14305
Crystalline Matrix Breccia
2497 grams

Figure 1: Sawn surface of 14305 showing dark clast in lighter matrix. Cube and scale are in cm. NASA S86-30442.

Introduction
Lunar sample 14305 is a Fra Mauro breccia similar in texture and clast distribution to 14321 (figure 1). This "football-sized" rock was collected about 100 m from the LM landing site at Apollo 14. A piece broke off during transit and was orginally numbered 14302. When both pieces were found to exactly fit together, 14302 was renumbered 14305,18.

Since 14305 has zap pits on both sides and has higher ^{26}Al on the bottom, it has had a complicated exposure history (i.e. has turned over). Using ^{53}Mn, Herpers et al. (1974) showed that the rock has "tumbled" (figure 2). Eugster et al. (1984) concluded that 14305 did not originate from Cone Crater, mainly because its exposure age is slightly higher than the age of Cone Crater.

One large, glass-lined, micrometeorite pit records the location on rock 14305 that almost ruptured the rock (see figure 3 in Gault et al. 1972).

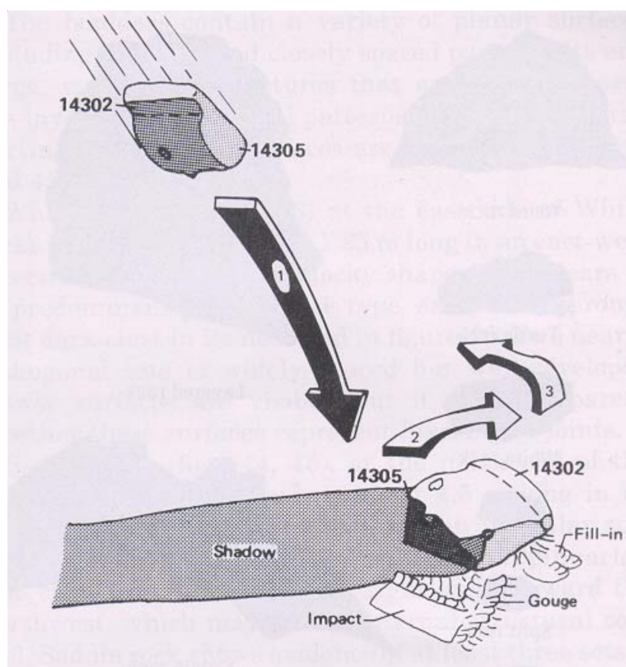


Figure 2: Illustration of emplacement and tumbling of 14305-14302 on lunar regolith.

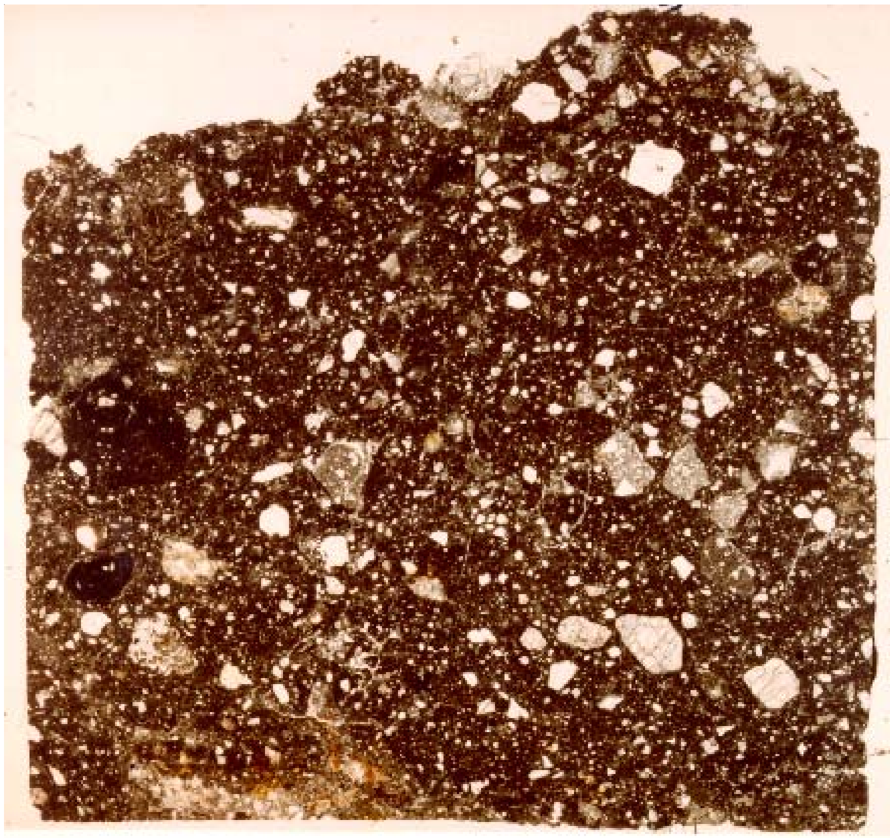


Figure 3: Thin section photomicrograph of 14305,255. NASA photo #S80-42342. Field of view about 2 cm.

The crystallization age of 14305 was found to be 3.92 b.y. with expsoure an exposure to cosmic rays of about 28 m.y. However, various clasts in this breccia are older (see below).

Petrography

Petrographic descriptions of breccia 14305 are found in Juan et al. (1972), Klein and Drake (1972), Dence and Plant (1972), Lovering et al. (1972), Carlson and Walton (1978), Shervais and Taylor (1983). According to the classification schemes of Simonds et al. (1977) and Stöffler et al. (1980), 14305 is a clast-rich, crystalline matrix breccia. The seriate matrix (down to <25 microns) consists of intergrown, blocky decussate pyroxenes with plagioclase laths and granular opaques (figure 3). Lithic clasts >1 mm comprise about 30% of the sample (Wilshire and Jackson 1972). Dark gray microbreccia is the dominant clast type (figure 1), with basalt, plagioclase-olivine cumulates and granites as minor clast types (figure 8). Juan et al. found that the fine-grain basalt clasts were like 14310. They also reported gabbroic anorthosite from the highlands. Shervais et al. (1985) also studied the plagioclase rich basalt clasts in 14305 and termed them VHK basalts.

Twedell et al. (1978) mapped some of the surfaces of 14305 and Carlson and Walton (1978) summarized what was known up to that time. Shervais and Taylor (1983) documented what was known about breccia sample 14305 in 1983 and began a search for rock clasts as part of a "pull-apart" project. They "mapped" some of the new surfaces created by new saw cuts. The most important finding from the study of 14305 was the discovery a large clast of very old mare basalt (see below).

Mineralogy

***Pyroxene**:* Klein and Drake (1972) present pyroxene analyses – including orthopyroxene in the matrix. Pyroxene compositions of the clasts in this breccia are reproduced in figures 5, 6 and 10.

Spinel: Dence and Plant (1972) give an analysis of pink spinel in 14305,5.

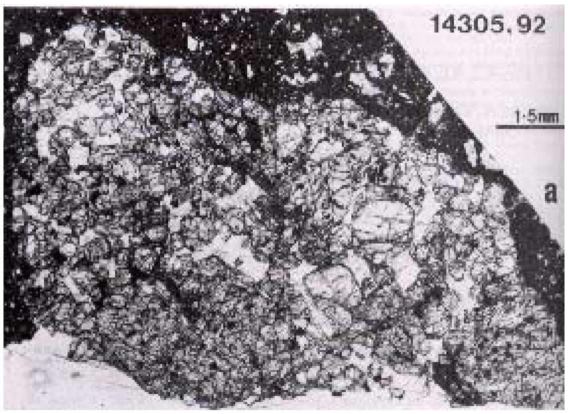


Figure 4: Thin section photomicrograph of basalt clast in 14305 (from Taylor et al. 1983). This is the olivine gabbronorite that proved to be 4.2 b.y.

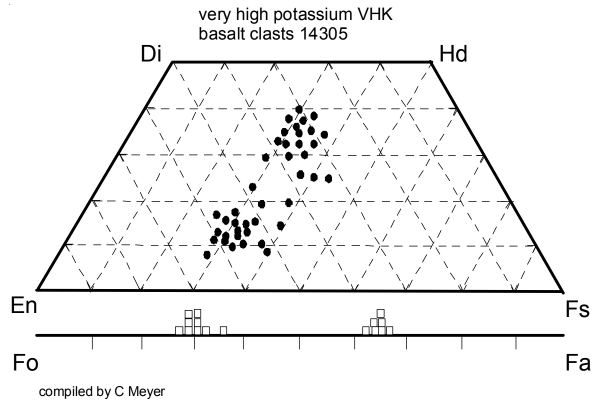


Figure 6: Olivine and pyroxene compositions of VHK basalt clasts in 14305 (after Shervais et al. 1983).

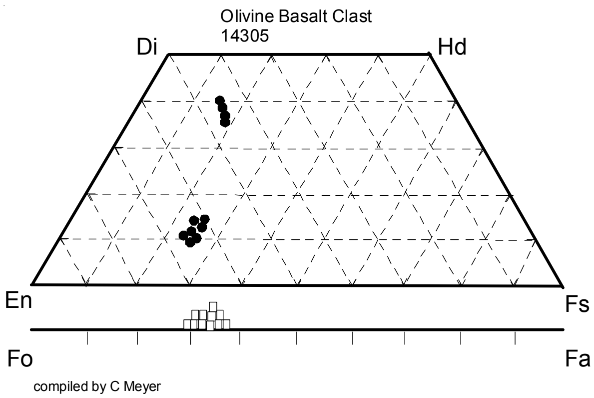


Figure 5: Composition of mafic minerals in olivine basalt clast in 14305,92 (from Taylor et al. 1983).

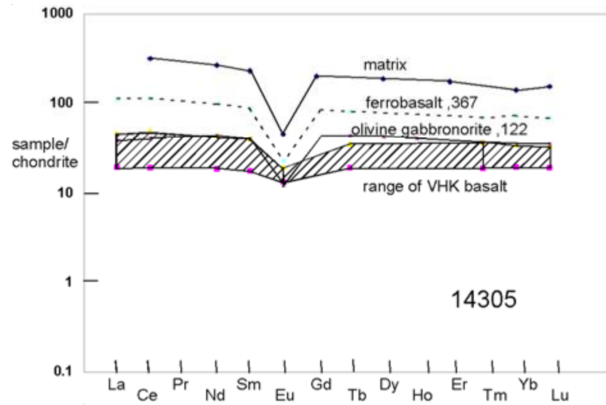


Figure 7: Normalized rare-earth-element diagram for 14305 matrix and some of its basalt clasts. (data from table 2)

Phosphate: Brown et al. (1972) and Warren et al. (1983) give analyses of whitlockite. Analyses for apatite from clasts can be found in Shervais et al. (1984).

Ternary Feldspar: Shervais and Taylor (1983) reported feldspars with roughly equal amounts of K, Na and Ca in granophryic clasts in 14305.

Zircon: Lovering et al. (1972) found U-rich zircon in a monzonite clast. Meyer et al. (1988, 1991) studied zircons in two norite clasts in 14305. Taylor et al. (2007) studied zircons from sawdust and Nemchin et al. (2008) dated 6 zircons in thin section.

Significant clasts

,122 Olivine Gabbronorite (mare basalt)

Hunter and Taylor (1983) and Taylor et al. (1983) describe a large clast of olivine gabbronorite (basalt) in thin section 14305,92 (table 2, figure 4, 5 and 13). They dug the remainder of this clast out of the adjacent epoxy mount and determined the age by Rb-Sr internal mineral isochron 4.2 b.y. (see below). This clast is a mare basalt very similar to 12005.

,304 VHK Basalt

Shervais et al. (1985) studied several high potassium basalt clasts (table 2, figure 6). One of these was dated by Shih et al. (1983) (figure 14).

,367 ferrobasalt

An analysis of an "ilmenite ferrobasalt" is presented in Shervais et al. (1985), but no details are given (figure 7).

c1 from ,18

Warren and Wasson (1980) analyzed a white troctolite clast from the top corner of 14305,18. Thin section ,268 showed that this clast was 30% olivine (Fo_{87}), 70% plagioclase (An_{95}). This clast is similar to 14172 (which might be a piece of same rock). The clast is pristine (Ir < 0.05 ppb).

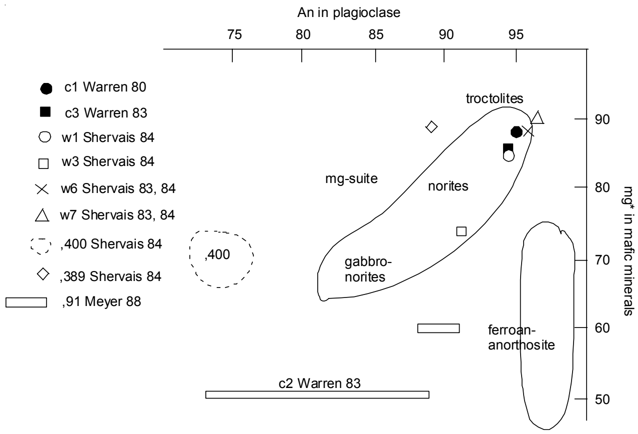


Figure 8: Composition of plagioclase and mafic minerals for white clasts in 14305 (see text for explanation).

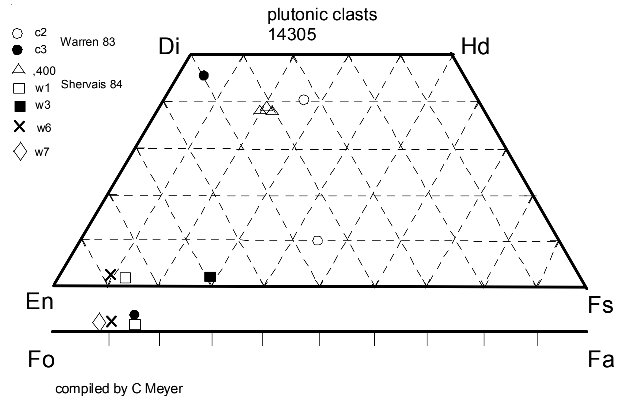


Figure 10: Pyroxene and olivine compositions of troctolite, anorthosite and norite clasts in 14305 (from Warren et al. 1983 and Shervais et al. 1983).

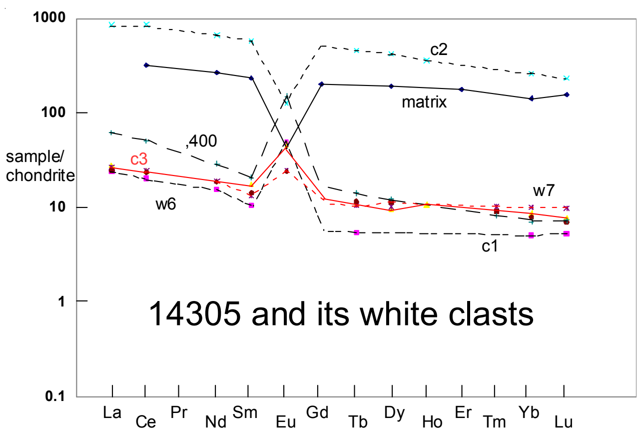


Figure 9: Normalized rare-earth-element diagram for 14305 matrix and its white clasts (data from table 2).

c2 trace-element-rich "anorthosite"

Warren et al. (1983) analyzed a whitlockite-rich anorthosite clast 14305,283 (table 2, figure 9). The plagioclase ranged widely in composition (An_{68-90}). Shervais et al. (1984) also studied an alkali anorthosite clast (,400) with plagioclase An_{71-77}.

c3

Warren et al. (1983) also found a troctolite clast (7 x 6 mm) on 14305,27 with 90% plagioclase (An_{94}), 10% mafic minerals (Fo_{85}) – see table 2 and figure 10.

w1

Shervais et al. (1984) identified a troctolitic anorthosite ,394 (no analysis) with 90% plagioclase (An_{95}), 10% olivine (Fo_{85}) and trace pyroxene (figures 8, 9 and 10).

w3

Shervais et al. (1984) studied a rare norite clast in thin section (no analysis). It was 92% plagioclase (An_{91}) and 8% enstatite (En_{73}).

w6 from ,27 and ,290

Shervais et al. (1983, 1984) analyzed (in duplicate) an enstatite troctolite clast (9 x 5 mm) that was dissected by the saw cut. The thin section showed 25% maskelynite (An_{96}), 25% olivine (Fo_{89}), and 5% enstatite (En_{90}).

w7 from ,27

Shervais et al. (1983, 1984) analyzed (in duplicate) a magnesium anorthosite clast that is made up mostly of plagioclase (An_{97}) with trace olivine (Fo_{90}). The chemical composition is similar to w6 (figure 9).

Granite

Shervais and Taylor (1983) studied several small clasts of "micrographic granite" in thin sections 14305,102 and ,111.

,77 Monzonite clast

Lovering et al. (1972) studied a 2 mm white fragment with ~35% plagioclase, 18% Ca-poor pyroxene in 44% interstitial mesostasis rich in Si and K. Apatite (50 ppm U), whitlockite (75 ppm U) and zircon (140-1300 ppm U) were accessory phases in this clast.

,91 Gabbronorite

Meyer et al. (1988) found and dated a small zircon included in an igneous rock clast with 48% plagioclase (An_{90}), 48% pyroxene (En_{70}), 2% ilmenite, apatite and whitlockite.

Table 1. Chemical composition of 14305.

reference	Keith 72	Fields 72	Yokoyama 72				LSPET72		Wanke 72		Willis 72		Philpotts 72		Palme78	
weight	380 g												sawdust			
SiO2 %							49.2	(a)	48.35	(c)	47.92	(d)	48.2			
TiO2							1.67	(a)	1.52	(c)	1.71	(d)	1.71			
Al2O3							16.1	(a)	16.25	(c)	15.47	(d)	15.16			
FeO							9.52	(a)	10.42	(c)	11.34	(d)	10.88		10.8	(e)
MnO							0.18	(a)	0.13	(c)	0.14	(d)	0.13		0.14	(e)
MgO							13	(a)	10.28	(c)	11.14	(d)	11.12			
CaO							7.4	(a)	9.93	(c)	9.96	(d)	10.13			
Na2O							0.85	(a)	0.76	(c)	0.73	(d)	0.87		0.8	(e)
K2O	0.64	(b)					1.2	(a)	0.64	(c)	0.68	(d)	0.73		0.64	(e)
P2O5											0.57	(d)	0.64			
S %											0.094	(d)	0			
sum											99.754		99.57			
Sc ppm									24	(e)					25.3	(e)
V							52	(a)								
Cr							1200	(a)	1330	(c)					1395	(e)
Co							32	(a)	31	(c)					33.4	(e)
Ni							205	(a)	200	(c)					300	(e)
Cu							13	(a)	10.9	(c)						
Zn									2.1	(c)						
Ga									5	(c)					4.9	(e)
Ge ppb									44	(c)						
As									0.077	(c)						
Se																
Rb							31	(a)	25		17.9	(d)	19	(e)		
Sr							200	(a)	190		162	(d)	166	(e)	185	(e)
Y							210	(a)			238	(d)				
Zr							900	(a)			1158	(d)	1060	(e)		
Nb							49	(a)			70.7	(d)				
Mo																
Ru																
Rh																
Pd ppb																
Ag ppb																
Cd ppb																
In ppb																
Sn ppb																
Sb ppb																
Te ppb																
Cs ppm									1.36	(c)						
Ba							930	(a)	830	(c)	913	(d)	924	(e)	950	(e)
La							54	(a)	109	(c)					111	(e)
Ce									200	(c)			193	(e)	220	(e)
Pr									26	(c)						
Nd									140	(c)			121	(e)	137	(e)
Sm									23	(c)			34.4	(e)	32.4	(e)
Eu									2.6	(c)			2.56	(e)	2.6	(e)
Gd									38	(c)			40.1	(e)		
Tb									7.4	(c)					6.9	(e)
Dy									43	(c)			46.7	(e)	43.9	(e)
Ho									6.5	(c)						
Er									32	(c)			28.3	(e)		
Tm																
Yb							28	(a)	24.2	(c)			23.3	(e)	26	(e)
Lu									3.5	(c)			3.82	(e)	3.62	(e)
Hf									26	(c)			28.6	(e)	26.5	(e)
Ta									3.2	(c)					3.2	(e)
W ppb									1940	(c)					2.6	(e)
Re ppb																
Os ppb																
Ir ppb									10	(c)					11	(e)
Pt ppb																
Au ppb									6.7	(c)						
Th ppm	13.9	16.4	14.6	13.3	14.3	(b)			17.4	(c)					13.2	(e)
U ppm	3.8	4.13	3.8	3.8	3.8	(b)			5.15	(c)					3.6	(e)

technique (a) Optical Emission, (b) Radiation counting, (c) INAA, (d) XRF, (e) IDMS

Table 2. Chemical composition of 14305 clasts.

	monzonite	troctolite		anor?	troctolite	anor.	basalt	VHK bas.	VHK	K-anor.	Pxite
reference	*Lovering 72*	Warren 80	Warren 83	Warren 83	Shervais 83		Taylor 83	Shervais	Shih 86	Shervais 84	
weight	*ts only*	c1	c3	c2	,317	,322	,122	,304	,304	,400	,389
SiO2 %	59.6	43.64	43.4								
TiO2	0.6	0.04	0.54	1.69	0.13	0.13	3.6	2.4		0.2	<0.5
Al2O3	20.6	27.96	28.54		21.9	34	4	9.9		29.9	1.1
FeO	3.3	2.83	2.25	2.55	4.2	0.43	22.4	18.1		0.19	7.3
MnO		0.031	0.026	0.037	0.049	0.007	0.25	0.23		0.003	0.11
MgO	3.3	11.44	8.3		17.6	1.4	22	15		<1	35
CaO	7.9	14.28	15.96	16.8	11.7	20.7	6.5	9		15.3	0.73
Na2O	0.9	0.43	0.47	1.48	0.44	0.34	0.16	0.34		2.4	0.04
K2O	4.7	0.07	0.07	0.506	0.063	0.055	0.04	0.62		0.46	0.01
P2O5											
S %											
sum											
Sc ppm		1.78	2.6	8.6	3.9	0.75	56	50		0.54	4.7
V					70		190	120			40
Cr		140	201	111	2395	116	821	3968			
Co		19	12.6	3.6	17.8	2.5	56.5	37		0.4	28.5
Ni		19			20	10	150	60			110
Cu											
Zn		0.58									
Ga											
Ge ppb		12									
As											
Se											
Rb				5.3			0.606		14.18		
Sr			211	400	120	210	39.17		67.42		
Y											
Zr		120		196	<30	20	230	80			
Nb											
Mo											
Ru											
Rh											
Pd ppb											
Ag ppb											
Cd ppb											
In ppb											
Sn ppb											
Sb ppb											
Te ppb											
Cs ppm											
Ba		630	450	1180	140	110	<50	200		600	40
La		5.6	6.6	201	6.6	5.4	9.2	4.6		14.5	10.3
Ce		12.2	14.8	520	15	13	25	11.7		31	24
Pr											
Nd		7.1	8	305	9.4	7.3	20	8.5	8.447	13	15
Sm		1.56	2.16	86	2	1.95	6	2.6	2.803	3.1	2.5
Eu		2.72	2.6	7.2	1.45	1.35	0.7	0.75		**8.4**	0.13
Gd											
Tb		0.2	0.4	16.7	0.4	0.36	1.6	0.7		0.52	0.32
Dy			2.33	103	2.6	2.5	10.5	4.8		3	<3
Ho			0.6	20.1			2.3				
Er											
Tm							0.9	0.46		0.2	0.2
Yb		0.83	1.44	43	1.7	1	5.8	3.2		1.15	1
Lu		0.13	0.19	5.7	0.25	0.12	0.87	0.47		0.18	0.14
Hf		0.25	0.37	2.4	0.88	0.45	6.2	2.5		1.3	0.72
Ta		<0.3	0.07	0.49	0.05	0.07	1.6	0.65		0.22	0.2
W ppb			.								
Re ppb		0.6									
Os ppb											
Ir ppb		<0.05									
Pt ppb											
Au ppb		0.016									
Th ppm		0.22	0.46	21.6	0.35	0.52	1.2	0.61		1.3	0.94
U ppm		0.17	0.15	3	<0.1	<0.1	<0.4	<0.2		<0.5	<0.4

technique (a) INAA, (b) IDMS

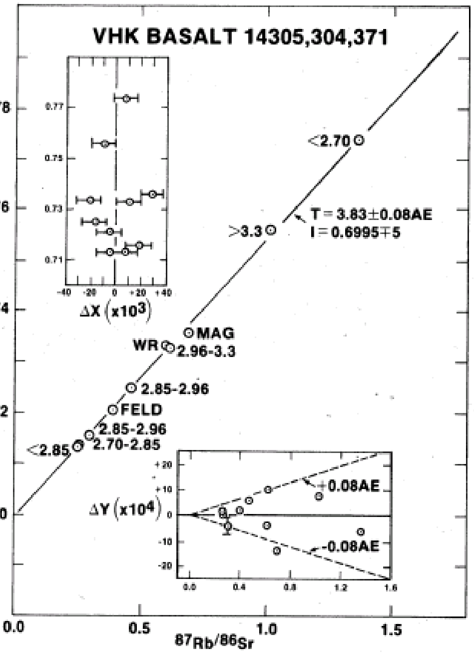


Figure 11: Rb-Sr isochron diagram of high-K basalt clast in 14305 (from Shih et al. 1986).

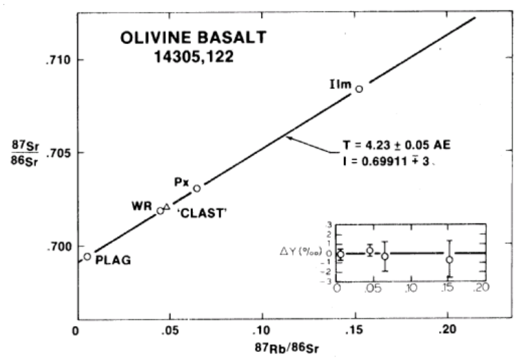


Figure 13: Rb-Sr isochron for clast in 14305 (from Taylor et al. 1983). Note the significant old age.

,103 Gabbronorite

Meyer et al. (1988) reported another small clast of gabbronorite (with included zircon) in thin section 14305,103.

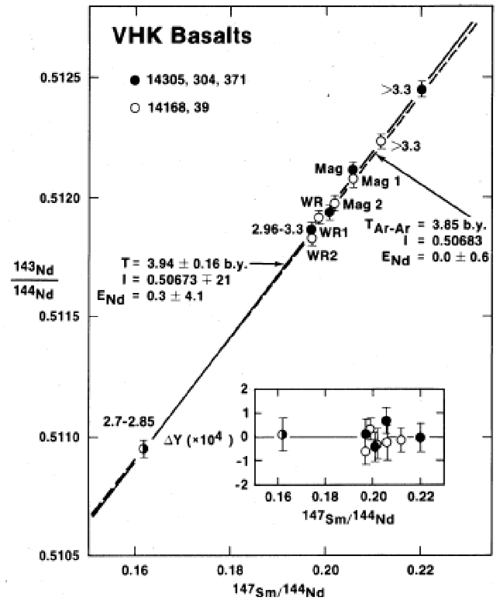


Figure 12: Sm-Nd isochron diagram for 14305 basalt clast (from Shih et al. 1986).

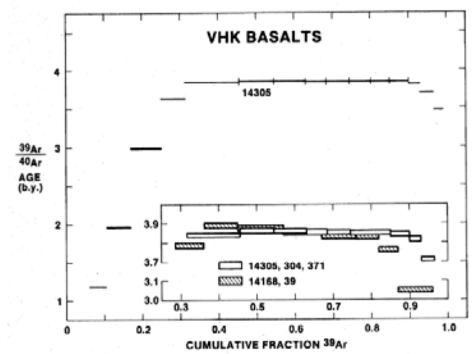


Figure 14: Ar plateau age for 14305 basalt clast (from Shih et al. 1986).

Chemistry

Keith et al. (1972) determined Th = 13.9 ppm for a large piece of 14305 by radiation counting (table 1). This is a good guide for which chemical analysis to use as representative of the bulk rock. Philpotts et al. (1972) analyzed the "sawdust" from 14305, which should be representative of the rock as a whole (figures

Summary of Age Data for 14305 (b.y. = billion years)

	Ar release	**Rb-Sr**	**Sm-Nd**	**U-Pb**	
Matrix	3.92 ± 0.03 b.y.				Eugster et al. (1984)
14305,122		4.23 ± 0.05			Taylor et al. 1983
14305,304	3.85 ± 0.02	3.83 ± 0.08	3.95 ± 0.17		Shih et al. 1986
14305,91				4.2 b.y.	Meyer et al. (1991)
Zircons				3.97 to 4.35 b.y.	Nemchin et al. (2008)
					Taylor et al. (2007)

Caution: Radiogenic decay constants not corrected.

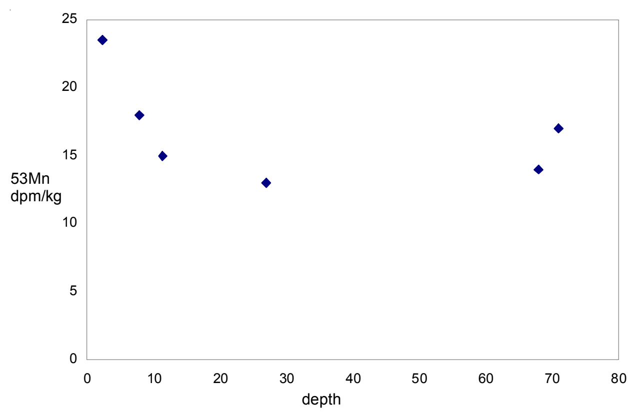


Figure 15: Depth profile for 53Mn in 14305. This is evidence for "tumbling" (Herpers et al. 1974).

7 and 9). Jovanovic and Reed (1976) determined Ru and Os.

Warren et al. (1980, 1983) and Shervais et al. (1983, 1984) analyzed a large number of clasts in 14305 (table 2, figures 7 and 9).

Radiogenic age dating

Eugster et al. (1984) determined an Ar release age of 3.92 ± 0.03 b.y. for several subsamples (presumably matrix material). Taylor et al. (1983) found the oldest mare basalt as a clast in this breccia (figure 13). Shih et al. (1986) dated one of the high K basalt fragments (figures 11, 12, 14). Meyer et al. (1991) were able to date a zircon in a gabbronorite clast by the ion microprobe method. Taylor et al. (2007) dated zircons from sawdust of 14305, while Nemchin et al. (2008) dated zircons found in thin section.

Cosmogenic isotopes and exposure ages

Eugster et al. (1984) determined an exposure age of 27.6 ± 1.5 for several subsamples of 14305 by the ^{81}Kr method. Since 14305 has higher ^{26}Al on the bottom side (160 ± 60 dpm) than the top side (63 ± 34 dpm/kg), it is thought that it has turned over in the regolith (Yokoyama et al. 1972). Herpers et al. (1974) also demonstrated that the rock had "tumbled" while on the lunar surface. They found that the ^{53}Mn depth profile was at a minimum in the middle of the rock (figure 15).

Other Studies

Eugster et al. (1984) determined the rare gas content of 14305.

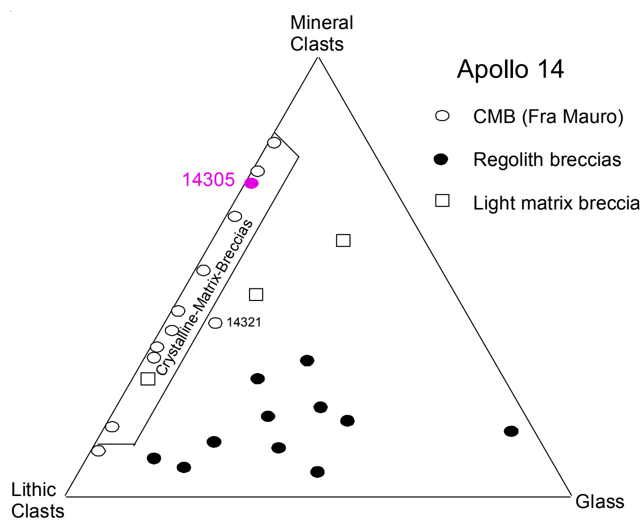
Herr et al. (1972) determined the activity of ^{53}Mn. Keith et al. (1972) determined activity of ^{26}Al, ^{22}Na, ^{54}Mn, ^{56}Co and ^{46}Sc.

Herpers et al. (1974) studied the density of cosmic ray tracks in olivine and plagioclase as a function of depth in this rock. They also determined the enrichment of ^{187}Re due to neutron capture.

Processing

14302 was re-labeled 14305,18 when it was found to be a broken piece of 14305. The main mass of 14305 was cut thru the center to yield a large slab for allocations (figure 17). In 1982, 14305,27 was again sawn to produce slab ,290 and again in 1985 to create slab ,483 (figure 22). 14305,29 was cut to produce slab ,459 (figure 19).

Shervais and Taylor (1983) produced a guidebook for this rock, summarizing the work up to 1983. There are over 100 thin sections of this rock (figure 24). This rock is featured in the Lunar Petrographic Educational Thin Section Package (Meyer 1988).



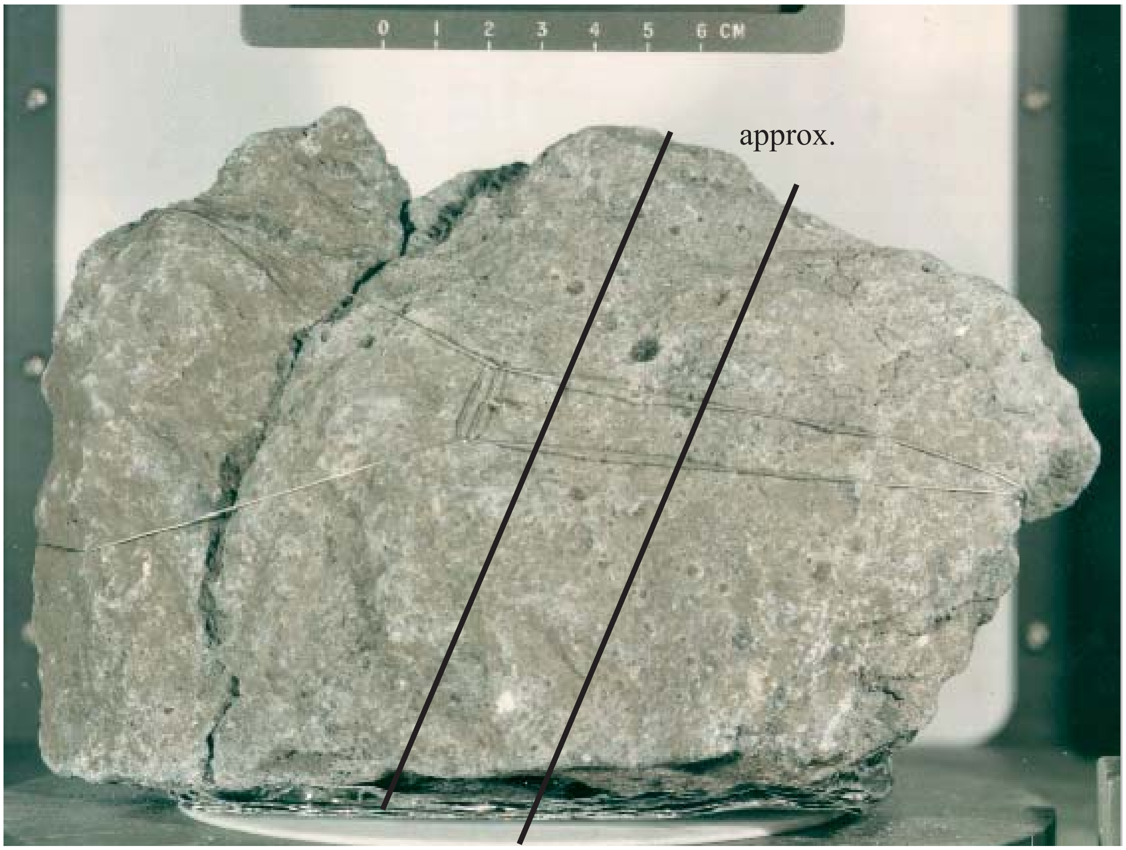


Figure 16 : NASA photo of 14305 with 14302 attached. # S71-31391. Scale at top is in cm.

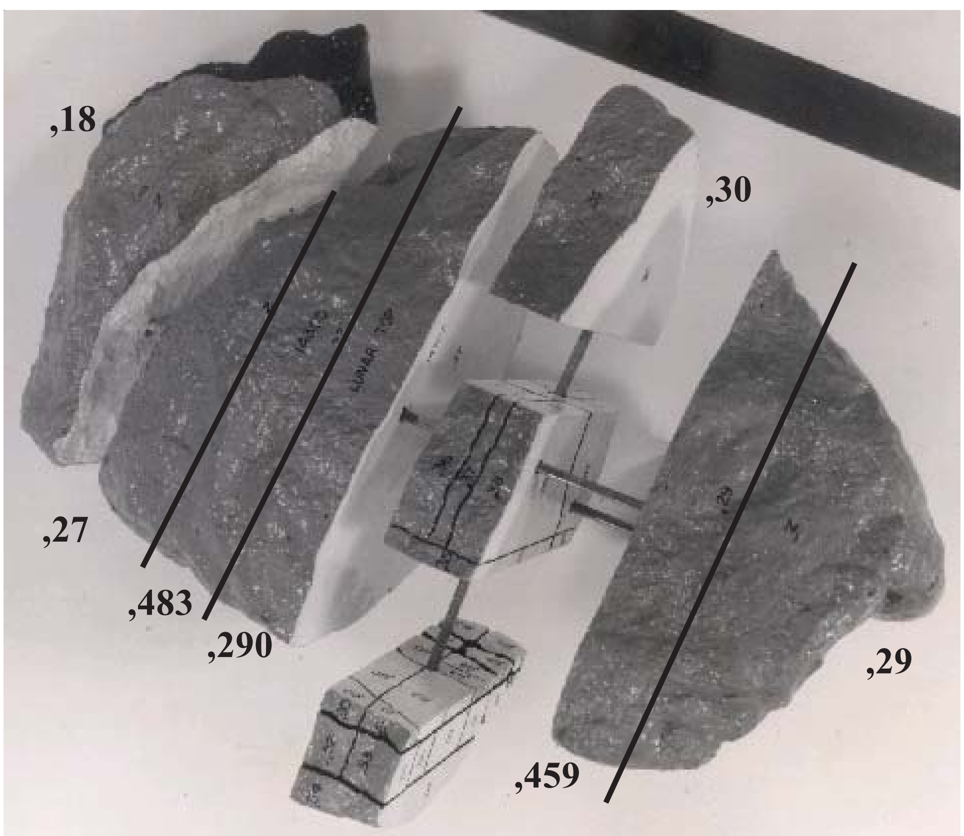
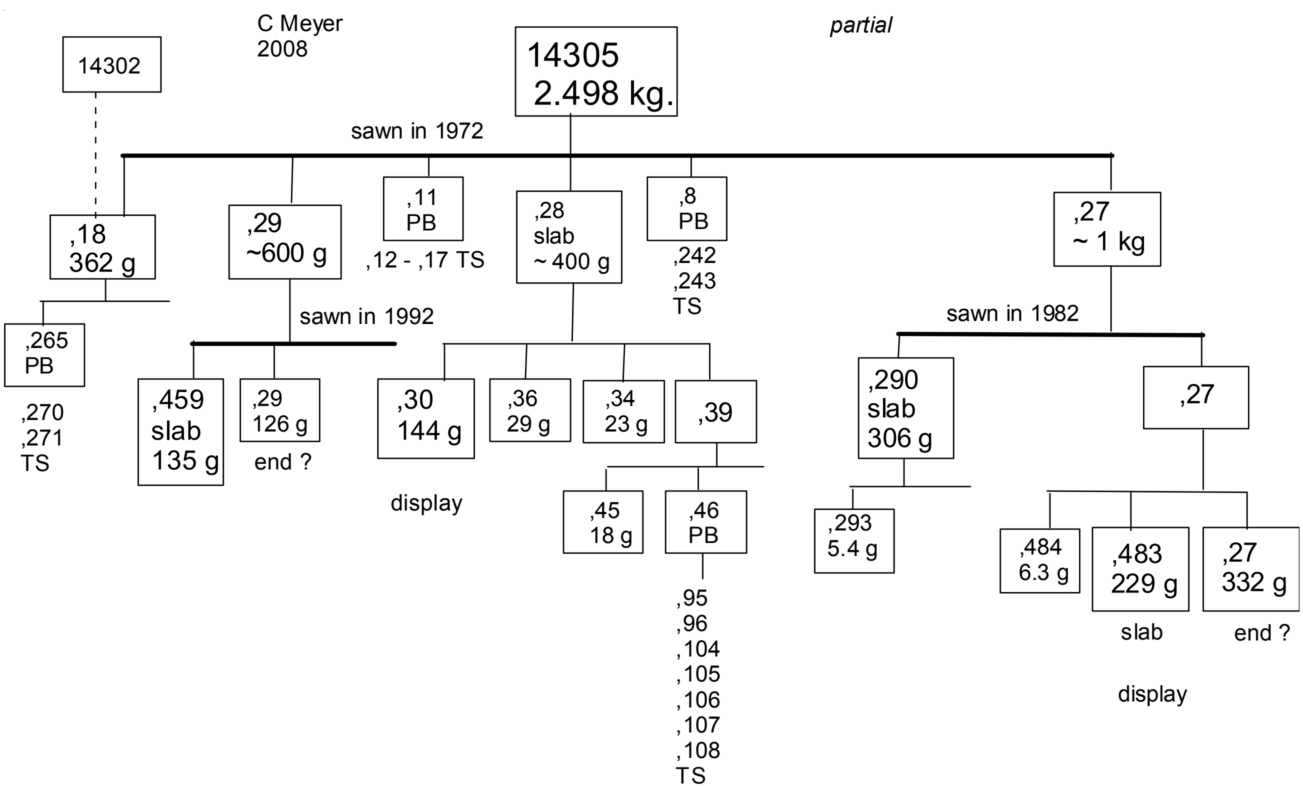


Figure 17: Exploded parts diagram for 14305 and 14302 (now called 14305,18)


C Meyer
2008
partial
14305
2.498 kg.
14302
sawn in 1972
,18
362 g
,265
PB
,270
,271
TS
,29
~600 g
sawn in 1992
,459
slab
135 g
,29
126 g
end ?
,11
PB
,12 - ,17 TS
,28
slab
~ 400 g
,30
144 g
display
,36
29 g
,34
23 g
,39
,45
18 g
,46
PB
,95
,96
,104
,105
,106
,107
,108
TS
,8
PB
,242
,243
TS
,27
~ 1 kg
sawn in 1982
,290
slab
306 g
,293
5.4 g
,27
,484
6.3 g
,483
229 g
slab
,27
332 g
end ?
display

,28 (slab)

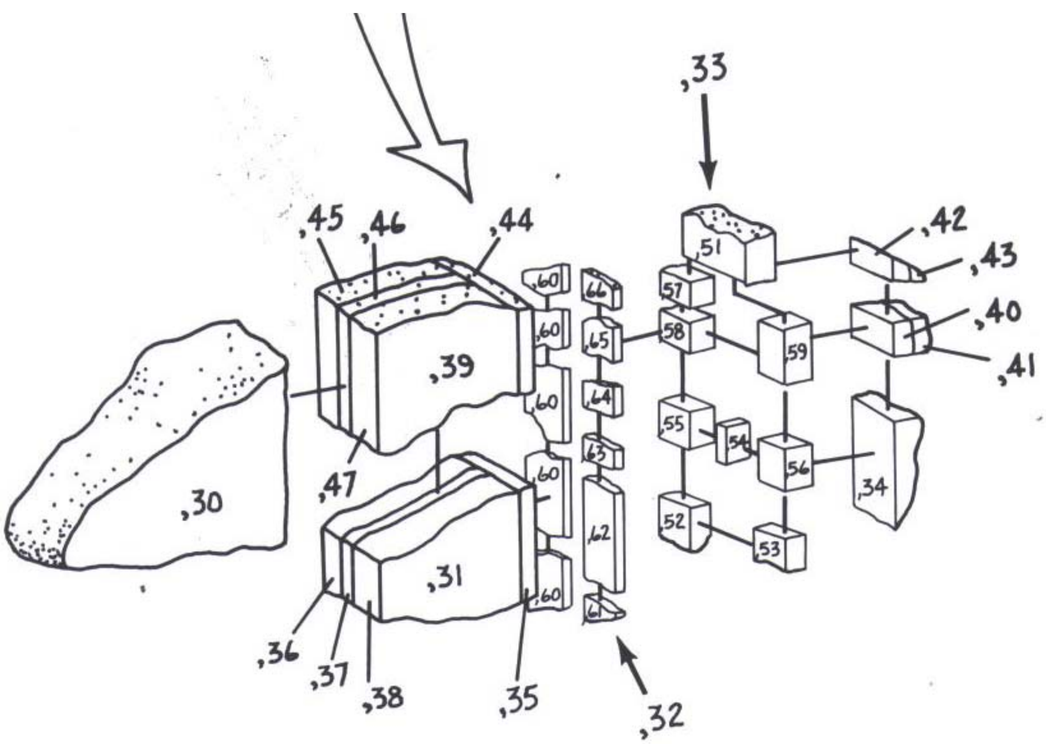

,33
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Figure 18: Sawn interior surface of 14305,30 (display piece) illustrating dark microbreccia clasts in light matrix. Cube is 1 inch. NASA photo #S77-21471.

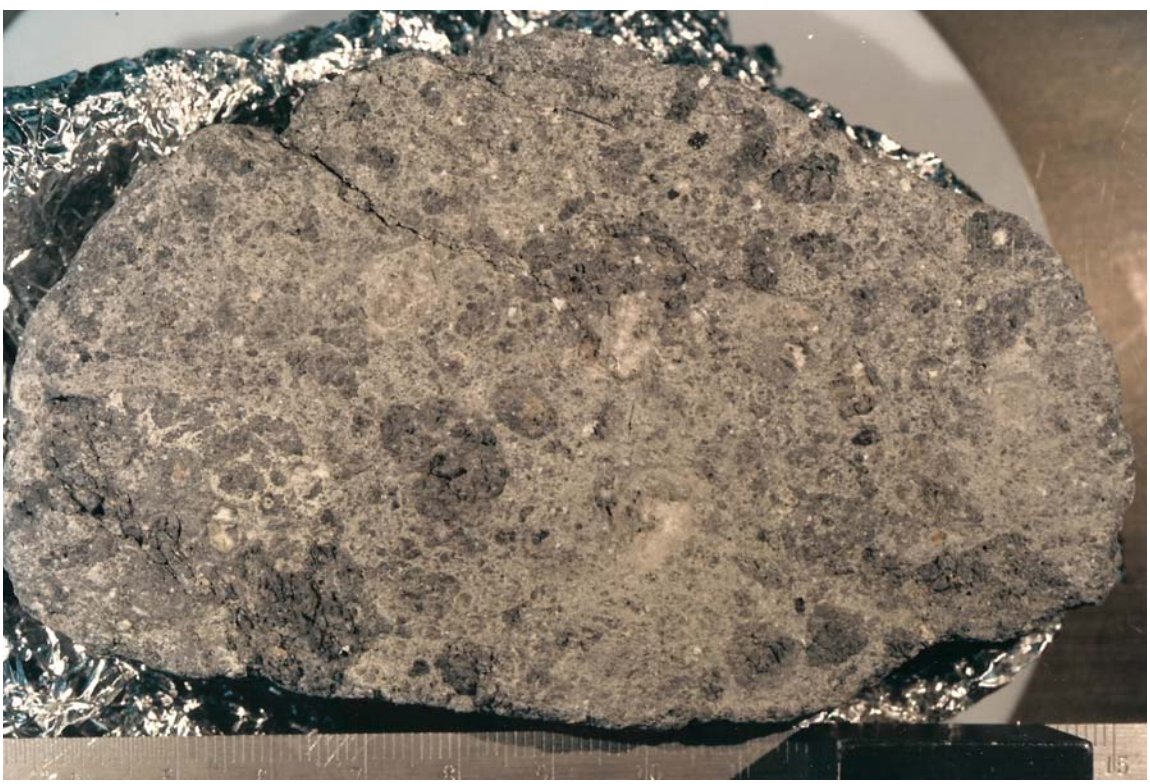

Figure 19: Interior surface of 14305,459. Scale is in cm. no number

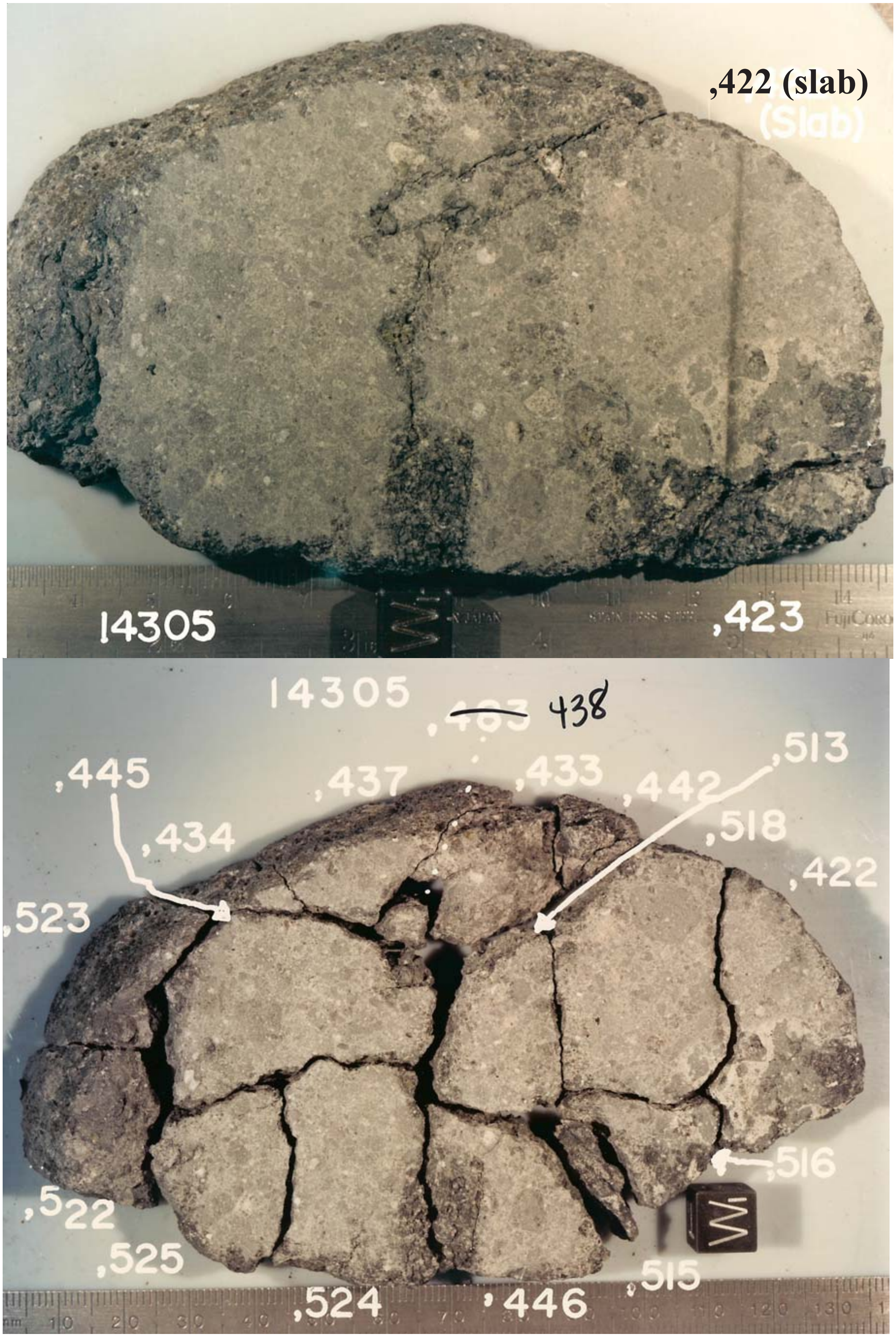

Figure 20: Photos of slab 14305,422 before and after processing. Cube is 1 cm. NASA S85-38255 and S87-29851.

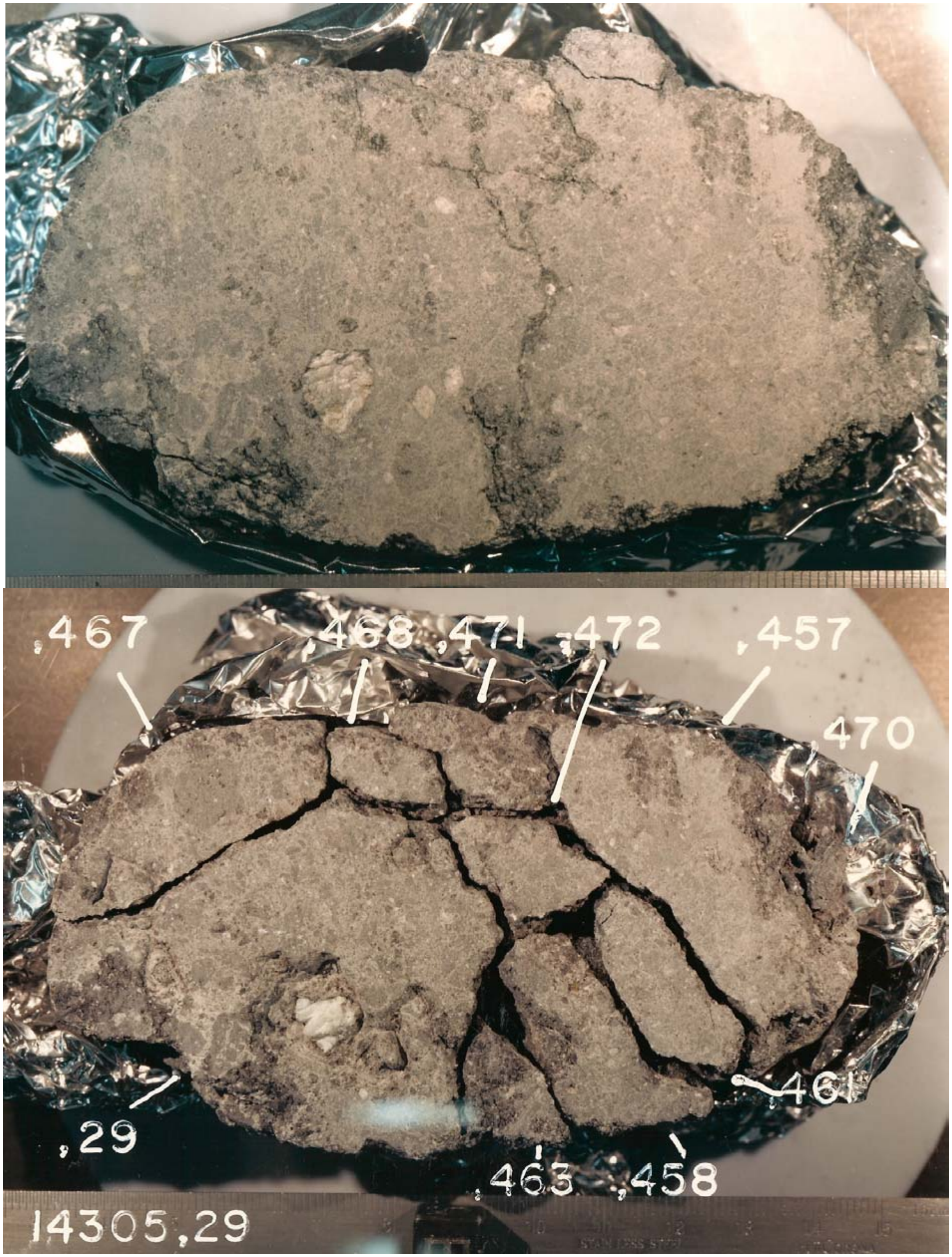

Figure 21: Photo of end piece 14305,29 showing processing chips. Scale is 1 cm. NASA S85-38259 and 39002.

Figure 22: Sawn surface of slab 14305,483. Cube is 1 cm. NASA photo S86-25842.

Figure 23: Sawn surface of 14305,27 (end piece). Scale bar in cm. NASA S86-25845.

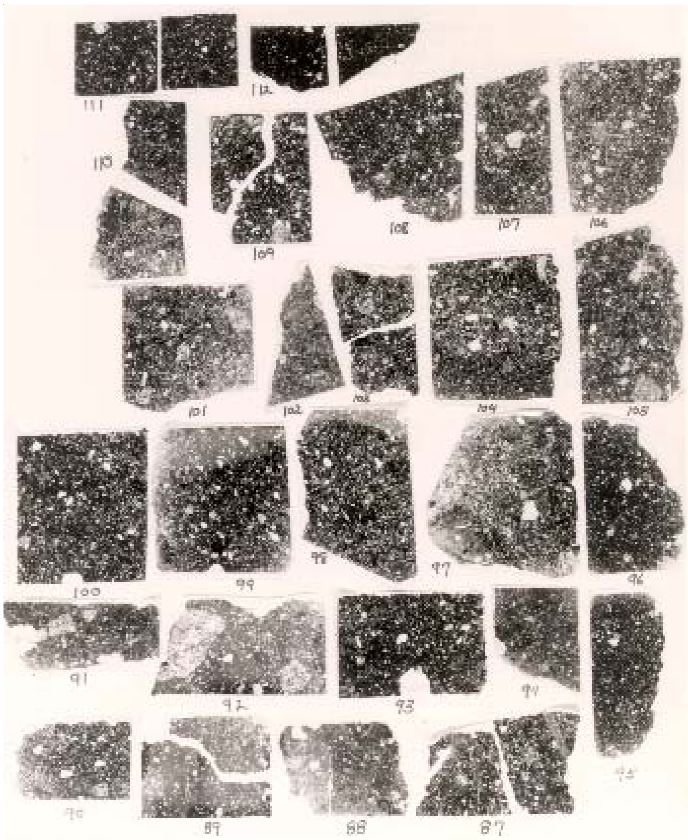

Figure 24: Numerous thin section of 14305. Note the large basalt clast in ,92. Each section is about 2 cm across.

Partial List of	**Photo #s for 14305**
S71-31391-9	color mug shots
S75-33045	,29 sawn surface
S85-39002	,29 processing
S77-21470-3	,30
S77-21474-5	,18
S77-21476	,27 sawn surface
S83-34589	
S85-38259	,29 end
S85-38255	,422 slab
S86-25842	,483 slab
S86-25845	,27 end
S86-30442	,290 slab
S87-29851	,438 slab

Clast correlations for 14305

	from	size mm	analyses	duplicate	thin section	age	authors
c1	,18	7 x 5	,264		,268		Warren 80
c2		6 x 5	,283	,303			Warren 83
c3	,27	7 x 6	,279	,301			Warren 83
w1	,29	8 x 3			,394		Shervais 84
w3	,29	2 x 1.5			,396		Shervais 84
w6	,27	9 x 5	,358	,317	,377 ,347		Shervais 83, 84
w7	,27	6 x 4	,361	,322	,362 ,320		Shervais 83, 84
,400	,51	10 x 5	,400		,412		Shervais 84
M1	,29E	4 x 3	,389		,405		Shervais 84
,122	,92				,92		Taylor 83
M1	,18		,304	,370	,343 ,344	,371	Shervais 85, Shih 85
M2	,18		,385	,384	,383		Shervais 85
M3	,18		,382		,388		Shervais 85
M11	,27		,373		,380		Shervais 85
,390			,390		,393		Shervais 85
,367			,367				Shervais 85

References for 14305

Ari T., Takeda H., Miyamoto M. and Kojima H. (2006) Apollo 14 oldest mare basalt revisted: Possible petrogenetic connection between mg gabbronorite and VHK basalt (abs#2387). Lunar Planet. Sci. XXXVII Lunar Planetary Institute, Houston.

Ari T., Kaiden H., Misawa K. and Kojima H. (2006) Ion microprobe study of Apollo 14 oldest basalt (abs). Antarctic Meteorites XXX, 3-4.

Carlson I.C. and Walton W.J.A. (1978) **Apollo 14 Rock Samples**. Curators Office. JSC 14240

Chao E.C.T., Minkin J.A. and Best J.B. (1972) Apollo 14 breccias: General characteristics and classification. Proc. 3rd Lunar Sci. Conf. 645-659.

Cisowski S.M., Collinson D.W., Runcom S.K., Stephenson A. and Fuller M. (1983) A review of lunar paleointensity data and implications for the origin of lunar magnetism. Proc. 13th Lunar Planet. Sci. Conf. A691-A704.

Collinson D.W., Runcorn S.K., Stephenson A. and Manson A.J. (1972) Magnetic properties of Apollo 14 rocks and fines. Proc. 3rd Lunar Sci. Conf. 2343-2361.

Dence M.R. and Plant A.G. (1972) Analysis of Fra Mauro samples and the origin of the Imbrium Basin. Proc. 3rd Lunar Sci. Conf. 379-399.

Dran J.C., Duraud J.P., Maurette M., Durrieu L., Jouret C. and Legressus C. (1972) Track metamorphism in extraterrestrial breccias. Proc. 3rd Lunar Sci. Conf. 2883-2903.

Eugster O., Eberhardt P., Geiss J., Grogler N., Jungck M., Meier F., Morgell M. and Niederer F. (1984a) Cosmic ray exposure histories of Apollo 14, Apollo 15 and Apollo 16 rocks. Proc. 14th Lunar Planet. Sci. Conf. in J. Geophys. Res. 89, B498-B512.

Fields P.R., Diamond H., Metta D.N., Rokop D.J. and Stevens C.M. (1972) 237Np, 236U and other actinides on the moon. Proc. 3rd Lunar Sci. Conf. 1637-1644.

Gault D.E., Horz F. and Hartung J.B. (1972) Effects of microcratering on the lunar surface. Proc. 3rd Lunar Sci. Conf. 2713-2734.

Goel P.S. and Kothari B.K. (1972) Total nitrogen contents of some Apollo 14 lunar samples by neutron activation analysis. Proc. 3rd Lunar Sci. Conf. 2041-2050.

Herpers U., Herr W., Kulus H., Michel R., Thiel K and Woelfle R. (1973) Manganese-53 profile, partlicle track studies and rhenium187 isotopic anomoly of breccia 14305. Proc. 4th Lunar Sci. Conf. 2157-2169.

Herr W., Herpers U. and Woelfle R. (1972) Study on the cosmic ray produced long-lived Mn53 in Apollo 14 samples. Proc. 3rd Lunar Sci. Conf. 1763-1769.

Hughes T.C., Keays R.R. and Lovering J.F. (1973) Siderophile and volatile trace elements in Apollo 14, 15 and 16 rocks and fines: Evidence for extralunar component and Tl-, Au- and Ag-enriched rocks in the ancient lunar crust. (abs) LS IV, 400-402.

Hunter R.H. and Taylor L.A. (1983) The magma ocean from the Fra Mauro shoreline: An overview of the Apollo 14 crust. Proc. 13th Lunar Planet. Sci. Conf. in J. Geophys. Res. 88, A591-A602.

Jovanovic S. and Reed G.W. (1976a) Chemical fractionation of Ru and Os in the Moon. Proc. 7th Lunar Sci. Conf. 3437-3446.

Jovanovic S. and Reed G.W. (1977) Trace element geochemistry and the early lunar differentiation. Proc. 8th Lunar Sci. Conf. 623-632.

Juan V.C., Chen J.C., Huang C.K., Chen P.Y. and Wang Lee C.M. (1972) Petrology and chemistry of some Apollo 14 lunar samples. Proc. 3rd Lunar Sci. Conf. 687-705.

Keith J.E., Clark R.S. and Richardson K.A. (1972) Gamma-ray measurements of Apollo 12, 14 and 15 lunar samples. Proc. 3rd Lunar Sci. Conf. 1671-1680.

Klein C. and Drake J.C. (1972) Mineralogy, peterolgy and surface features of some fragmental material from the Fra Mauro site. Proc. 3rd Lunar Sci. Conf. 1095-1113.

Lindstrom M.M., Knapp S.A., Shervais J.W. and Taylor L.A. (1984) Magnesian anorthosites and associated troctolites and dunite in Apollo 14 breccias. Proc. 15th Lunar Planet. Sci. Conf. in J. Geophys. Res. 89, C41-C49.

Lovering J.F., Wark D.A., Geadow A.J.W. and Sewell D.K.B. (1972) Uranium and potassium fractionation in pre-Imbrian lunar crstral rocks. Proc. 3rd Lunar Sci. Conf. 281-294.

LSPET (1971) Preliminary examination of lunar samples from Apollo 14. Science 173, 681-693.

Meyer C., Galindo C. and Yang V. (1991) Lunar Zircon (abs). Lunar Planet. Sci. XXII, 895-896. Lunar Planetary Institute, Houston.

Meyer C., Williams I.S. and Compston W. (1989) $^{207}Pb/^{206}Pb$ ages of zircon-containing rock fragments indicate continuous magrnatism in the lunar crust from 4350 to 3900 million years (abs). Lunar Planet. Sci. XX, 691-692. Lunar Planetary Institute, Houston.

Meyer C., Williams I.S. and Compston W. (1989) Zircon-containing rock fragments within Apollo 14 breccias indicate serial magmatism from 4350 to 4000 million years (abs). *In* Workshop on Moon in Transition: Apollo 14, KREEP, and evolved lunar rocks. LPI Tech Rpt. 89-03, 75-78. Lunar Planetary Institute, Houston.

Moore C.B., Lewis C.F., Cripe J., Delles F.M., Kelly W.R. and Gibson E.K. (1972) Total carbon, nitrogen and sulfur in Apollo 14 lunar samples. Proc. 3rd Lunar Sci. Conf. 2051-2058.

Morrison D.A., McKay D.S., Heiken G.H. and Moore H.J. (1972) Microcraters on lunar rocks. Proc. 3rd Lunar Sci. Conf. 2767-2791.

Nemchin A.A., Pidgeon R.T., Whitehouse M.J., Vaughan J.P. and Meyer C. (2008) SIMS study of zircons from Apollo 14 and 17 breccias: Implications for the evolution of lunar KREEP. Geochim. Cosmochim. Acta 72, 668-689.

Palme H., Baddenhausen H., Blum K., Cendales M., Dreibus G., Hofmeister H., Kmse H., Palme C., Spettel B. Vilcsek E. and Wanke H. (1978) New data on lunar samples and achondrites and a comparison of the least fractionated samples from the earth, the moon, and the eucrite parent body. Proc. 9th Lunar Planet. Sci. Conf. 25-57.

Philpotts J.A., Schnetzler C.C ., Nava D.F., Bottino M.L., Fullagar P.D., Thomas H.H., Schumann S. and Kouns C.W. (1972) Apollo 14: Some geochemical aspects. Proc. 3rd Lunar Sci. Conf. 1293-1305.

Reed G.W., Jovanovic S. and Fuchs L. (1973) Trace element relations between Apollo 14 and 15 and other lunar samples, and the implications of a moon-wide Cl-KREE coherence and Pt-metal coherence. Proc. 3rd Lunar Sci. Conf. 1989-2001.

Shervais J.W. and Taylor L.A. (1983) Breccia Guidebook No. 5 14305. JSC 19267 Curators' office.

Shervais J.W., Taylor L.A. and Laul J.C. (1983) Ancient crustal components in the Fra Mauro breccias. Proc. 14th Lunar Planet. Sci. Conf. *in* J. Geophys. Res. 88, 77-92.

Shervais J.W., Taylor L.A., Laul J.C. and Smith M.R.. (1985a) Pristine highland clasts in consortium breccia 14305: Petrology and Geochemistry. Proc. 15th Lunar Planet. Sci. Conf. *in* J. Geophys. Res. 89, C25-40.

Shervais J.W., Taylor L.A., Laul J.C., Shih C.-Y. and Nyquist L.E. (1985) Very high potassium (VHK) basalt: Complications in lunar mare petrogenesis. Proc. 16th Lunar Planet. Sci. Conf. in J. Geophys. Res. 90, D3-D18.

Shih C.-Y., Nyquist L.E., Bogard D.D., Bansal B.M., Wiesmann H., Johnson P., Shervais J.W. and Taylor L.A. (1986) Geochronology and petrogenesis of Apollo 14 very high potassium mare basalts. Proc. Lunar Planet. Sci. Conf. 16th in J. Geophys. Res. 91, D214-D228.

Simonds C.H., Phinney W.C., Warner J.L., McGee P.E., Geeslin J., Brown R.W. and Rhodes J.M. (1977) Apollo 14 revisited, or breccias aren't so bad after all. Proc. 8th Lunar Sci. Conf. 1869-1893.

Sutton R.L., Hait M.H. and Swann G.A. (1972) Geology of the Apollo 14 landing site. Proc. 3rd Lunar Sci. Conf. 27-38.

Swann G.A., Trask N.J., Hait M.H. and Sutton R.L. (1971a) Geologic setting of the Apollo 14 samples. Science 173, 716-719.

Swann G.A., Bailey N.G., Batson R.M., Eggleton R.E., Hait M.H., Holt H.E., Larson K.B., Reed V.S., Schaber G.G., Sutton R.L., Trask N.J., Ulrich G.E. and Wilshire H.G. (1977) Geology of the Apollo 14 landing site in the Fra Mauro Highlands. U.S.G.S. Prof. Paper 880.

Swann G.A., Bailey N.G., Batson R.M., Eggleton R.E., Hait M.H., Holt H.E., Larson K.B., McEwen M.C., Mitchell E.D., Schaber G.G., Schafer J.P., Shepard A.B., Sutton R.L., Trask N.J., Ulrich G.E., Wilshire H.G. and Wolfe E.W. (1972) 3. Preliminary Geologic Investigation of the Apollo 14 landing site. *In* Apollo 14 Preliminary Science Rpt. NASA SP-272. pages 39-85.

Taylor D.J., McKeegan K.D., Harrison T.M. and McCulloch M. (2007) 176Lu/176Hf in lunar zircons: Identification of an early enriched resevoir on the moon (abs#2130). Lunar Planet. Sci. XXXVIII Lunar Planetary Institute, Houston.

Taylor L.A., Shervais J.W., Hunter R.H., Shih C.-Y., Nyquist L.E., Bansal B.M., Wooden J. and Laul J.C. (1983) Pre-4.2 AE mare-basalt volcanism in the lunar highlands. Earth Planet. Sci. Lett. 66, 33-47.

Twedell D., Feight S., Carlson I. and Meyer C. (1978) Lithologic maps of selected Apollo 14 breccia samples. Curators Office. JSC 13842

Wänke H., Baddenhausen H., Balacescu A., Teschke F., Spettel B., Dreibus G., Palme H., Quijano-Rico M., Kruse H., Wlotzka F. and Begemann F. (1972) Multielement analysis of lunar samples and some implications of the results. Proc. 3rd Lunar Sci. Conf. 1251-1268.

Warner J.L. (1972) Metamophism of Apollo 14 breccias. Proc. 3rd Lunar Sci. Conf. 623-643.

Warren P.H. and Wasson J.T. (1980a) Further foraging of pristine nonmare rocks: Correlations between geochemistry and longitude. Proc. 11th Lunar Planet. Sci. Conf. 431-470.

Warren P.H., Taylor G.J., Keil K., Kallemeyn G.W., Shirley D. and Wasson J.T. (1983d) Seventh foray: Whitlockite-rich lithologies, a diopside-bearing troctolitic anorthosite, ferroan anorthosite and KREEP. Proc. 14th Lunar Planet. Sci. Conf. in J. Geophys. Res. 88, B151-B164.

Warren P.H. (1993) A concise compilation of petrologic information on possibly pristine nonmare Moon rocks. Am. Mineral. 78, 360-376.

Willis J.P., Erlank A.J., Gurney J.J., Theil R.H. and Ahrens L.H. (1972) Major, minor, and trace element data for some Apollo 11, 12, 14 and 15 samples. Proc. 3rd Lunar Sci. Conf. 1269-1273.

Williams R.J. (1972) The lithification of metamorphism of lunar breccias. Earth Planet. Sci. Lett. 16, 250-256.

Wilshire H.G. and Jackson E.D. (1972) Petrology and stratigraphy of the Fra Mauro Formation at the Apollo 14 site. U.S. Geol. Survey Prof. Paper 785.

Wlotzka F., Jagoutz E., Spettle B., Baddenhausen H., Balacescu A. and Wanke H. (1972) On lunar metallic particles and their contribution to the trace element content of Apollo 14 and 15 soils. Proc. 3rd Lunar Sci. Conf. 1077-1084.

Wlotzka F., Spettel B. and Wanke H. (1973) On the compositon of metal from Apollo 16 fines and the meteoritic component. Proc. 4th Lunar Sci. Conf. 1483-1491.