15415

Ferroan Anorthosite

269.4 grams

"don't lose your bag now, Jim"

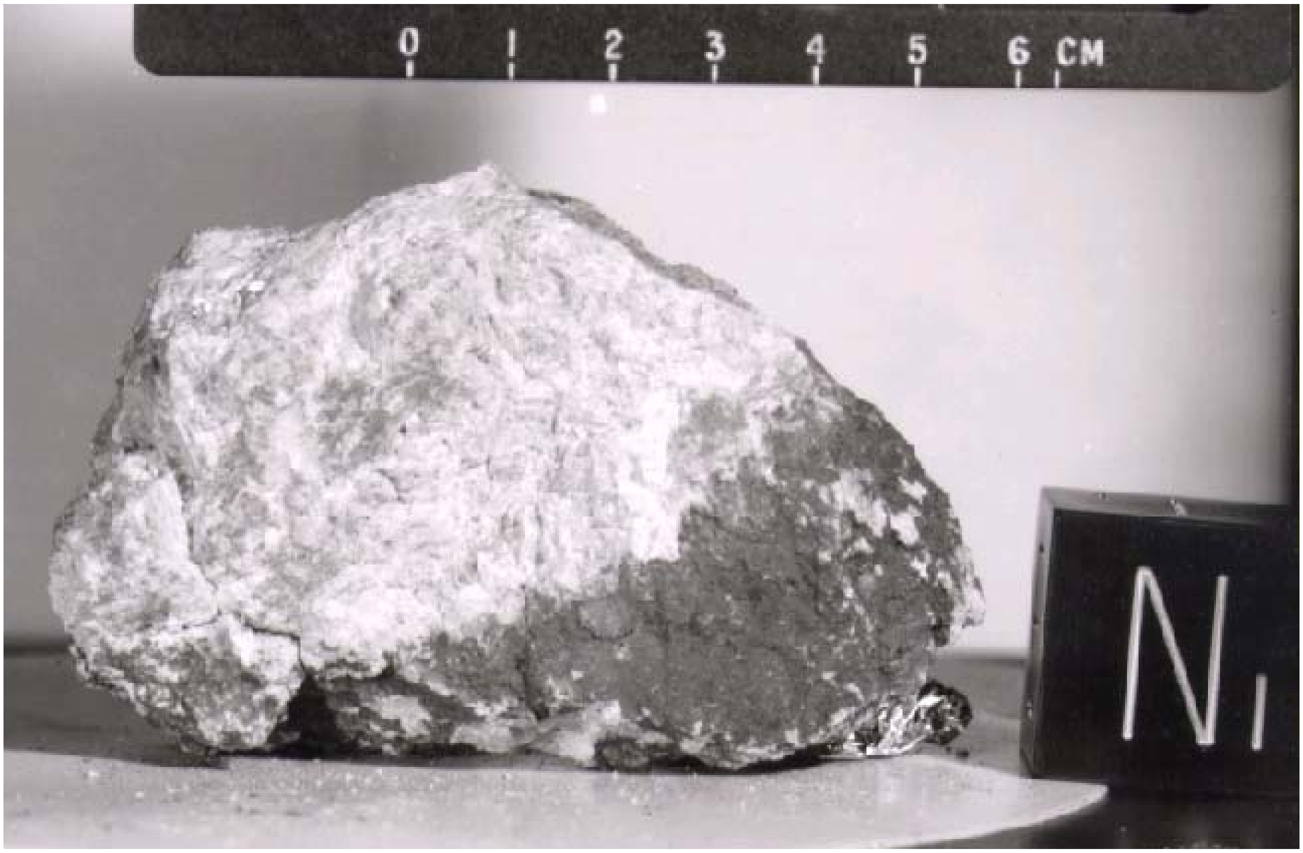

Figure 1: Photo of 15415 before processing. Cube is 1 inch. NASA# S71-44990

Transcript

CDR Okay. Now let's go down and get that unusual one. Look at the little crater here, and the one that's facing us. There is this little white corner to the thing. What do you think the best way to sample it would be?

LMP I think probably – could we break off a piece of the clod underneath it? Or I guess you could probably lift that top fragment off.

CDR Yes. Let me try. Yes. Sure can. And it's a white clast, and it's about – ***oh, boy!***

LMP Look at the – glint. Almost see twinning in there.

CDR Guess what we found? Guess what we just found?

LMP I think we found what we came for.

CDR Crystal rock, huh? Yes, sir. You better believe it. Look at the plag in there. Almost all plag – as a matter of fact – ***oh, boy***, I think we might – ourselves something close to anorthosite, because its crystalline and there's just a bunch – it's just almost all plag. What a beaut.

LMP That really is a beauty. And, there's another one down there.

CDR Yes. We'll get some of these. - - - No, let's don't mix them – let's make this a special one. I'll zip it up. Make this bag 196, a special bag. Our first one. Don't lose your bag now, Jim. ***O, boy.***

Transearth Coast Press Conference

CC Q2: Near Spur Crater, you found what may be "Genesis Rock", the oldest yet collected on the Moon. Tell us more about it.

CDR Well, I think the one you're referring to was what we felt was almost entirely plagioclase or perhaps anorthosite. And it was a small fragment sitting on top of a dark brown larger fragment, almost like on a pedestal. And Jim and I were quite impressed with the fact that it was there, apparently waiting for us. And we hoped to find more of it, and, I'm sure, had we more time at that site, that we would have been able to find more. But I think this one rock, if it is, in fact, th beginning of the Moon, will tell us an awful lot. And we'll leave it up to the experts to analyze it when we get back, to determine its origin.

Figure 2: Photomicrograph of thin section of 15415, crossed polarizers, showing polysynthectic twinning in mildly shocked plagioclase and trigonal grain boundaries. Field of view is 3 mm. NASA # S71-52630

Introduction

Lunar anorthosite 15415 was found perched on a clod of soil breccia (15435) on the rim of Spur Crater (Wilshire et al. 1972). Spur Crater is about 50 meters above the mare surface on the slope of Hadley Delta. It is subdued in nature and apparently old. The samples collected from Spur Crater had a range of exposure ages indicating that the material excavated may have been pre-exposed and/or may include material added from other sources after the Spur event (Arvidson et al. 1975).

During a transearth coast press conference, 15415 was called "Genesis Rock" and the name has stuck in spite of the fact that it may not be the oldest rock from the Moon. The astronauts correctly recognized that it was coarse-grained, made almost entirely of plagioclase and probably from the lunar highlands (figure 1). Thin sections also show that it is an anorthosite made almost entirely of coarse-grained plagioclase (figure 2) and that it is only mildly shocked. Age dating proved difficult, but an age of about 4 b.y. was determined by the Ar plateau method. However, the very low initial $^{87}Sr/^{86}Sr$ ratio attests to it great antiquity and the lack of meteoritical siderophiles proves its pristinity (lack of contamination by impacts).

In summary, 15415 is a unique lunar sample, in that, it is a pristine coarse-grained, unbrecciated anorthosite made up of mostly (98%) calcic plagioclase (An_{96}). For a rock to have this much plagioclase, the rock must have formed by a process of plagioclase accumulation. It is generally understood that the original crust of the moon formed by plagioclase floatation from a magma ocean (see Warren 1985). But the exact connection of 15415 to this process is unclear, because Ar dating of 15415 showed it to be too young to have formed from the original lunar magma ocean.

Ryder (1985) provided a comprehensive review of all aspects of 15415. The section on 15435 provides a picture of the sample on the moon.

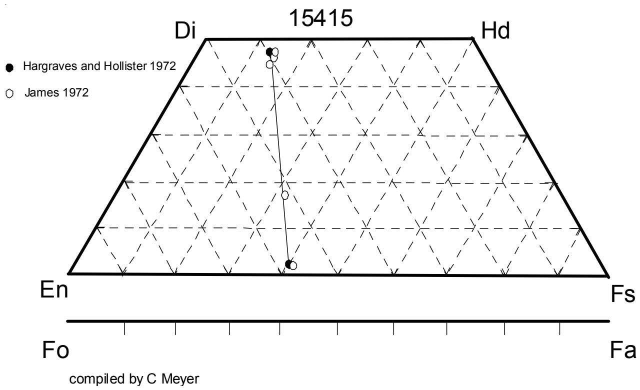

Figure 3: Pyroxene composition for 15415 (data from James 1972, Hargraves and Hollister 1972).

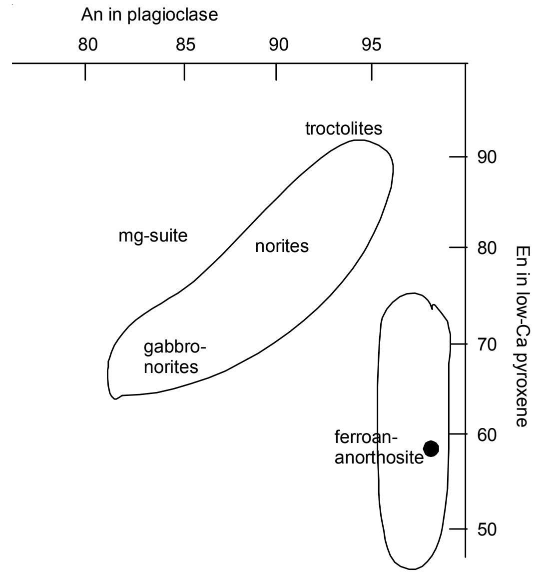

Figure 4: Plagioclase-low-Ca pyroxene diagram showing that 15415 plots in field of ferroan anorthosite.

Petrography

15415 is made up of 98% plagioclase, with minor pyroxene and trace ilmenite and silica (see mode). In some areas, the maximum grain size of plagioclase in 15415 is 1.8 cm (Wilshire 1972), or 3 cm (James 1972) with crystals grown together with smooth grain boundaries and trigonal intersections (typically a metamorphic texture). Stewart et al. (1972) coined the term Apollonian metamorphism to describe the texture of plagioclase and mineral assemblage of 15415.

Minor diopsidic augite (Ca-pyroxene) occurs as inclusions in plagioclase, polygons along grain boundaries and septa between large plagioclase grains. The pyroxene grains are small (~100 microns) and show exsolution of pigeonite and orthopyroxene. Discrete grains of orthopyroxene are also present. Evans et al. (1978) conclude from the structure of orthopyroxene that the last temperature of metamorphism was 500 to 600 deg. C.

15415 is classified as a ferroan anorthosite based on the calcic composition of the plagioclase and Fe-rich composition of the low-Ca pyroxene (figure 4). The mineralogical mode is difficult to determine because of the large grains size of the plagioclase.

Portions of 15415 have a cataclastic texture. Other portions exhibit mild shock causing offsets in the polysynthetic twinning in plagioclase (figure 2).

Mineralogy

Plagioclase: The plagioclase in 15415 is unzoned and uniformly An_{96-97} (see table). It contains only minor amounts of FeO and MgO. Plagioclase in 15415 exhibits both albite and pericline twinning (figure 2). Papike et al. (1997) used the ion microprobe to analyze plagioclase for the REE (figure 5). Palme et al. (1984) carefully analyzed plagioclase mineral separates by INAA (table).

Stewart et al. (1972) and Czank et al. (1973) determined the crystal structure (P1) and found both short and long range cation ordering. Lally et al. (1972), Heuer et al. (1972) and Nord et al. (1973) used high voltage electron microscope techniques to study plagioclase in 15415.

Mineralogical Mode for 15415

	Steele and Smith 1971	Wishire 1972	James 1972	Hargraves and Hollister 1972	Stewart 1972
Plagioclase	97 vol. %	99	95-99	>98	99
Augite	~3		tr.	~1	0.8
Orthopyroxene			tr.		0.2
Ilmenite	tr.		t.		tr.
Silica			tr.		tr.
Spinel					tr.
Olivine		tr.?			
Apatite		tr.?			

Plagioclase in 15415

electron probe (wt.%)

	Hargraves 72		Hanson 79	McGee 93	Stewart 72	Dixon 75	Papike 97
SiO2	44.19	43.92			43.36	44.8	43.2
Al2O3	35.77	36.24			36.04	34.5	37
FeO	0.16	0.09	0.102	0.085	0.08	0.08	0.086
MgO			0.05	0.071	0.07	0	0.042
CaO	19.66	19.49			19.34	20.1	19.5
Na2O	0.22	0.26			0.32	0.35	0.375
K2O			0.023		0.05	0.02	0.01
Ab			3.5		2.9		3.34
An	97	97		96.9	96.5		96.6
Or					0.3		0.059

ion probe (ppm)

	Meyer 74	Meyer 79	Steele 80	Papike 97	plagioclase fragments by INAA Palme 84				
Li	1.6	2	2						
Mg	280	300	305						
Ti	90	91	75						
Sr	177	190	200	141	191	212	246	220	232
Y				0.114					
Ba	9	11	6.5	6.54	6	7	21	22	22
La				0.161	0.14	0.12	0.364	0.391	0.385
Ce				0.498					
Nd				0.265					
Sm				0.065	0.038	0.035	0.108	0.103	0.112
Eu				1.02	0.79	0.74	1.29	1.28	1.27
Gd				0.057					
Dy				0.046					
Er				0.016					
Yb				0.009			0.032	0.023	0.028
Na									
Fe ppm									
Sc ppm					0.157	0.155	0.27	0.12	0.216
Cr ppm					3.6	1	8.5	1.9	3.6
Co ppm					0.32	0.358	0.088	0.012	0.015

Pyroxene: The composition of pyroxene in 15415 is given in figure 3. The bulk of the pyroxene in 15415 is diopsidic augite $Wo_{46}En_{39}Fs_{16}$ (Hargraves and Hollister 1972), but thin lamellae and small patches of hypersthene analyze as $Wo_{2.5}En_{58}Fs_{39.5}$. Evans et al. (1978) determined the crystal structure (Pbca) and unit cell size of orthopyroxene for 15415. Smith and Steele (1974) suggested that some of the pyroxene in 15415 might have formed by exsolution of FeO and MgO from plagioclase, reacting with silica at grain boundaries.

Ilmenite: Trace ilmenite is found in the outer portions of pyroxene grains.

Chemistry

Hubbard et al. (1971), Wanke et al. (1975), Haskin et al. (1981) and Ganapathy et al. (1973) have analyzed 15415 (table 1). The bulk rock composition is similar to the plagioclase composition as determined by ion probe (figure 5). Morgan et al. (1972) and Reed and Jovanovic (1972) also report chemical data.

Radiogenic elements were determined in an attempt to age date the rock (table 2).

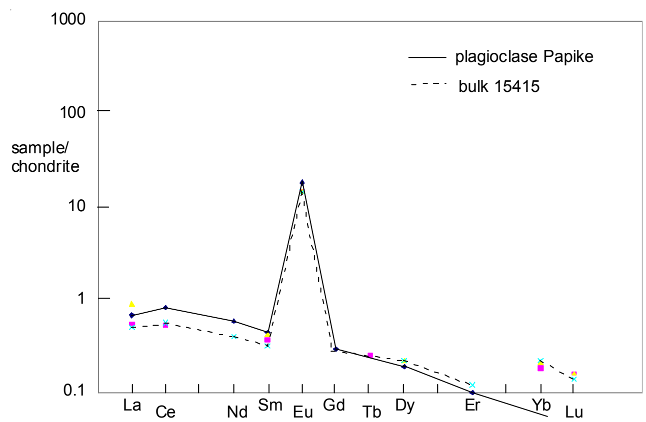

Figure 5: Normalized rare-earth-element composition diagram for 15415 plagioclase and whole rock.

Radiogenic age dating

Tatsumoto et al. (1972), Nunes et al. (1972) and Tera et al. (1972) determined U, Th and Pb isotopic data, but could not date the rock in this way. Tera et al. (1972) found that the Pb isotopic composition of 15415 was evolved, such that it "represents the evolution of about 0.5 b.y. after the formation of the moon".

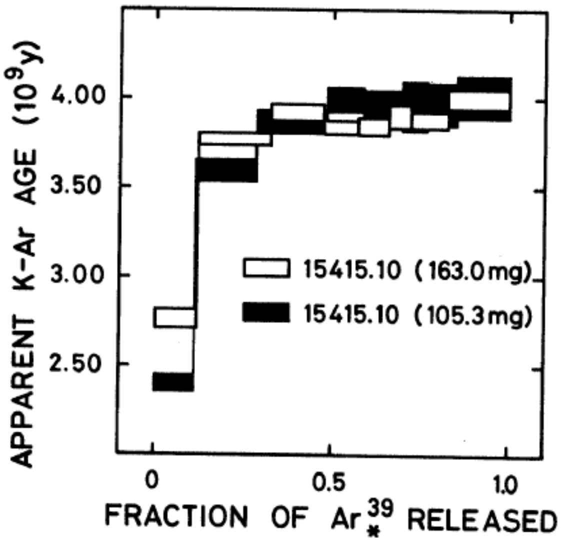

Figure 6: Argon plateau age for 15415 (from Stettler et al. 1973).

Summary of Age Data for 15415

	Ar/Ar
Husain et al. 1972	4.09 ± 0.19 b.y.
Turner et al. 1972	4.05 ± 0.15
Stettler et al. 1973	3.99 ± 0.06
	3.91 ± 0.1
Albarede 1978	4.08 (recalculated)

PS: This data not corrected with new decay constant.

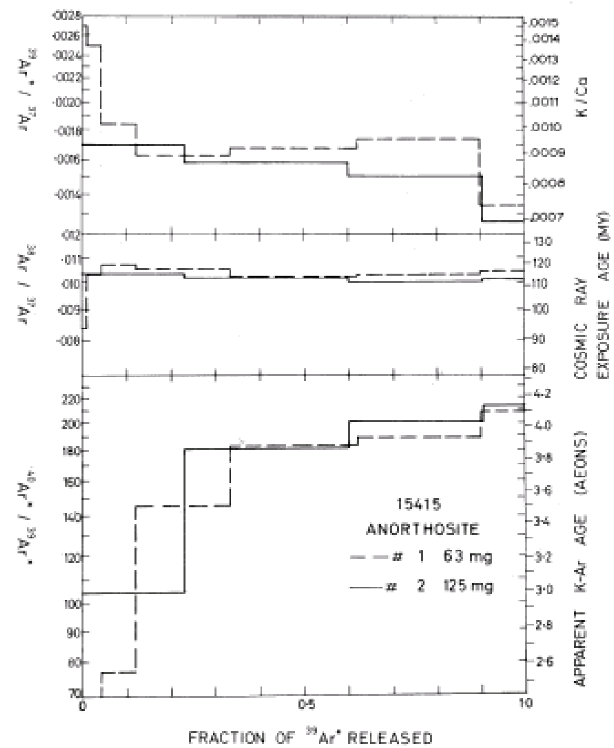

Figure 7: Argon plateau age for 15415 as determined by Turner et al. 1972.

15415 also proved impossible to data by Rb-Sr systematics. Whole rock Rb-Sr data were presented by Wasserburg and Papanastassiou (1971), Nyquist et al. (1972), Tatsumoto et al. (1972) and Papanastassiou and Wasserburg (1973). These analysts determined that the $^{87}Sr/^{86}Sr$ ratio was extremely low.

The argon 39/40 technique proved more useful, although good thermal release plateaus were not achieved (figure 6 and 7). However, one must consider the apparent metamorphic texture of this rock in order to interpret the apparent Ar age (~4 b.y.), the low initial $^{87}Sr/^{86}Sr$ along with substantial He and Ar loss. Francis Albarede (1978) applied linear inversion techniques to recalculate the argon data of Turner et al. and discover the complex thermal history of 15415.

Cosmogenic isotopes and exposure ages

Husain et al. (1972), Turner (1972) and Stettler et al. (1973) determined ^{38}Ar exposure ages of 90, 112 and 100 m.y. respectively for 15415. Eugster et al. (1984) determined 104 ± 15 m.y. by ^{81}Kr and inferred a multistage exposure history. Eugster et al. determined that 15415 has lost about 90% of its He and 40% of its Ar.

Keith and Clark (1972) reported activities 116 ± 9 dpm/kg for ^{26}Al, 36 ± 5 dpm/kg for ^{22}Na, 0.4 ± 0.9 dpm/kg for ^{54}Mn, 3 ± 4 dpm/kg for ^{56}Co.

Table 1. Chemical composition of 15415.

reference	Hubbard 71			Wanke 75		Haskin 75			Ganapathy 73	
weight										
SiO2 %				44.93						
TiO2	0.025	0.016	(a)	0.018						
Al2O3				35.71			35.5	(b)		
FeO				0.2		0.199	0.202	(b)		
MnO							0.0061	(b)		
MgO	0.16	0.16	(a)	0.53						
CaO				20.57			21	(b)		
Na2O	0.38	0.38		0.384		0.364	0.356	(b)		
K2O	0.015	0.014	(a)	0.017						
P2O5										
S %										
sum										
Sc ppm				0.4	(b)	0.437	0.434	(b)		
V										
Cr		63	(a)	19	(b)	19.3	20.3	(b)		
Co				0.26	(b)	0.194	0.19	(b)		
Ni				3	(b)	12.2	13.3	(b)		
Cu				57.4	(b)					
Zn				31.8	(b)				0.26	(c)
Ga				3.1	(b)					
Ge ppb				20	(b)				1.2	(c)
As				0.004	(b)					
Se									0.23	(c)
Rb	0.17	0.15	(a)						0.11	(c)
Sr	178	172	(a)	173	(b)	202	198	(b)		
Y										
Zr										
Nb										
Mo										
Ru										
Rh										
Pd ppb										
Ag ppb									1.73	(c)
Cd ppb									0.57	(c)
In ppb									0.178	(c)
Sn ppb										
Sb ppb									0.067	(c)
Te ppb									2.1	(c)
Cs ppm						0.031	0.025	(b)	0.023	(c)
Ba	6.2	6.28	(a)	6.5	(b)	6	6	(b)		
La		0.118	(a)	0.21	(b)	0.13	0.133	(b)		
Ce	0.32	0.35	(a)			0.32	0.33	(b)		
Pr										
Nd	0.2	0.175	(a)							
Sm	0.049	0.046	(a)	0.062	(b)	0.056	0.054	(b)		
Eu	0.807	0.806	(a)	0.82	(b)	0.805	0.805	(b)		
Gd	0.062	0.05	(a)							
Tb						0.01	0.007	(b)		
Dy	0.063	0.044	(a)	0.054	(b)					
Ho										
Er		0.019	(a)							
Tm					(b)					
Yb	0.045	0.035	(a)	0.035	(b)	0.029	0.028	(b)		
Lu		0.003	(a)	0.0041	(b)	0.0036	0.0061	(b)		
Hf				0.017	(b)	0.011	0.014	(b)		
Ta										
W ppb				26	(b)					
Re ppb									0.00084	(c)
Os ppb										
Ir ppb									<0.01	(c)
Pt ppb										
Au ppb				0.77	(b)				0.117	(c)
Th ppm		0.027	(a)							
U ppm		0.01	(a)	0.0015	(b)					

technique (a) IDMS, (b) INAA, (c) RNAA

Table 2.

	Rb ppm	Sr ppm	87Sr/86Sr	U ppm	Th ppm	K %
Wasserburg et al. 1971	0.23	226.2	0.69926			
	0.19	163.1	0.69916			
Nyquist et al. 1972	0.142	172.2	0.69926			
	0.17	177	0.69938			
	0.196	240	0.69926			
	0.145	173	0.69917			
Wiesmann and Hubbard	0.15	172	0.69926	0.0098	0.027	0.012
Hubbard et al. 1971	0.17	178	0.69938	0.011		
Tatsumoto et al. 1972	0.217	173.3	0.69914	0.0017	0.0036	0.0151
				0.0014	0.0034	
Tera et al. 1972				0.00087	0.0035	
Keith and Clark 1974				0.003	0.028	0.0124

Other Studies

15415 has been the object of many studies (summarized in table, see also Ryder 1985).

Eugster et al. (1984) determined that the rare gas content and isotopic ratios of 15415. They reported that 15415 had experienced significant diffusion losses, because 98% of the ^{3}He and possibly 40% of the radiogenic ^{40}Ar is apparently lost.

Other Studies on 15415

authors	*topic*
Schurmann and Hafner 1972	Mossbauer spectra
Hoyt et al. 1972	thermoluminescence
DesMarais et al. 1974, 1974	carbon-based compounds
Moore et al. 1973	carbon and hydrogen
Niebuhr et al. 1973	electron spin resonance
Hewins and Goldstein 1975	Ni, Co in Fe metal
Simmons et al. 1975	cracks
Simoneit et al. 1973	thermal release
Roedder and Weiblen 1972	minute inclusions
Chung and Westphal 1973	dielectric spectra
magnetic properties	
Gose et al. 1972	
Pearce et al. 1972	
spectral studies	
Adams and McCord 1972	
Charette and Adams 1977	
seismic velocities	
Chung 1973	
Mitzutani and Newbigging 1973	
isotopes	
Epstein and Taylor 1972	oxygen and silicon
Clayton et al. 1972, 1973	oxygen
Clayton and Mayeda 1975	oxygen

Processing

15415 was originally (1972) subdivided by prying off one end (,34) and sawing off the other end (,33) (see diagram and figure 8). Sample 15415,33 was further subdivided by additional sawing. In 1975, 15415 was further subdivided to provide pieces (,139 and ,140) to go to remote storage (figure 9). Twenty-two thin sections were prepared from ,3 and from ,55.

List of Photo #s

S71-42951-42956	color
S71-44977-44508	
S71-45172-45178	color
S71-52630	
S72-15899	sawing
S75-31801-31804	
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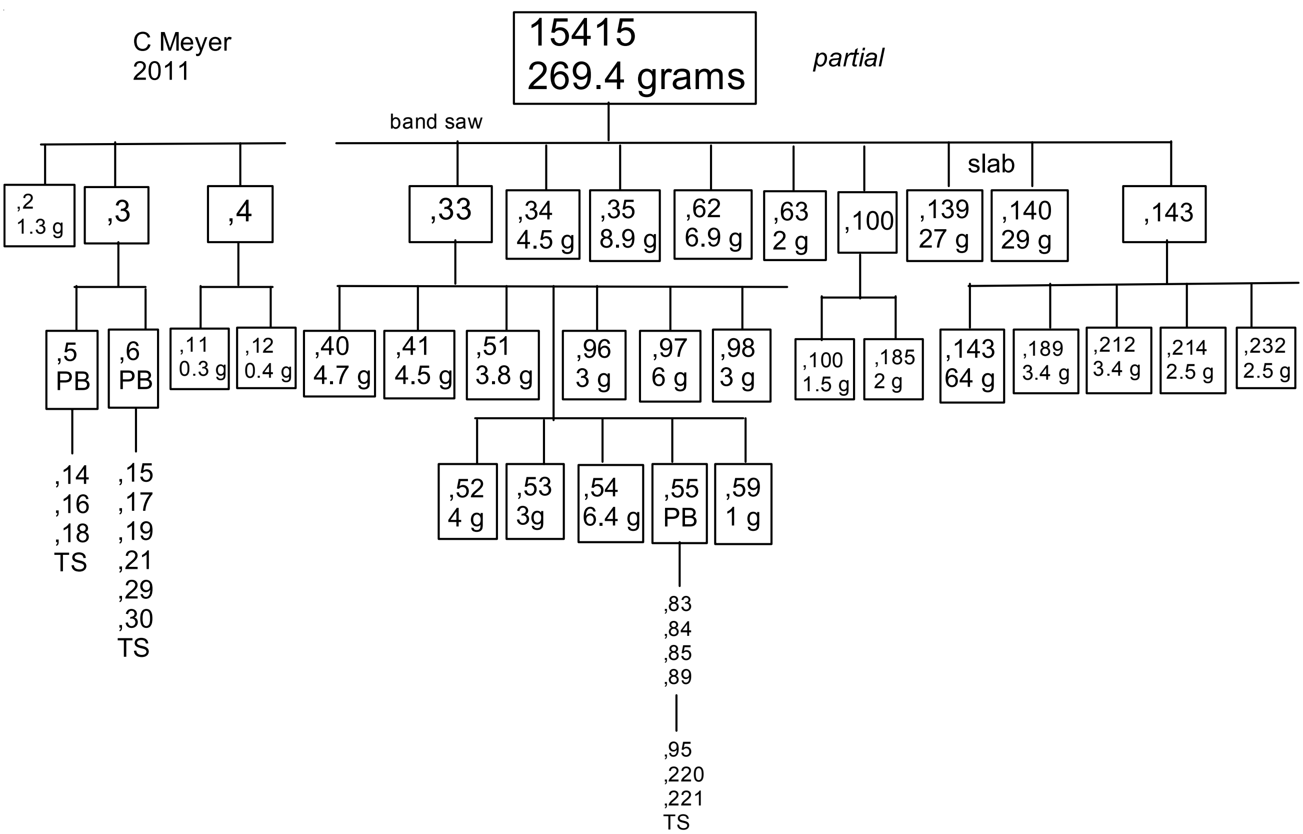
S79-27286	



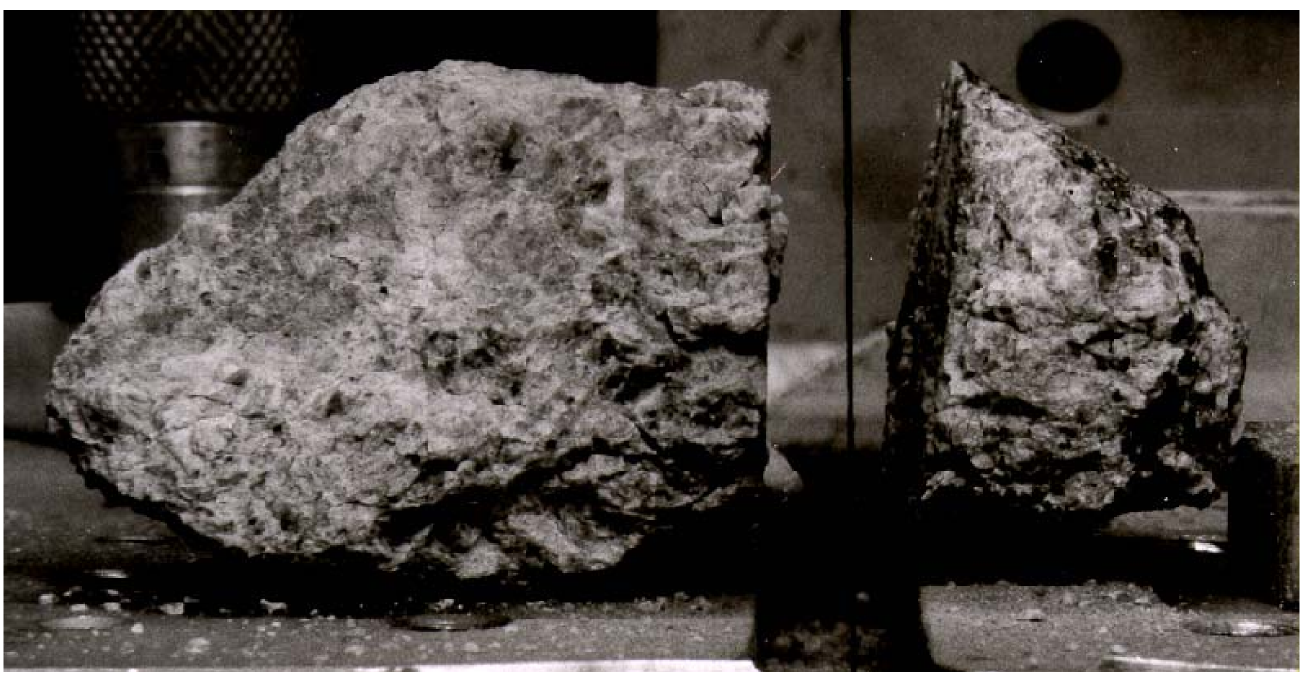


Figure 8: First saw cut of 15415,0 yielding 15415,33. NASA photo # S712-15899. Sample is about 3 inches high.

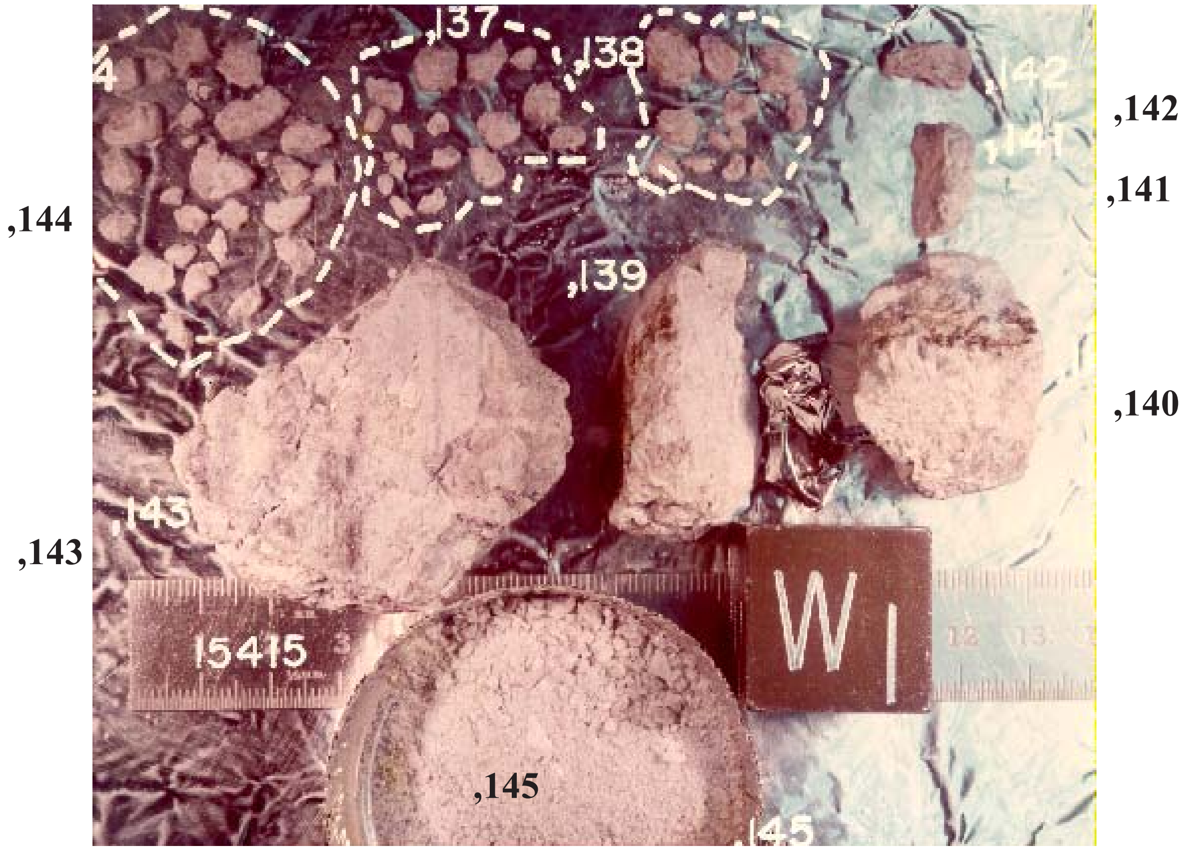


Figure 9: Subdivision of 15415,0 yielding ,143, ,139 ,140 and pieces and crumbs. NASA photo # S75-32659. Cube is 1 inch.

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