67016

Feldspathic Fragmental Breccia

4262 grams

Figure 1: Photo of 67016,1. Cube is 1 inch. NASA # S81-26050.

Introduction

67016 is a feldspathic fragmental breccia with both light and dark clasts (figures 1 and 17) collected from the lip of North Ray Crater (Ulrich 1973; Muehlberger et al. 1980). This large rock is thought to be analogous to terrestrial suevite (impact breccia). It is *not* a regolith breccia, because it has relatively low Ni, Ir and Au, low rare gas content and low maturity (I_s/FeO).

67016 is 3.95 b.y. old with an exposure age of 50 m.y. (the apparent age of North Ray Crater). It contains, as a plutonic igneous clast, the oldest lunar sample dated (4.56 b.y.). It also contains a trace-element-rich clast termed “sodic ferrogabbro” as well as numerous other lithic clasts.

The breccias from North Ray Crater are diverse in nature; as are the clasts in 67016 (Lindstrom and Salpas 1983).

Petrography

Nord et al. (1975) describe 67016 as a porous breccia with dark-lithic clasts and lighter plagioclase fragments. The porous light-colored matrix that envelopes the clasts consist mostly of plagioclase with minor pyroxene and olivine. Ilmenite is polycrystalline and heavily deformed. Nord et al. reported that “small 100 micron granitic fragments were very common in the matrix and have reacted with the matrix to produce narrow pyroxene reaction rims”.

Figure 2: 67016 on the Moon. AS16-116-18659

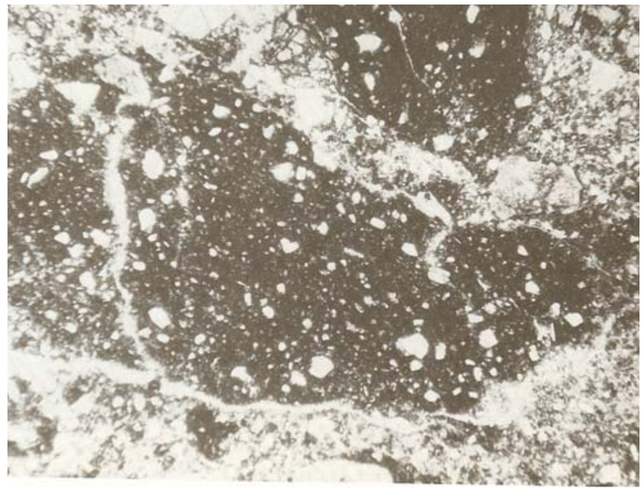


Figure 3: Photomicrgraph if thin section of 67016 showing "breccia-in-breccia" texture. Norman (1981) likened this to "suevite" often found at terrestrial craters.

Norman (1981) provided an overview of the petrography of 67016 and determined that it is analogous to a terrestrial suevite. It is a light-gray breccia with approximately 20% dark melt clasts and 10% white lithic clasts (2 to 5 cm) and scattered single grains of plagioclase, mafic minerals and rare opaques set in a fine-grained, seriate matrix. It has a breccias-in-breccia texture (figure 3) with numerous light and dark clasts (figure 4). The lithic clasts include feldspathic granulitic impactite, ferroan anorthosite, subophitic impact melt and a variety of other types. According to Norman (1981), the matrix around metal grains in 67016 is stained a dull orange (rust?). Hunter and Taylor (1981) also reported abundant rust(?) on metal grains in 67016.

Figure 2 shows 67016 perched in the rim of North ray Crater. Micrometeorite craters and surface patina are reported on unabraded exterior surfaces (Ryder and Norman 1980 and Norman and Garcia 1981) and indicate that the rock was "tumbled" on the lunar surface.

Takeda et al. (1990) compared 67016 with lunar meteorite Y86032.

Norman et al. (1991) and Norman and Taylor (1992) describe sodic noritc anorthosite clasts in 67016. One of these (,326/8) was dated to be very old (Alibert et al. 1994).

Lindstrom and Salpas (1981) analyzed a unique clast they termed "sodic ferrogabbro". Norman (1981) terms this material "ilmenite-silica" gives the mode and mineral compositions.

Mineralogy

Olivine: The olivine in 67016 ranges in composition from Fo_{58} to Fo_{78} (figure 5).

Ilmenite: Nord et al. (1975) found that minor ilmenite in 67016 was "polycrystalline".

Plagioclase: Norman (1981) determined the composition of numerous plagioclase grains in the matrix, melt breccia, granulitic clasts and plutonic clasts (figure 6). The plutonic clasts were An_{95-98} while matrix etc. ranged from An_{82-98}.

Pyroxene: Norman (1981) and Takeda et al. (1990) determined the composition of pyroxene grains in clasts and matrix of 67016 (figure 5).

Metallic Iron: Hunter and Taylor (1981) reported iron grains with rust (?)

Chemistry

Norman and Taylor (1992) determined the composition of many units and clasts in 67016. Note that their analyses for K, U and Th for a bulk sample (2.2 grams) agrees with the radiation counting by Eldridge et al. (1975) for a 482 gram piece (table 1a). They also give

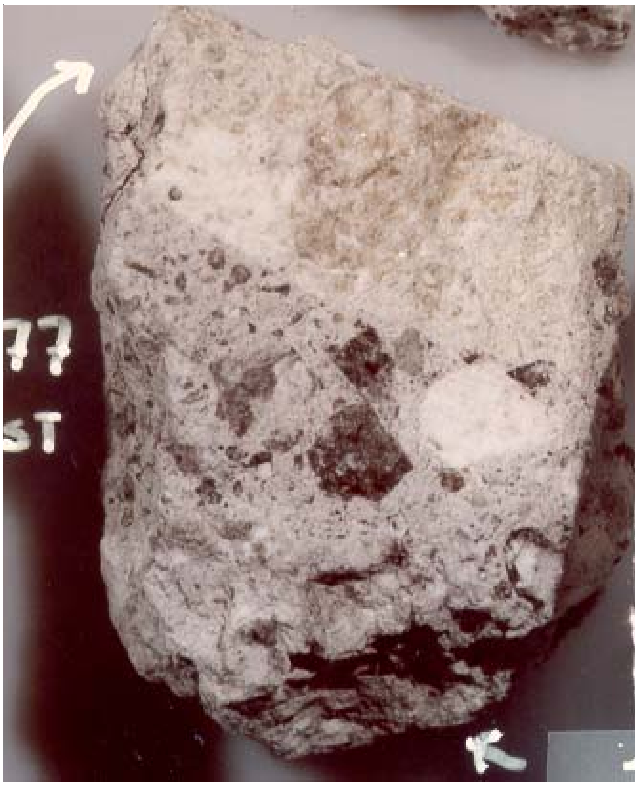


Figure 4: Photo of clasts and matrix in 67016,277. NASA # S82-27849. Size of clast is about 1.5 cm. Bother light and dark clasts are included in light grey matrix.

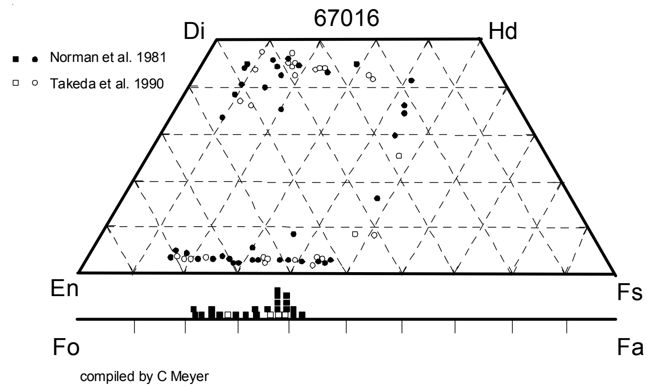


Figure 5: Pyroxene and olivine compositon of clasts in 67016 (from Norman 1981 and Takeda et al. 1990).

an analysis of the ferroan noritic anorthosite clast that they dated (,326/8). Lindstrom and Salpas (1983) also analyzed a large number of splits of 67016 (table 1b), including a rare-earth-rich "sodic ferrogabbro clast" (,289, figure 7).

Gibson and Chang (1974) found a trace of carbonate in 67016 by temperature release (figure 9) and determined the isotopic composition of carbon and oxygen. However Gibson and Andrawes (1978) only found nitrogen by crushing.

Meteoritic siderophiles are moderately abundant (Ir = 1-3 ppm), but less than for a regolith breccia (Hertogen et al. 1977).

Radiogenic age dating

Turner and Cadogen (1975) and Alibert et al. (1994) have dated materials from 67016. Turner and Cadegen determined an age of 3.95 ± 0.07 b.y. for a dark clast (figure 10) while Alibert et al. found that a ferroan noritic anorthosite clast was as old as 4.562 ± 0.068 b.y. (figure 11).

Cosmogenic isotopes and exposure ages

Turner and Cadogen (1975) determined an ^{38}Ar-^{37}Ar exposure age of 50 m.y. Eldridge et al. (1975) reported the cosmic-ray induced activity for ^{26}Al = 88 dpm/kg., ^{22}Na = 35dpm/kg. and ^{54}Mn = 15 dpm/kg. Bhandari et al. (1973) reported track densities and a "suntan age" of about 1 m.y. and calculate that 67016 has spent less than 15 m.y. within the top 10 cm of the lunar regolith.

Indeed, North Ray Crater has been shown to be ~ 50 m.y. old!

Other Studies

Pearce et al. (1973) determined the magnetic properties and found fairly stable remenant magnetization.

Housley et al. (1976) found that this rock did not have significant intensity of FMR (I_s/FeO).

Mineralogical Mode

	Norman 1981
Mineral Fragments	
Plagioclase	33 vol. %
Mafic	3
Opaques	1
Melt breccia clasts	23
Rock Clasts	11
Matrix	29
Other	1

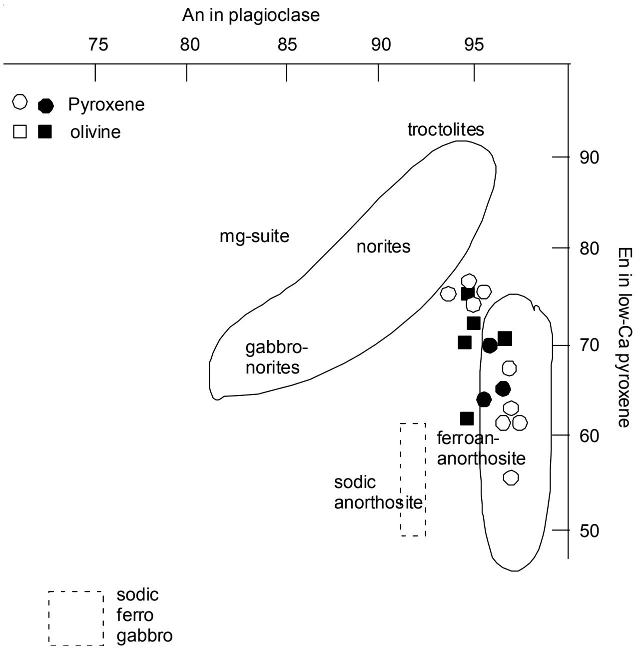


Figure 6: Composition of plagioclase and mafic minerals in clasts in 67016 (from Norman 1981, Takeda et al. 1990, Norman et al. 1991). Trends are from Paul Warren and/orOdette James.

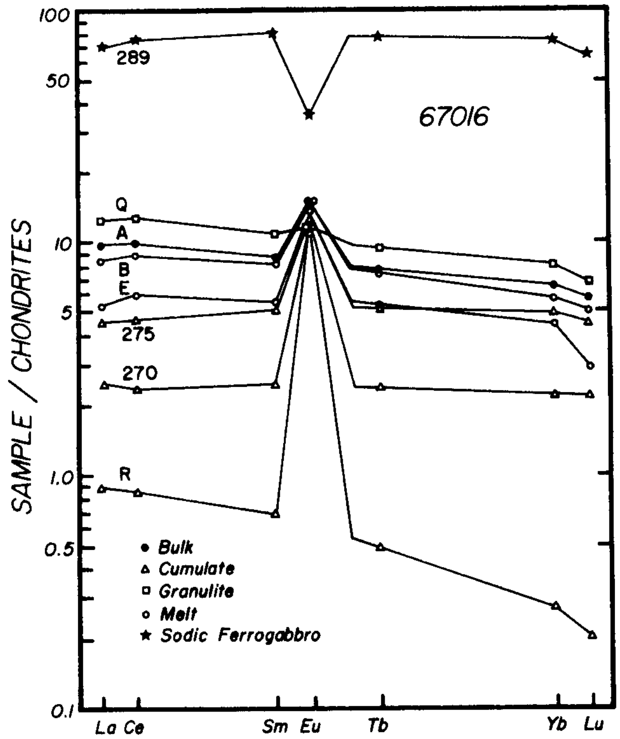


Figure 7: Normalized rare-earth-element diagram for clasts and "bulk" in 67016 studied by Lindstrom and Salpas 1983.

Processing

Ryder and Norman (1980) summarized the analytical work to that time. Norman and Garcia (1981) described the pieces of 67016 in "guidebook #5" and give a full genealogy diagram. This rock sample was never sawn for fear of Pb contamination. Instead the sample was "picked apart", much like a communion loaf. 67016,1 is currently 2500 grams big – and ready for more work!

67016 was returned, along with 61016, in the big bag called the BSLSS. There were 360 grams of fines in the residue of this bag. Imagine the confusion! There are 43 thin sections of 67016.

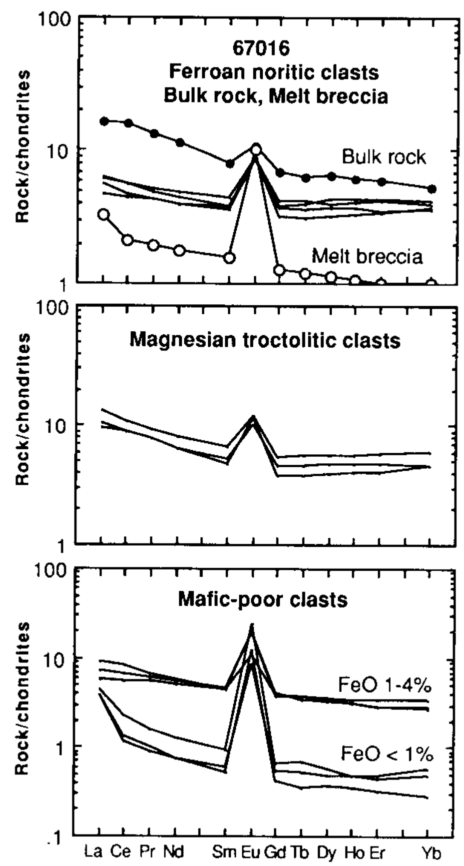


Figure 8: Normalized rare-earth-element diagram for clasts in 67016 studied by Norman and Taylor 1992.

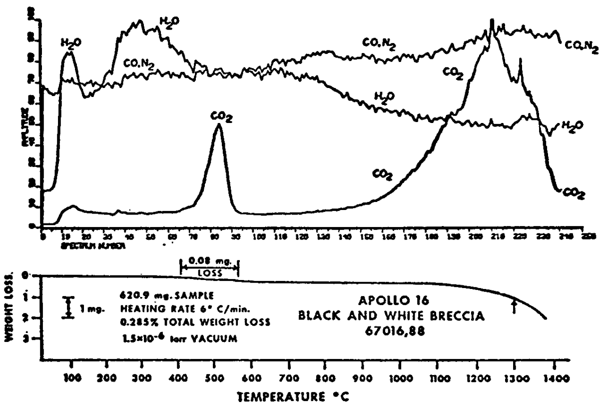


Figure 9: Gas release curves for 67016 (from Gibson and Chang 1974).

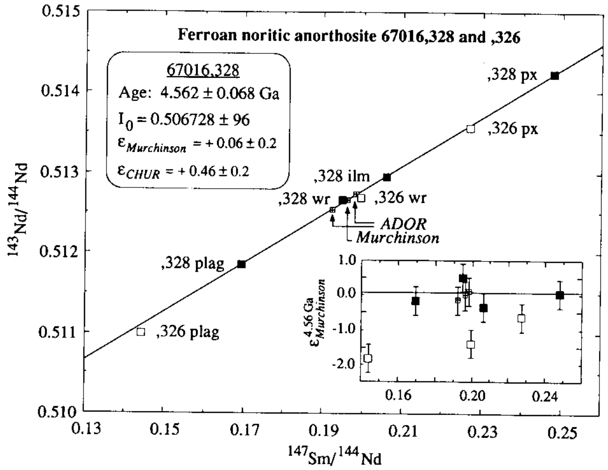


Figure 11: Sm/Nd isochron for ferroan noritic anorthosite clast in 67016 (from Alibert et al. 1994).

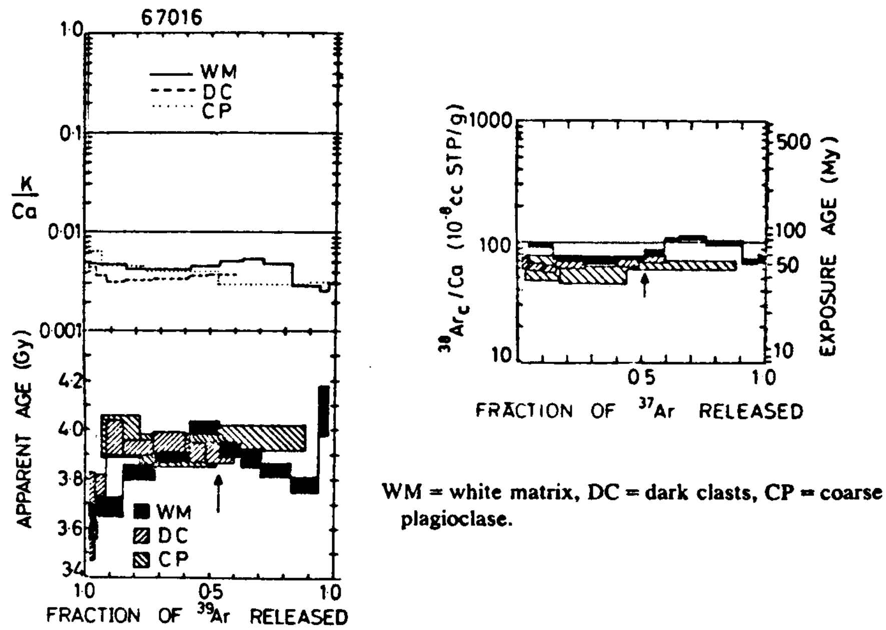


Figure 10: Argon plateau age for the dark clasts in 67016 and for "coarse plagioclase" (from Turner and Cadogen 1975).

Summary of Age Data for 67016

	Nd/Sm	Ar/Ar	
Turner and Cadogen 1975		3.95 ± 0.07 b.y.	dark clast
		3.95 ± 0.07	plag.
Alibert et al. 1994	4.562 ± 0.068		ferroan noritic anorthosite clast

Table 1a. Chemical composition of 67016.

reference	Duncan 73		Brunfeldt 73		Taylor 74		Wanke 76		Garg 76		Hertogen 77				Eldridge 75		Lindstrom81	
weight															482 g		bulk	
SiO2 %	45.25	(a)			44.9	(d)	44.8	(b)										
TiO2	0.44	(a)			0.22	(d)	0.35	(b)										
Al2O3	30.01	(a)	30.9	(b)	30.1	(d)	28.2	(b)										
FeO	3.57	(a)	3.7	(b)	3.45	(d)	3.94	(b)	3.92	(b)							3.55	(b)
MnO	0.051	(a)	0.05	(b)			0.05	(b)										
MgO	3.5	(a)	6.8	(b)	3.7	(d)	4.34	(b)										
CaO	16.85	(a)	16.1	(b)	16.8	(d)	16.73	(b)									15.8	(b)
Na2O	0.48	(a)	0.55	(b)	0.47	(d)	0.49	(b)									0.508	(b)
K2O	0.06	(a)			0.06	(d)	0.04	(b)							0.058	(f)		
P2O5	0.072	(a)					0.02	(b)										
S %	0.006	(a)					0.019	(b)										
sum																		
Sc ppm			6.9	(b)	10	(c)	6.57	(b)	7.36	(b)							6.67	(b)
V			50	(b)	23	(c)												
Cr			440	(b)			540	(b)	383	(b)							448	(b)
Co			7.4	(b)	15	(c)	10.4	(b)	8.77	(b)							6.5	(b)
Ni	36.7	(a)	65	(b)	110	(c)	100	(b)			14	182	58	(e)			66	(b)
Cu					3	(c)												
Zn	4.1	(a)									0.75	5.59	9.13	(e)				
Ga																		
Ge ppb											6.7	77	11.6	(e)				
As																		
Se											19.2	16.6	12.6	(e)				
Rb	1.1	(a)	0.9	(b)	0.71	(c)					0.34	0.66	1.11	(e)				
Sr	191	(a)	170	(b)			162	(b)									182	(b)
Y	15.5	(a)			15	(c)	16	(b)										
Zr	62.5	(a)			48	(c)	46	(b)	77.1	(b)								
Nb	4.5	(a)			4.12	(c)												
Mo																		
Ru																		
Rh																		
Pd ppb											1.3	2.09	1.93	(e)				
Ag ppb											0.75	0.69	0.68	(e)				
Cd ppb											0.49	1.34	0.56	(e)				
In ppb											0.65	0.53	0.46	(e)				
Sn ppb																		
Sb ppb											0.2	0.26	0.12	(e)				
Te ppb											89	42	52	(e)				
Cs ppm					0.04	(c)					11.2	20.4	38.8	(e)				
Ba	67	(a)	65	(b)	69	(c)	60	(b)									63	(b)
La			3.1	(b)	4.52	(c)	3.76	(b)									3.22	(b)
Ce			8.7	(b)	12.1	(c)	10.1	(b)	16.7	(b)							9.03	(b)
Pr					1.54	(c)												
Nd					6.25	(c)	7.6	(b)										
Sm			1.98	(b)	1.82	(c)	1.64	(b)									1.57	(b)
Eu			0.86	(b)	1	(c)	1.06	(b)	1.04	(b)							1.07	(b)
Gd					2.42	(c)												
Tb			0.35	(b)	0.37	(c)	0.33	(b)	0.55	(b)							0.365	(b)
Dy					2.51	(c)	2.11	(b)										
Ho					0.59	(c)												
Er					1.66	(c)												
Tm					0.26	(c)												
Yb			1.5	(b)	1.6	(c)	1.35	(b)									1.33	(b)
Lu			0.26	(b)	0.25	(c)	0.19	(b)									0.192	(b)
Hf			1.5	(b)	1.36	(c)	1.16	(b)	1.65	(b)							1.38	(b)
Ta			0.14	(b)			0.18	(b)									0.195	(b)
W ppb																		
Re ppb											0.06	0.262	0.2	(e)				
Os ppb											2.71	3.26	2.38	(e)				
Ir ppb							10	(b)			1.14	2.9	2.31	(e)				
Pt ppb																		
Au ppb							4.8	(b)			0.08	1.01	0.46	(e)				
Th ppm			0.5	(b)	0.73	(c)	0.53	(b)							0.69	(f)	0.58	(b)
U ppm			0.19	(b)	0.17	(c)					0.09	0.216	0.27	(e)	0.2	(f)	0.16	(b)

technique: (a) XRF, (b) INAA, (c) SSMS, (d) e. probe, (e) RNAA, (f) radiation counting

Table 1b. Chemical composition of 67016.

	bulk	**sodic ferrogabbro clast**					
reference	Lindstrom and Salpas 1983 (b)						
weight	82.4 mg	**,289**	melt rock	anorthosite	Mg rich	Fe rich	granulite
SiO2 %			average (8)	average (5)	average (2)	average (2)	average (7)
TiO2							
Al2O3	29.4	17.4	31.3	35	31.3	22.9	27.7
FeO	3.55	9.79	3.7	0.9	2.6	8.5	4.7
MnO							
MgO	3.5	4.8	3	1	2.8	6.8	7.8
CaO	16	15	18	19.7	17.1	14.75	15.3
Na2O	0.51	0.765	0.53	0.38	0.49	0.28	0.45
K2O							
P2O5							
S %							
sum							
Sc ppm	6.67	36.9	7.4	1.5	5.4	21	6
V							
Cr	448	257	474	97	319	1040	700
Co	6.5	8.33	9.5	0.7	2.09	6.6	25
Ni	60	100	58			34	260
Cu							
Zn							
Ga							
Ge ppb							
As							
Se							
Rb							
Sr	182	170	164	171	193	130	170
Y							
Zr							
Nb							
Mo							
Ru							
Rh							
Pd ppb							
Ag ppb							
Cd ppb							
In ppb							
Sn ppb							
Sb ppb							
Te ppb							
Cs ppm							
Ba	63	375	38	40	37	33	70
La	3.22	23.3	2.2	0.9	1.3	1.4	4.2
Ce	9.03	66	5.8	2.5	3.3	4	11.4
Pr							
Nd							
Sm	1.57	14.7	1.1	0.42	0.6	0.96	1.95
Eu	1.07	2.41	1	0.86	1	0.75	1.04
Gd							
Tb	0.365	3.95	0.28	0.09	0.14	0.27	0.45
Dy							
Ho							
Er							
Tm							
Yb	1.33	14.7	0.95	0.27	0.5	1.16	1.7
Lu	0.192	2.15	0.14	0.04	0.08	0.18	0.25
Hf	1.38	14	0.86	0.3	0.37	0.6	1.6
Ta	0.195	1.35	0.16	0.05	0.1	0.04	0.27
W ppb							
Re ppb							
Os ppb							
Ir ppb							
Pt ppb							
Au ppb							
Th ppm	0.58	4.95	0.24	0.09	0.3	0.09	1.05
U ppm	0.16	1.55	0.06		0.05	0.06	
technique:	*(b) INAA*						

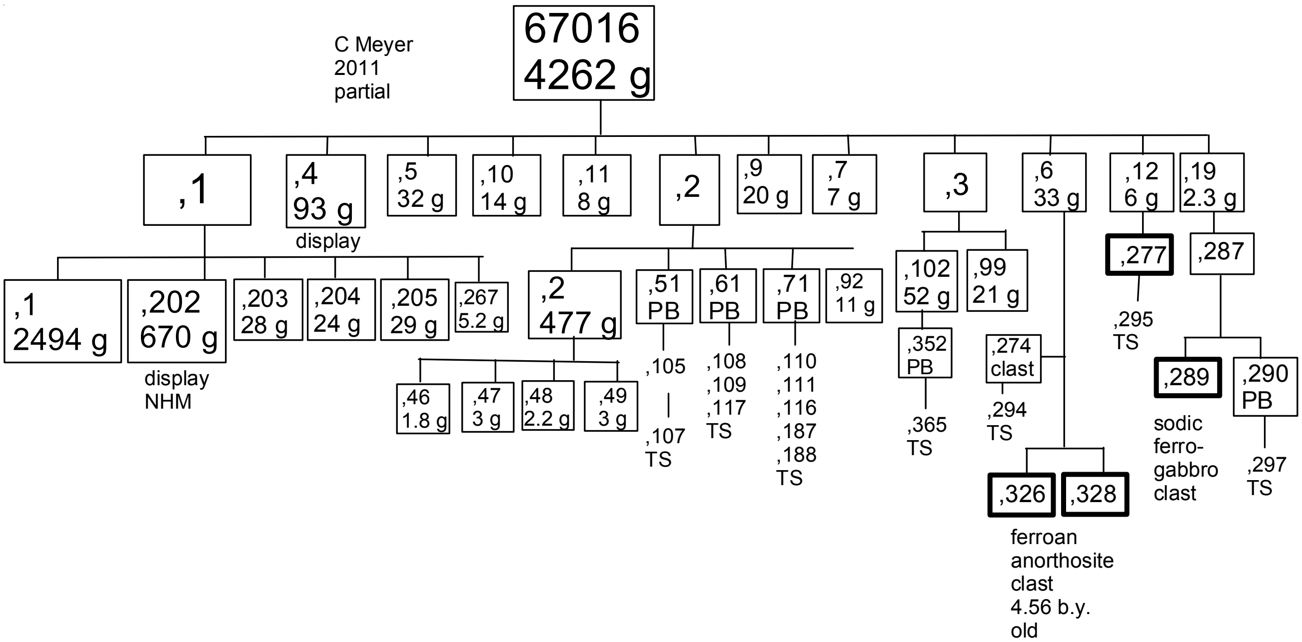
note: numerous analyses of individual clasts are given in Lindstrom and Salpas 1983.

Table 1c. Chemical composition of 67016.

	bulk		bulk	bulk		**ferroan noritic anorthosite**						
reference	Norman and Taylor 1992					**,326/8**		**,326/8**		Alibert et al. 1994		
weight	2.2 g		2.2	2.2		1.577 g		1.557				
SiO2 %	44.43	(d)				45.31	(d)					
TiO2	0.38	(d)	0.49	0.49	(g)	0.4	(d)	0.486	(g)			
Al2O3	30.36	(d)	29.92	30.48	(g)	26.22	(d)	25.64	(g)			
FeO	3.81	(d)	4.78	3.69	(g)	6.56	(d)	7.96	(g)			
MnO	0.05	(d)	0.054	0.055	(g)	0.09	(d)	0.104	(g)			
MgO	3.79	(d)	3.79	3.81	(g)	5.3	(d)	5.42	(g)			
CaO	16.6	(d)	17.27	17.44	(g)	15.81	(d)	16.04	(g)			
Na2O	0.52	(d)	0.617	0.686	(g)	0.28	(d)	0.388	(g)			
K2O	0.06	(d)	0.05	0.047	(g)	0.02	(d)	0.02	(g)			
P2O5												
S %												
sum												
Sc ppm			7.5	7.5	(g)			17.5	(g)			
V			12.6	12.5	(g)			23.5	(g)			
Cr			270	192	(g)			570	(g)			
Co			94	15	(g)			7	(g)			
Ni			561	75	(g)			37	(g)			
Cu			3	2	(g)			28	(g)			
Zn												
Ga												
Ge ppb												
As												
Se												
Rb												
Sr			187	184	(g)			137	(g)			
Y			17	18	(g)			9	(g)			
Zr	78	(c)	66	69	(g)	30	(c)	25	(g)			
Nb	5	(c)				2.4	(c)					
Mo												
Ru												
Rh												
Pd ppb												
Ag ppb												
Cd ppb												
In ppb												
Sn ppb												
Sb ppb												
Te ppb												
Cs ppm												
Ba	79	(c)	72	72	(g)	29	(c)	25	(g)			
La	6	(c)				2.04	(c)					
Ce	15	(c)				4.51	(c)					
Pr	1.84	(c)				0.59	(c)					
Nd	8	(c)				2.83	(c)			3.31	2.93	(h)
Sm	1.86	(c)				0.88	(c)			1.07	0.966	(h)
Eu	0.95	(c)				0.77	(c)					
Gd	2.13	(c)				0.97	(c)					
Tb	0.37	(c)				0.18	(c)					
Dy	2.51	(c)				1.22	(c)					
Ho	0.52	(c)				0.28	(c)					
Er	1.5	(c)				0.85	(c)					
Tm												
Yb	1.33	(c)				0.92	(c)					
Lu	0.15	(c)				0.04	(c)					
Hf	1.34	(c)				0.65	(c)					
Ta												
W ppb												
Re ppb												
Os ppb												
Ir ppb												
Pt ppb												
Au ppb												
Th ppm	0.61	(c)				0.13	(c)					
U ppm	0.15	(c)				0.04	(c)					

technique: (c) SSMS, (d) e. probe (g) ICP, (h) IDMS

note: there are numerous analyses of additional clasts in 67016 in Norman and Taylor 1992.



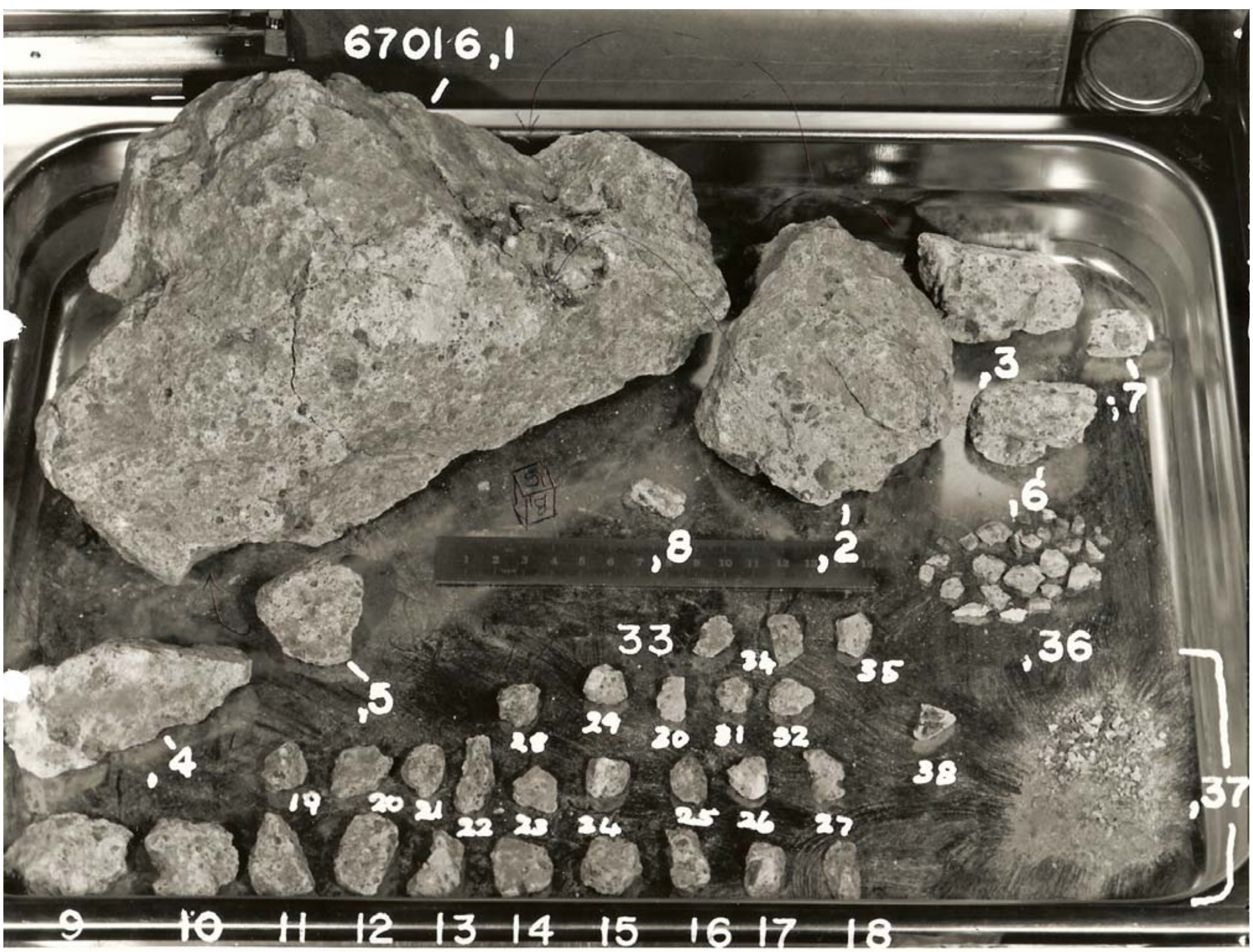


Figure 12: Initial processing photo of 67016. ,2 fits on top of ,1. Scale is in cm. S72-44015

Figure 13: Photo of 67016,2. NASA S73-20360. Sample about 3 inches.

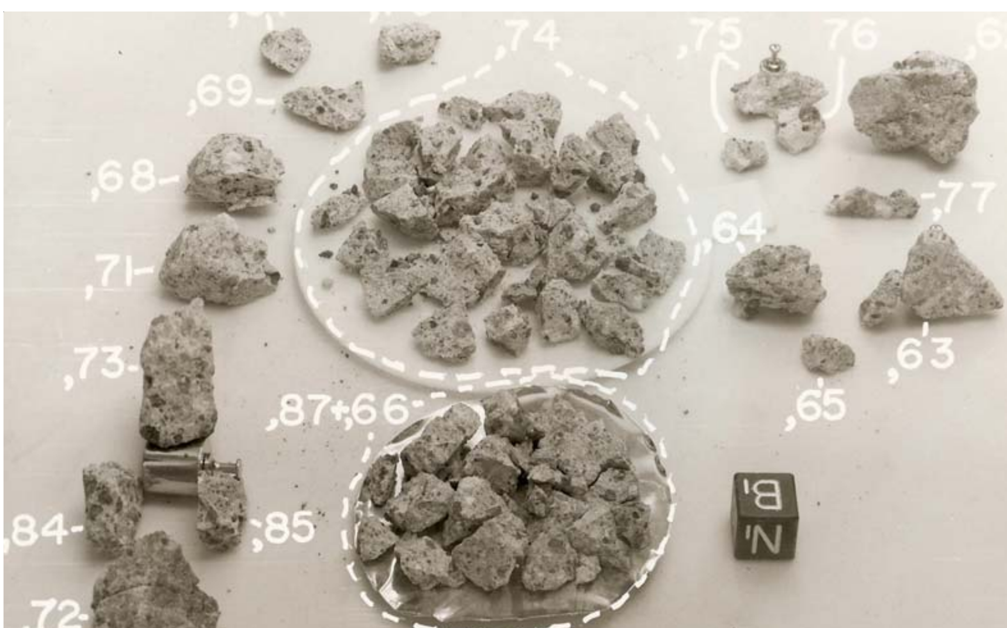


Figure 14 : Subdivision of67015 ,2 with cm cube for scale. S73-21754

Figure 15: Photo of 67016,3 before subdivision. Dark clast is 1 cm. S72-39228

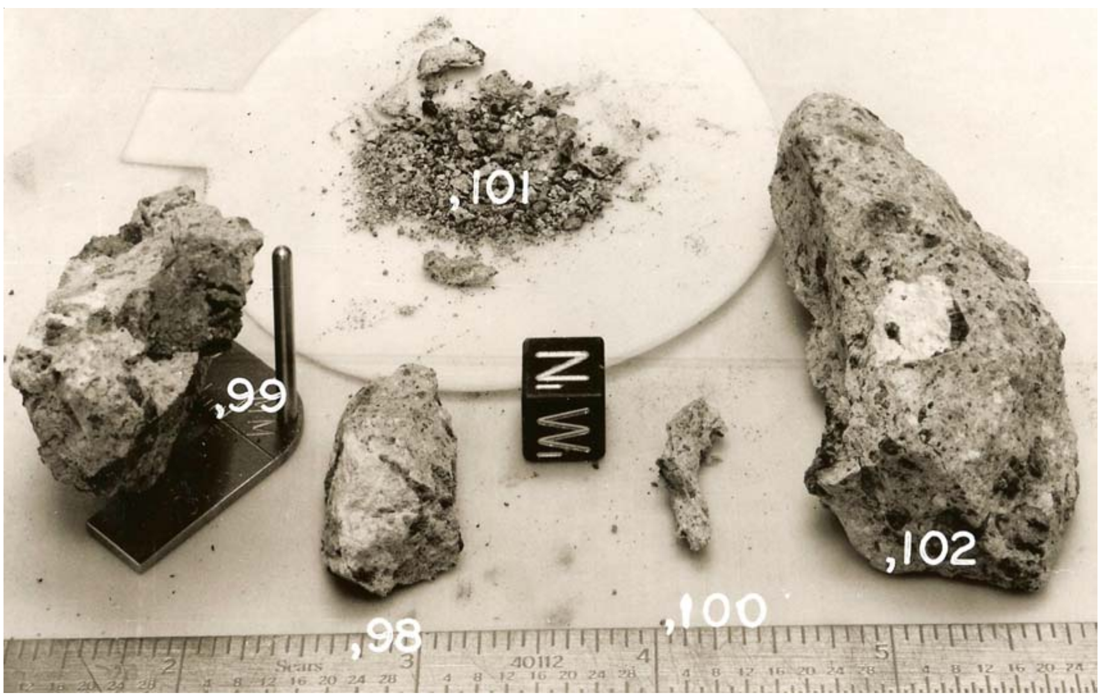


Figure 16: Processing photo of 67016,3 showing both white and dark clasts. Cube is 1 cm. S73-22087.

Figure 17: Photo of 67016,9. NASA S80-27407. Sample about 2 inches.

References for 67016.

Alibert C., Norman M.D. and McCulloch M.T. (1994) An ancient age for a ferroan anorthosite clast from lunar breccia 67016. *Geochim. Cosmochim. Acta* **58**, 2921-2926.

Alibert C., Norman M.D. and McCulloch M.T. (1994) Erratum. *Geochim. Cosmochim. Acta* **58**, 5369-5370.

Bhandari N., Goswami J. and Lal D. (1973) Surface irradiation and evolution of the lunar regolith. Proc. *4th Lunar Sci. Conf.* 2275-2290.

Butler P. (1972a) Lunar Sample Information Catalog Apollo 16. Lunar Receiving Laboratory. MSC 03210 Curator's Catalog. pp. 370.

Brunfelt A.O., Heier K.S., Nilssen B., Sundvoll B. and Steinnes E. (1973) Geochemistry Apollo 15 and 16 materials. *Proc. 4th Lunar Sci. Conf.* 1209-1218.

Colson R.O. (1992) Mineralization on the Moon ? Theoretical consideration of Apollo 16 "rusty rocks", sulfide replacement in 67016 and surface-correlated volatiles on lunar volcanic glass. *Proc. 22nd Lunar Planet. Sci. Conf.,* 427-436.

Duncan A.R., Erlank A.J., Willis J.P. and Ahrens L.H. (1973) Composition and inter-relationships of some Apollo 16 samples. *Proc. 4th Lunar Sci. Conf.* 1097-1113.

Eldridge J.S., O'Kelley G.D. and Northcutt K.J. (1973) Radionuclide concentrations in Apollo 16 lunar samples determined by nondestructive gamma-ray spectrometry. *Proc. 4th Lunar Sci. Conf.* 2115-2122.

Garg A.N. and Ehmann W.N. (1976a) Zr-Hf fractionation in chemically defined lunar rock groups. *Proc. 7th Lunar Sci. Conf.* 3397-3410.

Gibson E.K. and Chang S. (1974c) Abundance and isotopic composition of carbon in lunar rock 67016: suggestions of a carbonate-like phase (abs). *Lunar Sci*. **VI,** 287-289. Lunar Planetary Institute, Houston.

Gibson E.K. and Andrawes F.F. (1978a) Nature of the gases released from lunar rocks and soils upon crushing. *Proc. 9th Lunar Planet. Sci. Conf.* 2433-2450.

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. 8th Lunar Sci. Conf.* 17-45.

Housley R.M., Cirlin E.H., Goldberg I.B., Crowe H., Weeks R.A. and Perhac R. (1975) Ferromagnetic resonance as a method of studying the micrometorite bombardment history of the lunar surface. *Proc. 6th Lunar Sci. Conf.* 3173-3186.

Hunter R.H. and Taylor L.A. (1981) Rust and schreibersite in Apollo 16 highland rocks: Manifestations of volatile-element mobility. *Proc. 12th Lunar Planet. Sci. Conf.* 253-259.

Korotev R.L. (1996c) On the relationship between the Apollo 16 ancient regolith breccias and feldspathic fragmental breccias, and the composition of the prebasin crust in the Central Highlands of the Moon. *Meteor. & Planet. Sci.* **31**, 403-412.

Lindstrom M.M. and Salpus P.A. (1981) Geochemical studies of rocks from North Ray Crater Apollo 16. *Proc. 12th Lunar Planet. Sci. Conf.* 305-322.

Lindstrom M.M. and Salpus P.A. (1982) Geochemical studies of feldspathic fragmental breccias and the nature of North Ray Crater Ejecta. *Proc. 13th Lunar Planet. Sci. Conf.* A671-A683. JGR

LSPET (1973b) The Apollo 16 lunar samples: Petrographic and chemical description. *Science* **179**, 23-34.

LSPET (1972c) Preliminary examination of lunar samples. *In* Apollo 16 Preliminary Science Report. NASA SP-315, 7-1—7-58.

Muehlberger W.R., Horz F., Seiver J.R. and Ulrich G.E. (1980) Mission objectives for geological exploration of the Apollo 16 landing site. *In* Proc. Conf. on **Lunar Highlands Crust**, 1-49 (eds. Papike and Merrill). Lunar Planetary Institute, Houston.

Nord G.L., Christie J.M., Heuer A.H. and Lally J.S. (1975b) North Ray Crater breccias: An electron petrographic study. *Proc. 6th Lunar Sci. Conf.* 779-797.

Norman M.D. and Garcia G.G. (1981) Guidebook for lunar breccia #5, 67016. Curators Office, JSC-17393.

Norman M.D., Taylor G.J. and Keil K. (1991) New lunar rock types: Sodic anorthosites, and noritic, sulfur-rich kindred of ferroan anorthosites. *Geophys. Res. Lett*. **18**, 2081-2084.

Norman M.D. and Taylor S.R. (1992) Geochemistry of lunar crustal rocks from breccia 67016 and the composition of the Moon. *Geochim. Cosmochim. Acta* **56**, 1013-1024.

Norman M.D. (1981) Petrology of suevitic lunar breccia 67016. *Proc. 12th Lunar Planet. Sci. Conf.* 235-252.

Pearce G.W., Gose W.A. and Strangway D.W. (1973) Magnetic studies on Apollo 15 and 16 lunar samples. *Proc. 4th Lunar Sci. Conf.* 3045-3076.

Ryder G. and Norman M.D. (1980) Catalog of Apollo 16 rocks (3 vol.). Curator's Office pub. #52, JSC #16904

Sutton R.L. (1981) Documentation of Apollo 16 samples. In Geology of the Apollo 16 area, central lunar highlands. (Ulrich et al.) U.S.G.S. Prof. Paper 1048.

Takeda H., Miyamoto M., Mori H., Wentworth S.J. and McKay D.S. (1990) Mineralogical comparison of the Y86032-type lunar meteorites to feldspathic fragmental breccia 67016. *Proc. 20th Lunar Planet. Sci. Conf.,* 91-100. Lunar Planet. Institute, Houston.

Taylor S.R., Gorton M., Muir P., Nance W., Rudowski R. and Ware N. (1974) Lunar highland composition (abs). *Lunar Sci.* **V**, 789-791. Lunar Planetary Institute, Houston.

Turner G. and Cadogan P.H. (1975a) The history of lunar bombardment inferred from ^{40}Ar-^{39}Ar dating of highland rocks. *Proc. 6th Lunar Sci. Conf.* 1509-1538.

Ulrich G.E. (1973) A geologic model for North Ray Crater and stratigraphic implications for the Descartes region. *Proc. 4th Lunar Sci. Conf.* 27-39.

Ulrich G.E., Hodges C.A. and Muehlberger W.R. (1981) Geology of the Apollo 16 Area, Central Lunar Highlands. U.S. Geol. Survey Prof. Paper 1048

Ulrich, Muehlberger and many others (1973) Apollo 16 geologic exploration of Descartes: A geologic summary. *Science* **179**, 42-49.

Wänke H., Palme H., Kruse H., Baddenhausen H., Cendales M., Dreibus G., Hofmeister H., Jagoutz E., Palme C., Spettel B. and Thacker R. (1976) Chemistry of lunar highland rocks: a refined evaluation of the composition of the primary matter. *Proc. 7th Lunar Sci. Conf.* 3479-3499.