

76240

Shadowed Soil (portion frozen) - 490.54 grams

76260 - 293 grams

76280 - 446 grams

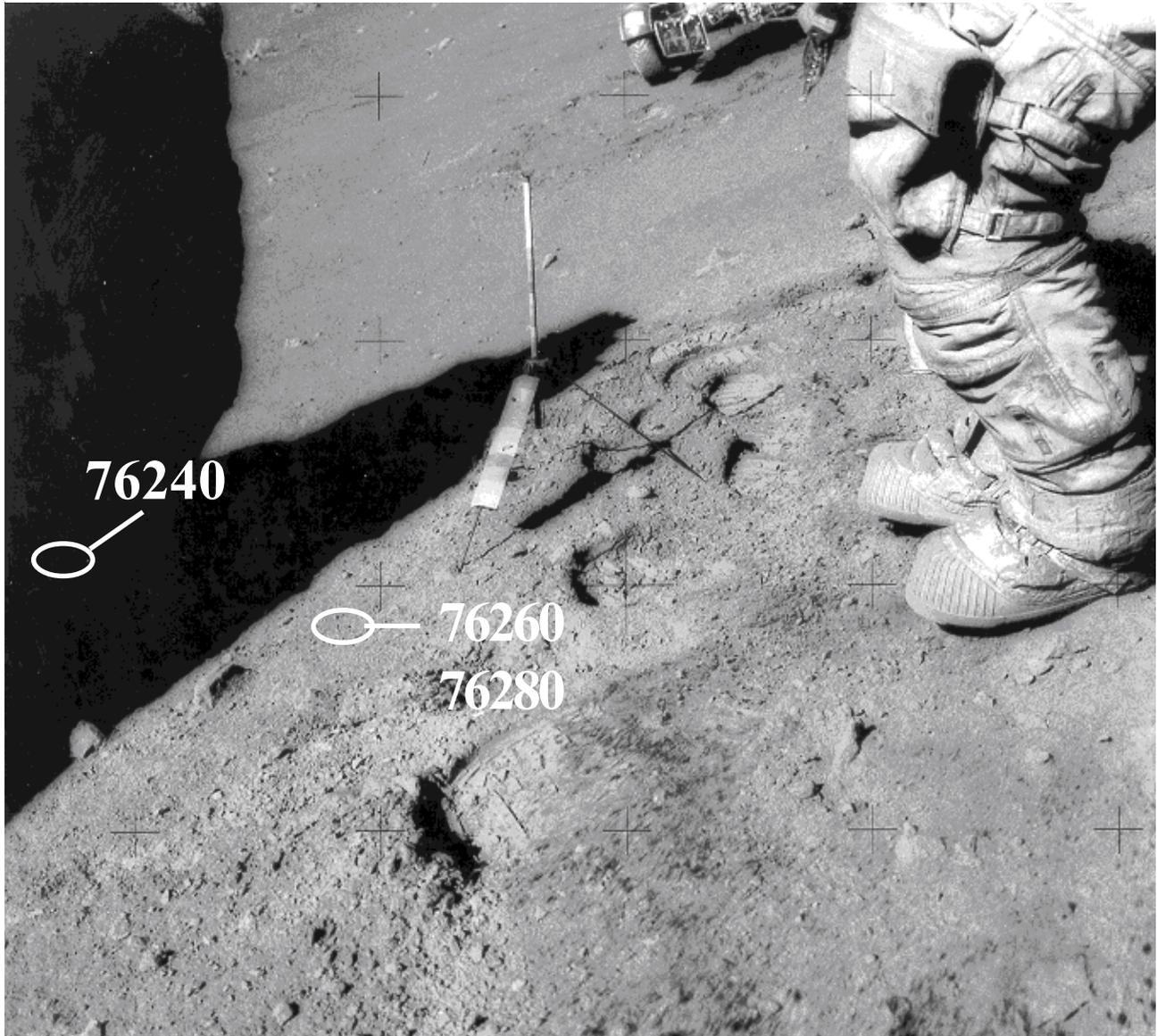


Figure 1: Location of shadowed soil 76240 and reference soil 76260/76280. NASA photo AS17-141-21605.

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

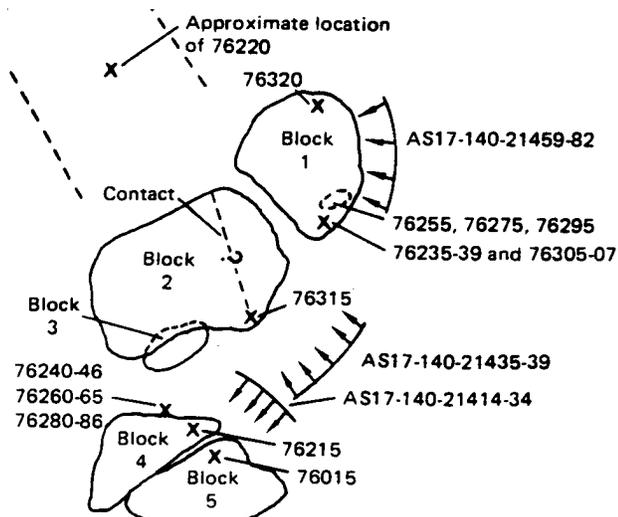


Figure 2: Location of shadowed soil 76240 - under block 4, station 6, North Massif, Apollo 17. From Wolfe et al. 1981. North is up. Block 4 is about 5 meters across.

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 ²²Na and ²⁶Al 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

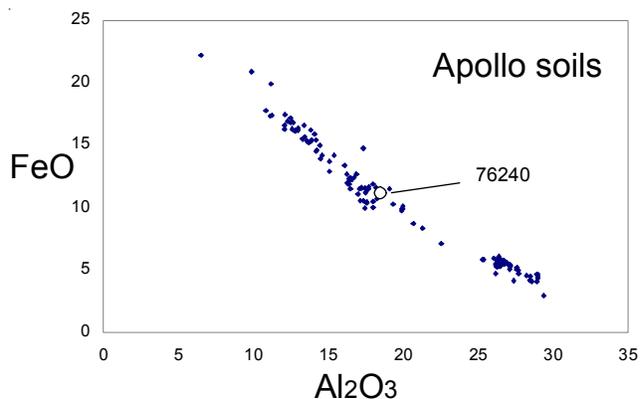


Figure 3: Chemical composition of 76240 compared with other lunar soils.

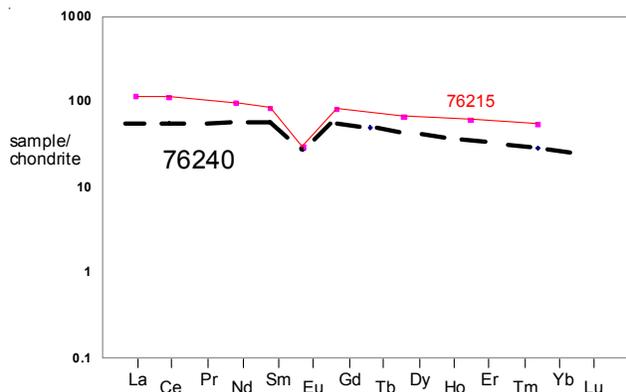


Figure 4: Normalized rare-earth-element pattern for shadowed soil (dashed line) compared with boulder matrix.

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

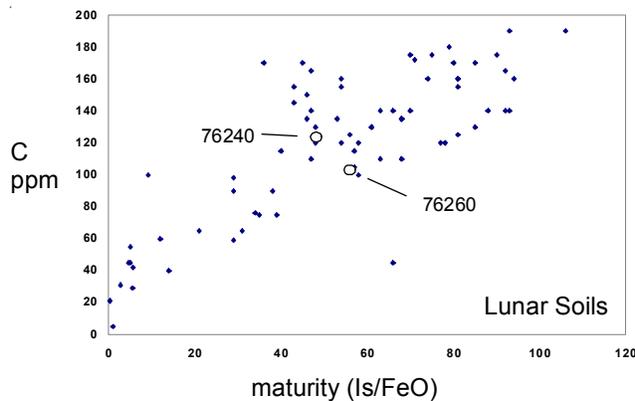


Figure 5: Carbon content and maturity index for shaded soil 76240 and reference soil 76260.

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) and 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).

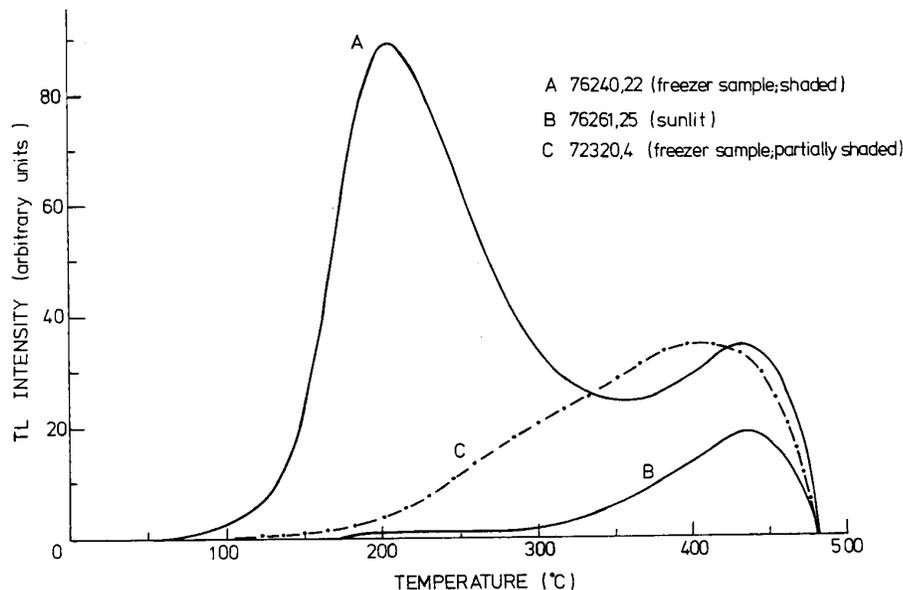


Figure 6: Natural thermoluminescence “glow curves” for three lunar soils with different radiation and thermal histories (Durrani et al. 1976). Frozen sample 76240 gives off more light (curve A) and starts at a lower temperature than the reference soil 76260 (curve B).

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”.

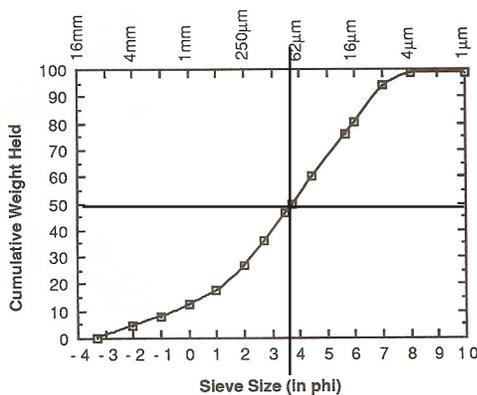
Fruchter et al. (1981) suggest that cosmic-ray-activated material is eroded off the top of the boulder, finding its way under the boulder – by gardening of the regolith.

Other Studies

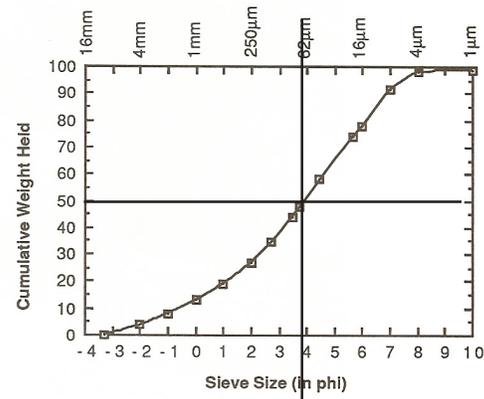
Durrani et al. (1976) found substantial release of natural thermoluminescence on slow heating of 76240 . The sample used had been kept frozen following return to the Earth at the request of Durrani. A reference sunlit soil which had not been kept cold was found to release less light on heating (figure 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



average grain size = 67 microns

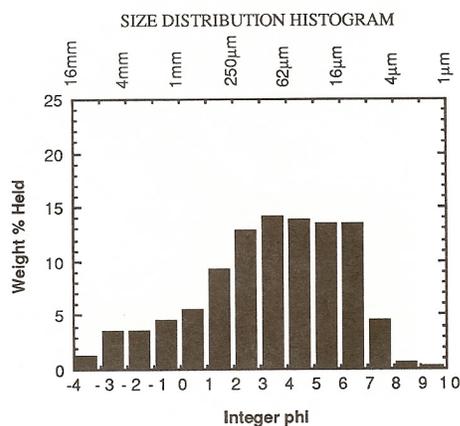


Figure 7: Grain size distribution for 76260 (Graf 1993, data from McKay).

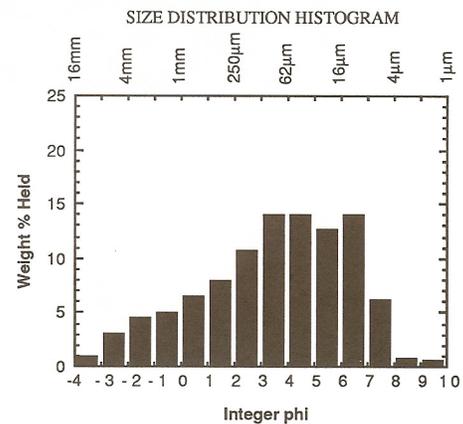


Figure 8: Grain size distribution for 76280 (Graf 1993, data from McKay).

Table 1. Chemical composition of 76240.

reference weight	Baedecker74	Rhodes74	Morgan74	Korotev92	76240 Keith74	76261 Keith74	76240 Rancitelli74	76261 Rancitelli74
SiO ₂ %		43.2 (c)						
TiO ₂		3.31 (c)						
Al ₂ O ₃		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)						
Na ₂ O	0.48	(b) 0.43 (c)		0.415	0.422	(b)		
K ₂ O		0.12 (c)					0.142	0.122
P ₂ O ₅		0.09 (c)					0.132	0.116
S %		0.07 (c)						(e)
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
U ppm			0.55	(a) 0.5	0.49	(b)	0.618	0.49
technique:							0.6	1.92
								(e)

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

reference weight	76261 (control for 76240)				76281 control				76215	
	Baedecker74 sunlit soil	Rhodes74	Morgan74	Korotev92	Rhodes74 subsurface	Korotev 92			Simonds75 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			7.9	(a)				0.87	(a)	
Ag ppb			39	(a)				1.08	(a)	
Cd ppb	37	(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

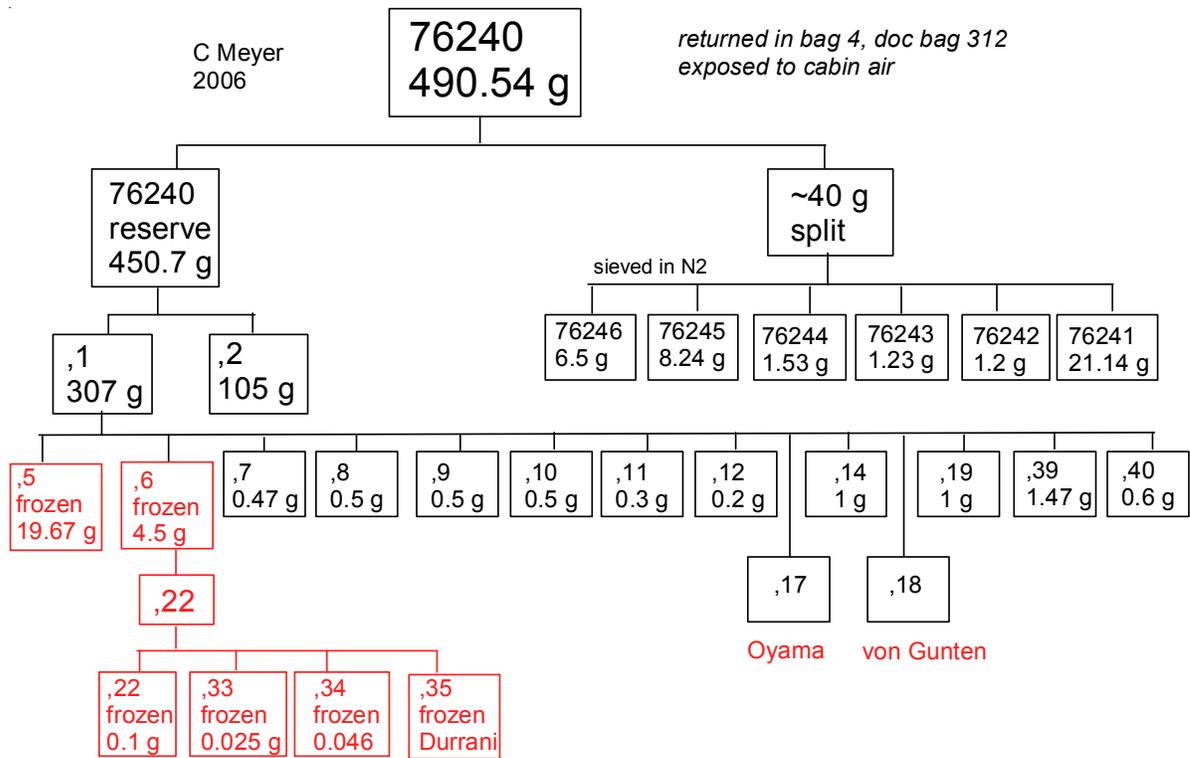


Table 3: Radiation counting results (dpm/kg).

	Keith 74		Rancitelli 74		predicted saturation
	76240	76261	76240	76261	
²² Na	41	148	42	143	250
²⁶ Al	156	182	151	171	
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	

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