

**21020**  
**Basalt (B1)**  
 0.062 grams

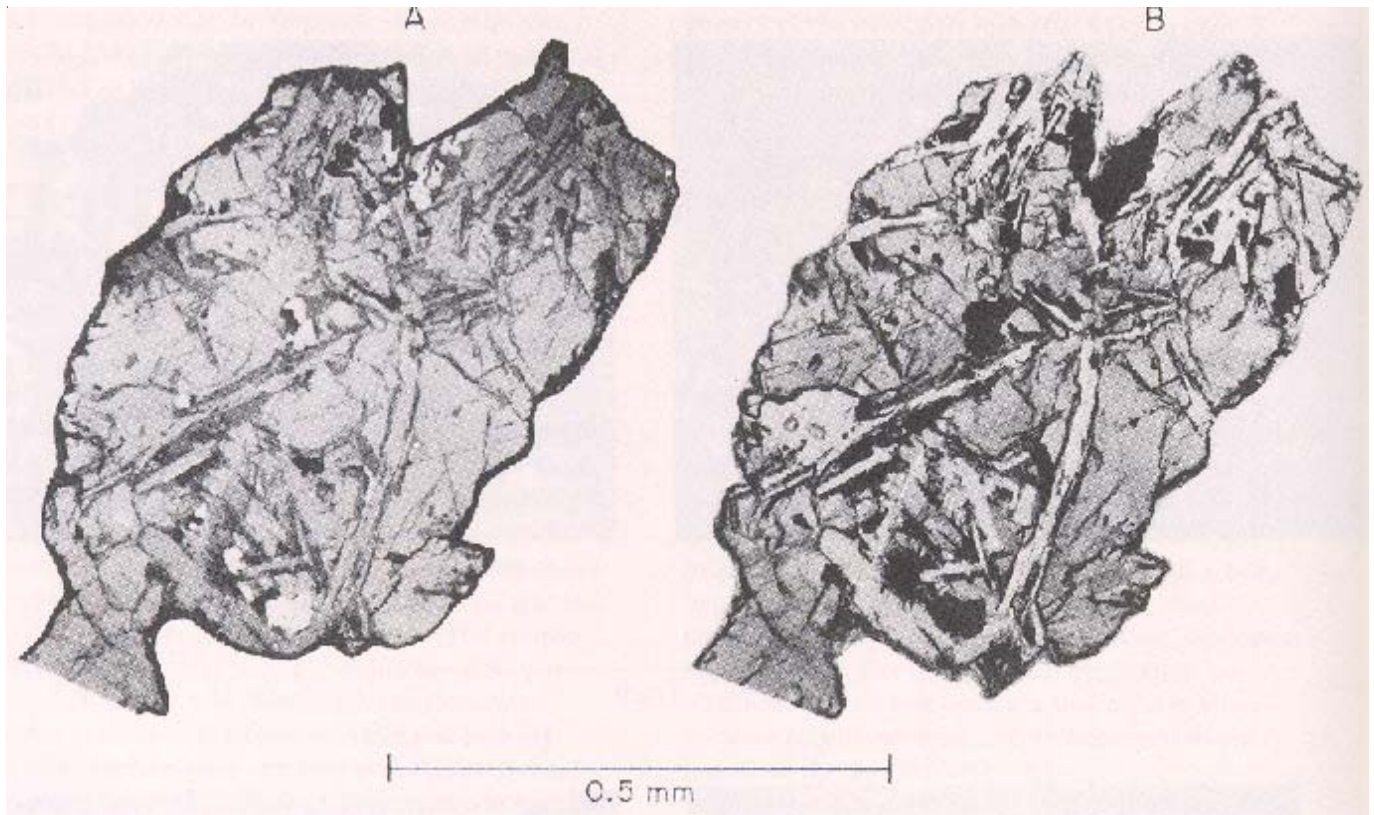


Figure 1: Photo of thin section of basalt fragment B1 from Luna 16 core (from Albee et al. 1972). Dominant pyroxene encloses laths of plagioclase. A is reflected light, B is transmitted light.

**Introduction**

Luna 16 was, in fact, the third mission to return samples from the Moon (Vinogradov 1971). The automatic Soviet spacecraft landed in the eastern equatorial portion of the Moon, successfully collected a core from Mare Fecunditatis and automatically returned it to Earth. The Academy of Science USSR shared these precious samples with various countries and two 1.5 gram aliquots were exchanged with US investigators for representative samples of Apollo 11 and 12. Among these samples was a 62 gram chip of basalt from layer B, apparently typical of Luna 16 basalts. Numerous

studies of these samples were published together in volume 13 of Earth Planetary Science Letters (1972), and in a thick Russian book edited by Vinogradov (1974)(in Cyrillic).

Sample B1 (62 mg), from the 15-28 cm depth zone of the Luna 16 core, was selected for dating and gave an age of ~3.4 b.y. Thin section studies showed it to be a fragment of mare basalt (figure 1).

**Mineralogical Mode of Luna 16 basalts**

	B1	G37	G36	(norm)
	Albee	Steele	Hollister	Vinogradov
Olivine	tr.	15	17.3	
Pyroxene	50 %	30	45.5	(50)
Plagioclase	40	50	33.5	(40)
Ilmenite	7	6	3.7	(7)

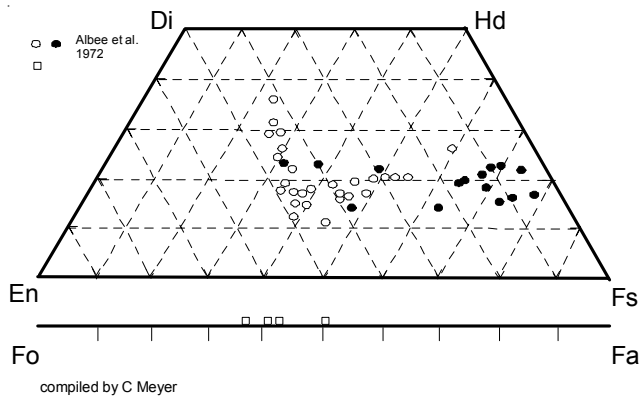


Figure 2: Pyroxene composition for Luna 16 basalt B1 (replotted from Albee et al. 1972).

### Petrography

Photographs of Luna 16 basalt particles are found in Ivanov et al. (1973). Luna sample B-1 is a fine-grained ophitic basalt composed of 50% clinopyroxene, 40% plagioclase, 7% ilmenite and minor ulvöspinel, olivine, troilite, mesostasis and other minor phases (Albee et al. 1972). The fragment was covered with an irregular, thin, vitreous-appearing “glaze” with numerous zap pits on all sides, but the basaltic texture was apparent. Plagioclase on the outside seemed to appear shocked (Albee et al. 1972). It was noted that one side of the 2 mm particle (B1) seemed to have been a vug wall.

Additional fragments of basalt from the Luna 16 core were studied by Grieve et al. (1972), Bence et al. (1972), Hollister and Kulick (1972), Steele and Smith (1972) and Cimbalnikova et al. (1977)(see also section on Luna 16 core)..

### Chemistry

Albee et al. (1972) determined the major element composition by broad-beam-electron-microprobe and a few trace elements by isotope dilution mass spectroscopy on the small fragment B1, showing it to be representative of basalts from Luna 16 (table 1). Fragment B1 and other Luna 16 basalts appear to have relatively high Ti (figure 3).

The rare-earth-element pattern for the Luna 16 soil matches that of the basalt rather closely (figure 4), indicating that the KREEP component is restricted to the Apollo samples.

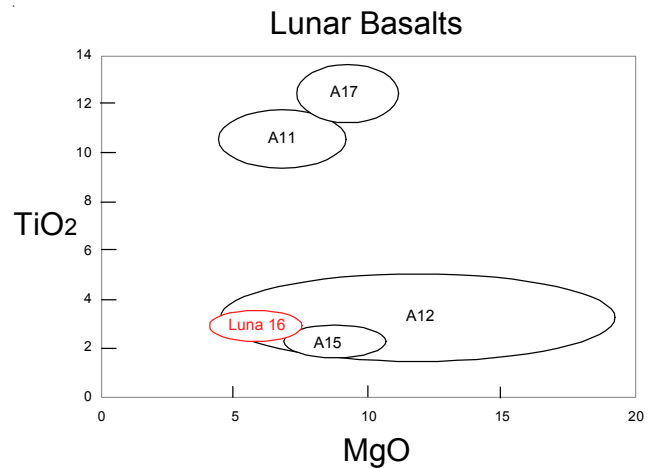


Figure 3: Composition of basalts from Luna 16 compared with other sites.

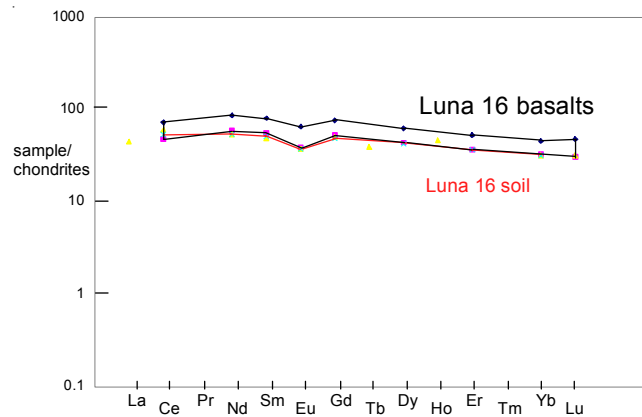


Figure 4: Normalized rare-earth-element composition diagrams for Luna 16 basalts. Data from table 1 (Philpotts et al. 1972, Jerome et al. 1972). Luna 16 soil from Hubbard et al. (1972) matches basalts rather well!

### Radiogenic age dating

Papanastassiou et al. (1972) and Huneke et al. (1972) have dated basalt fragment B1 and obtained concordant ages (table).

### Cosmogenic isotopes and exposure ages

Huneke et al. (1972) determined an exposure age of 475 m.y. by  $^{38}\text{Ar}$ .

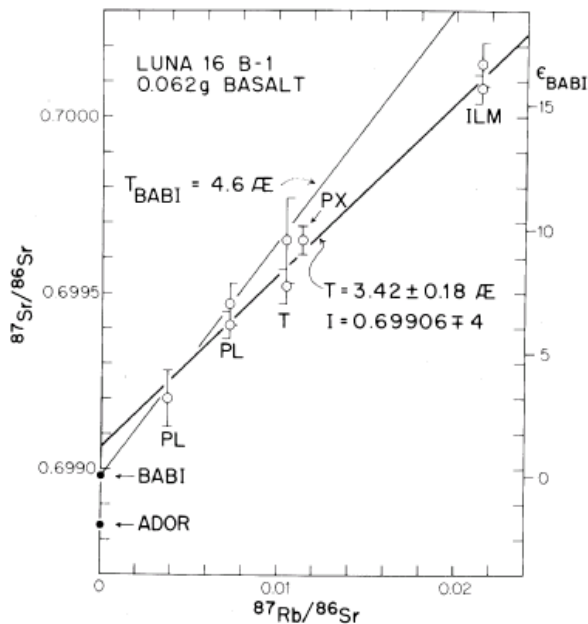


Figure 5: Rb-Sr isochron diagram for basalt fragment B1 from Luna 16 (from Papanastassiou et al. 1972).

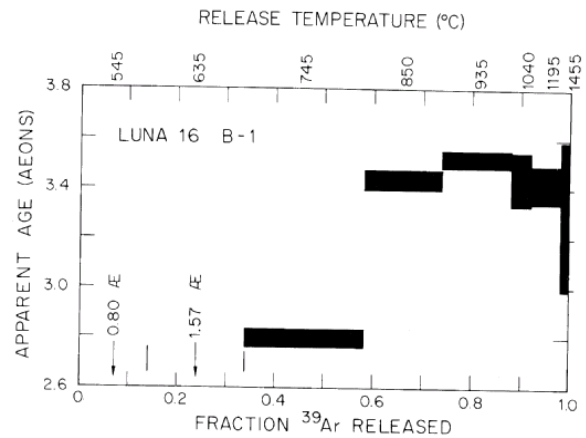


Figure 6: Argon plateau age for basalt fragment B1 (from Huneke et al. 1972).

### Summary of Age Data for Luna 16 basalt B1

	Ar/Ar	Rb/Sr
Huneke et al. 1972	$3.45 \pm 0.04$ b.y.	
Papanastassiou et al. 1972		$3.42 \pm 0.18$

### References for L16B (21020)

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Cimbalnikova A., Palivova M., Frana J. and Mastalka A. (1977) Chemical composition of crystalline rock fragments from Luna 16 and Luna 20 fines. In **The Soviet-American conference on cosmochemistry of the moon and planets**. 263-275.

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Hollister L.S. and Kulik Ch.G. (1972) Luna 16 sample G36: Another crystalline product of an extremely mafic magma. *Earth Planet. Sci. Lett.* **13**, 312-315.

Huneke J.C., Podosek F.A. and Wasserburg G.J. (1972) Gas retention and cosmic-ray exposure ages of a basalt fragment from Mare Fecunditatis. *Earth Planet. Sci. Lett.* **13**, 375-383.

Ivanov A.V., Tarasov L.S., Rode O.D. and Floresnsky K.P. (1973) Comparative characteristics of regolith samples delivered from the lunar mare and highland regions by automatic stations Luna-16 and Luna-20. *Proc. 4<sup>th</sup> Lunar Sci. Conf.* 351-364.

Papanastassiou and Wasserburg G.J. (1972) Rb-Sr age of a Luna 16 basalt and the model age of lunar soils. *Earth Planet. Sci. Lett.* **13**, 368-374.

Steele I.M. and Smith J.V. (1971b) Mineral and bulk compositions of three fragments from Luna 16. *Earth Planet. Sci. Lett.* **13**, 323-327.

Vinogradov A.P. (1971) Preliminary data on lunar ground brought to Earth by Automatic Probe "Luna 16". *Proc. 2<sup>nd</sup> Lunar Sci. Conf.* 1-16.

**Table 1. Chemical composition of Luna 16 Basalts**

reference weight	Vinogradov 71	Albee 1972 B1	Jerome 72 L16-19	Grieve 72 G38	Keil 72	Philpotts 72 A29	G27	Jakes 72 glasses							
SiO <sub>2</sub> %	43.8	45.5	a	45.17	43.36	44.2	46.6	a	44.57	f					
TiO <sub>2</sub>	4.9	4.04	a	3.6	d	2.9	4.37	2.48	6.1	a	2.62	f			
Al <sub>2</sub> O <sub>3</sub>	13.65	13.95	a	15.3	d	16.98	15.13	16.45	15.7	a	15.92	f			
FeO	19.35	17.77	a	15.8	d	13.21	17.48	13.67	17.2	a					
MnO	0.2	0.26	a	0.21	d	0.22	0.27	0.2	0.28	a	14.43	f			
MgO	7.05	5.95	a	9.28	d	4.02	4.97	4.3	3.7	a	9.01	f			
CaO	10.4	11.96	a	11.5	d	13.32	12.77	12.65	11.3	a	11.86	f			
Na <sub>2</sub> O	0.33	0.63	a	0.34	d	0.69	0.7	0.69	0.46	a	0.32	f			
K <sub>2</sub> O	0.15	0.21	a	0.2	d	0.17	0.17	0.21	0.24	a	0.123	0.17	e	0.09	f
P <sub>2</sub> O <sub>5</sub>		0.15	a						0.12	a					
S %															
sum															
Sc ppm	20	c		50.2	d										
V	42.5			97	d										
Cr				1990	d										
Co	29			30.9	d										
Ni	147														
Cu	13														
Zn	26														
Ga	1.2														
Ge ppb															
As															
Se															
Rb		1.58	b						2.1	1.5	e				
Sr	445	436.6	b						303	468	e				
Y	58														
Zr															
Nb															
Mo															
Ru															
Rh															
Pd ppb															
Ag ppb															
Cd ppb															
In ppb															
Sn ppb															
Sb ppb															
Te ppb															
Cs ppm	0.75	0.054	b												
Ba		218	b	360	d				215	230	e				
La	7.7			10.7	d										
Ce	24.6			37.2	d				29	44	e				
Pr	4.8														
Nd	25			24.7	d				27.4	39.4	e				
Sm	7.1			7.2	d				8.23	11.9	e				
Eu	1.2			2.15	d				2.2	3.7	e				
Gd	4.8			10	d				10.4	15.2	e				
Tb	0.9			1.44	d										
Dy	5.2								10.7	15.2	e				
Ho	2			2.6	d										
Er	5								5.95	8.43	e				
Tm	0.4			0.75	d										
Yb	3.6			5.23	d				5.4	7.53	e				
Lu	0.3			0.78	d				0.75	1.18	e				
Hf	0.3			6.32	d										
Ta															
W ppb				17	d										
Re ppb															
Os ppb															
Ir ppb															
Pt ppb															
Au ppb				1.7	d										
Th ppm				1.06	d										
U ppm		0.3	b												

technique (a) e-probe, (b) idms, (c) ms and es, (d) , (e) idms, (f) eprobe

**Table 1b. Chemical composition of Luna 16 Basalts and Soil**

reference weight	Cimalnikova 77 ave of 11	Helmke 72 A-31 C-29			Hubbard 72 L16 soil	Philpotts soil	soil	
SiO <sub>2</sub> %					44			(b)
TiO <sub>2</sub>	4.6	(a)			3.3			(b)
Al <sub>2</sub> O <sub>3</sub>	11	(a)			16			(b)
FeO	22.6	(a)			16			(b)
MnO	0.28	(a)			0.23			(b)
MgO	7.1	(a)			8.3			(b)
CaO	10.7	(a)			12.1			(b)
Na <sub>2</sub> O	0.5	(a)			0.42			(b)
K <sub>2</sub> O	0.2	(a)			0.1			(b)
P <sub>2</sub> O <sub>5</sub>								
S %								
sum								
Sc ppm	75	(a)	26	54				(a)
V	76	(a)						
Cr			1900	2050				(a)
Co	29	(a)	21	14				(a)
Ni								
Cu								
Zn								
Ga			4.3	3.6				(a)
Ge ppb								
As								
Se								
Rb					1.87	1.85	1.9	(c)
Sr	744	(a)			295	244	271	(c)
Y								
Zr						224	227	(c)
Nb								
Mo								
Ru								
Rh								
Pd ppb								
Ag ppb								
Cd ppb								
In ppb								
Sn ppb								
Sb ppb								
Te ppb								
Cs ppm								
Ba	371	(a)	203	243	171	169	172	(c)
La	18	(a)	12	19.4				(a)
Ce	65	(a)	30	66	32.6	31.2	32.5	(c)
Pr								
Nd	61	(a)			24.7	26.4	26.3	(c)
Sm	15	(a)	8.1	16	7.65	7.98	8.18	(c)
Eu	4.4	(a)	2.04	4.04	2.11	2.16	2.22	(c)
Gd				17	9.57	10.5	10.5	(c)
Tb	2.7	(a)		3.1				(a)
Dy	22.5	(a)	8.8	17.9	10.4	10.1	10.4	(c)
Ho	4	(a)	2.1	3.9				(a)
Er				12	5.88	5.78	5.87	(c)
Tm	2.4	(a)						
Yb	9	(a)	5.2	10.9	5.26	5.45	5.44	(c)
Lu	1.4	(a)	0.69	1.51		0.822	0.841	(c)
Hf	12	(a)	0.46	1.3			5.88	(c)
Ta								
W ppb								
Re ppb								
Os ppb								
Ir ppb								
Pt ppb								
Au ppb								
Th ppm	1.3	(a)						
U ppm	1	(a)						

technique (a) INAA, (b) XRF new, (c) Idms