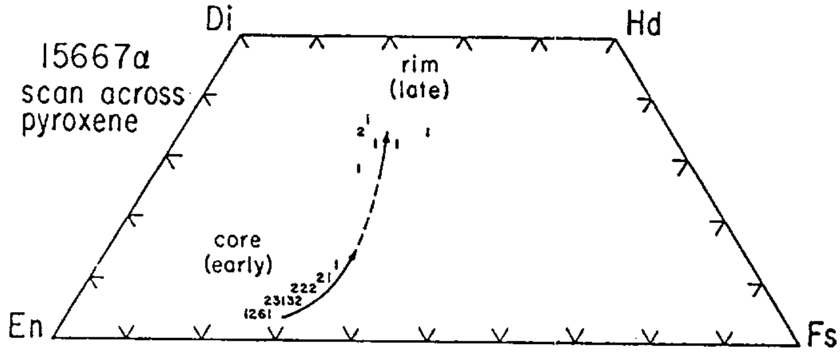


Figure 3. Compositions of pyroxene phenocrysts in 15667 (Steele et al., 1972a).

15668 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 15.10 g

INTRODUCTION: 15668 is an olivine-bearing mare basalt which is vesicular (Fig. 1). The groundmass is the finest grained of all olivine-normative mare basalts. The olivines form phenocrysts macroscopically conspicuous and up to about 2 mm across. In chemistry, the sample appears to be a fairly average member of the Apollo 15 olivine-normative mare basalt group. It has a ^{40}Ar-^{39}Ar plateau age of 3.13 ± 0.06 b.y. Vesicles occupy 15-20% of the volume. Most surfaces are rounded and saturated with zap pits, with only a few fresh areas. 15668 was collected as part of the rake sample from Station 9A.

PETROLOGY: The thin section (,13) is of a very fine-grained olivine porphyritic basalt (Fig. 2), with a vesicle on one side. Only three small olivine phenocrysts are in the section; the large (2 mm) conspicuous olivine phenocrysts macroscopically visible are lacking. Rhodes and Hubbard (1973) reported a mode of 59.6% pyroxene, 31.2% plagioclase, 1.1% ilmenite, 0.3% chrome spinel, 3.5% ulvospinel, 3.0% mesostasis, 0.5% vesicles, and only 0.8% olivine.

The groundmass is very fine-grained and distinctly subophitic, and quite unlike most olivine-normative mare basalts. Tiny plagioclase laths or needles are partly embedded in pyroxenes. A few plagioclase laths are curved. The small olivine phenocrysts contain euhedral chromite, but the most common opaque phase in the sample is ulvospinel. There is in most instances a sharp boundary from chromite to ulvospinel rims. Residual phases are glass, minor fayalite, and ulvospinel; cristobalite is absent and ilmenite is rare (although a few large grains are present). Some interstitial glasses show immiscibility, and the residual opaques commonly show a dendritic growth.

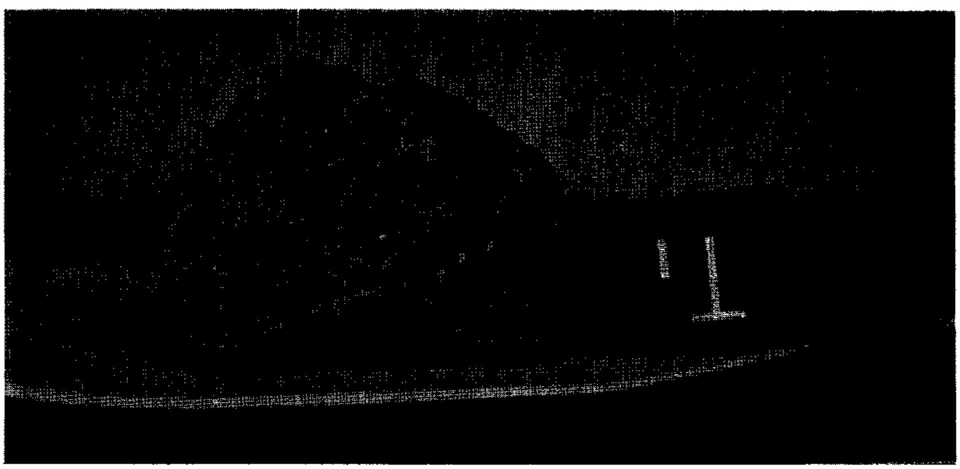


Figure 1. Pre-chip view of 15668. S-71-49729

Figure 2. Photomicrographs of 15668,13. Width about 3 mm. a) transmitted light; b) crossed polarizers.

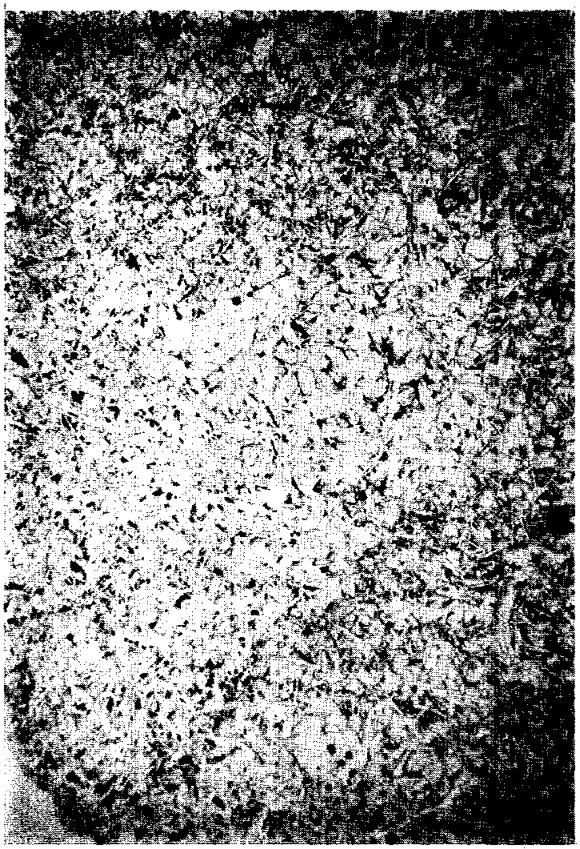


Fig. 2a

Fig. 2b

CHEMISTRY: Bulk rock chemical analyses (Table 1, Fig. 3) are quite consistent, and suggest that all either completely avoided olivine phenocrysts or contained a representative amount of them. The normative olivine content of about 10% suggests the latter is the case. Chappell and Green (1973) found the composition to be so similar to their analyses of 15658 and 15674 that they suggested all were fragments of the same rock; however, 15668 is much finer-grained than either.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Husain (1972) reported a ^{40}Ar-^{39}Ar plateau age of 3.15 ± 0.06 m.y., a little lower than other Apollo 15 mare basalts. Husain et al. (1972) increased the uncertainty to 0.08 m.y. and reported a K-Ar age of 2.50 b.y., indicating extensive gas loss. Husain (1974) reported Ar-isotopic step-wise heating data with extensive discussion and reported the plateau age as 3.13 ± 0.06 b.y., from the 1100°C to 1600°C fraction (Fig. 4). The highest temperature fraction alone has an age similar to other Apollo 15 basalts. Husain (1974) reported the K-Ar age as 2.607 ± 0.025 b.y., with the $^{40}Ar^*$ loss being 30%.

TABLE 15668-1. Bulk rock chemical analyses

		,2	,4	,3	,5	,2
Wt %	SiO2	45.48	45.01			
	TiO2	2.56	2.53	2.74		
	Al2O3	9.09	8.73	8.20		
	FeO	22.22	22.58	22.3		23.0
	MgO	9.19	9.96			
	CaO	10.23	10.16		11.2	
	Na2O	0.26	0.28	0.266		
	K2O	0.05	0.04		0.045	
	P2O5	0.08	0.07			
(ppm)	Sc			44		
	V					
	Cr		3700	4250		
	Mn	2405	2405			
	Co			55		
	Ni					
	Rb					
	Sr					
	Y					
	Zr					
	Nb					
	Hf			2.3		
	Ba					
	Th					
	U					
	Pb					
	La			4.5		
	Ce					
	Pr					
	Nd					
	Sm			3.1		
	Eu			0.92		
	Gd					
	Tb					
	Dy					
	Ho					
	Er					
	Tm					
	Yb			1.6		
	Lu			0.29		
	Li					
	Be					
	B					
	C					
	N					
	S	800	500			
	F					
	Cl					
	Br					
	Cu					
	Zn					
(ppb)	I					
	At					
	Ga					
	Ge					
	As					
	Se					
	Mo					
	Tc					
	Ru					
	Rh					
	Pd					
	Ag					
	Cd					
	In					
	Sn					
	Sb					
	Te					
	Cs					
	Ta			370		
	W					
	Re					
	Os					
	Ir					
	Pt					
	Au					
	Hg					
	Tl					
	Bi					
		(1)	(2)	(3)	(4)	(5)

References and methods:

(1) Rhodes and Hubbard (1973); XRF
(2) Chappell and Green (1973); XRF
(3) Fruchter et al. (1973); INAA
(4) Husain (1974); irradiation, Ar-isotopes
(5) Pearce et al. (1973); magnetic

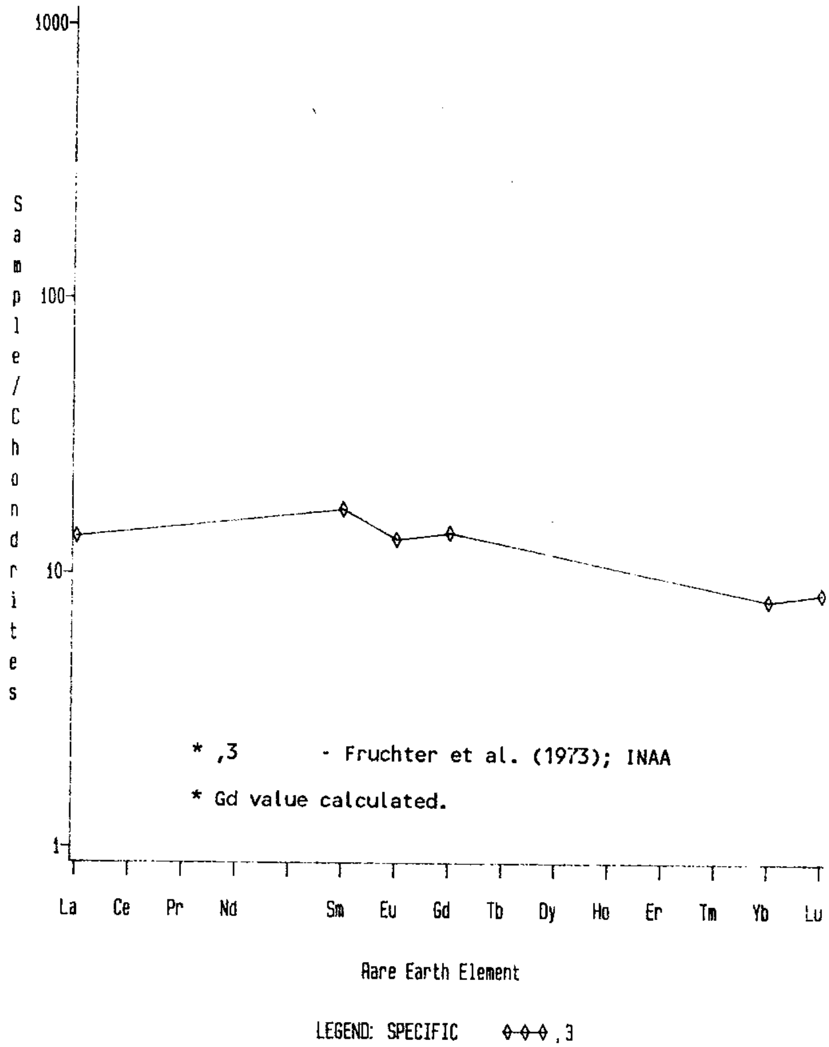
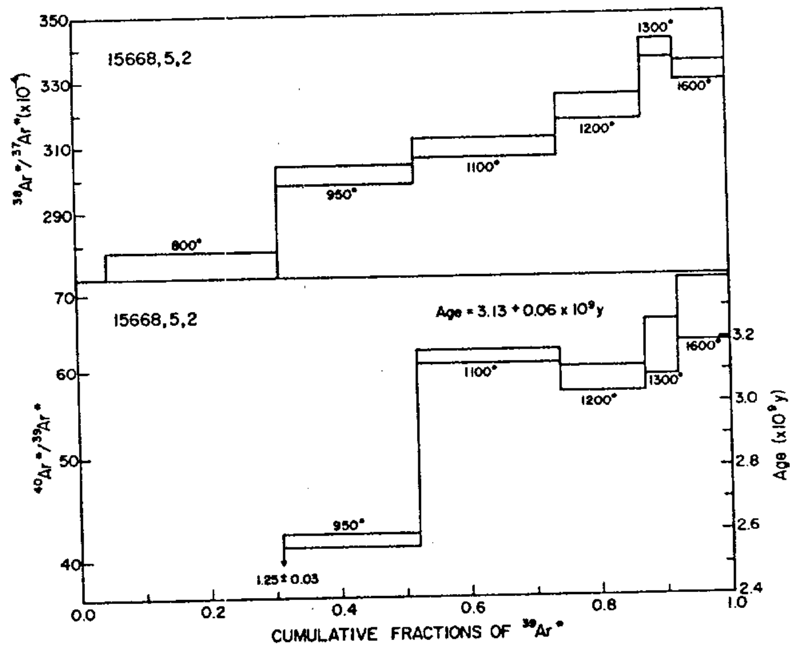


Figure 3. Rare earths in 15668.

Figure 4. Ar-release diagrams and age for 15668 (Husain, 1974).



RARE GAS AND EXPOSURE: Husain (1974) used his step-wise release Ar isotopic determinations to calculate a ^{38}Ar-Ca exposure age of 486 ± 20 m.y. for 15668, in contrast to the 520 ± 32 m.y. age previously reported (Husain et al., 1972).

PHYSICAL PROPERTIES: Pearce et al. (1973) reported room temperature magnetic properties for ,2. J_s was 0.10 emu/g and χ_p was 38.9 emu/g Oe. The magnetic measurements indicated 0.045% metallic iron equivalent and 17.8% ferrous iron (23.0% FeO equivalent).

PROCESSING AND SUBDIVISIONS: About 1/3 of the sample was chipped off (,1) and subdivided to give ,1 to ,5 which were used for the allocations. Part of,2 was used to make thin section ,13. ,0 is now 9.77 g.

15669 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 4.40 g

INTRODUCTION: 15669 is a fine-grained, olivine-porphyritic mare basalt which is vesicular (Fig. 1). The olivines are small but visible macroscopically. In chemistry, the sample is an average Apollo 15 olivine-normative mare basalt. Most surfaces are fresh with part of the "N" face apparently exposed. 15669 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15669 is a fine-grained, vesicular basalt which is olivine-phyric (Fig. 2). The texture, grain size, mode, and mineral chemistry are very similar to 15665. Dowty et al. (1973b) reported a mode of 59% pyroxene, 20% plagioclase, 10% olivine, 7% opaques, 4% miscellaneous, and no silica phase. Dowty et al. (1973a) adjusted this slightly to 60% pyroxene and 3% miscellaneous. They noted the amoeboid, corroded, resorbed olivines and that the ilmenites were patchy and skeletal. Dowty et al. (1973c) tabulated microprobe analyses of Fe-metal, olivines, pyroxenes, and plagioclases; and Nehru et al. (1973) tabulated microprobe analyses of spinel group minerals and ilmenites. Nehru et al. (1974) listed a representative chromite analysis and noted that resorbed and rounded chromite grains without mantles of ulvospinel were present. The limited mineral chemical data (Fig. 3) is similar to that for 15665 and other fine-grained Apollo 15 olivine-normative mare basalts.

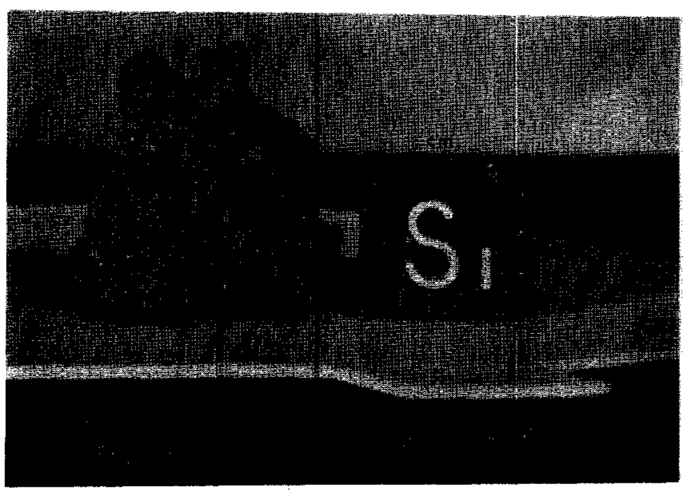


Figure 1. Pre-chip view of 15669. S-71-49545

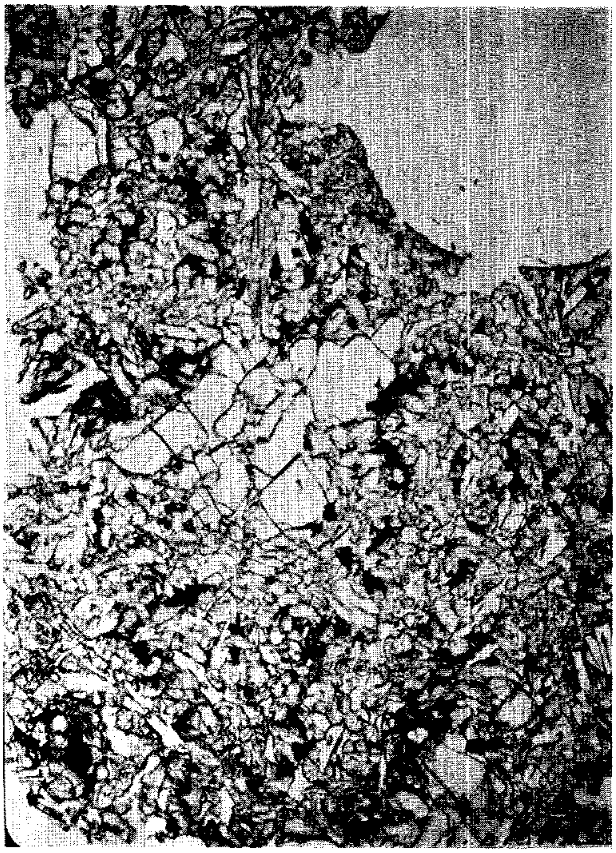


Fig. 2a

Fig. 2b

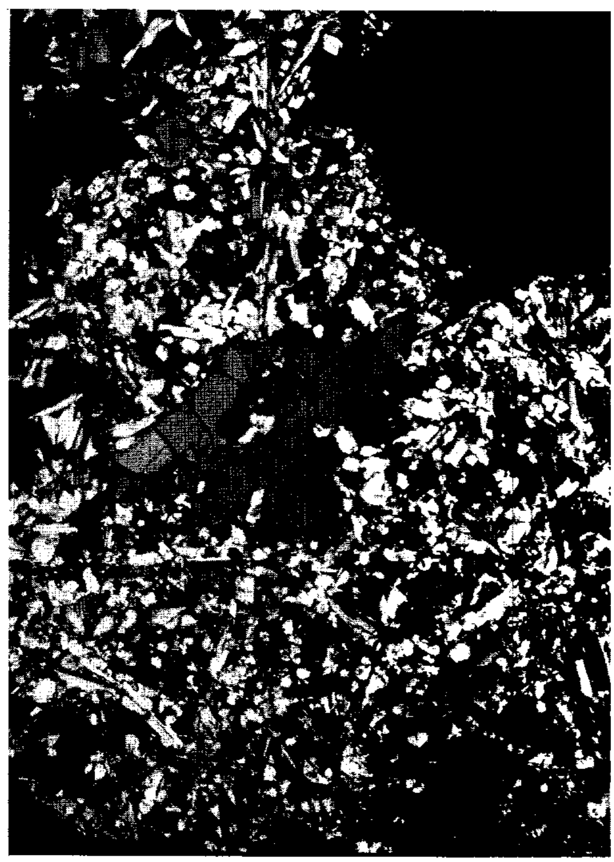
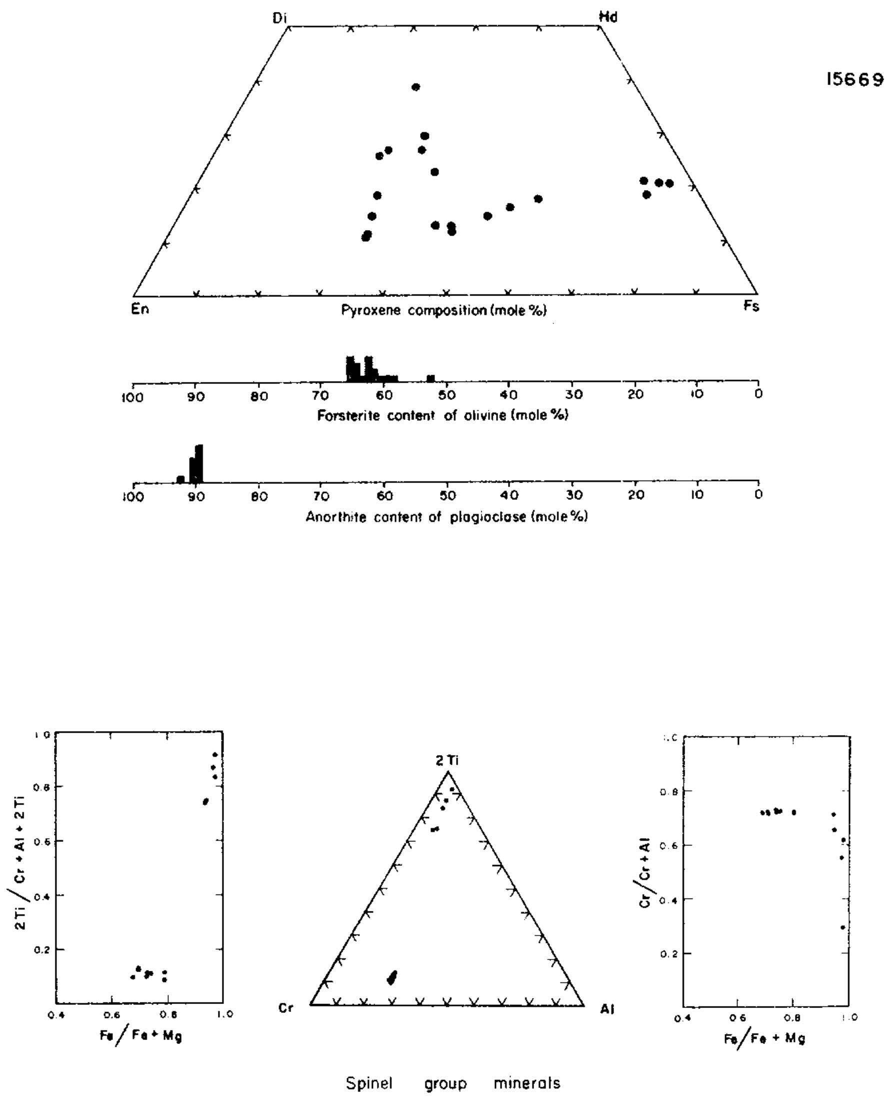


Figure 2. Photomicrographs of 15669,2. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

Figure 3. Chemistry of minerals in 15669 (Dowty et al., 1973b).



CHEMISTRY: A bulk chemical analysis by Ma et al. (1978) (Table 1, Fig. 4) shows that 15669 is an average member of the Apollo 15 olivine-normative mare basalt group. A defocussed beam microprobe analysis by Dowty et al. (1973a,b) (Table 2) has similar magnesium but appears to be anomalously high in FeO and TiO_2 and low in Al_2O_3.

PROCESSING AND SUBDIVISIONS: Single chips ,1 and ,2 were taken from the "N" end. Thin sections ,3; ,7; and ,8 were made from daughters of ,2. ,1 was further subdivided to produce material for chemical analysis and is now small chips. ,0 is now 3.21 g.

TABLE 15669-1. Bulk rock chemical analysis

		,4
Wt %	SiO2	
	TiO2	2.4
	Al2O3	9.3
	FeO	22.3
	Mg	10
	CaO	11.3
	Na2O	0.267
	K2O	0.040
	P2O5	
(ppm)	Sc	41
	V	203
	Cr	3670
	Mn	2080
	Co	45
	Ni	65(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.6
	Ba	55(b)
	Th	
	U	
	Pb	
	La	5.1
	Ce	
	Pr	
	Nd	
	Sm	3.5
	Eu	0.87
	Gd	
	Tb	0.8
	Dy	4.4
	Ho	
	Er	
	Tm	
	Yb	2.1
	Lu	0.32
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	370
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ± 45 ppm
(b) ± 35 ppm

Figure 4. Rare earths in 15669.

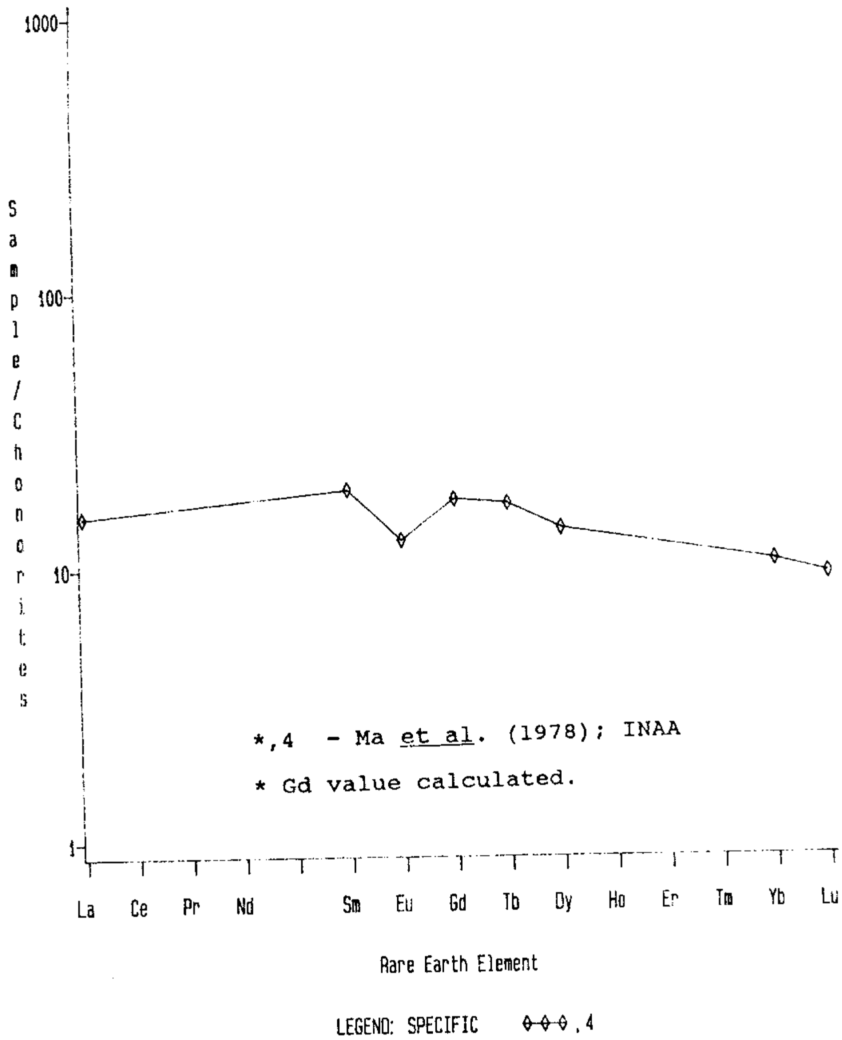


TABLE 15669-2. Defocussed beam microprobe bulk analysis (Dowty et al., 1973a, b)

Wt %	SiO2	44.3
	TiO2	3.1
	Al2O3	8.0
	FeO	24.3
	MgO	10.1
	CaO	9.4
	Na2O	0.31
	K2O	0.03
	P2O5	0.07
ppm	Cr	2465
	Mn	2170

15670 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 2.00 g

INTRODUCTION: 15670 is a medium-grained olivine-bearing mare basalt which is vuggy (Fig. 1). Some olivines form phenocrysts up to 2 mm across, and pyroxenes are up to 3 mm long. One small area is rounded and has a glass patch; there are no zap pits. 15670 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15670 is an olivine-bearing mare basalt (Fig. 2). The dominant phase is pyroxene which includes small granular grains and large (up to 3 mm long) zoned and twinned pigeonites. A few olivines are phenocrysts up to 2 mm across which are anhedral and contain crystallized silicate melt inclusions. The groundmass is an ophitic to subophitic arrangement of smaller pyroxenes and some olivines, and plagioclase. Opaques range from chromite to ulvospinel to ilmenite. Cristobalite is present. Steele et al. (1980) used the ion probe to analyze for minor elements in plagioclase, reporting 13 ppm Li, 1570 ppm Mg, 465 ppm K, 325 ppm Sr, and 25 ppm Ba, for an $An_{90.1}$ composition. The reported value of 4.5 ppm Ti is evidently a typographic error; comparison with the plotted data suggests the true value is 405 ppm. Hence these plagioclases have the high Mg, Sr, and Ti of other mare basalts.

PROCESSING AND SUBDIVISIONS: 15670 was chipped into three pieces. ,0 is now 1.24 g and ,1 is 0.18 g. ,2 was mainly used up in making thin sections ,2 and ,6.

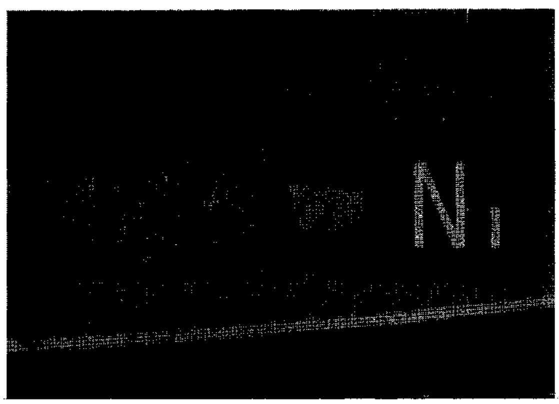


Figure 1. Pre-chip view of 15670. S-71-49761

Fig. 2a

Fig. 2b

Figure 2. Photomicrograph of 15670,2. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

15671 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 6.10 g

INTRODUCTION: 15671 is a medium-grained, olivine-bearing mare basalt which is vesicular (Fig. 1). Olivines do not form phenocrysts. In chemistry, the sample is a primitive member of the Apollo 15 olivine-normative mare basalt group. Pyroxenes tend to be concentrated around some vesicles. One side is slightly rounded with several zap pits; others lack pits but have rare glass patches. 15671 was collected as part of the rake sample from Station 9A.

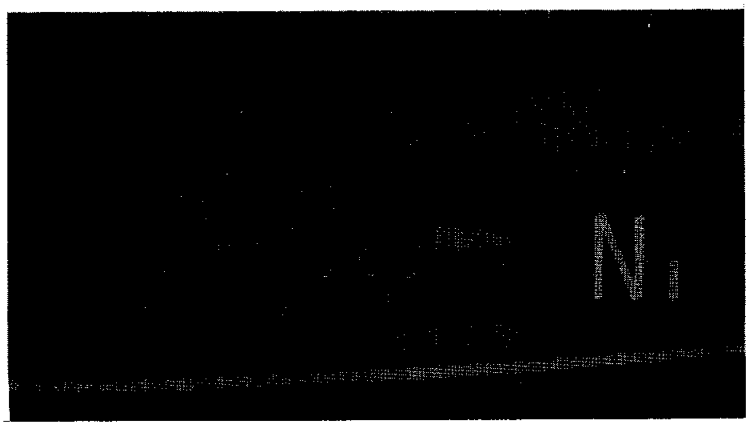


Figure 1. Pre-chip view of 15671. S-71-49721

PETROLOGY: 15671 is a medium-grained, olivine-bearing basalt (Fig. 2). The pyroxenes are dominantly zoned pigeonites about 1 mm in dimension; the larger ones contain small olivine inclusions. Most olivines are smaller than 1 mm. The plagioclases are lathy to stubby, and many are hollow. The texture is generally subophitic with some radiate patches. Chromite, ulvospinel, ilmenite, sulfide, cristobalite, and sparse metal are present.

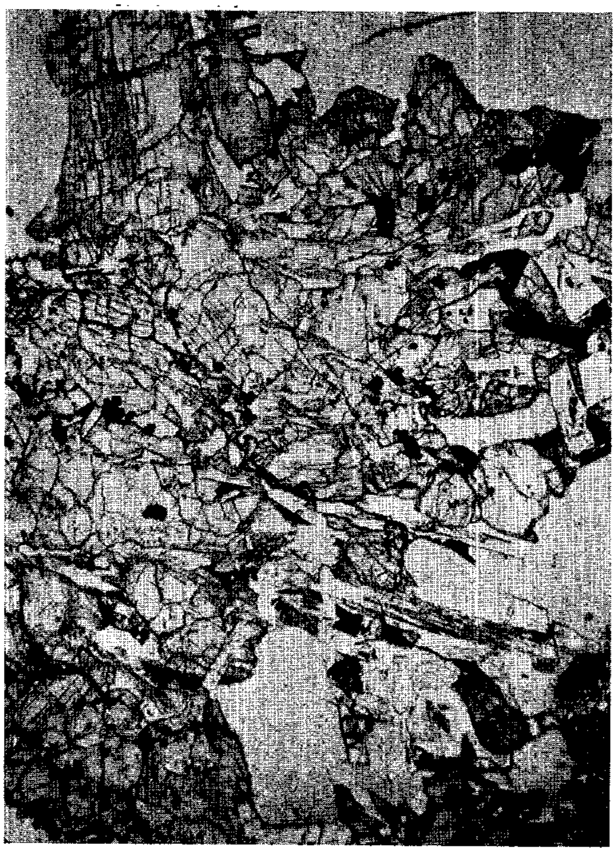


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15671,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15671-1. Bulk rock chemical analysis

		,4
Wt %	SiO2	
	TiO2	2.0
	Al2O3	8.7
	FeO	21.6
	MgO	12
	CaO	8.5
	Na2O	0.251
	K2O	0.038
	P2O5	
(ppm)	Sc	38
	V	201
	Cr	4480
	Mn	2045
	Co	49
	Ni	35(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.2
	Ba	60(b)
	Th	
	U	
	Pb	
	La	4.6
	Ce	
	Pr	
	Nd	
	Sm	3.1
	Eu	0.74
	Gd	
	Tb	0.6
	Dy	3.9
	Ho	
	Er	
	Tm	
	Yb	2.0
	Lu	0.29
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	390
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma *et al.* (1978); INAA

Notes:

(a) ± 20 ppm
(b) ± 30 ppm

CHEMISTRY: A bulk analysis by Ma et al. (1978) shows that 15671 is a member of the Apollo 15 olivine-normative mare basalt suite. The low rare earths and Ti, and high (though imprecisely measured) MgO suggest that it is a primitive or cumulate member.

PROCESSING AND SUBDIVISIONS: Chipping produced several chips, three of which were labelled ,1 and another ,2. ,2 was mainly used to make thin sections ,3 and ,6. In 1976, ,1 was divided and two chips allocated for chemistry and a further thin section ,11. ,0 is now 4.90 g.

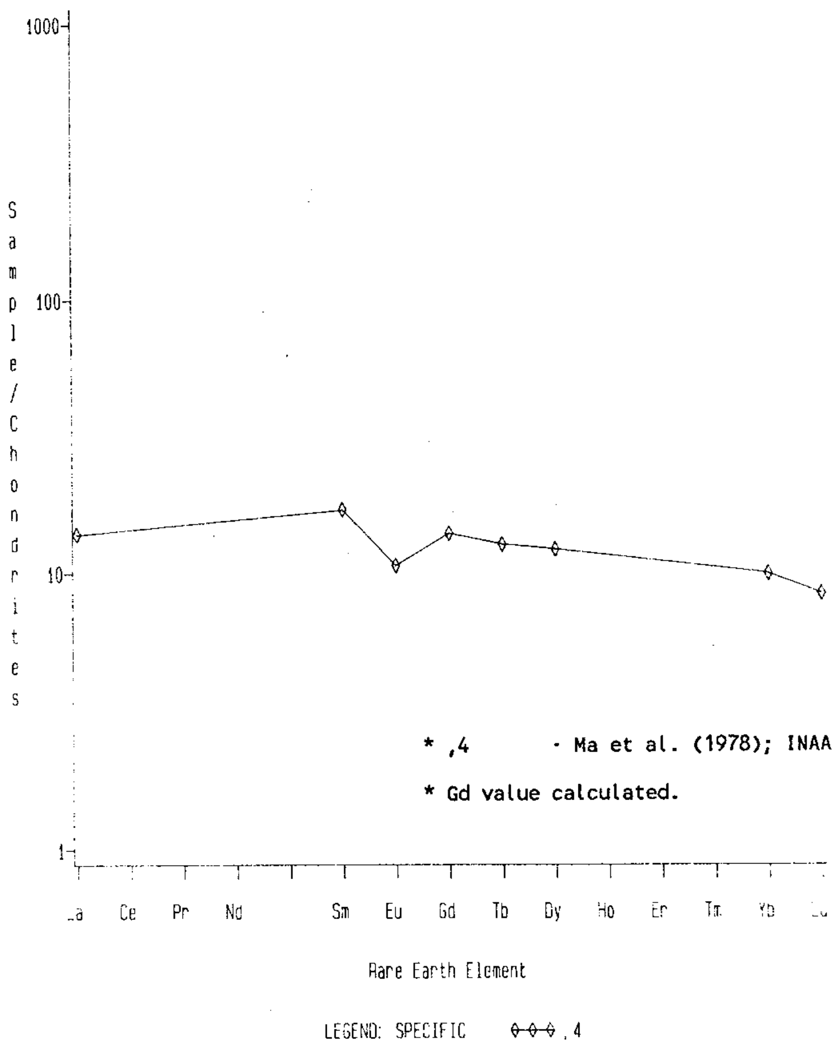


Figure 3. Rare earths in 15671.

15672 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 21.40 g

INTRODUCTION: 15672 is a medium-grained, olivine-bearing mare basalt which is vesicular (Fig. 1). The olivines do not form phenocrysts but some of the pyroxenes do. In chemistry, the sample is a primitive member of the Apollo 15 olivine-normative mare basalt group. It appears to have a distinct top and bottom in that one side is rounded with a moderate zap pit density. 15672 was collected as part of the rake sample from Station 9A.

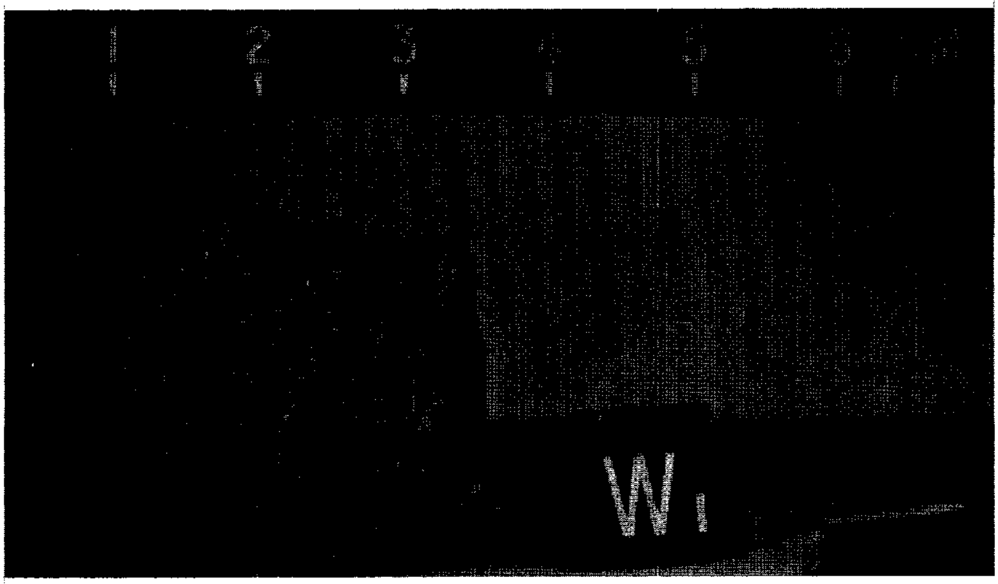


Figure 1. Pre-chip, non-pitted surface of 15672. S-71-49818

PETROLOGY: 15672 is a medium-grained, olivine-bearing, vesicular basalt (Fig. 2). Pyroxene prisms reach 2 mm long, and are zoned; many contain small olivine inclusions. Most olivines are less than 0.5 mm across and are anhedral. Plagioclases are laths about 1 mm long. Cristobalite, fayalite, ilmenite, ulvospinel, euhedral chromites, and residual glass are also present. Dowty et al. (1973b) reported a mode of 58% pyroxene, 22% plagioclase, 10% olivine, 6% opaques, 0.4% silica, and 3.6% miscellaneous. (Dowty et al., 1973a, adjusted this to 11% olivine, 2% miscellaneous). They found that some pyroxenes appeared porphyritic, and that some chromites were mantled with ulvospinel. Dowty et al. (1973c) tabulated microprobe analyses of pyroxene, olivine, plagioclase, Ba-K feldspar, Si-K glass, and Fe-metals; Nehru et al. (1973) tabulated microprobe analyses of spinel group minerals and two ilmenites. Nehru et al. (1974) tabulated an ulvospinel analysis but gave no specific discussion of 15672 in their general discussion of opaque minerals. Fe-metal grains generally contain 1.1 to 1.6% Co and 2.7 to 6.4% Ni, but grains with up to 3.7% Co and 22% Ni are present. Ilmenites contain 0.80 to 1.04% MgO. Mineral analyses are generally similar to those from other Apollo 15 olivine-normative mare basalts (Fig. 3).

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15672,14. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: Bulk rock analyses are listed in Table 1 and the rare earths shown in Figure 4. The data are very consistent with each other and show the sample to be low in Ti and rare earths and high in MgO compared with average Apollo 15 olivine-normative mare basalts, i.e., the sample is rather primitive. Cuttitta et al. (1973) and Christian et al. (1972) have an Yb determination inconsistent with the other analyses and with other Apollo 15 olivine-normative mare basalts, and their data for Yb cannot be considered reliable. They also analysed for, and found no, Fe_2O_3. They reported an "excess reducing capacity" (over FeO) of 0.12. The defocussed beam microprobe analysis (Table 2) is inconsistent with the other chemical analyses, indicating a more evolved olivine-normative basalt, and suggesting sampling problems due to grain size.

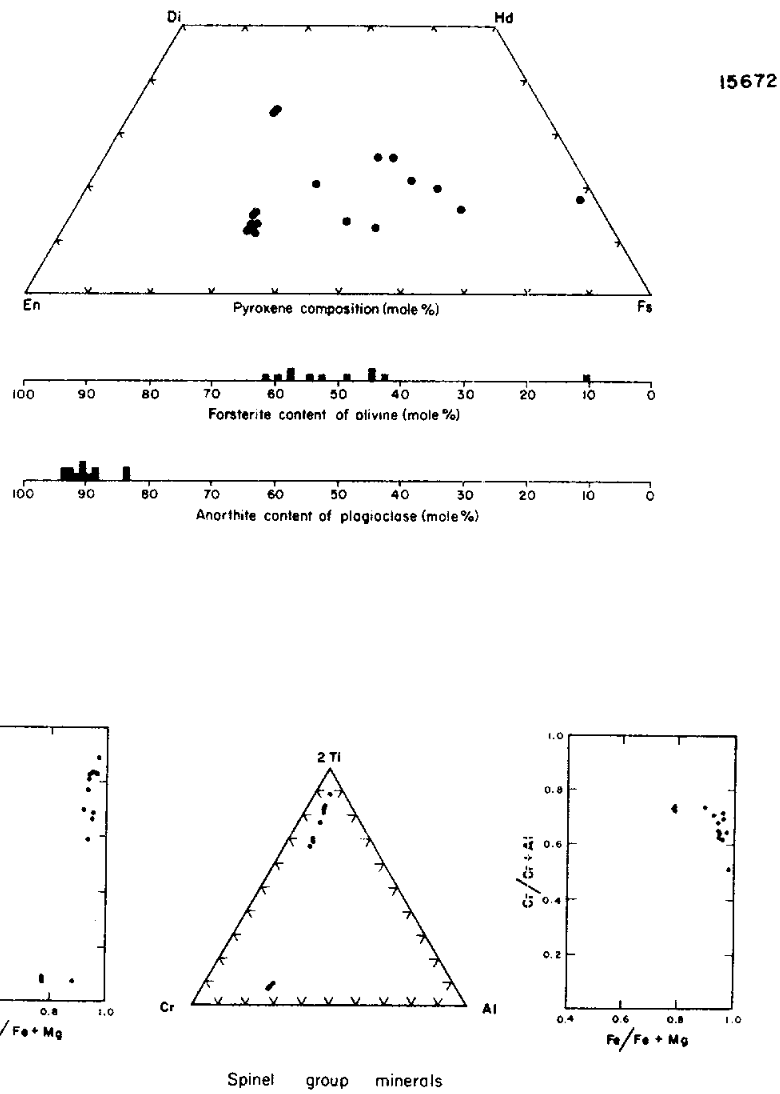


Figure 3. Compositions of minerals in 15672 (Dowty et al., 1973b).

TABLE 15672-1. Bulk rock chemical analyses

		,4	,3	,1A	,1B
Wt %	SiO2	44.8			
	TiO2	2.16	2.1	2.2	1.9
	Al2O3	8.62	8.7	9.0	8.4
	FeO	21.78	22.5	21.2	21.1
	MgO	11.98	12	11.9	12.2
	CaO	9.44	8.6	9.1	9.2
	Na2O	0.28	0.243	0.263	0.245
	K2O	0.06	0.035	0.035	0.032
	P2O5	0.12			
(ppm)	Sc	31	40	39	40
	V	180	200	229	230
	Cr	3220	4410	3885	3505
	Mn	2090	2060	2045	2045
	Co	66	53	49	49
	Ni	69		79	77
	Rb	1.2			
	Sr	120			
	Y	24			
	Zr	59	<180		
	Nb	<10			
	Hf		2.5	2.2	2.1
	Ba	56	60	32(a)	21(b)
	Th				
	U				
	Pb				
	La	<10	4.5	4.2	3.9
	Ce				
	Pr				
	Nd				
	Sm		3.0	2.9	2.6
	Eu		0.86	0.77	0.66
	Gd				
	Tb		0.6	0.49	0.53
	Dy		4.2	3.8	4.0
	Ho				
	Er				
	Tm				
	Yb	4.0	2.1	1.9	1.8
	Lu		0.30	0.33	0.37
	Li	5.6			
	Be				
	B				
	C				
	N				
	S				
	F				
	Cl				
	Br				
	Cu	11			
	Zn				
(ppb)	I				
	At				
	Ga	4500			
	Ge				
	As				
	Sc				
	Mo				
	Tc				
	Ru				
	Rh				
	Pd				
	Ag				
	Cd				
	In				
	Sn				
	Sb				
	Te				
	Cs				
	Ta		500	310	340
	W				
	Re				
	Os				
	Ir				
	Pt				
	Au				
	Hg				
	Tl				
	Bi				
		(1)	(2)	(3)	(3)

References and methods:

(1) Christian et al. (1972), Cuttitta et al. (1973); XRF, semi-micro chem., opt. emiss. spec.
(2) Laul and Schmitt (1973); INAA
(3) Ma et al. (1976); INAA

Notes:

(a) ± 19 ppm
(b) ± 15 ppm

PROCESSING AND SUBDIVISIONS: Chipping produced several chips (,1 to ,5). ,2 was used partly to produce thin sections ,14 and ,18. Several of the other chips were allocated for chemistry, etc. In 1975, ,1, which consisted of several chips, was subdivided to produce materials for chemical analysis and further thin sections, ,12 and ,13. ,0 is now 18.65 g.

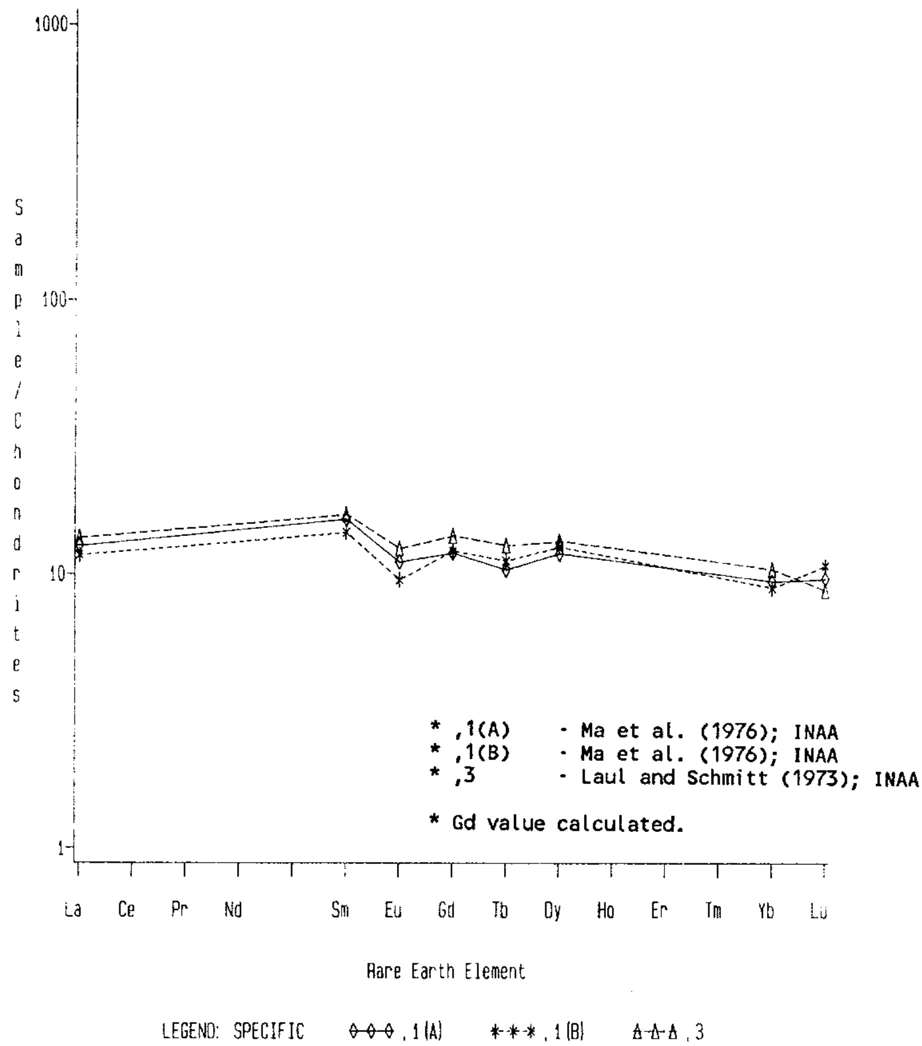


Figure 4. Rare earths in 15672.

TABLE 15672-2. Defocussed beam microprobe bulk analysis (Dowty *et al*., 1973a,b)

Wt %	SiO_2	44.7
	TiO_2	2.75
	Al_2O_3	10.4
	FeO	21.6
	MgO	9.3
	CaO	9.9
	Na_2O	0.38
	K_2O	0.03
	P_2O_5	0.09
ppm	Cr	3765
	Mn	1850

15673 MEDIUM-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 5.90 g

INTRODUCTION: 15673 is a medium- to fine-grained, olivine-bearing mare basalt which is vesicular (Fig. 1). Olivines do not form phenocrysts. In chemistry, the sample is a primitive member of the Apollo 15 olivine-normative mare basalt suite. No zap pits are present on the sample but a few (welded?) dust patches are present. 15673 was collected as part of the rake sample from Station 9A.

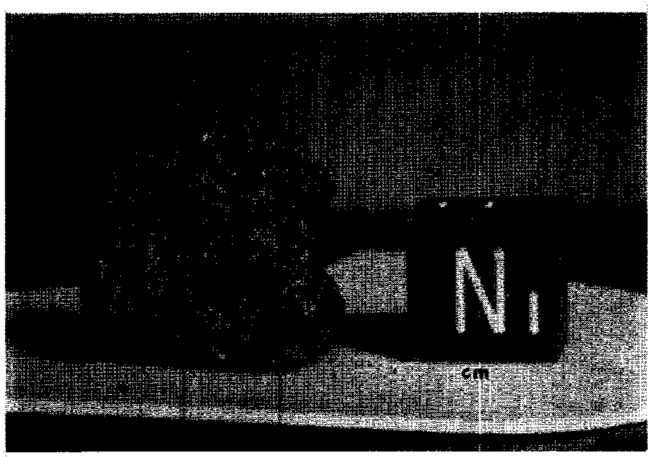


Figure 1. Pre-chip view of 15673. S-71-49845

PETROLOGY: 15673 is a vesicular, olivine-bearing mare basalt of medium grain size (Fig. 2). The texture is gabbroic or subophitic and very few crystals are larger than 1 mm across. The dominant phase is pyroxene, which is zoned.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15673,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: A bulk analysis by Ma et al. (1978) (Table 1, Fig. 3) has low rare earths and TiO_2, and high (though imprecisely determined) MgO, indicating that 15673 is a primitive member of the Apollo 15 olivine-normative mare basalt group.

PROCESSING AND SUBDIVISIONS: Chipping produced ,1 (several chips) and ,2 (single chip). The latter was used to make thin sections ,3 and ,6. In 1976, ,4 was taken from ,1 and used for chemical analysis and to make thin section ,12. ,0 is now 4.64 g.

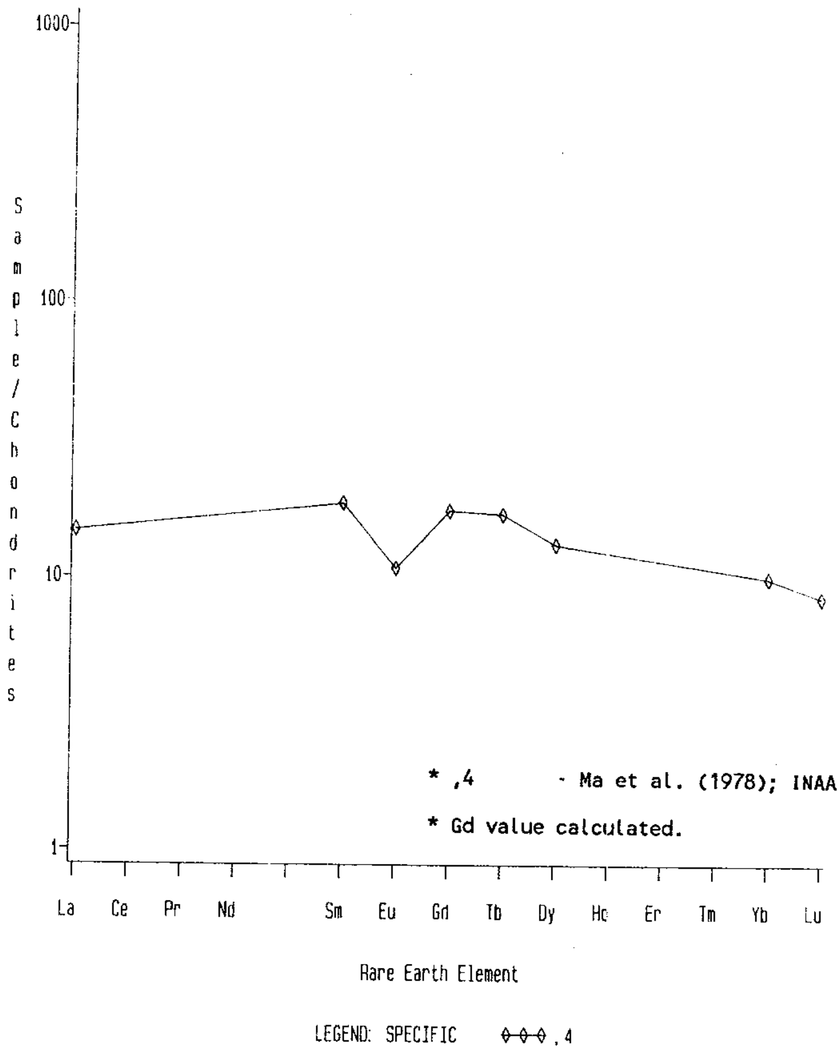


Figure 3. Rare earths in 15673.

TABLE 15673-1. Bulk rock chemical analysis

		,4
Wt %	SiO2	
	TiO2	1.9
	Al2O3	8.7
	FeO	20.7
	MgO	12
	CaO	8.8
	Na2O	0.254
	K2O	0.046
	P2O5	
(ppm)	Sc	37
	V	200
	Cr	4220
	Mn	1990
	Co	47
	Ni	15(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.5
	Ba	
	Th	
	U	
	Pb	
	La	4.9
	Ce	
	Pr	
	Nd	
	Sm	3.4
	Eu	0.75
	Gd	
	Tb	0.8
	Dy	4.2
	Ho	
	Er	
	Tm	
	Yb	2.0
	Lu	0.29
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	410
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ± 15 ppm

15674 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 35.7 g

INTRODUCTION: 15674 is a fine-grained, olivine-bearing mare basalt (Fig. 1). The olivines form small phenocrysts. In chemistry, the basalt appears to be an average member of the olivine-normative mare basalt group. It is tough, with angular corners. One side has abundant 1 mm-sized zap pits and indicates a "simple", single-orientation surface history. The sample is slightly vuggy. It was collected as part of the rake sample at Station 9A.

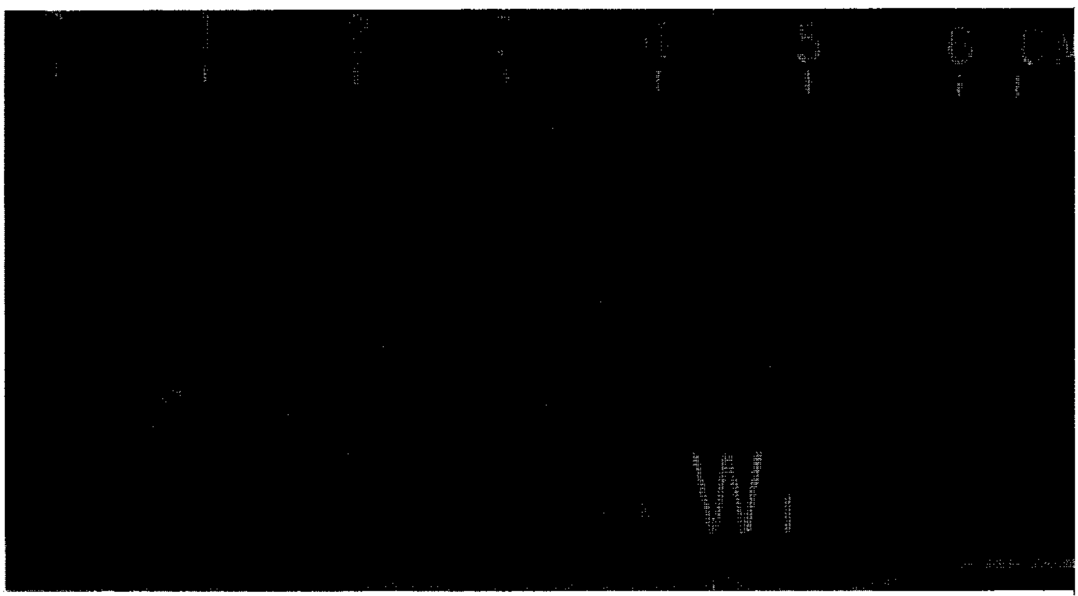


Figure 1. Pre-chip view of 15674. S-71-49834

PETROLOGY: 15674 has a fine-grained groundmass of granular pyroxene with some olivine, and raggedy plagioclases, and a few anhedral olivine phenocrysts (Fig. 2). The granular mafic grains tend to cluster with each other and with opaque minerals. In places the plagioclase grows radially.

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15674,5. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: Chemical analyses are listed in Table 1, with rare earths shown in Figure 3. The analyses agree only moderately well. The composition is of an average-to-slightly-more-fractionated-than-average Apollo 15 olivine-normative basalt. Compston et al. (1972) noted the systematic lower abundances of their Rb analyses made by XRF (reported in Chappell and Green, 1973) as compared with the more reliable ID/MS data. Chappell and Green (1973) found the composition to be so similar to those of 15658 and 15668 that they suggested they were all broken pieces of the same rock. However, 15658 is a much coarser-grained olivine basalt, and 15668 is a much finer-grained olivine basalt, precluding this suggestion.

RADIOGENIC ISOTOPES: Compston et al. (1972) reported Rb-Sr isotopic data (Table 2). For a 3.3 b.y. age, the data give an initial $^{87}Sr/^{86}Sr$ ratio of 0.69950, indistinguishable from that of other Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: A piece was chipped off and it was further chipped to produce material for allocations. ,0 is now 28.91 g. The only thin section, ,5, was made from ,2.

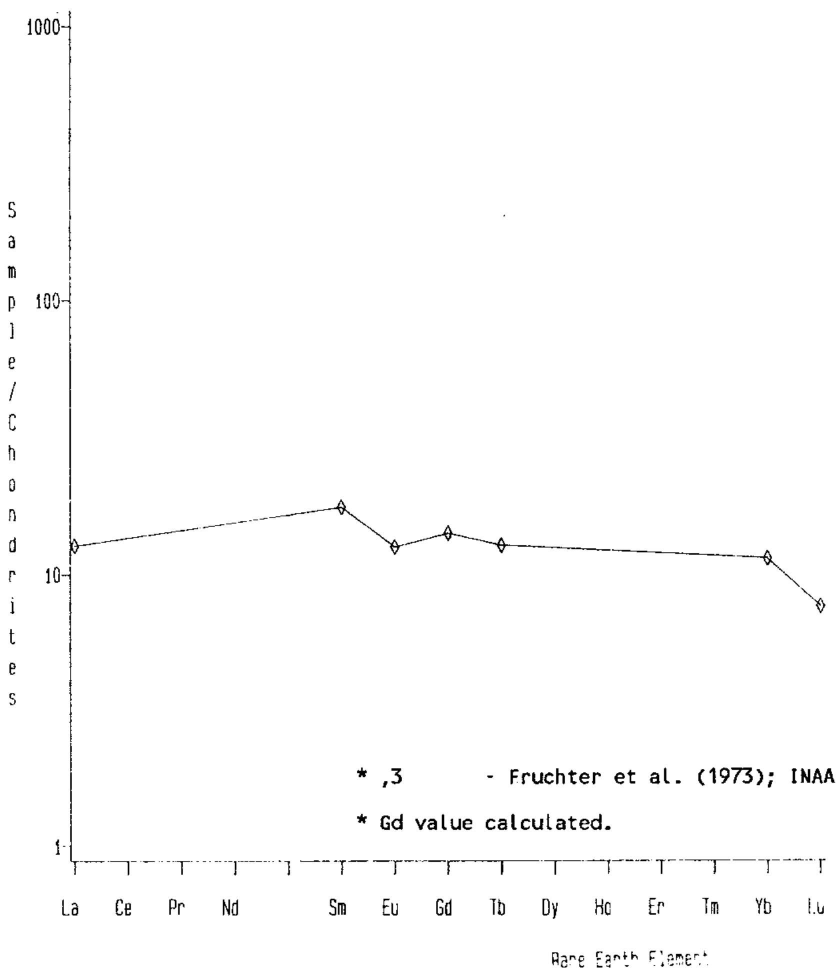


Figure 3. Rare earths in 15674.

TABLE 15674-1. Bulk rock chemical analyses

		,4(,11)	,4(,11)	,3
Wt %	SiO2	45.04		
	TiO2	2.58		2.91
	Al2O3	8.95		8.11
	FeO	22.78		21.54
	MgO	9.36		
	CaO	10.15		
	Na2O	0.28		0.26
	K2O	0.05		
	P2O5	0.08		
(ppm)	Sc			42
	V			
	Cr	3220		3940
	Mn	2400		
	Co			52
	Ni			
	Rb	0.65	0.80	
	Sr	100.9	100.3	
	Y	24		
	Zr	89		
	Nb	7		
	Hf			2.2
	Ba			
	Th			
	U			
	Pb			
	La			4.2
	Ce			
	Pr			
	Nd			
	Sm			3.2
	Eu			0.87
	Gd			
	Tb			0.6
	Dy			
	Ho			
	Er			
	Tm			
	Yb			2.3
	Lu			0.26
	Li			
	Be			
	B			
	C			
	N			
	S	600		
	F			
	Cl			
	Br			
	Cu			
	Zn			
(ppb)	I			
	At			
	Ga	3100		
	Ge			
	As			
	Se			
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag			
	Cd			
	In			
	Sn			
	Sb			
	Te			
	Cs			
	Ta			470
	W			
	Re			
	Os			
	Ir			
	Pt			
	Au			
	Hg			
	Tl			
	Bi			
		(1)	(2)	(3)

References and methods:

(1) Chappell and Green (1973), Compston *et al.* (1972); XRF
(2) Compston *et al.* (1972); ID/MS
(3) Fruchter *et al.* (1973); INAA

TABLE 15674-2. Rb-Sr isotopic data (Compston *et al.*, 1972)

Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	T_{BABI}
0.80 (ID)	100.3 (ID)	0.0231	0.70059 ± 10	4.56 b.y.
0.65 (XRF)	100.9 (XRF)	--	0.70056 ± 10 (a)	--

(a) unspiked

15675 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 34.5 g

INTRODUCTION: 15675 is a fine-grained, olivine-bearing mare basalt (Fig. 1). The olivines form small phenocrysts. In chemistry it appears to be an average member of the Apollo 15 olivine-normative mare basalt group. It is tough with abundant zap pits (probably an equilibrium population) although one side is a fresh surface. One 3 mm pit is present. 15675 was collected as part of the rake sample at Station 9A.

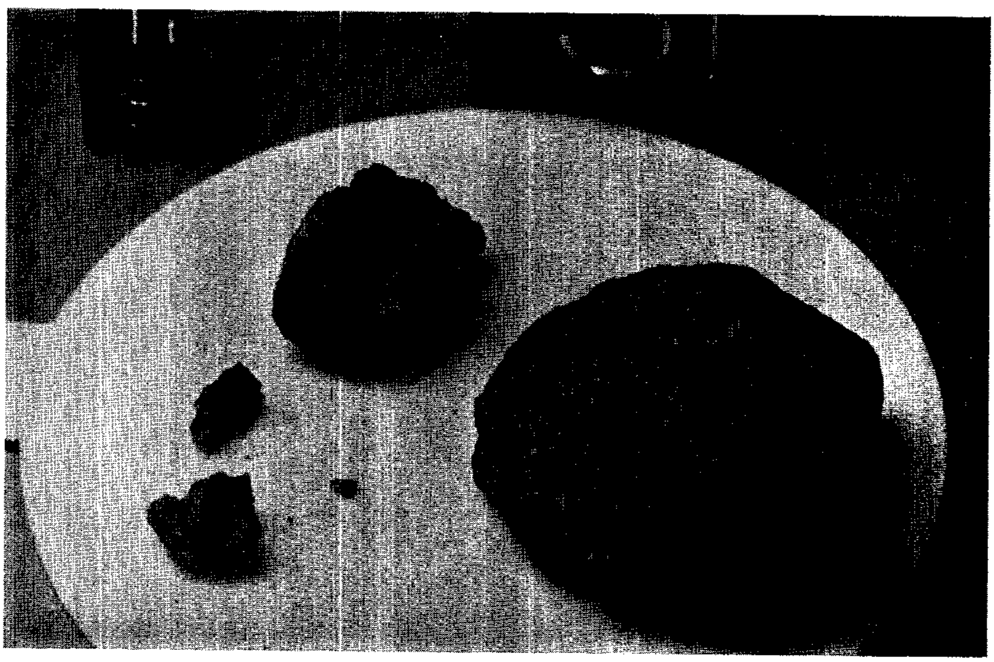


Figure 1. Post-chip view of 15675. Intermediate-sized chip is ,2; others are ,1.

PETROLOGY: 15675 is a fine-grained, olivine-normative mare basalt (Fig. 2). The olivines form small, anhedral phenocrysts.

CHEMISTRY: A bulk rock chemical analysis is presented in Table 1, with the rare earths plotted in Figure 3. The sample appears to be an average Apollo 15 olivine-normative mare basalt, although the critical element Mg is not measured precisely with the INAA technique.

PHYSICAL PROPERTIES: Gose *et al*. (1972) and Pearce *et al*. (1973) measured a magnetic intensity of 3.8×10^{-6} emu/g for the bulk sample, a typical value for Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: Three small chips were taken from ,0 (now 30.29 g) and subdivided. A thin section ,7 was made from ,4.

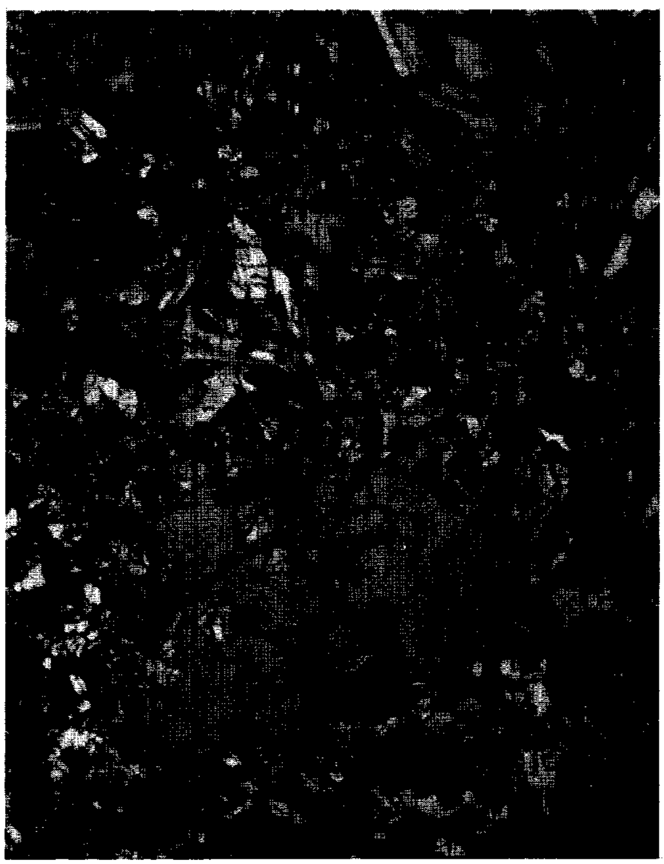


Figure 2. Photomicrograph of 15675,7. Width about 2 mm. Crossed polarizers.

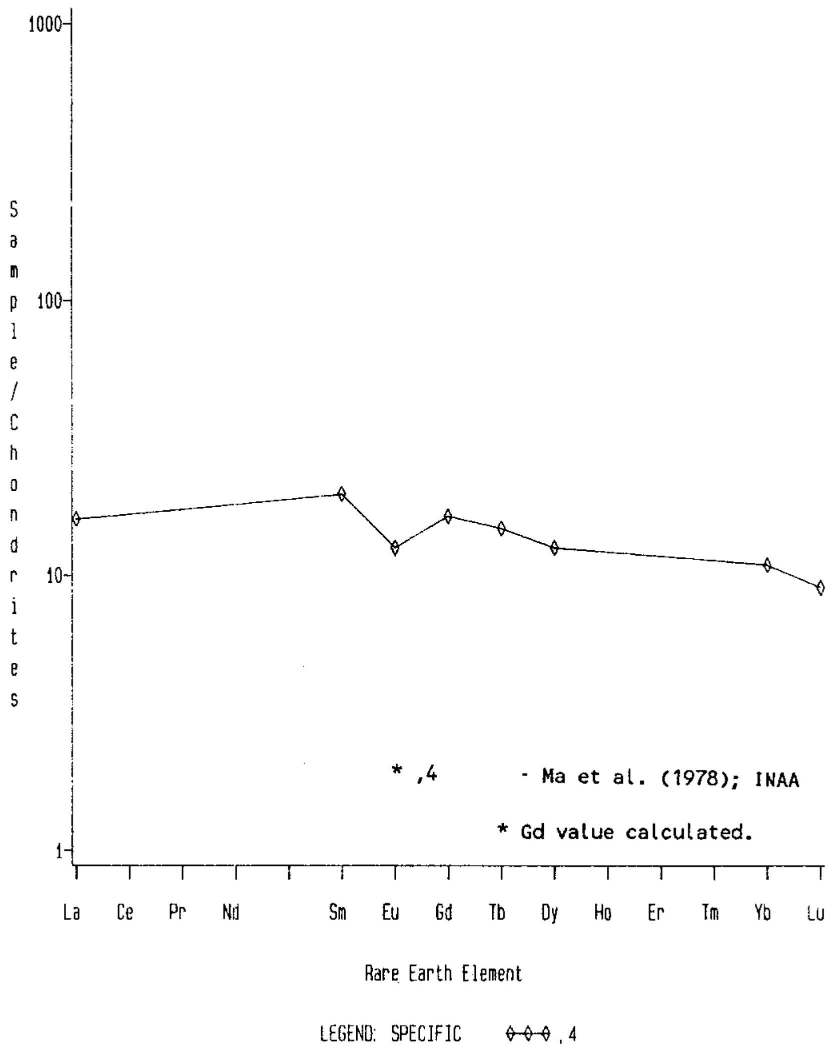


Figure 3. Rare earths in 15675,4.

TABLE 15675-1. Bulk rock chemical analysis

		,4
Wt %	SiO2	
	TiO2	2.2
	Al2O3	9.0
	FeO	21.4
	MgO	10
	CaO	9.1
	Na2O	0.262
	K2O	0.044
	P2O5	
(ppm)	Sc	42
	V	189
	Cr	3370
	Mn	2010
	Co	46
	Ni	65(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.5
	Ba	65(b)
	Th	
	U	
	Pb	
	La	5.3
	Ce	
	Pr	
	Nd	
	Sm	3.6
	Eu	0.87
	Gd	
	Tb	0.7
	Dy	4.0
	Ho	
	Er	
	Tm	
	Yb	2.2
	Lu	0.31
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	480
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma *et al.* (1978); INAA

Notes:

(a) uncertainty ± 30 ppm
(b) uncertainty ± 40 ppm

15676 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 25.3 g

INTRODUCTION: 15676 is a fine-grained, olivine-bearing mare basalt. The olivines form small phenocrysts. In chemistry, it appears to be an average member of the Apollo 15 olivine-normative mare basalt group. It is tough, irregular, and rounded (Fig. 1). 15676 was collected as part of the rake sample at Station 9A.

Figure 1. Post-sawing view of 15676. S-71-59558

PETROLOGY: 15676 is one of the finest-grained olivine-bearing mare basalts (Fig. 2). It contains sparse, small (less than 1 mm) olivine phenocrysts in a groundmass of small raggedy plagioclase laths and tiny (most less than 100 microns) granular pyroxenes. Some tiny olivine grains are also present. Dowty et al. (1973a,b) found a mode of 59% pyroxene, 9% olivine, 27% plagioclase, 4% opaque minerals, 0.5% silica phase, and 0.5% miscellaneous. They also provided mineral chemistry summaries (Fig. 3), with tabulations of pyroxene, olivine, plagioclase, potash feldspar, glass, and metal microprobe analyses in Dowty et al. (1973c). Nehru et al. (1973) tabulated spinel group mineral and ilmenite analyses. The residual silica glass contains up to 7.7% K_2O; the potash feldspar contains 9.0% BaO. Nehru et al. (1974) included 15676 in their general discussion of opaque minerals in Apollo 15 rocks but made no specific mention.

Fig. 2a

Figure 2. Photomicrographs of 15676,15. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: Bulk rock chemical analyses are listed in Table 1, and a defocussed beam microprobe bulk analysis in Table 2. The rare earths are shown in Figure 4. The Cu abundance listed in Cuttitta et al. (1973) is listed erroneously as 0.25 ppm, and La and Yb abundances of Cuttitta et al. (1973) and Christian et al. (1972) are anomalously high. These authors listed an "excess reducing capacity" of +0.12.

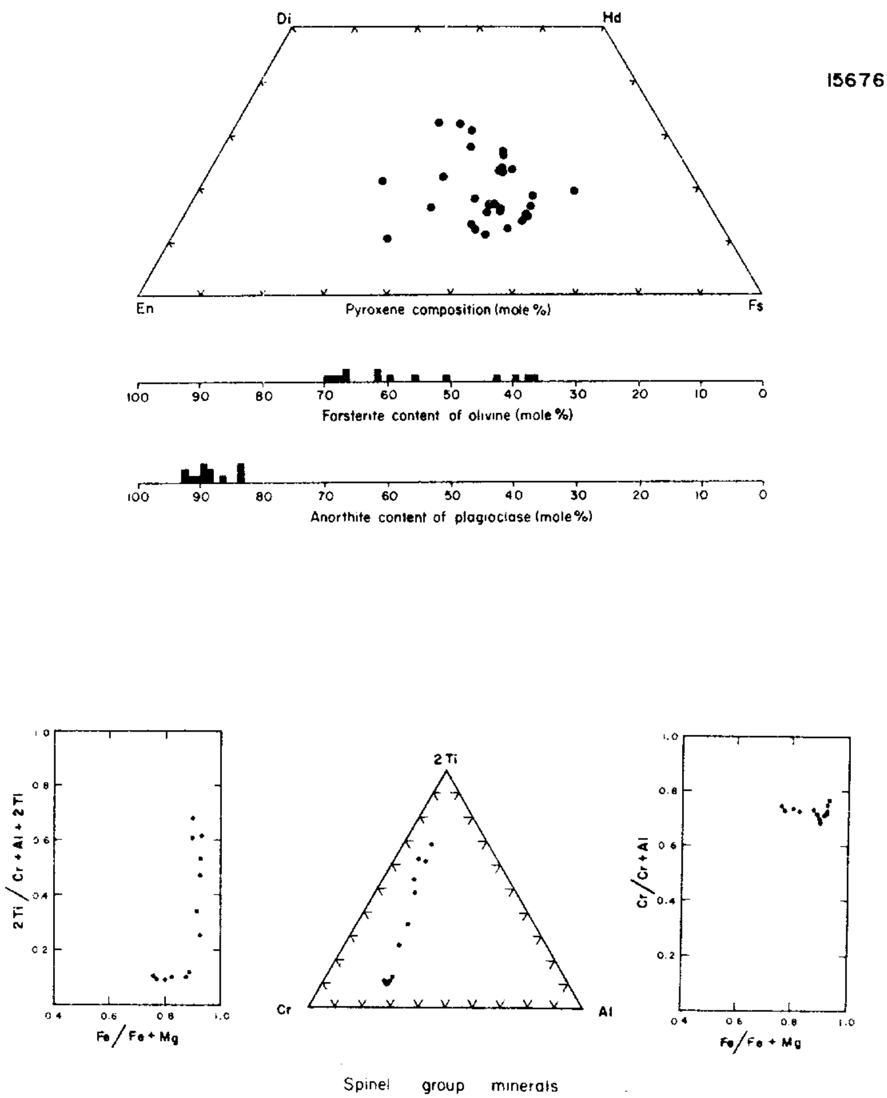


Figure 3. Chemistry of minerals in 15676 (Dowty et al., 1973b).

The chemistry is of an average Apollo 15 olivine-normative basalt. Ma et al. (1976) found it to have a higher Sm/Eu than most other olivine-normative basalts, and suggested it was (with 15607) a second magma type, even though another split analyzed by Laul and Schmitt has a "normal" Sm/Eu ratio. The latter they attribute to "excess" plagioclase, i.e., sampling problems. The defocussed beam analysis is remarkably similar to the more conventional analyses with the exception of its high TiO_2.

PROCESSING AND SUBDIVISIONS: An end was sawn off (Fig. 1) and split to produce ,1 and ,2, which were subdivided for allocations. Thin sections were made from two subchips, ,5 (thin sections ,10 and ,11) and ,8 (thin sections ,14 and ,15). ,0 is now 22.56 g.

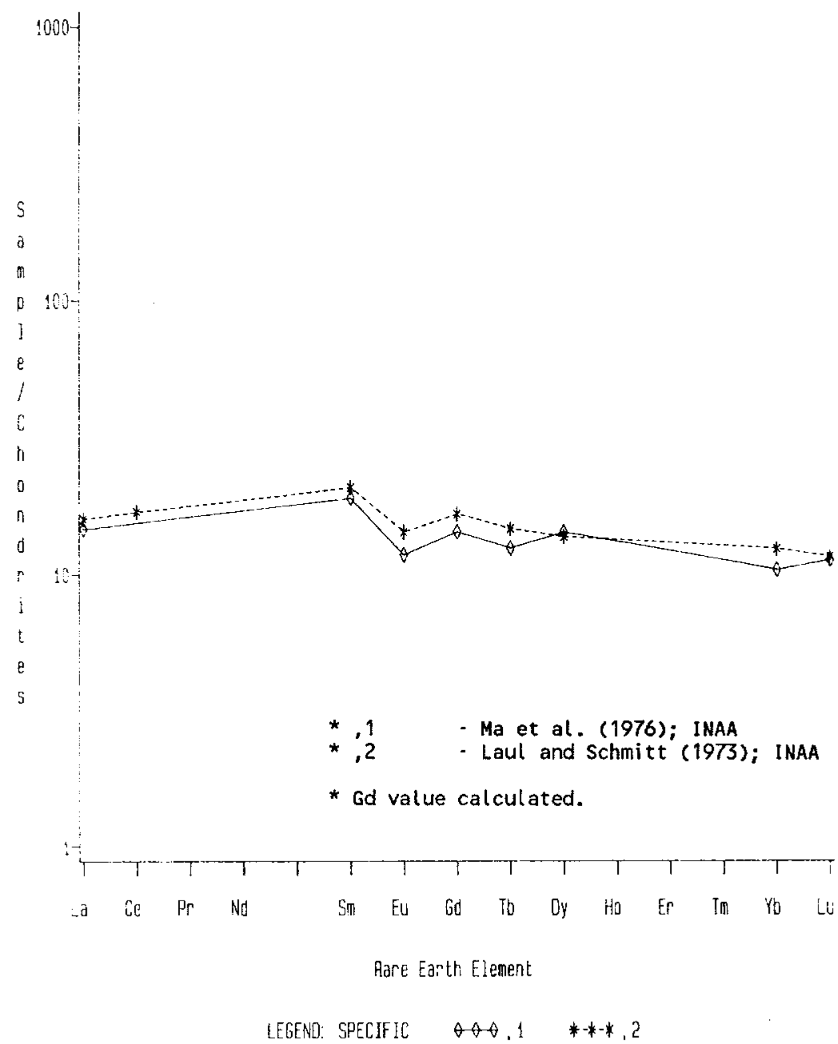


Figure 4. Rare earths in 15676.

TABLE 15676-1. Bulk rock chemical analyses

		,6	,2	,1
Wt %	SiO2	44.10		
	TiO2	2.66	2.7	2.6
	Al2O3	8.76	9.5	8.5
	FeO	23.03	22.5	21.7
	MgO	9.82	8	9.1
	CaO	10.10	10.7	9.3
	Na2O	0.31	0.275	0.275
	K2O	0.06	0.048	0.042
	P2O5	0.11		
(ppm)	Sc	37	42	40
	V	190	200	197
	Cr	3220	3390	2400
	Mn	2170	2080	2070
	Co	60	43	44
	Ni	63		45
	Rb	<1		
	Sr	130		
	Y	27		
	Zr	70	<230	
	Nb	<10		
	Hf		3.1	2.6
	Ba	56	<120	
	Th			
	U			
	Pb			
	La	12	5.3	4.9
	Ce		15	
	Pr			
	Nd			
	Sm		3.8	3.5
	Eu		1.0	0.82
	Gd			
	Tb		0.7	0.59
	Dy		4.4	4.6
	Ho			
	Er			
	Tm			
	Yb	3.9	2.5	2.1
	Lu		0.40	0.39
	Li	7.7		
	Be	<1		
	B			
	C			
	N			
	S			
	F			
	Cl			
	Br			
	Cu	25		
	Zn			
(ppb)	I			
	At			
	Ga	3600		
	Ge			
	As			
	Se			
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag			
	Cd			
	In			
	Sn			
	Sb			
	Te			
	Cs			
	Ta		600	390
	W			
	Re			
	Os			
	Ir			
	Pt			
	Au			
	Hg			
	Tl			
	Bi			
		(1)	(2)	(3)

References and methods:

(1) Cuttitta et al. (1973), Christian et al. (1972); XRF, semi-micro chem, opt emiss. spec.
(2) Laul and Schmitt (1973); INAA
(3) Ma et al. (1976); INAA

TABLE 15676-2. Defocussed beam microprobe bulk analysis (Dowty et al., 1973a, b)

Wt %	SiO2	44.2
	TiO2	3.0
	Al2O3	8.9
	FeO	22.4
	MgO	9.2
	CaO	9.5
	Na2O	0.31
	K2O	0.01
	P2O5	0.08
ppm	Cr	2530
	Mn	2090

15677 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 6.40 g

INTRODUCTION: 15677 is a fine-grained, olivine-porphyritic mare basalt. It is slightly vuggy and has an eroded surface (Fig. 1). In chemistry the sample is a primitive member of the Apollo 15 olivine-normative mare basalt suite. Zap pits occur on all faces, except one which appears to be a fresh fracture. Rounding of the rock corresponds with the pitting, and some small glass splashes are present. 15677 was collected as part of the rake sample at Station 9A.

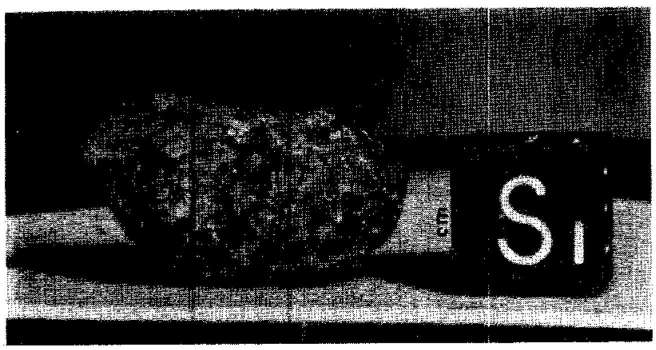


Figure 1. Pre-saw view of 15677. S-71-49851

PETROLOGY: 15677 is a fine-grained, olivine-phyric mare basalt (Fig. 2). The olivine phenocrysts are small (1 mm or less), scattered, and anhedral. Some contain crystallized silicate melt inclusions. The groundmass is generally subophitic to ophitic, with a few radiate patches. The pyroxenes are granular and small, as are groundmass olivines, and the plagioclases range from irregular laths to 1 to 2 mm ophitic grains. Chromite, ulvospinel, ilmenite, cristobalite, fayalite, sulfide, and scarce Fe-metal are present.

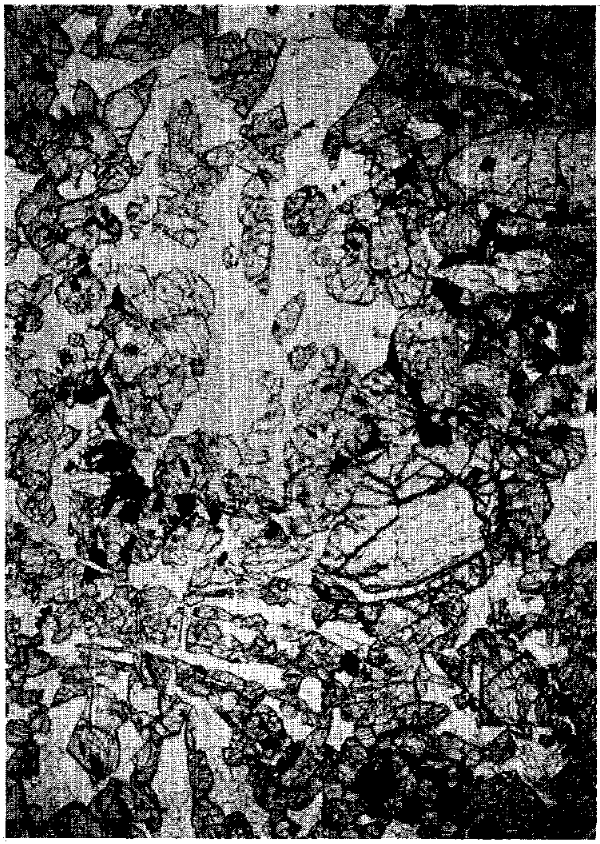


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15677,6. Widths about 2 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: A bulk analysis by Ma et al. (1978) (Table 1, Fig. 3) has low rare earths and TiO_2, and high (although imprecisely determined) MgO, indicating that 15677 is a primitive member of the Apollo 15 olivine-normative mare basalt group.

PROCESSING AND SUBDIVISIONS: ,1 was sawn from one end, and made into a potted butt from which thin sections ,6 to ,8 were made. In 1977, further chipping (to avoid sawn face and exterior) produced ,3 (two chips) and ,4 (two chips). ,3 was used for chemical analysis and to make thin section ,10. ,0 is now 4.69 g.

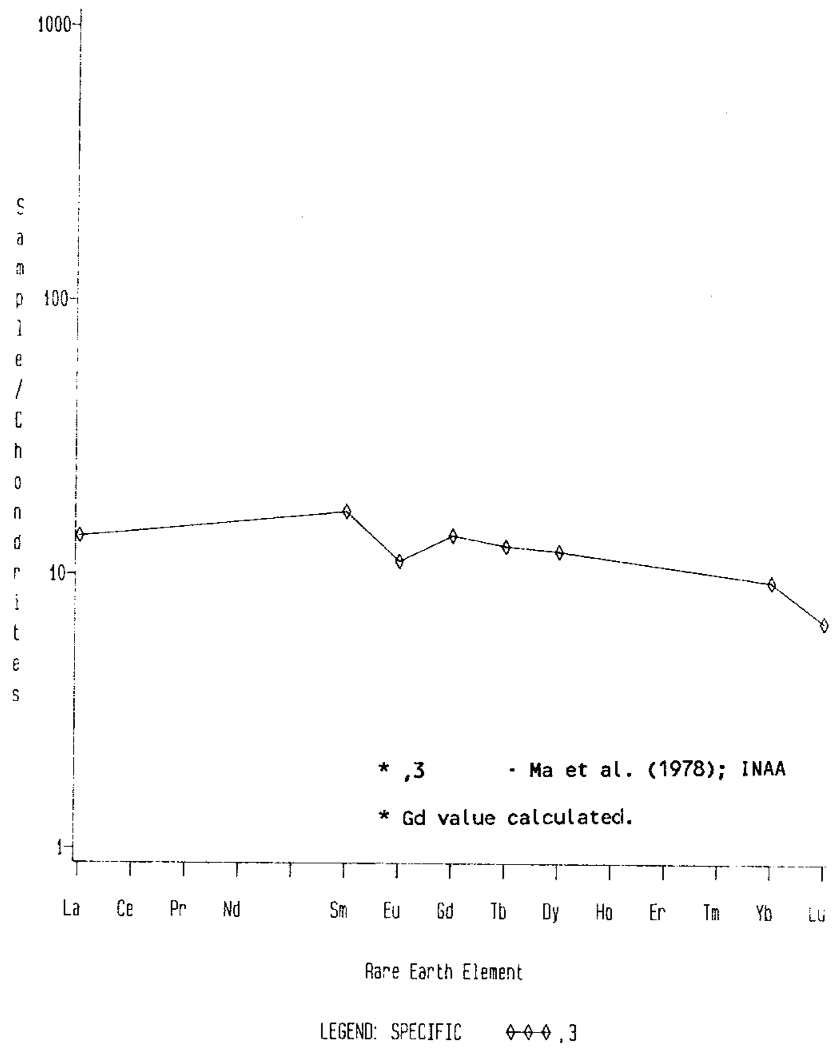


Figure 3. Rare earths in 15677.

TABLE 15677-1. Bulk rock chemical analysis

		,3
Wt %	SiO2	
	TiO2	2.0
	Al2O3	8.8
	FeO	22.5
	MgO	12
	CaO	8.4
	Na2O	0.251
	K2O	0.040
	P2O5	
(ppm)	Sc	40
	V	211
	Cr	4100
	Mn	2045
	Co	55
	Ni	25(a)
	Rb	
	Sr	
	Y	
	Zr	
	Nb	
	Hf	2.2
	Ba	
	Th	
	U	
	Pb	
	La	4.6
	Ce	
	Pr	
	Nd	
	Sm	3.1
	Eu	0.78
	Gd	
	Tb	0.6
	Dy	3.9
	Ho	
	Er	
	Tm	
	Yb	1.9
	Lu	0.23
	Li	
	Be	
	B	
	C	
	N	
	S	
	F	
	Cl	
	Br	
	Cu	
	Zn	
(ppb)	I	
	At	
	Ga	
	Ge	
	As	
	Se	
	Mo	
	Tc	
	Ru	
	Rh	
	Pd	
	Ag	
	Cd	
	In	
	Sn	
	Sb	
	Te	
	Cs	
	Ta	460
	W	
	Re	
	Os	
	Ir	
	Pt	
	Au	
	Hg	
	Tl	
	Bi	
		(1)

References and methods:

(1) Ma et al. (1978); INAA

Notes:

(a) ± 15 ppm

15678 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 7.50 g

INTRODUCTION: 15678 is a fine-grained, olivine porphyritic mare basalt which is slightly vuggy and fractured and has an eroded surface (Fig. 1). In chemistry the sample is a fairly average Apollo 15 olivine-normative mare basalt. It has an ^{40}Ar-^{39}Ar plateau age of 3.38 ± 0.05 b.y. Zap pits are abundant on two sides but less obvious on others. Glass splashes, welded dust, and other coatings are also present. 15678 was collected as part of the rake sample from Station 9A.

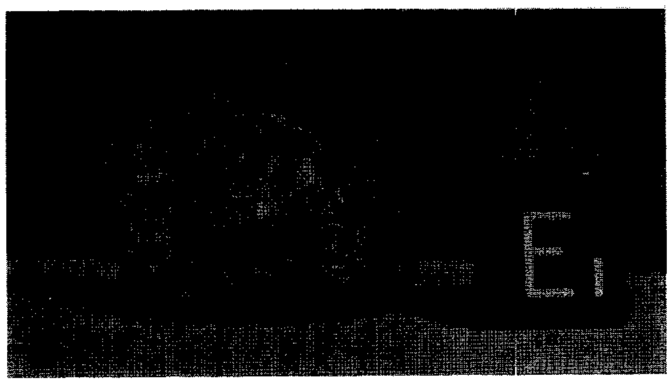


Figure 1. Pre-chip view of 15678. S-71-49858

PETROLOGY: 15678 is a fine-grained, olivine-phyric mare basalt (Fig. 2). The olivine phenocrysts are small (less than 1 mm), scattered and anhedral. The dominant phase, pyroxene, occurs as small granular grains, enclosed in and interstitial to irregular pyroxene laths, i.e., a subophitic to ophitic texture. Dowty et al. (1973b) reported a mode of 55% pyroxene, 30% plagioclase, 7% olivine, 7% opaque minerals, 1% miscellaneous, and no silica phase. Dowty et al. (1973a) adjusted the mode to 8% olivine and 6% opaque minerals. Dowty et al. (1973c) tabulated microprobe analyses of pyroxenes, olivines, plagioclases, Si-K glass, and Fe-metals; Nehru et al. (1973) tabulated microprobe analyses of spinel group minerals and ilmenites. Nehru et al. (1974) included 15678 in their general discussion of opaque minerals but added no specific data or comment. The metal grains contain 1.4 to 2.5% Co and 2.0 to 11.2% Ni; the ilmenites contain 0.90 to 2.43% MgO. The mineral chemistry is similar to that of many other fine-grained Apollo 15 olivine-normative basalts (Fig. 3).

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15678,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

CHEMISTRY: Bulk analyses are listed in Table 1 and the rare earths shown in Figure 4. The major element chemistry is that of an average Apollo 15 olivine-normative mare basalt; the rare earths are somewhat lower than average.

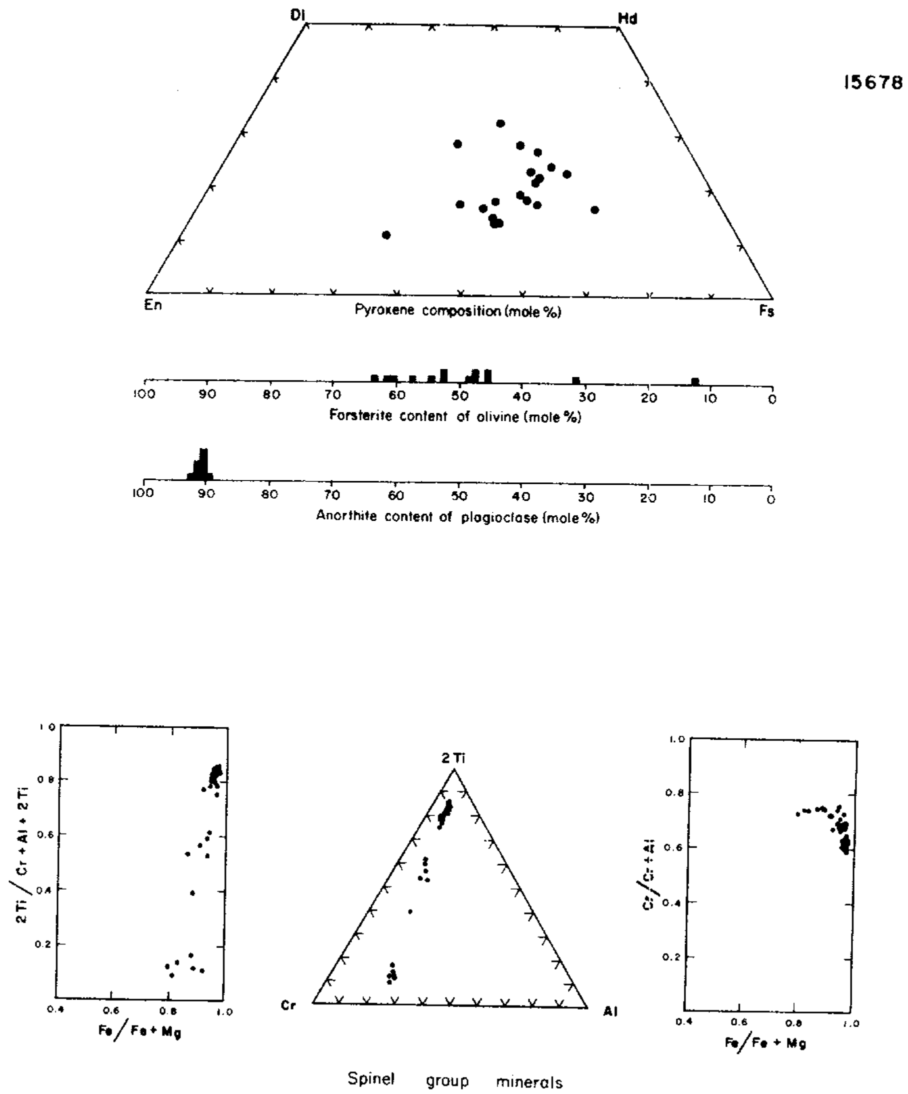


Figure 3. Compositions of minerals in 15678 (Dowty et al., 1973b).

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Husain et al. (1972) reported an ^{40}Ar-^{39}Ar age of 3.28 ± 0.06 b.y. and a K-Ar age of 2.51 b.y. Husain (1974) reported the stepwise-heating Ar isotopic data and revised the ^{40}Ar-^{39}Ar plateau age to 3.38 ± 0.05 b.y. and the K-Ar age to 2.607 ± 0.039 b.y. 40.2% of the $^{40}Ar^*$ had been lost, resulting in the low K-Ar ages.

RARE GAS AND EXPOSURE: Husain et al. (1972) used their Ar isotopic data to calculate a ^{38}Ar-Ca exposure age of 150 ± 20 m.y. This was revised to 164 ± 7 m.y. by Husain (1974).

PROCESSING AND SUBDIVISIONS: Chipping produced ,1 (a few pieces), and ,2 to ,4. ,2 was partly used in making thin sections ,6 and ,7; other pieces were used for analyses. ,0 is now 6.11 g.

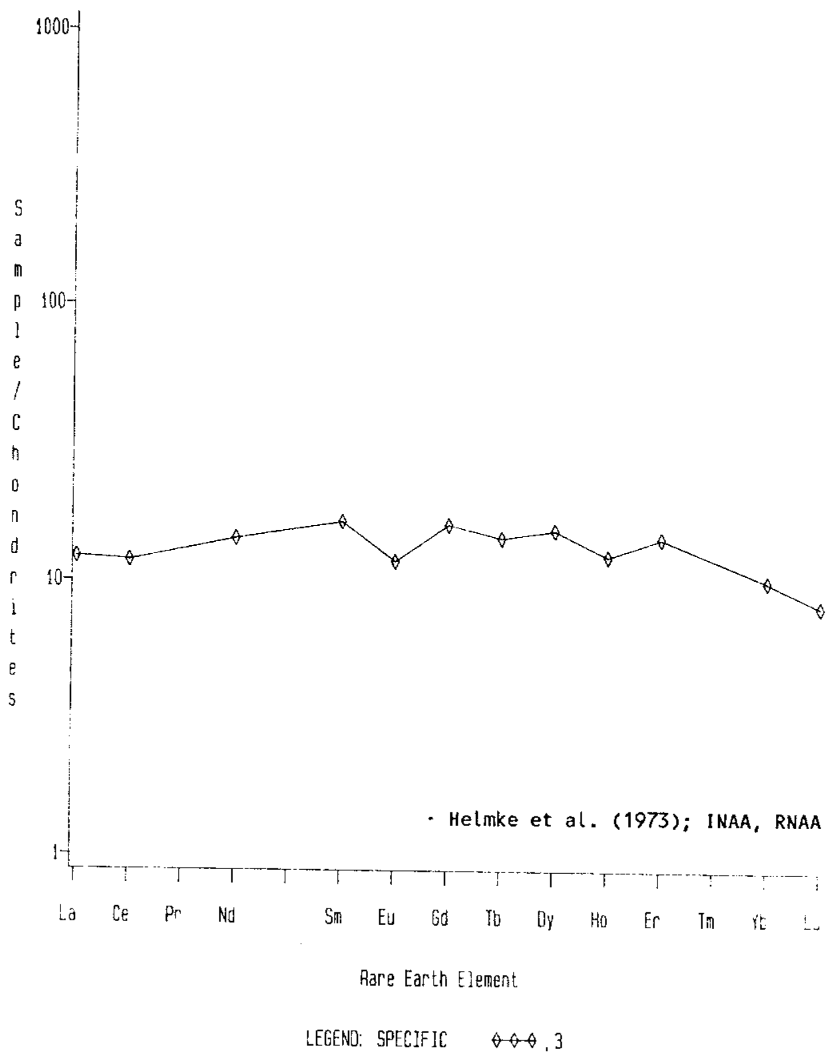


Figure 4. Rare earths in 15678.

TABLE 15678-1. Bulk rock chemical analyses

		,3	,4
Wt %	SiO2	46.0	
	TiO2	2.56	
	Al2O3	8.90	
	FeO	22.0	
	MgO	9.76	
	CaO	10.1	9.2
	Na2O	0.264	
	K2O	0.039	0.042
	P2O5		
(ppm)	Sc	42.8	
	V		
	Cr	4230	
	Mn	2160	
	Co	49	
	Ni		
	Rb	0.6	
	Sr		
	Y		
	Zr		
	Nb		
	Hf	2.0	
	Ba		
	Th		
	U		
	Pb		
	La	4.05	
	Ce	10.5	
	Pr		
	Nd	8.6	
	Sm	2.97	
	Eu	0.82	
	Gd	4.0	
	Tb	0.68	
	Dy	4.9	
	Ho	0.87	
	Er	2.9	
	Tm		
	Yb	2.02	
	Lu	0.277	
	Li		
	Be		
	B		
	C		
	N		
	S		
	F		
	Cl		
	Br		
	Cu		
	Zn		
(ppb)	I		
	At		
	Ga		
	Ge		
	As		
	Se		
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd		
	In		
	Sn		
	Sb		
	Te		
	Cs	29	
	Ta		
	W		
	Re		
	Os		
	Ir		
	Pt		
	Au		
	Hg		
	Tl		
	Bi		
		(1)	(2)

References and methods:

(1) Helmke et al. (1973); INAA, RNAA, AAS.
(2) Husain (1974); Ar istopes, irradiation.

TABLE 15678-2. Defocussed beam microprobe bulk analysis (Dowty et al., 1973a,b)

Wt %	SiO2	45.5
	TiO2	2.64
	Al2O3	9.4
	FeO	22.6
	MgO	9.0
	CaO	10.3
	Na2O	0.38
	K2O	0.05
	P2O5	0.08
ppm	Cr	3290
	Mn	2325

15679 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.70 g

INTRODUCTION: 15679 is a small chip (Fig. 1) which is macroscopically similar to samples 15674 through 15678, which are fine-grained, olivine-phyric mare basalts. Small yellow-green olivines are visible macroscopically. The sample is rounded but has few zap pits. There are several glass splashes. 15679 was collected as part of the rake sample from Station 9A. It has never been subdivided or allocated.

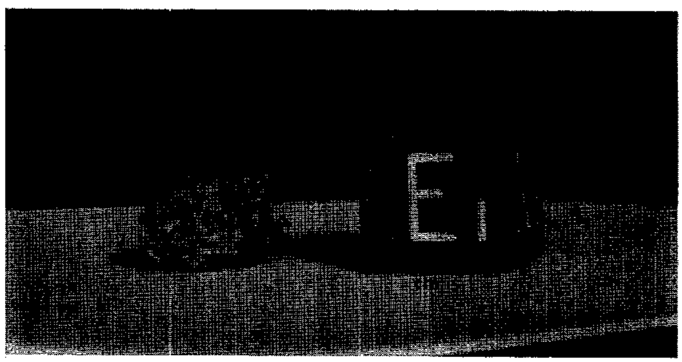


Figure 1. Sample 15679. S-71-49854

15680	FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?)	ST. 9A	0.30 g

INTRODUCTION: 15680 is a small fragment (Fig. 1) of a fine-grained, olivine-bearing basalt which is macroscopically similar to samples 15674 through 15678, which are fine-grained, porphyritic olivine-normative mare basalts. 15680 was collected as part of the rake sample from Station 9A. It has never been subdivided or allocated.

Figure 1. Sample 15680. S-71-49828

15681 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT(?) ST. 9A 0.30 g

INTRODUCTION: 15681 is a small fragment (Fig. 1) of a fine-grained, olivine-bearing basalt which is macroscopically similar to samples 15674 through 15678, which are fine-grained, porphyritic olivine-normative mare basalts. 15681 was collected as part of the rake sample from Station 9A. It has never been subdivided or allocated.

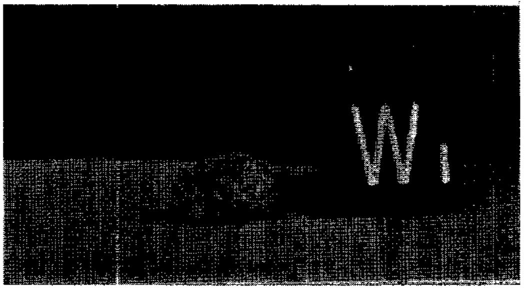


Figure 1. Sample 15681. S-71-49870

15682 PORPHYRITIC SPHERULITIC QUARTZ-NORMATIVE ST. 9A 50.6 g
MARE BASALT

INTRODUCTION: 15682 is a pyroxene-phyric mare basalt with a spherulitic groundmass. In chemistry, it is a low-MgO variety of the Apollo 15 quartz-normative mare basalt group. It has an Rb-Sr isochron age of 3.44 ± 0.07 b.y. It is tough, rounded, irregularly shaped, and has prominent zap pits. It was collected as part of the rake sample from Station 9A.

PETROLOGY: 15682 is a pyroxene-phyric basalt (Fig. 2). It was described, with modal and mineral chemical data, by Dowty et al. (1973a,b; 1974) (Fig. 3); microprobe analyses of minerals were tabulated in Dowty et al. (1973c). Nehru et al. (1973, 1974) tabulated opaque mineral analyses. Dowty et al. (1973a,b) found the mode to have 62% pyroxene, 22% plagioclase, 7% opaque minerals, 0.4% silica mineral, and 8.6% miscellaneous; they found two small, irregular olivine crystals. Dowty et al. (1974) counted 34% phenocryst volume. The phenocrysts are skeletal and zoned, with fairly abrupt, inclusion-rich rims. Most pyroxenes are less than 3 mm long. The groundmass plagioclases range from 0.03 to 2.0 mm long (i.e., almost as long as some pigeonite phenocrysts) but some are stubby and enclosed in patchy pyroxenes. Some large stubby plagioclases have pyroxene crystals in their cores ("intrafasciculate"). There are extremely fine bundles of plagioclase needles included in the larger groundmass pyroxenes. Dowty et al. (1974) provided x-ray diffraction data including the cell parameters. $\Delta\beta$ is 1.77° to 2.15° (average 1.9°), indicating a "middle-rate" cooling.

Cooling history: Lofgren et al. (1974) found pyroxenes (as described in Dowty et al., 1973) to resemble those grown in a quartz-normative basalt composition crystallized at linear cooling rates in the range 1.2° to 30°C/hr. Lofgren et al. (1975) refined these estimates to 2° to 5°C/hr for the phenocrysts to 1° to 5°C/hr for the groundmass. In a similar but more sophisticated study, Grove and Walker (1977) estimated an early cooling rate of 0.1°C/hr from the pyroxene nucleation density, an integrated cooling rate of 0.5°C/hr from the pyroxene sizes, and a late cooling rate of 1.5°C/hr from the plagioclase sizes. They estimated final cooling about 70 cm from a conductive boundary. The rates are intermediate to slow compared with many basalts.

CHEMISTRY: Bulk chemical analyses are given in Table 1, and a bulk defocussed beam microprobe analysis in Table 2. The rare earths are shown in Figure 4. The analyses are fairly consistent and the low MgO suggests that 15682 is among the most fractionated of the Apollo 15 quartz-normative basalts. Helmke et al. (1973) found the Sm/Eu to be intermediate to their two groups, i.e., could not be assigned.

RADIOGENIC ISOTOPES: Papanastassiou and Wasserburg (1973) determined a Rb-Sr internal isochron age of 3.44 ± 0.07 b.y. ($\lambda = 1.39 \times 10^{-11}$ yrs) on plagioclase, "ilmenite", "cristobalite", separates and a whole rock determination. The initial $^{87}Sr/^{86}Sr$ ratio of 0.69926 ± 7 is indistinguishable from other Apollo 15 mare basalts. Nyquist et al. (1972, 1973) also determined Rb and Sr isotopes on a whole rock sample (Table 3). Extrapolated to the age of the basalt, their initial $^{87}Sr/^{86}Sr$ is also indistinguishable from other Apollo 15 mare basalts.

PROCESSING AND SUBDIVISIONS: 15682 was chipped to produce several small pieces (Fig. 1). ,2 was partly used in making thin sections ,6 and ,12. ,0 is now 44.50 g.

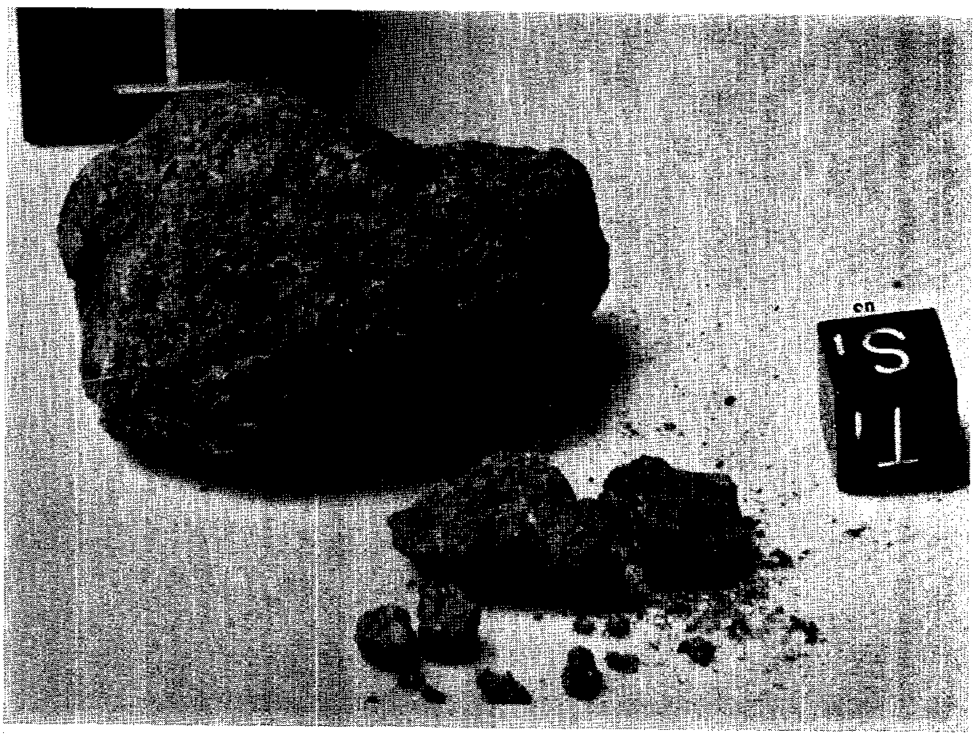


Figure 1. Post-split view of 15682. S-71-59260

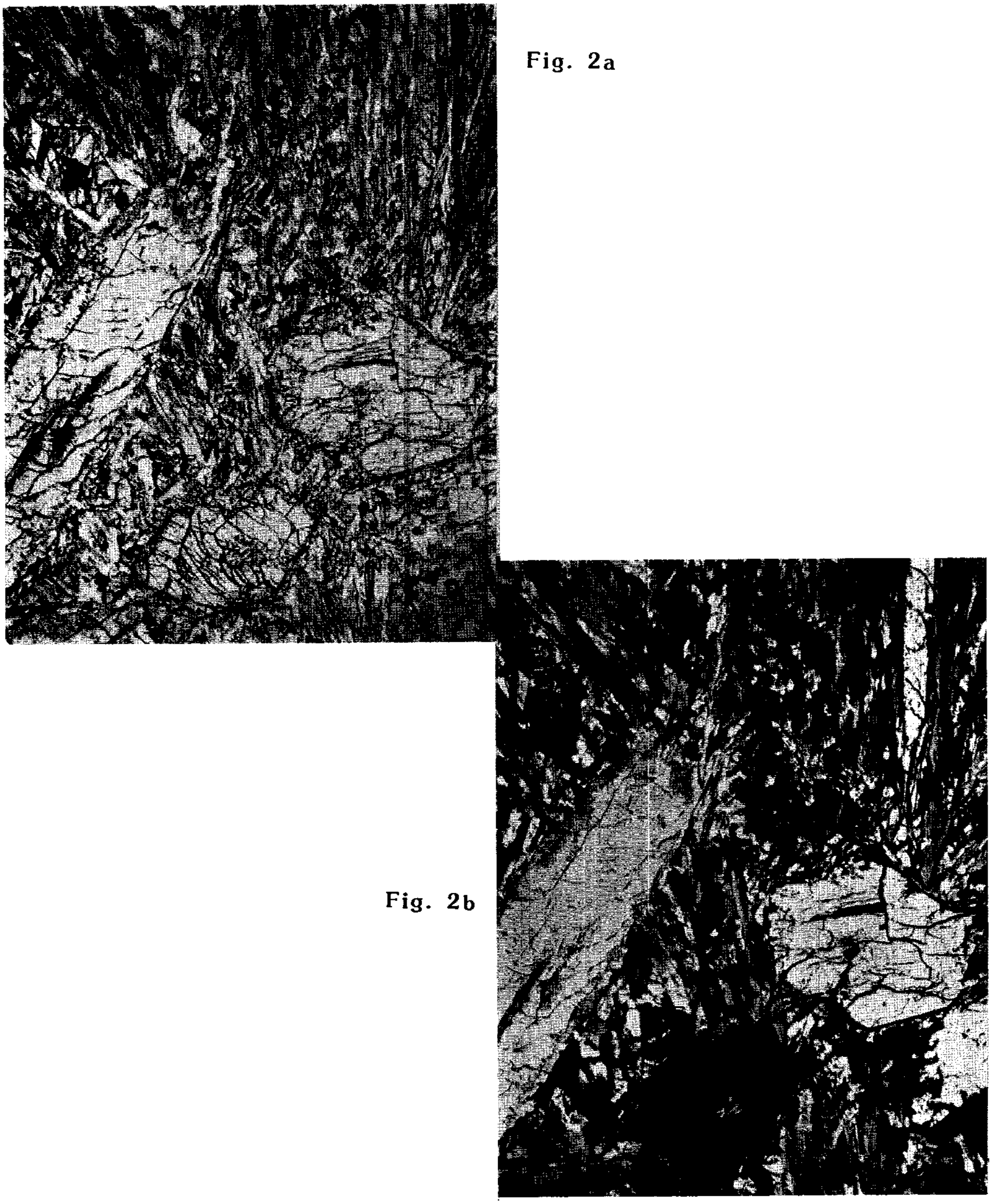
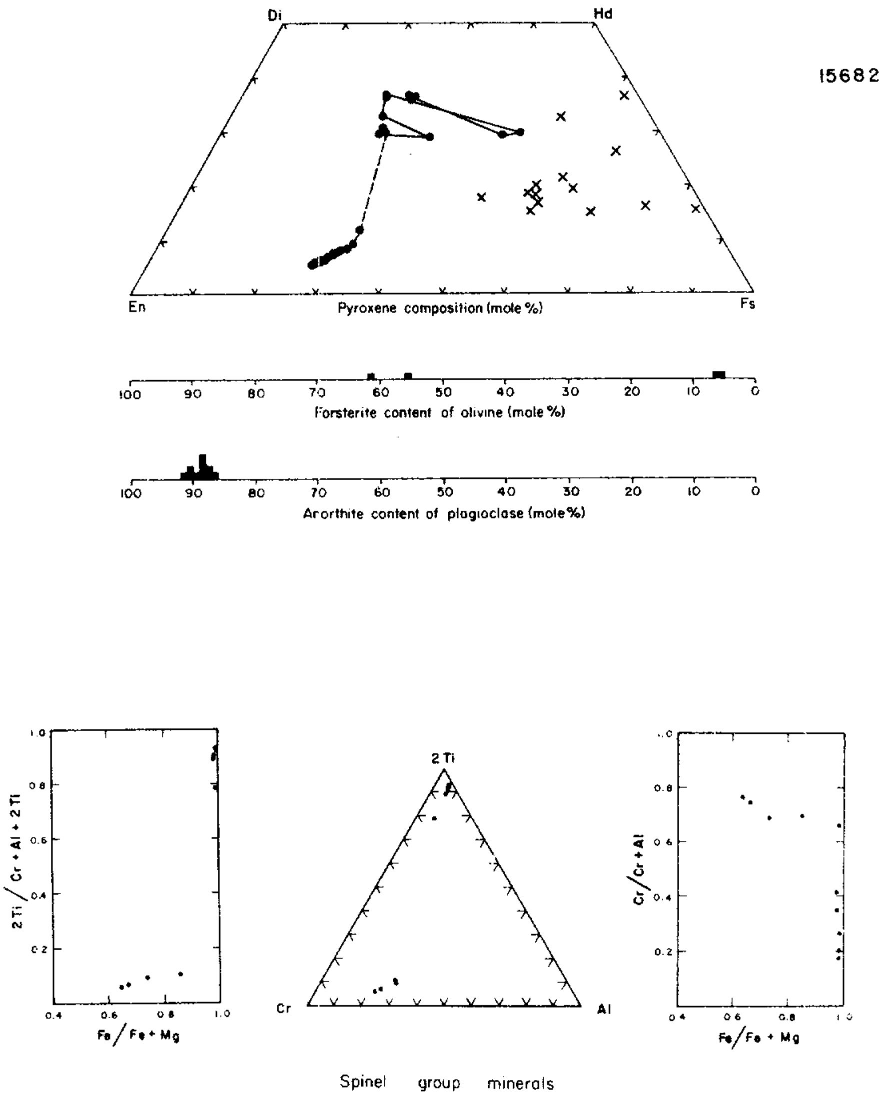


Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15682,6. Widths about 3 mm. a) transmitted light; b) crossed polarizers.



<u>Figure 3</u>. Chemistry of minerals in 15682 (Dowty <u>et al</u>., 1973b).

TABLE 15682-1. Bulk rock chemical analyses

		,4	,4	,4	,4	,3
Wt%	SiO2					48.5
	TiO2	2.25				2.13
	Al2O3					9.88
	FeO	18.2				20.6
	MgO	7.94				7.17
	CaO					10.6
	Na2O	0.39(a)				0.351
	K2O	0.068				0.061
	P2O5					
(ppm)	Sc					42.7
	V					
	Cr					2980
	Mn					2060
	Co					42
	Ni					
	Rb	1.154	1.143	1.145		1.1
	Sr	130	129.8	128.7		
	Y					
	Zr				110	
	Nb					
	Hf				2.9	2.8
	Ba	88.1				
	Th					
	U	0.213				
	Pb					
	La	8.04				6.89
	Ce	22.8				17.8
	Pr					
	Nd	16.3				13.7
	Sm	5.08				4.43
	Eu	1.308				1.10
	Gd	6.80				6.0
	Tb					0.95
	Dy	7.26				6.6
	Ho					1.49
	Er	4.28				3.8
	Tm					
	Yb	3.45				2.9
	Lu	0.612				0.410
	Li	5.56				
	Be					
	B					
	C					
	N					
	S					
	F					
	Cl					
	Br					
	Cu					
	Zn					<3
(ppb)	I					
	At					
	Ga					3800
	Ge					
	As					
	Se					
	Mo					
	Tc					
	Ru					
	Rh					
	Pd					
	Ag					
	Cd					
	In					
	Sn					
	Sb					
	Te					
	Cs					60
	Ta					
	W					
	Re					
	Os					
	Ir					
	Pt					
	Au					
	Hg					
	Tl					
	Bi					
		(1)	(2)	(3)	(4)	(5)

References to Table 15682-1

References and methods:

(1) Hubbard et al. (1973), Wiesmann and Hubbard (1975); XRF, AAS, ID/MS
(2) Nyquist et al. (1972, 1973); ID/MS
(3) Papanastassiou and Wasserburg (1973); ID/MS
(4) Church et al. (1972); ID/MS
(5) Helmke et al. (1973); INAA, AAS, RNAA

Notes:

(a) reported as 0.34% in Wiesmann and Hubbard (1975).
(b) does not include other data also published but which is included in col. 1.

TABLE 15682-2. Defocussed beam bulk microprobe analysis (Dowty et al., 1973b)

Wt%	SiO2	48.0
	TiO2	2.15
	Al2O3	10.5
	FeO	21.0
	MgO	7.3
	CaO	11.3
	Na2O	0.45
	K2O	0.09
	P2O5	0.08
ppm	Cr	2330
	Mn	2015

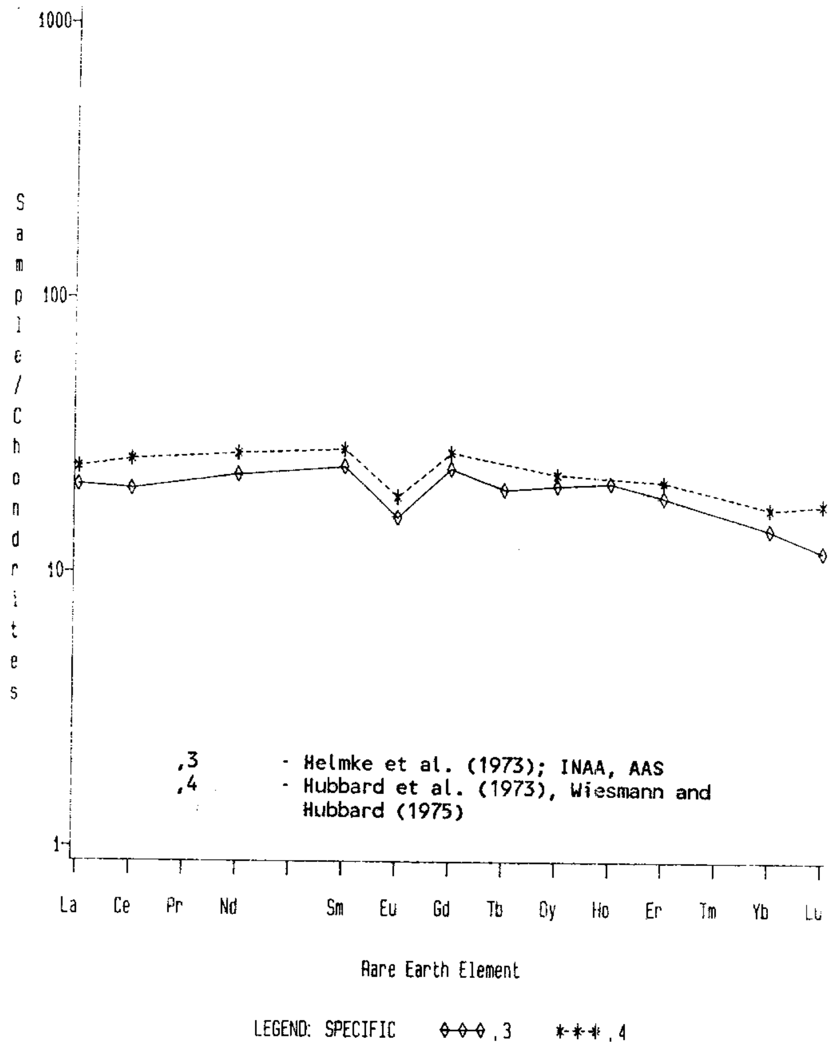


Figure 4. Rare earths in 15682.

TABLE 15682-3. Rb-Sr whole rock data

Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	T_{BABI}	References
1.14	130	0.0255	.70071 ± 8(a)	4.40	Nyquist et al. (1972, 1973)
1.14	129	0.0258	.70048 ± 5	4.06	Papanastassiou and Wasserburg (1973)

(a) reported as 0.70065 ± 8 in Wiesmann and Hubbard (1975).

15683 FINE-GRAINED OLIVINE-NORMATIVE MARE BASALT ST. 9A 22.00 g

INTRODUCTION: 15683 is a fine-grained, olivine porphyritic mare basalt which is vuggy (Fig. 1). In chemistry it is an average-to-evolved Apollo 15 olivine-normative mare basalt. It has an ^{40}Ar-^{39}Ar plateau age of 3.27 ± 0.06 b.y. The sample is coherent but with a few non-penetrative fractures. 15683 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15683 is a fine-grained, olivine-phyric mare basalt (Fig. 2). The olivines are less than 1 mm across. Pyroxenes and small olivines are granular and partly enclosed by plagioclase, which are generally irregular laths up to 1 mm long. Cristobalite, fayalite, chromite, ulvospinel, and ilmenite are also present. Steele et al. (1980) reported analyses for minor elements made with the ion probe: 14 ppm Li, 1330 ppm Mg, 380 ppm K, 325 ppm Ti, 290 ppm Sr, and 20 ppm Ba for a composition of $An_{90.5}$. The data are similar to those of other mare basalts.

CHEMISTRY: Bulk analyses are listed in Table 1 and the rare earths shown in Figure 3. The sample is an Apollo 15 olivine-normative basalt; the high Ti, the rare earths, and the low MgO indicate that it is a rather evolved variety.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Husain et al. (1972) reported an ^{40}Ar-^{39}Ar plateau age of 3.27 ± 0.06 b.y., and a K-Ar age of 2.86 b.y. Husain (1974) presented the Ar stepwise-heating release isotopic data and revised the plateau age to 3.36 ± 0.03 b.y. Only 29% of the argon is released in the plateau region. 23% of the $^{40}Ar^*$ had been lost and the K-Ar age was 2.95 ± 0.07 b.y.

RARE GAS AND EXPOSURE: Husain et al. (1972) reported a ^{38}Ar-Ca exposure age of 290 ± 19 m.y., revised to 310 ± 14 m.y. by Husain (1974) in which the Ar stepwise heating release isotopic data are tabulated.

PROCESSING AND SUBDIVISIONS: Chipping produced pieces ,1 to ,4. ,2 was used to produce thin sections ,2 and ,8. Other chips were used for chemical and isotopic analyses. ,0 is now 19.25 g.

Figure 1. Pre-chip view of 15683. S-71-49887

Fig. 2a

Fig. 2b

Figure 2. Photomicrographs of 15683,8. Widths about 3 mm. a) transmitted light; b) crossed polarizers.

TABLE 15683-1. Bulk rock chemical analyses

		,4	,3
Wt %	SiO2	45.8	
	TiO2	2.91	
	Al2O3	8.04	
	FeO	22.8	
	MgO	9.60	
	CaO	9.37	9.2
	Na2O	0.297	
	K2O	0.053	0.041
	P2O5		
(ppm)	Sc	40.5	
	V		
	Cr	3970	
	Mn	2130	
	Co	49	
	Ni		
	Rb	0.8	
	Sr		
	Y		
	Zr		
	Nb		
	Hf	2.5	
	Ba		
	Th		
	U		
	Pb		
	La	5.26	
	Ce	14.6	
	Pr		
	Nd	11.1	
	Sm	4.20	
	Eu	0.98	
	Gd	5.6	
	Tb	0.93	
	Dy	5.96	
	Ho	1.06	
	Er	2.9	
	Tm		
	Yb	2.44	
	Lu	0.362	
	Li		
	Be		
	B		
	C		
	N		
	S		
	F		
	Cl		
	Br		
	Cu		
	Zn	3(a)	
(ppb)	I		
	At		
	Ga	4100	
	Ge		
	As		
	Se		
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd		
	In		
	Sn		
	Sb		
	Te		
	Cs	38	
	Ta		
	W		
	Re		
	Os		
	Ir		
	Pt		
	Au		
	Hg		
	Tl		
	Bi		
		(1)	(2)

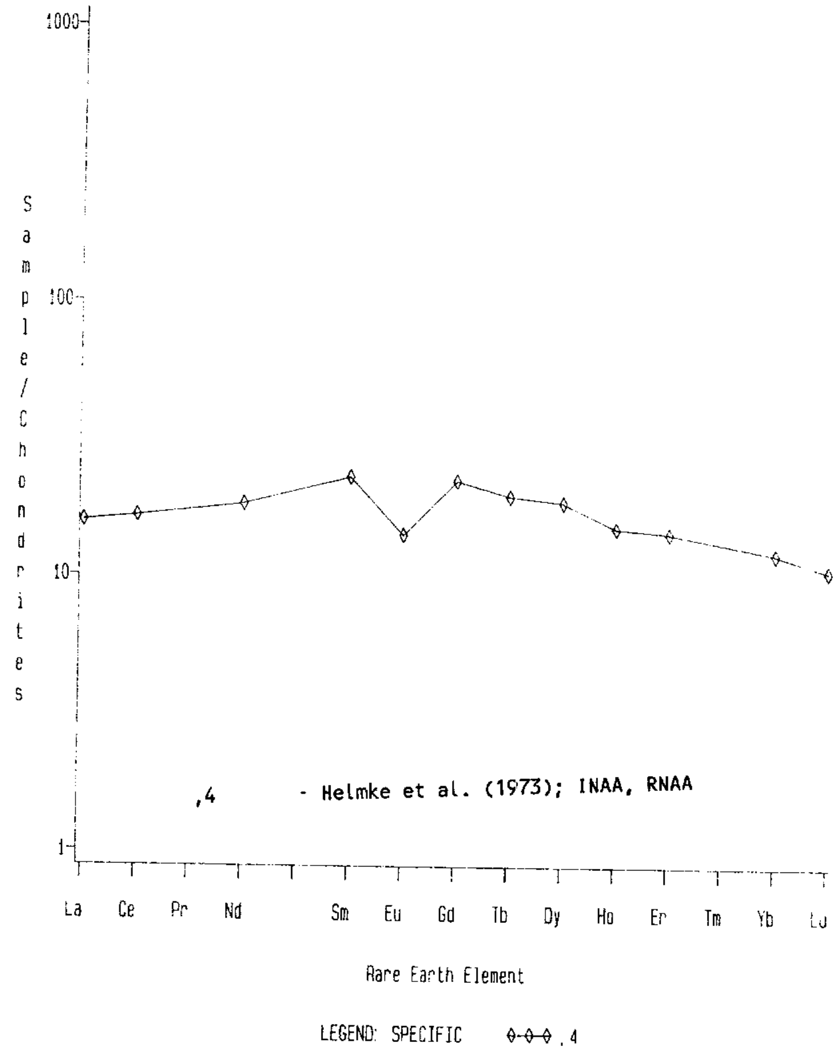
References and methods:

(1) Helmke et al. (1973); INAA, RNAA, AAS.
(2) Husain (1974); Ar-isotopes, irradiation.

Notes:

(a) ± 1 ppm

Figure 3. Rare earths in 15683.



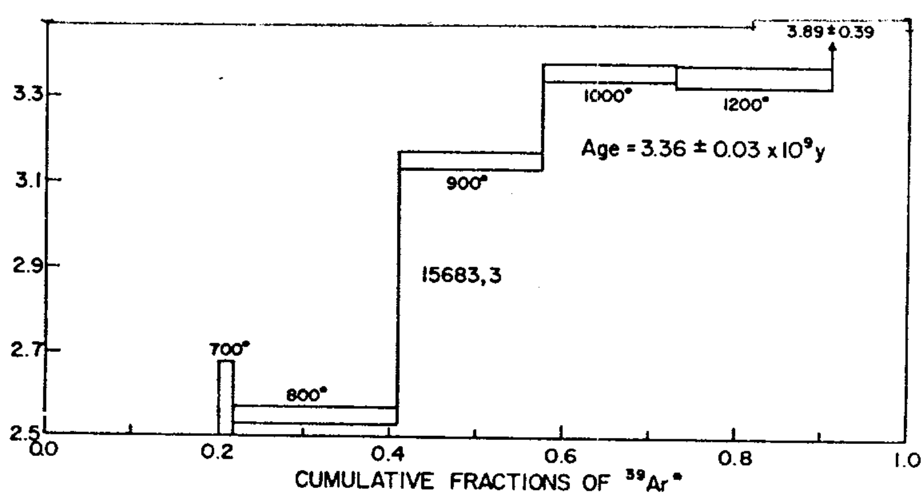


Figure 4. ^{40}Ar-^{39}Ar plateau age for 15683 (Husain, 1974).

15684 GLASS CONTAINING MARE BASALT CLASTS ST. 9A 1.40 g

INTRODUCTION: 15684 is a fragment of glass which contains small clasts, the most prominent of which is a shocked pyroxene-phyric mare basalt (Fig. 1). The shock has converted the plagioclase to maskelynite. The glass composition more closely resembles quartz-normative mare basalt than it does any regolith. Zap pits are present in varied amounts around the sample; one side appears to have none. 15684 was collected as part of the rake sample from Station 9A.

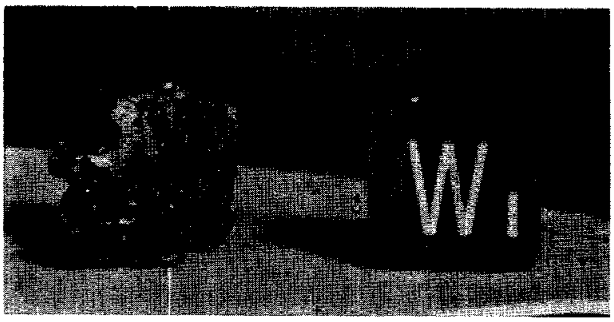


Figure 1. Pre-chip view of 15684 showing basalt clast.
S-71-49840

PETROLOGY: Most of 15684 is a black glass apparently formed in a single event, but the thin sections are dominated by a pyroxene-phyric basalt clast (Fig. 2). The glasses in the sample were described and analyzed by Schaal and Horz (1977). The glass coat is vesicular with flow structures, and covers nearly the entire basalt clast in thin section. It formed a thermal aureole in many grains that it coats, with edge melting visible in pyroxene grains. The glass is mainly yellow-green. There are colorless and reddish brown schlieren with flow bands consisting of aligned opaque phases. Other smaller glass fragments are present; analyses were tabulated by Schaal and Horz (1977) and shown in Figure 3. Most of the glass coat more closely resembles Apollo 15 mare basalt than Apollo 15 regolith, so appears to have formed directly from a basaltic substrate.

Fig. 2a

Fig.2b

Fig. 2c

Figure 2. Photomicrographs of 15684,3. Widths about 3 mm. a) exterior glass (bottom) and basalt (top); transmitted light. b) pyroxene-phyric basalt clast; transmitted light. c) as b), crossed polarizers, showing that all plagioclase is at extinction (maskelynite).

The basalt was described with microprobe analyses by Dowty et al. (1973a, b, c; 1974), Nehru et al. (1973), and Schaal and Horz (1977) (Figs. 4, 5). According to Dowty et al. (1973a, b; 1974) it is pyroxene-phyric and so severely shocked that the plagioclase is mostly isotropic and melted locally. The groundmass consists of large subradiating pyroxene and plagioclase laths. Dowty et al. (1974) reported 36% phenocrysts; shock effects precluded useable x-ray patterns. Schaal and Horz (1977) reported a mode of 66% clinopyroxene (mainly pigeonite), 28% plagioclase (mainly maskelynite), about 8% ilmenite, and traces of kamacite and troilite. They listed microprobe analyses for augite, pigeonite, maskelynite, and ilmenite (see also Fig. 5). The moderate shock effects are pervasive and indicate peak pressures of less than 450 Kbar. Pyroxene grains are granulated and mosaic, and some contain closely spaced fractures and shock lamellae. Lofgren et al. (1975), in a comparison of the texture (as reported by Dowty et al., 1974) with those produced in dynamic crystallization experiments on an Apollo 15 quartz-normative mare basalt composition, inferred a cooling rate of less than 1°C/hr for the phenocrysts and 1-5°C/hr for the matrix of the basalt.

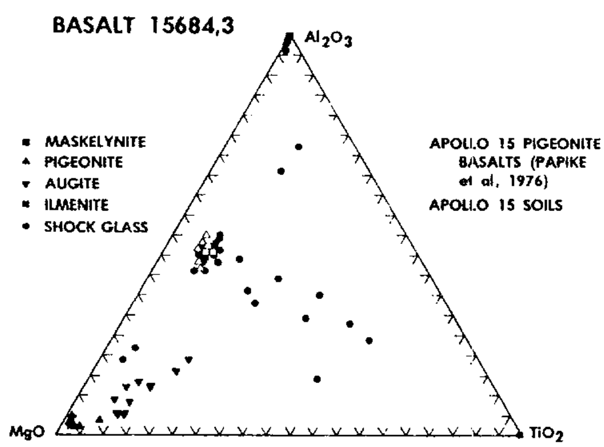


Figure 3. Compositions of glass in 15684 (Schaal and Horz, 1977).

CHEMISTRY: A defocussed beam microprobe analysis of the basalt (Table 1) is not particularly definitive even as to basalt type, and probably is subject to severe errors (note that it was normalized to 100%). The high SiO_2 and low TiO_2 are consistent with a quartz-normative mare basalt.

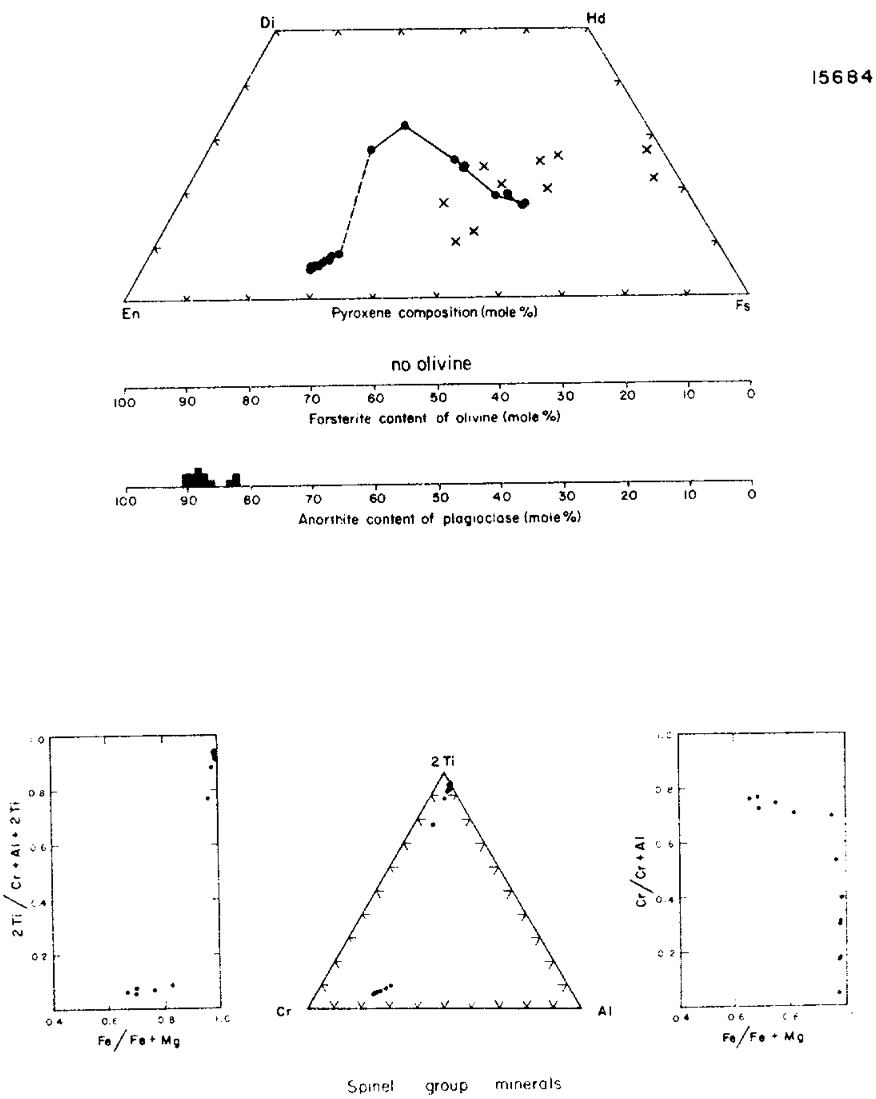


Figure 4. Compositions of minerals in 15684 pyroxene-phyric basalt clast (Dowty et al., 1973b).

PROCESSING AND SUBDIVISIONS: Chipping was made to include the larger basalt fragment visible in Figure 1, and produced chip ,1, which was used to make thin sections ,3 and ,4. In 1977, more chipping produced ,6 (chips), and ,7 (two small chips of exterior glass). ,7 was partly used to make thin section ,9. ,0 is now 0.63 g.

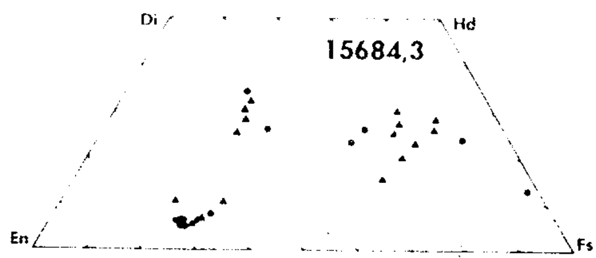


Figure 5. Compositions of pyroxenes in 15684 pyroxene-phyric basalt clast (Schaal and Horz, 1977).

TABLE 15684-1. Defocussed beam microprobe bulk analysis (Dowty et al., 1973a,b) (normalized to 100%)

Wt %	SiO2	47.6
	TiO2	1.45
	Al2O3	8.4
	FeO	21.5
	MgO	10.8
	CaO	8.9
	Na2O	0.33
	K2O	0.05
	P2O5	0.03
ppm	Cr	3865 (a)
	Mn	2250 (b)

(a) reported as ~3630 in Dowty et al. (1973b)
(b) reported as ~2170 in Dowty et al. (1973b)

15685	REGOLITH BRECCIA/GLASS	ST. 9A	0.80 g

INTRODUCTION: 15685 is a small, angular fragment which appears to be dominantly a regolith breccia with small (less than 1 mm) clasts, and possibly some black glass (Fig. 1). It has never been allocated or subdivided.

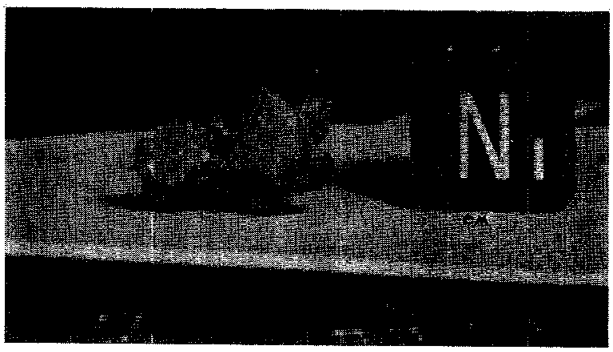


Figure 1. Sample 15685. S-71-49875

15686 REGOLITH BRECCIA/GLASS ST. 9A 0.90 g

INTRODUCTION: 15686 is a small, angular fragment which appears to be dominantly a regolith breccia with small (less than 1 mm) clasts, and some black glass (Fig. 1). It has never been allocated or subdivided.

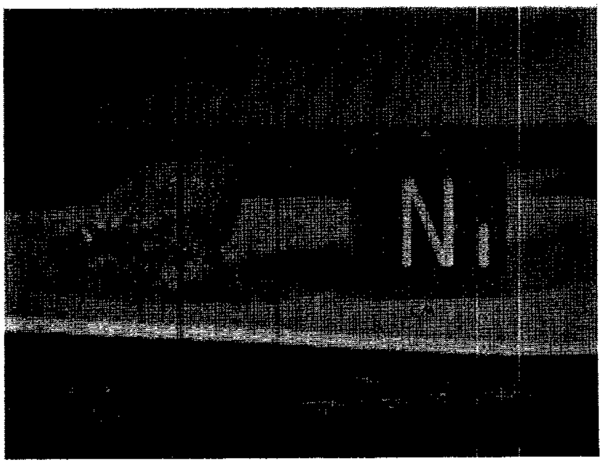


Figure 1. Sample 15686. S-71-49871

15687 AGGLUTINITIC GLASS ST. 9A 1.40 g

INTRODUCTION: 15687 is a vesicular, agglutinitic, black glass, containing small mare basalt and mineral fragments (Fig. 1). It was collected as part of the rake sample from Station 9A.

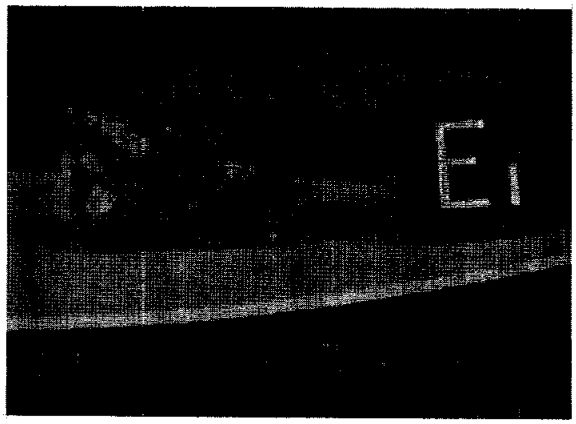


Figure 1. Pre-saw view of 15687. S-71-49880

PETROLOGY: 15687 is an agglutinitic glass which is vesicular (Fig. 2). Steele et al. (1977) described it as consisting of a fine-grained or glassy matrix (60%), 15% lithic clasts (mare basalt), 15% mineral clasts, and 10% porosity. Two clasts contain high-Fe plagioclases, and mare pyroxenes (Fig. 3). They have roughly equal amounts of plagioclase and pyroxene which are small (0.2 mm).

PROCESSING AND SUBDIVISIONS: One small piece was sawn off one end (,1) and used to produce thin sections ,6 to ,8. ,0 is now 1.34 g.

Figure 2. Photomicrograph of 15687,7. Width about 3 mm. Transmitted light.

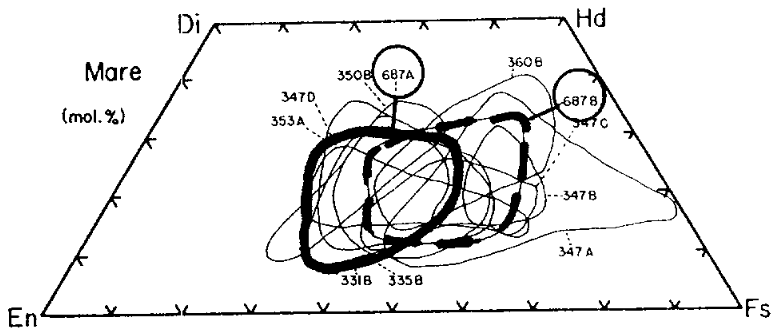


Figure 3. Compositions of pyroxenes in two mare basalt clasts in 15687 (Steele et al., 1977).

15688 AGGLUTINITIC GLASS ST. 9A 5.30 g

INTRODUCTION: 15688 is a vesicular agglutinitic glass containing small fragments which are dominantly mare basalts (Fig. 1). In chemistry it is similar to an Apollo 15 mare basalt. 15688 was collected as part of the rake sample from Station 9A.

PETROLOGY: Dowty et al. (1973b) described the sample as a monomict microbreccia consisting of mare basalt. It is a dark vesicular glass containing clasts of mare basalt, perhaps of the olivine-phyric type, and very few, if any, clasts of other types. McKay and Wentworth (1983) found it to be compact with a high fracture porosity, rare agglutinates and spheres, and abundant shock features. McKay et al. (1984) and Korotev (1984 unpublished) reported I_s/FeO of 0 (for ,13), i.e., totally immature. However, the measurement was probably made on a basalt fragment.

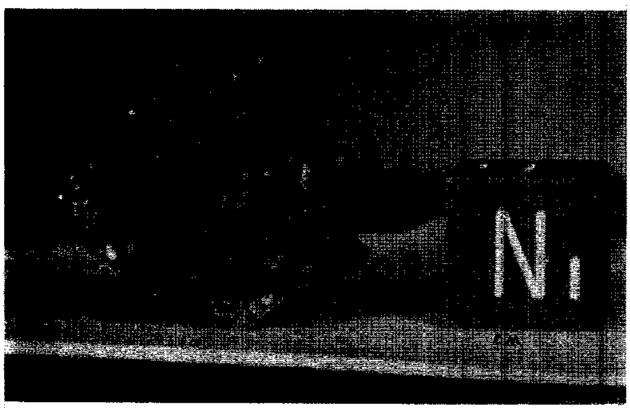


Fig. 1a

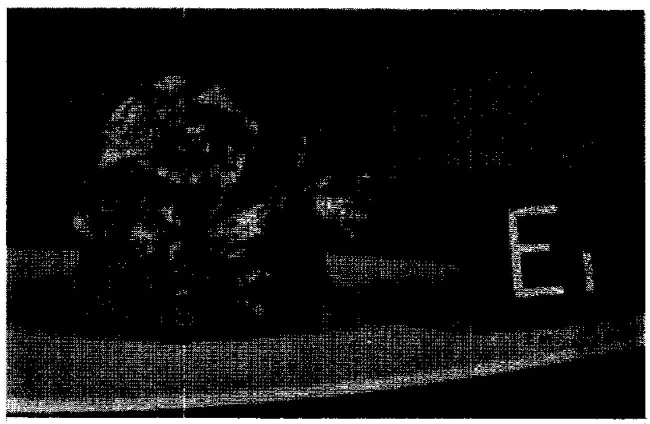


Fig. 1b

Figure 1. Pre-split views of 15688 a) S-71-49841; b) S-71-49842.

CHEMISTRY: Two analyses are listed in Table 1, with the rare earths shown in Figure 2. Helmke et al. (1973) considered 15688 to be a basalt; their analysis showed 3% normative olivine but they tentatively identified it with the quartz-normative basalt group. It is not clear what they analyzed, but it is clearly only barely if at all contaminated with KREEP and may well be a basalt clast. Helmke and Haskin (1972) reported the same data but with Hf as 7 ppm (erroneous), Cr as 4200 ppm, and Zn as less than 5 ppm (they also erroneously labelled the sample 15668,2 instead of 15688,2 in one table). The analysis of Korotev (1984 unpublished) was, from data pack information, clearly made on basalt, not glassy fragments. The data are not clearly equatable with either an olivine-normative or a quartz-normative mare basalt; FeO and MgO suggest olivine-normative, whereas TiO_2 and SiO_2 (by difference) suggest quartz-normative.

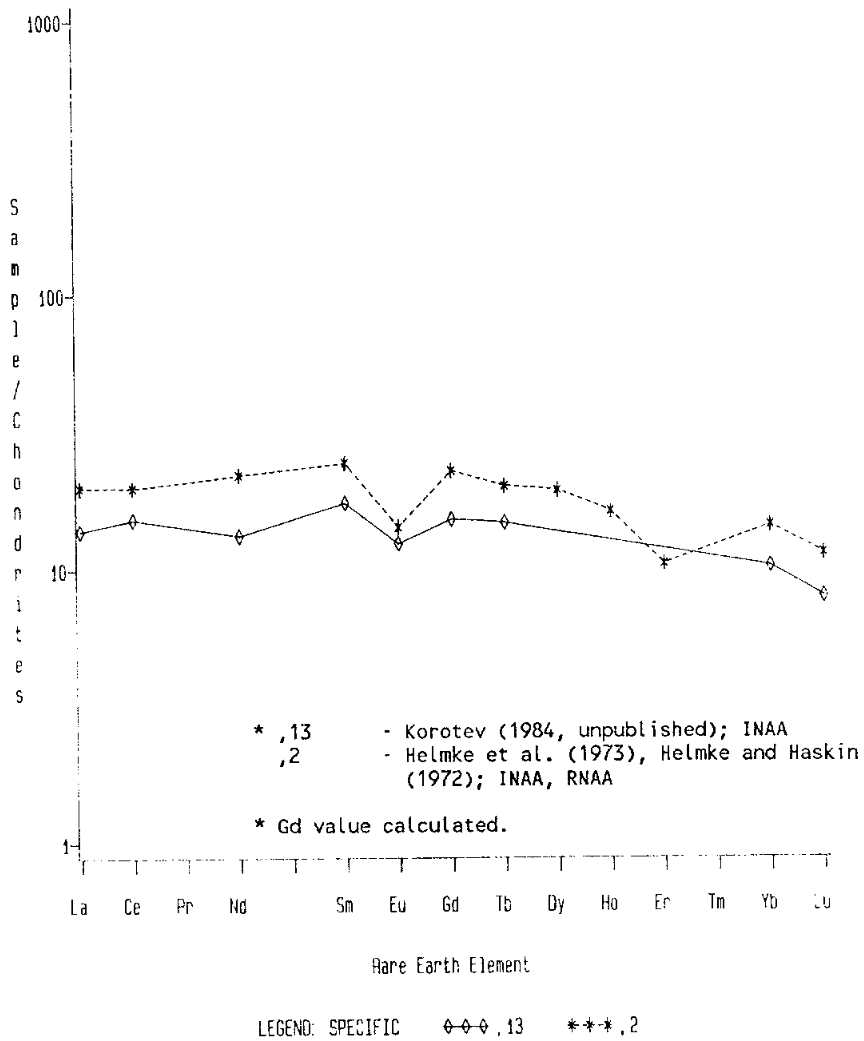


Figure 2. Rare earths on 15688 materials.

PROCESSING AND SUBDIVISIONS: 15688 was sawn to produce ,1; a small piece ,2 was also removed at the same time. ,1 was potted and partly used to make thin sections ,7 through ,10, all of which are dominantly bubbly agglutinitic glass. ,2 was used for chemical analysis. In 1983 interior matrix chips were removed (,13) leaving a mixed set of glass and basalt chips (,14). In data records, ,13 appears to be entirely mare basalt chips, accounting for the low I_s/FeO measured. ,0 is now 3.56 g.

TABLE 15688-1. Chemical analyses of 15688 materials

		,2	,13
Wt %	SiO2	47.7	
	TiO2	2.34	2.08
	Al2O3	9.93	8.4
	FeO	20.8	22.7
	MgO	9.92	10.4
	CaO	9.93	8.8
	Na2O	0.344	0.265
	K2O	0.074	
	P2O5		
(ppm)	Sc	39.5	42.6
	V		180
	Cr	4160	4050
	Mn	2080	2140
	Co	54	54.6
	Ni		63
	Rb	1.3	
	Sr		70
	Y		
	Zr		70
	Nb		
	Hf	2.8	2.45
	Ba		47
	Th		0.24
	U		<0.2
	Pb		
	La	6.62	4.61
	Ce	17.6	13.5
	Pr		
	Nd	13.3	8
	Sm	4.45	3.17
	Eu	0.99	0.86
	Gd	5.7	
	Tb	0.95	0.70
	Dy	6.2	
	Ho	1.14	
	Er	2.1	
	Tm		
	Yb	2.90	2.05
	Lu	0.394	0.272
	Li		
	Be		
	B		
	C		
	N		
	S		
	F		
	Cl		
	Br		
	Cu		
	Zn	5(a)	
(ppb)	I		
	At		
	Ga	3700	
	Ge		
	As		
	Se		
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd		
	In		
	Sn		
	Sb		
	Te		
	Cs	47	60
	Ta		420
	W		
	Re		
	Os		
	Ir		<2
	Pt		
	Au		<4
	Hg		
	Tl		
	Bi		
		(1)	(2)

References and methods:

(1) Helmke et al. (1973), Helmke and Haskin (1972); INAA, RNAA, AAS.
(2) Korotev (1984 unpulished); INAA.

Notes:

(a) ± 2 ppm

15689 REGOLITH BRECCIA ST. 9A 2.80 g

INTRODUCTION: 15689 is a regolith breccia containing white clasts (biggest about 5 mm) (Fig. 1). It was originally described as unique on account of its bright, orange-brown, sugary clasts. One white clast is a fragment of pristine (but shocked) norite. 15689 was collected as part of the rake sample from Station 9A.

PETROLOGY: 15689 is a regolith breccia consisting of a pale brown fine matrix containing mineral and lithic clasts, devitrified brown glass, and pale yellow glasses. One large clast is a norite (Fig. 2); other lithic clasts include a fine-grained highlands granulite and a fine-grained subophitic-intersertal impact melt (similar to Apollo 16 "VHA's"). Steele et al. (1977) reported a mode of 5% glass, 60% lithic clasts, 15% mineral clasts, 20% fine matrix, and 0% porosity for one thin section. The large proportion of "lithic clasts" results from the single large clast of norite, which consists of low-Ca pyroxene and maskelynite. This clast (clast B) has a 4 mm pyroxene and is similar to pristine norite 78235. The pyroxene is about $En_{74}Wo_3$ (Fig. 3), and the plagioclase is An_{91} with low iron. There is minor equigranular diopside (Al_2O_3 about 1%), and several veins, similar to other norites, in which there are chromite, whitlockite, Ca-Cr-Zr armalocolite, a K-Na-Si-Al phase, diopside (Al_2O_3 about 4%), troilite, and metal. Metal analyses are listed in Steele et al. (1977) and are non-meteoritic (about Co 2.7%, Ni 5.7%). Hansen et al. (1979) reported microprobe minor element data for plagioclase ($An_{92.5}$) in the norite: MgO 0.039%; FeO 0.039%, K_2O 0.058%. Steele et al. (1980) reported ion probe trace element data for the plagioclases in the norite ($An_{92.3}$): Li 11 ppm, Mg 230 ppm, Ti 250 ppm, Sr 290 ppm, Ba 300 ppm. Part of this data was plotted in count form in Steele and Smith (1979). Steele et al. (1977) also reported a small shocked intersertal clast with "large" plagioclases (0.4 mm) and minor pyroxene. The plagioclases were high Ca and low Fe, i.e., highlands. Olivines and pyroxenes were analyzed (Fig. 3).

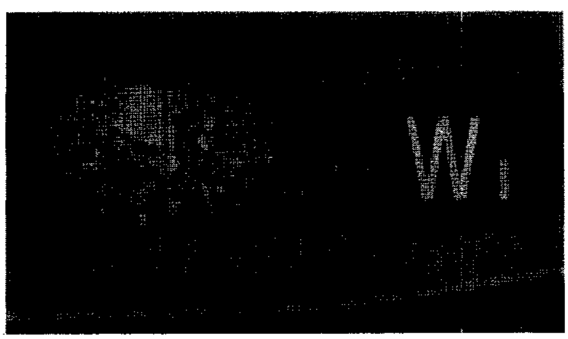


Figure 1. Pre-chip view of 15689. S-71-49814

PROCESSING AND SUBDIVISIONS: Chipping produced a single chip (,1) which contained the white norite clast; this does not appear to be the large clast seen in Figure 1. ,1 was partly used to produce thin section ,6 and ,7. Some small chips (,2) were also chipped off. ,0 is now 2.10 g.

Figure 2. Photomicrograph of 15689,7 showing pristine norite clast. Width about 3 mm. Transmitted light.

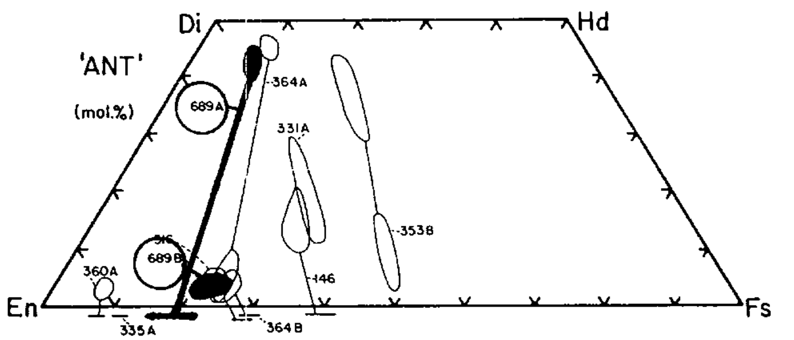


Figure 3. Pyroxene and olivine compositions in two clasts for 15689. "A" is the pristine norite. "B" is subophitic (Steele et al., 1977).

15695 MEDIUM-GRAINED OLIVINE-NORMATIVE(?) MARE BASALT ST. 9A 10.67 g

INTRODUCTION: 15695 is a vesicular, medium- to fine-grained mare basalt (Fig. 1). It consists of about 30% white laths (plagioclase), 25-30% honey brown pyroxene, and the remainder is a dark mafic mineral or glass. Olivine is not readily apparent, but the vesicularity suggests an olivine-normative basalt. The sample is medium light-gray, angular to subangular, and coherent. The vesicles are smooth-walled, and up to 2 mm across. The sample has no zap pits. 15695 was collected as part of the rake sample from Station 9A, but was separated from the rake fines (15600) only in 1975. It has never been subdivided or allocated.

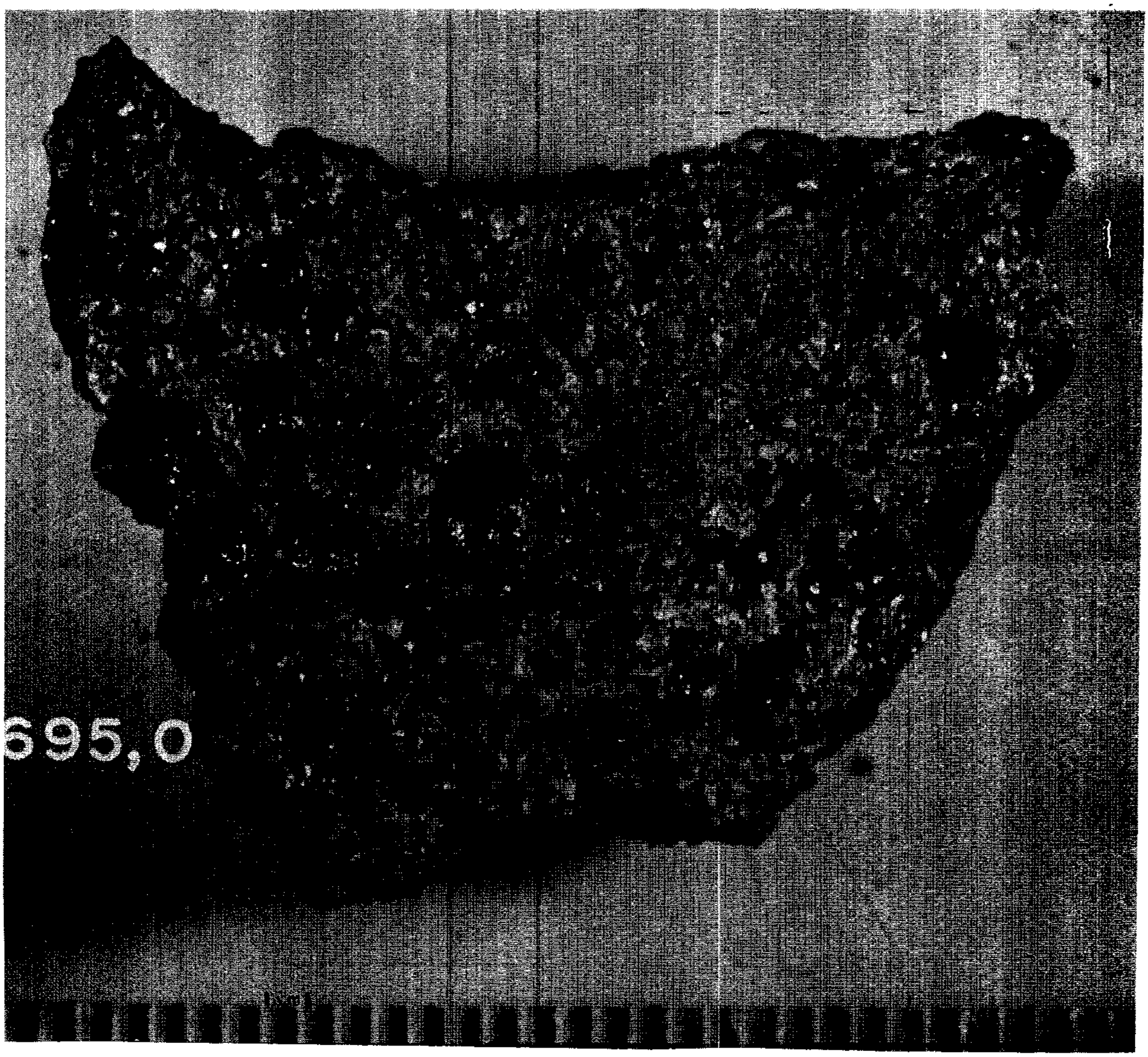


Figure 1. Sample 15695. S-75-33962

15696 MEDIUM-GRAINED OLIVINE-NORMATIVE(?) ST. 9A 12.83 g
MARE BASALT

INTRODUCTION: 15696 is a vesicular, medium- to fine-grained mare basalt (Fig. 1). It consists of about 30% white laths (plagioclase), 25-30% honey brown pyroxene, and the remainder is a dark mafic mineral or glass. Olivine is not readily apparent, but the vesicularity suggests an olivine-normative basalt. The sample is medium light-gray, angular to subangular, and coherent. The vesicles are smooth-walled, and up to 3 mm across. The sample has no zap pits. 15696 was collected as part of the rake sample from Station 9A, but was separated from the rake fines (15600) only in 1975. It has never been subdivided or allocated.

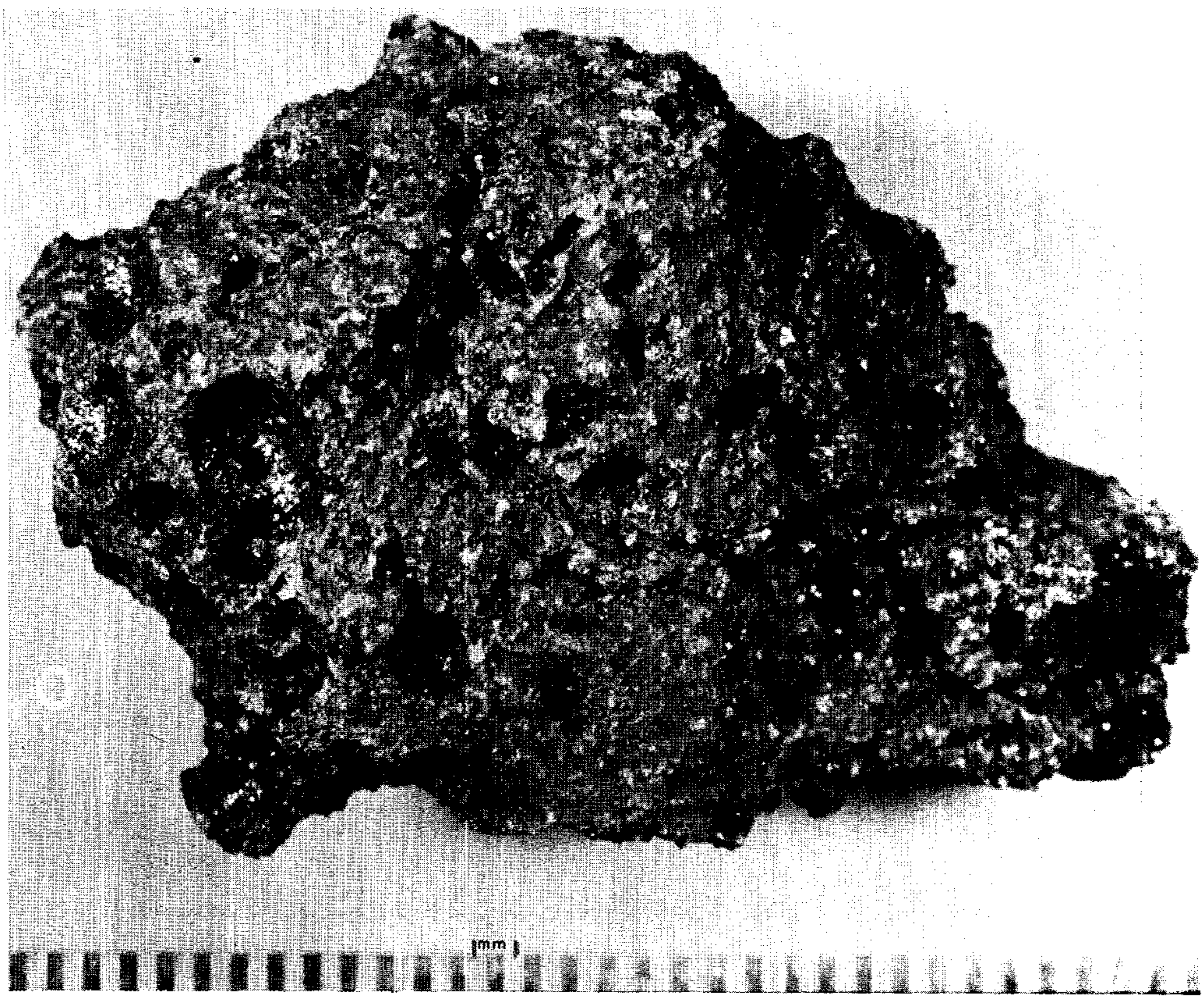


Figure 1. Sample 15696. S-75-33959

15697 FINE-GRAINED OLIVINE-NORMATIVE(?) MARE BASALT ST. 9A 4.13 g

INTRODUCTION: 15697 is a medium dark gray, coherent, vuggy basalt (Fig. 1). It is fine-grained but has clear yellow-green minerals up to about 1 mm long which may be olivine phenocrysts; most plagioclases and brown pyroxenes are much less than 1 mm across. the sample has apparently welded dust over much of its surface but zap pits were not observed. 15697 was collected as part of the rake sample from Station 9A, but was separated from the rake fines (15600) only in 1975. It has never been subdivided or allocated.

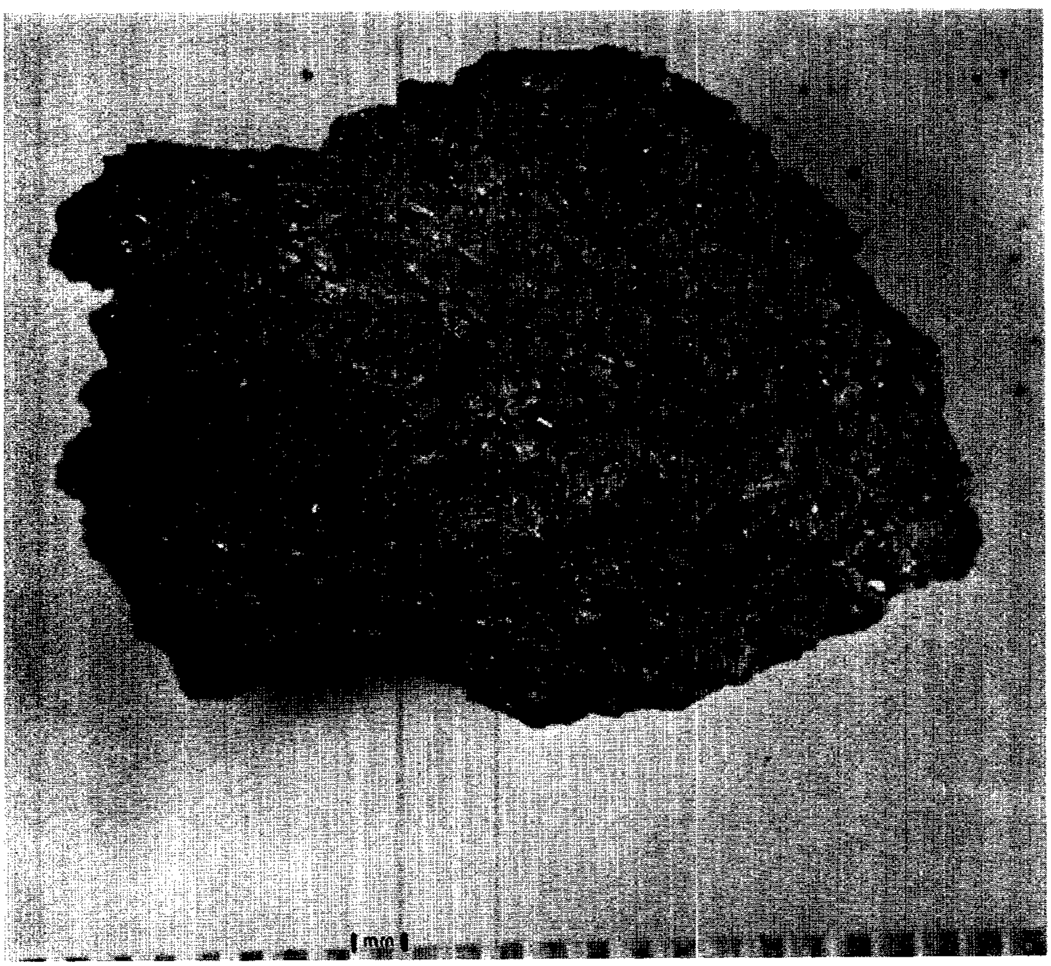


Figure 1. Sample 15697. S-75-33964

15698 GLASS BOMB ST. 9A 3.93 g

INTRODUCTION: 15698 is a rounded, dark gray, tough, smooth, glass object (Fig. 1). Small vugs (0.5 mm wide by 0.5 mm deep) on one patch are smooth-walled. Small amounts of soil adhere to the smooth glassy surface, but no zap pits are present. In one place an interior piece of white material is exposed, and the thinner glass in this area is a dark honey brown. Possibly the entire interior is a breccia, or the exposed material is a small clast in the glass. 15698 was collected as part of the rake sample from Station 9A, but was separated from the rake fines (15600) only in 1975. It has never been subdivided or allocated.

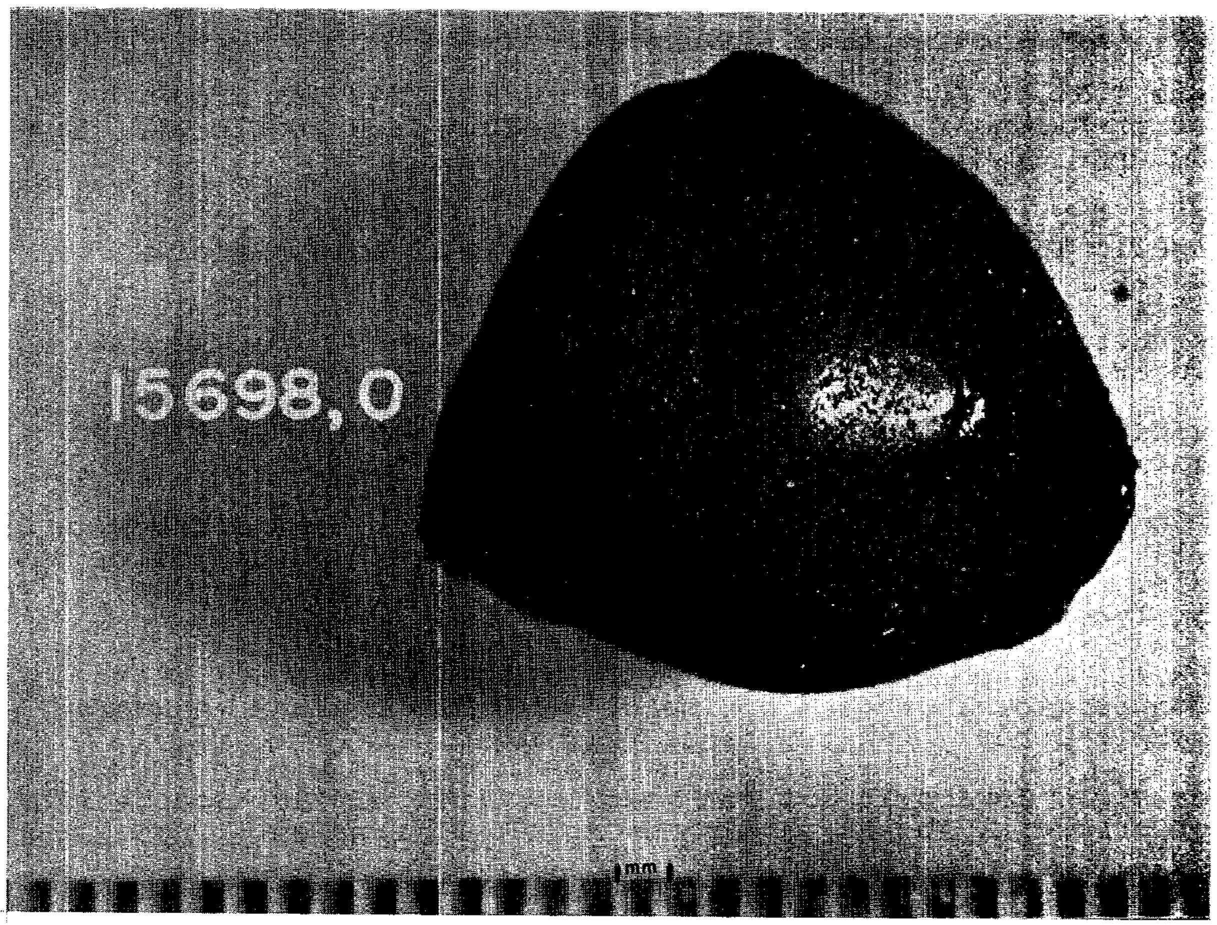


Figure 1. Sample 15698. S-75-33961

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NOTES

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