

71055**High-Ti Mare Basalt****669.6 g, 19.5 x 9.5 x 2.5 cm****INTRODUCTION**

71055 was described as a light brownish gray, angular and intergranular basalt (Apollo 17 Lunar Sample Information Catalog, 1973), containing many zap pits on S (few on other surfaces) and 20-25% vugs (< 1-12mm) (Fig. 1). It has a homogeneous mineralogy, but a heterogeneous vug distribution. Vugs do not appear to be layered and pyroxene which projects into them is thin and needle-like. This basalt was collected from Station 1A.

PETROGRAPHY AND MINERAL CHEMISTRY

Brown et al. (1974, 1975a,b) described 71055 as a Type IB basalt which is comprised of: 45.3% clinopyroxene; 29.0% opaque minerals; 21.2% plagioclase; 2.6% silica; and 1.9% olivine. These authors described both mineral chemistry and petrography within the general confines of their Type IB category. Dymek et al. (1975) have studied thin section 71055,75 in detail. These

authors described 71055,75 as a vesicular, fine- to medium-grained, olivine-bearing ilmenite basalt with a seriate grain size distribution. The overall texture is plagioclase poikilitic. Dymek et al. (1975) also reported that 71055,75 is comprised of. 46% pyroxene; 27% plagioclase; 17% ilmenite; 3% olivine; and 2% silica. Minor amounts of Cr-ulvospinel, troilite, native Fe, Ca-phosphate, and mesostasis are also present. Olivine (up to 0.2mm) occurs as rounded cores to pyroxene (Fig. 2), although rarely olivine

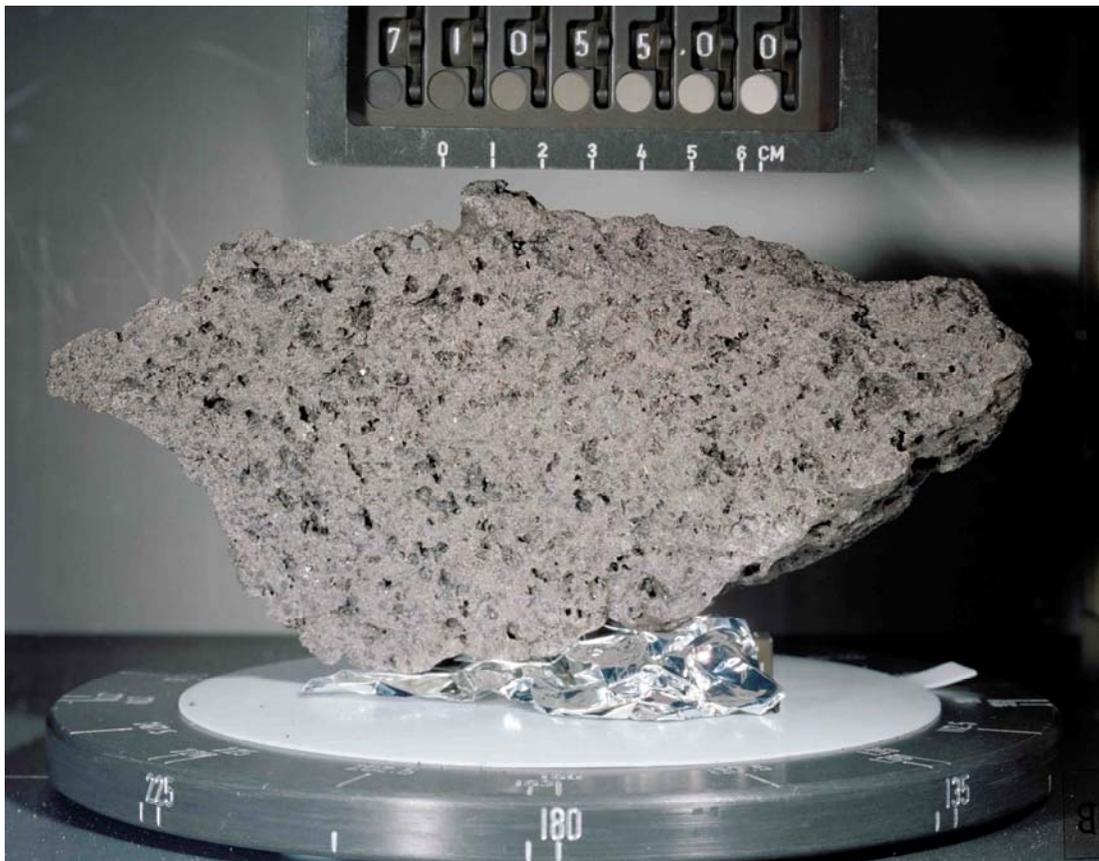


Figure 1: Hand specimen photograph of 71055,0.

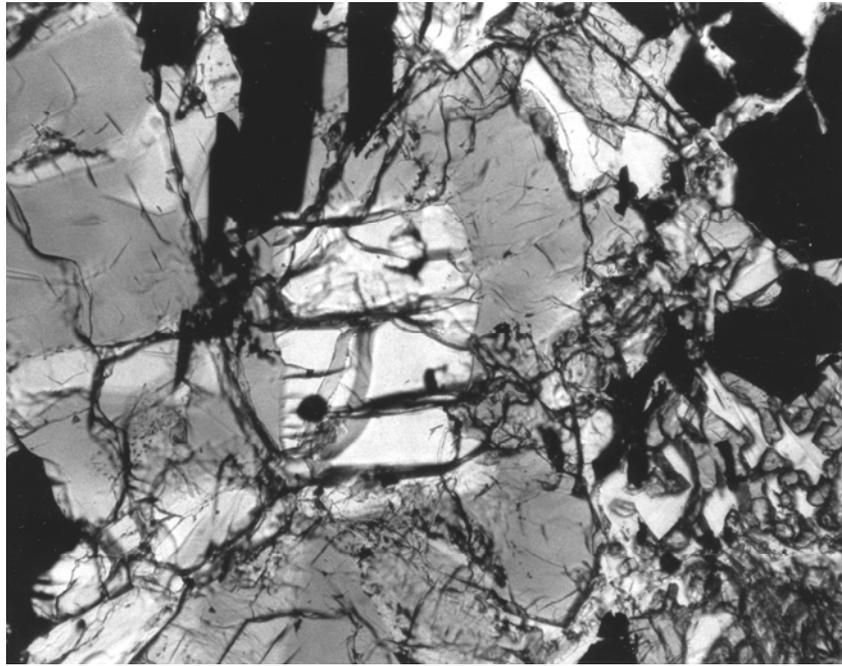


Figure 2: Photomicrograph of 71055,64 depicting an olivine phenocryst rimmed with pyroxene. Field of view is 1.25 mm.

contains only a thin pyroxene rim. The range in olivine composition is Fo₆₅₋₇₅, although the largest variation within one grain is only 5 mole % Fo. Ilmenite occurs as dominantly subequant, skeletal grains (up to 1mm) with "sawtooth" margins. Ilmenite forms inclusions in pyroxene and is intergrown with pyroxene and plagioclase. The ilmenites exhibit a range in MG# (4-13), with the most magnesian types forming rims on Cr-ulvospinel. Muhich et al. (1990) reported variations in ilmenite compositions in 71055 which correlated with the degree of exsolution. Ilmenites with abundant exsolution were richer in Mg relative to those without exsolution. No armalcolite was identified.

Pyroxenes are complex - the largest grains are typically composite. Pale pink (Al- and Ti-poor) to dark pink (Al- and Ti-rich) are arranged in parallel bands, in a radiating,

spherulitic pattern, or forming an hour-glass structure. These may have olivine cores, and contain inclusions of ilmenite, with which they occasionally form a graphic intergrowth. Smaller (up to 0.2mm) stubby pyroxene granules are enclosed poikilitically in plagioclase. Elongate pyroxenes (stubby, tabular, to acicular) form spherulitic intergrowths with plagioclase (Fig. 3). Plagioclase occurs as large, poikilitic grains (up to 1.5mm), discrete lath-like subequant grains (0.05-0.5mm), and elongate sheaves intergrown with pyroxene (Fig. 3). The measured range of plagioclase composition was An₇₇₋₈₄, although there is no direct correlation between petrographic type and composition. The large pyroxene grains zone towards Mg-rich, Ca-poor compositions. Al and Ti also decrease. The other petrographic types of pyroxene exhibit marked Fe enrichment relative to the larger types.

AIM ratios are constant at ~2. Spectral measurements suggest the presence of a substantial amount of Ti³⁺ (Sung et al., 1974a,b).

Taylor et al. (1992) report 71055,74 as being comprised of: 20% ilmenite, 42% clinopyroxene, 29% plagioclase, 5% silica, 3% olivine, and traces of native Fe, troilite, and apatite. These authors used 71055 in a study of magnetic beneficiation, and concluded that for fine-grained basalts, beneficiation requires grinding to a smaller grain size to effectively separate ilmenite from pyroxene.

Dymek et al. (1975) proposed the following crystallization sequence for 71055: Olivine, ilmenite, and Cr-ulvospinel formed first, but their relative order is difficult to determine; olivine and ulvospinel ceased to crystallize, but ilmenite continued to crystallize with pyroxene



Figure 3: Photomicrograph of 71055,68 depicting a "bow-tie" or subvariolic structure. Field of view is 2.5 mm.

and plagioclase throughout. The aluminous titan-augites formed next, in part by reaction between olivine and melt. This was followed by pigeonite, possibly due to the first appearance of plagioclase causing an abrupt decrease in Ca. However, this is not documented by the Al content of the pyroxene. Silica, native Fe, troilite and a potassic mesostasis were the last phases to crystallize.

WHOLE-ROCK CHEMISTRY

Although several whole-rock analyses have been performed on 71055 for trace elements (Philpotts et al., 1974; Brunfelt et al., 1974; Baedecker et al., 1974; Boynton et al., 1975; Dickinson et al., 1989), only one reported a complete analysis of major element oxide contents (Rose et al., 1974) of 71055,51 (Table 1). This sample contains 13.41 wt% TiO₂ with a MG# of 45.6. Miller et al. (1974)

reported element wt% abundances of 71055,56. Rose et al. (1974) analyzed 71055,51 by XRF and thus did not analyze for all the REE. However, elements such as Y, Nb, Ga, Be, and Li (69, 27, 8, 1, < 1, and 9.6 ppm, resp.) have been analyzed. Other analyses have only included the middle and heavy REE (e.g., Baedecker et al., 1974) (Fig. 4). The three complete REE profiles which have been reported (Philpotts et al., 1974; Brunfelt et al., 1974; Boynton et al., 1975) exhibit moderate variations in overall abundance (HREE = 25-35 times chondritic abundances - Fig. 4), but the negative Eu anomaly exhibits large variations between the different analyses ($[Eu/Eu^*]_N = 0.50-0.69$). However, all profiles are convex-upward and LREE-depleted (Fig. 4).

Garg et al. (1976a,b) determined Zr (221 and 213 ppm) and Hf (6.74 and 7.03 ppm) abundances

in 71055. Dickinson et al. (1988, 1989) determined the abundance of Ge (2.7 ppb) in 71055. Carbon, nitrogen, and sulfur abundances (54, 79, and 1860 pg/g, resp. - Table 1) have been determined for 71055 by Sill et al. (1974) and Moore et al. (1974a,b).

ISOTOPES

Lead isotope studies have been undertaken by Chen et al. (1979) and Tilton and Chen (1979), the results of which are reported in Table 2. Tera et al. (1974) and Murthy and Coscio (1976) reported a crystallization age for 71055 of 3.64 ± 0.09 Ga, with an initial $^{87}Sr/^{86}Sr$ ratio of 0.69910 ± 4 (Table 3). No Sm-Nd work has been conducted upon this sample. Oxygen isotope work was conducted by Mayeda et al. (1975) on mineral separates from 71055,45 (Table 3). Arvidson et al. (1976) obtained krypton and xenon data for

Table 1: Whole-rock chemistry of 71055.

	,56	,51	,38	,36	,31	,31	,171
	I	X/O/S	ID	I	I	I	I, R
	1	2	3	4	5	6	7
SiO ₂ (wt %)	37.45	38.14					
TiO ₂	12.05	13.41		14.21		14.35	
Al ₂ O ₃	8.32	8.62		8.18		10.02	
Cr ₂ O ₃		0.41		0.407	0.192	0.181	0.41
FeO	19.48	19.20		19.09	21.16	18.58	16.0
MnO	0.258	0.26		0.258	0.163	0.153	
MgO	10.46	9.04		8.80			
CaO	9.52	10.77		11.34		10.64	12.2
Na ₂ O	0.45	0.31		0.31	0.42	0.41	0.34
K ₂ O		0.06	0.028	0.04			
P ₂ O ₅		0.08					
S							
Nb (ppm)		27					
Zr		223					
Hf				6.6	7.0	6	5.7
Ta				1.54	1.3	1.6	1.4
U				0.132			
Th				0.32	<0.65		0.46
W				0.089			
Y		69					
Sr		170	121	104			
Rb		0.9	0.362	0.9			
Li		9.6	9.32				
Ba		315	62.4	39			63
Cs				0.07			
Be		<1					
Zn		<4		3	1.9		
Pb		<2					
Cu		31		4.4			
Ni		43		<10	2.0		
Co		51		21.6	26	22	18
V		88		129			364
Sc		87		95	94	82	80
La		<10		4.67		4.6	4.6
Ce			15.6	13.4	23	22	13
Nd			17.0				33
Sm			6.72	7.05		6.1	6.0

Table 1: (Concluded).

	,56	,51	,38	,36	,31	,31	,171
	I	X/O/S	ID	I	I	I	I, R
	1	2	3	4	5	6	7
Eu			1.36	1.49	1.5	1.8	1.3
Gd							
Tb				1.74	2.1	2.0	1.6
Dy			13.0	14.3			
Er			7.74				0.87
Yb			7.75	5.4	5.7	6.3	6.4
Lu				1.10		1.1	1.0
Ga				3.0	4.27		22
F							
Cl							
C							
N							
H							
He							
Ge (ppb)					3.3		2.4
Ir					1.1		
Au					0.082		
In					4.7		
Ru							
Os							

References: 1 = Miller et al. (1974); 2 = Rose et al. (1974); 3 = Philpotts et al. (1974); 4 = Brunfelt et al. (1974); 5 = Baedecker et al. (1974); 6 = Boynton et al. (1975); 7 = Dickinson et al. (1989).

Analysis by: I = INAA; X = XRF; O = Optical emission; S = Semimicro chemical methods; ID = Isotope Dilution; R = RNAA.

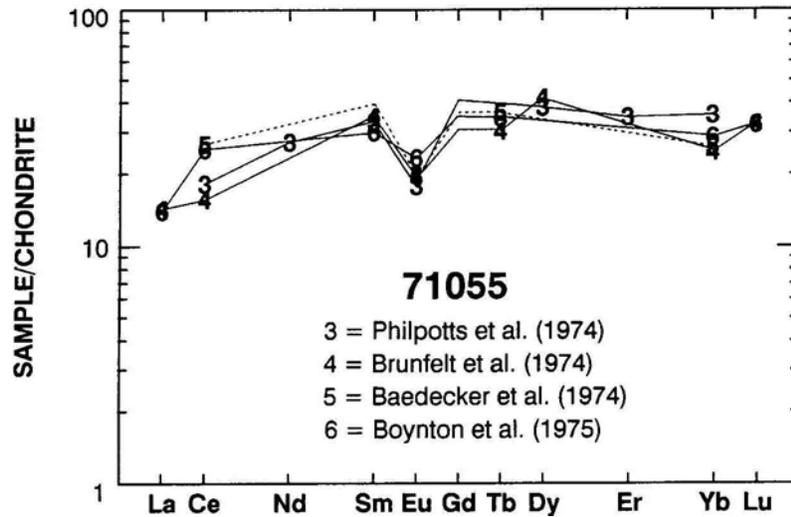


Figure 4: Chondrite- normalized rare-earth element profile of 71055.

71055 (Table 4), and reported an exposure age of 110 ± 7 Ma for 71055.

EXPERIMENTAL

Several diverse experimental studies have been conducted upon 71055. Engelhardt (1979) used 71055 in an investigation of ilmenite in the crystallization sequence of lunar rocks. This study noted that ilmenite in 71055,68 started to crystallize before plagioclase and ended before pyroxene crystallization.

O'Hara and Humphries (1975) studied the crystallization sequence of the phenocryst assemblages in 71055 through oxygen fugacity and

temperature-controlled experiments. These authors noted that spinel crystallized first, followed by armalcolite and olivine, then ilmenite. Pyroxene and plagioclase are late crystallizing phases. Usselman et al. (1975), in a study of cooling rates and textures of Apollo 17 high-Ti basalts, estimated that 71055 cooled at a rate of 103 °C/hr. Finally, Trice et al. (1974) studied the elastic properties of 71055 in order to gain insight into the near-surface structure at the Taurus-Littrow area.

MAGNETIC STUDIES

Two magnetic studies have been undertaken utilizing 71055.

Brecher (1974) undertook a comparative study of the magnetic properties of a number of Taurus-Littrow basalts. Watson et al. (1974) reported the thermomagnetic properties of 71055, noting the average NRM of 71055 is 2.0×10^{-5} emu/gm.

PROCESSING

71055,0 has been entirely subdivided. The largest remaining portion of this sample is 394.6g (71055,8). Several sub-samples exist weighing between 20-40g (.7, .10, .14, .26, and .38). Fifteen thin sections have been cut from this sample (71055,64-71, and .72-78).

Table 2a: Pb isotopic ratios and elemental abundances for 71055.
Data from Chen et al. (1979) and Tilton and Chen (1979).

Sample	Weight (mg)	Concentration (ppm) ^a			²³² Th	²³⁸ U
		Pb	U	Th	²³⁸ U	²⁰⁴ Pb
71055						
Whole rock-1R ^b	99	0.2147 (+ 4, -14)	0.1077 (6)	0.353 (5)	3.39 (5)	636 (+ 64, -4)
Acid wash ^c		-	0.00460 (4)	0.0230 (2)	5.18 (6)	-
Total		-	0.1123 (6)	0.376 (5)	3.46 (5)	-
Whole rock-2R	66	0.1614 (+ 3, -18)	0.0828 (3)	0.277 (2)	3.46 (3)	632 (+ 132, -3)
Acid wash		-	0.00835 (8)	0.0425 (4)	5.26 (7)	-
Total		-	0.0912 (3)	0.320 (2)	3.62 (3)	-
Whole rock-3	101	0.2558 (+ 11, -9)	0.1285 (5)	0.448 (3)	3.60 (2)	760 (+ 34, -42)
Whole rock-4R	131	0.1524 (+ 5, -8)	0.0771 (3)	0.266 (9)	2.77 (2)	398 (+ 8, -61)
Acid wash		0.0791 (+ 5, -4)	0.0307 (2)	0.164 (2)	5.50 (6)	175 (+ 3, -4)
Total		0.2315 (+ 7, -9)	0.1078 (4)	0.3706 (22)	3.55 (2)	292 (+ 9, -6)
Whole rock-5R	176	0.1545 (+ 10, -12)	0.0790 (2)	0.209 (1)	2.74 (2)	418 (+ 4, -3)
Acid wash		0.0765 (+ 3, -3)	0.0294 (1)	0.161 (2)	5.67 (7)	169 (+ 2, -3)
Total		0.2310 (+ 10, -12)	0.1084 (2)	0.370 (2)	3.53 (2)	298 (+ 7, -4)
Pyroxene D-R	62	0.2964 (+ 12, -10)	0.1446 (5)	0.473 (3)	3.38 (2)	585 (+ 29, -36)
Acetone wash		0.00224 (1)	6.6 × 10 ⁻⁵ (0.5)	0.00019 (0.2)	3.07 (4)	1.98 (1)
Acid wash		-	0.0132 (1)	0.0746 (7)	5.86 (7)	-
Total		-	0.1578 (5)	0.5476 (31)	3.59 (2)	-
Pyroxene-1R	62	0.1116 (+ 9, -13)	0.0551 (1)	0.1546 (9)	2.90 (2)	376 (+ 46, -27)
Acetone wash		0.00245 (3)	-	-	-	-
Acid wash		0.0445 (+ 7, -2)	0.0154 (2)	0.0789 (9)	5.29 (8)	89 (+ 1, -5)
Total		0.1561 (+ 11, -13)	0.0705 (2)	0.2335 (13)	3.42 (2)	221 (+ 11, -13)
Pyroxene-2	51	0.1400 (+ 10, -16)	0.0647 (3)	0.214 (1)	3.41 (2)	284 (+ 26, -16)
Water wash		0.00409 (+ 71, -2)	0.00014 (0.1)	0.00010 (0.1)	0.75 (1)	2.41 (+ 2, -11)
Pyroxene-3	58	0.1631 (+ 4, -25)	0.0806 (3)	0.268 (1)	3.43 (1)	544 (+ 159, -2)

Table 2a: (Concluded).

Sample	Weight (mg)	Concentration (ppm) ^a			²³² Th	²³⁸ U
		Pb	U	Th	²³⁸ U	²⁰⁴ Pb
Water wash		0.0007	0.00002	0.00005	2.5	1.5
Ilmenite-R	61	0.3500 (+ 13, -17)	0.1612 (6)	0.487 (2)	3.12 (1)	409 (+ 18, -11)
Acid wash		0.06055 (+ 2, -60)	0.0312 (4)	0.186 (1)	6.15 (8)	316 (+ 35, -4)
Total		0.4106 (+ 13, -18)	0.1924 (7)	0.673 (2)	3.61 (2)	390 (+ 21, -7)
Plagioclase-1R	73	0.06645 (+ 65, -100)	0.01343 (8)	0.0442 (4)	3.40 (3)	37 (+ 16, -6)
Acid wash		0.02655 (+ 6, -55)	0.00423 (3)	0.0182 (1)	4.44 (4)	17 (+ 6, -1)
Total		0.09300 (+ 65, -114)	0.01766 (8)	0.0624 (4)	3.65 (3)	29 (+ 1, -1)
Plagioclase-2R	31	0.0757 (+ 2, -14)	0.0269 (1)	0.0683 (4)	2.62 (1)	161 (+ 95, -1)
Acid wash		0.0400 (+ 4, -9)	0.0103 (6)	0.0546 (3)	5.5 (3)	41 (+ 5, -3)
Total		0.1157 (+ 44, -42)	0.0372 (6)	0.1229 (5)	3.41 (5)	90 (+ 19, -2)

^aNumbers in parentheses correspond to 2 σ errors for mass spectrometric ratio measurements, $\pm 0.1\%$ uncertainties for the concentrations of tracers, and chemical blanks.

^bResidues from cold 1NHCl leaches.

^cSamples contacted with cold 1NHCl for 10 minutes.

Table 2b: Observed and corrected lead isotopic ratios in 71055,21.

Data from Chen et al. (1979) and Tilton and Chen (1979).

Sample	Blank (pg)	Observed Ratios			Corrected Ratios		
		²⁰⁸ Pb	²⁰⁷ Pb	²⁰⁴ Pb	²⁰⁸ Pb	²⁰⁷ Pb	²⁰⁴ Pb
		²⁰⁶ Pb	²⁰⁶ Pb	²⁰⁶ Pb	²⁰⁶ Pb	²⁰⁶ Pb	²⁰⁶ Pb
WR-1R	107	0.90186 (86)	0.54868 (80)	0.001825 (28)	0.8983 (+9, -40)	0.5478 (+8, -16)	0.00167 (+3, -16)
WR-2R	107	0.89425 (98)	0.54294 (68)	0.002023 (26)	0.8871 (+10, -73)	0.5412 (+7, -22)	0.00170 (+3, -30)
WR-3	158	0.91376 (40)	0.52947 (29)	0.001588 (22)	0.9095 (+20, -15)	0.5283 (+7, -6)	0.00139 (+9, -7)
WR-4R	132	0.82960 (60)	0.56287 (50)	0.002850 (36)	0.8313 (+18, -32)	0.5635 (+3, -6)	0.00263 (+9, -14)
Acid wash	60	1.2221 (15)	0.51477 (90)	0.005506 (64)	1.2286 (+35, -28)	0.5150 (+17, -14)	0.00528 (+18, -15)
Total					0.9550 (+22, -38)	0.5484 (+3, -6)	0.00345 (+12, -18)
WR-5R	132	0.8327 (40)	0.5551 (38)	0.00269 (16)	0.8358 (+48, -58)	0.5560 (+40, -42)	0.00253 (+19, -24)
Acid wash	60	1.2410 (14)	0.5196 (8)	0.005636 (40)	1.2485 (+29, -24)	0.5202 (+14, -12)	0.00545 (+25, -10)
Total					0.9594 (+55, -67)	0.5453 (+40, -42)	0.00340 (+26, -32)
PxD-R	158	0.9108 (10)	0.54867 (35)	0.002039 (22)	0.9048 (+32, -26)	0.5472 (+9, -7)	0.00177 (+12, -9)
Acetone wash	24	1.971 (10)	0.7961 (90)	0.0490 (6)	-	-	-
Px-1R	140	0.84550 (96)	0.55461 (75)	0.003305 (28)	0.8309 (+51, -73)	0.5513 (+17, -22)	0.00270 (+20, -29)
Acetone wash	24	1.982 (10)	0.8245 (80)	0.0476 (6)	-	-	-
Acid wash	59	1.3765 (40)	0.5595 (10)	0.0105 (3)	1.366 (+10, -4)	0.5553 (+35, -10)	0.00984 (+70, -30)
Total					0.9619 (+59, -84)	0.5523 (+17, -22)	0.00445 (+33, -48)
Px-2	140	0.9472 (12)	0.5566 (10)	0.00411 (4)	0.9335 (+51, -72)	0.5532 (+20, -25)	0.00350 (+22, -31)
Water wash	59	1.982 (7)	0.8100 (70)	0.0488 (13)	1.976 (+7, -17)	0.8085 (+70, -98)	0.0484 (+13, -20)
Px-3	78	0.9151 (12)	0.5353 (9)	0.00218 (2)	0.9092 (+12, -100)	0.5338 (+9, -33)	0.00192 (+2, -44)
Water wash	33	2.012 (20)	0.8240 (20)	0.0521 (4)	1.988 (+12, -87)	0.8229 (+70, -59)	0.0513 (+3, -30)
Ilm-R	137	0.91167 (80)	0.56638 (70)	0.002611 (28)	0.9071 (+20, -29)	0.5653 (+10, -12)	0.00241 (+8, -12)
Acid wash	24	1.261 (3)	0.4528 (26)	0.004042 (12)	1.2574 (+30, -78)	0.4511 (+16, -41)	0.00382 (+1, -33)
Total					0.9548 (+21, -30)	0.5498 (+10, -12)	0.00260 (+9, -13)
Pl-1R	137	1.1255 (17)	0.8643 (11)	0.01503 (10)	1.106 (+7, -11)	0.8651 (+15, -13)	0.0142 (+3, -5)
Acid wash	24	1.6176 (24)	0.71121 (86)	0.02775 (16)	1.613 (+2, -9)	0.7100 (+9, -27)	0.0275 (+4, -5)
Total					1.239 (+8, -12)	0.8244 (+14, -12)	0.0177 (+4, -6)
Pl-2R	78	0.8520 (15)	0.7301 (9)	0.00592 (4)	0.8258 (+15, -446)	0.7280 (+9, -43)	0.00488 (+4, -17)
Acid wash	33	1.535 (4)	0.6142 (30)	0.01764 (20)	1.524 (+7, -13)	0.6096 (+43, -57)	0.0169 (+4, -8)
Total					1.035 (+18, -559)	0.6925 (+9, -41)	0.00848 (+7, -29)

^aNumbers in parentheses are 2σ errors from the mass spectrometry.

^bUncertainties are corrected for 0.1-0.2 ng Pb blanks and for 2σ errors in mass spectrometry. Isotopic composition of blank:

$$^{204}\text{Pb}:^{206}\text{Pb}:^{207}\text{Pb}:^{208}\text{Pb} = 1.00 = 18.90 = 15.60 = 38.60.$$

Table 3: Rb-Sr and O isotope ratios for 71055.

Rb-Sr Composition (Tera et al., 1974)				
	I(Sr)			AGE (Ga)
71055	0.69910 + 4			3.64 + 0.09
$\delta^{18}\text{O}$ Composition (Mayeda et al., 1975)				
	Cristobalite	Plag	Pyroxene	Ilmenite
71055,45	6.75	5.82	5.36	4.01

Table 4: Krypton & xenon data from 71055.Data from Arvidson et al. (1976). Results given in units of 10^{-12} cm³ STP/g.

Temp (°C)	⁸⁴Kr	⁷⁸Kr	⁸⁰Kr	⁸¹Kr	⁸²Kr	⁸³Kr	⁸⁶Kr			
750	6.4	3.223 ±2.078	14.472 ±0.755		34.19 ±1.41	39.48 ±1.85	28.11 ±0.31			
1500	41.3	31.867 ±0.689	83.856 ±1.627	0.3088 ±0.0138	132.13 ±2.40	174.10 ±3.45	11.25 ±0.46			
Temp (°C)	¹³²Xe	¹²⁴Xe	¹²⁶Xe	¹²⁸Xe	¹²⁹Xe	¹³⁰Xe	¹³¹Xe	¹³⁴Xe	¹³⁶Xe	
750	5.1	7.115 ±0.373	6.681 ±2.511	22.36 ±1.12	107.32 ±2.69	23.91 ±0.64	110.62 ±1.96	35.44 ±1.25	28.87 ±0.77	
1500	86.1	49.025 ±0.309	82.808 ±0.481	125.51 ±0.73	169.65 ±1.07	79.67 ±0.37	347.47 ±2.02	20.23 ±0.18	14.08 ±0.18	