A Micromorphological Analysis of Stratigraphic Integrity and Site Formation at Cactus Hill, an Early Paleoindian and Hypothesized Pre-Clovis Occupation in South-Central Virginia, USA

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Twenty thin sections were studied from Cactus Hill, a ca. 20 ka stratified sand dune site in Virginia, USA, with a Clovis and hypothesized pre-Clovis component. The high-resolution soil micromorphology investigation focused on testing the integrity of Clovis and pre-Clovis stratigraphy from one location where there is a high density of artifacts. Site formation processes were dominated by eolian (dune) sand formation. There was also ephemeral topsoil development and associated occupation, along with their penecontemporaneous disturbance and dispersal by scavenging animals (assumed) and localized down-working by small invertebrate mesofauna (as evidenced by aggregates of fine phytolith-rich humic soil and fine soil-coated charcoal fragments). Partial erosion of these occupation soils (deflation?) was followed by successive sand burial. Post-depositional processes affecting these sand-buried occupations involved only small-scale bioturbation and overprinting of clay lamellae, suggesting site stratigraphy has been stable for a long time. Soil micromorphological analysis has defined a difference between occupational units (pre-Clovis and Clovis) and sterile units found between these units as well as above and below. In summary, according to this analysis, the site appears intact with only minor disturbances affecting the long-term integrity of the stratigraphy. © 2008 Wiley Periodicals, Inc.

INTRODUCTION

The archaeology of the Nottoway River and site of Cactus Hill (Figure 1) have been studied for more than 15 years (McAvoy, 1992; McAvoy & McAvoy, 1997). Although the topmost levels at Cactus Hill contain Holocene-age artifacts, the main interest in the site comes from two discrete levels of late Pleistocene material, a Clovis layer and a stratum of artifacts below the Clovis layer presumed to be pre-Clovis. Clovis is the name for a distinctive fluted projectile point and the associated tool assemblage found across North America, dated to about 12.5–14 ka (10.8–11.6 ka uncalibrated

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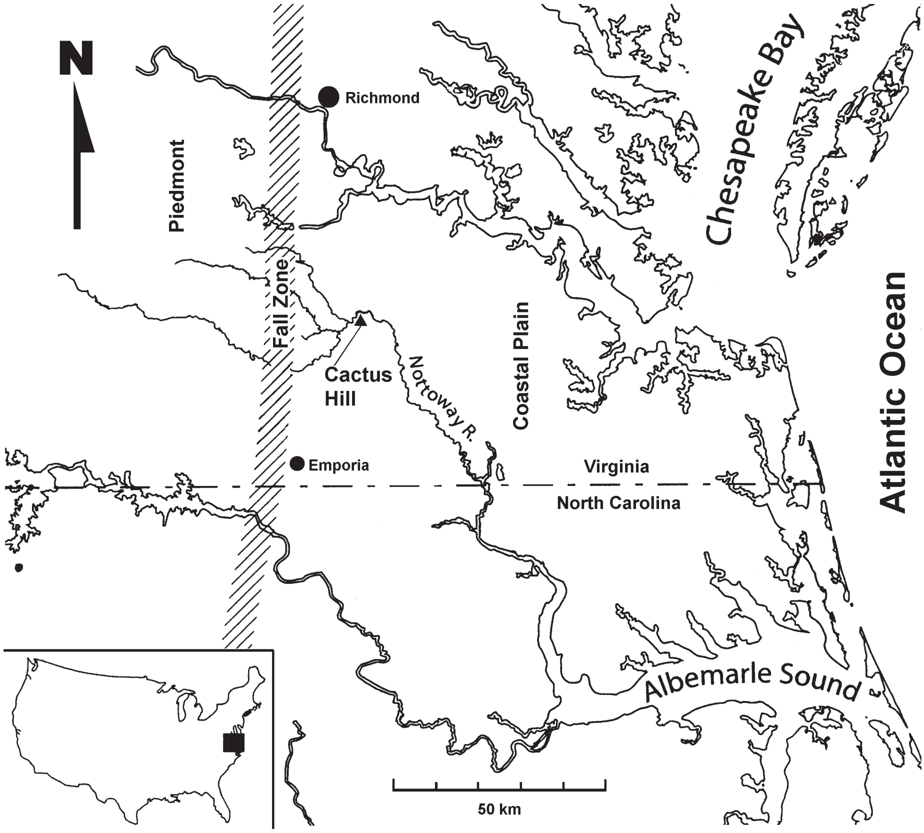

Figure 1. Geographic location of the Cactus Hill site on the coastal plain of Virginia, just east of the fall line representing the eastern edge of the Piedmont and characterized by a drop in elevation of 20–35 m onto the western coastal plain.

radiocarbon age) (Taylor, Haynes, & Stuiver, 1996). As it is disputed that Clovis represents the earliest migration to the New World (Goebel, Waters, & O'Rourke, 2008; Waters & Stafford, 2007; Bradley & Stanford, 2004; Dillehay, 1997; Adovasio, Donahue, & Stuckenrath, 1990), sites such as Cactus Hill which may contain evidence of an earlier culture are highly significant. The stratigraphy of such sites, however, requires careful examination and appraisal, which is the subject of this investigation.

Here we present a detailed soil micromorphological study, carried out on an archived sediment block collected in 1993 from Unit 2/9, as another contribution to the multidisciplinary investigation at Cactus Hill (Feathers et al., 2006; McAvoy et al., 2004) (Figures 2, 3a, 3b). Our investigation supplements an earlier independent soil micromorphological investigation conducted in another area of this extensive (2.4 hectares) site that documented the ubiquitous occurrence of clay lamellae within the deposits (Perron, 1999).

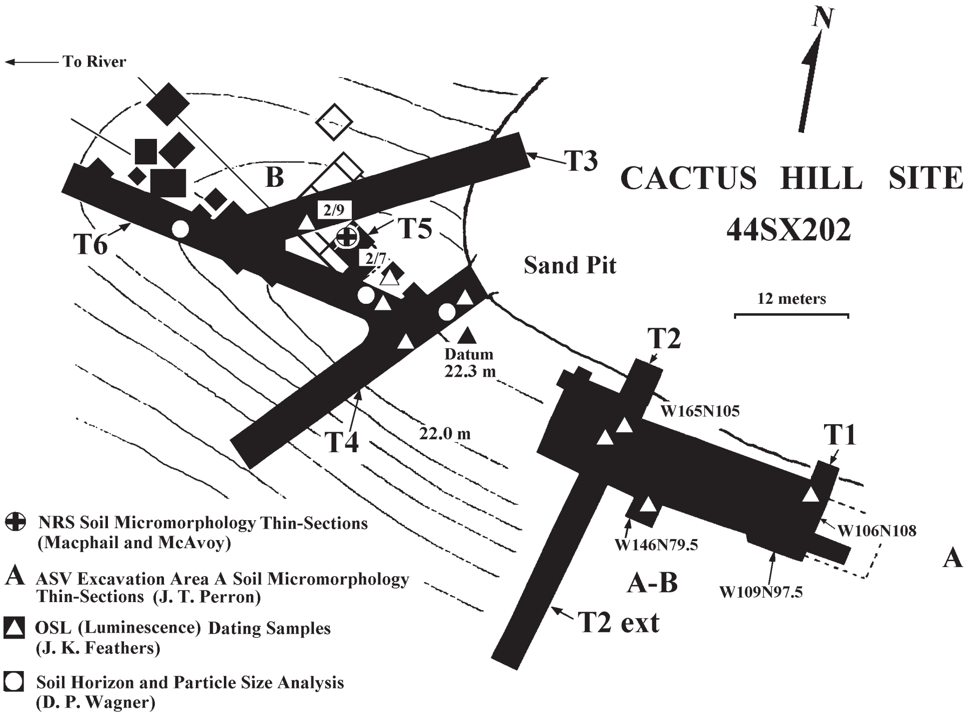

Figure 2. The Cactus Hill site, 44SX202, area A, A–B, and B excavation plan showing trenches 1 through 6 (T1 through T6); selected excavation units. The figure also specifically identifies the location of this current soil micromorphology study; where the J.T. Perron study was conducted; the locations of J.K. Feathers' OSL dating samples; and the locations of D.P. Wagner's soil particle size and soil horizon investigations.

Environmental Setting and Archaeology

Cactus Hill formed as a Late Pleistocene sand dune (ca. 22 m asl) and is composed of 85–94% sand (McAvoy et al., 2000, 2004). The dune at the location of the archaeological site is an oval-shaped ridge approximately 37 m in width (north to south) and 160 m in length where it extends to the east from the bank of the Nottoway River. Along the ridge centerline containing the archaeological site, the dune sand varies in total depth (thickness) from 1.5 to 1.95 m, and it is situated upon a Pleistocene-age terrace of compact sandy clay loam. During its formation the sand dune was occupied by humans, as evidenced by early Archaic material (ca. 8.8–9.2 ka, uncalibrated radiocarbon age), a Clovis layer (ca. 10.9 ka), and a presumed pre-Clovis artifact concentration (ca. 15–16.9 ka). These age determinations, with underlying sand dune deposits yielding an older radiocarbon date (ca. 19.7 ka BP), are all apparently consistent with optically stimulated luminescence (OSL) dates from the same strata (Feathers et al., 2006; McAvoy & McAvoy, 1997; Wagner & McAvoy, 2004). Cultural levels are characterized by charcoal, large and small artifacts of a variety of lithic materials, thermally altered hearth stone, and occasional small calcined

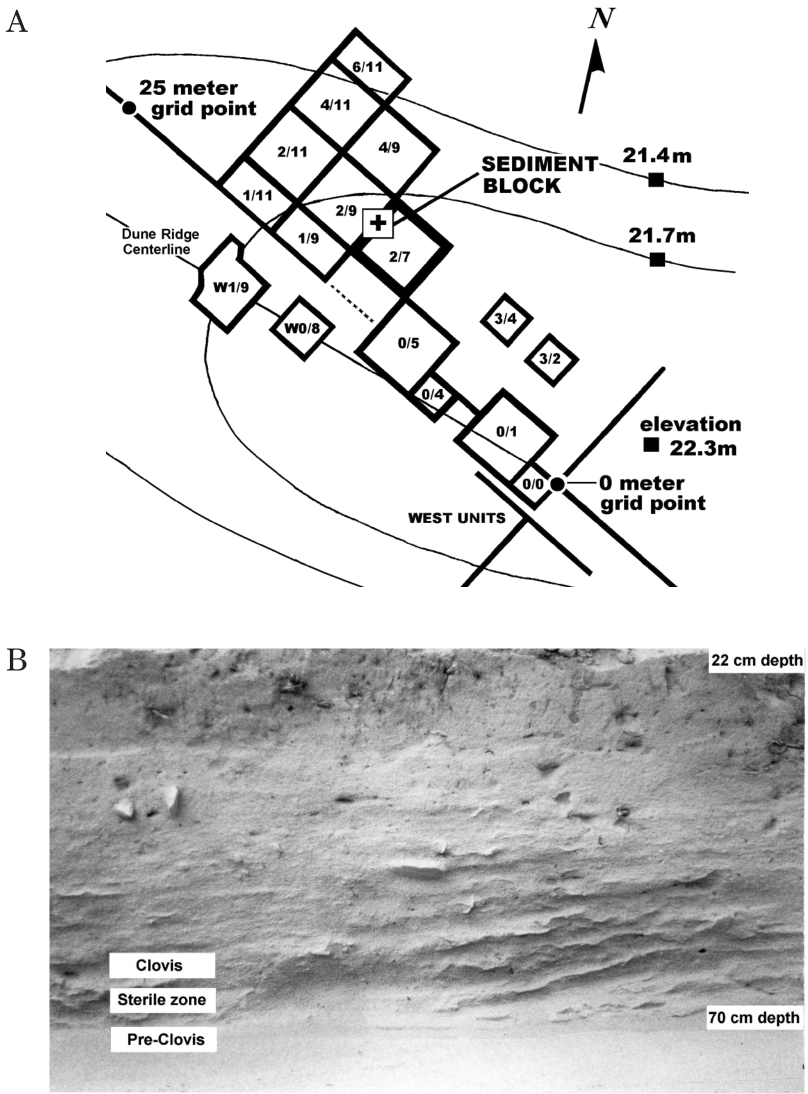

Figure 3. (a) Cactus Hill area B excavation units on the dune ridge, showing the location of the balk separating units 2/9 and 2/7 from which the monolith sediment block was removed for soil micromorphology. (b) The east wall profile brushed to expose lamellae in unit 2/9, excavated from below the plow zone (below 22 cm) to more than 70 cm depth, also showing the lowermost excavated levels, from which the 17.5 cm sediment block (57.5 to 75 cm depth) was removed from Levels 5, 6, and 7, containing the “Clovis,” “sterile zone,” and “pre-Clovis” layers.

bone fragments. In the upper levels of the deposit, the Archaic-period (Holocene) artifacts were usually manufactured of locally obtainable coarse-grain quartzite, and they were based upon a bifacial core and flake technology. Below the Archaic-period artifacts, in the upper or Clovis level of the two discrete levels of late Pleistocene material, Clovis points and unifacial tools are recovered, consisting of fine-grain lithics foreign to the site area such as chert, chalcedony, and jasper. Both bifacial core flakes and blade-core flakes (core blades) are found at this level of the site. Below the Clovis layer, presumed pre-Clovis artifacts are recovered of still different stone material, which is fine-grain quartzite and metavolcanic stone found in the site area as river cobbles. Some of the artifacts recovered in this level were based upon bifacial core technology, but most (about 75 percent) of the larger artifacts are core blades struck from small polyhedral blade cores of quartzite. In form and lithic material, the Clovis and presumed pre-Clovis lithic assemblages are quite different.

Field evidence of soil formation has also been identified in these sediments, including a series of buried soils (see below; Table II) that are assumed to broadly correspond to the dated occupations, which are also reflected in concentrations of phosphorus (Feathers et al., 2006; McAvoy et al., 2004). Although the deposits do not preserve pollen, phytolith and charcoal analyses indicate that pre-Clovis soils had a monocotyledonous (e.g., grass) and pine woodland cover; overlying sediments contain charcoal from hardwoods (McAvoy et al., 2004).

Objectives of New Soil Micromorphology Investigation

Data gleaned from soil and geological investigations (Feathers et al., 2006; McAvoy et al., 2004) confirmed the eolian origin of the sediments at Cactus Hill and the post-depositional pedological impact of iron-clay lamellae formation, i.e., the evolution of argillic pedofeatures in bands and thin layers (Phillips, Foss, & Goodyear, 2006; Soil Survey Staff, 1999:82–83) (see Figures 4, 5). These lamellae were also recorded in an area of the site with a lower density of cultural material independently investigated by Perron (1999). The area of Unit 2/9 was excavated in thin layers, termed Level 1 (ca. 20–28 cm) to Level 7 (ca. 69–>74 cm) (Figures 2a, 2b; Table I). The present soil micromorphological investigation with high-resolution sampling was carried out in order to fully investigate the context of Levels 5c–7 employing a sediment block taken from the pre-excavated balk section at Unit 2/9 (see Figure 3b), where two cultural layers are separated, and underlain by culturally sterile sands (Table I). The chief objective was to investigate the stratigraphic integrity of the two cultural layers ("Clovis": Level 5c; "Pre-Clovis": Level 6b and upper Level 7), and the culturally sterile sediments between (Level 6a) and below (lower Level 7) them (Table I).

MATERIALS AND METHODS

Excavations at Cactus Hill during 1993 in the balk separating units 2/9 and 2/7 (Figure 3a), Area B, allowed the recovery of a 17.5-cm-long block of sediment from Levels 5c to 7 that encompassed four archaeological layers (Table I) (McAvoy & McAvoy, 1997). This area had produced one of the best-preserved Clovis cultural

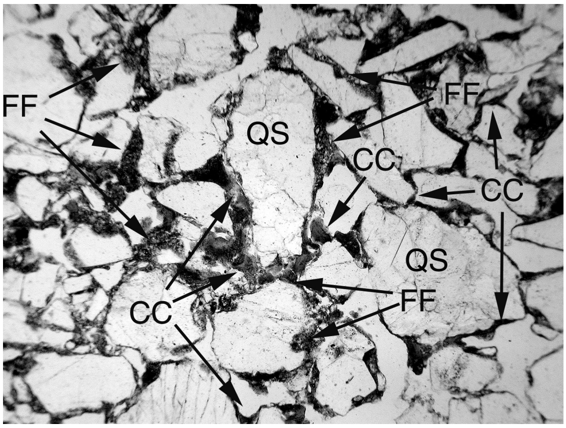

Figure 4. Photomicrograph of typical "clay lamellae" (microfacies type [MFT] 1c); very dominant, well sorted, medium sand-size, angular to subangular quartz, quartzite, and feldspar, with ca. 20% voids (35% voids outside "clay lamellae") (see Table IIa); note fine fabric (FF), quartzite sand (QS), and clay coatings (CC). Plane polarized light (PPL); frame width is ~5.7 mm.

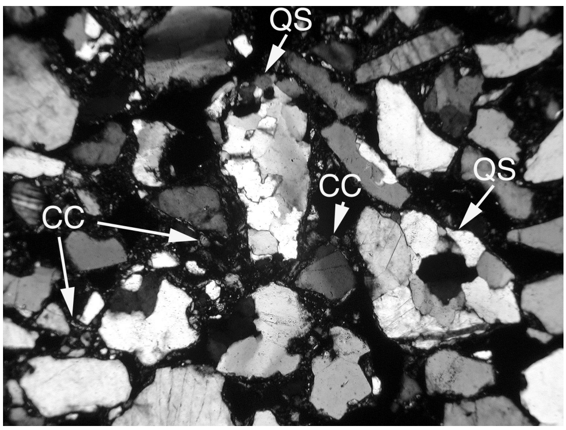

Figure 5. As Figure 4, but under crossed polarized light (XPL); note quartzite sand (QS) and clay coatings (CC).

deposits at Cactus Hill, below which a pre-Clovis hearth-like feature had been dated to 15,070 ± 70 ^{14}C yr B.P.; these deposits were also the focus of a detailed environmental (including phytoliths and phosphate) and chronological (^{14}C and OSL) study (McAvoy et al., 2000, 2004; Feathers et al., 2006).

The 17.5-cm-long sediment column, collected at a depth of 57.5–75 cm below the modern land surface, was impregnated with resin and subsampled (horizontally sliced) to give a series of blocks that were further subsampled (vertically sliced) to produce 20 thin sections in total: an uppermost 7-cm-thick block (thin sections 1A–1D, 4A–4D); a middle 7-cm-thick block (thin sections 2A–2D, 5A–5D) and a lowermost 3.5-cm-block (thin sections 3A–3D) (see Table I). The 20 thin sections were observed at magnifications from ×1 to ×400, under plane polarized light (PPL), crossed polarized light (XPL), oblique incident light (OIL), and employing fluorescence microscopy (blue light). Blue light fluorescence microscopy was used in order to search for autofluorescent materials, such as recent root material and calcium phosphate in the form of bone or mineralized coprolites. Thin sections were described according to Bullock et al. (1985) and Stoops (2003), with data being extracted from

Table I. Archaeological context of the twenty thin sections made from the 1993 archived block of sediment from Unit 2/9, Cactus Hill (McAvoy and McAvoy 1997, 102–113) (See Figures 3a and 3b).

Excavated Levels	Depth below Datum	Archaeology	Thin Sections
Plow zone, mechanically removed,	0″ to 8″ below datum (0 to 20.3 cm)	Not applicable	
Level 1	8″ to 11″ (20.3 to 27.9 cm)	Historic, Woodland, Late Archaic, and Middle Archaic	
Level 2	11″ to 14″ (27.9 to 35.6 cm)	Late Archaic, Middle Archaic, and Early Archaic	
Level 3	14″ to 16″ (35.6 to 40.6 cm)	Late Archaic (feature bottoms), Middle Archaic, and Early Archaic	
Level 4	16″ to 18″ below datum (40.6 to 45.7 cm),	Late Archaic (feature bottoms), Middle Archaic, Early Archaic, and some Clovis	
Level 5a	18″ to 20″ (45.7 to 50.8 cm)	Middle Archaic (feature bottoms), Early Archaic, and some Clovis	
Level 5b	20″ to 22″ (50.8 to 55.9 cm)	Middle Archaic (feature bottoms), Early Archaic, and Clovis	
Level 5c	22″ to 24″ below datum (55.9 to 61 cm)	Some Early Archaic and Clovis	Top of archived block; thin sections 1A–1D; 4A–4D
Level 6a	24″ to 25.5″ (61 to 64.8 cm)	Mostly sterile sand	Middle of archived block; upper parts of thin sections 2A–2D; 5A–5D
Level 6b	25.5″ to 27″ (64.8 to 68.6 cm)	Thin layer of pre-Clovis at base of this excavated level	Lower middle part of archived block; lower parts of 2A–2D; 5A–5D
Level 7	27″ to >29″ (68.6 to >73.7 cm)	The very upper part of level 7 is a continuation of the pre-Clovis level; the lower part is culturally sterile sand	Base of archived block; thin sections 3A–3D

semi-quantitative counts and the analysis of the fine fabric and pedofeatures (see Figures 4, 5), here termed *soil microfabric types* (SMTs), and *microfacies types* (MFTs) (Table IIa) (Courty, Goldberg, & Macphail, 1989; Courty, 2001; Goldberg & Macphail, 2006: Chapter 16; Macphail & Cruise, 2001). Different coarse soil inclusions and the character of coarse charcoal fragments found within the deposits were also described (Table IIb; Figures 6–11).

Table II. Cactus Hill soil micromorphological descriptions.

Table IIa. Soil micromorphology (see Figures 4 & 5) of sediments including soil microfabric type (SMT) and microfacies type (MFT) for the three successive groups of thin section-subsamples and related field stratigraphy (see Table I) .

Material (MFT/SMT)	Sample Number Examples	Soil Micromorphology (SM) of Sediments	Phase and Relative Depths; Comments
Microfacies types 1a, 1b, and 1c/SMT 1a and 1b	2/9L5-6-1A & 4A, 1B & 4B, 1C & 4C, 1D & 4D ca. 57.5–64.5 cm	SM: *Structure*: MFT 1a, 1b, and 1c—generally heterogeneous (see Coarse:Fine C:F ratios) with few thin (2–3 mm) lamellae (e.g., in upper part of 2/9L5-6-1A); massive with fine (2–3 mm) burrowed microfabric; ca. 35% voids, very dominant simple packing voids (MFT 1b—lamellae: ca. 20% voids, common simple and complex packing voids with frequent to common fine (250 μm) vughs, some closed (MFT 1c—lamellae)); *Coarse Mineral*: Coarse: Fine (limit at 10 μm), equal amounts of 85:15 (MFT 1a) and 95:05 (MFT 1b); (MFT 1c—lamellae: 70:30 if textural features included); very dominant, well-sorted, medium sand-size, angular to subangular quartz, quartzite, and feldspar, with very few micas and heavy minerals; very few silt-size quartz and mica; *Coarse Organic/ Anthropogenic*: rare (x1–2) coarse (1–6 mm) Fe/Mn stained soil inclusions (see below), rare (x1–2) coarse (1 mm) soil inclusions (see below), rare (<2%) charcoal (400–1500 μm), commonly rounded, or fragmented, or coated (see below); rare (x1) gravel-size (7 mm) angular quartzite/chert, rare (x1) coarse (3 mm) Fe/Mn nodules of cemented sand grains (with nonlaminated and microlaminated clay coatings and infills), very rare fine (400 μm) roots and fungal bodies, showing blackening of dark reddish brown colors (PPL, OIL), rare sand grains showing likely rubified (burned) reddish iron staining; rare silt-size fragments of clay coatings (papule-like); *Fine Fabric*: SMT 1a: speckled and dusty dark yellowish brown (PPL), isotic or very low interference colors (single grain, linked grain to coated grain [monic, gefuric to chitonic] related distribution, speckled b-fabric; XPL; SMT 1b—lamellae: bridged and coated related distribution, pale yellowish orange with reddish brown specks (OIL); rare likely mineralized tissue fragments and organic staining; *Pedofeatures*: *Textural*: MFT 1a—rare very thin (40 μm) clay coatings and impure coatings containing rare silt-size mica; MFT 1b—lamellae: abundant thin (40–240 μm) nonlaminated and microlaminated, pale	*Early Archaic & Clovis (0–50 mm) and into top of sterile (50–75 mm (120 mm))*: *Artifact-bearing* unit contains relatively high amounts of fine soil (C:F of 85:15) compared to the underlying *sterile* layer (C:F of 95:05), and more lamellae; lamellae contain less void space compared to general soil matrix.

		yellowish brown to blackish (PPL) clay coatings and infills; *Amorphous*: rare Fe/Mn staining of mineral grains, including likely mineral replacement of organic matter (see below for Fe/Mn cemented inclusions); *Fabric*: abundant fine (2–3 mm) burrows with rare broad (7 mm) loosely infilled burrows; *Excrements*: rare very thin (50 µm) organo-mineral excrements and organic excrements associated with relict roots.	
Microfacies 1a, 1b, and 1c/SMT 1a and 1b	2/9L5-6-2A & 5A, 2B & 5B, 2C & 5C, 2D & 5D ca. 64.5–71.5 cm	SM: *Structure*: MFT 1a, 1b and 1c—broadly layered with MFT 1b dominating upper half of slides and MFT 1a dominating lower half of slides where thin (1–4 mm thick) lamellae are more common; massive with fine (2–3 mm) burrowed microfabric; ca. 35% voids, very dominant simple packing voids (MFT 1c—lamellae: ca. 20% voids, common simple and complex packing voids with frequent to common fine (250 µm) vughs, some closed (MFT 1c—lamellae); *Coarse Mineral*: C:F (limit at 10 µm), 95:05 becoming 85:15 with depth (MFT 1c—lamellae: 70:30 if textural features included); very dominant, well-sorted, medium sand-size angular to subangular quartz, quartzite, and feldspar, with very few micas and heavy minerals; very few silt-size quartz and mica; *Coarse Organic/ Anthropogenic*: rare (x1) coarse (1 mm) soil inclusions (see below), very rare (<1%) charcoal (max. 1 mm; coated; see below); rare (x1) coarse (3 mm) Fe/Mn nodules of cemented sand grains (see below), very rare fine (400 µm) roots and fungal bodies, showing blackening of dark reddish brown colors (PPL, OIL), rare sand grains showing likely rubified (burned) reddish iron staining; rare silt-size fragments of clay coatings (papule-like); *Fine Fabric*: SMT 1: speckled and dusty dark yellowish brown (PPL), isotic or very low interference colors (single grain, linked grain to coated grain [monic, gefuric to chitonic] related distribution, speckled b-fabric; XPL); SMF 1c—lamellae: bridged and coated related distribution, pale yellowish orange with reddish brown specks (OIL); rare likely mineralized tissue fragments and organic staining; *Pedofeatures*: *Textural*: MFT 1a—rare very thin (40 µm) clay coatings and impure coatings containing rare silt-size mica; MFT 2b—lamellae: abundant thin (40–240 µm) nonlaminated and microlaminated, pale yellowish brown to blackish (PPL) clay	*Sterile (ca. 50–120 mm) over 'pre-Clovis' (ca. 120–145 mm)*: *Artifact-bearing* unit contains relatively high amounts of fine soil (C:F of 85:15) compared to the underlying *sterile* layer (C:F of 95:05), and more lamellae; lamellae contain less void space compared to general soil matrix.

(Continued)

Table II. *(Continued)*

Material (MFT/SMT)	Sample Number Examples	Soil Micromorphology (SM) of Sediments	Phase and Relative Depths; Comments
		coatings and infills; *Amorphous*: rare Fe/Mn staining of mineral grains, including likely mineral replacement of organic matter (see below for Fe/Mn cemented inclusions); *Fabric*: abundant fine (2–3 mm) burrows with rare broad (7 mm) loosely infilled burrows; *Excrements*: rare very thin (50 µm) organo-mineral excrements and organic excrements associated with relict roots.	
Microfacies types 1a, 1b, and 1c/SMT 1a and 1b	2/9L5-6-3A, 3B, 3C and 3D ca. 71.5-75.0 cm	SM: *Structure*: MFT 1b and 1c—generally homogeneous (MFT 1b) with very few thin (0.8–1.2 mm) lamellae; massive with fine (2–3 mm) burrowed microfabric; ca. 40% voids, very dominant simple packing voids (MFT 1c—lamellae: ca. 25% voids, common simple and complex packing voids with frequent to common fine (250 µm) vughs, some closed (MFT 1c—lamellae); *Coarse Mineral*: C:F (limit at 10 µm), 95:05 (MFT 1c—lamellae: 70:30 if textural features included); very dominant, well-sorted, medium sand-size angular to subangular quartz, quartzite, and feldspar, with very few micas and heavy minerals; very few silt-size quartz and mica; *Coarse Organic/Anthropogenic*: rare (x1) coarse (1 mm) soil inclusions (see below), very rare (<1%) charcoal (max. 0.5 mm; coated; see below); rare (x1) gravel-size (5 mm) angular quartzite/chert, very rare fine (400 µm) roots and fungal bodies, showing blackening of dark reddish brown colors (PPL, OIL), rare sand grains showing likely rubified (burned) reddish iron staining; rare silt-size fragments of clay coatings (papule-like); *Fine Fabric*: SMT 1a: speckled and dusty dark yellowish brown (PPL), isotic or very low interference colors (single grain, linked grain to coated grain [monic, gefuric to chitonic] related distribution, speckled b-fabric; XPL; MFT 3b—lamellae: bridged and coated), pale yellowish orange with reddish brown specks (OIL); rare likely mineralized tissue fragments and organic staining; *Pedofeatures*: *Textural*: MFT 1a—rare very thin (40 µm) clay coatings and impure coatings containing rare silt-size mica; MFT 3b—lamellae: abundant thin (40–240 µm) nonlaminated and microlaminated, pale yellowish brown to blackish (PPL) clay coatings and infills; *Amorphous*: rare Fe/Mn staining of mineral grains, including likely mineral replacement of organic matter;	*Lowermost sterile (ca. 145–175 mm):* low fine soil content except for in the very few lamellae.

		Fabric: abundant fine (2–3 mm) burrows; *Excrements*: rare very thin (40 µm) organic excrements and moderately broad (600 µm) aggregated organic excrements associated with relict roots.	
Coarse inclusions of fine soil aggregates (sometimes Fe stained) (SMT 2)	e.g., 2/9L5-6-1A & 4A, 1B & 4B	Very coarse sand and gravel-size (1–6 mm) subrounded to subangular fine soil inclusions: massive, but commonly with very fine (<150 channels µm) and burrows (800 µm), C:F, 40:60, very dominant angular and subangular medium sand-size quartz etc., SMT 2: speckled grayish brown (PPL), low interference colors (porphyric, speckled b-fabric, e.g., with fine mica; XPL), pale grayish brown (OIL); occasional to abundant fine amorphous organic matter with occasional plant tissues (mineralized), with occasional to many phytoliths; rare charcoal (max. 150 µm); soil sometimes coated with likely ferruginous 150-µm-thick hypocoating (and iron impregnated organic matter), with rare 100-µm-thick nonlaminated clay coatings; rubefied rarely; rare examples are fine and coarse layered (crust fragment?).	*Aggregate of soil broadly relict of bioturbated ancient topsoils*: much finer C:F compared to sediments in which they occur; much higher amounts of included relict organic matter, phytoliths and fine charcoal.
Coarse inclusions of sandy soil aggregates (SMT 3)	e.g., 2/9L5-6-4A	Very coarse sand-size (1 mm) crumb-like (broad excrement?) burrow inclusion?; C:F, 50:50, medium quartz sand with SMT 3: dark, dusty brown (PPL), very low interference colors (porphyric, speckled b-fabric, XPL), pale yellowish brown (OIL); very abundant fine amorphous organic matter with nonmineralized (birefringent) tissue fragments; occasional fragmenting nonlaminated clay coatings.	*Strongly humic nonmineralized crumb-like/excremental? soil inclusions:* rare example of likely *"recent"* burrowed material.
Coated charcoal	Ubiquitous	Very coarse sand-size and gravel-size (1–3 mm) wood charcoal, commonly embedded within 200 µm of fine soil material (as in coarse inclusions) with discontinuous Fe hypocoatings and, lastly, occasional nonlaminated clay coatings on the exterior.	*Coated charcoal/charcoal relict of occupations?:* fine soil material and Fe-Mn coatings have probably contributed to the preservation of these relatively coarse charcoal fragments.

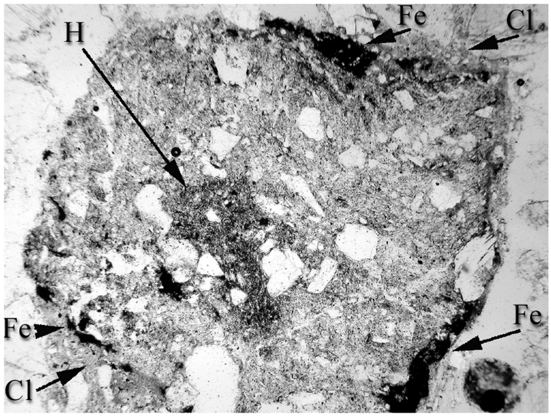

Figure 6. Photomicrograph of a coarse (3 mm) aggregate of fine soil (thin section 1A) that contains phytoliths and relict humus (including humus-rich burrow—H); it is iron stained (Fe) and partially coated with illuvial clay (Cl) (Table IIb). Clay coatings post-date iron staining. Plane polarized light (PPL); frame length is ~2.3 mm.

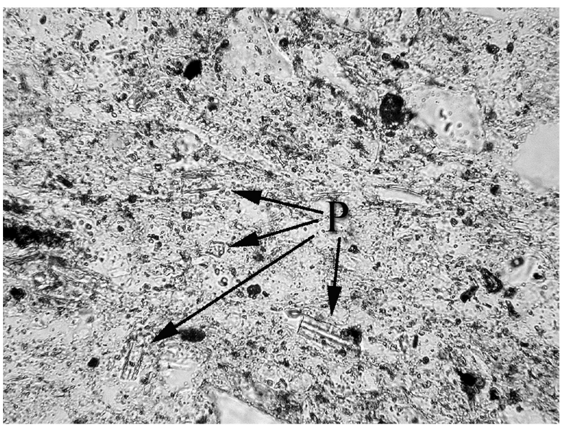

Figure 7. Detail of Figure 6, showing presence of phytoliths (P) and relict humus. PPL; frame length is ~230 µm.

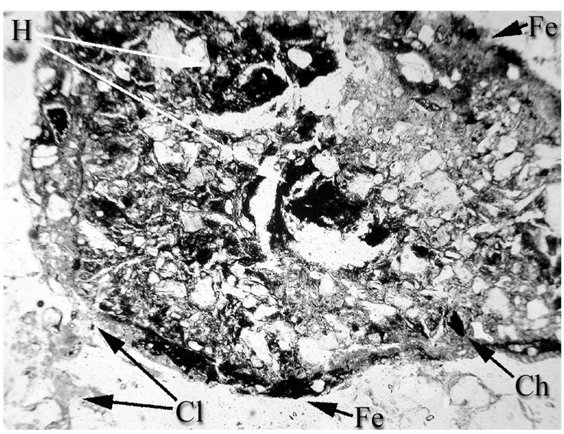

Figure 8. Photomicrograph of coarse (2.5 mm) aggregate of fine soil (thin section 4B), showing a burrowed and channel microfabric, rich in relict humus (H) (see Table IIb); note charcoal (Ch) fragment near base of coarse inclusion. Note iron-stained (Fe) edges (hypocoatings) and later clay coatings (CL). PPL; frame length is 2.3 mm.

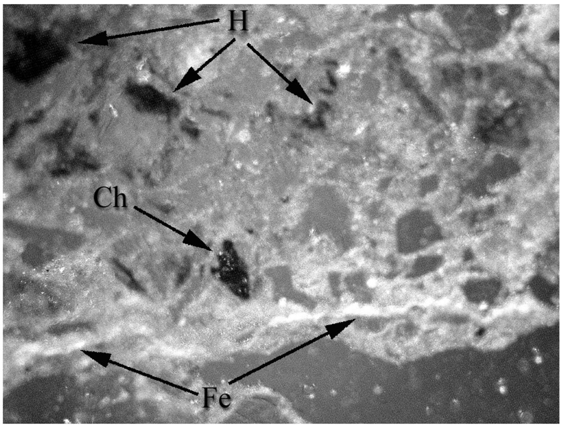

Figure 9. Detail of Figure 8; note relict dark humus (H), "bright" ferruginized (Fe) humus and iron-stained margins, and fine charcoal fragment (Ch). Oblique incident light (OIL); frame length is 900 µm.

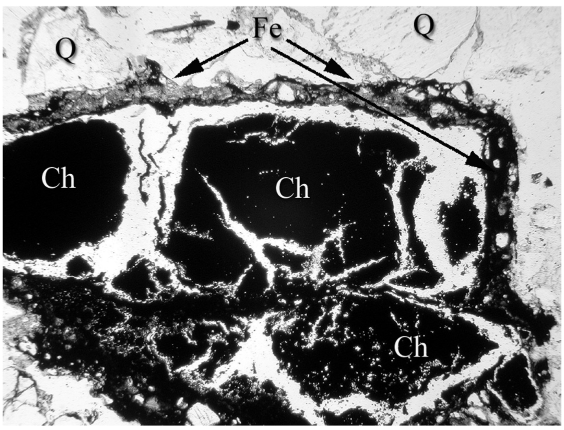

Figure 10. Photomicrograph of iron stained (Fe), fine soil-coated piece of charcoal (Ch) in thin section 5D—now slightly fragmented—within the quartz (Q) sand sediment (see Table IIb). PPL; frame length is 2.3 mm.

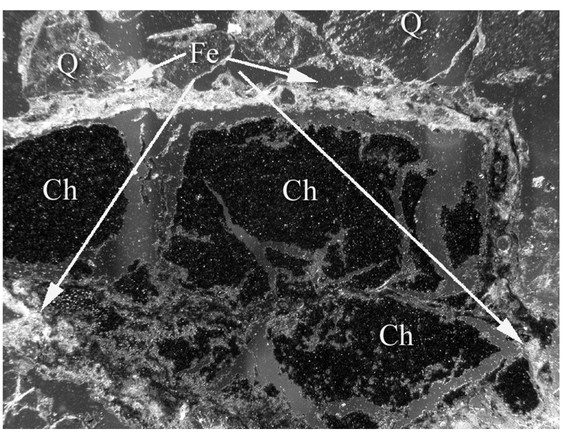

Figure 11. As Figure 10, with OIL showing ferruginized (Fe) fine soil coating of the charcoal (Ch) fragment, within the quartz (Q) sand sediment.

RESULTS AND INTERPRETATION

Examples of the microfabric types, their description, and types of inclusions are presented in Figures 4–11 and Table II.

Microfacies Types (MFTs) and Clay Lamellae

The analysis of the microstratigraphy resulted in the identification of three main microfacies (all with similar soil microfabric types 1a–1c): (1) MFT 1a: sands with moderate amounts of fine (ca. <10 μm) material (Coarse:Fine [C:F] ratios 85:15); (2) MFT 1b: sands with low amounts of fine (ca. <10 μm) material (C:F ratios 95:05); and (3) MFT 1c: clay lamellae with moderately high amounts of fine material (C:F 70:30) (Figures 4, 5). The MFT 1c microfacies is characterized by iron-stained, nonlaminated and microlaminated clay coatings and infills. Although iron and manganese staining and formation of iron-clay lamellae are not unequivocal pedological features, the amount of biological working by small invertebrate mesofauna in the sediments clearly shows that these have had a pedological history even if only as entisols; there is both evidence of ubiquitous thin organo-mineral excrements and, more significantly, fragmentary examples of bioworked humic soil relict of presumably thin A1h horizon formation (Babel, 1975; Bal, 1982) (Figures 6–9). Thus, the deposits analyzed need to be regarded as a cumulic soil-sediment sequence and/or as a paleosol/series of paleosols (see below).

The microfacies identified in the stratigraphic sequence from top to bottom at Cactus Hill are as follows within Levels 5c–7:

- Archaeological Layer A: *Early Archaic and Clovis level:* MFT 1a (with "thin" MFT 1c—clay lamellae; see below)
- Archaeological Layer B: *Culturally sterile sand level (layer between levels 5c and 6b):* MFT 1b (with "thin" MFT 1c—clay lamellae; Figures 4, 5)
- Archaeological Layer C: *Pre-Clovis blade level:* MFT 1a (with "thick" MFT 1c—clay lamellae)
- Archaeological Layer D: *Culturally sterile sand below the pre-Clovis blade level:* MFT 1b (with "thin" MFT 1c—clay lamellae)

There are therefore clear stratigraphic differences between the archaeological units identified through excavation at Unit 2/9 at Cactus Hill. Although few in number, clay lamellae are more common and thicker (2–3 mm thick; Figures 4, 5) in MFT 1a compared to the ones in MFT 1b (0.8–1.2 mm). They do not, however, appear strictly to respect the archaeological stratigraphy, but may have been positively influenced during their formation by the presence of higher amounts of fine material in areas of SMT 1a, which acted as a weak hydraulic barrier, for example, by creating less pore space than the more sandy areas (20% voids compared to 35% voids; see Figures 4, 5). Thus, the clay lamellae and the clay coatings that occur ubiquitously can be mainly ascribed to post-depositional phases of pedogenesis affecting this dune (see Introduction). It should be noted that phosphorus can be preferentially concentrated in clay coatings (Parfenova, Mochalova, & Titova, 1964). This may partially explain any coincidence between the (post-depositional) clay lamellae-affected cultural layers and phosphorus concentrations, in addition to the relative concentrations of relict fine organic matter (seen in thin section) and bone fragments (recovered during excavation), which are other chief sources of phosphorus.

Coarse Inclusions

A very small number of coarse inclusions were identified, namely: (1) coarse inclusions of fine soil aggregates (sometimes iron-stained) (Figures 5–8), (2) coarse inclusions of sandy soil aggregates, (3) coarse mineral inclusions (angular quartzite and chert), (4) coarse "coated" charcoal (Figures 9, 10), and (5) ferruginous nodules (also mapped in the 1993 section).

(1) Of particular interest are the coarse (1–6 mm) inclusions of fine soil aggregates that are sometimes iron-stained and contain what appears to be mineralized relict organic matter, albeit sometimes in large amounts (Figures 6, 7). Phytoliths, which are usually very sparse (and too few to count) in the microfabric at Cactus Hill, are ubiquitous (occasional to many) in these included aggregates of fine soil. Of equal importance in terms of the radiocarbon dating carried out so far at Cactus Hill, is the presence of rare very fine charcoal fragments (Figures 8, 9; see Figures 10, 11). In terms of microfabric type, these soil inclusions contain a lower proportion of coarse (>10 µm) to fine (<10 µm) material (C:F 40:60) than generally present (C:F 95:05 or 85:15). Some also have a biologically worked (channel and burrow) microfabric. One example displays layered fine soil. Finally, these soil inclusions are iron-stained (hypocoating with minor Fe impregnation), with clay coatings succeeding all previous pedofeatures (see Figures 6, 7). It is also possible that some could be slightly burned, like some mineral grains generally found in the thin sections at Cactus Hill. These fine soil inclusions may be relict fragments of Ah horizon material (mineralized humus and phytoliths) that became iron-stained (see 4 below, coated charcoal).

(2) Only two coarse sandy soil aggregates were found. These contain amorphous organic matter with non-mineralized (birefringent) tissue fragments (but no charcoal or obvious phytoliths concentrations), thus indicating that these are rare instances of probably "recent" burrowing.

(3) Examples of angular chert and quartzite (micro-artifacts) were present in the thin sections.

(4) Coarse charcoal is ubiquitous, albeit occurring rarely to very rarely, and including 17 large fragments. It is interesting to note that these coarse (1–3 mm) charcoal grains were coated by fine soil materials that became ferruginized and eventually coated with illuvial clay, the last related to clay lamellae (Figures 10, 11). This earliest coating probably protected the charcoal from fragmentation, a common fate of charcoal affected by wetting and drying and which may help explain the preservation of charcoal suitable for ^{14}C-dating at Cactus Hill.

Post-Depositional Processes

Plant remains, in the form of fine (400 µm) root remains and likely fungal bodies, are very rare. None were autofluorescent under blue light, indicating an absence of recent roots. Root material could be differentiated from charcoal by its reddish brown color (PPL, OIL), a color that implies both aging and possible ferruginization, a typical process in buried aerobic sands, and one that can occur rapidly in dead roots after burial (ca. 30 years, Macphail et al., 2003; see also Babel, 1975). Some roots and associated root channels are associated with rare, very thin (40 μm) organic excrements and moderately broad (600 μm) aggregated organic excrements.

In general, the most common evidence of small invertebrate mesofaunal activity is an excremental fabric found associated with abundant fine (2–3 mm) burrows (Bal, 1982). Organo-mineral excrements are aggregated, forming a bridged (gefuric) and coated (chitonic) distribution, again a likely function of aging in buried sandy soils (Macphail et al., 2003). In comparison, broad (7 mm), loosely infilled burrows containing organo-mineral excrements are rare. This indicates that the stratigraphy is *currently* only recording activity by small invertebrates with little evidence of large insect or small mammal activity.

Archaeological levels seem to have broadly consistent soil microfabric and microfacies types with evidence of bioturbation by fine roots and small mesofauna. Despite the fact that 20 thin sections were examined, there is no *present and obvious* evidence of coarse rooting or large animal burrows working material between levels. Nevertheless, it is inconceivable that paleosurfaces were not bioturbated by larger fauna (Johnson, 2002), for example, by scavenging animals, especially if middens were present during the Clovis and pre-Clovis occupations. Soil micromorphology has shown how rapidly bioturbation disperses cultural material on old land surfaces into the soil (Goldberg & Byrd, 1999; Lewis, Wiltshire, & Macphail, 1992; Roberts & Parfitt, 1999). At Playa Vista, California, Mission Period (ca. 18th–19th century) hearths are burrowed, but clearly much less dispersed compared to older, Archaic occupations (Altschul et al., 2005; Goldberg & Macphail, 2007; Mayer & Homburg, 2006). Equally, paleosurfaces and associated soils can be lost through deflation, or buried by renewed eolian activity, both situations leading to the development of "weakly formed surface soils" (Cremeens & Hart, 1995: Figure 2.1); the fragmentary evidence of earlier-formed humic topsoils that are no longer evident is evidence of soil deflation. It can be suggested that a vegetation of grass and pine woodland trapped dust, leading to the development of a fine, humic, and phytolith-rich topsoil. (A micromorphological study of exposed bare sands in the Netherlands found that 2–3.5-cm-thick Ah horizons formed over a period of 2–13 years, and noted the important role of mesofauna; Mücher, 1997.) Experimental studies have demonstrated, however, that after burial by sands, the extant small invertebrate mesofauna population that becomes buried seems to do little mixing in comparison to extant surface biota (maximum thickness of the *buried* burrowed zone being 20 mm at Wareham; Macphail et al., 2003).

Clearly then, the stratigraphy identified at Unit 2/9 at Cactus Hill must be considered as residual of a series of sedimentary, pedological (*sensu lato*), and probable disturbance and erosional (likely deflation) events. The last suggestion is indicated, for example, by the presence of fragmentary traces of earlier Ah1 horizons that are rich in relict organic matter and phytoliths (Figures 6–9), coarse charcoal

(Figures 10, 11), and the apparent lack of coarsely burrowed and disturbed surface soils that elsewhere are associated with animal scavenging of occupations and middens (Goldberg & Byrd, 1999; Goldberg & Macphail, 2007; Mayer & Homburg, 2006). For example, comparisons of Mission Period occupation levels with those from earlier (>6,000 B.P.) periods at Playa Vista showed how artifacts and humic occupation soil had become increasingly dispersed through time; burrows within the Mission Period hearths, for example, clearly mixed humic soil down-profile into once archaeologically "sterile" sediments. It is not yet possible to identify the exact series of site formation processes responsible for the current stratified sequence of suggested pre-Clovis and overlying sterile and Clovis layers, because of the principle of equifinality, but bioturbation, erosion, and possible slope movement all need to be considered (Johnson, 2002). Future investigations at Cactus Hill will undoubtedly allow refinement of this present suggested interpretation of site formation processes.

DISCUSSION AND CONCLUSIONS

The employment of multiple thin section samples of three excavated levels at Unit 2/9 Cactus Hill permitted a comprehensive and representative soil micromorphological study of Clovis and reputed pre-Clovis artifact-bearing layers and the "sterile zones" between and below them. Analysis of the different microfacies types reveals a broad relationship between artifact-bearing layers and soils with relatively high proportions of fine (ca. <10 μm) material and coarse (ca. 1–6 mm) inclusions such as (a) flakes of chert or quartzite, (b) aggregates of fine soil, and (c) fine soil-coated charcoal. Sterile and natural layers contain lower amounts of fine material and generally fewer coarse inclusions. Iron-clay coatings and lamellae are ubiquitous but are more common in soil layers with the highest proportions of fine material. Inclusions of fine soil aggregates have traits relict of a topsoil origin, namely: high amounts of relict fine organic matter, a biologically worked microfabric (fine channels and burrows), phytoliths, and, more rarely, inclusions of fine charcoal. Coarse charcoal fragments are coated by the same kind of fine soil material, and likewise show iron staining before being coated with illuvial clay. These sparse inclusions are possibly fragments of soils and associated biota contemporary with artifacts from the same layers. Unfortunately, no pollen was preserved at the site to expand our paleoenvironmental understanding of the area, these sands being a poor medium for pollen preservation. Site formation processes at Cactus Hill consisted of eolian (dune) sand sedimentation and a number of post-depositional processes that probably included bioturbation (site disturbance and downward movement of humic topsoil and charcoal), erosion (probably deflation) of these disturbed occupation soils, and latterly iron-clay lamellae formation. Although at present there is only evidence of small-scale biological working, thus implying little disturbance of the archaeological layers for probably millennia (a finding that is consistent with both the radiocarbon and OSL dating), analog studies of open sites indicate that it is likely that the original cultural deposits were affected by scavenging and burrowing fauna. This has led to the probable penecontemporaneous broad horizontal and vertical dispersal of artifacts and associated soils from each cultural period.

Micromorphological observations and previous analyses conducted at the site (e.g., charcoal, phosphorus, phytoliths, and radiocarbon and OSL dating) allow the following conclusions:

1. Eolian sand deposition (dune formation) may have been interspersed with ephemeral topsoil formation under mixed grasses and pine woodland, with low vegetation trapping dust that permitted the formation of a fine, humic, and phytolith-rich topsoil.
2. Humans occupied these short-lived stabilized surfaces, depositing artifacts and charcoal.
3. Penecontemporaneous scavenging and burrowing animals began the process of artifact dispersal and mixing of any fine soil into the dune sands.
4. Eolian sedimentation, perhaps interrupted by erosional processes such as deflation, led to the present stratified sequence. This sequence, on the basis of the small-scale bioturbation features recorded in thin section, was probably stable for millennia. Clay lamellae overprinted this stabilized stratigraphy.
5. Soil micromorphological analysis has defined a difference between occupational units (pre-Clovis and Clovis) and sterile units found between these units as well as above and below.
6. According to this analysis, and other independent investigations of this part of Cactus Hill, the site appears intact with only minor disturbances affecting the long-term integrity of the stratigraphy.

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REFERENCES

Adovasio, J.M., Donahue, J., & Stuckenrath, R. (1990). The Meadowcroft rockshelter radiocarbon chronology 1975–1990. American Antiquity, 55, 348–354.

Altschul, J.H., Ciolek-Torrello, R., Grenda, D.R., Homburg, J.A., Benaron, S., & Stoll, A.Q. (2005). Ballona archaeology: A decade of multidisciplinary research. Proceedings of the Society for California Archaeology, 18, 283–301.

Babel, U. (1975). Micromorphology of soil organic matter. In J.E. Giesking (Ed.), Soil components: Organic components, Vol. 1 (pp. 369–473). New York: Springer-Verlag.

Bal, L. (1982). Zoological ripening of soils. Agricultural Research Report. Wageningen: Centre for Agricultural Publishing and Documentation.

Bradley, B., & Stanford, D. (2004). The North Atlantic ice-edge corridor: A possible Palaeolithic route to the New World. World Archaeology, 36, 459–478.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., & Tursina, T.N. (1985). Handbook for soil thin section description. Wolverhampton: Waine Research Publications.

Courty, M.A. (2001). Microfacies analysis assisting archaeological stratigraphy. In P. Goldberg, V.T. Holliday, & C.R. Ferring (Eds.), Earth sciences and archaeology (pp. 205–239). New York: Kluwer.

Courty, M.A., Goldberg, P., & Macphail, R.I. (1989). Soils and micromorphology in archaeology. Cambridge: Cambridge University Press.

Cremeens, D.L., & Hart, J.P. (1995). On chronostratigraphy, pedostratigraphy, and archaeological context. In M.E. Collins, B.J. Carter, B.G. Gladfelter, & R.J. Southard (Eds.), Pedological perspectives in archaeological research (pp. 15–33). SSSA Special Publication No. 44. Madison, WI: Soil Science Society of America, Inc.

Dillehay, T.D. (1997). Monte Verde: A late Pleistocene settlement in Chile, Vol. II: The archaeological context and interpretation. Washington, DC: Smithsonian Institution Press.

Feathers, J.K., Rhodes, E.J., Huot, S., and McAvoy, J.M. (2006). Luminescence dating of pre-Clovis strata at the Cactus Hill site, Virginia, USA. Quaternary Geochronology, 1, 167–187.

Goebel, T., Waters, M.R., & O'Rourke, D.H. (2008). The late Pleistocene dispersal of modern humans in the Americas. Science, 319, 1497–1502.

Goldberg, P., and Byrd, B.F. (1999). The interpretive potential of micromorphological analysis at prehistoric shell midden sites on Camp Pendleton. Pacific Coast Archaeological Society Quarterly, 35, 1–23.

Goldberg, P., & Macphail, R.I. (2006). Practical and theoretical geoarchaeology. Oxford: Blackwell Publishing.

Goldberg, P., & Macphail, R.I. (2007). Playa Vista archaeological and historical project (California): Soil micromorphology—preliminary report. Unpublished report, Statistical Research, Inc., Tucson, AZ.

Johnson, D.L. (2002). Darwin would be proud: Bioturbation, dynamic denudation, and the power of theory in science. Geoarchaeology, 17, 7–40.

Lewis, J.S., Wiltshire, P., & Macphail, R.I. (1992). A late Devensian/early Flandrian site at Three Ways Wharf, Uxbridge: Environmental implications. In S. Needham & M.G. Macklin (Eds.), Alluvial archaeology in Britain, Oxbow (pp. 235–248). Oxford: Oxbow Monograph 27.

Macphail, R.I., Crowther, J., Acott, T.G., Bell, M.G., & Cruise, G.M. (2003). The experimental earthwork at Wareham, Dorset after 33 years: Changes to the buried LFH and Ah horizon. Journal of Archaeological Science 30, 77–93.

Macphail, R.I., & Cruise, G.M. (2001). The soil micromorphologist as team player: A multianalytical approach to the study of European microstratigraphy. In P. Goldberg, V. Holliday, & R. Ferring (Eds.), Earth science and archaeology (pp. 241–267). New York: Kluwer Academic/Plenum Publishers.

Mayer, J., & Homburg, J.A. (2006). Micromorphology of intermediate period "middens" in the Ballona of Coastal California. In Archaeological Sciences of the Americas Symposium, September 13–16, 2006, Schedule of Events and Abstracts (pp. 39–40). Tucson, AZ: The University of Arizona.

McAvoy, J.M. (1992). Nottoway River survey, Part I: Clovis settlement patterns. Archaeological Society of Virginia Special Publication, 28, 171.

McAvoy, J.M., & McAvoy, L.D. (1997). Archaeological investigations of the site 44SX202, Cactus Hill, Sussex County, Virginia. Richmond: Virginia Department of Historic Resources.

McAvoy, J.M., Baker, J.C., Feathers, J.K., Hodges, R.L., McWeeney, L.J., & Whyte, T.R. (2000). Summary of research at the Cactus Hill archaeological site, 44SX202, Sussex County, Virginia (Grant #6345–98). National Geographic Society, 15.

McAvoy, J.M., Feathers, J.K., Macphail, R.I., & Wagner, D.P. (2004). Verification of the age and integrity of strata containing pre-Clovis artifacts at the Cactus Hill site, 44SX202, Virginia (Grant #7069–01). National Geographic Society, 12.

Mücher, H.J. (1997). The response of a soil ecosystem to mowing and sod removal: A micromorphological study in the Netherlands. In S. Shoba, M. Gerasimova, & R. Miedema (Eds.), Soil micromorphology: Studies on soil diversity, diagnostics and dynamics (pp. 271–281). Moscow-Wageningen: International Soil Science Society.

Parfenova, E.I., Mochalova, E.F., and Titova, N.A. (1964). Micromorphology and chemism of humus-clay new-formations in grey forest soils. In A. Jongerius (Ed.), Soil micromorphology (pp. 201–212). Amsterdam: Elsevier.

Perron, J.T. (1999). Micromorphology of the Cactus Hill site (44SX202), Sussex County, Virginia. Unpublished dissertation, Harvard University Anthropology Department, Cambridge.

Phillips, D.H., Foss, J.E., & Goodyear, A.C. (2006). Micromorphology of lamellae formed in an alluvial soil, Big Pine Tree archaeological site, South Carolina. Soil Survey Horizons, 47, 46–50.

Roberts, M.B., & Parfitt, S. A. (1999). Boxgrove. A Middle Pleistocene hominid site at Eartham Quarry, Boxgrove, West Sussex. London: English Heritage.

Soil Survey Staff (1999). Soil taxonomy. Agriculture Handbook 436. Washington, DC: U.S. Department of Agriculture, U.S. Government Printing Office.
Stoops, G. (2003). Guidelines for analysis and description of soil and regolith thin sections. Madison, WI: Soil Science Society of America, Inc.
Taylor, R.E., Haynes, C.V., & Stuiver, M. (1996) Clovis and Folsom age estimates: Stratigraphic context and radiocarbon calibration. Antiquity, 70, 515–525.
Wagner, D.P., & McAvoy, J.M. (2004). Pedoarchaeology of Cactus Hill, a sandy Palaeoindian site in southeastern Virginia. Geoarchaeology 19, 297–322.
Waters, M.R., & Stafford, T.W., Jr. (2007). Redefining the age of Clovis: Implications for the peopling of the Americas. Science, 315, 1122–1126.

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