72415 - 72418

Cataclastic Dunite

58.74 grams

Figure 1: Boulder 3 at Station 2, with large dunite clast (72415-72418). The bright spot is the location of samples. A sample of the boulder matrix (72435) was chipped from the top right corner (blue gray patch). Note the clastic nature of boulder. The boulder is about 70 cm. AS17-137-20968.

Introduction

Samples 72415 –72418 were chipped from a large clast in Boulder 3 at Station 2, South Massif, Taurus-Littrow (figure 1). The two largest pieces fit together and were numbered 72415 (figure 2). 72415 weighs 32.34 grams, 72416 weighs 11.53 grams, 72417 weighs 11.32 grams and 72418 weighs 3.55 grams (figures 2 and 3). All pieces have brown patina and numerous micrometeorite craters on one side. All pieces have the same mineralogy and texture.

Sample 72415 - 72418 is a cataclastic dunite made up of 93% olivine (Fo_{86-89}), 4% plagioclase (An_{85-97}) and 3% pyroxene ($En_{84}Wo_3Fs_{10}$ and $En_{50}Wo_{42}Fs_4$). It also includes minute blebs of symplectite. It has been determined as very old (4.55 b.y.) and "is inferred to be the product of the primary differentiation of the moon" (Papanastassiou and Wasserburg 1975, Dymek et al. 1975). However, Ryder (1992) found that the chemical variation in olivine was such that the rock may instead have a shallow, hypabyssal origin. Relatively high siderophile element and high Pb content indicate possible contamination problems. *The old age needs confirmation, and indeed the origin of this important sample might require a re-interpretation!*

Ryder (1992) provided a detailed and thorough review of the research conducted on 72415 and 72417 in his Apollo 17 catalog.

Petrography

72415-72418 is one of the oldest and most mafic lunar samples (figure 5). This dunite is comprised of angular

Figure 2: Photograph of freshly broken surface of 72415. Sample is 4.5 cm across. NASA# S73-27577

to sub-rounded clasts (~60%) of pale-green to yellow olivine (up to 1 cm) set in a fine-grained, granulated matrix of mostly olivine. This cataclastic texture apparently resulted from simple crushing, without substantial recrystallization. Other minerals include pyroxene and plagioclase with minor troilite, iron grains, Cr-spinel, whitlockite and armalcolite reported (Dymek et al. 1975).

Regions of vermicular "symplectite" assemblages include: Cr-spinel + high-Ca pyroxene ± low-Ca pyroxene ± olivine ± plagioclase ± metal are a primary feature of this rock, but the lack of consistent phase assemblage has made interpretation difficult (Dymek et al. 1975, Bell and Mao 1975, Bell et al. 1975). Dymek et al. find these are late-stage magmatic products, while Bell et al. propose that they are the breakdown product of a preexisting garnet phase indicating high pressure origin. This debate was never solved.

Mineralogical Mode of 72415

	Dymek et al. 1975	Laul and Schmitt 1975
Olivine	93 vol. %	87 – 98 (normative)
Plagioclase	4	1 - 11
Pyroxene	3	
Spinel	tr.	

The slight zoning in Fe/Mg and trace CaO content (av. ~0.1 %) of olivine in dunite 74215 is more consistent with a hypabyssal than a deep-seated plutonic origin (Ryder 1992).

72415 is severely granulated and the large olivine grains are internally polygonalized (figure 4). Snee and Ahrens (1975) studied the shock features in olivine and conclude the rock reached 330-440 kbar pressure. Some plagioclase has been converted to maskelynite, but surprizingly, many plagioclase laths are mostly crystalline (Dymek et al. 1975). Richter et al. (1976) carefully studied the microcracks and sintering effects in 72415. They found healed and sealed cracks were common, but open ones were rare. Lally et al. (1976) also made a detailed study of the shock deformation, recovery and recrystallization of 72417, finding four stages of annealing. The overall conclusion of many authors, was that the rock experienced complex a sequence of shock and thermal events.

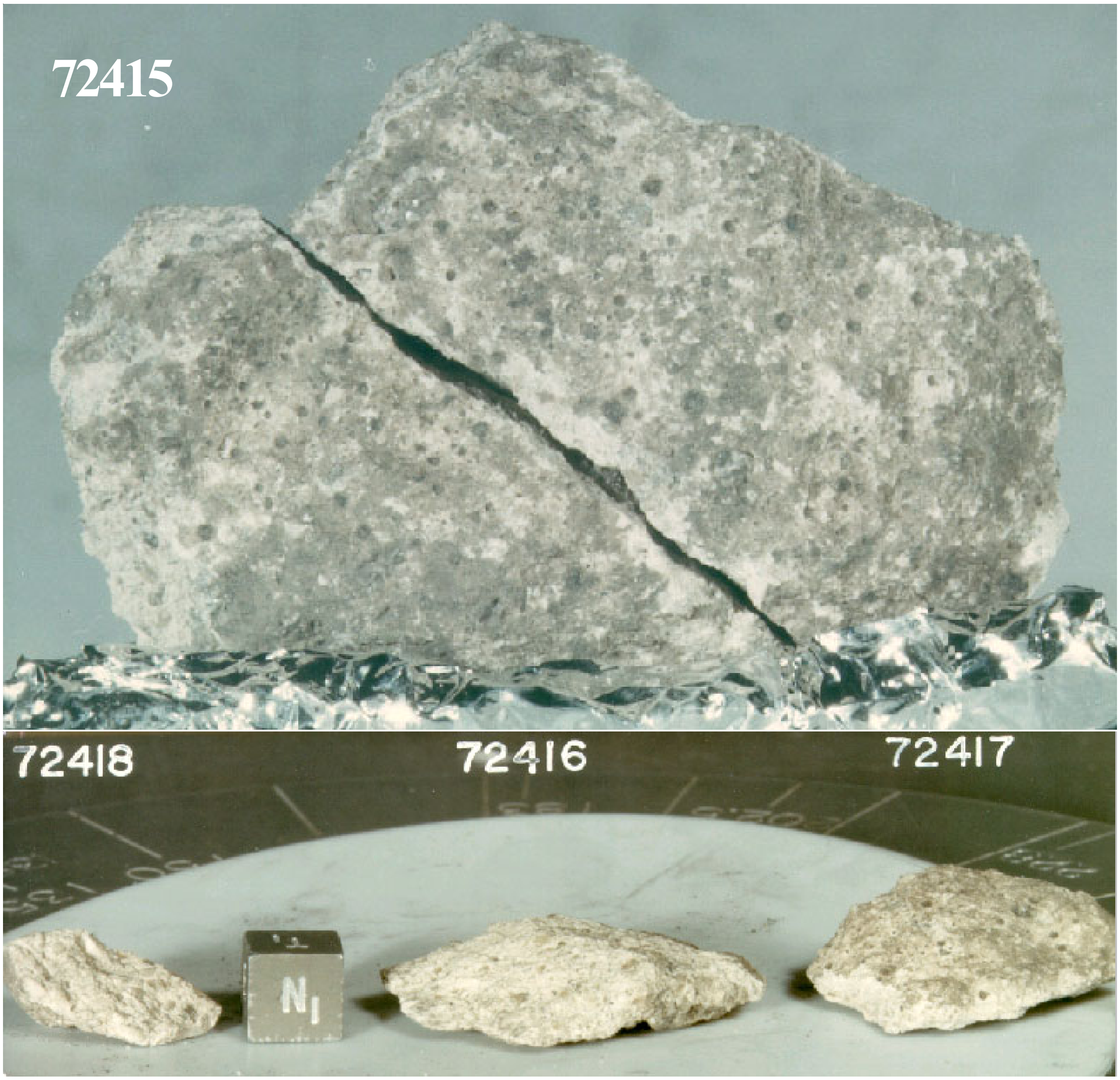


Figure 3: Photographs of pieces of cataclastic dunite showing micrometeorite craters on outer surfaces. Cube is 1 cm. NASA# S73-16200 and S73-17969

Mineralogy

Olivine: Ryder (1992) found a small, but significant, variation in the composition of olivine in 72415 (Fo_{86-89}). He also determined that the CaO content of olivine (~0.1%) was intermediate between plutonic and basaltic olivine, and proposed that 72415 was formed in a shallow intrusion, rather than in a deep-seated plutonic environment (such as was inferred by the Wasserburg Consortium). Ryder (1983) and Bersch (1990) found 220-70 ppm Ni in olivine.

Pyroxene: Dymek et al. (1975) found both orthopyroxene ($En_{84}Wo_3Fs_{10}$) and augite ($En_{50}Wo_{42}Fs_4$) in 72415 (Figure 6). Ishii et al. (1976) calculated an equilibrium temperature of 1120 deg C for the last equilibration of pyroxenes.

Plagioclase: Some of the plagioclase in 72415 has been shocked to maskelynite (Snee and Ahrens (1975), while many plagioclase laths remain unshocked (Dymek et al. 1975).

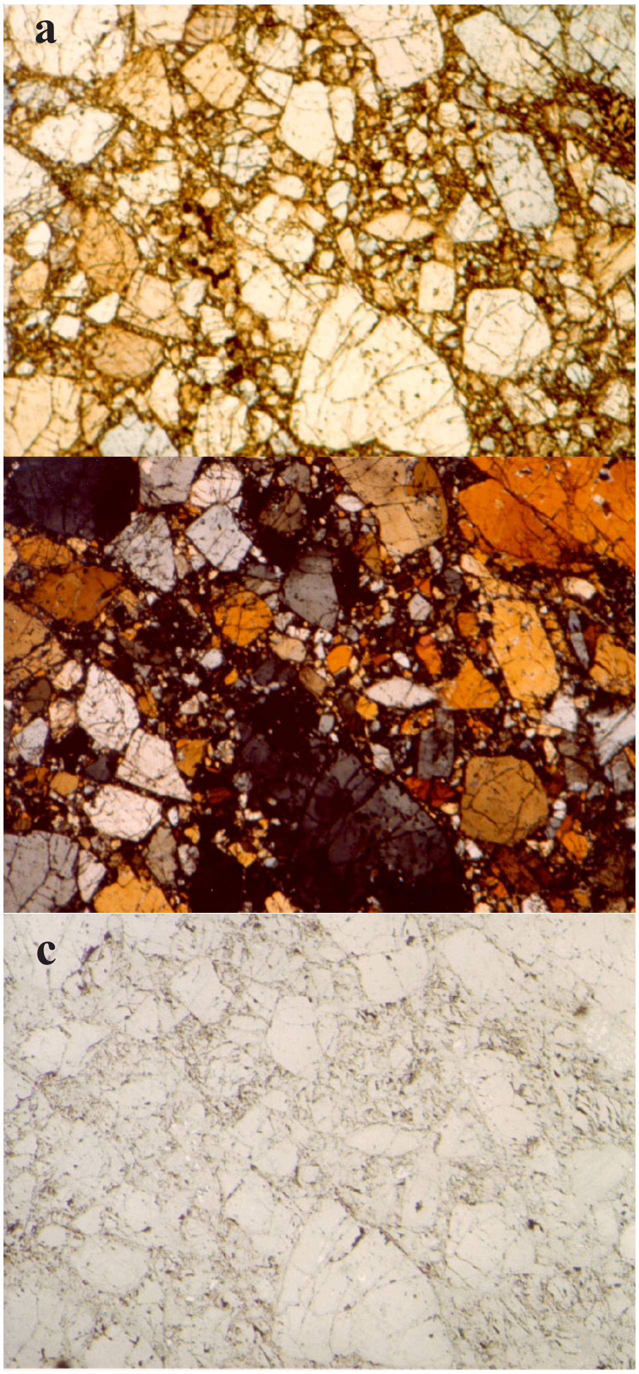


Figure 4: Photomicrographs of thin section of 72415,25 showing large olivine grains in ground-up olivine matrix. Field of view is 2.5 mm. NASA# S79-27287-27289. a) partially crossed nicols, b) crossed polarizers, c) reflected light.

Symplectite: Albee et al. (1974), Dymek et al. (1975) and Bell et al. (1975) reported various small blebs of complexly intergrown Cr-spinel + high-Ca pyroxene ± low-Ca pyroxene ± olivine ± plagioclase ± metal.

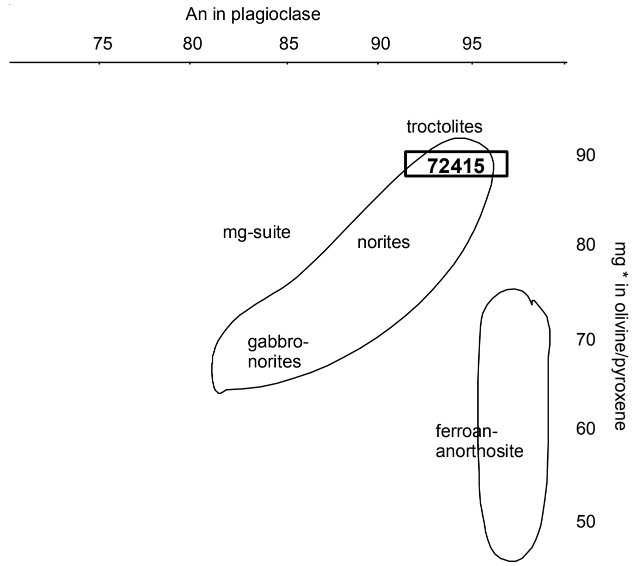


Figure 5: Composition of plagioclase and mafic minerals in 72415/7 (from James 1980).

Metal Grains: Dymek et al. (1975) and Ryder (1992) found the metal grains in 72415-72417 were high in Ni and Co (figure 7).

Armalcolite: Dymek et al. reported a single grain of armalcolite.

Chemistry

The trace siderophile element composition (Ir, Au, Re etc) of 72415 and 72417 are not as low as for other pristine lunar samples (see discussion in Heiken et al. 1992). Laul and Schmitt (1975) analyzed 9 splits of 72417 and found high Ni (150-410 ppm) and high Au (1-4 ppb) in all of the splits (average given in table 1). Walker et al. (2004) determined Re, Os, Ir, Ru, Pt and Pd. Pd was uniquely low. Yet there is no reason to believe that this cataclastic dunite is in any way a mixture of components. There is the obvious patina on the surface of this sample, but it is hard to believe that it contaminated all the splits.

Laul and Schmitt (1975) found a range of Al contents in the multiple, small splits that they analyzed, indicating a wide range in normative plagioclase content (1-11%). *(No thin section shows anything like 10% plagioclase!)* The trace element content is very low (and variable) as would be expected for small splits, had picked from a dunite (figure 8).

Chemical data obtained during radiometric dating experiments is summarized in table 2. Additional chemical data can be found in Jovanovic and Reed

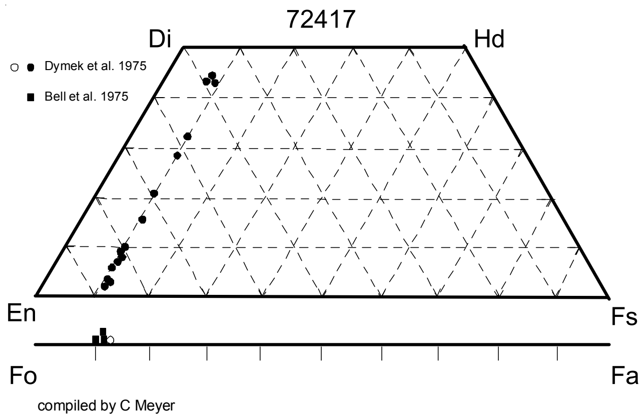


Figure 6: Pyroxene and olivine composition in 72417 (data replotted from Dymek et al. 1975, Bell et al. 1975).

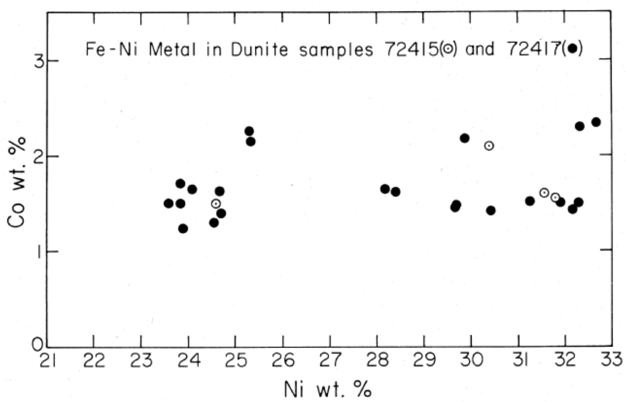


Figure 7: Composition of minute metal grains in 72415 and 72417 (from Dymek et al. 1975).

(1975) and Gibson and Moore (1974). The relatively high Ru and Os determined by Jovanovic and Reed needs an explanation.

Radiogenic age dating

While the age of Rb-Sr age of 72417 has been determined as 4.55 ± 0.1 b.y. (figure 9), it should be remembered that this sample has been highly shocked and has had a complex thermal history. Certainly, the sample must have been heated when it became incorporated in the matrix of the boulder at ~3.9 b.y. (see figure 1 and the section on 72435). *72417 may the oldest moon rock, but it would certainly help to have some confirming, concordant age!*

The U-Pb systematics have been studied by Premo and Tatsumoto (1992) (figure 10). Tera et al. (1974) found the Pb in the sample was "disturbed".

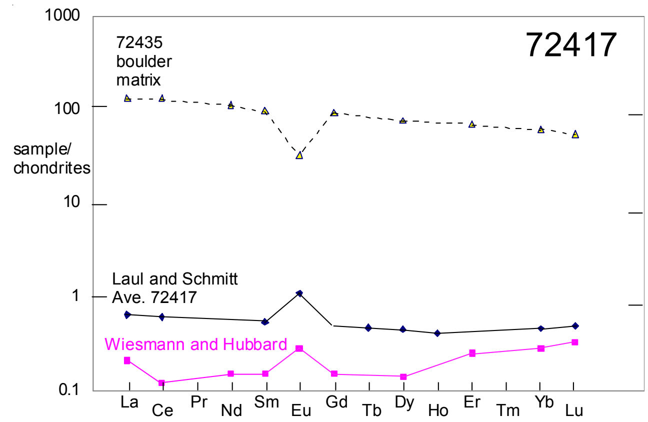


Figure 8: Normalized rare-earth-element patterns for dunite clast (72417) compared with that of boulder matrix (72435). Data from Wiesmann and Hubbard 1975, Laul and Schmitt 1975.

Cosmogenic isotopes and exposure ages

Kieth et al. (1974) measured ^{26}Al (77 dpm/kg), ^{22}Na (290 dpm/kg), ^{54}Mn (77 dpm/kg), ^{56}Co (150 dpm/kg) and ^{46}Sc (8 dpm/kg) for a 30 gram piece of 72415 within a few days of return from the moon. Yokoyama et al. (1974) found that the sample was "saturated" in ^{26}Al.

Other Studies

Pierce et al. (1974) and Brecher (1975) studied the magnetic properties of 72415. Clayton and Mayeda (1975) and Mayeda et al. (1975) reported on oxygen isotopic analysis of 72417.

Processing

The larger piece of 72415 was sawn in 1974 with the wire saw (figure 11). Most of the thin section come from just one chip (,18) and seem to have missed the large crystal in ,17. 72417 was entirely allocated to the Wasserburg Consortium (see Dymek et al. 1975, Papanastassiou and Wasserburg 1975, Laul and Schmitt 1975).

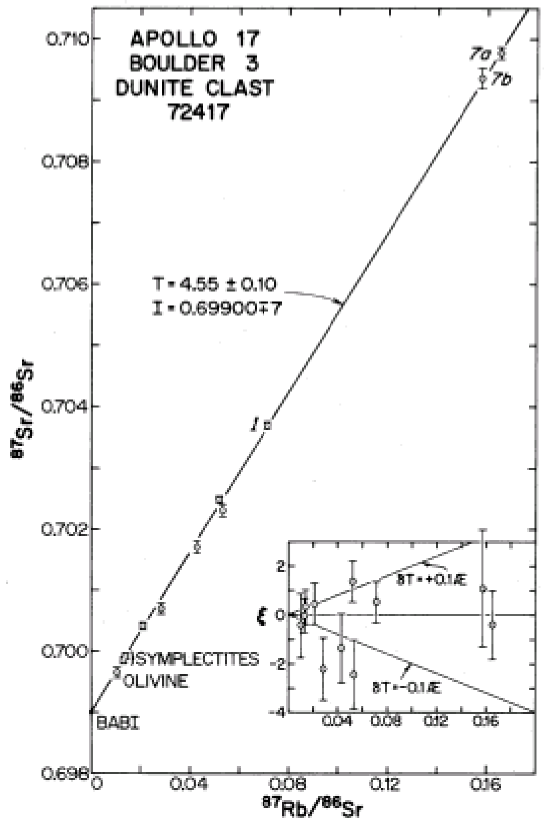


Figure 9: Rb-Sr internal mineral isochron for 72417 (from Papanastassiou and Wasserburg 1975).

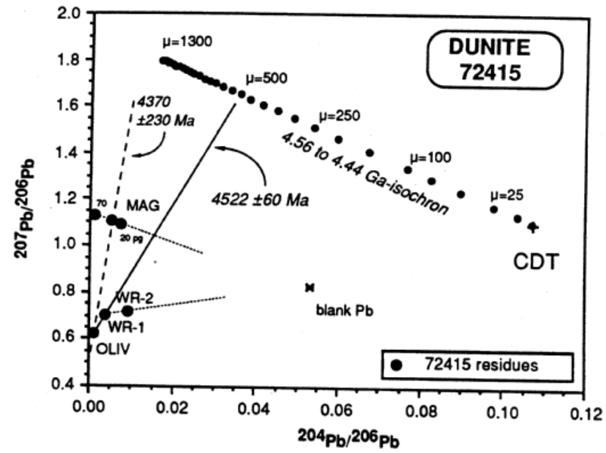
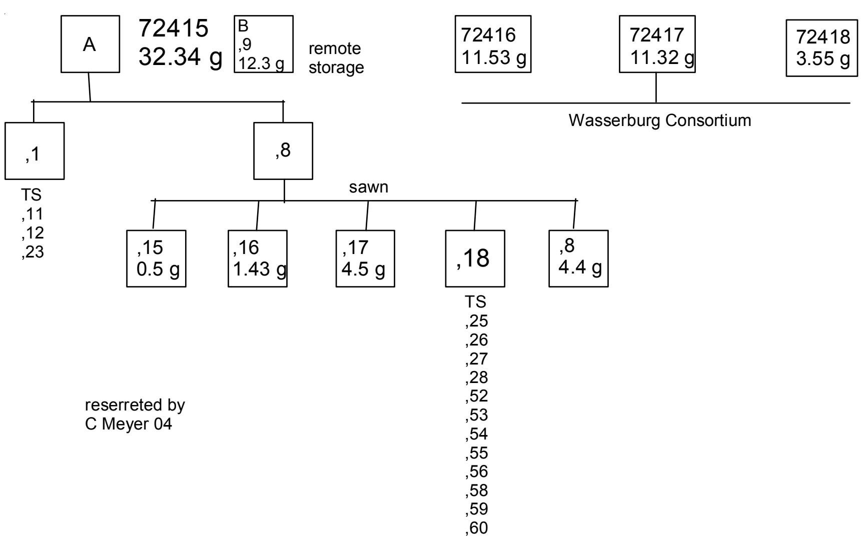


Figure 10: Pb-Pb diagram for separates from 72415 (from Nunes and Tatsumoto 1992).



Summary of Age Data for 72415-72417

	Rb-Sr	U-Pb	Ar-Ar
Papanastassiou and Wasserburg 1975	4.55 ± 0.1 b.y.		
Premo and Tatusmoto 1993		4.37 – 4.52 b.y.	
Huneke quoted in Dymek et al. 1975			3.95 ± 0.1

Caution: Not corrected for new decay constants.

Table 1. Chemical composition of 72415 and 72417.

			72417															
reference	LSPET 73		Laul 75		Wiesmann 75		Higuchi 75			Morgan 1988								Walker 2004
weight	72415		average		72417		72415	72417		72415				72417				72415
SiO2 %	39.93	(a)																
TiO2	0.03	(a)																
Al2O3	1.53	(a)	1.3	(b)														
FeO	11.34	(a)	11.9	(b)														
MnO	0.13	(a)	0.113	(b)														
MgO	43.61	(a)	45.4	(b)														
CaO	1.14	(a)	1.1	(b)														
Na2O	<0.02	(a)	0.013	(b)														
K2O	0	(a)	0.0024	(b)														
P2O5	0.04	(a)																
S %	0.01	(a)																
sum																		
Sc ppm			4.3	(b)														
V			50	(b)														
Cr	2326	(a)	2326	(b)	2501	(c)												
Co			55	(b)														
Ni			160	(b)			149	411	(d)					538	650	314		
Cu																		
Zn							2.1	9.8	(d)	2.4	2.4	2.3	4.1	2.5	2.1	9.6	2.3	
Ga																		
Ge ppb							29.8	261	(d)	250	30	71	320	349	542	186	270	
As																		
Se							4.9	5.1	(d)	10	10	5	12	31	5.4	9	3	
Rb					0.066	(c)	0.045	0.027	(d)									
Sr			8.2	(b)	2.24	(c)												
Y																		
Zr					3	(c)												
Nb																		
Mo																		
Ru																		0.164
Rh																		
Pd ppb																		
Ag ppb							0.25	30.2	(d)					14.5	5	46		0.013
Cd ppb							0.37	0.85	(d)					5.2	4	26		
In ppb														0.72	0.21	0.25		
Sn ppb																		
Sb ppb							0.47	2.81	(d)					1.78		3.4		
Te ppb							0.36	0.56	(d)									
Cs ppm							14.2	14.1	(d)									
Ba			4.1	(b)	3.27	(c)												
La			0.15	(b)	0.05	(c)												
Ce			0.37	(b)	0.07	(c)												
Pr																		
Nd					0.07	(c)												
Sm			0.08	(b)	0.022	(c)												
Eu			0.061	(b)	0.016	(c)												
Gd					0.03	(c)												
Tb			0.017	(b)														
Dy			0.11	(b)	0.035	(c)												
Ho			0.023	(b)														
Er					0.04	(c)												
Tm																		
Yb			0.074	(b)	0.045	(c)												
Lu			0.012	(b)	0.008	(c)												
Hf			0.1	(b)	0.015	(c)												
Ta																		
W ppb																		
Re ppb							0.005	0.099	(d)	0.158	0.04	0.06	0.07	0.0007	0	0.02	0.04	0.004
Os ppb														0.043	0.03	0.71		0.072
Ir ppb							0.005	3.13	(d)	2.4	0.02	0.02	0.11	0.048	0.05	0.46	0.01	0.058
Pt ppb																		0.225
Au ppb	Kieth 74						0.255	2.55	(d)									
Th ppm	<0.15																	
U ppm	<0.06				<0.005	(c)	0.006	0.003	(d)									

technique (a) XRF, (b) INAA, (c) IDMS, (d) RNAA, (e) ICP-MS

Table 2: Composition of 72415-72418.

	U ppm	Th ppm	K2O %	Rb ppm	Sr ppm	Nd ppm	Sm ppm	technique	
Papanastassiou + W 75				splits only					IDMS
Wiesmann + Hubbard 75	<0.005			0.066	2.24	0.07	0.022	IDMS	
Laul et al. 1975			0.0024		8.2		0.08	INAA	
Higuhci and Morgan 75	0.0062			0.045				RNAA	
	0.0028			0.027					
Morgan and Wanless 1988	0.0024								
	0.0006								
	0.0051								
Premo and Tats 1992	?	?						IDMS	
Kieth et al. 1974	<0.06	<0.15	0.0084					counting	
Jovanovic and Reed 1975	0.002							chem.	
	0.002								

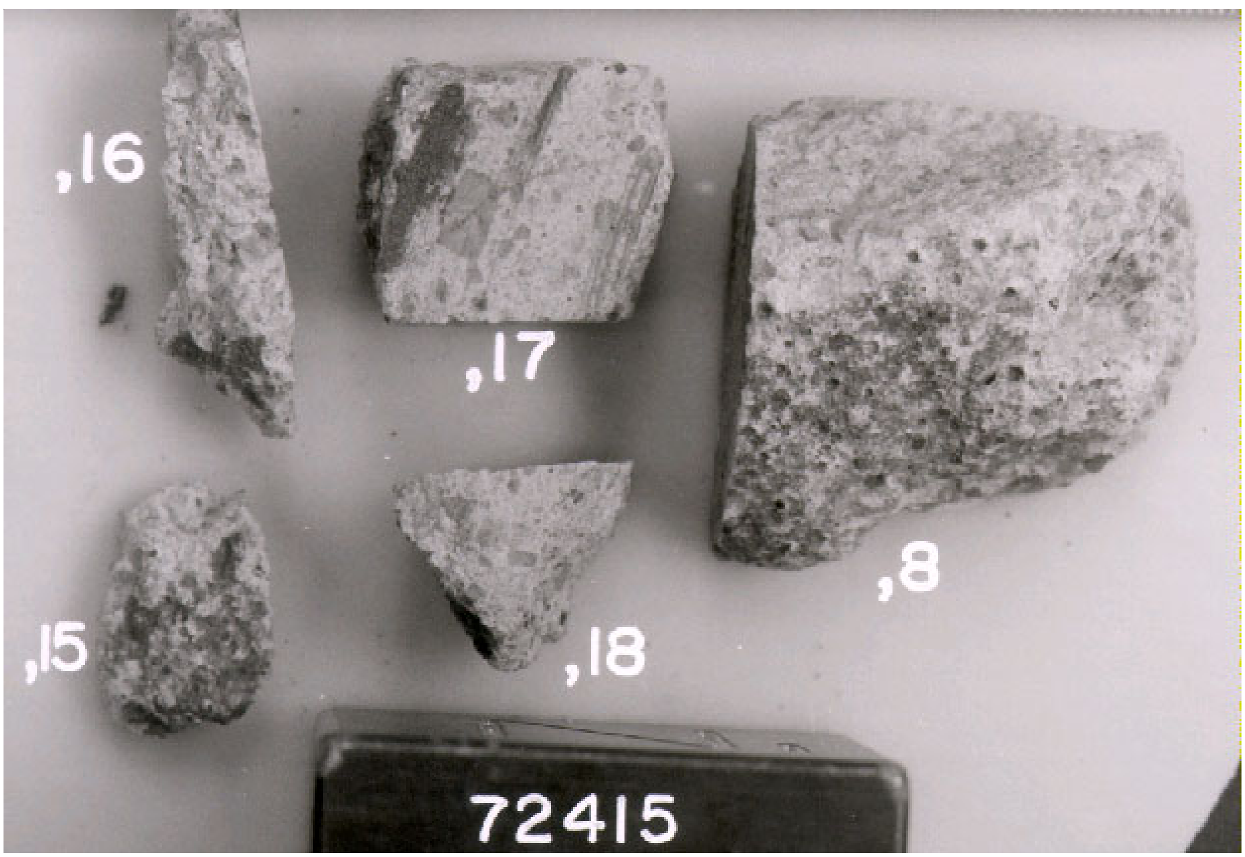


Figure 11: The largest piece of 72415 was sawn to produce a slab (,18 and ,17). Edge of cube is 1 inch. NASA# S74-19014.