76240

Shadowed Soil (portion frozen) - 490.54 grams

76260 - 293 grams

76280 - 446 grams

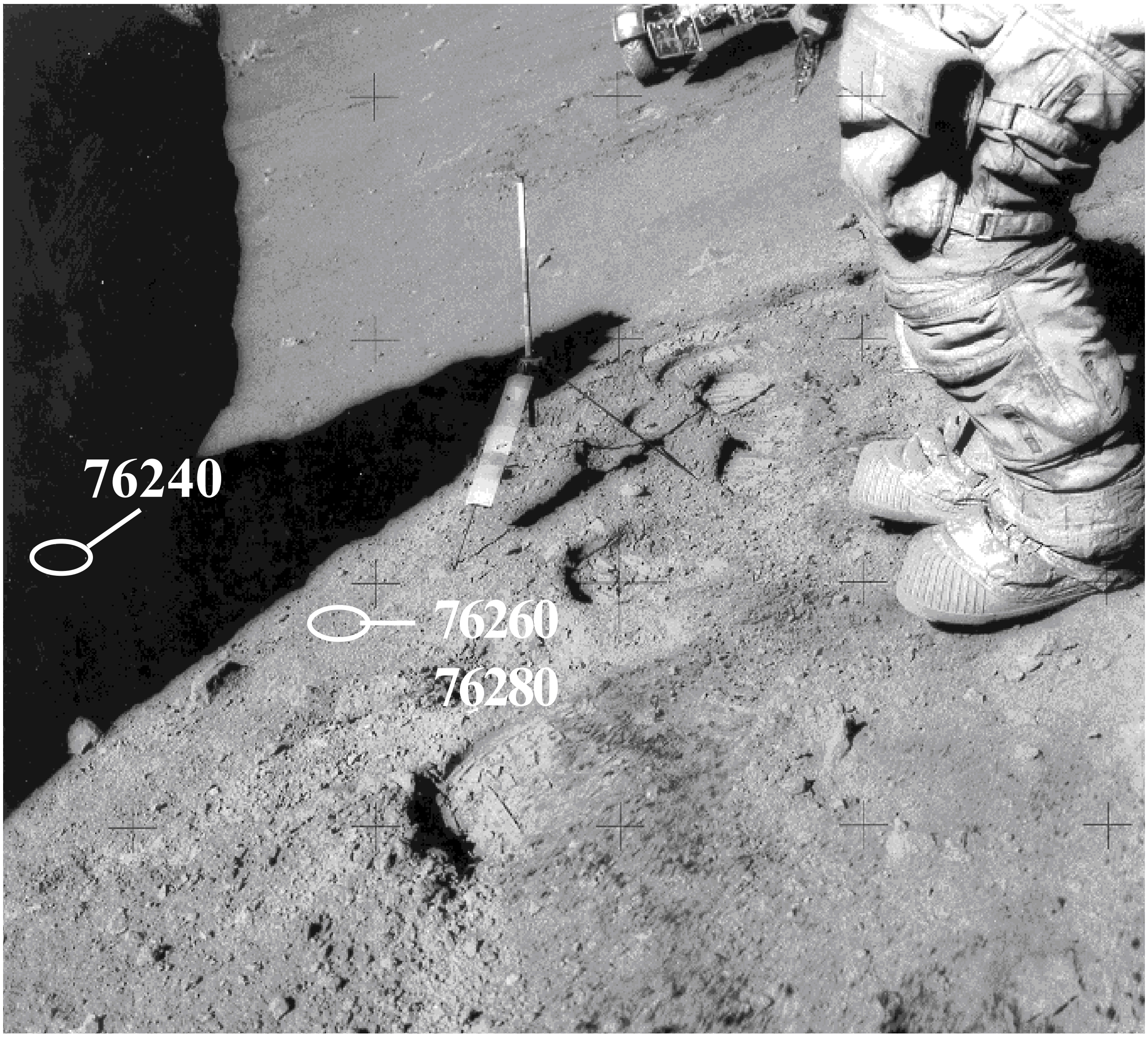


Figure 1: Location of shadowed soil 76240 and reference soil 76260/76280. NASA photo AS17-141-21605.

Introduction

76240 is a "permanently shadowed" soil sample collected ~1 meter under the overhang of a 5x4x3 meter boulder (#4) at station 6, South Massif (figure 1), which was downslope from blocks #2 and #3 (figure 2). This material has remained in the shadow for as long as the big boulder has been there (~22 m.y.; Crozaz and others 1974). 76261 and 76281 were collected nearby for comparison.

76240 is a surface sample collected from a depth of 0 – 4 or 5 cm and has a maturity index Is/FeO = 56 (submature) with about 48% agglutinates (Heiken and McKay 1974). Sample 76240 is to be compared with reference soil 76260 (Is/FeO = 58; 45% agglutinates) collected from the sunlit surface nearby (figure 1). Sample 76280 (Is/FeO = 45; 45% agglutinates) was collected from beneath 76260 (1 – 5 cm depth). Sample

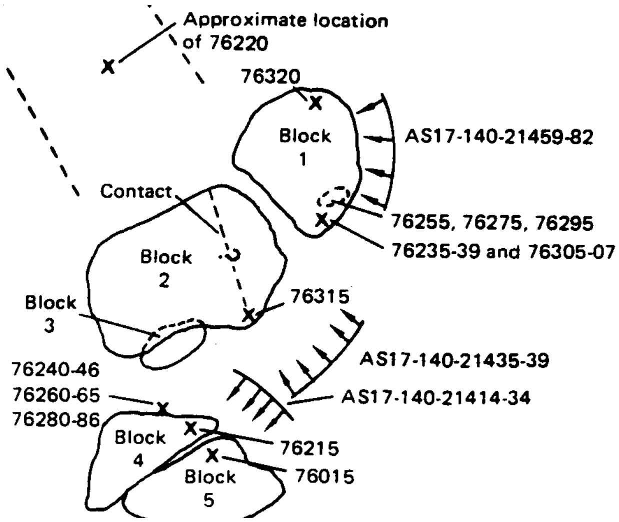


Figure 2: Location of shadowed soil 76240 - under block 4, station 6, North Massif, Apollo 17. From Wolfe et al. 1981. North is up. Block 4 is about 5 meters across.

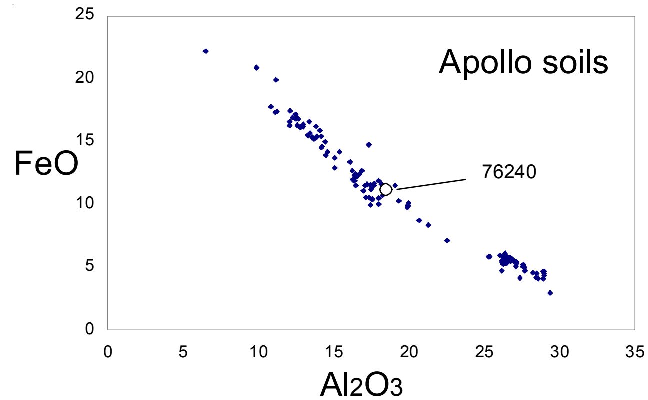


Figure 3: Chemical composition of 76240 compared with other lunar soils.

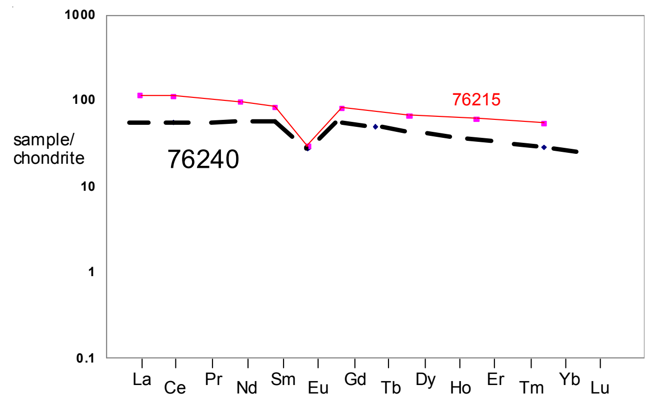


Figure 4: Normalized rare-earth-element pattern for shadowed soil (dashed line) compared with boulder matrix.

76240 has a mean grain size of 53 microns compared with 76260 and 76280 of 58 microns (McKay et al. 1974). *One may conclude that these soils are very like each other, except that 76240 was permanently shadowed from the sun for the length of time that the boulder has been on top of it.*

The large station 6 boulders sit on the local soil, shielding the soils underneath from recent cosmic rays, and also partially shielding adjacent soils. Indeed the ^{22}Na and ^{26}Al activity measured for 76240 are less than they would have been if the shadowed soil had been unshielded. However, this shadowed soil sample still has an activity higher than expected. Taken at face value, the boulder would have to have been emplaced within the last 1 m.y. (but, in fact, we know it to be ~22 m.y.). One possibility is that the shadowed soil has recently received a component of unshadowed soil "kicked" under the boulder by nearby impacts into adjacent soil.

The station 6 soils contain (as an important component) "dark mantle materials that extend locally onto the lower slopes of the Massif" (Wolfe et al. 1981).

Modal content of soils 76241, 76261 and 76281 (90-150 micron).

From Heiken and McKay (1974).

	76241	76261 (ref)	76281 (ref)
Agglutinates	48	45.3 %	45.3 %
Basalt	3.3	4.3	6.7
Breccia	19.7	18.2	16.3
Anorthosite	1.6	1	1.3
Norite	-	0.3	-
Gabbro	-		
Plagioclase	12	10.3	10.7
Pyroxene	7	12.6	11
Olivine	1.3	0.7	-
Ilmenite	2	1	1.3
Orange glass	0.7	0.7	1.3
Glass other	4.3	5.2	6

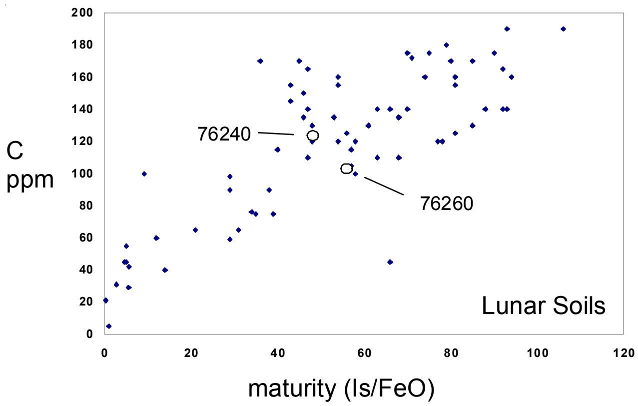


Figure 5: Carbon content and maturity index for shaded soil 76240 and reference soil 76260.

Sample 76215 is a breccia sample from the top of the boulder that protects 76240.

Petrography

76240 appears to be similar to reference soils 76260 and 76280 collected just outside the shadow.
Morris (1978) determined the maturity index of 76240, 76261 and 76281 as (I_s/FeO =56, 58 and 45, respectively). The grain size distribution is shown in figures 7 and 8.

Meyer (1973) cataloged the 4 – 10 mm coarse-fine particles and Jolliff et al. (1996) studied numerous 2 – 4 mm coarse-fine particles from 76283.

Chemistry

Hubbard et al. (1974), Morgan et al. (1974), Baedecker et al. (1974) and Korotev and Kremser (1992) determined the composition of the shadowed soil 76240 and sunlit comparison samples 76260, 76280 (tables 1 and 2, figure 3 and 4). Simonds (1975) and others determined the composition of the boulder (sample 76215). Figure 4 shows the difference in chemical composition between the soil and the boulder. Figure 5 presents the carbon content.

Volatiles

Von Guten et al. (1982) found excess Hg in shadowed sample 76240 compared with sunlit control sample 76260. Baedecker et al. (1974) and Morgan et al. (1974) found excess Cd in the shadowed soil (76240), compared with the reference soil (76260). However, Jovanovic and Reed (1974) found the same amount of Hg in 76240 as in 76260 (2 – 3 ppm).

Moore et al. (1974) a nd Gibson and Moore (1974) showed that 76240 had the same amount of sulfur as 76260 (~850 ppm). Jovanovic and Reed (1974) determined Hg, Os, Ru and U in 76241, 76261 (< 1 mm fraction). Norris et al. (1983) determined C and N (and their isotopic compositions).

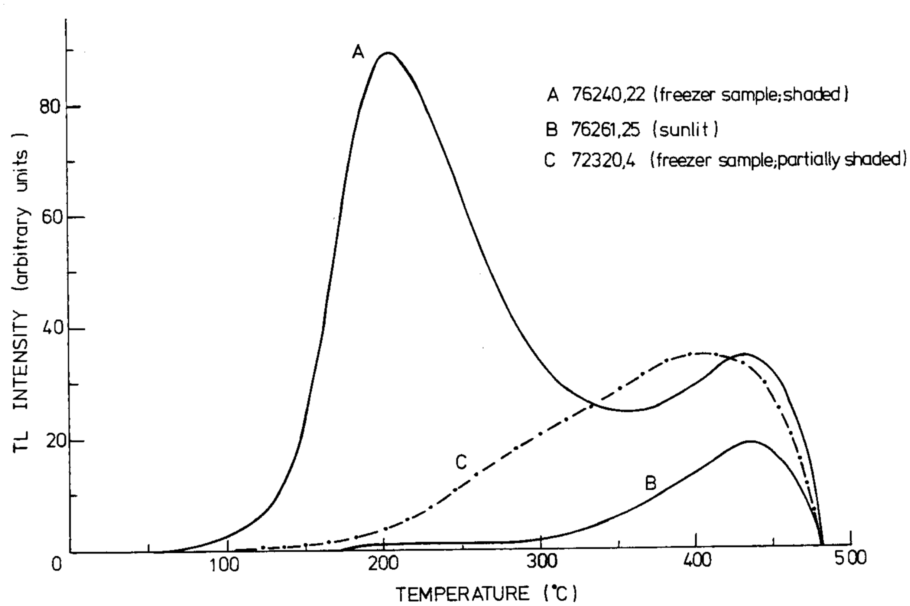


Figure 6: Natural thermolumenscence "glow curves" for three lunar soils with different radiation and thermal histories (Durrani et al. 1976). Frozen sample 76240 gives off more light (curve A) and starts at a lower temperature than the reference soil 76260 (curve B).

Cosmogenic isotopes and exposure ages

Keith et al. (1974) and Rancitelli et al. (1974) determined the cosmic ray induced activity of 76240 and 76260 (table 3). There is surprisingly high activity for ^{22}Na and ^{56}Co (both short half-lives) for 76240 (permanently shadowed soil sample) indicating that the boulder was emplaced rather recently (< m.y.). However, Crozaz et al. (1974) and Arvidson et al. (1975) give 22 m.y. as the time of emplacement of the station 6 boulder based on ^{81}Kr exposure ages of boulder samples (76315, 76015, 76055). This creates an interesting dilemma !

Strangely, Keith et al. (1974) and Yokoyama et al. (1975) found that 76240 was "saturated" with ^{22}Na (41 dpm/kg) and the "^{26}Al activity was considerably higher that might be expected". Keith et al. offer two explanations: "that the boulder rolled over this soil recently or, more reasonably, that the filleting has been the result of movement of material from the top few millimeters of the regolith under the boulder as a result of small meteorite bombardment".

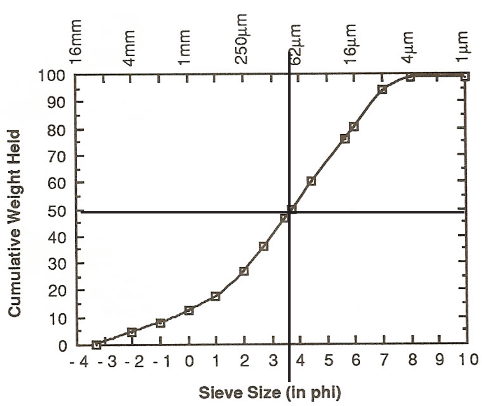
Fruchter et al. (1981) suggest that cosmic-ray-activated material is eroded off the top of the boulder, finding its way under the boulder – by gardening of the regolith.

Other Studies

Durrani et al. (1976) found substantial release of natural thermoluminescence on slow heating of 76240. The sample used had been kept frozen following return to the Earth at the request of Durrani. A reference sunlit soil which had not been kept cold was found to release less light on heating (figure 6). Durrani et al. used their data to calculate the average temperature (256 deg. K) and the duration of the shadow (~65, 000 yr.)!

Processing

A portion (20 G) of this shadowed sample was placed in a freezer (~ January 30, 1973), but was removed on or about January 1974 (CO#1637) to split a cold portion for SADurrani (details are important). The sample was delivered (cold) to Durrani March 22, 1974. The remainder of the frozen sample has been in the freezer ever since (no further processing). Other samples have been in sealed in cans and bags.



average grain size = 74 microns

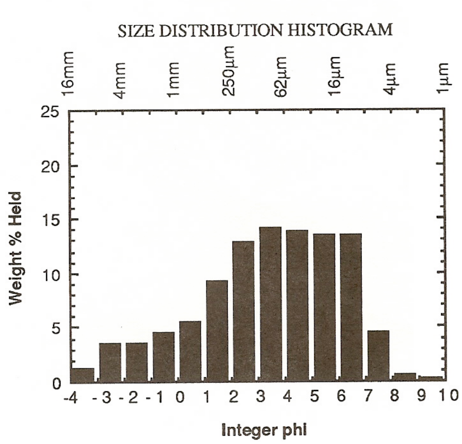
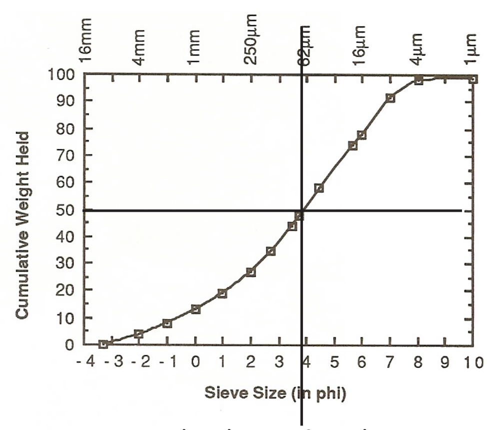


Figure 7: Grain size distribution for 76260 (Graf 1993, data from McKay).



average grain size = 67 microns

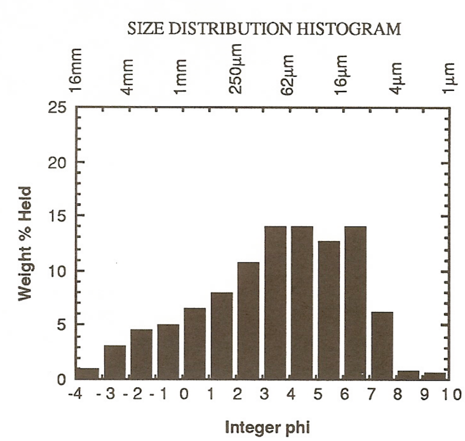


Figure 8: Grain size distribution for 76280 (Graf 1993, data from McKay).

Table 1. Chemical composition of 76240.

										76240	76261	76240	76261	
reference	Baedecker74		Rhodes74		Morgan74		Korotev92			Keith74	Keith74	Rancitelli74		
weight	shadowed soil													
SiO2 %			43.2	(c)										
TiO2			3.31	(c)										
Al2O3			17.85	(c)										
FeO	12.35	(b)	10.92	(c)			10.4	10.3	(b)					
MnO	0.16	(b)	0.16	(c)										
MgO			11.05	(c)										
CaO			11.97	(c)										
Na2O	0.48	(b)	0.43	(c)			0.415	0.422	(b)					
K2O			0.12	(c)						0.142	0.122	0.132	0.116	(e)
P2O5			0.09	(c)										
S %			0.07	(c)										
sum														
Sc ppm	31	(b)					29.3	27.6	(b)					
V														
Cr	1980	(b)					1890	1870	(b)					
Co	37	(b)					27.1	29	(b)					
Ni	215	(a)			220	(a)	170	230	(b)					
Cu														
Zn	24.7	(a)			25	(a)								
Ga	5.32	(a)												
Ge ppb	465	(a)			420	(a)								
As														
Se					240	(a)								
Rb					2.8	(a)								
Sr							160	160	(b)					
Y														
Zr	210	(b)					200	190	(b)					
Nb														
Mo														
Ru														
Rh														
Pd ppb														
Ag ppb					9.4	(a)								
Cd ppb	72	(a)			82	(a)								
In ppb	2.5	(a)												
Sn ppb														
Sb ppb					1.34	(a)								
Te ppb					17	(a)								
Cs ppm					0.13	(a)								
Ba							121	132	(b)					
La							10.4	11.7	(b)					
Ce	34	(b)					28.2	32	(b)					
Pr														
Nd							22	22	(b)					
Sm							6.24	6.88	(b)					
Eu	1.6	(b)					1.37	1.35	(b)					
Gd														
Tb	1.8	(b)					1.41	1.47	(b)					
Dy														
Ho														
Er														
Tm														
Yb	4.8	(b)					5.07	5.33	(b)					
Lu							0.707	0.744	(b)					
Hf	6.7	(b)					5.07	5.42	(b)					
Ta	0.88	(b)					0.74	0.76	(b)					
W ppb														
Re ppb					0.82	(a)								
Os ppb														
Ir ppb	7.2	(a)			8.57	(a)	7.8	7.1	(b)					
Pt ppb														
Au ppb	3.3	(a)			3.81	(a)	4.6	2.6	(b)					
Th ppm	2.7	(b)					1.77	1.84	(b)	2.5	2.1	2.3	1.92	(e)
U ppm					0.55	(a)	0.5	0.49	(b)	0.618	0.49	0.6	0.52	(e)

technique: (a) RNAA, (b) INAA, (c) XRF, (d) IDMS, (e) radiation count.

Table 2. Chemical composition of 76260, 76280 and boulder.

	76261 (control for 76240)									76281 control					76215	
reference	Baedecker74		Rhodes74		Morgan74		Korotev92			Rhodes74		Korotev 92			Simonds75	
weight	sunlit soil									subsurface					boulder	
SiO2 %			43.64	(c)						43.56	(c)				46.13	(c)
TiO2			3.38	(c)						3.83	(c)				1.24	(c)
Al2O3			17.96	(c)						17.8	(c)				18.73	(c)
FeO	11.1	(b)	10.93	(c)			10.4	10.7	(b)	11.26	(c)	11	11.2	(b)	8.08	(c)
MnO	0.15	(b)	0.16	(c)						0.16	(c)					
MgO			10.75	(c)						10.55	(c)				12.43	(c)
CaO			12.11	(c)						12.18	(c)				11.5	(c)
Na2O	0.44	(b)	0.45	(c)			0.427	0.403	(b)	0.43	(c)	0.388	0.399	(b)		
K2O			0.12	(c)						0.11	(c)				0.24	(d)
P2O5			0.11	(c)						0.09	(c)				0.24	(c)
S %			0.07	(c)						0.07	(c)				0.07	(c)
sum																
Sc ppm	30	(b)					27.1	28.9	(b)			31.2	31.4	(b)		
V																
Cr	1840	(b)	1916	(c)			1794	1930	(b)	1984	(c)	2031	2020	(b)		
Co	32	(b)					34	29.4	(b)			29.9	29.9	(b)		
Ni	194	(a)	182	(c)	160	(a)	220	200	(b)	169	(c)	170	190	(b)	54	(a)
Cu				(c)												
Zn	23.5	(a)	26	(c)	23	(a)				33	(c)				2.5	(a)
Ga	5.21	(a)														
Ge ppb	408	(a)			300	(a)									31.5	(a)
As																
Se					210	(a)									60	(a)
Rb			2.7	(c)	2.7	(a)				2.3	(c)				6.1	(d)
Sr			151	(c)			185	150	(b)	150	(c)	160	180	(b)		
Y			52	(c)						48	(c)					
Zr			197	(c)			200	230	(b)	174	(c)	160	150	(b)	459	(d)
Nb			15	(c)						13	(c)					
Mo																
Ru																
Rh																
Pd ppb																
Ag ppb					7.9	(a)									0.87	(a)
Cd ppb	37	(a)			39	(a)									1.08	(a)
In ppb	3.9	(a)														
Sn ppb																
Sb ppb					106	(a)									0.44	(a)
Te ppb					13.6	(a)										
Cs ppm					0.115	(a)									0.192	(a)
Ba							158	124	(b)			131	116	(b)	294	(d)
La							11.4	11.1	(b)			8.74	9.25	(b)	27.3	(d)
Ce							30.2	29.9	(b)			25	25.7	(b)	68.9	(d)
Pr																
Nd							20	20	(b)			19	20	(b)	43.7	(d)
Sm							6.58	6.63	(b)			5.9	6.24	(b)	12.3	(d)
Eu	1.5	(b)					1.4	1.34	(b)			1.33	1.36	(b)	1.7	(d)
Gd															15.9	(d)
Tb							1.46	1.44	(b)			1.39	1.4	(b)		
Dy															16.5	(d)
Ho																
Er															9.9	(d)
Tm																
Yb							5.22	5.21	(b)			4.92	5.09	(b)	9	(d)
Lu							0.732	0.724	(b)			0.673	0.704	(b)		
Hf	5.6	(b)					5.26	5.07	(b)			4.86	4.99	(b)		
Ta							0.79	0.75	(b)			0.82	0.73	(b)		
W ppb																
Re ppb					0.67	(a)									0.07	(a)
Os ppb																
Ir ppb	7.1	(a)			6.46	(a)	10	5.5	(b)			7	7.1	(b)	0.809	(a)
Pt ppb																
Au ppb	3.6	(a)			2.52	(a)	3.1	2.8	(b)			3.2	2.2	(b)	0.526	(a)
Th ppm							1.84	1.73	(b)			1.44	1.42	(b)	4.61	(d)
U ppm					0.49	(a)	0.49	0.44	(b)			0.37	0.43	(b)	1.26	(d)

technique: (a) RNAA, (b) INAA, (c) XRF, (d) IDMS

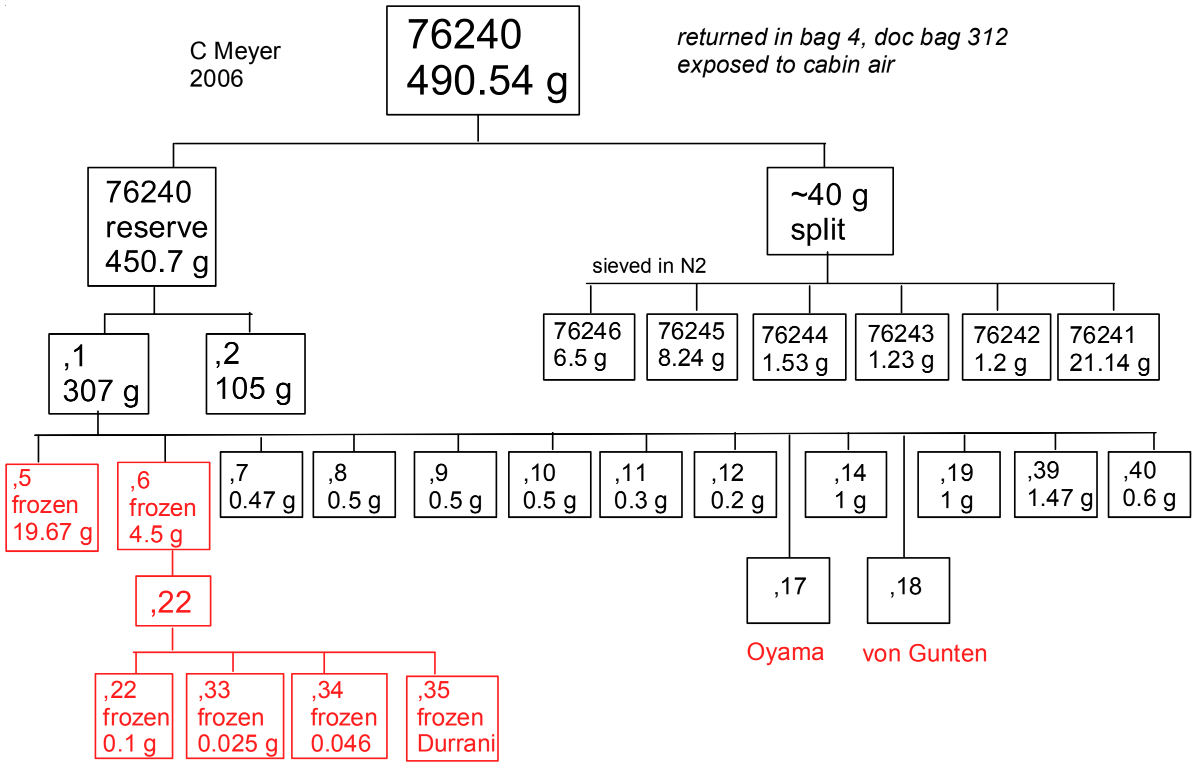
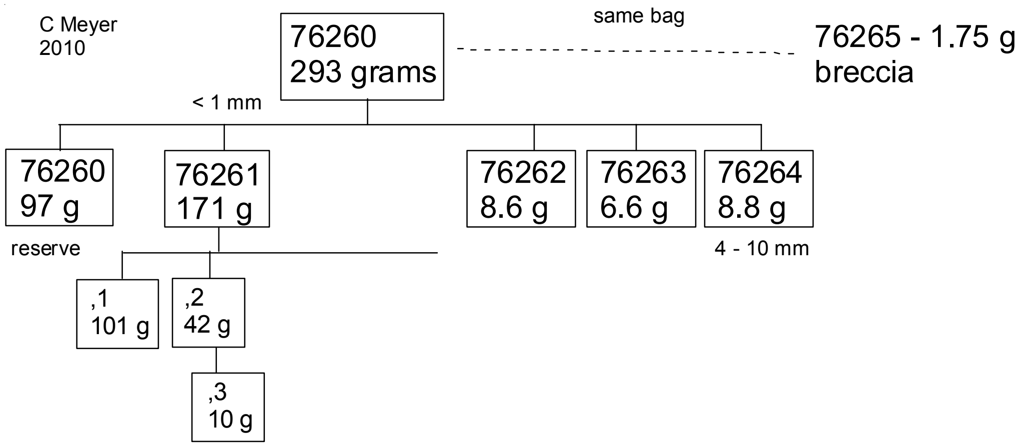
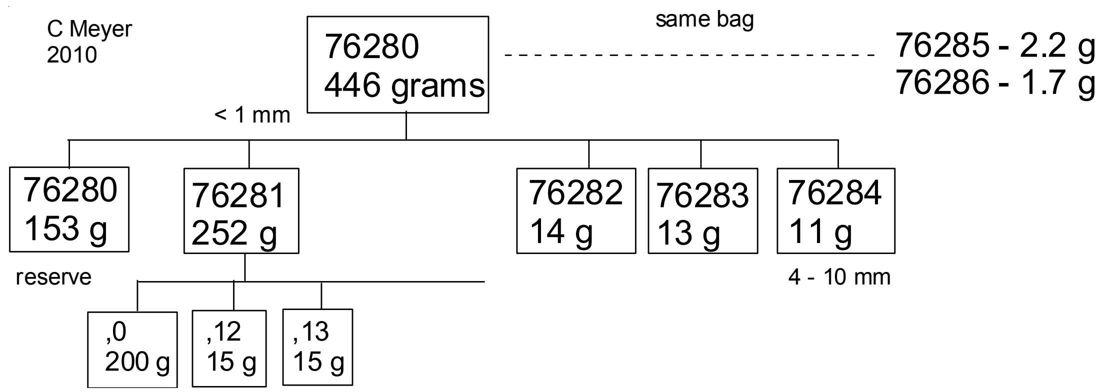


Table 3: Radiation counting results (dpm/kg).

	Keith 74		Rancitelli 74		predicted saturation
	76240	76261	76240	76261	
^{22}Na	41	148	42	143	
^{26}Al	156	182	151	171	250
^{46}Sc	7.2	23	8	27	
^{48}V	7	18	2.6	<29	
^{51}Cr			<200		
^{54}Mn			21	106	
^{56}Co	28	240	27	246	
^{57}Co			<12		
^{58}Co			<12		
^{60}Co			0.8	<2.5	
K ppm	1180	1020	1100	970	
Th ppm	2.5	2.1	2.3	1.92	
U ppm	0.618	0.49	0.6	0.52	
weight g	,2	,1	104.98	100.7	





References for 76240, 76260 and 76280

Baedecker P.A., Chou C.-L., Sundberg L.L. and Wasson J.T. (1974) Volatile and sidrophilic trace elements in the soils and rocks of Taurus-Littrow. *Proc. 5th Lunar Sci. Conf.* 1625-1644.

Bogard D.D., Hirsch W.C. and Nyquist L.E. (1974) Noble gases in Apollo 17 fines: Mass fractionation effects in trapped Xe and Kr. *Proc. 5th Lunar Sci. Conf.* 1975-2003.

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

Crozaz G., Drozd R., Hohenberg C.M., Morgan C., Ralston C., Walker R.M. and Yuhas D. (1974) Lunar surface dynamics: Some general conclusions and new results from Apollo 16 and 17. *Proc. 5th Lunar Sci. Conf.* 2475-2500.

Durrani S.A., Kazal K.A.R. and Ali A. (1976) Temperature and duration of some Apollo 17 boulder shadows. *Proc. 7th Lunar Sci. Conf.* 1157-1177.

Fruchter J.S., Reeves J.H., Evans J.C. and Perkins R.W. (1981) Studies of lunar regolith dynamics using measurements of cosmogenic radionuclides in lunar rocks, soils and cores. *Proc. 12th Lunar Planet. Sci. Conf.* 567-575.

Gibson E.K. and Moore G.W. (1974) Sulfur abundances and distributions in the valley of Tarrus-Littrow. *Proc. 5th Lunar Sci. Conf.* 1823-1838.

Gibson E.K. and Andreas F.F. (1978) Nature of the gases released from lunar rocks and soils upon crushing. *Proc. 9th Lunar Planet. Sci. Conf.* 2, 2433-2450.

Graf J.C. (1993) Lunar Soils Grain Size Catalog. NASA Reference Pub. 1265, March 1993

von Guten H.R., Wegmuller F. and Krahenbuhl U. (1982) Low temperature volatilization on the Moon. *Proc. 13th Lunar Planet. Sci. Conf.* J. Geophys. Res. 87, A279-A282.

Heiken G.H. (1974) A catalog of lunar soils. JSC Curator

Heiken G.H. (1975) Petrology of lunar soils. *Rev. Geophys. Space Phys.* **13**, 567-587.

Heiken G.H. and McKay D.S. (1974) Petrography of Apollo 17 soils. *Proc. 5th Lunar Sci. Conf.* 843-860

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

Korotev R.L. and Kremser D.T. (1992) Compositional variations in Apollo 17 soils and their relationship to the geology of the Taurus-Littrow site. *Proc. 22nd Lunar Planet. Sci. Conf.* 275-301.

LSPET (1973a) Apollo 17 lunar samples : Chemical and petrographic description. *Science* **182**, 659-690.

LSPET (1973) Preliminary examination of lunar samples. Apollo 17 Preliminary Sci. Report. NASA SP-330. 7-1.

McKay D.S., Fruland R.M. and Heiken G.H. (1974) Grain size and the evolution of lunar soils. *Proc. 5th Lunar Sci. Conf.* 887-906.

Meyer C. (1973) Apollo 17 Coarse Fines (4-10 mm) Sample Location, Classification and Photo Index. Curator Report. pp. 182.

Mitchell J.K., Carrier W.D., Costes N.C., Houston W.N., Scott R.F. and Hovland H.J. (1973) 8. Soil-Mechanics. *In* Apollo 17 Preliminary Science Rpt. NASA SP-330. pages 8-1-22.

Moore C.B., Lewis C.F. and Cripe J.D. (1974) Total carbon and sulfur contents of Apollo 17 lunar samples. *Proc. 5th Lunar Sci. Conf.* 1897-1906.

Moore C.B., Lewis C.F., Cripe J.D. and Volk M. (1974b) Total carbon and sulfur contents of Apollo 17 lunar samples (abs). *Lunar Sci*. **V**, 520-522. Lunar Planetary Institute, Houston.

Morgan J.W., Ganapathy R., Higuichi H., Krahenbuhl U. and Anders E. (1974) Lunar basins: Tentative characterization of projectiles, from meteoritic elements in Apollo 17 boulders. *Proc. 5th Lunar Sci. Conf.* 1703-1736.

Morris R.V. (1976) Surface exposure indicies of lunar soils: A comparative FMR study. *Proc. 7th Lunar Sci. Conf.* 315-335.

Morris R.V. (1978) The surface exposure (maturity) of lunar soils: Some concepts and Is/FeO compilation. *Proc. 9th Lunar Sci. Conf.* 2287-2298.

Morris R.V., Score R., Dardano C. and Heiken G. (1983) Handbook of Lunar Soils. Two Parts. JSC 19069. Curator's Office, Houston

Norris S.J., Swart P.K., Wright I.P., Grady M.M. and Pillinger C.T. (1983) A search for combustable, isotopically light carbon and nitrogen components in lunar samples and breccias. *Proc. 14th Lunar Planet. Sci. Conf.* B200-B210.

Papike J.J., Simon S.B. and Laul J.C. (1982) The lunar regolith: Chemistry, Mineralogy and Petrology. *Rev. Geophys. Space Phys*. **20**, 761-826.

Pearce G.W. and Chou C.-L. (1976) Relationships between siderophile elements and metallic iron contents of Apollo 16 and 17 lunar soils (abs). *Lunar Sci.* **VII**, 673-675.

Rancitelli L.A., Perkins R.W., Felix W.D. and Wogman N.A. (1974) Solar flare and lunar surface process characterization at the Apollo 17 site. *Proc. 5th Lunar Sci. Conf.* 2185-2204.

Rhodes J.M., Rodgers K.V., Shih C.-Y., Bansal B.M., Nyquist L.E., Wiesmann H. and Hubbard N.J. (1974) The relationships between geology and soil chemistry at the Apollo 17 landing site. *Proc. 5th Lunar Sci. Conf.* 1097-1118.

Schonfeld E. (1974) The contamination of lunar highland rocks by KREEP: Interpretations by mixing models. *Proc. 5th Lunar Sci. Conf.* 1269-1286.

Silver L.T. (1974) Patterns of U-Th-Pb distributions and isotope relations in Apollo 17 soil (abs). *Lunar Sci*. **V**, 706-708.

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. USGS Prof. Paper 1080.