

12021
Pigeonite Basalt
 1876.6 grams



Figure 1: Photo of 12021,36 showing elongate pyroxene in broken surface.

Introduction

12021 is a porphyritic pigeonite basalt (figure 1) that has been dated at 3.3 b.y. old.

Hörz and Hartung (1972) found that 12021 must have changed orientation at least once because “old” zap pits were found beneath the soil line. In any case, the orientation found by Hörz and Hartung (based on cratered – uncratered surfaces) differs from that found by Sutton and Schaber (1971) (based on surface photography).

Petrography

Weill et al. (1971) describe 12021 as a porphyritic basalt with elongate pyroxene phenocrysts up to 2 cm in length set in a variolitic groundmass of pyroxene, plagioclase and ilmenite (figure 2). Mesostasis includes silica phases, metallic iron, and glass. French et al. (1972) describe 12021 as “generally coarse grained. A striking feature is the presence of large anhedral pyroxene phenocrysts up to 10 mm long. No olivine was observed”.

Mineralogical Mode of 12021

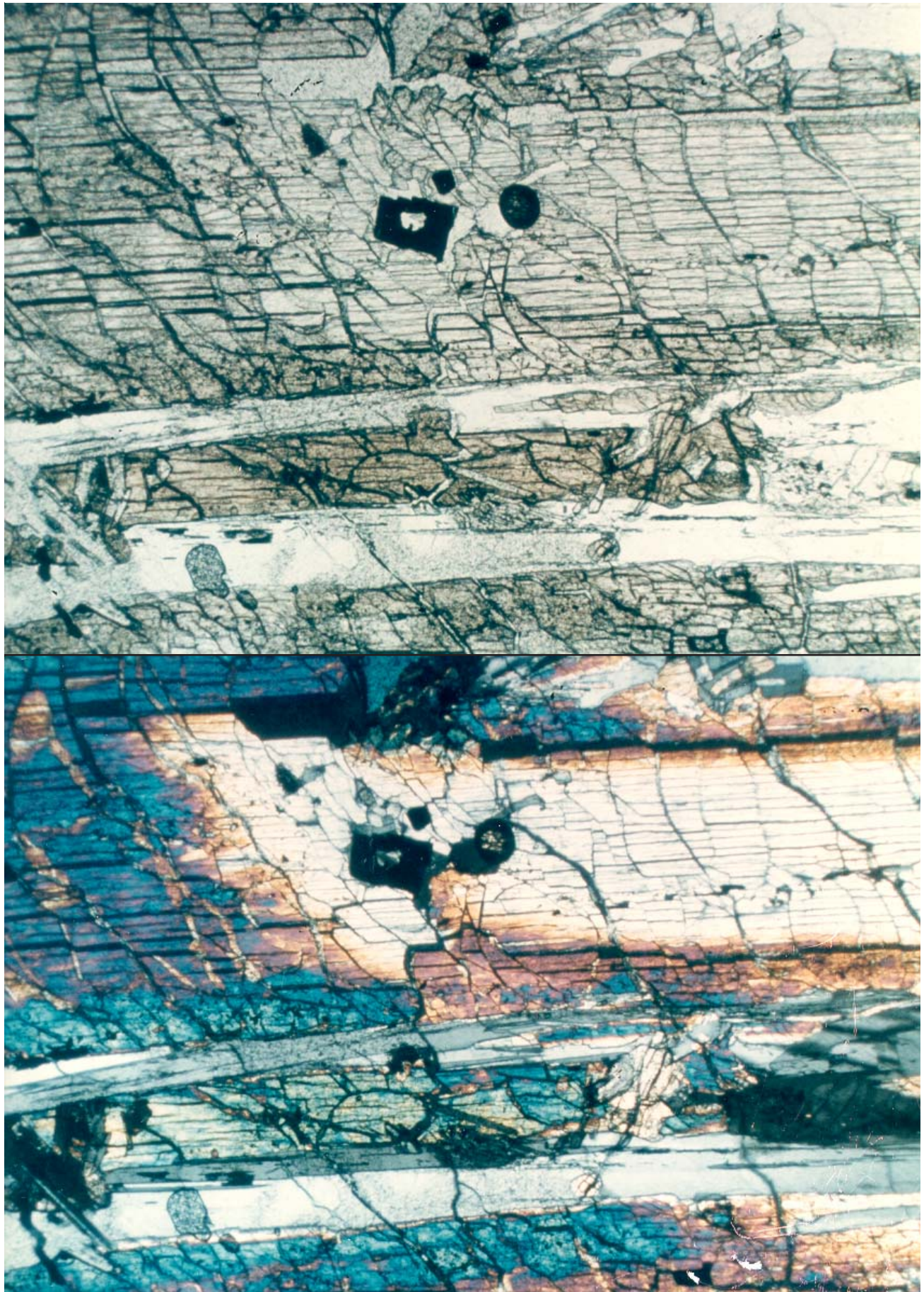
	McGee et al. 1977	Neal et al. 1994	Boyd and Smith 1971	Klein et al. 1971	Papike et al. 1976	Brown et al. 1971
Olivine	--	1				
Pyroxene	50-71	71.3	64	70.5	62.6	66
Plagioclase	22-34	25.5	27	22.7	30.7	22.4
Opagues	5-12	1.7	5	5.5	5.6	11.6
“silica”	5	0.2	2	1.3	0.3	
mesostasis	0.8				0.8	



Figure 2: Photomicrograph of thin section of 12021,3 showing elongate and sector-zoned pyroxene. Field of view is 3 cm. NASA # S70-25401.

Figure 3: Photomicrographs of large pyroxene in 12021,145. NASA #S70-49467-468. Scale is 2.2 mm.





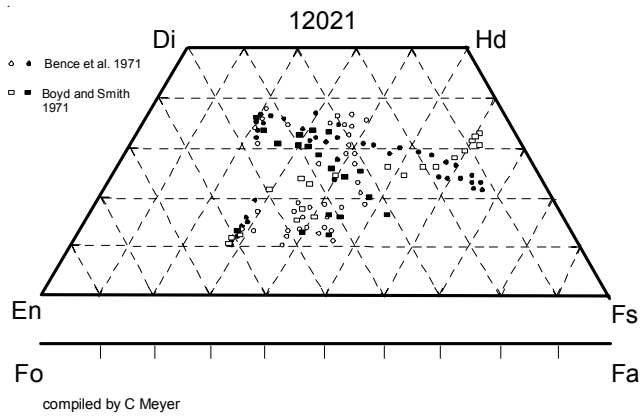


Figure 4: Only some of the many analyses of pyroxene in 12021 by numerous investigators (there was no olivine reported).

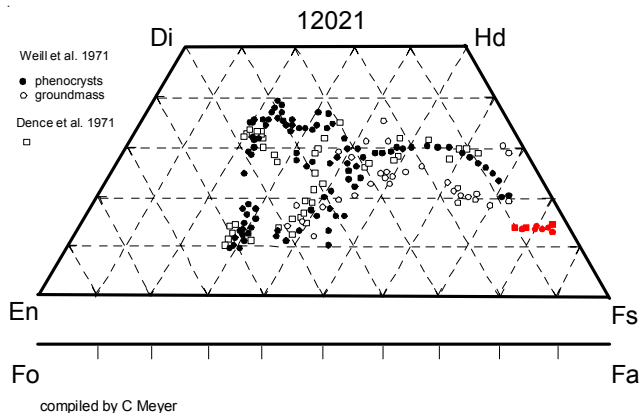


Figure 5: Additional pyroxene analyses including pyroxferroite (red).

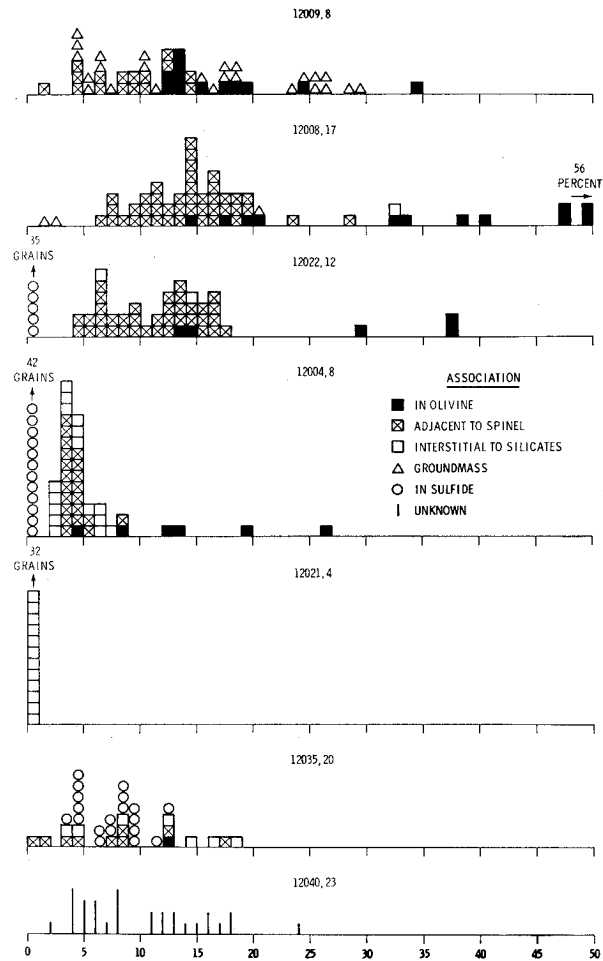


Figure 6: Histogram of Ni concentrations of metal grains in 7 lunar samples (lifted from Brett et al. 1971).

Drever et al. (1972) discuss the texture of 12021 and introduce a new term *intrafasciculate* to describe the hollow cores of elongate plagioclase and pyroxene needles in this rock. They explain that “this intravasciculate texture is closely related to the “plumose” texture commonly referred to as variolitic” in descriptions of Apollo 12 basalts.

Mineralogy

Olivine: none in 12021

Pyroxene: Weill et al. (1971), Klein et al. (1971), Boyd and Smith (1971), Dence et al. (1971), Walter et al. (1971) and Bence et al. (1970, 1971) studied the complex zoning patterns in the large pyroxenes in 12021 (figures 4 and 5). Pigeonite cores have sharp boundaries with augite rims and groundmass pyroxene

is increasingly Fe-rich. Many of the large pyroxene crystals are sector zoned. Papike et al. (1971) and Ross et al. (1973) reported crystallographic data and discussed epitaxy, exsolution and phase relations of pyroxene from 12021.

Pyroxferroite: Boyd and Smith (1971) and Weill et al. (1971) found large (~500 micron) grains of “pyroxferroite” in the groundmass of 12021. When in contact with Fe-augite, the boundary is sharp.

Plagioclase: Plagioclase is An₉₁₋₉₆. Long (1.5 cm) crystals of plagioclase often have a non-plagioclase cores (*as in straws*) (figure 7, Walter et al. 1971). Wenk et al. (1972) determined crystal structure for anorthite in 12021. This was termed *intrafasciculate* by Drever et al. (1972).

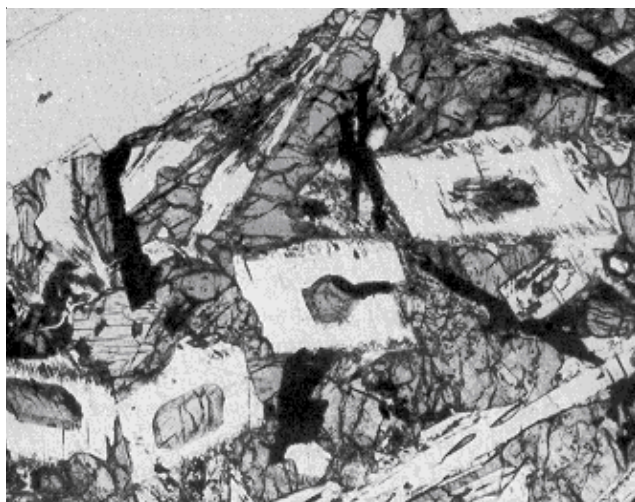


Figure 7: Hollow plagioclase crystal in 12021 (from Walter et al. 1971). Field of view about 500 microns.

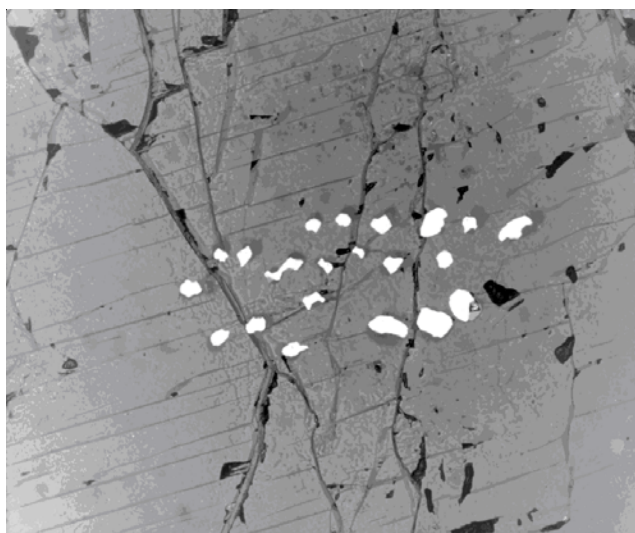


Figure 8: Unusual group of iron grains in 12021, 4. NASA #S70-20751. Field of view about 1 mm. See also figure in Walter et al. 1971.

Opaques: Ilmenite, chromite, troilite and tranquillityite (see metal).

Silica: In 12021, cristobalite occurs as clear, subhedral grains up to 75 microns across, and displays characteristic mosaic twinning and curved features (Weill et al. 1971). Tridymite forms long needles. Appleman et al. (1971) and Dollase et al. (1971) reported the crystal structure of tridymite in 12021.

Metal: Brett et al. (1971) determined that there was essentially no Ni content in the metallic iron grains in 12021 (figure 6) while Walter et al. (1971) reported

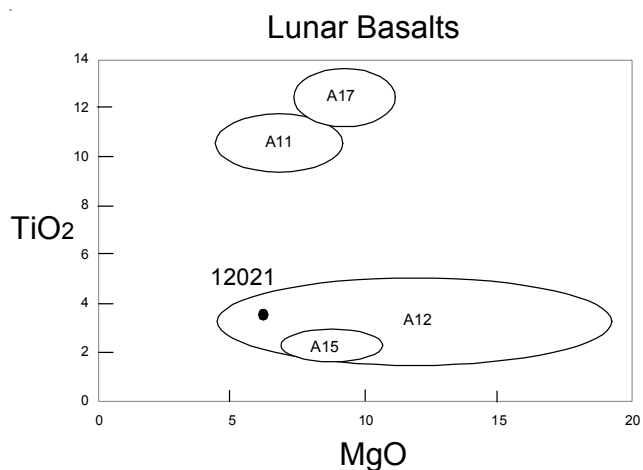


Figure 9: Composition of lunar basalts with that of 12021 indicated.

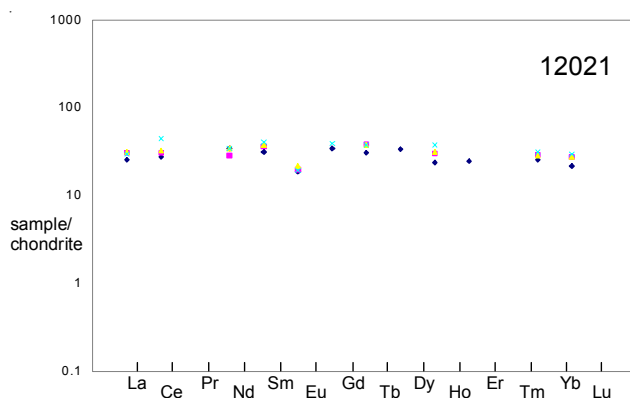


Figure 10: Normalized rare-earth-element composition diagram for 12021 (data from table 1).

0.5 wt. % Ni in iron needles in pyroxene (figure 8). This is unusual when compared with other lunar basalts.

Chemistry

The chemical composition of 12021 was determined by numerous investigators, using a variety of techniques (table 1). This sample is found to be relatively low in Mg (figure 9). It has a relatively flat REE pattern (figure 10).

Radiogenic age dating

Cliff et al. (1971) determined a mineral isochron in the Rb/Sr system for 12021 with an age of 3.3 ± 0.1 b.y (figure 11). Papanastassiou and Wasserburg (1971a) reported 3.33 ± 0.06 b.y. (figure 12).

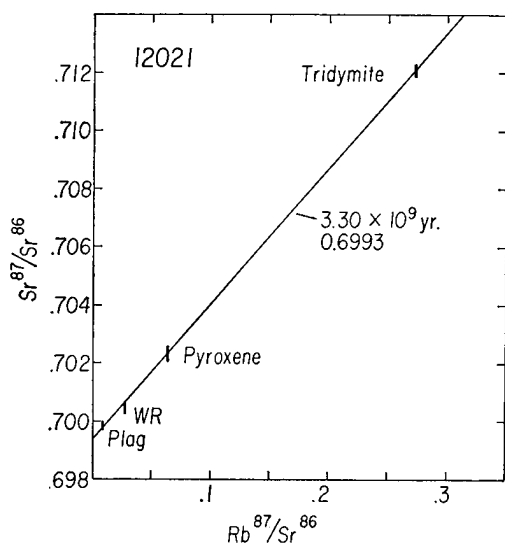


Figure 11: Rb/Sr isochron for 12021 (from Cliff et al. 1971).

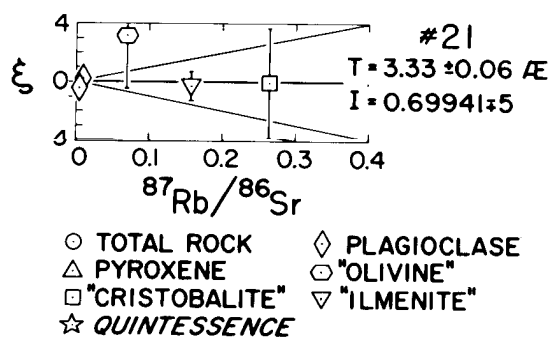


Figure 12: Rb-Sr ages and initial Sr/Sr intercept for Apollo 12 basalt 12021 (from Papanastassiou and Wasserburg 1971a).

Cosmogenic isotopes and exposure ages

Marti and Lugmair (1971) determined a $Kr^{81} - K^{83}$ exposure age of 303 ± 18 m.y.

Other Studies

Fleischer et al. (1971) determined the nuclear track densities in pyroxene and estimated the surface residence time. Price et al. (1971) reported track lengths > 1 mm in pyroxene apparently due to high-energy, heavy ($Z \sim 80$) cosmic rays.

Processing

Originally some small pieces (,1 to ,15) were broken off one end. Then a large piece (B, 33) was split off and subdivided by sawing with a wire saw (figures 14 and 15). 12021,8 was apparently used for public display (see picture).

There are 39 thin sections

List of Photo #s for 12021

S69-61985	
S69-64084	
S69-64109	
S70-16782 – 16783	TS
S70-16792 – 16793	TS
S70-20751	iron
S70-20960	TS
S70-49145 – 49150	TS
S70-49467 – 49468	TS
S74-27037	, 8 display
S74-23060	
S76-21649	
S76-21646	slices
S79-27123 – 27124	TS

Summary of Age Data for 12021

	Ar/Ar	Rb/Sr
Cliff et al. 1971		3.3 ± 0.1 b.y.
Papanastassiou and Wasserburg 1971a		3.33 ± 0.06

Table 1a. Chemical composition of 12021.

reference weight	Kushiro71	Goles71	O'Kelly71 1877 g	Morrison71	Cuttitta71	Haskin71	Engel71	Kharkar71				
SiO ₂ %	46.46	(a) 46	47	(b)	46.5	46.7	(d)	47.05	(a)			
TiO ₂	3.44	(a) 3.5	3.5	(b)	3.84	(b) 3.51	3.45	(d)	3.74	(a) 4.17	(b)	
Al ₂ O ₃	10.55	(a) 10	10.5	(b)	11.15	(b) 10.5	11.1	(d)	10.97	(a)		
FeO	19.68	(a) 19.2	19.2	(b)	20.07	(b) 19.4	19.1	(d)	19.04	(a) 18.91	(b)	
MnO	0.26	(a) 0.25	0.25	(b)	0.28	(b) 0.27	0.27	(d)	0.25	(a) 0.26	(b)	
MgO	7.6	(a)			7.29	(b) 7.48	7.38	(d)	7.08	(a)		
CaO	11.37	(a) 9.9	10.5	(b)	12.7	(b) 11.3	11.5	(d)	11.34	(a) 11.2	(b)	
Na ₂ O	0.35	(a) 0.26	0.27	(b)	0.28	(b) 0.3	0.3	(d)	0.29	(a) 0.27	(b)	
K ₂ O	0.07	(a)		0.06	(c) 0.07	(b) 0.06	0.05	(d)	0.08	(a)		
P ₂ O ₅	0.01	(a)				0.09	0.09	(d)	0.09	(a)		
S %												
sum												
Sc ppm		51	48.3	(b)	45	(b) 51	48	(d)	64	55	(b)	
V			130	(b)	190	(b) 130	147	(d)	160			
Cr	2737	(a) 2060	1870	(b)	2500	(b) 2850	3180	(d)	2400	2390	(b)	
Co		29.6	27.7	(b)	37	(b) 38	36	(d)	22	32	(b)	
Ni					87	(b) 16	13	(d)	3			
Cu					9.7	(b) 13	14	(d)	11			
Zn					4.2	(b) 4.3	4	(d)				
Ga					3.4	(b) 4.7	5.4	(d)				
Ge ppb												
As												
Se												
Rb						1.2	1.4	(d)				
Sr						84	73	(d)	130			
Y						53	48	(d)	58			
Zr			100	(b)	140	(b) 133	112	(d)	180			
Nb												
Mo												
Ru												
Rh												
Pd ppb												
Ag ppb												
Cd ppb												
In ppb												
Sn ppb												
Sb ppb					32	(b)						
Te ppb												
Cs ppm												
Ba		120	130	(b)	72	(b) 71	88	(d)	86			
La		7.29	7.46	(b)	7.2	(b)		6.16	(b)	6.3	(b)	
Ce		19	20	(b)	27	(b)		17.1	(b)	49	(b)	
Pr												
Nd		13	16	(b)	16	(b)		16	(b)			
Sm		5.43	5.68	(b)	6	(b)		4.75	(b)	3.7	(b)	
Eu		1.12	1.24	(b)	1.1	(b)		1.055	(b)	1.2	(b)	
Gd					8	(b)		6.9	(b)			
Tb		1.41	1.38	(b)	1.4	(b)		1.14	(b)	1.79	(b)	
Dy								8.3	(b)	14.3	(b)	
Ho		1.7	1.8	(b)	2.1	(b)		1.36	(b)			
Er								4	(b)			
Tm					0.53	(b)						
Yb		4.81	4.77	(b)	5.3	(b) 5.4	5.7	(d)	4.2	(b) 10	4.4	(b)
Lu		0.68	0.69	(b)	0.72	(b)		0.523	(b)	0.83	(b)	
Hf		4.03	4.09	(b)	4.6	(b)				4.2	(b)	
Ta		0.4	0.41	(b)	0.7	(b)				0.79	(b)	
W ppb					150	(b)						
Re ppb												
Os ppb												
Ir ppb												
Pt ppb												
Au ppb												
Th ppm		1.7	1.5	(b) 0.98	(c) 1.1	(b)				0.08	(b)	
U ppm				0.26	(c)					0.29	(b)	

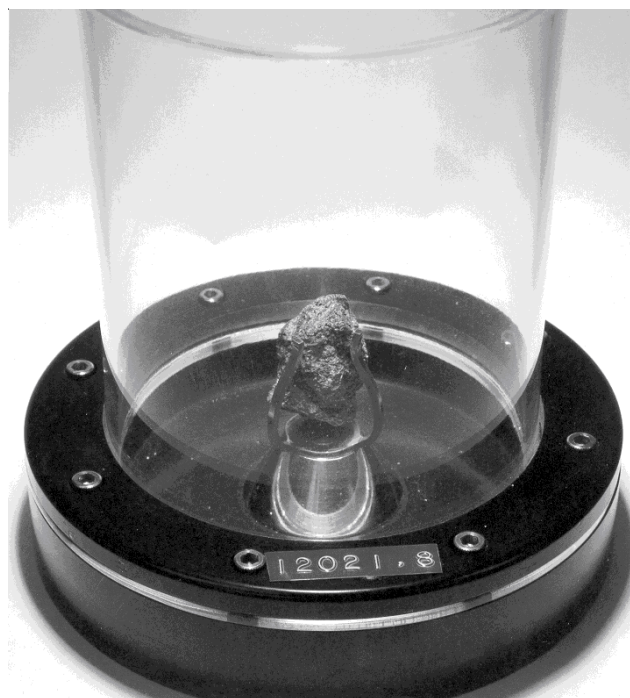
technique: (a) conventional wet, (b) INAA, (c) radiation counting, (d) mixed microchem. XRF, emis. Spec.

Table 1b. Chemical composition of 12021.

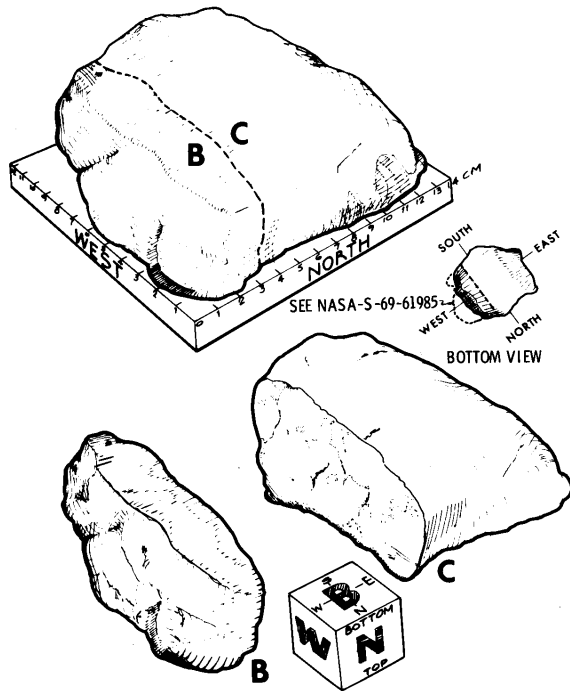
reference weight	Brunfelt71		Klein71 Neal2001		Tatsumoto71	
SiO ₂ %			46.2	(a)		
TiO ₂	3.22	3.22	(e)	3.9	(a)	
Al ₂ O ₃	11.28	10.45	(e)	12.5	(a)	
FeO				19.4	(a)	
MnO	0.27	0.27	(e)	0.24	(a)	
MgO	19.17	19.68	(e)	5.7	(a)	
CaO				11.33	(a)	
Na ₂ O	0.25	0.24	(e)	0.29	(a)	
K ₂ O	0.058	0.059	(e)	0.04	(a)	
P ₂ O ₅				0.08	(a)	
S %						
sum						
Sc ppm	54.6	52.5	(e)	54	(g)	
V	192	217	(e)	117	(g)	
Cr	2570	2650	(e)	2295	(g)	
Co	31.7	31.2	(e)	34	(g)	
Ni				6.7	(g)	
Cu	8.1	8.3	(e)	15.4	(g)	
Zn	1.2	1.2	(e)	26	(g)	
Ga	3.7	3.5	(e)	3.7	(g)	
Ge ppb						
As	0.09	0.18	(e)			
Se	0.226	0.221	(e)			
Rb	1.19	1.3	(e)	0.96	(g)	
Sr	137		(e)	112	(g)	
Y				39	(g)	
Zr				109	(g)	
Nb				8.75	(g)	
Mo				0.12	(g)	
Ru						
Rh						
Pd ppb						
Ag ppb	100	130	(e)			
Cd ppb						
In ppb	640	470	(e)			
Sn ppb						
Sb ppb	40	40	(e)	40	(g)	
Te ppb						
Cs ppm	0.062	0.073	(e)	0.06	(g)	
Ba	46	42	(e)	67	(g)	
La	5.9	6.7	(e)	6.48	(g)	
Ce	24	17	(e)	20.2	(g)	
Pr				2.82	(g)	
Nd				15.6	(g)	
Sm	5.32	5.55	(e)	5.81	(g)	
Eu	1.05	1.04	(e)	1.13	(g)	
Gd				7.7	(g)	
Tb	1.28	1.21	(e)	1.36	(g)	
Dy	9.1	9.5	(e)	8.52	(g)	
Ho	2.32	2.22	(e)	1.63	(g)	
Er	7.9	8	(e)	4.87	(g)	
Tm				0.66	(g)	
Yb	10.2	9.4	(e)	4.47	(g)	
Lu	1.65	1.48	(e)	0.59	(g)	
Hf	3.8	3.3	(e)	3.62	(g)	
Ta	0.43	0.41	(e)	0.53	(g)	
W ppb	0.26	0.21	(e)	130	(g)	
Re ppb						
Os ppb						
Ir ppb	0.1		(e)			
Pt ppb						
Au ppb	2.1	2.2	(e)			
Th ppm	5.2	3.8	(e)	0.87	(g)	0.932 (f)
U ppm	3.3	3.4	(e)	0.29	(g)	0.261 (f)
technique:			(e) various NAA,	(f) IDMS,	(g) ICP-MS	



Figure 13: Photomicrograph of thin section 12021,135 illustrating elongate pyroxene crystals growing from a common nucleation point. Section is about 2 cm long. NASA S70-43351.

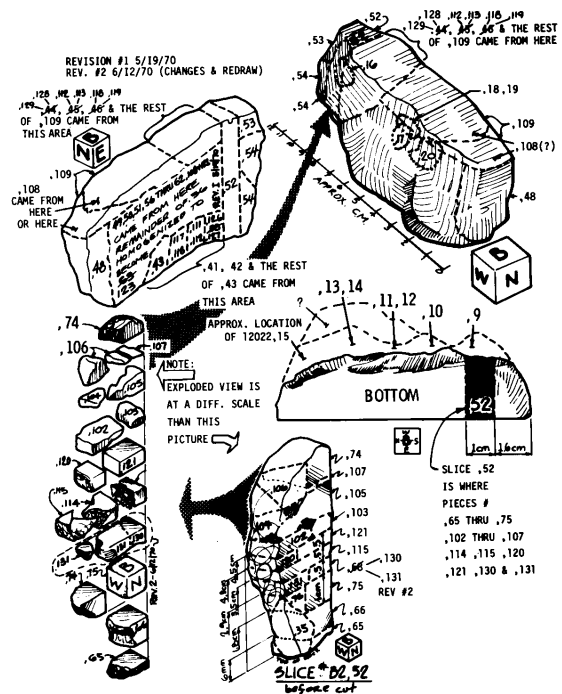


THE CUTTING OF LUNAR ROCK NO. 12021



DRWG COMPLETED APRIL 26, 1970

THE CUTTING AND CHIPPING OF SLICE 'B'
NO. 12021,33



DRWG COMPLETED MAY 4, 1970

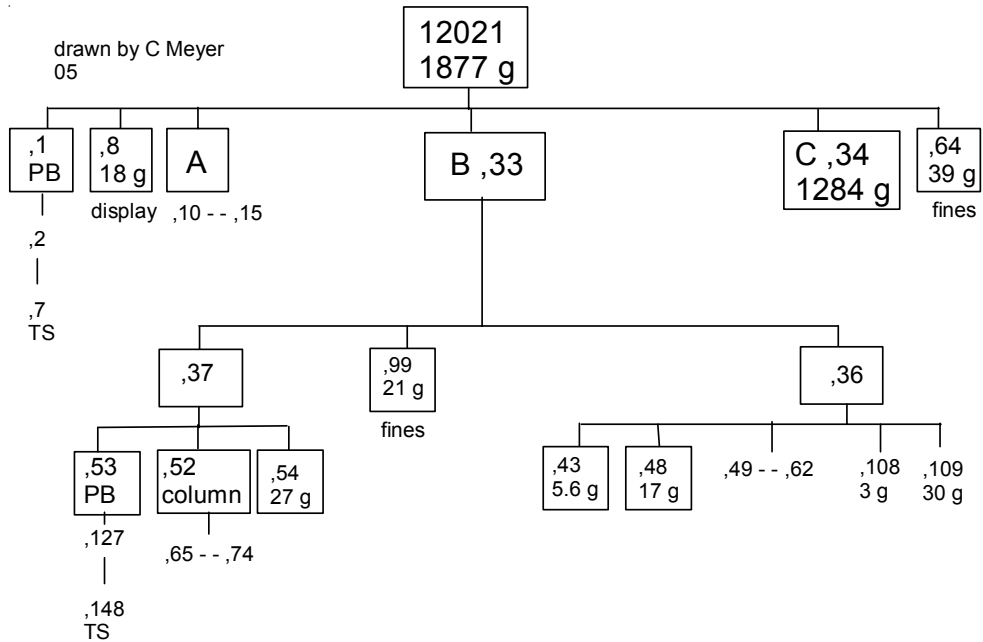




Figure 14: Slices known as 12021,37.



Figure 15: Pieces cut from 12021,52.

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