

INTRODUCTION: 66095 is a fine-grained, subophitic impact melt, containing lithic and mineral clasts. A distinctive characteristic of 66095 is its abundant rust (β -FeOOH, akaganeite), a secondary consequence of its great abundance of volatiles. The origin of the volatiles is controversial. A small part of the surface of 66095 has a glass coat.

66095 consists of two contiguous pieces (Fig. 1) broken from a block (50 x 25 x 15 cm) on the south rim of a 10 m crater near the base of Stone Mountain. Their orientation is known. The parent block was rectangular; the two fragments are subrounded except for a fracture face. The light gray sample has numerous fractures producing a friability, whereas individual pieces are tough. Zap pits are present on the lunar-exposed surfaces.

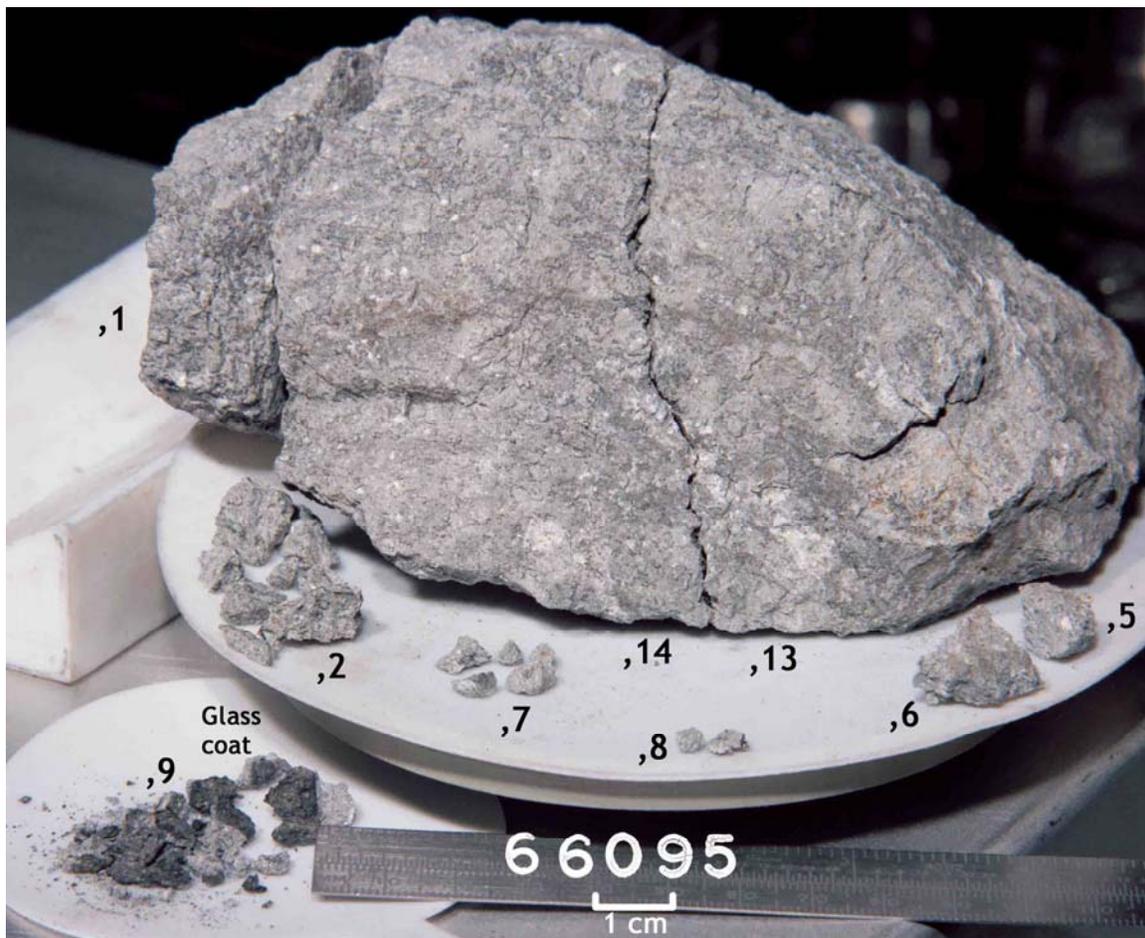


FIGURE 1. S-72-41839.

PETROLOGY: General petrographic descriptions with mineral analyses are provided by Garrison and Taylor (1979a,b,1980), Meyer et al. (1979), and Vaniman and Papike (1981). Emphasis on studies of opaque and/or volatile-rich mineral phases is made by El Goresy et al. (1973a,b), L. Taylor et al. (1973a,b, 1974a,b) and Misra and Taylor (1975). Bell and Mao (1973) report the abundances of minor elements in plagioclase. (LSPET (1973) obliquely and erroneously refers to 66095 as a high grade breccia).

Most of 66095 is a fine-grained, subophitic to ophitic impact melt (Fig. 2); the remainder is lithic and mineral clasts. The melt contains 50-60% plagioclase laths, up to 30% pigeonite, and about 10% olivine with some interstitial glassy material; and accessory amounts of FeNi metal, troilite, sphalerite, schreibersite, cohenite, and ilmenite (Garrison and Taylor, 1980). Rare transparent spinels are also present. Reported silicate mineral compositions are summarized in Table 1 and phase compositions in Figures 3a and 3b.

El Goresy et al. (1973a,b) report the presence of, and analyze, sphalerite, a Cl-bearing Zn-rich sulfate, a Cl-bearing Zn-rich phosphate, and a Pb-rich phase, in association with “goethite,” and in one grain cohenite coexisting with FeNi metal and schreibersite. They favor a cometary or Cl meteorite impact origin for the volatiles, with Pb distilled from adjacent rocks, rather than a fumarolic origin.

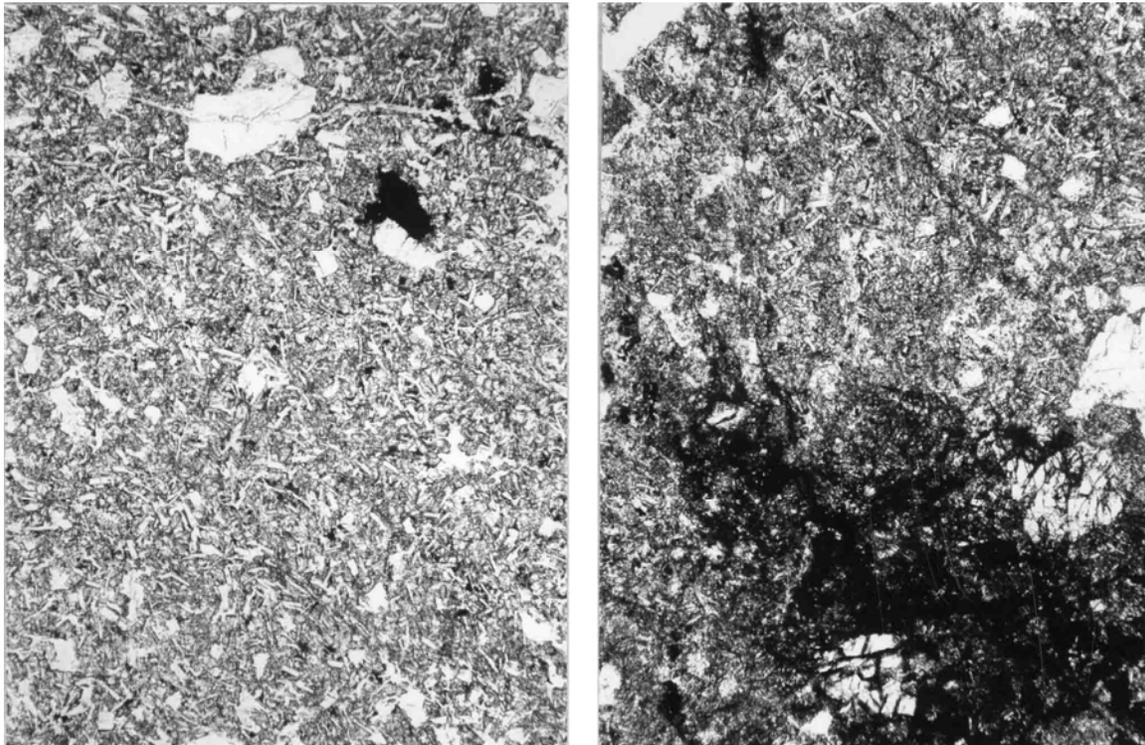


FIGURE 2. a) 66095,85. General view, ppl. Width 1 mm.
b) 66095,82. Large rusty patch, ppl. Width 1 mm.

TABLE 1. Compositions of silicates in 66095 melt.

<u>Plag (An)</u>	<u>Px (En/Wo)</u>	<u>Olivine (Fo)</u>	<u>Reference</u>
89-94	72/7 - 65/18	77	Garrison and Taylor (1979a,b,1980)
95±2	-	80.5±1	L. Taylor <u>et al.</u> (1973b)

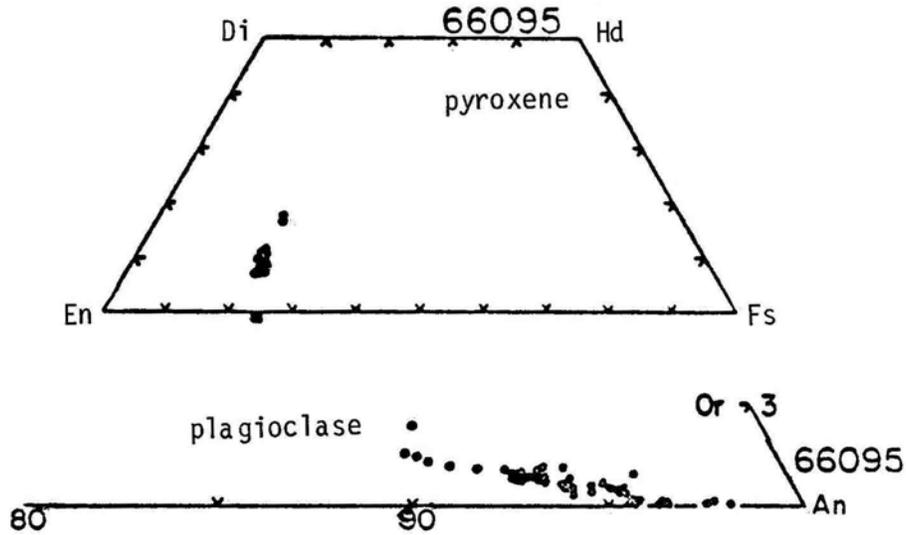


FIGURE 3a. Silicate mineral compositions, olivine plotted along base of pyroxene diagram, from Vaniman and Papike (1981).

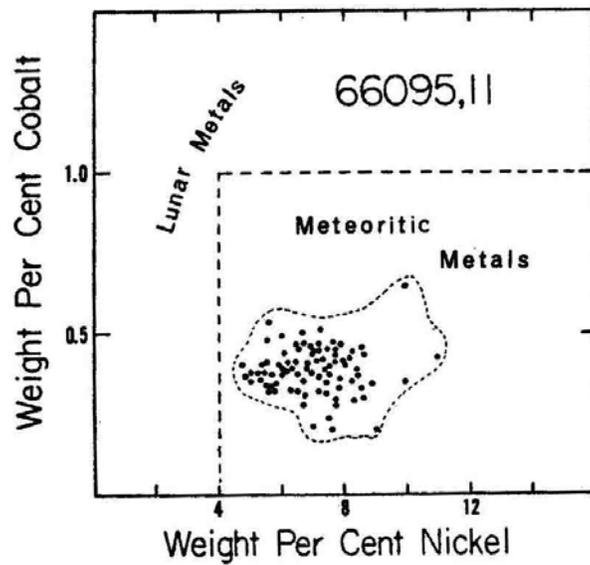


FIGURE 3b. Metal compositions, from L.A. Taylor et al. (1973b).

L. Taylor et al. (1973b) studied opaque minerals, providing analyses. Noting the presence of Cl in the “goethite,” they suggest that lawrencite (FeCl₂) was present in the rock which has been oxidized to create the rust. While rust is being created at present, they suggest it was also present on the Moon. L. Taylor et al. (1973b, 1974a,b) defined the “goethite” phase as akaganeite (β-FeOOH) from x-ray diffraction and crystal field spectra. The water required for the rapid oxidation of lawrencite is believed to be terrestrial and possibly from in the spacecraft.

Misra and Taylor (1975) studied FeNi and schreibersite and their relationships. Geothermometry based on FeNi and schreibersite compositions suggests an equilibration temperature of 600-650°C.

The basaltic impact melt contains ~20% lithic and mineral clasts (Fig. 2), described and analyzed by Garrison and Taylor (1979a,b, 1980) and Meyer et al. (1979). The lithic clasts are summarized in Table 2. Mineral clasts are dominated by plagioclase but include olivine and rare pleonaste.

The “basalts,” interpreted as clasts by Meyer et al. (1979) and Garrison and Taylor (1980), are mineralogically similar to the basaltic impact melt host and may be textural variants (common in impact melts) of the melt rather than clasts. The other, non-melt, clasts have olivine rather than pyroxene as the dominant mafic phase. Metal analyses for all metal-bearing clasts lie in the range 4-12% Ni, 0.4-1.2% Co (Garrison and Taylor, 1980).

TABLE 2. Summary characteristics of clasts in 66095 (from Meyer et al.,1979).

<u>CLAST TYPE</u>	<u>TEXTURE</u>	<u>MODES</u>	<u>MIN COMPS</u>
ANORTHOSITE	Coarse-grained Granulitic (various degrees of shock) Plag 10-500µm; Ol 1-100µm	Plag 90-100% Ol 0-10%	An 91-99 Fo 75-80
ANORTHOSITE-TROCTOLITE	Coarse-grained Equigranular Plag 450-1600 µm; Ol 20-200 µm.	Plag 90-95% Ol 5-10%	An 98 Fo 61-69
	Cataclastic - Stringers Plag 30-300 µm; Ol 5-200 µm	Plag 80-95% Ol 5-20%	An 91-98 Fo 78-81
PLAGIOCLASE	Coarse-grained (various degrees of shock up to Maskelynite) Plag .04-1cm	Plag 100%	An 91-99
BASALT	Fine-grained Porphyritic Plag 10-300 µm, Ol + Px 10-100 µm as Phenocrysts	Matrix <50% (Plag + Px)	An 92-95 Fo 74-76

66095 is shocked, and penetrated by several “rootless” veins filled with shock-melted silicate glass (El Goresy et al., 1973a; Garrison and Taylor 1979a, 1980). Complete major element analyses are given by Garrison and Taylor (1980). The compositions vary from vein to vein but are roughly equivalent to the compositions of bulk rock.

CHEMISTRY: Published chemical studies of 66095 are listed in Table 3. A summary chemistry of the bulk rock is given in Table 4.

The chemistry of 66095 is similar to that of other basaltic impact melts at the Apollo 16 site, except for its volatiles. It is less feldspathic and more enriched in incompatible elements than local soils. REE plots are given in Figure 4. The split ,37 analyzed by Hubbard et al. (1973, 1974) and Nyquist et al. (1973) is atypical in that much of it is a single white clast, according to data pack photographs.

TABLE 3. Chemical work on 66095.

<u>Reference</u>	<u>Split Analyzed</u>	<u>Elements Analyzed</u>
Duncan <u>et al.</u> (1973)	,47	Majors, some trace
Nakamura <u>et al.</u> (1973)	,52	Majors, REEs
Brunfelt <u>et al.</u> (1973)	,48	Majors, REEs, other trace, incl. vols.
Hubbard <u>et al.</u> (1973)	,37	Majors
Jovanovic and Reed (1973)	,17 ,23	F,Cl,other vols. and refractories.
Krahenbühl <u>et al.</u> (1973)	,55	Meteoritic siderophiles and volatiles.
LSPET (1973)	,5	Majors, some trace.
Nava (1974)	,50	Majors
Allen <u>et al.</u> (1974)	,23	²⁰⁴ Pb,Bi,Tl,Zr
Kerridge <u>et al.</u> (1975b)	,43	C,S,C-compounds
Gibson and Moore (1973)	,40	H ₂ O, CO ₂
Hubbard <u>et al.</u> (1974)	,36 ,37	REEs, other traces
Jovanovic and Reed (1976a)	,23	Ru, Os
Des Marais (1978)	,198	C, N, S
Hughes <u>et al.</u> (1973)	,56	Os, Ir, Au, Ag, Re
Friedmann <u>et al.</u> (1974)	,20 ,31 ,62	C, H ₂ O
Nunes and Tatsumoto (1973), Nunes <u>et al.</u> (1973)]	,41	U, Th, Pb
Nyquist <u>et al.</u> (1973)	,37	Rb, Sr
Rancitelli <u>et al.</u> (1973b)	,13	K, U, Th

TABLE 4. Summary chemistry of 66095.

SiO ₂	45
TiO ₂	0.72
Al ₂ O ₃	24
Cr ₂ O ₃	0.14
FeO	6.7
MnO	0.08
MgO	9.0
CaO	13.5
Na ₂ O	0.45
K ₂ O	0.15
P ₂ O ₅	0.24
Sr	159
La	22.5
Lu	1.00
Rb	3.9
Sc	6.8
Ni	~ 650
Co	~ 45
Ir ppb	16-33
Au ppb	~ 18
C	10-90
N	< 0.1
S	~ 1000
Zn	20-92
Cu	~ 3

Oxides in wt%; others in ppm
except as noted.

Of significance is the high volatile content, e.g., Cl, Pb, Zn, Ir, Cd, Tl, and water (Brunfelt et al. 1973; Jovanovic and Reed, 1973; Krahenbuhl et al. 1973; Nunes and Tatsumoto, 1973, and others). Jovanovic and Reed (1973) and Allen et al. (1974) note that most of the Cl and other volatiles are leached by hot water. Krahenbuhl et al. (1973) suggest that a fumarolic rather than an impact origin for the volatiles is most likely because (1) the volatiles are not in chondrite proportions and (2) Pb is also enriched and is lunar (from Nunes and Tatsumoto, 1973). Most of the chemical discussions in the listed references concern volatiles, but Nakamura et al. (1973) note that their analysis has

a 9% positive Ce anomaly (normalized to the Leedy chondrite REE abundances) (note however that the La/Ce ratio of 66095 by Nakamura et al. and other authors is not significantly different from another lunar rock with a significant KREEP content, nor is a significant Ce anomaly present when normalization is to an average chondrite composition).

Ganapathy et al. (1973) place 66095 in their meteoritic Group R, later updated to Group 1H (Hertogen et al., 1977).

Cirlin and Housley (1980) established thermal release profiles for Pb, Zn, and Cd for grains disaggregated from 66095. The profiles demonstrate that the major fraction of these volatiles is released below 1000°C and were present on the surfaces of the grains.

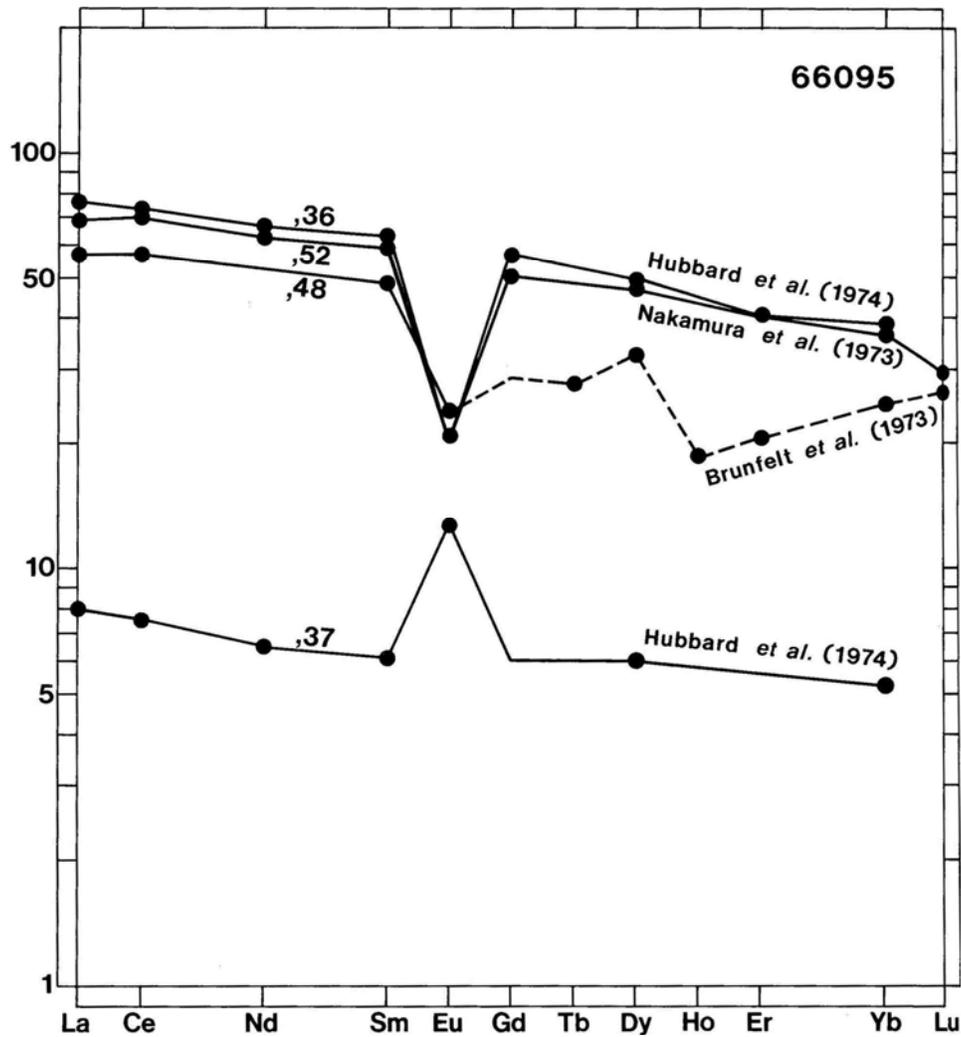


FIGURE 4. Rare earths.

STABLE ISOTOPES: Considerable work on stable isotopes has been performed on 66095, mainly in attempts to elucidate the origin of the volatiles. Clayton et al. (1973) established that the silicates in 66095 have normal lunar oxygen isotopic ratios: $\delta^{18}\text{O}$ of a plagioclase was +5.73 and of a light clast was +5.81.

Friedmann et al. (1974) measured O and H isotopic ratios on water released by heating 66095, and the C and O isotopic ratios of similarly released CO_2 (Tables 5a, b). They also analyzed $\delta^{18}\text{O}$ of water released from heating an iron oxide sample from 66095 (Table 5c) and $\delta^{18}\text{O}$ of 66095 silicates.

TABLE 5. C, H, and O isotopic data, from Friedmann et al. (1974).

Temperature (°C)	Water (ppm)	δD	CH_4, CO		CO_2	
			C (ppm)	$\delta^{13}\text{C}$	C (ppm)	$\delta^{13}\text{C}$
<i>Rock 66095-62 (2.46 g)</i>						
100°-270°	223	- 80	0.2		1.9	- 43
270°-690°	158	- 75	0.1		6.3	- 12
690°-935°	7.2	- 200			2.4	- 22
935°-1350°	1.8	- 170			0.2	
Total	390				11.1	
Weighted average		- 81				- 20
<i>Rock 66095-31 (4.67 g)</i>						
100°-270°	60	- 100			1.1	- 24
270°-690°	156	- 140	0.02		21.7	- 26
690°-970°	9.0	- 150			14.9	- 38
970°-1350°	4.5	- 160	4.5	- 19	16.7	- 33
Total	230				59	
Weighted average		- 130				- 30
Combustion (+ 975°)	137	- 110			15.0	- 21

Temperature (°C)	Water			CO_2			CH_4, CO
	ppm	δD	$\delta^{18}\text{O}$	C (ppm)	$\delta^{18}\text{O}$	$\delta^{13}\text{C}$	C (ppm)
<i>Rock 66095-20 (6.19 g)</i>							
25°	1,300	- 140	- 1 ± 1	3.6	+ 44	- 18	
25°-110°	360	- 160	+ 6 ± 2	7.1	+ 31	- 17	
110°-200°	500	- 140	+ 5 ± 2	2.9	+ 48	- 12	
200°-350°	240	- 85	+ 5 ± 2	20	+ 28	- 17	~ 2
350°-490°	~ 15	Sample lost		~ 1	+ 46		~ 1
490°-670°	20	- 183	+ 20 ± 10	2.6	+ 24	- 18	
110°-350°	740*		+ 5 ± 2				

Weight (g)	Temperature (°C)	Water	
		ppm	$\delta^{18}\text{O}$
<i>Rock 66095-20</i>			
1.15	115°-280°	150	+ 5 ± 2
	280°-400°	75	

The isotopic composition of C is not unusual by comparison with other lunar rocks. The water released has $\delta^{18}\text{O}$ ‰ similar to terrestrial water, but the $\delta^{18}\text{O}$ ($\sim +5$ ‰) is dissimilar to terrestrial water and similar to typical lunar silicates. Similarly, the water released by the iron oxide phase had $\delta^{18}\text{O}$ of $+5$ ‰ and the silicates had $\delta^{18}\text{O}$ of $+6.3$ ‰. They conclude that the water is not a terrestrial contaminant. Contrarily, Epstein and Taylor (1974) found that the water released from 66095 had both $\delta^{18}\text{O}$ and $\delta^{18}\text{O}$ (-100 and -15 ‰ respectively) similar to terrestrial water. They find it inconceivable that the large quantities of water produced (loosely bound and most released by 200°C) could have been present in a lunar oxidation and temperature environment. Friedman et al. (1974) suggest that the water in the sample analyzed by Epstein and Taylor (1974) (which had been stored longer prior to analysis) had exchanged water with terrestrial sources.

Kerridge et al. (1975b) report $\delta^{34}\text{S}$ ($+1.9$ ‰) and $\delta^{13}\text{C}$ (-24.2 , -23.5 ‰) values but do not specifically discuss them. The $\delta^{13}\text{C}$ values, like those reported by Friedman et al. (1974) for released CO_2 , are considerably less than those of local soils ($\delta^{13}\text{C} \sim +12$ ‰), as are the $\delta^{34}\text{S}$ values (soils $\sim +6$ to $+10$ ‰). Des Marais (1978) reports $\delta^{13}\text{C}$ values for different temperature releases ranging from -13.1 to -22.7 ‰. Allen et al. (1974) report the abundance of ^{204}Pb (considered stable because of its exceptionally long half-life).

GEOCHRONOLOGY AND RADIOGENIC ISOTOPES: Nyquist et al. (1973) report Rb-Sr isotopic data for 37 (Table 6). This split is a white-clast-rich fragment not typical of the whole rock, and, although not specifically discussed by Nyquist et al. (1973), this is reflected in the low Rb content and low $^{87}\text{Sr}/^{86}\text{Sr}$ as compared with typical lunar basaltic impact melts.

Turner et al. (1973) report Ar isotopic data for 66095. The release patterns (Fig. 5) are complex and do not yield a well-defined ^{40}Ar - ^{39}Ar age. However Turner et al. (1973) tabulate an age of 3.6-3.8 b.y. The release patterns may be complicated by the presence of old relict clasts.

TABLE 6. Rb-Sr data for 66095,37 (from Nyquist et al.,1973; Nyquist 1977).

Rb ppm	Sr ppm	$^{87}\text{Sr}/^{86}\text{Sr}$	T_{BABI}	T_{LUNI}	Calc. I at 3.9 b.y.
1.591	162.7	0.70068 ± 7	$3.9 \pm .27$ b.y.	$4.15 \pm .27$ b.y.	0.68998

Adjusted for interlaboratory bias to conform to Cal Tech Data.

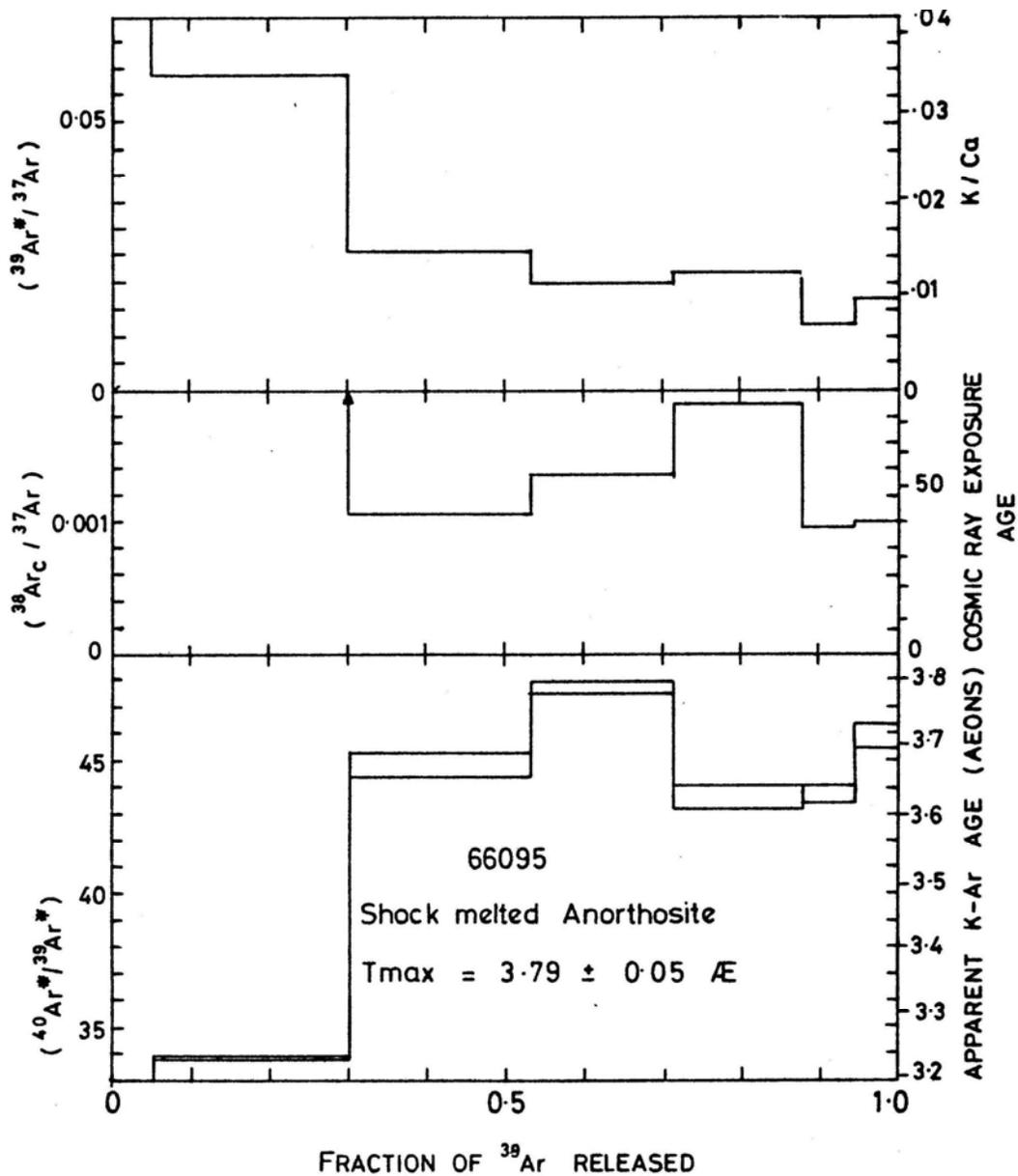


FIGURE 5. Ar releases, from Turner et al. (1973).

Nunes and Tatsumoto (1973) report U, Th, and Pb isotopic abundances, also summarized in Nunes et al. (1973). The data are for whole rock and for separates, and include acid leaches. The rock is unusually abundant in lead, 85% of which is excess, i.e. unsupported by in situ U and Th. The leachable lead is isotopically distinct from the residual lead, which is similar to Apollo 16 soils. An internal U-Pb isochron gives an age of 3.82 b.y. (Fig. 6). Nunes and Tatsumoto (1973) conclude (1) the excess lead is lunar and (2) the excess lead was introduced into the rock in a discrete event 3.8-4.0 b.y. ago. The data also are consistent with, and suggest, major lunar crustal differentiation ~4.47 b.y. ago.

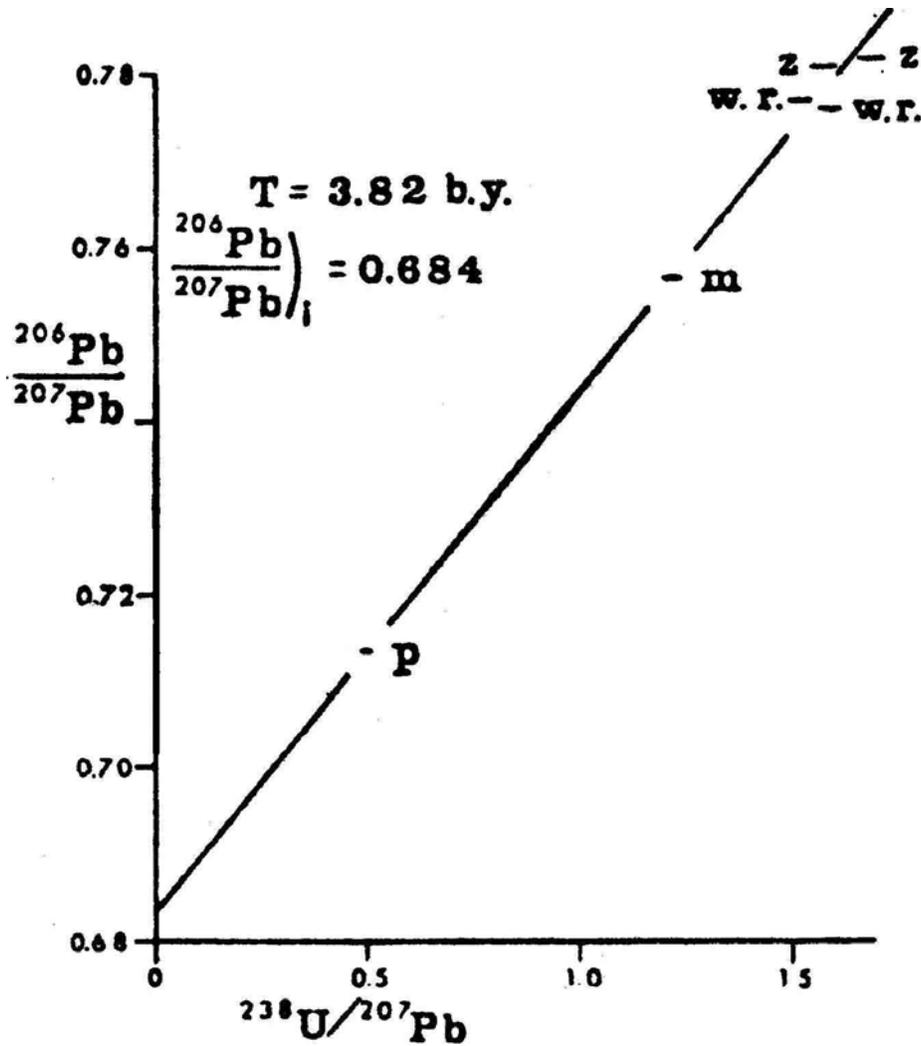


FIGURE 6. Internal isochron, from Nunes and Tatsumoto (1973).

Hinthorne and Andersen (1974) report ion microprobe analyses for ${}^{207}\text{Pb}/{}^{206}\text{Pb}$ and ${}^{208}\text{Pb}/{}^{206}\text{Pb}$ in four Cl-rich areas in 66095,81. The ratios are similar to those in the leached materials analyzed by Nunes and Tatsumoto (1973). Thus the latter is associated with oxide and Cl-rich regions of troilite alteration. Hinthorne and Andersen (1974) suggest that the leachable lead has the same origin as Cl, S, and OH and that it is not Lunar. Th and Pb are localized differently: Th with FeNi grains and Pb with Cl-rich areas.

RARE GASES AND EXPOSURE AGES: Heymann and Hubner (1974) analyzed a portion of 66095,17 for inert gases. They suggest that contamination of 66095 with as little as 0.2% Apollo 16 fines, possibly in the form of the glassy veins, can produce the observed

isotopic ratios and abundances of inert gases. They calculate a ^{21}Ne spallation age of 1.1 ± 0.5 m.y., although this age is imprecise because the sample irradiation history is unknown. Turner et al. (1973) report Ar isotopic data but the release patterns are complex (Fig.5). Taken at face value the variations correspond to exposure ages of 40-80 m.y. and possibly imply a complex history of near surface irradiation for the components prior to their incorporation into 66095.

Rancitelli et al. (1973a) provide ^{22}Na and ^{26}Al data without discussion. Bhandari et al. (1976) report ^{26}Al data, a track density/depth profile, and residence time/depth analyses. Solar flare tracks suggest an exposure age of 1 m.y., and a crater count exposure age is ~ 0.2 m.y. Bhandari et al. (1976) report a ^{26}Al exposure age of 0.7 ± 0.1 m.y. Fruchter et al. (1978) report ^{26}Al and ^{53}Mn data providing exposure ages of 0.9 ± 0.2 and 1.4 ± 0.3 m.y. respectively. The sample is substantially undersaturated with ^{26}Al and ^{53}Mn suggesting that its excavation postdates South Ray. The data are indicative of a relatively simple surface history.

PHYSICAL PROPERTIES: Nagata et al. (1973) tabulate the basic magnetic properties of 66095 and also measured the stability of natural remanent magnetization (NRM) against alternating field (AF) demagnetization. The magnetic data also provide a total Fe^0 content of 1.21% and the nickel content of kamacite: 5.5-6.0%. Pearce et al. (1973) also provide basic magnetic data and derive a total Fe^0 of 1.44% and a total Fe^{2+} of 5.55-5.57%. The change in intensity and direction of NRM with AF demagnetization is shown in Figure 7; there is a very pronounced soft NRM. Cisowski et al. (1974) use the value of saturation magnetization to calculate a Fe^0 abundance of 1.2% and $\sim 7\%$ total iron. Schwerer and Nagata (1976) tabulate some magnetic properties relevant to the characterization of the superparamagnetic-ferromagnetic components. Brecher (1975) lists 66095 as an example of a rock having “textural remanence.”

Weeks (1973b) provides electromagnetic resonance spectra for several fragments from the rock. Tsay and Live (1976) and Tsay and Baumann (1977) use electron spin resonance to detect the presence of minute amounts of paramagnetic Fe^{3+} (detected at 77°K) which they infer is probably from terrestrial oxidation. They detected 82 ppm Fe^{3+} and 6900 ppm (0.69%) Fe^0 .

PROCESSING AND SUBDIVISIONS: 66095 has been extensively subdivided. The first divisions are shown in Figure 1. ,1 (233 g) and ,13 (495 g) remain as large pieces, but ,14 (433 g) has been totally subdivided and renumbered. Its two largest daughters were ,60 (60 g) and ,61 (155 g), with most other splits much smaller. In 1980, ,60 was sawn into three pieces and renumbered: ,294 (22.8 g) and ,296 (16.9 g) are the end pieces and ,295 (17.7 g) is the slab. Small chips, all but one being basalt, were taken from these three pieces.

