

Mare Basalt, Touchstone

70215

8110 grams



Figure 1: Close-up of surface of 70215,261 showing zap pits and apparent vugs. Sample is about 12 cm long. NASA # S89-34498.

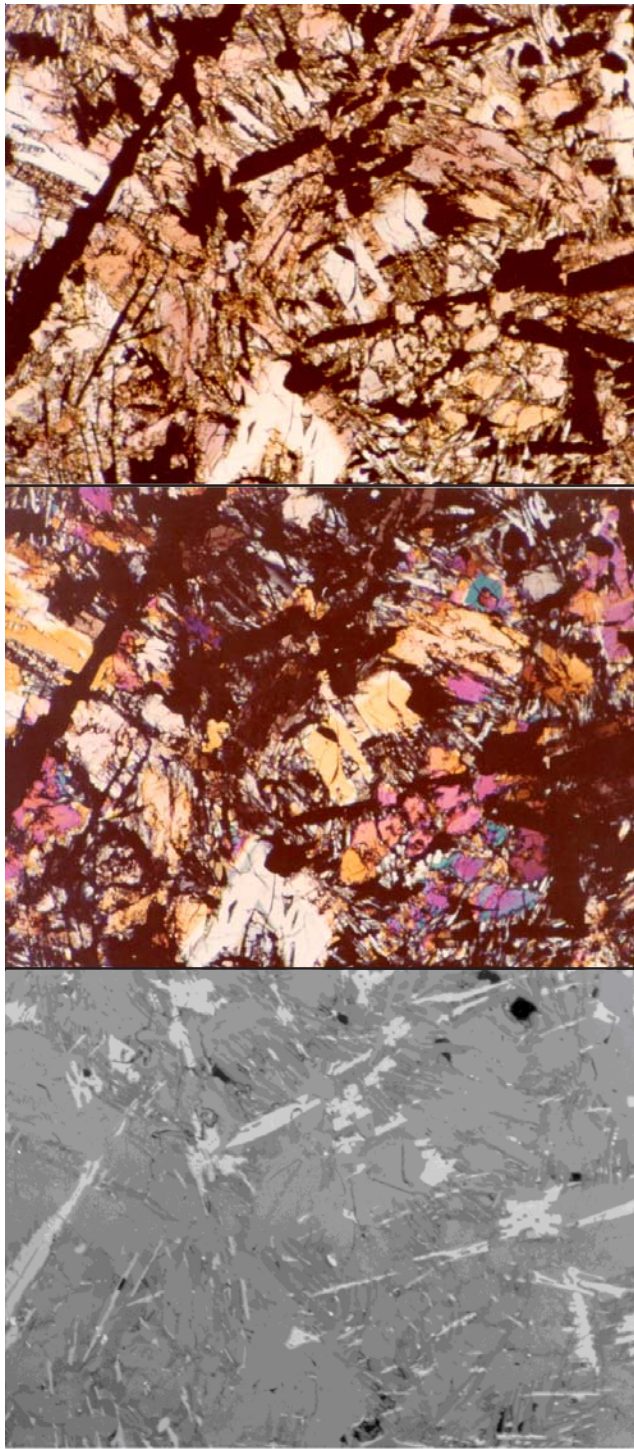


Figure 2: Photomicrographs of thin section 70215,89 (field of view 1.3 mm). Top = plane polarized light, middle = crossed-nicols, bottom = reflected). NASA # S79-26738-26740. Olivine is clear, surrounded by colored pyroxene. Ilmenite is opaque with high reflectivity. Plagioclase is interstitial, with low reflectivity.

Introduction

Did you ever want to reach out and touch the Moon? Here's your chance. Lunar sample 70215 is a dense, fine-grained porphyritic mare basalt that has been used to create “touchstones” for public display (see list under Processing). It was collected about 60 m from the Lunar Module and is one of the largest stones returned from the Moon.

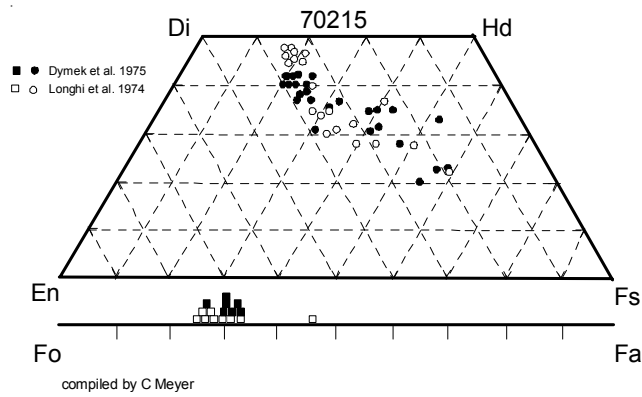
Neal and Taylor (1993) catalogued 70215 as a “high-Ti, Mare Basalt” and it contains an abundance of ilmenite (~13%). Although it has been dated by Kirsten and Horn (1974) at 3.84 ± 0.04 b.y., the Apollo 17 basalts average in age around 3.72 b.y.

70215 was found sitting on the surface and has micrometeorite craters on all faces, proving that it has “tumbled” during its residence on the lunar surface. It contained small vugs with projecting plates of ilmenite and pyroxene (figure 1). 70215 has been used for numerous scientific experiments, including experimental petrology, physical properties and magnetic properties. A sizeable portion of the rock remains available for additional studies.

Petrography

Wilshire (in Apollo 17 Lunar Sample Catalog), Longhi et al. (1974), Dymek et al. (1975), Brown et al. (1975), McGee et al. (1977) and Neal and Taylor (1993) gave various descriptions of 70215. It has variously been termed a “fine-grained, subvariolic basalt”, “spherulitic, fine-grained high-Ti basalt”, “Type 1A, Apollo 17 high-Ti basalt”, “fine-grained porphyritic basalt” and “medium dark gray, fine-grained basalt”. Walker et al. (1976) and McGee et al. (1977) noted that there were distinctly different textural regions in thin sections of 70215. Walker et al. simply termed these “grainy” and “fuzzy” regions and noted a slight (but significant) variation in bulk composition. The contact between the regions is gradational, but can be seen in thin sections ,145 and ,147. Both regions contain a small amount of irregular pore space and rare vesicles 0.05 to 0.1 mm in diameter. Figure 2 shows the texture of one region. The reason for a variation in texture (and composition) in this rock has not been explained.

McGee et al. (1977) describe the finer-grained region consisting of “phenocrysts of olivine and ilmenite in a groundmass of fan-shaped intergrowths of plagioclase and pyroxene. The olivine displays a variety of shapes



compiled by C Meyer
 Figure 3: Pyroxene and olivine composition in 70215 (adapted from Longhi et al. 1974 and Dymek et al. 1975).

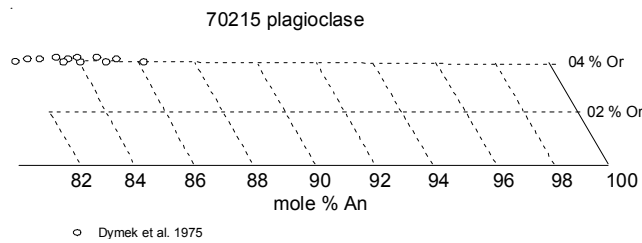


Figure 4: Plagioclase composition in 70215 (from Dymek et al. 1975).

including elongate, hollow prisms (0.1x0.4 to 0.2x0.8mm), equant and subequant grains (0.1-0.3mm) and skeletal, euhedral phenocrysts (0.1-0.3mm). Ilmenite phenocrysts occur as equant grains (0.4mm) and as laths (0.6-2.0mm) with irregular jagged edges which commonly contain cores of armalcolite and lamellae of rutile.” The matrix contains minute (0.3mm) “bow-tie” intergrowths of plagioclase and pyroxene along with needle-like laths of ilmenite. Olivine phenocrysts contain small octahedra of Cr-ulvöspinel.

McGee et al. (1977) describe the coarser-grained region consisting of “equal size olivine and pyroxene phenocrysts (0.3-0.8mm) set in a matrix consisting of feathery to acicular intergrowths of subparallel

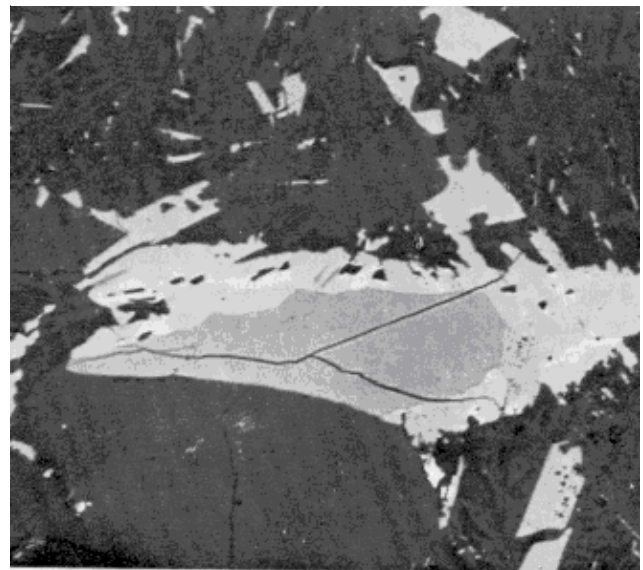


Figure 5: An armalcolite grain adjacent to olivine grain in 70215,159, illustrating the reaction relationship of armalcolite with the melt, forming ilmenite with rutile exsolution. The armalcolite grains was protected on one side by the attached olivine. Grain is about 100 microns across. Picture from El Goresy et al. (1974).

plagioclase and pyroxene crystals. Olivine phenocrysts are epitaxially overgrown with pyroxene. Rare anhedral grains of plagioclase are present. Skeletal laths of ilmenite (0.01-0.08mm) are commonly arranged in parallel sets which display optical continuity. Lamellae of rutile are common in ilmenite.” Troilite and native iron occur in the matrix.

At low pressure, olivine and armalcolite were the first phases to crystallize during cooling of the 70215 lava (figure 6). On further cooling, these first-forming phases partially reacted with the melt to form clinopyroxene and ilmenite (figure 5). Rapid cooling apparently prevented early plagioclase nucleation, with Ca and Al being used up in the pyroxene, before plagioclase finally joined the crystallization sequence

Mineralogical Mode 70215

	Longhi et al. 1974	Dymek et al. 1975	McGee et al. 1977	Brown et al. 1975
Olivine	7 %	6	6-9	9.2
Pyroxene	42	58	41-58	41
Plagioclase	29	18	13-29	12.8
Opaques	18			37
Ilmenite		13	13-37	
Chromite + Usp.				
Silica	4	4	4	
mesostasis				

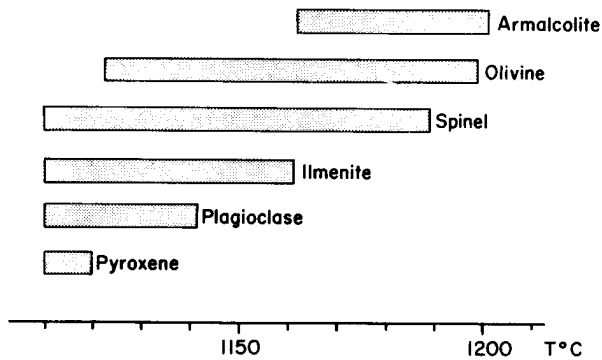


Figure 6: Low pressure crystallization sequence for 70215 (from Kesson 1975).

(Dymek et al. 1975). Mesostasis contains silica (4%) and K-rich glass.

Neal et al. (1990) updated the chemical classification of Apollo 17 basalts originally proposed by Rhodes et al. (1976) and classified 70215 as type high-Ti, B2 (see figure 10). It can be related to other Apollo 17 basalts by fractional crystallization in the source region and/or near surface fractionation of olivine, Cr-spinel and/or ilmenite (Walker et al. 1975).

Mineralogy

Olivine: Olivine phenocrysts in 70215 show the effect of “rapid crystallization, being poorly formed, hollow, and skeletal in habit” (Dymek et al. 1975). Olivine (Fo₇₅₋₆₅) contains only minor amount of “trace elements”.

Pyroxene: Pink pyroxene typically occurs as reaction rims on olivine. It is high in Ca (Wo₃₇₋₄₄) and in minor elements (Al, Ti, Cr). Groundmass pyroxene is more iron rich (figure 3).

Plagioclase: Plagioclase in 70215 is found as intergrowths with Fe-rich pyroxene, often in ‘bowtie’ spherulite textures. It is relatively sodic An₈₆₋₈₀ (figure 4).

Armalcolite: Rare armalcolite is found in cores of large ilmenite (figure 5).

Ilmenite: Ilmenite replaced armalcolite by reaction with the melt. Muhich et al. (1990) reported variations in ilmenite composition, partially due to rutile exsolution.

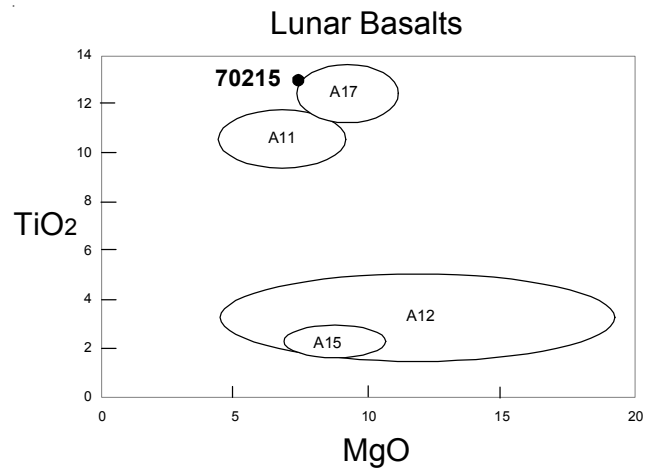


Figure 7: Composition of 70215 compared with that of other lunar basalts.

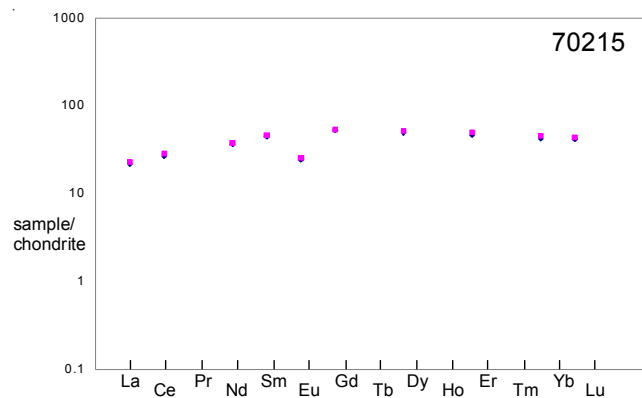


Figure 8: Normalized rare-earth-element composition diagram for 70215 (data from Shih et al. 1975 and Masuda et al. 1974).

Cr-ulvöspinel: Cr-ulvöspinel occurs as small octahedra in olivine and pyroxene phenocrysts (Dymek et al. 1975).

Chemistry

The chemical composition of 70215 has been determined by LSPET (1973), Rhodes et al. (1974), Shih et al. (1975), Wanke et al. (1975), Duncan et al. (1974), Rose et al. (1974), Masuda (1974), Dickinson et al. (1989), Brunfelt et al. (1974) and Morgan et al. (1974)(Table 1). The high TiO₂ content (~ 13 wt. %) is typical of Apollo 17 basalts (figure 7). The light REE are significantly depleted (figure 8) indicating that the source region was already evolved (Shaffer et al. 1990). Figure 10 uses the Ba/Rb ratio and Sm content to distinguish between type A and type B basalts and showing that 70215 is type B.

Gibson et al. (1974, 1975, 1976), Moore et al. (1974) and Petrowski et al. (1974) reported 2210, 2040 and 1689 ppm S (respectively); Garg and Ehmann (1976) reported 214 ppm Zr and 6.8 ppm Hf; Hughes and Schmitt (1985) reported 6.2 ppm Hf; Muller (1976), Moore and Lewis (1976) and Goel et al. (1975) reported 3, 88 and 20 ppm N (respectively); and Moore and Lewis (1976) reported 31 ppm C. Eldridge et al. (1974) reported U, Th and K contents of 70215,4. Merlivat (1974, 1976) determined hydrogen and deuterium. Reese and Thode (1974) reported sulfur (1581 ppm) and sulfur isotopes.

Radiogenic age dating

Nyquist et al. (1976) tried to date 70215 by Rb-Sr, but couldn't obtain a wide enough spread in Rb-Sr to obtain an age. Kirsten and Horn (1974) determined a Ar/Ar plateau age of 3.84 ± 0.04 b.y. (corrected to 3.79 b.y.) (figure 9). However, type B basalts are 3.69 b.y., while Apollo 17 basalts taken together appear to be 3.72 b.y. (Paces et al. 1991) so that the old Ar/Ar age for 70215 seems anomalous. Schaeffer et al. (1977) used a laser to obtain numerous Ar/Ar ages of minerals and intergrowths in 70215 ranging from ~3.6 b.y. for olivine to ~3.8 b.y. for intragrowths. Thus, 70215 still needs to be dated and initial isotope ratios better defined.

Summary of Age Data for 70215

	Ar/Ar
Kirsten and Horn 1974	3.84 ± 0.04 b.y.
Schaeffer et al. 1977	3.63 -3.85

Note: old decay constant

Cosmogenic isotopes and exposure ages

Kirsten and Horn (1974) determined a cosmic ray exposure age of 100 ± 12 m.y. with the ^{38}Ar and Drozd et al. (1977) reported a Kr-Kr exposure age of 126 ± 3 m.y. which they attribute to the age of Camelot Crater.

Other Studies

Longhi et al. (1974), Kesson (1975), Green et al. (1975), O'Hara and Humphries (1975) and Walker et al. (1976) attempted to determine the depth of origin of high-Ti basalts by performing high pressure experiments on 70215 and synthetic compositions (figures 11-14). The slight variation in starting composition, along with experimental details, led to considerable discussion (see Walker et al., Kesson and Ringwood 1976).

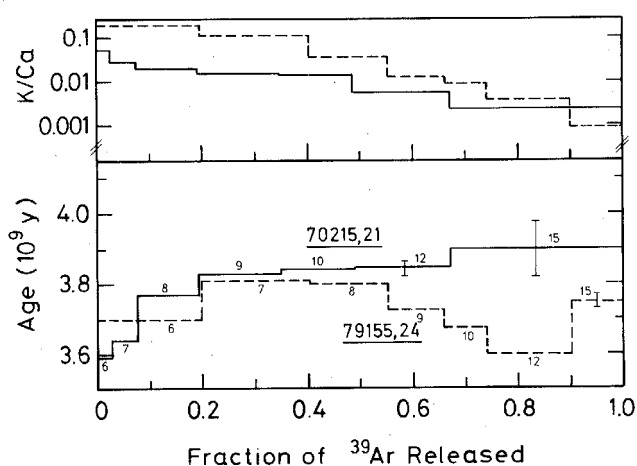


Figure 9: Argon $^{39}/^{40}$ release pattern for 70215 and 79155 (from Kirsten and Horn 1974).

The remanent magnetism of 70215 was studied by Runcorn et al. (1974), Nagata et al. (1974), Schwerer and Nagata (1976), Pearce et al. (1974), Sugiura and Strangeway (1980), Hargaves and Dorety (1975), Cisowski et al. (1977), Collinson et al. (1975) and Stephenson et al. (1974, 1975) (figure 19).

Mizutani and Osako (1974) determined seismic wave velocities as a function of pressure of 70215. They also reported thermal diffusivities. Warren et al. (1974) and Tittman et al. (1975, 1976 and 1978) studied the effect of adsorbed volatiles upon the attenuation of ultrasound in 70215. Ahrens et al. (1977) used pieces of 70215 to study the shock compression alteration of the dynamic properties of the lunar surface.

Processing

Sample 70215 broke into two subequal pieces (3 and 4) (figure 15). Two slabs were cut from 4 (figures 16-18) leading to many allocations. There are a total of 25 thin sections, 5 touchstones and three displays. The Constellation "display" is also a touchstone and is being used to "promote" ISRU on future lunar expeditions.

Touchstones	,238	Space Center Houston
	,287	Kennedy Space Center
	,84	Smithsonian Air and Space
	,286	Mexico City
	,263	Vancouver, BC
Displays	,93	Alamogordo, NM
	,41	traveling display
	,11	Constellation exhibit

Table 1. Chemical composition of 70215.

reference weight	LSPET73	Rhodes74	Wiesmann75 Shih 75	Wanke75	Duncan74	Rose74	Masuda74 Eldridge74	Dickinson89	Brunfeldt74
SiO2 %	37.19	38.46 (a)		38.3 (c)	37.91 (a)	37.62 (d)			
TiO2	13.14	12.48 (a)	14.5 (b)	12.53 (c)	13.08 (a)	13.2 (d)			13.08 (d)
Al2O3	8.67	9.01 (a)		8.71 (c)	8.86 (a)	8.79 (d)			9.11 (d)
FeO	19.62	19.46 (a)		19.94 (c)	19.96 (a)	19.22 (d)		16.2 20.1 (c)	19.09 (d)
MnO	0.28	0.29 (a)		0.25 (c)	0.264 (a)	0.27 (d)			0.27 (d)
MgO	8.52	7.91 (a)		8.32 (c)	7.99 (a)	9.34 (d)			7.47 (d)
CaO	10.43	10.94 (a)		10.63 (c)	10.77 (a)	10.82 (d)		12.9 13.3 (c)	10.92 (d)
Na2O	0.32	0.42 (a)		0.37 (c)	0.38 (a)	0.31 (d)		0.34 0.39 (c)	0.43 (d)
K2O	0.04	0.05 (a)	0.0435 (b)	0.045 (c)	0.041 (a)	0.08 (d)	0.039 (e)		0.05 (d)
P2O5	0.09	0.1 (a)		0.1 (c)	0.114 (a)	0.07 (d)			
S %	0.18	0.17 (a)		0.162 (c)	0.188 (a)				
sum									
Sc ppm				85.9 (c)		92 (d)		77 88 (c)	89 (d)
V					50 (a)	64 (d)		349 320 (c)	117 (d)
Cr	2874	2668 (a)	3030 (b)	2710 (c)	2949 (a)	2805 (d)		2400 2300 (c)	2510 (d)
Co				21.3 (c)	23 (a)	33 (d)		15 22 (c)	20.4 (d)
Ni	2	4 (a)			<3 (a)	1 (d)			<10 (d)
Cu				6.4 (c)	<3 (a)	22 (d)			4.2 (d)
Zn	5	6 (a)		3 (c)	<2 (a)	4 (d)		59 (c)	2 (d)
Ga				3.56 (c)		6.3 (d)		20 (c)	3.1 (d)
Ge ppb								2.2 2.4 (c)	
As				46 (c)					
Se				0.17 (c)					
Rb	0.2	0.9 (a)	0.356 (b)	0.36 (c)	1 (a)	1 (d)			0.3 (d)
Sr	121	123 (a)	121 (b)	143 (c)	122 (a)	170 (d)			127 (d)
Y	75	69 (a)		58 (c)	63.6 (a)	73 (d)			
Zr	183	185 (a)		176 (c)	192 (a)	223 (d)			
Nb	20	21 (a)		18 (c)	20.8 (a)	20 (d)			
Mo									
Ru									
Rh									
Pd ppb									
Ag ppb									
Cd ppb									
In ppb									
Sn ppb									
Sb ppb									
Te ppb									
Cs ppm				0.013 (c)					0.02 (d)
Ba			56.9 (b)	59 (c)	77 (a)	475 (d)	61.8 (b)	47 65 (c)	48 (d)
La			5.22 (b)	5.54 (c)			5.35 (b)	4.7 5.8 (c)	4.96 (d)
Ce			16.5 (b)	19.6 (c)			17.3 (b)	13 17 (c)	11.3 (d)
Pr				3 (c)					
Nd			16.7 (b)	19 (c)			17 (b)	22 (c)	
Sm			6.69 (b)	6.7 (c)			6.98 (b)	6 6.9 (c)	6.78 (d)
Eu			1.37 (b)	1.4 (c)			1.45 (b)	1.3 1.4 (c)	1.4 (d)
Gd			10.4 (b)	9.1 (c)			10.3 (b)		
Tb				1.8 (c)				1.7 2 (c)	1.66 (d)
Dy			12.2 (b)	11.5 (c)			12.7 (b)		12.5 (d)
Ho				2.5 (c)					
Er			7.4 (b)	7.2 (c)			7.91 (b)	0.62 (c)	
Tm								1.4 (c)	
Yb			7.04 (b)	6.97 (c)		5 (d)	7.45 (b)	6.7 7.2 (c)	5.9 (d)
Lu			1.03 (b)	1.06 (c)			1.07 (b)	1.1 1.2 (c)	1.11 (d)
Hf				6.33 (c)				7.6 6.4 (c)	8.3 (d)
Ta				1.55 (c)				1.5 1.6 (c)	1.6 (d)
W ppb				86 (c)					75 (d)
Re ppb									
Os ppb									
Ir ppb									
Pt ppb									
Au ppb				0.3 (c)					
Th ppm				0.34 (c)			0.36 (e)	0.38 0.39 (c)	0.21 (d)
U ppm			0.13 (b)	0.091 (c)			0.13 (e)		0.072 (d)

technique: (a) XRF, (b) idms, (c) INAA, RNAA, (d) combined, (e) radiation counting

Table 1b. Chemical composition of 70215.

reference weight	Morgan 74	Miller74	
SiO2 %		38.1	37 (c)
TiO2		12.84	12.78 (c)
Al2O3		8.5	8.7 (c)
FeO		20.7	19.2 (c)
MnO		0.26	0.25 (c)
MgO		11.9	9.1 (c)
CaO		10.8	10.6 (c)
Na2O		0.38	0.43 (c)

K2O
P2O5
S %
sum

Sc ppm

V

Cr

Co

Ni 1 (c)

Cu

Zn 2.1 (c)

Ga

Ge ppb 1.66 (c)

As

Se 176 (c)

Rb 0.36 (c)

Sr

Y

Zr

Nb

Mo

Ru

Rh

Pd ppb

Ag ppb 1.1 (c)

Cd ppb 1.8 (c)

In ppb

Sn ppb

Sb ppb 0.18 (c)

Te ppb 2.1 (c)

Cs ppm 0.015 (c)

Ba

La

Ce

Pr

Nd

Sm

Eu

Gd

Tb

Dy

Ho

Er

Tm

Yb

Lu

Hf

Ta

W ppb

Re ppb

Os ppb

Ir ppb

Pt ppb

Au ppb

Th ppm

U ppm 0.118 (c)

technique: (c) INAA, RNAA

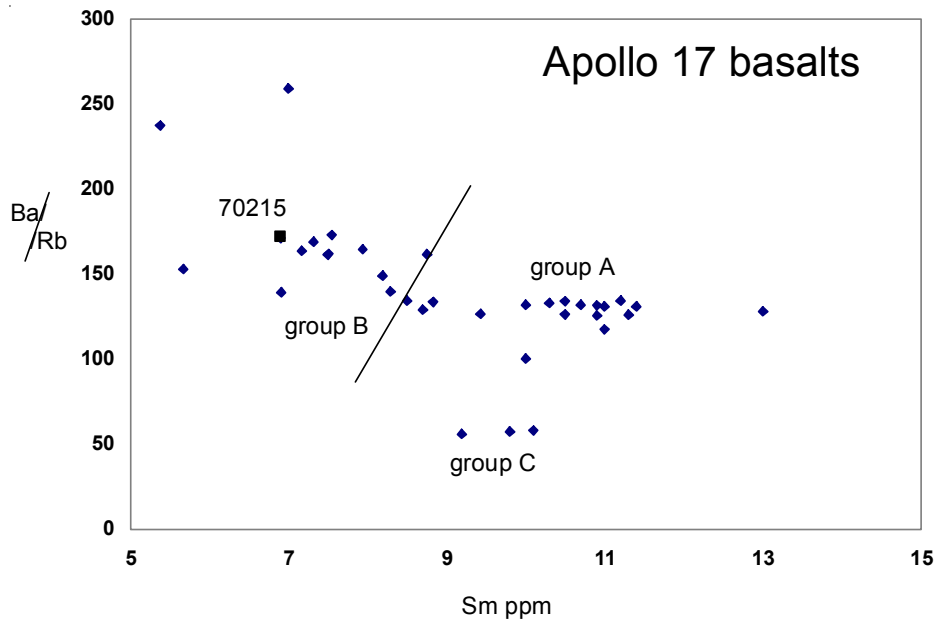


Figure 10: Trace element content of Apollo 17 basalts showing that 70215 is a type B Apollo 17 basalt.

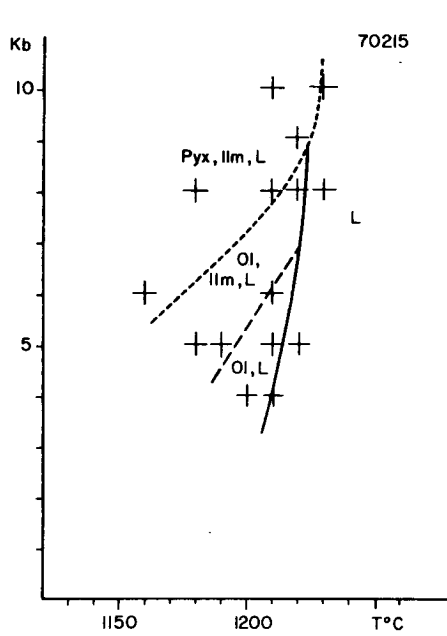


Figure 11: High pressure phase diagram for 70215 (from Kesson 1975).

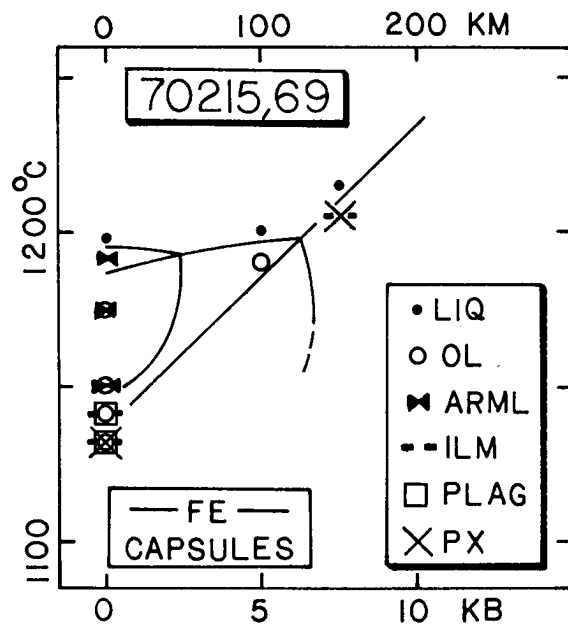


Figure 12: High pressure phase diagram for 70215 (from Walker et al. 1976).

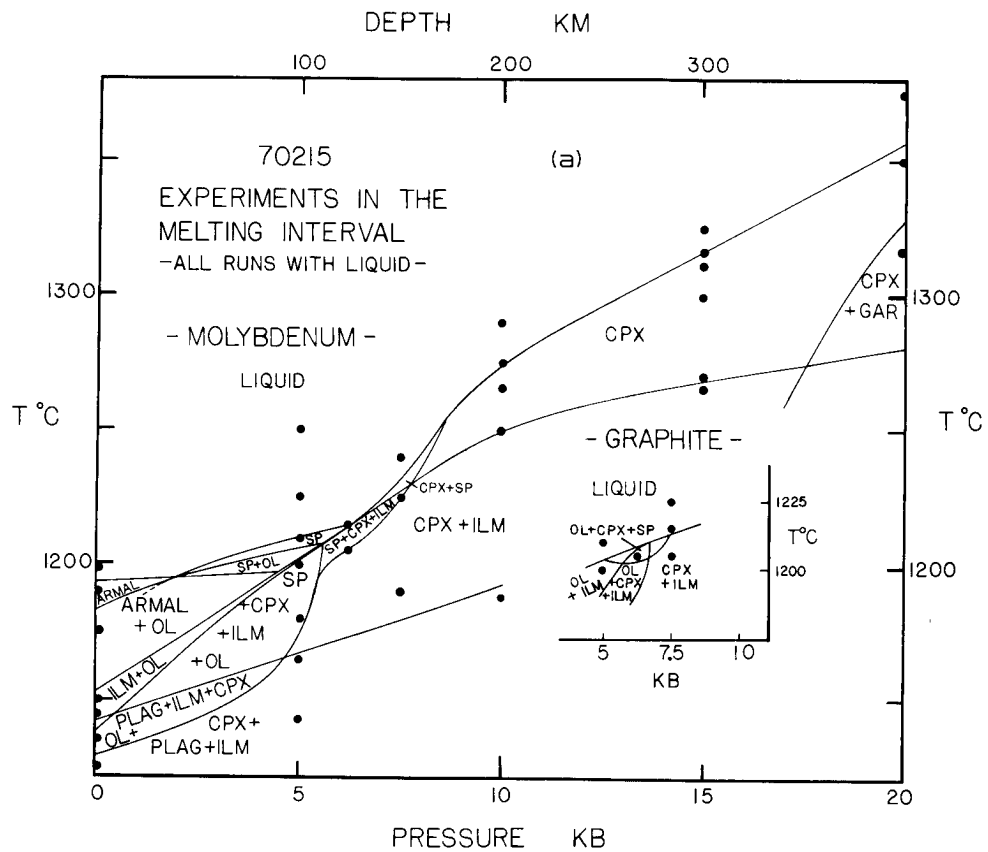


Figure 13: High pressure phase diagram for basalt 70215 determined in Mo and graphite capsules showing that a liquid of 70215 composition is "multiply saturated" at about 150 km depth on the moon (from Longhi et al. 1974).

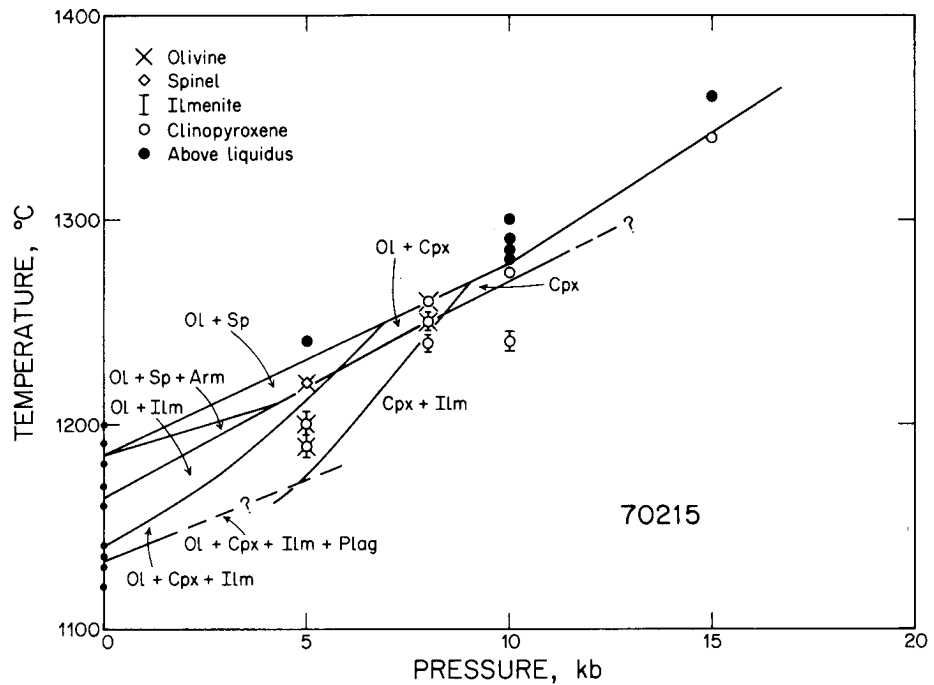
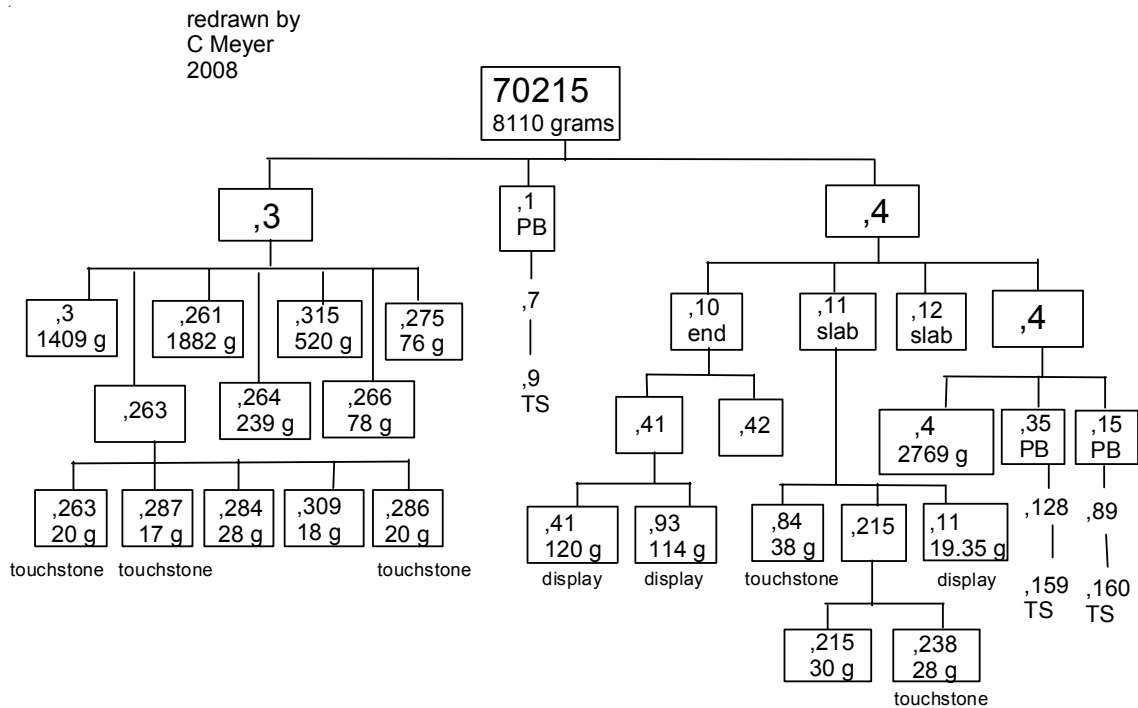


Figure 14: Experimental phase diagram showing multiple saturation (without ilmenite) at about 8 kbar (from Green et al. 1975).



Figure 15: Photo of 70215 illustrating zap pits. Scale and cube are in cm. NASA photo # S73-15710.



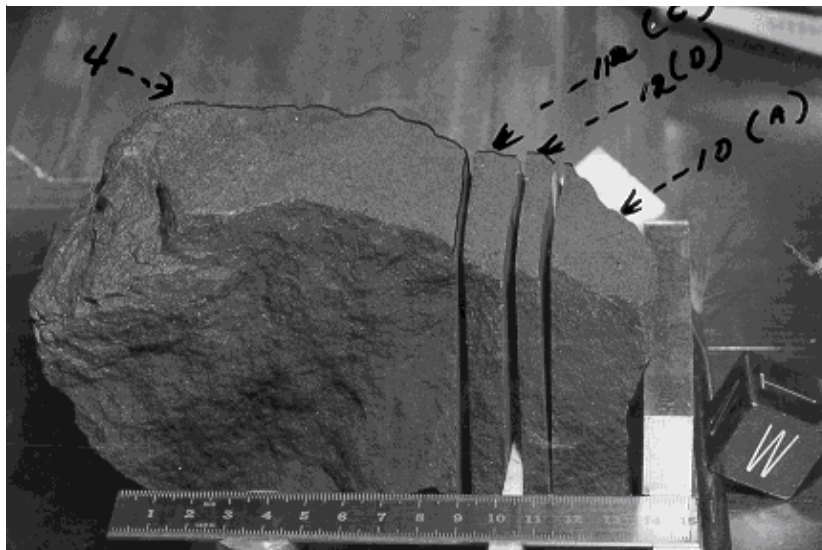


Figure 16: First two slabs (,11 and ,12) and end piece (,10) cut from 70215,4 (picture from data pack). Cube is 1 inch. NASA # S76-21651.

,4 ,11 ,12 ,10



Figure 17: Parts diagram for slab 70215,11. Cube is 1 inch. Scale is in cm. NASA # S73-31669.

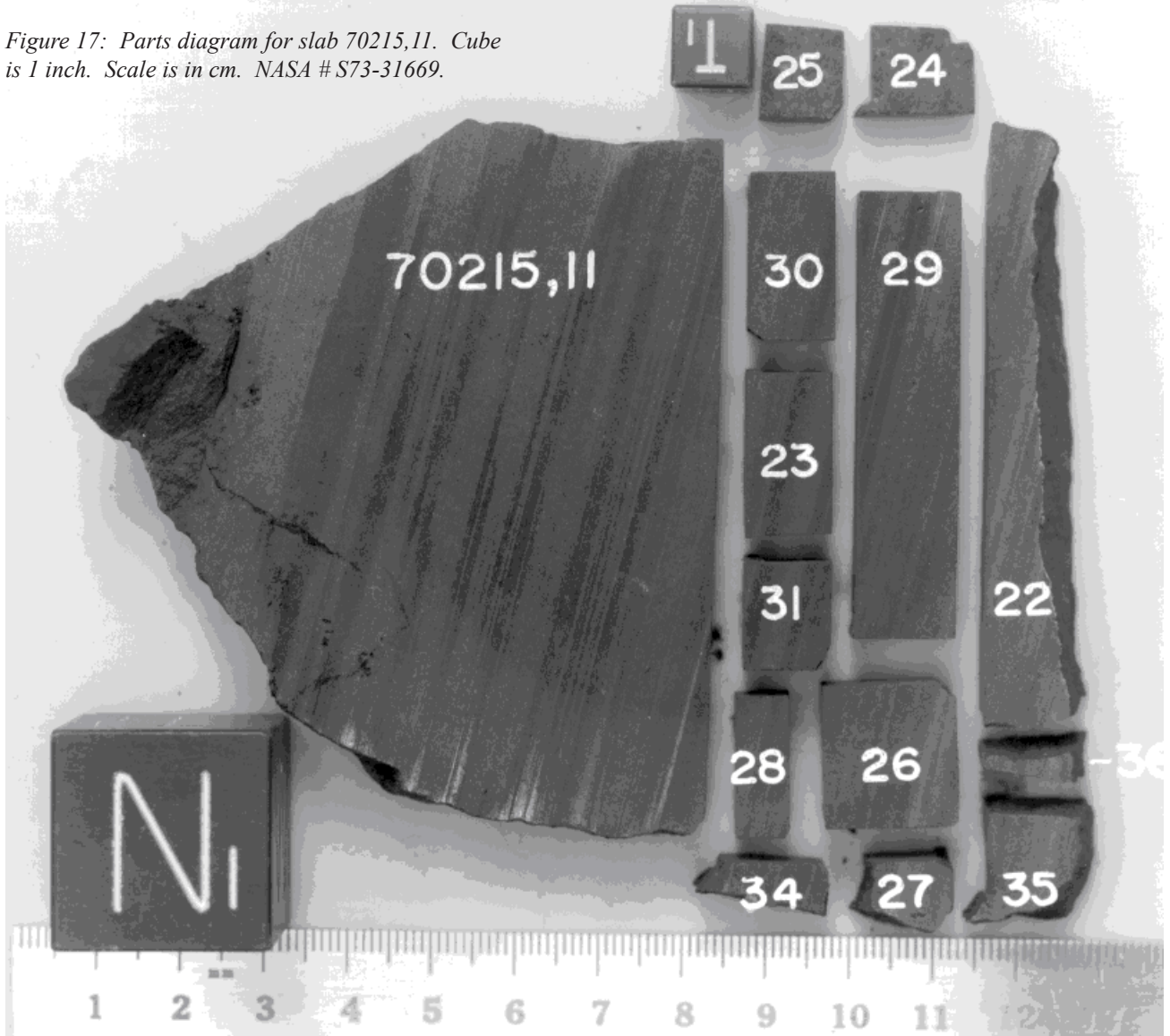
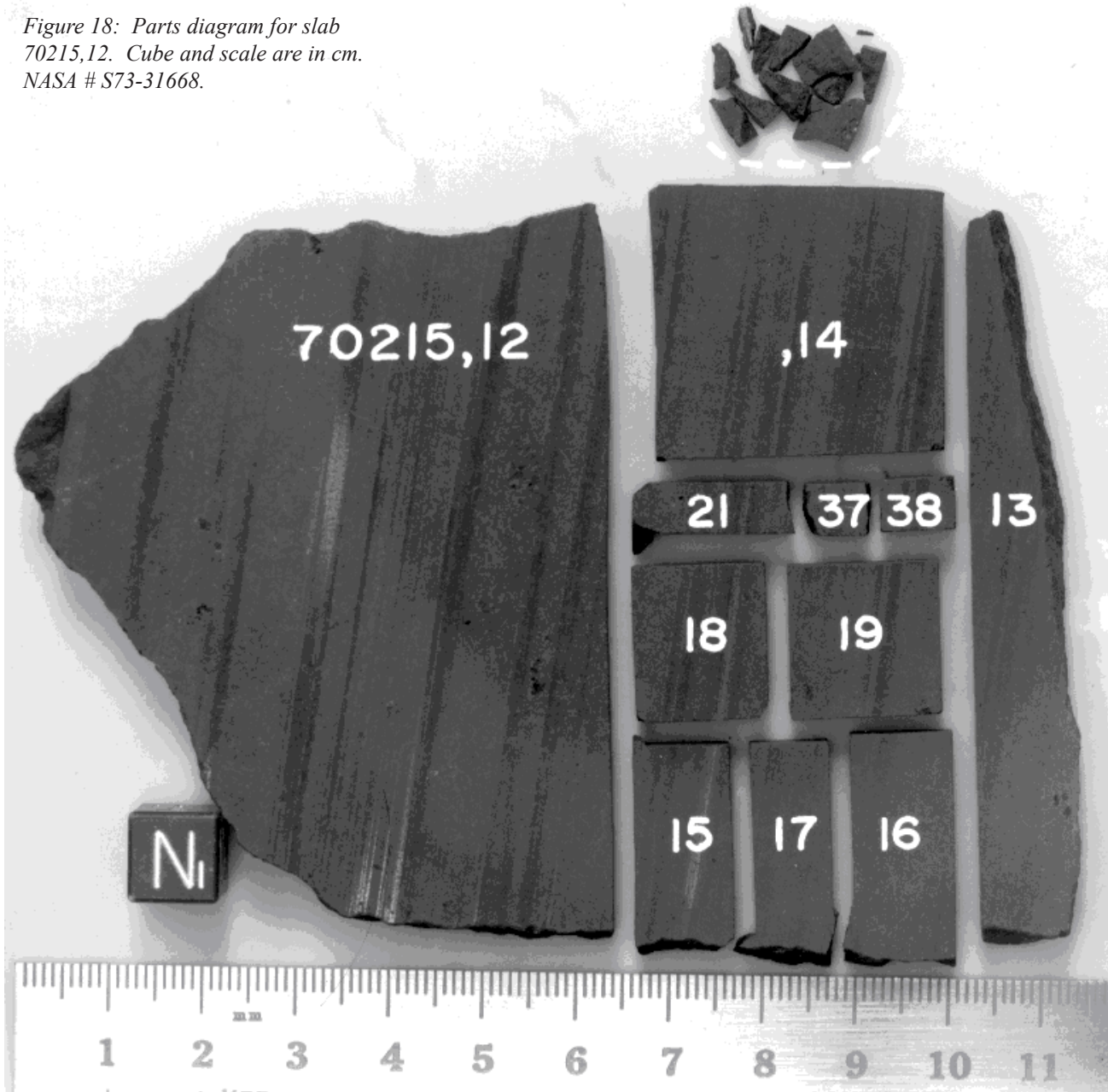


Figure 18: Parts diagram for slab
70215,12. Cube and scale are in cm.
NASA # S73-31668.



List of Photo #s for 70215

- S73-24213-24228 B&W
- S73-15706-15712 mug, color
- S73-15707 broken surface, both
- S73-31668-31669
- S76-21651 exploded parts
- S73-31175-31179
- S73-31664-31670
- S74-24789
- S75-24751
- S79-26738-26740
- S89-34488-34501

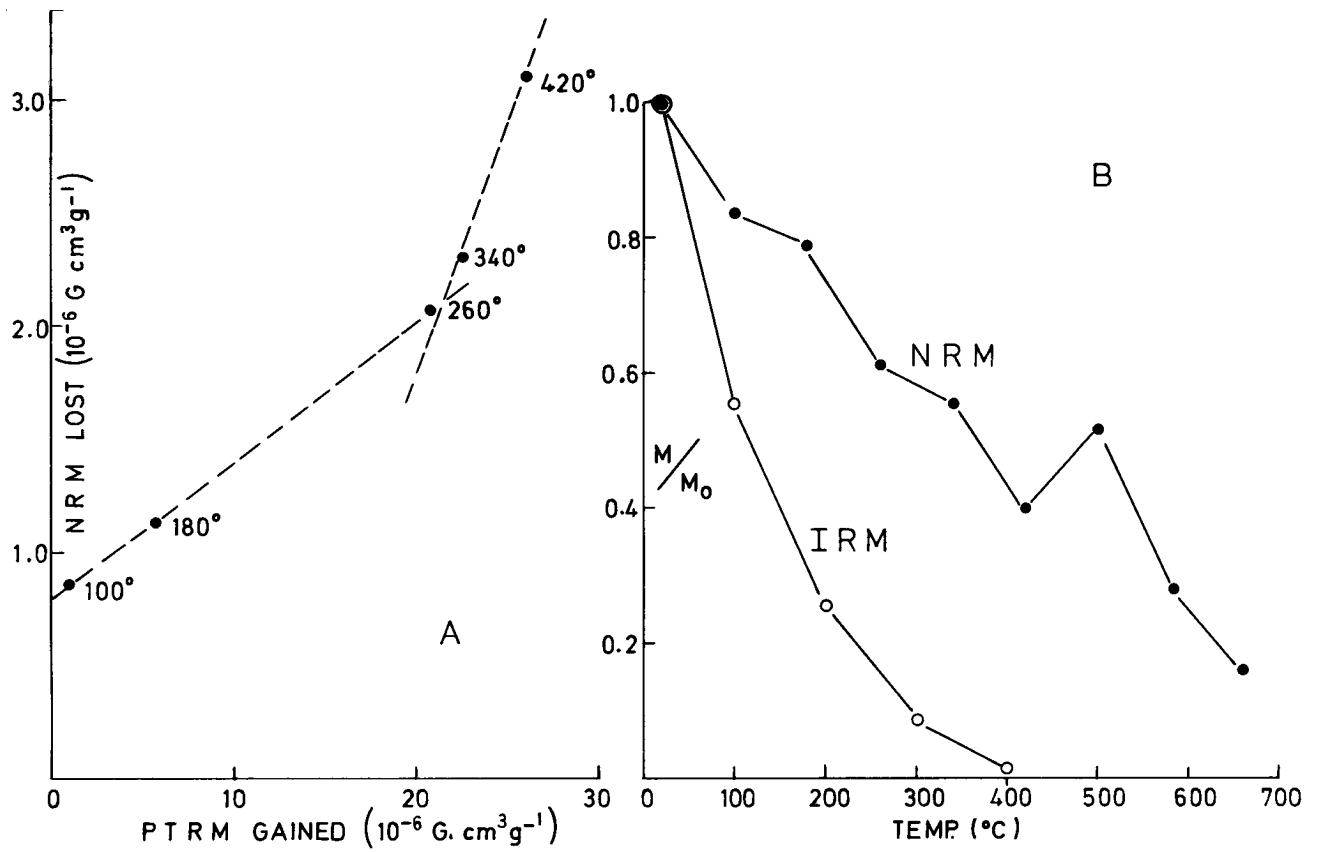


Fig. 8. Thellier determination of ancient field intensity (A) and thermal demagnetization of NRM and IRM acquired in 30 Oe(B) for 70215,45.

Figure 19: Two figures out of Stephenson et al. (1974) pertaining to remanent magnetization of 70215.

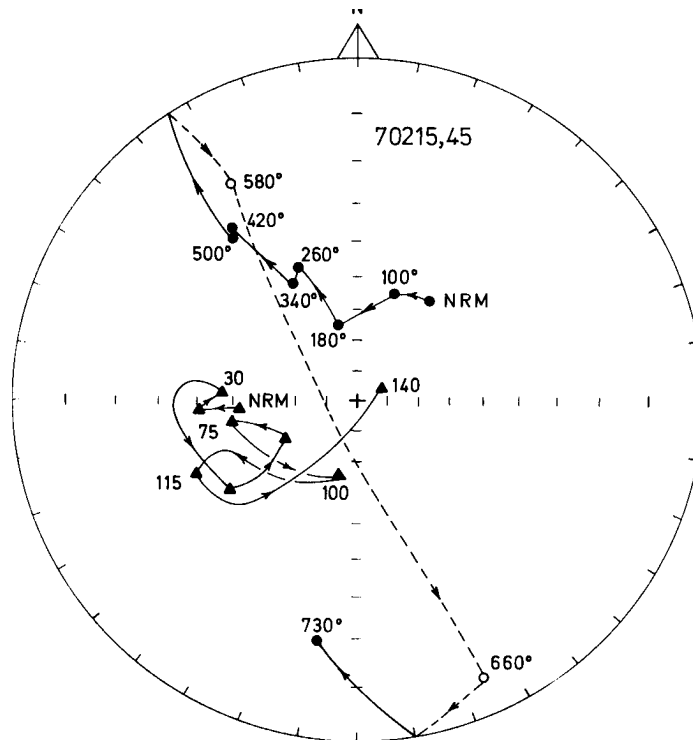


Fig. 7. AF and thermal demagnetization of chips from 70215,45. ● Thermal demagnetization; ▲ AF demagnetization.

References 70215

- Ahrens T.J., Jackson I. and Jeanloz R. (1977a) Shock compression and adiabatic release of a titaniferous lunar basalt. Proc. 8th Lunar Sci. Conf. 3437-3455.
- Ahrens T.J., Jackson I. and Jeanloz R. (1977b) Dynamic properties of ilmenite-rich mare basalt and the relative ages of lunar cratered surfaces (abs). Lunar Sci. VIII, 1-3. Lunar Planetary Institute, Houston.
- Bansal B.M., Wiesmann H. and Nyquist L. (1975) Rb-Sr ages and initial ⁸⁷Sr/⁸⁶Sr ratios for Apollo 17 mare basalts. In Conference on Origins of Mare Basalts and Their Implications for Lunar Evolution (Lunar Science Institute, Houston), 1-5.
- Blank H., Nobile R., Traxel K. and El Goresy A. (1981) Partitioning of trace elements among coexisting opaque oxides in Apollo 17 basalts using a proton probe microanalyzer (abs). Lunar Planet. Sci. XII, 89-91. Lunar Planetary Institute, Houston.
- Blank H., El Goresy A., Janicke J., Nobile R. and Traxel K. (1984) Partitioning of Zr and Nb between coexisting opaque phases in lunar rocks - determined by quantitative proton microprobe analysis. Earth Planet. Sci. Letters 68, 19-33.
- Brown G.M., Peckett A., Emeleus C.H., Phillips R. and Pinsent R.H. (1975a) Petrology and mineralogy of Apollo 17 mare basalts. Proc. 6th Lunar Sci. Conf. 1-13.
- Brunfelt A.O., Heier K.S., Nilssen B., Steinnes E. and Sundvoll B. (1974) Elemental composition of Apollo 17 fines and rocks. Proc. 5th Lunar Sci. Conf. 981-990.
- Butler P. (1973) Lunar Sample Information Catalog Apollo 17. Lunar Receiving Laboratory. MSC 03211 Curator's Catalog. pp. 447.
- Cisowski S.M., Hale C. and Fuller M. (1977) On the intensity of ancient lunar fields. Proc. 8th Lunar Sci. Conf. 725-750.
- Collinson D.W., Runcom S.K. and Stephenson A. (1975) On changes in the ancient lunar magnetic field intensity (abs). Lunar Sci. VI, 158-160. Lunar Planetary Institute, Houston
- Des Marais David J. (1978a) Carbon, nitrogen and sulfur in Apollo 15, 16 and 17 rocks. Proc. 9th Lunar Planet. Sci. Conf. 2451-2467.
- Dickinson T., Taylor G.J., Keil K. and Bild R.W. (1989) Germanium abundances in lunar basalts: Evidence of mantle metasomatism. Proc. 19th Lunar Planet. Sci. 189-198. Lunar Planetary Institute, Houston
- Droz R.J., Hohenberg C.M., Morgan C.J., Podosek F.A. and Wroge M.L. (1977) Cosmic-ray exposure history at Taurus-Littrow. Proc. 8th Lunar Sci. Conf. 3027-3043.
- Duncan A.R., Erlank A.J., Willis J.P., Sher M.K. and Ahrens L.H. (1974a) Trace element evidence for a two-stage origin of some titaniferous mare basalts. Proc. 5th Lunar Sci. Conf. 1147-1157.
- Dymek R.F., Albee A.L. and Chodos A.A. (1975a) Comparative mineralogy and petrology of Apollo 17 mare basalts: Samples 70215, 71055, 74255, and 75055. Proc. 6th Lunar Sci. Conf. 49-77.
- Eldridge J.S., O'Kelley G.D. and Northcutt K.J. (1974a) Primordial radioelement concentrations in rocks and soils from Taurus-Littrow. Proc. 5th Lunar Sci. Conf. 1025-1033.
- El Goresy A., Ramdohr P., Medenbach O. and Bernhardt H.-J. (1974a) Taurus-Littrow TiO₂-rich basalts: Opaque mineralogy and geochemistry. Proc. 5th Lunar Sci. Conf. 627-652.
- Garg A.N. and Ehmann W.N. (1976a) Zr-Hf fractionation in chemically defined lunar rock groups. Proc. 7th Lunar Sci. Conf. 3397-3410.
- Garner E.L., Machlan L.A. and Barnes I.L. (1975) The isotopic composition of lithium, potassium, and rubidium in some Apollo 11, 12, 14, 15, and 16 samples. Proc. 6th Lunar Sci. Conf. 1845-1855.
- Gibson E.K. and Moore G.W. (1974a) Sulfur abundances and distributions in the valley of Taurus-Littrow. Proc. 5th Lunar Sci. Conf. 1823-1837.
- Gibson E.K. and Moore G.W. (1974b) Total sulfur abundances and distributions in the valley of Taurus-Littrow: Evidence of mixing (abs). Lunar Sci. V, 267-269. Lunar Planetary Institute, Houston
- Gibson E.K., Chang S., Lennon K., Moore G.W. and Pearce G.W. (1975a) Sulfur abundances and distributions in mare basalts and their source magmas. Proc. 6th Lunar Sci. Conf. 1287-1301.
- Gibson E.K., Chang S., Lennon K., Moore G.W. and Pearce G.W. (1975b) Carbon, sulfur, hydrogen and metallic iron abundances in Apollo 15 and Apollo 17 basalts (abs). Lunar Sci. VI, 290-292. Lunar Planetary Institute, Houston
- Gibson E.K., Usselman T.M. and Morris R.V. (1976a) Sulfur in the Apollo 17 basalts and their source regions. Proc. 7th Lunar Sci. Conf. 1491-1505.
- Goel P.S., Shukla P.N., Kothari B.K. and Garg A.N. (1975) Total nitrogen in lunar soils, breccias, and rocks. Geochim.

- Cosmochim. Acta 39, 1347-1352.
- Green D.H., Ringwood A.E., Hibberson W.O. and Ware N.G. (1975a) Experimental petrology of Apollo 17 mare basalts. Proc. 6th Lunar Sci. Conf. 871-893.
- Hargraves R.B. and Dorety N.F. (1975) Remanent magnetism in two Apollo 16 and two Apollo 17 rock samples (abs). Lunar Sci. VI, 331-333. Lunar Planetary Institute, Houston
- Huffman G.P., Schwerer F.C., Fisher R.M. and Nagata T. (1974a) Iron distributions and metallic-ferrous ratios for Apollo lunar samples: Mossbauer and magnetic analyses. Proc. 5th Lunar Sci. Conf. 2779-2794.
- Hughes S.S. and Schmitt R.A. (1985) Zr-Hf-Ta fractionation during lunar evolution. Proc. 16th Lunar Planet. Sci. Conf. in J. Geophys. Res. D31-D45.
- Kesson S.E. (1975b) Mare basalts: melting experiments and petrogenetic interpretations. Proc. 6th Lunar Sci. Conf. 921-944.
- Kesson S.E. and Ringwood A.E. (1976) Mare basalt petrogenesis in a dynamic Moon. Earth Planet. Sci. Lett. 30, 155-163.
- Kirsten T. and Horn P. (1974a) Chronology of the Taurus-Littrow region III: ages of mare basalts and highland breccias and some remarks about the interpretation of lunar highland rock ages. Proc. 5th Lunar Sci. Conf. 1451-1475.
- Longhi J., Walker D., Grove T.L., Stolper E.M. and Hays J.F. (1974) The petrology of the Apollo 17 mare basalts. Proc. 5th Lunar Sci. Conf. 447-469.
- LSPET (1973a) Apollo 17 lunar samples : Chemical and petrographic description. Science 182, 659-690.
- LSPET (1973c) Preliminary examination of lunar samples. Apollo 17 Preliminary Science Report. NASA SP-330, 7-1—7-46.
- Masuda A., Tanaka T., Nakamura N. and Kurasawa H. (1974) Possible REE anomalies of Apollo 17 REE patterns. Proc. 5th Lunar Sci. Conf. 1247-1253.
- McGee P.E., Warner J.L., Simonds C.E. and Phinney W.C. (1979) Introduction to the Apollo collections. Part I: Lunar Igneous Rocks. Part II: Lunar Breccias. Curator's Office. JSC
- Merlivat L., Lelu M., Nief G. and Roth E. (1974a) Deuterium, hydrogen, and water content of lunar material. Proc. 5th Lunar Sci. Conf. 1885-1895.
- Merlivat L., Lelu M., Nief G. and Roth E. (1974b) Deuterium content of lunar material (abs). Lunar Sci. V, 498-500. Lunar Planetary Institute, Houston.
- Merlivat L., Lelu M., Nief G. and Roth E. (1976) Spallation deuterium in rock 70215. Proc. 7th Lunar Sci. Conf. 649-658.
- Miller M.D., Pacer R.A., Ma M.-S., Hawke B.R., Lookhart G.L. and Ehmann W.D. (1974) Compositional studies of the lunar regolith at the Apollo 17 site. Proc. 5th Lunar Sci. Conf. 1079-1086.
- Mizutani H. and Osako M. (1974a) Elastic-wave velocities and thermal diffusivities of Apollo 17 rocks and their geophysical implications. Proc. 5th Lunar Sci. Conf. 2891-2901.
- Mizutani H. and Osako M. (1974b) Elastic wave velocities and thermal diffusivities of Apollo 17 rocks (abs). Lunar Sci. V, 518-519. Lunar Planetary Institute, Houston.
- Moore C.B., Lewis C.F. and Cripe J.D. (1974a) Total carbon and sulfur contents of Apollo 17 lunar samples. Proc. 5th Lunar Sci. Conf. 1897-1906.
- Moore C.B., Lewis C.F., Cripe J.D. and Volk M. (1974b) Total carbon and sulfur contents of Apollo 17 lunar samples (abs). Lunar Sci. V, 520-522. Lunar Planetary Institute, Houston.
- Moore C.B. and Lewis C.F. (1976) Total nitrogen contents of Apollo 15, 16 and 17 lunar rocks and breccias (abs). Lunar Sci. VII, 571-573. Lunar Planetary Institute, Houston.
- Morgan J.W., Ganapathy R., Higuchi H., Krahenbuhl U. and Anders E (1974a) Lunar basins: Tentative characterization of projectiles, from meteoritic elements in Apollo 17 boulders. Proc. 5th Lunar Sci. Conf. 1703-1736.
- Muhich T., Vaniman D. and Heiken G. (1990) Ilmenite in high-Ti Apollo 17 basalts: Variations in composition with degree of exsolution (abs). Lunar Planet. Sci. XXI, 817-819. Lunar Planetary Institute, Houston
- Müller O., Grallath E. and Tolg G. (1976a) Nitrogen in lunar igneous rocks. Proc. 7th Lunar Sci. Conf. 1615-1622.
- Nagata T., Sugiura N., Fisher R.M., Schwerer F.C., Fuller M.D. and Dunn J.R. (1974a) Magnetic properties of Apollo 11-17 lunar materials with special reference to effects of meteorite impact. Proc. 5th Lunar Sci. Conf. 2827-2839.
- Neal C.R. and Taylor L.A. (1993) Catalog of Apollo 17 rocks, central valley. Volumes 2 and 3. Curators Office #26088 JSC, Houston

- Neal C.R., Taylor L.A., Patchen A.D., Hughes S.S. and Schmitt R.A. (1990a) The significance of fractional crystallization in the petrogenesis of Apollo 17 Type A and B high-Ti basalts. *Geochim. Cosmochim. Acta* 54, 1817-1833.
- Nyquist L.E., Bansal B.M. and Wiesmann H. (1975a) Rb-Sr ages and initial $^{87}\text{Sr}/^{86}\text{Sr}$ for Apollo 17 basalts and KREEP basalt 15386. *Proc. 6th Lunar Sci. Conf.* 1445-1465.
- Nyquist L.E., Bansal B.M. and Wiesmann H. (1976a) Sr isotopic constraints on the petrogenesis of Apollo 17 mare basalts. *Proc. 7th Lunar Sci. Conf.* 1507-1528.
- O'Hara M.J. and Humphries D.J. (1975) Armalcolite crystallization, phenocryst assemblages, eruption conditions and origin of eleven high titanium basalts from Taurus Littrow (abs). *Lunar Sci. VI*, 619-621. Lunar Planetary Institute, Houston.
- Paces J.B., Nakai S., Neal C.R., Taylor L.A., Halliday A.N. and Lee D.-C. (1991) A strontium and neodymium isotopic study of Apollo 17 high-Ti mare basalts: Resolution of ages, evolution of magmas, and origin of source heterogeneities. *Geochim. Cosmochim. Acta* 55, 2025-2043.
- Papike J.J., Bence A.E. and Lindsley D.H. (1974) Mare basalts from the Taurus-Littrow region of the moon. *Proc. 5th Lunar Sci. Conf.* 471-504.
- Papike J.J., Hodges F.N., Bence A.E., Cameron M. and Rhodes J.M. (1976) Mare basalts: Crystal chemistry, mineralogy and petrology. *Rev. Geophys. Space Phys.* 14, 475-540.
- Pearce G.W., Strangway D.W. and Gose W.A. (1974a) Magnetic properties of Apollo samples and implications for regolith formation. *Proc. 5th Lunar Sci. Conf.* 2815-2826.
- Pearce G.W., Gose W.A. and Strangway D.W. (1974b) Magnetism of the Apollo 17 samples (abs). *Lunar Sci. V*, 590-592. Lunar Planetary Institute, Houston
- Petrowski C., Kerridge J.F. and Kaplan I.R. (1974) Light element geochemistry of the Apollo 17 site. *Proc. 5th Lunar Sci. Conf.* 1939-1948.
- Rees C.E. and Thode H.G. (1974a) Sulfur concentrations and isotope ratios in Apollo 16 and 17 samples. *Proc. 5th Lunar Sci. Conf.* 1963-1973.
- Rhodes J.M., Rodgers K.V., Shih C., Bansal B.M., Nyquist L.E., Wiesmann H. and Hubbard N.J. (1974a) The relationships between geology and soil chemistry at the Apollo 17 landing site. *Proc. 5th Lunar Sci. Conf.* 1097-1117.
- Rhodes J.M., Hubbard N.J., Wiesmann H., Rodgers K.V., Brannon J.C. and Bansal B.M. (1976a) Chemistry, classification, and petrogenesis of Apollo 17 mare basalts. *Proc. 7th Lunar Sci. Conf.* 1467-1489.
- Rose H.J., Cuttitta F., Berman S., Brown F.W., Carron M.K., Christian R.P., Dwornik E.J. and Greenland L.P. (1974a) Chemical composition of rocks and soils at Taurus-Littrow. *Proc. 5th Lunar Sci. Conf.* 1119-1133.
- Runcorn S.K., Collinson D.W., and Stephenson A. (1974) Magnetic properties of Apollo 16 and 17 rocks – interim report (abs). *Lunar Sci. V*, 653-654. Lunar Planetary Institute, Houston
- Russell W.A., Papanastassiou D.A., Tombrello T.A. and Epstein S. (1977a) Ca isotope fractionation on the Moon. *Proc. 8th Lunar Sci. Conf.* 3791-3805.
- Schaeffer G.A. and Schaeffer O.A. (1977a) $^{39}\text{Ar}/^{40}\text{Ar}$ ages of lunar rocks. *Proc. 8th Lunar Sci. Conf.* 2253-2300.
- Schaeffer O.A., Muller H.W. and Grove T.L. (1977a) Laser ^{39}Ar - ^{40}Ar study of Apollo 17 basalts. *Proc. 8th Lunar Sci. Conf.* 1489-1499.
- Schaeffer O.A., Muller H.W. and Grove T.L. (1977b) Laser ^{39}Ar - ^{40}Ar study of Apollo 17 basalts (abs). *Lunar Planet. Sci. VIII*, 837-839. Lunar Planetary Institute, Houston.
- Schwerer F.C. and Nagata T. (1976) Ferromagnetic-superparamagnetic granulometry of lunar surface materials. *Proc. 7th Lunar Sci. Conf.* 759-778.
- Shaffer E., Brophy J.G. and Basu A. (1990) La/Sm ratios in mare basalts as a consequence of mafic cumulate fractionation from an initial lunar magma (abs). *Lunar Planet. Sci. XXI*, 1130-1131. Lunar Planetary Institute, Houston
- Shih C.-Y., Haskin L.A., Wiesmann H., Bansal B.M. and Brannon J.C. (1975a) On the origin of high-Ti mare basalts. *Proc. 6th Lunar Sci. Conf.* 1255-1285.
- Shih C.-Y., Wiesmann H. and Haskin L.A. (1975b) On the origin of high-Ti mare basalts (abs). *Lunar Sci. VI*, 735-737. Lunar Planetary Institute, Houston
- Stephenson A., Collinson D.W. and Runcorn S.K. (1974) Lunar magnetic field paleointensity determinations on Apollo 11, 16, and 17 rocks. *Proc. 5th Lunar Sci. Conf.* 2859-2871.
- Stephenson A., Runcorn S.K. and Collinson D.W. (1975) On changes in intensity of the ancient lunar magnetic field. *Proc. 6th Lunar Sci. Conf.* 3049-3062.

- Sugiura N. and Strangway D.W. (1980) Comparison of magnetic paleointensity methods using a lunar sample. Proc. 11th Lunar Planet. Sci. Conf. 1801-1813.
- Tittmann B.R., Curnow J.M. and Housley R.M. (1975a) Internal friction quality factor $Q > 3100$ achieved in lunar rock 70215,85. Proc. 6th Lunar Sci. Conf. 3217-3226.
- Tittmann B.R., Housley R.M. and Abdel-Gawad M. (1975b) Internal friction quality factor > 3100 achieved in lunar rock 70215,85 (abs). Lunar Sci. VI, 812-814. Lunar Planetary Institute, Houston.
- Tittmann B.R., Ahlberg L. and Cumow J. (1976) Internal friction and velocity measurements. Proc. 7th Lunar Sci. Conf. 3123-3132.
- Tittmann B.R., Ahlberg H., Nadler H., Curnow J., Smith T. and Cohen E.R. (1977) Internal friction quality-factor Q under confining pressure. Proc. 8th Lunar Sci. Conf. 1209-1224.
- Tittmann B.R., Nadler H., Richardson J.M. and Ahlberg L. (1978) Laboratory measurements of p-wave seismic Q on lunar and analog rocks. Proc. 9th Lunar Planet. Sci. Conf. 3627-3635.
- Walker D., Longhi J., Stolper E., Grove T. and Hays J.F. (1974) Experimental petrology and origin of titaniferous lunar basalts (abs). Lunar Sci. V, 814-816. Lunar Planetary Institute, Houston
- Walker D., Longhi J. and Hays J.F. (1975a) Heterogeneity in titaniferous lunar basalts. In Conference on Origins of Mare Basalts and their Implications for Lunar Evolution, 169-173. Lunar Science Institute, Houston
- Walker D., Longhi J., Stolper E.M., Grove T.L. and Hays J.F. (1975b) Origin of titaniferous lunar basalts. Geochim. Cosmochim. Acta 39, 1219-1235.
- Walker D., Longhi J. and Hays J.F. (1976a) Heterogeneity in titaniferous lunar basalts. Earth Planet. Sci. Lett. 30, 27-36
- Wänke H., Palme H., Baddenhausen H., Dreibus G., Jagoutz E., Kruse H., Palme C., Spettel B., Teschke F. and Thacker R. (1975a) New data on the chemistry of lunar samples: Primary matter in the lunar highlands and the bulk composition of the moon. Proc. 6th Lunar Sci. Conf. 1313-1340.
- Warren N., Trice R. and Stephens J. (1974) Ultrasonic attenuation: Q measurements on 70215,29. Proc. 5th Lunar Sci. Conf. 2927-2938.
- Wolfe E.W., Bailey N.G., Lucchitta B.K., Muehlberger W.R., Scott D.H., Sutton R.L and Wilshire H.G. (1981) The geologic investigation of the Taurus-Littrow Valley: Apollo 17 Landing Site. US Geol. Survey Prof. Paper, 1080, pp. 280.

Wilshire in Butler