61220 – 279 grams
61240 – 452 grams
Immature Trench Soil

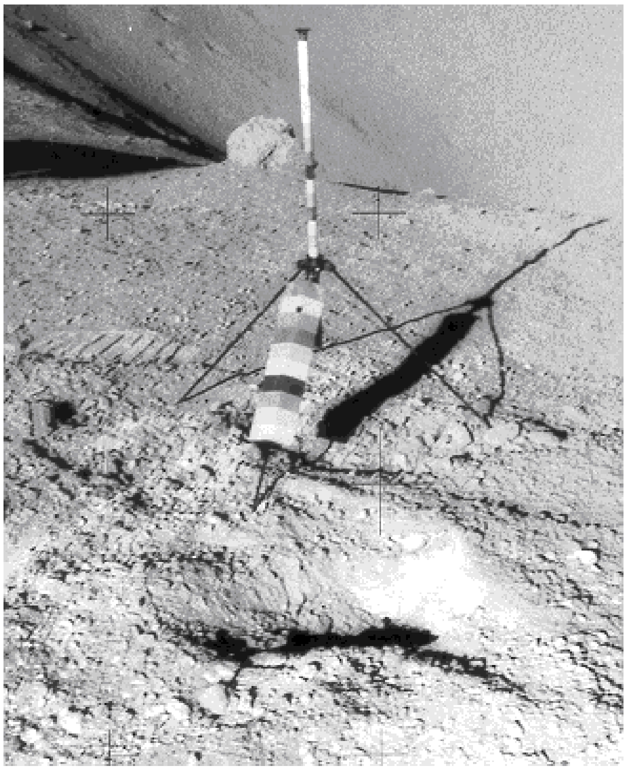


Figure 1: Trench dug on rim of Plum Crater, Apollo 16. AS16-109-17801. 61220 was from the white material at the bottom of this trench; 62240 was from the darker material near the top of the trench. Gnomen is 0.5 m.

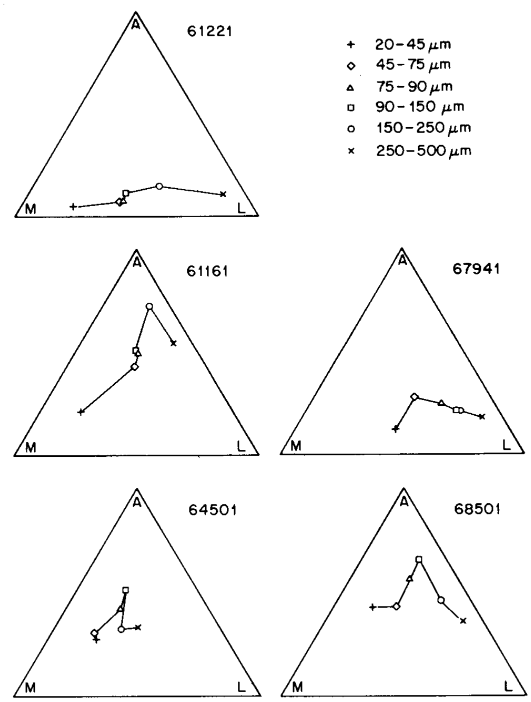


Figure 2: Proportion diagrams of agglutinates (A), minerals (M) and lithic breccia (L) fragments in various Apollo 16 soils as function of grain size, showing 61221 as unusually low in agglutinates for all size range (from Houck 1982).

Introduction

Lunar soil 61220 is different from other lunar soil samples. It is an immature soil that was taken from bottom of a trench dug on the east rim of Plum Crater. The depth is uncertain, but less than 30 cm (figure 1). Soil 61220 is lighter in color than the surface soil (61240) (Morris et al. 1983).

Based on outgassing properties (trace CN), Gibson and Moore (1973) speculated that this soil might include cometary material, but this hypothesis has not been confirmed by other investigators (see, for example, Epstein and Taylor 1973). However, this soil is unusual in several respects and the origin of its volatile content remains an enigma.

Modal content of 61221 and 61241 (90-150 micron).
From Heiken et al. 1973.

	61221	61241
Agglutinates	6.3 %	27.1
Basalt	0.6	2.3
Breccia	33.9	34.5
Anorthosite	13.8	5
Norite	2	-
Gabbro	0.3	0.3
Plagioclase	24.6	19.9
Pyroxene	4.6	4
Olivine	-	
Ilmenite	-	
Glass other	12.2	3.3

Mineralogic Mode for 61221

	LSPET 73	Morris 83	Houck 82
Agglutinates	8	6.3	6.3
Glass fragments			9.9
Colorless	23	10.9	
Brown		1.3	
Olivine	1		0.2
Pyroxene	8	4.6	6.9
Plagioclase	35	17	29.5
Maskeleynite		7.6	
Metabreccia	12	18.3	32.8
Vitric breccia	10	15.6	11.7
Anorthosite		13.6	1.9
Basalt	1	0.6	-
Norite		2	-

Petrography

Karen Houck (1982) determined the detailed mineralogic mode of 61221 and its various grain sizes, finding this sample unusual (figure 2). Houck (1982) and Heiken et al. (1973) found a high proportion of glass, but everyone agrees that the sample is low in agglutinate content. Ridley et al. (1973) reported that it contained a lot of maskelynite (or plagioclase glass).

The maturity index, determined by magnetic properties, is low (Is/FeO = 9.2)(Morris 1979). The average grain size is large; 212 microns for 61220 and 117 microns for 61240 (figure 3a,b).

Cadenhead et al. (1977) found that 61221 had a high surface area for its low maturity index, while 61241 was within the normal range (figure 16). Cadenhead

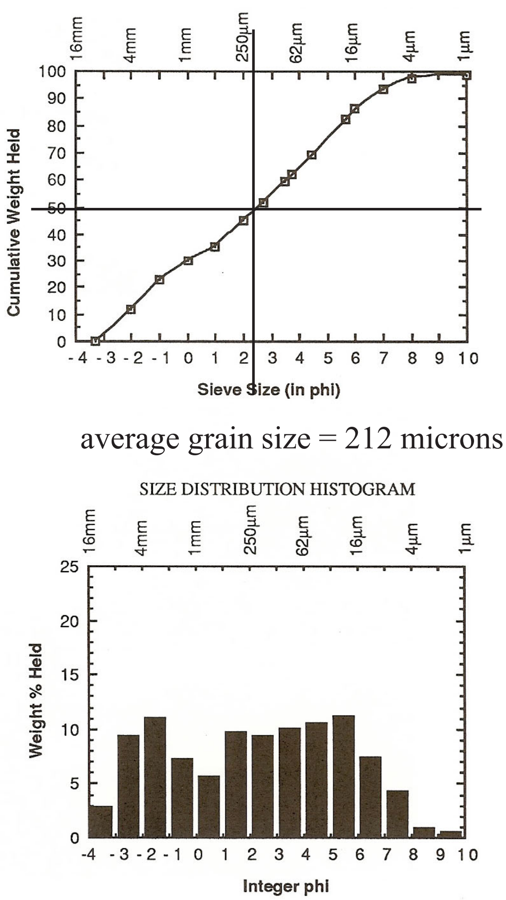


Figure 3a: Grain size distribution of 61220 (unsieved) (Graf 1991, from data by McKay)

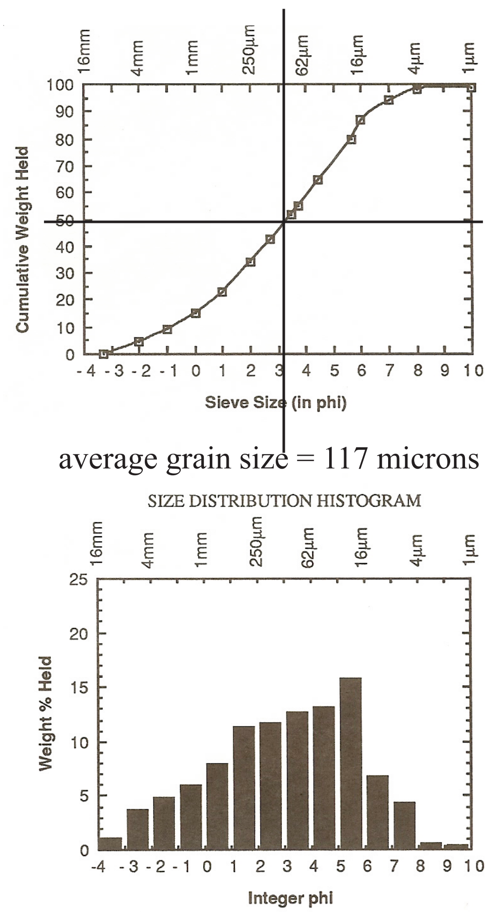


Figure 3b: Grain size distribution of 61240 (unsieved) (Graf 1991, from data by McKay).

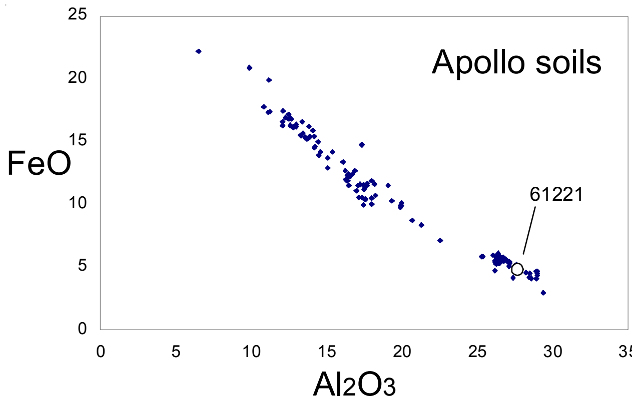


Figure 4: Composition diagram for lunar soils showing that 61221 is high aluminous.

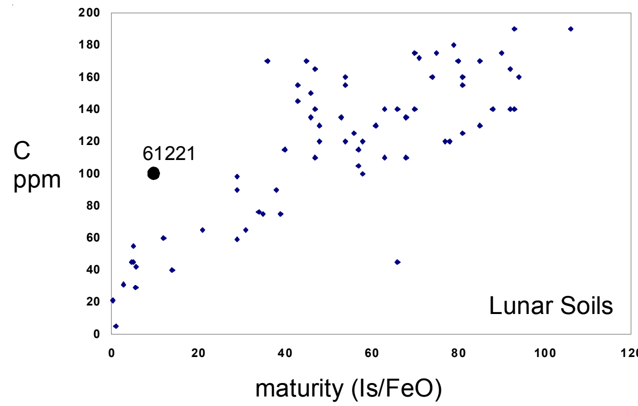


Figure 6: 61221 is special in that it has relatively high carbon content and low maturity.

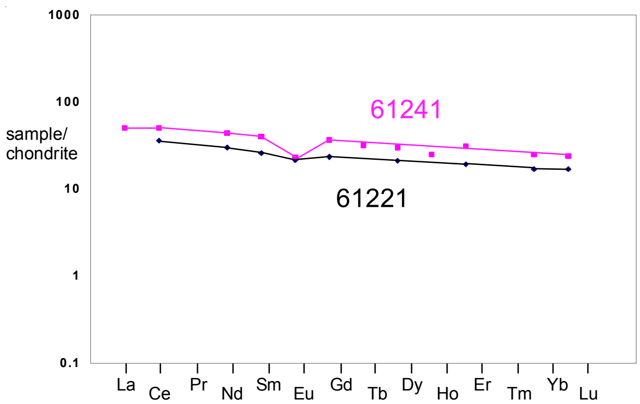


Figure 5: Normalized rare-earth-element diagram for 61221 and 61241 (see tables).

et al. speculate that 61221 was created through a single impact event.

Glass

Ridley et al. (1973) and Meyer (1978) studied the glass particles in 61221. Ridley et al. argued that clusters in glass composition allowed them to identify "Highland Basalt" and other "rock types". However, the composition of "Highland Basalt" closely matches the composition of the bulk soil (figures 14 and 15). Meyer attempted to show that "average" glass composition is contaminated by trace elements, because at least some of the glass is made from the regolith or from breccia (mixtures).

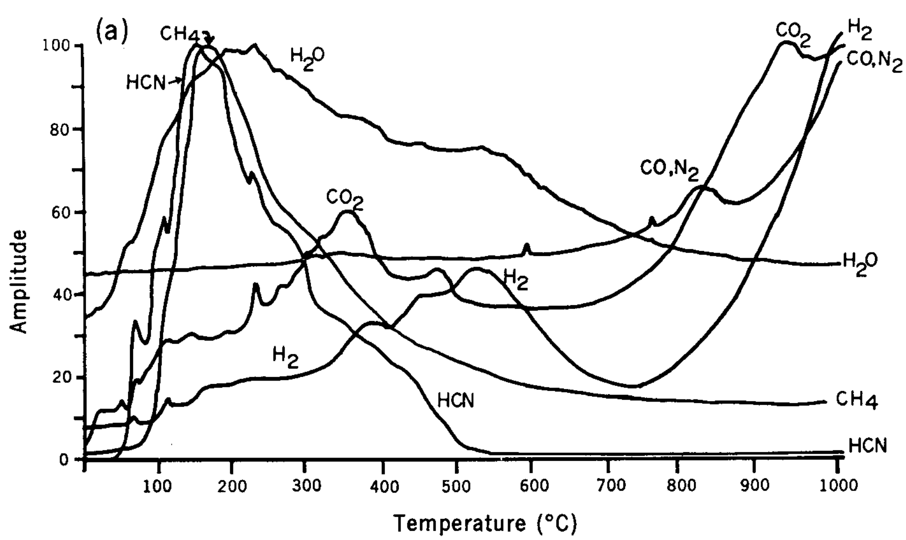


Figure 7: Temperature release curves for volatiles from 61221 (Gibson and Moore 1973). Note the verticle scale is "arbitrary".

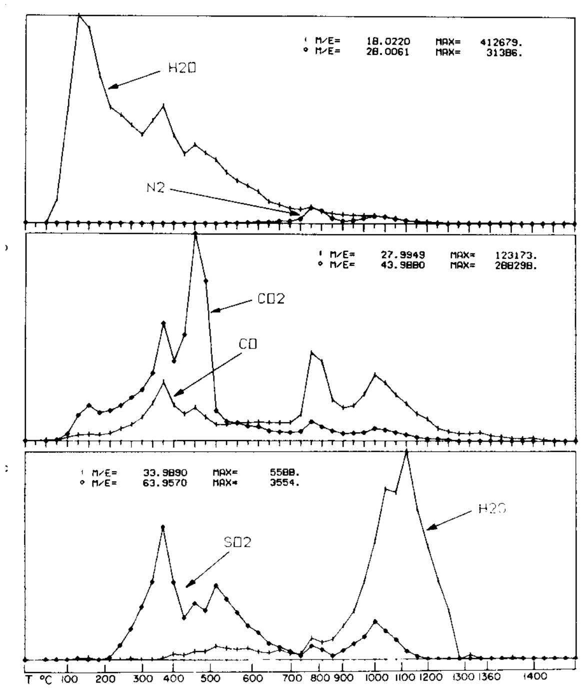


Figure 8a: Temperature release curves for 61221 (from Wszolek et al. 1973).

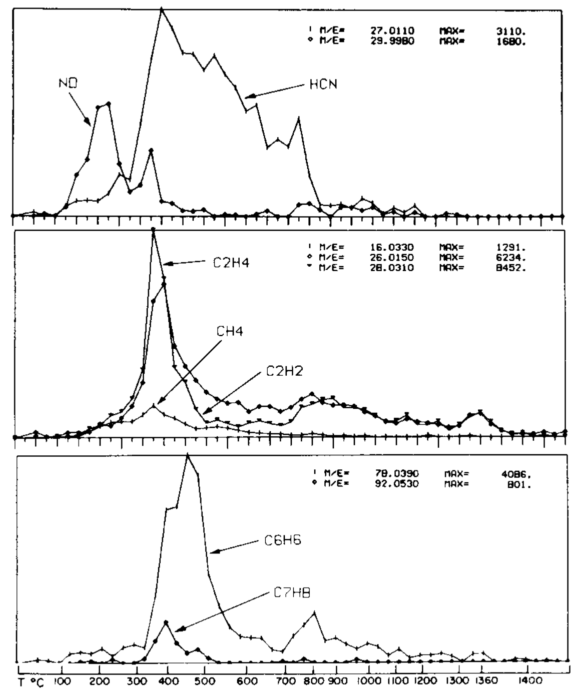


Figure 8b: Temperature release curves for 61221 (from Wszolek et al. 1973).

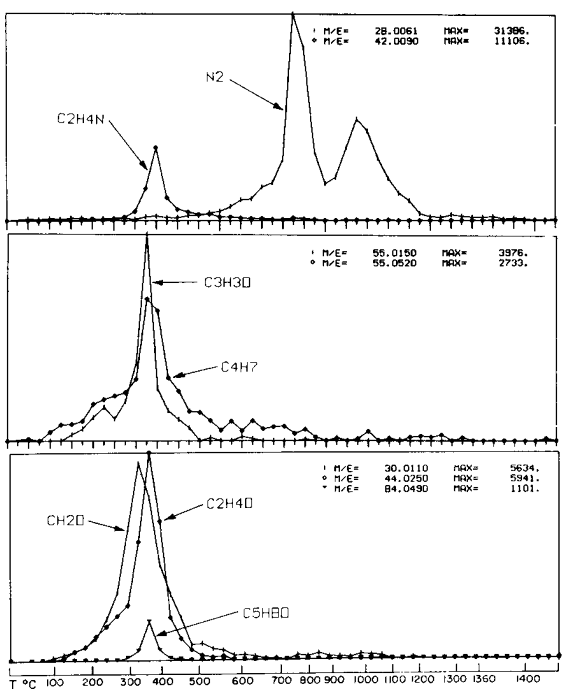


Figure 8c: Temperature release curves for 61221 (from Wszolek et al. 1973).

Coarse Fines

Marvin and Mosie (1980) made a catalog of coarse fines (1-4 mm) from 61220 and these have been subsequently investigated by various labs. Marvin (1972) included coarse-fines from 61240 in her catalog of 4-10 mm particles. Several small rocks from these soils were given individual sample numbers and are briefly described in the Apollo 16 Rock Sample Catalogs by Butler (1972) and Ryder and Norman (1980).

Marvin and Warren (1980) studied the particles of pristine "micro-gabbro" found in the coarse fines (table 3). 61224,6 is composed of ~63% pyroxene (0.2 – 3 mm) and ~34% plagioclase (0.3 – 1 mm). Plagioclase is An_{83} and pyroxene is $En_{65}Fs_{32}Wo_{3}$ and $En_{43}Fs_{17}Wo_{40}$. Takeda et al. (1981) studied the nature of the exsolved pyroxene in 61224,6, discussing the cooling history.

Chemistry

The chemical composition of 61221 was originally reported by LSPET (1973), Bansal et al. (1972), Haskin et al. (1973), Rose et al. (1973) and others (table 1). Boynton et al. (1976) provided a complete analysis for 61241 (table 2). Finkelman et al. (1975) and Korotev et al. (1981) also measured the composition of the fine fraction from these samples, and Rhodes et al. (1975) studied the agglutinates in 61241. These soils are highly aluminous (figure 4). 61241 has a higher trace element content than 61221, from the bottom of the trench (tables 1 and 2, figure 5).

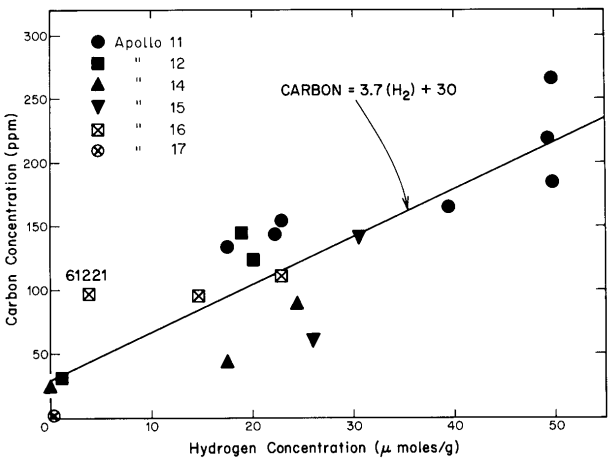


Figure 9: Carbon and hydrogen in 61221 compared with other lunar soils (from Epstein and Taylor 1973).

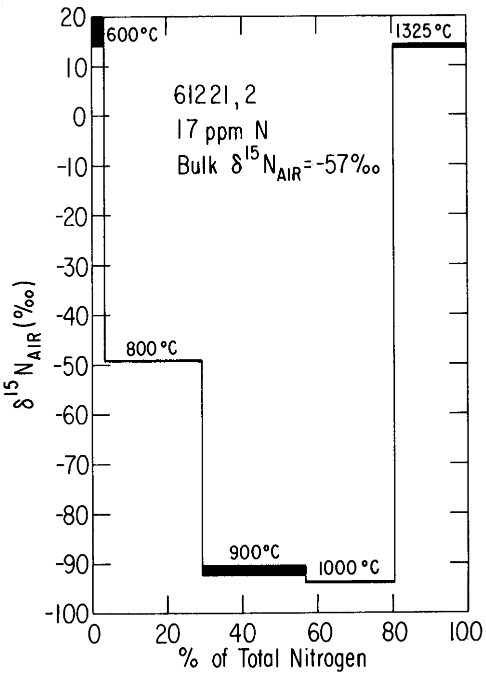


Figure 10: Isotopic composition of nitrogen released from 61221 during stepwise heating (Becker et al 1976).

Gibson and Moore (1973b) give the sulfur content of 61221 as 496 ppm. Jovanovic and Reed (1973) studied the halogens in 61221 and 61241 finding that they were within the range of other Apollo 16 materials. Allen et al. (1974) found that ^{204}Pb, Bi, Tl and Zn were within the overall range of Apollo 16 soils.

Mark et al. (1973) and Nyquist et al. (1973) determined the Rb, Sr and K contents and Sr isotopic composition for 61221 and 61241.

61221 has relatively high carbon content (~100 ppm) for its maturity (Moore et al. 1973, figure 6). Gibson and Moore (1973a) and Wszolek et al. (1973) studied the temperature release of volatiles from 61221 (figures 7, 8 a,b,c). These temperature release patterns are different from that of other lunar materials, with more carbon based molecules coming off at a lower temperature. Gibson and Moore speculated that the volatiles might have a cometary origin, while Wszolek et al. interpreted this unusual volatile pattern might be from an impact by a carbonaceous chondrite. However, DesMarais et al. (1973) found the carbon content and species similar to that of other lunar soils.

Epstein and Taylor (1973) found that the H/D isotope ratio was like that of terrestrial water (figure 11) and provide an indepth discussion of the H, C and oxygen isotope measurements with respect to Gibson and Moore's cometary hypothesis. Sill et al. (1974) have also suggested a cometary origin for gas trapped in 78155. But no firm evidence has been established.

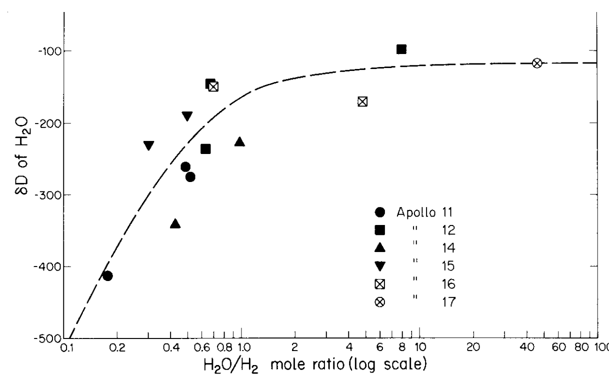


Figure 10: Hydrogen isotope diagram for 61221 and other soils (Epstein and Taylor 1973).

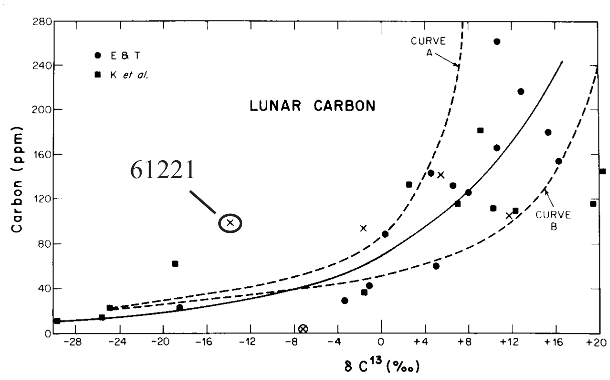


Figure 12: Carbon isotope composition of 61221 (from Epstein and Taylor 1973).

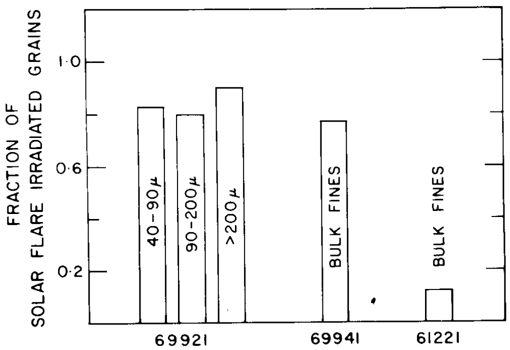


Figure 13: Tracks in 61221 compared with tracks measured for 69921 (Rao et al. 1979).

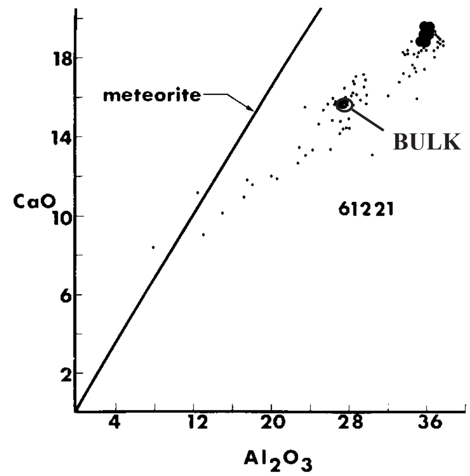


Figure 14: Glass composition in 61221 showing clusters for "Highland Basalt" and maskelynite (Ridley et al. 1973). BULK composition for table 1 is added (for good measure).

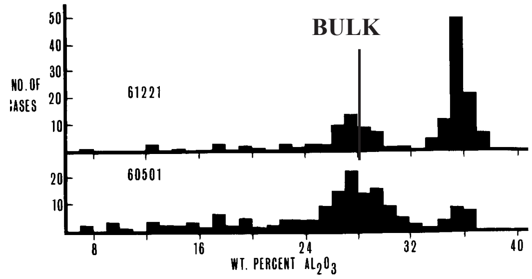


Figure 15: Al2O3 content of glass particles in 61221 compared with 60501 (Ridley et al. 1973). The "cluster" at 28% Al2O3 (Highland Basalt) is suspiciously like the composition of the bulk regolith (line).

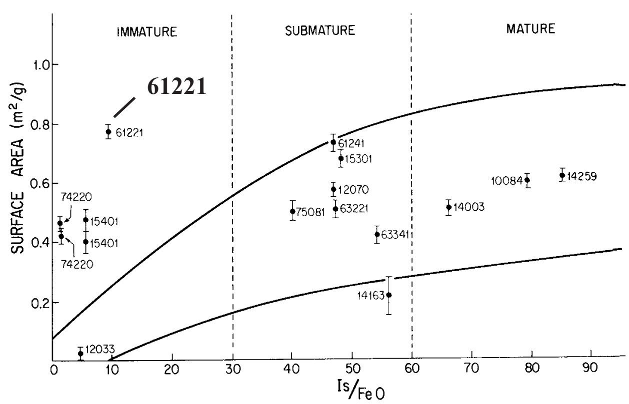


Figure 16: 61221 has a high surface area for its maturity (Cadenhead et al. 1977).

Becker et al. (1976) determined the nitrogen isotope ratio as a function of release temperature (figure 10).

Krahenbuhl et al. (1973) and Ganapathy et al. (1974) give concentrations for three small particles from 61222.

Cosmogenic isotopes and exposure ages

Walton et al. (1973) determined the cosmic ray exposure age of 61221 and 61241 by ^{21}Ne as 250 m.y. and 240 m.y., respectively. Imamura et al. (1974) studied ^{54}Mn in both samples finding that they were consistent with the ^{54}Mn depth profiles of deep drill samples. The main conclusion is that both sample are saturated with ^{54}Mn activities predicted for their depth and must have remain exposed and relatively undisturbed for >5 m.y. (perhaps the age of Plum Crater).

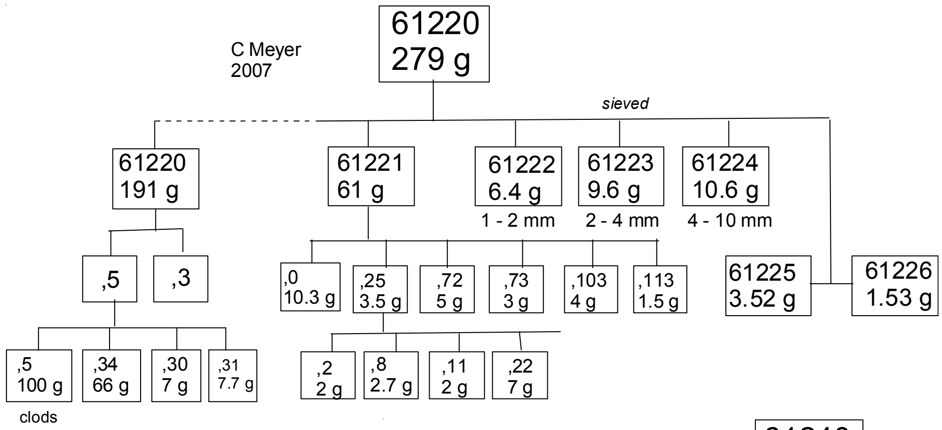
Fireman et al. (1973) reported ^{37}Ar, ^{39}Ar and ^{3}H, while Fields et al. (1973) studied the interaction of the cosmic-ray flux with U.

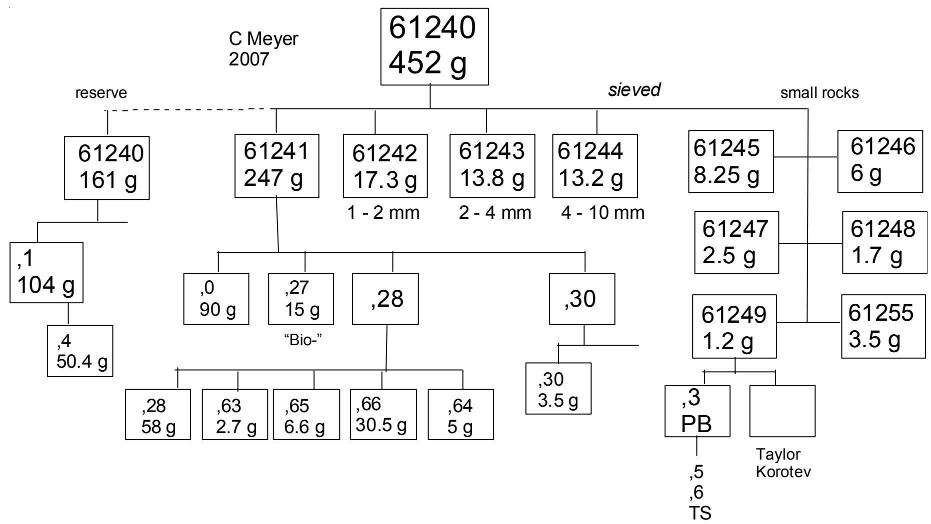
Other Studies

Taylor and Epstein (1973) studied the isotopic composition of silicon and oxygen removed by partial fluorination and compared results with surface soils.

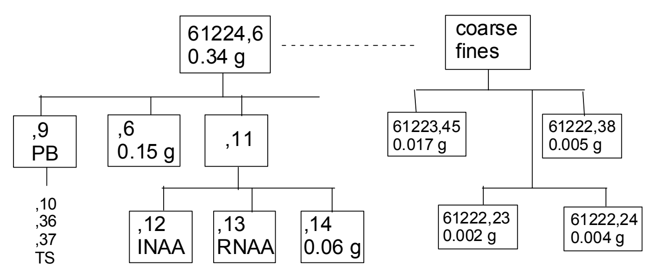
Bogard and Nyquist (1973), Walton et al. (1973) and Nautiyal et al. (1981) determined rare gas contents of 61221 and found that 61221 had considerable excess ^{40}Ar and ^{4}He.

Fleischer and Hart (1974) and Rao et al. (1979) determined the density of cosmic-ray tracks in 61221 (figure 13).





Pristine Gabbro



Processing

Soils 61220 and 61240 were brought back in ALSRC#1, but it did not seal and the samples were exposed to spacecraft (LM and CM) and Pacific Ocean atmospheres. A fairly large portion of 61220 remains unsieved. There is a note in the inventory that 61220 contains "clods".

Several small rocks were removed – see table.

Small rocks found in 61220 and 61240

61224,6	0.5 g	Micro-gabbro
61225	3.52 g	Crystalline Impact Melt
61226	1.53	Cataclastic Anorthosite
61245	8.25	Fine-grained Impact Melt
61246	6.05	Fine-grained Impact Melt
61247	2.48	Poikilitic Impact Melt
61248	1.71	Fagmental Polymict Breccia
61249	1.17	Basaltic Impact Melt (?)
61255	1.13	Cindery Glass

Table 1. Chemical composition of 61221.

			Bansal 72		61220												
reference	Krahenbuhl73		Wiesmann 74		Gibson 73		Haskin 73		Rose 73		Korotev 81			Finkelman75			
weight					LSPET 73						150-90	<20 microns		1mm-90	30-90	<30	
SiO2 %			45.4	(c)	45.35	(c)	46.1	(h)	45.2	(e)							
TiO2			0.45	(b)	0.49	(c)	1.05		0.51								
Al2O3			28.25	(c)	28.25	(c)	26.4		28.3								
FeO			4.55	(c)	4.55	(c)	5.71		4.61		4.36	4.63	(f)				
MnO					0.06	(c)	0.058		0.06								
MgO			5.02	(c)	5.02	(c)	6		4.92								
CaO			16.21	(c)	16.21	(c)	15.7		16.02								
Na2O			0.5	(b)	0.42	(c)	0.52		0.42		0.549	0.532	(f)				
K2O			0.086	(c)	0.09	(c)	0.132		0.08								
P2O5					0.1	(c)			0.11								
S %					0.06	(c)											
sum																	
Sc ppm							7	(d)	6.9		7.2	7.7	(f)	8	8	10	(g)
V									20					14	20	24	(g)
Cr			526	(b)	590	(c)	600	(d)	615		575	760	(f)				
Co							17	(d)	9.2		24.5	14.5	(f)	10	15	16	(g)
Ni					109	(c)			160		330	210	(f)	150			(g)
Cu									6.2					5			(g)
Zn	21.5	(a)					23	(d)	22					18	21		(g)
Ga							6.2	(d)	4.6					3	3	4	(g)
Ge ppb	345	(a)															
As																	
Se	206	(a)															
Rb	2	(a)	1.96	(b)			2.3	(d)	1.8					1			(g)
Sr			188	(b)	182				145					180	160	170	(g)
Y									26					28	30	35	(g)
Zr			110	(b)					85					86			(g)
Nb																	
Mo																	
Ru																	
Rh																	
Pd ppb																	
Ag ppb	11	(a)															
Cd ppb	140	(a)															
In ppb																	
Sn ppb																	
Sb ppb	1.6	(a)															
Te ppb	14.7	(a)															
Cs ppm	0.09	(a)					0.096	(d)									
Ba			96.5	(b)					88					93			(g)
La							9.1	(d)			7.2	9.9	(f)			17	(g)
Ce			21.6	(b)			22.7	(d)			18.5	26.5	(f)				
Pr																	
Nd			13.5	(b)			14.5	(d)									
Sm			3.82	(b)			4.35	(d)			3.35	4.5	(f)				
Eu			1.21	(b)			1.28	(d)			1.19	1.18	(f)				
Gd			4.6	(b)			5.3	(d)									
Tb							0.9	(d)			0.78	0.97	(f)				
Dy			5.12	(b)			5.76	(d)									
Ho							1.1	(d)									
Er			3.06	(b)			3.2	(d)									
Tm																	
Yb			2.77	(b)			3.01	(d)	1.8		2.65	3.3	(f)	3	2.8	3.2	(g)
Lu			0.41	(b)			0.44	(d)			0.38	0.44	(f)				
Hf			3.3	(b)			3	(d)			2.3	3.1	(f)				
Ta											0.4	0.4	(f)				
W ppb																	
Re ppb	0.578	(a)															
Os ppb																	
Ir ppb	6.21	(a)															
Pt ppb																	
Au ppb	4.94	(a)															
Th ppm			1.56	(b)							1.2	1.4	(f)				
U ppm			0.38	(b)													

technique: (a) RNAA, (b) IDMS, (c) XRF, (d) INAA, (e) combined methods, (f) INAA, (g) OES, (h) AA

Table 2. Chemical composition of 61241.

reference	LSPET73		Boynton76		Haskin73		Krahenbuhl73		Rose73		Finkelman73			
weight			261 mg								1mm-90	30-90	<30	
SiO2 %	45.32	(a)			45.6	(d)			45.14	(e)				
TiO2	0.57	(a)	0.77	(b)	0.9				0.55	(e)				
Al2O3	27.15	(a)	25.89	(b)	26.6				27.35	(e)				
FeO	5.33	(a)	5.27	(b)	5.14				5.42	(e)				
MnO	0.07	(a)	0.06	(b)	0.068				0.06	(e)				
MgO	5.75	(a)	5.47	(b)	5.71				5.34	(e)				
CaO	15.69	(a)	15.8	(b)	15.9				15.6	(e)				
Na2O	0.55	(a)	0.47	(b)	0.5				0.57	(e)				
K2O	0.1	(a)	0.1	(b)	0.124				0.12	(e)				
P2O5	0.13	(a)							0.11	(e)				
S %	0.07	(a)												
sum														
Sc ppm			9.1	(b)	8.8	(b)			6.9	(e)	10	8	10	(f)
V			18	(b)					18	(e)	15	18	21	(f)
Cr	720	(a)	760	(b)	607				684	(e)				
Co			22.4	(b)	23.8				14	(e)	200	16	16	(f)
Ni	220	(a)	276	(c)					240	(e)	>1000	320	340	(f)
Cu									8.8	(e)	15	>55	>55	(f)
Zn			25.4	(c)	23		22.5	(b)	27	(e)	7	90	213	(f)
Ga			5.4	(c)	5.1				4	(e)	3	3	4	(f)
Ge ppb			620	(c)			582							
As														
Se							257							
Rb	2.7	(a)			1.9		2.2		2.7	(e)	2	6	11	(f)
Sr	175	(a)							160	(e)	180	160	170	(f)
Y	37	(a)							38	(e)	40	30	40	(f)
Zr	162	(a)							117	(e)	110	110	135	(f)
Nb	9.8	(a)												
Mo														
Ru														
Rh														
Pd ppb														
Ag ppb							11							
Cd ppb			124	(c)			119							
In ppb			13.9	(c)										
Sn ppb											<10	<10	62	(f)
Sb ppb							1.55							
Te ppb							15.6							
Cs ppm					0.121		0.105							
Ba			120	(b)					105	(e)	78	94	112	(f)
La			12	(b)	11.8						<10	<10	<10	(f)
Ce			29	(b)	30.5									
Pr														
Nd					20									
Sm			5.2	(b)	5.85									
Eu			1.1	(b)	1.29									
Gd					7.2									
Tb			1.1	(b)	1.16									
Dy			6.1	(b)	7.2									
Ho					1.4									
Er					4.9									
Tm														
Yb			3.7	(b)	4.08				2.4		3.3	2.9	3.7	(f)
Lu			0.5	(b)	0.59									
Hf			3.3	(b)	4.5									
Ta			0.4	(b)										
W ppb														
Re ppb							0.762	(c)						
Os ppb														
Ir ppb			7.1	(c)			9.64	(c)						
Pt ppb														
Au ppb			5.2	(c)			5.31	(c)						
Th ppm	1.7	(a)	1.8	(b)										
U ppm			0.52	(b)										

technique: (a) XRF, (b) INAA, (c) RNAA, (d) AA, (e) mixed, (f) OES

Table 3. Chemical composition of 61224,6.

reference	Marvin80
weight	
SiO2 %	50.7
TiO2	0.4
Al2O3	13.2
FeO	9.91
MnO	0.16
MgO	12.8
CaO	11.6
Na2O	0.91
K2O	0.017
P2O5	
S %	
sum	
Sc ppm	20.8
V	
Cr	1991
Co	23.6
Ni	8.3
Cu	
Zn	4
Ga	
Ge ppb	4.3
As	
Se	
Rb	
Sr	
Y	
Zr	170
Nb	
Mo	
Ru	
Rh	
Pd ppb	
Ag ppb	
Cd ppb	4.1
In ppb	0.6
Sn ppb	
Sb ppb	
Te ppb	
Cs ppm	
Ba	32
La	1.47
Ce	4.3
Pr	
Nd	9
Sm	0.87
Eu	1.43
Gd	
Tb	0.22
Dy	
Ho	
Er	
Tm	
Yb	1.06
Lu	0.16
Hf	0.55
Ta	0.16
W ppb	
Re ppb	0.012
Os ppb	
Ir ppb	0.15
Pt ppb	
Au ppb	0.08
Th ppm	0.19
U ppm	<0.6

technique: (a) INAA and RNAA.

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