78235

DRAFT

Shocked Norite

199 grams (two pieces)

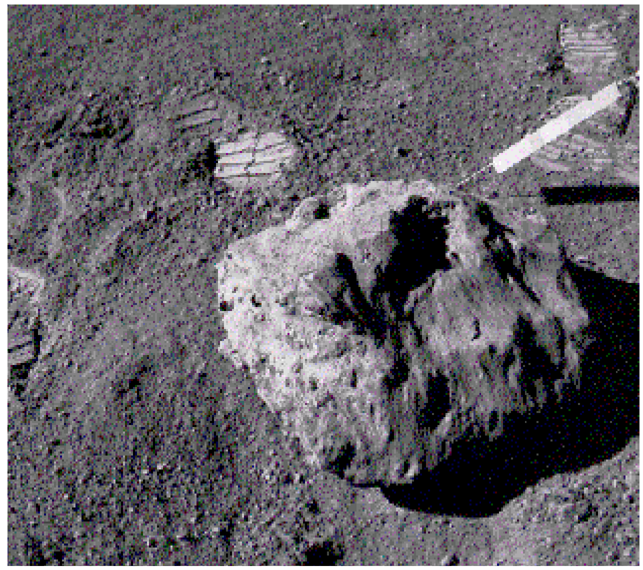

Figure 1: Station 8 boulder found perched on soil before sampling the top left corner. NASA #AS17-146-22370. Footprints for scale.

Introduction

Samples 78235-78238 were chipped off the top of a small glass-covered boulder (~ 0.5 meter) which was found "perched" on top of the lunar regolith at Station 8 (Jackson et al. 1975; Wolfe et al. 1981). The pieces fell in the soil from which they were collected. Sample 78237 was found to fit 78235, so they were numbered together as 78235 (199 grams). Samples 78236 and 78238 were chipped off of an adjacent area and 78236 was used for many of the allocations. Samples 78255 and 78256 were chipped from the bottom of the boulder. All of these samples were found to be similar (if not identical) to one another (Meyer 1994).

The Station 8 boulder (figure 1) was accurately described by the astronauts on the lunar surface:
06 20 20+ CDR *"I think I'll get one more swap off there. Well, that disappeared. Get it this way. That disappeared ,*

Figure 2: PET photo of 78237 norite showing glass coating on bottom, glass veins, highly shocked plagioclase and yellowish orthopyroxene. Cube is 1 cm. NASA # S73-15381.

Mineralogical Mode (vol. %)

	Jackson et al. 1975	McCallum and Mathez 1975	Dymek et al. 1975	Steele 1975
Orthopyroxene	40-60 %	51.2	40	~30
Clinopyroxene	< 0.1	0.01	tr.	tr.
Plagioclase	60-40	48.2	40	~55
Silica		0.25		tr.
Apatite		0.02	tr.	tr.
Whitlockite		0.012	tr.	tr.
Glass			20	15

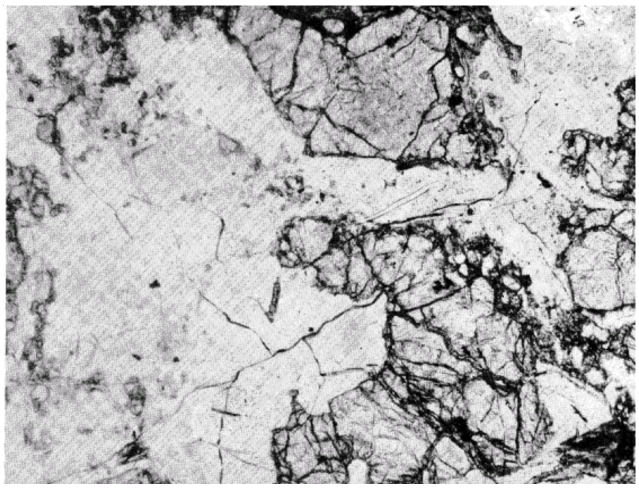

Figure 3: Thin section photomicrograph of 78235 showing coarse orthopyroxene and plagioclase. Field of view is 4 mm.

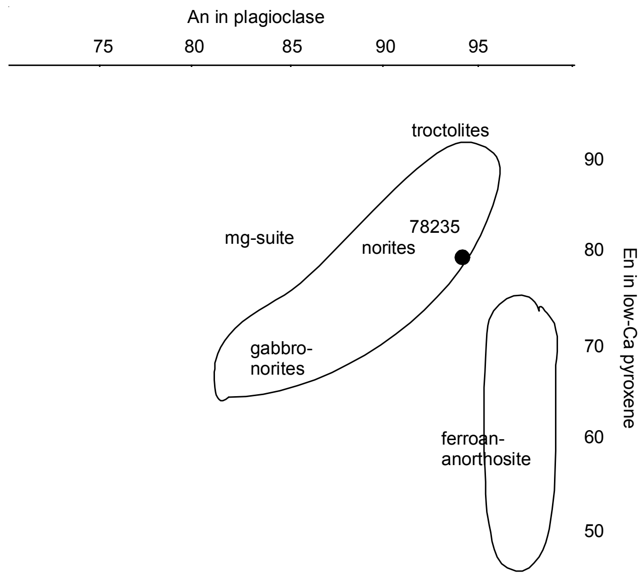

Figure 4: An-En diagram showing that 78235 is an end member of the mg-norite suite.

too? Boy, is that pretty inside. Whoo! We haven't seen anything like this. I haven't. Unless you've been holding out on me." LMP *"No, this is a nice crystalline rock. This is about 50-50 mixture of what looks like maskelynite or at least blue-grey plagioclase, and a very – let's say light yellow-tan mineral, probably orthopyroxene. It's fairly coarsely crystalline. By coarsely crystalline, probably, the average grain size will turn out to be about 3 or 4 millimeters, maybe half a centimeter".*

Zap pits found on sample from top and bottom (see 78255) of this "perched" boulder indicate that it has rolled around on the lunar surface (Jackson et al. 1975).

Petrography

Sample 78235 is a heavily shocked plutonic norite of cumulate origin with a glass coating and glass veins (Jackson et al. 1975). Cumulus orthopyroxene is tabular, and generally ranges in size from 0.2 by 0.3 cm to 0.5 by 0.7 cm. Cumulus plagioclase ranges from 0.3 by 0.4 cm to 0.7 by 1.0 cm. Both minerals are partially shattered and much of the plagioclase is converted to maskelynite (figures 2 and 3). Small amounts of bright-green postcumulus clinopyroxene can be seen in hand specimen. Jackson et al. give a description of the fabric and suggested history of the boulder. 78235 is considered an end member of the mg-norite suite (figure 4).

Trace amounts of metal, troilite, chromite, Nb-rutile, zircon and baddeleyite are also reported (Dymek et al. 1975; McCallum and Mathez 1975; Sclar and Bauer 1975, 1976; Steele 1975).

The shock event that disturbed 78235 has been investigated by Sclar and Bauer (1975, 1976). The presence of maskelynite indicates that the shock pressure was between 300 and 400 kbar, and the presence of glass veins may mean that the rock experienced pressures in excess of 500 kbar. Sclar and Bauer (1976) have speculated that fine oriented rods of metallic iron in the plagioclase and maskelynite are due to subsolidus reduction of iron during shock (*but this feature was also observed in 76535*).

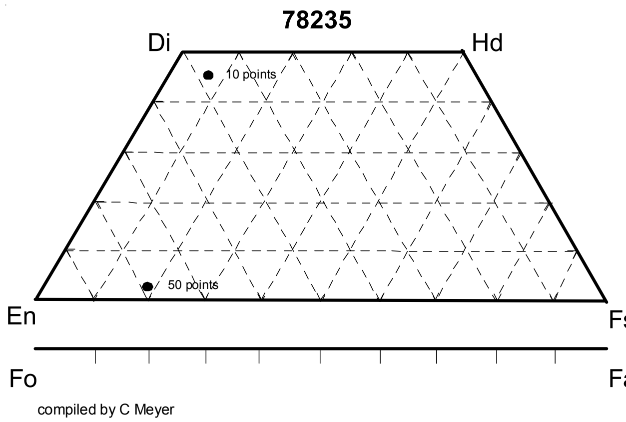

Figure 5: Pyroxene composition for 78235 norite from McCallum and Mathez (1975).

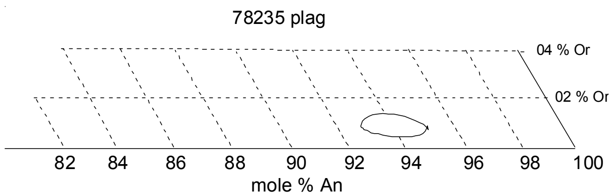

Figure 6: Plagioclase composition for 78235 from Dymek et al. (1975), McCallum and Mathez (1975).

Mineralogy

Pyroxene: The composition of pyroxene in 78235 has been reported by McCallum and Mathez (1975), Dymek et al. (1975), Takeda et al. (1982) and Bersch et al. (1991). Homogeneous orthopyroxene $Wo_3En_{78}Fs_{19}$ is dominant, with minor augite $Wo_{47}En_{45}Fs_8$ (figure 5). McCallum and Mathez estimated a temperature of equilibration of ~800 deg C.

Steele (1975) found that the x-ray determined structure of orthopyoxene grains from the soil adjacent to 78235 had symmetry of space group $P2_1ca$ which requires long annealing time (Smyth 1974) suggesting plutonic conditions. It was noted by them that this is in contrast to the orthopyoxene commonly found in the "noritic" breccias from Apollo 17. Takeda et al. (1982) have also studied the structure of orthopyroxene in 78236. Winzer et al. (1975), Bersch et al. (1991), Hinthorne et al. (1977), Steele et al. (1980), Papike et al. (1994) and Palme et al. (1984) have reported the trace element content.

Trace amounts of augite are found intergrown with chromite, and other minor phases in the boundary areas.

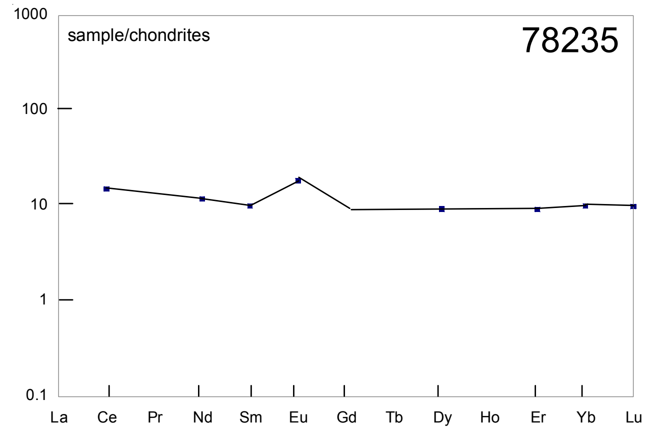

Figure 7: Normalized rare earth element pattern for 78235 norite (data from Winzer et al. 1975).

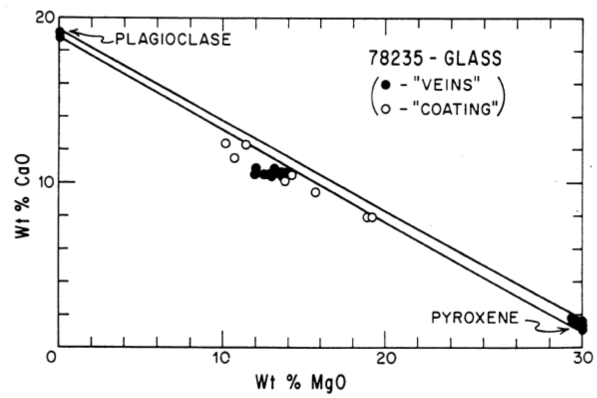

Figure 8: Chemical composition of glass veins and coating on boulder at station 8 (figure from Dymek et al. 1975).

Plagioclase: The composition of plagioclase (An_{93-95}) in 78235 is given in figure 6. Much of it has been converted to maskelynite by shock. Winzer et al. (1975), Hansen et al. (1979) and Steele et al. (1980) and Papike et al. (1994) have determined the trace element content of plagioclase in 78235.

Silica: Steele (1975) and Dymek et al. reported silica.

Chromite: Dymek et al., McCallum and Mathez, Sclar and Bauer and Dymek et al. found chromite intergrown with augite and other accessory phases.

Phosphate: Both whitlockite and apatite are present (Steele 1975). McCallum and Mathez (1975) and Hinthorne et al. (1977) report analyses.

Table 1. Chemical composition of 78235.

													78234 ****	
reference	Winzer 75		Winzer 75		Winzer 75		Higuchi 75		Higuchi 75		Keith 74		Warren 87	
weight	**norite**		rind glass		vein glass		**norite**		glass		whole sample		coarse fine	
SiO2 %	49.5	(b)	49.7	(b)	49.8	(b)							50.93	(f)
TiO2	0.16	(a)	0.16	(a)	0.19	(a)							0.25	(f)
Al2O3	20.87	(b)	17.58	(b)	17.15	(b)							14.36	(f)
FeO	5.05	(b)	7.39	(b)	7.52	(b)							7.33	(f)
MnO	0.08	(b)	0.11	(b)	0.12	(b)							0.126	(f)
MgO	11.76	(b)	14.51	(b)	14.98	(b)							16.43	(f)
CaO	11.71	(b)	9.86	(b)	9.92	(b)							9.24	(f)
Na2O	0.35	(b)	0.34	(b)	0.35	(b)							0.25	(f)
K2O	0.061	(b)	0.058	(b)	0.06	(b)					0.059	(e)	0.055	(f)
P2O5	0.04	(a)	0.07	(a)	0.08	(a)								
S %														
sum														
Sc ppm													13	(f)
V														
Cr														
Co													29.3	(f)
Ni ppm							12	(d)	450	(d)			11.5	(f)
Cu														
Zn ppm							1.5	(d)	2	(d)				
Ga														
Ge ppb							18.9	(d)	131	(d)				
As														
Se ppb							7.5	(d)	176	(d)				
Rb ppm							0.922	(d)	1.1	(d)				
Sr													107	(f)
Y														
Zr													29	(f)
Nb														
Mo														
Ru														
Rh														
Pd ppb														
Ag ppb							0.4	(d)	0.96	(d)				
Cd ppb							2.9	(d)	5.4	(d)				
In ppb														
Sn ppb														
Sb ppb							0.079	(d)	1.1	(d)				
Te ppb							< 0.8	(d)	3.5	(d)				
Cs ppm							64.3	(d)	80.8	(d)				
Ba	79.6	(c)	87.3	(c)	62.5	(c)							53	(f)
La													3.3	(f)
Ce	9.16	(c)	23.2	(c)	20.5	(c)							8.6	(f)
Pr														
Nd	5.4	(c)	9.48	(c)	9.5	(c)							4.5	(f)
Sm	1.49	(c)	1.52	(c)	2.04	(c)							1.49	(f)
Eu	1.03	(c)	0.819	(c)	0.815	(c)							0.7	(f)
Gd														
Tb													0.38	(f)
Dy	2.26	(c)	2.34	(c)	2.97	(c)							2.73	(f)
Ho														
Er	1.47	(c)	1.66	(c)	1.77	(c)								
Tm														
Yb	1.64	(c)	1.63	(c)	1.91	(c)							2.33	(f)
Lu	0.241	(c)	0.258	(c)	0.297	(c)							0.35	(f)
Hf													1.66	(f)
Ta													0.25	(f)
W ppb														
Re ppb							0.0117	(d)	1.66	(d)				
Os ppb														
Ir ppb							0.135	(d)	25.9	(d)				
Pt ppb														
Au ppb							0.421	(d)	5.08	(d)				
Th ppm											0.59	(e)	0.62	(f)
U ppm							0.36	(d)	0.2	(d)	0.196	(e)	0.22	(f)

technique (a) colorimetry, (b) flame AA, (c) IDMS, (d) RNAA, (e) radiation counting, (f) INAA (coarse fine)

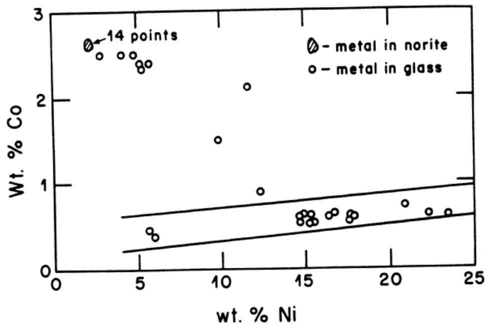

Figure 9: Composition of metal grains in 78235 indicating two differnent origins for metal in the rock (from McCallum and Mathez 1975).

Baddeleyite: McCallum and Mathez (1975) give and analysis of baddeleyite. Hinthorne et al. (1977) were able to date it.

Zircon: Hinthorne et al. (1977) studied a large zircon.

Rutile: McCallum and Mathez (1975) report an analysis of rutile (with high Nb). Steele (1975) reported as much as 14% Nb_2O_5.

Metal: McCallum and Mathez (1975), Hewins and Goldstein (1975) and Mehta and Goldstein (1980) have studied the provenance of iron metal in 78235. The metal grains in the norite have high Co/Ni ratio while the metal grains in the glass coating have low Co/Ni ratio indicating meteoritic contamination of the glass (figure 9).

Troilite: Steele (1975) reported large discrete grains of troilite.

Glass: The abundant, flow-banded, glass that surrounds and invades this sample has been carefully described by McCallum and Mathez (1975) and Dymek et al. (1975).

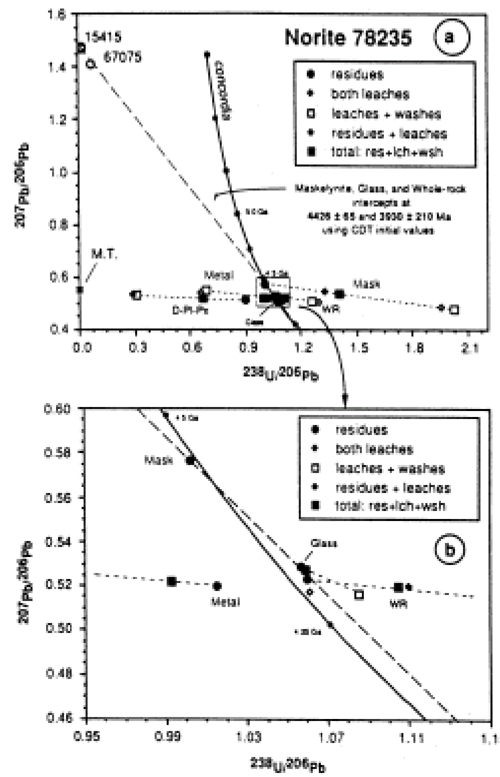

Figure 10: U-Pb systematics of 78235 from Premo and Tatsumoto (1991).

Chemistry

The chemical composition of 78235 was determined by Winzer et al. (1975) and Higuchi and Morgan (1975) (table 1 and figure 7). Warren (1987) reported the chemical composition of a coarse-fine from the soil (78234) and Warren and Wasson (1979) have analyzed 78255. *Note: this is coarse-grained rock and the small sample size allocated for chemical analyses may necessarily lead to non-representative analyses.*

The glass coatings and veins have also been analyzed (Winzer et al., Sclar and Bauer, Steele, McCallum and Mathez, and Dymek et al.). The composition of the glass coating and of the glass veins appear to be a mixture of the plagioclase and the pyroxene (figure 8).

Summary of ages for 78235 and 78236

	Pb/Pb	U/Pb	Rb/Sr	Sm/Nd	Ar/Ar
Hinthorne et al. (1977)	4.25 ± 0.09 b.y.				
Premo and Tatsumoto (1992)		4.426 ± 0.065			
Nyquist et al. (1981)			4.38 ± 0.02	4.43 ± 0.05	4.39
Carlson and Lugmair (1982)				4.34 ± 0.04	
Aeschlimann et al. (1982)					4.11 ± 0.02

Radiogenic age dating

Hinthorne et al. (1977) dated 78235 by Pb-Pb ion probe method (see table). Ages from three baddeleyites and one zircon in thin section 78235,49 were all consistent at 4.25 ± 0.09 b.y. These data required correction for unspecified molecular ion interferences. It is also difficult to understand how the U-Pb system in minor phases could not have been affected by the shock melting that is evident in this rock. For these reasons this Pb-Pb age is generally not accepted – although it has been generally confirmed by more recent work (see table).

Premo and Tatsumoto (1991 and 1992) have studied the U-Th-Pb isotopic systematics of 78235 and determined an initial crystallization age of 4.426 ± 0.065 b.y. with a disturbance at 3.93 ± 0.21 b.y. (figure 10). Sample 78236 (from the same rock) has also been dated by Nyquist et al. (1981), Carlson and Lugmair (1982) and Aeschimann et al. (1982) (see section on 78236).

Cosmogenic isotopes and exposure ages

Keith et al. (1974) determined the cosmic ray and solar flare induced activity from the large solar flare of August 1972 using the top and bottom of this boulder (table 2).

Drozd et al. (1977) determined an exposure age of 292 ± 14 m.y. for 78235 using the ^{81}Kr-Kr method.

Other Studies

Jackson et al. (1975) studied the fabric of this coarse-grain rock.

Processing

78235 is one of the rocks featured in the Lunar Petrographic Educational Thin Section Set (Meyer 2003).

Photo #s
S73-15180

Table 2: Solar flare activity (Keith et al. 1974).

sample	**78235**	78255
dpm/Kg		
^{26}Al	77 ± 7	65 ± 6
^{22}Na	111 ± 8	50 ± 5
^{54}Mn	55 ± 8	10 ± 5
^{56}Co	52 ± 9	30 ± 20
^{46}Sc	1.4 ± 0.9	<15
^{48}V	<12	