70215

High-Ti Mare Basalt
8110 g, 23 x 13 x 10.5 cm

INTRODUCTION

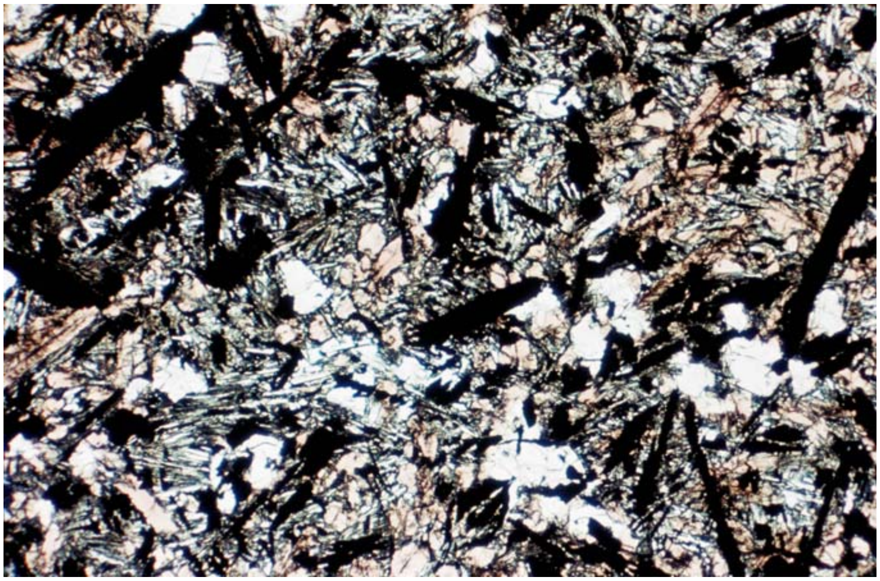
70215 was described as a medium dark gray (with a brownish tint), fine-grained basalt (Fig. 1), containing zap pits on all faces and rare vugs up to 3mm in diameter (Apollo 17 Lunar Sample Information Catalog, 1973). These vugs contain projecting plates and prisms of ilmenite and pyroxene. The fabric is intersertal to intergranular and the shape blocky to subangular with one flat surface. Surface T is slickensided, This sample was collected approximately 60m east of the Lunar Module.

PETROGRAPHY AND MINERAL CHEMISTRY

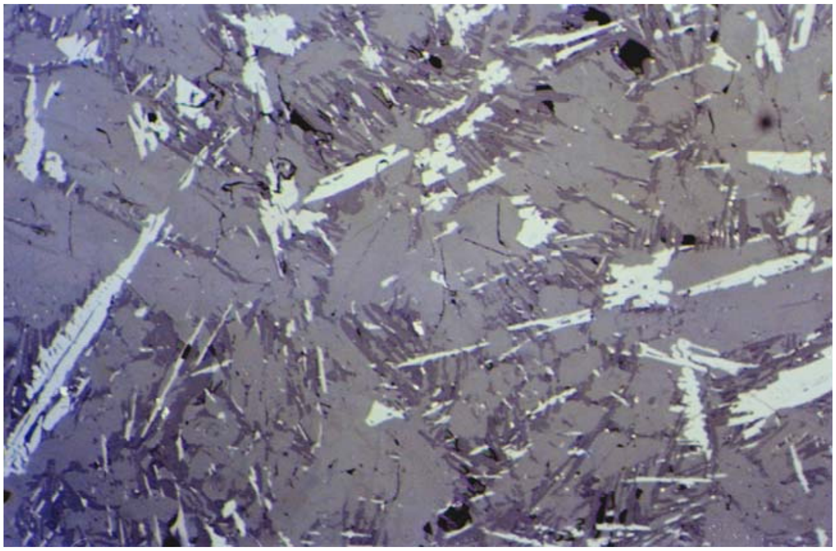
Wilshire (Apollo 17 Lunar Sample Information Catalog, 1973) described 70215,7 as a fine-grained, sub-variolitic basalt with microphenocrysts of ilmenite, olivine, and clinopyroxene (Fig. 2ab). Sheafs of plagioclase laths are locally developed. Phenocrysts make up 52% of this thin section. Rutile and chromite exsolution lamellae (< 0.005mm) occur in ilmenite, and ilmenite lamellae occur in ulvospinel. Ilmenite also occurs as rims on ulvospinel.

Longhi et al. (1974) described thin section 70215,149 as a spherulitic, fine-grained, high-Ti basalt with a texture suggesting disequilibrium crystallization during a period of rapid cooling. These authors reported a mode of 7% olivine, 42% clinopyroxene, 29% plagioclase, 18% opaque

Figure 1: Hand specimen photograph of 70215,0.



2a: Transmitted light.



2b: Reflected light.

Figure 2: Photomicrographs of 70215. Fields of view in both cases are 2.5 mm.

minerals (mostly ilmenite), and 4% silica phase. Two textural domains exist. In the first, olivine and ilmenite phenocrysts (containing numerous inclusions) are set in a groundmass of smaller olivines, ilmenites, and 0.3mm "bowtie" spherulites of clinopyroxene and plagioclase. Interstitial silica, native Fe, and troilite are present. In the second, coarser domain, ilmenite and pink titan-augite form a subophitic texture with spherulites of augite and skeletal plagioclase,

Brown et al. (1975) described 70215,142 as a Type IA Apollo 17 high-Ti basalt, containing 9.2% olivine, 37% opaques, 12.8% plagioclase, and 41% clinopyroxene. The texture of this sample is discussed within the confines of the general Type IA group defined by Brown et al. (1975).

Dymek et al. (1975) studied 70215,158, describing it as a fine-grained porphyritic basalt comprised of clinopyroxene (58%), plagioclase (18%, ilmenite (13%), olivine 6%), and SiO_2 (4%), with minor amounts of armalcolite, Cr-ulvospinel, rutile, troilite, and native Fe. A small amount of K-rich mesostasis is present. 70215,158 is characterized by abundant phenocrysts of olivine, ilmenite; and clinopyroxene set in a texturally variable groundmass. Approximately three quarters of the groundmass consists of a variolitic intergrowth of acicular grains of plagioclase, SiO_2, and ilmenite, with blocky to acicular clinopyroxene. The remainder consists of tiny needles of ilmenite that alternate with fan spherulites of plagioclase and clinopyroxene. Olivine phenocrysts are skeletal (i.e., rapid crystallization), some intergrown with ilmenite. An overgrowth of pyroxene is usually present. Cr-ulvospinel inclusions may be present. Most ilmenites occur as skeletal needles with "sawtooth" edges, although blocky, anhedral types occur. Rare armalcolites are rimmed with rutile-bearing ilmenite. Furthermore, occasional phenocrysts of Cr ulvospinel contain oriented lamellae of ilmenite. Plagioclase occurs as elongate untwinned grains scattered throughout the groundmass.

Mineral chemistry is generally similar between the different thin sections described above. Brown et al. (1975) described the mineral chemistry of 70215 within the general context of Type IA basalts. Dymek et al. (1975) noted olivine compositions from $_{F065-75}$ with only minor core-to-rim zonation, whereas Longhi et al. (1974) noted a larger olivine range (Fo50-75) with no core-to-rim zonation. Ilmenite composition is related to crystal habit. Those with "sawtooth" margins have generally higher Mg contents (Fe/ (Fe+Mg) = 0.84-0.89) than the blocky, subequant (Fe/(Fe+Mg) = 0.88-0.93) and groundmass (Fe/(Fe + Mg) 0.95) types. Muhich et al. (1990) reported variations in ilmenite composition in 70215 which correlated with the degree of exsolution, Ilmenites with abundant exsolution were richer in Mg relative to those without exsolution. Armalcolite exhibits only a minor range in composition (Fe/ (Fe+Mg) = 0.48-0.53) and spinel compositions are generally uniform (Fe/ (Fe + Mg) = 0.82). Pyroxene compositions range from titan-augite to augite (phenocrysts) to more Fe-rich varieties (groundmass). No pigeonite is present (Fig. 3; Px quad of Longhi et al., 1974). As Fe increases, Al, Ti, and Cr decrease. Al/Ti ratios are generally constant at ~2, although some of the aluminous titan-augites contain Al/Ti ratios > 2, indicating the presence of AI^{VI}. Plagioclase exhibits little variation (An_{75-81})

The proposed crystallization sequence for 70215 is generally olivine + armalcolite to ilmenite + rutile to cpx -to plagioclase + Fe-rich pyroxene + ilmenite + silica. Armalcolite and olivine react with the magma to form ilmenite and clinopyroxene, respectively. Longhi et al. (1974) concluded that spinel

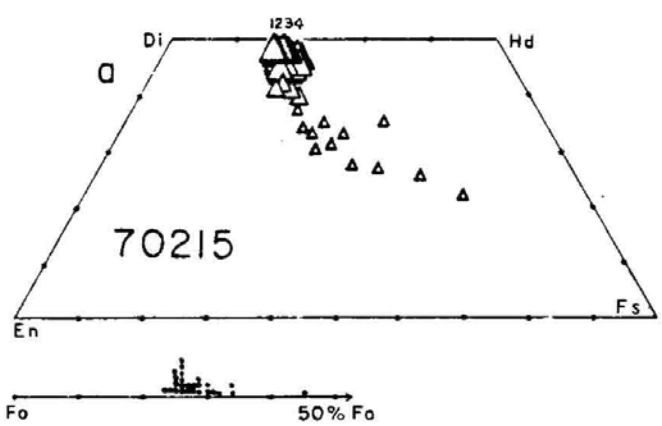


Figure 3: Pyroxene and olivine compositions of 70215.

crystallized between ilmenite and cpx, whereas Dymek et al. (1975) indicated that spinel crystallized with olivine. E1 Goresy et al_ (1974ab, 1977ab) studied the opaque mineralogy of 70215 in detail. These authors concentrated upon the sub-solidus equilibration of the spinel-ilmenite assemblage and inverted zoning in chromian - ulvospinel.

WHOLE-ROCK CHEMISTRY

The whole rock composition of 70215 has been reported by many authors. Rhodes et al. (1976) classified 70215 as a Type B high-Ti basalt. 70215 is further classified as a Type B2 basalt using the criteria of Neal et al. (1990). The major element composition of 70215 has been reported by Rhodes et al. (1974, 1976), Rose et al. (1974), LSPET (1973), Wanke et al. (1975), Shih et al. (1975), Duncan et al. (1974), and Dickinson et al (1989) (Table 1). LSPET (1973) report that 70215 is olivine-normative. Selected trace elements (Table 1) have been reported by LSPET (1973), Rhodes et al. (1974), Rose et al. (1974), Duncan et al. (1974), Brunfelt et al. (1974), Masuda (1974), Shih et al. (1975), Wanke et al. (1975), and Dickerson et al. (1989). There is some variation between different analyses for both major and trace element abundances (Table 1).

The REE profile of 70215 has been determined by four different authors (Brunfelt et al., 1974, Masuda et al., 1974; Wanke et al., 1975; Shih et al., 1975). The four profiles are similar (Fig. 4) although that determined by Brunfelt et al. (1974) is the least smooth. The profiles are all LREE-depleted, with a slight decrease in the HREE relative to the MREE. The negative Eu anomaly is of the same magnitude in each case ($[Eu/Eu^*]_N$ = 0.52-0.58). The MREE reach 30-35 times chondritic values. Shaffer et al. (1990) used the LaJSm value of 70215 in a discussion of mafic cumulate fractionation in an initial lunar magma.

70215 has also been used in more specialized studies of bulk composition. Hydrogen concentrations have been reported by Merlivat et al. (1974, 1976) as 0.62 - 0.75 pmole/g, whereas Gibson et al. (1986) report 2.3 pg/g H in 70215. Gibson et al. (1974, 1975, 1976) reported the sulfur content in 70215 as 2210 pg/g, whereas Petrowski et al. (1974) reported 1689 ppm and Moore et al. (1974) 2040 pg/g S. Nitrogen contents for 70215 have been reported as < 8 to 3 ppm by Muller (1974, 1976), 88 pg/g by Moore and Lewis (1976), and 16-23 ppm by Goel et al. (1975). Carbon abundances for 70215 have been determined by Moore et al. (1974) and Moore and Lewis (1976) at 31 pg/g.

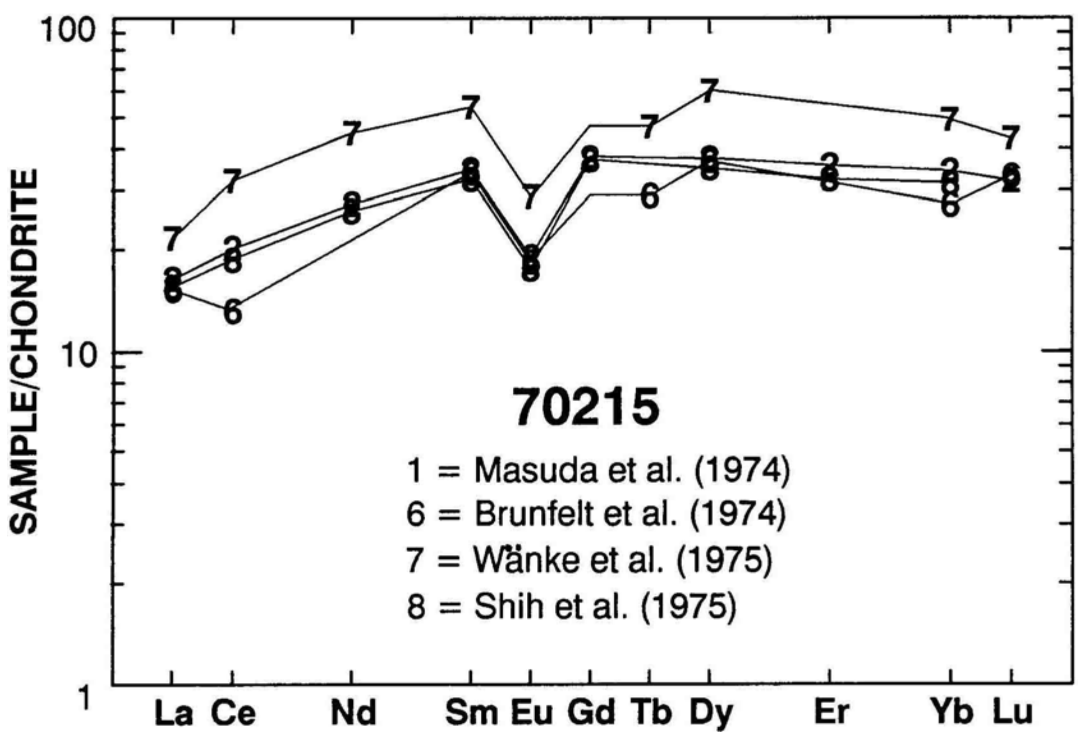


Figure 4: Chondrite-normalized rare-earth element profiles of 70215.

Table 1: Whole-rock chemistry of 70215.

Ref.	1	2	3	4	5	6	7	8	9
	X	I	X	X	X	N	N	I	R, N
SiO_2 (wt %)	37.19		37.91	37.62	38.46				
TiO_2	13.14		13.08	13.20	12.48	13.08			
Al_2O_3	8.67		8.86	8.79	9.01	9.11			
Cr_2O_3	0.42		0.43	0.41	0.39	0.37			0.35, 0.34
FeO	19.62		19.96	19.22	19.40	19.09			16.2, 20.1
MnO	0.28		0.26	0.27	0.29	0.27			
MgO	8.52		7.99	9.34	7.91	7.47			
CaO	10.43		10.77	10.82	10.94	10.92			12.9, 13.3
Na_2O	0.32		0.38	0.31	0.42	0.43			0.34, 0.39
K_2O	0.04		0.04	0.08	0.05	0.05			
P_2O_5	0.09		0.11	0.07	0.10				
S	0.18		0.19		0.17				
Nb (ppm)	20		20.8	20	21		22		
Zr	183		192	223	185		271		160
Hf						8.3	8.82		7.6, 6.4
Ta						1.6	1.78		1.5, 1.6
U						0.072		0.13	
Th						0.21			0.38, 0.39
W						0.075			
Y	75		63.6	73	69		93		
Sr	121		122	170	123	127	195	121	
Rb	<0.2		<1	1.0	0.9	0.3		0.356	
Li				11			8.3		
Ba		61.8	77	475		48	85	56.9	47, 65
Cs						0.02			
Be				<1					
Zn	5		<2	<4	6	2			59
Pb				<2					
Cu			<3	22		4.2			
Ni	2		<3	<1	4	<10			
Co			23	33		20.4	19.5		15, 22
V			50	64		117			349, 320
Sc				92		89	84.0		77, 88
La		5.35		<10		4.96	7.08	5.22	4.7, 5.8
Ce		17.3				11.3	27.5	16.5	13, 17
Nd		17.0					28	16.7	22
Sm		6.98				6.79	10.8	6.69	6.0, 6.9
Eu		1.45				1.40	2.19	1.37	1.3, 1.4

Table 1: (Concluded).

Ref.	1	2	3	4	5	6	7	8	9
	X	I	X	X	X	N	N	I	R, N
Gd		10.3						10.4	
Tb						1.66	2.7		1.7, 2.0
Dy		12.7				12.5	20.5	12.2	
Er		7.91						7.40	0.62
Yb		7.45				5.9	10.7	7.04	6.7, 7.2
Lu		1.07				1.11	1.44		1.1, 1.2
Ga				6.3		3.1			20
F							49		
Cl							3.5		
Br							0.011		
C									
N									
H									
He									2.2, 2.4
Ge (ppb)									
Ir									
Au									
Ru									
Os									

References: 1 = LSPET (1973); 2 = Masuda et al. (1974); 3 = Duncan et al. (1974); 4 = Rose et al. (1974); 5 = Rhodes et al. (1974); 6 = Brunfelt et al. (1974); 7 = Wänke et al., 1975); 8 = Shih et al. (1975); 9 = Dickinson et al (1989) [Two anal.].

Analyses by: X = XRF; I = Isotope Dilution; N = INAA; R = RNAA.

Germanium abundance in 70215 was determined at 2.2 ppb by Dickinson et al. (1988) (Table 1). Garg and Ehmann (1976) and Hughes and Schmitt (1985) reported Zr and Hf abundances for 70215. Garg and Ehmann (1976) measured 213-215 ppm Zr and 6.72-6.96 ppm Hf in 70215,46, and Hughes and Schmitt (1985) reported 70215,78 as containing 6.2 ± 0.2 ppm Hf with a Zr/Hf ratio of 28.3± 4.6.

ISOTOPES

Rb-Sr isotope data for 70215 have been reported by Bansal et al. (1975), and Nyquist et al. (1975, 1976) (Table 2). These authors report a present day $^{87}Sr/^{86}Sr$ ratio of 0.69965±7 for the whole-rock. A meaningful isochron was not obtained from the mineral separates due to the small range in $^{87}Sr/^{86}Sr$ ratio. No Sm-Nd or Pb isotope data has been obtained from 70215.

39Ar-^{40}Ar age dating has been conducted on 70215 using whole-rock (Kirsten and Horn, 1974) (Table 3) and laser (Schaeffer et al., 1977)

Table 2: Sr isotopic composition of 70215.
Data from Nyquist et al. (1975, 1976) and Barisal et al. (1975).

	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	T_B	T_L
70215,2	0.356	121	0.0085±4	0.69965±7	4.51±0.8	5.06±0.82
"floats"	0.571	181	0.0091±1	0.69965±6		
$p > 4.3$	0.168	34.9	0.0139±1	0.70023±4		
$p < 2.85$	0.60	322	0.0054±4	0.69944±6		

B = Model age relative to BABI
L = Model age relative to LUNI

Table 3: Ar-Ar and K-Ar data from 70215,21.
Data from Kirsten and Horn (1974), Gas released in 10^{-8} ccSTP/g.

^{40}Ar	1710
^{39}Ar	15.9
^{38}Ar	12.3
^{37}Ar	1725
^{36}Ar	1.31
K (ppm)	345±25
Ca (%)	7.2±0.5
Exposure Age (m.y.)	100±12
Total Ar Age (b.y.)	3.77±0.10
Plateau Age (b.y.)	3.84±0.04

techniques (Table 4). Schaeffer et al. (1977) reported mineral ages ranging from 3.63-3.85 Ga in 70215,182, whereas Kirsten and Horn (1977) reported a whole-rock plateau age of 3.84±0.04 Ga and an exposure age of 100 ± 12 Ma (Table 3).

Other radiogenic isotopes measured in 70215 include $^{39}K/^{41}K$ and $^{42}K/^{40}K$ (13.859 and 575.9, resp.) by Garner et al. (1975). Calcium isotopes have also been analyzed by Russell et al. (1977), who reported 70215 to contain a 8($^{40}Ca/^{44}Ca$) value of -1.1±0.2. Drozd et al. (1977) report a Kr-Kr exposure age of 126 ± 3 Ma for 70215.

Carbon and sulfur represent the only stable isotope determinations made upon 70215. Petrowski et al. (1974) reported a 8^{13}C Woo PDB) of -39.3 and Des Marais (1978) reported a 8^{13}C of -23.5 for 70215. The 8345 Woo CDT) has been reported as + 1.5 (Petrowski et al., 1974), 0.0 (Gibson et al., 1975), and + 0.6 (Rees and Thode, 1974).

EXPERIMENTAL

70215 has been used in a variety of experiments ranging from crystallization sequences to electrical properties. Ahrens et al. (1977ab) used 70215 to study the shock compression and dynamic properties of 70215. Their results implied that either previous mare cratering ages were overestimated, or that the integrated meteoroid influxes may have undergone an even sharper decline during the first

Table 4: Laser Ar-Ar data from 70215,182.
Data from Schaeffer et al. (1977). Units in 10-12 cm^3

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	Temp (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	^{40}Ar/^{39}r	Age (Ga)
Olivine	----	473.0±16.5	7.70±0.49	8.10±3.62	648.3±186.2	6.45±6.45	61.3±4.47	3.63±0.10
Pyroxene	----	830.2±15.4	12.74±0.57	12.39±4.60	1710.8±222.1	10.62±7.86	65.01±3.15	3.72±0.07
Plag-Px Aggregates	----	1145.9±28.9	18.46±0.74	12.37±5.58	1028.5±281.6	10.59±8.05	62.00±2.94	3.65±0.07
Armal-Ilm Intergrowth	----	714.9±25.6	11.02±0.66	10.81±6.26	593.2±362.2	11.07±7.86	64.64±4.53	3.72±0.10
Pyroxene	----	370.2±4.3	5.19±0.33	2.94±2.94	655.3±5.0	4.79±4.79	71.07±4.62	3.85±0.09
Pyroxene	600	516.5±5.1	7.56±0.14	2.32±1.47	854.9±4.3	3.63±2.87	68.16±1.46	3.78±0.04
Plag-Px Aggregates	600	444.0±5.5	6.47±0.17	2.83±1.47	624.9±3.7	10.39±2.40	67.86±2.13	3.78±0.05
Plag-Px Aggregates	600	799.0±8.3	11.35±0.20	2.94±2.94	1004.6±8.2	2.87±2.87	70.34±1.45	3.83±0.04
Armal-Ilm Intergrowth	600	738.7±8.1	10.56±0.31	3.36±1.57	866.2±8.4	4.79±4.79	69.81±2.19	3.82±0.05

1.5 Ga of lunar history than previously thought.

Mizutani and Osako (1974ab) analyzed elastic wave velocities and thermal diffusivities in 70215. These authors demonstrated the different thermal conductivities between highland and mare regions.

Tittman et al. (1975ab, 1976, 1978) reported the internal friction quality factor from 70215,85 under varying pressures. Results demonstrated the effect of adsorbed volatiles upon the internal friction quality factor (Q) and explains, in part, the differences between terrestrial and lunar seismic profiles through lack of adsorbed H_2O on the Moon.

Blank et al. (1981, 1984) used 70215,159 to examine the trace element partitioning between ilmenite and armalcolite, noting that Zr was preferentially partitioned into armalcolite. Other partitioning experiments were conducted on 70215 by Longhi et al. (1978) in order to determine the distribution of Fe and Mg between olivine and lunar basaltic liquids.

Longhi et al. (1974), Green et al. (1974,1975ab), Walker et al. (1974,1975ab), and O'Hara and Humphris (1975) used 70215 in melting experiments in order to determine source mineralogy, degree of partial melting, and post-melting evolution. Green et al. (1974, 1975a,b) noted that at low pressures, olivine, armalcolite, and ilmenite are liquidus phases, whereas at high-pressures the high-Ti parental magma is not saturated with an Fe-Ti oxide phase. Longhi et al. (1974) concluded that 70215 can be generated by partial melting of an olivine + cpx + Fe-Ti oxide source at depths of 100-150 km.

Walker et al. (1974, 1975a,b, 1976) concluded that the source region for titaniferous basalts was a late-stage ilmenite-rich cumulate produced from the residual liquid of the primordial differentiation of the outer portions of the Moon. According to this model, the ilmenite rich layer was sandwiched between the lunar feldspathic crust and a complementary cumulate.

MAGNETIC STUDIES

70215 has been used for a variety of magnetic studies. These have primarily concentrated upon: the intensity of, and changes in, ancient lunar magnetic fields (Cisowski et al., 1977; Collinson et al., 1975); remanent magnetism of specific lunar samples (Runcorn et al., 1974; Nagata et al., 1974b; Pearce et al., 1974b; Sugiura and Strangeway, 1980a,b; Hargraves and Dorety, 1975;

Stephenson et al., 1974, 1975); Fe distribution and the metallic Fe - ferrous Fe ratio (Huffmann et al., 1974; Schwerer and Nagata, 1976); the effect of meteorite impact upon magnetic fields (Nagata etal., 1974a, 1975; Pearce et al., 1974a).

PROCESSING

To date, 26 thin sections have been made of 70215. These sample numbers are ,7-9 ,89, ,128 ,141-149_,150-160_,251. 70215,0 has been entirely subdivided, but 4487.48 of 70215,3 and 2769.0 g of 70215,4 remain.