14318
Ancient Regolith Breccia
600.2 grams

Figure 1: Photo of 14318. Sample is 10 cm long. NASA S71-29142.

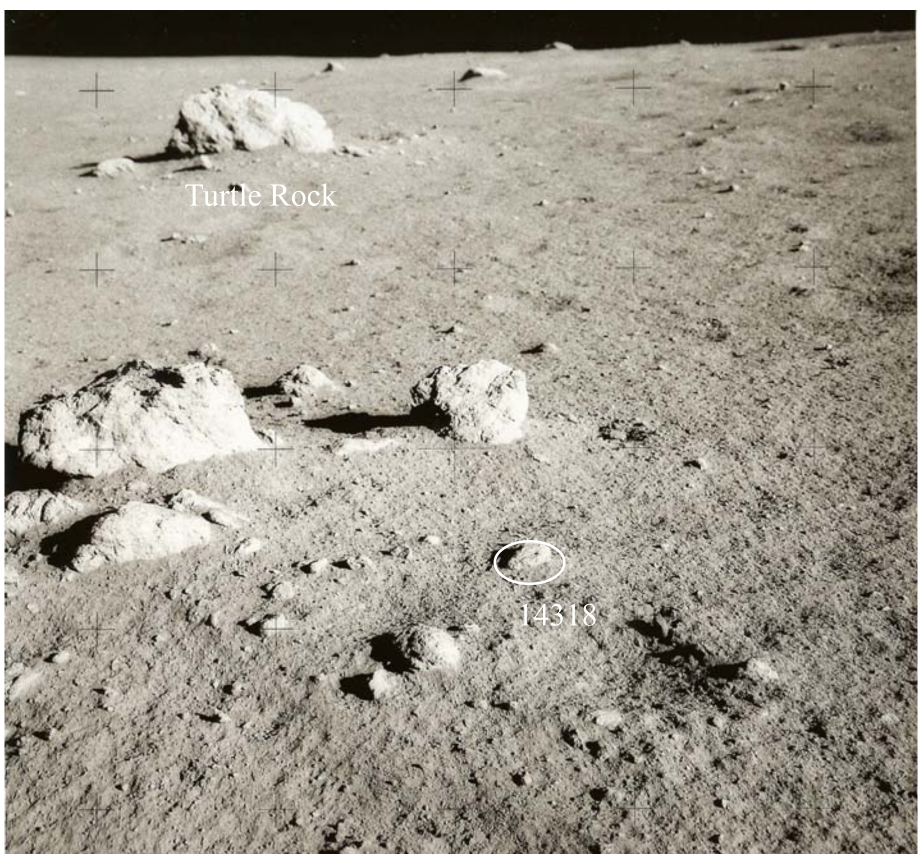


Figure 2: Photo of 14318 on the lunar surface. AS14-68-9469.

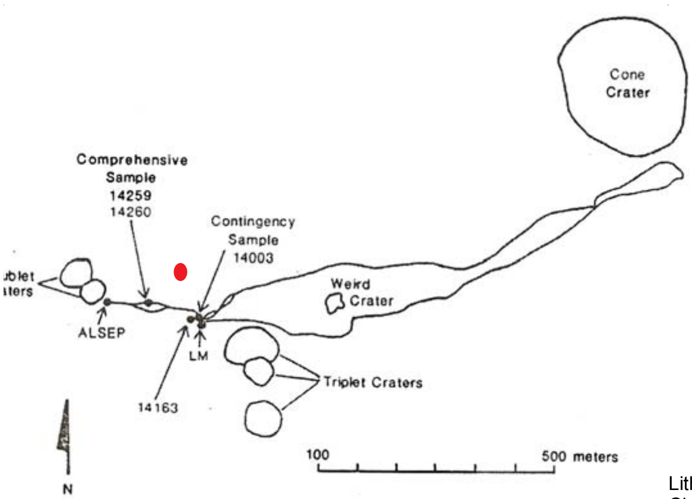


Figure 3: Location of 14318 on Apollo 14 traverse map.

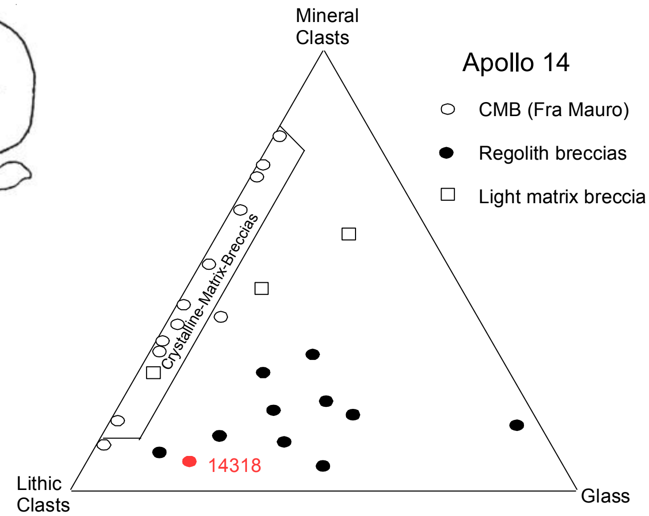


Figure 4: Simonds diagram for Apollo 14 breccias.

Mineralogical Mode for 14318

	Simonds et al. 1977	Drozd et al. 1976	Simon et al. 1989
Matrix	42.5 %		40.6
Clasts			
Plagioclase	2		4.7
Mafic	1.5		5.6
Breccia	35		
Glass	2.5	11.4	11.7
Granulite	11		
Mare basalt	4		0.1
Felds basalt	1		0.4
Agglutinate		10.2	1

Mineralogical Mode for 14318

	Drozd et al. 1977
Mineral fragments	14.7 %
Lithic fragments	59.6
Colored glass	7.7
Agglutinate glass	10.2
Colorless glass	1.2
Chondrules	4
Devitrified glass	2.5

Introduction

Fruland (1983) and Simon et al. (1989) included 14318 in the suite of regolith breccias, while Simonds et al. (1977) termed it a vitric matrix breccia. Most notable is the abundance of chondule-like clasts (Kurat et al. 1972; King et al. 1972), some with basaltic texture. 14318 differs from most regolith breccias by the high proportion of lithic clasts and significantly less abundance of brown matrix glass. It may have formed from an immature soil.

14318 was picked up at the "North Boulder Field" (station H) about 100 meters northwest of the LM (Swann et al. 1977). It is a blocky, angular rock, heavily pitted on all sides (figure 1). A series of well developed, parallel fractures is parallel to one surface of the rock and long axis. The rock has broken along one of these fractures and no pits are present on the broken vesicular glass. The glass-lined fractures appear to cut clasts and matrix alike. The rock is a coherent breccia with an estimated 50 percent clasts. Of these 60 percent are judged to be light and 40 percent dark or mesocratic. One light clast has a dark clast within it and several dark clasts contain light clasts.

Horz et al. (1972) and Sutton et al. (1971) determined the orientation of 14318 on the surface from the density distribution of microcraters and by reproducing the lighting angle of the surface photography. The exposure age of 14318 is 39 m.y.

14318 was found to have "excess fission Xe" (Behrmann et al. 1973; Reynolds et al. 1974; Swindle et al. 1985) as well as an excess of implanted ^{40}Ar (Eugster et al. 2001). Thus it is thought to be an "ancient regolith breccia" and may prove to be a key to understanding early Earth-Moon history.

Figure 5: Photo of sawn surface of 14318. Cube is 1 cm. NASA S78-34405.

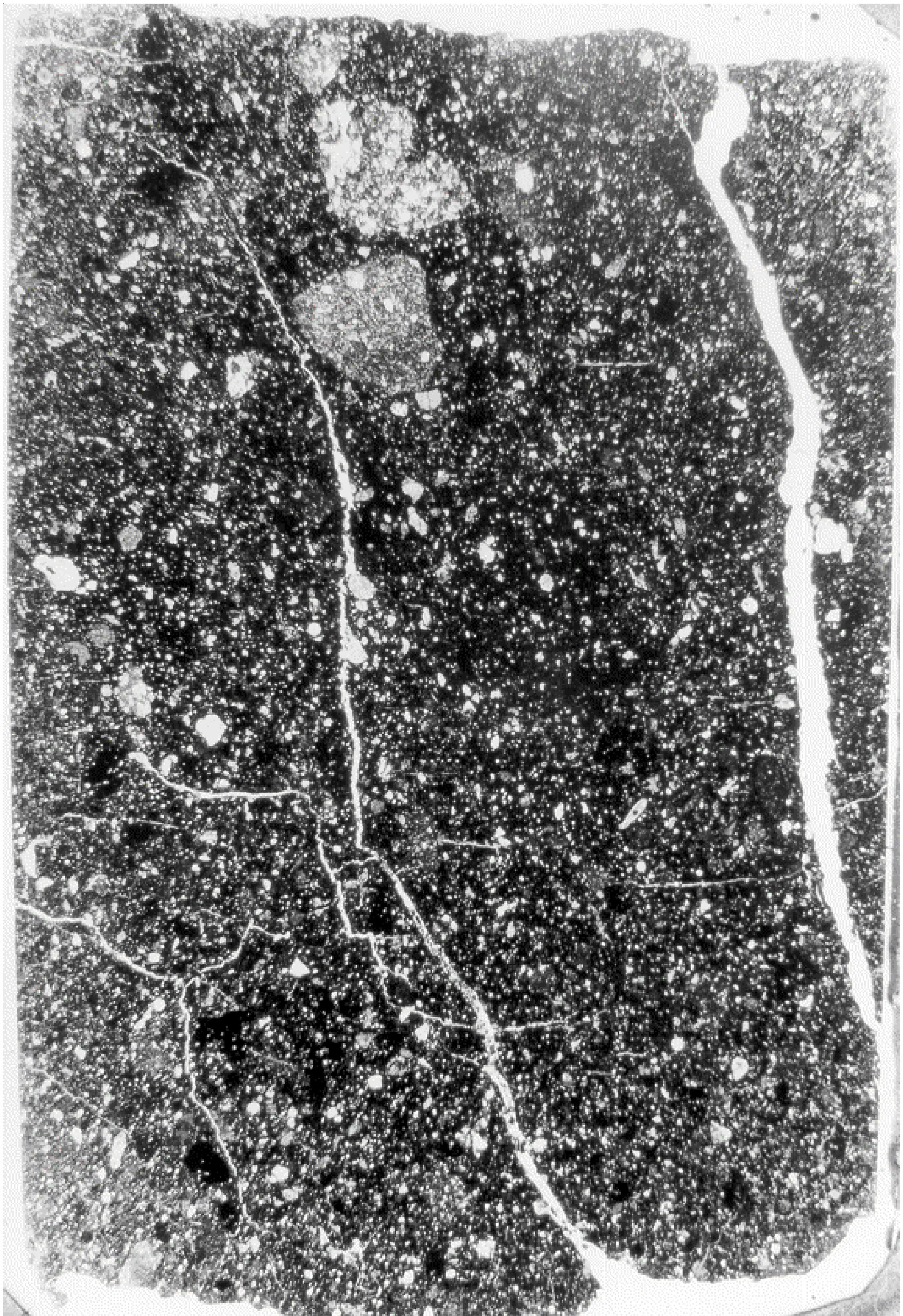


Figure 6: Photomicrograph of thin section 14318,44. Scale 1.5 x 3 cm. S71-44337.

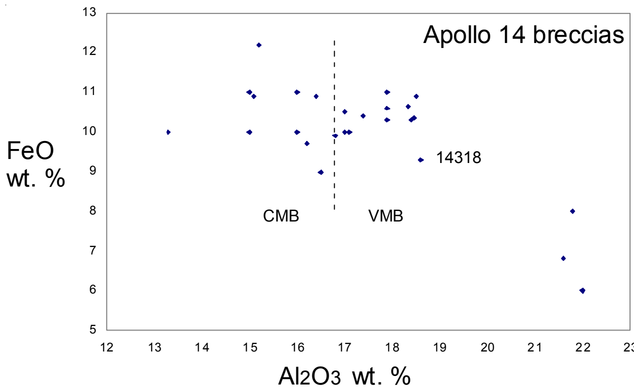


Figure 7: Composition of Apollo 14 breccias with 14318 shown.

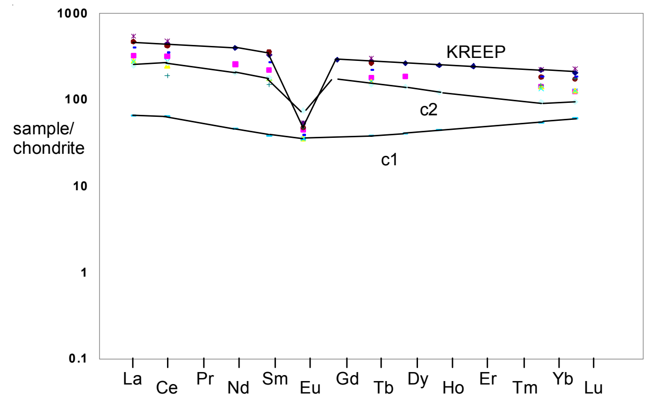


Figure 8: Normalized rare-earth-element diagram for 14318 matrix and clasts. KREEP pattern is for comparison. c1 and c2 are probably pristine white clasts studied by Warren et al. (1983, 1986).

Petrography

14318 was found near the location of 14315 and has some similar features (figure 2). Kurat et al. (1972, 1974) and King et al. (1972) described 14318 and studied the numerous chondrule-like objects (figure 11). This sample is a clast-rich, matrix-poor breccia (figure 4). It is a complex microbreccia, composed of lithic fragments, chondrules, glass spherules, glass and mineral fragments set in a fine-grained, partly glassy matrix (figure 6). The lithic fragments, chondrules, glasses etc. are welded to the matrix and partly recrystallized, indicating formation at a relatively high temperature.

Simon et al. (1989) compare 14318 with other soil breccias from Apollo 14. There is additional information about grain size chemistry/petrology in Swindle et al. (1985). Nelen et al. (1972) and Ruzicka et al. (2000), King et al. (1972) and Kurat et al. (1972) focused on the chondrules.

14318 was one of the samples studied by the Imbrium Consortium led by John Wood (Ryder et al. 1976). von Englehardt et al. (1972), Stoffler et al. (1976), Chao et al. (1972) and Quaide and Wrigley (1972) also gave petrographic descriptions. No one has looked at all the thin sections at one time.

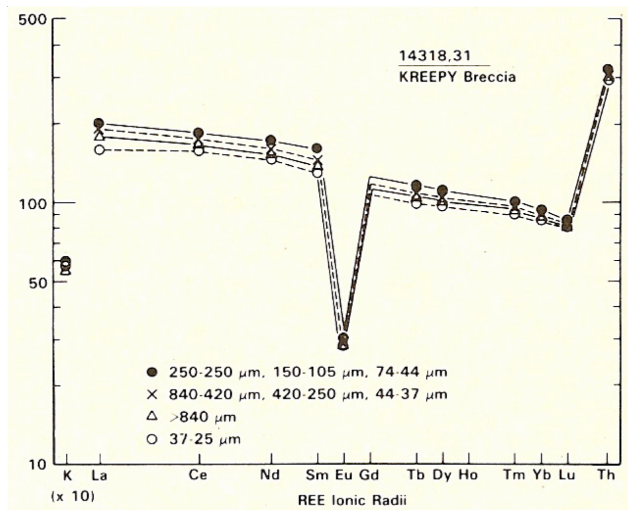


Figure 9: Normalized rare-earth-element diagram for different grain sizes of 14318 (Swindle et al. 1985).

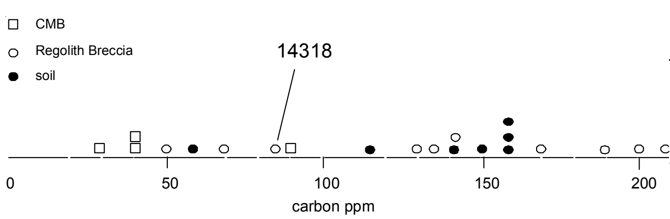


Figure 10: Carbon content of Apollo 14 samples from Moore et al. (1972).

14318 has many different lithic clasts (figure 15). Many of them are trace-element-rich alkali, high alumina basalt (AHAB = KREEP) (Kurat et al. (1974). Figure 12 compares the composition of the crystalline chondrules with the glass spherules. Warren et al. (1993) studied two large clasts and Shervais et al. (1983) reported on another.

Significant Clasts

Gabbronorite ,4

Shervais et al. (1983) studied a small clast (1.6 x 1 mm) of unshocked "gabbronorite" found in thin section. It has ~48% plagioclase (An_{95}), ~44% orthopyroxene (En_{53-72}), ~7% clinopyroxene and trace ilmenite (figure 9).

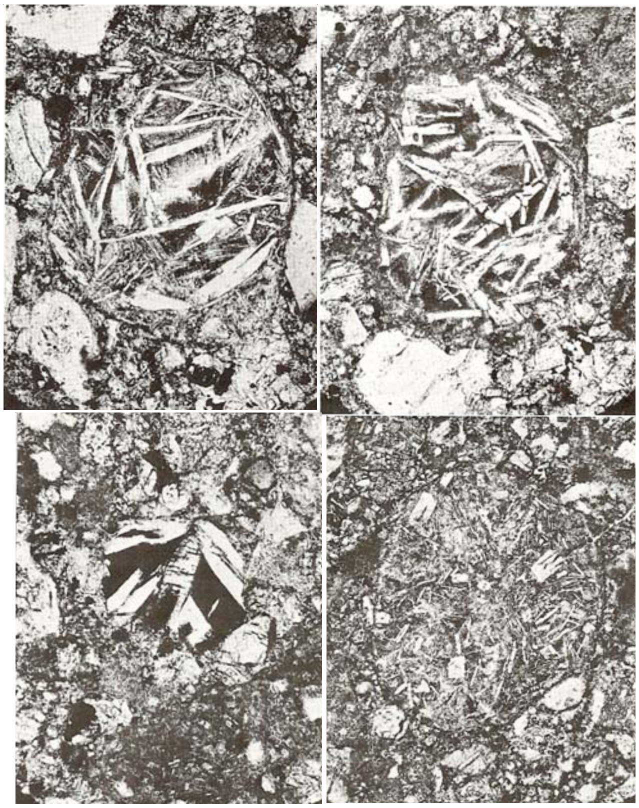


Figure 11: Chondrules from 14318 a la. Kurat et al. (1972). Scale about 200 microns each.

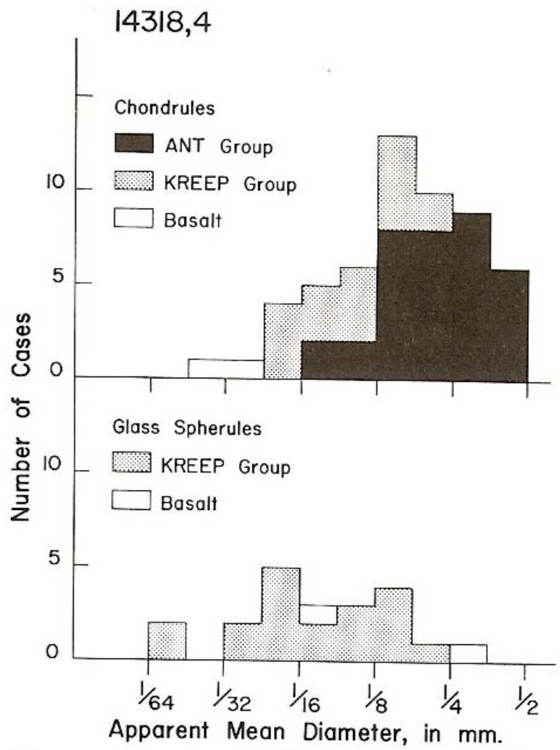


Figure 12: Comparison of crystalline chondrules and glass spherules in 14318 a la. Kurat et al. (1972).

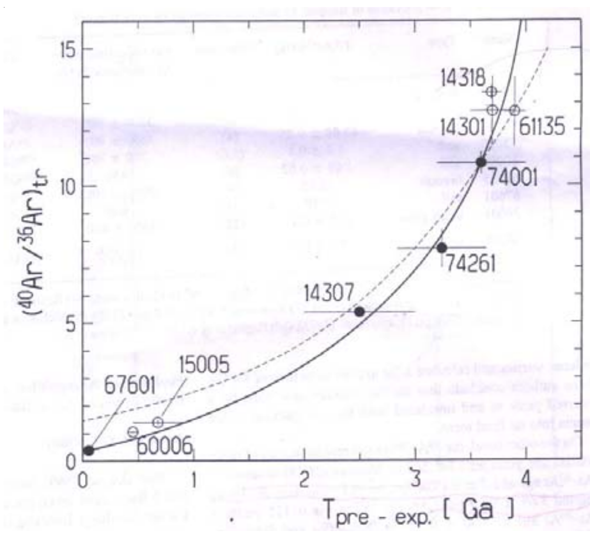


Figure 13. Excess 40Ar in lunar breccia (Eugster et al. 2001).

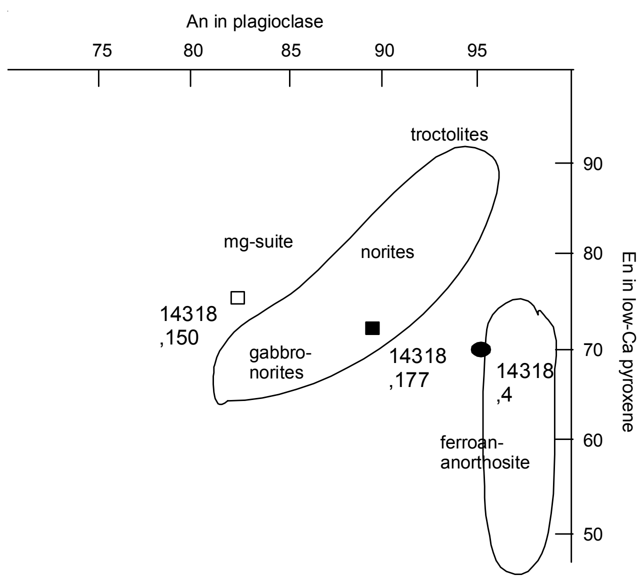


Figure 14: Composition of plagioclase and pyroxene in white clasts in 14318 (from Shervais et al. 1983).

Mg-suite olivine norite "C1" ,146 TS,149 TS,177

Warren et al. (1983) determined the composition of this 1.5 g clast (table 1) and gave details on the mineralogy (figure 9). Bersch et al. (1991) and Shervais and McGee (1998) studied the mineral chemistry. The clast is composed of 55% plagioclase (An_{89})(up to 1.7 mm), 35% orthopyroxene ($En_{72.4}$)(1 mm), ~12% olivine (Fo_{71})(1.9 mm) with trace ilmenite, troilite and metal. It is considered "probably" pristine by Warren (1993).

Table 1. Chemical composition of 14318.

													clast						clast	
reference	Rose 72			Keith72		Laul72							Warren83		Simon 89		Kurat74		Warren86	
weight				600.2 g		sawdust			clasts				,144		153 mg				,150	
SiO2 %	47.9	47.97	(c)										49.4	(b)			45	(e)	46.6	(b)
TiO2	1.44	1.48	(c)			1.6	1.2	1.8	1.7	1	1.1	(b)	0.62	(b)	1.67	(b)	2.6	(e)	1.07	(b)
Al2O3	18	17.8	(c)			16.3	16.1	17.8	18.9	15.9	19.3	(b)	18.7	(b)	18.6	(b)	12.2	(e)	23.24	(b)
FeO	9.43	9.62	(c)			9.9	10.7	9.8	11.5	7.7	7.5	(b)	7.98	(b)	9.35	(b)	18.1	(e)	5.57	(b)
MnO	0.13	0.13	(c)			0.105	0.109	0.113	0.107	0.099	0.101	(b)	0.106	(b)	0.14	(b)			0.076	(b)
MgO	9.63	9.79	(c)										12.27	(b)	9.8	(b)	8.3	(e)	8.95	(b)
CaO	11.1	11.16	(c)			10	11.3	10.8	10.3	9.4	10.3	(b)	10.1	(b)	11.1	(b)	10.2	(e)	13.1	(b)
Na2O	0.81	0.79	(c)			0.728	0.728	0.821	0.976	0.852	0.837	(b)	0.66	(b)	0.77	(b)	0.4	(e)	1.06	(b)
K2O	0.62	0.6	(c)	0.59	(a)	0.58	0.53	0.63	0.61	3.3	2.1	(b)	0.23	(b)	0.61	(b)	0.72	(e)	0.38	(b)
P2O5	0.55	0.56	(c)														0.85	(e)		
S %																				
sum																				
Sc ppm	24	22	(c)			17.9	17.1	18.6	17.5	16.6	15.3	(b)	12.8	(b)	19.1	(b)			11.7	(b)
V	50	47	(c)			46	30	46	45	24	25	(b)			38	(b)				
Cr	1232	1300	(c)			1320	1231	978	1013	828	664	(b)	1080	(b)	1230	(b)			875	(b)
Co	30	38	(c)			31	28	26	86	28	12	(b)	20.3	(b)	33	(b)			15.4	(b)
Ni	330	420	(c)										52	(b)	430	(b)			21	(b)
Cu	*150*	*170*	(c)																	
Zn	15	15	(c)										3.4	(b)						
Ga	4.4	4.5	(c)										5	(b)					8.2	(b)
Ge ppb													70	(b)					8.8	(b)
As																				
Se																				
Rb	16	14	(c)										6.1	(b)	16	(b)			7.9	(b)
Sr	160	140	(c)												100	(b)			261	(b)
Y	260	260	(c)																	
Zr	720	820	(c)			800	600	1400	950	600	1300	(b)	370	(b)	880	(b)			780	(b)
Nb	48	52	(c)																	
Mo																				
Ru																				
Rh																				
Pd ppb																				
Ag ppb																				
Cd ppb													44	(b)						
In ppb																				
Sn ppb																				
Sb ppb																				
Te ppb																				
Cs ppm													0.29	(b)	0.82	(b)			0.21	(b)
Ba	760	640	(c)			700	600	1100	1000	2600	1700	(b)	470	(b)	860	(b)			690	(b)
La	75	66	(c)			66	65	129	110	58	95	(b)	15.6	(b)	76.7	(b)			58	(b)
Ce						151	170	290	255	115	215	(b)	39	(b)	194	(b)			160	(b)
Pr																				
Nd													21.1	(b)	117	(b)			93	(b)
Sm						26	26	51	53	22	40	(b)	5.7	(b)	32.5	(b)			26.7	(b)
Eu						2	2	3	2.7	2.7	2.2	(b)	1.96	(b)	2.54	(b)			4.2	(b)
Gd																				
Tb						5.8	5.9	11	9.6	5.7	8.1	(b)	1.4	(b)	6.6	(b)			5.4	(b)
Dy													9.9	(b)	46	(b)			34.5	(b)
Ho													2.5	(b)					6.8	(b)
Er																				
Tm																				
Yb	22	23	(c)			23	22	37	30	24	30	(b)	8.9	(b)	23.2	(b)			15.5	(b)
Lu						3.1	3.1	5.6	4.2	4.3	4.5	(b)	1.49	(b)	3.04	(b)			2.31	(b)
Hf						20	21	42	32	23	27	(b)	8	(b)	22.8	(b)			19.2	(b)
Ta						2.3	2.4	5.1	4.6	5	3.7	(b)	0.74	(b)	3.2	(b)			1.81	(b)
W ppb																				
Re ppb													0.024	(b)					0.025	(b)
Os ppb																			0.39	(b)
Ir ppb													0.2	(b)	8	(b)			0.096	(b)
Pt ppb																				
Au ppb													0.27	(b)	6.6	(b)				
Th ppm				12	(a)	12	13	24	18	24	17	(b)	3.8	(b)	13.3	(b)			7.6	(b)
U ppm				3.27	(a)	4.1	2.1	6.1	6	6.3	5.4	(b)	1.25	(b)	3.5	(b)			2.1	(b)

technique: (a) radiation counting, (b) INAA (c) "microchemical", (d) e. probe

Table 2: Composition of lithic fragments in 14318 (from Kurat et al. 1974).

Oxides	ANT Suite: Anorthosite LF24	ANT Suite: Troctolitic anorthosite LF13	ANT Suite: Anorthositic norite LF18	Alkalic high-alumina basalt group: Av.	Alkalic high-alumina basalt group: Range	Mare basalt LF30	Dunite LF6
SiO_2	44·2	43·2	45·4	46·8	(45·6–50·0)	48·8	40·3
TiO_2	0·14	0·15	0·24	1·30	(0·40–2·20)	2·69	0·32
Al_2O_3	32·6	28·1	25·9	18·5	(15·8–22·2)	13·9	3·7
Cr_2O_3	0·04	0·07	0·15	0·17	(0·10–0·25)	0·22	0·12
FeO	0·76	4·6	5·8	9·3	(6·7–11·7)	15·0	12·2
MnO	0·04	0·04	0·08	0·14	(0·10–0·18)	0·23	0·11
MgO	0·84	6·9	5·8	9·3	(7·1–12·3)	5·9	41·2
CaO	19·2	14·6	15·1	11·3	(9·3–13·8)	11·6	1·70
Na_2O	0·42	0·66	0·39	0·80	(0·38–1·17)	0·61	0·07
K_2O	0·06	0·09	0·17	0·47	(0·17–1·09)	0·18	0·02
P_2O_5	0·06	0·08	0·08	0·52	(0·17–0·99)	0·10	0·36
Total	98·36	98·49	99·21	98·60		99·23	100·10
No. specimens	1	1	1	8		1	1

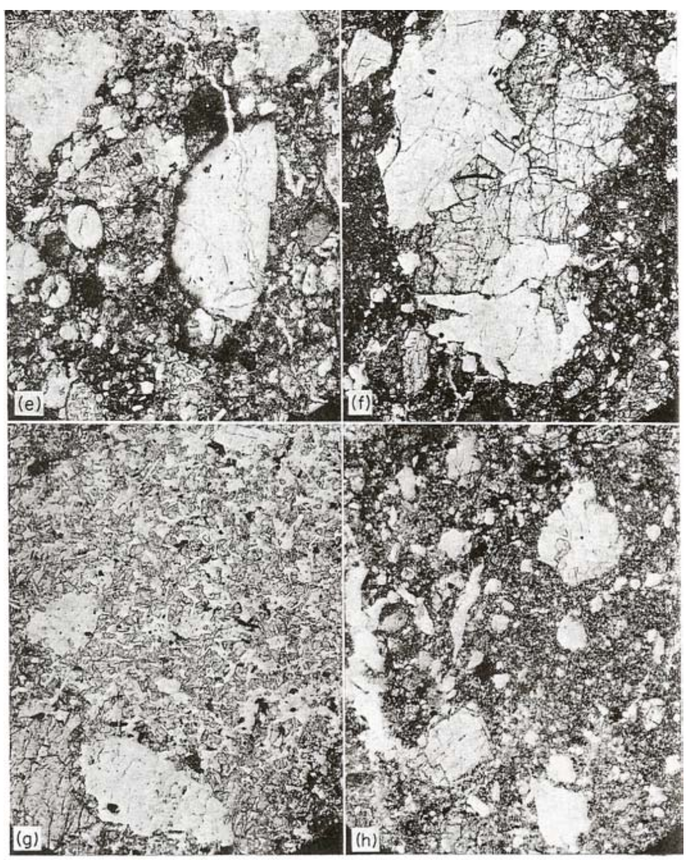


Figure 15: Glass and lithic fragments in 14318 (e) glass sphere, (f) ANT, (g) AHAB and (f) AHAB breccia (from Kurat et al. 1974).

Table 3a: Composition (averages) of glass types found in 14318 (Kurat et al. 1974).

	ANT Suite			AHAB† Group			
	Troctolitic anorthosite	Anorthositic norite		Fragments and spherules		Amoeboid matrix glass	
	G18	Av.	Range	Av.	Range	Av.	Range
SiO_2	44·6	46·2	(44·2–47·8)	48·6	(45·5–52·4)	47·7	(47·1–48·7)
TiO_2	0·40	0·35	(0·17–0·69)	1·02	(0·25–2·40)	0·99	(0·93–1·05)
Al_2O_3	31·2	25·0	(22·5–28·5)	19·6	(14·0–22·9)	20·5	(19·7–21·2)
Cr_2O_3	0·11	0·18	(0·06–0·24)	0·20	(0·13–0·32)	0·21	(0·19–0·23)
FeO	3·7	5·2	(3·6–7·0)	8·7	(6·9–11·9)	8·4	(8·3–8·6)
MnO	0·06	0·11	(0·05–0·15)	0·13	(0·04–0·20)	0·16	(0·14–0·20)
MgO	3·9	6·9	(5·7–8·6)	7·9	(6·8–9·5)	7·2	(6·8–7·7)
CaO	16·8	14·4	(13·1–16·0)	12·4	(9·9–14·4)	12·4	(12·1–12·6)
Na_2O	0·53	0·34	(0·01–0·59)	0·71	(0·39–1·31)	0·66	(0·64–0·69)
K_2O	0·23	0·10	(<0·01–0·24)	0·37	(0·17–0·99)	0·47	(0·44–0·51)
P_2O_5	0·17	0·07	(0·02–0·15)	0·35	(0·01–1·06)	0·29	(0·22–0·36)
Total	101·70	98·85		99·98		98·98	
No. specimens	1	9		12		4	

Table 3b: Composition (averages) of glass types found in 14318 (Kurat et al. 1974).

High-alkali quartz basalt comp.		Basalt		Miscellaneous			
Av.	Range	Av.	Range	G39	GS8	GS12	
51·6	(50·5–53·3)	44·7	(43·5–47·0)	49·3	52·9	54·7	SiO_2
3·3	(2·85–3·9)	2·61	(2·27–3·4)	0·38	1·44	3·4	TiO_2
10·1	(9·0–10·7)	12·2	(9·6–13·9)	29·7	19·4	10·8	Al_2O_3
0·16	(0·11–0·21)	0·29	(0·22–0·33)	<0·01	0·07	0·10	Cr_2O_3
16·2	(14·8–17·6)	18·1	(16·8–19·7)	0·87	9·7	15·6	FeO
0·30	(0·26–0·33)	0·28	(0·20–0·33)	0·22	0·12	0·26	MnO
5·1	(3·3–6·3)	8·3	(7·3–8·7)	0·31	6·3	4·4	MgO
8·0	(7·5–8·8)	10·2	(8·2–11·2)	12·2	10·9	8·1	CaO
1·32	(1·13–1·48)	0·40	(0·17–0·99)	2·21	0·30	0·10	Na_2O
1·42	(1·20–1·63)	0·72	(0·23–1·50)	1·84	0·23	1·57	K_2O
1·69	(1·42–1·90)	0·85	(0·30–1·86)	0·13	0·03	0·38	P_2O_5
99·19		98·65		97·16	101·39	99·41	Total
4		4		1	1	1	No. specimens

Mg-norite "C2" ,150 TS,152

Warren et al. (1986) and Warren (1993) also list this clast as "probably" pristine. It has a high REE content, like KREEP with very high Eu. The mineral mode is 65% plagioclase (An_{82}), 25% orthopyroxene (figure 9).

Chemistry

Rose et al. (1972), Laul et al. (1972), and Simon et al. (1982) analyzed the matrix, while Warren et al. (1983, 1986) and Laul et al. (1972) analyzed some of the clasts (table 1, figures 7 and 8). Kurat et al. (1974) also determined the composition of lithic clasts (table 2) and of compositional clusters of glass (table 3). Swindle et al. (1985) reported analyses of eight grain size separates (figure 9).

Holland et al. (1972) and Moore et al. (1972) reported the carbon content (figure 10).

Figure 16: 14318 after first saw cut with wire saw positioned for second cut to make slab. Sample is about 10 cm across. NASA S71-38662.

Figure 17: Group photo of pieces from end of 14318. Largest piece is about 1 inch.

Cosmogenic isotopes and exposure ages

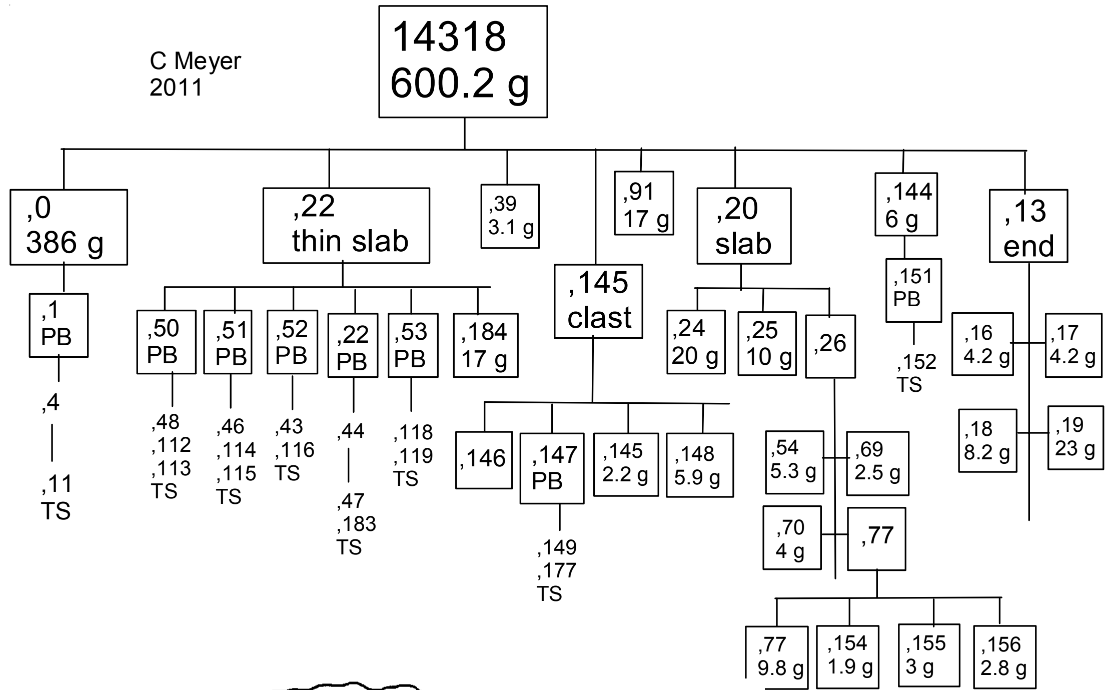
14318 was found to have ^{26}Al activity of 117 dpm/kg, ^{22}Na = 41 dpm/kg, ^{54}Mn = 10 dpm/kg and ^{56}Co = 28 dpm/kg (Keith et al. 1972).

Drozd et al. (1974) reported an exposure age of 38.8 ± 1.3 m.y. determined by the ^{81}Kr method. Eugster et al. (2001) found excess ^{40}Ar (figure 13).

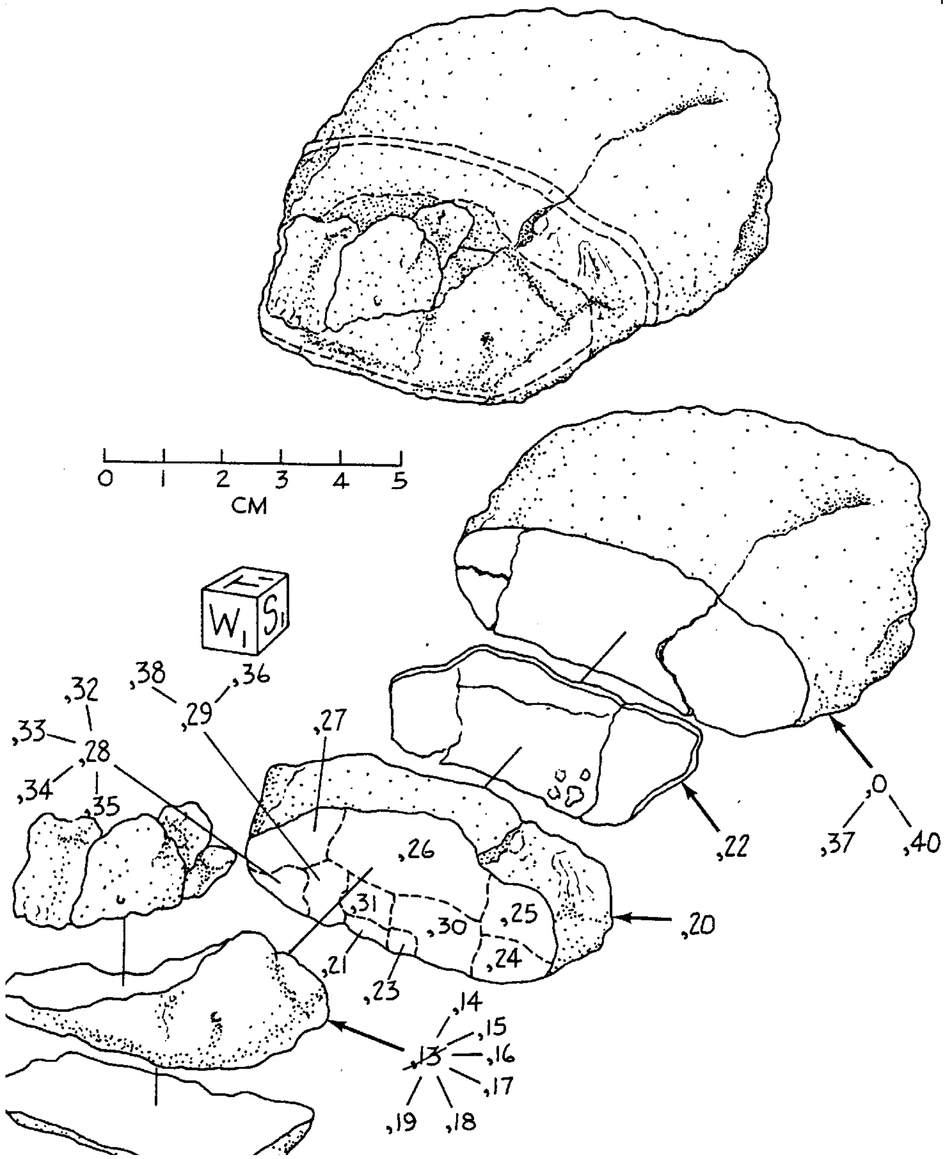
By studying grain size separates, Swindle et al. (1985) found there to be two rare gas components – a volume component and a surface component.

Other Studies

Hutcheon et al. (1972), Macdougall et al. (1973) and Graf et al. (1973) reported fossil cosmic-ray and solar –flare tracks.



C Meyer
2011
14318
600.2 g
,0
386 g
,1
PB
,4
,11
TS
,22
thin slab
,50
PB
,48
,112
,113
TS
,51
PB
,46
,114
,115
TS
,52
PB
,43
,116
TS
,22
PB
,44
,47
,183
TS
,53
PB
,118
,119
TS
,184
17 g
,39
3.1 g
,145
clast
,146
,147
PB
,149
,177
TS
,145
2.2 g
,148
5.9 g
,91
17 g
,20
slab
,24
20 g
,25
10 g
,26
,54
5.3 g
,69
2.5 g
,70
4 g
,77
,77
9.8 g
,154
1.9 g
,155
3 g
,156
2.8 g
,144
6 g
,151
PB
,152
TS
,13
end
,16
4.2 g
,17
4.2 g
,18
8.2 g
,19
23 g



0 1 2 3 4 5
CM
W1
S1
,32
,38
,36
,33
,28
,29
,34
,35
,27
,26
,31
,30
,25
,24
,21
,23
,20
,22
,0
,37
,40
,13
,14
,15
,16
,17
,18
,19

Morrison et al. (1972), Neukum et al. (1973) and Horz et al. (1972) studied the density and distribution of zap pits.

Collinson et al. (1972) studied the magnetic properties, Chung et al. (1972) reported on the dielectric properties and Gibb et al. (1972) determined the Mossbauer spectra.

Tatsumoto et al. (1972) tried to determine the Pb isotopes.

Srinivasan (1973), Reynolds et al. (1974) , Behrmann et al. (1973), Drozd et al. (1974, 75 and 76), Swindle et al. (1985) and Eugster et al. (2001) all tried to solve the puzzle of rare gases in 14318.

Processing

14318 was returned in weigh bag 1038 which was opened in the Crew Reception Area before the sample was entered into the NNPL for description. There are 37 thin sections. One end was cut off and two slabs prepared with the wire saw (figure 16 and 17).

14318 was an object of the Imbrium Consortium led by John Wood (Ryder et al. 1976).

References for 14318

Behrmann C.J., Drozd R.J. and Hohenberg C.M. (1973) Extinct lunar radio-activities: Xenon from 244Pu and 129I in Apollo 14 breccias. *Earth Planet. Sci. Lett*. 17, 446-455.

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. Letters* **18**, 2085-2088.

Carlson I.C. and Walton W.J.A. (1978) **Apollo 14 Rock Samples**. Curators Office. JSC 14240

Chao E.C.T., Minkin J.A. and Best J.B. (1972) Apollo 14 breccias: General characteristics and classification. *Proc. 3rd Lunar Sci. Conf.* 645-659.

Christophe-Michel-Levy M. and Levy C. (1972) The magnesian spinel-bearing rocks from the Fra Mauro formation. *Proc. 3rd Lunar Sci. Conf.* 887-894.

Chung D.H., Westphal W.B. and Olhoeft G.R. (1972) Dielectric properties of Apollo 14 lunar samples. *Proc. 3rd Lunar Sci. Conf.* 3161-3172.

Collinson D.W., Runcorn S.K., Stephenson A. and Manson A.J. (1972) Magnetic properties of Apollo 14 rocks and fines. *Proc. 3rd Lunar Sci. Conf.* 2343-2361.

Drozd R.J., Hohenberg C.M., Morgan C.J. and Ralston C.E. (1974) Cosmic-ray exposure history at the Apollo 16 and other lunar sites: lunar surface dynamics. *Geochim. Cosmochim. Acta* **38**, 1625-1642.

Drozd R., Hohenberg C. and Morgan C. (1975) Krypton and xenon in Apollo 14 samples: Fission and neutron capture effects in gas-rich samples. *Proc. 6th Lunar Sci. Conf.* 1857-1877.

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. 7th Lunar Sci. Conf.* 599-623.

Eugster O., Terribilini Dario, Polnau E. and Kramers J. (2001) The antiquity indicator argon-40/argon-36 for lunar surface camples calibrated by uranium-235-xenon-136 dating. *Meteoritics & Planet. Sci*. **36**, 1097-1115.

Fruland R.M. (1983) Regolith Breccia Workbook. JSC 19045

Gibb T.C., Greatrex R., Greenwood N.N. and Battey M.H. (1972) Mossbauer studies of Apollo 14 lunar samples. *Proc. 3rd Lunar Sci. Conf.* 2479-2493.

Graf H., Shirck J., Sun S and Walker R. (1973) Fission track astrology of three Apollo 14 gas-rich breccias. *Proc. 4th Lunar Sci. Conf.* 2145-2155.

Holland P.T., Simoneit B.R., Wszolek P.C. and Burlingame A.L. (1972) Compounds of carbon and other volatile elements in Apollo 14 and 15 samples. *Proc. 3rd Lunar Sci. Conf.* 2131-2147.

Hörz F., Morrison D.A. and Hartung J.B. (1972) The surface orientation of some Apollo 14 rocks. *Modern Geology* **3**, 93-104.

Hutcheon I.D., Phakey P.P. and Prioce P.B. (1972) Studies bearing on the history of lunar breccias. *Proc. 3rd Lunar Sci. Conf. 2845*-2866.

Keith J.E., Clark R.S. and Richardson K.A. (1972) Gamma-ray measurements of Apollo 12, 14 and 15 lunar samples. *Proc. 3rd Lunar Sci. Conf.* 1671-1680.

King E.A., Butler J.C. and Carman M.F. (1972) Chondrules in Apollo 14 samples and size analyses of Apollo 14 and 15 fines. *Proc. 3rd Lunar Sci. Conf.* 673-686.

Kurat G., Keil K., Prinz M. and Nehru C.E. (1972) Chondrules of lunar origin. *Proc. 3rd Lunar Sci. Conf.* 707-721.

Kurat G., Keil K. and Prinz M. (1974) Rock 14318: A polymict lunar breccia with chondritic texture. *Geochim. Cosmochim. Acta* **38**, 1133-1146.

Laul J.C., Wakita H., Showalter D.L., Boynton W.V. and Schmitt R.A. (1972) Bulk, rare earth, and other trace elements in Apollo 14 and 15 and Luna 16 samples. *Proc. 3rd Lunar Sci. Conf.* 1181-1200.

LSPET (1971) Preliminary examination of lunar samples from Apollo 14. *Science* **173**, 681-693.

Macdougall D., Rajan R.S., Hutcheon I.D. and Price P.B. (1973) Irradiation history and accretionary processes in lunar and meteoritic breccias. *Proc. 4th Lunar Sci. Conf.* 2319-2336.

Moore C.B., Lewis C.F., Cripe J., Delles F.M., Kelly W.R. and Gibson E.K. (1972) Total carbon, nitrogen and sulfur in Apollo 14 lunar samples. *Proc. 3rd Lunar Sci. Conf.* 2051-2058.

Morrison D.A., McKay D.S., Heiken G.H. and Moore H.J. (1972) Microcraters on lunar rocks. *Proc. 3rd Lunar Sci. Conf.* 2767-2791.

Nelen J., Noonan A. and Fredriksson K. (1972) Lunar glasses breccias and chondrules. *Proc. 3rd Lunar Sci. Conf.* 723-737.

Neukum G., Horz F., Morrison D.A, and Hartung J.B. (1973) Crater populations on lunar rocks. *Proc. 4th Lunar Sci. Conf.* 3255-3276.

Phinney W.C., McKay D.S., Simonds C.H. and Warner J.L. (1976a) Lithification of vitric- and elastic-matrix breccias: SEM photography. *Proc. 7th Lunar Sci. Conf.* 2469-2492.

Quaide W. and Wrigley R. (1972) Mineralogy and origin of Fra Mauro fines and breccias. *Proc. 3rd Lunar Sci. Conf.* 771-784.

Reynolds J.H., Alexander E.C., Davis P.K and Srinivasan B. (1974) Studies of K-Ar dating and xenon extinct radionuclides in breccia 14318: implications for early lunar history. *Geochim. Cosmochim. Acta* **38**, 401-417.

Rose H.J., Cuttitta F., Annell C.S., Carron M.K., Christian R.P., Dwornik E.J., Greenland L.P. and Ligon D.T. (1972) Compositional data for twenty-one Fra Mauro lunar materials. *Proc. 3rd Lunar Sci. Conf.* 1215-1229.

Ruzicka A., Snyder G.A. and Taylor L.A. (2000) Crystal-bearing lunar spherules: Impact melting of the Moon's crust and implications for the origin of meteoritic chondrules. *Meteoritics & Planet. Sci*. **35**, 173-192.

Ryder and 27 authors (1976) Interdisciplinary studies by the Imbrium Consortium: Samples 14064, 14082, 14312, 14318, 15405, 15445 and 15455. 2 vol.

Ryder G. and Spudis P. (1980) Volcanic rocks in the lunar highlands. Proc. Conf. Lunar Highlands Crust 353-375. eds. Papike and Merrill LPI

Shervais J.W., Taylor L.A., and Laul J.C. (1983) Ancient crustal components in the Fra Mauro breccias. *Proc. 14th Lunar Planet. Sci. Conf.* B177-B192.

Shervais J.W. and McGee J.J. (1998) Ion and electron microprobe study of trctolites, norites and anorthosites from Apollo 14: Evidence for urKREEP assimilation during petrogenesis of Apollo 14 Mg-suite rocks. *Geochim. Cosmochim. Acta* **62**, 3009-3023.

Simon S.B., Papike J.J., Shearer C.K., Hughes S.S. and Schmitt R.A. (1989) Petrology of Apollo 14 regolith breccias and ion microprobe studies of glass beads. *Proc. 19th Lunar Planet. Sci. Conf.* 1-17.

Simonds C.H., Warner J.L. Phinney W.C. and McGee P.E. (1976a) Thermal model for impact breccia lithification: Manicouagan and the moon. *Proc. 7th Lunar Sci. Conf.* 2509-2528.

Simonds C.H., Phinney W.C., Warner J.L., McGee P.E., Geeslin J., Brown R.W. and Rhodes J.M. (1977) Apollo 14 revisited, or breccias aren't so bad after all. *Proc. 8th Lunar Sci. Conf.* 1869-1893.

Srinivasan B. (1973) Variation in the isotopic composition of trapped rare gases in lunar sample 14318. *Proc. 4th Lunar Sci. Conf.* 2049-2064.

Stoffler D., Knoll H-D., Reimold W. and Schulien S. (1976) Grain size statistics, composition and provenance of fragmetal particles in some Apollo 14 breccias. *Proc. 7th Lunar Sci. Conf.* 1965-1985.

Sutton R.L., Hait M.H. and Swann G.A. (1972) Geology of the Apollo 14 landing site. *Proc. 3rd Lunar Sci. Conf.* 27-38.

Sutton R.L., Batson R.M., Larson K.B., Schafer J.P., Eggleton R.E. and Swann G.A. (1971) Documentation of the Apollo 14 samples. U.S. Geological Survey, Rpt. 32.

Swann G.A., Trask N.J., Hait M.H. and Sutton R.L. (1971a) Geologic setting of the Apollo 14 samples. *Science* **173**, 716-719.

Swann G.A., Bailey N.G., Batson R.M., Eggleton R.E., Hait M.H., Holt H.E., Larson K.B., Reed V.S., Schaber G.G., Sutton R.L., Trask N.J., Ulrich G.E. and Wilshire H.G. (1977) Geology of the Apollo 14 landing site in the Fra Mauro Highlands. U.S.G.S. Prof. Paper 880.

Swann G.A., Bailey N.G., Batson R.M., Eggleton R.E., Hait M.H., Holt H.E., Larson K.B., McEwen M.C., Mitchell E.D., Schaber G.G., Schafer J.P., Shepard A.B., Sutton R.L., Trask N.J., Ulrich G.E., Wilshire H.G. and Wolfe E.W. (1972) 3. Preliminary Geologic Investigation of the Apollo 14 landing site. *In* Apollo 14 Preliminary Science Rpt. NASA SP-272. pages 39-85.

Swindle T.D., Caffee M.W., Hohenberg C.M., Hudson G.B., Laul J.C., Simon S.B. and Papike J.J. (1985) Noble gas component organization in Apollo 14 breccia 14318: 129I and 244Pu regolith chronology. P*roc. 15th Lunar Planet. Sci. Conf.* C517-C539.

Tatsumoto M., Hedge C.E., Doe B.R. and Unruh D.M. (1972) U-Th-Pb and Rb-Sr measurements on some Apollo 14 lunar samples. *Proc. 3rd Lunar Sci. Conf.* 1531-1555.

von Engelhardt W., Arndt J., Stoffler D. and Schneider H. (1972) Apollo 14 regolith and fragmental rocks, their compositions and origins by impacts. *Proc. 3rd Lunar Sci. Conf.* 753-770.

Warner J.L. (1972) Metamophism of Apollo 14 breccias. *Proc. 3rd Lunar Sci. Conf.* 623-643.

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

Warren P.H., Taylor G.J., Keil K., Kallemeyn G.W., Roesner P.S. and Wasson J.T. (1983) Sixth foray for pristine nonmare rocks and an assessment of the diversity of lunar anorthosites. *Proc. 13th Lunar Planet. Sci. Conf.* A615-A630.

Warren P.H., Shirley D.N. and Kallemeyn G.W. (1986) A potpourri of pristine moon rocks, including a VHK mare basalt and a unique, augite-rich Apollo 17 anorthosite. *Proc. 16th Lunar Planet. Sci. Conf.* D319-D330.

Williams R.J. (1972) The lithification of metamorphism of lunar breccias. *Earth Planet. Sci. Lett.* **16**, 250-256.

Wilshire H.G. and Jackson E.D. (1972) Petrology and stratigraphy of the Fra Mauro Formation at the Apollo 14 site. U.S. Geol. Survey Prof. Paper 785.