67075 CATACLASTIC ANORTHOSITE, NEAR PRISTINE 219 g

INTRODUCTION: 67075 is an anorthosite breccia which is so friable it has broken into many small fragments and powders (Fig. 1). Mafic grains are not uniformly distributed, but tend to be concentrated in clots or "veins." Overall the plagioclase content is more than 95%. The sample is contaminated, at least in part, with a small amount of meteoritic material. The variations in mafic mineral compositions suggest that the rock is polymict, but is derived from a genetically-related suite of anorthositic rocks.

The sample was collected from the southeast rim of North Ray Crater and was originally two white, subrounded fragments. They were perched and unburied. Because of the breakage into many small pieces, lunar orientation information has been lost, and zap pits are absent.

PETROLOGY: A comprehensive petrographic description, including microprobe and x-ray precession data, is given by McCallum et al. (1975), and less detailed accounts by Peckett and Brown (1973), Brown et al. (1973), Steele and Smith (1973), Smith and Steele (1974), Nord et al. (1973; includes high voltage electron microscopy studies) and Dixon and Papike (1975). Specific studies are El Goresy et al. (1973a) on opaque phases, Meyer et al. (1974) and Meyer (1979) on ion probe analyses of trace elements in plagioclase, Steele and Smith (1975) on minor elements in olivines, Hansen et al. (1979a) on minor elements in plagioclases, Okamura et al. (1976) on spinel exsolution from pyroxenes and Ghose et al. (1975) on cation ordering studies of olivines and pyroxenes. Hewins and Goldstein (1975b) use published data to calculate a pyroxene exsolution equilibration temperature.

67075 is a brecciated anorthosite (Fig. 2). It contains plagioclase, olivine, low-Ca pyroxene, high-Ca pyroxene, and traces of Cr-spinel, ilmenite, Fe-Ni metal, and troilite (McCallum et al., 1975). Smith and Steele (1974) also observed silica. The mafic grains are not evenly distributed but occur in zones or veins which may represent crushed, originally coarse, mafic crystals. Plagioclases occur as single fragments up to 2 mm long, in micro-anorthosite (polygonally-textured) clasts and as shocked, vitrified grains. They have restricted compositions of An_{93-98} (Steele and Smith, 1973; McCallum et al., 1975); Brown et al. (1973) report An_{92-96}. Meyer et al. (1974) and Meyer (1979) found low trace elements in plagioclases (Table 1), similar to whole-rock values.

Hansen et al. (1979a) report that minor element microprobe analyses for several plagioclase types show no significant differences between grains, which average 2.8 mol% Ab, 0.029% MgO, 0.069% FeO, and 0.016% K_2O.

Olivines are isolated, small, and unzoned. Reported compositions range from Fo_{40} to Fo_{60} (McCallum et al., 1975; Brown et al., 1973; Steele and Smith 1973, 1975).

McCallum et al. (1975) report a bimodal compositional distribution (Fig. 3). Steele and Smith (1975) report minor element compositions for olivines.

FIGURE 1. Cube is 1 cm. S-72-37539.

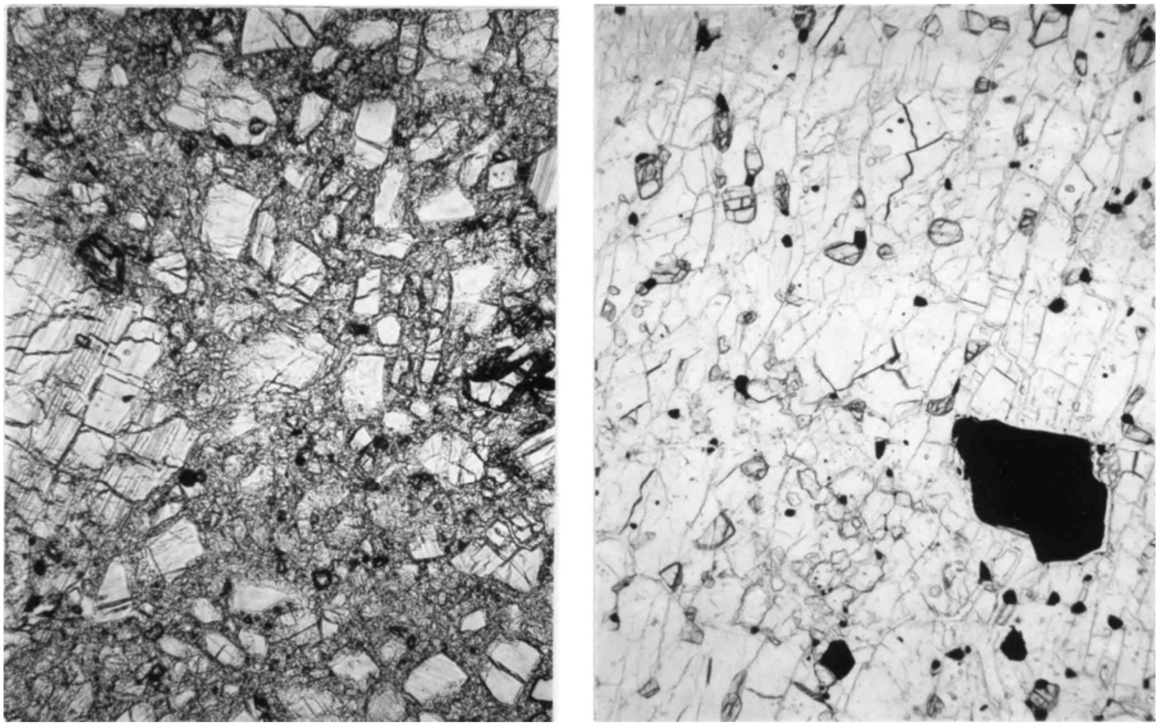


FIGURE 2. a) 67075,42. Brecciated area, ppl. Width 2 mm.
b) 67075,3. Granoblastic area, ppl. Width 1 mm.

Figure 3 also shows pyroxene compositions. High-Ca pyroxene and low-Ca pyroxene (both pigeonite and orthopyroxene) are roughly equal in volume and occur in anhedral grains up to 800 µm diameter. Large grains show distinct exsolution lamellae 20-30 µm wide, but pyroxenes in the polygonal clasts do not show exsolution. X-ray precession photographs show that most low-Ca pyroxenes are inverted or partially inverted pigeonites with well developed exsolution. Ghose et al. (1975) conclude from cation-ordering studies that slow cooling followed crystallization—a cation equilibration temperature from K_D in orthopyroxene is 650°C. Hewins and Goldstein (1975b) calculated a (Wood-Banno) pyroxene equilibration temperature of ~880°C.

El Goresy et al. (1973a) report compositions for spinels (Fig. 4). There are two occurrences of Ti-chromite: one primary, the other (associated with sulfide and exclusively exsolved from pyroxene) El Goresy et al. (1973a) interpret as reduced from Cr-Al-ulvospinel. This interpretation was criticized by McCallum et al. (1975). Okamura et al. (1976) report the compositions of, and x-ray data for, spinel lamellae exsolved from augites.

TABLE 1. Minor elements in plagioclase.

	Na_2O %	Li ppm	Mg ppm	Ti ppm	Sr ppm	Ba ppm
Meyer et al.(1974)	0.43	1.6	210	63	154	10
Meyer (1979)		3.2	300			16

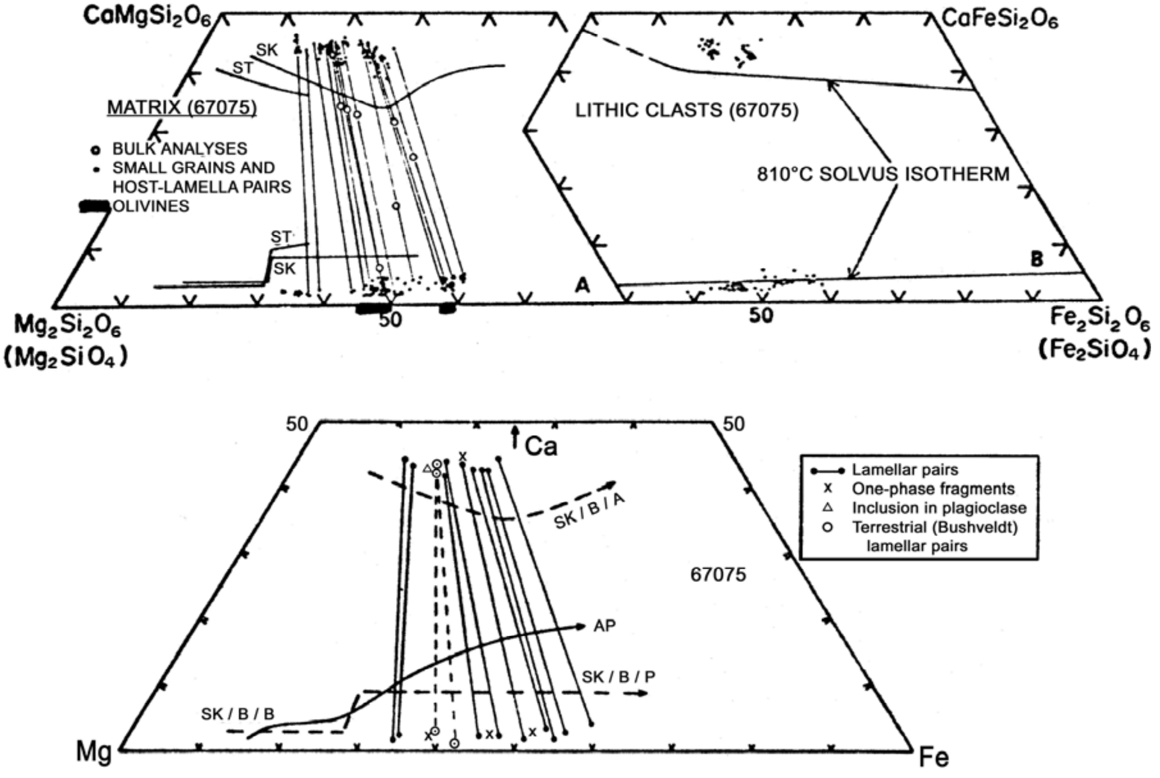


FIGURE 3. Compositions of pyroxenes and olivines in 67075, from Brown et al. (1973). SK = Skaergaard trend, B = Bushveldt trend, A = augite, P = pigeonite, AP = trend for lunar pigeonites.

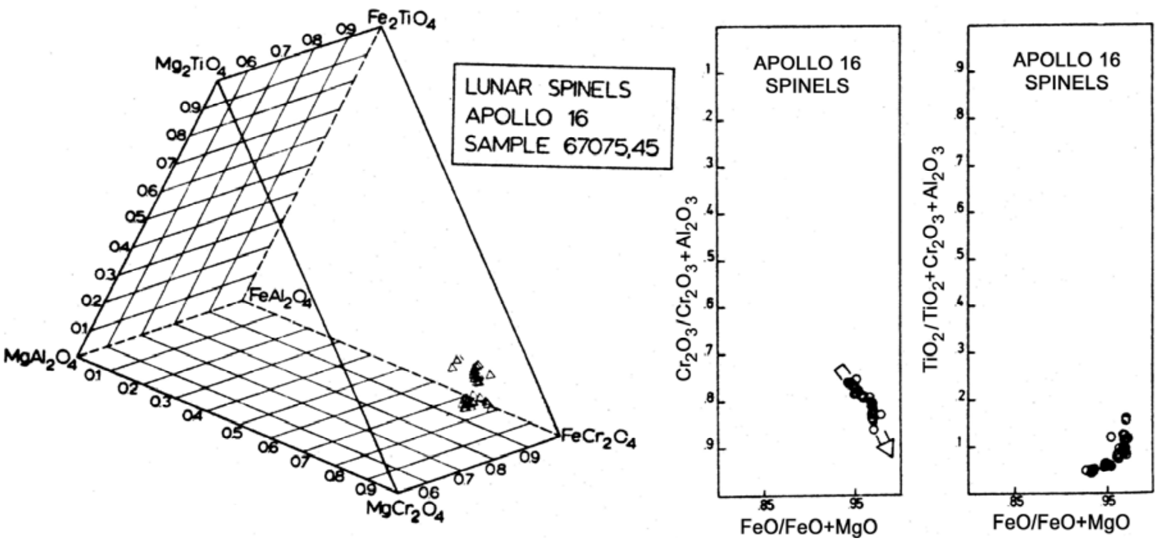


FIGURE 4. From El Goresy et al. (1973a).

Nord et al. (1975) show that 67075 lithified under conditions which did not appreciably alter the internal structure of clasts. Unlike other Apollo 16 breccias (except possibly 67016) considered by Nord et al. (1975), 67075 could have been lithified by the North Ray Crater event itself.

Peckett and Brown (1973), Brown et al. (1973) and McCallum et al. (1975) all suggest that 67075 was assembled from genetically-related fragments of a layered plutonic anorthosite complex. This interpretation can explain the pyroxene exsolutions and the range of compositions of mafic minerals.

CHEMISTRY: Chemical studies are listed in Table 2 and a summary chemistry in Table 3. Rare-earth elements are shown in Figure 5. The compositions vary in mafic content, a reflection of the heterogeneous distribution of mafic phases in 67075. It is clearly a ferroan anorthosite. The sample is slightly contaminated with meteoritic siderophiles and Hertogen et al. (1977) classify the signature as Group 7.

GEOCHRONOLOGY AND RADIOGENIC ISOTOPES: Whole-rock Rb-Sr isotopic data are presented by Nyquist et al. (1974, 1976) (Table 4).

Nyquist et al.(1976) also report Rb-Sr isotopic data for mineral separates and report an internal isochron age of 3.66 ± 0.63 b.y. (Fig. 6). The data scatter and the pyroxene datum Pxl is omitted from the age calculation—this pyroxene may have been altered by leaching in heavy liquids.

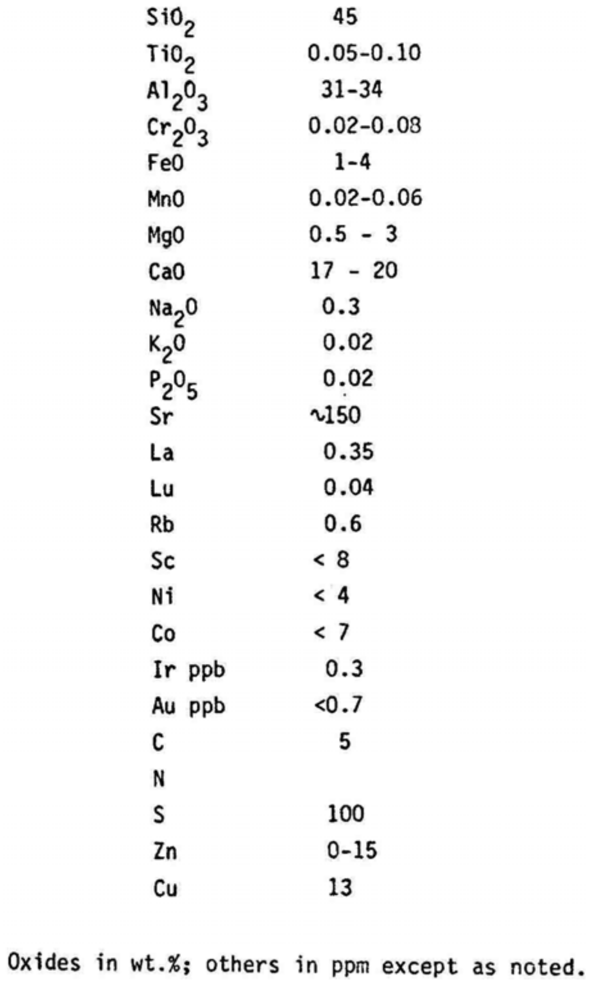
TABLE 2. Chemical studies of 67075, whole-rock.

Reference	Split #	Elements analyzed
LSPET (1973)	,4	majors, Rb, Y, Zr, Cr
Haskin *et al.* (1973)	,17	majors, REEs, other trace (∿ 30 els.)
Hubbard *et al.* (1974)	,53,55	REEs,other trace
Wänke *et al.* (1975)	,11	majors, REEs, siderophiles, other trace (∿ 40 els.)
Wänke *et al.* (1977)	,11	V
Scoon (1974)	,22	majors
Hertogen *et al.*(1977)	,9	meteoritic siderophiles and volatiles
Moore *et al.*(1973)	,7	C
Jovanovic and Reed (1976a)	,10	Ru, Os
Jovanovic and Reed (1976b)	,10	F, Cl, Br, U, P_2O_5
Nyquist *et al.* (1974)	,53	Rb, Sr
Nyquist *et al.* (1976)	,17	Rb, Sr
Silver (1973)	,5	U, Th, Pb
Oberli *et al*, (1979)	,34	U, Th, Pb
Marti *et al.* (1973)	,8	K

Turner et al. (1973) report Ar isotopic data, which have simple systematics. The release diagram is shown as Figure 7. The 900-1250°C release gives an age of 4.04 ± 0.05 b.y. Huneke et al. (1977) report whole rock and plagioclase Ar isotopic data. The age spectra are anomalous (Fig. 8) and different to that of Turner et al. (1973). The ages increase, then decrease, then increase again with temperature. The plagioclase clast is less disturbed than the whole-rock; the >850°C release gives a K-Ar age of 3.95 ± 0.1 b.y. No ages are significantly older than 4.0 b.y.

U-Th-Pb isotopic data are given by Silver (1973) and Oberli et al. (1979). Silver's (1973) results show the lead to be moderately radiogenic but unsupported by the observed U and Th abundances. The lead may contain one of the oldest lunar components identified. Oberli et al. (1979) made new determinations, showing Silver's (1973) data to be in error. The new data appear to be compatible with the “cataclysm array” (i.e. other rocks with ~4.0 b.y. ages) (Fig. 9) and thus compatible with a primary age of 4.47 b.y.

TABLE 3. Summary chemistry of 67075.



SiO_2	45
TiO_2	0.05-0.10
Al_2O_3	31-34
Cr_2O_3	0.02-0.08
FeO	1-4
MnO	0.02-0.06
MgO	0.5 - 3
CaO	17 - 20
Na_2O	0.3
K_2O	0.02
P_2O_5	0.02
Sr	∿150
La	0.35
Lu	0.04
Rb	0.6
Sc	< 8
Ni	< 4
Co	< 7
Ir ppb	0.3
Au ppb	<0.7
C	5
N	
S	100
Zn	0-15
Cu	13

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

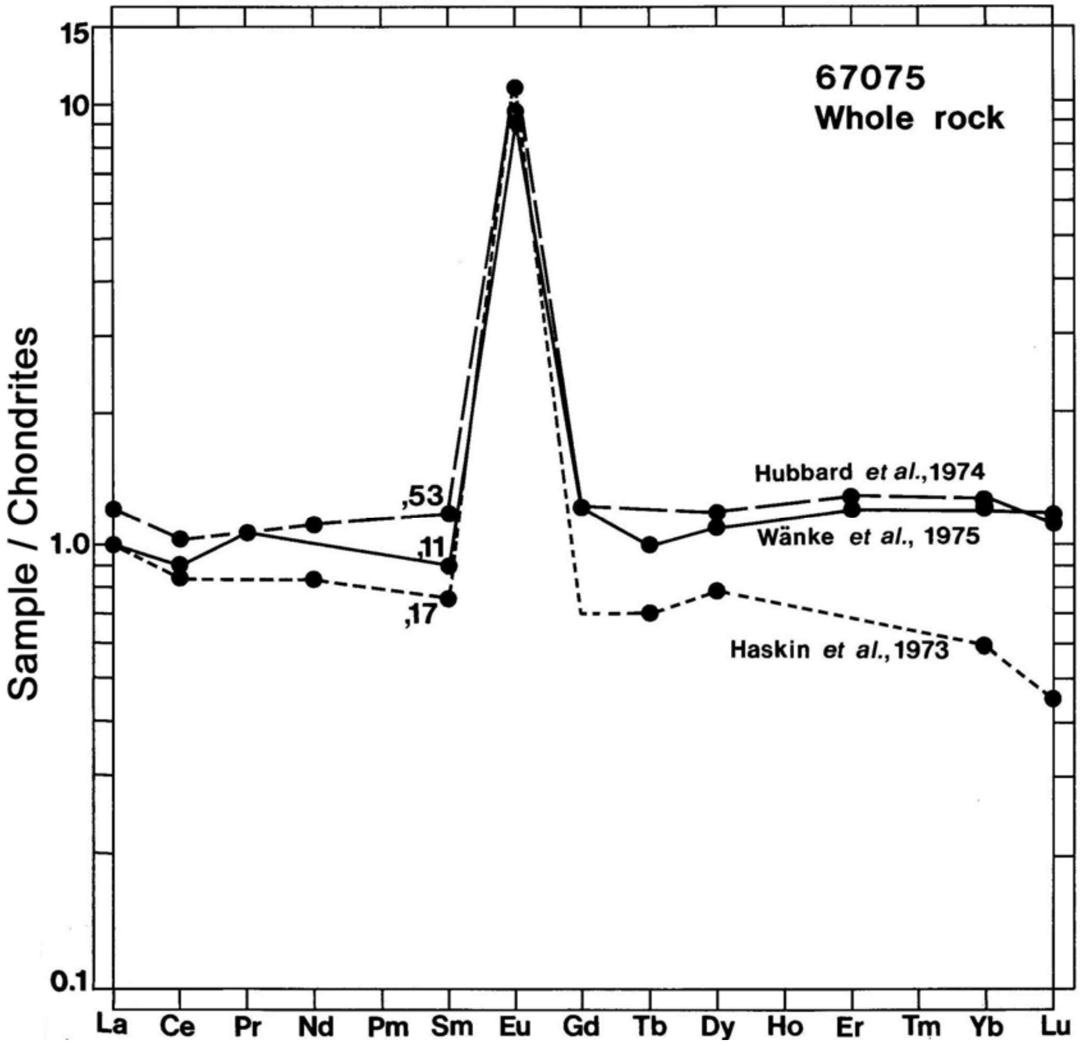


FIGURE 5. Rare earths.

TABLE 4.

	Split	Rb_{ppm}	Sr_{ppm}	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	T_{BABI} (b.y.)	T_{LUNI} (b.y.)
Nyquist et al. (1974)	,53	0.593	145.0	0.0118±3	0.69984±7	4.38±.52	4.78±.52
Nyquist et al. (1976)	,17	0.499	158.0	0.0092±2	0.69958±3	3.66±.31	4.18±.31

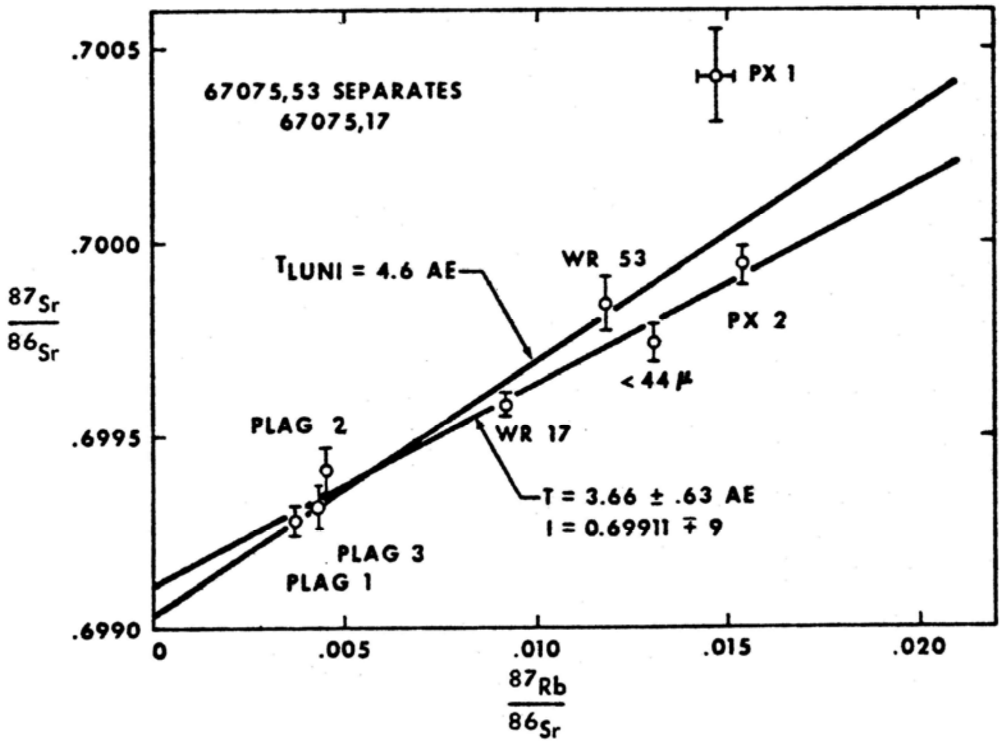


FIGURE 6. Rb-Sr isotopic data, from Nyquist et al (1976).

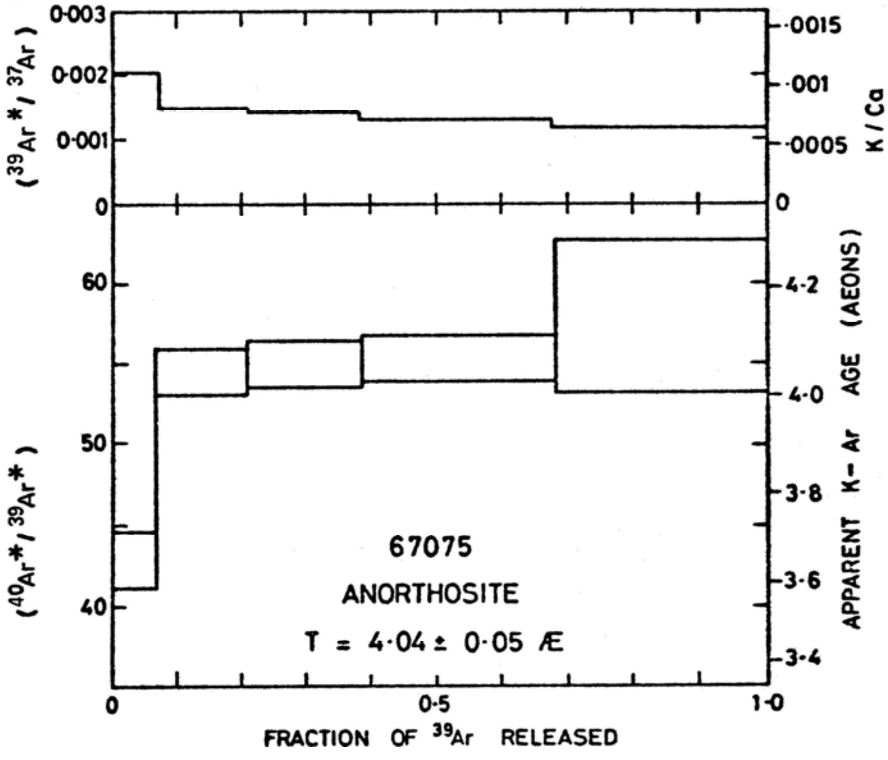


FIGURE 7. Ar releases, from Turner et al. (1973).

RARE GAS AND EXPOSURE AGES: Turner et al. (1973) report Ar isotopic data and calculate an exposure age of 46 m.y. Marti et al. (1973) report Kr isotopic data for an interior chip and calculate an exposure age of 48.5 ± 5.5 m.y. Hohenberg et al. (1978) compare observed (published data) with predicted cosmogenic Ar, Kr, and Xe abundances, and list exposure ages of 50.2 m.y. and 49 m.y.

Lightner and Marti (1974a) report Xe isotopic data and report that the sample contains little trapped Xe. Drozd et al. (1977) note that $(^{131}Xe/^{126}Xe)_{SPALL} = 3.35$, among the lowest observed among the samples they studied.

PHYSICAL PROPERTIES: Weeks et al. (1973) report electron paramagnetic resonance studies of plagioclase, with reference to Ti^{3+} and Fe^{3+} abundances. Both Ti^{3+} and Fe^{3+} are low, even compared to most other Apollo 16 samples.

PROCESSING AND SUBDIVISIONS: 67075 is so friable that it broke into many small pieces and powder during transportation to Earth (Fig. 1). Thus no saw-cuts or extensive chipping were necessary.

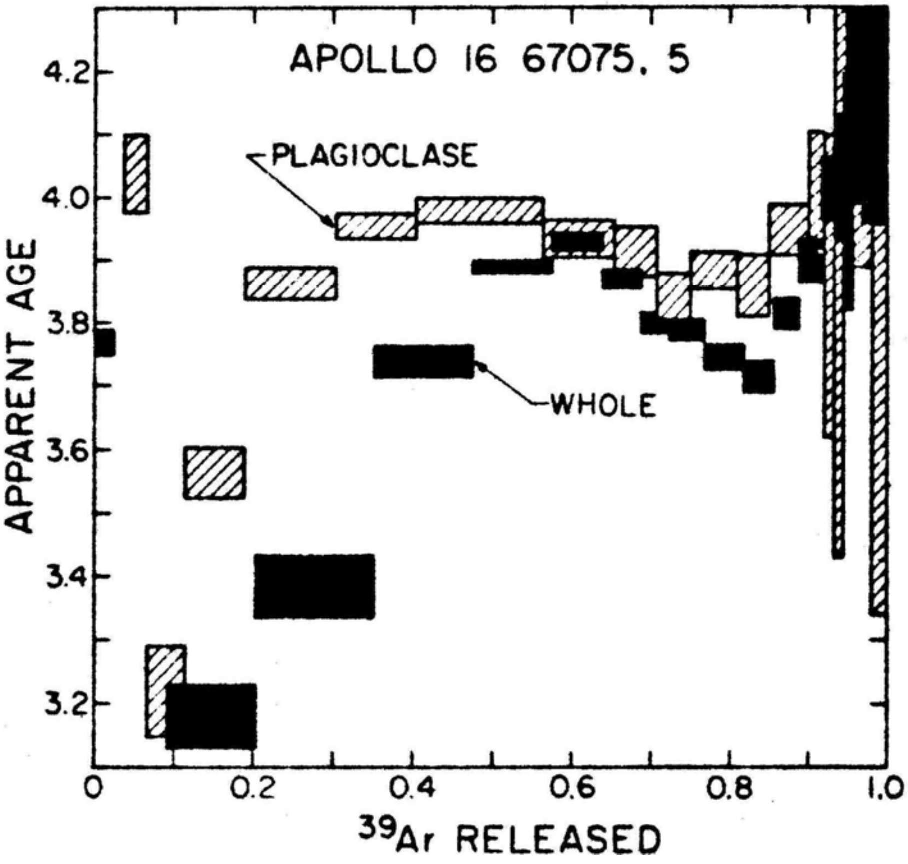


FIGURE 8. Ar releases, from Huneke et al. (1977).

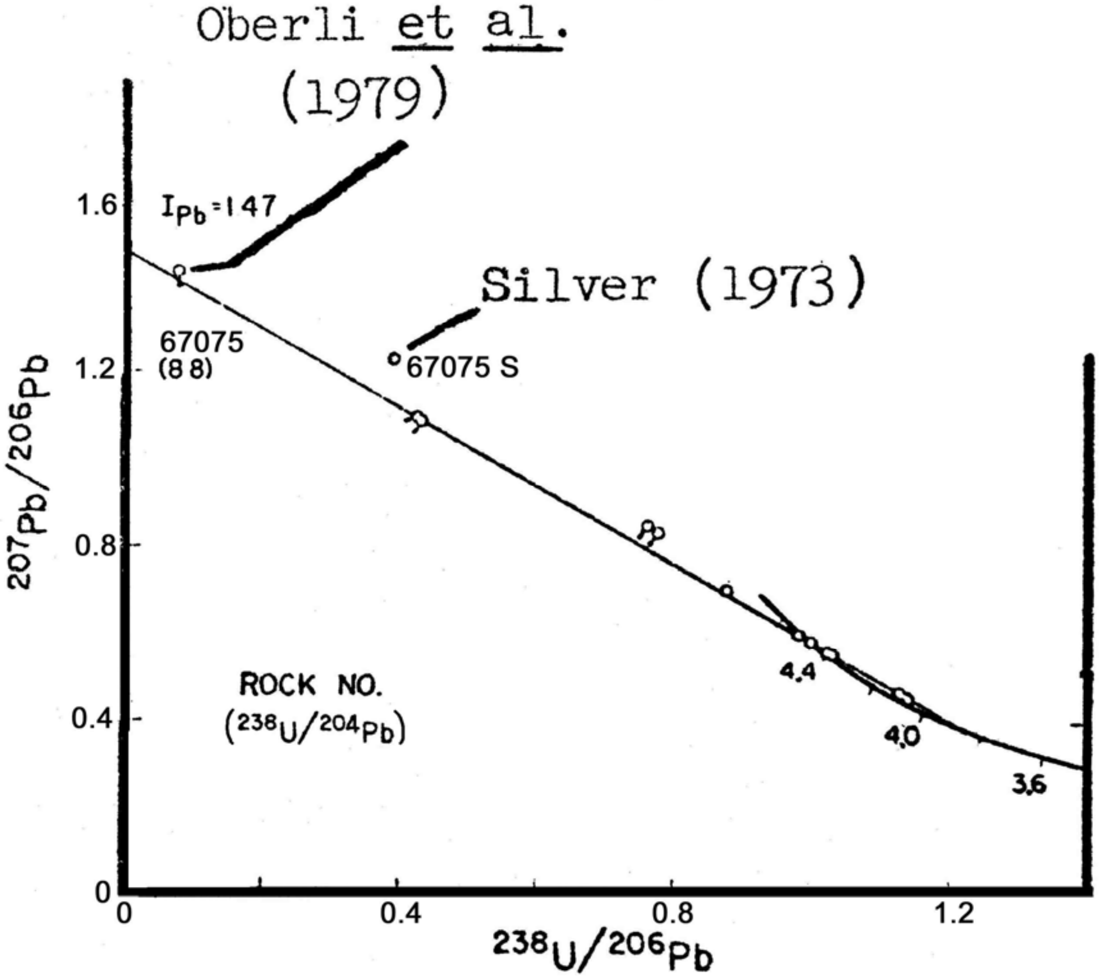


FIGURE 9. U-Pb isotopic data.