DRAFT

15405

Breccia

513.1 grams

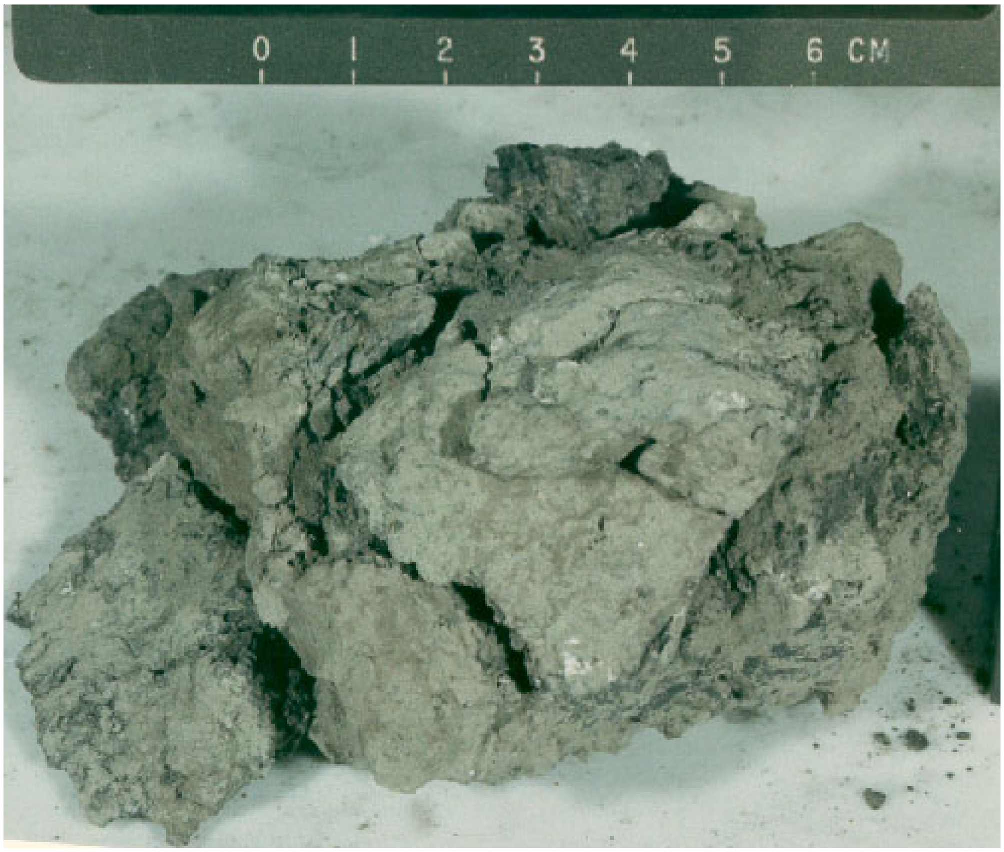


Figure 1: Initial PET photograph of 15405. NASA # S71-44126. Note that 15405 is made of several pieces.

Introduction

15405 was chipped from a prominent boulder (3 meter) at station 6A on the Apennine Front which the astronauts described as a "big breccia". Marvin (1976) describes the specimen as a rough and angular, welded mass of small, blocky slablets. It was broken into several fragments (figure 1), but the main mass was found to be tough and required sawing to obtain interior pieces (figure 2 and 3).

15405 was first studied by a consortium led by Rama Murthy, then by the "Imbrium Consortium" (led by Wood and Marvin). Early work is nicely summarized by Graham Ryder (1985).

Petrography

15405 is a clast-bearing impact-melt rock with a crystalline matrix made up of fine-grained intergrown pyroxene, plagioclase and ilmenite laths (figure 4). Prominent clasts include mineral fragments of plagioclase and pyroxene (figure 5), along with lithic clasts of KREEP basalt, granite and quartz monzodiorite (QMD). Flow banding in the matrix includes small irregularly-shaped vugs (figure 3).

The clast population of 15405 generally lacks fragments of mare basalt, glass, anorthosite, norite or troctolite, but is instead rich in KREEP basalt. Warren (1993) lists four apparently pristine clasts from 15405 that have been studied (two alkaline suite and two KREEP-like).

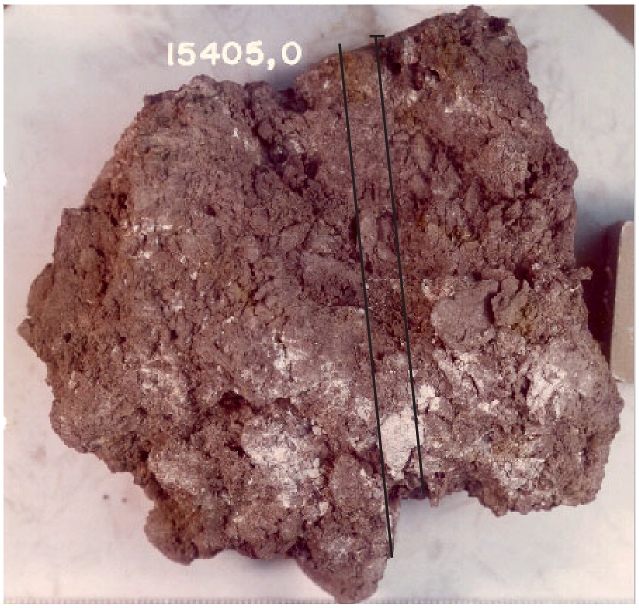


Figure 2a: Photo of largest piece of 15405,0 (T1 surface). NASA # S75-21518. End to end is ~ 7 cm. Position of saw cuts for slab (,92 ,95) are shown.

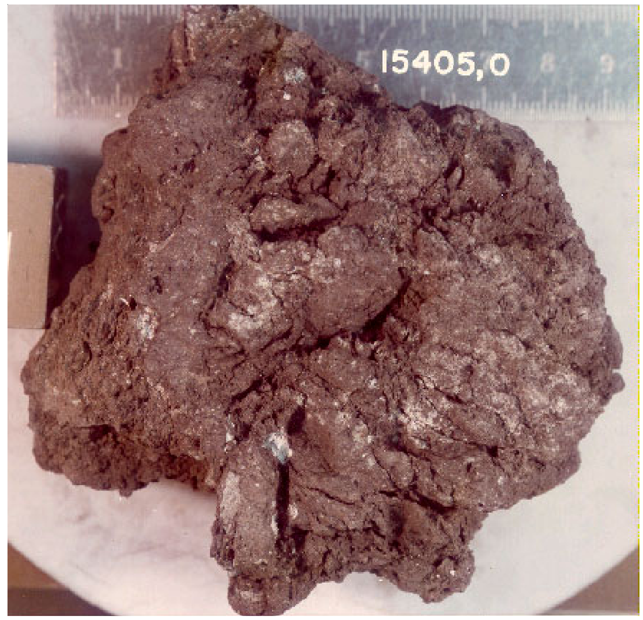


Figure 2b: Photo of 15405,0 (B1 surface). NASA # S75-21519. Cube is 1 inch.

Figure 3: Photo of sawn surface of 15405,0 showing clasts and 'flow-banding' in matrix. S85-38199. Sample is about ~ 9 cm long and prominant white clast is ~ 0.9 cm long.

The KREEP basalt clasts are described by Ryder and Bower (1976) and Ryder (1976). They have fine-grained subophitic texture (figure 6) with about equal amounts of plagioclase and zoned pyroxene (figure 7) and were found to be similar to Apollo 15 KREEP basalts (see section on 15382). *No large clasts of KREEP basalt were found or studied from 15405.*

Three large clast(s) of quartz monzodiorite (QMD) were analyzed and described Ryder (1976), Taylor et

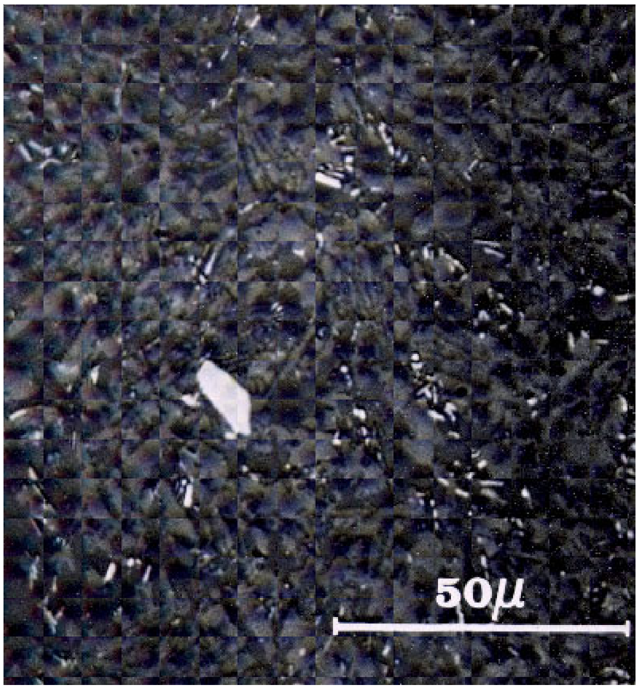


Figure 4: Reflected light photo of thin section of 15405 showing that matrix is made up of interlocking pyroxene and plagioclase laths.

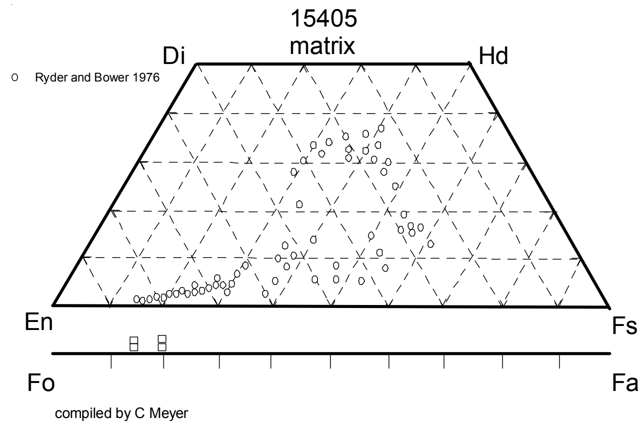


Figure 5: Compostion diagram of pyroxene cyrstals in matrix of 15405.

al. (1980) and Takeda et al. (1981). QMD clast A was large (~1 cm; 2.5 grams) and coarse-grained (figure 8) and includes subsamples ,56 ,57 ,85 etc. QMD clast B was extracted from slab ,95 (figure 17) and includes subsamples ,110 ,115. 15405,145 is a thin section with a small portion of QMD clast B (figure 12). Taylor et al. (1980) estimate the mineral mode of QMD as 35% each of plagioclase and pyroxene, 10-15% each of silica and K-feldspar and 0.5 to 1% each of zircon, ilmenite, whitlockite and minor chromite and Fe metal. The pyroxene in 15405 QMD is Fe-rich and unzoned, but exsolved (figure 9). Takeda et al. (1981) studied pyroxene exsolution in QMD.

Granite clasts were reported, but it is unclear whether they are remelted QMD or not (Ryder 1976). McGee et al. (1978) describe granite clasts as coarse-grained (>1 mm) and typically crushed or melted. They consist of untwined plagioclase, clinopyroxene, cristobalite (?), and K-feldspar. Ilmenite, Fe-metal, troilite, chromite and phosphate are present in minor amounts. *No large clasts of "granite" were found or studied from 15405.*

Clast ,170 (chipped from ,0) is a feldspathic alkali norite with plutonic texture and very high trace element content studied by Lindstrom et al. (1988) and Marvin et al. (1991). Cumulus plagioclase (An_{89}; 0.6 mm) and pigeonite (En_{61}; 1 mm) are enclosed in post cumulate plagioclase and pyroxene (see figure 13).

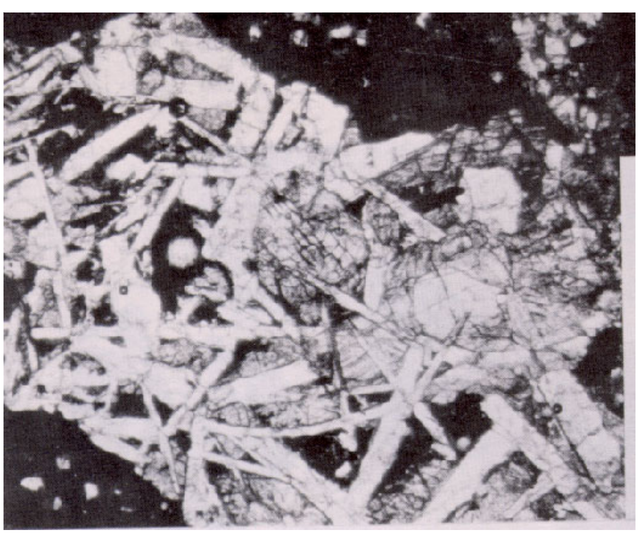


Figure 6: Photomicrograph of KREEP basalt clast in 15405 (from Ryder

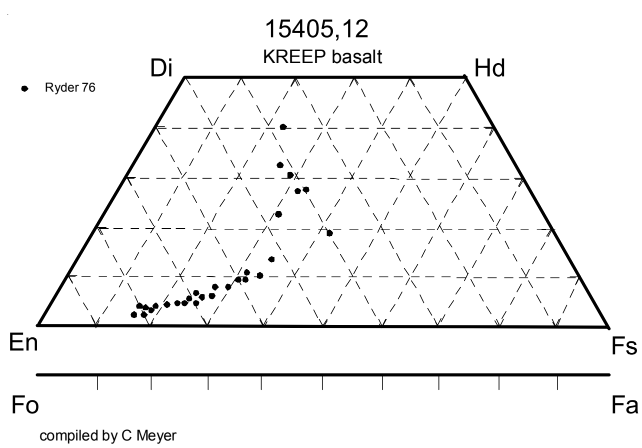


Figure 7: Pyroxene in KREEP basalt fragments found in thin section only in 15405 (from Ryder 1976).

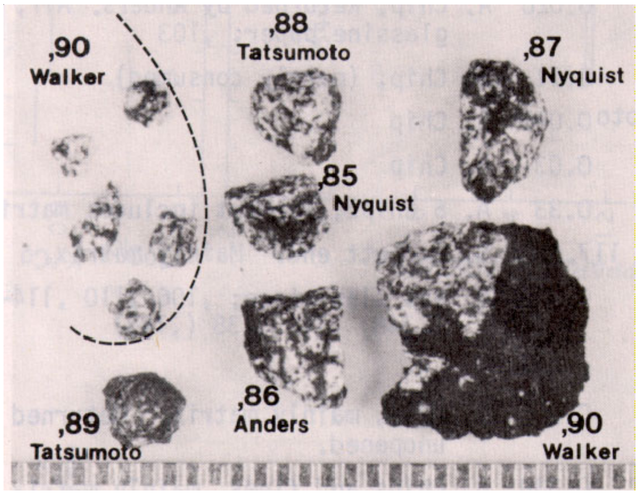


Figure 8: Processing photo of quartz monzodiorite (QMD) clast A (from Ryder 1979).

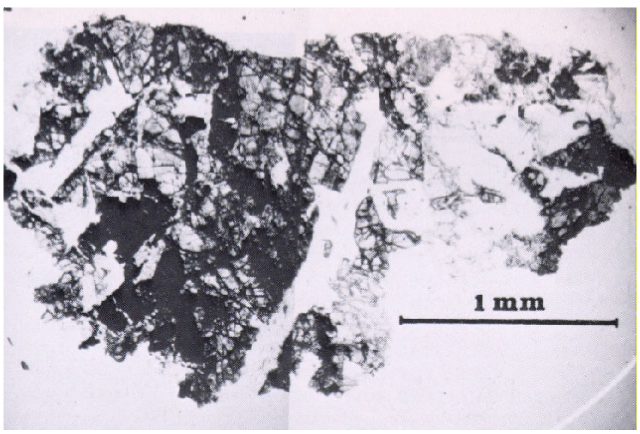


Figure 10: Photomicrograph of QMD 15405,56 (clast A) (from Ryder 1976).

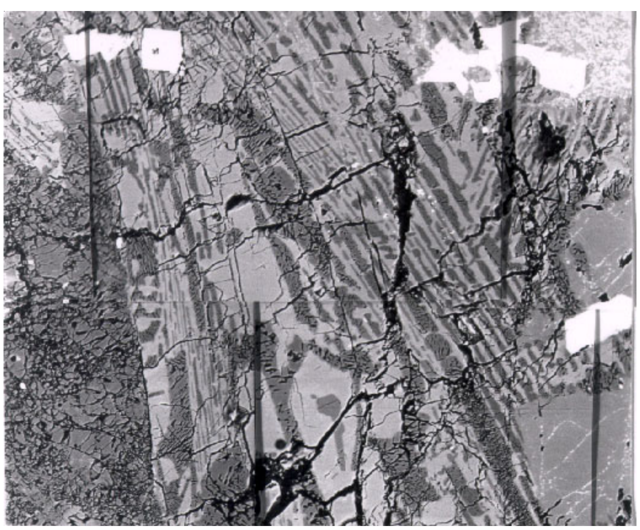


Figure 12: Backscatterd electron (BSE) image of granitic portion of QMD 15405,145 (clast B), showing lace-like intergrowth of K-feldspar and silica. Bright grains are zircons (from Meyer et al. 1996). Field of view is 2 mm.

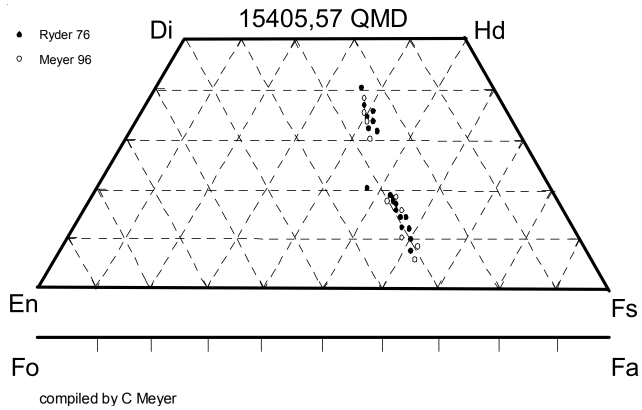


Figure 9: Pyroxene composition in 15405,57 and ,145 quartz monzodiorite (from Ryder 1976 and Meyer 1996).

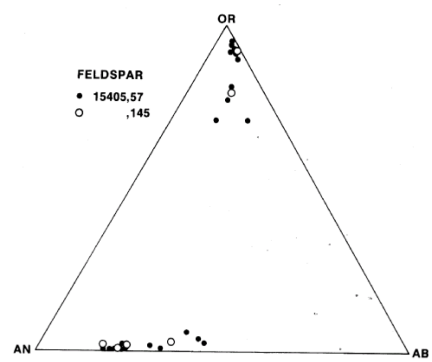


Figure 11: Composition diagram of feldspars in two clasts of QMD (from Meyer et al. 1996).

Clast ,181 (chipped from ,0) is a cataclastic alkali anorthosite studied by Lindstrom et al. (1988). It is mostly granulated plagioclase (An_{84}; 0.6 mm), with minor ilmenite and rare phosphate, but contains no pyroxene (see figure 14).

Ryder and Bower (1976) also briefly describe small clasts of "olivine vitrophyre" in thin section descriptions.

The close association of QMD and KREEP basalts in this breccia, along with similar REE patterns, led Ryder (1976) to suggest there might be a "close association" of QMD with KREEP basalt. But we now know the ages of KREEP basalt are about 3.9 b.y, while the initial age of the QMD was about 4.3 b.y. Thus, this "association" is unlikely. Rutherford et al. (1976) discuss silicate liquid immiscibility as a process leading to QMD, but Ryder (1976) and Taylor et al. (1980) found the chemical evidence against an origin by liquid immiscibility.

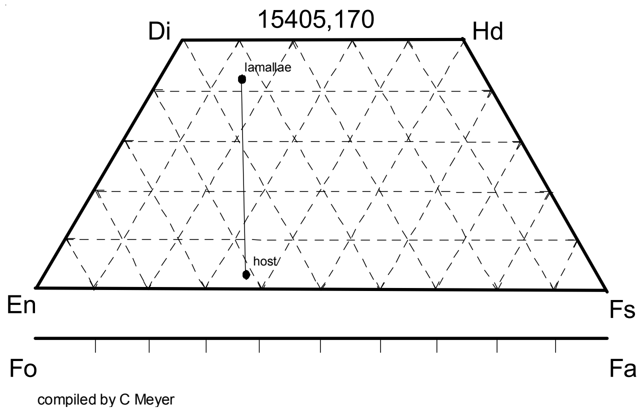


Figure 13: Composition diagram of pyroxene in alkali norite (AN) clast in 15405,170 (from Lindstrom et al. 1988).

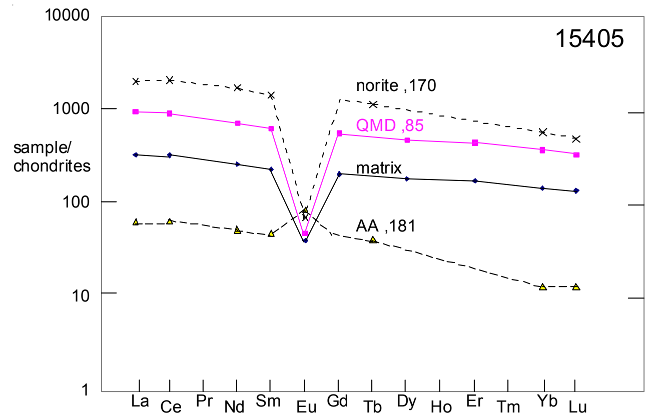


Figure 14: Normalized rare-earth-element diagram for matrix and clasts in 15405. Data from Nyquist et al. (1976) and Lindstom et al. (1988). Sample-split 15405,170 is called an "alkali norite", but must include a large whitlockite grain.

Chemistry

The bulk composition of the matrix is similar to that of KREEP basalt (table 1 and figure 14). The composition of individual clasts in 15405 is given in table 2 and figure 14. The high REE content of the norite clast is due to a large whitockite grain and probably not representative. A number of clasts are pristine (Ir < 0.1 ppb) and even the matrix is relatively low in meteoritic siderophiles.

Radiogenic age dating

Bernatowicz et al. (1978) used the 39/40 Ar plateau age method to attempt to date the matrix and the QMD clast (figure 16). Nyquist et al. (1977) attempted to date QMD by Rb/Sr and found that the Sr was highly radiogenic, but could not obtain a well defined age. Tatsumoto and Unruh (1976) used U/Pb techniques, but found that the Pb was disturbed and could not obtain an age. Finally, Meyer et al. (1996) used the ion

Summary of Age Data for 15405

	Ar/Ar	U/Pb
Bernatowicz et al. 1978	1.29 ± 0.04 b.y.	
Meyer et al. 1996		4.294 ± 0.026 and 1320 ± 0.250

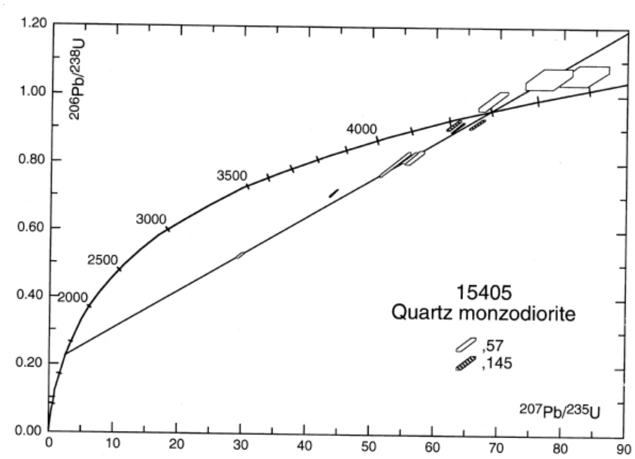


Figure 15: U-Pb concordia diagram for two QMD clasts in 15405 (from Meyer et al. 1996). Data collected by SHRIMP ion microprobe analyses of zircons needles found in thin section. The two intercepts at 4.3 b.y. and 1.3 b.y are thought be the time of intial crystallization of QMD and Pb-loss at subsequent breccia formation.

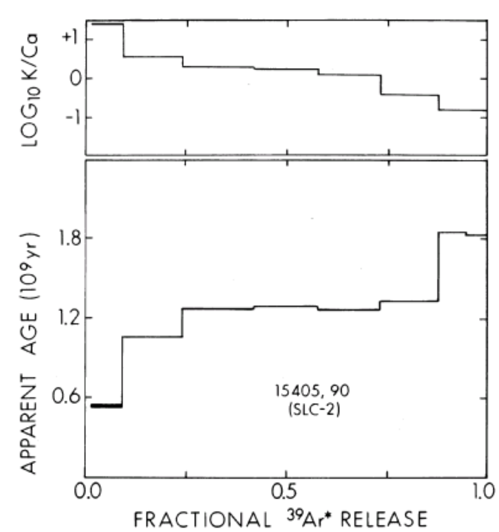


Figure 16: Ar plateau for QMD clast in 15405 (by Bernatowicz et al. 1978).

Table 1. Chemical composition of 15405 matrix.

	sawdust				,117					impact melt			*average melt*	
reference	Laul 73		Christian 76		Nyquist 76		Ganapathy 73	Gros 76		Lindstrom 88			Marvin 91	
weight	*191 mg*				46 mg					,173	,174	,175		
SiO2 %			51.49	(a)										
TiO2	1.2	(c)	1.8	(a)						1.99		2.03	1.94	(c)
Al2O3	13.8	(c)	15.44	(a)						14.8		15.5	15.5	(c)
FeO	12.8	(c)	11.17	(a)						10.9	10.8	10.1	10.8	(c)
MnO	0.183	(c)	0.19	(a)										
MgO	14	(c)	7.33	(a)						7.3		8.4	7.8	(c)
CaO	10.3	(c)	9.98	(a)						10.3	9.4	10.5	10.2	(c)
Na2O	0.547	(c)	0.81	(a)						0.856	0.861	0.829	0.86	(c)
K2O	0.4	(c)	0.82	(a)	0.71	(d)						1.2	0.98	(c)
P2O5			0.72	(a)										
S %														
sum														
Sc ppm	23	(c)	23	(a)						22.3	22.1	20.7	22.1	(c)
V	91	(c)	22	(a)										
Cr	2050	(c)	1505	(a)						1630	1580	2000	1700	(c)
Co	36	(c)	9.8	(a)						18.4	17.7	20.8	18.5	(c)
Ni			43	(a)				83	(b)	60	45	50		
Cu			6.8	(a)										
Zn			4.1	(a)			4.1	4.2	(b)					
Ga			4	(a)										
Ge ppb							94	62.6	(b)					
As														
Se							89	78	(b)					
Rb					20.5	(d)	25.6	27.4	(b)	24	29	19	24	(c)
Sr			190	(a)	168	(d)				190	180	150	173	(c)
Y			360	(a)										
Zr	500	(c)	1100	(a)						1100	1100	800	990	(c)
Nb			80	(a)										
Mo														
Ru														
Rh														
Pd ppb								1.7	(b)					
Ag ppb							2.9	2.22	(b)					
Cd ppb							16	17.7	(b)					
In ppb							1	1.47	(b)					
Sn ppb														
Sb ppb							0.067	1.06	(b)					
Te ppb							2.1	4.9	(b)					
Cs ppm							1.16	1.12	(b)	1.05	1.05	0.75	0.95	(c)
Ba	480	(c)	1200	(a)	767	(d)				880	880	680	845	(c)
La	46	(c)	55	(a)	78.7	(d)				83.4	87.3	67.6	78.2	(c)
Ce	114	(c)			197	(d)				222	229	180	215	(c)
Pr														
Nd					120	(d)				130	137	105	128	(c)
Sm	20.9	(c)			34.2	(d)				37.5	38.9	29.9	36.5	(c)
Eu	1.45	(c)			2.27	(d)				2.34	2.39	2.39	2.39	(c)
Gd					40.3	(d)								
Tb	3.6	(c)								7.95	8.24	6.45	7.99	(c)
Dy					44.2	(d)								
Ho														
Er					28	(d)								
Tm														
Yb	14	(c)	32	(a)	23.5	(d)				27.5	28	21.7	25.9	(c)
Lu	2.1	(c)			3.32	(d)				3.75	3.8	2.9	3.59	(c)
Hf	16.2	(c)								31.2	29.5	23.9	28.6	(c)
Ta	2	(c)								3.5	3.6	2.82	3.4	(c)
W ppb														
Re ppb							0.147	0.121						
Os ppb								1.16						
Ir ppb							1.64	1.28		<2	<2	<2		
Pt ppb														
Au ppb							0.93	0.525		1.5	<2	<2		
Th ppm	10	(c)								16	16.2	11.6	15.1	(c)
U ppm	2.3	(c)					5.1	4.69	(b)	4.29	4.43	3.14	4.19	(c)

technique (a) combined XRF, semicmicro chem., emiss. Spec., (b) RNAA, (c) INAA, (d) IDMS

Table 2. Chemical composition of 15405 clasts.

	QMD		,85		,85		QMD	white c		Alk Anor	Akl Norite	Im melt		KREEP bas	granite	
reference	Taylor 80		Nyquist 76		Ryder 79		Gros 1976	Ganapathy 73		Lindstrom 88				Ryder 76		
weight			17 mg							,181	,170	,171		,12	,12	
SiO2 %														50.5	68	(d)
TiO2	2.6	(a)									0.36	0.38	(a)	0.69	0.9	(d)
Al2O3	11.9	(a)								30.4		22.8	(a)	16.25	10.15	(d)
FeO	14.1	(a)			15.1	(a)				0.302	4.3	8.61	(a)	8.48	6.99	(d)
MnO	0.18	(a)												0.07	0.12	(d)
MgO	3.8	(a)								1	4.4	7	(a)	10.54	1.53	(d)
CaO	8.9	(a)								17.6	16.4	13.3	(a)	9.44	4.89	(d)
Na2O	0.81	(a)			0.87	(a)				0.91	0.86	0.537	(a)	0.72	0.79	(d)
K2O	2.1	(a)	1.71	(b)	1.8	(a)						<0.8		0.53	3.39	(d)
P2O5														0.25	0.52	(d)
S %																
sum																
Sc ppm	29	(a)			30.7	(a)				9.25	29.6	11.2	(a)			
V	33	(a)														
Cr					1220	(a)				570	1180	1130	(a)			
Co	8	(a)			7.8	(a)				18	10	11.6	(a)			
Ni							<2		(c)	<50	<40	<40	(a)			
Cu										5	46		(a)			
Zn					60	(a)	6.3	4.9	(c)							
Ga																
Ge ppb							345	160	(c)							
As																
Se							89	104	(c)							
Rb			40.6				39	20.7	(c)	<2	5	<12	(a)			
Sr			154							580	230	150	(a)			
Y																
Zr	1620									80	220	250	(a)			
Nb																
Mo																
Ru																
Rh																
Pd ppb																
Ag ppb							2.15	2.5	(c)							
Cd ppb							18.9	9.8	(c)							
In ppb							45.2	1	(c)							
Sn ppb																
Sb ppb							1.4	0.35	(c)							
Te ppb							9.4	1.9	(c)							
Cs ppm							1.19	0.925	(c)	0.19	0.26	0.1	(a)			
Ba	1900	(a)	1490	(b)						180	890	160	(a)			
La	183	(a)	224	(b)	210	(a)				15.1	470	20	(a)			
Ce	413	(a)	555	(b)	560	(a)				39.2	1254	52.4	(a)			
Pr																
Nd	287	(a)	328	(b)						24	780	27	(a)			
Sm	77.4	(a)	92	(b)	93	(a)				7.08	213	8.65	(a)			
Eu	2.75	(a)	2.69	(b)	2.52	(a)				4.85	4	1.16	(a)			
Gd			110	(b)												
Tb	14.9	(a)			19.7	(a)				1.48	42	1.85	(a)			
Dy	101	(a)	116	(b)												
Ho																
Er			71.7	(b)												
Tm																
Yb	55.2	(a)	60.9	(b)	65	(a)				2.08	94	6.66	(a)			
Lu	8.2	(a)	8.06	(b)	9	(a)				0.32	11.9	0.99	(a)			
Hf	44.7	(a)								2.29	11	6.67	(a)			
Ta	10.1	(a)								0.08	0.96	0.86	(a)			
W ppb																
Re ppb							0.046	0.059	(c)							
Os ppb							0.007		(c)							
Ir ppb							0.006	0.343	(c)	<1	<3	<1	(a)			
Pt ppb																
Au ppb							0.051	0.25	(c)	<1	<6		(a)			
Th ppm	39.4	(a)								0.53	39.4	4.73	(a)			
U ppm	11.1	(a)					11.5	4.1	(c)	0.07	1.6	1.25	(a)			

technique (a) INAA, (b) IDMS, (c) RNAA, (d) defocused beam analysis (electron probe)

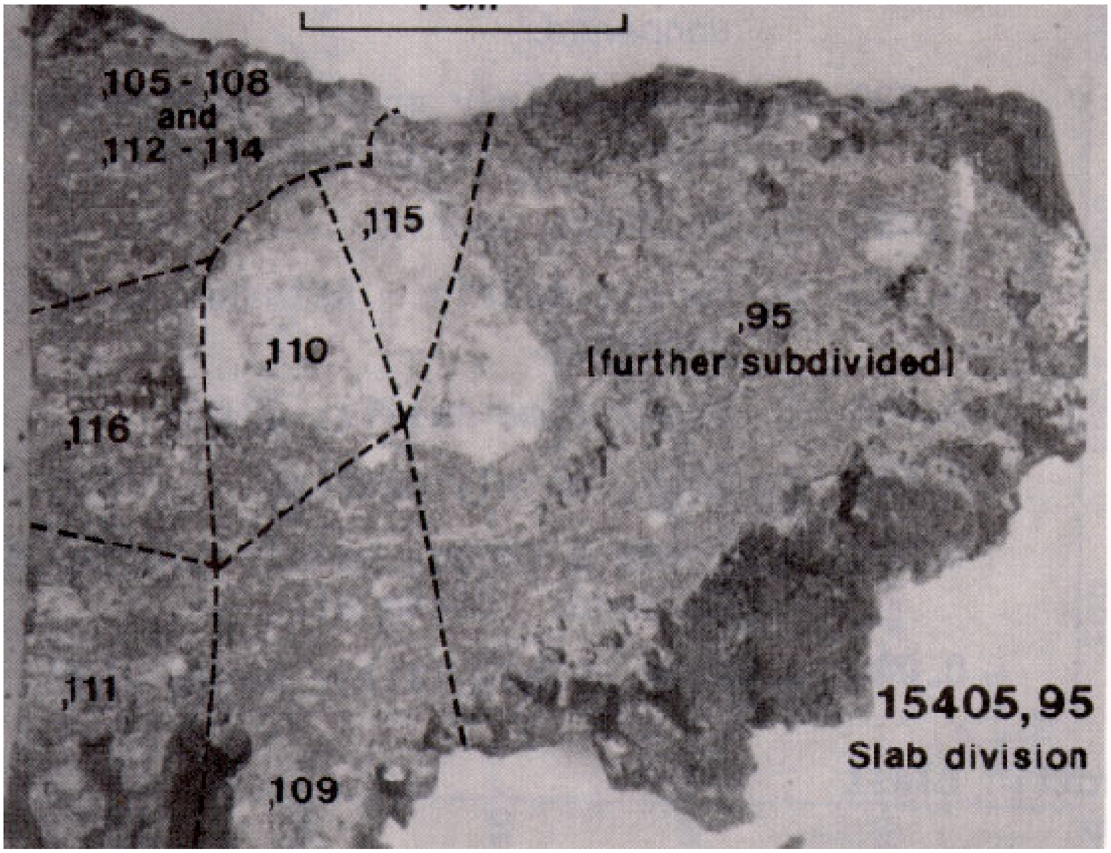
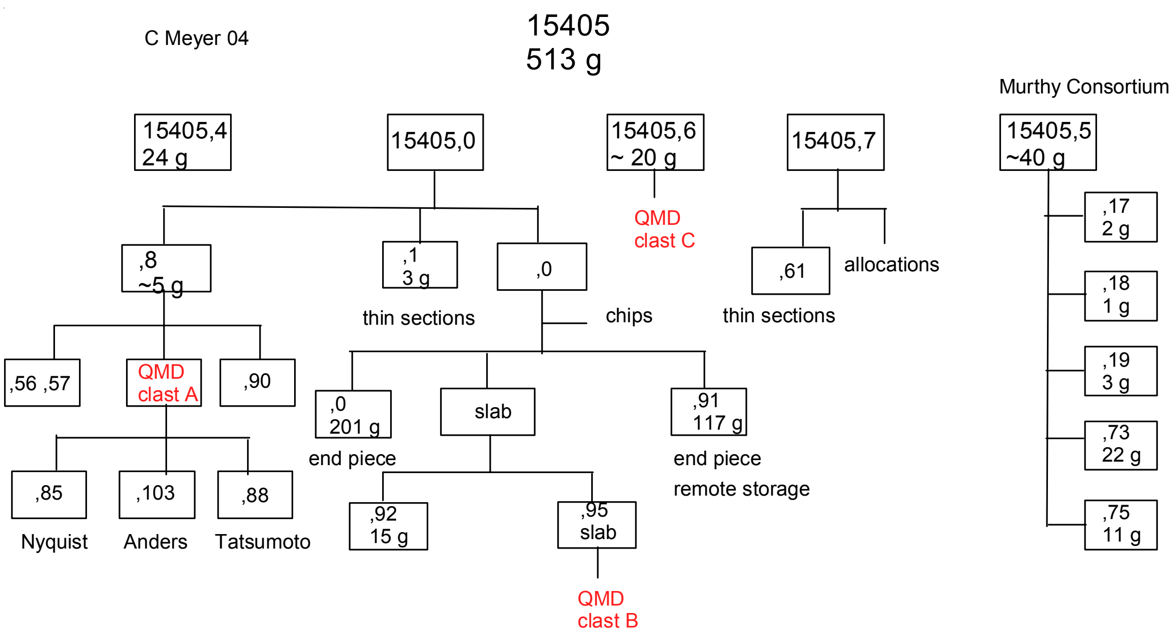


Figure 17: Processing diagram for half of slab (,95) cut from 15405. The white clast is clast B of QMD lithology and is also exposed on ,0 (figure 3).



microprobe U/Pb technique to date zircons intergrown with other phases *insitu* in thin sections of QMD clasts A and B (figure 15).

Cosmogenic isotopes and exposure ages

Drozd et al. (1976) determined an exposure age of 11 ± 1.1 m.y. by ^{81}Kr and 6 m.y. by ^{21}Ne.

Other Studies

Rare gas studies are reported in Drozd et al. (1976).

Fleischer and Hart (1972, 1973) and Podosek and Walker (1976) measure fission track density and U in the matrix.

Processing

Initially several large pieces (,4 ,5 ,6 ,7 ,8) broke off of the rock (see flow diagram). Sample 15405,5 was allocated for consortium study led by Rama Murthy and was analyzed by Laul and Schmitt (1972, 1973). The main piece, termed 15405,0, was sawn in 1975 to create a slab, which broke in two main pieces (,95 and ,92). One butt end (, 91) is in remote storage. Processing of the rock was documented by the Imbrium Consortium, led by John Wood and Ursula Marvin, in their 1976, 1977 reports.

List of Photo #s

S71-44126	dust covered
S75-21518-28519	15405,0
S76-24833	processing ,95
S85-38199	,0 sawn surface