67215

Fragmental Polymict Breccia

273 grams

Figure 1: After dusting, both sides of 67215,0 have nicely preserved micrometeorite craters (zap pits). Cube is 1 cm. S92-33079

Introduction

67215 was collected from the rim of North Ray Crater (figure 5). It is a white polymict breccia made up of mostly calcic plagioclase and a few relict lithic clasts. The sample as a whole, is made up of a mix of highland rock types (anorthosite, norite, granulite, breccia etc.). Olivine has a wide range of composition and pyroxene has coarse exsolution. Ages around 3.9 b.y. have been determined. Detailed studies are beginning to show that 67215 is not your typical ferroan anorthosite.

67215 was a grab sample that was placed in a special padded bag to protect delicate surface features (Horz et al. 1972). Indeed, it has lots of zap pits on top and bottom (figures 1 - 2).

Petrography

James McGee (1987) provided a detailed petrographic description of 6 thin sections of 67215 – what follows here is mostly taken from that description. The granulated white matrix of 67215 has seriate grain size distribution (figure 4b). The average grain size is about 50 microns, but some mineral fragments up to 150 microns are present. Grains are rounded and often have shock features. The mineral mode of the matrix is about is about 80% plagioclase, with ~20% olivine and pyroxene and trace amounts of ilmenite, troilite and Ni-Fe metal. There is lots of rust according to Hunter and Taylor (1981). Finally, the matrix is well-enough sintered so that the rock holds together.

McGee found that lithic clasts make up about 20% of the rock, but reported that they are often indistinct and

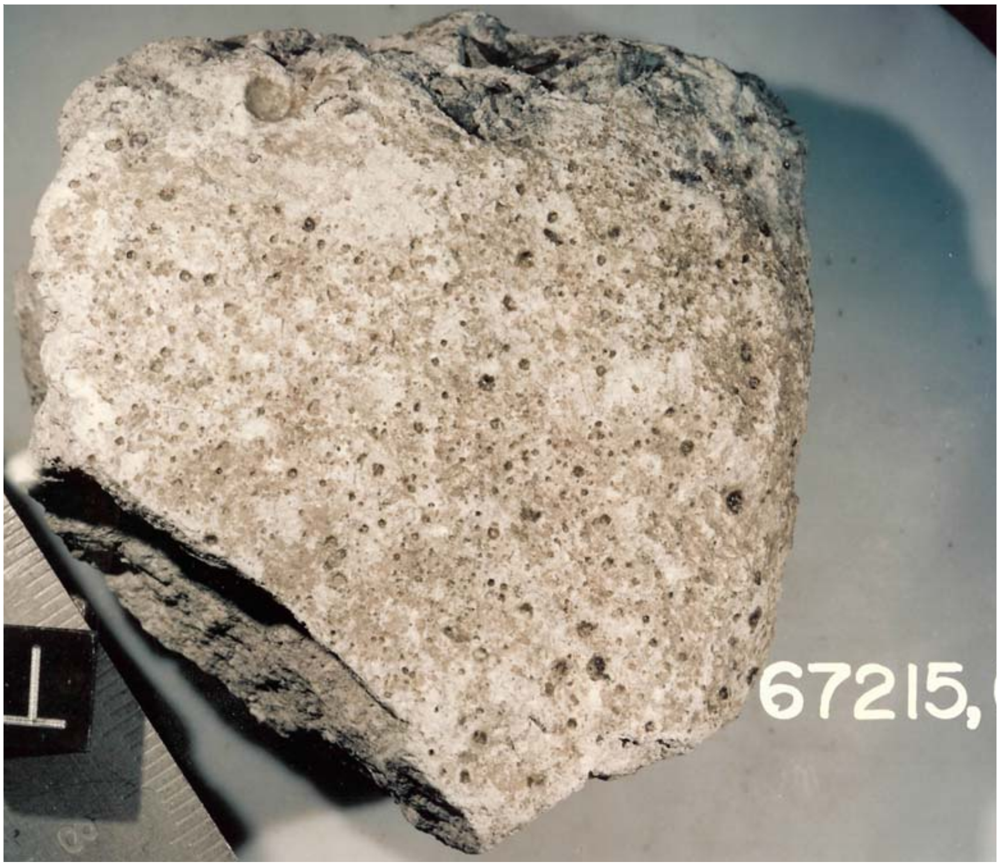


Figure 2: Photo of 67215. Cube is 1 cm. S92-33080.

Figure 3: Side view of 67215. Large aphanitic clast is 1 cm. S92-32806.

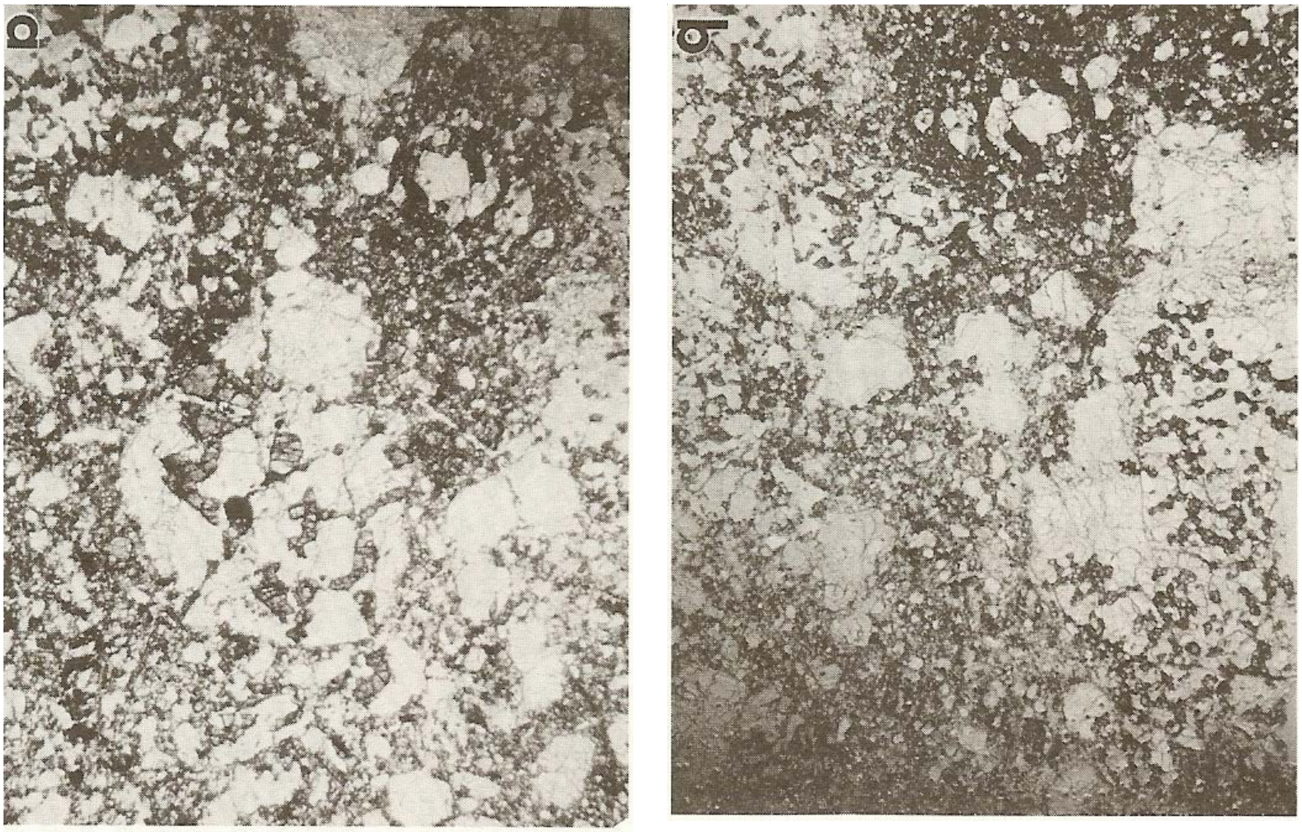


Figure 4 a,b: Two photomicrographs thin sections of 67215 (from McGee 1987). 3 mm across. See also figure 14.

grade into the matrix (figure 4a). Note the large dark grey aphanitic clasts in fine-grained white matrix (figure 3). Most clasts are about 1 mm in size with about 80 – 90 % plagioclase. About half of the clasts have "metamorphic" texture, 25% have "igneous" texture and 25% are so sheared as to not allow textural description. The relict igneous clasts have subophitic to intergranular to poikilitic texture. The metamorphic-textured clasts have polygonal plagioclase and granoblastic or poilioblastic mafic minerals.

"Impact-melt rock" with intergranular texture also occur as large clasts (McGee 1987). They have more plagioclase (90%) with about 10% pigeonite and trace chromite and felsic glass. Mineral composition of the impact-melt rocks are significantly different. Plagioclase has a wide range, pyroxene and olivine is more mafic than other parts of 67215.

Significant Clasts

MgGee (1987) described a "large" anorthosite clast with one grain of anorthite ~ 4 mm in size, a "large" grain of augite with coarse exsolution and a chromite inclusion.

Norman et al. (2003) identified and extracted a norite clast (67215c) with unbrecciated igneous texture that seems to match the mineral chemistry of the rest of the rock. The chemical composition also seem to match the matrix (table). However, they were not able to get concordant ages by Ar/Ar, Rb-Sr and Sm-Nd. However, the Sm-Nd data for the mafic component was spot on the ferroan anorthosite array of 4.46 b.y.

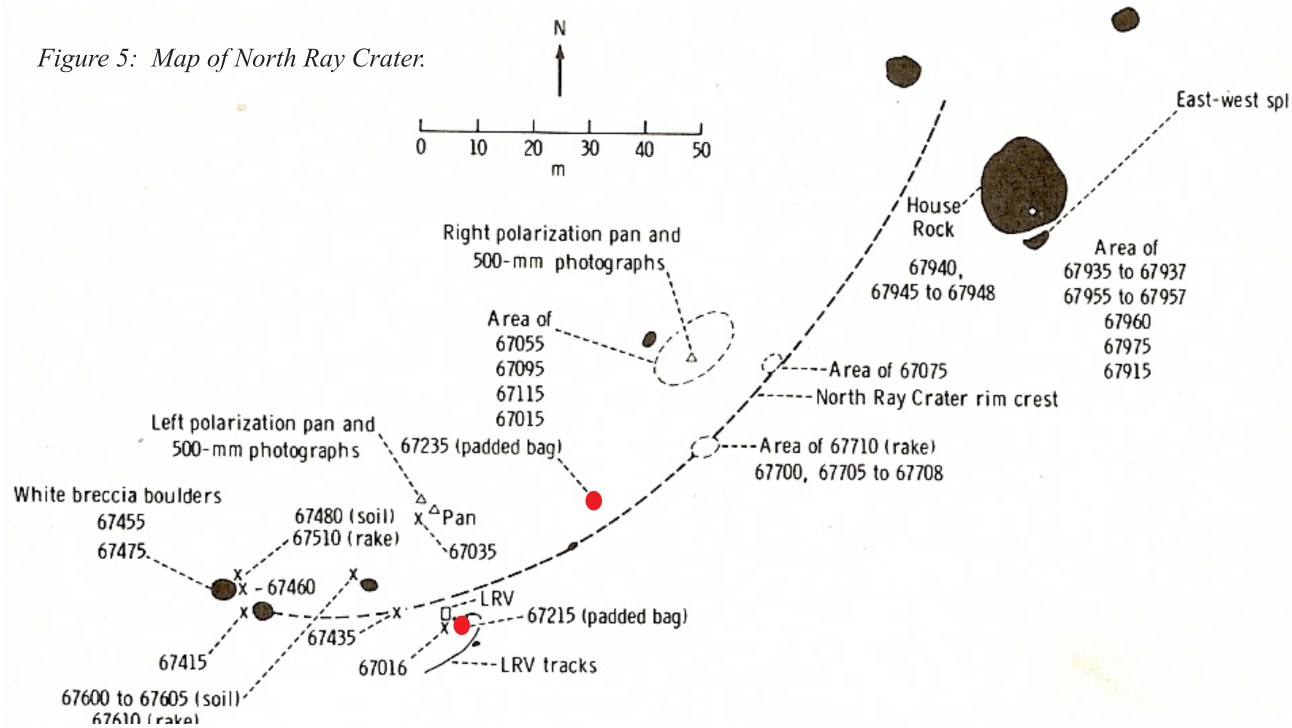
Mineralogy

Olivine: Olivine has a wide range of composition which can be correlated with clast type (figure 6).

Pyroxene: Pyroxene also has a wide range of composition and is generally exsolved (figures 7 and 8). Floss et al. (1998) noted that the pyroxene had unusual trace element chemistry.

Plagioclase: Almost all plagioclase found in matrix or clasts in 67215 is $An_{97\pm1}$. However, some plagioclase in the impact melt lithology is sodic. Floss et al. (1987) determined the trace element composition of plagioclase

Figure 5: Map of North Ray Crater.



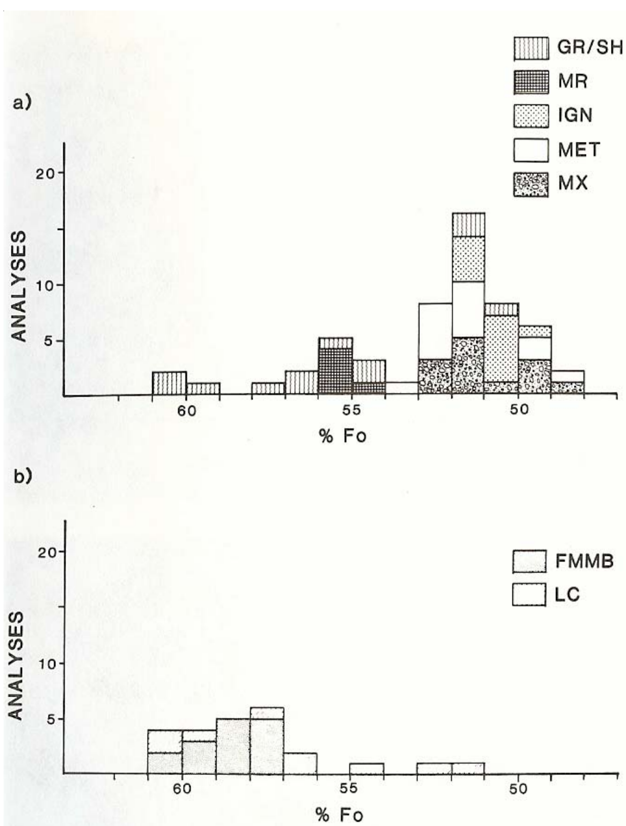


Figure 6: Olivine composition in different lithologies of 67215 (McGee 1987).

Transcript

CC If you see a fist-sized igneous rock near the Rover we'll use the padded bags here, if not we'll just forget them for now.

LMP Okay. I bet you all of this stuff up here is really shocked. Does that make any difference to you? And therefore it's not going to be too hard.

CC All right, if you find a good dense one that you think has a good hard surface on it we'll go ahead and take it.

LMP We'll pick one up and give it a try anyway.

CDR I'm going to get one right here. It's too big for the padded bag.

LMP No, it'll go in. Well let's give it a go. (67235)

LMP Why don't you put it in number 6 there John, Now, let's see if I can find another one here.

CDR Okay, get a smaller one, Charlie. (67215)

LMP I'll tell you that the regolith is about an inch deep her in most places. There's just lots of rocks under this stuff. You can barely get the shovel in anywhere. Okay we got those two rocks for your padded bags, but I'm not sure they are going to do you any good they are so dust covered. I hit one with the shovel here that I've got in my hand that you just saw me pick up and it didn't break anyway so at least it's that hard.

CDR The Velcro came off both those bags and we weren't able to put them tight like they're supposed to be. We put them in the SCB.

CC Fine, let's just leave them in the SCB.

LMP Okay. They're right on top in number 6 and there're no rocks on top of them.

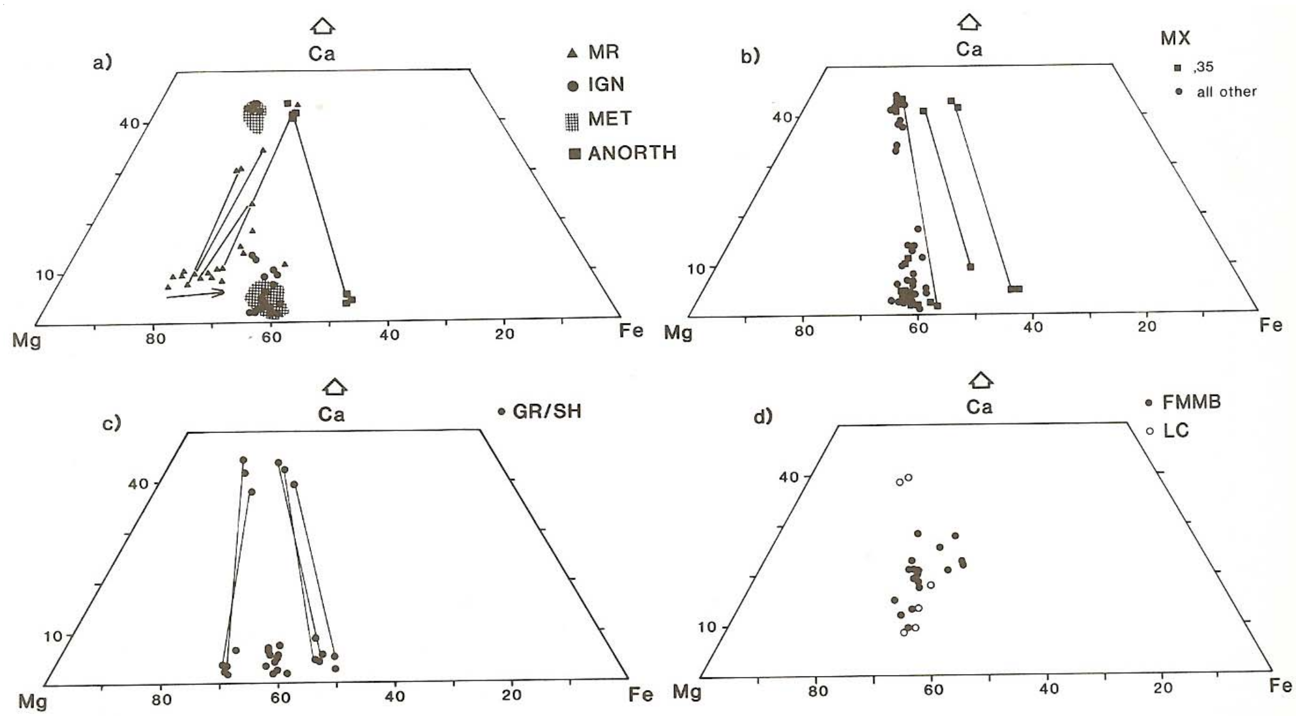


Figure 7: Pyroxene composition in different regions of 67215 as determined by McGee (1987).

Metal: The metal in the clasts is the same as in the matrix (3.5 % Ni, 1.2 % Co). They have rusted.

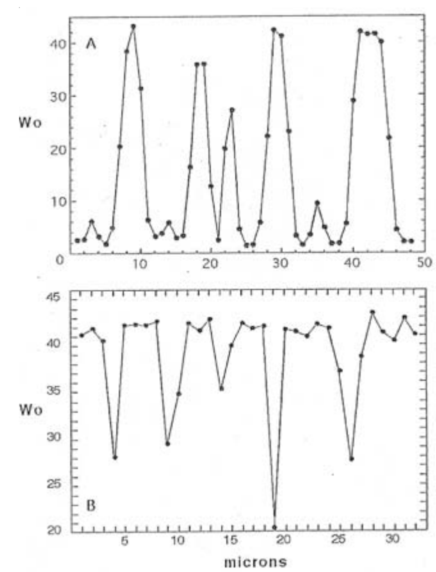


Figure 8: Coarse exsolution in both high-Ca and low-Ca pyroxene in 67215 (Norman et al. 2003).

Chemistry

There is a trace of meteoritic siderophiles in the matrix and the clasts of 67215 (Warren et al. 1990). However, the clasts are probably *pristine* samples of the highland crust.

Radiogenic age dating

Marvin et al. (1986) reported an imprecise age of ~3.75 b.y. for a clast of ferroan anorthosite in 67215 (figure 9). Norman et al. (2003) determined ages of an igneous-textured norite clast (figures 10 – 12), but they are not *concordant*.

Other Studies

Cushing et al. (1999) studied grain size and pyroxene compositions to discuss equilibrium temperature (1000 deg C) of metamorphic conditions. McCallum et al. (2002) noted that 67215 was *not your typical ferroan* anorthosite !

Table 1. Chemical composition of 67215.

reference	Lindstrom83		Lindstrom86			Warren90		Norman2003		
weight									***clast ,46***	
SiO2 %										
TiO2	0.43	(a)	0.33		(a)			0.24	0.18	(b)
Al2O3	24.3	(a)	27.4		(a)			27.36	28.26	(b)
FeO	7.95	(a)	6.39	6.43	(a)	5.79	(a)	5.73	5.48	(b)
MnO						0.081	(a)	0.08	0.08	(b)
MgO	6.8	(a)	5.3		(a)			4.63	4.29	(b)
CaO	14.9	(a)	16.2	15.8	(a)	13.72	(a)	16.21	16.26	(b)
Na2O	0.302	(a)	0.3	0.29	(a)	0.3	(a)	0.31	0.32	(b)
K2O						0.019	(a)	0.019	0.018	(b)
P2O5										
S %										
sum										
Sc ppm	17.3	(a)	12.8	13.2	(a)	11.6	(a)	13.4	11.2	(b)
V								20	16	(b)
Cr	978	(a)	755	736	(a)	690	(c)			
Co	13.6	(a)	12	14.3	(a)	12.4	(c)	10	16	(b)
Ni	45	(a)	26	48	(a)	32	(c)	28	49	(b)
Cu								1.3	0.9	(b)
Zn								12	10	(b)
Ga						1.9	(c)	2.8	3.1	(b)
Ge ppb						37	(c)			
As										
Se										
Rb						<5	(c)	0.9	0.5	(b)
Sr	104	(a)	150	147	(a)	140	(c)	139	156	(b)
Y								6.3	5.1	(b)
Zr			25		(a)	<93	(c)	11.6	10.9	(b)
Nb								0.57	0.53	(b)
Mo								0.01	0.02	(b)
Ru										
Rh										
Pd ppb										
Ag ppb										
Cd ppb										
In ppb										
Sn ppb								110	50	(b)
Sb ppb										
Te ppb										
Cs ppm			0.072	0.063	(a)			0.099	0.049	(b)
Ba	20	(a)	16	16	(a)	24	(c)	17	22.4	(b)
La	0.867	(a)	1.576	1.427	(a)	0.91	(c)	0.88	0.95	(b)
Ce	2.67	(a)	4.3	4	(a)	2.14	(c)	2.32	2.31	(b)
Pr								0.32	0.31	(b)
Nd			3	2.7	(a)	1.73	(c)	1.6	1.43	(b)
Sm	0.6	(a)	0.855	0.827	(a)	0.47	(c)	0.55	0.45	(b)
Eu	0.74	(a)	0.726	0.702	(a)	0.76	(c)	0.75	0.82	(b)
Gd								0.75	0.63	(b)
Tb	0.17	(a)	0.199	0.25	(a)	0.111	(c)	0.13	0.11	(b)
Dy								0.93	0.75	(b)
Ho						0.17	(c)	0.21	0.17	(b)
Er								0.63	0.52	(b)
Tm										
Yb	0.77	(a)	0.752	0.794	(a)	0.6	(c)	0.64	0.54	(b)
Lu	0.121	(a)	0.125	0.132	(a)	0.09	(c)	0.096	0.078	(b)
Hf	0.35	(a)	0.8	1.68	(a)	0.3	(c)	0.31	0.26	(b)
Ta	0.05	(a)	0.125	0.147	(a)	0.028	(c)	0.033	0.029	(b)
W ppb										
Re ppb						64	(c)			
Os ppb						1.21	(c)			
Ir ppb			1.1	0.8	(a)	1.21	(c)			
Pt ppb										
Au ppb						0.23	(c)			
Th ppm			0.096	0.15	(a)	<0.09	(c)	0.07	0.068	(b)
U ppm	0.03	(a)	0.032	0.043	(a)			0.019	0.024	(b)

technique: (a) INAA, (b) ICPMS, (c) INAA+RNAA

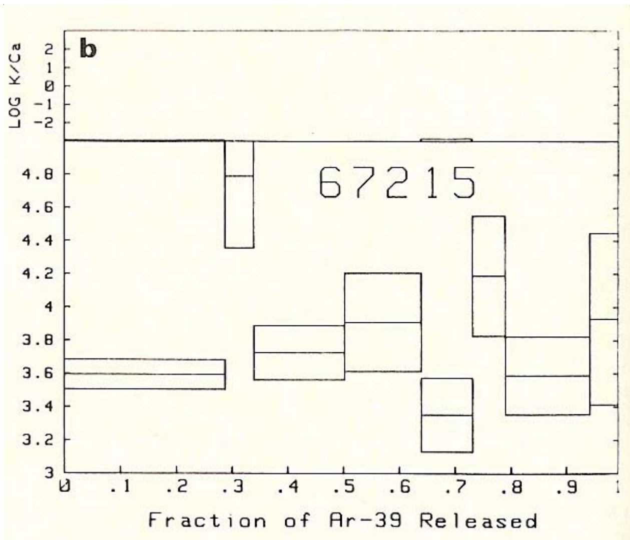


Figure 9: Ar-Ar plateau diagrsm for 67217 ferroan granulite (Marvin et al. 1986).

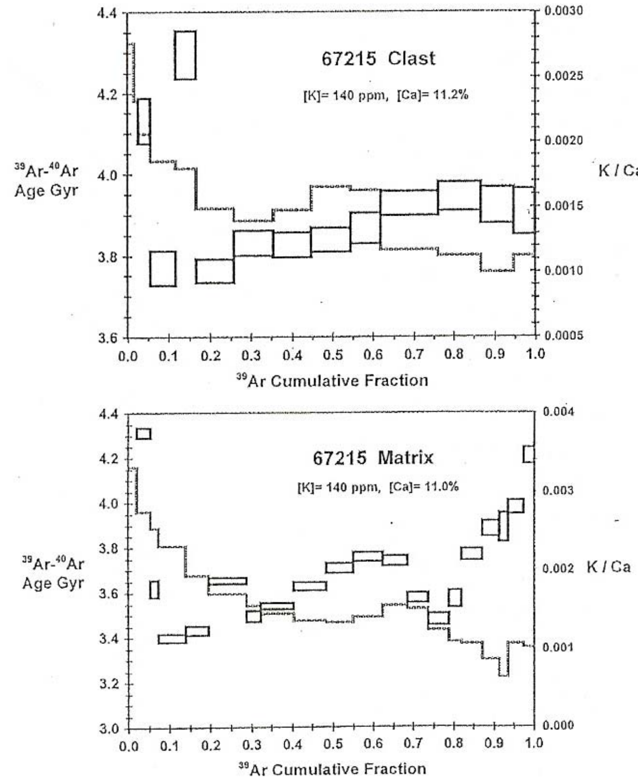


Figure 10: Tw Ar-Ar plateau diagrams for clast and matrix of 67215 (Norman et al. 2003)>

Summary of Age Data for 67215

	Ar-Ar	Sm-Nd	Rb-Sr
Schaeffer and Sch	3.75 b.y.		
Norman et al.	3.93 ± 0.08		
		4.40 ± 0.11	3.93 ± 0.06

Caution: decay constants used, may not be current choice

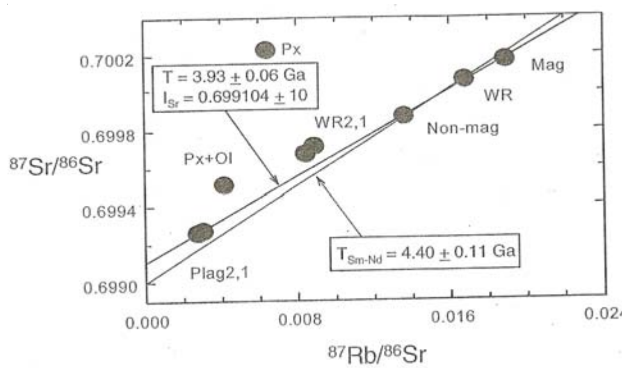


Figure 11: Rb-Sr internal mineral isochron for 67215 (Norman et al. 2003).

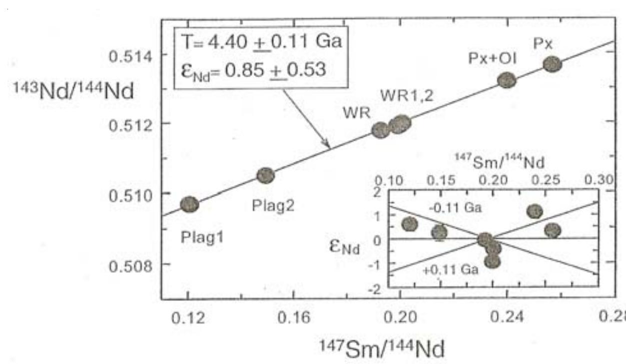
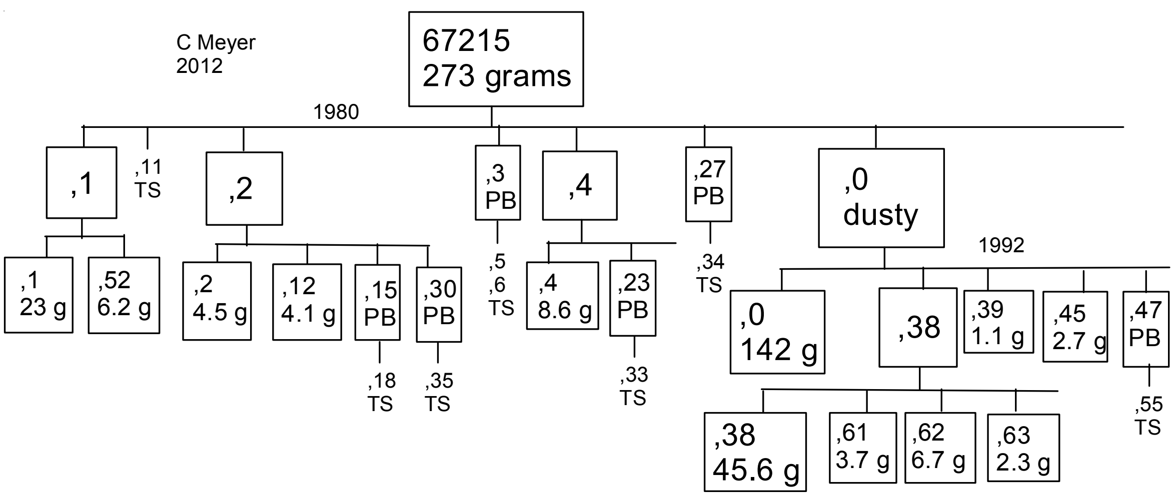


Figure 12: Sm-Nd isochron for 67215 (Norman et al. 2003).

Figure 13: Processing diagram for 67215. Cube is 1 cm. S92-32802



Processing

Initially there were three picees of 67215 (,0 ,1 and ,2), separated by distinct cracks (see Ryder and Norman 198). After dusting these three pieces looked more alike than initially. For some reason, study of 67215 did not begin until 1980 (probably because it was so complicated).

There are 9 thin sections of 67215 (which is not enough).

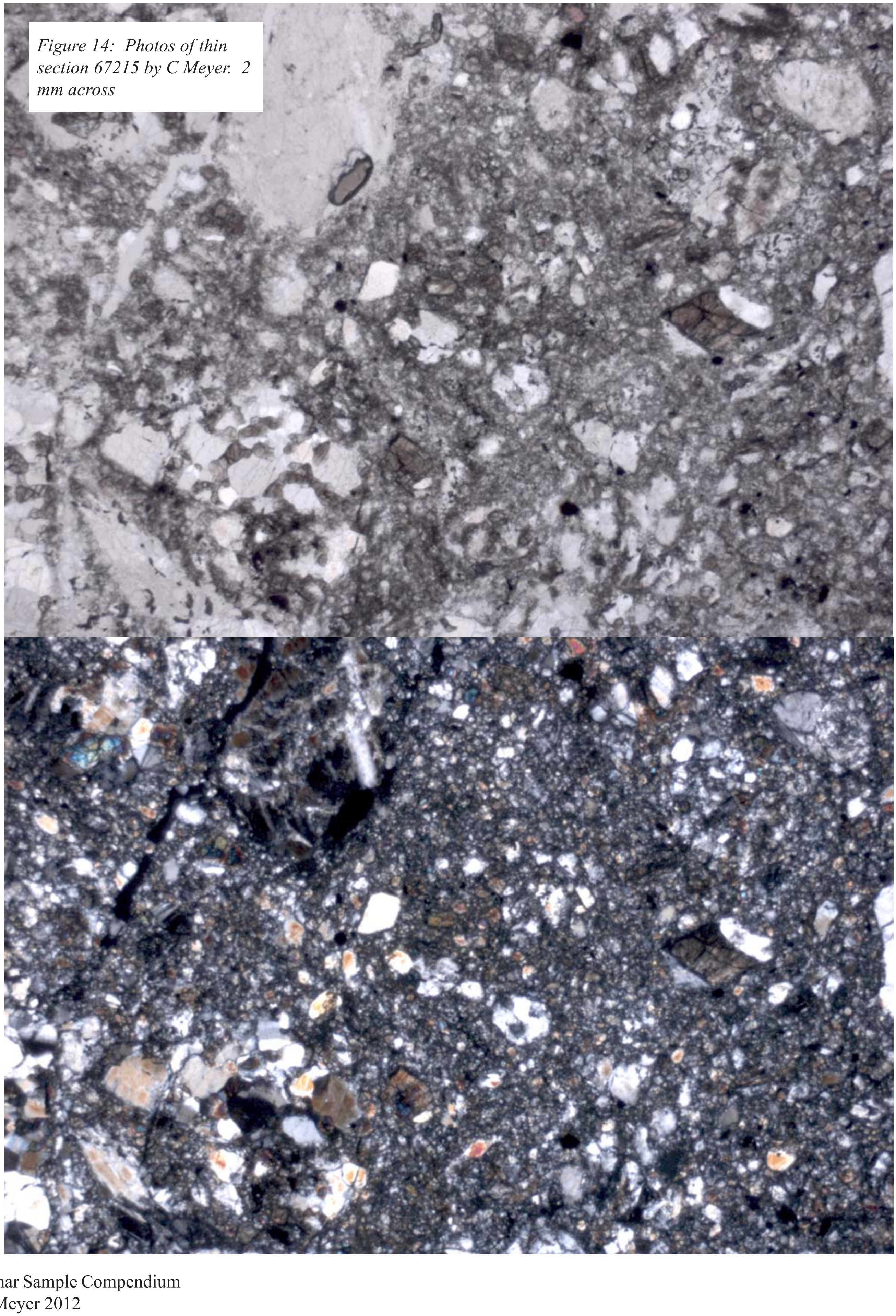


Figure 14: Photos of thin section 67215 by C Meyer. 2 mm across

References for 67215

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

Cushing J.A., Taylor G.J., Norman M.D. and Keil K. (1999) The granulitic impactite suite: Impact melts and metamorphic breccias of the early lunar crust. *Meteorit. Planet. Sci*. **34**, 185-195.

Floss C., James O.B., McGee J.J. and Crozaz G. (1998) Lunar ferroan anorthosite petrogenesis: Clues from trace distributions in FAN subgroups. *Geochim. Cosmochim. Acta* **62**, 1255-1283.

Hörz F., Carrier W.D., Young J.W., Duke C.M., Nagle J.S. and Fryxell R. (1972) Apollo 16 special samples. In Apollo 16 Preliminary Science Rpt. NASA **SP-315** page 7-24 to 7-54

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.

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. J. Geophys. Res.

Lindstrom M.M. and Lindstrom D.J. (1986) Lunar granulites and their precursor anorthositic norites of the early lunar crust. *Proc. 16th Lunar Planet. Sci. Conf*. in J. Geophys. Res. **91**, D263-D276.

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.

Marvin U.B., Lindstrom M.M., Bernatowicz T.J. and Podosek F.A. (1987) The composition and history of breccia 67015 from North Ray Crater. *Proc. 17th Lunar Planet. Sci. Conf*. E471-E490 in J. Geophys. Res. **92**.

McCallum I.S., Schwartz J.M., Camara F. and Norman M. (2002) Sample 67215: An anomalous ferroan anorthosite (abs#1830). *Lunar Planet Sci.* **XXXIII** Lunar Planetary Institute, Houston.

McGee J.J. (1987b) Petrology of brecciated ferroan noritic anorthosite 67215. *Proc. 18th Lunar Planet. Sci. Conf.* 21-31. Lunar Planetary Institute, Houston.

Norman M.D., Borg L.E., Nyquist L.E. and Bogard D.D. (2003) Chronology, geochemistry, and petrology of a ferroan noritic anorthosite from Descartes breccia 67215: Clues to the age, origin, structure and impact history of the lunar crust. *Meteor. & Planet. Sci.* **38**, 645-661.

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

Stöffler D., Ostertag R., Reimold W.U., Borchardt R., Malley J. and Rehfeldt A. (1981) Distribution and provenance of lunar highland rock types at North Ray Crater, Apollo 16. *Proc. 12th Lunar Planet. Sci. Conf.* 185-207.

Stöffler D., Bischoff A., Borchardt R., Burghele A., Deutsch A., Jessberger E.K., Ostertag R., Palme H., Spettel B., Reimold W.U., Wacker K. and Wanke H. (1985) Composition and evolution of the lunar crust in the Descartes highlands. *Proc. 15th Lunar Planet. Sci. Conf.* in J. Geophys. Res. **90**, C449-C506.

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.

Warren P.H., Jerde E.A. and Kallemeyn G.W. (1990) Pristine moon rocks: An alkali anorthosite with coarse augite exsolution from plagioclase, a magnesian harzburgite and other oddities. *Proc. 20th Lunar Planet. Sci. Conf.* 31-59. Lunar Planetary Institute, Houston.

Warren P.H. (1993) A concise compilation of petrologic information on possibly pristine nonmare Moon rocks. *Am. Mineral.* **78**, 360-376.