DRAFT

77215

Cataclastic Norite

846.4 grams

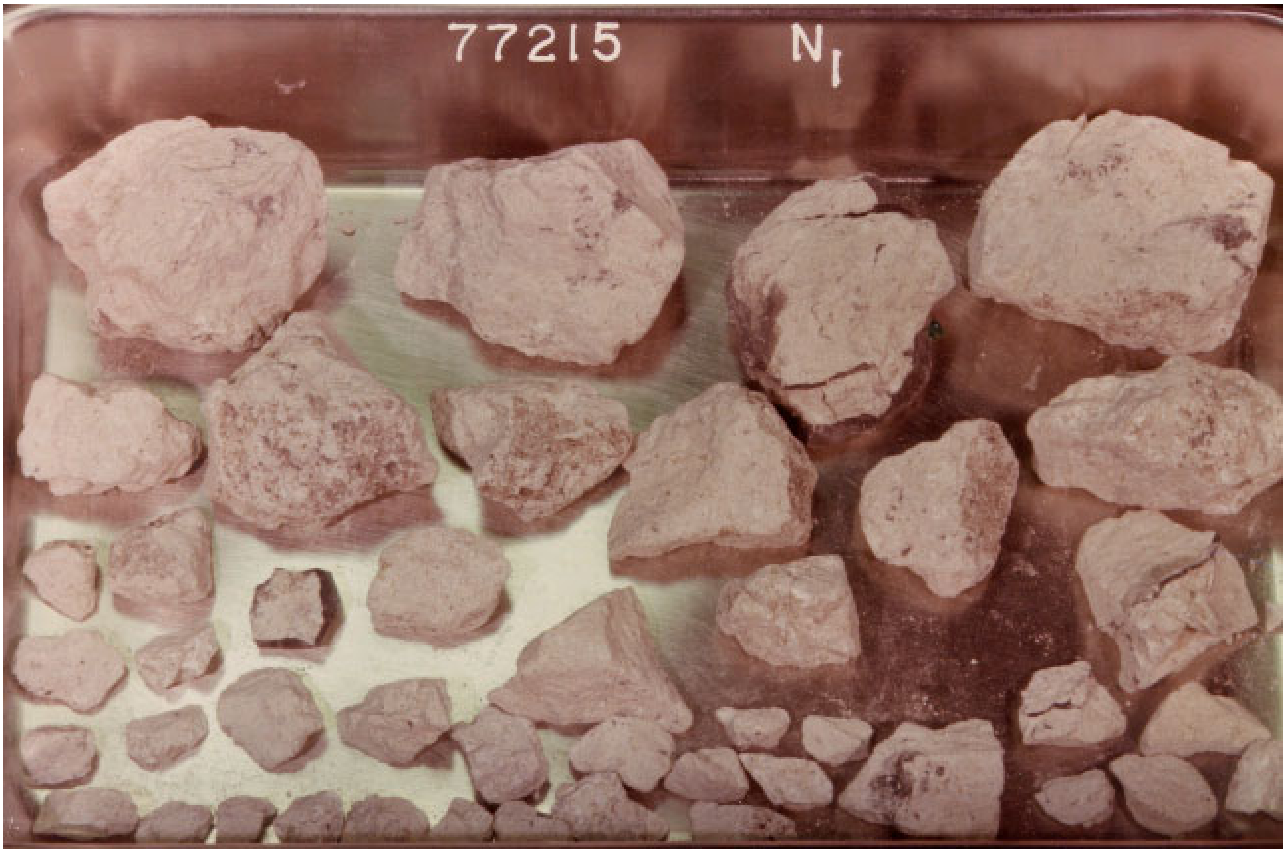


Figure 1: Tray full of pieces of 77215. Some pieces are covered with "off-white" patina including obvious zap pits. NASA photo # S73-17779.

Introduction

Apollo 17 sample 77215 represents the oldest lithology in the Station 7 boulder. It is cut by a dark dike and surrounded by two generations of melt rock. 77215 probably a brecciated pigeonite-anorthite cumulate (figure 3), but the small size of the remnant lithic clasts prevents any certain determination of cumulate origin (Chao et al. 1976). The pigeonite has inverted to orthopyroxene with augite exsolution. The presence of undevitrified noritic glass in 77215 is significant to understanding the thermal history of this boulder.

77215 was collected from the obvious large white clast in the Station 7 boulder (Wolfe and others 1981). While it appeared "off-white" or "light-gray" in the surface photography, the fresh surfaces of the sample proved to be pure white in the laboratory (figure 1). One piece of 77215 (piece 19) includes the dark dike material of 77075 (figure 4). Other pieces contain thin dark veins (as in sample 77077).

This sample and others from the Station 7 boulder were studied by the International Consortium led by Ed Chao (see summaries by Chao et al. 1976, Winzer et al. 1977 and Minkin et al. 1978). The results on 77215 were also summarized in the catalog by Meyer (1994).

The Consortium was unable to provide exactly similar subsamples to individual member for study and analysis, because of the clastic nature of the 77215. Subsamples were assigned to individual consortium participants on the basis of suitability for their

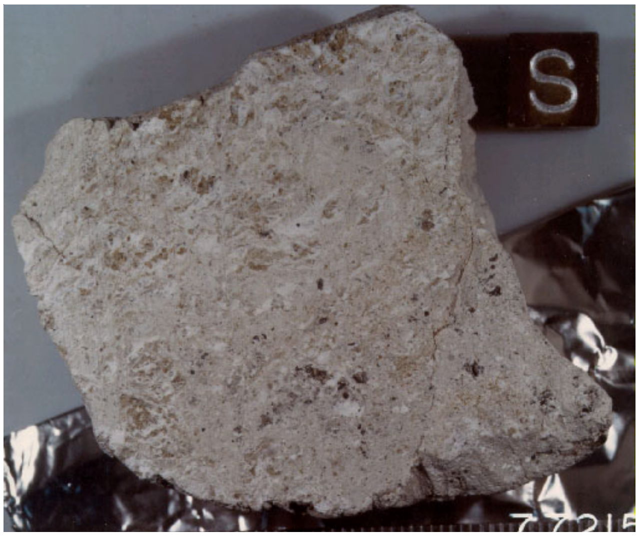


Figure 2: Sawn surface of 77215,16 showing relict igneous texture. NASA photo # S83-34595. One cm cube for scale.

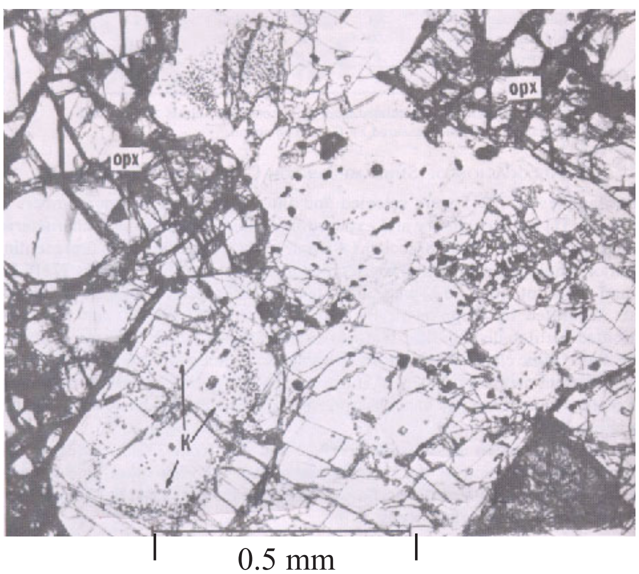


Figure 3: Photomicrograph of a norite clast in thin section 77215,139 (from Chao et al. 1976). Small inclusions of K-feldspar(K) are characteristic.

Mineralogical Mode of 77215

	Chao et al. 1974	Chao et al. 1976
Plagioclase	52 vol. %	54
Orthopyroxene	45	41.5
Augite		0.4
Silica		1.8
Troilite		0.6
Ilmenite		0.1
Metal		0.3
Spinel		0.2
K-feldspar		0.3
Glass		1.0

Figure 4: Slab 77215,82 showing dark dike in 77215,19. Note rounded xenocrysts in fine-grained dike. Cube is 1 cm for scale. NASA photo # S75-21979.

experiments and the resulting data cannot now be exactly correlated (Minkin et al. 1978).

Petrography

77215 is a friable breccia that broke up into many pieces on the way back from the moon (figure 1). Some pieces have small areas of unbrecciated norite with primary igneous texture (figures 2 and 3). However, most of the lithic clasts in 77215 have been intensely granulated or smeared out to form schlieren, so that the relict host rock(s) are only represented by very small clasts (Chao et al. 1976).

The modal mineralogy of 77215 is approximately 41% orthopyroxene and 54% plagioclase with trace amounts of troilite, ilmenite, clinopyroxene, spinel, silica, K-feldspar, and other trace phases. Although it contains some gray glass, it is low in Ir and Ni. Thus, 77215 is (or rather was) a pristine norite that has been shocked and crushed in place. Most of the plagioclase has not been converted to maskelynite by the mild shock pressure.

The plagioclase and pyroxene in 77215 have a narrow range of chemical composition (An_{90-91} and $Wo_{3-5}En_{63-68}Fs_{29-32}$) and plot in the range of lunar norite (figure 7). 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 orthopyroxene host, 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

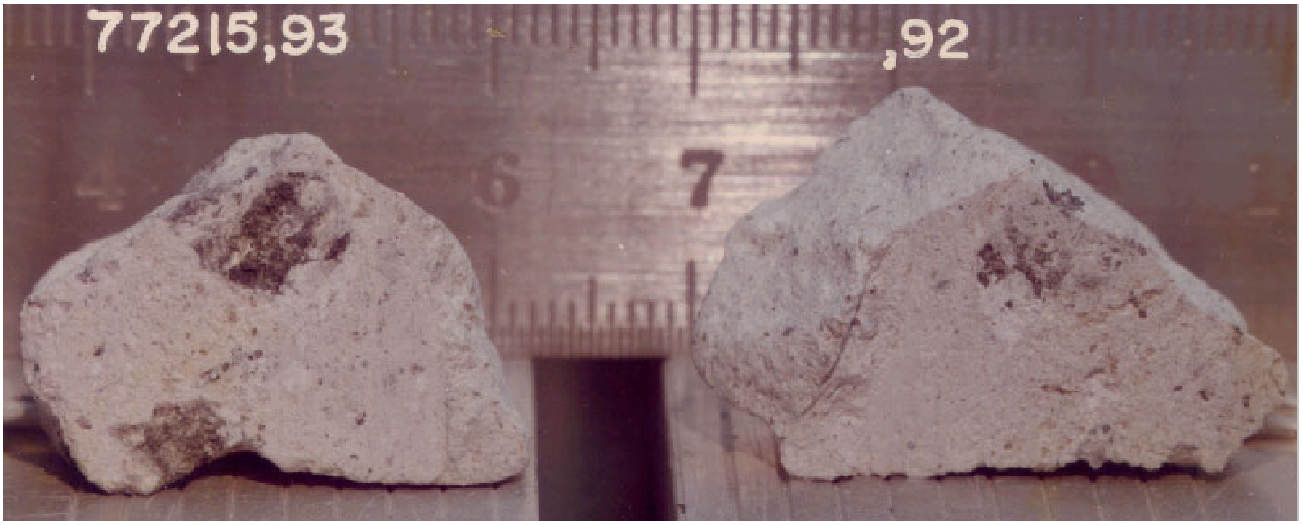


Figure 5: Sawn surfaces of 77215,92 with cm scale. Note obvious clasts in fine-grained, crushed matrix. NASA # S75-21980.

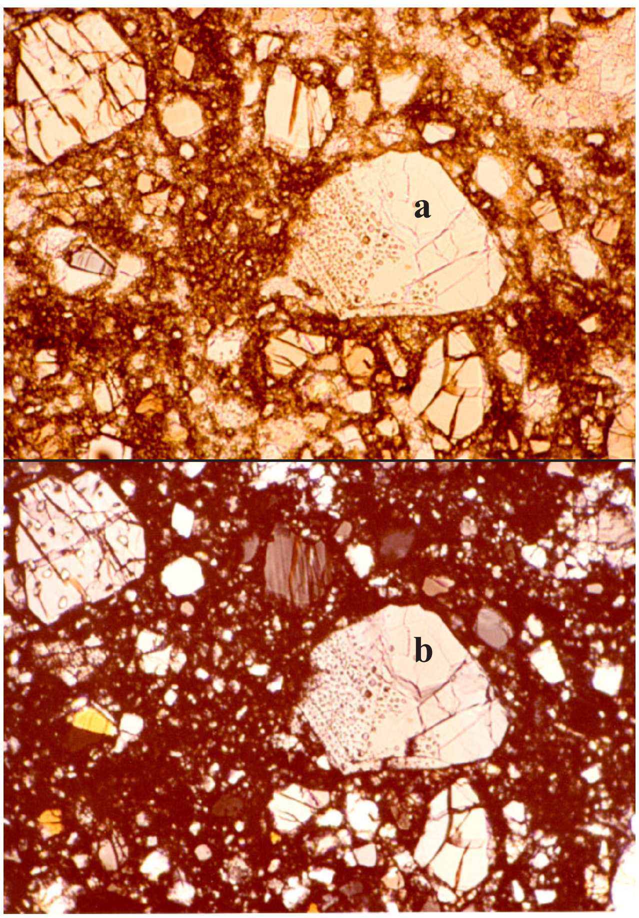


Figure 6: Photomicrograph of thin section of 77215,14. a) plane polarized light, b) cross-polarized light, showing glass matrix. NASA photo #s S79-27400 and 27401. Field of view is 1.4 mm.

can form in geologically short periods of time (<30,000 yr.) at elevated temperature. 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 initially hot crust of the moon. According to Huebner et al., the exsolved pyroxenes seen in 77215 do not necessarily suggest the deep-seated origin, as originally proposed by Chao et al. (1974).

Significant Clasts

Huebner et al. (1975) report a lithic clast, 3.5 mm long, in thin section 77215,13 that consists entirely of orthopyroxene and plagioclase, in roughly equal proportions. The grain size is 0.5 to 2 mm, and the texture is subophitic. They consider that the clast is an unbrecciated piece of the parental cumulate rock that has escaped granulation.

A gray impact glass clast in 77215,29 was subdivided for detailed study (Chao et al. 1976). The chemical analysis (labeled ,130) of this clast and microprobe analyses (Chao et al. 1976) showed it to have the bulk composition of the norite (figure 8).

Mineralogy

Pyroxene: The pyroxene in 77215 is orthopyroxene (host) with exsolved augite lamellae and blebs (Huebner et al. 1975)(figure 8). Winzer et al. (1977) analyzed pyroxene separates for 77215 and Papike et al. (1994) used the ion microprobe method to determine the trace element content of orthopyroxene. Anderson and Lindsley (1982) have carefully calculated the

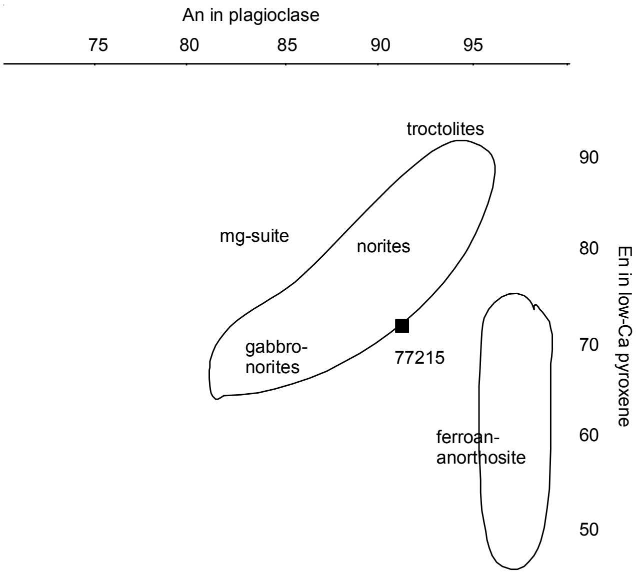


Figure 7: Composition of plagioclase and pyroxene in 77215.

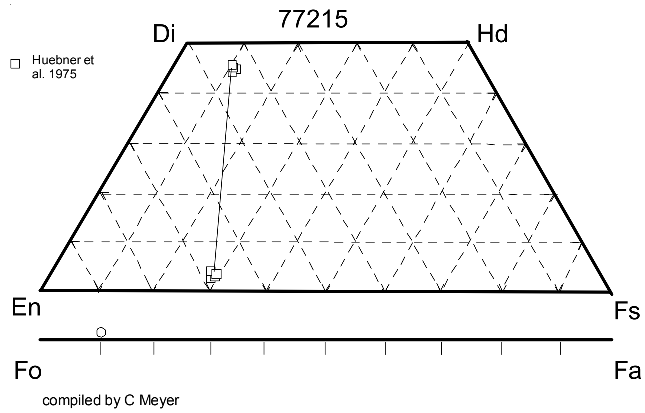


Figure 8: Compostion of orthopyroxene with exsolved augite in 77215(from Huebner et al. 1975). Rare olivine is out of equilibium.

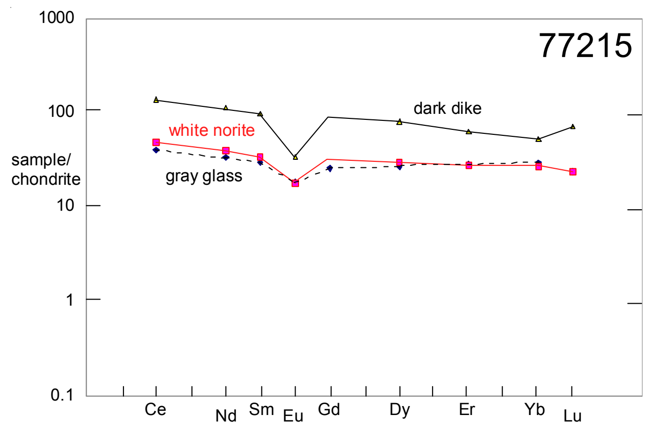


Figure 9: Normalized rare-earth-element composition of 77215 and dike (data from Winzer et al. 1977).

equilibrium temperature of pyroxene pairs in 77215 (T = 850 ± 30 deg C).

Plagioclase: Huebner et al. (1975) report that the plagioclase in 77215 is $Or_{0.7}Ab_{8.2}An_{91.1}$, with low Mg and Fe content, typical of plagioclase from plutonic lunar rocks. Chao et al. (1976) report the composition as $An_{88-92}Ab_{11-7}Or_1$. Plagioclase has not been converted to maskelynite by shock. Winzer et al. (1977) provide trace element analysis of plagioclase separates.

K-feldspar: Plagioclase grains frequently contain square to rectangular inclusions of K-feldspar ($Or_{97}Ab_1An_2$) or granitic glass (Chao et al. 1976).

Other: Chao et al. (1976) report "clusters" of accessory minerals consisting of Fe-Co metal, troilite, ilmenite, chromite, anorthite, orthopyroxene, silica, rare augite and whitlockite. Chao et al. (1976) and Huebner et al. (1975) also report grains of Zr-Ti-Ca-Fe oxide.

Glass: Gray glass clasts and veins with the approximate composition of the bulk norite are present in 77215 (Chao et al. 1976). An analysis of this glass is found in table 1.

Chemistry

The consortium created two large, homogeneous splits for accurate chemical analysis (split 77215,45 weighed 1.13 grams and split ,152 weighed 0.62 grams). Table 1 and figure 9 give the composition of the white norite and the dark dike material. The gray glass has the same composition as the white norite.

The white noritic portion of 77215 is pristine (low Ir, Higuchi and Morgan 1975, Ebihara et al. 1991, Wolf et al. 1979). The dark dike material has the same composition as 77075.

Radiogenic age dating

The argon 39/40 plateau age for 77215 is significantly lower than the age determined by Rb/Sr or Sm/Nd internal mineral isochrons (as was also the case for norite sample 78235). The best Ar age (3.98 b.y.) seems to be from the plagioclase separate (figure 12), which probably represents the time of formation of the melt sheet (figure 10). The original crystallization age of the parental norite appears to be ~ 4.4 b.y. (Nakamura et al. 1976). This is only one of a few samples of the

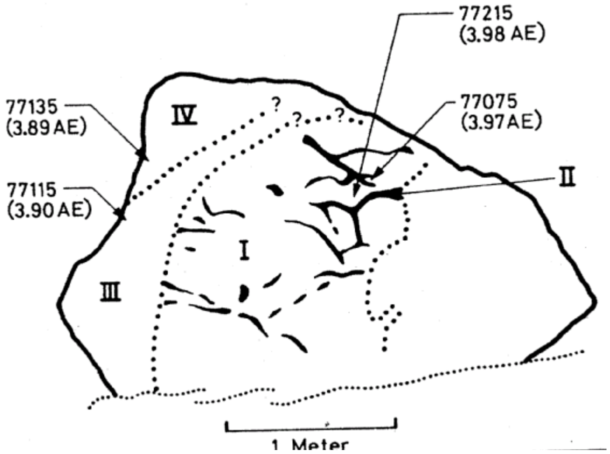


Figure 10: Summary diagram for ages determined by Argon release from samples of Station 7 boulder (from Stettler et al. 1978).

original crust of the moon that have been successfully dated (figure 13 and 14).

U-Th-Pb data for 77215 are disturbed (Nunes et al. 1974).

Cosmogenic isotopes and exposure ages

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

Processing

The International Consortium selected subsamples 77215,19 ,22 ,29 ,37 ,45 and ,58 for study because they are representative of the clast assemblages of this breccia. Some notes on the distribution of these subsamples is given in the appendix to Chao et al. (1976). Detailed description of the splits is recorded in Open File Report 78-511. Butler and Dealing (1974) outlined the original processing and distribution of samples from this boulder.

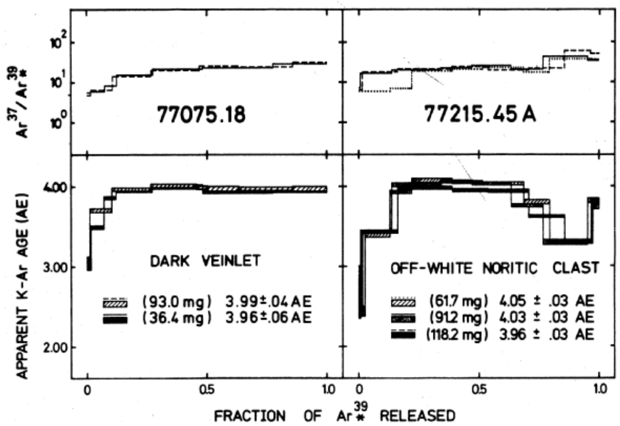


Figure 11: Argon release diagram for 77075 and 77215 (from Stettler et al. 1974).

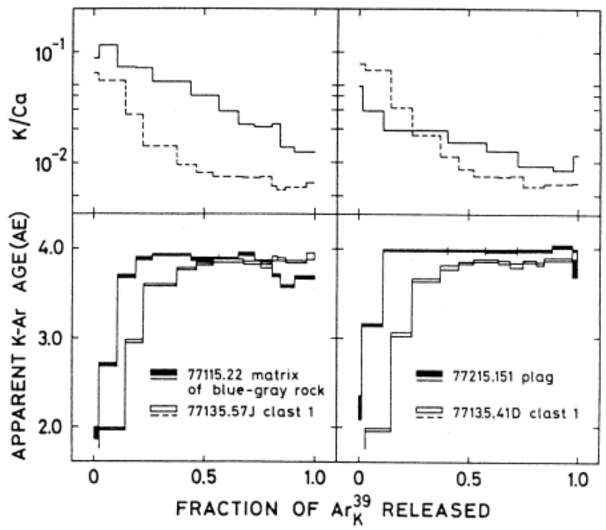


Figure 12: Ar release diagram for plagioclase in 77215 (from Stettler et al. 1978).

List of Photo #s for 77215

S73-17778-17779	tray full
S83-34595	,16 sawn surface
S75-21979	
S75-21992	,19 sawn
S75-21980	,29 sawn

Summary of Age Data for 77215

	Ar-Ar	Rb/Sr	Sm/Nd
Stettler et al. 1974	3.96 ± 0.03 b.y.		
Stettler et al. 1978	3.98 ± 0.03 (plag.)		
Nakamura et al. 1976		4.42 ± 0.04	4.37± 0.07

Caution: These ages use old decay constants.

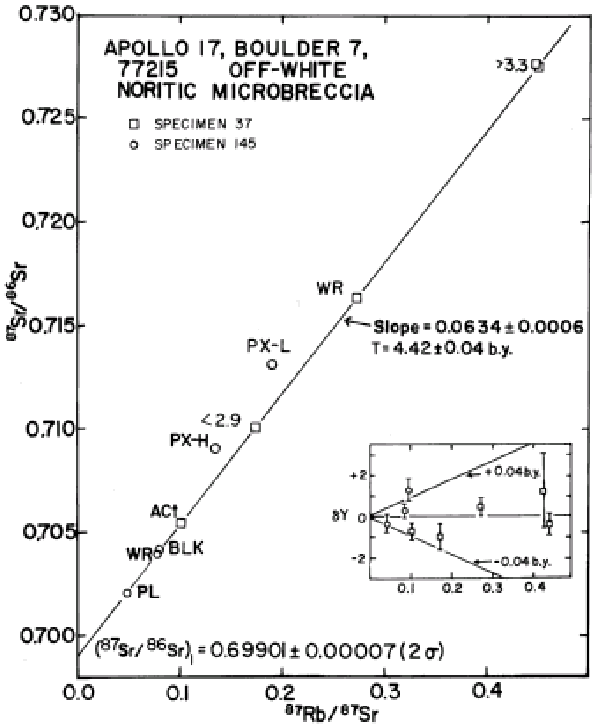


Figure 13: Rb/Sr isochron for 77215 as determined by Nakamura et al. (1976).

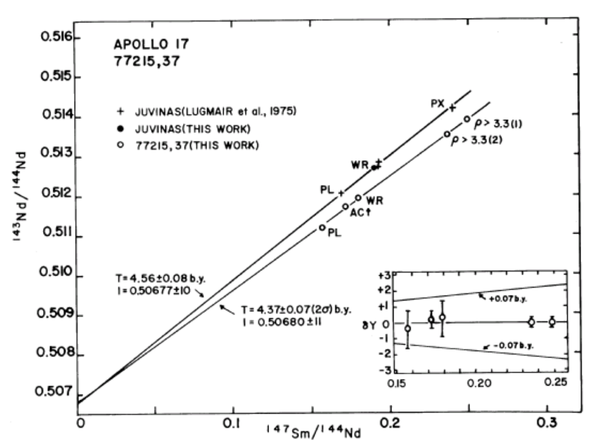
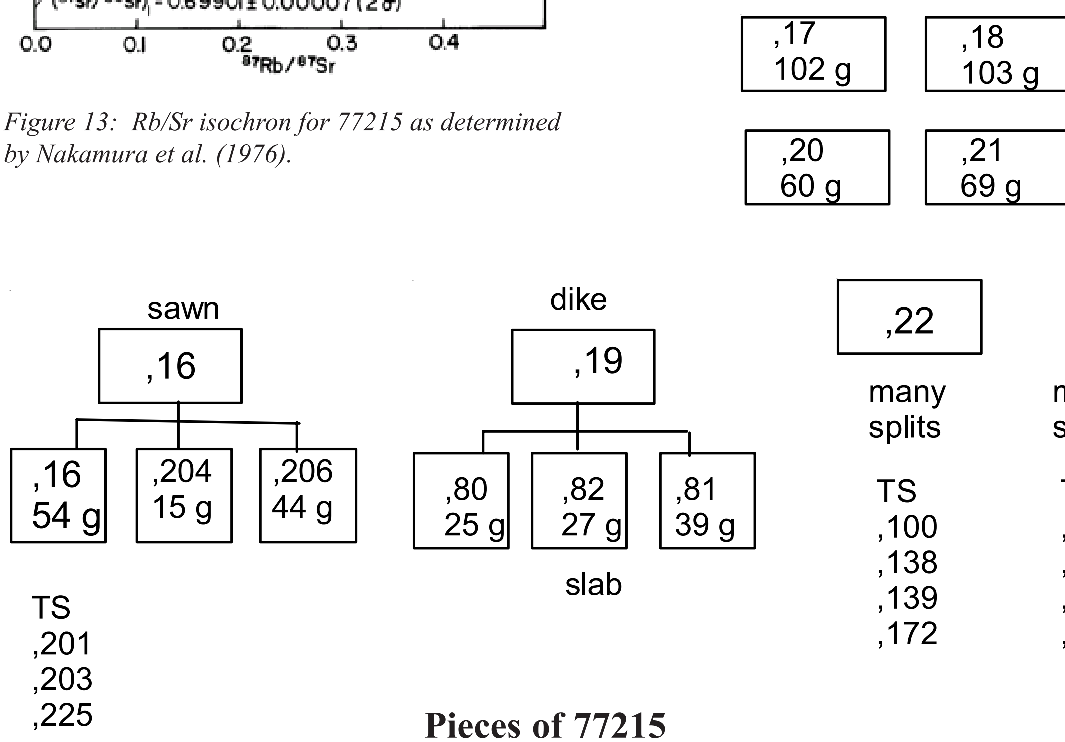


Figure 14: Sm-Nd internal mineral isochron for 77215 by Nakamura et al. (1976).



Pieces of 77215

Table 1. Chemical composition of 77215

	norite	matrix	glass	black dike	dike	dike					*77077 white*
reference	Winzer 74	Winzer 77						Higuchi 75	Ebihara 92		*Warren 78*
weight	*98 mg*	,152	,130	,115	,119	,121		,37	,35		*for comparison*
SiO2 %	51.3	51.1	51.1	46.8	47.2	46	(b)				50.9 (e)
TiO2	0.32	0.3	0.37	1.37	1.35	1.32	(c)				0.3 (e)
Al2O3	15.06	13.98	14.32	17.44	16.89	17.75	(b)				16.16(e)
FeO	10.07	10.38	10.32	9.39	9.36	9.04	(b)				8.74 (e)
MnO	0.16	0.17	0.17	0.12	0.12	0.11	(b)				0.15 (e)
MgO	12.56	14.31	13.23	13.16	12.93	12.74	(b)				10.6 (e)
CaO	8.96	8.65	9.08	10.88	10.76	10.94	(b)				9.94 (e)
Na2O	0.43	0.39	0.55	0.65	0.68	0.68	(b)				0.44 (e)
K2O	0.14	0.18	0.15	0.24	0.23	0.24	(b)				0.22 (e)
P2O5	0.11	0.14	0.1	0.28	0.27	0.26	(c)				
S %											
sum											
Sc ppm											13.8 (e)
V											
Cr	2189	2463	2463	1300	1368	958	(b)				
Co											25.2 (e)
Ni								<3	50	(d)	< 1.7 (e)
Cu											
Zn								3	2.95	(d)	2.84 (e)
Ga											5 (e)
Ge ppb								14.3	47.1	(d)	18.7 (e)
As											
Se								77	83.2	(d)	
Rb	3.54	3.21		6.51	6.48	6.26	(a)	4.9	12.3	(d)	
Sr	105	102	103	171	169	174	(a)				
Y											
Zr	171		147	419			(a)				150 (e)
Nb											
Mo											
Ru											
Rh											
Pd ppb									1.45	(d)	
Ag ppb								0.62	1.89	(d)	
Cd ppb								4.4	4.39	(d)	
In ppb									<0.1	(d)	
Sn ppb											
Sb ppb								0.121	1.04	(d)	
Te ppb								1	1.92	(d)	
Cs ppm								0.18	0.393	(d)	
Ba	166	154	154	350	349	336	(a)				220 (e)
La											9.9 (e)
Ce	27.2	24.6	29.6	84.4	73.3	79.1	(a)				25 (e)
Pr											
Nd	16.8	15.5	18	51.9	51.7	50.8	(a)				16 (e)
Sm	4.68	4.4	5.05	14.4	14.5	13.8	(a)				4.28 (e)
Eu	1.08	1.03	1.01	1.93	1.9	1.97	(a)				1.12 (e)
Gd	6.64	5.21					(a)				
Tb											1 (e)
Dy	7.08	6.64	7.31	19.6	19.4	18.4	(a)				
Ho											
Er	4.51	4.57	4.44	10		10.7	(a)				
Tm											
Yb	4.98	4.88	4.45	8.59	10.5	9.94	(a)				4.5 (e)
Lu	0.766	0.592	0.835	1.76		1.68	(a)				0.67 (e)
Hf						3	(a)				3.4 (e)
Ta											0.38 (e)
W ppb											
Re ppb								0.0047	0.173	(d)	
Os ppb									3.04	(d)	
Ir ppb								0.0221	2.66	(d)	0.0029(e)
Pt ppb											
Au ppb								0.0108	0.557	(d)	0.056(e)
Th ppm											2 (e)
U ppm								0.92	0.799	(d)	0.59 (e)

technique (a) IDMS, (b) AA, (c) colorimetry, (d) RNAA, (e) INAA

Table 2: Composition of 77215

	U ppm	Th ppm	K2O %	Rb ppm	Sr ppm	Nd ppm	Sm ppm	technique
Winzer et al. 1974			0.14	3.54	105	16.8	4.68	IDMS
			0.18	3.21	102	15.5	4.4	IDMS
Nakamura et al. 1976			0.127	6.177	65.46	14.84	4.372	IDMS
			0.0842	2.326	86.81			
Nunes et al. 1974	0.5068	1.993						IDMS
Higuchi et al. 1975	0.92			4.9				RNAA
Ebihara et al. 1992	0.799			12.3				RNAA