65015 POIKILITIC IMPACT MELT 1802 g

INTRODUCTION: 65015 is a clast-rich poikilitic impact melt that contains high abundances of incompatible elements and clasts of ancient, isotopically unequilibrated plagioclase. Macroscopically it is angular, homogeneous and very coherent (Fig. 1).

This sample was collected from the lower slope of Stone Mountain but the exact lunar orientation is unknown. An obvious soil line encircles the sample (Fig. 1).
Zap pits are abundant above this ring and absent below it indicating a relatively simple exposure history.

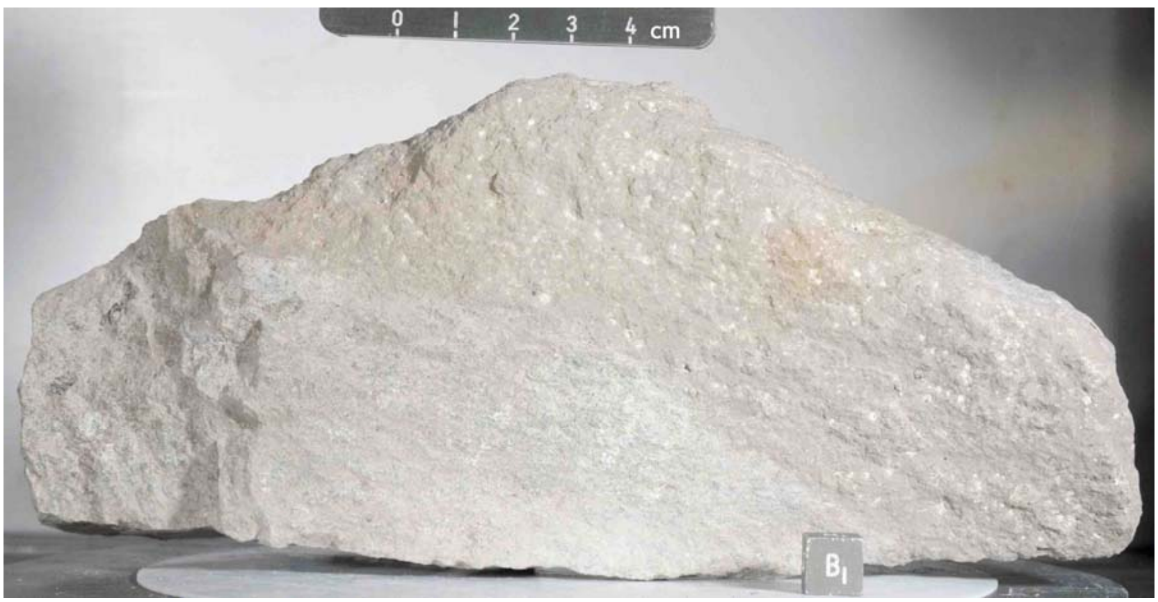


FIGURE 1. S-72-39211.

PETROLOGY: Petrographic descriptions are given by Albee et al. (1973), Simonds et al. (1973), McGee et al. (1979) and Vaniman and Papike (1981). 65015 is an impact melt characterized by a well developed poikilitic texture in which oikocrysts of pyroxene (low Ca >> high Ca) enclose abundant clasts (>100 μm) and chadacrysts (<100 μm) (Fig. 2). Modes are given in Table 1.

The groundmass comprises abundant: small (<100 μm) chadacrysts of plagioclase, olivine, high-Ca pyroxene, metal, and troilite enclosed by somewhat larger (up to ~1 mm) oikocrysts of pyroxene. X-ray crystallographic data on an augite-pigeonite crystal are given by Takeda (1973). Interoikocryst areas are K-rich and contain abundant accessory minerals such as whitlockite, ilmenite, metal and troilite. The larger clasts also tend to be concentrated in the interoikocryst regions.

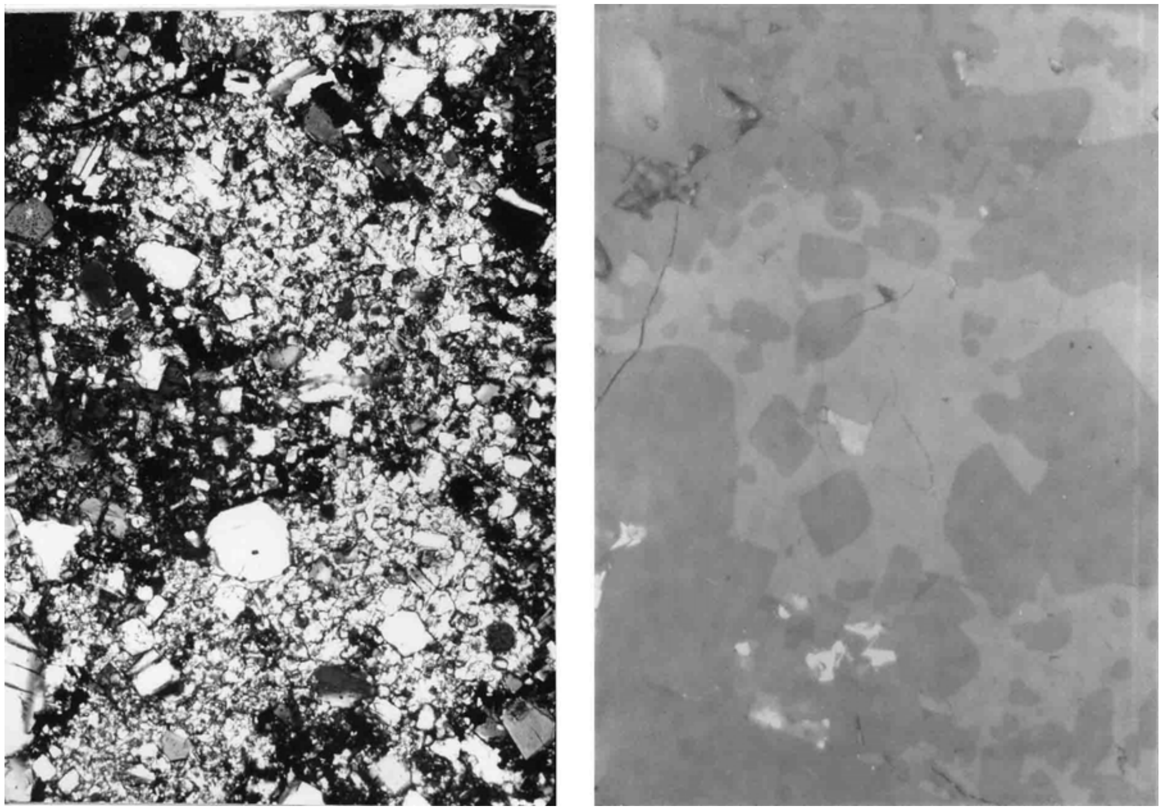


FIGURE 2. 65015,13. a) general view, xpl. Width 1 mm. b) rfl. Width 0.2 mm.

The clasts are predominantly angular fragments of plagioclase (up to ~0.5 mm) with subordinate amounts of olivine, high-Ca pyroxene, metal, granoblastic anorthosite, basaltic impact melt, noritic anorthosite, and devitrified maskelynite. Many of the plagioclase clasts are discontinuously rimmed by more sodic and more Fe-rich compositions (Figs. 3 and 4). Most of the olivine and high-Ca pyroxene clasts are embayed. From trace elements in the plagioclase clasts and chadacrysts, Meyer et al. (1974) and Meyer (1979) conclude that the clasts could not be in equilibrium with the bulk of the rock (Fig. 5 and Table 2). Metal occurs both as rounded clasts and as interoikocryst crystals, and is very homogeneous in composition (Fig. 6) (Albee et al., 1973; El Goresy et al.,1973a; Misra and Taylor, 1975).

This rock has been somewhat annealed but not as extensively as, for example, 64815. Clasts in 65015 tend to be quite angular and plagioclase chadacrysts, though somewhat rounded, clearly retain their euhedral shape (Fig. 2).

<u>EXPERIMENTAL PETROLOGY</u>: Taylor et al. (1976) performed subsolidus annealing experiments on 65015 to determine the change in composition and morphology of metal grains with time. Such annealing had little or no effect on the metal in this rock (Fig. 7) indicating that the metal was already largely equilibrated.

TABLE 1. Modes of 65015 (vol %).

	,83 (Albee et al., 1973)	(Simonds et al.,1973)
Plagioclase	57.1	61 (includes mesostasis)
Low-Ca pyroxene	28.9	29
High-Ca pyroxene	6.4	6
Olivine	1.1	1
Opaques	1.7	3
Ilmenite	1.2	
Fe-metal	0.4	
Troilite	0.1	
K-rich interstitial material	3.6	
Whitlockite	0.7	

TABLE 2. Minor elements in plagioclase determined by ion microprobe (Meyer et al., 1974; Meyer, 1979).

	Na_2O (%)	Li	Mg	K	Ti	Sr	Ba
Xenocrysts (12 analyses)	0.45	6	570	320	87	161	7
Xenocrysts (7 analyses)		4.2-8.6 avg.6.2	400-800 avg.610				
Chadacrysts (6 analyses)	0.43	5	380	400	78	170	35
Chadacrysts (1 analysis)	1.36	20	600	1000	360	450	183

All elements ppm except as noted.

CHEMISTRY: Abundant chemical data have been published for 65015, referenced in Table 3. Trace element abundances in accessory mineral phases are given by Lovering and Wark (1974), and Wasson et al. (1975) also report an analysis of a metal spherule taken from the rock.

Chemically, 65015 is similar to other KREEP-rich Apollo 16 impact melts, except that it is somewhat more aluminous than most (Table 4). Rare earth elements in 65015 are among the highest of any Apollo 16 rocks (Table 4, Fig. 8) and are only slightly less abundant than in Apollo 15 KREEP basalts 15382 and 15386. The high Zr and Hf abundances and the high Zr/Hf ratio are also typical of KREEP (Ehmann and Chyi, 1974; Garg and Ehmann, 1976). The high abundances of siderophile elements in 65015 (Table 4) indicate meteoritic contamination. Hertogen et at. (1977) assign 65015 to ancient meteoritic group 1H, a group largely restricted to the Apollo 16 site. Wasson et al. (1975) note that siderophile ratios of the bulk rock differ from those in a separated metal spherule (Table 4), implying incomplete equilibration between the metal and the rock. 65015 is depleted in volatiles, both in absolute abundances and relative to involatile elements (e.g. Tl/Cs) (Krahenbuhl et al., 1973; Jovanovic and Reed, 1973 and others).

Sato (1976) measured the oxygen fugacity of 65015 directly using the solidelectrolyte oxygen cell method. Self-reduction by as much as 1.5 log fO_2 units was observed during the first heating cycle. The values after the shift (Table 5) were reproducible in subsequent cycles.

TABLE 3. Chemical work on 65015 whole rock

Reference	Split #	Elements Analyzed
Janghorbani et al. (1973)	,54	Majors
Haskin et al. (1973)	,60	Majors, trace incl. rare earths
Hubbard et al. (1973)	,45	Majors, trace incl. rare earths
S.R. Taylor et al. (1973)	,62	Majors, trace incl. rare earths
Duncan et al. (1973)	,57	Majors, some trace
Baedecker et al. (1974 a,b)	,63	Fe, Sc, other trace incl. rare earths
Miller et al. (1974)	,54	Fe, Co, Sc, Cr, Eu, La
Ehmann and Chyi (1974)	,54	Zr, Hf
Boynton et al. (1975)	,63	Some majors and trace
Wasson et al. (1975)	,63	Trace, incl. siderophiles and rare earths
Wänke et al. (1976)	,133	Majors, trace (∼40 elements)
Wänke et al. (1977)	,133	V
Wasson et al. (1977)	,63	Majors, trace incl. rare earth and Co
Krähenbühl et al. (1973)	,51	Meteoritic siderophiles and volatiles
Hughes et al. (1973)	,44	Meteoritic siderophiles and volatiles
Jovanovic and Reed (1973)	,32	U, Li, Cl, Br, I, Hf
Jovanovic and Reed (1976a)	,32	Ru, Os
Jovanovic and Reed (1976b)	,32	Cl, P, F, U
Jovanovic and Reed (1977)	,32	Hg
Reed et al. (1977)	,32	Volatilized Tl, Zn
Kerridge et al. (1975b)	,64	C, S
Des Marais (1978)	,174	C, N, S
Nyquist et al. (1973)	,45	Rb, Sr
Kirsten et al. (1973)	,61	Ca, K
Nunes et al. (1973)	,52	U, Th, Pb
Jessberger et al. (1974)	,56	Ca, K
Tera et al. (1973,1974)	,56	K, U, Th, Pb
Papanastassiou and Wasserburg (1972b)	,56	Rb, Sr

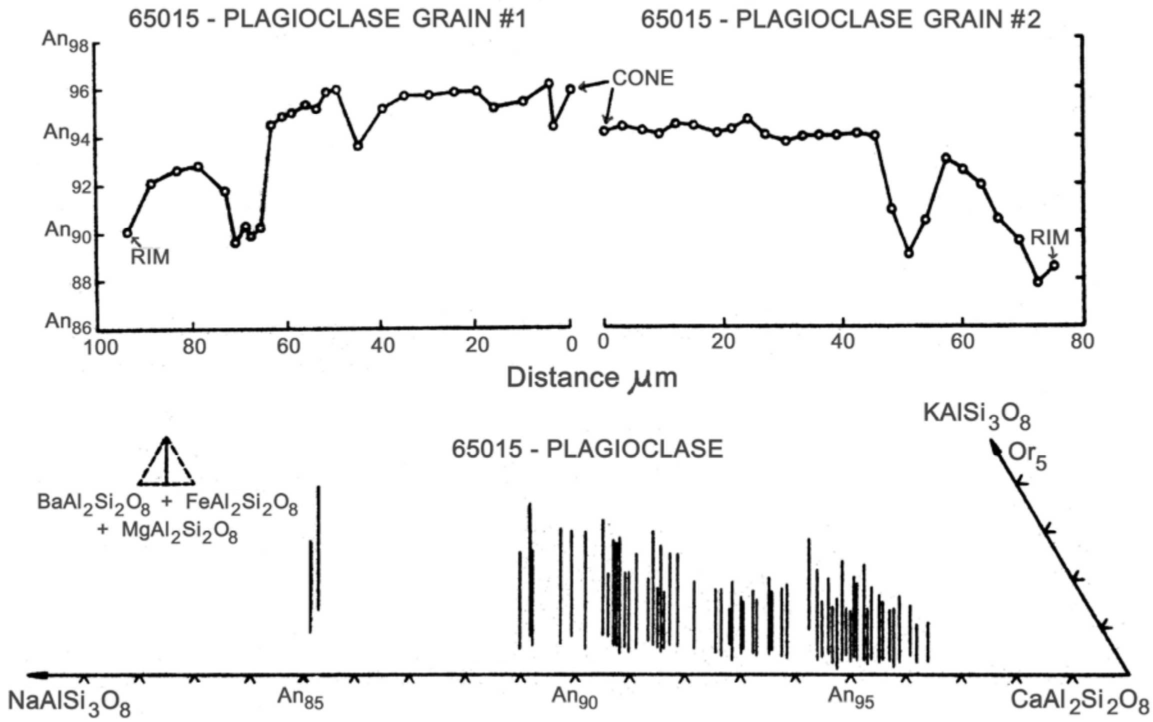


FIGURE 3a. Plagioclase compositions; from Albee et al.(1973).

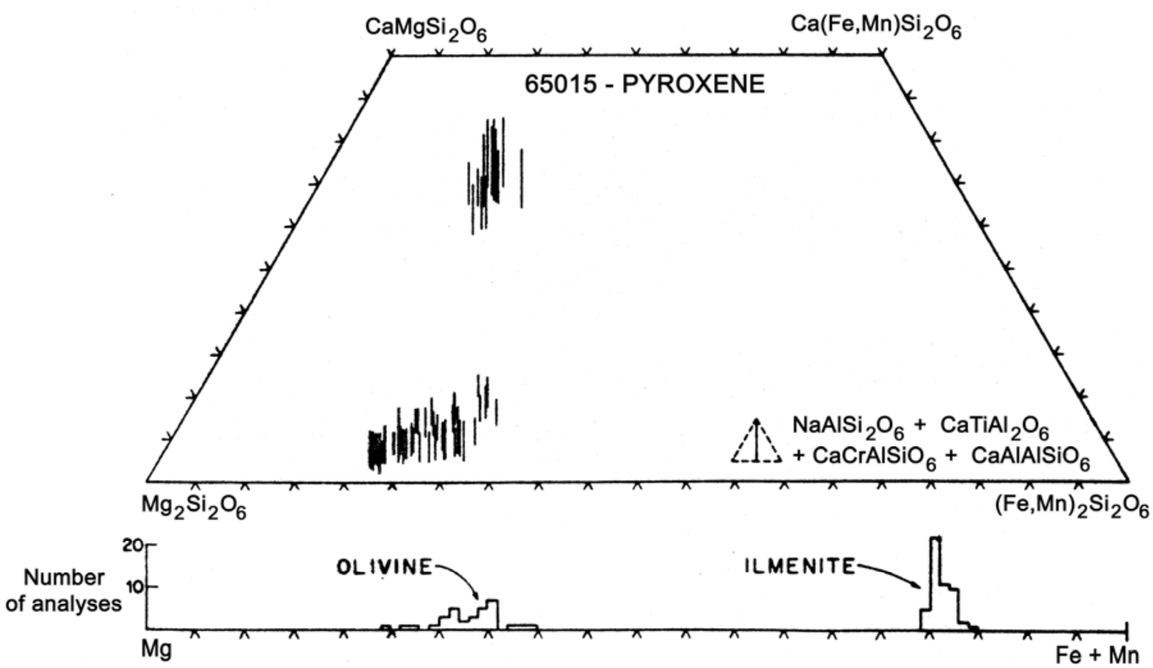


FIGURE 3b. Mafic mineral compositions; from Albee et al. (1973).

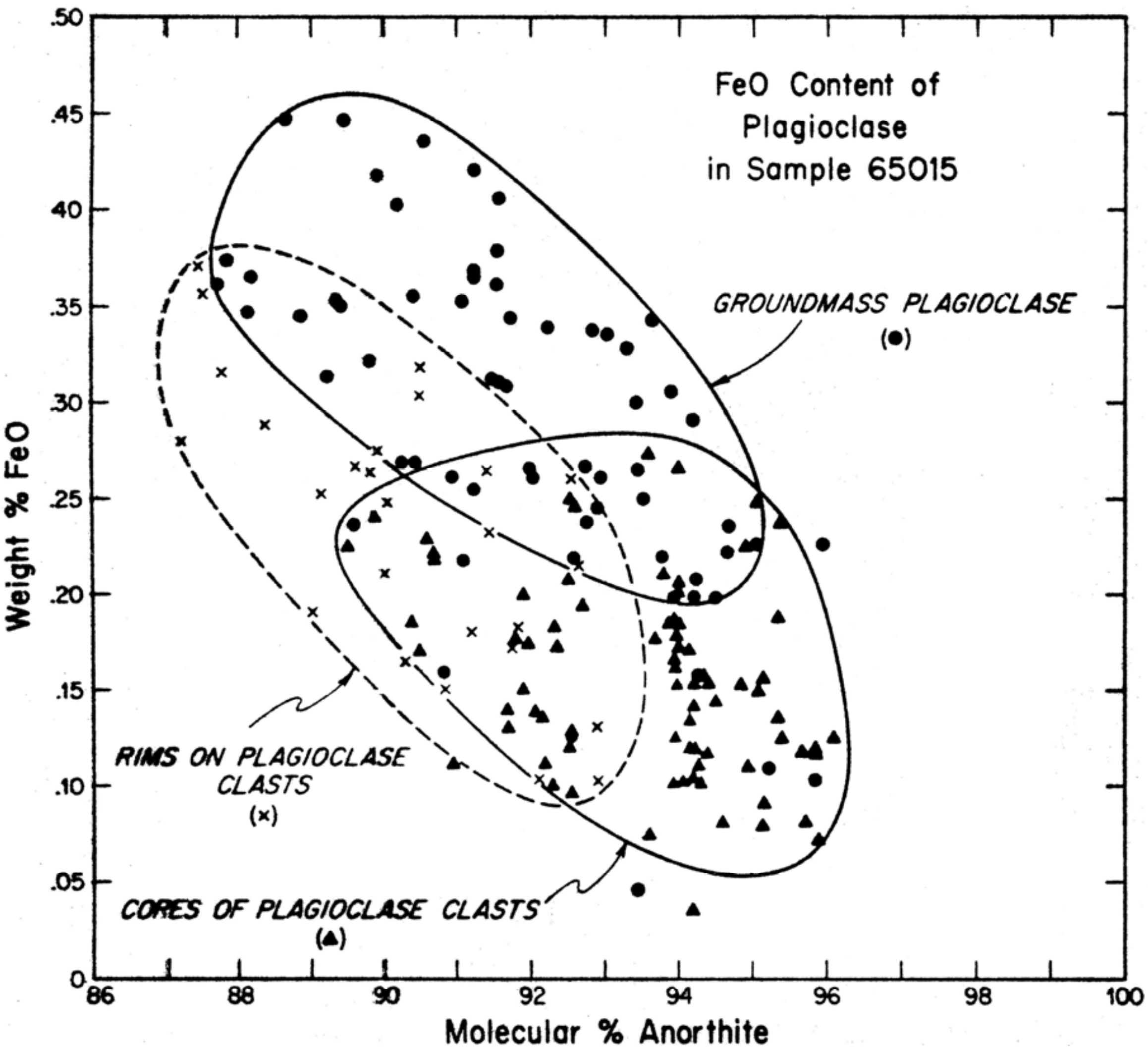


FIGURE 4. FeO in plagioclase; from Albee et al. (1975).

TABLE 5. Average oxygen fugacity values of 65015.

T (^{o}C)	-log fO_2 (atm)
1000	17.0
1050	16.3
1100	15.6
1150	14.9
1200	14.1

STABLE ISOTOPES: Kerridge et al. (1975b) provide whole rock C and S isotopic data, Taylor and Epstein (1973) report O and Si isotope data for the whole rock and mineral separates and Clayton et al. (1973) give O isotope data for mineral separates (Table 6).

From the lack of δO^{18} enrichment commonly found in lunar soils, Taylor and Epstein (1973) conclude that 65015 must have formed from material without a significant surface exposure history. Clayton et al. (1973) calculate a temperature of equilibration of 1020° C from the isotopic-fractionation between plagioclase and ilmenite.

TABLE 6. Stable isotope abundances in 65015 (all values °/oo).

Sample	δC^{13}	δS^{34}	δO^{18}	δSi^{30}
whole rock	-16.7	+1.8	+5.94	-0.02
high-Ca pyroxene			+5.71	-0.22
low-Ca pyroxene			+5.63	-0.13
plagioclase			+6.04	-0.04
			+5.76	
ilmenite			+3.8	

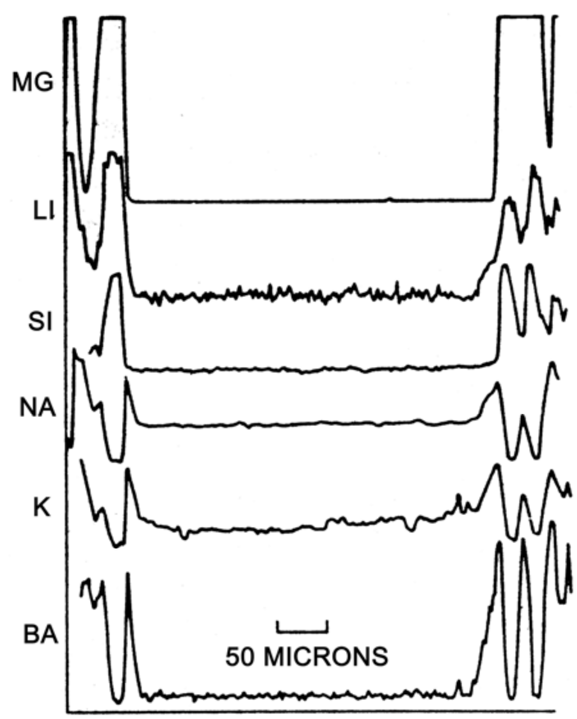


FIGURE 5. Minor elements in plagioclase inclusion; from Meyer (1979).

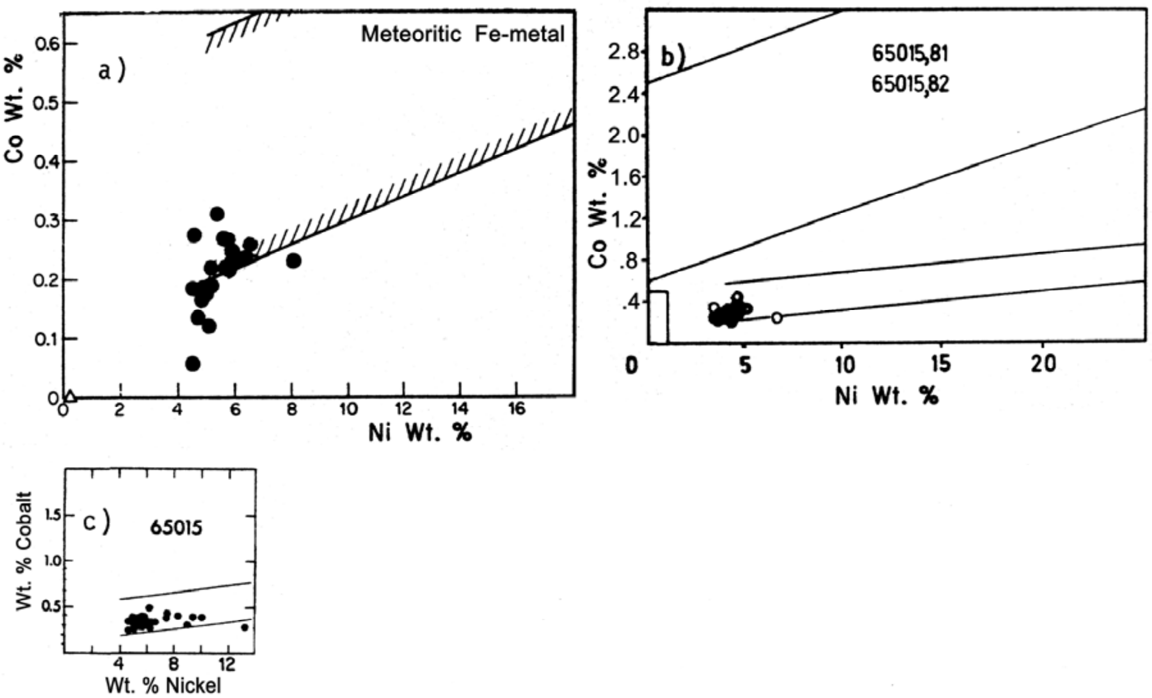


FIGURE 6. Metals. a) from Albee et al.(1973).
b) from El Goresy et al. (1973a). c) from Misra and Taylor (1975).

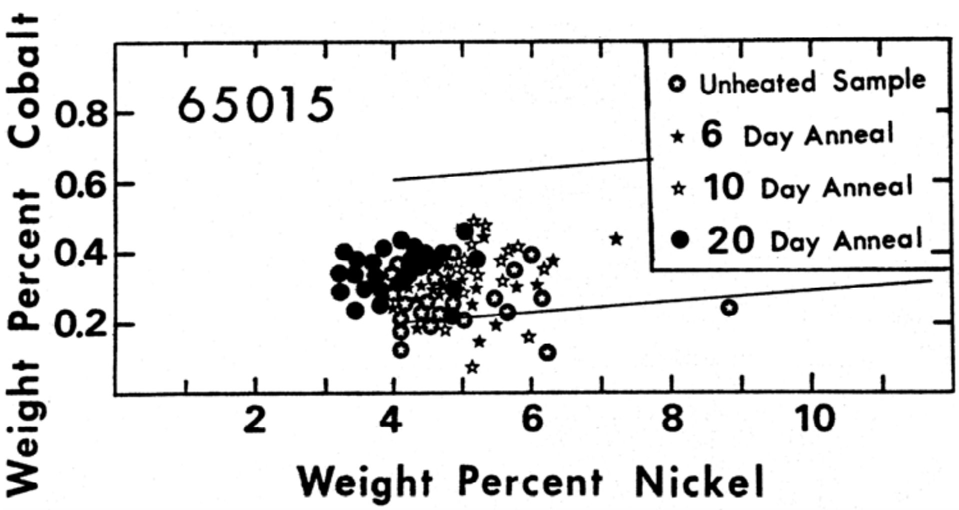


FIGURE 7. From L.A. Taylor et al. (1976).

TABLE 4. Summary chemistry of 65015.

	Bulk rock	Metal spherule
SiO_2	47.5	
TiO_2	1.18	
Al_2O_3	20.0	
Cr_2O_3	0.20	
FeO	8.4	
MnO	0.12	
MgO	9.8	
CaO	12.0	
Na_2O	0.56	
K_2O	0.350	
P_2O_5	0.40	
Sr	158	
La	56.9	
Lu	2.64	
Rb	9.0	
Sc	14.8	
Ni	185-730	56,700
Co	~35	
Ir ppb	12.6	990
Au ppb	10.3	1,070
C	10(?)	
N	0.7	
S	~975	
Zn	0.9	3.2
Cu	4.5	

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

<u>RADIOGENIC ISOTOPES AND GEOCHRONOLOGY</u>: Extensive geochronological work has been performed on 65015. All of the systems indicate a major disturbance 3.9 - 4.0 b.y. ago, which is most simply interpreted as the age of the crystallization of 65015 from an impact melt. Rb-Sr and Ar systematics indicate incomplete equilibration between some plagioclase clasts and the matrix, consistent with ion microprobe data (Meyer et al., 1974).

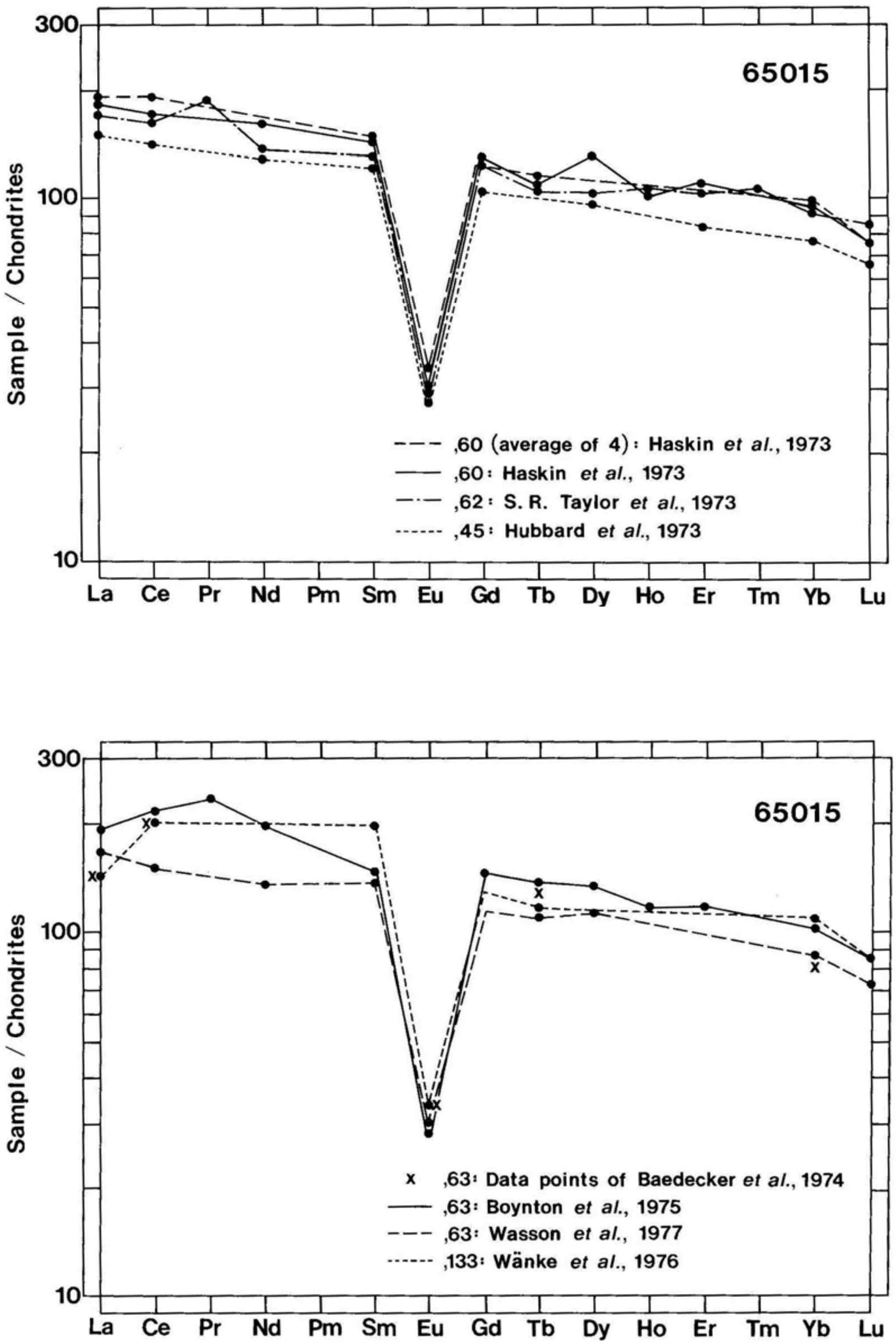


FIGURE 8. Rare earth elements.

Rb-Sr data have been determined on whole rock and mineral separates by Papanastassiou and Wasserburg (1972b) and Tera et al. (1973) and on a whole rock sample by Nyquist et al. (1973) (Table 7). These data reveal the presence of ancient, isotopically unequilibrated clasts of plagioclase (Papanastassiou and Wasserburg, 1972b). Three separates of xenocrystic plagioclase fall distinctly below a 3.93 ± 0.02 b.y. isochron defined by whole rock and "quintessence" separates, and on a mixing line with BABI (Fig. 9). If 65015 remained a closed system during the 3.9 - 4.0 b.y. disturbance, then an isochron connecting the most primitive clasts with the whole rock separates yields the time of crystallization of the rock. Such an isochron gives an age of 4.42 ± 0.04 b.y. with I = 0.69917 ± 8. However it seems likely that the 3.93 b.y. age obtained from the whole rock and "quintessence" splits actually dates the time of crystallization of 65015 from an impact melt and the requirement for a closed system probably cannot be met. Thus the 4.42 b.y. "primary" age probably has no real geochronological significance.

Sm-Nd data on a whole rock chip are reported by Lugmair and Carlson (1978) (Table 8). No large plagioclase xenocrysts were present in this chip so the sample is considered representative of the fine-grained matrix. The Sm-Nd isotopic systematics of 65015 are very similar to those of the KREEP-rich samples from other landing sites (Fig. 10). The light REE enrichment characteristic of 65015 (and other KREEP-rich samples) was established well before the 3.9 - 4.0 b.y. disturbance and could not have been produced by partial melting at this time (Lugmair and Carlson, 1978).

TABLE 7. Rb-Sr isotopic data for 65015.

Sample	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$ measured	T_{BABI} (b.y.)	Reference
whole rock A	0.1629±7	0.70945±5	4.48±0.03	Papanastassiou and Wasserburg (1972b)
whole rock B	0.1504±6	0.70874±8	4.52±0.04	
Plagioclase A	0.02574±10	0.70080±6		
Plagioclase B	0.0900±4	0.70520±6		
Plagioclase C	0.0972±6	0.70561±5		
Quintessence	0.981±4	0.75542±10	4.02±0.02	
Plagioclase M	0.00242	0.69920±7		Tera *et al.* (1973)
Plagioclase	0.02919	0.70110±12		
Pyroxene L	0.03555	0.70240±10		
"Phosphates"A	0.05703	0.70348±5		
Ilmenite	0.2019	0.71163±7		
Quintessence	0.998	0.75607±11		
whole rock	0.1606±12	0.70935±6	4.45±0.06	Nyquist *et al.* (1973)

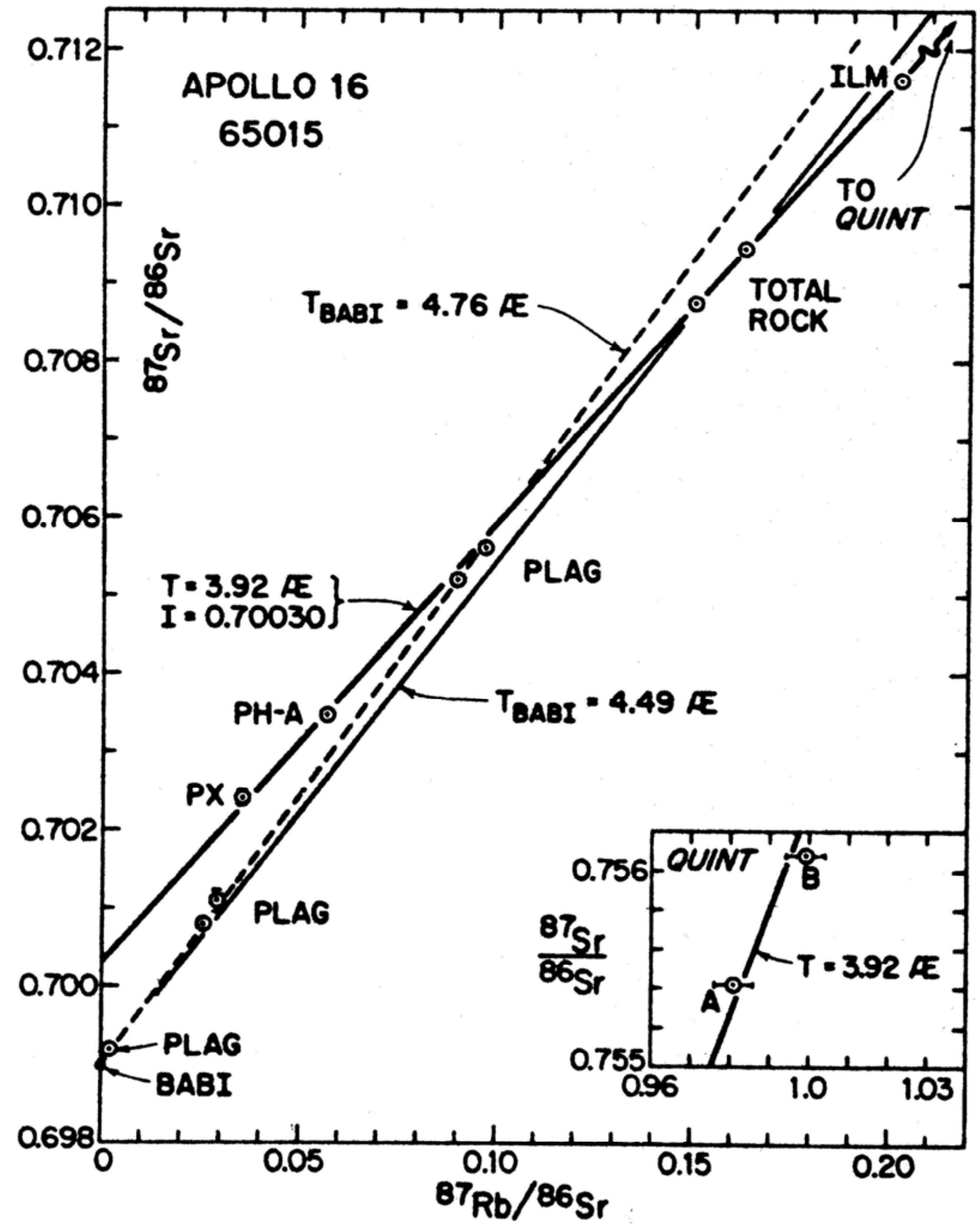


FIGURE 9. Rb-Sr; from Tera et al, (1973).

Ar-Ar data on whole rock splits yield a plateau age of 3.92 ± 0.04 b.y. (Kirsten et al., 1973) (Fig. 11) and total Ar ages of 3.81 ± 0.06 b.y. (Kirsten et al., 1973) and 3.852 ± 0.005 b.y. (Jessberger et al., 1974). Jessberger et al. (1974) also report Ar isotopic data on separates (of varying purity) of plagioclase, pyroxene, and "phosphates," some of which have also been analyzed for Rb-Sr (Papanastassiou and Wasserburg, 1972b). Ar data on the purest plagioclase separate give a well defined, intermediate temperature plateau age of 3.98 b.y. At higher temperatures the apparent age of this separate rises to

4.47 b.y., confirming the presence of ancient, isotopically unequilibrated clasts (Figs. 12 and 13). The pyroxene and "phosphate" separates and the whole rock split did not show such evidence for ancient clasts but did show anomalous decreases in apparent age at high temperatures (Figs. 13, 14, and 15). Huneke and Smith (1976) interpret these anomalous release patterns as resulting from the recoil transfer of significant ^{39}Ar from K-rich areas of the rock to surrounding mafic minerals.

TABLE 8. Sm-Nd isotopic data for 65015 (Lugmair and Carlson, 1978).

Sample	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	T_{ICE} (b.y.)	T_{JUV} (b.y.)
65015,31	27.96	101.0	0.1673	0.511883±19	4.32±0.12	4.60±0.02

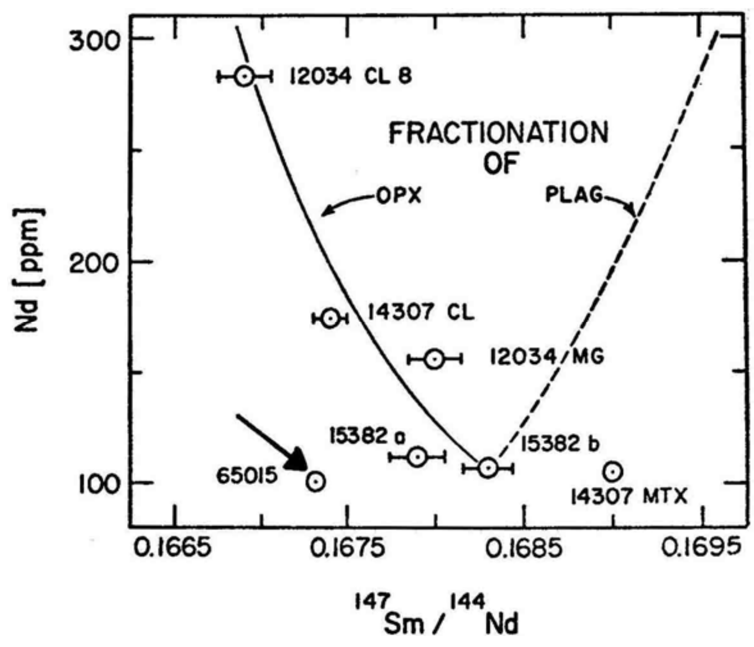


FIGURE 10. Sm-Nd; from Lugmair and Carlson (1978).

Schaeffer et al. (1979) report total K-Ar laser ages of the matrix of 3.87 ± 0.01 and 3.82 ± 0.01 b.y. and laser ages of 3.73 - 3.94 b.y. for plagioclase clasts. These authors also discuss blank problems which cast some doubt on their earlier results (Schaeffer et al., 1978) which seemed to indicate the presence of plagioclase clasts with ages up to 4.5 b.y.

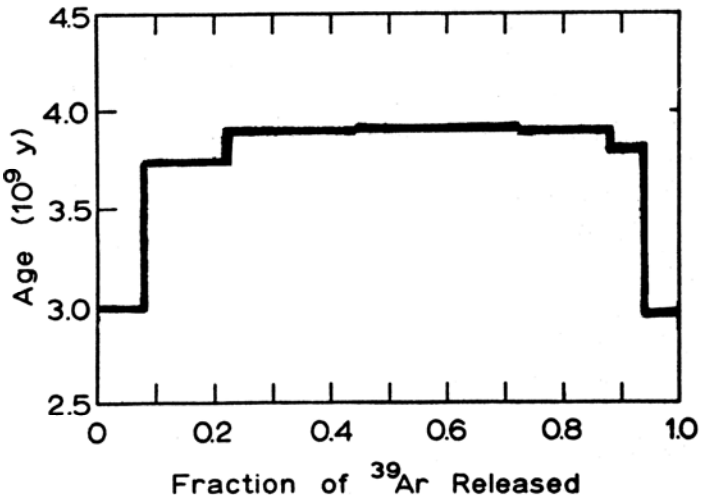


FIGURE 11. Ar-Ar release, whole rock; from Kirsten et al.(1973).

U-Th-Pb isotopic data are given by Tera et al. (1973,1974) for whole rock and plagioclase separates and by Nunes et al. (1973) for a whole rock sample. 65015 is very rich in U and Th and its Pb is very radiogenic. Both whole rock analyses are concordant at 3.99 b.y. (Fig. 16).

RARE GAS/EXPOSURE AGE: From track profiles Bhandari et al. (1973) determined that 65015 spent 1.2 m.y. at the lunar surface and 50 m.y. within the upper 10 cm of the regolith. This contrasts with ^{38}Ar exposure ages of 365 m.y. calculated by Kirsten et al. (1973) and 460 - 490 m.y. calculated by Jessberger et al. (1974) for the whole rock and mineral separates.

PHYSICAL PROPERTIES: Brecher (1977) finds that the directional magnetic properties of 65015 are correlated with one of two major planes of observed fractures. Other room temperature magnetic data are given by Stephenson et al. (1977).

Elastic properties at confining pressures up to 5 kb are provided by Todd et al. (1973). Electrical parameters (Fig. 17) are reported by Olhoeft et al. (1973) and Alvarez (1977). Todd et al. (1973) also compare the calculated and measured values of the mean volume thermal expansion coefficient of 65015. The calculated values are less than those measured due to cracks and fractures in the rock into which mineral grains can expand.

On the basis of electron spin resonance (ESR) studies, Tsay and Live (1974) conclude that 65015 has been annealed at ~1000°C (Fig. 18).

Hapke et al. (1978) provide ultraviolet reflectance spectra for a split of 65015 ground to <74 μm, but list the sample as 65016.

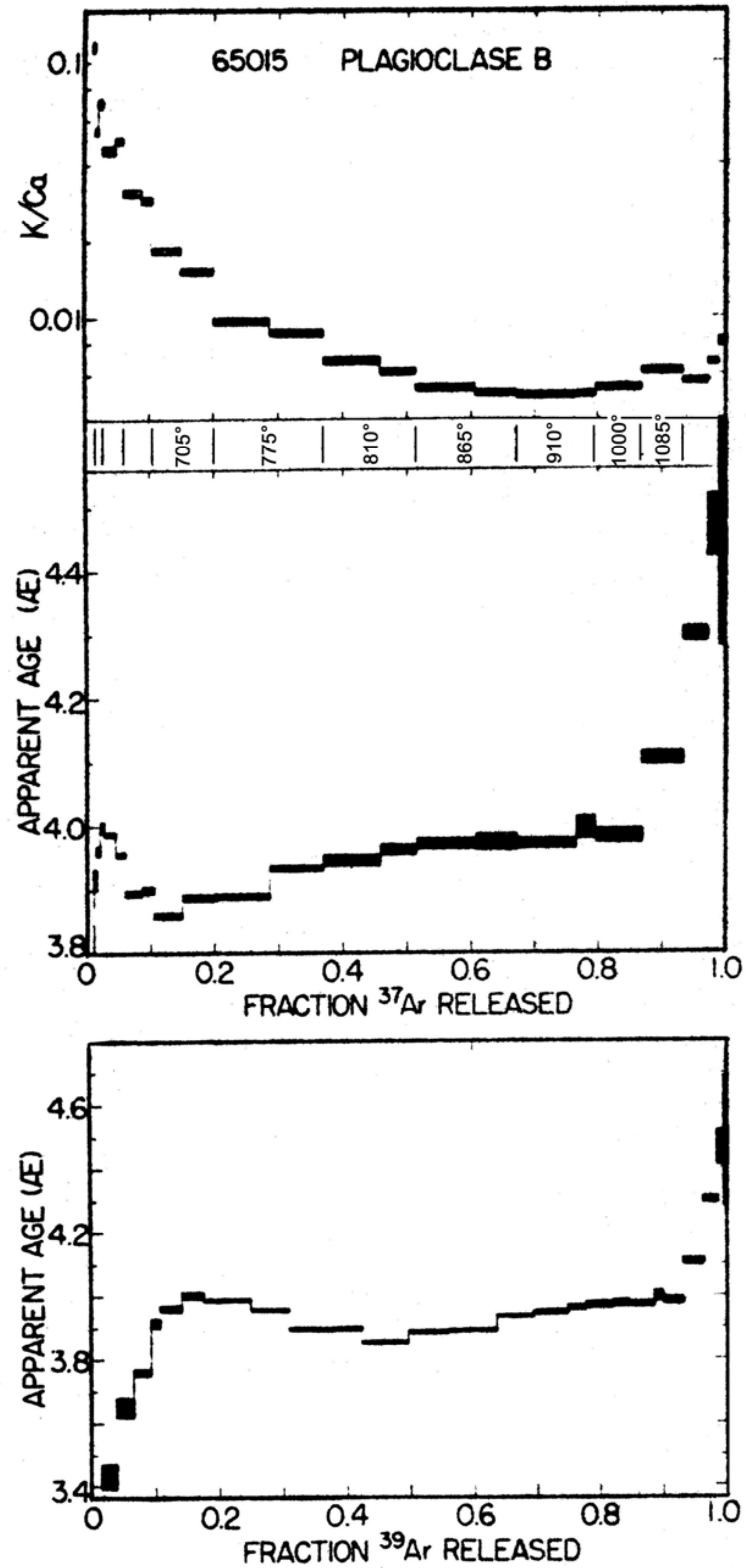


FIGURE 12. Ar-Ar release, plagioclase; from Jessberger et al. (1974).

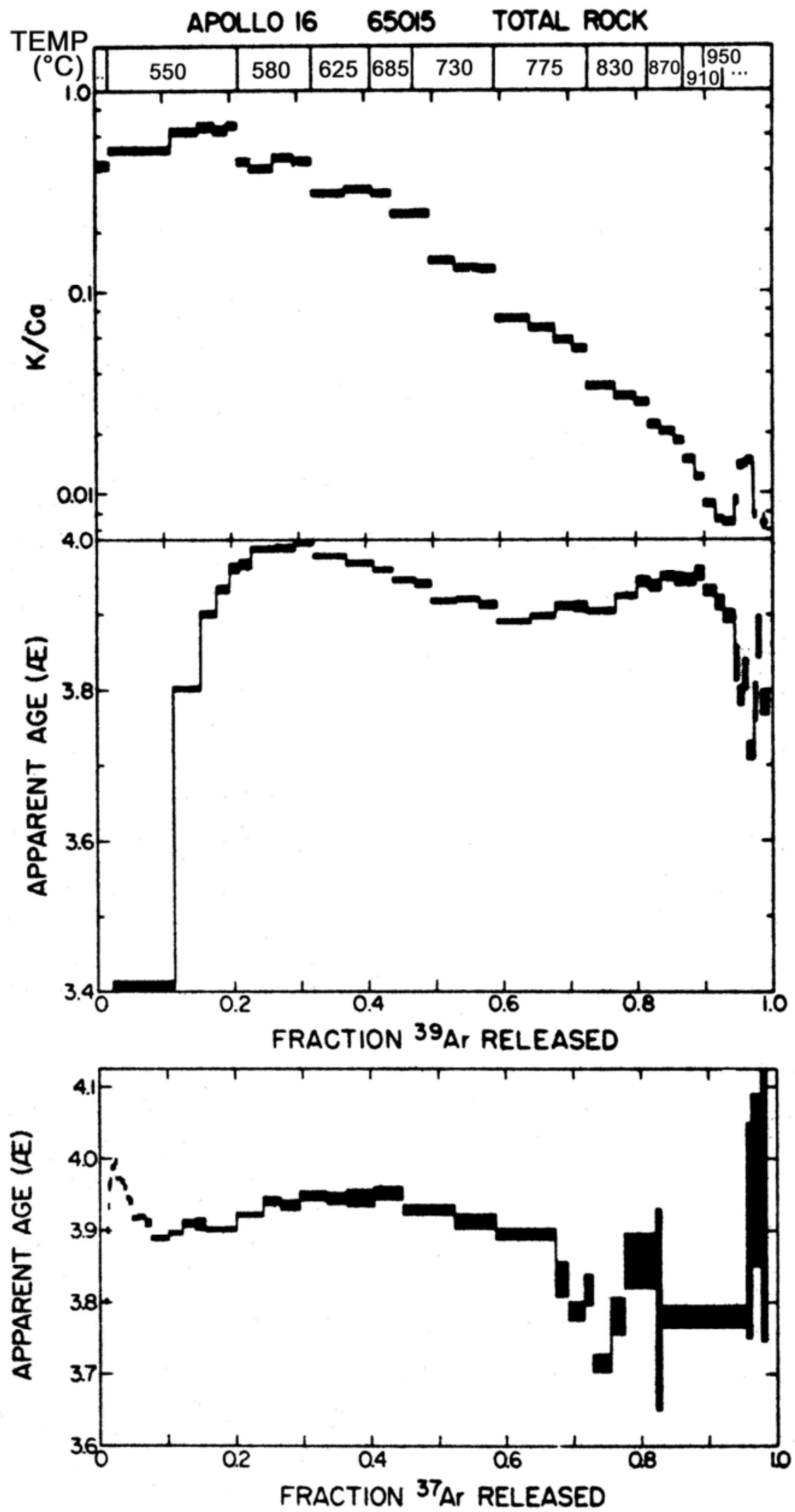


FIGURE 13. Ar-Ar release, whole rock; from Jessberger et al. (1974).

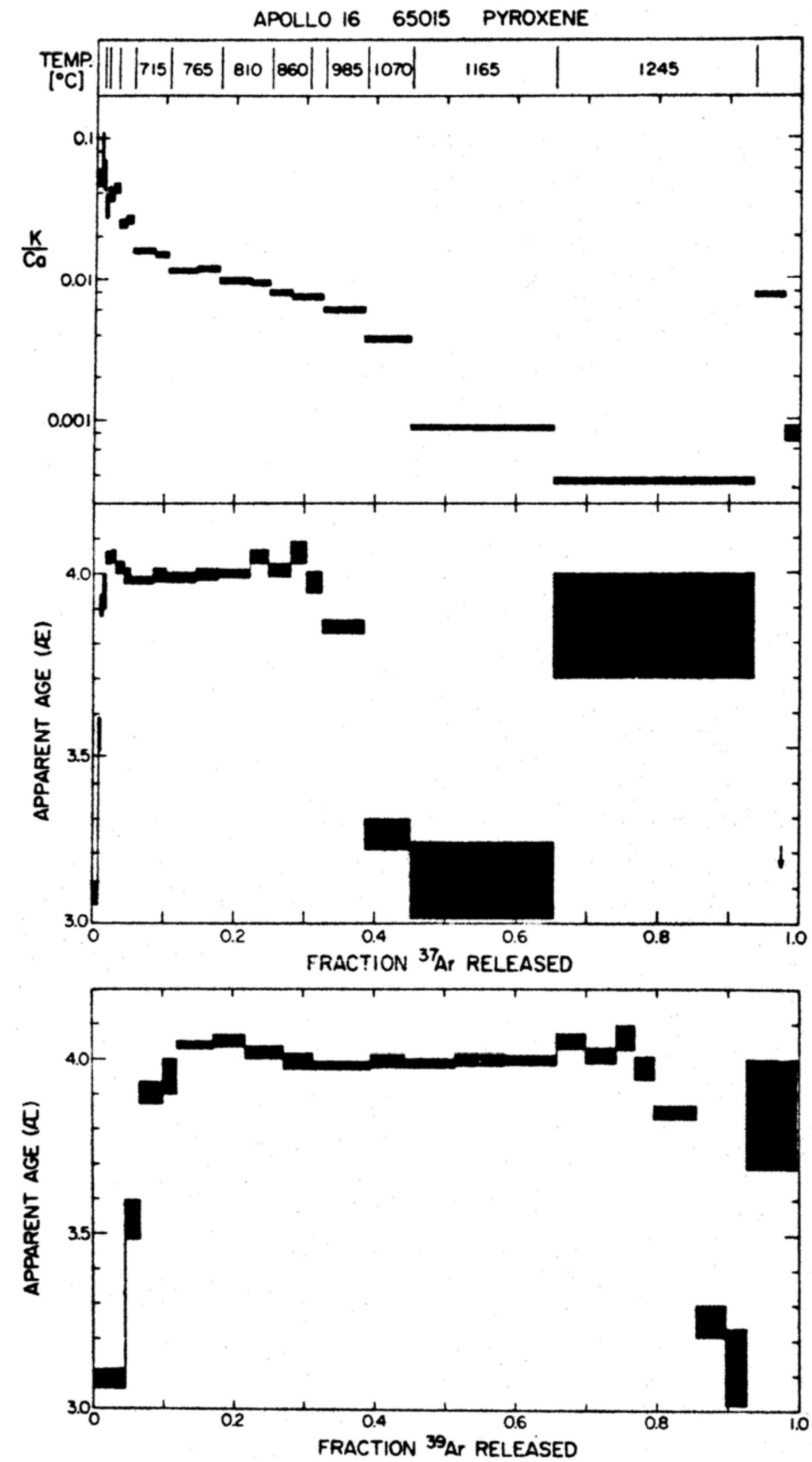


FIGURE 14. Ar-Ar release, pyroxene; from Jessberger et al. (1974).

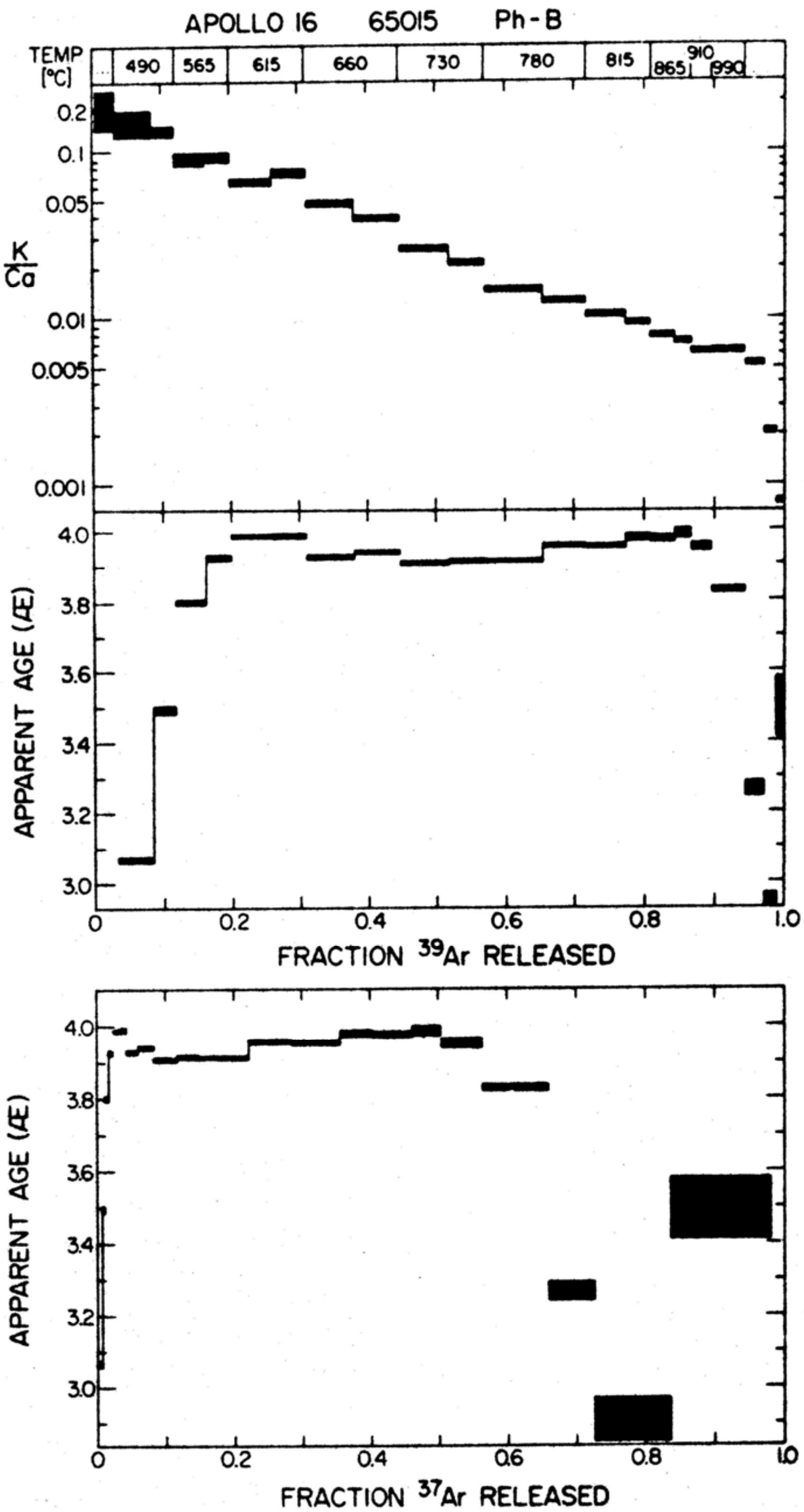


FIGURE 15. Ar-Ar release, mixed phases; from Jessberger et al. (1974).

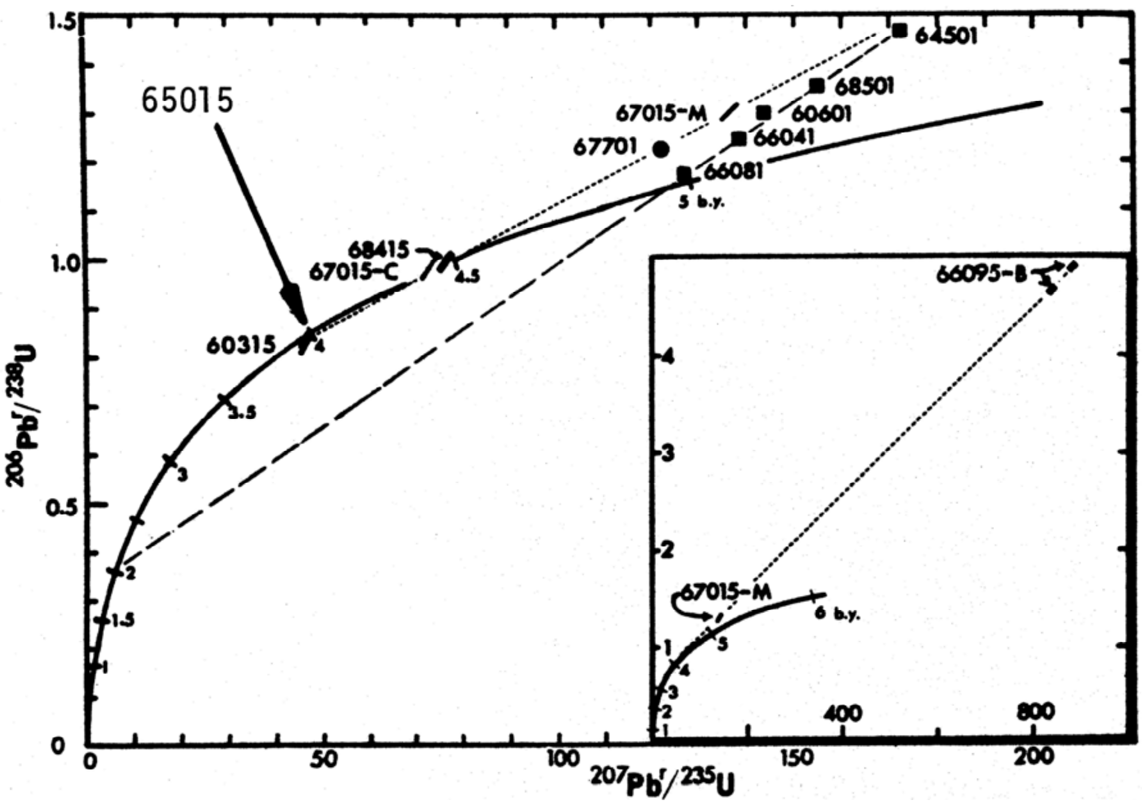
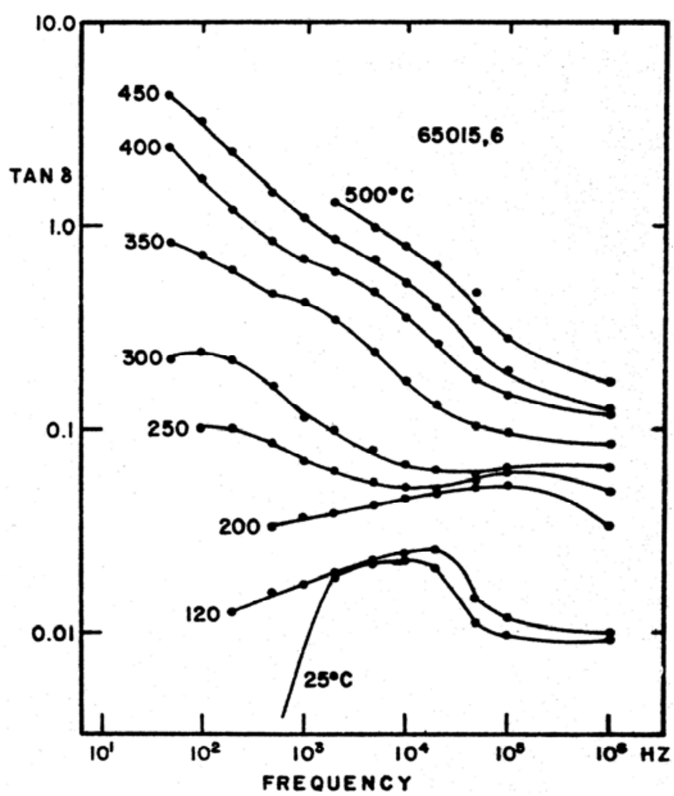


FIGURE 16. U-Pb Concordia; from Nunes et al. (1973).



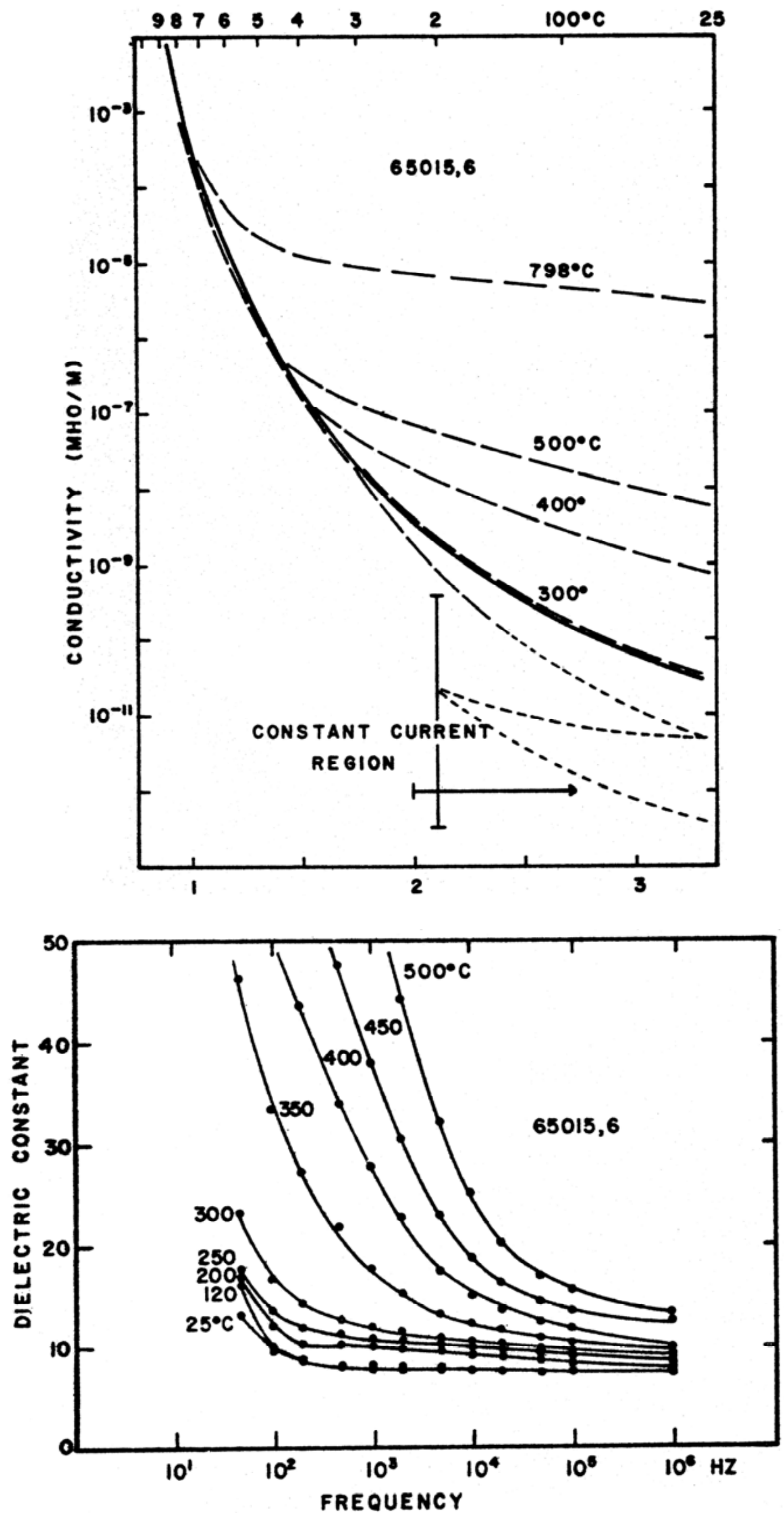


FIGURE 17. Electrical characteristics; from Olhoeft et al. (1973).

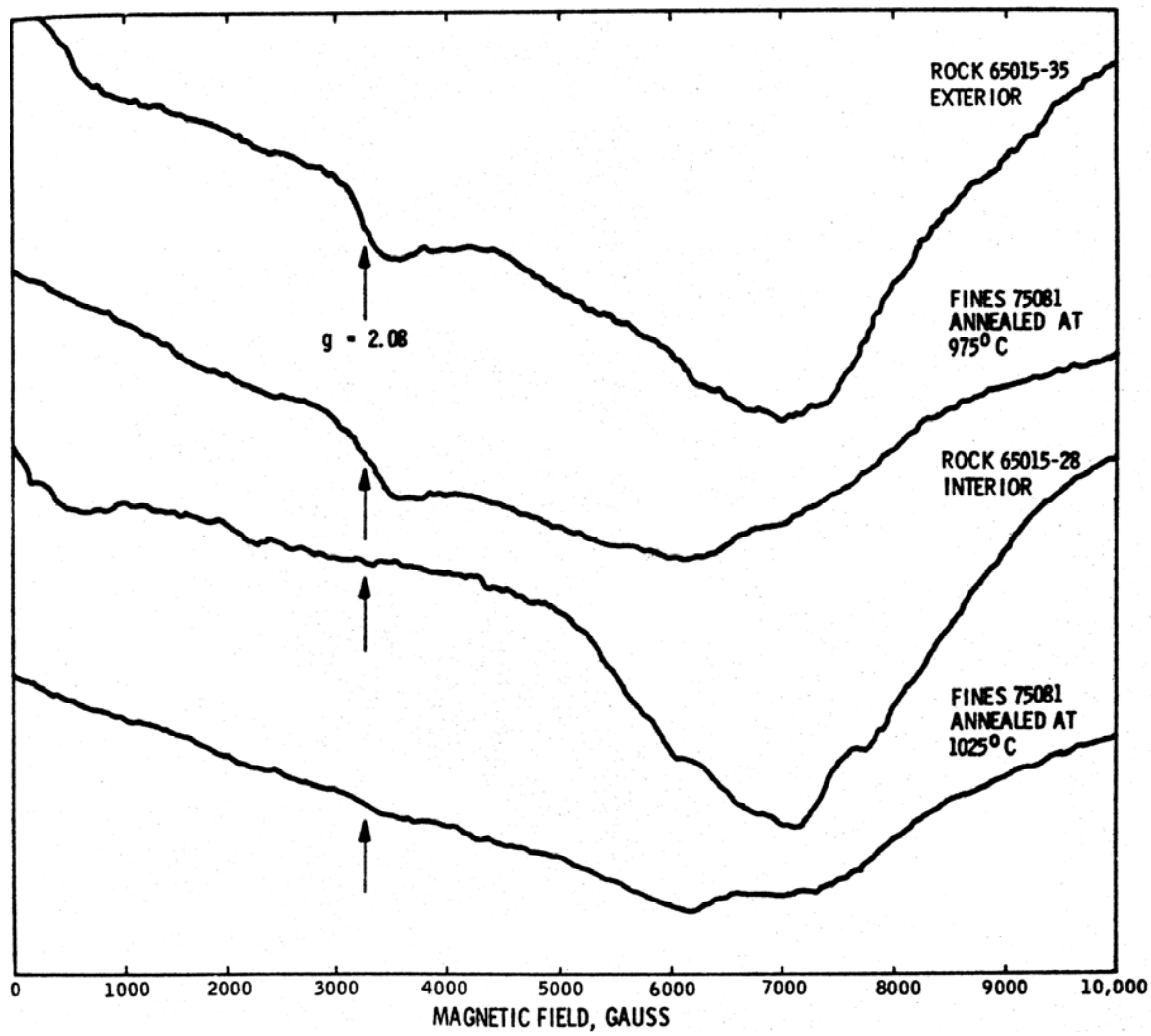


FIGURE 18. Electron spin resonance;
from Tsay and Live (1974).

<u>PROCESSING AND SUBDIVISIONS</u>: 65015 has been extensively split and widely allocated. In 1972 it was cut into three main pieces including a slab (Figs. 19 and 20). The slab and the W butt end were subdivided for allocations. Many documented and undocumented pieces of all sizes exist. The largest single pieces in existence are ,25 (1322.3 g) and ,73 (215.2 g).

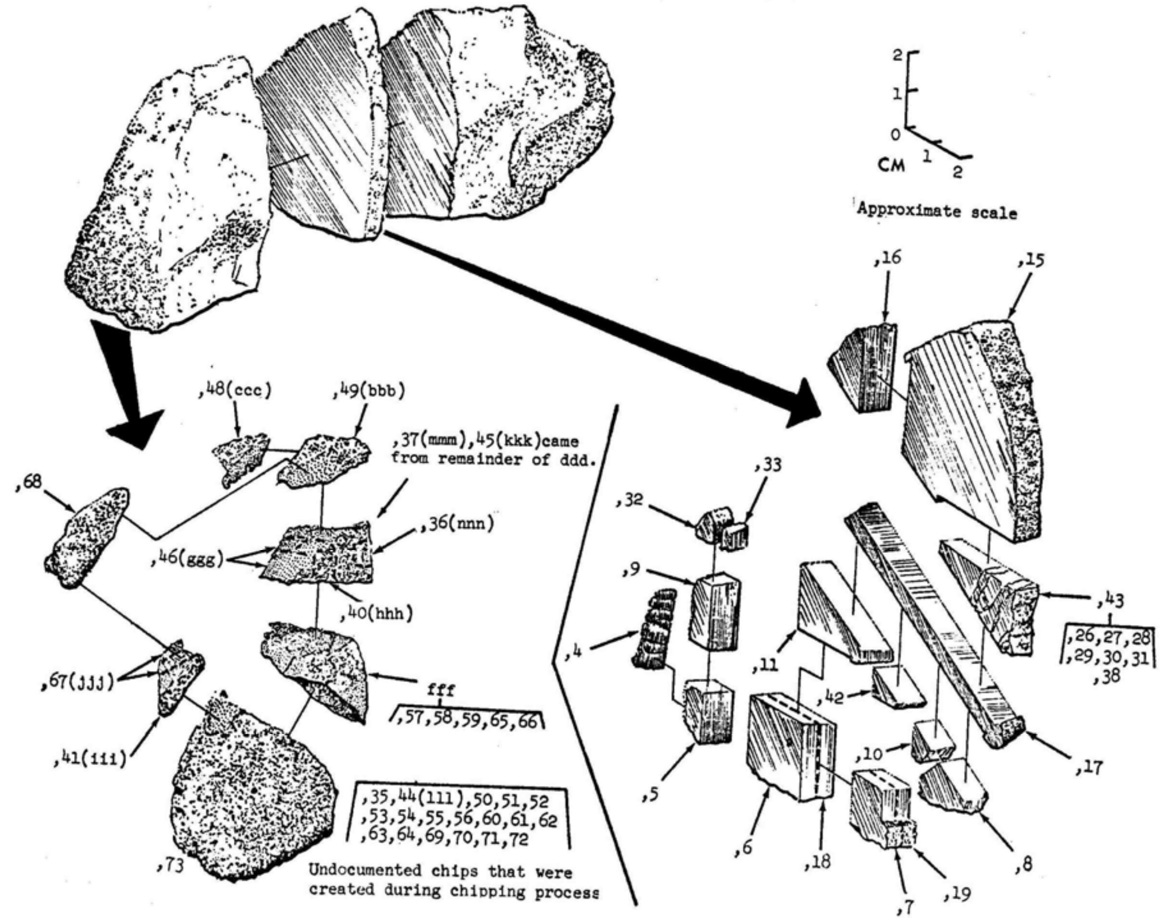


FIGURE 19. Cutting diagram.

FIGURE 20. Slab subdivision. Cube has 1 cm sides. S-72-47359.