60335

Basaltic Impact melt

317.8 grams

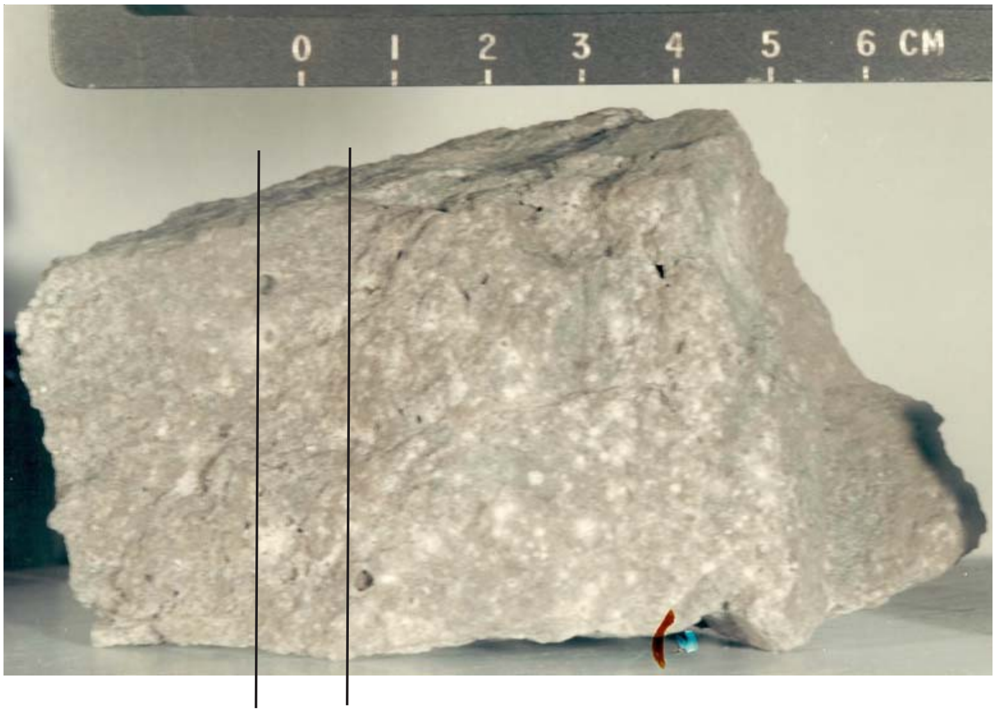

Figure 1: Photo of 60335 N1 showing approximate position of slab. Scale is in cm. S72-38282 (out of focus).

Introduction

60335 is a coherent basaltic impact melt rock that was found partially buried in the regolith about 70 meters from the Lunar Lander (Sutton 1981). It is aluminous in composition, with relative high trace element content. It is found to contain substantial Ni, Ir and Au.

The Pb/Pb age of 60335 was determined to be 4.08 b.y.

60335 was chosen as a key sample for geophysical measurements, because it appeared to be uniform in nature. It was also the subject of magnetic measurement (*in situ*) while on the lunar surface.

Petrography

Ryder and Norman (1980) give a superior petrographic description of 60335 in their Apollo 16 Catalog. They state that:

"60335 is a basaltic impact melt rock that exhibits a variety of melt textures. Most commonly, normally zoned, subhedral plagioclase phenocrysts (An_{95-86}) and shocked, anhedral plagioclase xenocrysts (An_{97-95}, up to 4 mm) grade into a finer grained matrix of equant to lathy plagioclase partially enclosed by olivine (Fo_{85-79}, single crystals up to 10 mm). In other areas, a Si-K-rich glassy mesostasis fills the intersticies. Overgrowths of orthopyroxene (Wo_5En_{76}), pigeonoite (Wo_3En_{68}) and augite occasionally rim the olivines and many of the plagioclase phenocrysts display a clear rim over a shocked core. Pigeonite occasionally shows augite exsolution lamalle. Minor phases include silica,

Mineralogical Mode for 60335

	Walker et. al. 1973	Vaniman and Papike 1980
Olivine	16 wt %	9
Pyroxene	10	14
Plagioclase	64	56.5
Opaques	2	1.2
Mesostasis	8 (glassy)	3.6
Clasts		15

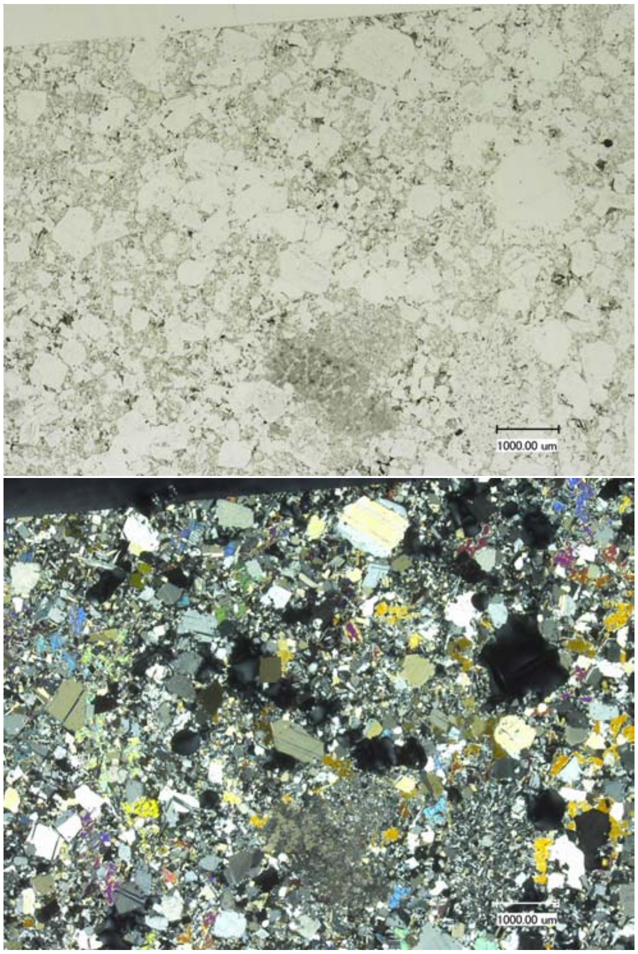

Figure 2: Photomicrographs of thin section 60335,69 by C Meyer @30x.

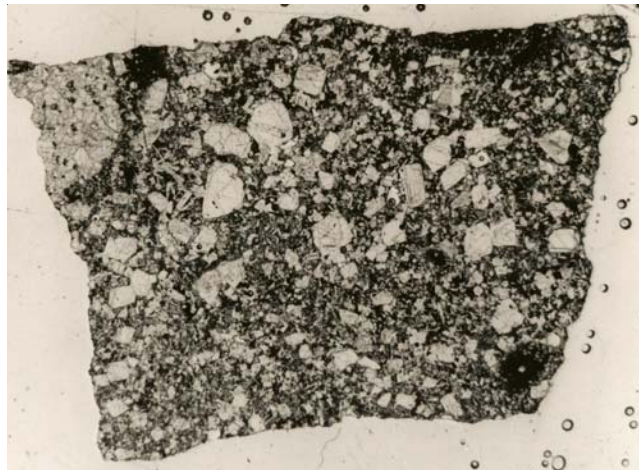

Figure 3: Photomicrograph of thin section 60335,13. Scale unknown. S72-43575.

phosphates, Zr-armalcolite, ilmenite, ulvospinel, metal and schreibersite."

"Less common melt textures in this rock include radiating clusters of plagioclase, often cored by an incompletely digested clasts and poikilitic patches in which 0.5 mm olivine encloses many small clasts and crystallites of plagioclase. Although Walker et al. (1973) and the Apollo 16 Lunar Sample Information Catalog (Butler 1972) interpret certain poikilitic areas as lithic clasts, an extensive survey of library thin section convinces us (Ryder and Norman) that these patches crystallized from the same melt that produced the bulk of the rock. Evidence for this interpretation includes the arcuate boundaries of the patches against vesicles, the tendency of the poikilitic patches to completely fill irregularly shaped areas and the fact that some of the poikilitic olivines are single crystals with olivines that are dfinitely a part of the ophitic matrix."

"Lithic clasts include granoblastic anothosite (2 mm) and granoblastic troctolite (5 mm) with accessory ilmenite and metal. Most of the lithic clasts are shocked with a well defined reaction rim of fine-grained, unshocked plagioclase."

The texture of 60335 is illustrate in figures 2, 3 and 11. Warner et al. (1973) and Hubbard et al. (1973) originally classified 60335 as a highland basalt. However, Prinz et al. (1974) correctly argued that it was not an endogenous basalt, but rather a melted mixture of highland rocks (i.e. an impact melt). Walker et al. (1973) noted plagioclase-rich xenoliths in the rock. Brown et al. (1973), Nord et al. (1973) and Vaniman and Papike (1981) also studied 60335. Misra and Taylor (1975) and Taylor et al. (1976) studied the metallic iron and Hunter and Taylor (1981) reported rust and schreibersite.

Mineralogy

Pyroxene: Walker et al. (1973) and Vaniman and Papike (1980) determined the pyroxene composition (figure 4).

Metal: Misra and Taylor (1975) and Taylor et al. (1976) studied the metal composition (figure 5).

Schreibersite: Hunter and Taylor (1981) reported that there was schreibersite in thin sections of 60335.

Armalcolite: Brown et al. (1973) determined the composition of Zr-rich armalcolite in 60335.

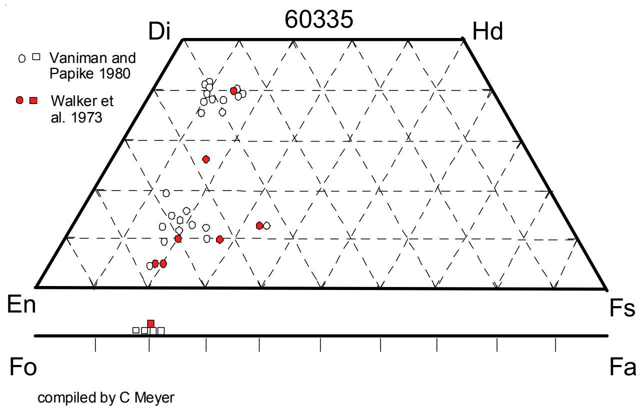

Figure 4: Pyroxene and olivine in 60335 (lifted from Vaniman and Papike 1980).

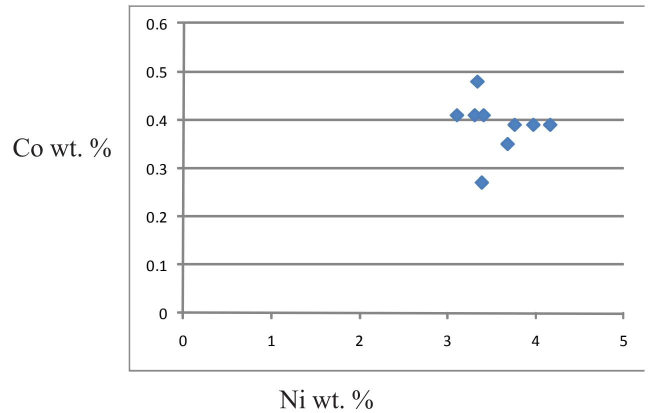

Figure 5: Ni and Co content of Fe grains in 60335 (Misra and Taylor 1975).

Chemistry

LSPET (1972), Clark and Keith (1973), Haskin et al. (1973), Rose et al. (1973), Hubbard et al. (1974) Wanke et al. (1976), Ebihara et al. (1992) and Norman et al. (2010) determined the chemical composition (table). 60335 is homogeneous and aluminous in composition (figure 6).
It has relatively high trace element content. Barnes et al. (1973) determined Ni = 333 ppm in 60335. Wanke reported very high Ni, Ir and Au (720 ppm and 17 ppm).

Radiogenic age dating

No isochron ages have been reported for 60335. Barnes et al. (1973) determined the age for 60335 as 4.08 b.y. by Pb/Pb, U/Pb and Th/Pb (concordant). Nyquist et al. (1974) and Barnes et al. (1973) have reported the Sr isotopic composition of the "whole rock".

Cosmogenic isotopes and exposure ages

Clark and Keith (1974) determined the cosmic-ray-induced activity of 60335 as ^{22}Na = 48 dpm/kg, ^{26}Al = 140 dpm/kg, and ^{46}Sc = 3 dpm/kg. Bhandari et al. (1976, 1977) studied the solar flare and cosmic ray induced tracks.

Other Studies

Morrison et al. (1973) reported the density of micrometeorite craters on all sides.

The magnetization of 60335 was measured on the lunar surface with a Lunar Portable Magnetometer (figure 10) and again with a second LPM when the sample reached the laboratory (Dyal et al. 1972). However , the degree of magnetization of 60335 was found to be so low that no conclusions could be reached (figure 7).

The seismic velocity and physical parameters of 60335 were measured by Warren et al. 1973). Figure 8 shows the velocity of sound as a function of pressure (well below terrestrial samples due to numerous cracks).

Processing

A slab was cut through the middle of 60335 (figures 1 and 11).

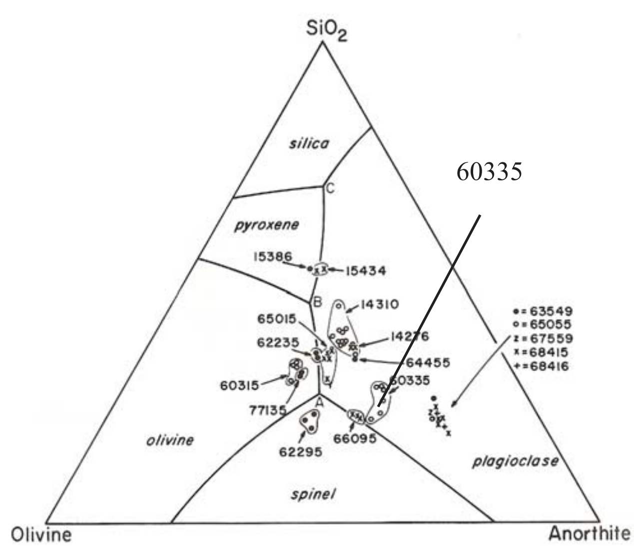

Figure 6: Major element content of 60335 plotted on" Walker" diagram.

Table 1. Chemical composition of 60335.

reference	LSPET73	Clark73		Haskin73		Rose73		Wanke 76		Fruchter74		Wiesmann75		Norman2010		Ebihara92	
weight		whole										Hubbard 74					
SiO2 %	46.19			44.8	(d)	46.33	(d)	46.47		46.19	(a)			47.5	(c)		
TiO2	0.58			0.65	(d)	0.57	(d)	0.62		0.58	(a)			0.37	(c)		
Al2O3	25.27			24.4	(d)	25.01	(d)	24		25.27	(a)			28.7	(c)		
FeO	4.51			5.39	(d)	4.6	(d)	5.07		4.51	(a)			2.8	(c)		
MnO	0.07			0.071	(d)	0.08	(d)	0.07		0.07	(a)			0.044	(c)		
MgO	8.14			7.84	(d)	7.7	(d)	8.14		8.14	(a)			4.4	(c)		
CaO	14.43			14.7	(d)	14.23	(d)	14.2		14.43	(a)			15.6	(c)		
Na2O	0.52			0.63	(d)	0.62	(d)	0.57		0.52	(a)	0.54	(b)	0.53	(c)		
K2O	0.23	0.21	(e)	0.28	(d)	0.27	(d)	0.23		0.23	(a)	0.24	(b)	0.13	(c)		
P2O5	0.19					0.21	(d)	0.23									
S %	0.07							0.082									
sum																	
Sc ppm				7.9	(a)	9.4	(d)	8.53		6.7	(a)			5.5	(c)		
V						26	(d)							13.8	(c)		
Cr	900			910	(a)			890		700	(a)	850	(b)	457	(c)		
Co				16	(a)	24	(d)	37		15.2	(a)			8	(c)		
Ni	77			300	(a)	392	(d)	720						163	(c)	201	(f)
Cu						8.5	(d)	7.4						3.3	(c)		
Zn				2	(a)	4	(d)	4.3						2.2	(c)	1.3	(f)
Ga				3.46	(a)	3.2	(d)	3.12						3.9	(c)		
Ge ppb								700								197	(f)
As								193									
Se								230								164	(f)
Rb	6.4			7.1	(a)	7.3	(d)	6.3				6.18	(b)	4	(c)	6.19	(f)
Sr	162					125	(d)	140				163	(b)	200	(c)		
Y	62					58	(d)	57						42	(c)		
Zr	281					240	(d)	294				292	(b)	177	(c)		
Nb	16					12	(d)	10						9.7	(c)		
Mo																	
Ru																	
Rh																	
Pd ppb																10.2	(f)
Ag ppb																0.73	(f)
Cd ppb														34	(c)	5.1	(f)
In ppb																14.5	(f)
Sn ppb														10	(c)		
Sb ppb														9	(c)	1.62	(f)
Te ppb																5.32	(f)
Cs ppm				0.28	(a)			0.256	(a)					0.172	(c)	0.294	(f)
Ba						160	(d)	195	(a)	170	(a)	193	(b)	138	(c)		
La				22	(a)			21.1	(a)	16.2	(a)	19.9	(b)	13.4	(c)		
Ce				58	(a)			56.4	(a)	39	(a)	51.5	(b)	35	(c)	65.1	(f)
Pr								7.8	(a)					4.9	(c)		
Nd				36.4	(a)			36	(a)	29	(a)	32.4	(b)	21.7	(c)	39.2	(f)
Sm				10	(a)			8.92	(a)	8.2	(a)	9.05	(b)	6.12	(c)		
Eu				1.38	(a)			1.21	(a)	1.2	(a)	1.28	(b)	1.34	(c)	1.46	(f)
Gd								10.3	(a)			10.6	(b)	6.9	(c)		
Tb				2.03	(a)			1.9	(a)	1.5	(a)			1.23	(c)	2.27	(f)
Dy				13.9	(a)			11.7	(a)			11.5	(b)	7.62	(c)		
Ho				2.9	(a)			2.5	(a)					1.61	(c)		
Er								7.5	(a)			6.77	(b)	4.27	(c)		
Tm																	
Yb				6.88	(a)	5.6	(d)	6.64	(a)	5.1	(a)	6.23	(b)	4.01	(c)	7.45	(f)
Lu				0.95	(a)			0.923	(a)	0.8	(a)	0.675	(b)	0.58	(c)	1.15	(f)
Hf				7	(a)			6.86	(a)	5.1	(a)	7.3	(b)	4.31	(c)		
Ta								0.81	(f)	0.6	(a)			0.45	(c)		
W ppb								301	(f)								
Re ppb								3.8	(f)							0.44	(f)
Os ppb																4.11	(f)
Ir ppb								17	(f)							4.03	(f)
Pt ppb																	
Au ppb								16.8	(f)							4.07	(f)
Th ppm		2.75	(e)					2.85	(f)	2.8	(a)			2.2	(c)		
U ppm		0.92	(e)					0.92	(f)			1	(b)	0.62	(c)	1.07	(f)

technique: (a) INAA, (b) IDMS, (c) ICP, (d) microchemical, (e) radiation counting, (f) RNAA

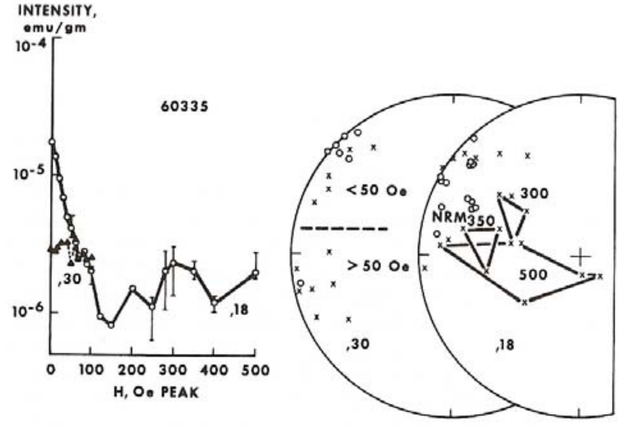

Figure 7: AF demagnetization of 60335 (Pearce et al. 1973).

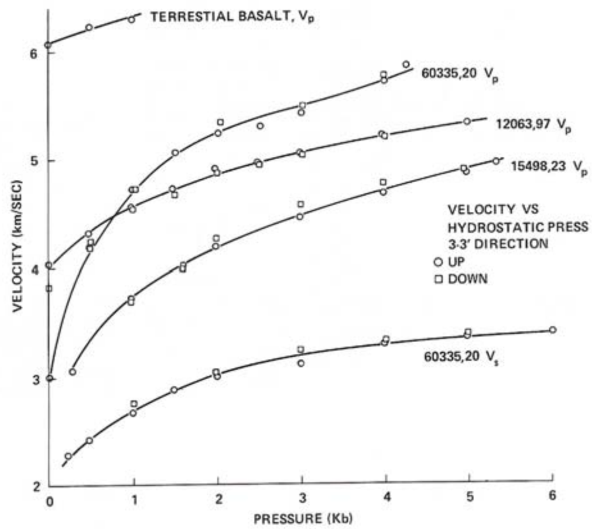

Figure 8: Sound velocity as function of hydrostatic pressure (Warren et al. 1973).

Figure 9: Photo of 60335 on lunar surface showing it was partially burried. AS16 -116-18713.

Figure 10: Photo of Lunar Portable Magnetometer wiht 60335 on top. AS16-116-18721.

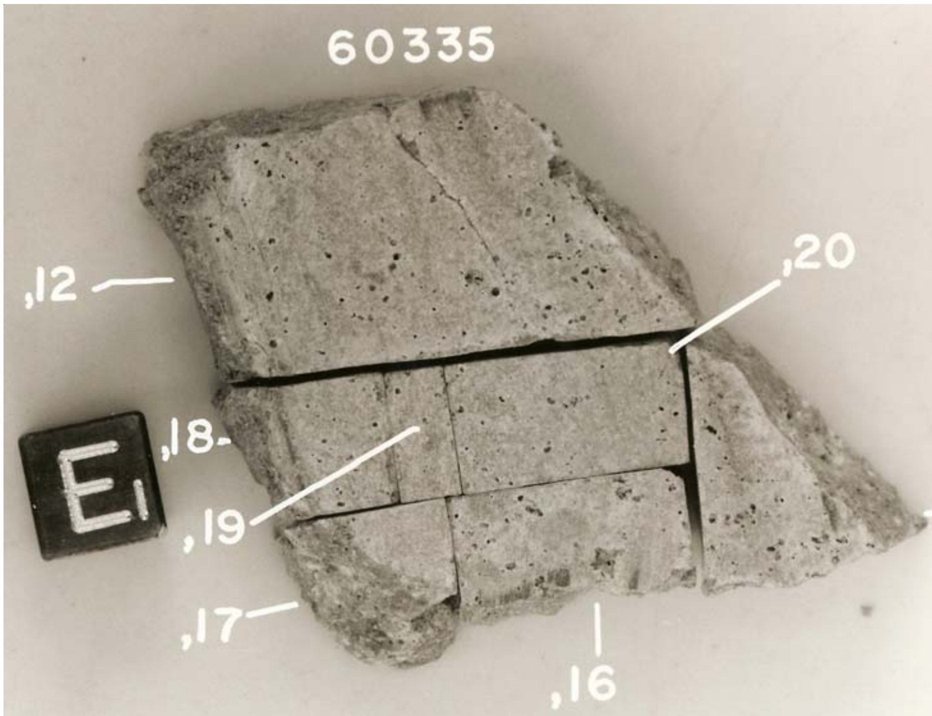

Figure 11: Photo of slab cut from 60335 showing numerous small vesicles and vugs. Cube is 1 cm. S72-51198.

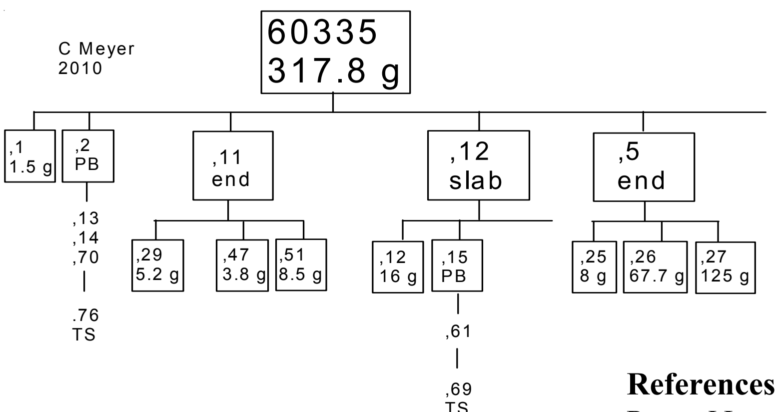

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Figure 12: Pieces of 60335,5. Cube is 1 cm. S72-51190.

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