DRAFT

60009 - 60010

Double Drive Tube

ALSEP Site

Introduction

This core is said to be one of the 'best studied' from the moon (Papike et al. 1982). It was collected as a double drive tube about 60 cm long and one of three collected from the Apollo 16 ALSEP site (fige 1). It was from the rim of a small (50-60 cm) shallow crater. 60009 is the lower segment, 60010 the upper. This drive tube was studied in detail instead of the deep drill, because it was less disturbed and 4 cm in diameter compared with only 2 cm for the drill core. However, it was found that "few, if any, of the modal variations in 60010/9 are stratigraphically correlatable" with the deep-drill 60001 - 60006 collected only 50 meters away (Simon et al. 1978). The same was true for a comparison with 60014 – 60013 (Korotev and Morris 1993).

Using tracks, Blanford et al. (1977) identified a buried soil boundary and profile about 50-52 cm down. It was exposed for ~6 x 10^6 years before the upper portion of the cores was deposited. This unit is coarse-grained and feldspathic (see below).

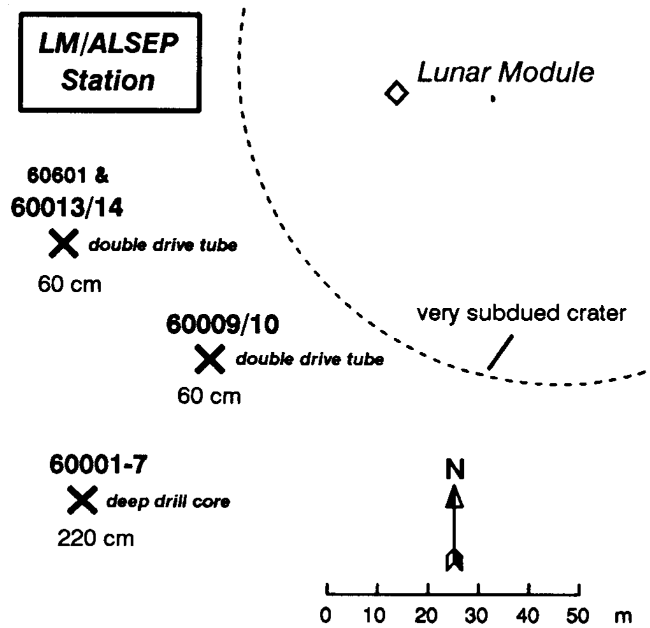


Figure 1: Map of ALSEP site at Apollo 16 (from Korotev 1991).

The upper 12.5 cm of the core has undergone *in situ* maturation and reworking which occurred after the original mixing and deposition (Morris 1978, Papike et al. 1982). It is more mature than the rest of the core. There is also something special about the very bottom of the core.

Fruland et al. (1982) performed a complete review of all the data, although the critical detailed chemical data wasn't available until 1991.

Petrography

The description of the double drive tube based on X-radiographs (Horz et al. 1972) and on initial description during dissection (Nagle et al. 1976) already indicated that there was a lot of variability in lithology of this core. Fruland et al. (1982) provide a complete description based on observations during disection.

Morris and Gose (1976), Housley et al. (1976) and Morris (1978) present the maturity as a function of depth in the double drive tube 600010/9 and found that the top 12.5 cm was higher maturity than the rest of the core, which they attribute to modern *in situ* reworking (gardening).

McKay et al. (1976, 1977) determined the grain size analysis and the petrological mode (Table 1), but didn't find as many agglutinates as would be indicated by the maturity index. Simon et al. (1978) also reported the mode based on a study of thin sections (see Table 2 for summary) and Vaniman et al. (1978) reported compositional data for minerals, glasses and rock fragments.

Fruland et al. (1982) provide the following description of the feldspathic unit starting at 50 cm depth, based on observations during dissection. *"Between 50 and 54 cm is the unit with the coarsest grain size in 60009/10, and one of the coarsest units in any lunar core. The matrix is relatively light-colored, and appears to consist of very irregularly-shaped two-centimeter-diameter areas of light and dark soil. These areas appear to be equidimensional,*

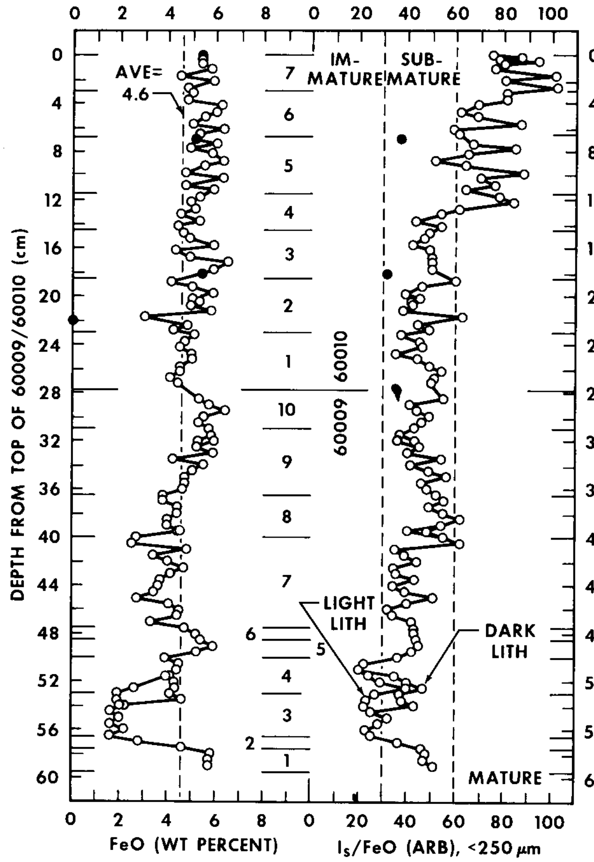


Figure 2: Maturity Index for 60010/9 double drive tube (from Morris and Gose 1976).

but with interfingering, crenulate margins. The most distinctive characteristic of the interval is the concentration of rock fragments, which make up over 75% of the mass of the unit, and are so abundant that they form a packed, framework texture. This unit can be described as a gravel deposit with interstitial soil. Most of the rock fragments readily shed dust, and are tough, grey, fine-grained crystalline rocks. White (plagioclase) crystals also occur and are up to one cm in diameter."

Vaniman et al. (1978) also reported several (9) small fragments of mare basalt.

McKay et al. (1976), Gose and Morris (1976) and Goswami et al. (1976) noted at "sharp discontinuity" in petrologic character, maturity and track density near the bottom of the core (~59 cm).

Papike et al. (1982) found that there was essential agreement among the various measures of maturity and that "these sample show a wide range of maturity", "explained by mixing mature and more mature 'end-members' soils; with three petrographic end-members required".

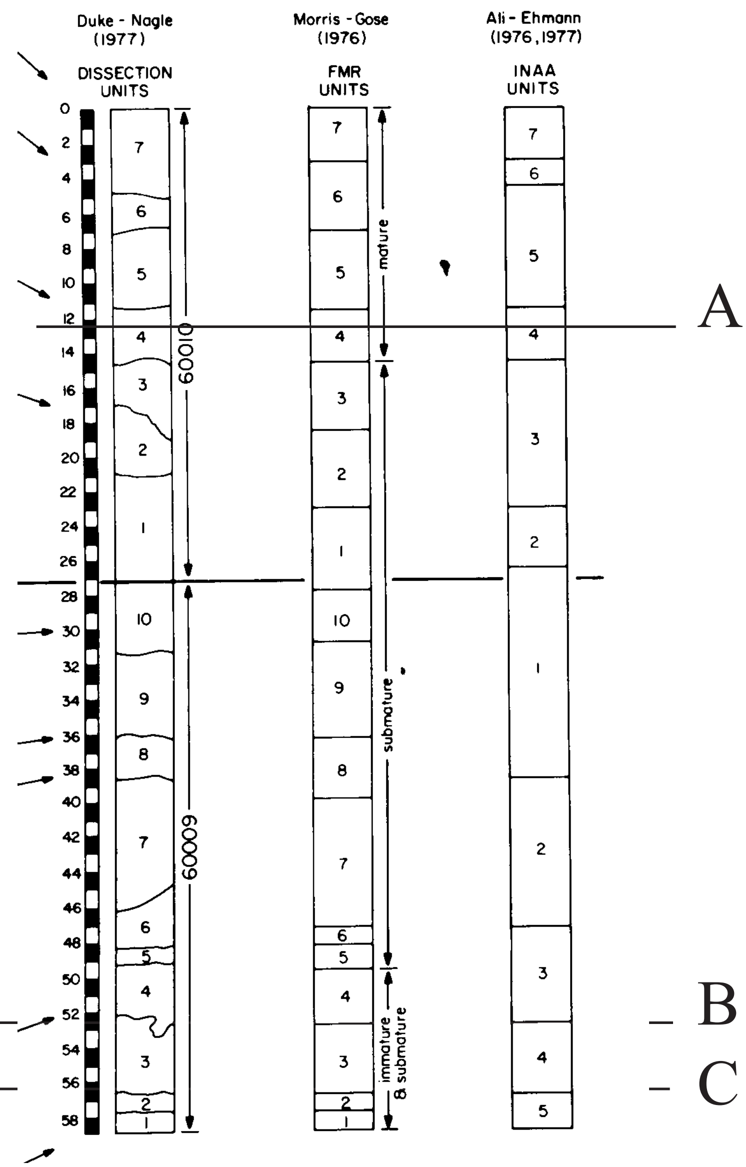


Figure 3: Comparison of units recognized in 60010/9 by various workers. A at about 12.5 cm is the bottom of the mature zone, B - C is the plagioclase-rich zone (modified from Vaniman et al. 1978).

Chemistry

Korotev (1991) has an appendix that gives a lot of data (every 0.5 cm). He finds that "*the 60009/10 core shows greater compositional variation with depth than any other lunar core*". In particular, *"the soil at 54 cm depth in 60009 is the most feldspathic yet found among Apollo 16 regolith samples; no other Apollo 16 soil is comparably poor in Sc and other elements associated with mafic mineral phases."* This same unit was also identified by Ali and Ehmann (1977). However, the

Table 1: Petrographic mode for 60010 - 60009.
from McKay et al. 1976, 1977

%	60010 (all 90 - 150 micron)						60009 (all 90 - 150 micron)				
depth cm	0.5	4	11	14	20	25					
crushed ANT-suite	3	3.7	3.8	6.3	5.6	4.5	1.5	7.2	2.7	4.2	2.1
light matrix breccia	0.1	0.5	1.6	1.2	0.6	1.7	0.8	3.8	1.7	0.8	3.6
metamorphosed breccia	5.6	6.5	5.4	8.3	10.6	7	12	10	13.8	5	9.3
poikilitic rocks	16.3	11.7	15.6	14.7	23.3	12.5	13.2	4	10.3	4.4	10.1
subophitic melt rocks	0.7	0.5	0.2	0.7	1.4	0.7		0.8	1.2		1.4
olivine porphy meta.		0.3							0.2		0.1
mare basalt									0.3		
brown matrix breccia	7.6	11.2	13.2	6.3	7.9	10.5	7.1	8.5	7.3	1	13.1
felds melt rock		0.3	0.4	0.2	1.4	0.3	3.4	0.8	1.2	1.2	1.4
mesostasis melt rock	1.9	3.7	1	2.2	2.7	2.5	1.5	0.7	2.3	1.4	1.4
plagioclase	15	11.9	20.2	32	17.5	38.2	26.6	47	25	76.2	19.6
pyroxene	1.4	0.8	1.8	4.2	5.1	1.8	0.8	0.7	2.5	1.4	0.1
olivine	0.4	0.3		1	0.6	0.8	3	1.5	0.8	0.6	0.3
opaques		0.3			0.6	0.3	0.4	0.2	0.2	0.2	0.6
yellow-orange glass	0.1	1.3	0.4	0.7	0.4	0.5	1.5	0.3	1.3		1.1
colorless glass	4.4	2.7	4	2.5	5	1.7		0.7			
quench recrys. glass	5.4	5.7	5.6	1.7	5.9	3.3	3.4	0.3	2.5	0.4	2.4
agglutinate glass							3	0.8	1.5	0.4	2

Table 2: Petrographic mode for 60010/9.
summary from Simon et al. 1978 (thin sections)

%	upper soil	coarse-grained base
DMB and agglutinate	12.1	5.8
RNB and poik	8.2	6.1
ANT and LMB	4.9	8.6
Feld. basalt	0.6	0.9
plagioclase	17.9	27
pyroxene, olivine	1	1.2
glasses	1.2	0.5
large clasts	17.8	21.9
small clasts	25.5	28.4
matrix	56.7	49.7

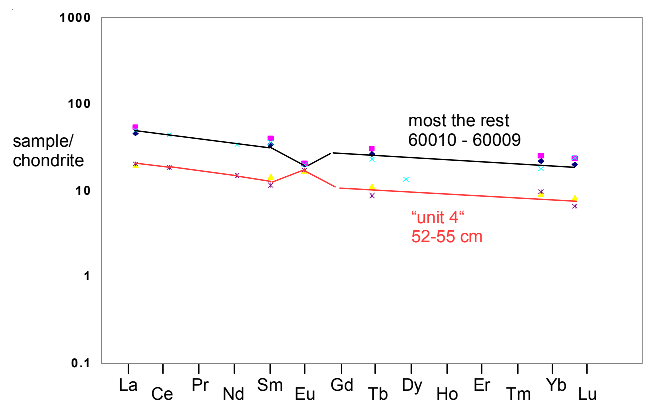


Figure 5: Normalized rare-earth-element content of 60010 - 60009.

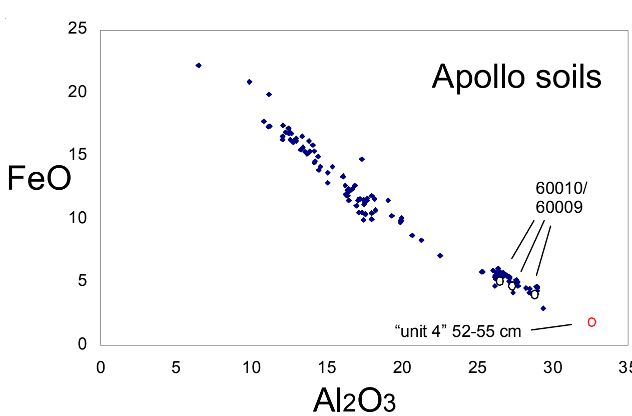


Figure 4: Chemical composition of 60010/9 including "unit 4".

white soil at 52-55 cm does not contain as much Ir as the other soils (unit 4, table).

Blanchard et al. (1976, 1977) determined the chemical composition of various size and magnetic separates of the core (Tables 4 and 5). They found a rare-earth-element-rich layer at about 20 cm. They also found the fine fraction and the magnetic fraction were enriched in trace elements compared with the bulk samples (similar result to Papike et al. 1982).

Cosmogenic isotopes and exposure ages

Fruchter et al. (1977, 1978, 1979) and Nishiizumi et al. (1979) determined the solar and cosmic ray induced activity of ^{22}Na, ^{26}Al and ^{53}Mn (figures 6 and 7). At

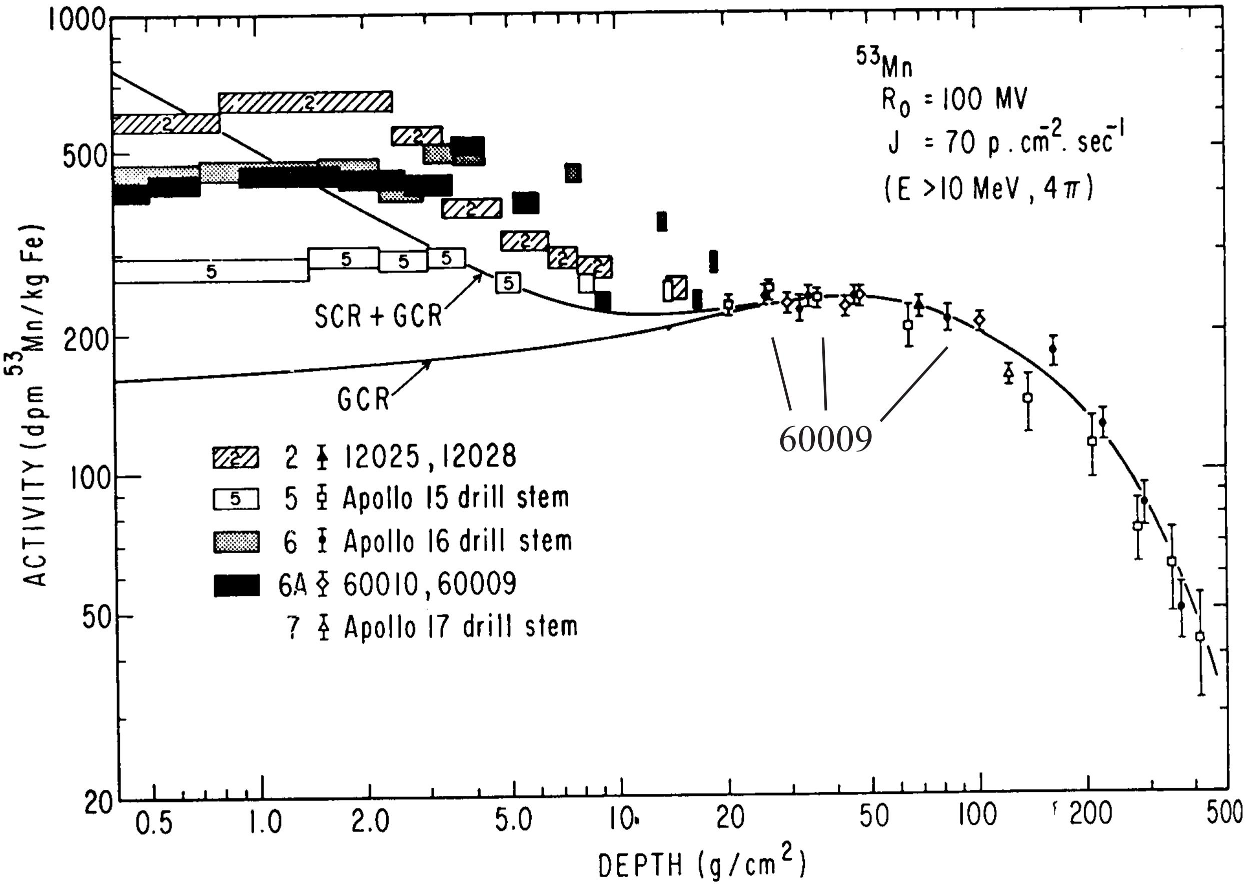


Figure 6: 53Mn activity in lunar cores including 60010 - 60009 along with theoretical curves using Reedy-Arnold mode. (from Nishiizumi et al. 1979).

the top of the core the data does not fall on the theoretical curve, hence the top has recently been disturbed by cratering or gardening within the past 10 m.y. Evans et al. (1980) use this data to calculate a regolith accumulation rate of 1-2 cm/m.y.

Bogard and Hirsch (1976, 1977) studied the noble gas evidence for a complex depositional and irradiational history of the core, requiring addition of pre-irradiated material. ^{4}He and ^{36}Ar were found to be closely coordinated with maturity. They found that the bottom of the core was deposited in the last 125 m.y.

Other Studies

Banerjee et al. (1977) have studied the remanent magnetization stratigraphy along the length of epoxy encapsulated sections of the core 60010/9.

Goswami et al. (1976), Crozaz and Dust (1977) and Blanford et al. (1977, 1979) studied the cosmic and solar ray tracks in crystals from the core (figures 8, 9 and 10). McKay et al. (1977) and Blanford et al. (1979)

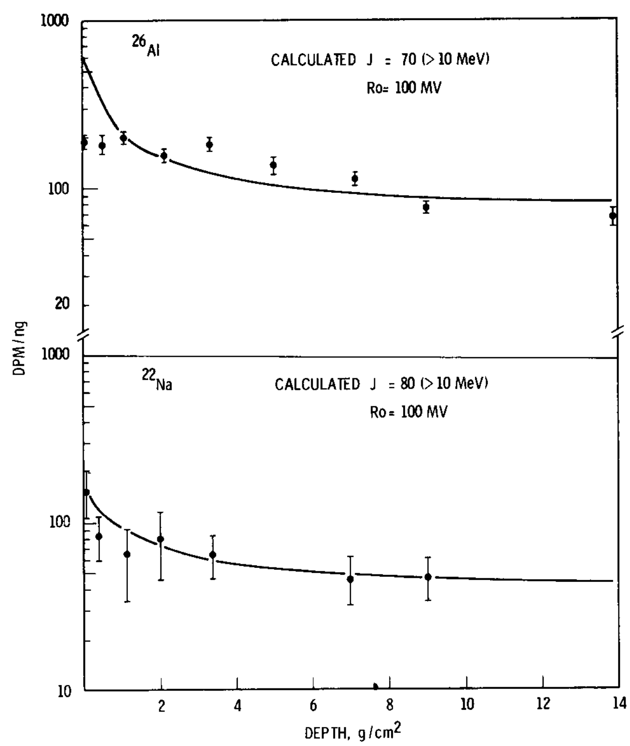


Figure 7: Activity of 22Na and 26Al in top portion of 60010 (from Fruchter et al. 1977).

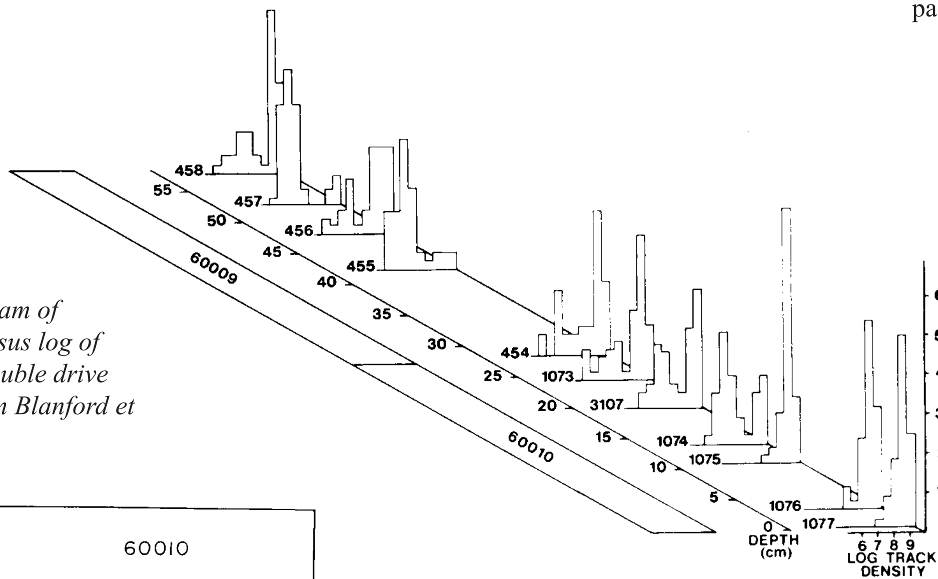
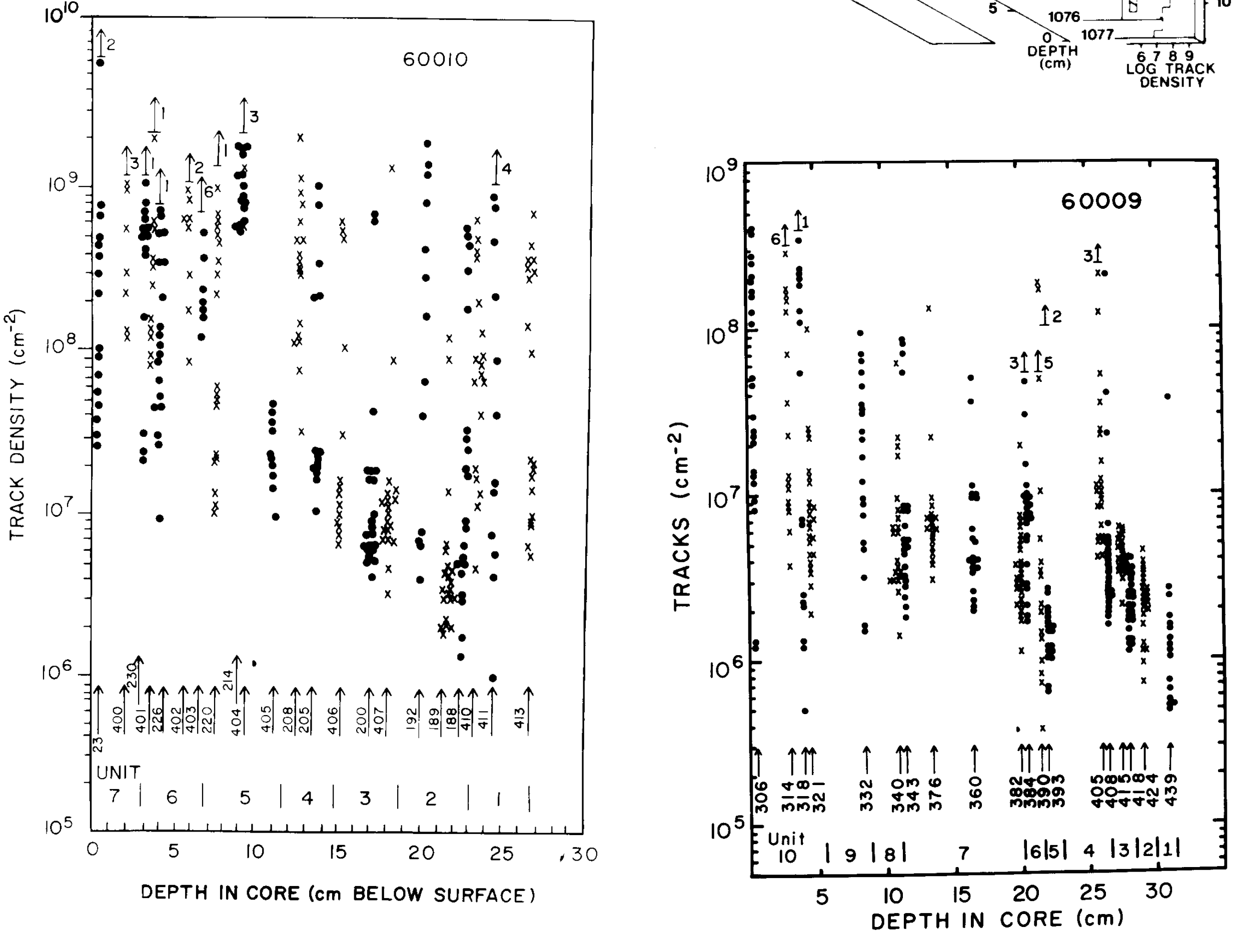


Figure 8: Histogram of percent grains versus log of track density in double drive tube 6009/10 (from Blanford et al. 1977).



Figures 9a,b: Track densities in individual feldspar grains from 60010 and 60009 (from Crozaz and Dust 1977).

concluded that the top 50 cm of this core was formed in a single depositional event with reworking the top 12 cm. However, Crozaz and Dust (1977) showed that there were numerous small layers and favor instead a slow accretion rate (0.4 cm/m.y.) with small slabs with accretion rates up to 1.3 cm/m.y.

Processing

When this core was X-rayed it was about 69 cm in length, but was compressed during extrusion to about 60 cm. Complete sets of thin section were made for this core, and an epoxy encapsulated reference core is available.

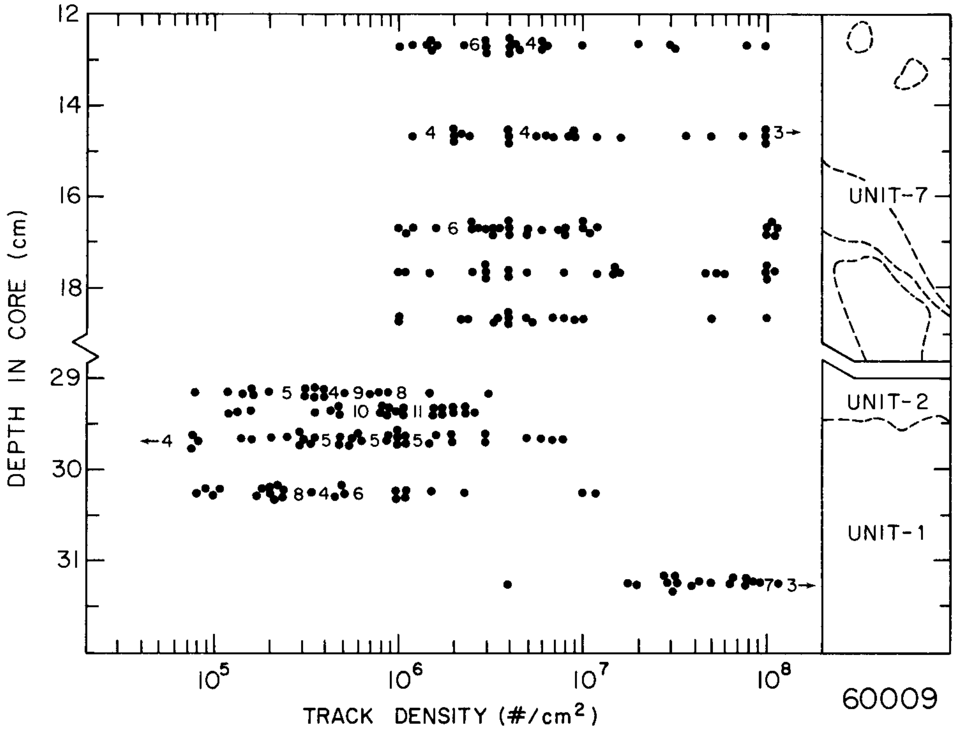


Figure 10: Track densities for selected samples from 60009 - 60010 (from Goswami et al. 1976).

Table 3. Chemical composition of 60009/10.

		60010	60009		60009					60010	
reference	Korotev91				Ali + Ehmann76					Ali + Ehmann77	
weight	ave.	ave	ave		unit 1	unit 2	unit 3	unit 4	unit 5	ave9	
SiO2 %	both	top13 cm	52-55cm		46.4	45.8	45.4	44.3	48.1	46.1	(a)
TiO2					0.63	0.5	0.63	0.4	0.7	0.61	(a)
Al2O3					27.8	29.5	28.1	33.4	26.8	28	(a)
FeO	4.61	5.36	2.23	(a)	4.64	3.8	4.36	2.13	5.4	5.23	(a)
MnO					0.076	0.06	0.071	0.04	0.09	0.081	(a)
MgO					7.11	5.93	6.95	3.95	7.5	5.95	(a)
CaO	16.1	15.4	18.1	(a)	16.2	17.4	17.5	18.2	15.5	16.6	(a)
Na2O	0.448	0.455	0.4	(a)	0.42	0.42	0.42	0.41	0.45	0.418	(a)
K2O					0.11	0.066	0.11	0.042	0.15	0.105	(a)
P2O5											
S %											
sum											
Sc ppm	7.82	9.34	3.54	(a)	7.24	5.93	6.72	3.04	8.6	8.36	(a)
V					23.8	23	22	12	38	24.2	(a)
Cr	639	761	281	(a)	770	480	740	260	930	804	(a)
Co	26.5	30.7	10.5	(a)	23.4	19.4	19.9	8.74	27.1	36	(a)
Ni	394	457	141	(a)						536	(a)
Cu											
Zn											
Ga	note: there is a lot more data in these pubs than can be repeated here.										
Ge ppb											
As											
Se											
Rb											
Sr											
Y											
Zr											
Nb											
Mo											
Ru											
Rh											
Pd ppb											
Ag ppb											
Cd ppb											
In ppb											
Sn ppb											
Sb ppb											
Te ppb											
Cs ppm											
Ba	118	139	52	(a)	133	156	101	60	124	134	(a)
La	10.8	12.7	4.6	(a)	12.2	11.3	10.8	4.8	13.8	11.6	(a)
Ce					30.3	26.8	27.6	11.3	40.2	26.6	(a)
Pr											
Nd					22.7	12.8	21	6.8	28.6	15.6	(a)
Sm	5.01	5.9	2.13	(a)	4.5	4	4.2	1.7	5.5	5.3	(a)
Eu	1.12	1.17	0.95	(a)	1.12	1.18	1.18	0.97	1.24	1.12	(a)
Gd											
Tb	0.96	1.11	0.4	(a)	0.84	0.74	0.73	0.32	1	0.83	(a)
Dy										3.3	(a)
Ho											
Er											
Tm											
Yb	3.54	4.15	1.48	(a)	3.75	3.34	3.21	1.59	4.27	2.92	(a)
Lu	0.485	0.575	0.2	(a)	0.42	0.4	0.37	0.16	0.5	0.59	(a)
Hf	3.82	4.48	1.54	(a)	2.65	2.9	2.5	0.96	2.33	3.6	(a)
Ta	0.43	0.51	0.19	(a)	0.61	0.5	0.46	0.17	0.6	0.5	(a)
W ppb											
Re ppb											
Os ppb											
Ir ppb	12.3	15	3.4	(a)							
Pt ppb											
Au ppb	7.2	8	2.6	(a)							
Th ppm	1.86	2.25	0.76	(a)	1.72	1.23	1.46	0.6	2.4	1.14	(a)
U ppm	0.46	0.53	0.19	(a)							

technique: (a) INAA

Table 4. Chemical composition of 60010 (Blanchard 1977).

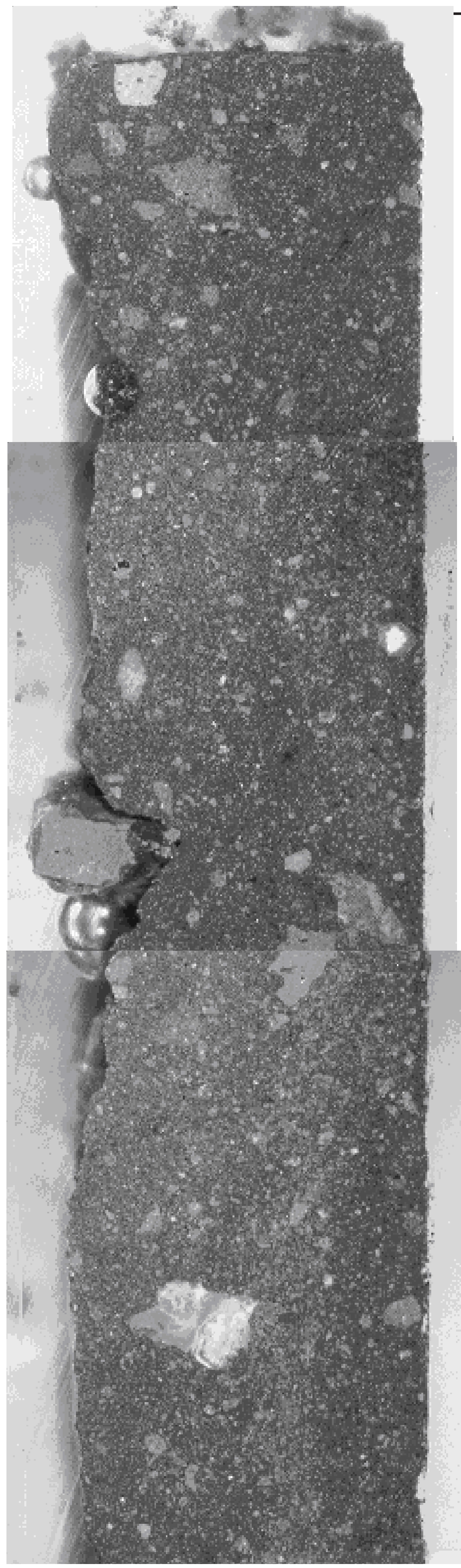
Is/FeO	90			92			67			47			26			53		
size	bulk	90-150	<20	bulk	90-150	<20	bulk	90-150	<20	bulk	90-150	<20	bulk	90-150	<20	bulk	90-150	<20
depth	0.5-1.0			3.5-4.0			11-11.5			14-14.5			20-20.5			24.5-25		
SiO2 %																		
TiO2		*note: this data is hidden in a place where no one can find it !*																
Al2O3																		
FeO	5.27	5.27	5.25	5.4	5.91	5.35	6.1	5.41	5.3	5	4.77	5.34	6.4	5.65	5.45	4.47	4.01	4.66
MnO																		
MgO																		
CaO																		
Na2O	0.47	0.47	0.47	0.47	0.47	0.46	0.46	0.48	0.46	0.48	0.45	0.49	0.51	0.5	0.51	0.45	0.46	0.46
K2O																		
P2O5																		
S %																		
sum																		
Sc ppm	9.3	9.1	9.2	9.4	9.5	9.3	9.4	9.4	9.2	8.7	7.9	8.9	13.2	10.5	10.1	7.9	6.7	8.2
V																		
Cr	840	830	930	860	800	990	800	930	890	830	660	940	970	890	1170	650	560	730
Co	23.5	29.2	23.2	29.2	44.8	24.4	61	29.5	25.1	20.6	22.1	26	26.3	33.6	20.7	18.9	20.8	21.3
Ni	320	410	410	410	650	530	970	530	2190	260	270	420	340	470	460	270	370	1280
Cu																		
Zn																		
Ga																		
Ge ppb																		
As																		
Se																		
Rb																		
Sr																		
Y																		
Zr																		
Nb																		
Mo																		
Ru																		
Rh																		
Pd ppb																		
Ag ppb																		
Cd ppb																		
In ppb																		
Sn ppb																		
Sb ppb																		
Te ppb																		
Cs ppm																		
Ba																		
La	12.1	12.1	13.3	13.6	12.1	13.1	12	11.7	12.9	12.3	9.5	12.6	17.2	13.5	18.4	10.3	10.2	12
Ce	32.9	33.1	34.6	36.2	32.4	35	31.7	30.6	33.2	32.7	26.8	33.7	46.3	36.1	48	28.3	25.9	31.8
Pr																		
Nd																		
Sm	5.9	5.9	6.2	6.5	5.8	6.1	5.7	5.6	6	5.8	4.6	5.9	8.5	6.6	8.7	4.9	4.3	5.7
Eu	1.16	1.16	1.17	1.17	1.16	1.15	1.13	1.15	1.13	1.09	1.07	1.12	1.28	1.2	1.27	1.1	1.02	1.1
Gd																		
Tb	1.26	1.3	1.39	1.46	1.27	1.25	1.32	1.27	1.24	1.17	0.95	1.2	1.84	1.5	1.94	1.14	0.95	1.19
Dy																		
Ho																		
Er																		
Tm																		
Yb	4.4	4.3	4.3	4.6	4.4	4.5	4.3	4.2	4.1	4.4	3.4	4.2	6.6	4.9	5.5	3.6	3.1	3.9
Lu	0.62	0.61	0.63	0.65	0.61	0.62	0.6	0.59	0.59	0.59	0.46	0.56	0.91	0.7	0.81	0.51	0.43	0.52
Hf	4.2	4.3	4.4	4.6	4.4	4.4	4.6	4.5	5	4.2	3.7	4.3	7.2	4.7	6	3.7	3.1	4.8
Ta	0.63	0.62	0.62	0.66	0.73	0.69	0.53	0.63	0.59	0.57	0.43	0.54	0.91	0.73	0.83	0.57	0.38	0.51
W ppb																		
Re ppb																		
Os ppb																		
Ir ppb																		
Pt ppb																		
Au ppb																		
Th ppm	1.9	2.1	2	2.3	2.2	2.2	1.9	2	2	2.1	1.7	2.1	3.1	2.3	3	1.8	1.4	2
U ppm																		

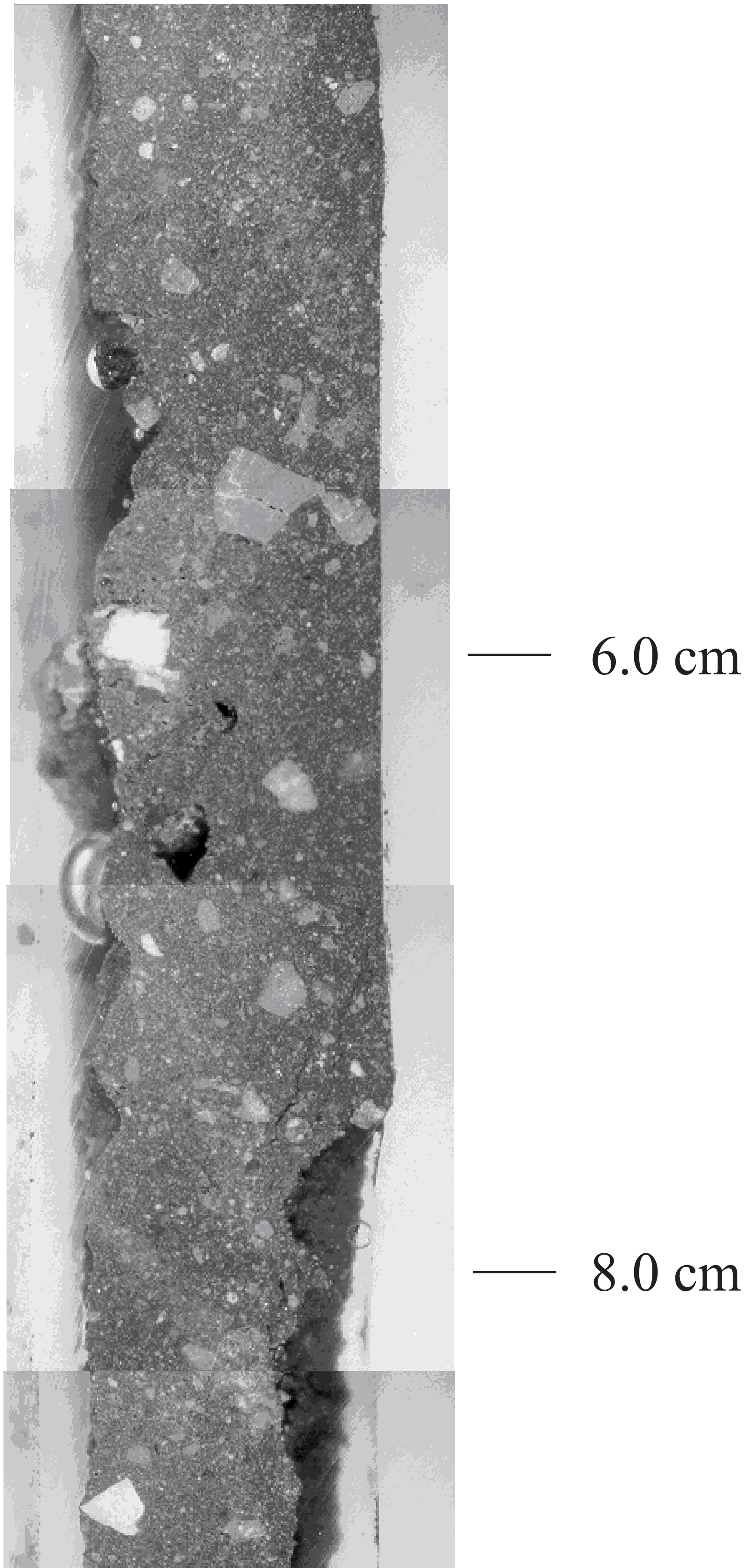
technique: (a) INAA

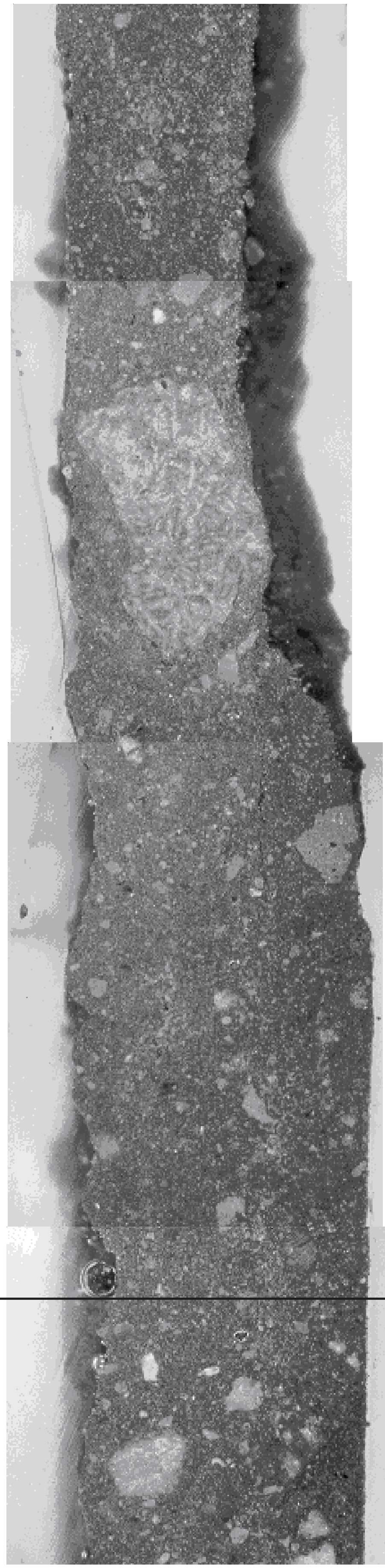
Table 5. Chemical composition of 60009 (Blanchard 1976).

sample	454			455			456			457			458		
size	bulk	90-150	<20	bulk	90-150	<20	bulk	90-150	<20	bulk	90-150	<20	bulk	90-150	<20
SiO2 %															
TiO2															
Al2O3															
FeO	5.17	4.56	5.13	3.54	3.34	4.66	5.06	5.19	5.2	1.99	1.58	2.64	5.2	5.95	5.7
MnO															
MgO															
CaO															
Na2O	0.52	0.49	0.7	0.41	0.42	0.44	0.49	0.48	0.5	0.42	0.41	0.44	0.5	0.5	0.53
K2O															
P2O5															
S %															
sum															
Sc ppm	8.3	8.1	8.8	5.6	5.5	7.7	9.4	9.7	9.2	3.24	2.6	4.38	9.56	10.2	9.8
V															
Cr	740	660	880	470	430	740	770	800	850	270	190	420	760	820	890
Co	32	18.8	24	14	14.4	16.9	19	23.3	22	6.8	4.7	10.6	22	37.5	27.7
Ni	450	240	420	200	170	250	220	290	360	90	50	180	280	500	460
Cu															
Zn															
Ga															
Ge ppb															
As															
Se															
Rb															
Sr															
Y															
Zr															
Nb															
Mo															
Ru															
Rh															
Pd ppb															
Ag ppb															
Cd ppb															
In ppb															
Sn ppb															
Sb ppb															
Te ppb															
Cs ppm															
Ba															
La	13.4	10.7	13.6	7.1	6.2	9.8	12.8	11.6	13.7	4.08	2.94	6.16	12.7	12.3	14.7
Ce	34.5	28.5	35.5	18.4	16.5	25.4	33.2	31.4	35.8	11	7.6	17.6	35.2	32.4	40.3
Pr															
Nd															
Sm	6.1	5.1	6.3	3.16	2.83	4.21	6.1	5.6	6.3	1.85	1.39	2.71	5.8	5.7	6.9
Eu	1.19	1.12	1.22	0.94	0.95	1	1.16	1.18	1.17	0.92	0.9	0.98	1.19	1.18	1.25
Gd															
Tb	1.59	1.35	1.64	0.62	0.49	0.78	1.08	1.06	1.16	0.31	0.25	0.48	1.07	1.32	1.18
Dy															
Ho															
Er															
Tm															
Yb	4.5	3.8	4.5	2.3	2.1	3.2	4.5	4.4	4.5	1.39	1.2	2	4.4	4.7	4.5
Lu	0.59	0.52	0.6	0.31	0.29	0.43	0.63	0.6	0.61	0.19	0.17	0.27	0.59	0.64	0.66
Hf	4.9	3.8	4.6	2.4	2.1	3.2	4.5	4.6	4.6	1.4	3.7	2	4.7	6.2	4.8
Ta	0.66	0.55	0.66	0.36	0.29	0.47	0.49	0.48	0.58	0.15	0.13	0.24	0.6	0.65	0.74
W ppb															
Re ppb															
Os ppb															
Ir ppb															
Pt ppb															
Au ppb															
Th ppm	2	1.5	2.3	1.1	0.9	1.4	2.3	1.9	2.2	0.54	0.4	0.83	1.9	1.8	2.6
U ppm															

technique: (a) INAA


top
0.5 cm
60010,6006
epoxy
encapsulated
core
2.0 cm
4.0 cm

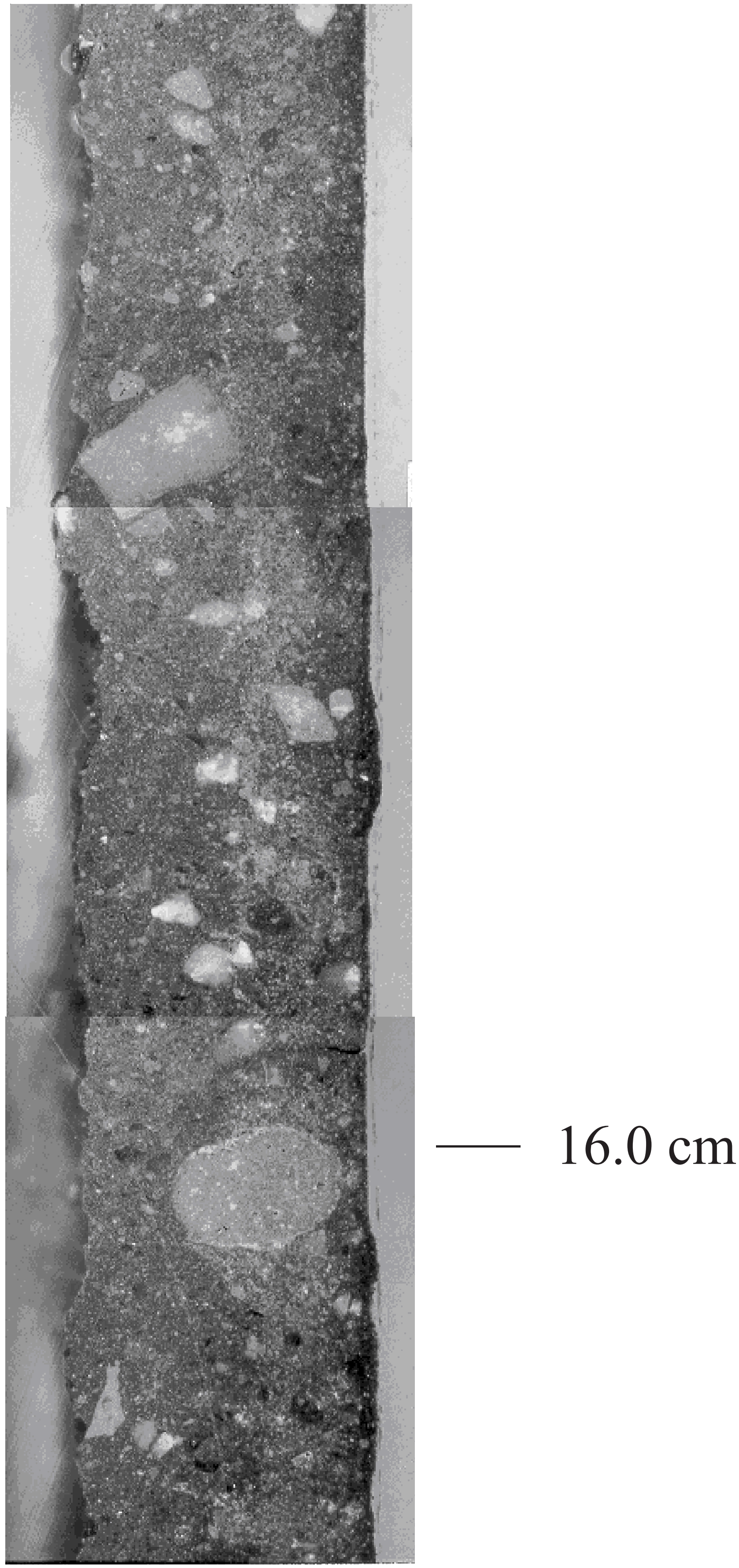

6.0 cm
8.0 cm



11.0 cm

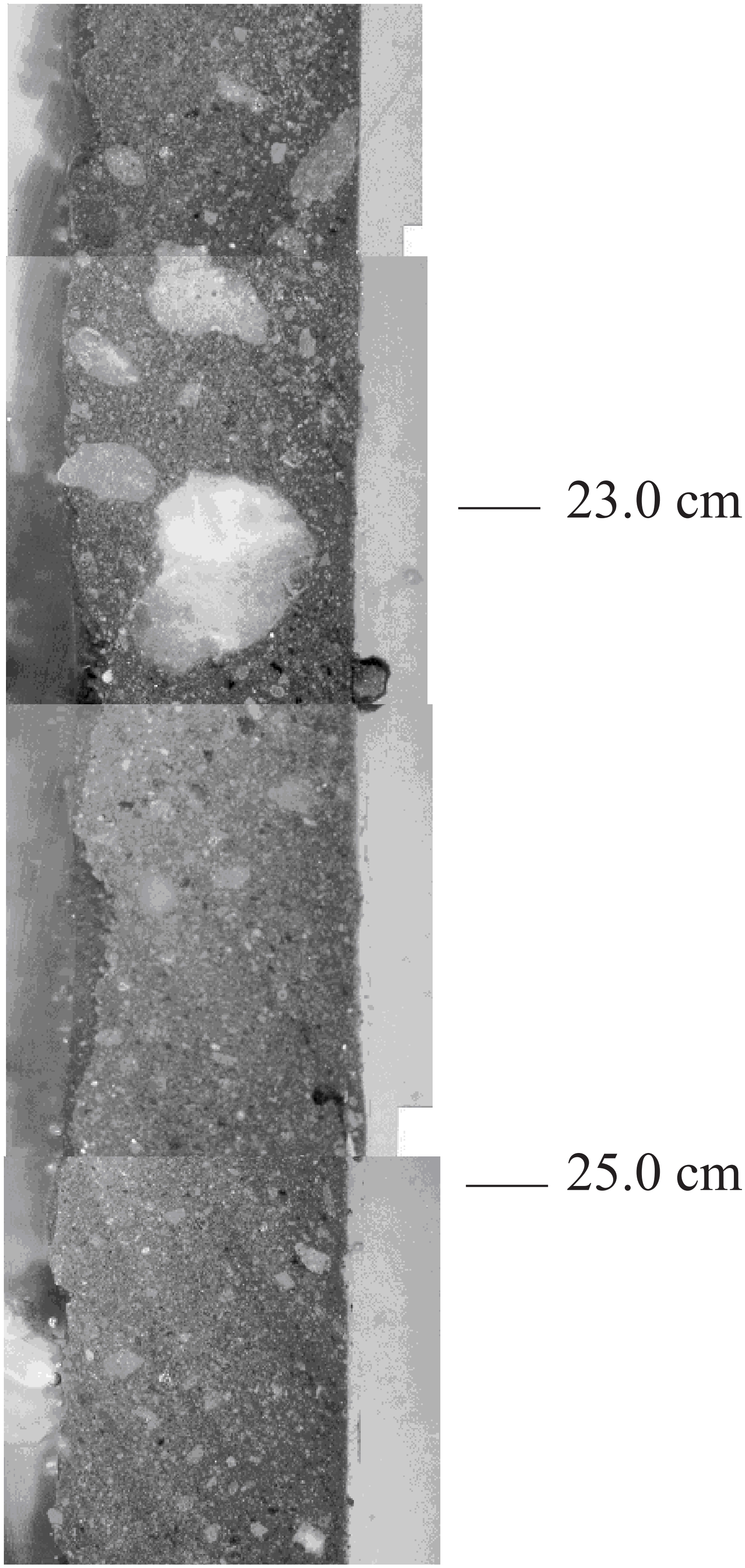
~ bottom of high maturity zone

13.0 cm

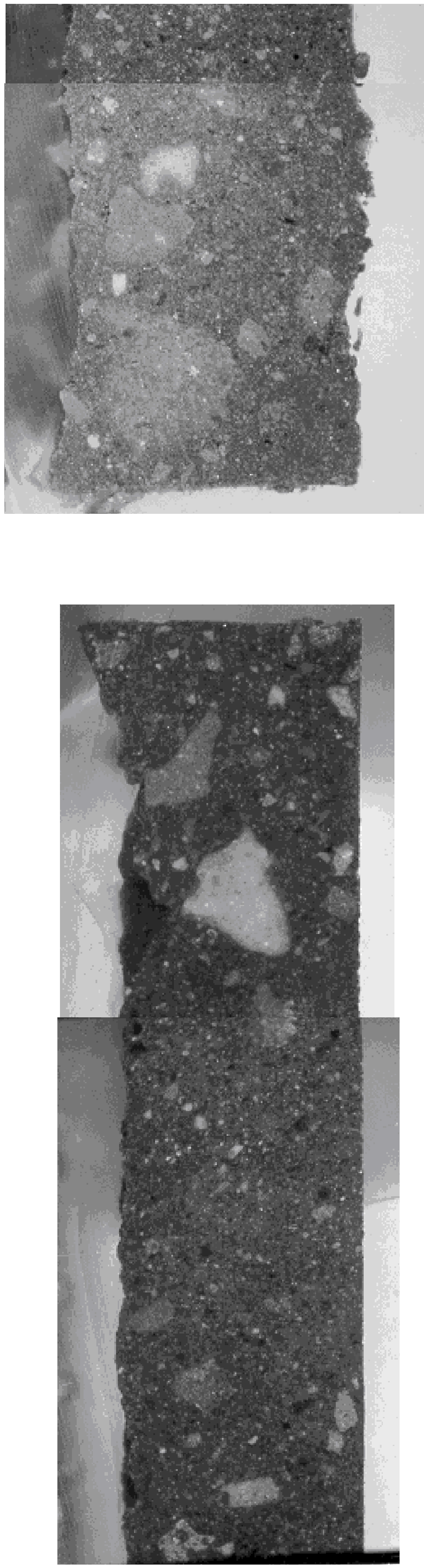


16.0 cm

22.0 cm



23.0 cm
25.0 cm

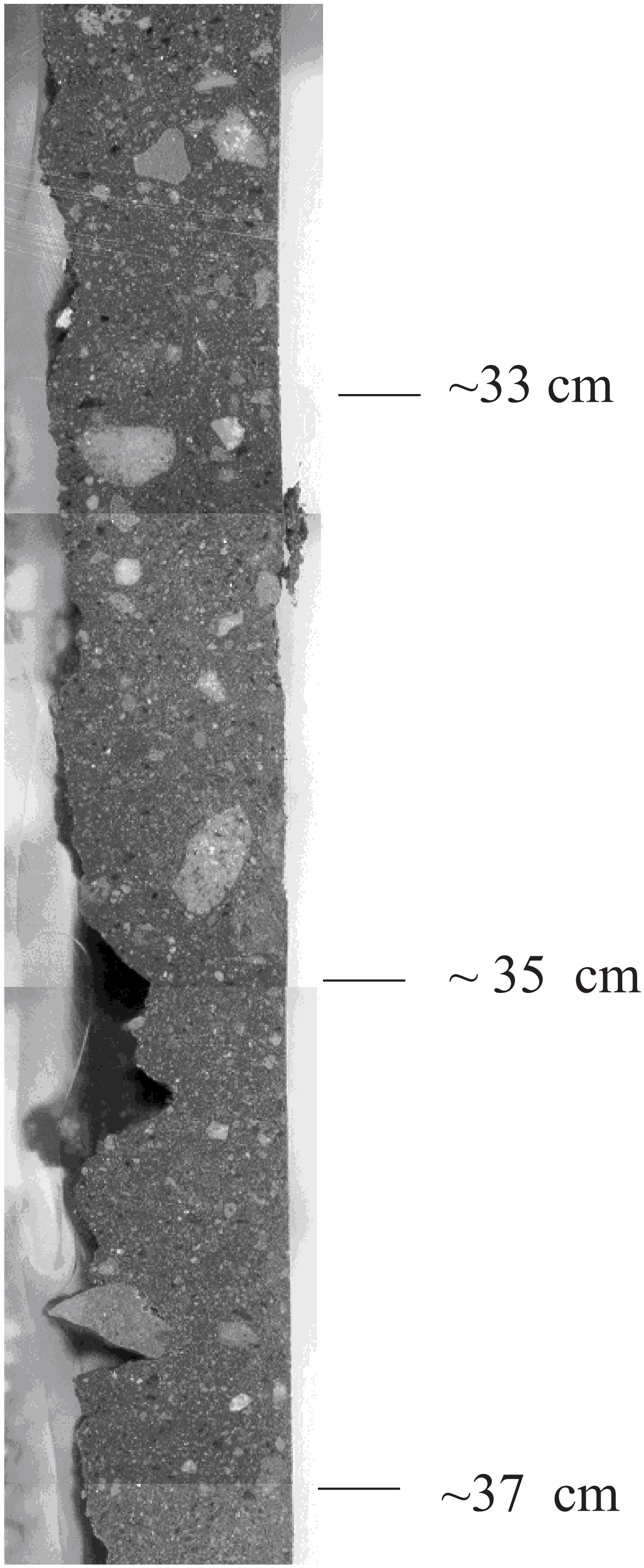


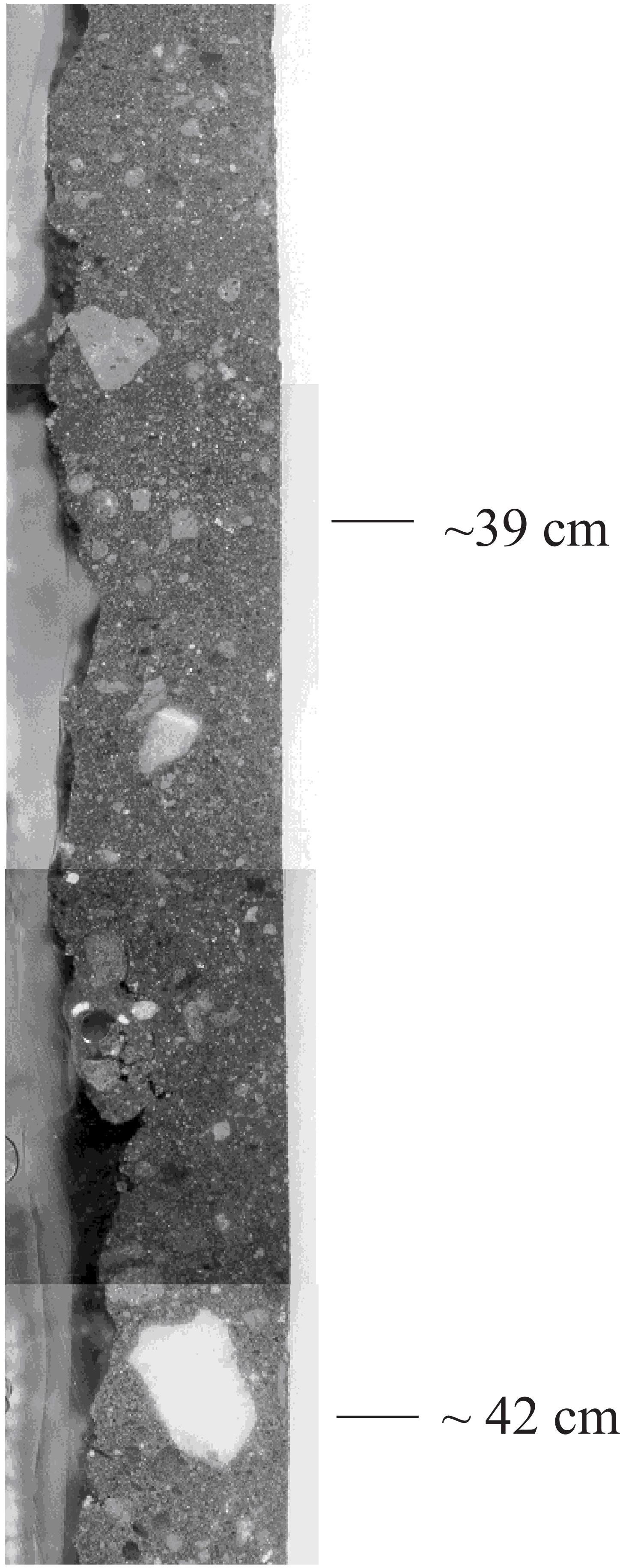
27.0 cm

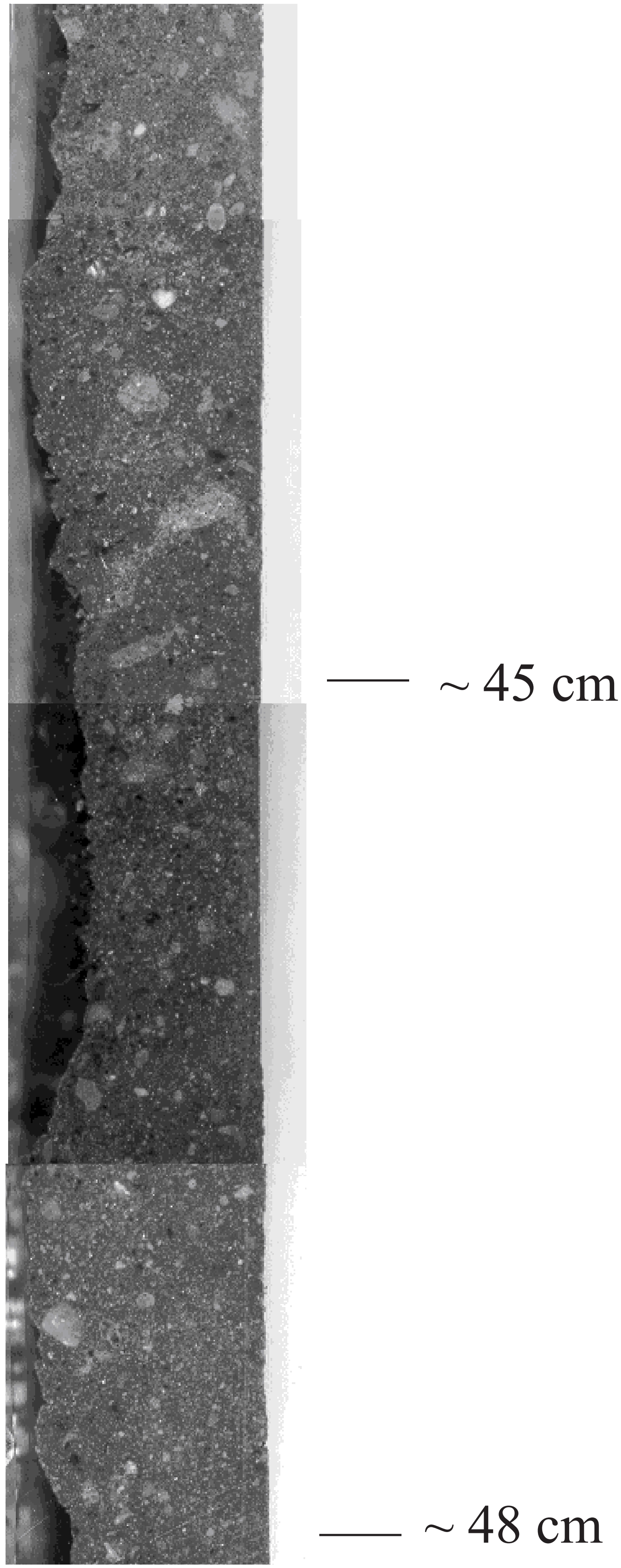
60010,6006
bottom

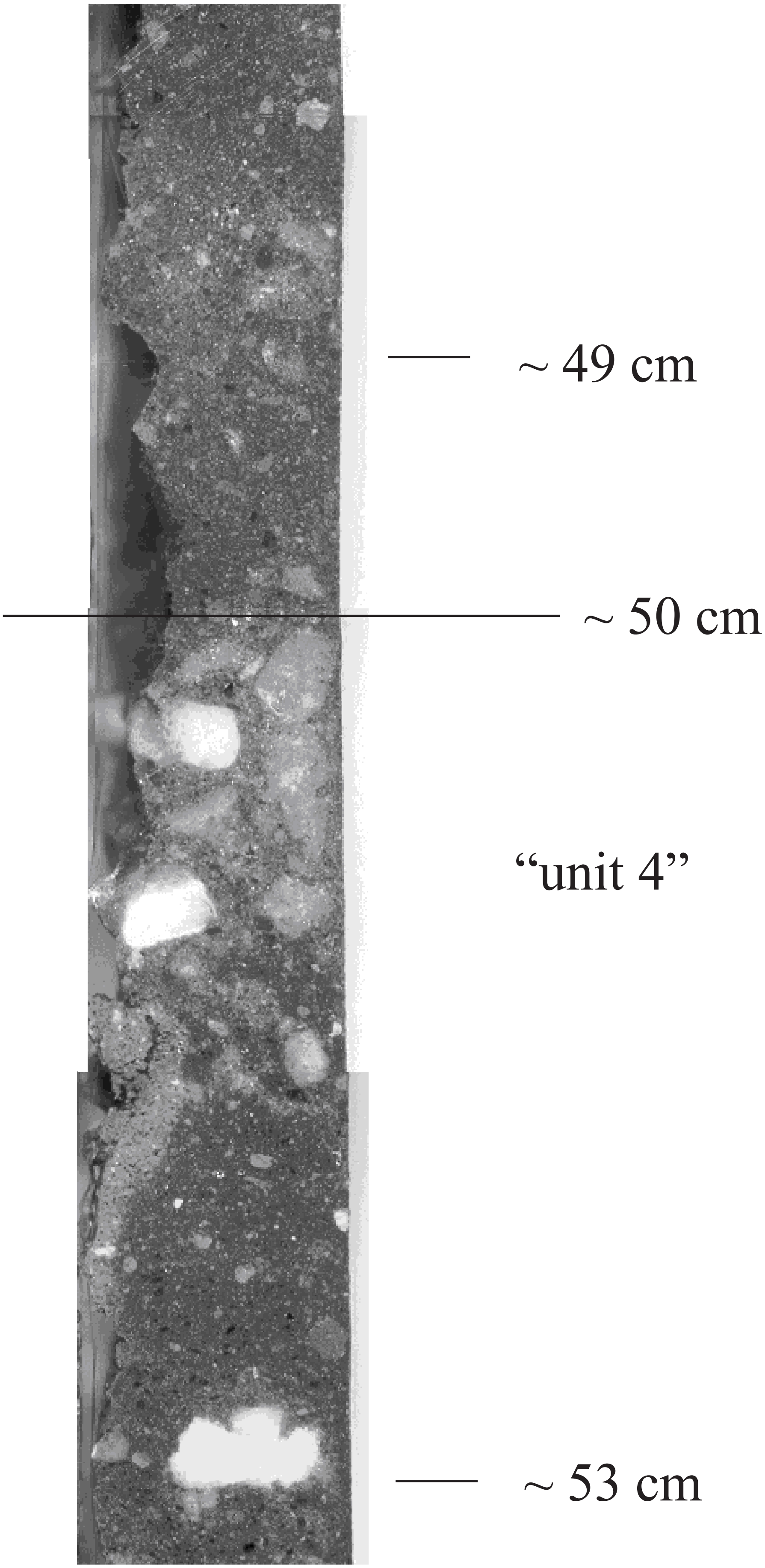
~28
60009,6006
top

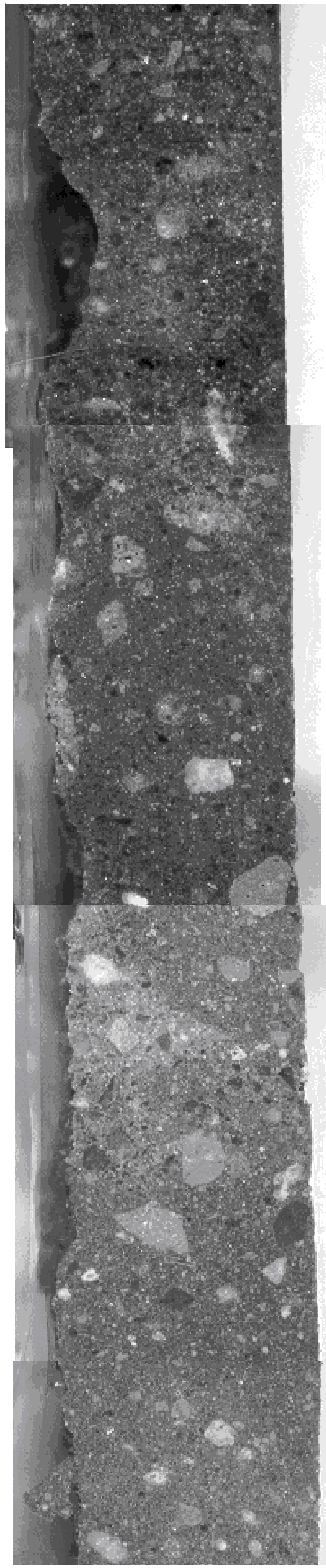
~30 cm


~33 cm
~ 35 cm
~37 cm


~39 cm
~ 42 cm


~ 45 cm
~ 48 cm

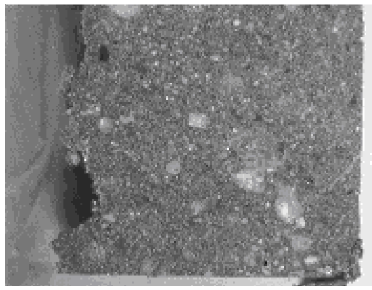

~ 49 cm
~ 50 cm
"unit 4"
~ 53 cm



~ 54 cm

~ 56 cm

~ 59 cm



— ~ 60 cm

60009,6006
bottom

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