78235, 78236 and 78238

Shocked Norite

199, 93.1 and 57.6 grams

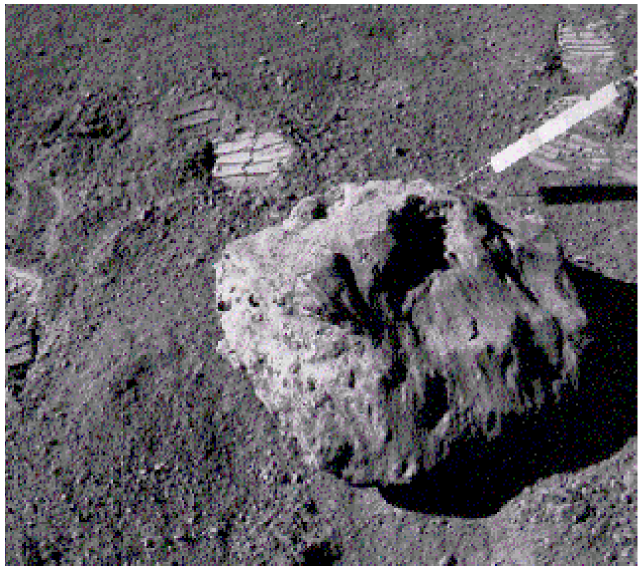


Figure 1: Station 8 boulder found perched on soil before sampling the top left corner. NASA #AS17-146-22370. Footprints for scale.

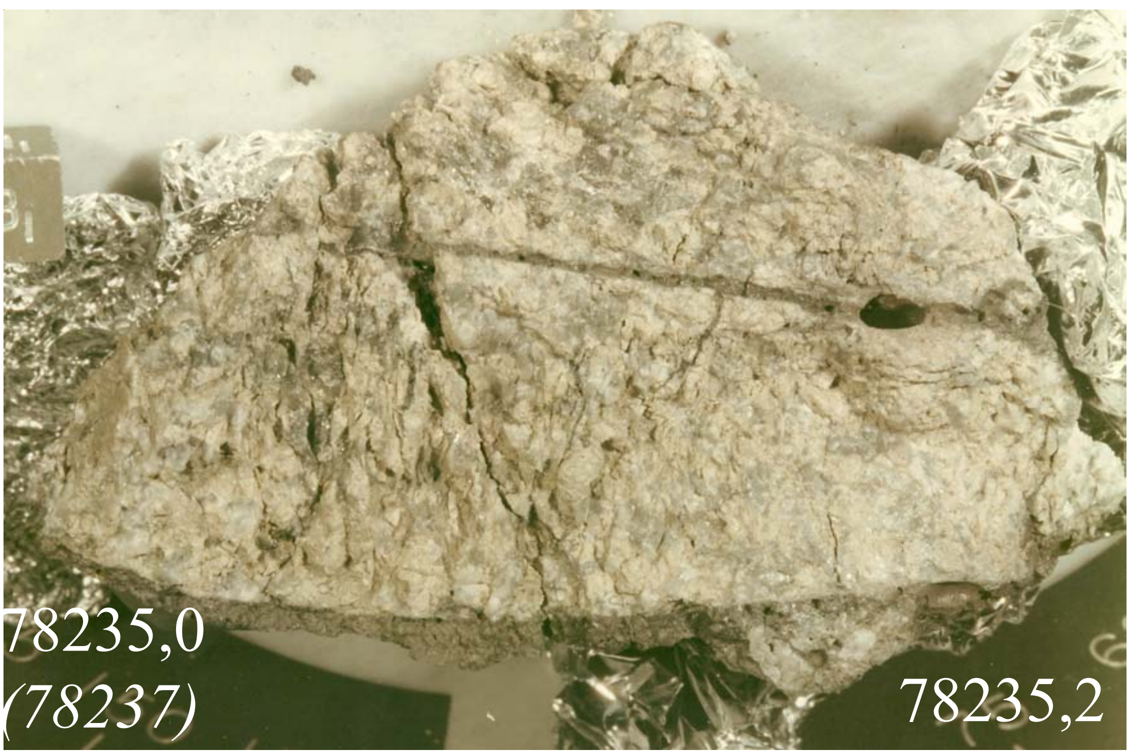


Figure 2: Photo of 78237 and 78235 norite (combined to be 78235) showing glass veins, highly shocked plagioclase and yellowish orthopyroxene. Cube is 1 cm. NASA # S73-17814.

Figure 3: PET photo of freshly broken surface of 78236. Cube is 1 cm. Photo number S73-15393.

Figure 4: Photo of 78238 showing glass vein. Side of 1 cm cube is showing at right. NASA S73-15461

Figure 5: The outer surface of each piece was coated with 1/4 inch of brown glass. This is the reverse side of 78238 in figure 4. S73-15463.

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 9figure 1). Sample 78237 was found to fit 78235, so they were numbered together as 78235 (199 grams)(figure 2). Samples 78236 and 78238 were chipped off adjacent areas and 78236 was used for many of the allocations. Samples 78255 and 78256 were chipped from the bottom of the boulder, after rolling it over. 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 , 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".*

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

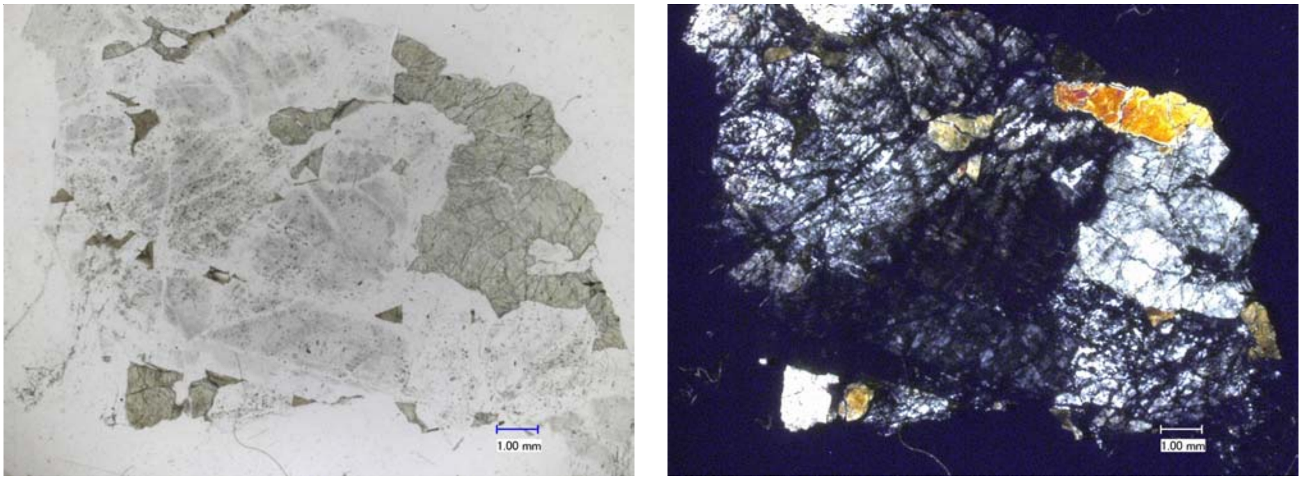


Figure 6 a,b: Thin section photomicrographs of 78238,17 showing shock features in plagioclase (maskelynite). Photos by C Meyer @ 20 x.

Zap pits found on samples from top and bottom (see also 78255) of this "perched" boulder indicate that the boulder has rolled around on the lunar surface (Jackson et al. 1975). The fact that the boulder was covered with glass, indicated it may have been a "bomb". The age has been determined to be about 4.3 b.y. which has been used to constrain the end of the magma ocean, and beginning of mg-suite magmatism. It has been exposed to cosmic rays for about 300 m.y. The glass coating has not been dated.

Petrography

Sample 78235 is a heavily-shocked 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 6 a,b). 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 9).

Additional modal mineralogy (Edmunson et al. 2009).

Samples	78235,6[a]	78235,49[b]	78236,8[c]	78238[a,d]
Orthopyroxene	51	51.2	53.6	32
Clinopyroxene	0.01	0.01	0.6	<0.1
Plagioclase	48	48.2	39.2	68
High-Si glass	0.25	0.25	2.4	Trace
K-feldspar	Trace		Trace	Trace
Phosphate	0.03	0.032	Trace	Trace
Baddeleyite	Trace	Trace		Trace
Zircon	Trace	Trace		Trace
Troilite	Trace	Trace	Trace	
Ilmenorutile	Trace	Trace	Trace	Trace
Ilmenite				Trace
Chromite	Trace	Trace	Trace	Trace
Fe metal	Trace	Trace	Trace	
Impact melt			4.0	

[a] James and Flohr (1983).
[b] McCallum and Mathez (1975).
[c] Nyquist et al. (1981).
[d] Unspecified thin section(s).

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*).

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 7). McCallum and Mathez estimated a temperature of equilibration of ~800 deg C.

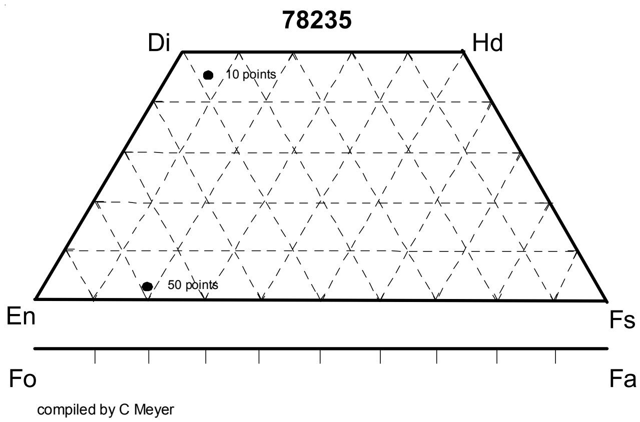


Figure 7: Pyroxene composition for 78235 norite from McCallum and Mathez (1975).

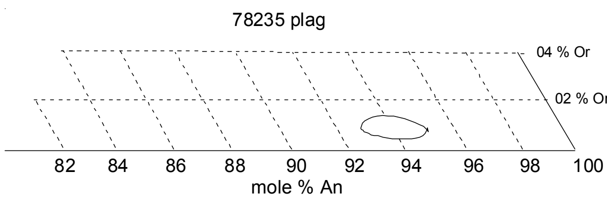


Figure 8: Plagioclase composition for 78235 from Dymek et al. (1975), McCallum and Mathez (1975).

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.

Plagioclase: The composition of plagioclase (An_{93-95}) in 78235 is given in figure 8. 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.

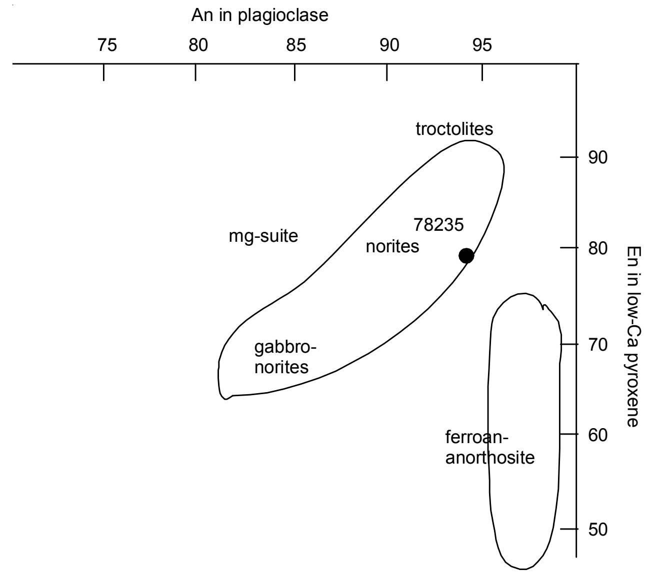


Figure 9: An-En diagram showing that 78235 is an end member of the mg-norite suite.

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.

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.

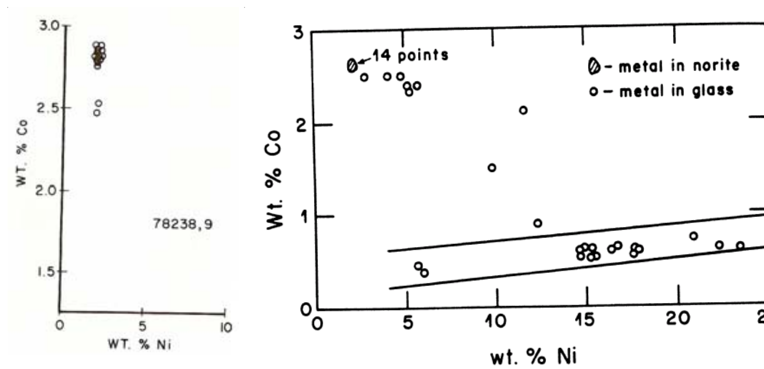


Figure 10: Co and Ni contents of 78235 and 238 (Hewins and Goldstein 1975 and McCallum and Mathez 1975).

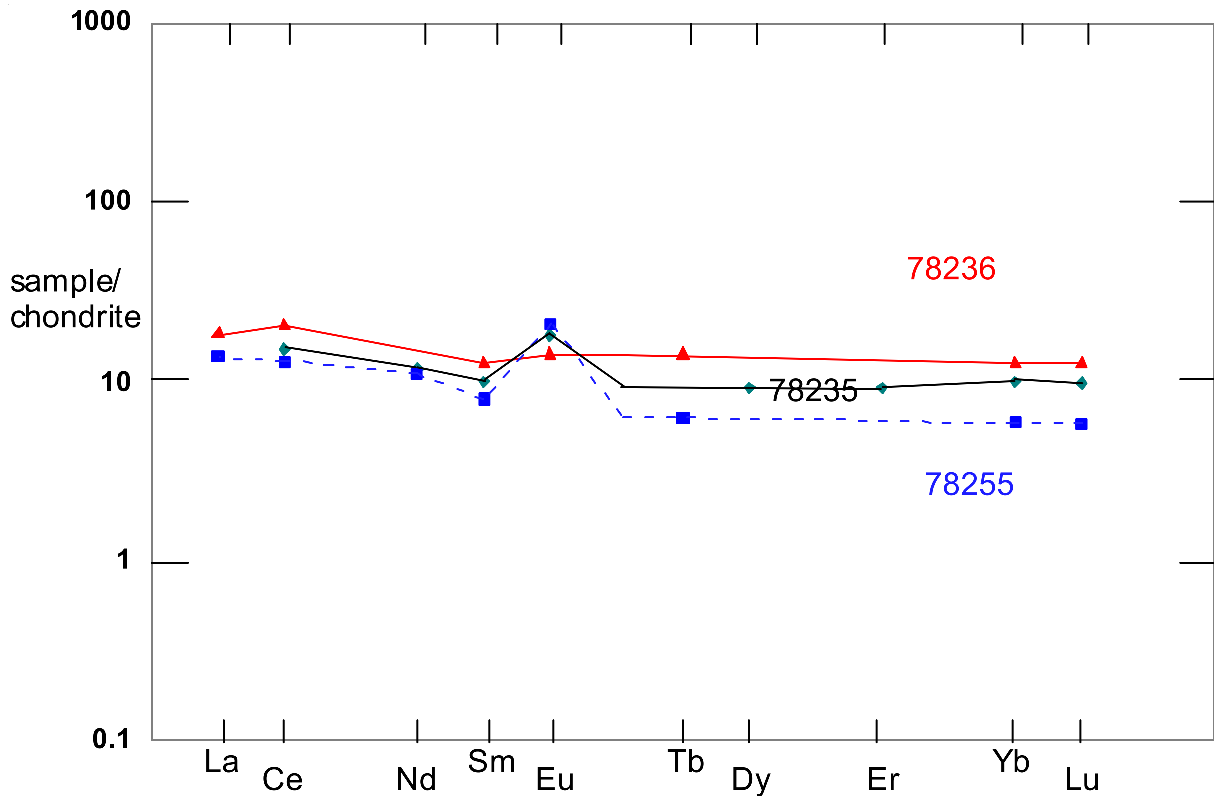


Figure 11: Normalized rare-earth-element diagram for samples of station 8 boulder. This data is in agreement, considering the coarse grain size of the rock and small alloquot used for analysis. Data from Blanchard, Warren and Wasson and Winzer (see tables).

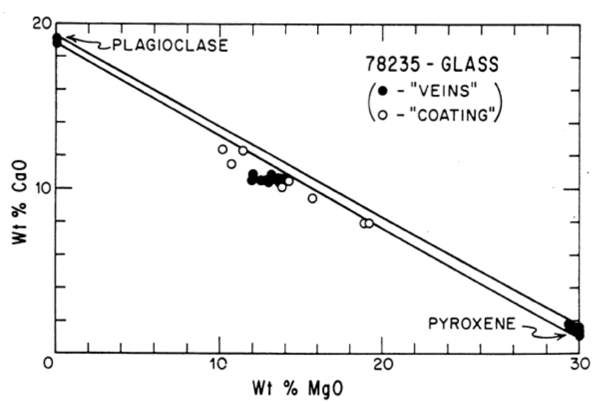


Figure 12: Chemical composition of glass veins and coating on boulder at station 8 (figure from Dymek et al. 1975).

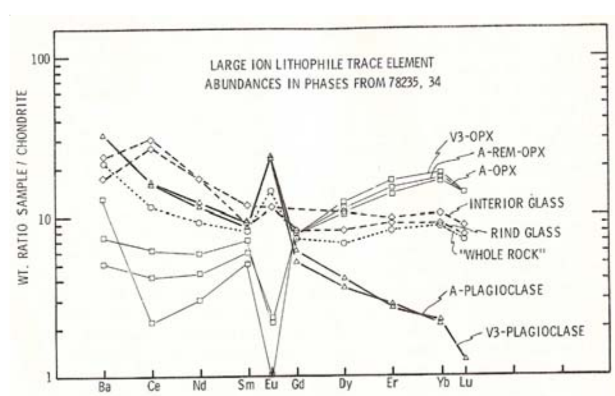


Figure 13: Normalized rare-earth-element diagram for mineral seperates from 78235 (Winzer et al. 1975). see also Blanchard and McKay (1981) for a similar diagram for 78236.

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 10).

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

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)

Table 2. Chemical composition of 78236.

reference	Blanchard 81		Nyquist 81	
weight				
SiO2 %	50.15			
TiO2	0.18			
Al2O3	17.66			
FeO	6.49			
MnO	0.12			
MgO	14.28			
CaO	10.12			
Na2O	0.31			
K2O	0.04			
P2O5	0.08			
S %	0.02			
sum				
Sc ppm	11.2	(a)		
V				
Cr	2120	(a)		
Co	28.2	(a)		
Ni				
Cu				
Zn				
Ga				
Ge				
As				
Se				
Rb			0.862	(b)
Sr			104	(b)
Y				
Zr				
Nb				
Mo				
Ru				
Rh				
Pd ppb				
Ag ppb				
Cd ppb				
In ppb				
Sn ppb				
Sb ppb				
Te ppb				
Cs ppm				
Ba				
La	4.47	(a)		
Ce	12.8	(a)		
Pr				
Nd			7.02	(b)
Sm	1.93	(a)	2	(b)
Eu	0.82	(a)		
Gd				
Tb	0.53	(a)		
Dy				
Ho				
Er				
Tm				
Yb	2.12	(a)		
Lu	0.32	(a)		
Hf	1.7	(a)		
Ta	0.2	(a)		
W ppb				
Re ppb				
Os ppb				
Ir ppb				
Pt ppb				
Au ppb				
Th ppm	0.6	(a)		
U ppm				

technique (a) INAA, (b) IDMS

Table 3: 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	

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).

Chemistry

The chemical composition of 78235 was determined by Winzer et al. (1975) and Higuchi and Morgan (1975) (table 1 and figure 11). 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 bulk composition of 78235 plots near the pyroxene-plagioclase coetectic on the phase diagram for lunar highland rocks at low pressure (Walker et al. 1973). The chemical composition of mineral seperates has been reported (figure 13).

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 12).

Radiogenic age dating

Hinthorne et al. (1977) dated 78235 by Pb-Pb ion probe method (see table). Although 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).

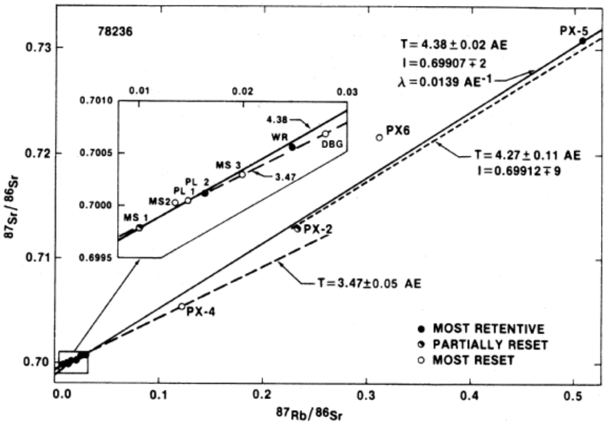


Figure 14: Rb-Sr isochron for 78236. From Nvauist et al. (1981).

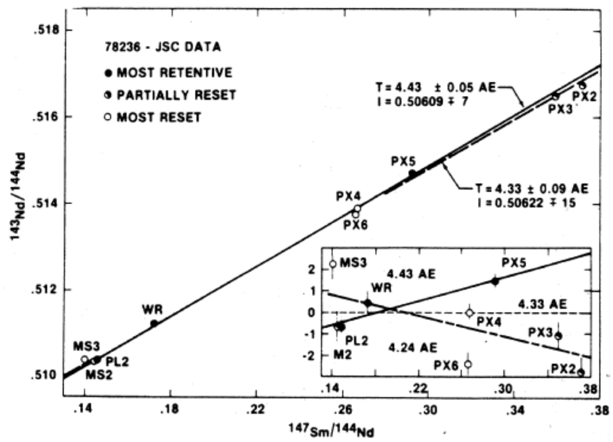


Figure 15: Sm-Nd isochron for 78236. From Nyquist et al. (1981).

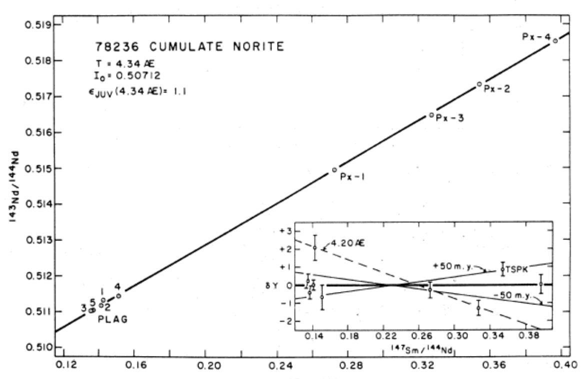


Figure 16: Sm-Nd isochron for 78236. From Carlson and Lugmair (1981).

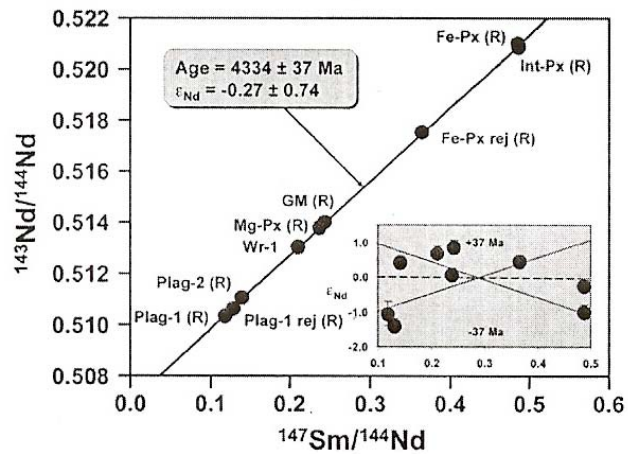


Figure 17: Sm-Nd isochron for 78238 (Edmundson et al. 2009).

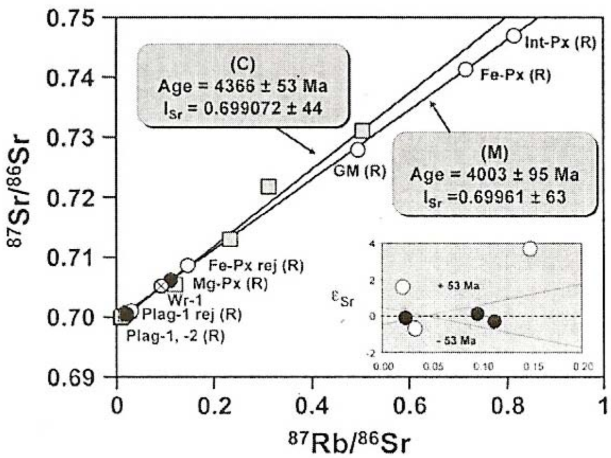


Figure 18: Rb-Sr isochron for 78238 and 78236 (Edmunson et al. 2009).

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 20). Sample 78236 (from the same rock) has also been dated by Nyquist et al. (1981), Carlson and Lugmair (1982), Aeschimann et al. (1982) and Edmumson et al. (2009)(see figure 14 - 21).

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
Edmunson et al. 2009	4.333 ± 0.059		4.366 ± 0.053	4.334 ± 0.037	

Caution: beware decay constants

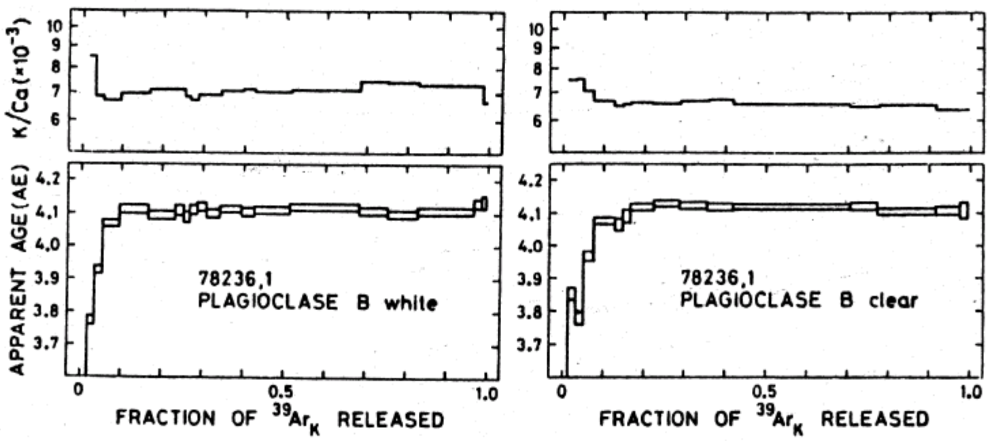


Figure 19: Ar release pattern for plagioclase from 78236. From Aeschlimann et al. (1982).

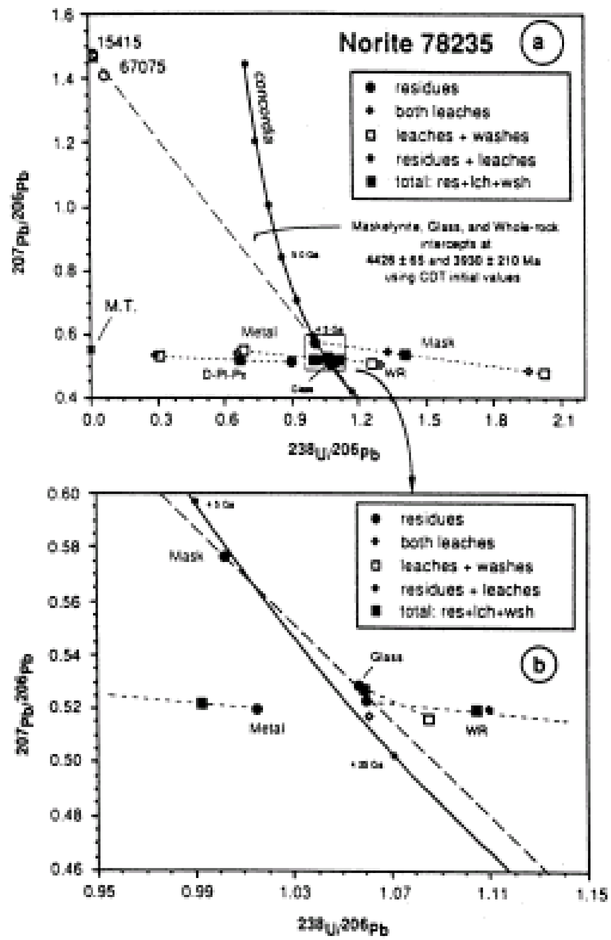


Figure 20: U-Pb systematics of 78235 from Premo and Tatsumoto (1991).

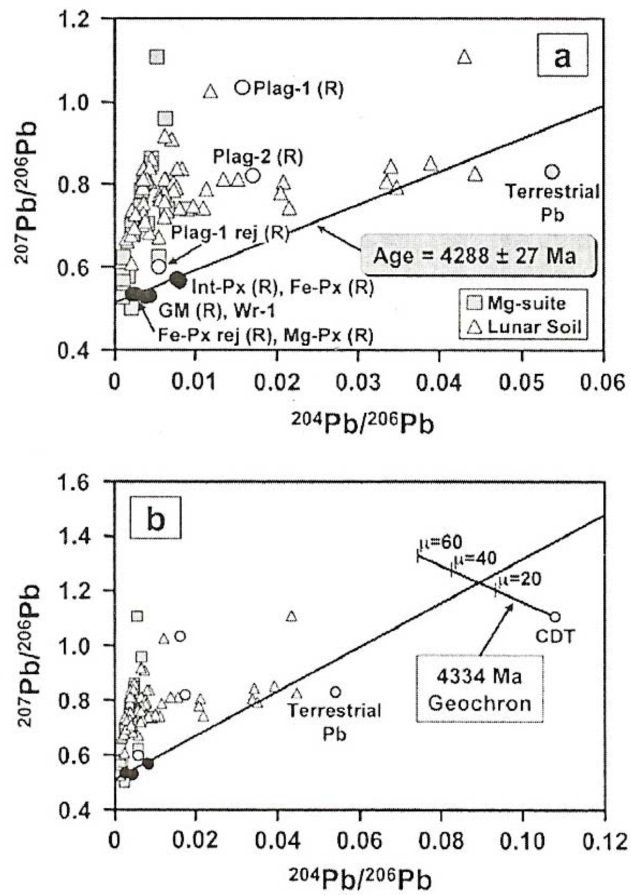
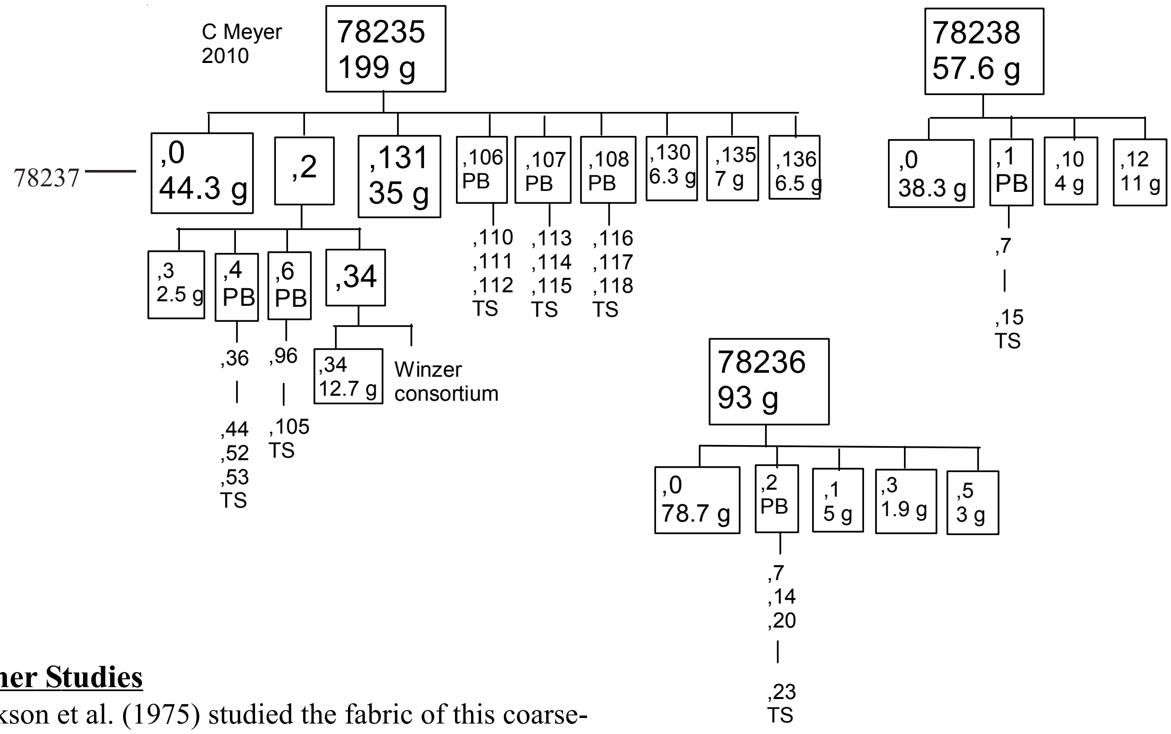


Figure 21: Pb-Pb study of 78238 (Edmunson et al. 2009).

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, Sclar and Bauer (1975, 1976) studied shock features and Simmons et al. (1975) remarked on the presence of "microcracks".

Mayeda et al. (1975) reported oxygen isotope analyses of plagioclase and of pyroxene from 78235 (*they should have calculated a temperature*).

Processing

After the pieces were chipped off of the boulder, they fell in the regolith. During PET, 78237 and 78235 were found to fit together (figure 2) so 78237 was renumbered 78235,0. T8236 and 78238 are identical, as is 78255 (from the other side of boulder).

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

Figure 22: Reverse side of 78236 - see also figure 3. The whole bouldr was covered with this thick brown glass coating.

References for 78235, 78236 and 78238

Aeschlimann U., Eberhardt P., Geiss J., Grogler N., Kurtz J. and Marti K. (1982) On the age of cumulate norite 78236 (abs). *Lunar Planet. Sci.* **XIII**, 1-2. Lunar Planetary Institute, Houston.

Bersch M.G., Taylor G.J., Keil K. and Norman M.D. (1991) Mineral compositions in pristine lunar highland rocks and the diversity of highland magmatism. *Geophys. Res. Lett.* **18**, 2085-2088.

Blanchard D.P. and McKay G.A. (1981) Remnants from the ancient lunar crust III: Norite 78236 (abs). *Lunar Planet. Sci.* **XII**, 83-85. Lunar Planetary Institute, Houston.

Boyet M. and Calson R.W. (2007) A highly depleted moon or a non-magma ocean origin for the lunar crust? *Earth Planet. Sci. Lett.* **262**, 505-516.

Butler P. (1973) **Lunar Sample Information Catalog Apollo 17.** Lunar Receiving Laboratory. MSC 03211 Curator's Catalog. pp. 447.

Carlson R.W. and Lugmair G.W. (1980) 78236, a primary, but partially senile, lunar norite (abs). *Lunar Planet. Sci.* **XI**, 125-128. Lunar Planetary Institute, Houston

Carlson R.W. and Lugmair G.W. (1981a) Time and duration of lunar highlands crust formation. *Earth Planet. Sci. Lett.* **52**, 227- 238.

Drozd R.J., Hohenberg C.M., Morgan C.J., Podosek F.A. and Wroge M.L. (1977) Cosmic-ray exposure history at Taurus-Littrow. *Proc. 8th Lunar Sci. Conf.* 3027-3043.

Dymek R.F., Albee A.L. and Chodos A.A. (1975b) Comparative petrology of lunar cumulate rocks of possible primary origin: Dunite 72415, troctolite 76535, norite 78235, and anorthosite 62237. *Proc. 6th Lunar Sci. Conf.* 301-341.

Edmunson J., Borg L.E., Nyquist L.E. and Asmerom Y. (2005) Three-system isotopic study of lunar norite 78238: Rb-Sr results (abs#1473). *Lunar Planet. Sci.* **XXXVI**, Lunar Planetary Institute, Houston.

Edmunson J., Gaffney A.M. and Borg L.E. (2006) Disturbance of U-Pb isotopic systematics in lunar samples: Mare basalt 10017 and norite 78235 (abs#1506). *Lunar Planet. Sci.* **XXXVII**, Lunar Planetary Institute, Houston.

Edmunson J., Borg L.E., Nyquist L.E. and Asmerom Y. (2009) A combined Sm–Nd, Rb–Sr, and U–Pb isotopic study of Mg-suite norite 78238: Further evidence for early differentiation of the Moon.
Geochim. Cosmochim. Acta **73**, 514-527.

ElGoresy A., Engelhardt W.von, Arndt J. and Manglier D. (1976) Shocked norite 78235: primary textures and shock features (abs). Lunar Sci. VII, 239-241. Lunar Science Institute, Houston.

Hansen E.C., Steele I.M. and Smith J.V. (1979a) Lunar highland rocks: Element partitioning among minerals 1: Electron microprobe analyses of Na, K, and Fe in plagioclase; mg partitioning with orthopyroxene. *Proc. 10th Lunar Planet. Sci. Conf.* 627-638.

Hewins R.H. and Goldstein J.I. (1975a) The provenance of metal in anorthositic rocks. *Proc. 6th Lunar Sci. Conf.* 343-362.

Higuchi H. and Morgan J.W. (1975a) Ancient meteoritic component in Apollo 17 boulders. *Proc. 6th Lunar Sci. Conf.* 1625-1651.

Hinthorne J.R., Conrad R.L. and Church S.E. (1977) Lead-lead age and rare earth element determinations in lunar norite 78235 (abs). *Lunar Sci.* **VIII**, 444-446. Lunar Planetary Institute, Houston.

Jackson E.D., Sutton R.L. and Wilshire H.G. (1975) Structure and petrology of a cumulus norite boulder sampled by Apollo 17 in Taurus-Littrow valley, the Moon. *Geol. Soc. Am. Bull.* **86**, 433-442.

James O.B. (1980) Rocks of the early lunar crust. *Proc. 11th Lunar Planet. Sci. Conf.* 365-393.

James O.B. and Flohr M.K. (1983) Subdivision of the Mg-suite noritic rocks into Mg-gabbronorites and Mg-norites. *Proc. 13th Lunar Planet. Sci. Conf. in* J. Geophys. Res., A603-A614.

Jost D.T. and Marti K. (1982) Pu-Nd-Xe dating: Progress towards a "solar system" Pu/Nd ratio (abs). *Lunar Planet. Sci.* **XIII,** 371-372. Lunar Planetary Institute, Houston.

Keith J.E., Clark R.S. and Bennett L.J. (1974a) Determination of natural and cosmic ray induced radionuclides in Apollo 17 lunar samples. *Proc. 5th Lunar Sci. Conf.* 2121-2138.

LSPET (1973) Apollo 17 lunar samples: Chemical and petrographic description. *Science* **182**, 659-672.

LSPET (1973) Preliminary Examination of lunar samples. Apollo 17 Preliminary Science Rpt. NASA SP-330. 7-1 – 7-46.

Marti K. (1983) Recoils: New opportunities to study and date early solar system processes (abs). *Lunar Planet. Sci.* **XIV**, 462-463. Lunar Planetary Institute, Houston.

Mayeda T., K., Shearer J. and Clayton R.N. (1975) Oxygen isotope fractionation in Apollo 17 rocks. *Proc. 6th Lunar Sci. Conf.* 1799-1802.

McCallum I.S. and Mathez E.A. (1975) Petrology of noritic cumulates and a partial melting model for the genesis of Fra Mauro basalts. *Proc. 6th Lunar Sci. Conf.* 395-414.

McCallum I.S., Okamura F.P., Mathez E.A. and Ghose S. (1975) Petrology of noritic cumulates: Samples 78235 and 78238 (abs). *Lunar Sci.* **VI**, 534-536. Lunar Planetary Institute, Houston.

Mehta S. and Go1dstein J.I. (1980a) Metallic particles in the glassy constituents of three lunar highland samples 65315, 67435, and 78235. *Proc. 11th Lunar Planet. Sci. Conf.* 1713-1725.

Meyer C. (1994) Catalog of Apollo 17 rocks. Vol. 4 North Massif

Meyer C. (2003) The Lunar Petrographic Educational Thin Section Set (revised) – on line.

Muehlberger et al. (1973) Documentation and environment of the Apollo 17 samples: A preliminary report. Astrogeology 71 322 pp superceeded by Astrogeolgy 73 (1975) and by Wolfe et al. (1981)

Muehlberger W.R. and many others (1973) Preliminary Geological Investigation of the Apollo 17 Landing Site. *In* **Apollo 17 Preliminary Science Report.** NASA SP-330.

Nyquist L.E., Reimold W.U., Wooden J.L., Bansal B.M., Wiesmann H. and Shih C.-Y. (1981a) Sr and Nd cooling ages of cumulate norite 78236 (abs). *Lunar Planet. Sci.* **XII**, 782-784. Lunar Planetary Institute, Houston.

Nyquist L.E., Reimold W.U., Bogard D.D., Wooden J.L., Bansal B.M., Wiesmanm H. and Shih C.-Y. (1981b) A comparative Rb-Sr, Sm-Nd and K-Ar study of shocked norite 78236: Evidence of slow cooling in the lunar crust? *Proc. 12th Lunar Planet. Sci. Conf.* 67-97.

Nyquist L.E. and Shih C.-Y. (1992) The isotopic record of lunar volcanism. *Geochim. Cosmochim. Acta* **56**, 2213-2234.

Palme H., Spettel B., Wanke H., Bischoff A. and Stoffler D. (1984b) Early differentiation of the Moon: Evidence from trace elements in plagioclase. *Proc. 15th Lunar Planet. Sci. Conf.* C3-C15.

Papike J.J., Fowler G.W. and Schearer C.K. (1994b) Orthopyroxene as a recorder of lunar crust evolution: An ion microprobe investigation of Mg-suite norites. *Am. Mineral.* **79**, 796-800.

Premo W.R. (1991) Rb-Sr and Sm-Nd ages for lunar norite 78235/78236: Implications on the U-Pb isotopic systematics in this high-Mg rock (abs). *Lunar Planet. Sci.* **XXII**, 1089-1090. Lunar Planetary Institute, Houston.

Premo W.R. and Tatsumoto M. (1990) Pb isotopes in norite 78235 (abs). *Lunar Planet. Sci.* **XXI**, 977-978. Lunar Planetary Institute, Houston.

Premo W.R. and Tatsumoto M. (1991b) U-Th-Pb isotopic systematics of lunar norite 78235. *Proc. 21st Lunar Planet. Sci. Conf.* 89-100. Lunar Planetary Institute, Houston.

Ryder G. and Norman M.D. (1979a) Catalog of pristine non-mare materials Part 1. Non-anorthosites, revised. NASA-JSC Curatorial Facility Publ. JSC 14565, Houston. 147 pp.

Sclar C.B. and Bauer J.F. (1975a) Shock-induced subsolidus reduction-decomposition of orthopyroxene and shock-induced melting of norite 78235. *Proc. 6th Lunar Sci. Conf.* 799-820.

Sclar C.B. and Bauer J.F. (1975b) Shock-induced subsolidus reduction-decomposition of orthopyroxene and shock-induced melting in norite 78235 (abs). *Lunar Sci.* **VI**, 730-731. Lunar Planetary Institute, Houston.

Sclar C.B. and Bauer J.F. (1976a) Subsolidus reduction phenomena in lunar norite 78235: Observations and interpretations. *Proc. 7th Lunar Sci. Conf.* 2493-2508.

Sclar C.B. and Bauer J.F. (1976b) Redox reactions involving nonvolatile ionic species as a mechanism of shock-induced subsolidus reduction of Fe+2 in plagioclase and orthopyroxene: Indications from lunar norite 78235 (abs). *Lunar Sci.* **VII**, 791-793. Lunar Planetary Institute, Houston.

Simmons G., Siegfried R. and Richter Dorthy (1975a) Characteristics of microcracks in lunar samples. *Proc. 6th Lunar Sci. Conf.* 3227-3254.

Smyth J.R. (1974) Low orthopyroxene from a lunar deep crustal rock: A new pyroxene polymorph of space group P21ca. *Geophys. Res. Lett.* **1**, 27-29

Steele I.M. (1975) Mineralogy of lunar norite 78235: Second lunar occurrence of P21ca pyroxenes from Apollo 17 soils. *Am. Mineral.* **60**, 1086-1091.

Steele I.M., Hutcheon I.D. and Smith J.V. (1980) Ion microprobe analysis and petrogenetic interpretations of Li, Mg, Ti, K, Sr, Ba in lunar plagioclase. *Proc. 11th Lunar Planet. Sci. Conf.* 571-590.

Takeda H., Mori H. and Miyamoto M. (1982) Comparison of thermal history of orthopyroxenes between lunar norites 78236, 72255, and diogenites. *Proc. 13th Lunar Planet. Sci. Conf.* in J. Geophys. Res. **87** A124-A130.

Walker D., Grove T.L., Longhi J., Stopler E.M. and Hays J.F. (1973a) Origin of lunar feldspathic rocks. *Earth Planet. Sci. Lett*. **20**, 325-336.

Warren P.H. and Wasson J.T. (1979a) The compositional-petrographic search for pristine nonmare rocks: Third foray. *Proc. 10th Lunar Planet. Sci. Conf.* 583-610.

Warren P.H., Jerde E.A. and Kallemeyn G.W. (1987) Pristine moon rocks: A large felsite and a metal-rich ferroan anorthosite. *Proc. 17th Lunar Planet. Sci. Conf*. in J. Geophys. Res. **90**, E303-E313.

Winzer S.R., Nava D.F., Lum R.K.L., Schuhmann S., Schuhmann P. and Philpotts J.A. (1975b) Origin of 78235, a lunar norite cumulate. *Proc. 6th Lunar Sci. Conf.* 1219-1229.

Winzer S.R., Lum R.K.L., Sehuhmann S. and Philpotts J.A. (1975c) Large ion lithophile trace element abundances in phases from 78235,34, a lunar norite cumulate (abs). *Lunar Sci.* **VI,** 872-873. Lunar Planetary Institute, Houston.

Wolfe E.W., Bailey N.G., Lucchitta B.K., Muehlberger W.R., Scott D.H., Sutton R.L and Wilshire H.G. (1981) The geologic investigation of the Taurus-Littrow Valley: Apollo 17 Landing Site. US Geol. Survey Prof. Paper, 1080, pp. 280.