77215

Cataclastic Norite
846.4 g; largest piece is 6.5 x 4.5 x 2.5 cm (41 or more pieces)

INTRODUCTION

Sample 77215 was sampled from the large white clast in the Station 7 Boulder *(see the section on the Station 7 Boulder, page 235).* It was quite friable and broke up into many pieces on the way back from the Moon (Fig. 1). One of the pieces (,19, now 80,81 and 82) contains the dark dike similar to 77075 (Fig. 2) and other pieces contain black dikelets (similar to 77077). Some pieces have small areas of unbrecciated norite with primary igneous texture (Fig. 3). The large cataclastic -"norite" sample may itself contain other clasts of similar igneous material (Fig. 4). Most of the lithic clasts in 77215 have been crushed and fractured, and some have been intensely granulated and stretched or smeared out to form schlieren, so that the relict host rock types are only represented by very small clasts (Chao et al., 1976). This made consortium work very difficult to coordinate because samples representative of the major lithic clasts in 77215 were generally too small for allocation to all consortium members (Minkin et al., 1978). Selected subsamples were therefore assigned to individual consortium participants for analysis on the basis of suitability for their experiments, and the resulting data cannot now be exactly correlated for this sample as a whole (as is sometimes done). In general, the whole sample seems to be one material, but care should be exercised because of the cataclastic nature of the sample.

PETROGRAPHY

Sample 77215 is a pristine norite that has been shocked and crushed in place. It contains lithic fragments of "norite" and apparent "anorthosite" set in a porous mass of fine mineral fragments and thin glass veins (Fig. 5). The modal mineralogy is approximately 41% orthopyroxene and 54% plagioclase with trace amounts of troilite, ilmenite, clinopyroxene, spine], silica, K-feldspar, zirconolite, whitlockite, and Fe-Co metal (Table 1). The fragments of "anorthosite" may be plagioclase-rich regions within the original norite (Chao et al., 1976).

Figure 1: Tray full of 77215. Note that some pieces have "off-white" patina. S73-17778.

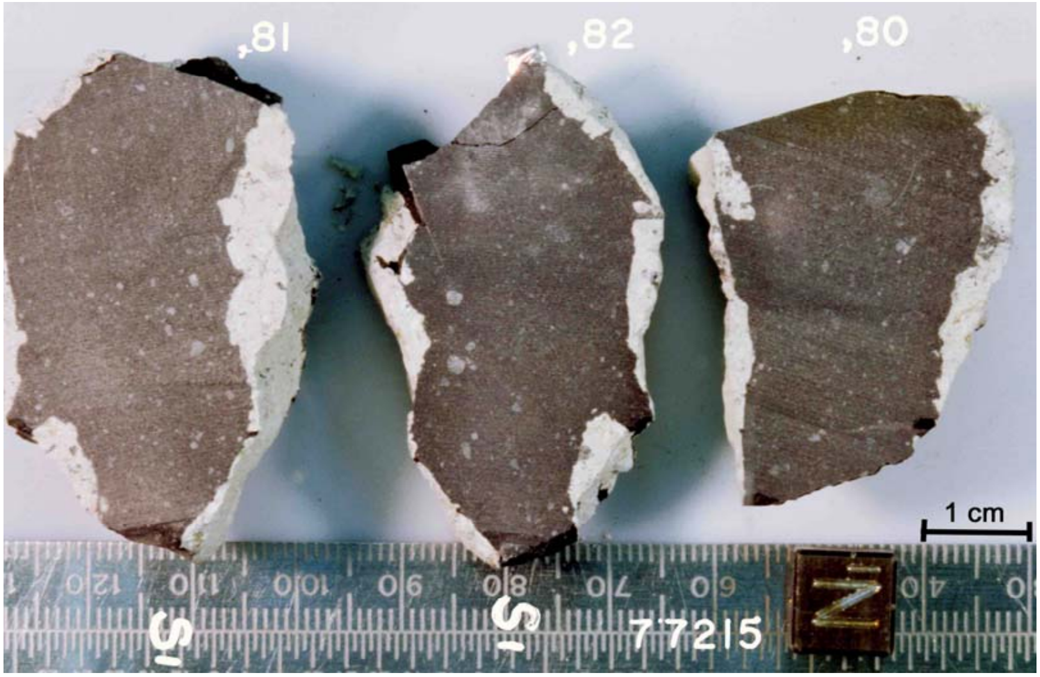

Figure 2: Photograph of sawn surfaces of slab and butt ends of 77215,19. Cube is I cm. S75-21992.

Figure 3: Photograph of 77215,16, showing igneous textures of some regions in the rock. Cube is 1 cm. S83-34595.

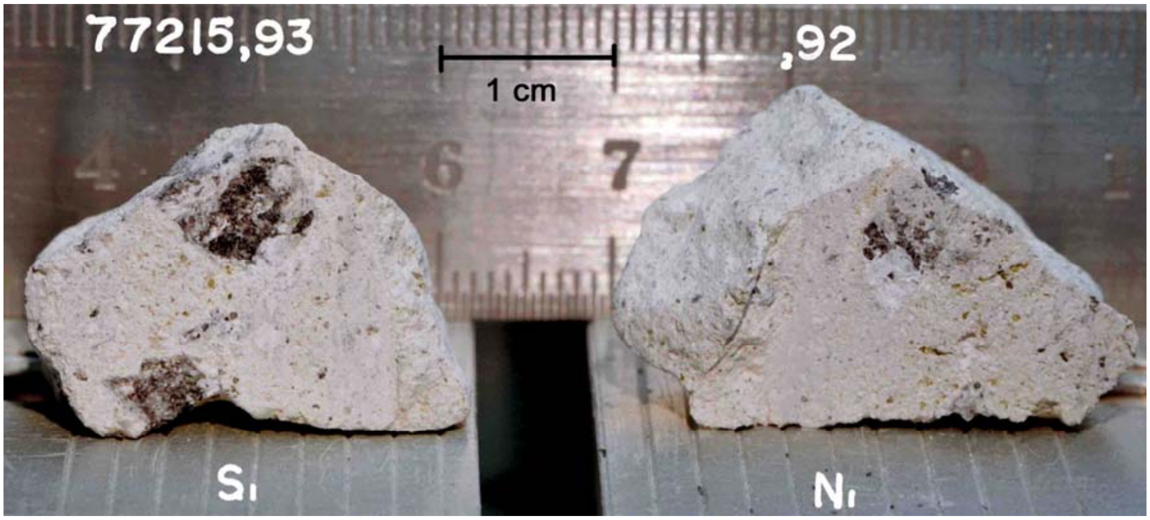

Figure 4: Photograph of saw cut through 77215,92. 575-21980. Scale bar is in cm.

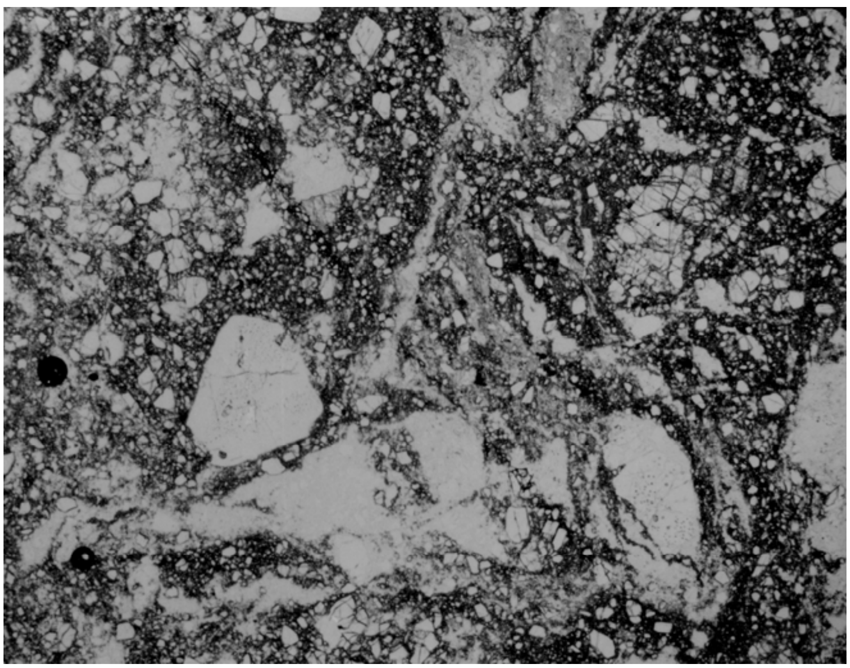

Figure 5: Photomicrograph of thin section 77215,12. Field of view is 4 x 5 mm.

According to Chao et al. (1976), the original uncrushed norite is medium-to coarse-grained (up to 3 mm, with an average of about 1 nun) and has a holocrystalline igneous texture. Its principal assemblage consists of idiomorphic greenish-yellow orthopyroxene and clear to milky white calcie plagioclase. The plagioclase has a narrow compositional range (An_{88-92} Ab_{11-7} Or_1), mostly An_{90-91}. Plagioclase grains frequently contain small inclusions of K-feldspar (An_2 Ab_1 Or_{97}), silica, and granitic glass. The plagioclase is not chemically zoned and has not been converted to maskelynite by the shock pressure. The orthopyroxene also has a narrow compositional range ($Wo_{3-5}En_{63-68}Fs_{29-32}$), The orthopyroxene in 77215 is notable for having well-developed, yet texturally diverse, augite blebs and lamellae ($Wo_{41-43}En_{44-47}Fs_{12-13}$). Huebner et al. (1975) distinguish these blebs as "worms, planes, hachures, and septa." Within a single orthopyroxene, all augite is in the same optical orientation, but this does not seem to be crystallographically controlled. Augite lamellae are 5-10µm thick, rarely 30 pm thick. The host and exsolved pyroxenes are optically and chemically homogeneous (Fig. 6).

Pyroxenes in 77215 show some of the features of "inverted pigeonites." Huebner et al. (1975) explain that the misoriented nature of the augite, relative to the host orthopyroxene, is a common feature of pyroxenes that originally crystallized as homogeneous pigeonite crystals at high temperatures. According to Huebner et al., coarse pyroxene exsolution lamellae can form in geologically short periods of time (<30,000 yr.) at elevated temperatures (>300 ° C. Huebner et al. argue that such conditions could have been met in the upper levels of the lunar crust during early lunar history as a consequence of the cooling of anorthositic crustal material. According to Huebner et al., the exsolved pyroxenes do not necessarily suggest the deep-seated origin as originally proposed by Chao et al. (1974). Anderson and Lindsley (1982) have carefully calculated the equilibrium temperature of the pyroxene pairs in 77215.

The anorthite, orthopyroxene, and minor augite account for 97.35% of the norite. The rest, 2.7%, consists of mesostasis, with a variety of accessory minerals, that occurs in the interstitial areas between the anorthite and orthopyroxene. K-feldspar with a fine network of thin silica lamellae is a common accessory mineral in these interstitial areas. Clusters of accessory minerals occur in the norite clast and in the brecciated matrix. Fe-Co metal, troilite, ilmenite, chromite, plagioclase (An_{91-92}), orthopyroxene ($Wo_4En_{64-72}Fs_{24-32}$), silica, rare augite, whitiockite, zirconolite, and rare armalcolite occur in these clusters. All these accessory phases are thought to be from the parent norite (Chao et al., 1976).

MINERAL CHEMISTRY

Chao et al. (1974), Huebner et al. (1975), and Chao et al. (1976) report the compositions of the minerals in 77215. The plagioclase and pyroxene are uniform in composition (Fig. 7).

Winzer et al. (1977) report analyses of orthopyroxene and plagioclase mineral separates for the white noritic portion of 77215 (Fig. 8). Papike et al. (1994) have also used the ion probe to determine the REE in orthopyroxene from 77215,203.

WHOLE-ROCK CHEMISTRY

Winzer et al. (1974 and 1977) report analyses of various portions of the 77215 sample, including dikes, glass, and the white noritic material
(Table 2 and Fig. 9). The grey glass appears to be melted norite, while the black glass has been injected from the surrounding matrix. Wolf et al. (1979) report the trace siderophile and volatile elements (Table 3). This rock is a pristine norite. James (1994) has also reviewed the siderophile and volatile element composition.

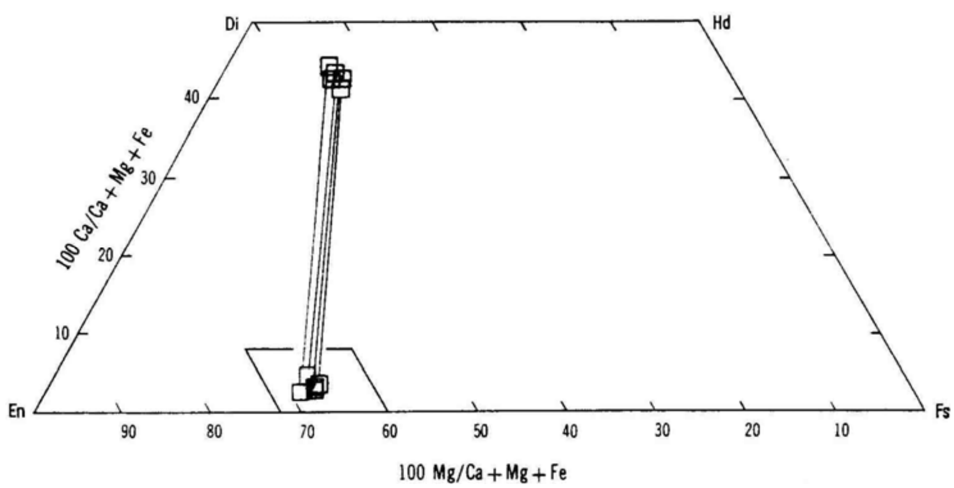

Figure 6: Pyroxene composition for 77215 norite. From Huebner et al. (1975).

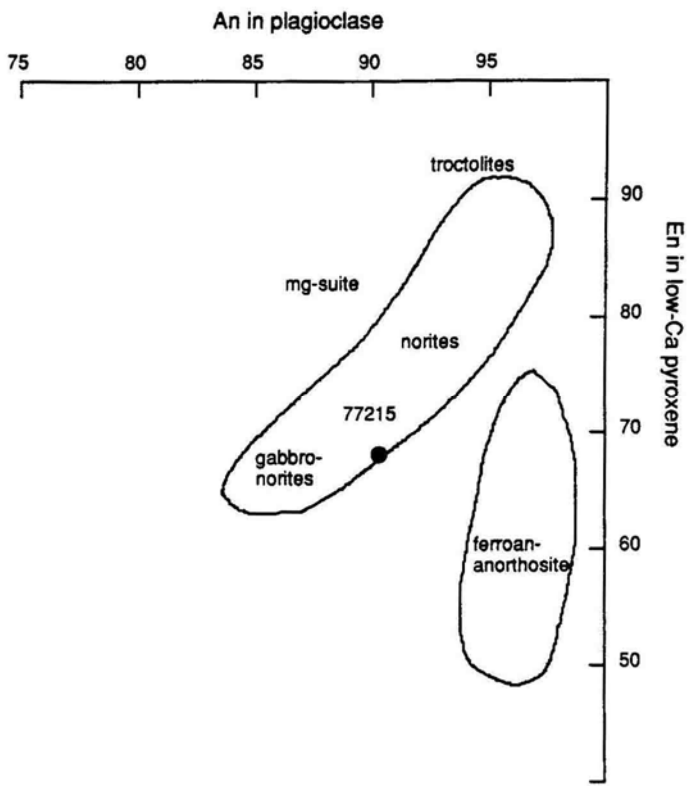

Figure 7: Plagioclase and pyroxene composition of 77215. Fields from James and Flohr (1983).

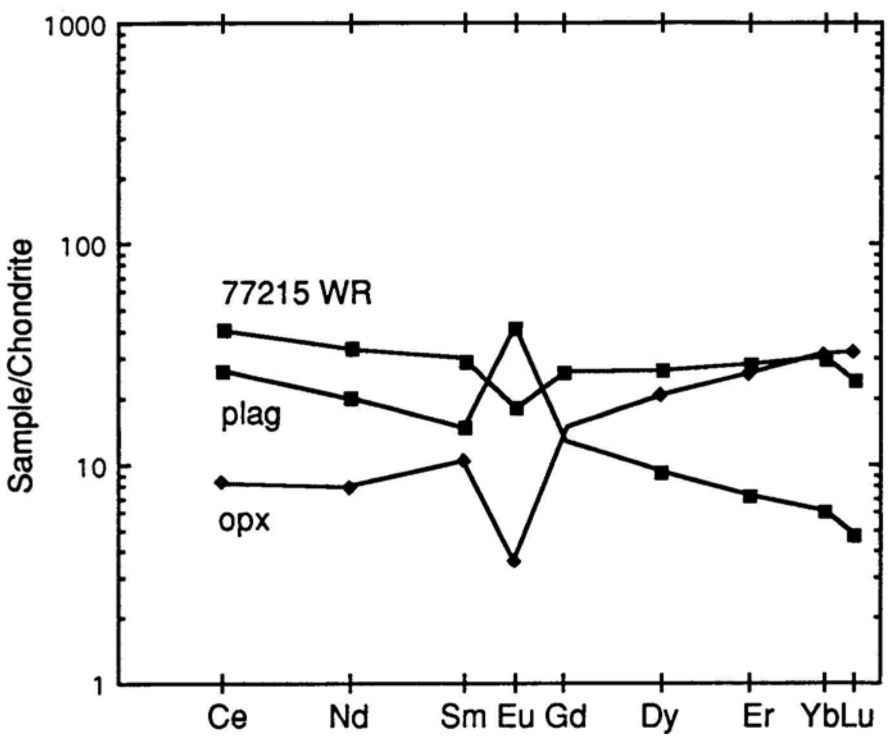

Figure 8: Normalized rare earth element diagram for whole rock and minerals in the noritic portion of 77215. Data from Winzer et al. (1977).

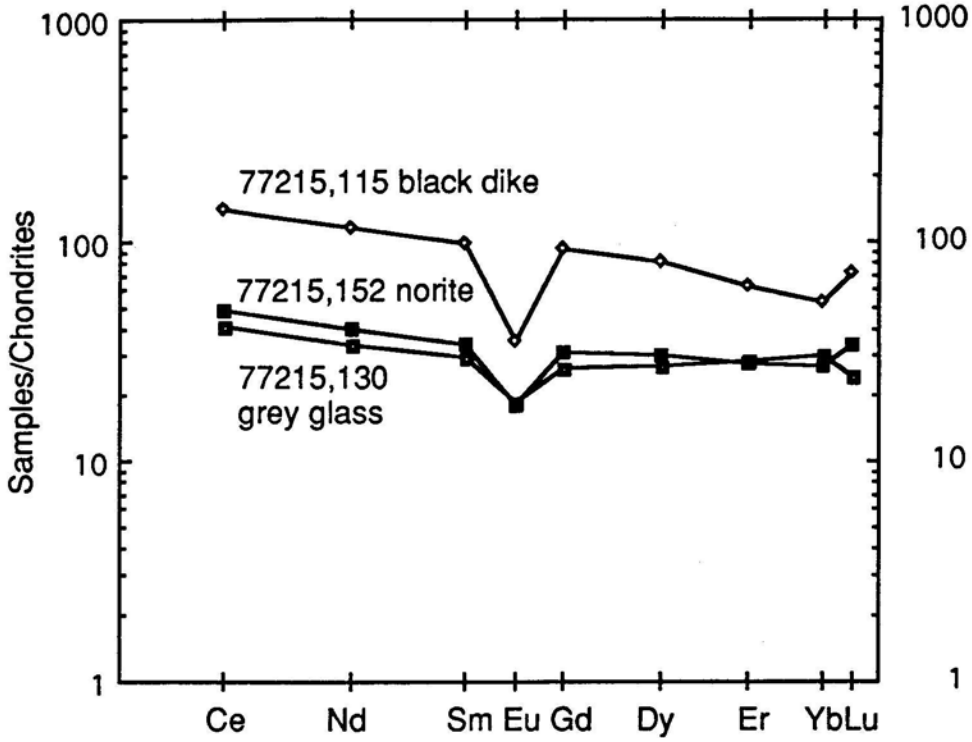

Figure 9: Normalized rare earth element data for portions of 77215. Data from Winzer et al. (1977).

SIGNIFICANT CLASTS

Chao et at. (1976) describe two clasts (1 and 2) of least-shocked norite that they separated from fragment 77215,22 and distributed for age dating.

Chao et al. (1976), Huebner et al. (1975), and Minkin et al. (1978) describe a region (or "clast") within 77215 that has highly magnesian olivine grains (Fo_{83-97}) and calcic plagioclase (An_{90-91}).

Huebner et al. (1975) briefly describe a small clast in thin section 77215,13 that consists entirely of orthopyroxene and plagioclase in equal proportions with a subophitic texture. The composition of the pyroxene and plagioclase is the same as for the isolated grains and grain fragments observed elsewhere in the sample.

The orthopyroxene within the clast contains the exsolved augite. This norite clast is probably a small sample of the source material for the breccia-a relict that escaped granulation.

RADIOGENIC ISOTOPES

Stettler et al. (1978) separated feldspar from clast 2 (sample,151) from fragment 77215,22 and obtained a well-defined ^{39}Ar-^{4O}Ar plateau age of 3.98 ± 0.03 to.y. (Fig. 10). This confirms the ages of 3.96 to 4.05 b.y. (Fig. 11) reported earlier based on intetmediate temperature plateau from samples of crushed matrix material (Stettler et al., 1974).

Nakamura et al. (1976) obtained Rb-Sr and Sm-Nd data (Tables 4 and 5) and internal isochrons of 4.42 ± 0.04 b.y. and 4.37 ± 0.07 b.y. respectively, for the bulk sample 77215,37 (Figs. 12 and 13). This is one of the few pristine samples of the original crust that have been dated!

A thermal event must have heated the noritic breccia at 3.98 Ky. without disturbing the Rb-Sr and Sm-Nd isotopic systems. This could have been the event that intruded the dike material and enclosed the norite clast in the melt sheet represented by the boulder matrix (samples 77115 and 77135), or it could have been mild heating throughout the time span 3.9 to 4.4 b.y.

Nunes et al. (1974) have also reported U-Th-Pb data for 77215 (Table 6). This system has been disturbed.

COSMOGENIC RADIOISOTOPES AND EXPOSURE AGES

Stettler et al. (1974) determined an exposure age of 27.2 m.y.

PROCESSING

The initial processing and distribution of 77215 are outlined in Butler and Dealing (1974). It was studied by the international consortium led by E.C.T. Chao (see final report by Minkin et al., 1978). Some notes on the distribution of 77215 are given in the appendix to Chao et al. (1976). Detailed description of the splits is given in open-file report 78-511.

The largest pieces of 77215 that remain unprocessed are: ,18 (103 g); ,17 (101 g); ,21 (69 g); and ,22 (60 g). Twenty-five thin sections have been prepared.

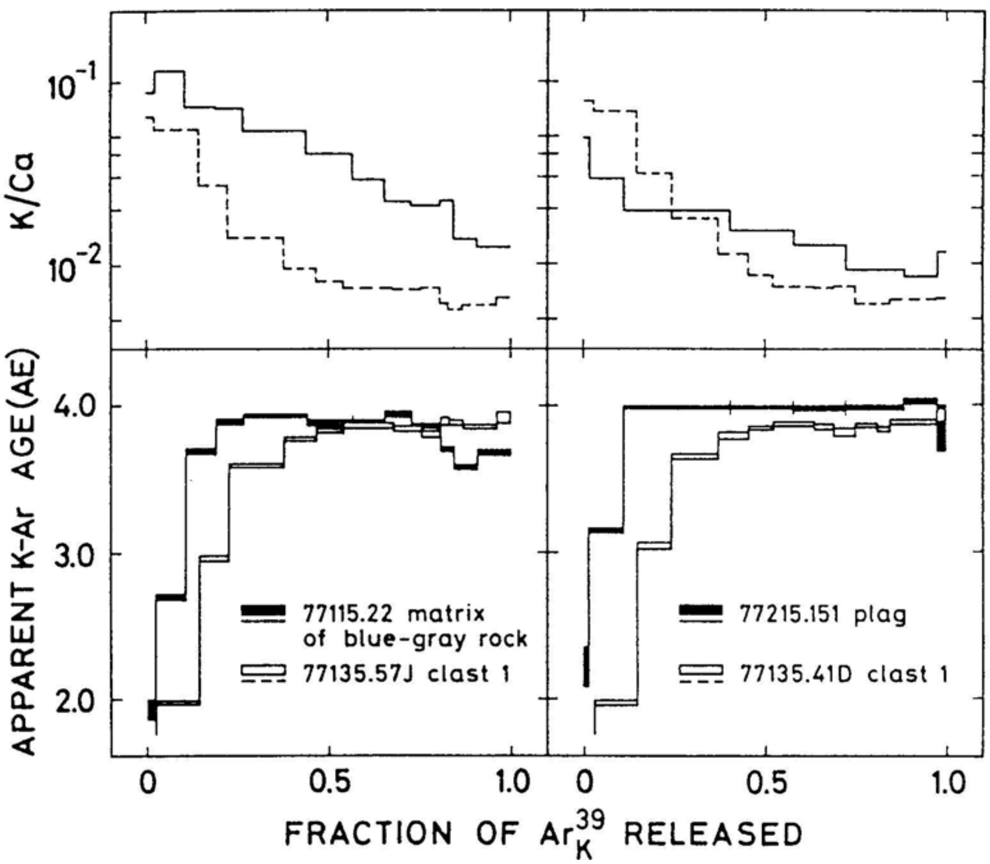

Figure 10: ^{39}Ar-^{40}Ar temperature release pattern for plagioclase from a norite clast in 77215. From Stettler et al. (1978).

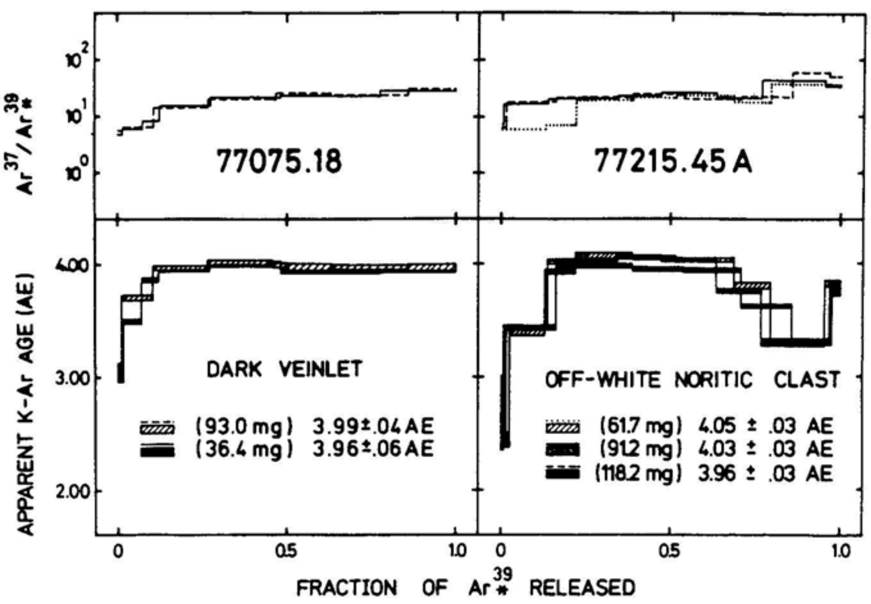

Figure 11: ^{39}Ar-^{40}Ar temperature release pattern for composite noritic material from 77215.
From Stettler et al. (1974).

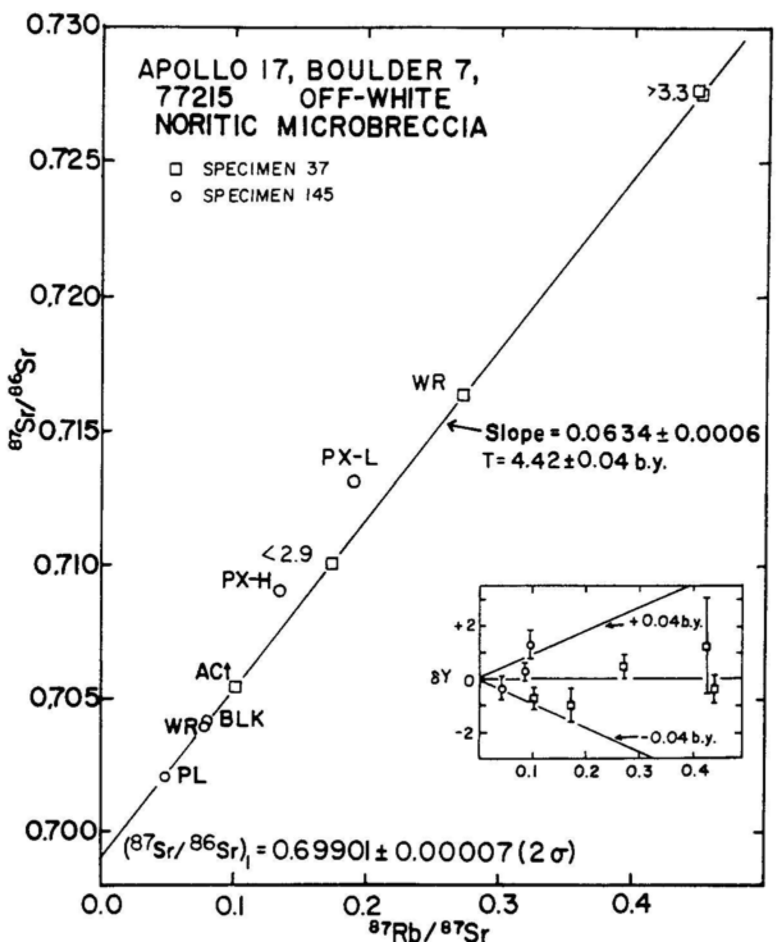

Figure 12: Rb-Sr internal isochron for 77215. From Nakamura et al. (1976).

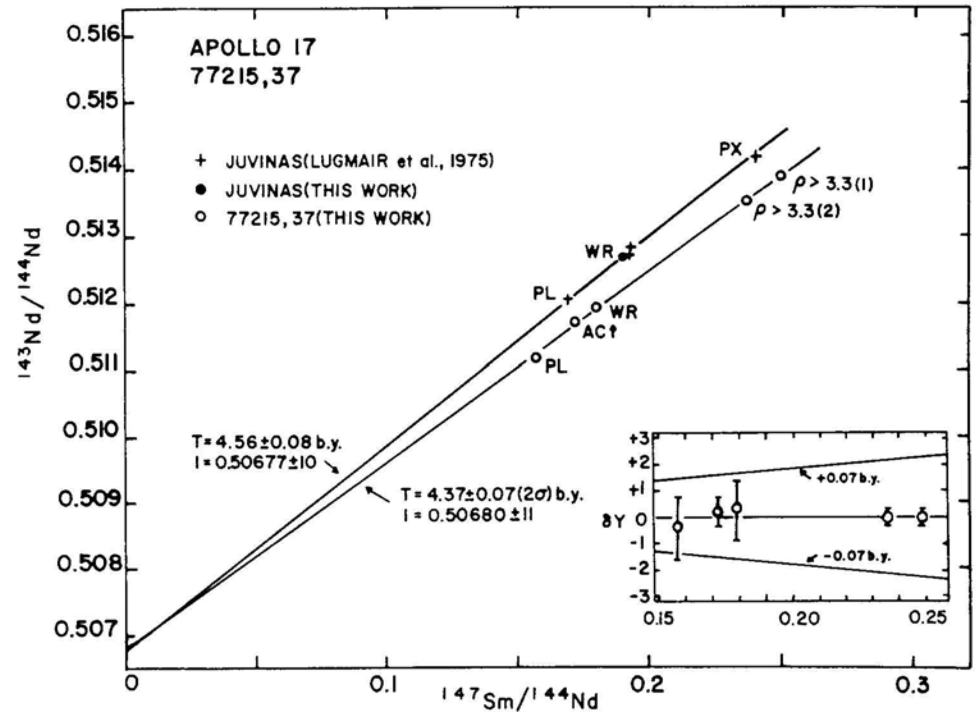

Figure 13: Sm-Nd internal isochron for 77215. From Nakamura et al. (1976).

Table 1: Fragment population off 77215,138.
From Chao et al. (1976).

	Fragment type		Vol. %	
	Norite		8.3	
	"Anorthosite"		10.2	
	Gray glass		6.4	
	Mineral clasts		75.1	
	Total		100.0	
Mineral clasts	**>30 μm**	**<30 μm**	**Total***	**Recalculated to 100%**
Orthopyroxene	7.4	23.7	31.0	41.3
Plagioclase	6.3	34.2	40.5	54.0
Troilite	.2	.2	.5	.6
Ilmenite	.1	–	.1	.1
Fe-Co metal	.2	.1	.2	.3
Clinopyroxene	.2	.1	.3	.4
Spinel	.2	–	.2	.2
Silica phase	.04	1.3	1.4	1.8
K-feldspar	.06	.1	.2	.3
Glass-coated clast	.10	.6	.7	1.0
Total	14.8	60.3	75.1	100.0

*Volume percent recalculated from point count 1251 clasts >30 μm and 1370 clasts <30 μm, measured by C. L. Thompson.

Table 2: Whole-rock chemistry of 77215.
a) Winzer et al. (1974); b) Winzer et al. 0977)

Split Technique	,45 (a) AA, IDMS norite	,152 (b) AA, IDMS norite	,115 (b) AA, IDMS black dike	,119 (b) AA, IDMS dike	,121 (b) AA, IDMS dike	,130 (b) AA, IDMS grey glass
SiO_2 (wt%)	51.3	51.1	46.8	47.2	46.0	51.1
TiO_2	0.32	0.30	1.37	1.35	1.32	0.37
Al_2O_3	15.06	13.98	17.44	16.89	17.75	14.32
Cr_2O_3	0.32	0.36	0.19	0.20	0.14	0.36
FeO	10.07	10.38	9.39	9.36	9.04	10.32
MnO	0.16	0.17	0.12	0.12	0.11	0.17
MgO	12.56	14.31	13.16	12.93	12.74	13.23
CaO	8.96	8.65	10.88	10.76	10.94	9.08
Na_2O	0.43	0.39	0.65	0.68	0.68	0.55
K_2O	0.14	0.18	0.24	0.23	0.24	0.15
P_2O_5	0.11	0.14	0.28	0.27	0.26	0.10
Nb (ppm)						
Zr	171	–	419			147
Hf		–				
Sr	105	102	171	169	174	103
Rb	3.54	3.21	6.51	6.48	6.26	
Li	12.3	12.4	21	21.9	26.5	
Ba	166	154	350	349	336	154
La						
Ce	27.2	24.6	84.4	73.3	79.1	29.6
Nd	16.8	15.5	51.9	51.7	50.1	18
Sm	4.68	4.4	14.4	14.5	13.8	5.05
Eu	1.08	1.03	1.93	1.90	1.97	1.01
Gd	6.64	5.21	–			
Dy	7.08	6.64	19.6	19.4	18.4	7.31
Er	4.51	4.57	10	–	10.7	4.44
Yb	4.98	4.88	8.59	10.5	9.94	4.45
Lu	0.766	0.592	1.76		1.68	0.835

Table 3: Trace element data for 77215. Concentrations in ppb.
From Higuchi and Morgan (1975) and Ebihara et al. (1991).

	Sample 77215,35	Sample 77215,37
Ir	2.66	0.0221
Os	3.04	
Re	0.173	0.0047
Au	0.557	0.0108
Pd	1.45	
Ni (ppm)	50	<3
Sb	1.04	0.121
Ge	47.1	14.3
Se	83.2	77
Te	1.92	1
Ag	1.89	0.62
Br		42.4
In	<0.10	
Bi	0.645	0.13
Zn (ppm)	2.95	3
Cd	4.39	4.4
Tl	0.637	0.61
Rb (ppm)	12.3	4.9
Cs	393	180
U	799	920

Table 4: K and Rb-Sr analytical data for 77215.
From Nakamura et al. (1976).

Sample	Weight (mg)	K (%)	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$ [1]	$^{87}Sr/^{86}Sr$ [2]
77215,37 (density separates)						
Acetone float	29.12	0.127	4.933	136.7	0.1044	0.70553 ± 4
ρ>2.9 g/cm^3	29.41	0.387	11.10	184.2	0.1743	0.70990 ± 7
Whole rock	29.67	0.127	6.177	65.46	0.2733	0.71641 ± 12
ρ>3.3 g/cm^3	31.09	0.0081	0.526	3.387	0.4504	0.72738 ± 7
ρ>3.3 g/cm^3	25.13	0.0092	0.611	3.936	0.4499	0.72748 ± 20
77215,145 (hand-picked mineral concentrates)						
Plagioclase	3.33	0.154	3.442	204.1	0.0488	0.70207 ± 3
Whole rock	18.19	0.0842	2.326	86.61	0.0777	0.70397 ± 3
Black material (glass?)	6.24	0.148	2.908	105.2	0.0800	0.70422 ± 5
Pyroxene	7.56	0.0053	0.2303	4.958	0.1344	0.70909 ± 4
Pyroxene (ρ>3.3 g/cm^3)	7.96	0.0063	0.2752	4.187	0.1902	0.71306 ± 7

[1] Uncertainties are estimated to be ≤0.3%.
[2] Uncertainties correspond to last significant figures and are 2σ mean.

Table 5: Sm-Nd analytical data from 77215.
From Nakamura et al. (1976).

Sample	Weight (mg)	Sm (ppm)	Nd[1] (ppm)	$^{147}Sm/^{144}Nd$ [2]	$^{143}Nd/^{144}Nd$ [3]
77215,37					
Plagioclase	9.66	4.084	15.784	0.1564	0.51129 ± 7
Acetone float	129.39	5.516	19.42	0.1717	0.51178 ± 4
Whole rock	21.26	4.372	14.84	0.1780	0.51200 ± 7
Pyroxene (1) (ρ>3.3 g/cm^3)	115.37	2.173	5.329	0.2474	0.51397 ± 2
Pyroxene (2) (ρ>3.3 g/cm^3)	119.01	2.217	5.724	0.2341	0.51359 ± 2
Juvinas					
Whole rock (this study)	92.11	2.021	6.361	0.1920	0.51256 ± 2
Whole rock[4] (La Jolla)				0.1936	0.51264 ± 4

[1] Nd concentrations were calculated using our data normalized to $^{142}Nd/^{146}Nd = 1.58170$ in Table 3, and $^{148}Nd/^{146}Nd = 0.33466$ and $^{150}Nd/^{146}Nd = 0.32752$.
[2] Uncertainties are estimated to be 0.1–0.2%.
[3] Ratios were normalized to $^{142}Nd/^{146}Nd = 1.5817$. Uncertainties correspond to the last figure and are 2σ mean.
[4] G. W. Lugmair, pers. comm. (1976).

Table 6: U-Th-Pb for 77215.
From Nunes et al. (1974).

Split	77215,37 whole rock	olivine	plagioclase
wt (mg)	158.4	208	194.2
U (ppm)	0.5068	0.7764	0.2390
Th (ppm)	1.993	1.815	1.198
Pb (ppm)	1.079	1.239	0.6817
$^{232}Th/^{238}U$	4.06	2.42	5.18
$^{238}U/^{204}Pb$	1455	479.0	85.4