THE DETRITAL ZONE IN THE SHORTY CRATER CORES

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Abstract. The lower part of lunar cores 74002/1 contains pure fine-grained black soil grading upward to orange soil. The section, however, between 10 cm and the lunar surface contains a mixture of orange and dark soil with a clast-in-matrix texture and some agglutinates. Therefore, this upper section is interpreted as a detrital zone. Although Shorty Crater was formed approximately 30 m.y. ago, all indicators of soil age give a much shorter time for residence of the detrital zone. Both absolute agglutinate content and authigenic agglutinate content indicate a surface residence of less than 8 m.y. for the detrital portion of the core. Most calculated ages of the detrital zone cluster are around 3 m.y. Grain size distribution is characteristic of an immature soil and there is little evidence, indicated by lack of upward fining and decrease in coarsest grain sizes, of *in situ* maturation of the section. Mixing with adjacent soils is very low, even though such soils lie only 0.5 M from the sampling site. Four of the five sub-strata in the upper 10 cm could have been produced by the impact event that produced the 20 M wide boulder field near the sampling site on the Shorty Crater rim. This event would distribute perched clasts over the sampling site. Thickness of the detrital part of the section is in keeping with its being ejecta from the boulder bed crater. The thickness of the agglutinate-rich zone, 1.5 cm, is reasonable for a less-than 4 m.y. residence time.

1. Introduction

It is the purpose of this paper to present evidence indicating that the detrital zone on top of the orange soil at Shorty Crater is much younger than the crater itself and to discuss some depositional implications of this interpretation.

Double drive tube 74002/1 was taken to sample a stratigraphic profile through an outcropping of orange soil. The core recovered material from the lunar surface (Muehlberger *et al.* 1973, pp. 6–51) to 67.7 cm (Lunar Core Catalog). Sampling disturbance is present (Bailey and Ulrich, 1975, p. 154) but pre-sampling photographs, such as AS17-137-20990, show it to have minor, if any, effect. From the base of the core to 10 cm, grain size is very fine, the soil is massive or irregularly fractured, and there is a progressive upward increase in orange glass accompanied by a decrease in black devitrified glass (Lunar Core Catalog). At 10 cm, the grain size and texture changes wherein large irregular orange and rounded gray clasts appear and the matrix assumes a petrographic composition that approximates an average of compositions between 10 and 15 cm (Figure 2). Matrix composition varies little and the clastic texture (with soil clasts and rock fragments) persists upward to the top of the core. Orange and black particles (Table III) are, to a significant degree, more fragmented in the upper 10 cm than in the next 5. Accordingly, this upper 10 cm is interpreted to be a detrital zone which has developed on the Shorty Crater rim after emplacement of the orange soil. It is this part of the section with which this paper is concerned.

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Advantages to studying this section as a regolithic profile are: (1) soils and materials are distinctinve and easily identified so that effects of maturation and mixing can be defined with more precision than usually for lunar soils; (2) age of Shorty Crater, hence the starting point for regolithic processes, has been defined and reasonably well-established by several workers at 30 m.y. (Kirsten *et al.* 1973, Eberhardt *et al.* 1974, Fleischer *et al.* 1974, Hintenberger *et al.* 1974).

2. Location of the Section

Drive tube 74002/1 was collected at Station 4 of the Apollo 17 mission. The site was located near the trenched center of a meter-wide band of orange soil surrounded by gray soils in roughly vertical contact (see Lunar Surface Photographs AS17-137-20990). Trenching indicated orange material to be concentrically zoned (Schmitt and Cernan, 1973, pp. 5–16). The core was taken near the center of the orange soil area. The sampling site was located near the top of the Shorty Crater rim (Figure 1), as seen in Lunar Surface Photos AS17-137-21010, with only a large mare basalt boulder (74255) being much higher topographically. The boulder was located approximately 5 M due west of the coring site. A field of perched boulders, approximately 20 M wide, lies 15–20 M from the sampling site, as seen in Lunar Surface Photo AS17-137-21009, and illustrated in Figure 1. Otherwise, surface fines and filleted boulders prevail in most of Station 4 photography.

3. Methods and Procedures

General characteristics of the entire double drive tube and procedures for processing this core are summarized in the Lunar Core Catalog (Jan. 1978 Supplement). Continuous section data presented here relate to petrography and depositional structures observed during dissection and are supplemented by detailed study of grain mounts for selected intervals.

Continuous data, collected along the entire length of the core during dissection and supplemented by post-dissection photography, include aspects of texture, structure and petrographic composition. These data are summarized in Table II A–C and Figure 2 A–D. Binocular microscopic textural data include an estimate of abundance of particles over 0.1 mm. Microscopic photographic data on depositional structures include location of recognizable strata, packing and orientation of large particles and characteristics of clast margins. Microscopic composition data include percentages of orange and dark droplets in the fraction over 0.1 mm. In the top 5.5 cm of the core, many coarse particles were retained on the 1 mm sieve. Such particles, including rounded clasts of orange soil and dark soil, angular fragment of mare basalts, and agglutinates, were measured and weighed, and quantitative assessments of size distribution and particle abundance could then be calculated. Abundance of friable orange and dark clasts was also estimated on post-dissection photographs; such data were especially useful between 5.5 and 10 cm, where orange clasts had crenulate margins and could not be dissected whole.

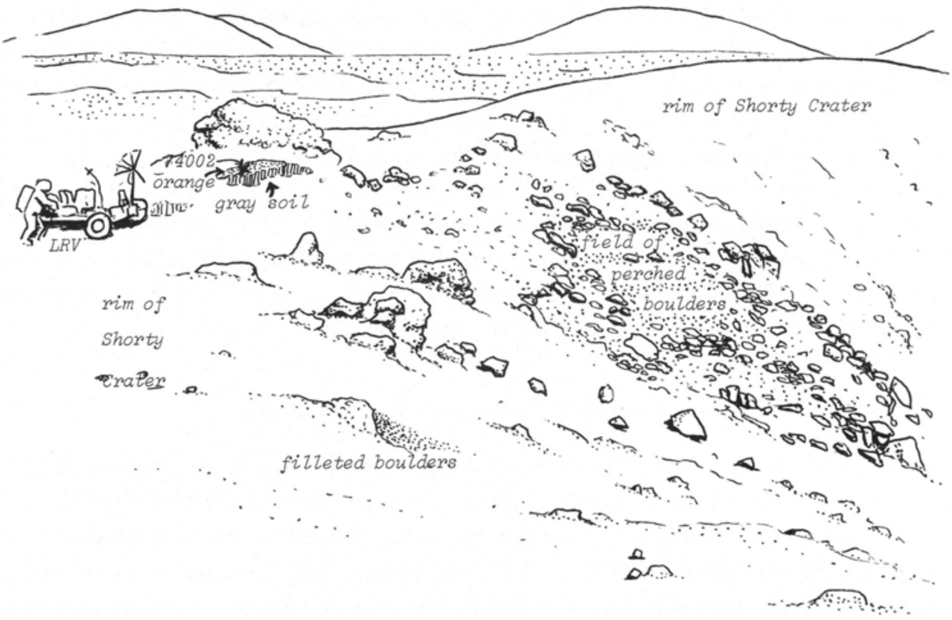


Fig. 1. Location of orange and grey sampled soil, drive tubes 74002 (and 74001) and outcrop features described in text (from NASA photo AS17-137-21009).

The continuous data collected under the binocular microscope during dissection, document typical changes through the section and provide a precise location of inflection points and abrupt lithologic changes, but such data have a major limitation in that they rarely cover all aspects of a given parameter, and generally leave many parameters undescribed. To partially compensate for these limitations and to provide an independent check on data collected during dissection, relatively complete intensive textural and compositional petrographic data were obtained from the detailed study of grain mounts taken from dissection splits at selected intervals. Information on all grain mounts is presented in the Lunar Core Catalog. Only that relevant to this study is included here. Grain mounts were taken at 2.5, 7.5, 12.5, 14.0 and 15.5 cm (samples 74002, 99, 98, 97, 07, and 95 respectively). Data from the grain mounts are presented in Table III. By analyzing the grain mounts before dissection 3 was undertaken, it was possible to obtain more precise continuous data.

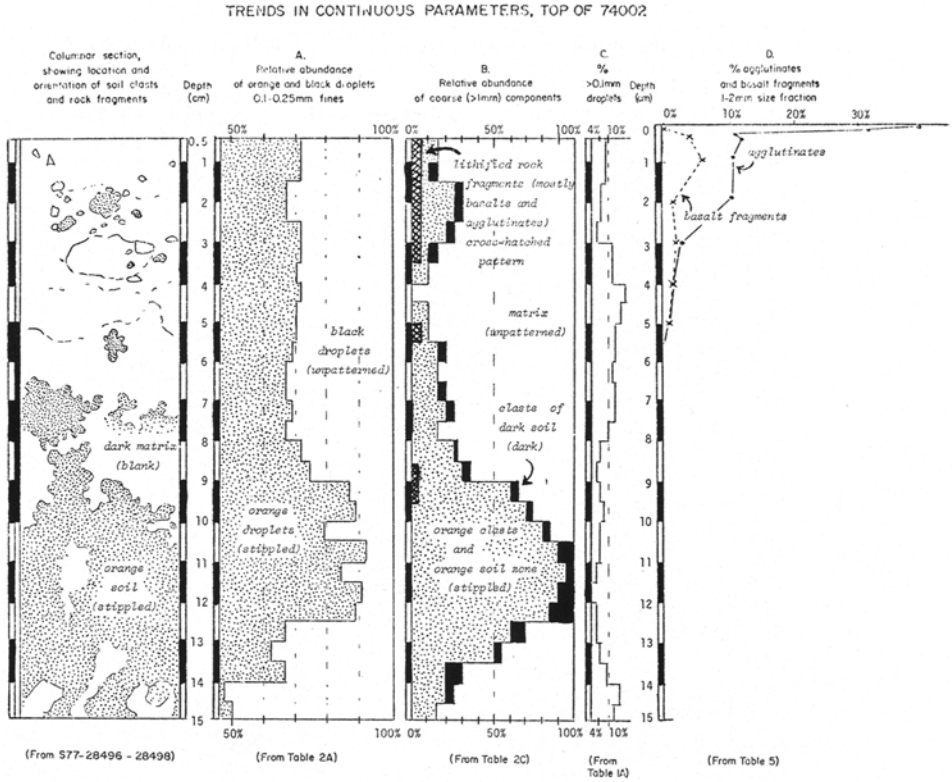
Textural data from grain mounts include point-count abundances of the following size fractions: 0.01–0.06 mm, 0.06–0.12 mm, 0.12–0.25 mm and 0.25–0.5 mm. Petrographic point-count abundances of orange glass, black devitrified glass, mineral particles, basalt fragments, ropy glass and breccia particles were determined in each slide for 0.06–0.12 and 0.12–0.25 mm size classes (Table IIIA). Because these slides were not polished, highly birefringent minerals such as pyroxene and olivine were distinguished on the basis of fracture and twinning, and polycrystalline grains were classified as basalt fragments. Elongate colorless twisted irregular isotropic particles in the 0.06–0.12 and 0.12–0.25 mm size fractions were identified as ropy glass, but detailed electron microscopic criteria used by Fruland (1977, p. 337) could not be comparably used because this study was limited to binocular petrography. Agglomerates of fine-grained dark and orange particles were placed in the general category "soil clasts" because it was not feasible to study matrix and binding agents. Data on morphological variations attempt to follow Heiken *et al.* (1977, p. 421) in distinguishing spherical, ovoid, single and compound droplets. Data here also include abundance of indeterminate irregular fragmented particles which cannot be classified by original shape because of fracturing on all sides (Table IIIB).

4. Description of Units – Number of Strata

Underlying the detrital part of 74002 is the concentration of orange soil, designated Unit 4 in the Lunar Core Catalog. Its description is included here to define the sub-detrital complex and to give evidence for depth of reworking. The orange soil zone has a color of 10 YR 2/1 (Munsell Book of Color). This zone appears massive and semi-cohesive in dissection. Under the binocular microscope, the zone appears relatively homogeneous with less than 5% being dark material which is distributed in irregular, mm-wide vertical streaks and patchy areas. Grain mount point counts and binocular estimates indicate that organge glass averages 90% of the total between 10 and 12.5 cm and makes up 50–75% of the next 2.5 cm. Particle size in Unit 4 is the finest in the double drive tube. The uppermost continuous orange soil occurs in 10 cm but crenulate-margined projections from this zone interfinger with overlying strata to 6 cm.

Unit 5, from 5.5 to 10 cm, is characterized by the occurrence of 1.3 cm wide friable clasts of orange soil set in a dark matrix. The base of Unit 5 is defined at 10 cm where the clast-in-matrix texture appears. In this unit from 8.5 to the top of the core (Figure 2) the abundance of orange droplets averages 70%. Composition and fragmentation of this unit is statistically (Table III) identical to that of Unit 5 structures and clast populations are, however, noticeably different. The abundance of orange clasts diminishes upwards (Figure 2) but large vertically aligned clasts persist to an irregular surface at approximately 5.5 cm. This surface is defined as the top of the unit. The orange clasts have crenulate margins and interfinger so completely with the surrounding matrix that it is impossible to dissect and extract orange clasts separately from the matrix. There are a few 5 mm rounded clasts of gray soil scattered through the unit, such clasts can be seen on dissection photograph S-77-28496. The uppermost cm of this unit appears to contain slightly smaller clasts than the lower 3.5 cm, but the characteristic vertical alignment of crenulate orange clasts persists to the irregular surface at 5.5 cm.

Unit 6, from 5.5 cm to the lunar surface, is much less cohesive, as shown in the x-radiograph, than lower strata. This unit contains basalt rock fragments and agglutinates in addition to clasts of orange and gray soil seen in Unit 5. Lithified particles are very rare below 1.5 cm and are not uncommon, but not really abundant, in the area of their



maximum concentration which lies between 1.5 cm and the lunar surface. Clasts average much smaller than in Unit 5 and most show rounded, rather than crenulate, margins. Only at 1.5 to 3.5 cm are there abundant orange clasts with irregular margins. Fabric of Unit 6 is distinctly different from that of Unit 5 in that many rock fragments show a horizontal alignment and the pronounced vertical alignment seen in Unit 5 is not present in 6. Three subunits can be recognized. The lowest, from 4.5 to 5.5 cm, is very irregular, fine-grained, and has abundant glass droplets as seen in both the dissection and post-dissection photographs such as S-77-28497. From 15 to 4.5 cm, there is a marked increase in abundance of orange clasts (Figure 2). At 1.5 cm there is a pronounced (from less than 1 to approximately 3%) increase in both agglutinates and basalt fragments while the grain size shows decrease (Table IA). Absolute concentration, however, of agglutinates and basalt fragments remains low through the entire unit.

5. Interpretation of the Detrital Zone

Understanding of the history of the detrital portion of the section requires a determination of the age of the detrital zone – is it the age of Shorty Crater, or is it younger? –

TABLE IA

Continuous textural data, upper part of 74001. Estimated abundance of coarse (> 0.1 mm) droplets

(cm) Depth	As Used In LCL Inventory	After Dissection 1 (% of Total)	After Dissection 2 (% of Total)	Ave.
1.9– 0.5	010–05			
1.5– 1.0	015–10	8	6	7
2.0– 1.5	020–15	8	4	6
2.5– 2.0	025–20	6	5	6
3.0– 2.5	030–25	6	4	5
3.5– 3.0	035–30	10	8	9
4.0– 3.5	040–35	10	8	9
4.5– 4.0	045–40	15	10	12
5.0– 4.5	050–45	10	12	11
5.5– 5.0	055–50	10	10	10
6.0– 5.5	060–55	10	10	10
6.5– 6.0	065–60	10	8	9
7.0– 6.5	070–65	10	10	10
7.5– 7.0	075–70	8	12	10
8.0– 7.5	080–75	6	10	8
8.5– 8.0	085–80	4	8	6
9.0– 8.5	090–85	4	6	5
9.5– 9.0	095–90	6	5	6
10.0– 9.5	100–95	6	8	7
10.5–10.0	105–00	5–6	6	6
11.0–10.5	110–05	5	8	6
11.5–11.0	115–10	4	6	5
12.0–11.5	120–15	4	4	4
12.5–12.0	125–10	4	6	5
13.0–12.5	130–25	6	4	5
13.5–13.0	135–30	6	6	6
14.0–13.5	140–35	8	8	8
14.5–14.0	145–40	12	10	11
15.0–14.5	150–45	10	10	10

and an assessment of the amount of reworking and lateral mixing during the period of detrital development.

5.1. Age of Core Soils and Age of Shorty Crater

Most rocks and soils at Shorty Crater show a two-phase exposure irradiation history (Eugster *et al.*, 1977) with the spallation phase giving ages of 30–50 m.y. and the surface exposure phase giving ages of 2.5–3 m.y. These ages are summarized in Table IV. Most authors attribute the 30–50 m.y. age to the formation of Shorty Crater, and the 2.5–3 m.y. age to a recent change in shielding at the rim crest.

Evidence from studies of 74002 indicates the uppermost soils in the core were exposed at the surface for a time period more in keeping with the 2.5–3 m.y. exposure than the 30 m.y. age. This evidence, in the form of absolute abundance of petrographic agglutinates

TABLE IIA

Continuous compositional data. Abundance of orange and dark (see Figure 2, columnA)

Depth (mm) LCL Inventory	Dissertion 3 Orange	Dark
010–05	72	28
015–10	72	28
020–15	66	34
025–20	66	34
030–25	72	28
035–30	72	28
040–35	70	30
045–40	72	28
050–45	70	30
055–50	70	30
060–55	68	32
065–60	66	34
070–65	66	34
075–70	68	32
080–75	66	34
085–80	72	28
090–85	74	26
095–90	86	14
100–95	88	12
105–00	78	22
110–05	92	8
115–10	84	16
120–15	90	10
125–20	88	12
130–25	66	33
135–30	62	38
140–35	66	33
145–40	46	54
150–45	50	50

and area coverage by authigenic agglutinates, is as follows; abundance of petrographic agglutinates in sieved bulk soils has been used since 1972 (McKay *et al.*) to obtain estimates of soil ages. Limitations and source of error in this method include: (1) agglutinates are generated by surface-related processes, but agglutinate content is measured by point-count or weight, not surface-related area; (2) agglutinates can increase proportionally with exposure age, only until the saturation point is neared (Morris, 1976); (3) mixing of soils with different exposure ages and agglutinate contents could give equivocal agglutinate ages; (4) aggluntinate abundance in the coarse fraction (the only fraction available for this study) is low and subject to greater statistical uncertainty than for studies of finger grain sizes, where more particles are available; (5) exact agglutinate production rate is uncertain. Nevertheless, the fact that agglutinate abundance generally shows a good correlation with exposure-related parameters, such as track density (McKay *et al.*, 1972; p. 989), indicates that it is a useful method for estimating of soil exposure time.

TABLE IIB

Continuous compositional data. Weight % of agglutinates and basalt fragments (see Figure 2, column D)

size class – 1–2 mm

Interval	Sample Numbers	Basalt Fgms. Wt.	%	Aggultinates Wt.	%	Total Wt. In Interval
0– 1 mm	,2 ,3	. . .	.	0.011	100	0.011
1– 2 mm	,4 ,5	. . .	.	0.020	44	0.045
2– 3 mm	,6 ,7	. . .	.	0.016	31	0.053
3– 4 mm	,8 ,9	0.003	5	0.006	10	0.060
4– 5 mm	,10 ,11	. . .	.	0.009	12	0.075
5–15 mm	,87–,89 and ,2068–71	0.020	7	0.027	10	0.270
15–25 mm	,84–,86 and ,2064–67	0.006	2	0.023	10	0.239
25–35 mm	,80–,83 and ,2061–63	0.010	2	0.012	3	0.397
35–45 mm	,77–,79 and ,2058–60	0.005	1	0.004	1	0.365
45–55 mm	,74–,76 and ,2055–57	. . .	.	. . .	. . .	0.173

Agglutinate abundance here is calculated as a proportion of the coarse fraction of the top 5.5 cm, so that data from this dissection will be comparable to rake and scoop-soil data, presented in Heiken (1974). By comparing average agglutinate content of coarse and fine soils, it can be expected, on the basis of Lunar Soil Catalog data (Heiken, 1974), that there will be 40% as many agglutinates in the > 1 mm fraction as the 90–150 μm fraction used as the basis of original exposure age calculations (McKay *et al.* 1972). There are 1.3% agglutinates in the > 1 mm fraction of the bulk soil at the top of 74002. Using the Apollo 16 production rate of McKay and Heiken (1973, p. 42) of 1% per 2.5 m.y. (scaled to 1% per 6.25 m.y. for coarse fraction) gives an exposure estimate of 8 m.y. Using the production rate proposed by Goswami and Lal (1974, p. 285) of 1% per m.y. (scaled to 1% of coarse fraction/2.5 m.y.) gives an exposure age of 3 m.y. The second calculation is in agreement with the bulk soil agglutinate age of Goswami and Lal (1974, p. 2647). Either age is much less than the formation age of Shorty Crater.

Estimating rate of surface coverage by authigenic agglutinates uses an approach similar to that used in dating rock surfaces by micro-crater counts. In core dissection studies, all glass-soil particles over 1 mm are regarded as agglutinates, but glass-on-rock is classified as splash glass. Agglutinates are interpreted as being *in situ* and authigenic if they show a clean, dust-free upper surface and have unbroken edges. In cores, such agglutinates are

TABLE IIC

Estimated abundance of coarse components, as seen in dissection and photographs (all numbers are expressed in percent of total in 5 mm interval.)

Depth (mm) LCL Inventory	Dissection 1 rock fgms.	Dissection 1 orange clasts	Dissection 1 dark clasts	Dissection 1 matrix	Dissection 2 rock fgms.	Dissection 2 orange clasts	Dissection 2 dark clasts	Dissection 2 matrix	Dissection 3 rock fgms.	Dissection 3 orange clasts	Dissection 3 dark clasts	Dissection 3 matrix	Average rock fgms.	Average orange clasts	Average dark clasts	Average matrix
001–00	5	5	5	85									5	5	5	85
002–01	–	10	5	85									–	10	5	85
003–02	5	15	–	80									5	15	0	80
004–03	5	10	tr	85									5	10	tr	85
005–04	5	10	tr	85									5	10	tr	85
010–05	5	10	–	95	5	10	–	85	10	5	5	80	5	10	tr	85
015–10	5	10	10	90	5	5	5	85	10	5	5	80	5	5	5	85
020–15	5	10	10	75	5	15	5	75	5	35	–	60	5	20	5	70
025–20	5	15	10	70	5	20	5	70	10	25	5	60	5	20	5	65
030–25	5	10	–	85	5	20	10	65	5	10	5	80	5	15	5	75
035–30	–	–	–	100	5	5	5	85	10	5	10	75	5	5	5	85
040–35	–	–	–	100	–	10	–	90	5	15	–	80	tr	10	–	90
045–40	–	5	–	95	5	–	5	90	–	–	–	100	tr	tr	tr	95
050–45	–	20	–	80	5	–	–	95	–	–	–	100	tr	10	–	90
055–50	–	20	–	80	10	–	–	90	–	–	5	95	5	5	–	90
060–55	–	20	–	80	–	20	5	75	–	–	10	90	–	15	5	80
065–60	–	10	–	90	–	20	–	80	–	5	–	95	–	15	–	85
070–65	–	–	5	95	–	20	–	80	–	30	5	65	–	15	5	80
075–70	–	5	5	90	–	20	–	80	–	40	10	50	–	20	5	75
080–75	–	5	–	95	–	15	–	85	–	25	–	75	–	15	–	85
085–80	–	20	–	80	–	40	–	60	–	20	–	80	–	25	–	75
090–85	–	20	–	80	–	50	–	50	–	25	–	75	–	30	–	70
095–90	–	35	–	65	–	70	10	20	5	65	–	20	tr	60	5	35
100–95	–	50	–	50	–	80	10	10	tr	90	–	10	tr	70	5	25
105–00	–	65	–	35	–	90	10	–	–	80	10	10	–	80	5	15
110–05	–	90	10	–	–	95	5	–	–	80	20	–	–	90	10	–
115–10	–	95	5	–	–	95	5	–	–	100	–	–	–	95	5	–
120–15	–	80	20	–	–	85	15	–	–	100	–	–	–	90	10	–
125–20	–	85	15	–	–	65	35	–	–	100	–	–	–	85	15	–

TABLE IIC (*Continued*)

Depth (mm)	Dissection 1				Dissection 2				Dissection 3				Average			
LCL Inventory	rock fgms.	orange clasts	dark clasts	matrix	rock fgms.	orange clasts	dark clasts	matrix	rock fgms.	orange clasts	dark clasts	matrix	rock fgms.	orange clasts	dark clasts	matrix
130–25	–	75	25	–	–	20	–	80	–	85	15	–	–	60	10	30
135–30	–	60	–	40	–	10	–	90	–	80	20	–	–	50	5	45
140–35	–	10	–	90	–	–	–	100	–	65	35	–	–	20	10	70
145–40	–	–	–	100	–	–	–	100	–	65	10	25	–	20	5	75
150–45	–	–	–	100	–	–	–	100	–	50	–	50	–	15	tr	85

concentrated in well-defined zones as much as 2–3 cm thick. Assuming the agglutinaceous zone represents an exposure surface, the residence age of such a zone can be estimated by calculating surface area covered by authigenic agglutinates and relating area coverage to production. Unlike microcraters on rocks, agglutinates occur in zones rather than at exactly the same horizon presumably because of different conditions of impact of individual micrometeorites into the soft regolith surface. Errors and uncertainties are introduced because of areal saturation by long micrometeorite bombardment, by uncertainties in agglutinate production rate, and by uncertainties in relating agglutinate area to microcrater area. The coverage estimate used here is determined from the model in Hartung *et al.* (1973, p. 3221) in which class 1 micrometeorite (100 microgram particles, which produce approximately 4 mm spall and 1 mm glass pits in rock and are assumed for purposes of calculation to produce mm-sized agglutinates in soil) can cover 3% of the area of a surface in a million years. In 74002, the agglutinaceous zone extends from the lunar surface to 2.5 cm (Figure 2), although agglutinates are very common only above 1.5 cm. In the top 5 mm of the core, authigenic agglutinates covered 5.6% of the cross-sectional area of the core and between 5 mm and 2.5 cm, agglutinates covered another 3.7% of the core area. Total coverage was 9.3% and at a coverage rate of 3.5 m.y., the upper part of 74002 has a surface exposure time of 2.7 m.y. This age is comparable to bulk soil age similar to track ages of McDougall *et al.* (1974), and Goswami and Lal (1974) for nearby rocks and soils. As with total agglutinate content, the authigenic agglutinate age is much less than the age of Shorty Crater.

6. Mixing, Maturation and Proximity of Materials

Most of the detrital material in 74002 appears to be reworked, rather than admixed, because orange and black glass, similar to that in the lower part of the section, predominates in the matrix of the upper 10 cm. The coarse fraction of > 1 mm contains a maximum of 11% basalt fragments (Table II) with the other 89% being clasts of dark and orange soil. Coarse fractions of all other intervals contained even less basalt and more orange and black clasts. Such a low abundance of basalt and high percentage of orange and black material is consistent with a minimum of mixing and the material being largely derived from below.

Orange particles comprise approximately 70% of glassy fines above 10 cm in both grain mount (Table III) and as observed throughout the section during dissection (Table II, Figure 2). This composition seems to be an average of composition of material between 10 and 15 cm. Orange glass is less common at depths greater than 17 cm and incorporation of large amounts of such soil into the upper 10 cm would lower the concentration of orange glass in the matrix to well below 70%. Accordingly, much detrital soil in 74002 seems to be derived from an equivalent to the material from 10–15 cm, in other words, to very shallow reworking of the upper part of the orange zone.

The fact of minimum transport of admixed material can be determined by comparing core location (Muelberger *et al.*, 1973; pp. 6–51) to edge of orange-dark soil outcrop as

TABLE IIIA

Summary of grain mount data, upper part of 74002. Compositional summary for coarser size classes, grain mounts from drive tube 74002

Sample No.	Size Class	Orange Glass No. of Points	Orange Glass % of Total	Black "Glass" No. of Points	Black "Glass" % of Total	Mineralized Droplets No. of Points	Mineralized Droplets % of Total	Soil-Rich Particles No. of Points	Soil-Rich Particles % of Total	Total Points Counted
–,99	3	121	56	65	30	6	3	22	11	214
	4	128	45	87	31	61	17	19	7	284
	5	148	61	45	19	43	18	6	2	242
–,98	3	114	53	76	35	11	5	15	7	216
	4	109	47	56	24	62	26	6	3	233
	5	164	59	49	18	60	22	4	1	276
–,97	3	141	70	53	26	6	3	0	0	200
	4	159	67	48	20	30	13	0	0	236
	5	200	73	32	12	41	15	0	0	272
–,96	3	112	53	91	43	7	3	0	0	210
	4	114	35	122	38	87	27	0	0	322
	5	171	42	120	29	116	28	0	0	407
–,95	3	97	43	112	50	16	7	0	0	226
	4	105	37	94	33	83	30	0	0	282
	5	143	44	83	26	96	29	0	0	322

as seen in Lunar Surface Photos AS17-173-20990. The minimum distance of gray soils such as 74240 and 74260 is estimated to be 0.5 M. The amount of mixed material in grain mount –,99 from 2.5 cm, can be ascertained by comparing percentage of ropy glass in –,99 (0.5%) to that in 74240 and 74260 and estimating proportions admixed to obtain the quantity of ropy glass found in 74002. Using data of Fruland (1977, p. 339, Table I) in which 12 to 20% (depending on grain size) ropy glass was found in the gray soils, it is calculated that 2.4 to 3.6% of 74240 or 74260 could be mixed into 74002,99 to account for the 0.5% of ropy glass seen in that sample. Basalt also makes up < 1% of –,99, although it makes up 24–30% of gray soils found nearby (Heiken and McKay, 1974; p. 847). A maximum of 4% of gray soils could be admixed to produce the relative quantity of basalt fragments seen in –,99. Such an abundance of admixed material in the fines is similar to the 2% basalt found in the coarse fraction of the same interval and points to a low degree of mixing, even though the soils bearing the ropy glass and basalt are as little as 0.5 M away.

Although the soil at the top of the drive tube is mostly derived from below, it shows little evidence of *in situ* maturation. Criteria for maturation are derived from the model of McKay *et al.* (1974, p. 596). According to this mode, clast populations that are newly introduced into the regolith should contain a high proportion of particles in coarsest grain size classes. With increasing comminution and maturation comes a decrease in maximum size and more even distribution of grain size, until most particles are in finer size classes

TABLE IIIB

Summary of grain mount data, upper part of 74002. Morphological variations in orange and black particles, grain mounts from drive tube 74002

	Orange particles												
	Spherical Droplets				Ovoid Droplets				Indet.				
	Complete		Broken		Complete		Broken		Broken		Compound		Total
Sample No.	No. of Points	% of Points	No. of Points	% of Points	No. of Points	% of Points	No. of Points	% of Points	No. of Points	% of Points	No. of Points	% of Points	Points Counted
–,99	23	4.9	124	22.0	8	1.7	122	26.2	164	35.3	23	4.9	465
–,98	33	5.9	131	23.2	23	4.1	136	24.1	203	36.0	38	6.7	564
–,97	96	18.3	96	18.3	47	9.0	127	24.2	118	22.5	40	7.6	524
–,96	35	14.0	79	25.0	32	10.1	92	29.1	58	18.4	19	6.0	316
–,95	45	16.4	63	23.0	15	5.5	56	20.4	61	22.3	34	12.4	274
	Black particles												
							Compound Particles						
	Spheres		Ovoid Droplets		Broken, Equant		Spheres		Ovoid Particles				
–,99	9	5.0	4	2.0	41	20.0	68	34.0	78	39.0			200
–,98	6	6.0	4	4.0	16	16.0	28	28.0	48	47.0			102
–,97	9	5.0	6	3.0	44	21.0	54	25.0	92	45.0			205
–,96	11	5.0	12	6.0	46	22.0	58	26.0	87	42.0			214
–,95	14	7.0	10	5.0	43	21.0	59	28.0	76	37.0			202

TABLE IV

Calculations of Shorty Crater exposure ages

Sample	Investigator	Method	Age
		Older age values	
74220	Hintenberger *et al.* (1974) p. 2019	^{21}Ne	27 m.y.
74220	Hintenberger *et al.* (1974) p. 334	^{3}He, ^{21}Ne, ^{38}Ar	30 m.y.
74220	Eberhardt *et al.* (1974) p. 197	^{37}Ar/^{38}Ar	30 m.y.
74220	Kirsten *et al.* (1973) p. 596	^{38}Ar, ^{21}Ne	30 m.y.
74220	Fleischer *et al.* (1974) p. 377	solar, galactic tracks	4–7 m.y. and 20–35 m.y.
74001	Eberhardt *et al.* (1974) p. 197	^{21}Ne, ^{38}Ar	45 m.y.
74275	Eberhardt *et al.* (1974) p. 197	^{37}Ar/^{38}Ar	25 m.y.
		Newer age values	
74275	Fechtig *et al.* (1974) p. 222	microcrater counts	0.1–1 m.y.
74275	Goswami and Lal (1974) p. 2646	solar flare tracks	2.8 m.y.
74220	MacDougall *et al.* (1974) p. 482	galactic tracks	2.5 m.y.
74220	Goswami and Lal (1974) p. 2655	petrographic agglutinates	3 m.y.
74220	Hutcheon *et al.* (1974) p. 2597	galactic tracks	9.1–13.6 m.y.
74261	Goswami and Lal (1974) p. 2649	solar flare tracks	~ 2 m.y.

(and agglutination balances comminution). Size histograms are used to provide a judgment of soil maturity; data from 74002 are presented in table V, Figure 3. In the histograms used for comparison, fresh, unreworked ejecta from Meteor Crater, Arizona, and Odessa Crater, Texas, have the greatest proportion of grains in the coarsest size fraction. Lunar soils 14141 and 73241 classified as immature by McKay *et al.* (1974, p. 899) and dated at 8–15 m.y. and 20 m.y. respectively by Crozaz *et al.* (1974), p. 2494) are also relatively coarse grained. Finer more mature soils are represented by an average of Apollo 16 North Ray Crater soils 67460, 67480 and 67600, 67700 and 67940, all of which have similar size distributions and are dated at 50 m.y. (Crozaz *et al.*, 1973); and an average of two soils from Apollo 17 Camelot Crater, 75060 and 75080, dated at 65–85 m.y. (Goswami and Lal, 1974; p. 2655).

In 74002 all clast populations of orange soil, mare basalts, and agglutinates show a size distribution comparable to that of undegraded Odessa or Meteor Crater ejecta and size distribution of bulk soil from 0–5.5 cm (lumped to be comparable to lunar soil samples

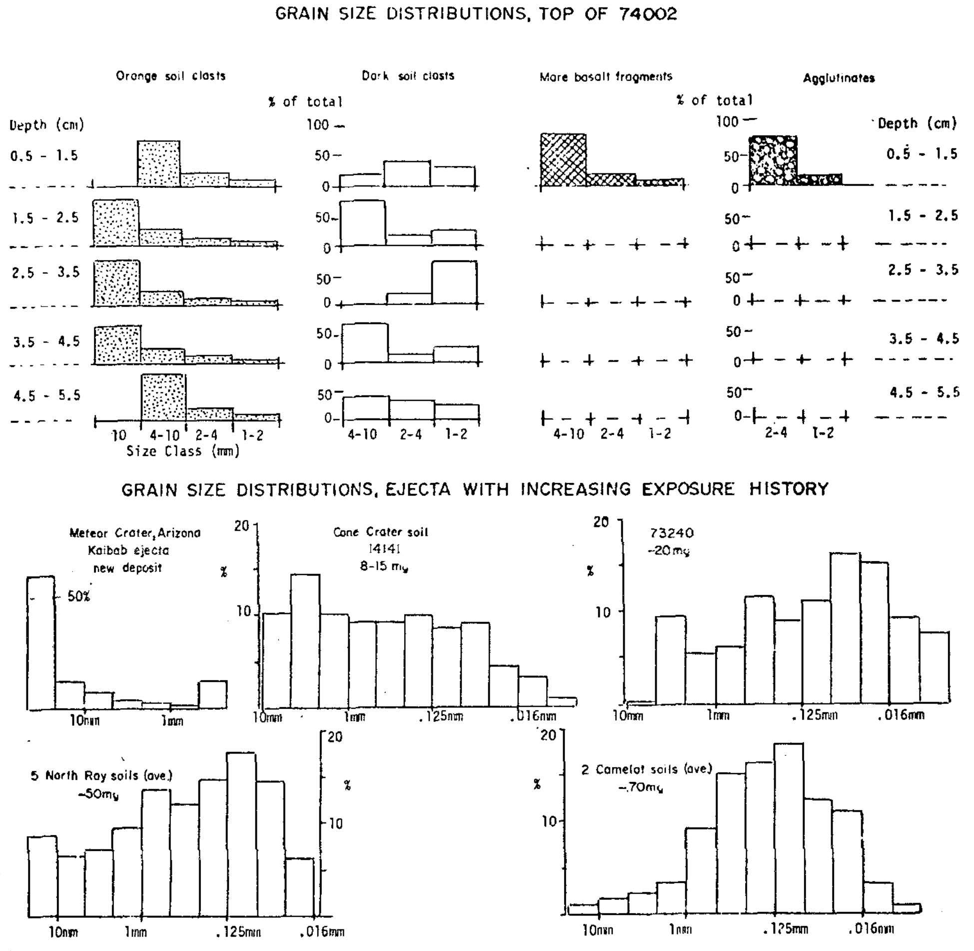


Fig. 3. Comparison of grain size distributions in 74002 to grain size distributions in ejecta with increasing exposure history.

collected with the scoop or rake) is similar to the youngest lunar soil such as 14141 than to those exposed 50 m.y. (Figure 3). Furthermore, there is no upward trend to evenness in size distribution, nor is there a progressive upward decrease in grain size. Dissection photos such as S-77-28179 show 5 mm orange clasts occur right up to the lunar surface. The only possible indication of the maturation process is the slight decrease in maximum size in friable clasts, of orange and dark soil, at the very top of the section between 0.5 and 1.5 cm. Although there are not enough immature and submature lunar samples to quantify rate of depletion of coarsest fractions, a simple comparison of size distributions indicates that the detrital zones do not show *in situ* maturation commensurate with a 30 m.y. surface residence. Not only is soil age much less than crater age, but maturation is less, as well.

TABLE V

Size distribution of major clast types recovered during seiving of upper 5.5 mm of 74002

Size Class Dissection Interval (mm)	Clasts of semi-cohesive orange soil									Semi-cohesive clasts of dark soil						
	over 10 mm		10–4 mm		4–2 mm		2–1 mm			10–4 mm		4–2 mm		2–1 mm		
	Wt.	%	Wt.	%	Wt.	%	Wt.	%	Sum	Wt.	%	Wt.	%	Wt.	%	Sum
015–05	...	...	0.839	69	0.245	20	0.130	11	1.214	0.061	21	0.138	47	0.093	32	0.292
025–15	2.911	72	0.986	24	0.045	1	0.093	2	4.035	0.483	72	0.071	11	0.117	17	0.671
035–25	5.334	73	1.456	20	0.257	4	0.243	3	7.290	...	...	0.052	28	0.132	72	0.184
045–35	2.178	65	0.894	26	0.190	6	0.118	3	3.380	0.520	61	0.101	12	0.238	28	0.859
055–45	...	...	0.366	81	0.064	14	0.018	4	0.448	0.235	41	0.189	33	0.153	26	0.577
	Agglutinates									Mare Basalt Fragments						
005–04	...	...	...	...	0.038	80	0.009	20	0.047							
015–05										0.444	86	0.050	10	0.020	4	0.514

7. Summary – a Model for Origin of the Detrital Zone

Evidence indicates that much of the detrital zone above 10 cm could be related to the impact event that produced a field of perched boulders near the sampling site (Figure 1). Occurrence of the 20M-wide boulder field, 10–15M from the sampling site, is documented in Lunar Surface Photos AS17-137-21007-21009, where it can be seen that most boulders near the sampling site, as well as those in the boulder field are perched and unfilleted (AS17-137-20990) whereas most others on the rim of Shorty Crater are filleted (see AS17-137-21012, for example) if not semi-buried. Large rock 76055 is streamlined away from the boulder field. The perched and unfilleted aspect of the boulders is evidence of a fairly recent disturbance, most likely an impact. Although a well-defined crater is not present, there is a noticeable shallowing of the Shorty Crater rim profile at the boulder field and there is a boulder train extending down the steep crater wall to a concentration of boulders at the break in slope at the crater floor (AS17-137-29097-29099). This information from the lunar surface photographs suggests that there was an impact on the steep part of the crater rim. Because the rim was already at repose, the impact was accompanied by slumping, rather than development of the usual bowl-shaped crater.

Strata and structures in the upper part of 74002 are of the type and in the size range expected at a distance of 15–20M from a 20M crater (assuming the 20M boulder field is approximately equivalent to a 20M crater). Strata show evidence of the overtuning commonly associated with impact structures as described in Gault *et al.* (1968, p. 185). From 10–5.5 cm there is a progressive decrease in orange clasts, and droplets in the matrix are most abundant from 7–5.5 cm (Figure 2); these trends are reversed from 5.5 to 1.5 cm. There is a horizontal fabric above 5.5 cm; that is, clasts between 5.5 cm and the lunar surface show horizontal alignment. Such alignment requires gravity-influenced deposition such as would be found in an ejecta blanket.

The equation used by McGetchin, Settle and Head (1973, p. 226) predicts 5.0 cm of ejecta of 1 diameter from a 20M lunar crater; this is in approximate agreement with the 5.5 cm of soil being ejected from the 20M boulder. Vertically disrupted strata have been found more than 1 crater diameter from 20–40M experimental craters (Jones, 1976); such disruption could account for the vertical alignment of structures between 5.5 and 10 cm, if they are related to the 20M boulder bed event.

The homogeneous matrix fines could be shallowly derived from the orange soil zone closer to the 20M crater or they could be homogenized surficial reworked material, newer than Shorty and older than the boulder field. Further studies are needed to differentiate between these (or other) possibilities.

The top 1.5 cm show some decrease in grain size and contain the main concentration of agglutinates in the core, thus showing indications of surface reworking. The inferred depth of reworking is in keeping with the model predictions of Gault (1973) and Arnold (1974) that give approximately a 50% probability of 1–1.5 cm or reworking in 3 to 4 m.y., the inferred age of the detrital deposit.

The scenario proposed herein to account for the observed strata in the upper part of

74002. First, the Shorty event excavated buried orange soil and deposited it on the rim of Shorty Crater, approximately 30 m.y. ago (Kirsten *et al.*, 1973). Discrete M-sized domains of different colored soil indicate material was deposited as megaclasts on the rim of Shorty Crater. At a much newer data, approximately 2.5–3.0 m.y. ago, the surface of the orange clast was stripped off by the event that produced a 20M boulder field near the crater, and a thin ejecta layer was then deposited. This ejecta consisted mostly of locally-reworked material. Reworking and agglutination of the uppermost 1.5 cm appears to be the principal process affecting the soil since the boulder field event.

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