

Reassessment of the Paleoenvironment and Preservation of Hominid Fossils From Hadar, Ethiopia

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ABSTRACT Samples of paleosols from locality AL-333, known for numerous specimens of *Australopithecus afarensis*, were analyzed in order to reconstruct the original soils and environment of burial of the associated fossil hominids. The bones were found in swale-like features, within the calcareous and coarse-grained basal portion of a paleosol. This is more like an assemblage of bones buried during a single depositional episode, such as a flood, than an assemblage accumulated on a soil over a long period of time by carnivores or other means of death. What killed the hominids remains unclear, but considering the association of originally disarticulated bones of such hydraulically distinct types as phalanges and maxillae, it is very likely that they died and partially rotted at or very near this site. The paleosols at AL-333, here named the Fo and Go clay paleosols, have calcareous rhizoconcretions, granular surface horizons, prismatic peds, and shallow calcareous nodules and stringers like soils now supporting grassy woodland in semiarid regions. Although this group of hominids was buried in streamside gallery woodland, there is evidence from Laetoli, Tanzania, that *A. afarensis* ventured out into open wooded grassland as well. Evidence for this should be sought from other paleosols at Hadar.

Paleoanthropologists are usually constrained by the incomplete nature of the fossil record to identify specimens by their morphology alone. Thus, a morphological species concept is used, as historically used in the Linnaean binomial system, even though extant species may be defined *biologically* (Mayr, 1982). Other species concepts that usually are applied to the fossil record are variations on this theme (Radosevich, in preparation). Situations where one can apply the biological species concept to the fossil record are very rare. Thus, the hypothesis posed by Johanson in 1976 that such a site may have been discovered at Hadar presents an exciting possibility: the sampling of a group of truly contemporary hominids, possibly close to or at the separation of robust from gracile lineages or clades. Because there are many opinions, based on the evi-

dence of morphology alone (cf. Boaz, 1988; Delson, 1985), as to where the hominids of AL-333 fit into the overall picture of human evolution, we have investigated whether this assemblage was deposited attritionally or catastrophically, based on geological evidence.

The fossil locality AL-333, 4 km northwest of the junction of the Kada Hadar and Awash River in the Afar region of Ethiopia (Fig. 1), contains the most prolific known concentration of early fossil hominids, some 3.2 million years old (Brown, 1982; Sarna-Wojcicki et al., 1985). Remains of at least 13 individuals, including two juveniles and two infants, have been recovered. This hominid accumulation is stratigraphically near the top of the

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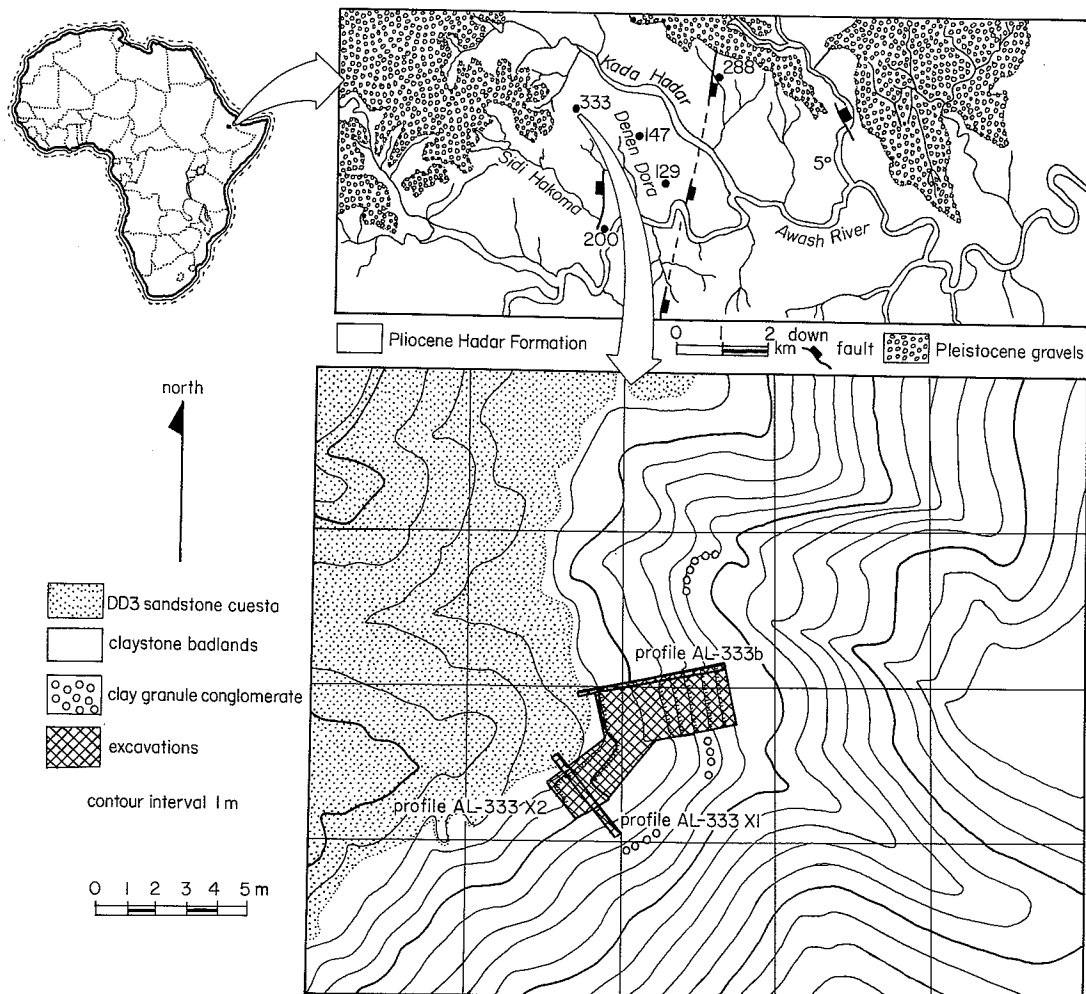


Fig. 1. Geological map of the area around Hadar Localities AL-333 (for "first family") and AL-288 ("Lucy") and site plans for AL-333 excavation, Ethiopia.

Denen Dora Member, below the DD3 Sandstone of Aronson and Taieb (1981). Eighteen fossils were found in place and come from a narrow (20 cm thick) horizon over a lateral distance of about 4 m in a paleontological excavation into the badlands slope (Johanson et al., 1982). These individuals represent some of the earliest demonstrable hominids known. This general area is also well known for a partial skeleton of a fossil hominid, nicknamed "Lucy" (AL-288), but these remains were found washed out of a sandstone paleochannel. This former stream could have carried the carcass of "Lucy" some distance from her original habitat (Aronson and

Taieb, 1981; Gray, 1980). In contrast, our reassessment of locality AL-333 shows that the fossils are preserved within paleosols (fossil soils) that may yield clues to the kind of paleoenvironment in which they died. This view of locality AL-333 has consequences for both the taxonomy and ecology of the fossil hominids.

The fossils have been referred to a single species, *Australopithecus afarensis*, owing to evidence of considerable sexual dimorphism and an interpretation that they may have been catastrophically entombed in flood deposits (Johanson et al., 1982). The true contemporaneity and designation of species in

the fossil assemblage has been controversial (Aronson and Taieb, 1981; Gray, 1980; cf. Olson versus Senut and Tardieu, in Delson, 1985). This problem can be reassessed from the nature and location of the bones within the entombing soils. Are the bones from the parent material or upper profile of the paleosols?

A second problem concerns the locomotory lifestyle of these early hominids. They were clearly habitual bipeds and yet show curved fingers and toe bones similar to those of apes that regularly spend time in trees (Susman et al. in Delson, 1985). Associated fossil mammals and pollen in this general stratigraphic interval are evidence of dry savanna, probably with thicket and gallery woodland (Gray, 1980; Bonnefille et al., 1987). A reassessment of this paleoenvironment and of where in the mosaic the hominids were preserved also can be gained from a study of the paleosols.

MATERIALS AND METHODS

Original field observations and excavation were undertaken (by M. Taieb) in December 1975 as part of the International Afar Research Expedition. Interpretation of the paleosols (by S. Radosevich and G. Retallack) was based mainly on site plans, photographs, and oriented specimens received from M. Taieb. The paleosol samples analyzed were taken within the excavated area (AL-333X1, Fig. 1). Petrographic thin sections were made of each specimen, in order to determine the proportion of sand, silt, and clay and the variation in mineral assemblages within the profile (Tables 1, 2). The specimens also were analyzed for major and trace elements, using instrumental neutron activation analysis (INAA) and atomic absorption spectrometry (AAS), and for organic carbon using the Walkley-Black technique (Tables 3, 4).

SEDIMENTS AND PALEOSOLS AT HADAR

The brown siltstones at site AL-333 have been regarded as a flood deposit, and this may be their depositional origin, considering that there are paleochannel sandstones elsewhere in the sequence. However, there is also evidence for appreciable soil formation at five separate stratigraphic levels within the excavation at this site (Fig. 2). The surfaces of the paleosols contain numerous fossil root traces, some of which are encrusted

with calcium carbonate. These tubular features emanate from erosional planes which are interpreted as ancient land surfaces. The erosional planes are especially indicated by overlying sandy claystones and, in some cases, thin clay granule conglomerates, as well as local swale-like erosional scours. Below these erosional planes there is a gradational change of texture, color, and structure that is characteristic of soil horizons. The surface (A) horizon of each of the paleosols has a granular ped structure defined by clay skins (Fig. 3), as is usual in some kinds of soil surface horizons (mollic epipedons of Soil Survey Staff, 1975). This soil structure, together with the observed pattern of fossil root traces, is evidence against extensive surficial erosion of the paleosols. The subsurface horizon (Bn) in most of the paleosols is clayey with clay-lined medium-sized prismatic peds running through most of the thickness of the horizon. Below this in some of the paleosols is a horizon (Bk) of caliche (Figs. 4, 5). Other paleosols, particularly those high and low in the excavation, lack these differentiated subsurface horizons (Bn and Bk) and consist instead of brown sandy claystone, with relict bedding.

Two distinctly different kinds of paleosols were seen in the excavation, and named from field designations given by M. Taieb. "Go" Series paleosols have thick (60 cm) profiles with well-developed calcareous (Bk) horizons, whereas "Fo" Series paleosols are thinner, with relict bedding and sparser, more scattered caliche nodules. The type Go clay is at and below 35 cm in the measured section (Figs. 6, 7), and the type Fo clay is at and below 183 cm, separated by the Fo clay eroded surface phase paleosol at 120 cm. The two type profiles are here named using conventions of Retallack (1988, 1990), and include a characterization of overlying and underlying strata in order to facilitate relocation.

Type Go clay paleosol (at 35 cm and below in measured section)

+7 cm: C horizon of overlying paleosol (unnamed, very weakly developed series); fine grained sandstone; abrupt wavy contact to

0 cm: A horizon; silty claystone, brown (7.5YR5/2); common fine (1–2 mm diameter), white (10YR8/2) calcareous rhizoconcretions; few small (6 mm diameter) calcareous, white (5Y8/2) metagranotubules, after bur-

TABLE 1. Mineral composition (volume) of paleosols from site AL-333, Hadar, Ethiopia (percentage based on 500 points)

	Sample No., cm below DD3														
	I-0, DD3	H-0, -45	H-4, -80	H-2, -100	G-0, -118	G-6, -132	G-4, -154	G-2, -173	F-0, -190	F-6, -210	F-4, -225	F-2, -245			
Quartz	1.4	0.6	0.8	1.8	0.2	0.8	1.8	1.4	3.2	2.0	2.2	1.8			
Plagioclase	0.4	0.4	0.2	0.0	0.0	0.2	0.0	0.0	1.2	0.0	0.2	0.0			
Opaque	0.0	0.6	1.8	2.0	0.4	1.2	3.0	2.8	6.6	5.4	7.4	7.0			
Clayey matrix	6.0	55.2	84.2	90.0	61.6	67.8	88.4	87.2	71.8	86.0	84.6	83.8			
Pyroxene	6.6	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.8	0.4	0.0	0.0			
Soft rock frag.	50.4	11.2	10.0	3.2	16.4	5.2	2.4	2.8	6.6	2.8	3.0	4.2			
Volcanic frag.	35.2	0.2	0.0	1.4	0.2	0.4	1.8	1.6	7.4	1.6	1.8	2.8			
Replaced grains	0.0	1.8	1.0	1.2	0.4	0.2	1.4	0.8	1.8	0.4	0.8	0.4			
Calcite	0.0	22.8	0.2	0.4	20.8	24.2	0.4	3.0	0.2	1.2	0.0	0.0			
Deformed grains	0.0	7.2	0.2	1.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0			
Other frags.	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Other minerals	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.2	0.0	0.0			

TABLE 2. Grain size distribution of paleosols from site AL-333, Hadar (volume percent based on 500 points)

Sample No.: cm below DD3	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
I-0: DD3	4.8	0.8	94.4	0.0
H-0: -45	56.0	25.4	18.6	0.0
H-4: -80	85.4	3.0	11.6	0.0
H-2: -100	91.6	3.6	4.8	0.0
G-0: -118	63.0	21.4	15.6	0.0
G-6: -132	68.8	22.8	8.4	0.0
G-4: -154	88.6	4.6	6.8	0.0
G-2: -173	86.8	7.0	6.2	0.0
F-0: -190	71.4	6.8	21.8	0.0
F-6: -210	86.2	7.0	6.8	0.0
F-4: -225	85.0	7.0	8.0	0.0
F-2: -245	83.4	8.4	8.2	0.0

TABLE 3. Major element and organic carbon composition (weight %) of paleosols from site AL-333, Hadar, Ethiopia¹

	Sample No., cm below DD3											
	I-0 DD3	H-0 -45	H-4 -80	H-2 -100	G-0 -118	G-6 -132	G-4 -154	G-2 -173	F-0 -190	F-6 -210	F-4 -225	F-2 -245
SiO ₂	52.4	46.77	48.03	47.9	17.8	47.6	49.5	49.83	49.4	49.23	45.23	45.3
TiO ₂	1.94	1.47	1.8	1.61	0.64	1.8	1.64	1.78	2.15	1.84	2.03	1.87
Al ₂ O ₃	13.03	12.81	13.03	13.27	4.86	13.09	13.29	13.28	13.9	13.76	13.63	12.76
Fe ₂ O ₃	8.29	9.13	9.34	9.6	3.27	9.55	9.38	9.6	9.9	9.74	9.91	9.49
FeO	1.10	0.11	0.0	0.0	0.27	0.05	0.16	0.16	0.27	0.19	0.22	0.0
MnO	0.13	0.07	0.69	0.21	0.56	0.07	0.08	0.08	0.12	0.08	0.08	0.08
MgO	3.61	4.20	3.68	3.53	1.52	3.52	3.49	3.42	3.15	3.39	3.47	3.47
CaO	6.06	3.89	2.61	2.48	36.32	3.09	2.59	2.33	3.68	2.4	2.4	4.03
Na ₂ O	2.92	1.78	1.7	1.76	0.70	1.76	1.76	1.76	2.94	1.96	2.01	2.24
K ₂ O	1.97	1.63	1.43	1.45	0.63	1.83	1.88	1.85	1.83	1.97	1.88	1.63
P ₂ O ₅	0.34	0.34	0.29	0.24	0.16	0.39	0.36	0.36	0.37	0.41	0.38	0.37
LOI	7.4	18.3	17.9	18.5	34.0	18.0	16.4	15.8	12.5	15.6	15.2	19.2
Totals	99.19	100.3	100.5	100.6	100.7	100.8	100.5	100.3	100.1	100.6	100.4	100.5
Tot Fe	9.51	9.25	9.34	9.6	3.57	9.61	9.56	9.78	10.2	9.95	10.15	9.5
Org. C	N/A	0.56	0.32	0.48	0.37	0.42	0.42	0.32	0.37	0.32	0.27	0.64

¹Based on atomic absorption spectrometry (AAS) by C. McBirney.TABLE 4. Trace element composition (ppm) of paleosols from site Al-333, Hadar, Ethiopia¹

	Sample No., cm below DD3											
	I-0 DD3	H-0 -45	H-4 -80	H-2 -100	G-0 -118	G-6 -132	G-4 -154	G-2 -173	F-0 -190	F-6 -210	F-4 -225	F-2 -245
Ba	644	245	305	541	154	386	245	258	451	283	309	283
Co	33	27	32	29	13	28	29	29	36	28	29	30
Cr	176	90	100	83	49	106	102	13	139	102	110	98
Cu	37	55	56	56	23	56	55	57	50	56	56	59
Li	14	18	19	20	10	18	17	18	21	18	19	21
Ni	62	58	60	60	22	60	58	62	58	62	66	80
Rb	47	50	51	51	22	53	55	58	48	57	54	48
Sr	865	314	253	258	149	323	245	241	513	251	263	488
Zn	103	111	113	115	49	113	115	118	115	119	119	111

¹Based on AAS by C. McBirney. Instrumental neutron activation analysis (INAA) results from Radosevich (1989). Analytical and systematic imprecision values can be found in Radosevich (1989).

rows; coarse granular and very coarse sub-angular blocky peds, defined by slickensided, dark brown (7.5YR4/2) argillans and few white (10YR8/2) calcans; strongly calcar-

eous; porphyroskelic skelmosepic; common displacive and replacive, needle fiber calcite; gradual wavy contact to

-17 cm: Bn: silty claystone; brown to dark

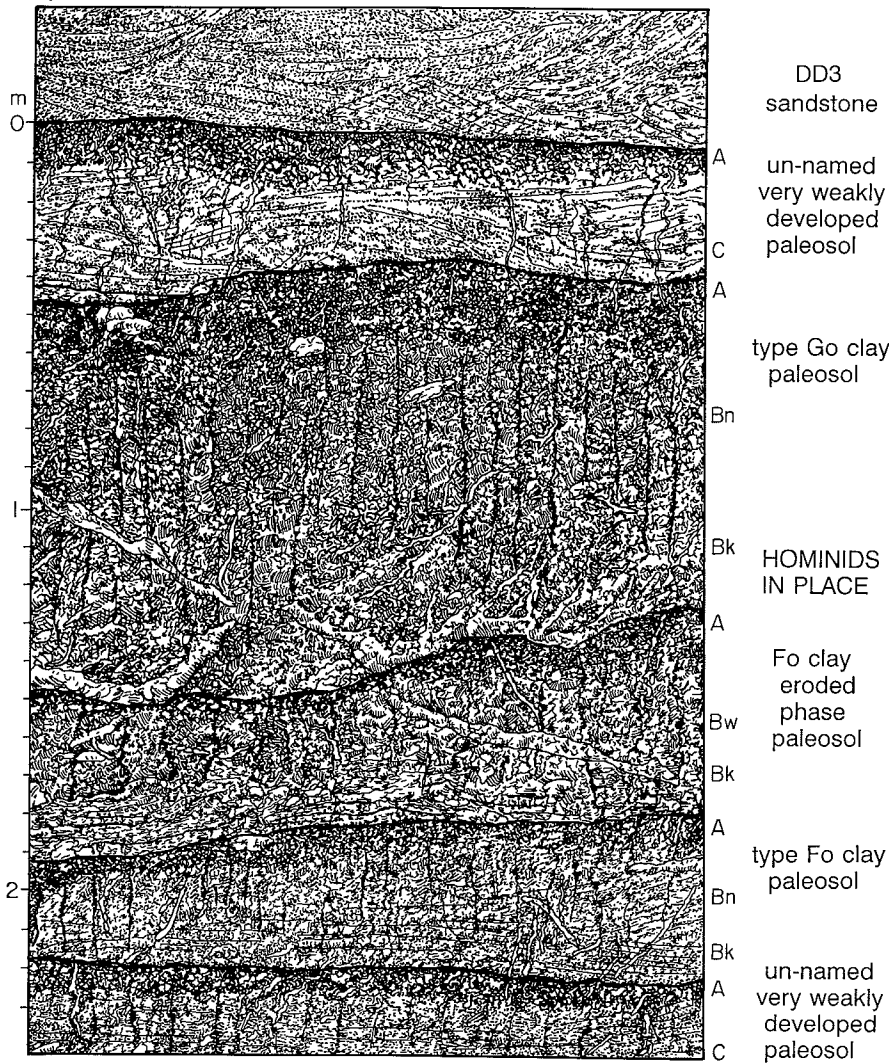


Fig. 2. Sketch of the excavated face at locality AL-333X1, Hadar, Ethiopia.

brown (7.5YR4/2); common large (ranging to 6 mm diameter) and fine root traces, in places with very dark (2.5Y3/2) mangans; medium prismatic peds, defined by slickensided dark brown (7.5YR3/2) argillans; few small (12 by 6 mm) white (10YR8/2) calcareous nodules, composed of smaller (2 mm) nodules; strongly calcareous; porphyroskelic skelmosepic in matrix and crystic in micritic nodules; clear irregular contact to -65 cm: Bk; silty claystone; brown (7.5YR5/2), with extensive petrocalcic stringers of white (10YR8/2) and pale brown

(10YR8/3); common relict bedding, picked out also by the petrocalcic stringers which have replaced areas of coarse grainsize filling symmetrical erosional hollows 1.5 to 2 m broad and 20 to 50 cm deep; on a smaller (hand specimen) scale the carbonate is angular and irregular in shape, as if preferentially formed in voids between granules of parent material and peds of soil; locally the calcite is stained by very dark gray (2.5Y3/2) mangans; very strongly calcareous; porphyroskelic to agglomeroplasmic insepic in clayey areas; crystic carbonate areas include



Fig. 3. Granular peds and fine root traces (dark), in the surface (A) horizon of the type Fo clay paleosol, Hadar, Ethiopia (sample F-O).

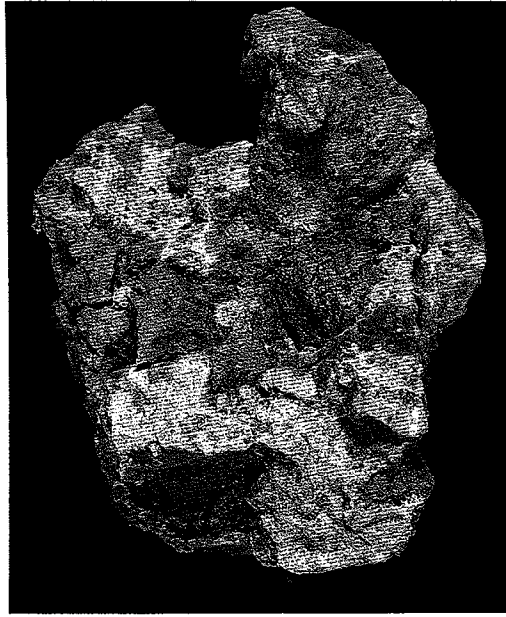


Fig. 4. Irregular white caliche nodule and enclosing brown claystone from calcic (Bk) horizon of type Go clay paleosol, Hadar, Ethiopia (sample G-O).

micritic, sparry, and needle fiber calcite, both replacing matrix and displacing peds and granules as fills of irregular and circumgranular cracks; some stout calcite needles isolated in clayey matrix have the crystal form of selenite, and probably are pseudomorphs of that sulfate; abrupt wavy contact to

-85 cm: A horizon of underlying paleosol (Fo clay eroded phase paleosol), silty claystone; brown (7.5YR5/2); with common large (up to 6 mm diameter) and fine (up to 3 mm) white (10YR8/2) calcareous rhizoconcretions; coarse granular and very coarse subangular blocky peds, defined by slickensided brown (7.5YR5/2) argillans; moderately calcareous; porphyroskelic skelmosepic.

Type Fo clay paleosol (at 183 cm and below in measured section)

+15 cm: Bk horizon of overlying paleosol (Fo clay eroded phase paleosol); sandy claystone; brown (10YR5/3); common fine (up to 4 mm), white (10YR8/2 and 2.5Y8/2) calcareous rhizoconcretions, and fine (up to 2 mm), pale brown (10YR8/3) root traces; indistinct

relict bedding and medium prismatic peds, with local very dark gray (10YR3/1) mangans on slickensided brown (7.5YR4/2) argillans; few white (2.5Y8/2) micritic nodules and small (3 mm diameter) yellowish red (5YR5/6) ferric concretions; weakly calcareous in clayey areas; porphyroskelic skelinsepic; abrupt smooth contact to

0 cm: A horizon; sandy claystone; brown (10YR5/3); common fine, brown (10YR5/3) root traces and few small (7 mm diameter), calcareous, white (10YR8/2) metagranotubules after burrows (?); indistinct coarse granular peds and traces of relict bedding; weakly calcareous in clayey matrix; intertext skelinsepic; gradual smooth contact to

-13 cm: Bn horizon; sandy claystone; brown (7.5YR5/2); common fine (1-3 mm diameter), white (10YR8/2) calcareous rhizoconcretions; indistinct coarse prismatic peds defined by slickensided brown (7.5YR5/2) argillans; distinct relict bedding; weakly calcareous; porphyroskelic skelinsepic; gradual irregular contact to

-27 cm: Bk horizon; sandy claystone; brown to dark brown (7.5YR4/2); common fine (1-3 mm diameter) pale brown (10YR8/3) calcareous rhizoconcretions; scat-

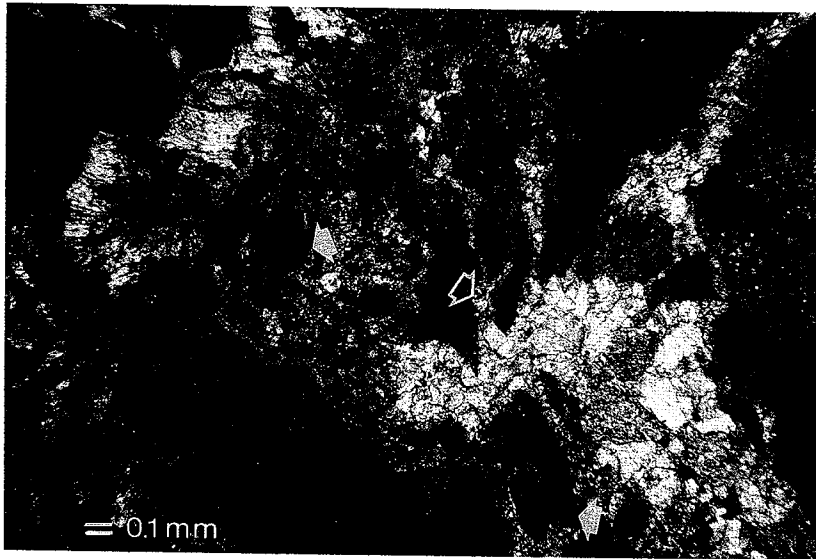


Fig. 5. Petrographic thin section under crossed nicols of calcic (Bk) horizon of the type Go clay paleosol, showing replacive micrite (solid white arrow), angular clay clods displaced by sparry calcite (open white arrow), and lenticular calcite crystals that may have replaced selenite gypsum (lower left) (sample G-O).

tered pale brown (10YR8/3) micritic nodules; weakly calcareous in clayey matrix; clear wavy contact to

-41 cm: A horizon of underlying paleosol (un-named very weakly developed series); silty claystone; brown to dark brown (7.5YR4/2); common fine (1-3 mm diameter) white (10YR8/2 and 2.5Y8/2) calcareous rhizoconcretions; coarse angular to very coarse subangular blocky peds, as well as clear relict bedding; weakly calcareous; porphyroscopic to agglomeroplasmic skelin-sepic.

Alteration after burial

Paleosols at Afar Locality 333 appear well preserved, with structures and profile forms similar to those of surface soils. However, they have probably been altered in several ways during burial. As in other paleosols in Africa (Retallack, 1991) and elsewhere (Retallack, 1990), those at Hadar have probably lost most of their original organic matter. They may also have gained some calcite, particularly the sparry calcite filling calcareous rhizoconcretions, as a cement after burial. Not all sparry calcite postdates soil formation, because some of it shows clear displacive texture of the type common in loose soils (Fig. 5). Burial reddening due to

dehydration of ferric hydroxides is another common alteration after burial, but is unlikely for Hadar paleosols, which are brown even though chemically oxidized (Fig. 7). Nor are compaction, illitization, or other phenomena of deep burial likely to have affected these paleosols. Locality 333 is only about 95 m below the local top of the Hadar Formation, and this is covered by about 10 m of Pleistocene gravels.

BURIAL OF THE HOMINIDS

Reinterpretation of this sequence as a succession of moderately to weakly developed paleosols implies that deposition was episodic on time scales of thousands of years. From this perspective it is noteworthy that the hominid fossils found in place were restricted to the calcic horizon (20 cm thick) of a fossil soil where it overlaps the A horizon of an underlying paleosol (at the level of 110 cm and below in Figs. 2, 6, 7). The caliche here shows a strongly developed swale-like form, where it has been preferentially formed in the coarser-grained fill of erosional scours into the upper part of the underlying paleosol. There is a relative increase in sand-sized particles within the hominid-bearing layer (7% in G2, G4, G6 to 15.6% in GO) (Fig. 6), although the absolute percentage remains

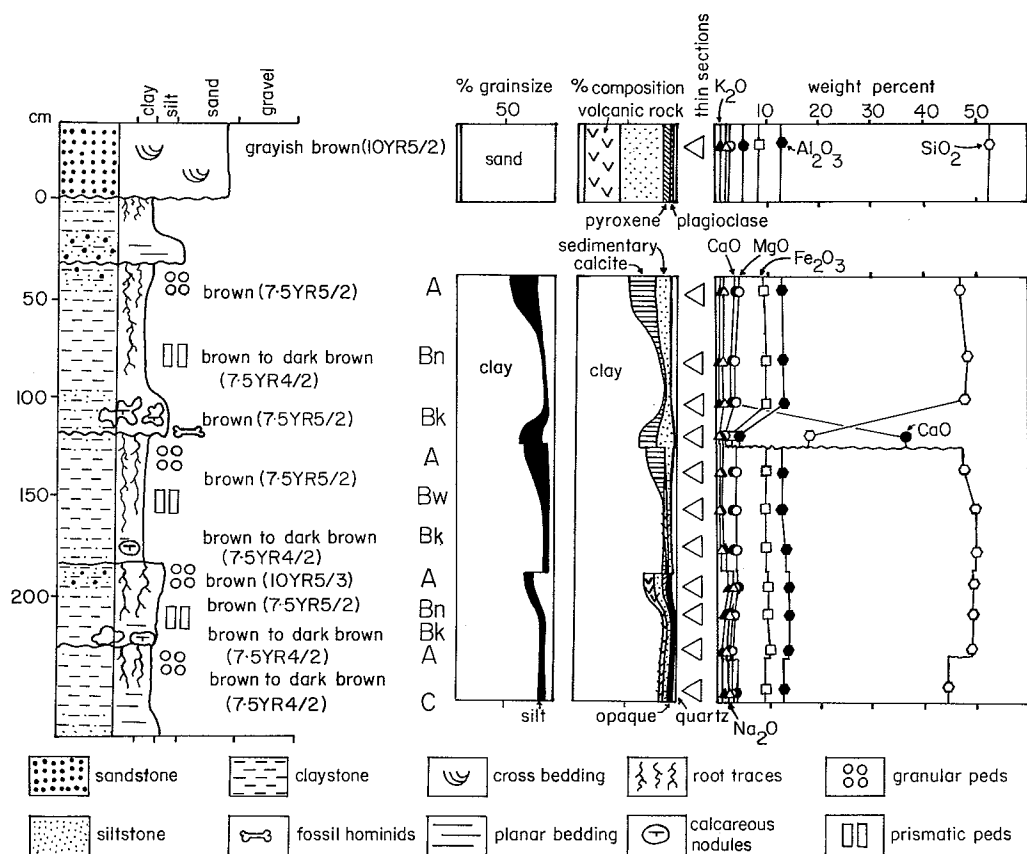


Fig. 6. Field column, petrographic and chemical composition of paleosols at site AL-333X2, Hadar, Ethiopia.

small enough to classify this material as silty-clay (Buol et al., 1981). These two features suggest catastrophic burial of the hominid bones by a fluvial event such as a flood. In contrast, an attritional assemblage of fossils should be concentrated in the upper portion of a paleosol, but with some bones having worked their way down into the profile (Bown and Kraus, 1981). What killed the hominids is not evident from our studies but has been addressed by previous speculations (Aronson and Taieb, 1981; Gray, 1980; Johanson et al., 1982). The hominids were not killed before excavation of the swale by floodwaters, but rather during or sometime after this event.

Affirmation of the catastrophic burial hypothesis for this assemblage also comes from the bones themselves. The only fossil mam-

mal bones recovered from the excavated part of the site are hominid. The proportion of adults and juveniles is similar to what one would expect in a single hominid band, as opposed to the greater number of very young and very old creatures found in attritional assemblages and in carnivore dens (Brain, 1981). The degree of bone weathering is Stage I in Behrensmeier's (1978) scheme, and is comparable for all the bones, as far as can be seen in the extensively prepared specimens (P. Shipman, unpublished). There also is a wide variety of bone shape and weight classes, ranging from maxillae with teeth to small toe bones, that would have been separated by fluvial transport of disarticulated bones or by long-term differential weathering. No clear evidence of scavenging or predation has yet been discerned on the

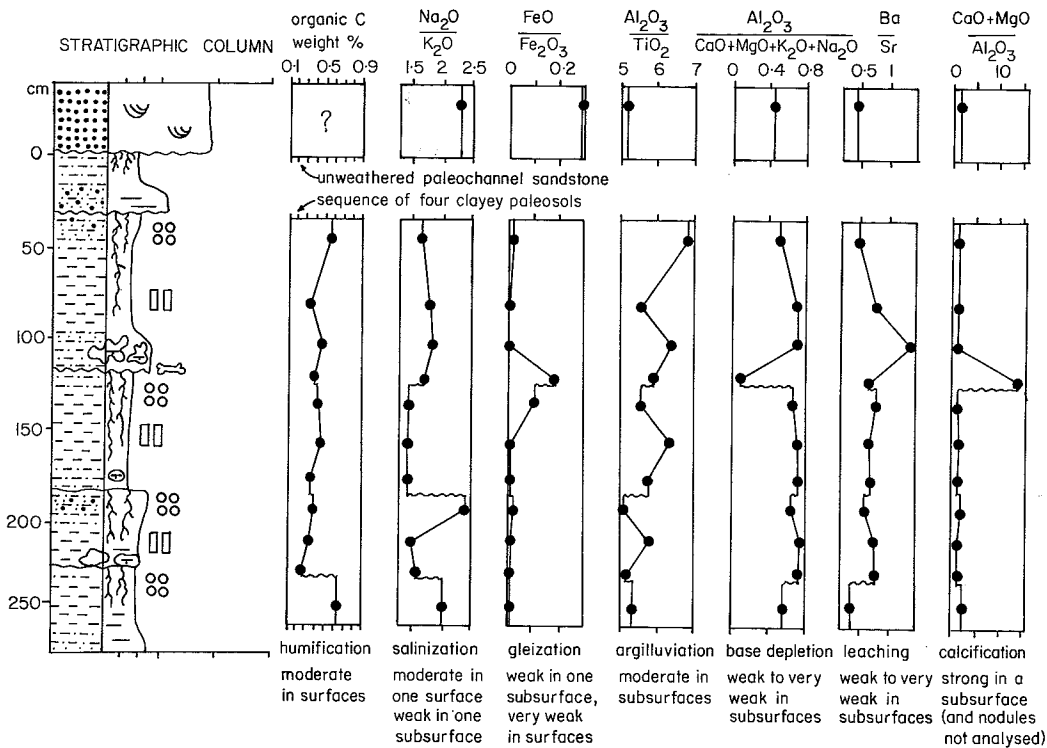


Fig. 7. Molecular weathering ratios, and their interpretation for paleosols of site AL-333X2, Hadar, Ethiopia.

bones; although such evidence could have been obscured during preparation. These facts support the catastrophic killing of a group rather than attritional accumulation bone by bone, yet there are no fully articulated skeletons, only an articulated partial foot and hand were discovered. Some degree of rotting, destruction, and scattering occurred between the event that killed them, and the event that deposited the slightly coarser grained alluvium on the swale-like scours. This time span was considerably less than 15 years, because bones at the surface of modern East African soils are completely disintegrated by then (Behrensmeier, 1981). We suggest that a period of months separated death and final burial, based on the Stage I weathering of the fossils. This group of a single species of hominid apparently suffered a mass kill during or after an erosive flood event, then disarticulation and scattering with little or no fluvial transportation downstream, some time before final burial in alluvium.

PALEOENVIRONMENT OF THE HOMINIDS

The paleosols at site AL-333 can be considered as trace fossils of the ecosystems in which the hominids lived. One way to reconstruct this paleoenvironment is to identify the paleosols in a soil classification and try to find modern analogues. This approach of taxonomic uniformitarianism is the paleopedological equivalent of interpreting wooded grassland vegetation for the site from its fossil rodents, antelopes, and pollen of taxa now common in dry-savanna (Bonnefille et al., 1987; Gray, 1980; Johanson et al., 1982; Sabatier, 1982).

The type Fo clay paleosol can be identified as a Fluventic Ustropept in the U.S. soil taxonomy (Soil Survey Staff, 1975), as a Calcic Cambisol in the classification of the Food and Agricultural Organization of UNESCO (FAO, 1977), as a Brown Clay in the Australian handbook of soils (Stace et al., 1968), and as an Inhoek drydale form in the South African system (MacVicar et al.,

1977). These identifications reflect in part the relict bedding and other signs of weak development of these paleosols, which may have developed into Go paleosols had they been given sufficient time. More significant as indicators of paleoenvironment are the Go Series paleosols, which can be identified as Mollic Solonetz (FAO, 1977), Natrustoll (Soil Survey Staff, 1975), Solonized Brown Soil (Stace et al., 1968), and Sterkspruit antioch profiles (MacVicar et al., 1977). The taxonomically diagnostic features of the Go paleosols include a well structured organic surface horizon, a prominent shallow subsurface calcareous horizon, prismatic peds, consistently large soda to potash ratios, and rare lenticular calcite replacement after gypsum at depth that may reflect salinization (Fig. 5). Salinization was not so extreme as in some desert soils, because the paleosols have evidence of calcareous nodules and rhizoconcretions, granular peds, and lack the strong development of domed columnar peds.

Modern soils like the Go clay paleosol are associated with more widespread Orthic Solonetz at low elevations on Quaternary alluvium in the inner coastal plain of southern Somalia from near Dudduma to Chisimaio (Map Units So10-2a, So11-2/3a of FAO, UNESCO, 1977). Vegetation in the northern part of this area is wooded grassland. The trees are mainly *Acacia* and *Commiphora*, which also form local gallery woodlands and thickets. The grasses are usually less than 1 m high and include *Chrysopogon*, *Aristida*, *Cenchrus*, and *Sporobolus*. To the south these soils support the same plant species in a vegetation better labeled thornbush savanna (FAO, UNESCO, 1977). Both are in the Somalia-Masai wooded grassland of the AEFAT vegetation map (White, 1983). The climate of this area is semi-arid, tropical. Nearby Mogadishu experiences 22–28°C in January, 31–36°C in July, with 127–254 mm rainfall annually. This area supports vegetation of a semi-desert type such as *Acacia*, shrubs, and bunch grass. Similar soils are also found in the grassland-woodland mosaic of the western Serengeti Plains of Tanzania (de Wit, 1978; Jager, 1982), particularly the Mukoma 1, Larale 2 and Kamarishe 3 profiles (of Jager) but the mixed carbonatite-gneiss parent material of these soils is very different from that of the Ethiopian paleosols. In Australia and South Africa comparable modern soils support open woodland and

wooded grassland in semi-arid regions (Gertenbach, 1983; Stace et al., 1968), and in the United States they support open grassland in arid to subhumid regions (Soil Survey Staff, 1975). This vegetation and climate is a good deal more lush and humid than that presently prevailing in the Awash valley, with its Xerosols, Lithosols, and Regosols, supporting semi-desert vegetation (Findlay et al., 1973).

A second method of reconstructing the habitat of the hominids at locality AL-333 is to consider paleoenvironmentally significant features of the paleosols. This approach can be considered the paleopedological equivalent of functional morphology of fossils. In a similar way, features of modern soils are formed by the interaction of factors such as climate, organisms, topographic relief, parent material, and time. Some of these features of environments can be interpreted from features of paleosols. Topographic relief and parent material of the paleosols at AL-333 are known from sedimentological studies of Aronson and Taieb (1981), and our own petrographic studies. The site was part of a river floodplain, probably quite close to a stream. Indeed, a geologically younger paleochannel overlies this short sequence of paleosols. The parent material of the paleosols was alluvium derived from the weathering of basaltic volcanic and sedimentary rocks of the nearby Ethiopian highlands.

The time for formation of the individual soil profiles can be approximated by the morphology of their calcic (Bk) horizons, by comparison with the well known chronosequence of calcareous soils around Las Cruces, New Mexico (Gile et al., 1981) and the Serengeti Plains of Tanzania (de Wit, 1978; Hay and Reeder, 1978). By these standards, the type Go clay paleosol represents some 25,000 to 75,000 years on quartzofeldspathic alluvium in New Mexico, or 2,000 to 9,000 years in the carbonatite ash of the Serengeti Plains. The Ethiopian parent materials were not so calcareous as the Tanzanian ones, thus the New Mexico study is a better standard of comparison. The Fo clay eroded surface phase and type Fo clay paleosols show development that in New Mexico would represent 8,000 to 15,000 years, and the other two profiles (bottom and top) show only minimal development of the calcic horizon, compatible with a short time of development. Deposition of the sequence was thus highly episodic.

Rainfall during soil formation can be inferred by comparison with studies relating this factor to depth of the calcic horizon within the profile in the summer-wet temperate Great Plains of North America (Jenny, 1941), the summer-dry Mojave Desert of California (Arkley, 1963), and the monsoonal climates of Punjab, India (Sehgal et al., 1968), and the Serengeti Plains of Tanzania (de Wit, 1978). All comparisons give a mean annual rainfall of some 300–700 mm for the type Go clay paleosol, and somewhat less for the others. The drier end of this range is more likely considering the lenticular calcite, perhaps pseudomorphous after gypsum (Fig. 5), and the present distribution of gypsum in surface soils (Dan and Yaalon, 1982; Porta and Herrero, 1990). A dry but not desertic climate also is indicated by other features of the paleosol: evidence of moderately large soda content in some profiles (Fig. 6), appreciable remaining organic carbon (Fig. 7), and well developed soil structure (Figs. 2, 3).

Soil structures in the paleosols and the nature of fossil root traces provide evidence of their former vegetation. Granular structure and abundant fine root traces are evidence of an herbaceous, probably grassy, cover to all the paleosols. Some also contain stout calcareous rhizoconcretions and a clayey prismatic subsurface (Bn) horizon that can be taken as indications of dry woodland. Those paleosols lacking these indications of larger woody plants also show relic bedding: an indication of a short time of development rather than a well established grassland. This is not to say that open grassland or lightly wooded grassland was not present. Open grassy vegetation is widespread in regions with sodic soils (Jager, 1982; Gertenbach, 1983), and there may be indications of it in other paleosols nearby that have not yet been examined. The paleosols that we have studied could represent a thicket or streamside gallery in a grassy woodland part of a wider mosaic of grassland vegetation.

The general habitat envisioned for *Australopithecus afarensis* at Hadar, Ethiopia, is similar to that in which the same species is thought to have lived at Laetoli, Tanzania (Leakey and Harris, 1986). The most compelling evidence of hominid activity at Laetoli are footprints in an extremely weakly developed paleosol of fresh volcanic ash under open, early successional dry wooded grass-

land. There also are better developed paleosols with granular surface horizons at Laetoli, as one of us (G. Retallack) has been able to confirm from observations of large blocks containing fossil bee nests from these localities (in the Kenyan National Museum). Only pairs of footprints have been found in the open country paleosols at Laetoli, whereas a larger group including both sexes and juveniles are found in the gallery woodland paleosols at Hadar. Thus, early hominids ranged through various parts of the savanna mosaic. This conclusion is tentative since it is based on a sample of only two localities where fossil hominids are known in place within paleosols. However, many fossil hominids from East Africa are preserved in place with paleosols (Retallack, 1990), and a fuller picture of early hominid ecology will emerge when these paleosols also are examined.

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