15382 KREEP BASALT ST. 7 3.2 g

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

Figure 1. Pre-split view of 15382. Scale in centimeters. S-72-32747

PETROLOGY: 15382 is different from other volcanic rock samples at the Apollo 15 site except 15386, but it is typical of many even-smaller-particles found in Apennine Front materials, mare plains regolith samples, and breccias 15405 and 15205. It has a clast-free, basaltic texture (Simonds et al., 1975). It has been described, and had mineral and bulk (defocussed beam microprobe) analyses reported by Dowty et al. (1973b, 1976), Crawford and Hollister (1977), and Hollister and Crawford (1977). Microprobe mineral and glass analyses were also reported by Hlava et al. (1973), and opaque mineral data were presented and discussed by Nehru et al. (1973, 1974).

According to Dowty et al. (1973b, 1976), 15382 consists of 4% silica phase, 49% plagioclase, 34% pyroxene, 5% opaque minerals, and 8% miscellaneous (mainly mesostasis). Crawford and Hollister (1977) found only 32.9% plagioclase and 41.9% pyroxene. The mesostasis areas contain cristobalite, ilmenite, glass, phosphates

(whitlockite and apatite), tranquillityite, armalcolite, and baddeleyite. Olivine is not present. The texture is intergranular to subophitic with plagioclase laths ~0.2 x 0.8 mm, often curved in the manner apparently confined to this type of basalt, and forming an interlocking mass (Fig. 2). The sample is finer-grained than 15386, and appears to have crystallized by single-stage, rapid cooling.

Figure 2. Portion of thin section 15382,6.
Transmitted light. Width about 2.7 mm. S-79-27741

Pyroxene compositions form a smooth trend from high-Mg, low Ca cores to pigeonite rims, with some subcalcic augite (<10%) (Fig. 3). The cores are orthopyroxene with up to 4% Al_2O_3. The orthopyroxene to pigeonite transition is sharp, and some cores are euhedral (Crawford and Hollister, 1977). Plagioclases are generally zoned from An_{86} to An_{80}, although Dowty et al. (1976) reported that a few plagioclase cores are as calcic as An_{95} (Fig. 4). FeO increases from 0.25 in the center to 0.5% at the edge (Dowty et al., 1976) (see also Fig. 5). Glass inclusions in the rims of plagioclase are unique (Crawford and Hollister, 1977).

Nehru et al. (1973, 1974) found that chromite is generally absent and that the dominant opaque phases are ulvospinel and ilmenite, dominantly in mesostasis areas. A few chromite cores do occur in ulvospinel, which is high in Cr and low in Al. Ilmenite has low MgO (1-3%). The rare metal phase contains less than 1% Ni. Engelhardt (1979) tabulated ilmenite paragenesis.

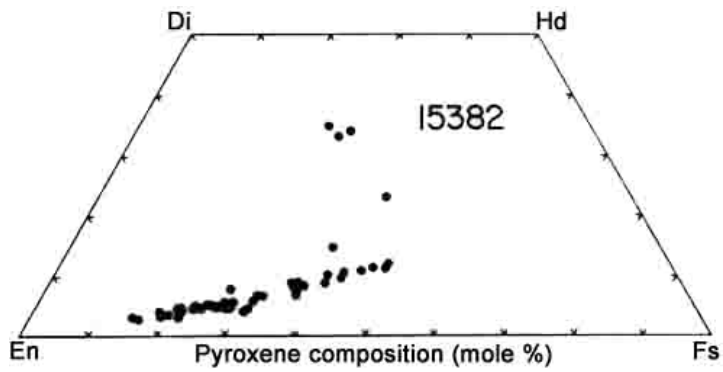

Figure 3. Compositions of pyroxenes in 15382 (Dowty et al., 1976).

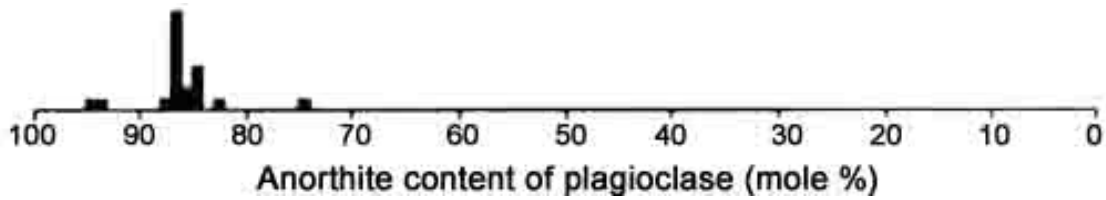

Figure 4. Compositions of plagioclases in 15382 (Dowty et al., 1976).

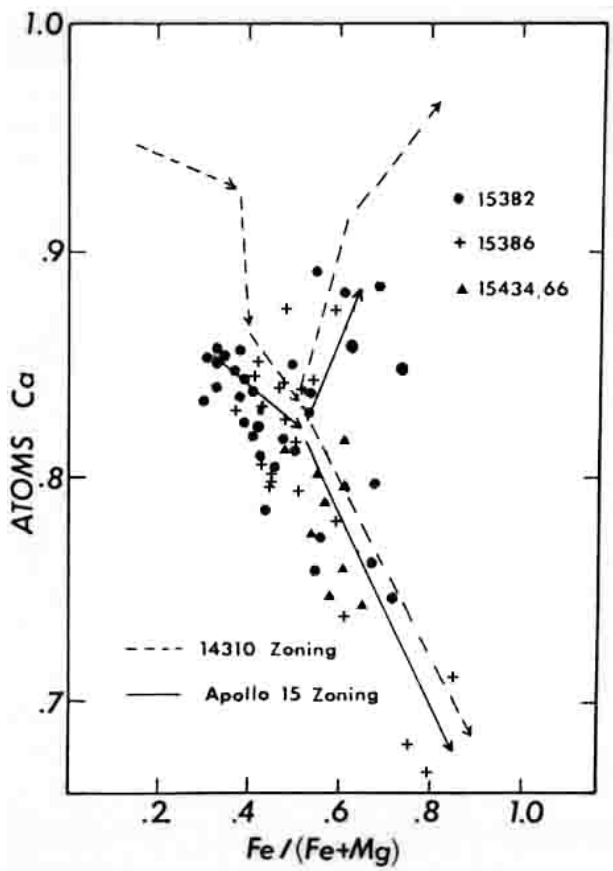

Figure 5. Compositions of plagioclases in 15382 (Crawford and Hollister, 1977).

Crawford and Hollister (1977) and Hollister and Crawford (1977) both described and discussed silicate liquid immiscibility in 15382. They suggested that an Fe-rich melt separated early in crystallization, after formation of core orthopyroxenes and plagioclases, i.e., after only about 20% crystallization. To reach the proposed field of immiscibility plagioclase must have crystallized alone early, a process inconsistent with the textural and compositional evidence for a cotectic melt. Hence, Hollister and Crawford (1977) propose a disequilibrium process. They relate the immiscible Fe-rich melt to mare basalts. Because these authors believed that rock 14310, a KREEP basalt, is volcanic, they suggested that 15382 experienced metal loss in an earlier stage of fractionation to reduce the siderophile content, and that the magma for 15382 rose more slowly to the surface such that evidence for high pressure minerals (as they claimed for 14310) was erased. This view is not widely held; rather, the low siderophiles are generally considered indigenous and the high siderophiles in 14310 considered to be meteoritic contamination.

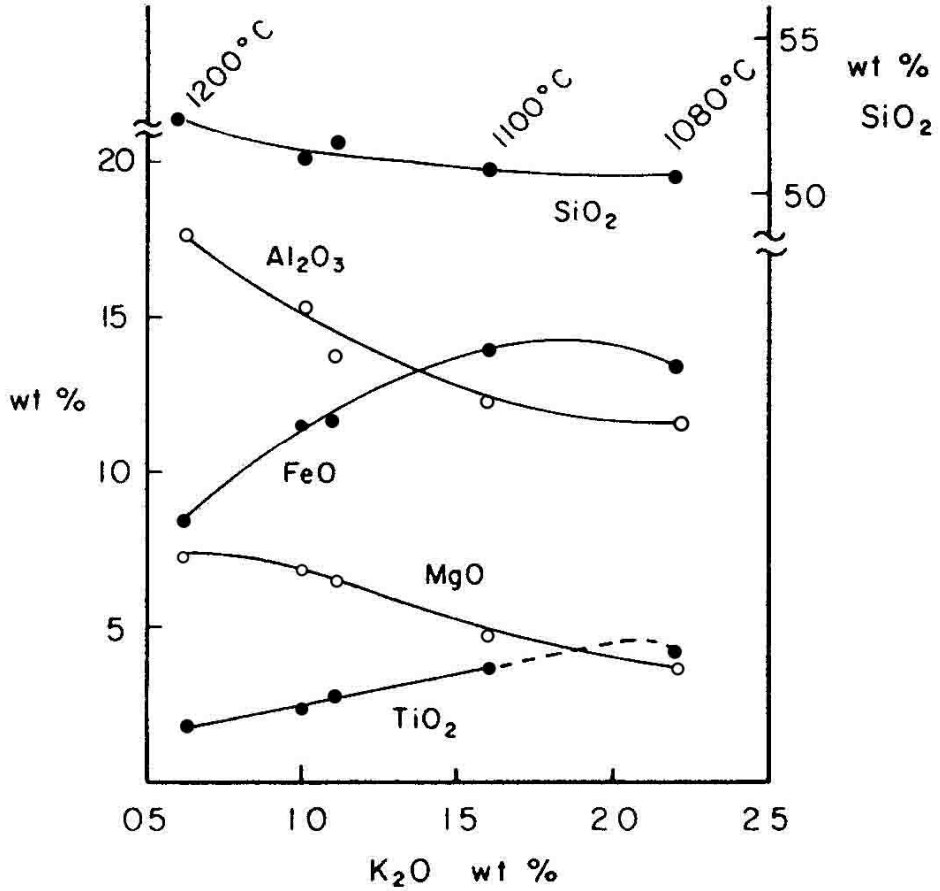

Figure 6. Liquid line of descent for 15382, experimental data (Hess et al., 1978). All liquids below 1180˚C coexist with low-Ca px and plag. Ilmenite crystallizes between 1100˚C and 1080C. Immiscible liquids occur at 1035˚C.

TABLE 15382-1. Chemical analyses

		,9	,0	,14	,15	a	b	,9	,14	,14b
Wt %	SiO2									
	TiO2	2.17		2.2						
	Al2O3	14.9		16.4						
	FeO	9.2		10.0						
	MgO	7.4		9.8						
	CaO	7.1		10.4				7.1		
	Na2O	0.85		0.81						
	K2O	0.632	0.59	0.53				0.38	0.550	
	P2O5									
(ppm)	Sc			19.0						
	V			60						
	Cr			2120						
	Mn			1110						
	Co			17						
	Ni			28	18					
	Rb	16.1			16.0				14.1	
	Sr	195							183	
	Y									
	Zr	1170		966						
	Nb									
	Hf	32.7		27						
	Ba	793		610						
	Th		10.5	1.0a						
	U	3.72	3.1		3.3					
	Pb									5.94
	La	79.5		68.1						
	Ce	212		218						
	Pr									
	Nd	127				111.8	107.2			
	Sm	35.2		29.7		31.06	29.84			
	Eu	2.77		2.72						
	Gd	42.9								
	Tb			6.2						
	Dy	45.7		40						
	Ho									
	Er	28.1								
	Tm									
	Yb	24.0		19.2						
	Lu	3.43		2.70						
	Li									
	Be									
	B									
	C									
	N									
	S									
	F									
	Cl									
	Br				0.142					
	Cu									
	Zn				2.6					
(ppb)	I									
	At									
	Ga									
	Ge				47.1					
	As									
	Se				72					
	Mo									
	Tc									
	Ru									
	Rh									
	Pd				<0.6					
	Ag				0.44					
	Cd				86.6					
	In				2.66					
	Sn									
	Sb				0.17					
	Te				1.0					
	Cs				725					
	Ta			3100						
	W									
	Re				0.0089					
	Os				0.018					
	Ir				0.0132					
	Pt									
	Au				0.0033					
	Hg									
	Tl				3.2					
	Bi				0.29					
		(1)	(2)	(3)	(4)	(5)	(5)	(6)	(7)	(8)

References for Table 15382-1

References and methods:

(1) Hubbard et al. (1973), Nyquist et al. (1972, 1973), Church et al. (1972); isotope dilution mass spec, colorimetry, AA.
(2) Schonfeld et al. (1972), O'Kelley et al. (1976); gamma ray spec.
(3) Murali et al. (1977); INAA.
(4) Gros et al. (1976); RNAA.
(5) Lugmair and Carlson (1978); isotope dilution, mass spec.
(6) Stettler et al. (1973); Ar, irradiation.
(7) Papanastassiou and Wasserburg (1976); isotope dilution, mass spec.
(8) Papanastassiou and Waserburg (1977), Tera and Wasserburg (1976); isotope dilution, mass spec., abundance calculated by summing 208, 207, and 206 proportions given.

Notes:

(a) appears to be typographical error.
(b) erroneously listed as ,114 by Tera and Wasserburg (1976).

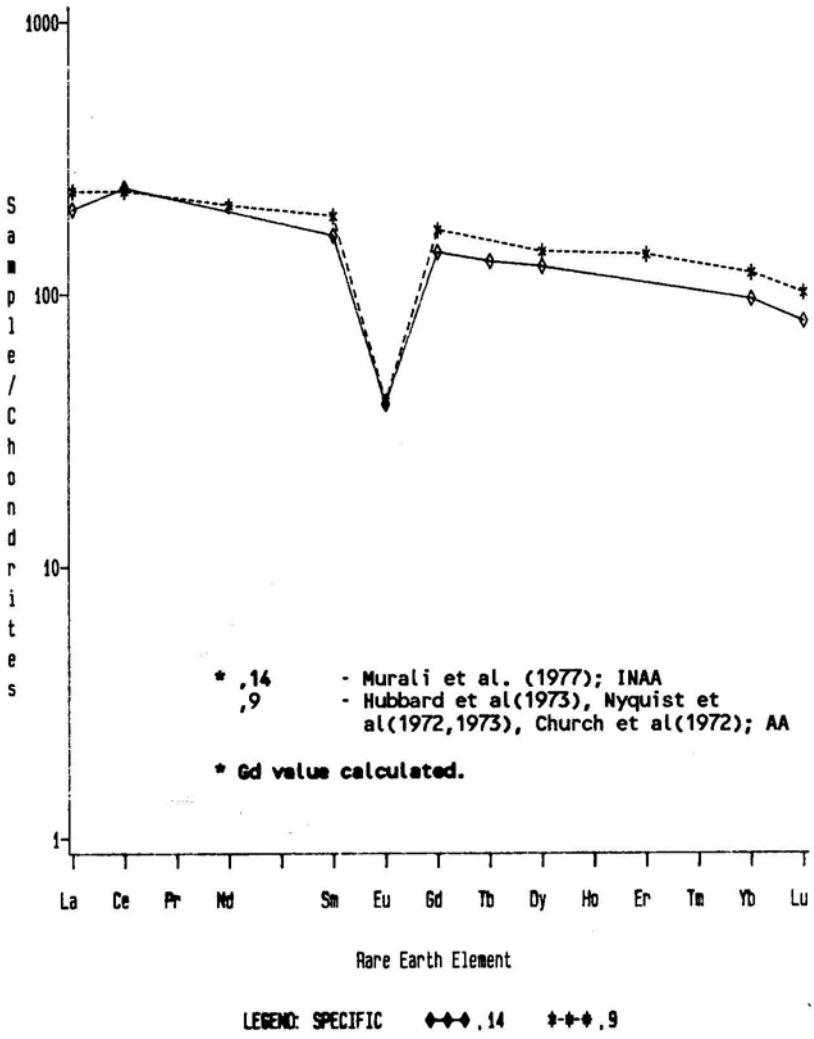

Figure 7. Rare earth element data for 15382.

Hess et al. (1978) conducted equilibrium and controlled cooling experiments on the composition for 15382 determined by Dowty et al. (1976). This analysis is more aluminous than the more conventional analyses (Table 1), but preliminary experiments on that composition yielded similar results. The liquid line of descent is shown as Figure 6; the data is tabulated in Hess et al. (1978). The basalt is saturated at the liquidus (1180-1185°C) with both plagioclase (An_{86}) and pyroxene ($En_{76}Wo_5$). The pyroxene is more evolved (Al-poorer, Ca-richer, Mg-poorer) than observed in the basalt itself. The high-Al pyroxene and the An_{95} grain of Dowty et al. (1976) may then be relics of an earlier magma stage. Ilmenite crystallizes between 1100 and 1080°C, and silicate liquid immiscibility takes place at 1035ºC. The liquid line of descent is one of iron enrichment and not silica enrichment, toward a ferrobasaltic composition, and not toward the silica-pyroxene-plagioclase eutectic. A granitic to monzodiorite composition is produced by silicate liquid immiscibility.

CHEMISTRY: Chemical analyses are listed in Table 1, and rare earths are plotted in Figure 7. Two microprobe defocussed-beam analyses are listed separately in Table 2. The analyses are in general agreement, and distinguish 15382 from mare basalts, regolith breccias, and anorthosites. The major element chemistry is that of a cotectic (plag + low-Ca px) basalt. The incompatible abundances and patterns are those of KREEP. Gros et al. (1976) note that volcanic KREEP, as shown by 15386, does not have intrinsically high siderophiles such as had been claimed by some authors for KREEP sample 14310.

TABLE 15382-2. Microprobe defocussed beam analyses

	,7[a]	,6,7,17[b]
SiO2	52.4	52.53
TiO2	1.78	1.29
Al2O3	17.8	18.44
Cr2O3	0.21	----
FeO	8.6	8.27
MnO	0.10	----
MgO	7.1	7.01
CaO	9.9	10.30
Na2O	0.96	----
K2O	0.57	0.46
P2O5	0.55	----
	99.97	98.3

(a) Dowty et al. (1973b, 1976)
(b) Hollister and Crawford (1977)

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Rb-Sr isotopic data for whole-rock samples was reported by Nyquist et al. (1972, 1973) and Papanastassiou and Wasserburg (1976a, b) (Table 3), without specific comment. Papanastassiou and Wasserburg (1976b) determined a Rb-Sr isochron which yielded an age of 3.90 ± 0.02 b.y. with an initial $^{87}Sr/^{86}Sr$ of 0.700241; the data on which this is based has not been published. This age and initial Sr (corrected for interlaboratory bias) are identical with those determined for 15386 by Nyquist et al. (1975).

TABLE 15382-3. Rb-Sr whole rock isotopic data

Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Rb$	T_{BABI}	Reference
16.1	195	0.240	0.71383±6	4.29	Nyquist et al. (1973)
14.1	183	0.2228	0.71266±6	4.29	Papanastassiou and Wasserburg (1976)

$\lambda = 1.39 \times 10^{-11}$ yr-1

Lugmair et al. (1976) discussed results for Sm-Nd whole rock data for 15386,14,9002, showing the evolution of ^{143}Nd (C) against time. The data define an intercept with a lunar "chondritic" evolution (represented by rock 15555, which is no longer preferred for such a purpose) at 4.72 ± 0.1 b.y., which requires a two-stage evolution. The data conflict with models relating KREEP to the source materials of mare basalts. Lugmair and Marti (1975) and Lugmair and Carlson (1978) reported whole rock Sm-Nd isotopic data for two small aliquots of ,14,9002 (Table 4). It is not stated whether the data discussed in Lugmair et al. (1976) is any or all of the data subsequently reported. The data are very similar to all other }CREEP samples (e.g., Figure 8) in both Sm/Nd and isotopic ratios, which indicate a moonwide process to make KREEP at 4.36 ± 0.06 b.y. (T_{ICE} ages). The specific T_{ICE} ages for 15382 are given in Table 4. The data in this case are referred not to 15555 but to the meteorite Juvinas, yielding T_{ICE} (at which the intercept with chondritic evolution defined by Juvinas occurs). In the T_{JUV} age, the initial $^{143}Nd/^{144}Nd$ of Juvinas is used in a fashion similar to BABI in the Rb-Sr system, and this model age has less physical reality than T_{ICE}.

Stettler et al. (1973) and Turner (1973) reported similar ^{40}Ar-^{39}Ar plateau ages of 3.90 ± 0.05 b.y. and 3.91 ± 0.04 b.y. respectively (Fig. 9), based on intermediate temperature plateaus. Turner et al. (1973) reported a 26% Ar loss, which does not allow a well-defined K-Ar age.

TABLE 15382-4. Sm-Nd whole rock isotopic data
(Lugmair and Carlson, 1978)

	Sm ppm	Nd ppm	$^{147}Sm/^{144}Nd$	$^{147}Nd/^{144}Nd$	T_{ICE}	$T_{JU}V$
a	31.06	111.8	.1679	.511889±21	4.38±.14	4.59±.02
b	29.84	107.2	.1683	.511894±16	4.42±.11	4.58±.02

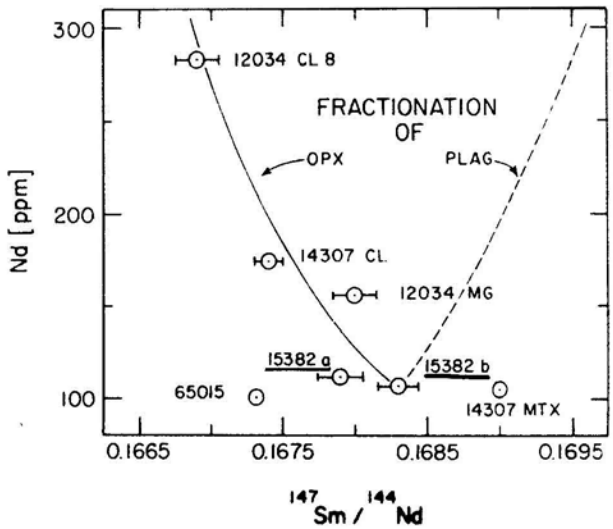

Figure 8. Sm-Nd isotopic data for whole rock samples
(Lugmair and Carlson, 1978)

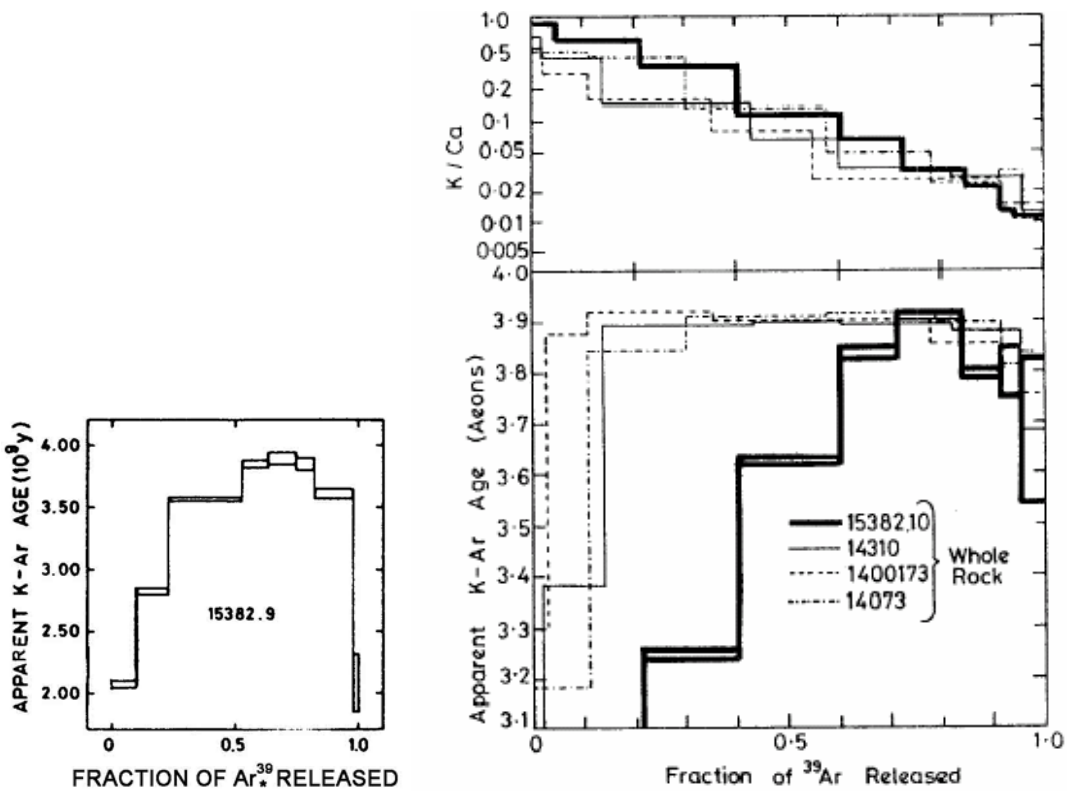

Fig. 9a Fig. 9b

Figure 9. ^{40}Ar-^{39}Ar release diagrams for 15382 whole rock samples.
a) Stettler et al., 1973. b) Turner et al., 1973.

Tera and Wasserburg (1976) reported whole rock Pb isotopic data without comment, (,14, erroneously listed as ,114), and Papanastassiou and Wasserburg (1976) reported the same data plus data for plagioclase. The data are nearly concordant at 4.38 b.y. Assuming the crystallization age of 3.90 + 0.02 b.y. also gives an upper intersection of about 4.4 b.y. The plagioclase is highly radiogenic and has $^{207}Pb/^{206}Pb$ nearly identical to that of the total rock because quintessence (mesostasis) dominates both samples.

Haines and Weiss (1978) reported fission track data for a subsample of ,14. The average track retention age is 3.2 $\pm$ 0.3 b.y., significantly lower than the ^{40}Ar-^{39}Ar and Rb-Sr ages for this sample. The data are consistent with either complete erasure of tracks at 3.2 b.y. (which seems more likely to the authors on thermal grounds) or later partial erasure from a lower temperature event.

RARE GAS AND EXPOSURE: Stettler et al. (1973) and Turner et al. (1973) report ^{38}Ar exposure ages of 230 and 240 m.y. respectively. O'Kelley et al. (1976) reported ^{26}Al values consistent with saturation, indicating exposure to cosmic rays for at least two million years or so.

PROCESSING AND SUBDIVISIONS: A slab was originally cut from this very small sample (Fig. 10). ,2 was made into a potted butt and entirely used for the only thin sections ,6; ,7; and ,17. ,1 is 0.27 g. ,0 was subsequently subdivided to leave mainly ,11 (0.68 g chips and fines) and ,12 (0.81 g chip), with ,14 allocated for P.I. subdivisions.

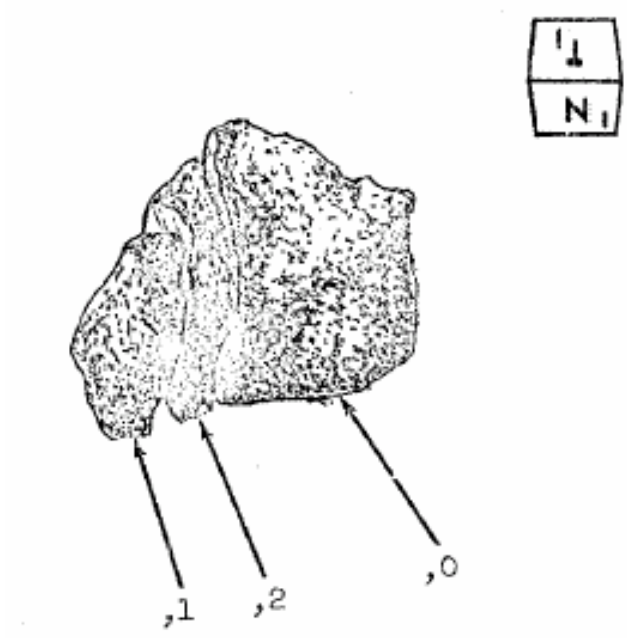

Figure 10. 1971 cutting diagram of completed sawing of 15382.