Queen Alexandra Range 94281

Anorthosite-bearing basaltic (polymict) regolith breccia

23.4 g

Figure 1: Photograph of QUE94281 in the Meteorite Processing Laboratory at JSC.

Introduction

In January 1994, a 23.4 g lunar breccia was found in the Footrot Flats region of the Queen Alexandra Range, Antarctica (Figs. 1 and 2). It's unusual appearance (Fig. 1) includes a black glassy fusion crust, a rough black zone, an aphanitic zone and a region of coarse-grained breccia. These characteristics led the JSC processing team to classify this as a regolith breccia containing mare and highlands materials and a 3:1 ratio. Petrographic studies showed this to be an immature regolith breccia, and this is supported by FMR measurements yielding values within the range of immature Apollo regolith (Lindstrom et al., 1996).

Petrography and Mineralogy

QUE 94281 is a polymict regolith breccia that is dominated by a very low Ti mare basalt component. Detailed examination of this meteorite has revealed that it contains many mineral fragments of basaltic derivation, distributed in a dark glassy matrix with rare anorthositic highlands clasts (Fig. 3). The latter are impact melt or granulitic textured.

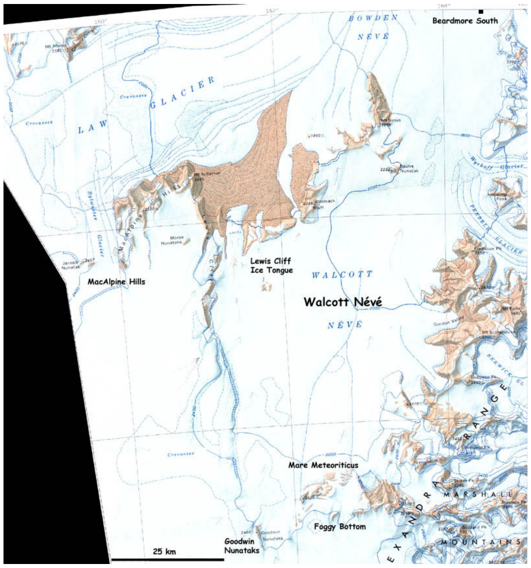


Figure 2: The Walcott Neve region of the Queen Alexandra Range, home of QUE meteorites. Foggy Bottom region is shown in the southern part of the map.

Pyroxene fragments exhibit a large compositional range from pigeonite to ferroaugite (Fig. 4 and 5). Some of the pyroxenes contain coarse exsolution lamellae, indicating that some material experienced slow cooling at some depth in the lunar crust (Arai and Warren, 1999). Plagioclase feldspar fragments fall into a narrow compositional range centered on An_{93} (Fig. 4). There is also rare olivine and it also exhibits a large range from Fo_{80} to nearly pure fayalite (Fig. 4).

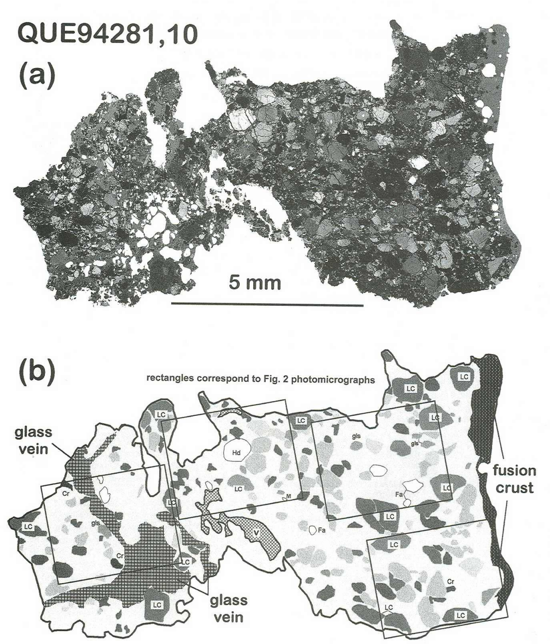


Figure 3: Backscattered electron image and sketch of section ,10 (from study of Jolliff et al., 1996).

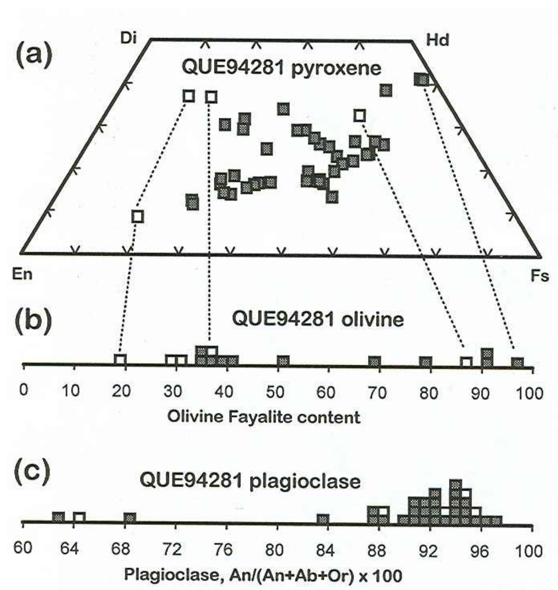


Figure 4: Pyroxene, olivine and plagioclase compositions from study of Jolliff et al. (1996).

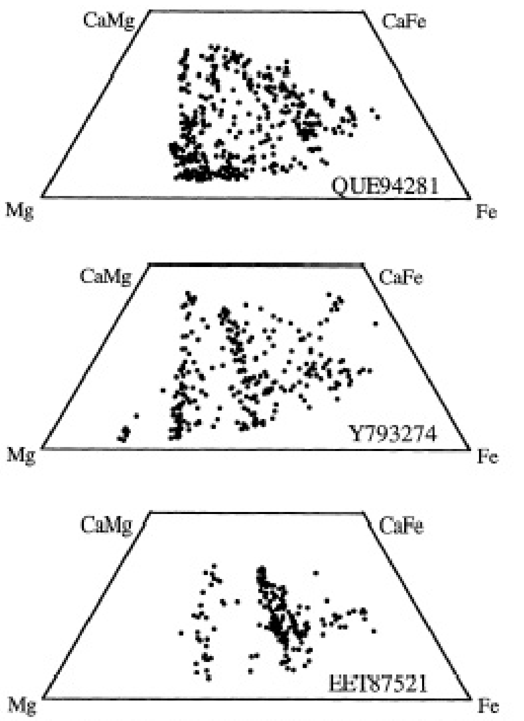


Figure 5: Pyroxene compositions from study of Arai and Warren (1999).

One of the most distinctive features of QUE 94281 is the preponderance of glasses. There are several different kinds of glass found in this meteorite and it is important to distinguish these (e.g., Jolliff et al., 1998; Arai and Warren, 1999; Lindstrom et al., 1996; Kring et al., 1996). The most common is melt breccia glass, but there are also melt veins, and mafic/picritic glasses that have some compositional similarities to pyroclastic glasses such as the Apollo 15 green glasses (Fig. 6).

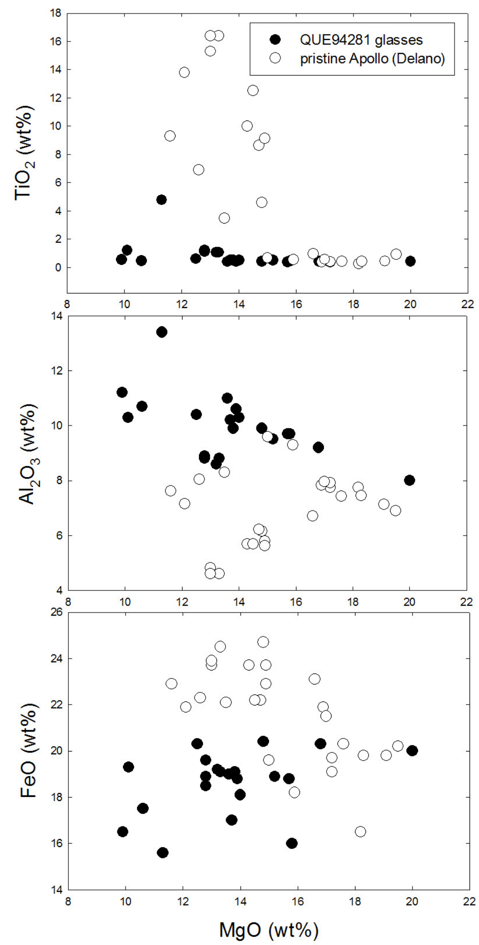


Figure 6: Mafic glass compositions from studies of Kring et al. (1996), Jolliff et al. (1998) and Arai and Warren (1999), and compared to the pristine glasses of Delano (1986).

Table 1: Major element compositions of mafic glasses in QUE 94281

Sample	Ref	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
J1	1	45.7	0.40	10.6	0.45	18.8	0.23	13.9	9.60	0.21	0.01	n.d.	99.9
J2	1	44.2	0.41	8.0	0.72	20.0	0.23	20.0	7.16	0.23	0.02	n.d.	101.0
J3	1	46.8	1.20	10.3	0.40	19.3	0.27	10.1	10.8	0.30	0.05	0.10	99.6
J4	1	43.0	4.78	13.4	0.39	15.6	0.22	11.3	10.6	0.08	0.01	<0.02	99.3
1	2	44.6	0.37	9.7	0.49	18.8	0.26	15.7	9.1	0.26	0.03	-	99.4
2	2	44.7	0.40	11.0	0.31	19.0	0.26	13.6	9.7	0.41	0.06	-	99.4
3	2	44.5	0.42	9.2	0.45	20.3	0.27	16.8	8.4	0.26	0.02	-	100.6
4	2	45.1	0.43	9.9	0.36	20.4	0.28	14.8	8.9	0.29	0.06	-	100.6
5	2	47.7	0.47	10.7	0.52	17.5	0.30	10.6	12.5	0.16	0.09	-	100.5
6	2	46.8	0.48	9.7	0.64	16.0	0.26	15.8	9.0	0.03	0.02	-	98.8
7	2	46.1	0.49	10.3	0.46	18.1	0.26	14.0	10.0	0.21	0.07	-	100.0
8	2	45.0	0.51	9.5	0.50	18.9	0.27	15.2	9.2	0.22	0.02	-	99.3
9	2	46.0	0.53	10.2	0.39	17.0	0.25	13.7	11.0	0.21	0.05	-	99.4
10	2	48.1	0.54	11.2	0.35	16.5	0.26	9.9	11.3	0.42	0.05	-	98.6
11	2	44.4	0.61	10.4	0.48	20.3	0.26	12.5	10.5	0.21	0.03	-	99.7
1	2	46.1	1.06	8.6	0.55	19.2	0.26	13.2	9.4	0.35	0.03	-	98.9
2	2	47.0	1.07	8.8	0.53	19.1	0.28	13.3	9.6	0.26	0.04	-	99.9
3	2	46.5	1.13	8.9	0.52	18.5	0.27	12.8	9.7	0.43	0.03	-	98.9
4	2	46.2	1.20	8.8	0.50	18.9	0.26	12.8	9.6	0.41	0.03	-	98.8
5	2	46.4	1.22	8.9	0.51	19.6	0.28	12.8	9.9	0.32	0.04	-	100.0
Kring	3	45.8	0.49	9.9	0.54	19.1	0.27	13.8	9.54	0.24	0.02	0.04	99.7

References: 1) Jolliff et al. (1998); 2) Arai and Warren (1999); 3) Kring et al. (1996)

Chemistry

Many fractions of QUE 94281 have been analyzed by neutron activation analysis (Table 2). There is compositional heterogeneity among the various splits and subsplits analyzed. However, there is a clear mixing trend between mare and highland end members, giving QUE 94281 an intermediate composition (Figs. 7 and 8). The suggestion has been made (Korotev et al., 2009) that QUE 94281 may be launch paired with Yamato 981031 and NWA 4881, based on their similar petrography and bulk composition (YQN grouping).

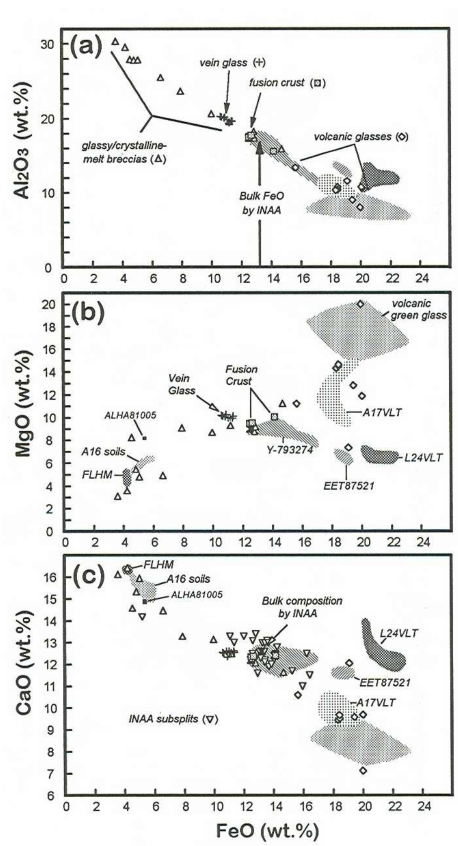


Figure 7: Compositional variation in QUE 94281 compared to other highland and mare materials (from study of Jolliff et al., 1998).

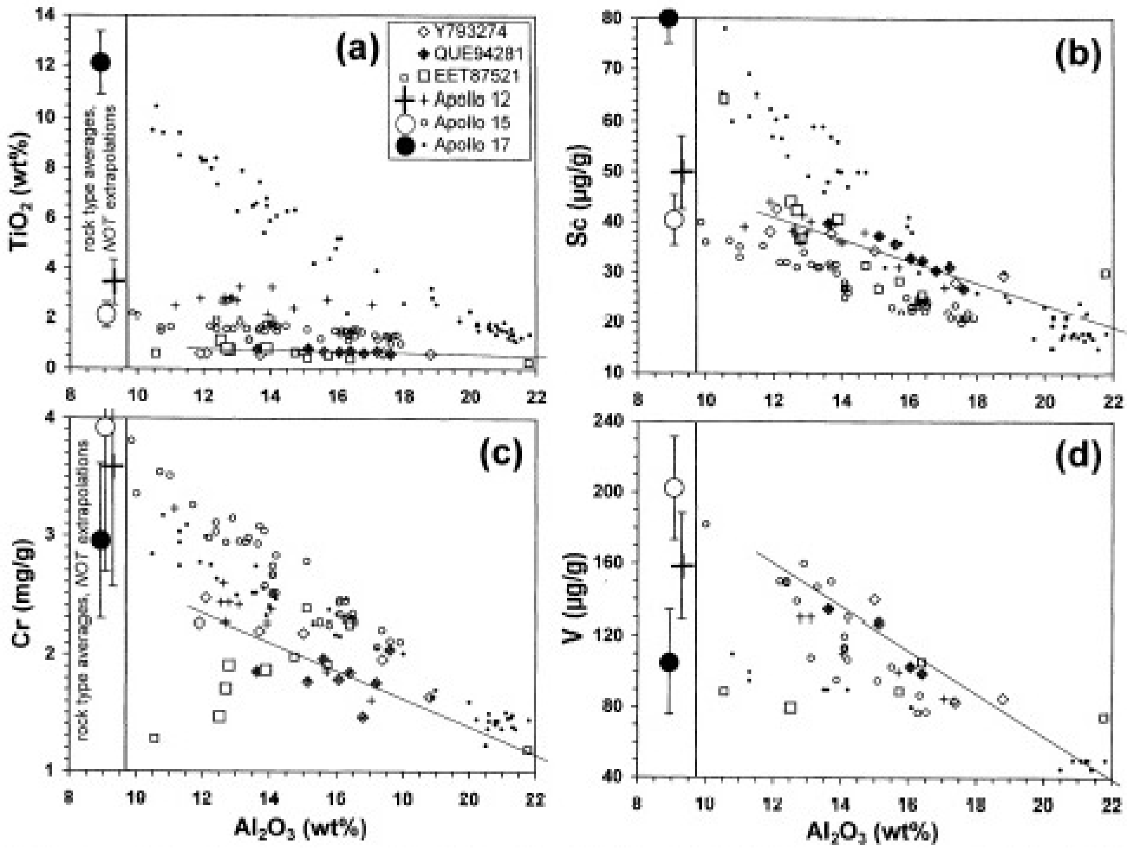


Figure 8: Compositional variation in QUE 94281 compared to other highland and mare materials (from study of Arai and Warren, 1999).

Radiogenic age dating

There has been very little isotopic work done on QUE 94281, but Eugster and Polnau (1998) demonstrated a K-Ar age of 3770 Ma based on analyses of glass, bulk and crystals (Fig. 9). There has been no published Rb-Sr, Sm-Nd, Lu-Hf or other radiogenic isotopic work reported for this meteorite.

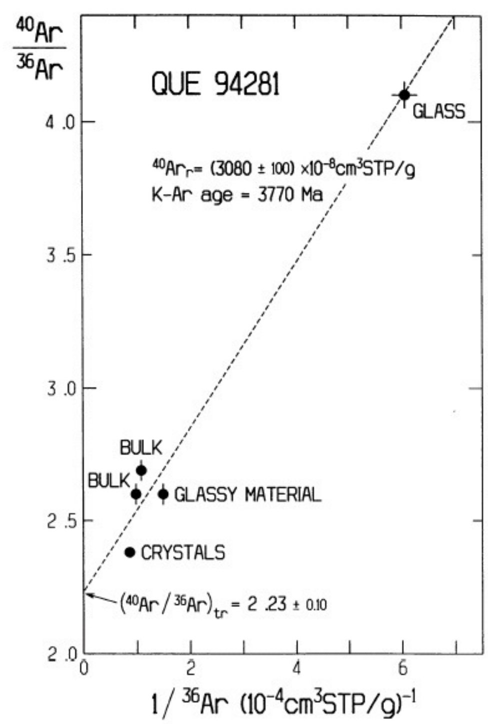


Figure 9: ^{40}Ar-^{36}Ar vs $1/^{36}Ar$ for QUE 94281, illustrating the radiogenic ^{40}Ar component allowing an age estimate of 3770 Ma (from study of Eugster and Polnau, 1998).

Cosmogenic isotopes and exposure ages

Although there are similarities in noble gas isotopic composition of QUE 94281 and Y793274 (Fig. 10), there are significant differences in the ejection age. QUE 94281 yields a much older ejection age (0.15 to 0.45 Ma) compared to Y793274 (< 0.04 Ma), indicating that these two may be related but not source crater paired.

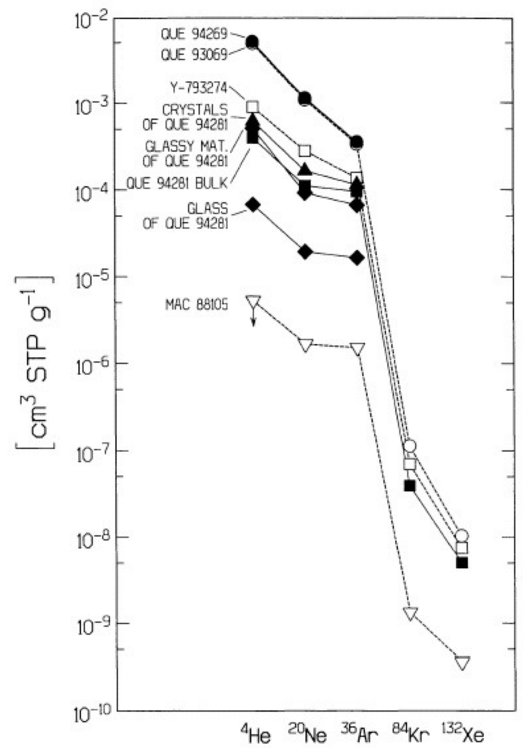


Figure 10: Noble gas isotopic composition of QUE 94281 compared to some lunar meteorites (from study of Eugster and Polnau, 1998).

Table 2a: Chemical composition of QUE 94281

reference	1	2	2	2	4	3
weight	179.6	224	258	286	463.7	Mean, 392.2
technique	c, g	c	c	c	e	c
SiO_2 %		47.28	47.70	48.77		
TiO_2	0.70	0.65	0.78	0.77		
Al_2O_3	16.4	16.06	15.11	13.60		
FeO	14.3	14.54	14.02	14.67	13.3	13.2
MnO	0.191	0.196	0.205	0.216		
MgO	9.68	7.62	7.79	8.45		
CaO	12.2	12.59	12.87	12.17	12.7	12.7
Na_2O	0.379	0.350	0.352	0.311	0.396	0.40
K_2O	0.0591	0.054	0.055	0.064		0.12
P_2O_5						
S %						
sum						
Sc ppm	32.4	32.9	37.3	39.8	28.9	28.4
V	99.2	103	127	135		
Cr	1847	1790	1770	1850	1786	1764

Co	40.4	42.8	46.8	45.7	45.6	45.3
Ni	110	108	261	166	295	300
Cu						
Zn		<40	<6	5.3		
Ga	4.52	4.8	4.5	4.1		
Ge		238	243	191		
As	1.94					
Se						
Rb						5.1
Sr	120	110	110	70	115	119
Y	30.0					
Zr	90.0	137	130	<80	95	100
Nb	5.18					
Mo						
Ru						
Rh						
Pd ppb						
Ag ppb						
Cd ppb				<400		
In ppb						
Sn ppb						
Sb ppb						
Te ppb						
Cs ppm					<0.2	0.09
Ba	72	84	68	59	76	78
La	6.26	6.5	6.0	5.5	6.66	6.77
Ce	18.0	14.7	13.5	13.9	17.8	18.1
Pr						
Nd	10.2	9.0	9.7	9.8	10	10.0
Sm	3.09	3.09	3.04	3.02	3.17	3.21
Eu	0.814	0.85	0.80	0.75	0.83	0.85
Gd	5.08					
Tb	0.634	0.64	0.62	0.68	0.68	0.68
Dy	4.10	4.3	4.1	4.4		
Ho	0.93	0.86	0.78	0.96		
Er						
Tm	0.41					
Yb	2.44	2.40	2.37	2.37	2.44	2.45
Lu	0.354	0.37	0.36	0.34	0.341	0.342
Hf	2.29	2.24	2.18	2.08	2.51	2.54
Ta	0.29	0.28	0.28	0.26	0.32	0.33
W ppb						
Re ppb		0.21	0.61	0.53		
Os ppb		2.9	9.3	5.9		
Ir ppb	3	4	9.7	6.4	10.7	10.5
Pt ppb						
Au ppb	<1.4	1.07	2.6	1.7	3	2.8
Th ppm	0.94	0.95	0.76	0.72	1.03	1.04

U ppm	0.29	0.23	0.18	0.17		0.26	0.27

technique (a) ICP-AES, (b) ICP-MS, (c) IDMS, (d) Ar, (e) INAA, (f) RNAA (g) SSMS
References: 1) Dreibus et al. (1996); 2) Arai and Warren (1999); 3) Jolliff et al. (1998); 4) Korotev et al. (2003)

Table 2b. Light and/or volatile elements for QUE 94281

reference	1
Li ppm	
Be	
Be	
C	
S	
F ppm	<10
Cl	134
Br	0.097
I	3.0
Pb ppm	
Hg ppb	
Tl	
Bi	

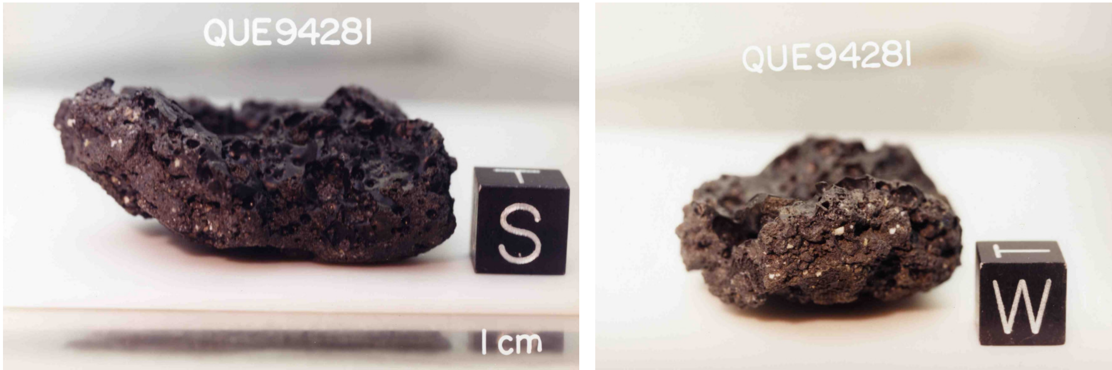


Figure 11: Two photographs of QUE 94281 in the Meteorite Processing Laboratory at JSC.

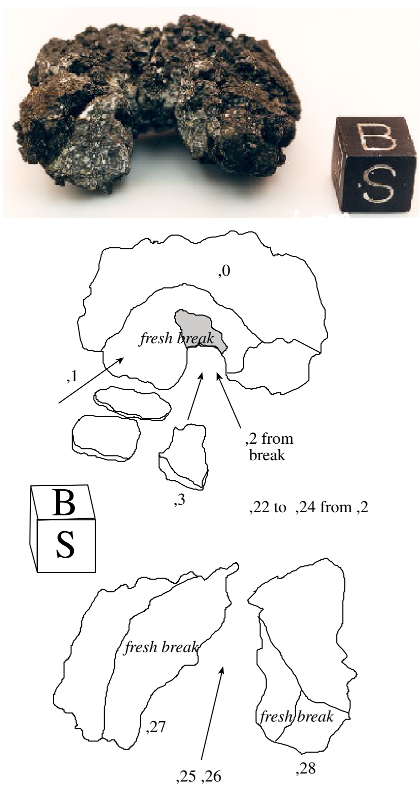


Figure 12: Sketch of subdivision of QUE 94281 compared to photograph of ,0 (top).

Processing

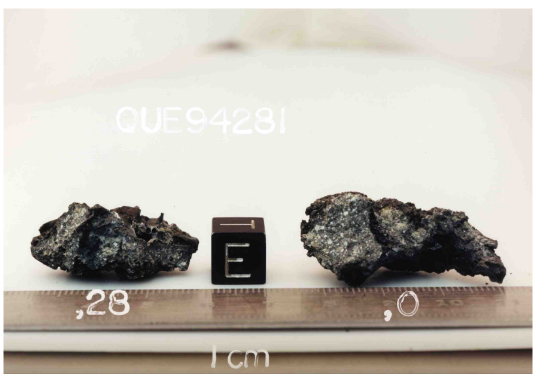
QUE 94281 was processed in (Figure 12 and 13) two stages with the initial processing in May 1995, and then extensive processing after MWG approved allocations in the Fall of 1995. Most allocations have come from splits ,1 ,27 and ,28.

Figure 13 (NEXT PAGE): Eight different views of QUE 94281 during it's processing history. Top left: reconstructed after splits taken; top right: ,0, ,1 and ,3 during initial processing; second row left: ,0 after initial processing; second row right: top view of ,0 after initial processing; third row left: splits ,28 and ,0 in second stage of processing; third row right: view of the opposite side of splits ,28 and ,0 during second stage of processing. Bottom left: close up of ,0 during second stage of processing; bottom right: close up view of split ,28 during second stage of processing.


QUE94281
,0
,1
1 cm

,1
,3
,0
QUE94281

QUE94281
1 cm

QUE94281

QUE94281
,28
,0
1 cm

QUE94281,0
1 cm cubes

QUE94281
1 cm

QUE94281
1 cm

Table 3: Allocation history of QUE 94281

SPLIT	parent	TS	WEIGHT	LOCATION	DESCRIPTION
0			7.597	JSC	documented chip
1	0		1.641	JSC	Chips and fines
2	0		0.469	JSC	Chips and fines
3	0		entirely subdivided		potted butt
		4	0.01	SI	thin section
		5	0.01	Kring	thin section
		6	0.01	JSC	thin section
		7	0.01	JSC	thin section
		8	0.01	Arai	thin section
		9	0.01	JSC	thin section
		10	0.01	Haskin	thin section
11	1		0.199	Nishiizumi	documented exterior chip
12	1		0.112	Nishiizumi	documented exterior chip
13	1		0.101	Sears	interior chip
14	1		0.153	Lindstrom M.	interior chips
15	1		0.152	Nishiizumi	interior chip
16	1		0.152	Herzog	locatable interior chips
17	1		0.3	Eugster	locatable interior chips
18	1		0.556	Dreibus	interior chips
19	1		0.255	Warren	interior chips
20	1		0.253	Lindstrom M.	interior chips
21	1		0.054	Lindstrom M.	exterior glass
22	2		0.354	Boynton	interior chip
23	2		0.111	Herzog	chip w/glass
24	2		0.054	JSC	interior chip
25	0		0.608	Warren	chaotic/glass
26	0		0.169	Lindstrom M.	chaotic/glass
27	0		1.271	JSC	chaotic/glass
28	0		4.24	JSC	chips
29	0		0.383	JSC	Chips and fines
32	27		0.057	Lindstrom M.	glass
33	27		0.254	Haskin	chaotic chips
34	27		0.097	Haskin	glass chips
35	24		0.075	Haskin	breccia chips
36	1		0.122	Haskin	breccia chips
37	24		0.027	Miyamoto	interior chips
38	28		0.812	JSC	Chips and fines

39	28	0.07	Vogt	interior chip
40	28	0.4	Ebihara	interior chip
41	28	0.22	Zolensky	chip w/fusion crust
42	38	0.04	Franchi	interior chip

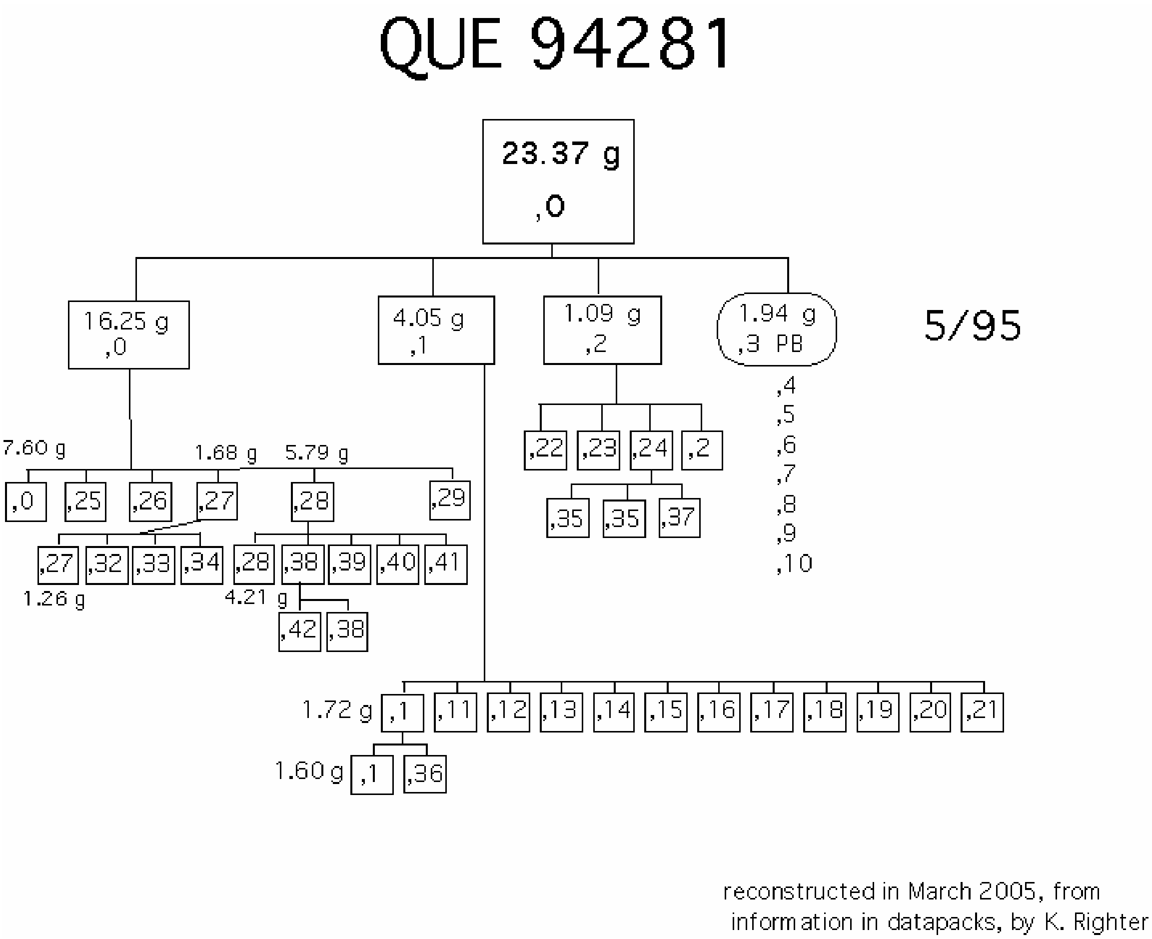


Figure 14: Genealogy of QUE 94281.