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

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.

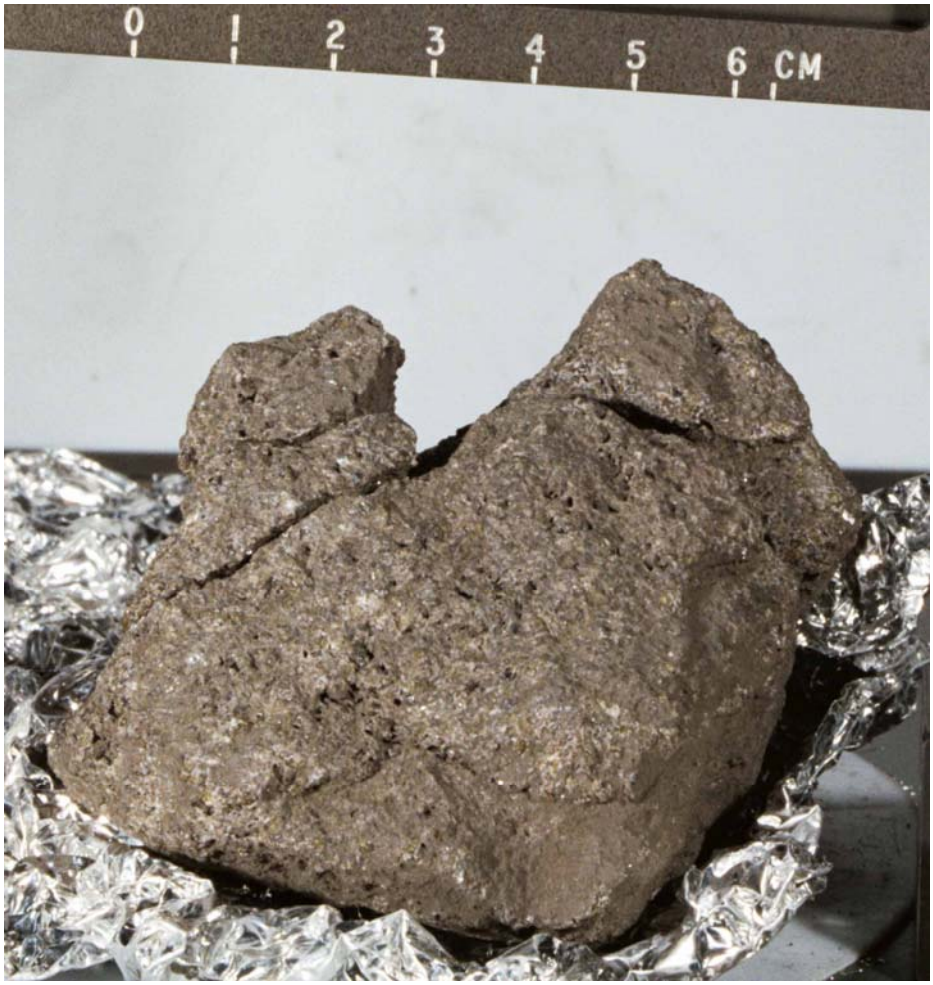

Fig. 1a.

Fig. 1b

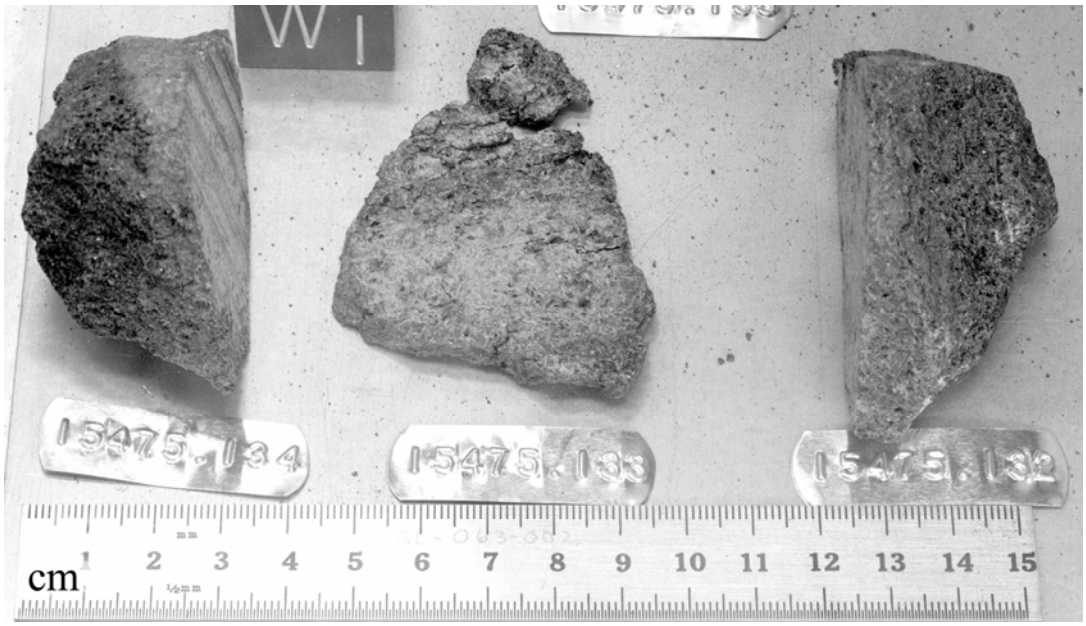

Fig. 1c

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

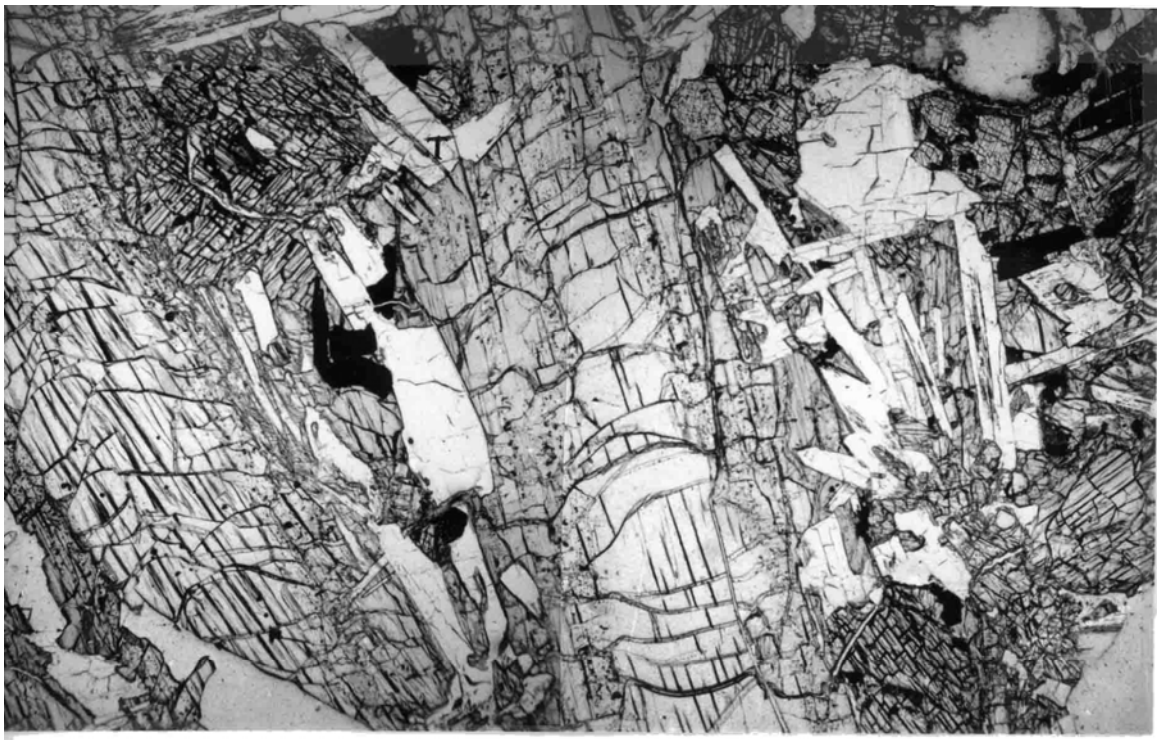

Fig. 2a

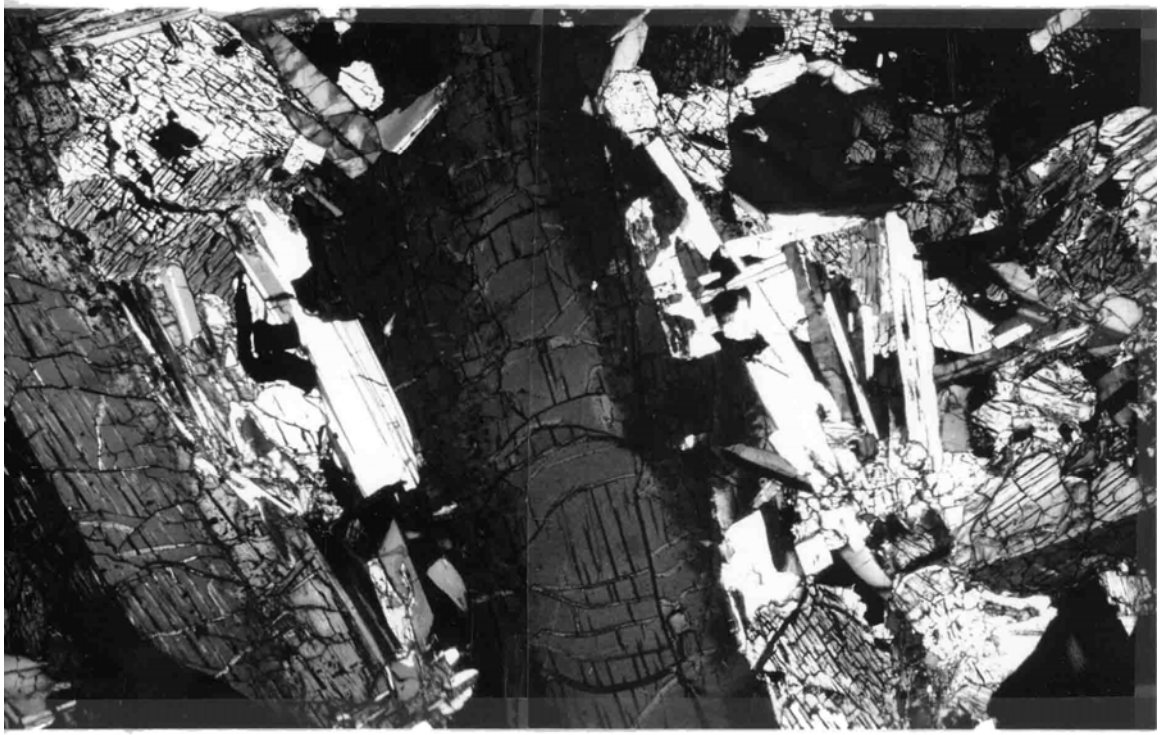

Fig. 2b

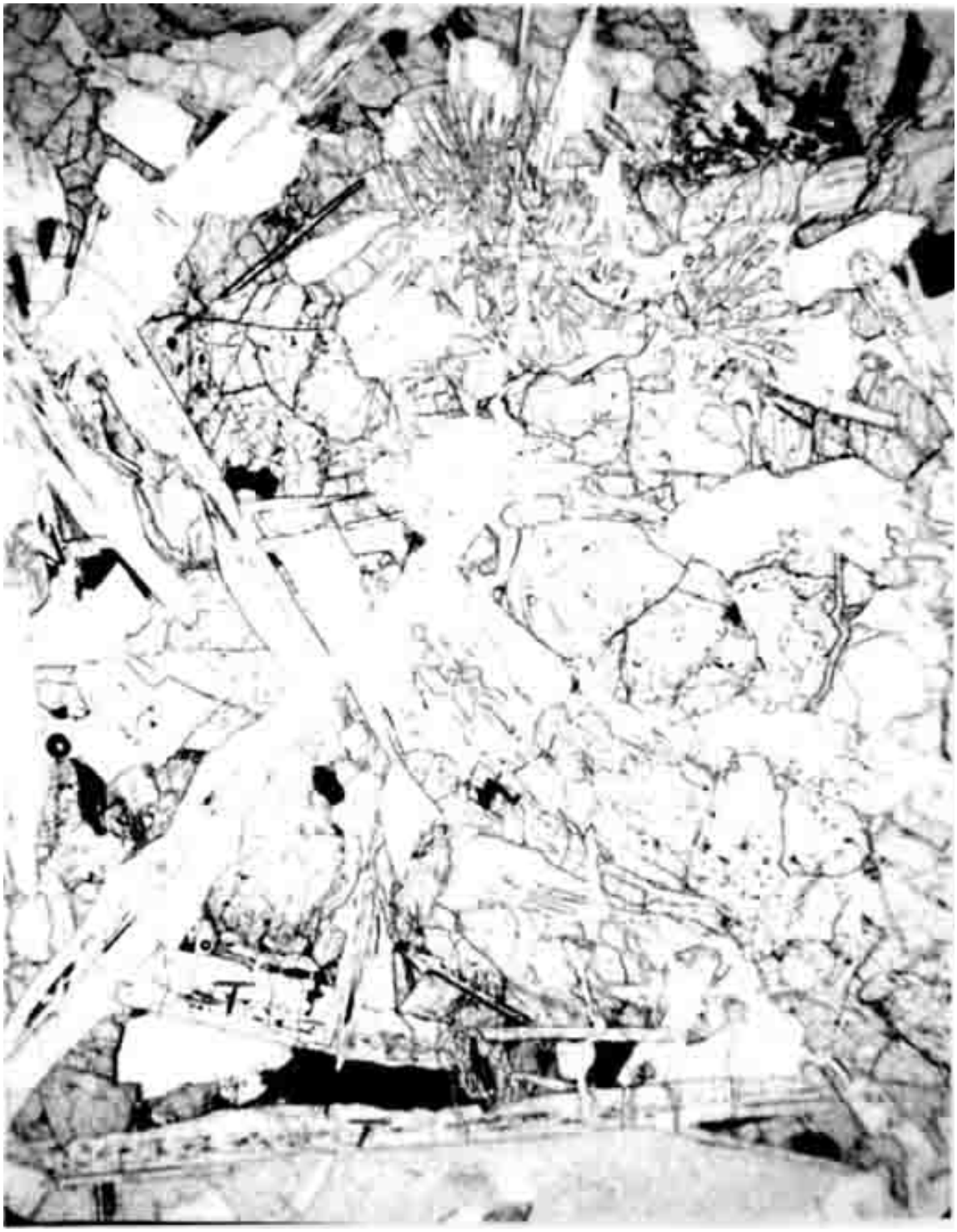

Fig. 2c

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 inclusion-rich 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 el. (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 + AI) 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.

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 phenocrysts 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.

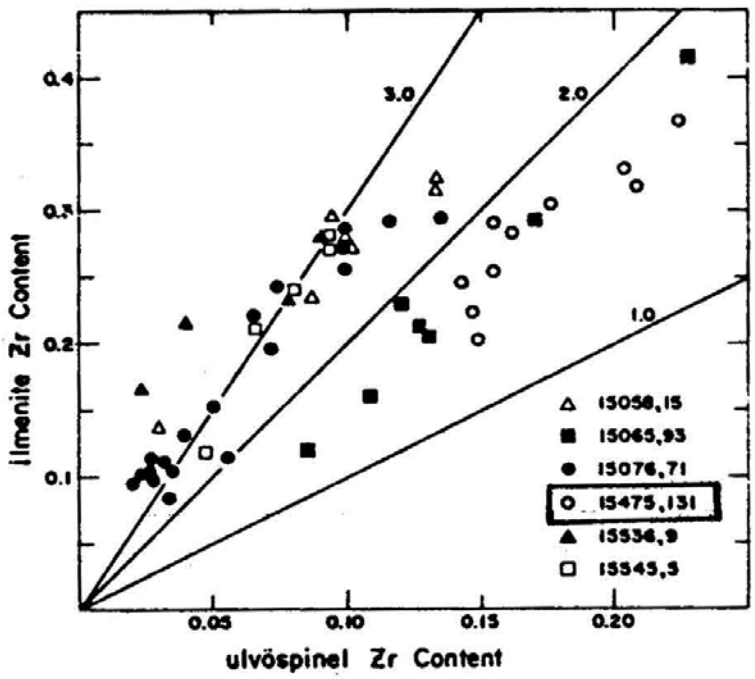

Figure 3. Zr partitioning between ilmenite and ulvospinel (L. Taylor and McCallister, 1972a).

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 TiO_2 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.

TALE 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, oolorimetry, 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); ?

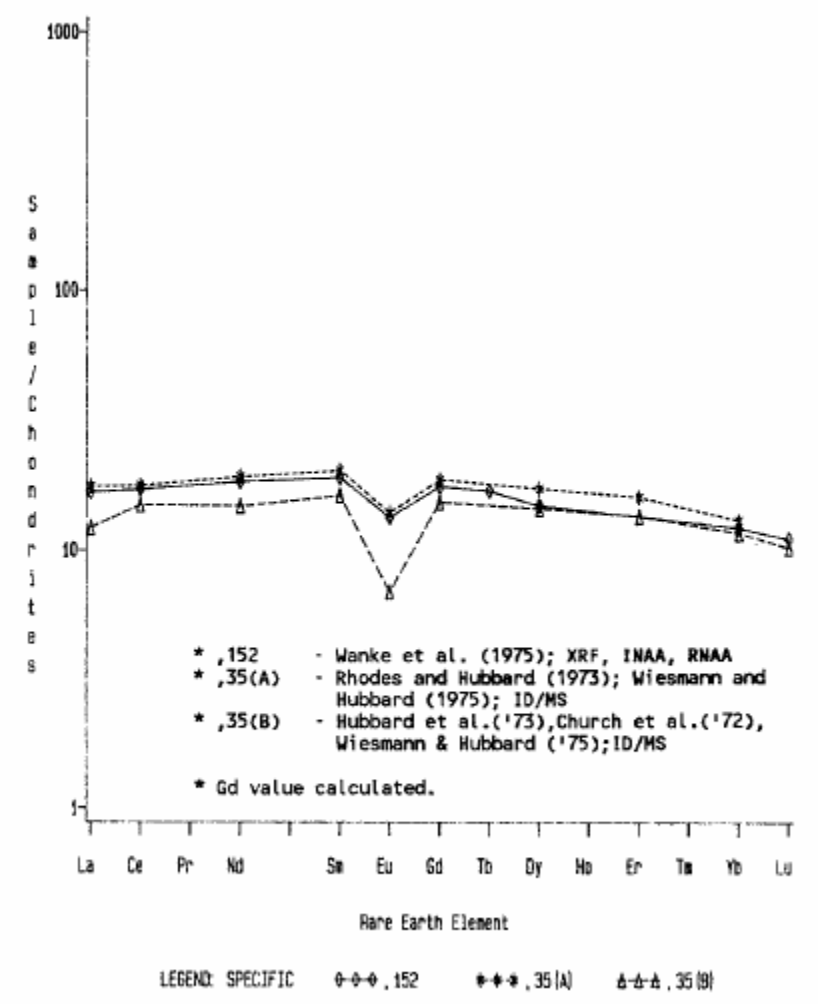

Figure 4. Rare earths in 15475.

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 100 g/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.