15386 KREEP BASALT ST. 7 7.5 g

INTRODUCTION: 15386 (Fig. 1) is a fragment of pristine (volcanic) basalt with KREEP rare-earth element abundances and patterns. It is coarser-grained than the otherwise-similar 15382. Like other KREEP basalts, it is older (~3.9 b.y.), more feldspathic, and more alkaline than Apollo 15 mare basalts. It is a tough sample, collected as part of the rake sample from the northeast rim of Spur Crater.

Figure 1. Macroscopic view of 15386,0 as it was in 1976. It has since been further subdivided. S-76-24072

PETROLOGY: 15386 is different from other volcanic rock samples at the Apollo 15 site except 15382, but is typical of many even smaller particles found in Apennine Front materials, mare plains regolith samples, and breccias 15405 and 15205. However, according to Steele et al. (1972a) it is not a common clast-type within Spur Crater breccias. It has a subophitic to intersertal texture (Fig. 2). Descriptions and mineral analyses been given by Steele et al. (1972a), Crawford et al. (1977), and Takeda et al. (1978, 1984). According to Steele et al. it contains 35% plagioclase laths, 50% interstitial pyroxene, 10% cristobalite, 3% plates of ilmenite, and minor sulfide, iron metal, and phosphates. There is no olivine. According to Simonds et al. (1975) 15386 contains about 50% plagioclase. Plagioclase and pyroxene crystallized simultaneously, and rapid cooling led to the small grain size, the lack of exsolutions, and the compositional range of the pyroxenes (below).

The pyroxenes have a wide range of Mg/Fe (Fig. 3). They have been most thoroughly investigated by Takeda et al. (1978). The cores are clear orthopyroxene, overgrown with rims of pigeonite which have numerous cracks. The pigeonite is untwinned, contains patches of augite, and is rimmed by augite. X-ray diffraction studies show that the core orthopyroxene shares (100) with pigeonite, and weak reflections show that augite shares a common (001) in the pigeonite. Takeda et al. (1978) found zoning trends similar to those found by Steele et al. (1972a) and tabulated some representative analyses. Core orthopyroxenes contain up to 4.1% Al_2O_3 and 1.28% Cr_2O_3.

The plagioclases are Na-rich and zoned, An_{85-70} (Steele et al., 1972a). Their Fe contents are lower than mare basalts and not on their trend (Fig. 4), but are similar to other KREEP basalts including 14310 (Fig. 5).

Takeda et al. (1984) studied the dark brown mesostasis, which is common as triangular interstices (~0.4 x 0.2 mm) and is characteristic of this basalt type, using microprobe, SEM, and ATEM techniques. Fe-rich pyroxene composes 48%, plagioclase 13%, silica 12%, silica/K-spar intergrowths 3%, ilmenite 11%, whitlockite 7%, troilite 2%, iron-metal 1%, and zirconolite 1% of the mesostasis. An unidentified Ca-rich phase is also present. A whitlockite analysis showed that most of the bulk rock Ce content can be accounted for by whitlockite.

The bulk composition of 15386 lies on the plagioclase-pyroxene cotectic in the Ol-Pl-Si system (McKay and Weill, 1976) and the source flow was probably a fractional crystallization product of a more primitive liquid. The composition, textures, and pristine chemistry (below) all suggest that 15386 is a volcanic flow, not an impact melt, but this interpretation is not universally held.

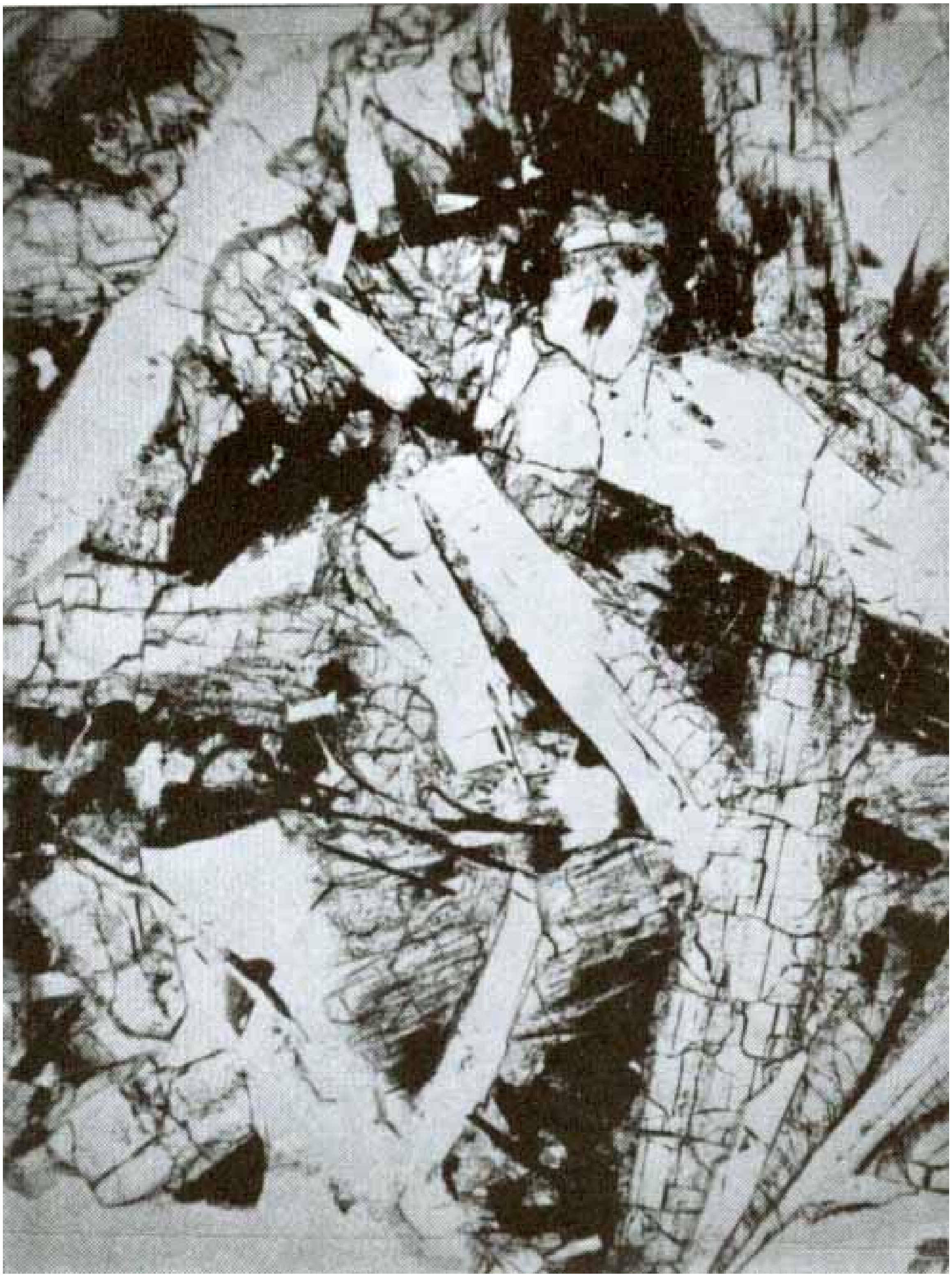

Figure 2. Transmitted light photograph of 15386,3. Width ~2 mm.

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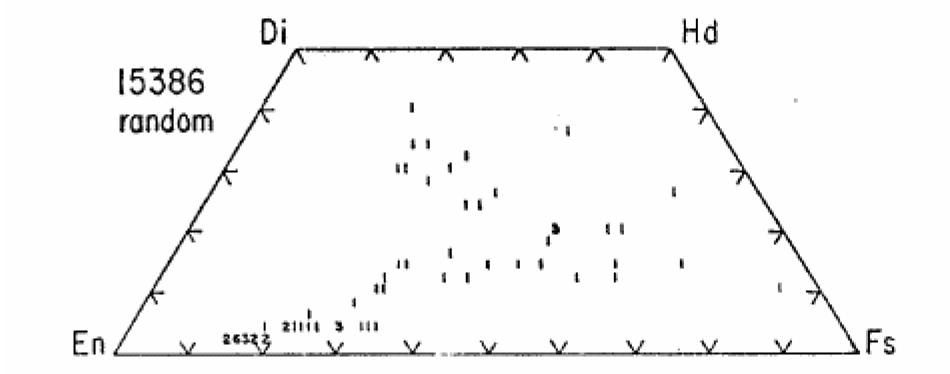


Figure 3. Compositions of pyroxenes in 15386 (Steele and Smith, 1972a).

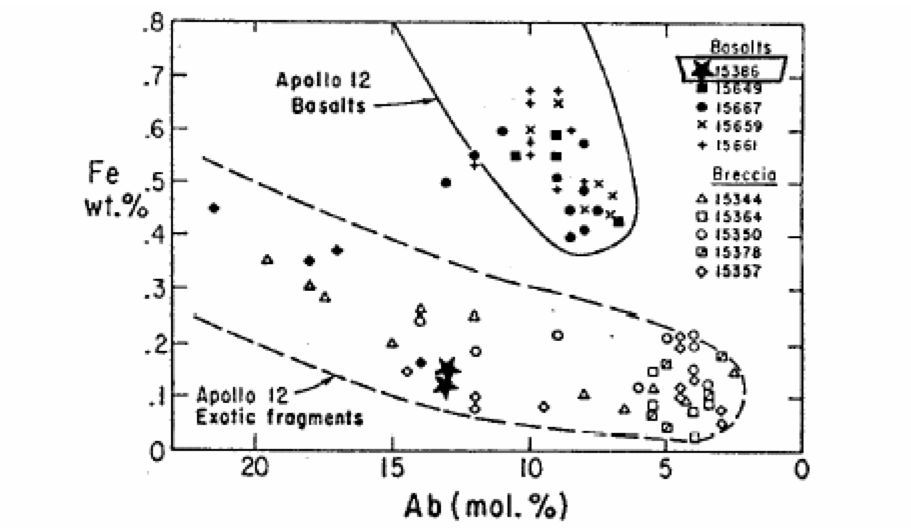


Figure 4. Compositions of plagioclases in 15386
(Steele and Smith, 1972a).

Crystallization experiments on 15386-iike or related compositions were conducted by Irving (1977a, b), Rutherford et al. (1980), and Dickinson and Hess (1982). Irving (1977a, b) used a synthetic composition similar to that determined by Rhodes and Hubbard (1973) (Table 1) to conduct experiments at pressures up to 5 Kb. The liquidus temperature increased from 1135 ± 10°C at 5 Kb. Although plagioclase (An_{75}) and low-Ca pyroxene coexist within 70°C of the liquidus at all pressures, there is no multiple saturation within the pressures of the crust or upper mantle, and the sample apparently evolved by the fractional crystallization of subcalcic pyroxene and calcic plagioclase. Rutherford et al. (1980) used a similar composition but slightly richer in FeO and Na_2O, and were especially interested in ilmenite saturation. In contrast with Irving (1977a, b), their liquidus temperature was almost unaffected by pressure (1 atmosphere, and 5 Kb), and the charge was saturated with both pyroxene and plagioclase within 30°C of the liquidus. Ilmenite saturation was attained with 5% TiO_2 in the liquid between 1087° and

1080°C at 1 atmosphere, and with 6% TiO_2 in the liquid between 1115 ° and 1090°C at 5 Kb. The data are used by Rutherford et al. (1980) to constrain the origin of both KREEP and of high-Ti mare basalt sources. Dickinson and Hess (1982) used a liquid composition produced by the crystallization of the Rutherford et al. (1980) starting material to investigate whitlockite saturation. 4.45% P_2O_5 was needed for saturation at 1200°C, decreasing to 2.44% at 1047°C.

CHEMISTRY: Chemical analyses are listed in Table 1 and the rare earths plotted in Figure 7. The data are generally consistent except that the analysis of Warren et al. (1978) has higher MgO and lower rare earths than does that of Rhodes and Hubbard (1973) and Hubbard et al. (1974). In Warren et al. (1978), the Ge units are wrongly listed as ppm instead of ppb, and in Warren and Wasson (1978) the Cd and In units are wrongly listed as ppm instead of ppb.

The low In indicates that 15386 is a volcanic rock, not a meteorite-contaminated impact melt, but the Ge and Au abundances are somewhat high and require special explanations (Warren et al., 1978). The rare earth element pattern is the common KREEP pattern.

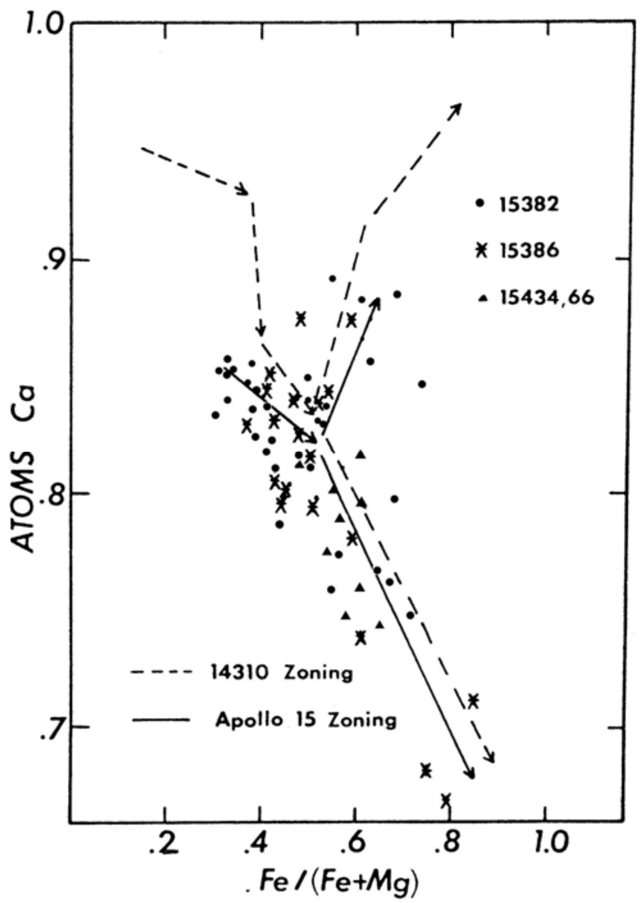


Figure 5. Compositions of plagioclases in 15386 (Crawford and Hollister, 1977).

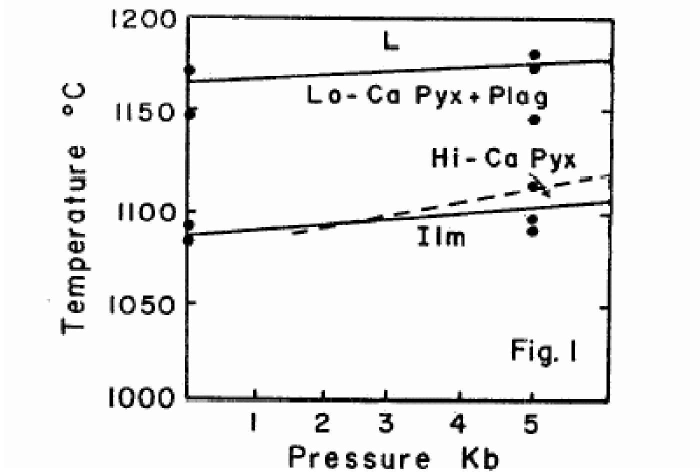


Figure 6. Crystallization experiment results for 15386
(Rutherford et al., 1980).

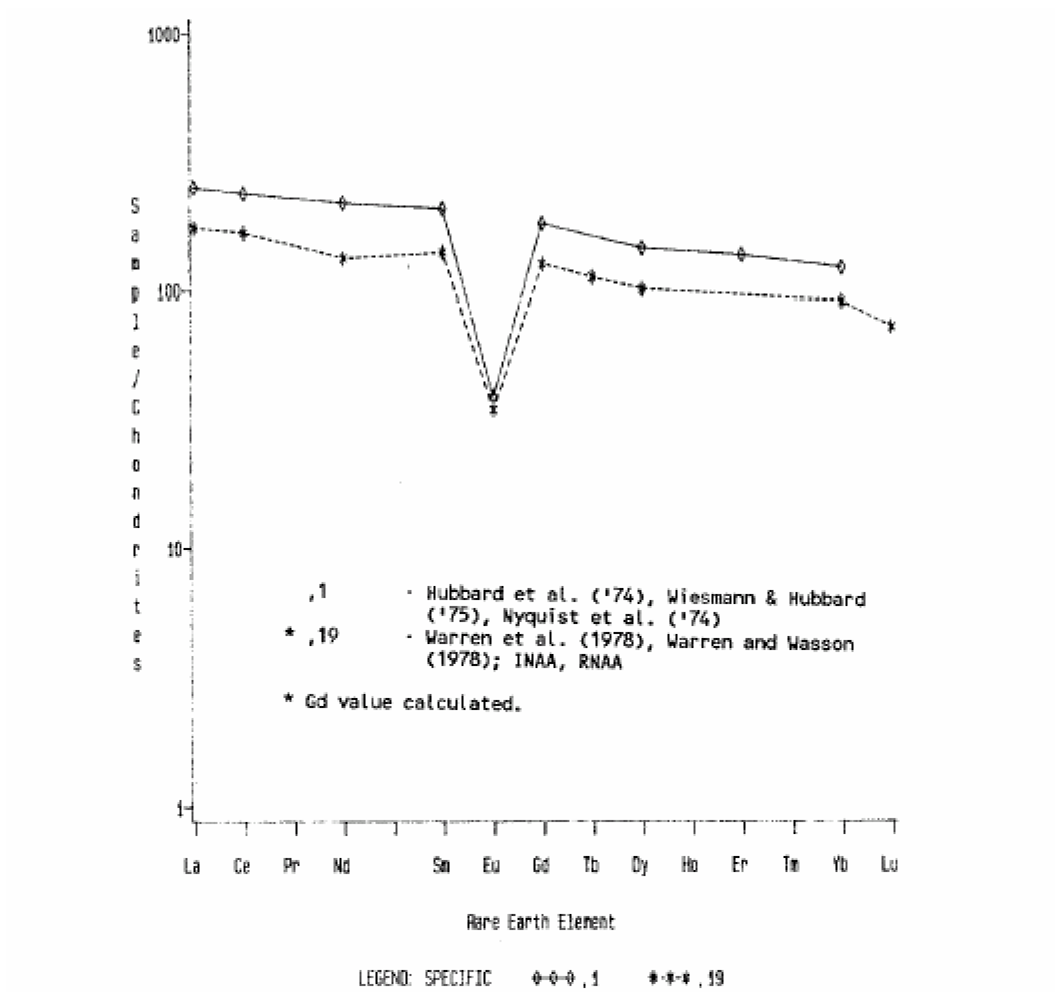


Figure 7. Rare earth element data for 15386.

TABLE 15386-1. Chemical analyses

		,19	,1	,1	,0	,25,27	,35	?
Wt %	SiO2		50.83					
	TiO2	1.9	2.23					
	Al2O3	15.3	14.77					
	FeO	10.2	10.55					
	MgO	10.5	8.17					
	CaO	9.5	9.71					
	Na2O	0.811	0.73					
	K2O	0.50	0.67	0.685	0.59			
	P2O5		0.70					
(ppm)	Sc	22.0						
	V	62						
	Cr	2430		2124				
	Mn	1150	1240					
	Co	23						
	Ni	12.5						<30
	Rb	14		18.46				
	Sr			187.4				
	Y							
	Zr	970						
	Nb							
	Hf	21					26.228	
	Ba	650		837				
	Th	10.0			11.80			
	U	2.8			3.30			
	Pb							
	La	58		83.5				
	Ce	147		211				
	Pr							
	Nd	80		131		129.6		
	Sm	25.5		37.5		36.0		
	Eu	2.4		2.72				
	Gd			45.4				
	Tb	5.3						
	Dy	32		46.3				
	Ho							
	Er			27.3				
	Tm							
	Yb	18.2		24.4				
	Lu	2.48					3.193	
	Li			27.2				
	Be							
	B							
	C							
	N							
	S		900					
	F							
	Cl							
	Br							
	Cu							
	Zn	3.5						
(ppb)	I							
	At							
	Ga	6200						
	Ge	61(a)						
	As							
	Se							
	Mo							
	Tc							
	Ru							
	Rh							
	Pd							
	Ag							
	Cd	10						
	In	1.8						
	Sn							
	Sb							
	Te							
	Cs	800						
	Ta	2400						
	W							
	Re							
	Os							
	Ir	0.061						
	Pt							
	Au	0.22(a)						
	Hg							
	Tl							
	Bi							
		(1)	(2)	(3)	(4)	(5)	(6)	(7)

References and methods:

(1) Warren et al. (1978), Warren and Wasson (1978); INAA, RNAA.
(2) Rhodes and Hubbard (1973); XRF
(3) Hubbard et al. (1974), Wiesmann and Hubbard (1975), Nyquist et al. (1974); isotope dilution, mass spec.
(4) O'Kelley et al. (1976); gamma ray spec.
(5) Carlson and Lugmair (1979a, b); isotope dilution, mass spec.
(6) Unruh and Tatsumoto (1984); isotope dilution, mass spec.
(7) Blanchard, unpublished; INAA

Notes:

(a) authors believe abundance high.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Nyquist et al. (1974) reported Rb and Sr whole rock isotopic data and followed this with a Rb-Sr internal isochron (Nyquist et al., 1975) (Table 2). The isochron, using the whole rock data, plagioclase separate, and mesostasis plus pyroxene separate gives an age of 3.94 ± 0.01 b.y. (= 1.39 x 10^{-11} yr^{-1}) or 3.86 b.y. (= 1.42 x 10^{-11} yr^{-1}), with initial $^{87}Sr/^{86}Sr$ = 0.70038 ± 3 (Fig. 8).

15386 is resolved from 15434, a particle of KREEP basalt separated from soil, in initial Sr isotopes, but not in age (Nyquist et al., 1975). The age is the same as 15382. The data indicate some precursor event represented more or less by the model ages, and a second melting event at the crystallization age.

TABLE 15386-2. Rb-Sr Isotopic Data (Nyquist et al., 1975)

Split	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
WR	18.46	187.4	0.285 ± 2	0.71640 ± 7
Plag	1.25	323.8	0.0112 ± 1	0.70102 ± 10
Mes + Px	43.04	129.8	0.959 ± 7	0.75441 ± 14

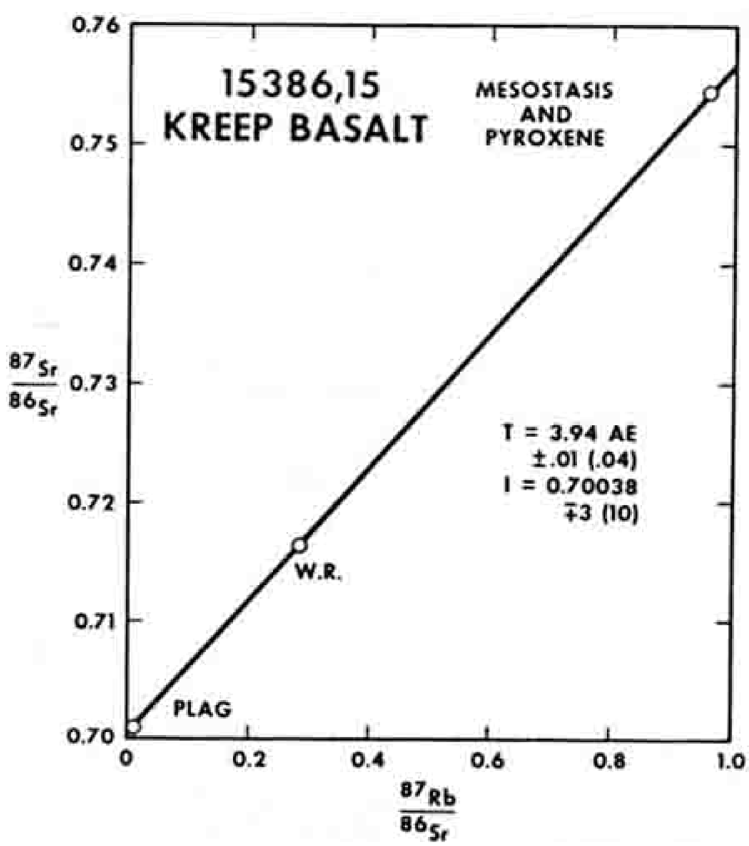
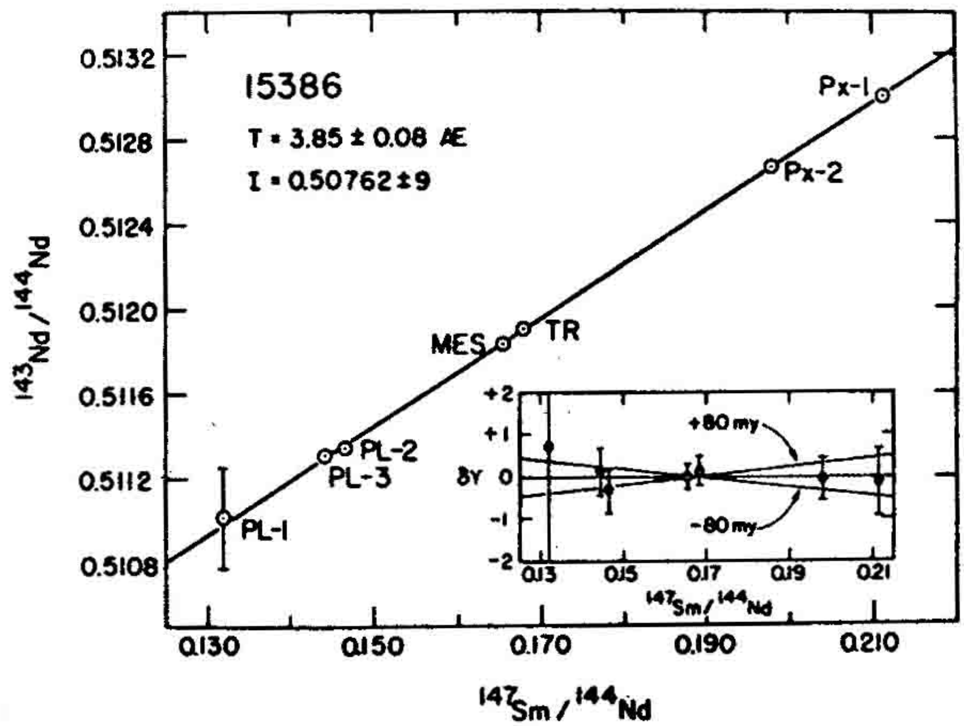


Figure 8. Rb-Sr isochron (Nyquist et al., 1975).

Carlson and Lugmair (1979a) reported whole-rock and mineral separate Sm and Nd isotopic data for 15386. The isochron (crystallization) age of 3.85 ± 0.08 b.y. (Fig. 9) is indistinguishable from the Rb-Sr isochron age (a preliminary report had 3.87 ± 0.12 b.y., Carlson and Lugmair, 1979b). The subchondritic initial $^{143}Nd/^{144}Nd$ requires that the KREEP rare earth pattern was established much earlier -- 4.36 b.y., similar to other KREEP model ages.



Sm-Nd evolution diagram for KREEP basalt 15386. The slope of the best fit line through the data points corresponds to an age of 3.85 ± 0.08 AE ($\lambda = 6.54 \times 10^{-12}$ yr^{-1}) in good agreement with that indicated by the Rb-Sr system

Figure 9. Sm-Nd isochron
(Carlson and Lugmair, 1979a).

Unruh and Tatsumoto (1983) reported Lu and Hf isotopic data for 15386 and other KREEP samples; unlike Sm-Nd data, there is a large range in the isotopic ratios for different KREEP samples. The data are discussed in terms of mare basalt sources and KREEP genesis without specific reference to 15386.

TABLE 15386-3. Rb-Sr Model Ages (b.y., ± 0.04)

	T_{BABI}	T_{LUNI}
λ: 1.39×10^{-11} yr^{-1}	4.25	4.28
λ: 1.42×10^{-11} yr^{-1}	4.15	4.18

EXPOSURE: O'Kelley et al. (1976) reported ^{26}Al disintegration count data. The ^{26}Al is saturated, indicating a surface exposure of at least one or two million years.

PROCESSING AND SUBDIVISIONS: Originally splits ,1 and ,2 were chipped off one end for allocations (Fig. 10). ,2 was made into thin sections, and all thin sections are from ,2. Subsequent allocations were made by further chipping of ,0, which is now 3.6 g.

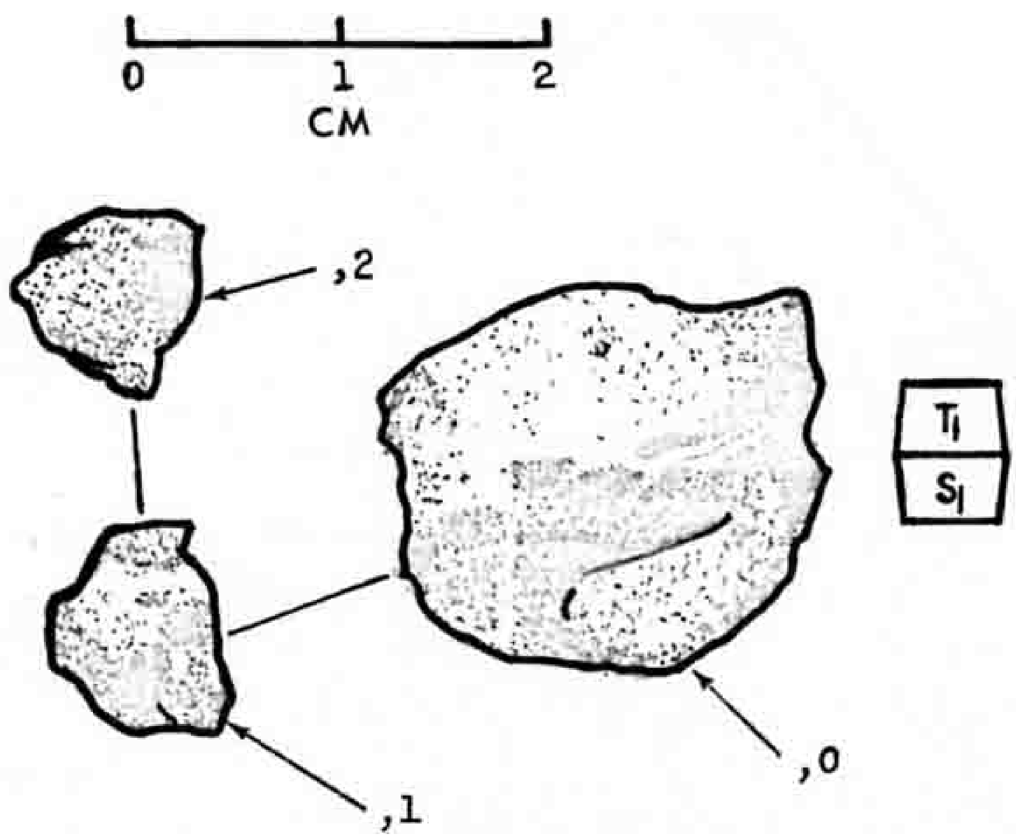


Figure 10. Initial processing of 15386.