15465 GLASS WITH REGOLITH BRECCIA CLASTS ST. 7 376.0 g

INTRODUCTION: 15465 consists of a vesicular dark glass enclosing several pieces of regolith breccias (Figs. 1, 2), although most studies have referred to it as a glass-coated regolith breccia. The sample was first studied in a Consortium led by Haskin; the Consortium sample was ,7 which was mainly a large piece of a dominant regolith breccia clast (Fig. 2). The glass (hence rock formation age) is about 1.1 b.y. old (Husain, 1972). At least one individual clast is a chemically pristine highlands igneous fragment.

15465 is blocky and angular, and tough with delicate protrusions. The glass is a dark greenish-gray; the breccias are medium light gray. The surface is rough and hackly, and one block of breccia has many zap pits on one side, but the glass has no zap pits. 15465 was collected with 15466 just inside the north-northwest rim of Spur Crater.

PETROLOGY: 15465 has two dominant components: vesicular glass, and regolith breccias (Figs. 3a, b). The glass appears to be the dominant component and engulfs the fragments of regolith breccias (Fig. 1), although the relationship has been frequently referred to as glass coating a breccia, including the Lunar Sample Information Catalog Apollo 15 (1971). Most petrographic reports (Delano, 1972; Cameron and Delano, 1973; Winzer, 1978) are of regolith breccia fragments.

The vesicular glass is greenish and has large clear patches (Fig. 3a). Faint flow-banding is present. The glass engulfs regolith breccias in varied stages of disaggregation; small fragments of breccia are well-disaggregated. Winzer et al. (1978) included 15465 in a study of glass coats on Apollo 15 breccias, but reported no data.

The regolith breccias are not identical, but there is a preponderance of porous breccias with prominent KREEP basalt fragments and yellow glass spheres along with their contingent of other glass, mineral, and lithic fragments. Delano (1972) and Cameron and Delano (1973) studied and analyzed 23 one-to-five millimeter chips from the Haskin Consortium sample ,7 (Fig. 2), which are brown glass matrix breccias (regolith breccias) and vesicular dark green glass described as splash glass. The breccias contain 5-10% rock fragments, 5-10% glass spheres and shards, 60-70% plagioclase fragments, 10-20% low-Ca pyroxene, and 5% high-Ca pyroxene. The matrices are composed of fine particles of brown glass. Of the rock fragments, 42.5% were KREEP basalts, with subophitic textures (referred to by Delano, 1972, as highland basalt) and a mineralogy like other KREEP basalts (Fig. 4). Recrystallized norites (with 19-26% Al_2O_3) composed 25% of the samples, mare basalts (many similar to 15555) composed 20% of the sample, and other lithologies (such as anorthosite, recrystallized polymict breccias, and shocked-igneous fragments) composed the remainder. Delano (1972) observed two types of mare basalt, one with poikilitic plagioclase, the other with porphyritic pyroxenes (remarkably, thin sections from other chips of the rock appear to lack mare basalt fragments). The

recrystallized norites have more calcic pyroxenes than the KREEP basalts (Fig. 4). Winzer (1978) described and analyzed several and varied lithic clasts in regolith breccia fragments, including apparent KREEP basalt fragments (clasts 8 and 9), impact melt, and one fragment of a poikilitic cristobalite enclosing small ilmenites. McKay et al. (1974) found the I_s/FeO ratio of a regolith breccia to be only 12, indicating a very immature regolith.

Colorless, green, yellow, and rarely red/orange glass are present in 15465 regolith breccia fragments, and in some the proportion of yellow glass is high compared with many other regolith breccias. Delano (1972) found two groups of glass--emerald green similar to other Apollo 15 green glasses, and a high-K glass, which appears to be the host glass of the sample. Winzer (1978) mentions a green glass in 15465 with euhedral to subhedral crystals of olivine (Fo_{76}), which appears to have crystallized slowly.

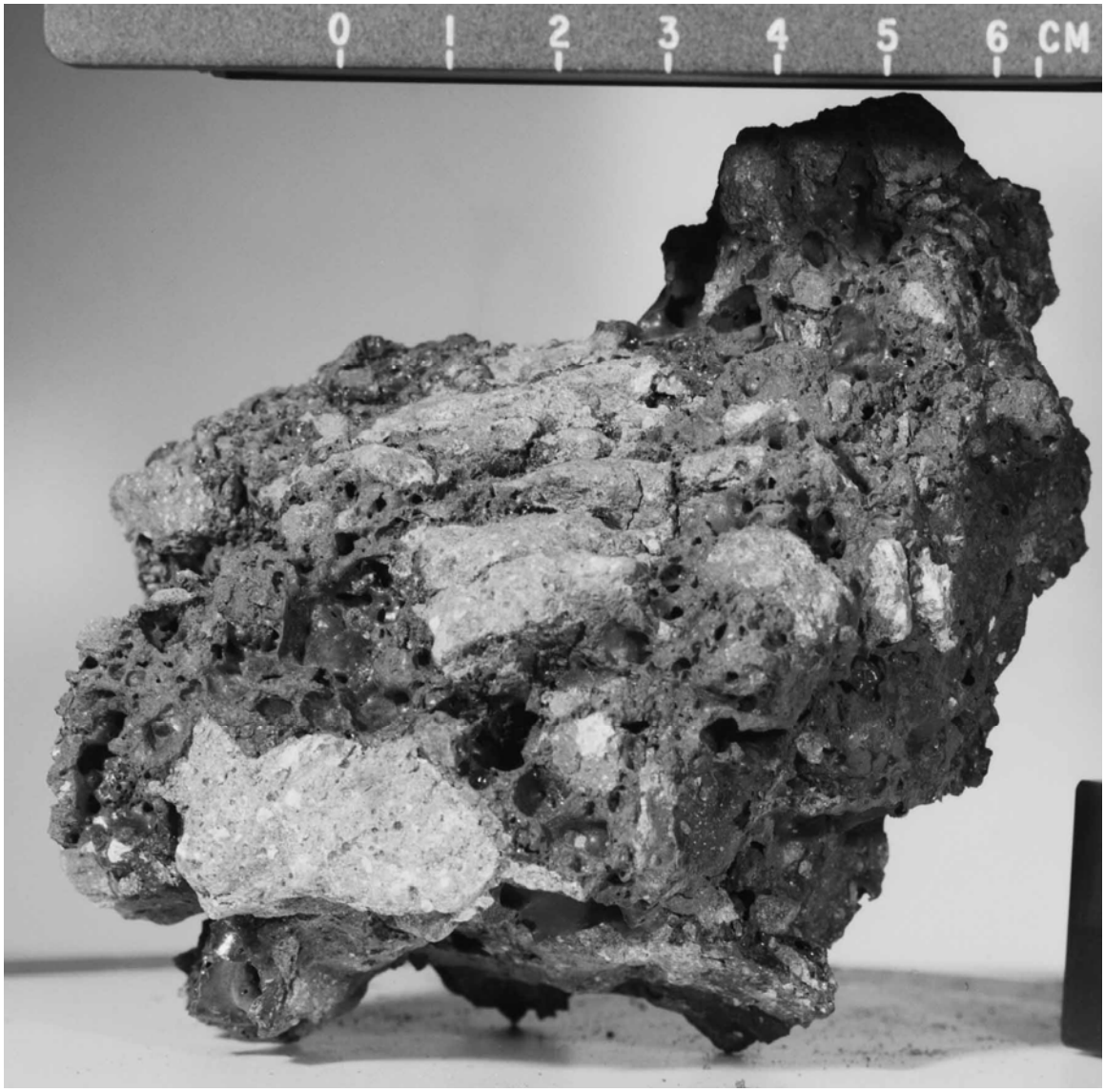


Figure 1. Pre-split view of heterogeneous sample 15465. S-71-46427

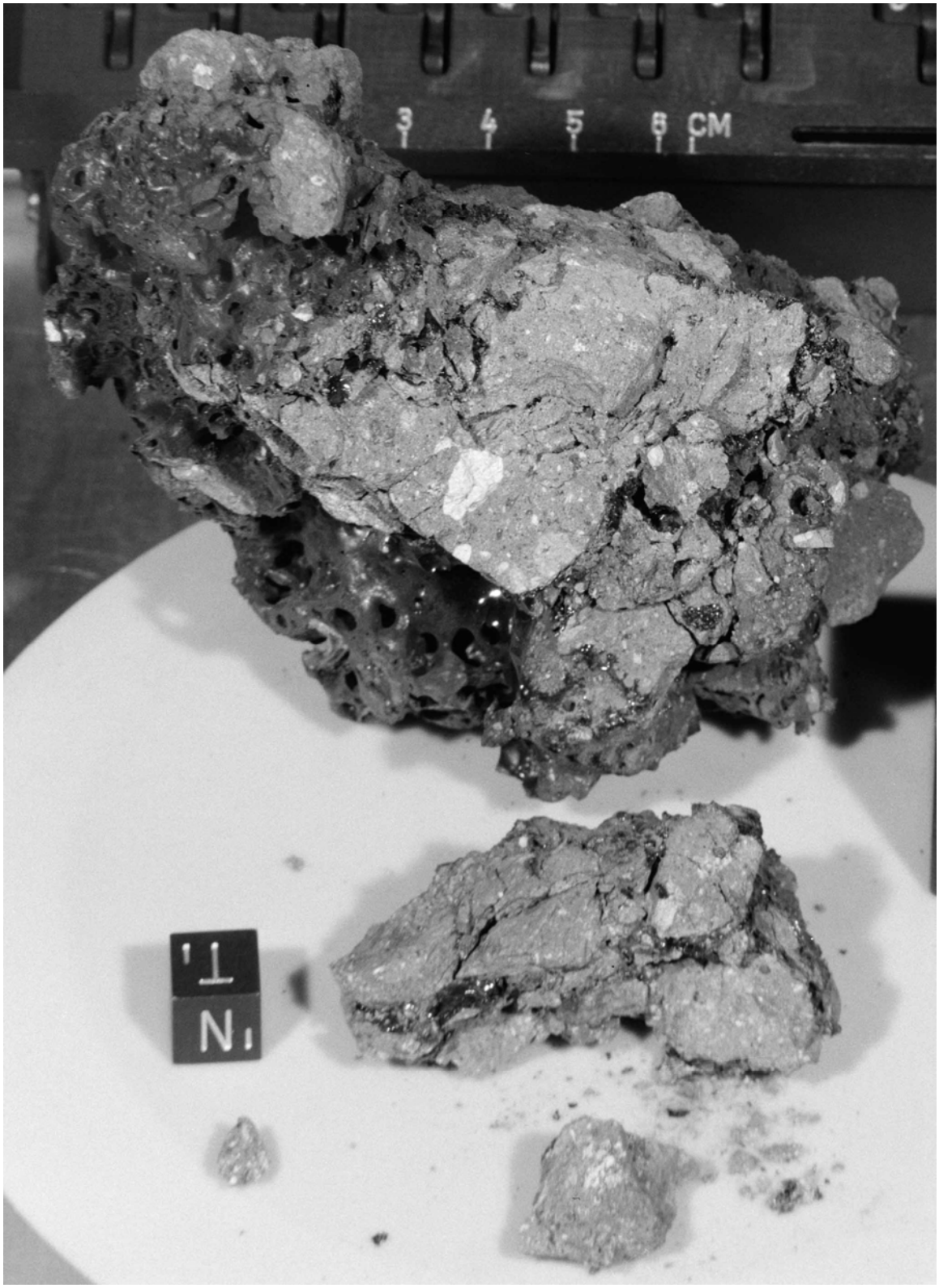


Figure 2. Post-split view, showing ,7 in foreground. S-71-60707

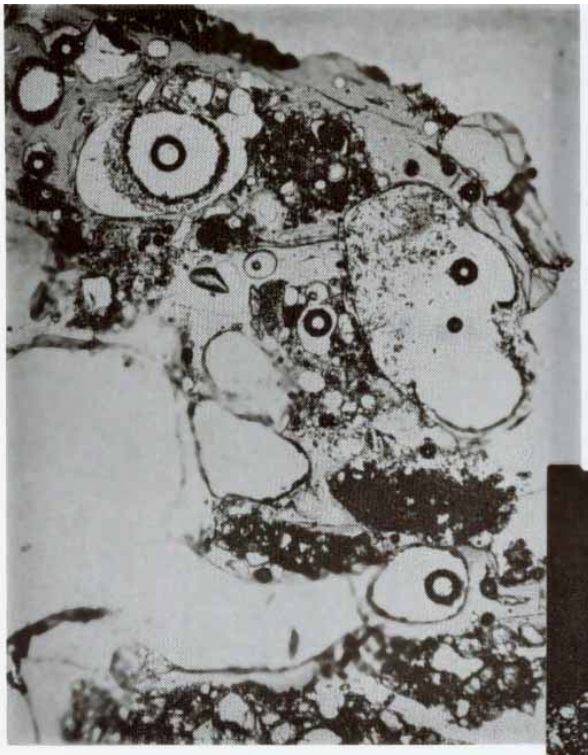


Fig. 3a

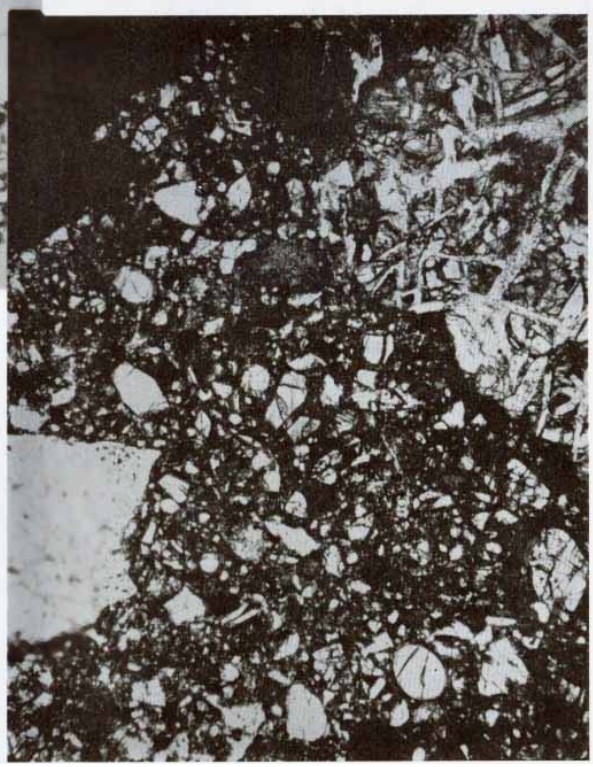


Fig. 3b

Figure 3. Photomicrographs of 15465.
a) ,28, vesicular glass with small regolith breccia clasts.
Transmitted light, width about 2 mm.
b) ,28, regolith breccia fragment, showing dark glass fragment (upper left),
KREEP basalt with conspicuous yellow/orange mesostasis (upper right),
and glass spheres, etc. Transmitted light. Width about 2 mm.
c) ,63 Clast ,59c of Warren and Wasson (1978) with two mafic grains
(white, fractured) and plagioclase. Partly crossed polarizers. Widths about 800 microns,
d) ,28, white cataclastic fragment, with some mafic grains (whitest).
Transmitted light. Width about 2 mm.

Fig. 3c

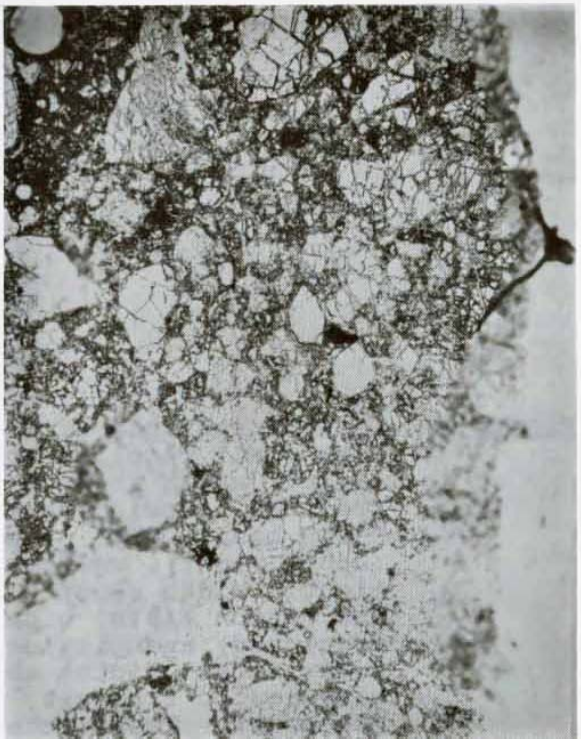


Fig. 3d

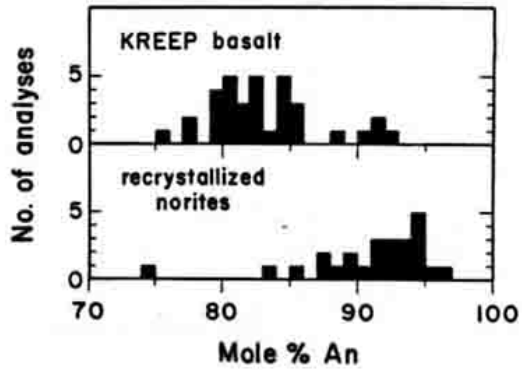
Warren and Wasson (1978) described an anorthosite (,56c) which is pristine, but no thin sections are known to exist. A second clast ,59c, was described macroscopically as "plag-rich...cataclastic gabbro with original texture still intact" (Lunar Sample Information Catalog Apollo 15, 1972). Thin sections show it to be a cataclastic norite (Fig. 2c), rather fine-grained, without obvious relics or clasts. It has 65% plagioclase (An_{94-95}) and 30% unexsolved orthopyroxene (En_{79-82}, $Wo_{2.4-3.7}$), 1-2% of a silica mineral, about 1% Ca-pyroxene, traces of rutile, and spinel. The sample may be pristine (Warren and Wasson, 1978). Another white clast in ,13 (e.g., thin sections ,28, Fig. 2d) is identified in the 15465 Data Pack as being the ,56c of Warren and Wasson (1978), but ,56c was apparently enclosed in glass; the white clast in ,28 (etc.) is enclosed in regolith breccia. This clast however is a plagioclase-rich, fine-grained highlands lithology, containing some mafic mineral grains.

Drever et al. (1973) studied radiate texture in a clast in 15465,29, but provided no information.

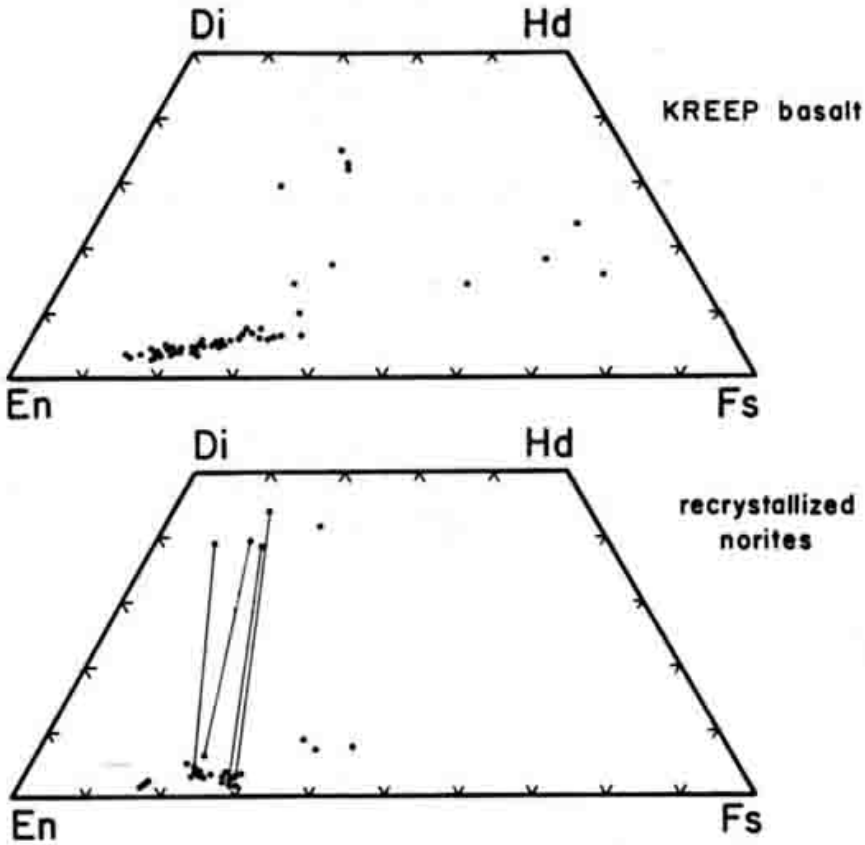
CHEMISTRY: Analyses of glass and bulk rock, of regolith breccias, and of clasts other than regolith breccias are listed in Table 1 to 3 respectively, and rare earth elements plotted in Figures 5 to 7, respectively. The glass and the regolith breccias are fairly similar in major elements, suggesting that the breccias were formed in a regolith from which the glass was also later made by impact. However, some of the regolith breccia analyses have higher rare earth element abundances. Analyses by Ehmann et al. (1975), Ali et al. (1976) and Stroube et al. (1977) have differences, albeit small, even though from the same splits and the same lab. Ali et al. (1976) had suggested that the glass and the breccia were different, for instance Cl was enriched in the glass. However, according to Stroube et al. (1977) that conclusion was erroneous and based on preliminary data for Cr and Ca. Jovanovic and Reed (1976, 1977) made some of their elemental analyses on leaches and residues; these are combined as a single bulk analysis in the tables. The Moore et al. (1973) carbon value of 45 ppm for a regolith breccia sample is higher than basalts, but not as high as most fines (regolith) samples.

Warren and Wasson (1978) determined, mainly on the basis of incompatible and siderophile elements (Table 3), that clast ,56c, an anorthositic fragment, was a pristine igneous lithology, and that ,59c, a more noritic fragment, might have been a pristine igneous sample. However, the latter had rare earths with the KREEP pattern, and the high siderophiles were not easily explicable as merely matrix contamination.

STABLE ISOTOPES: Clayton et al. (1973) determined δO^{18} TM (°/oo) of 5.66 for whole rock (= regolith breccia?), 5.80 for glass, and 5.69 for a plagioclase, in separates from ,7, the Consortium sample. These values are not unusual for lunar samples.



Plagioclase compositions from fifteen KREEP basalt fragments and nine recrystallized noritic fragments in 15465,7. No more than three analyses from any one rock fragment.



Pyroxene compositions from fifteen KREEP basalt fragments and nine recrystallized noritic fragments in 15465,7. Compositions are plotted in terms of mole proportions of Ca, Mg, and Fe. No more than four analyses from any one rock fragment. Tielines connect coexisting Ca-rich and Ca-poor pyroxenes in four recrystallized noritic fragments.

Figure 4. Compositions of minerals in KREEP basalt and recrystallized norite clast (Cameron and Delano, 1973).

TABLE 15465-1. Chemical analyses of glass and bulk rock of 15465.

		,16(a)	,16	,16	,15	,15	,15	,46	,47	,47	,7.3	,0
Wt %	SiO2										47.4	
	TiO2	1.1	1.1		1.1	1.1	1.4				1.40	
	Al2O3	17.8	17.8		15.1	14.9	15.9				17.0	
	FeO	12.9	11.5	11.5	11.9						11.4	
	MgO				10.2	10.0	11.1				10.5	
	CaO	6.9	10.4		10.2	10.3	11.5				12.1	
	Na2O	0.49	0.49	0.49	0.44						0.39	
	K2O			0.25	0.19						0.28	0.281
	P2O5											
(ppm)	Sc		23	22	22							
	V	54	53		71	77	78					
	Cr	2530(b)	2000	2300	2300							
	Mn	1200	1200		1300	1230	1320					
	Co	45	40									
	Ni											
	Rb											
	Sr											
	Y											
	Zr											
	Nb											
	Hf		8.3									
	Ba			280	220							
	Th		6.6									5.9
	U											1.46
	Pb											
	La			27	23							
	Ce											
	Pr											
	Nd											
	Sm			12	12							
	Eu		1.4	1.3	1.3							
	Tb											
	Dy											
	Ho											
	Er											
	Tm											
	Yb	9.8		7.2	6.8							
	Lu				1.08							
	Li											
	Be											
	B											
	C											
	N											
	S											
	F								>48, <53			
	Cl	146										
	Br											
	Cu											
	Zn										5.77	
(ppb)	I											
	At											
	Ga											
	Ge											
	As											
	Se											
	Mo											
	Tc											
	Ru							11				
	Rh											
	Pd											
	Ag											
	Cd											
	In											
	Sn											
	Sb											
	Te											
	Cs											
	Ta											
	W											
	Re											
	Os							13				
	Ir											
	Pt											
	Au											
	Hg											
	Tl										4.3	
	Bi											
		(1)	(2)	(2)	(2)	(2)	(2)	(3)	(4)	(5)	(6)	(7)

References and methods:

(1) Ali et al. (1976); INAA
(2) Stroube et al. (1977); INAA
(3) Jovanovic and Reed (1976); INAA
(4) Jovanovic and Reed (1977); INAA
(5) Reed et al. (1977); INAA
(6) Cameron and Delano (1973); microprobe
(7) Keith et al. (1972); gamma ray spectroscopy

Notes:

(a) apparently superseded by Stroube et al. (1977) in next column
(b) incorrectly reported as 2.534

TABLE 15465-2. Chemical analyses of regolith breccia clasts in 15465.

		,89	,16	,16(c)	,7	,11	,15	,16(c)	,47	,47	,47
Wt %	SiO2		48.6								
	TiO2			1.22	1.38		0.99	1.22			
	Al2O3		16.3	15.0	16.3		15.9	15.0			
	FeO	11.7	11.6	10.2	11.2		11.7	11.1			
	MgO		19.1(a)		10.1		10.5				
	CaO	10.5	<6	10.4	10.9		11.6	10.6			
	Na2O	0.61	0.57	0.58	0.57		0.467	0.58			
	K2O						0.204				
	P2O5										
(ppm)	Sc	22.9		20	24.6		22				
	V			66			69	66			
	Cr	2280		1700	2690		2200	2090(b)			
	Mn		1250	1320	1200		1260	1300			
	Co	30			33.7		39	34			
	Ni	106			108						
	Rb										
	Sr	140			120						
	Y										
	Zr	530									
	Nb										
	Hf	14.8		10.8	14.8						
	Ba	417			450		220				
	Th	6.3									
	U	1.76									
	Pb										
	La	40.4			38.2		23				
	Ce	106			90						
	Pr										
	Nd	61			62						
	Sm	18.5			17.7		12				
	Eu	1.80		1.4	1.75		1.2				
	Gd										
	Tb	3.70			3.59						
	Dy										
	Ho										
	Er										
	Tm										
	Yb	12.6		11.4	12.0		6.8	11.4			
	Lu	1.76			1.72		1.05				
	Li										
	Be										
	B										
	C					45					
	N										
	S										
	F									41.8	
	Cl							76			
	Br										
	Cu										
	Zn										14
(ppb)	I										
	At										
	Ga										
	Ge										
	As										
	Se										
	Mo										
	Tc										
	Ru								3.7		
	Rh										
	Pd										
	Ag										
	Cd										
	In										
	Sn										
	Sb										
	Te										
	Cs	380			380						
	Ta	1680									
	W										
	Re										
	Os								6.6		
	Ir	2.7									
	Pt										
	Au	1.2									
	Hg										
	Tl										2.99
	Bi										
		(1)	(2)	(3)	(4)	(5)	(6)	(3)	(7)	(8)	(9)

References and methods:

(1) Korotev (1984 unpublished); INAA
(2) Ehmann et al. (1975); INAA
(3) Stroube et al. (1977); INAA
(4) Blanchard (1973 unpublished); INAA
(5) Moore et al. (1973); combustion, gas chromotography
(6) Ali et al. (1976); INAA
(7) Jovanovic and Reed (1976); INAA
(8) Jovanovic and Reed (1977); INAA
(9) Reed et al. (1977); INAA

Notes:

(a) unrealistically high
(b) listed erroneously as 2.09%
(c) probably revisions of a single analysis

TABLE 15465-3. Chemical analyses of non-regolith breccia clasts in 15465.

		,56	,59
Wt %	SiO2	44.3	48.8
	TiO2	0.27	0.32
	Al2O3	34.0	21.9
	FeO	1.5	5.2
	MgO	0.83	10.54
	CaO	19.3	13.3
	Na2O	0.342	0.350
	K2O	0.022	0.097
	P2O5		
(ppm)	Sc	1.9	9.9
	V		
	Cr		1740
	Mn	110	59
	Co	7.5	15.5
	Ni	<4	110
	Rb		
	Sr		
	Y		
	Zr		
	Nb		
	Hf		2.4
	Ba		110
	Th		1.23
	U		0.35
	Pb		
	La	0.61	7.3
	Ce		21
	Pr		
	Nd		
	Sm	0.26	3.04
	Eu	0.8	0.99
	Gd		
	Tb		0.71
	Dy		
	Ho		
	Er		
	Tm		
	Yb		2.4
	Lu		0.36
	Li		
	Be		
	B		
	C		
	N		
	S		
	F		
	Cl		
	Br		
	Cu		
	Zn	0.98	10.2
(ppb)	I		
	At		
	Ga	4050	5710
	Ge	53	80
	As		
	Se		
	Mo		
	Tc		
	Ru		
	Rh		
	Pd		
	Ag		
	Cd	3.8	62
	In	0.34	<40
	Sn		
	Sb		
	Te		
	Cs		
	Ta		220
	W		
	Re		1.2
	Os		
	Ir	0.090	5.9
	Pt		
	Au	0.056	0.76
	Hg		
	Tl		
	Bi		
		(1)	(1)

References and methods:

(1) Warren and Wasson (1978); INAA

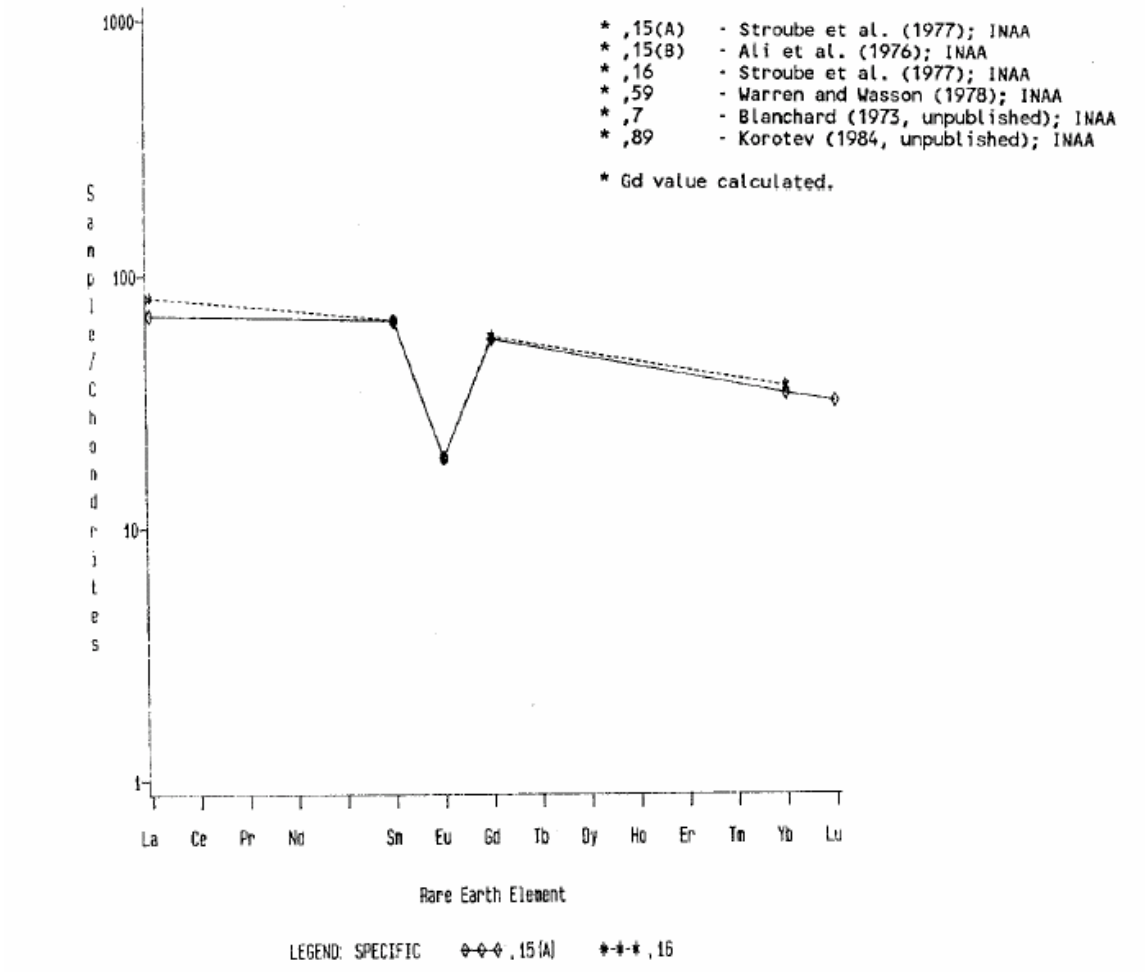


Figure 5. Rare earths in vesicular glass in 15465.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Husain (1973) derived a minimum age of 1.09 ± 0.14 b.y. from a complex gas release (^{40}Ar-^{39}Ar method) for a glass sample (referred to as surface glass). They suggested this age to represent that of Aristillus or Autolycus. Schaeffer et al. (1976) and Plieninger and Schaeffer (1976) conducted a laser probe Ar study on interior breccia fragments from 15465. They found widely varied solar wind ^{36}Ar in different pieces, indicating that rock formation was not accompanied by appreciable redistribution of argon in the breccias; hence the original ages of constituents can be measured. A 3-isotope plot (Fig. 8) gives two distinct lines, one representing an age of 3.91 ± 0.04 b.y., the other an age of 1.9 ± 0.1 b.y. The latter is from basalt (stated to be mare basalts) and feldspar clasts. Some of the basalts, with a K-rich mesostasis, give individual ages of 1.0 ± 0.5 b.y., the same as rock formation. These "young" basalts are puzzling, requiring either young volcanism or uniform degassing around the time of 15465 formation. The 3.9 b.y. age represents highland basalts

(=KREEP basalts), recrystallized norites, dark green glass spheres, other glass, and the groundmass (matrix) itself. The varied components make it not surprising that bulk breccia stepwide heating did not give a plateau (Husain, personal communication in Plieninger and Schaeffer, 1976). Plieninger and Schaeffer (1976) interpreted the 3.91 b.y. components to have been degassed during the Imbrium event.

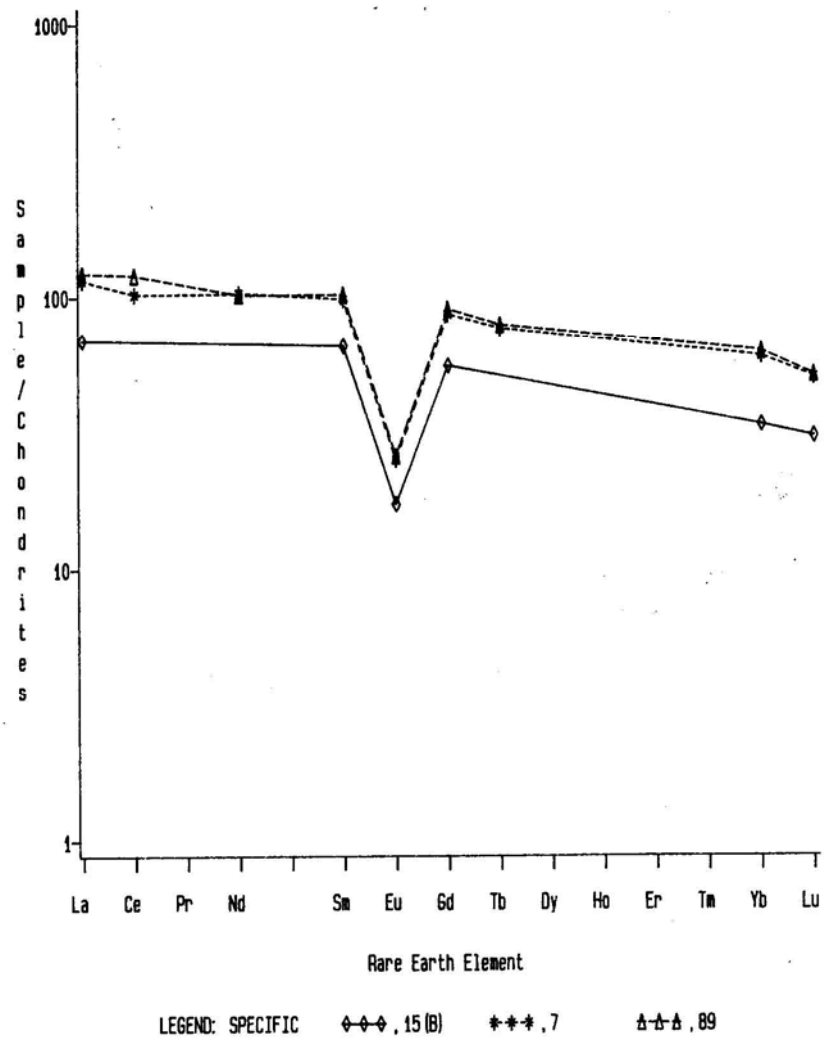


Figure 6. Rare earths in regolith breccia fragments in 15465.

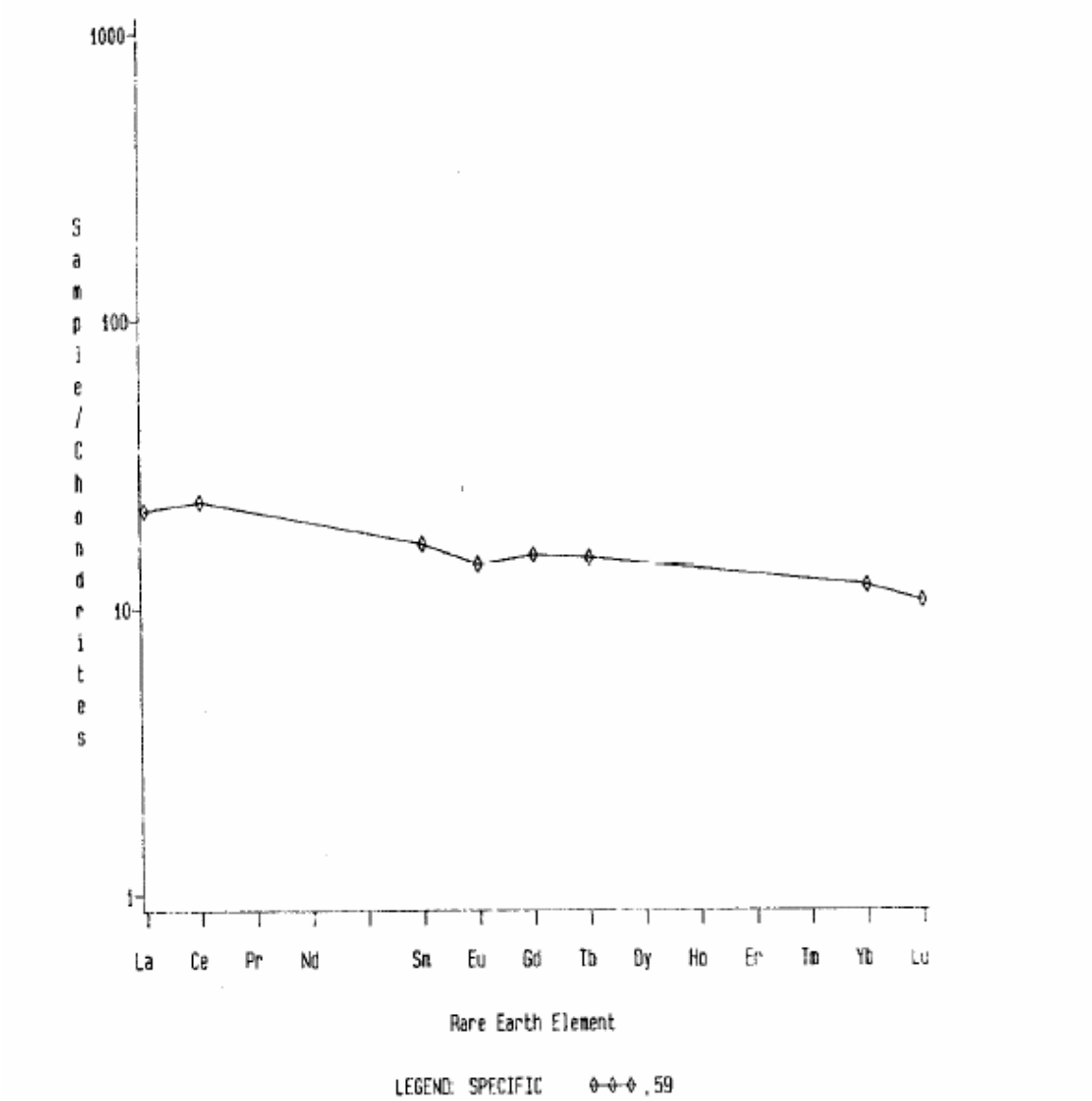
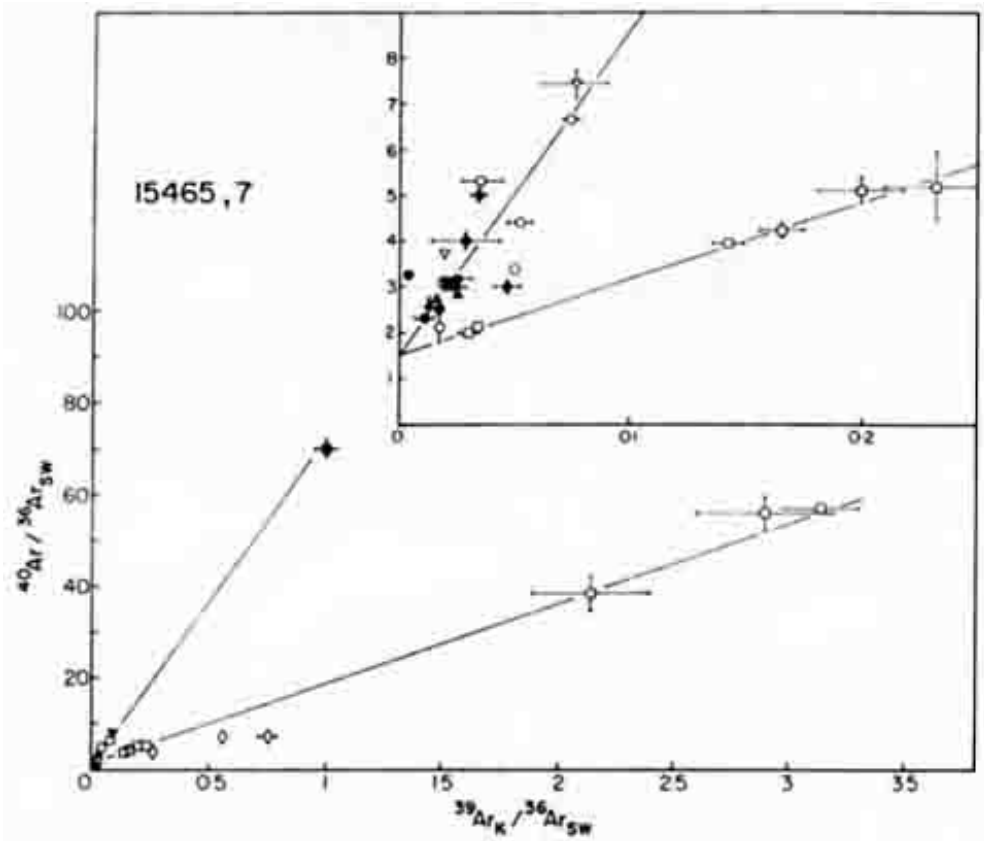


Figure 7. Rare earths in feldspathic clasts.

EXPOSURE: Keith et al. (1972) provided disintegration count data for ^{26}Al, ^{22}Na, ^{64}Mn, ^{56}Co, and ^{46}Sc. According to Yokoyama et al. (1974) the ^{26}Al is a saturated value, indicating an exposure of more than about 2 m.y.

PROCESSING AND SUBDIVISIONS: Several pieces were originally chipped from ,0, including the Consortium Sample ,7 (Fig. 2, 9). Several thin sections were obtained from ,1; ,13; and ,17 (,1 had originally been numbered 15469 but was found to have broken off 15465 in transit). Thin sections were cut from chip ,52 which was a granddaughter of ,9. Later chipping was done (Fig. 10) to acquire glass and interior chips, and a thin section was made from ,91, a daughter of ,44. Subsequently, more chipping acquired white clast material (,56; ,59; and ,61) and more thin sections were made. Most of the subdivisions of ,7, including the thin sections studied by Delano and Cameron, have not been documented.



Three isotope plot of $^{40}Ar/^{36}Ar_{SW}$ against $^{39}Ar_K/^{36}Ar_{SW}$. The slopes of the two lines are used to determine the $^{40}Ar/^{39}Ar$ ratios in the presence of trapped ^{40}Ar. Symbols: × mare basalts, □ highland basalts, ● glass spherules, ▼ noritic clasts, ▲ groundmass, ◆ feldspar crystal clasts, ◇ K-rich basalts, and ○ glass fragments. The error bars represent the errors in the ^{40}Ar and ^{39}Ar measurements. Errors in the ^{36}Ar values used for normalization do not contribute to the errors in the best-fit lines which determine $^{40}Ar/^{39}Ar$ ratios.

Figure 8. 3-isotope argon plot for components of 15465 (Plieninger and Schaeffer, 1976).

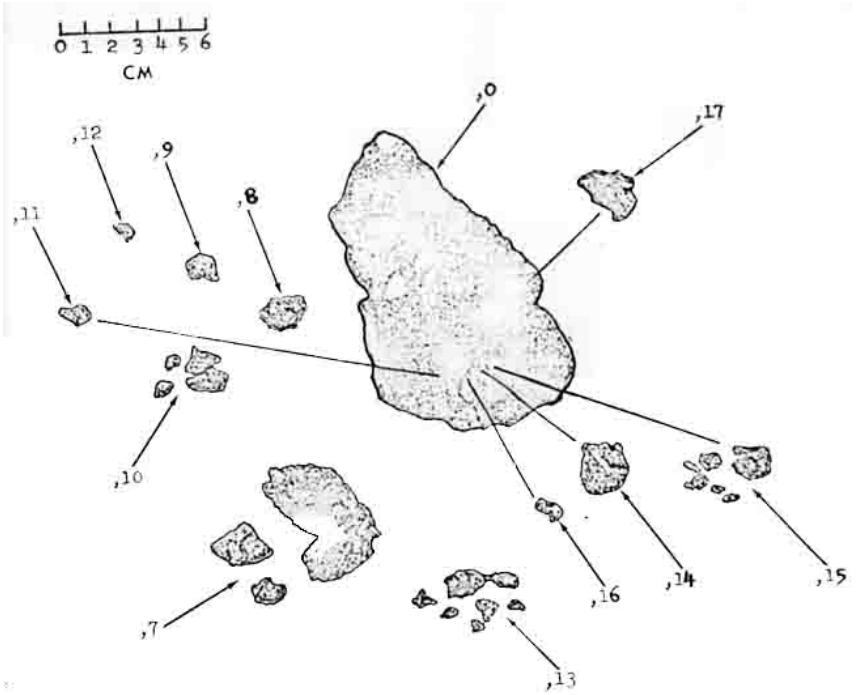


Figure 9. Original chipping of 15465.

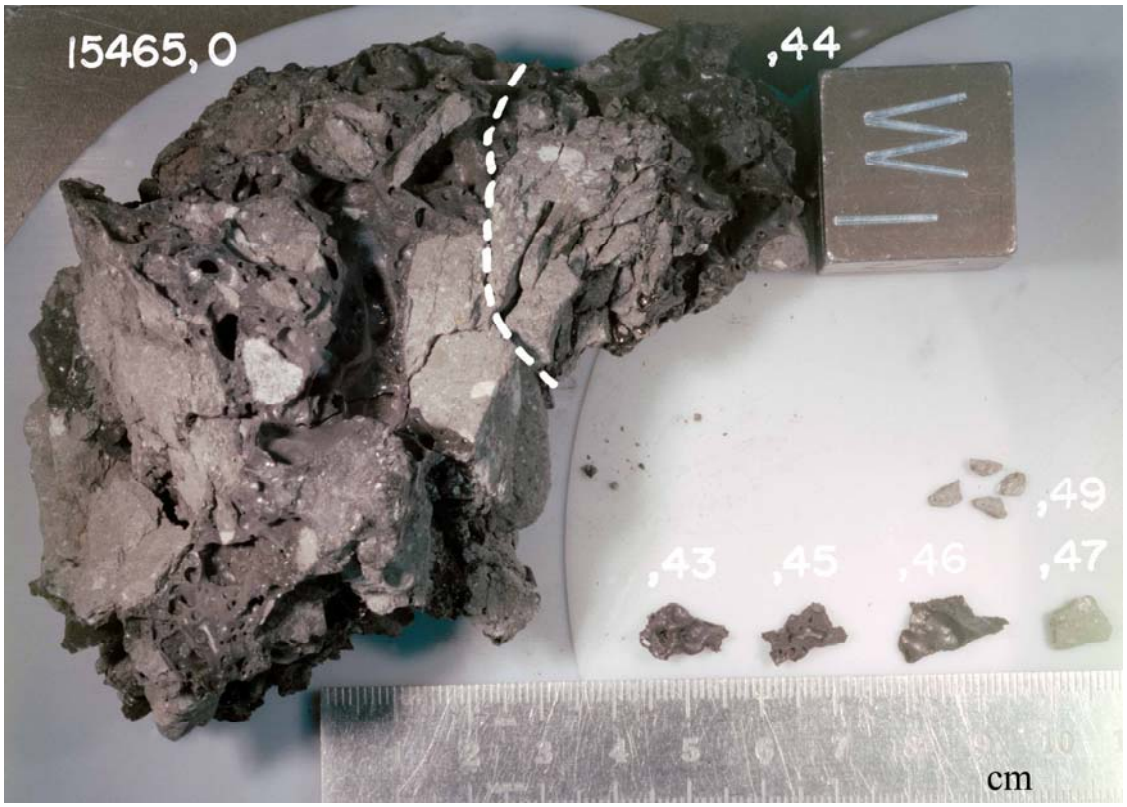


Figure 10. Origin of 15465,44 and smaller pieces. S-75-34267