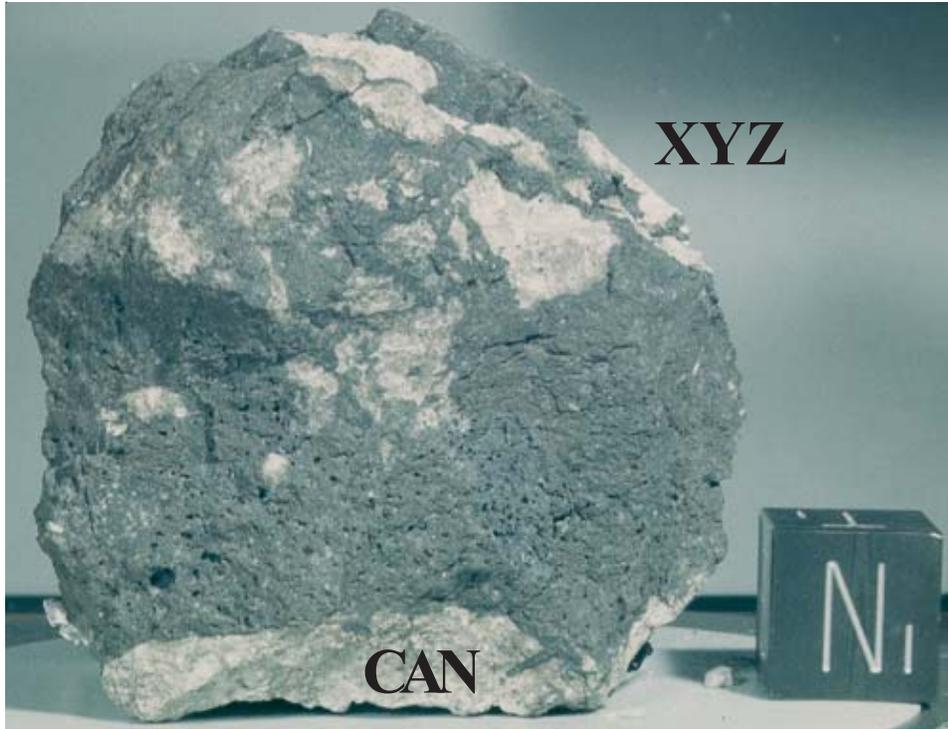


**15455**  
**Breccia with Shocked Norite**  
937.2 grams



*Figure 1: Photo of 15455 showing vesicular impact melt rock containing white clasts. Cube is 1 inch. NASA S71-43889. The large white clast (CAN) along the bottom was the main focus of research, but note the additional white clasts (XYZ). This side had a few micrometeorite craters.*

### **Introduction**

The large, shocked, norite clast in 15455 is one of the oldest lunar materials that have been identified (~4.5 b.y.). It is surrounded and intruded by dark breccia matrix with an age about 3.9 b.y. 15455 is similar to 15445, both found on the rim of Spur Crater. It has micrometeorite craters on several surfaces and a cosmic ray exposure age about 200 m.y. Together, these two breccia samples, and the nearby boulder, are thought to represent ejecta from the Imbrium Basin (Ryder and Wood 1977, Ryder and Bower 1977 and Hertogen et al. 1977).

15455 was returned as one large piece (figures 1, 2, 3) and 22 small fragments (1-3 grams each). 15455 has been the subject of several coordinated consortia studies led by Lee Silver (1970s), John Wood (1970s) and the Norite Consortium led by Larry Nyquist (1980s). The results have previously been summarized

in the catalog by Ryder (1985). Although there have been numerous studies of this important rock, it deserves more detailed investigation.

### **Petrography**

Wilshire, Morrison and Brett (1972, original Apollo 15 catalog), James (1977) and Ryder and Bower (1977) describe 15455 as an impact melt rock with significant clasts of plutonic rock. The matrix is described as a fragment-laden melt that has surrounded and intruded the enclosed clasts. The dark breccia matrix that makes up the majority of 15455 is coherent and dense in places and vesicular in others (figure 4). It is composed of a seriate mix of plagioclase, olivine and minor pink-spinel fragments (xenoliths) surrounded by a very fine-grained igneous-textured groundmass. Pyroxene is rare in the matrix material (Ryder 1985). Spudis et al. (1991) analyzed the small mineral clasts found in the

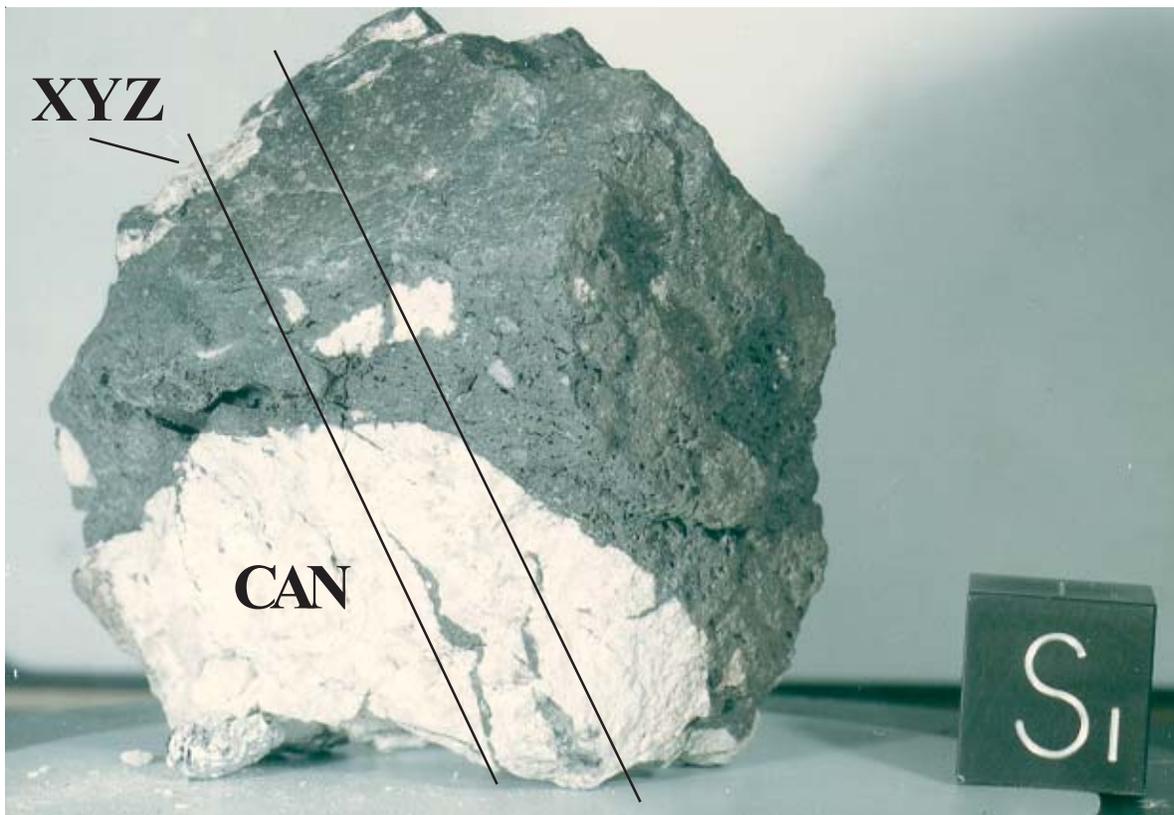


Figure 2: Photo of 15455 showing large cataclastic anorthositic norite clast (CAN) and approximate location of saw cuts. NASA S71-46588. Cube is 1 inch.

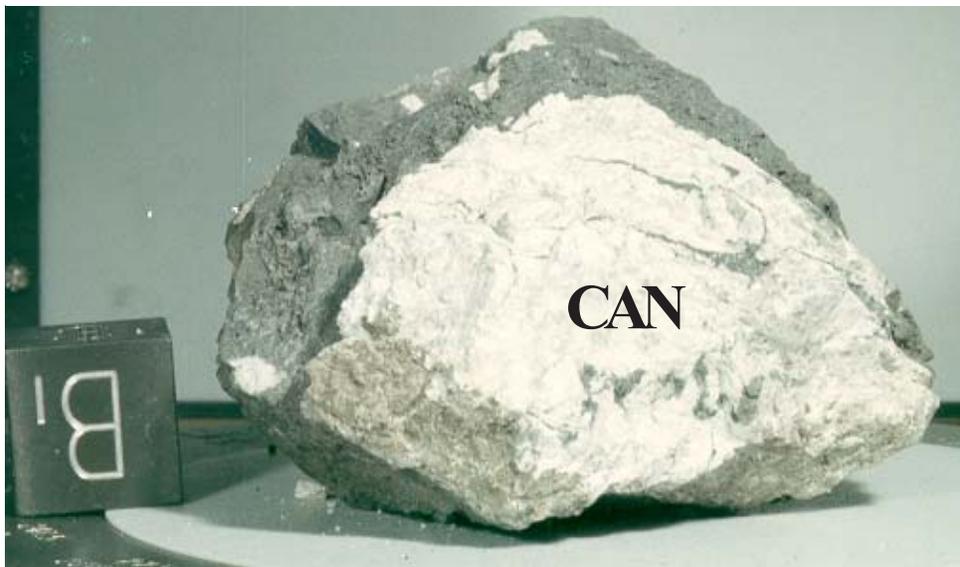


Figure 3: Photo of bottom of 15455 showing cataclastic anorthositic norite clast (CAN). Cube is 1 inch. NASA S71-46585.

breccia matrix, finding that they could be related to norites and troctolites, but not to basalts nor to ferroan anorthosites. James (1977) described rounded xenocrysts in the matrix of 15455 with spherulitic devitrified maskelynite (figure 5) indicating a shock

history more extreme than was experienced by the large norite clast. Christie et al. (1973) found no glass in the matrix, which they described as a dark, non-porous, annealed microbreccia.

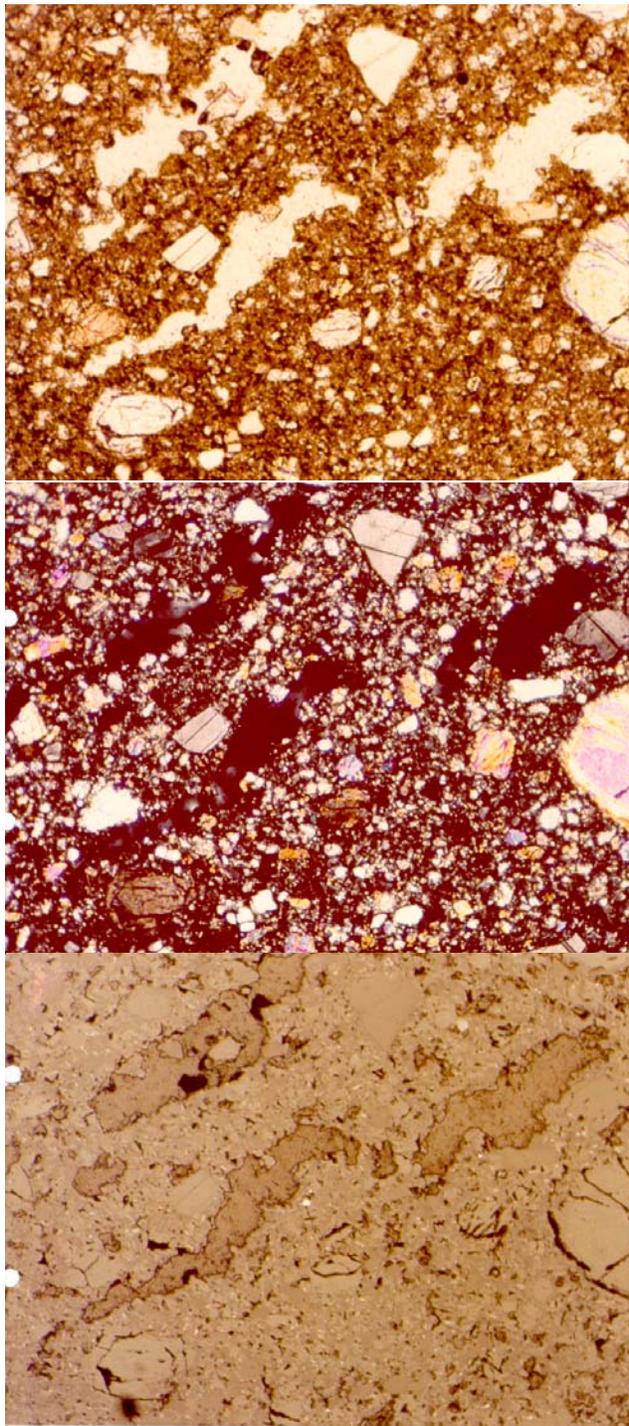


Figure 4: Three views of thin section 15455,162 - transmitted light, cross-polarized light and reflected light. NASA S71- 27693-27695. Field of view 1.3 mm. This represents the impact-melt breccia lithology and shows the elongate vugs.

Reid et al. (1977) found that the matrix material in 15455 had approximately the same composition as “LKFM” – a cluster of glass compositions found at several Apollo sites.

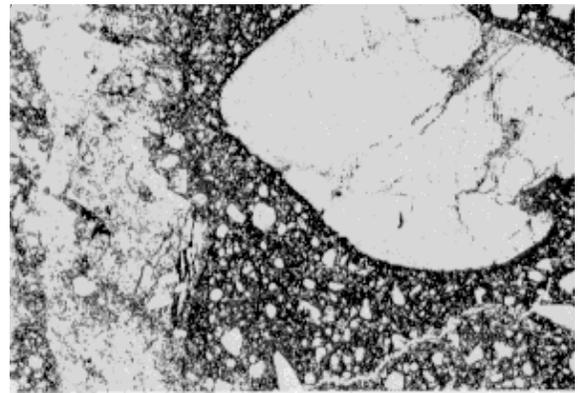


Figure 5: Photomicrograph of thin section of 15455 showing sharp contact of matrix with norite clast (left) with rounded fragment of spherulitic devitrified maskelynite included in matrix (from James 1977). Plane polarized light. Field of view 2.2 mm.

15455 contains several clasts, but only two have been studied:

#### **Significant Clasts**

**CAN Cataclastic Anorthositic Norite:** – The largest clast (about 200 grams, seen on S1-B1 end) is pristine norite with about 70% plagioclase, 30% orthopyroxene and trace augite (figure 7). The 15455 norite also contains a variety of accessory minerals: silica, armalcolite, chromite, ilmenite, rutile, a phosphate, zircon, baddelyite, Fe-metal and troilite (Ryder and Bower 1977).

The original grain size of this norite (CAN) was quite large (1-3 mm), but the grains are significantly fractured as if crushed and granulated while in place (Phinney et al. 1977, James 1977). Cross-cutting veins of dark matrix material cut through the white, norite material (figures 2, 22, 25-27). There is a “chill margin” surrounding this large clast (figure 6).

CAN has been the subject of the Norite Consortium led by Larry Nyquist (see Shih et al. 1993) and has been found to be extremely old (see below).

This large white clast may itself be composed of more than one material (not well established). Observations (by Wilshire and Morrison) made during the original preliminary examination were that “plagioclase ranges from 60% to more than 95% and the variation in proportion to pyroxene suggest an original layering”. This is supported by the initial trace element analysis

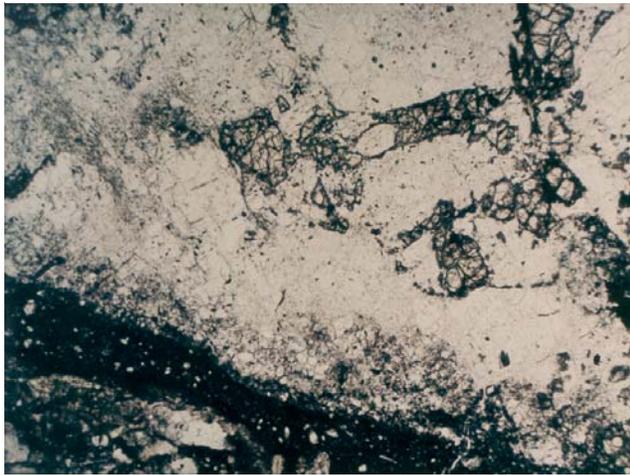


Figure 6: Photomicrograph of thin section of 15455 cataclastic anorthositic norite clast (CAN) showing relic coarse igneous texture. NASA S71-51729. Scale about 2 mm across.

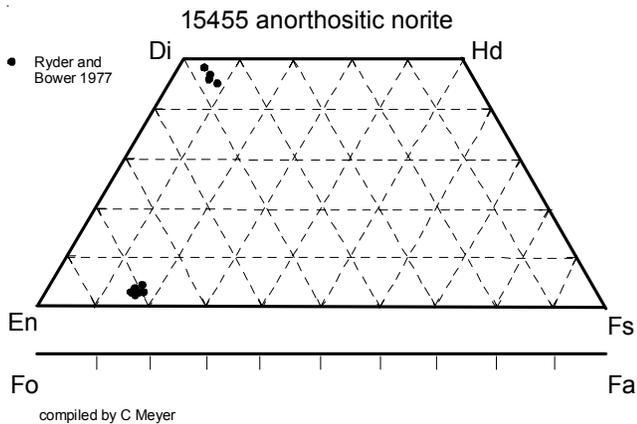


Figure 7: Pyroxene composition of large cataclastic anorthositic norite clast (CAN). Replotted from data by Ryder and Bower (1977).

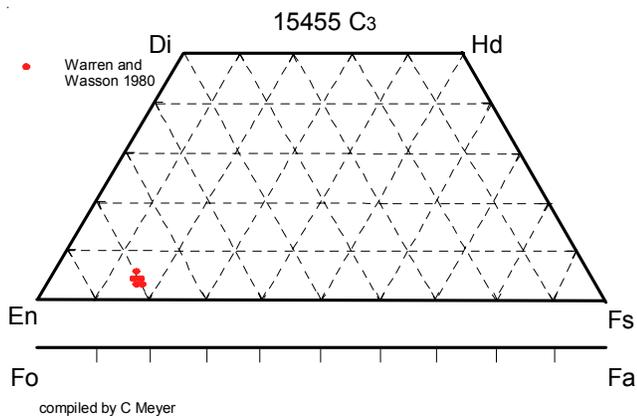


Figure 8: Pyroxene composition of norite clast C3 (replotted from Warren and Wasson 1980).

### Mineralogical Mode of 15455 CAN

	PET	Ryder and Bower 1977	Warren and Wasson 1980
Orthopyroxene	25 %	30	24
Plagioclase	75	70	75

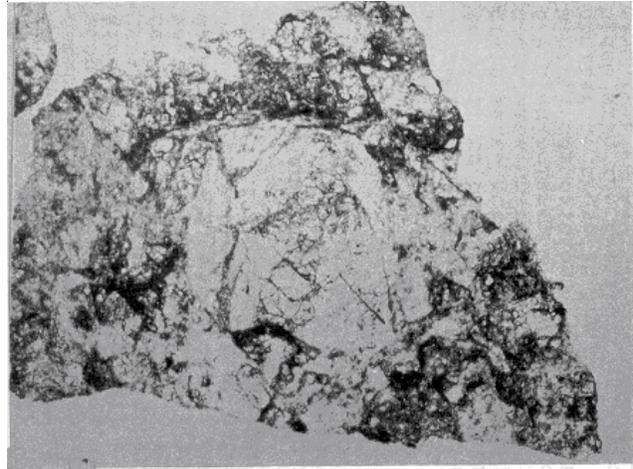


Figure 9: Thin section photo of cataclastic troctolitic anorthosite clast (CTA) in 15455,169 (from Ryder 1985). Field of view is 3 mm.

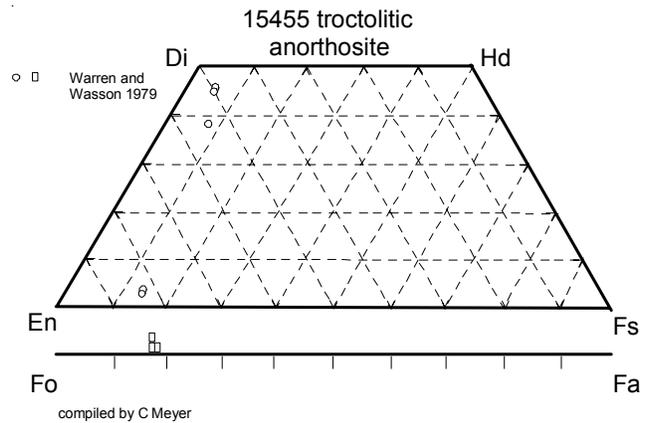


Figure 10: Pyroxene composition of egg-shaped, cataclastic troctolitic anorthosite clast (CTA) in 15455. Replotted from Warren and Wasson (1979).

### Mineralogical Mode of 15455 CTA

	Warren and Wasson 1979	Norn	Ryder 1985
Olivine	22	29	25
Pyroxene	11	13	
Plagioclase	66	58	75

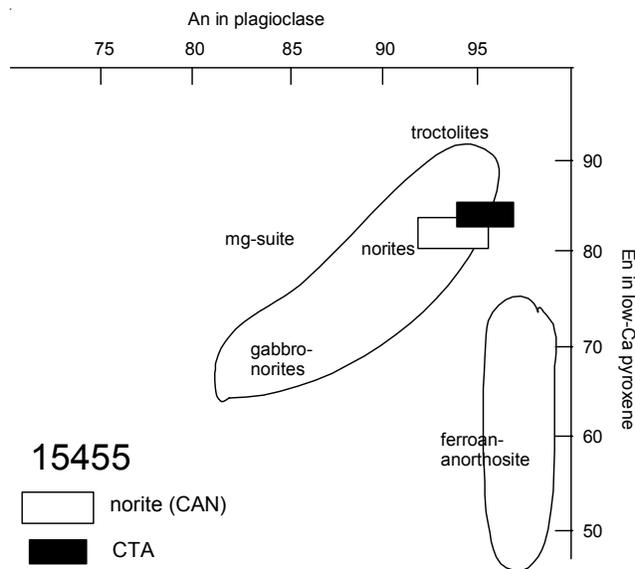


Figure 11: Plagioclase and pyroxene composition of largest clasts in 15455 (CAN and CTA). Data from Ryder and Bower (1977) and Warren and Wasson (1979).

of the white clast by Taylor et al. (1973) which is different from that by Philpotts (unpublished), Shih et al. (1993) and Warren and Wasson (1980) (Table 2 and figure 13). Warren and Wasson (1980) termed their split “c3”, to distinguish it from the material “c1” originally studied by Taylor et al. (1973) and Ganapathy et al. (1973).

**CTA Cataclastic Troctolitic Anorthosite:** This egg-shaped white clast (~3 grams) was exposed during cutting slab (figures 26 and 27). Warren and Wasson (1979) found that this clast (termed “c2”) had an “extreme cataclastic texture” while Ryder and Norman (1979) found it had a “feldspathic granulite texture”. It has an extremely fine grain size (100 to 350 microns) with more olivine than pyroxene (hence term troctolitic). Ganapathy et al. (1973) and Warren and Wasson (1979) found it has low meteoritic siderophile content and was thus “chemically pristine”. The REE pattern is not unlike that of the norite (figure 14).

**XYZ Complex:** This set of unstudied white clasts on W1 end is shown in figures 1 and 23.

**C, D, E, F:** Small white clasts exposed by saw cut (~1 gram ea.) as designated in catalog by Ryder (1985). D may be part of XYZ above (see figure 26). These clasts have not been studied and will prove to be difficult to extract in the glove box.

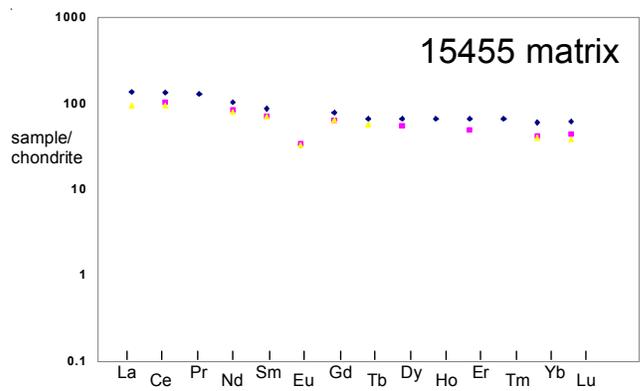


Figure 12: Normalized rare-earth-element composition diagram for matrix samples of 15455 (data by Taylor 1973, Philpotts (unpublished), and Lindstrom et al. 1988).

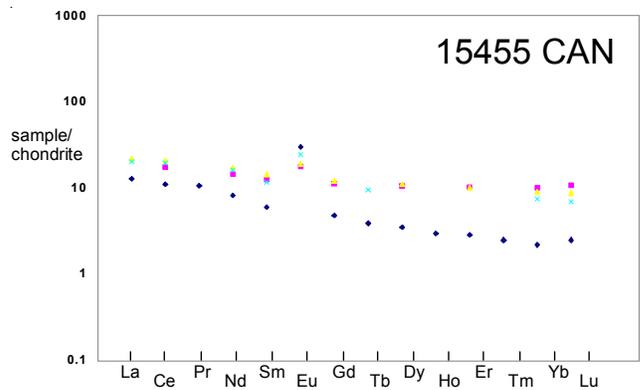


Figure 13: Normalized rare-earth-element diagram for the large white norite clast in 15455 (data from Taylor 1973, Philpotts (unpublished), Shih et al. 1993 and Warren and Wasson 1980 (C3)).

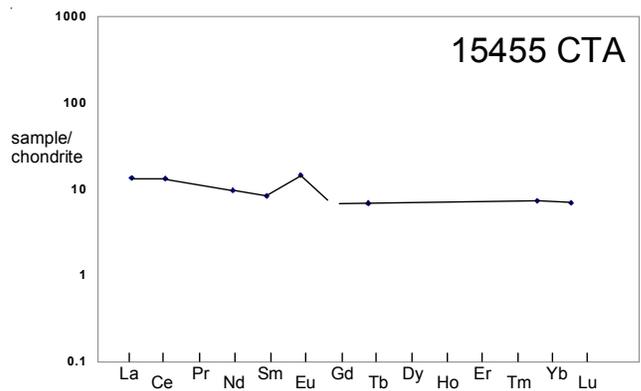


Figure 14: Normalized rare-earth-element diagram for egg-shaped troctolitic anorthosite clast (CTA) in 15455 (data by Warren and Wasson 1979).

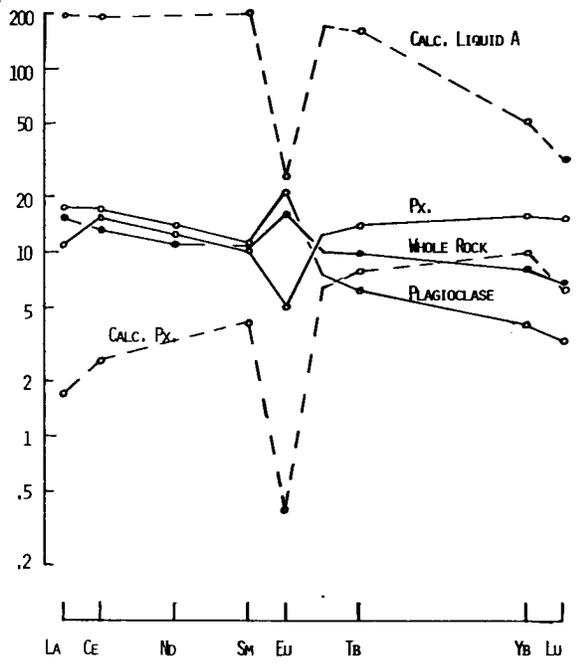


Figure 15: Trace element composition of 15455 (whole rock, plagioclase and pyroxene) and calculated composition of parent liquid (evolved). Blanchard and McKay 1980.

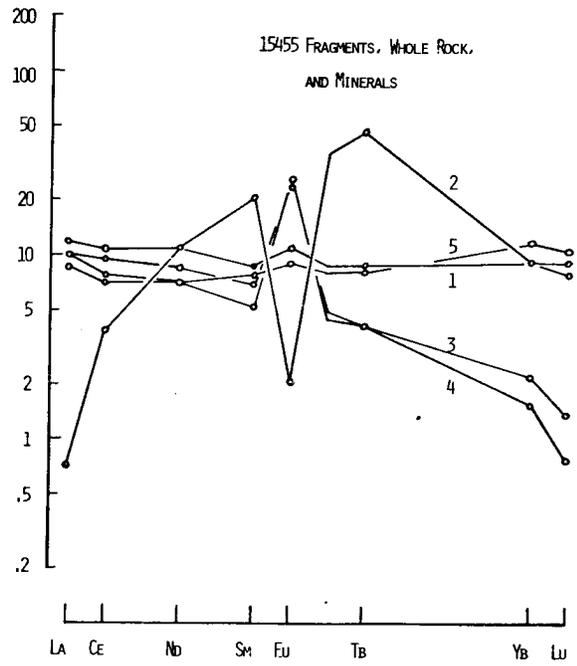


Figure 16: Trace element composition of 15455 (fragments 1 to 5) from Blanchard and McKay 1980.

**Mineralogy**

**Olivine:** Ryder and Bower (1977) and Spudis et al. (1991) find olivine ranges in composition Fo<sub>90-75</sub> in the matrix but Fo<sub>82</sub> in CTA (figure 10).

**Plagioclase:** Ryder and Bower (1977) showed plagioclase was An<sub>96-83</sub> in the matrix, but that it was An<sub>96-92</sub> in clasts CAN and CTA (figure 11).

**Metallic iron:** Hewins and Goldstein (1975) reported metal in norite clast with up to 10% Co.

**Chemistry**

Tables 1, 2 and 3 give the chemical composition of the matrix, and two largest clasts: the “norite” (CAN) and the “troctolite” (CTA).

Blanchard and McKay (1980) reported whole rock and mineral composition data for the cataclastic anorthositic norite clast (CAN) and determined that the parent liquid was already highly “evolved” when it formed (figure 15). Philpotts (unpublished), Shih et al. (1993) and Warren and Wasson (1980) analyzed the norite clast (CAN) finding similar results, but different from that of Taylor et al. (1973) (figure 13).

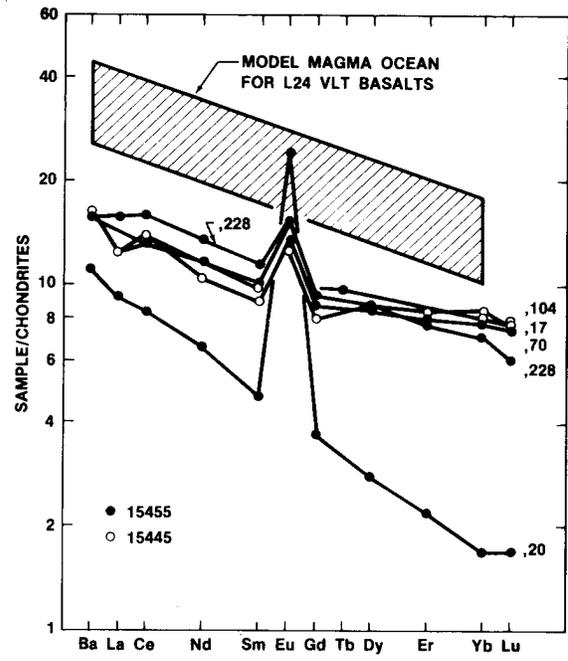


Figure 17: Comparison of 15455 norite and 15445 norites (from Nyquist et al. 1979).

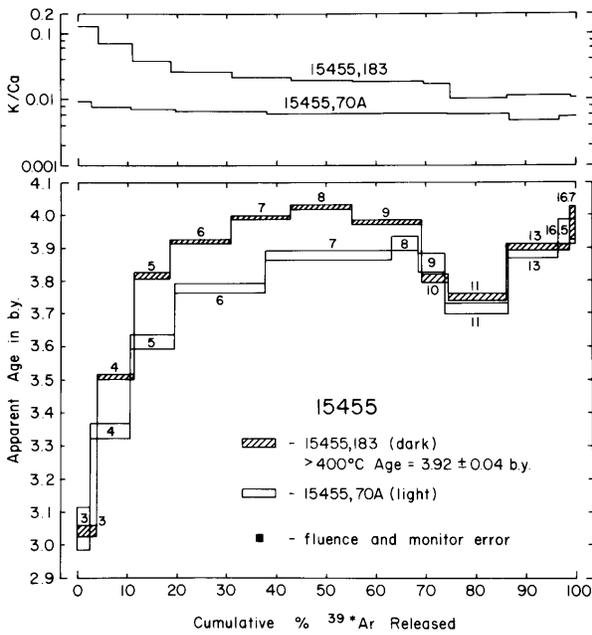


Figure 19: Ar/Ar plateau diagram for 15455 matrix and white clast (from Alexander and Kahl 1974).

Although the mineral mode and major element chemistry is different, Warren and Wasson (1979) found the CTA clast has a trace element signature similar to that of CAN (table 3, figure 14). Thus, this troctolitic anorthosite is related to the norite suite rather than the ferroan anorthosites (figure 11).

Taylor et al. (1972, 1973), Philpotts (unpublished) and Lindstrom et al. (1988) analyzed the matrix (Table 1, figure 12). Ganapathy et al. (1973) showed that matrix had high Ir and Au while Ganapathy et al. (1973) and Warren and Wasson (1979 and 1980) showed that the clasts were free of meteoritic tracers Ir and Au (hence termed “pristine”).

Lindstrom et al. (1988), Hertogen et al. (1977) and Nyquist et al. (1979) showed that the impact melt rock matrix of 15455 and that of 15445 were chemically similar (figure 17). It is thought the matrix represents ejecta from the Imbrium Basin.

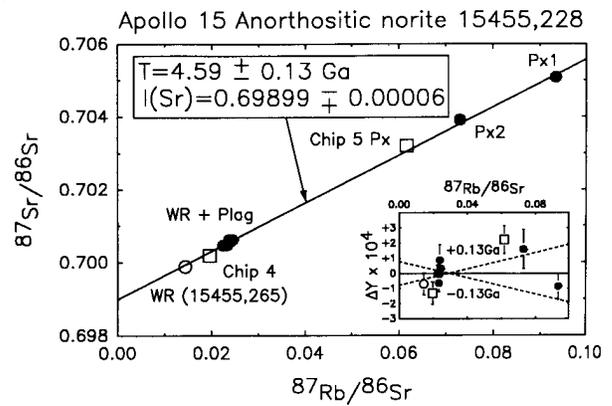


Figure 19: Rb/Sr mineral isochron for 15455,228 anorthositic norite clast (Shih et al. 1993).

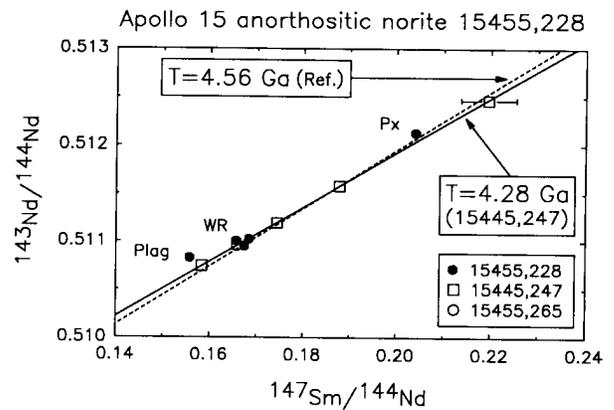


Figure 20: Nd/Sm mineral isochron for 15455,228 anorthositic norite clast (Shih et al. 1993).

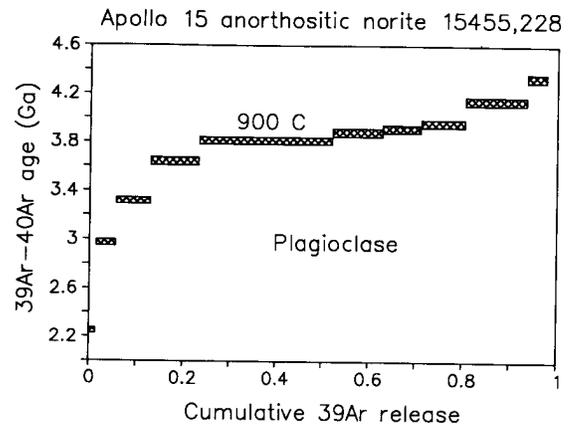


Figure 21: Ar/Ar plateau diagram for 15455,228 anorthositic norite clast (Shih et al. 1993).

### Summary of Age Data for 15455

	Ar/Ar	Rb/Sr	Nd/Sm
Alexander and Kahl 1974	3.94 ± 0.04 b.y. 3.82 ± 0.04		
Bernstein 1983	3.9 ± 0.25		
Shih et al. 1993	~ 3.9	4.59 ± 0.13	4.53 ± 0.29

**Table 1. Chemical composition of 15455 (matrix and whole).**

reference	Keith 73	black Taylor 73 ,14	dark ves Ganapathy 73 ,38	dark mx ,183	Philpotts Ryder85	Lindstrom 1988 ,258	,259	,260	
weight									
SiO2 %		47.3	(f)						
TiO2		1.35	(f)				1.71		(a)
Al2O3		17.1	(f)				16.3		(a)
FeO		8.79	(f)			9.53	9.79	9.66	(a)
MnO									
MgO		13.3	(f)				16.2		(a)
CaO		10.6	(f)				9.4		(a)
Na2O		0.58	(f)			0.552	0.548	0.527	(a)
K2O	0.128	(e) 0.17	(f)		0.143	(c) 0.14	<6		(a)
P2O5									
S %									
sum									
Sc ppm		13	(f)			17.3	17.9	17.8	(a)
V		39	(f)						
Cr		1800	(f)			1660	1700	1700	(a)
Co		22	(f)			32	38	39	(a)
Ni		184	(f)			260	330	350	(a)
Cu		3.3	(f)						
Zn				3.5	2.2	(d)			
Ga		3.3	(f)						
Ge ppb				385	456	(d)			
As									
Se				92	89	(d)			
Rb		2.7	(f)	2.2	2.7	(d) 2.91	(c)		
Sr						161	(c) 160	180	170
Y		93	(f)						
Zr		480	(f)			297	(c) 270	230	260
Nb		33	(f)						
Mo									
Ru									
Rh									
Pd ppb									
Ag ppb									
Cd ppb				2.3	2.5	(d)			
In ppb				0.34	0.35	(d)			
Sn ppb		220	(f)						
Sb ppb									
Te ppb				5.4	5.1	(d)			
Cs ppm		0.16	(f)	0.114	0.122	(d)	0.13	0.18	0.14
Ba		370	(f)			238	(c) 250	250	230
La		32	(f)				21.8	22	22.3
Ce		81	(f)			62	(c) 56.6	57	56.6
Pr		11.5	(f)						
Nd		47	(f)			38.6	(c) 33	36	36
Sm		12.8	(f)			10.6	(c) 10.3	10.3	10.3
Eu		1.82	(f)			1.91	(c) 1.87	1.85	1.81
Gd		15.5	(f)			12.6	(c)		
Tb		2.41	(f)				2.12	2.07	2.15
Dy		16	(f)			13.4	(c)		
Ho		3.76	(f)						
Er		10.7	(f)			7.74	(c)		
Tm		1.6	(f)						
Yb		9.8	(f)			6.85	(c) 6.9	6.45	6.45
Lu		1.5	(f)			1.08	(c) 0.95	0.93	0.95
Hf		9.8	(f)				8.12	7.84	7.76
Ta							1.01	1.04	1.03
W ppb									
Re ppb				0.63	0.41	(d)			
Os ppb									
Ir ppb				7	4.8	(d)	2	3.6	2.8
Pt ppb							2.2	3.2	2.4
Au ppb				5.8	4.6	(d)			
Th ppm	2	(e) 5.31	(f)				2.82	3.32	3.45
U ppm	0.53	(e) 1.37	(f)	0.875	0.715	(d)	0.75	0.62	0.65

technique: (a) INAA, (b) , (c) IDMS, (d) RNAA, (e) radiation counting, (f) ssms

**Table 2. Chemical composition of 15455 Norite Clast (CAN).**

reference weight	white		gabbro		C3					
	Taylor73	Ganapathy73	Philpotts (Ryder85)	Shih 93	Warren 80	Shih et al. 1993				
SiO <sub>2</sub> %	44.4	(f)			47.7	(b)				
TiO <sub>2</sub>	<0.07	(f)			0.1	(b)				
Al <sub>2</sub> O <sub>3</sub>	26.2	(f)			27	(b)				
FeO	4.2	(f)			2.91	(b)				
MnO					0.05	(b)				
MgO	10.9	(f)			6.96	(b)				
CaO	14.3	(f)			14.8	(b)				
Na <sub>2</sub> O	0.36	(f)			0.44	(b)				
K <sub>2</sub> O	<0.06	(f)	0.058	(c) 0.059	(c) 0.08	(b)				
P <sub>2</sub> O <sub>5</sub>										
S %										
sum										
Sc ppm		(f)			5.33	(a)				
V	16	(f)								
Cr	440	(f)			1180	(a)				
Co	10	(f)			27.2	(a)				
Ni	12	(f)			21	(a)				
Cu	1.3	(f)								
Zn			1.85	(d)	1	(a)				
Ga	2.6	(f)								
Ge ppb			9.4	(d)	56	(a)				
As										
Se			8.3	(d)						
Rb		(f) 1.1	(d) 1.09	(c) 1.13	(c)		1.133	1.065	1.104	(c)
Sr			124	(c) 138	(c)		137.9	126.5	134.8	(c)
Y	4.9	(f)								
Zr	11	(f)			70	(a)				
Nb	0.95	(f)								
Mo										
Ru										
Rh										
Pd ppb										
Ag ppb										
Cd ppb			1	(d)						
In ppb			0.05	(d)						
Sn ppb		(f)								
Sb ppb										
Te ppb			2.6	(d)						
Cs ppm		(f) 0.126	(d)							
Ba	42	(f)	58.7	(c) 59.7	(c) 125	(a)				
La	3	(f)		5.11	(c) 4.8	(a)				
Ce	6.7	(f)	10.5	(c) 12.6	(c) 11.8	(a)				
Pr	0.95	(f)								
Nd	3.73	(f)	6.66	(c) 7.79	(c) 7.4	(a)	5.368	6.584	6.248	(c)
Sm	0.88	(f)	1.86	(c) 2.13	(c) 1.74	(a)	1.495	1.804	1.729	(c)
Eu	1.67	(f)	1.03	(c) 1.07	(c) 1.38	(a)				
Gd	0.95	(f)	2.21	(c) 2.4	(c)					
Tb	0.14	(f)			0.35	(a)				
Dy	0.84	(f)	2.59	(c) 2.69	(c)					
Ho	0.17	(f)								
Er	0.46	(f)	1.64	(c) 1.61	(c)					
Tm	0.06	(f)								
Yb	0.36	(f)	1.65	(c) 1.48	(c) 1.22	(a)				
Lu	0.06	(f)	0.262	(c) 0.213	(c) 0.17	(a)				
Hf	0.17	(f)			0.67	(a)				
Ta					0.14	(a)				
W ppb										
Re ppb			0.0023	(d)	0.006	(a)				
Os ppb										
Ir ppb			0.002	(d)	0.02	(a)				
Pt ppb										
Au ppb			0.009	(d)	0.023	(a)				
Th ppm	0.05	(f)			0.59	(a)				
U ppm	0.23	(f) 0.195	(d)		0.18	(a)				

technique: (a) INAA, (b) fused bead, (c) IDMS, (d) RNAA, (e) radiation counting, (f) SSMS

**Table 3. Chemical composition of 15455 troctolite clast (CTA).**

reference	CTA Ganapathy 73 ,179	CTA Warren 79 ,106	CTA Shih 93 ,265
SiO <sub>2</sub> %		44.3	(b)
TiO <sub>2</sub>		0.08	(b)
Al <sub>2</sub> O <sub>3</sub>		21.9	(b)
FeO		5.79	(b)
MnO		0.07	(b)
MgO		16.1	(b)
CaO		11.6	(b)
Na <sub>2</sub> O		0.23	(b)
K <sub>2</sub> O		0.04	(b)
P <sub>2</sub> O <sub>5</sub>			
S %			
<i>sum</i>			
Sc ppm		4.1	(a)
V			
Cr		970	(a)
Co		25	(a)
Ni		26	(a)
Cu			
Zn	1.7	(d) 1.33	(a)
Ga		3.1	(a)
Ge ppb	11	(d) 14	(a)
As			
Se	9.6	(d)	
Rb	0.54	(d)	0.6087 (c)
Sr			122.1 (c)
Y			
Zr			
Nb			
Mo			
Ru			
Rh			
Pd ppb			
Ag ppb			
Cd ppb	0.91	(d) 2.9	(a)
In ppb	0.06	(d) 0.5	(a)
Sn ppb			
Sb ppb			
Te ppb	7.5	(d)	
Cs ppm	0.054	(d)	
Ba		77	(a)
La		3.2	(a)
Ce		8.1	(a)
Pr			
Nd		4.4	(a) 3.706 (c)
Sm		1.23	(a) 1.016 (c)
Eu		0.82	(a)
Gd			
Tb		0.25	(a)
Dy			
Ho			
Er			
Tm			
Yb		1.2	(a)
Lu		0.17	(a)
Hf		0.86	(a)
Ta		0.14	(a)
W ppb			
Re ppb	0.0058	(d) 0.01	(a)
Os ppb			
Ir ppb	0.024	(d) 0.024	(a)
Pt ppb			
Au ppb	0.042	(d) 1.9	(a)
Th ppm		0.58	(a)
U ppm	0.17	(d) 0.18	(a)

*technique: (a) INAA, (b) fused bead, (c) IDMS, (d) RNAA*

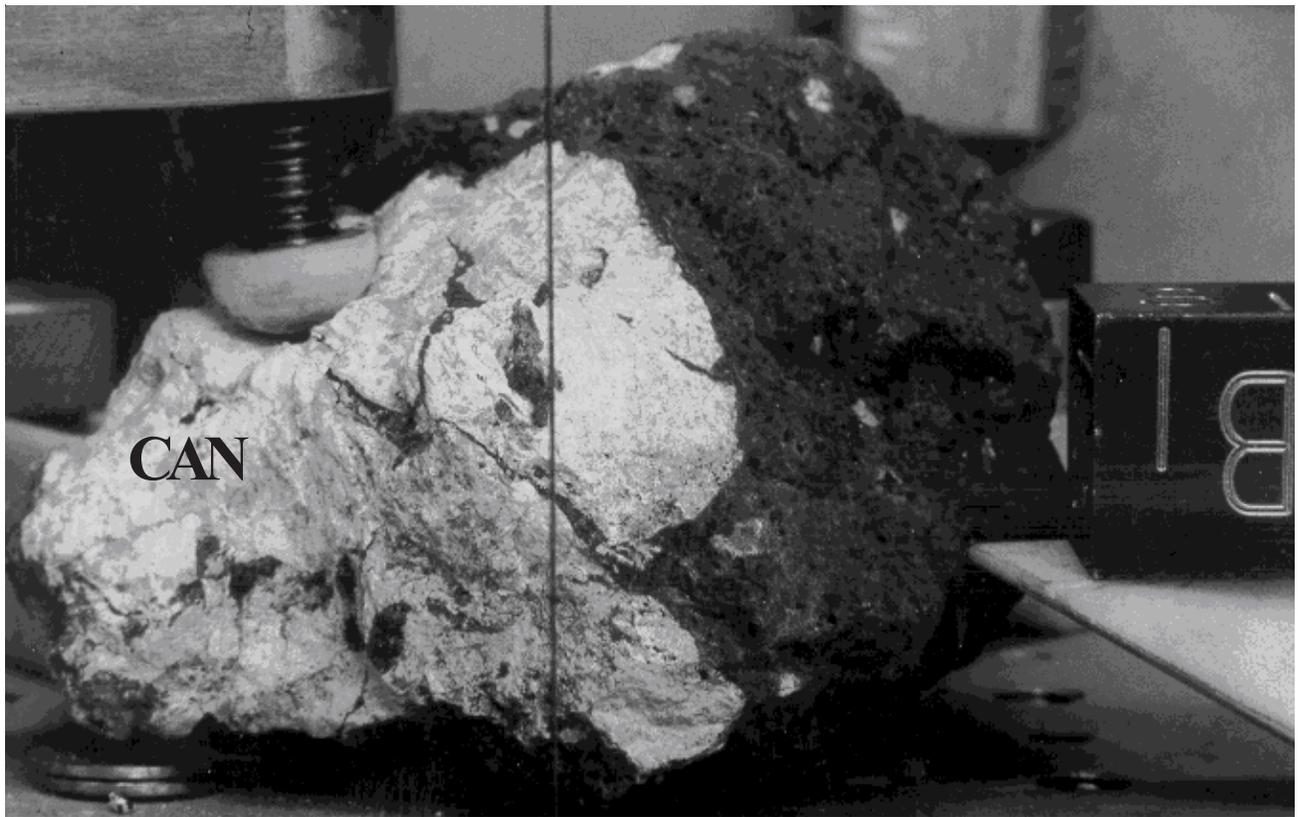
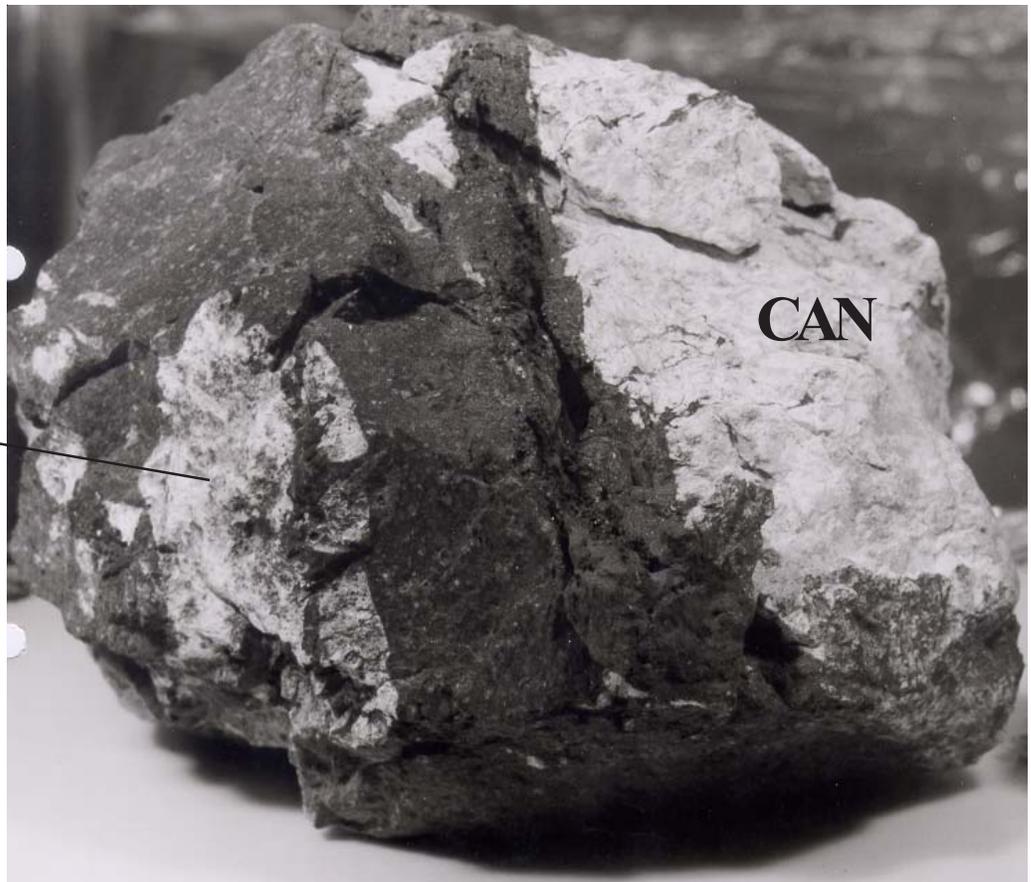


Figure 22: Sample 15455 as it was positioned for first saw cut to produce slab - see following figures. Cube is 1 inch. NASA S71-59598.

Figure 23: West end of 15455 showing large cataclastic anorthositic norite clast (CAN) and additional white clasts (XYZ). NASA S71-59172.

XYZ



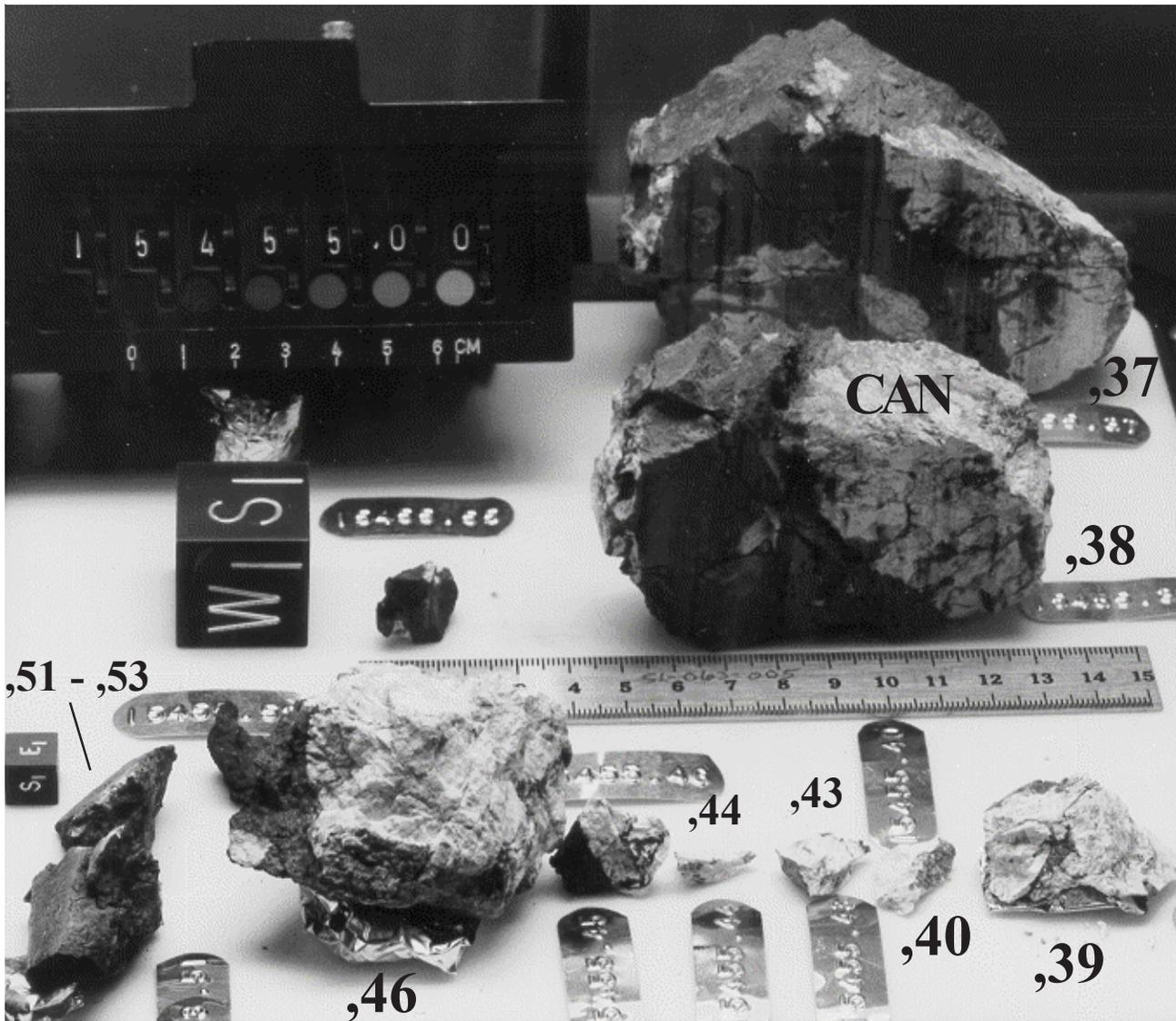


Figure 24: Group photo after sawing slab. Large cube is 1 inch, scale is in cm. NASA S71-60227.

### **Radiogenic age dating**

Shih et al. (1993) found that the norite clast was very old ( $4.59 \pm 0.13$ , figure 19). Shih et al. (1993) and Alexander and Kahl (1974) determined Ar/Ar plateau ages for the dark matrix (3.94 b.y.) and the light clast (3.82 b.y.) – inconsistent with textural relationships (figure 1). It is clear that the Ar/Ar age of the norite clast was partially reset.

Silver (1973) determined U, Th and Pb isotopes in both the matrix and the white clast (Table 5).

### **Cosmogenic isotopes and exposure ages**

Keith et al. (1973) determined the cosmic-ray-induced activity of  $^{22}\text{Na} = 42$  dpm/kg.,  $^{26}\text{Al} = 70$  dpm/kg.,  $^{54}\text{Mn} = 10$  dpm/kg.,  $^{56}\text{Co} = 6$  dpm/kg. and  $^{46}\text{Sc} = 5$  dpm/kg.

Alexander and Kahl (1974) determined  $^{38}\text{Ar}$  exposure age to be  $205 \pm 21$  m.y., while Bernstein (1983) determined 190 m.y.

### **Other Studies**

Cisowski et al. (1982)	magnetics
Housley et al. (1976)	magnetics
Epstein and Taylor (1972)	oxygen isotopes
Reed and Jovanovic (1972)	Cl, Br, Li
Jovanovic and Reed (1977)	
Modzeleski et al. (1972)	CO, CO <sub>2</sub> , CH <sub>4</sub>
Moore et al. (1973)	C
Heuer et al. (1972)	
Christie et al. (1973)	HEVM

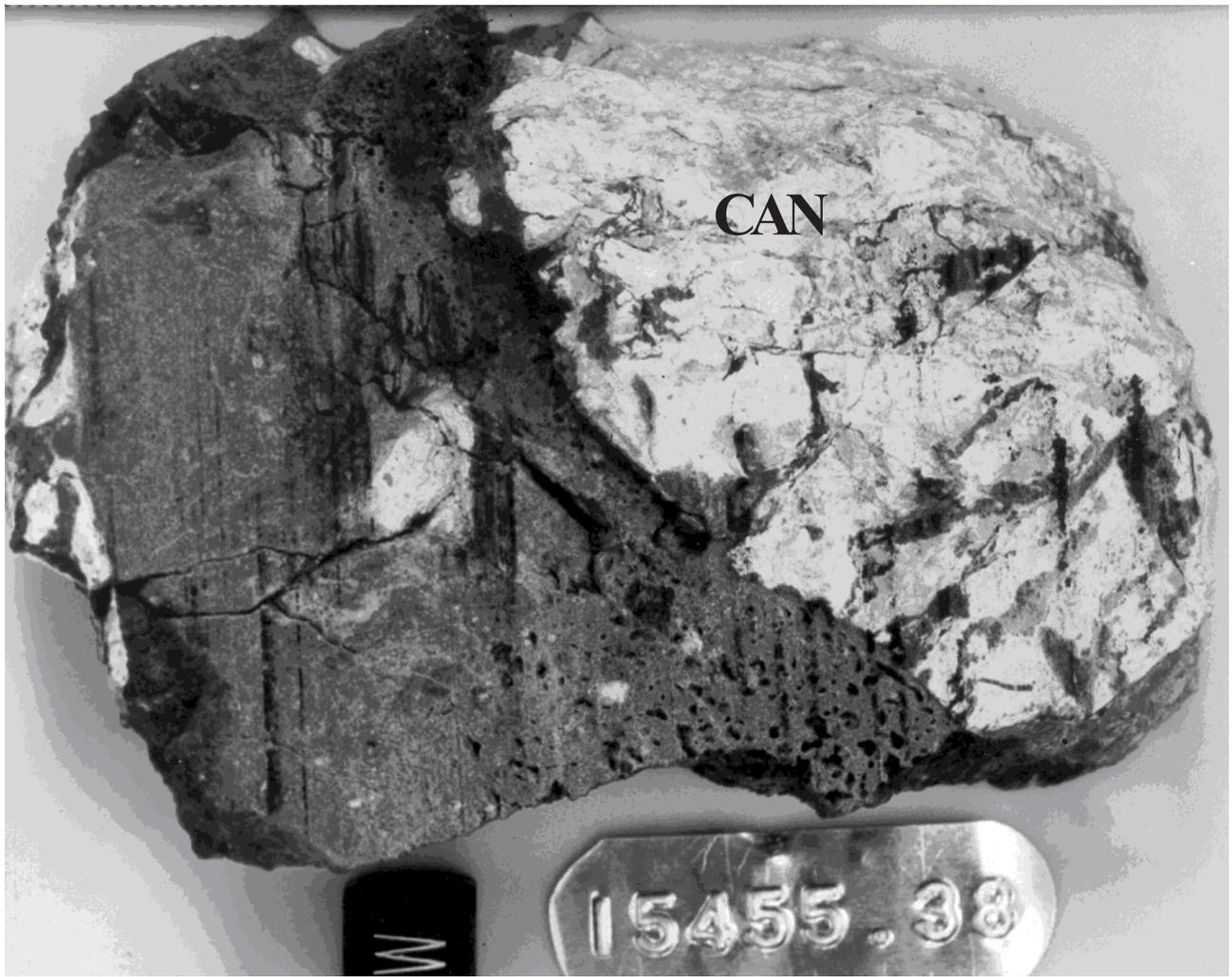


Figure 25: Sawn surface of slab (15455,38). NASA S71-60943. Cube is 1 cm.

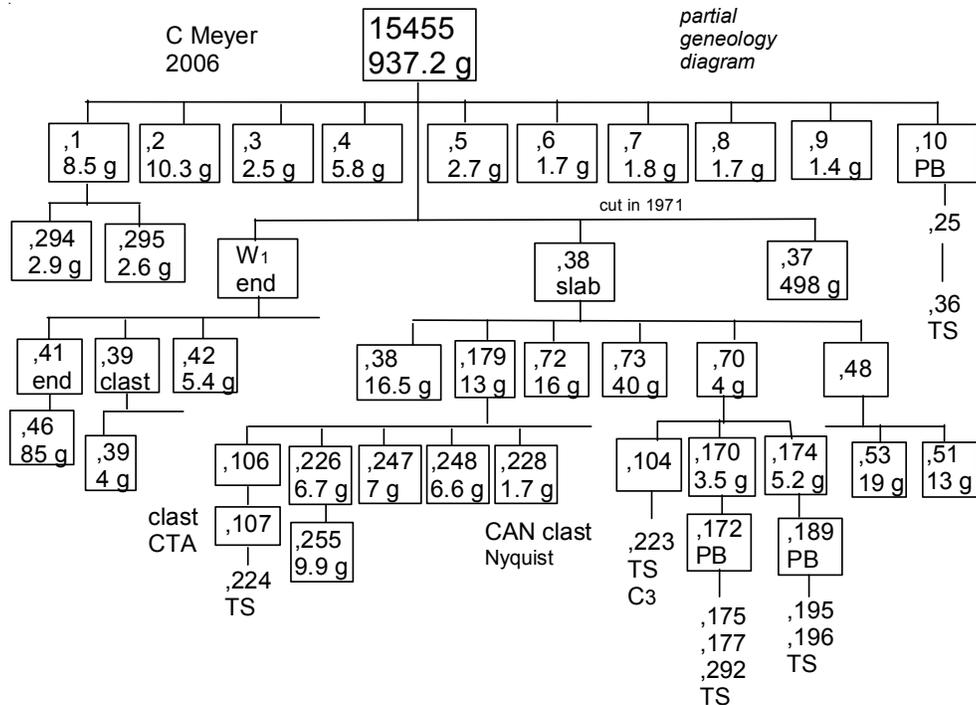




Figure 26: Opposite side of slab 15455,38 showing large anorthositic norite clast (CAN), egg-shaped troctolitic anorthosite (CTA) and clasts C, D, E, F (unstudied). NASA S71-59584. Cube is 1 inch.

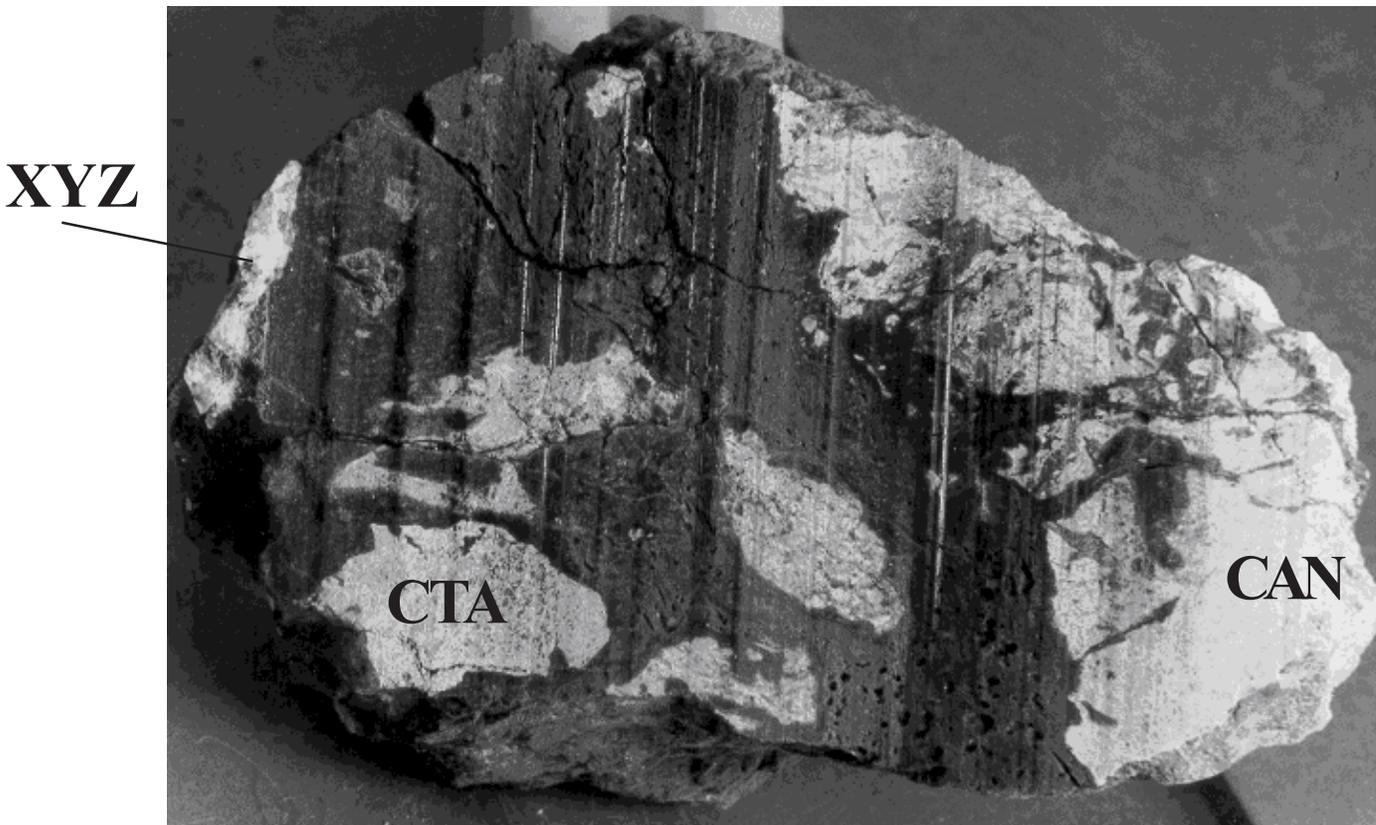


Figure 27 : Sawn surface of 15455,37 (butt end). NASA S71-59608. Note the saw marks.



Figure 28: Piece 15455,2. NASA S71-43895. Cube is 1 cm.



Figure 29: Piece 15455,4. 1 x 2.5 cm. NASA S71-44142.

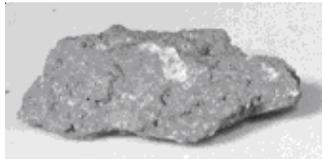


Figure 30: Piece 15455,5. 2 cm. NASA S71-44094.



Figure 31: Piece 15455,6. 1.5 cm. NASA S71-44146.



Figure 32: Piece of 15455,8. Cube is 1 cm. NASA S71-43919.



Figure 33: Piece of 15455,10. 1.5 cm. NASA S71-44084. (this piece used to make thin sections)



Figure 34: Piece 15455,12. NASA S71-44107. About 1 cm.



Figure 35: Piece of 15455,15. Cube is 1 cm. NASA S71-43899.

**Table 4. Thin sections of 15455.**

butt	Thin Sec.	butt	Thin Sec.	butt	Thin Sec.
,10	,25	,88	,169	,173	,176
	,26	,95	,162		,178
	,27		,166	,189	,195
	,28	,104	,223		,196
	,29	,106	,238	,236	,237
	,30	,107	,224		
	,31	,111	,233		
	,32		,235		
	,33	,112	,234		
	,34	,172	,175		
	,35		,177		
	,36		,292		
,86	,163				
	,167				
,87	,164				
	,168				
	,291				

### Processing

Numerous small pieces broke off of 15455 during return to Earth (figures 28 – 35). Additional pieces broke off while clamping down for the saw cut (figure 22). The sample broke up further during the second saw cut (figure 24).

Sawing exposed additional white clasts (figures 21 - 23). The egg-shaped clast CTA proved interesting. Sawing also showed the details of veining of the large norite clast (figure 21).

There are 34 thin sections of 15455 (table 4).

<b>Table 5</b>	clast	U ppm	Th ppm	K ppm	Rb ppm	Sr ppm	Nd ppm	Sm ppm	technique
Shih et al. 1993	CAN				1.133	137.9	5.368	1.495	idms
					1.065	126.5	6.584	1.804	idms
					1.104	134.8	6.248	1.729	idms
Silver 1973	CTA				0.6087	122.1	3.706	1.916	idms
	CAN	0.258	0.665						idms
	matrix	0.77	2.855						idms
Keith et a. 1973	whole	1.37	5.31						radiation counting

## References for 15455

- Alexander E.C. and Kahl S.B. (1974)  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  studies of lunar breccias. *Proc. 5<sup>th</sup> Lunar Sci. Conf.* 1353-1373.
- Arvidson R., Crozaz G., Drozd R.J., Hohenberg C.M. and Morgan C.J. (1975) Cosmic ray exposure ages of features and events at the Apollo landing sites. *The Moon* **13**, 259-276.
- Bailey N.G. and Ulrich G.E. (1975b) Apollo 15 voice transcript. USGS report # GD74-029.
- Bernstein M.L. (1983) 15445 and 15455: Origin and preliminary age data (abs). *Lunar Planet. Sci.* **XIV**, 33-34.
- Bersch M.G., Taylor G.J., Keil K. and Norman M.D. (1991) Mineral compositions in pristine lunar highland rocks and the diversity of highland magmatism. *Geophys. Res. Lett.* **18**, 2085-2088.
- Blanchard D.P. and McKay G.A. (1980) Remnants from the ancient lunar crust II: Norite 15455 (abs). *Lunar Planet. Sci.* **XI**, 82-84.
- Butler P. (1971) Lunar Sample Catalog, Apollo 15. Curators' Office, MSC 03209
- Christie J.M., Griggs D.T., Heuer A.H., Nord G.L., Radcliffe S.V., Lally J.S. and Fischer R.M. (1973) Electron petrography of Apollo 14 and 15 breccias and shock-produced analogs. *Proc. 4<sup>th</sup> Lunar Sci. Conf.* 365-382.
- Cisowski S.M., Collinson D.W., Runcom S.K., Stephenson A. and Fuller M. (1983) A review of lunar paleointensity data and implications for the origin of lunar magnetism. *Proc. 13<sup>th</sup> Lunar Planet. Sci. Conf.* A691-A704.
- Drozd R.J., Kennedy B.M., Morgan C.J., Podosek F.A. and Taylor G.J. (1976) The excess fission Xenon problem in lunar samples. *Proc. 7<sup>th</sup> Lunar Sci. Conf.* 599-623.
- Gros J., Takahashi H., Hertogen J., Morgan J.W. and Anders E. (1976) Composition of the projectiles that bombarded the lunar highlands. *Proc. 7<sup>th</sup> Lunar Sci. Conf.* 2403-2425.
- Hertogen J., Janssens M.-J., Takahashi H., Palme H. and Anders E. (1977) Lunar basins and craters: Evidence for systematic compositional changes of bombarding population. *Proc. 8<sup>th</sup> Lunar Sci. Conf.* 17-45.
- Herzberg C.T. (1978) The bearing of spinel cataclasites on the crust-mantle structure of the Moon. *Proc. 9<sup>th</sup> Lunar Planet. Sci. Conf.* 319-336.
- Herzberg C.T. and Baker M.B. (1980) The cordierite-to-spinel-cataclasite transition: Structure of the lunar crust. *Proc. Conf. Lunar Highlands Crust. Geochim. Cosmochim. Acta, Suppl. 12.* Pergamon Press. 113-132. Lunar Planetary Institute, Houston.
- Hewins R.H. and Goldstein J.I. (1975a) The provenance of metal in anorthositic rocks. *Proc. 6<sup>th</sup> Lunar Sci. Conf.* 343-362.
- James O.B. (1980) Rocks of the early lunar crust. *Proc. 11<sup>th</sup> Lunar Planet. Sci. Conf.* 365-393.
- Keith J.E., Clark R.S. and Richardson K.A. (1972) Gamma-ray measurements of Apollo 12, 14 and 15 lunar samples. *Proc. 3<sup>rd</sup> Lunar Sci. Conf.* 1671-1680.
- Lindstrom M.M., Marvin U.B., Vetter S.K. and Shervais J.W. (1988) Apennine front revisited: Diversity of Apollo 15 highland rock types. *Proc. 18<sup>th</sup> Lunar Planet. Sci. Conf.* 169-185. Lunar Planetary Institute, Houston.
- LSPET (1972a) The Apollo 15 lunar samples: A preliminary description. *Science* **175**, 363-375.
- LSPET (1972b) Preliminary examination of lunar samples. Apollo 15 Preliminary Science Report. NASA SP-289, 6-1—6-28.
- Moore C.B., Lewis C.F. and Gibson E.K. (1973) Total carbon contents of Apollo 15 and 16 lunar samples. *Proc. 4<sup>th</sup> Lunar Sci. Conf.* 1613-1923.

- Nyquist L.E., Reimold W.U., Wooden J.L., Bansal B.M., Wiesmann H. and Shih C.-Y. (1981a) Sr and Nd cooling ages of cumulate norite 78236 (abs). *Lunar Planet. Sci. XII*, 782-784. Lunar Planetary Institute, Houston.
- Philpotts in Ryder 1985
- Phinney W.C., Warner J.L. and Simonds C.H. (1977) Petrologic evidence for formation and solidification of impact melts (abs). *Lunar Sci. VIII*, 770-772. Lunar Planetary Institute, Houston.
- Reid A.M., Duncan A.R. and Richardson S.H. (1977) In search of LKFM. *Proc. 8<sup>th</sup> Lunar Sci. Conf.* 2321-2338.
- Ryder G. (1985) Catalog of Apollo 15 Rocks (three volumes). Curatorial Branch Pub. # 72, JSC#20787
- Ryder G. and Bower J.F. (1977) Petrology of Apollo 15 black-and-white rocks 15445 and 15455: Fragments of the Imbrium impact melt sheet? *Proc. 8<sup>th</sup> Lunar Sci. Conf.* 1895-1923.
- Ryder G. and Wood J.A. (1977) Serenitatis and Imbrium impact melts: Implications for large-scale layering in the lunar crust. *Proc. 8<sup>th</sup> Lunar Sci. Conf.* 655-688.
- Ryder G. and Norman M.D. (1979a) Catalog of pristine non-mare materials Part 1. Non-anorthosites, revised. NASA-JSC Curatorial Facility Publ. JSC 14565, Houston. 147 pp.
- Shih C.-Y., Nyquist L.E., Dash E.J., Bogard D.D., Bansal B.M. and Wiesmann H. (1993) Ages of pristine noritic clasts from lunar breccias 15445 and 15455. *Geochim. Cosmochim. Acta* **57**, 915-931.
- Silver L.T. (1973a) Uranium-Thorium-Lead isotopic relations in the remarkable debris blanket at Hadley-Apennine (abs). *Lunar Sci. IV*, 670-671. Lunar Planetary Institute, Houston.
- Steele I.M. and Smith J.V. (1975) Minor elements in lunar olivine as a petrologic indicator. *Proc. 6<sup>th</sup> Lunar Sci. Conf.* 451-467.
- Spudis P.D., Ryder G., Taylor G.J., McCormick K.A., Keil K. and Grieve R.A.F. (1991) Sources of mineral fragments in impact melts, 15445 and 15455: Toward the origin of low-K Fra Mauro basalt. *Proc. 21<sup>st</sup> Lunar Planet. Sci. Conf.* 151-165. Lunar Planetary Institute, Houston.
- Swann G.A., Hait M.H., Schaber G.C., Freeman V.L., Ulrich G.E., Wolfe E.W., Reed V.S. and Sutton R.L. (1971b) Preliminary description of Apollo 15 sample environments. U.S.G.S. Interagency report: 36. pp219 with maps
- Swann G.A., Bailey N.G., Batson R.M., Freeman V.L., Hait M.H., Head J.W., Holt H.E., Howard K.A., Irwin J.B., Larson K.B., Muehlberger W.R., Reed V.S., Rennilson J.J., Schaber G.G., Scott D.R., Silver L.T., Sutton R.L., Ulrich G.E., Wilshire H.G. and Wolfe E.W. (1972) 5. Preliminary Geologic Investigation of the Apollo 15 landing site. In Apollo 15 Preliminary Science Rpt. NASA SP-289. pages 5-1-112.
- Taylor S.R., Gorton M., Muir P., Nance W., Rudowski R. and Ware N. (1972b) Composition of the lunar highlands II The Apennine Front. In **The Apollo 15 Lunar Samples**, 262-264. Lunar Planetary Institute, Houston.
- Unruh D.M. and Tatsumoto M. (1976) KREEP basalt intrusion age: U-Th-Pb systematic of Imbrium Consortium samples (abs). *Lunar Sci. VII*, 885-887.
- Warren P.H. and Wasson J.T. (1978) Compositional-petrographic investigation of pristine nonmare rocks. *Proc. 9<sup>th</sup> Lunar Planet. Sci. Conf.* 185-217.
- Warren P.H. and Wasson J.T. (1979) The compositional-petrographic search for pristine nonmare rocks: Third foray. *Proc. 10<sup>th</sup> Lunar Planet. Sci. Conf.* 583-610.
- Warren P.H. and Wasson J.T. (1980) Further foraging of pristine nonmare rocks: Correlations between geochemistry and longitude. *Proc. 11<sup>th</sup> Lunar Planet. Sci. Conf.* 431-470.
- Wiesmann H. and Hubbard N.J. (1975) A compilation of the Lunar Sample Data Generated by the Gast, Nyquist and Hubbard Lunar Sample PI-Ships. Unpublished. JSC
- Wilshire, Morrison, Brett in Butler 1971
- Wood J.A. and a cast of 28 others (1977) Interdisciplinary studies by the Imbrium Consortium. Two volumes. Pink and Green literature.