Procedings of the Second International Conference on Pedo-Archaeology

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April 6-9, 1994

edited by:

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ANTHROPOLOGICAL STUDIES 10

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University of South Carolina
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PREFACE

The Second International Conference on Pedo-Archaeology was held in Columbia, South Carolina on April 6-9, 1994. The conference was sponsored by the South Carolina Institute of Archaeology and Anthropology (SCIAA) of the University of South Carolina, the Savannah River Archaeological Research Program of SCIAA, the Egyptian Studies Association of the University of South Carolina, the Waccamaw Center for Historical and Cultural Studies at Coastal Carolina University, and the Plant and Soil Science Department of the University of Tennessee.

One of the objectives of the conference was to incorporate the geology and pedology of the region with that of the local archaeology to give a field-based appreciation for pedo-archaeology in the midlands of South Carolina. To that end, John Foss, Albert Goodyear, and Tommy Charles conducted fieldwork in the previous spring at key sites in the vicinity of Columbia which were used as part of the field trip for the conference. Backhoe trenches were excavated and studied in several alluvial settings where typical expressions in the pedosedimentary cycle could be examined by conferees. Data from these trenches were analyzed by Foss and his colleagues at the University of Tennessee and made a part of the field trip guidebook. These trenches were reopened during the conference for on-site inspection.

Publication of these proceedings was regrettable delayed. The senior editor takes full responsibility for this. He also wishes to thank co-editor John Foss for his help in organizing the conference and for his contributions to the field trip studies, and co-editor Ken Sassaman for putting all the papers into the present format.

The Third International Conference on Soils, Geomorphology and Archaeology (aka Pedo-Archaeology) will be held in Luray, Virginia, May 22-24, 1997.
Stratigraphy and Soil Chronosequence of the Brasstown Sites: 
A Model for Age Assessment of Alluvium in 
the Southern Blue Ridge, U.S.A.

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The Brasstown Sites occur on the floodplain and terraces of Brasstown Creek, a 5th order stream draining Georgia's highest peaks in Towns County. The valley is about 1 km wide and contains a series of Pleistocene terrace remnants. The sites contain abundant Cherokee and Mississippian artifacts with lesser amounts of Woodland and Archaic material. Most of the artifacts occur on the terraces. Radiocarbon dates from the floodplain (T0) and lowest terrace (T1) facilitate construction of a soil chronosequence that elucidates the Pleistocene-Holocene boundary and provides a detailed example of the degree of soil development in pre-Holocene sediments. Wood samples overlying channel-lag deposits of the floodplain are dated at 1880 ± 70 yr B.P. (Beta-65973) and 1720 ± 60 yr B.P. (Beta-65974). Charcoal from a buried A-horizon (buried by 40 cm of historical sediment) within the floodplain is dated at 640 ± 60 yr B.P. (Beta-65972), which brackets the age of prehistoric floodplain sediments between about 1900-600 yr B.P. Floodplain soils are characterized by Entisols in the historical sediment and Inceptisols with weak Bw horizons in the prehistoric sediment. The lowest terrace (T1) is terminal Pleistocene in age, which is indicated by a 13,290 ± 80 yr B.P. (Beta-65975) date from wood overlying channel-lag deposits of T1. Soils on T1 contain Bt horizons that are about 0.9 m thick, 10YR4/5 to 5/4 in color, and contain moderately thick clay skins on ped faces in the top 20 cm of the Bt horizon. Terraces that are older than T1 are redder and contain more clay. Standard rubification indexes, iron oxide concentrations, and other chemical weathering indexes provide quantitative data that correlate well with the progressively older ages of terraces. Understanding that factors of soil formation other than time may create variance in these values, these data are useful for distinguishing pre-Holocene alluvium, and thus are useful for archaeological surveys.

The objective of this paper is to provide data on a soil chronosequence of stream terraces in the southern Blue Ridge Mountains of extreme north Georgia. Previous soil chronosequence studies in the Southeastern United States (Markewich et al., 1989) and elsewhere (Birkland, 1984) have shown the utility of soils as relative age indicators, but no studies are known for the southern Blue Ridge Mountains. Due to regional variance in factors of soil formation other than time (climate, parent material, biotic, and topographic factors) age correlations based on soil formation should be local and should maintain microenvironment and parent materials as constant as possible (Daniels and Hammer, 1992). This paper illustrates the use of easily measured soil development criteria as indexes for age assessment of alluvium in a small region, the southern Blue Ridge, and provides particular detail on the Pleistocene-Holocene transition, which can be quite useful for archaeologists in identifying culturally sterile strata, at least in part of the southern Blue Ridge province.

STUDY AREA

The Brasstown Sites are located on the floodplain and terraces on the west side of Brasstown Creek (Fig. 1), a fifth order stream which drains 65 km² upstream of the sites in the midst of Georgia's highest peaks that are as high as 1458 masl, and where total relief is about 900 m. The sites contain abundant Cherokee and Mississippian artifacts with lesser amounts of Woodland and Archaic material. The valley is approximately 1 km wide in the study area and contains a sequence of at least five fluvial terrace remnants that differ considerably in their age and soil development. In the study area Brasstown Creek is meandering and has the following dimensions: a map slope of 5 m km⁻¹, 10-14 m channel width, and 2.0-2.2 m bankfull depth. Riffles are composed of gravel and boulders, which generally range in size from 2-300 mm, and pools generally have sand beds. The cohesive stream banks and floodplain sediments are mainly composed of medium and fine sand that grades upward to silty clay.

Natural vegetation in the region is that of a mixed deciduous forest, mean annual rainfall is approximately
FIG. 1. Part of the Hiawassee, Georgia-North Carolina 7.5 minute U.S. Geological Survey 1:24,000 topographic map. Top of the frame is due north. The upper left corner of the frame is at 83°52'30" west longitude and 34°57'30" north latitude.
1520 mm yr⁻¹, and mean annual temperature is 13°C (Hodler and Schretter, 1986). Soils on the modern floodplain are Entisols and Inceptisols, and Ultisols are found on the terraces and uplands (Carson and Green, 1981). Bedrock is composed of biotite gneiss throughout most of the watershed, but the headwaters of Brasstown Creek cut across garnet-mica-schist and amphibolite-ultramafic rocks (Georgia Department of Natural Resources, 1976).

METHODS

Pedologic and stratigraphic investigations at the Brasstown Sites were done during the summer of 1993 using backhoe trenches, pits, and bucket-auger holes to outline the stratigraphy and soils. Soil profiles were described using standard Soil Conservation Service terminology (Birkland, 1984) and moist Munsell colors. Elevations were determined with electronic distance measuring equipment tied to the site datum. Lab methods involved particle size, dithionite extractable iron, and total chemical analysis. Soil profiles chosen for characterization of each terrace were from the most well-drained and least erosive portion of each stratigraphic unit. Particle size analysis was done by hydrometer and sieve methods (Gee and Bauder, 1986). Iron oxides were determined by the citrate-dithionite method involved particle size, dithionite extractable iron, and total chemical analysis. Soil profiles chosen for characterization of each terrace were from the most well-drained and least erosive portion of each stratigraphic unit. Particle size analysis was done by hydrometer and sieve methods (Gee and Bauder, 1986). Iron oxides were determined by the citrate-dithionite extraction of Olson and Ellis (1982). Total chemical digestes were done by dissolving the samples in a cocktail of HF-HCl-HNO₃ acids. Elemental concentrations for iron oxides and total chemical analyses were determined with an inductively coupled argon plasma generator at the University of Georgia Chemical Analysis Laboratory. Rubification values were measured using the Hurst Index (Hurst, 1977) and the Buntley-Westin Index (Buntley and Westin, 1965) with moist Munsell soil colors. The Hurst Index quantifies the hue (5R=5, 10R=10, 2.5YR=12.5, 5YR=15, 7.5YR=17.5, 10YR=20, 2.5Y=22.5, 5Y=25) and multiplies it by the value/chroma fraction. The Buntley-Westin Index quantifies the hue (2.5YR=6, 5YR=5, 7.5YR=4, 10YR=3, 2.5Y=2, 5Y=1), which is multiplied by the chroma.

STRATIGRAPHY AND SOILS

The stratigraphy of the valley fill at the Brasstown Sites consists of nine informal, allostratigraphic units overlying bedrock or saprolite (weathered bedrock) (Figs. 2 and 3). Allostratigraphic units are defined on the basis of bounding surfaces including soils, paleosols, geomorphic surfaces, and lithic contacts that are laterally traceable (North American Commission on Stratigraphic Nomenclature, 1983). Seven of the allostratigraphic units are fluvial deposits (units T0.0, T0.1, T1, T2, T3, T4, T5) and two units are composed of alluvial/colluvial fan deposits (units AF1 and AF2) derived from small watersheds and hillsides along the valley margin. The physical and chemical characteristics representative of each unit are shown in Fig. 4.

The fluvial deposits include historical (T0.0), late Holocene (T0.1), terminal Pleistocene (T1), and pre-late Pleistocene (T2-T5) sediments, based on radiocarbon dates from wood and charcoal samples recovered in backhoe trenches (Figs. 2 and 3). Units T0.1, T1, T2, T3, T4, and T5 are all similar in that they consist of 0.25-1.0 m of channel lag gravels overlain by 1-2 m of a top stratum of medium and fine loamy sand graded upward to clay loam and clay (Figs. 2-4). The graded top stratum represents lateral accretion sands graded upward to silty and clayey vertical accretion sediments. Colors of the units primarily reflect drainage conditions and soil development. The C-horizon colors generally are 5Y hues in unoxidized sediments below the water table and 2.5Y hues with mottles in the unsaturated zone. The B-horizon colors include 10YR hues in the youngest units (T0, T1, T2) and 7.5YR (T3, AF1) and 2.5YR (T4, T5, AF2) hues in the oldest units. The allostratigraphic units differ primarily in their degree of soil development, which ranges from Entisols in T0.0 to Ultisols in T2-T5. Unit T5 consists of upland alluvium situated on a narrow interfluve on the edge of the valley that is very weathered and overlies saprolite. The other fluvial units (T0-T4) overlie friable biotite gneiss. Unit T0.0 is somewhat unique because it primarily consists of 10-50 cm of vertical accretion sediments that bury unit T0.1 with only an isolated occurrence of channel lag gravels in a back-levee flood channel. The alluvial fan units (AF1 and AF2) differ from the terrace deposits because they do not exhibit a clear graded textural sequence, tend to be more poorly sorted than the terrace deposits, and exceed 2 m in thickness (Fig. 4), characteristics that are representative of a hillslope origin.

Unit T0.0

Unit T0.0 consists of 0.25-0.75 m of historical sediments that make up the surface of the modern floodplain of Brasstown Creek. An historical age is indicated by a lack of Cherokee Indian artifacts, laminated and massive bedding with little to no pedologic development, an Ap-C horizon soil profile (Entisol), and a radiocarbon date of 640 ± 60 yr B.P. from charcoal in the underlying buried A-horizon of unit T0.1. Unit T0.0 primarily consists of laminated/massive, yellowish brown (10YR 4.5/4) loam derived from overbank flooding. However, a channel lag deposit of back-levee flood gravels was identified in backhoe transect #1 (Fig. 3). Some portions of the floodplain contain laminae and thin beds of yellowish red (5YR 5/6) silty clay that may be derived from upland erosion caused by heavy equipment excavations and construction.

Unit T0.1

Unit T0.1 consists of late Holocene fluvial sediments that make up the bulk of the floodplain on the
FIG. 2. Composite stratigraphic section of the Brasstown Creek valley approximately 2 km north of Young Harris, Georgia. Soil profiles show the position of sites referenced in the text.

FIG. 3. Backhoe trench transect #1. Dots on the graphed line represent surveyed points.
FIG. 4. Particle size, iron and aluminum oxide, and soil profile data for each allostratigraphic unit found at the Brasstown sites.
west side of Brasstown Creek. However, T0.1 is buried by 0.25-0.75 m of historical sediments of unit T0.0 across the entire floodplain. Wood samples collected from unoxidized fine sandy sediment immediately above the channel lag gravels yielded dates of 1,720 ± 60 yr B.P. (Beta-65974) and 1,880 ± 70 yr B.P. (Beta-65973) indicating that lateral migration of the stream channel on the west side of the present channel probably occurred between 1600 and 1900 yr B.P. A radiocarbon date of 640 ± 60 yr B.P. (Beta-65972) from charcoal at the top of unit T0.1 indicates that vertical accretion of T0.1 ceased by about 600 yr B.P. This indicates that long-term average top stratum sedimentation rates within T0.1 were about 0.1 cm yr⁻¹ (135 cm / 1300 yr). The buried soil formed in the top of unit T0.1 is an Inceptisol and is typified by a brown (10YR 4/3 to 3/3) silt loam Ab horizon that overlies a brown (10YR 4/3) to yellowish brown (10YR 5/4) Bw horizon. Unit T0.1 contains a light scatter of Woodland artifacts buried within the unit and some late Archaic artifacts along the terrace scarp of unit T1.

**Unit T1**

Unit T1 consists of terminal Pleistocene fluvial sediments that make up the lowest terrace in the valley of Brasstown Creek. In fact, the maximum elevation of T1 is only 0.1 to 0.2 m above the maximum elevation of the modern floodplain (T0.0). Only a small remnant of T1 was identified in the southern part of the project area and it is possible that unit T1 is buried by historical sediment in other parts of the valley, although burial of T1 was not observed in any excavations within the study area. A terminal Pleistocene age is indicated by wood collected immediately above channel lag gravels at the western edge of this unit that yielded a date of 13,290 ± 80 yr B.P. (Beta-65975). This radiocarbon date and the sloping upper boundary of T1 gravels (Fig. 3) indicates that progressive downcutting to the level of the modern stream bed was completed by about 13,000 yr B.P. Assuming that sedimentation rates within the top stratum of T1 were not slower than rates of the late Holocene observed in unit T0.1 (0.1 cm yr⁻¹), then sedimentation and terrace formation of T1 probably was completed by 11,000 yr B.P. Thus, T1 was probably deposited between 14,000 and 11,000 yr B.P. The soil formed in T1 is characterized by a yellowish brown (10YR 4/5 to 5/4) Bt horizon that is about 0.9 to 1.0 m thick. This soil could possibly be classified as an Alfisol, but all terrace soils in the region are mapped as Ultisols (Carson and Green, 1981). No artifacts were recovered from T1 sediments to indicate anything other than a surface scatter of artifacts, which is consistent with a terminal Pleistocene age for this unit.

**Unit T2**

Unit T2 is about 1.0 to 1.5 m higher than T1 and consists of fluvial sediments that are considerably more weathered than T1. Unit T2 is the second terrace in the valley and makes up a large portion of the valley floor. Heavy scatters of Mississippian and Cherokee Indian artifacts occur on the surface, while the subsoil is culturally sterile. A precise age assignment to T2 is not possible because no dateable material was recovered. However, soil development and weathering characteristics of this unit indicate it is considerably older than T1. The soil formed in T2 is an Ultisol that is characterized by a bright yellowish brown (10YR 5/7) Bt horizon that is about 1.0 m thick.

**Unit T3**

Unit T3 is about 1.0 to 1.5 m higher than T2 and is similar to T2 except for its elevation and soil profile development. Unit T3 is the third terrace in the valley and is the most prominent high terrace in the study area because it is quite extensive throughout the valley. Unit T3 differs from T2 only on the basis of soil development and elevation. The soil formed on T3 is an Ultisol characterized by a brown to strong brown (7.5YR 4/4 to 7.5YR 4/6) Bt horizon that is about 0.75 m thick. The age of T3 is unknown, except that it is older than T2.

**Unit T4**

Unit T4 is about 1.0 to 1.5 m higher than T3 and is mostly buried by alluvial/colluvial fan deposits. Gravel of T4 was noted at the surface in a few localities and it appears that most of the top stratum of T4 was eroded or buried by alluvial fan deposits. No trenches or pits penetrated T4, but lateral projection of surface gravels indicate it is probably buried beneath alluvial/colluvial fan deposits near the valley margin. The age of T4 is unknown, except that it is older than T3.

**Unit T5**

Unit T5 occurs on the lowest upland interstream divide to the west of Brasstown Creek valley at about 20 m above the modern floodplain and consists of about 1.0 m of fluvial sediments over saprolite. The soil in T5 is virtually identical to saprolite, except for the presence of fluvial sands and gravels, and it is characterized by a dark red (2.5YR 3/6) Bt horizon that is about 0.8 m thick. The age of T5 is unknown, except that it is older than T4.

**Unit AF1**

Unit AF1 consists of surficial alluvial/colluvial fan deposits that occur near the valley margin and are made up of a poorly sorted loam to clay loam with a small percentage (<8%) of gravel scattered throughout the matrix. The soil within AF1 consists of a strong brown (7.5YR 4.5/6) Bt horizon that is only about 0.25 cm thick. The 7.5YR hue is partly inherited from the
eroded saprolite from which this unit was derived. The age of AF1 is uncertain, though it probably contains Holocene sediment, judging from the relatively weak paleosol is characterized by a red (2.5YR 4/6) Bt horizon that is more than 1.5 m thick. Unlike AF1, AF2 consists of poorly sorted sand, silt, and clay with a small percentage of gravel. Unlike the fluvial sediments of T0-T5, no textural grading is apparent in AF1 and AF2. The age of AF1 is uncertain, but judging from the well developed red soil in this unit it is probably pre-Holocene in age. Like AF1, no archaeological material was recovered from this unit.

Unit AF2

Unit AF2 consists of alluvial/colluvial fan deposits that are buried by AF1 and separated from AF1 by the top of a well developed paleosol in unit AF2. The paleosol is characterized by a red (2.5YR 4/6) Bt horizon that is more than 1.5 m thick. Like AF1, AF2 consists of poorly sorted sand, silt, and clay with a small percentage of gravel. Unlike the fluvial sediments of T0-T5, no textural grading is apparent in AF1 and AF2. The age of AF1 is uncertain, but judging from the well developed red soil in this unit it is probably pre-Holocene in age. Like AF1, no archaeological material was recovered from this unit.

CHRONOSEQUENCE OF SOILS

Units T0 through T5 differ primarily on the basis of elevation, age, and the extent of weathering and soil development. Age control based on radiocarbon dates indicates that T1 formed between 14,000 and 11,000 yrs B.P. and thus correlates very closely with the time of the peopling of North America (Meltzer, 1988). The subsoils in T1-T5 are culturally sterile, and the degree of soil development represented on T1-T5 provides a good correlation tool for identifying culturally sterile fluvial sediments throughout the Brasstown Creek valley, and perhaps in other parts of the southern Blue Ridge. In order to quantify the extent of soil development on each fluvial surface, several easily measured and reproducible weathering indices of B-horizons (% clay, redness indexes, iron oxide content, and cation ratios) (Birkland, 1984) were tabulated for each allostratigraphic unit. The results (Fig. 5) show progressive weathering of the subsoils with increasing age, and indicate that culturally sterile pre-Holocene sediments generally have the following characteristics in the B horizon: (1) clay content >28%, with averages >30%; (2) dithionite extractable iron is >2.0%; (3) maximum bases/alumina ratio <0.20; (4) maximum FeO/Fe2O3 ratio >2.0; (5) average Hurst Color Index <22; and (6) average Buntley-Westin Color Index >13. The Hurst and Buntley-Westin indices are simple measures that can be done in the field, and thus are useful for the purpose of archaeological surveys. The data presented here indicate an abrupt change between T1 and T2. Unit T1 occurs on the Pleistocene-Holocene boundary, and thus soils that are more weathered than T1 can be considered culturally sterile. Furthermore, the results of this study could probably be extrapolated to other fluvial sediments in the Blue Ridge Mountains of north Georgia. However, in applying these results it is important to realize that the representative data shown in Fig. 5 are from the least erosive and most well drained portion of each terrace remnant and that redness and other weathering characteristics can vary considerably with microtopography and its influence on drainage conditions. In general, soils become less red on sloping parts of the terraces and in drainageways and swales. In addition, in other valleys of the Blue Ridge Mountains variations in bedrock types could have a significant effect on the physical and chemical characteristics of the alluvial soils.

Redness values shed some light on the possible age of T5 and AF2. Markewich et al. (1989) indicate that most Coastal Plain soils with hues that are redder than 2.5YR have ages that are >1,000,000 yr B.P. Allowing for some reddening to have been inherited by saprolite and iron rich rocks of the Blue Ridge, it is probably safe to infer that T5 and AF2 are >100,000 yr B.P. based on the data of Markewich et al. (1989).

Buntley-Westin and Hurst redness values (Fig. 5) indicate that the historical sediment of T0.0 has inherited some redness from upland erosion of saprolite in the watershed because the redness values of T0.0 are more red than those of T0.1. Redness in the historical sediment of T0.0 probably reflects human-induced erosion in the watershed caused by logging and construction, and it illustrates the importance of understanding variations parent materials and geomorphic settings in evaluating soil chronosequences.

CONCLUSIONS

The data presented here indicate that easily measured weathering indices of B-horizons including percent clay, iron oxide content, cation ratios, and redness indexes exhibit progressive and predictable change with increasing age of fluvial surfaces. Data presented here provide quantification of the Pleistocene-Holocene transition, which is very useful data for archaeological survey regarding identification of culturally sterile strata. In addition, this study indicates that sedimentation of Brasstown Creek at the present "floodplain" level began at about 14,000 to 11,000 yr B.P., suggesting that parts of "modern" floodplains in the region could contain Paleoindian and younger archaeological materials buried beneath historical or Holocene sediments. This case study could be used to correlate relative ages of terraces and floodplain sediments throughout the southern Blue Ridge Mountains where similar geomorphic settings exist, provided that allowance is made for variations in other factors of soil formation besides time.
FIG. 5. Soil chronosequence data for the terrace sequence at the Brasstown sites. Triangles represent maximum and minimum values for the B-horizons, while the circles represent the average value for each B-horizon. Data from T0.0 are from historical sediment which is actually a C-horizon.
ACKNOWLEDGMENTS

We wish to thank the Georgia Department of Natural Resources for funding which made this study possible and Steve Williams for laboratory assistance.

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Stratigraphy and Landscape Evolution: Implications for the Development of Cultural/Temporal Models in the Sand Hills of West-Central Louisiana

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Construction of prehistoric cultural/temporal models in west-central Louisiana are difficult because occupational components are usually identified on the surface of highly eroded ridgetops or buried in loosely compacted aeolian and/or colluvial sands along the valley ridgeslopes and toeslopes. Also, stream drainages are narrow and contain little or no floodplain that could have been occupied. Faced with these problems and the fact that cultural features are rare, previous chronologies and artifact sequences have relied on the presence of diagnostic artifact types documented outside the physiographic region and from questionable associations of ceramic and projectile point clusters and soils. Recent multidisciplinary investigations conducted at Site 16VN794 suggest that these earlier models need reevaluation in light of natural site formation processes which affect the content, form, and structure of locally occurring sites.

This paper focuses on the pedological research undertaken at Site 16VN794—a site formed in nonfluvial deposits—which resulted in the construction of a landform development and soil genesis model for the microtopographic setting of the site. The geomorphic data are then combined with the results of the artifact typological analysis, radiocarbon dates, and mathematically derived soil sedimentation rates to construct a revised cultural artifact sequence for the region.

SITE SETTING

Site 16VN794 is situated within the Birds Creek drainage shed in west-central Louisiana. This drainage exhibits topographic relief of less than 30.5 m, all of which has resulted from stream erosion (Fig. 1). In the northern region of Birds Creek, ridgetops obtain elevations of 91 to 122 m with adjacent stream valleys occupying positions that are generally 18 to 30.5 m lower in elevation. Ridge slopes in this region vary from gentle to moderately steep and range between 5 and 25%. Locus A of Site 16VN794 rests on a benchlike shelf along the moderately steep valley wall at an elevation of 85 m. In contrast, Locus B is located south of Locus A on the lower terrace of the Birds Creek floodplain at an elevation of approximately 82 m.

Geologically, Miocene Series deposits in the vicinity are unconformably overlain by Pleistocene (possibly including latest Pliocene) deposits. In central and northern Vernon Parish, including the area of Site 16VN794, the Pleistocene Series is limited to thin terrace deposits that cap the major drainage divides. These deposits are erosional remnants of a thin blanket of Pleistocene sediments that once covered the entire area. In southern Vernon Parish, beginning approximately 8 km south of Site 16VN794, the Pleistocene Series is better preserved and covers the Miocene Series almost completely.

Miocene age sediments occurring in the vicinity of Site 16VN794 have strongly conditioned local soil characteristics. Soils in this vicinity are characterized as Ultisols or “red beds” and possess strong ferric oxide components with hues redder than 5YR. Geomorphological examination of archaeological profiles in the site vicinity confirmed the widespread presence of these soils and noted color hues consistent with red beds in the lower B2t deposits (Schedenrein, 1984:17).

EXCAVATION METHODS

The excavations at Site 16VN794 proceeded in two stages. Stage I involved hand excavation of linear trenches at both site loci to collect information on the geomorphic history of the site and to assess the integrity of its cultural deposits (Fig. 2). The soil data, in addition to a preliminary assessment of the vertical distribution of artifact types, indicated that the landscape had undergone intermittent cycles of erosion and colluvial deposition with a slow net increase in deposition since the mid-Holocene. Artifactual data supported this geomorphic interpretation, with the greatest density of pottery sherds and late arrow point types occurring in the upper excavation levels. The
A. Local topography surrounding Site 16VN794.

B. Cross sectional view of Birds Creek drainage.

FIG. 1. Topographic position of Site 16VN794.
FIG. 2. Stage I Data Recovery Investigation.
earlier dart point types were more confined to the lower levels of the site. In addition, intermediate excavation levels exhibited a greater mix of earlier and later diagnostic materials, a phenomenon not unexpected given conflated artifact assemblages due to slow soil accumulation rates. While the site posed certain methodological and interpretative problems, no evidence of massive disturbances was observed and a plan was developed for the more intensive Stage II excavations.

Stage II excavations involved the placement of large (5 by 10 m) excavation blocks dug in 1-m units at each of the occupation loci (Fig. 3). The block excavation at Locus A was eventually enlarged to pursue deeply buried cultural deposits occurring along the terrace edge. The large block excavations permitted tighter control over the natural and cultural stratigraphy, while attempting to fulfill the project research goal of chronostratigraphy building and artifact sequence development.

**PEDOLOGICAL INVESTIGATIONS AT SITE 16VN794**

The objectives of this pedologic study investigation were: (1) to study the morphologic characteristics of soils developed on Site 16VN794, (2) to investigate the particle size distribution, organic carbon, and elemental content of the two major soil profiles at Loci A and B, and (3) to interpret the soil-landscape development at this archaeological site.

The soil deposits at 16VN794 developed through the processes of eolian deposition and downslope movement. Over time, natural weathering of the sandy loam, loamy sand, and sandy clay loam matrices formed the stratigraphic horizons that are observable today. Microstratigraphic divisions based on macroscopic discontinuities or by artifact content were not recognized within these naturally formed horizons. The stratigraphic horizons at 16VN794 are characterized by varying degrees of disturbance as a result of past timbering operations, vegetative growth, burrowing animals, and, especially at Locus B, fluctuating water tables. All of these disturbance processes serve to stratigraphically mix the sandy deposits. The subsequent effects of this mixing on the spatial integrity of cultural materials have been well documented (Baker, 1978; Oman, 1979; Schiffer, 1972, 1976; Wood and Johnson, 1978).

Generally, the soil horizons conform to the present-day microtopographic settings of each site area (locus). At Locus A, situated on the west-facing slope of the upper terrace, the subsurface deposits tend to get thicker in the downslope position with the thinner deposits disappearing toward the top of the terrace. Similarly, at Locus B, situated on the toe slope or lower terrace of Birds Creek, the thinner deposits tend to disappear or become unrecognizable at the higher elevations of the landform.

The soil mapped at Locus A was Briley loamy fine sand (Soil Survey Staff, 1987). The Briley series is described as a deep, well-drained soil formed in sandy and loamy coastal plain sediments of Tertiary age. The Briley series is classified as an Aeric Paleudult in Soil Taxonomy, USDA (Soil Survey Staff, 1987). This soil would be deeply weathered (>200 cm) with a sandy surface 50 to 100 cm in thickness.

The soil delineated at Locus B was Guyton silt loam (Soil Survey Staff, 1987). Because of limitations of the scale used for the soil survey, the soil at Locus B was actually intermediate between the Briley and Guyton series. The Guyton series was noted closer to the stream at a lower elevation than Locus B, however. The Guyton series is described as a deep, poorly and very poorly drained soil that formed in thick loamy sediments on flood plains of streams draining silty Pleistocene terraces and parts of Coastal Plains (Soil Survey Staff 1987). Other soils mapped in similar landscapes as Locus B are Osier and Betin-Osier complexes.

The soils were described in archaeological excavations, and in some cases an auger was used to examine the sediments to depths of 2 m or more. Descriptions were made according to methods described by the Soil Survey Staff (1951) and Foss et al. (1985).

Particle size analysis was accomplished by sieving the sample through a 10-mesh sieve (2-mm openings), and then using the soil that passed through the sieve for all subsequent analysis. Sand separations were made by dry sieving; the sand fractions included very coarse (2-1 mm), coarse (<1.5 mm), medium (0.5-0.25 mm), fine (0.25-0.10 mm), and very fine (0.10-0.05 mm).

Organic carbon was determined by dry combustion, and elemental analyses were determined using an ICAP. A mixture of nitric and hydrochloric acids (0.75 M) was used for the extraction procedure.

The soils at Loci A and B were developed in coarse-textured sediments; most textures were either loamy sand, sandy loam, or sandy clay loams. The texture undoubtedly reflects the inherent sandy nature of the Coastal Plain sediments in this area. The exception to the sandy nature of most of the soils was the profile described on the flood plain; this soil was very silty and occurs commonly throughout the flood plain of the Birds Creek watershed.

The upland region at the site is dominated by the strongly weathered, reddish soils formed on Coastal Plain sediments. The soil is highly developed with a solum thickness (A and B horizons) of greater than 2 m. A fine sandy mantle overlies most parts of the landscape. The argillic horizon (Bt) is usually sandy clay loam and is red to reddish brown (2.5YR 4/6-4/4). The deeply weathered argillic horizon is a key horizon in identifying the more stable landscape component at the site. The argillic horizon was encountered in all profiles in Locus A and the upland auger sites.
FIG. 3. Stage II Data Recovery Investigation.
The soils at Locus A are associated with the Briley series in the USDA-SCS classification system. These soils have a number of very sandy horizons above the red argillie or 2Bt horizon. The A horizon is thin (6 cm) and grades into a transitional BA horizon. A very weak cambic horizon (Bw) occurred at 18-32 cm. From 48 to 65 cm, a mixed E and B horizon occurs which probably resulted from deposition of sediments from eroded upland soils and possibly some eolian additions. This same mixing of E and B horizons was also noted at 65 to 103 cm, but the horizon is dominated by remnants of the 2Bt horizon; again erosion and eolian additions are probably the causes of this mixing. Finally, the argillie horizon is encountered at 103 cm, with this horizon continuing to 160 cm.

Although the 2Btl horizon is encountered at 103 cm, the upper 40 to 50 cm may be a deposition zone of eroded 2Bt material from up slope. The color of the 2Btl and 2Bt2 horizons was on the 5YR hue while lower in the profile 2.5YR hues were noted; the 2.5YR hues may indicate the more unaltered 2Bt horizon. Particle size analyses of Locus A profile soils (Table 1) also show a discontinuity below 126 cm; the particle size analyses are probably the best evidence of mixing of eroded materials.

In other soils described at Locus A, the 2Bt horizon occurred at depths ranging from 89 to 123 cm. The mixed horizons of B/E were rather consistent in their occurrence at Locus A. This horizon is also described in several profiles in the Soil Survey of Fort Polk (Daigle et al., 1989).

The soils described at Locus B had minimal development and were very sandy in texture. The soils were somewhat poorly drained and had a water table at depths of 120-130 cm during the time of year they were sampled. Although the soil was mapped as Guyton, the soils at Locus B were more nearly like the Betin-Osier mapping unit; this unit is mapped on elongated sideloads and undulating headcut areas in positions transitional from upland to the bottomlands or in drainageways. The Betin-Osier unit is mapped just south of the study site. Again, the scale of mapping does not per mit the detail needed to accurately delineate these small archaeological study sites. The soils in Locus B do not fit the description of either Betin or Osier, however.

The texture of soils occurring at Locus B is loamy sand to sand. The soils have a thin A1 horizon that is characteristically dark brown to brown (10YR 4/3, 3/3). The lower A horizon is dark yellowish brown and has less organic carbon than the surface A horizon. One of the most interesting horizons of the profiles is the Bw or cambic; this horizon has a somewhat mottled appearance that seems to indicate mixing of a prior surface with additional sediment. Although this horizon was described as a Bw or cambic, it was once a surface horizon. This identification is further substantiated by the chemical analysis.

Soils at Locus B show the influence of a high water table; the formation of mottles at depths of 25 to 33 cm indicates the water level fluctuates from this level to depths greater than 1.5 m. The soils were classified as somewhat poorly drained.

### TABLE 1

Particle Size Distribution of Profiles at Locus A and B (Pipette Method)

<table>
<thead>
<tr>
<th>Trench A, Locus A</th>
<th>Size Class and Particle Diameter (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab#</td>
<td>Hor- Depth Depth MIDP USDA VCS CS MS FS VFS Sand Silt Clay Total Carbon</td>
</tr>
<tr>
<td>Hori- Depth Depth M-IDP USDA Text. VCS 2000-1000 1000-500 500-250 250-100 100-50 50 2 &lt;2 Carbon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top Depth Bottom</td>
</tr>
<tr>
<td>1 A</td>
<td>6 12.0</td>
</tr>
<tr>
<td>2 BA</td>
<td>18 12.0</td>
</tr>
<tr>
<td>3 Bw</td>
<td>32 12.0</td>
</tr>
<tr>
<td>4 EB</td>
<td>48 12.0</td>
</tr>
<tr>
<td>5 E</td>
<td>65 12.0</td>
</tr>
<tr>
<td>6 2Btl</td>
<td>103 12.0</td>
</tr>
<tr>
<td>7 2Bt2</td>
<td>150 12.0</td>
</tr>
<tr>
<td>8 2Btl B</td>
<td>150 150</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trench B, Locus B</th>
<th>Silts&amp;Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Silt&amp;Clay</td>
</tr>
<tr>
<td>1 A</td>
<td>0.4</td>
</tr>
<tr>
<td>2 A2</td>
<td>0.4</td>
</tr>
<tr>
<td>3 E</td>
<td>0.4</td>
</tr>
<tr>
<td>4 EB</td>
<td>0.4</td>
</tr>
<tr>
<td>5 BW</td>
<td>0.4</td>
</tr>
<tr>
<td>6 BC</td>
<td>0.4</td>
</tr>
<tr>
<td>7 CB</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Note: All values in percent unless otherwise noted; USDA Textural Classes: S - Sand, LS - Loamy Sand, SL - Sandy Loam; FSL - Fine Sandy Loam; FS - Fine Sand.
The particle size distribution of the two profiles sampled at Locus A and B is shown in Table 1. Because of the coarse-textured nature of the soil at Locus B, the percent clay was not determined but simply combined with silt. The dominant fraction of both soils was the fine sand (0.25-0.10 mm). All horizons had greater than 41% fine sand. Both profiles showed rather uniform particle size distribution; this was especially the case at Locus B. The uniformity in particle size indicates similar depositional environments for the sediments.

Based on texture, the profile at Locus A shows some evidence of a gradual discontinuity from 103 to 126 cm. This is based on the increasing content of medium sand and decreasing content of fine and very fine sands with depth. Total sand content also decreases sharply below 65 cm, and a slight increase in coarse sand below 126 cm shows a change in depositional pattern.

The parent material for the soils at Locus A is believed to be eolian sands overlying the Coastal Plain sediments. The sands have a dominant fine sand fraction that is typical for wind-blown deposits. Some downslope movement of eolian sands and eroded B horizon of the strongly weathered soil on Coastal Plain sediments is suggested; this explains the mixed E/B horizons. Soils at Locus B are also derived from the eolian sand, but the sands have been moved downslope by erosion during the Holocene. The erosion potential of these fine sands is very high, as this is one of the most erodible size fractions.

The organic carbon content of the soils at Locus A and B is given in Table 1. The organic carbon content of the surface of the profile at Locus A was 2.13%. This would be equivalent to approximately 3.77% organic matter. The high content of organic matter indicates that the surface has been stable for a significant period of time. A sharp decrease in organic carbon (C) with depth is common for most forested soils. The gradual decrease in organic carbon in this soil indicates possible accumulation from old surfaces or perhaps some organic matter migrating downward by pedoturbation processes.

The organic carbon in the profile at Locus B also shows a gradual decrease with depth; this may indicate some residual organic matter from previous surfaces or deposition of sediments from A horizons upslope. The organic carbon content of both profiles is quite high considering the coarse-textured nature of the soils.

Fig. 4 displays the distribution of extractable barium (Ba), calcium (Ca), strontium (Sr), and manganese (Mn) with depth in the profile at Locus A. These elements are generally associated with nutrient recycling by plants and thus accumulate in soil surfaces. The profile at Locus A shows accumulation of these elements in the present surface and some accumulation in the 2BE horizon at 65-103 cm. Some translocation of these elements down through the profile is likely because of the coarse-textured nature of the soils at Locus A and the length of time for weathering and leaching to occur. The elements cobalt (Co), copper (Cu), and boron (B) were also noted to have slightly higher contents in the 2BE horizon in contrast to surrounding horizons; this also indicates possible surface horizons.

Fig. 5 gives the distribution of barium, calcium, strontium, and manganese with depth in the profile at Locus B. As in the profile at Locus A, the elements barium, strontium, and manganese show accumulation in the present surface but also lower in the profile, especially in the E and EB horizons. Again, as a result of the coarse-textured nature of the soils, some translocation of elements is likely. Barium has been found to be tightly bound to organic matter and clay and thus shows minimal movement through soil profiles. The accumulation of barium in the E and EB horizons provides ample evidence of a former surface. The low content of calcium in subsoils is probably related to the initial low amounts of calcium and perhaps movement from the profile by leaching.

**RADIOCARBON CHRONOLOGY AND SOIL DEPOSITION RATES**

Early in the fieldwork phase, it became obvious that an insufficient number of datable cultural features existed to document diachronic changes in the artifact collection. Consequently, a bulk sampling strategy was developed to target specific soil horizons in areas relatively free of observable disturbances. The goal was to obtain a large enough sample (approximately 40 liters) from the soil matrix to recover a sufficient quantity of charcoal for radiocarbon dating. After processing, it became evident that a number of the samples contained insufficient quantities of charcoal for analysis. Consequently, charcoal samples were combined from the same levels in adjacent units or from contiguous levels in the same unit so that the targeted soil horizons could be dated. The radiocarbon age determinations for the two loci are presented in Table 2. In all eight radiocarbon samples including six bulk samples and two feature samples were submitted for dating. Four bulk samples were submitted for Locus A and four samples (two bulk samples and two feature samples) were submitted for Locus B.

Radiocarbon dates obtained from bulk samples collected at Locus A are illustrated in the lower half of Fig. 6. The uncorrected dates were used in this illustration to facilitate comparisons with other previously developed sequences for other regions. Unless specifically noted, uncorrected dates will be used in the following discussions. In constructing this figure, a mean depth for bulk samples was calculated using the minimum top and maximum bottom depths for each combined sample. The mean depth was then used to locate the date of the bulk sample relative to the
FIG. 4. Distribution of extractable Ba, Ca, Sr, and Mn with depth in Profile 591LAl Locus A.

FIG. 5. Distribution of extractable Ba, Ca, Sr, and Mn with depth in Profile 591LAl Locus B.
TABLE 2
Radiocarbon Dates from Locus A and Locus B at Site 16VN794

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Lab Number</th>
<th>Loci</th>
<th>Excavation Unit</th>
<th>Depth cm BS</th>
<th>Soil Horizon</th>
<th>C14 yr B.P. (5568) Uncorrected</th>
<th>Date, yr B.P. Calibrated (5568) Min-Max</th>
<th>Calendar Date Calibrated (5568) Min-Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>611</td>
<td>Beta-49293</td>
<td>A</td>
<td>40</td>
<td>96-106</td>
<td>2B/E</td>
<td>5050 ± 90</td>
<td>5928-5659</td>
<td>3979-3710 B.C.</td>
</tr>
<tr>
<td>702</td>
<td></td>
<td>A</td>
<td>24</td>
<td>86-96</td>
<td>2B/E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>846</td>
<td></td>
<td>A</td>
<td>39</td>
<td>92-102</td>
<td>2B/E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1293</td>
<td>Beta-49294</td>
<td>A</td>
<td>49</td>
<td>91-101</td>
<td>2B/E</td>
<td>4170 ± 110</td>
<td>4859-4539</td>
<td>2910-2590 B.C.</td>
</tr>
<tr>
<td>1294</td>
<td></td>
<td>A</td>
<td>49</td>
<td>91-101</td>
<td>2B/E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>625</td>
<td></td>
<td>A</td>
<td>40</td>
<td>114-124</td>
<td>2B/E-2Bt1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>704</td>
<td>Beta-49295</td>
<td>A</td>
<td>24</td>
<td>116-126</td>
<td>2B/E-2Bt1</td>
<td>5770 ± 140</td>
<td>6739-6419</td>
<td>4790-4470 B.C.</td>
</tr>
<tr>
<td>624</td>
<td></td>
<td>A</td>
<td>23</td>
<td>116-126</td>
<td>2B/E-2Bt1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>847</td>
<td></td>
<td>A</td>
<td>39</td>
<td>119-129</td>
<td>2Bt1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>628</td>
<td>Beta-50531</td>
<td>A</td>
<td>24</td>
<td>62-67</td>
<td>2E</td>
<td>3920 ± 90</td>
<td>4518-4247</td>
<td>2569-2298 B.C.</td>
</tr>
<tr>
<td>1003</td>
<td>Beta-48678</td>
<td>B</td>
<td>73</td>
<td>25-33</td>
<td>E-EB</td>
<td>1030 ± 50</td>
<td>976-925</td>
<td>974-1025 A.D.</td>
</tr>
<tr>
<td>1034</td>
<td>Beta-48679</td>
<td>B</td>
<td>73</td>
<td>38-50</td>
<td>BW</td>
<td>1520 ± 70</td>
<td>1516-1340</td>
<td>434-610 A.D.</td>
</tr>
<tr>
<td>936</td>
<td>Beta-48677</td>
<td>B</td>
<td>57</td>
<td>55-58</td>
<td>F.ea. 4</td>
<td>1890 ± 110</td>
<td>1940-1700</td>
<td>10-250 A.D.</td>
</tr>
<tr>
<td>1398</td>
<td>Beta-48680</td>
<td>B</td>
<td>95</td>
<td>55-110</td>
<td>F.ea. 11</td>
<td>4030 ± 110</td>
<td>4807-4853</td>
<td>2858-2404 B.C.</td>
</tr>
</tbody>
</table>

Note: range of quoted dates represent one standard deviation.

The Locus A dates generally provide a stratigraphically consistent chronological sequence beginning at approximately 6000 yr B.P. and continuing until 4000 yr B.P., after which time no carbon date information was collected. One date (Beta-49294), however, was collected from a single unit and is inconsistent with the remainder of the sequence. The charcoal for this date was recovered from Unit 49 just above the 2Bt1 horizon. Two other sample dates suggest that the Unit 49 date should be approximately one millennium older. The youngest date (3920 ± 90 yr B.P.) collected for this locus was taken from the lower half of the 2E horizon or near where the 2E horizon interfaced with the more disjunctive 2EB horizon. The 2EB horizon was difficult to define during the excavation given its variable degree of expression over long horizontal distances and a similar morphology to the larger more distinct 2E horizon. In many instances the only way to tell if the 2EB was present in any one unit was to closely inspect the profile after the unit had been completely excavated. For this reason, the 2EB horizon was not consistently differentiated from the broader 2E horizon during the fieldwork operations.

Radiocarbon dates obtained from bulk samples and feature fill collected at Locus B are illustrated in the upper half of Fig. 6. These dates generally provide a stratigraphically consistent chronological sequence for the locus. The four samples submitted from this locus range from approximately 4000 yr B.P. near the base of the block to 1000 yr B.P. near the top of the excavation. As was the case with Locus A, the upper excavation levels at Locus B remain to be adequately dated.

The two dates worthy of mention at this locus are those from the two cultural features. Feature 4 was a small rock cluster measuring 20 cm long by 10 cm wide and contained a sufficient quantity of charcoal for dating analysis. The morphology and size of this feature was suggestive of a small post that had been placed in the ground and supported by small rocks. The post eventually burned, leaving the charcoal. The depth (58 cm) at which this feature was first recognized probably represents the bottom portion of the post hole where the rocks were placed around the base of the post. Given that the post was placed into the ground at some unknown elevation, the date derived from this feature most likely relates to an occupation surface above the 58-cm level. In contrast, Feature 11 was discovered in the west wall of the block profile at a depth ranging from 55 to 110 cm below surface. The charcoal sample removed from this feature came from the middle to lower portions of the feature fill, in an area characterized by darker staining and large charcoal flecks. Consequently, the date obtained from the feature fill is interpreted as representing the bottom portion of the BW horizon just above the BW-BC.
FIG. 6. Radiocarbon date sequence for Loci A and B.
SOIL DEPOSITION RATES AT 16VN794

At Site 16VN794, the sedimentation rates for both loci were determined by a regression analysis of the vertical sequence of radiocarbon dates. As can be seen in Fig. 6, a near linear relationship appears to exist between the depths and age of the carbon dates obtained at both loci. One sample, Beta-49294, exhibits a much later date for the sample depth and is the only date that appears to significantly deviate from the overall pattern. The early dates of the sequence are found at Locus A, while the later dates are associated with Locus B. Two dates, Beta-50531 and Beta-48680, recovered from the two separate loci overlap in their temporal range with Beta-50531 (representing the youngest date from Locus A) and Beta-48680 (being the oldest date from Locus B). The sedimentation rates for both loci were calculated using the formula:

\[ y = mD + b \]

where \( y \) is the radiocarbon age, \( m \) is the slope of the line, \( D \) is the depth in cm below surface, and \( b \) is the intercept of \( y \). It should also be noted that these analyses were completed using three and four samples from each locus, an admittedly small sample size. As such, the results of this analysis should be viewed with caution until evaluated by research using larger samples.

On the basis of the radiocarbon dates recovered from the Site 16VN794, the average sedimentation at Locus A occurred at the rate of 0.02 cm/year from the Holocene onward, while at Locus B this rate was calculated at 0.04 cm/year.

LANDFORM DEVELOPMENT AND SOIL GENESIS

Based on the results of the soil and radiocarbon analyses discussed above, a landform development and soil genesis model is proposed for the environmental setting of 16VN794. The soils at the site were formed from Tertiary Coastal Plain sediments overlain by eolian sands of Holocene age. Fig. 7 shows the proposed stages of soil and landscape development at Locus A.

Stage I

This stage consists of deep weathering of the Tertiary Coastal Plain sediments. The evidence for the strong weathering processes is the thick, reddish, well expressed argillic horizon developed on the uplands throughout the site. The strong weathering consisted of clay development and translocation, weathering of primary minerals releasing iron and resulting in subsequent translocation to develop the thick B horizons. Soil weathering resulted in sola greater than 2 m in thickness.

FIG. 7. Stages of soil weathering at Locus A from the Pleistocene to the present.
Stage II

During the long weathering period in the Pleistocene, numerous cycles of erosion undoubtedly took place. Instability of landscapes and resulting erosion took place during climatic and vegetation changes. The exact extent of erosion is unknown, but dissection of landscapes and truncation of soil profiles indicate substantial erosion activity.

Stage III

Deposition of eolian sands is probably related to the late Pleistocene and the early to middle Holocene; but the bulk of deposition appears to have taken place around 6000 to 3500 yr B.P. Erosion of the exposed argillic horizon of the upland soil was taking place prior to the deposition of eolian sands as evidenced by early Holocene artifacts in the upper part of the 2Bt horizon and a date of approximately 6000 yr B.P. Erosion and subsequent deposition also took place at the same time eolian sands were being deposited; this has resulted in the mixed B/E horizons and mixed 2Bt1 horizons noted in soils at Locus A. It is postulated that continued slow accumulation of eolian sands took place during the Holocene and also erosion of eolian sand moving downslope to accumulate in less sloping flatter areas.

Stage IV

Continued erosion cycles of upland and deposition on the more stable parts of landscapes took place from late Holocene to the present. During recent agricultural and forestry activities, renewed erosion of uplands has taken place.

At Locus B, the soils were formed entirely from local colluvium. This colluvium was derived from downslope movement of the sandy material, which covered the upper portion of soils at Locus A and the surrounding upland area. As noted in the C-14 date of approximately 3500 yr B.P. for the fill taken from Feature 11 near the base of the excavation block, much of the deposition took place between 3000 to 6000 yr B.P., with minor but continual additions since 3000 yr B.P. The relatively late accumulation of soils at Locus B (middle to late Holocene) is interpreted as reflecting its relative position on the landscape. The lower elevation of Locus B, as well as its position near the base of an upland ridge, is an ideal setting for eolian and colluvial deposition. The texture of the soils at Locus B is very similar to the upper portion of the soils at Locus A and other upland sites; texture (especially fine sands) appears to be a diagnostic property of the eolian sand. The soils at Locus B show minimal development as a result of the fluctuating water table, young age of the parent material, and the dominant quartz mineralogy of the sediment.

Geomorphological evidence indicates that the soil deposition at 16VN794 occurred through exogenic processes (colluvium, loess, mud flows, etc.), which are greatly effected by changes in climate and vegetation. Climate dictates the amount of precipitation, which effects both soil stability and vegetation. During periods of severe drought, vegetation dies back, and soils lose their moisture, making them more susceptible to erosion. This speeds exogenic soil accumulation on stable surfaces. During cooler, moister, periods the rate of erosion decreases, resulting in relatively stable, slow, rates of deposition. At 16VN794, such a period of stable environment appears to have occurred by approximately 4000 yr B.P.

ARCHAEOLOGICAL SEQUENCE DEFINITION

Analyses conducted at Site 16VN794 indicate a very slow rate of soil accumulation, which has important implications for developing a cultural sequence of the region and conducting more detailed functional analyses of possible conflated archaeological assemblages. The development of cultural sequences in west-central Louisiana has traditionally been based on assumptions that deeper deposits represent early cultural components, and that artifacts tend to migrate only in a downward direction. Such assumptions are less valid for sites formed on stable surfaces with slow rates of sedimentation. Processes serving to mix and displace artifacts on sites with slow soil accumulation include tree throw, root churning, animal burrowing, and human activities. Studies (Bocek, 1986, 1992; Rowlett and Robbins, 1982) suggest that on such sites, artifacts will migrate from their stratum of origin to strata both above and below, and a significant percentage of these artifacts are likely to move beyond their stratum of origin. For sites with long-term or frequent reoccupation, these processes will thus result in severely mixed and/or conflated deposits. Migration will also be affected by the density of the matrix, and artifacts will tend to be brought to rest on denser surfaces, such as the interface between the Miocene clay and sands found in west-central Louisiana.

To further investigate some of these formation processes at Site 16VN794, a multidisciplinary approach using stratigraphic data, sedimentation rates, radiometric dates, and crossdating information was implemented. Compilation of these analyses results were crucial in the construction of the first artifact sequence, which can be dated, and was developed from archaeological information derived exclusively from west-central Louisiana (Figs. 8 and 9).

Geomorphological analysis conducted at 16VN794 suggests the site landscape was formed in four stages, the first two of which occurred before human occupation of the site. The first stage consisted of the deep weathering of Tertiary Coastal Plain sediments and the weathering of primary minerals to release iron,
FIG. 8. Vertical distribution of projectile points by excavation level at Locus A.

FIG. 9. Vertical distribution of projectile points by excavation level at Locus B.
which formed B horizons greater than 2 m thick. The second stage corresponded with the Pleistocene. During this stage numerous cycles of erosion took place in response to an unstable environment. The degree of dissection and profile truncation indicates that during this period erosion was severe.

The third stage was a period corresponding to the shift from the late Pleistocene to the early/middle Holocene when eolian sands began to be deposited. The bulk of this deposition appears to have occurred from 6000 to 3500 yr B.P. Cyclical periods of erosion was an ongoing process during this stage, as evidenced by the appearance of mixed B/E and 2Bt1 horizons. Net soil accumulation during this period was slow, with deposition by erosion providing a greater rate of soil accumulation in non-sloping areas.

The Early Archaic component defined for Locus A was identified in the 2Bt1 horizon by the presence of a corner-notched, serrated, basally-ground Palmer point, 4 plano-convex bifaces, 2 cortical backed unifaces, 4 indeterminate or broken unifaces, and 204 fragments ofdebitage. A fine grade, greenish-colored cobbles chert (that quickly formed patination when exposed to the atmosphere) was the raw material of preference for this component, and differs from the raw materials exhibited by later components. The occurrence of these materials in the mixed 2Bt1 horizon suggests that these materials originated on an early Holocene/late Pleistocene surface above the older Tertiary sediments, but were subsequently redeposited into the top layer of this earlier deposit some time during the early Holocene. Both the texture of the 2Bt1 soil (clayey loam) and the increased rate of soil accumulation served to isolate this earlier component from debris deposited by later occupations. Although two Early Archaic projectile points were recovered at Locus B, no recognizable component was identified at this location. It is possible that one did exist in the past, but was destroyed by the fluctuating water table.

The final stage of development witnessed the continued erosion of the uplands and deposition of these soils on stable sections of the landscape from the late Holocene through the present. Erosion has increased in frequency and duration during the historic period as a result of modern agricultural and forestry practices. It is within these later deposits that the Late Archaic component were identified. In the deepest sediments (70 to 120 cm) of this final stage of site development, an early Late Archaic component was defined. This early Late Archaic component at Locus A consisted of the following diagnostic points: 1 Yarborough, 1 Palmillas, 1 Summerville, and 2 Ensor. Radiocarbon dates for this component at 16VN794 range from 5780 to 4000 yr B.P. It should be noted that Yarborough points are considered diagnostic markers of Middle Archaic period by some investigators working in the southeast and plains states. As the Yarborough point recovered from 16VN794 was found at the base of the early Late Archaic deposit (111 to 117 cm bs), this may represent a Middle Archaic form at Fort Polk as well. Ensor points have been assigned a date of 5100 yr B.P. (Campbell et al., 1990:72) and are believed to represent one of the earliest Late Archaic tool forms in the project area. Both the Summerville and Palmillas points were considered intrusive to this component.

A later Late Archaic component (50 to 70 cm) dating from 3000 to 4000 yr B.P. was identified in the sediments above the early Late Archaic occupation described above. This later component was marked by the presence of Ensor points and a Gary point. The presence of Ensor points in this later component suggest this point form was popular over a long time period. Analysis of thedebitage and tool clusters associated with this late Late Archaic component in Locus A indicate that cutting/chopping and scraping activities may have occurred at discrete locations of the site.

At Locus B, an early Late Archaic component with a date range of ca. 3500 to 2500 yr B.P. (70 to 110 cm) exhibited a wide variety of diagnostic projectile point forms including Williams, Marcos, Figueroa, Ensor, Edgewood, Summerville, Castorville, Gary, Evans, Shumla, Delhi, Yarbrough, and unidentified, but potentially diagnostic points. The two most prominent Late Archaic point types in this component are the Marcos and Ensor points, which combined represent 35.9% of the projectile points (excluding the intrusive elements) included in this component. The absence of the Marcos points in the earlier sediments of Locus A suggest that this tool form was adopted into Late Archaic toolkits later than Ensor points. Other diagnostic tool forms that are included into Late Archaic toolkits after 3500 yr B.P. are Summerville, Edgewood, Figueroa, Gary, Castorville, Evans, and Delhi projectile points.

The most recent Late Archaic component identified at Site 16VN794 was at Locus B (50 to 70 cm) and dates from 2500 to 1300 yr B.P. This component is important for it helps define the terminal dates for many of the diagnostic markers of this period. Projectile points recovered in this component include Summerville, Marcos, Yarbrough, Ellis, Ensor, Figueroa, Shumla, Gary, and Williams-like points. The presence of Ensor, Summerville, Yarbrough, Williams, and Figueroa points indicates the continuance of these Late Archaic point styles to some time between ca. 2500 B.P. and 1500 yr B.P. The Marcos point was interpreted as being postdepositionally displaced into this component and is considered an earlier point form. Ellis points at 16VN794 appear to have had a short use-life and occurred sometime between ca 1700 to 1000 yr B.P. Besides the projectile points, both grog-tempered/sandy paste and grog-tempered ceramics occurred in this component.

Components that date from the terminal Middle Woodland Period through perhaps the Protohistoric Period were defined on the basis of pottery styles in
association with arrow points. Two components were identified with each component occurring at both Locus A and Locus B. The earliest component dates from ca. 1500 to 1300 yr B.P., and appears to span the terminal Middle Woodland and Late Woodland Periods. At Locus A, the earliest component correlates with depths ranging from 31 to 50 cm below surface, and includes 51 sherds and 8 diagnostic projectile points. The ceramic assemblage consists of a majority of grog-tempered Baytown Plain var. 1 sherds, with significant minorities of Baytown Plain var. 2 and Goose Creek Plain. Associated point forms are Cuney, Friley, Hayes/Alba, and Scallorn arrow points and Evans and Ensor dart points. The presence of the Ensor and Evans points in the Woodland components is considered indicative of postdepositional disturbance or recycling behavior.

At Locus B, the majority of the ceramics associated with the earliest component are found between 31 and 50 cm below surface and are most abundant between 41 and 50 cm. The occurrence of pottery with numerous dart forms below 50 cm suggests that there is some overlap between Woodland and Archaic components below this depth. Like Locus A, the ceramic assemblage consists of a majority of Baytown Plain var. 1 and lesser, but significant quantities of grog/sand tempered Baytown Plain var. 2 and sandy paste Goose Creek Plain. Small numbers of a bone-tempered plainware are also occur in this component. Associated arrow points include the Bassett, Friley, and Hayes/Alba point types.

The most recent component, which is present in the upper levels of both Locus A and Locus B, dates from the Late Woodland Period to as late as the Protohistoric Period. This component is dated from 1030 yr B.P. to circa 300 B.P. In Locus A, this upper Woodland Period component is found in rank levels 1 and 2, and includes 29 grog-tempered Baytown Plain var. 1 sherds, 4 Goose Creek Plain sherds, and 2 Baytown Plain var. 2 sherds. Nine arrow points (Bassett, Bonham, Cuney, Perdiz, Scallorn, and Friley) are also associated with this component. The date range of these points appears to extend into the Protohistoric Period.

At Locus B, the ceramics associated with the upper Woodland occupation are found between 0 and 30 cm below surface, and include approximately equal quantities of Goose Creek Plain, Baytown Plain var. 1, and Baytown Plain var. 2. Small numbers of bone-tempered and indeterminate gog tempered sherds and 4 Coles Creek Incised var. Mott were also found. The Coles Creek Incised ceramics are associated with the late Coles Creek Period, which Jeter and Williams (1989:124, 142) date from ca. 1250 B.P. to 950 yr B.P. Fifteen arrow points of the Clifton, Cuney, and Friley types were also found. These point forms appear to extend into the Protohistoric Period (to ca. 300 B.P.) at 16VN794. The soil strata in which this component is found are dated through regression analysis from 1030 yr B.P. to the present.

CONCLUSIONS

Analysis of sedimentation rates (albeit based on a limited number of samples) has important implications for the archaeological investigation of Site 16VN794 as well as for future analyses conducted in west-central Louisiana. The analysis demonstrates extremely slow sedimentation rates occurring at 16VN794, and by inference, for most sites in the project vicinity. As a result, it is expected that mixed assemblages caused by repeated occupations on long-term, slow-aggrading surfaces are likely to occur. Hence, the use of analytical methods such as volumetric densities of artifacts and features, spatial patterning of artifacts on arbitrarily defined excavation surfaces, and spatial relationships between artifacts and features, must be viewed with caution. In the future, archaeological analyses must develop more sophisticated geomorphological models. In turn, these models will provide a better understanding of site formation processes including landform development and soil genesis that are so critical for interpreting the archaeological record in west-central Louisiana.

ACKNOWLEDGMENTS

Our research was funded by the National Park Service, Southeast Region, Interagency Archeological Services Division and the United States Army. Park Service personnel who were extremely helpful throughout the duration of this project were Dr. Harry Scheele and Dr. David Anderson. We would also like to thank Dr. Charles Stagg and Mr. James "Gator" Grafton of the Environmental Office at Fort Polk as well as Mr. and Mrs. John and Billie Guy of Anacoco, Louisiana for their kindly assistance during the fieldwork activities.

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The modern soil and the buried Farmdale and Sangamon paleosols that are developed in thick loess deposits along the Mississippi River and its tributaries contain out-of-context granules and pebbles. These deep loess profiles occur on the uplands where the enigmatic grains could not have been deposited by alluviation or colluviation. It is hypothesized that these grains are former gastroliths, stones ingested by birds, that were originally deposited onto the surface of these soils whenever a bird died. It is further hypothesized that bioturbation caused these grains to become concentrated in the subsurface. Data from laser light scattering analysis indicate that many of the grains are former gastroliths. Sieve analysis shows that subtle stone-lines occur in one of the Farmdale and all of Sangamon paleosols examined and their positions in these soils suggest that bioturbation created them. Pebbles inferred to be former gastroliths that are associated with archaeological sites may be used to indicate the location of living surfaces, and their numbers may be used to estimate the relative importance of fowl as a dietary component. Also, pebbles concentrated into subtle stone-lines by bioturbation strongly suggest that bioturbation can produce stone-lines in any soil that contains stones.

Profiles of the modern soil developed in Peoria Loess and of the Farmdale and Sangamon paleosols developed in Roxana Loess and Loveland Loess respectively (Fig. 1) found along the Mississippi River and its tributaries contain out-of-context pebbles and granules\(^1\). Preliminary observation indicated that pebbles in the Farmdale and Sangamon paleosols occur in only the A, E, upper B horizons but not in the lower B and C horizons. All of the aforementioned soils are developed in thick loess deposits, so it is unlikely that the pebbles came up from any underlying gravelly surface. Furthermore, the profiles examined occupy upland localities where the pebbles could not have been introduced by either alluvial or colluvial processes.

If the pebbles are not the result of either alluvial or colluvial processes, then other possibilities must be offered. These pebbles may be former gastroliths brought to their present localities by biota. Gastroliths are stones swallowed by birds and other organisms that assist in the mastication of food (Campbell and Lack, 1985: 256). Former gastroliths ought to be left on any surface whenever a bird dies, and the longer a soil has been subaerially exposed, the more pebbles it should accumulate. Subsequent bioturbation by invertebrates (soil mixing by worms, ants, etc.) as modeled by Shaler (1891) should cause these former gastroliths to move from the surface towards the bottom of the zone of dominant bioturbation where given enough time a stone-line should form (Fig. 2).

To infer the origin of the out-of-context pebbles recovered from the modern soil and the Farmdale and Sangamon paleosols, they were analyzed with a video laser light scattering instrument that measures an object's, in this case a suspected gastrolith's, degree of surface polish. Johnston et al. (1990, 1994) have shown that gastroliths have higher degrees of polish than do pebbles of other origins. In addition, the depth at which the pebbles are found in the soil profiles is to be determined by systematic sieve analysis in order to assess whether bioturbation has produced stone-lines in these profiles.

FIELD SITES

Four sites in Illinois (Rocky Run, Athens Quarry, Moses Pit, and Thebes) and one site in Mississippi (the Vicksburg Standard Loess Section) were selected for this study (Fig. 3). Except for Athens Quarry, which is located on the uplands away from the bluffs of the Sangamon River, the other field sites are located along the bluffs of the Mississippi River or along its tributaries. The soils at each field site are developed in loess units that are at least 2 m thick.

Rocky Run is an archaeological site located on the bluffs between Rocky Run and the Mississippi River in Hancock County, Illinois. The fieldwork was conducted on the modern soil developed in Peoria Loess by Larry Abbott, a Ph.D. candidate in Geography at UIUC, who expected to find out-of-context pebbles during auger testing of the site and wanted an explanation concerning their origin.

Athens Quarry is an active limestone quarry in Menard County, Illinois. The newest quarry face provides an exposure of the buried Farmdale Soil that is developed in poorly drained Robein Silt (redeposited Roxana Loess).

\(^1\)Hereafter, pebbles and granules will be referred to as pebbles unless dictated by the context.
<table>
<thead>
<tr>
<th>Time Stratigraphy</th>
<th>14C YR BP</th>
<th>Loess Stratigraphy</th>
<th>Soil Stratigraphy</th>
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<tr>
<td>Holocene Stage</td>
<td>7000</td>
<td>Modern Soil</td>
<td></td>
</tr>
<tr>
<td>Valderan Substage</td>
<td>11000</td>
<td>Peoria Loess</td>
<td></td>
</tr>
<tr>
<td>Two Creekian</td>
<td>12000</td>
<td>Jules Soil</td>
<td></td>
</tr>
<tr>
<td>Woodfordian Substage</td>
<td>25000</td>
<td>Robein Silt (re-deposited Roxana Loess)</td>
<td>Farmdale Soil</td>
</tr>
<tr>
<td>Farmdalian Substage</td>
<td>28000</td>
<td>Roxana Loess</td>
<td></td>
</tr>
<tr>
<td>Sangamonian Stage</td>
<td>50000-75000</td>
<td>Loveland Loess</td>
<td>Sangamon Soil</td>
</tr>
<tr>
<td>Illinoian Stage</td>
<td>beyond radiocarbon dating</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIG. 1.** Time, loess, and soil stratigraphy of the late Pleistocene and Holocene in Illinois (modified from McKay, 1986 and Willman and Frye, 1970).

**FIG. 2.** Shaler's (1891) conceptual model showing that stones can be buried by earthworms.
FIELD SAMPLING TECHNIQUES

To extract any artifacts, pebbles, and CaCO$_3$ concretions at Rocky Run, Abbott conducted auger testing at 30-m intervals along transects normal to the eastern Mississippi River Bluff edge. Augering was done to depths of 2 to 5 m at 10-cm intervals, and the contents of each interval were dry screened with a 6.35-mm sieve. As a result of dry sieving, 268 pebbles were recovered from 44 pedons (auger holes) out of a possible 60 pedons. Of these, 47 pebbles from 15 pedons were set aside for further analysis that would infer whether they are former gastroliths.

One pedon was sampled from vertical exposures of the Farmdale Soil at Athens Quarry and Moses Pit. Likewise, one pedon was sampled from vertical exposures of the Sangamon Soil at Moses Pit, Thebes, and Vicksburg.

At Athens Quarry, bulk soil samples were taken from only the A and upper Bg horizons, the top 20 cm, of the Farmdale Soil. At Moses Pit, bulk samples of the entire Farmdale Soil, which encompassed all of the Roxana Loess Deposit, were taken at 10-cm intervals down to 50 cm and at 20-cm intervals down to 186 cm. Bulk samples of the Sangamon Soils at Moses Pit, Thebes, and Vicksburg were taken from what was assumed to be the top of the soil to the lower B horizon. The Sangamon paleosol at Moses Pit and Vicksburg was sampled at 10-cm intervals down to 70 cm and 90 cm, respectively. At Thebes, the Sangamon Soil was sampled at irregular intervals down to a depth of 180 cm.

LABORATORY ANALYSIS

Pebble Recovery

The bulk soil samples collected from Athens Quarry, Moses Pit, Thebes, and Vicksburg were reduced in a pestle and mortar and passed through a 2-mm sieve to catch any suspected gastroliths that might be present. Afterwards, the reduced soil samples were air dried and weighed. Any suspected gastroliths present were washed in deionized water, air dried, and weighed.

Control samples of non-gastroliths and known gastroliths were acquired so that they could be compared to the suspected gastroliths. The non-gastroliths were all collected from the Mounds Gravel Deposit that underlies the Loveland Loess Deposit at Moses Pit. Known gastroliths came from the gizzards of six game bird species: 1) Western Turkey, 2) Sharp Tailed Grouse, 3) Pheasant, 4) Mourning Dove, 5) Greater Prairie Chicken, and 6) Canada Goose. These gastroliths were extracted from their gizzards by D. Johnson and L. Abbott, Department of Geography at UIUC, for a previous study and were available for this research.
Light Scattering

Suspected gastroliths, except from Thebes\textsuperscript{2}, along with the control samples of non-gastroliths and known gastroliths were taken to Los Alamos National Laboratory where they were analyzed with a laser light scattering instrument that measures the degree of surface polish of any object—in this case of known gastroliths, non-gastroliths, and suspected gastroliths (Fig. 4).

Each pebble’s degree of surface polish was determined by measuring the following seven parameters: 1) the percent specular reflection\textsuperscript{3}; 2 and 3) the full width at half maximum (FWHM), measured in degrees, for the scattering intensity in the horizontal (I) and the vertical (O) planes; 4 and 5) the best fit values of T/s for scattering in the horizontal and vertical planes; and 6 and 7) the skewness and absolute kurtosis of the scattering intensity distribution (Johnston et al., 1994). Of these parameters, T/s is the only fitted parameter where T is the correlation length of surface roughness for points along the pebble surface and s is the root mean square (rms) of surface roughness.

Discriminant analysis using all seven parameters classified the known gastroliths, non-gastroliths, and suspected gastroliths as either gastroliths or non-gastroliths.

\textsuperscript{2}The soil samples from Thebes were collected by D. Johnson after the author had left to conduct the light scattering analysis.

\textsuperscript{3}Specular reflection is the direction in which a perfect mirror reflects all of its light. Well polished objects reflect more light in the specular direction than unpolished objects.

Strategy for Assessing Bioturbation

By sieving the bulk soil samples, the position of the suspected gastroliths within the soil profiles became known. The number of pebbles, expressed as a percent of the weight of the reduced soil samples, was plotted versus the depth from which they were found to indicate if stone-lines occur and where they occur. The position of any stone-lines present in the soil profiles should indicate the importance of bioturbation in concentrating the suspected gastroliths.

RESULTS AND DISCUSSION

Discriminant Function

Over 65\% of the known gastroliths were classified as gastroliths (Table 1). The known gastroliths not classified as gastroliths may have been those that were in the bird’s gizzard for a short time before being deposited onto the soil surface. In contrast, only 30\% of the non-gastroliths were classified as gastroliths.

Over 54\% of the suspected gastroliths were classified as gastroliths indicating that many of the suspected gastroliths are gastroliths. The percentage of suspected gastroliths predicted to be gastroliths varied among the different field sites (Table 1) suggesting that there were varying amounts of non-gastroliths and/or unpolished gastroliths at each of the field sites. Those inferred to be non-gastroliths in the modern soil from Rocky Run are either unpolished gastroliths or non-gastroliths brought to the site by its human inhabitants. Similarly, those inferred to be non-gastroliths in the Farmdale Soil from Athens Quarry probably are. The site is poorly drained and while the Farmdale Soil was subaerially exposed, cryoturbation could have intro-
TABLE 1
Results of Discriminant Analysis

<table>
<thead>
<tr>
<th>Actual Group</th>
<th>Number of Samples</th>
<th>Predicted Group Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Non-gastrolith</td>
</tr>
<tr>
<td>Non-gastrolith</td>
<td>107</td>
<td>75 (70.1%)</td>
</tr>
<tr>
<td>Gastroliths</td>
<td>150</td>
<td>52 (34.7%)</td>
</tr>
<tr>
<td>Suspected Gastroliths</td>
<td>308</td>
<td>135 (43.8%)</td>
</tr>
<tr>
<td>Rocky Run</td>
<td>47</td>
<td>21 (44.7%)</td>
</tr>
<tr>
<td>Athens Quarry</td>
<td>29</td>
<td>14 (48.3%)</td>
</tr>
<tr>
<td>Moses Pit (Sangamon Soil)</td>
<td>161</td>
<td>76 (47.2%)</td>
</tr>
<tr>
<td>Moses Pit (Farmdale Soil)</td>
<td>34</td>
<td>13 (38.2%)</td>
</tr>
<tr>
<td>Vicksburg</td>
<td>27</td>
<td>13 (35.1%)</td>
</tr>
</tbody>
</table>

duced pebbles up from the underlying till. There is also a significant number of pebbles from the Sangamon Soil at Moses Pit that were inferred to be non-gastroliths. Since Moses Pit occupies a backslope position, the non-gastroliths may have been derived from slopewash; alternatively, they may have been bioturbated up from the underlying Mounds Gravel Deposit by burrowing mammals.

In contrast, all of the suspected gastroliths in the Farmdale Soil from Moses Pit and in the Sangamon Soil from Vicksburg were inferred to be gastroliths. The percentage of suspected gastroliths recovered from these sites that were identified as gastroliths is about equal to the percentage of the known gastroliths that were identified as gastroliths. Furthermore, the pebbles recovered from both of these sites were separated from underlying terrace gravels by more than 2 m of loess.

Assessment of Bioturbation

At Rocky Run there is no discernable stone-line. Instead, most of the suspected gastroliths found in the 44 pedons were scattered throughout a zone that extended from the surface to 100 cm in depth. Most commonly, the suspected gastroliths were found with cultural material indicating that gastrolith-bearing gizzards may have been discarded along with the cultural material.

Similarly, there is no well defined stone-line in the Farmdale soil at Athens Quarry. However, a stone-line may exist in the lower B horizon that was not sampled.

Preliminary evidence shows that there are subtle stone-lines in the Farmdale and Sangamon Soils at Moses Pit and in the Sangamon Soils at Thebes and Vicksburg. The Farmdale Soil at Moses Pit exhibits a subtle stone-line in the upper Bw horizon indicating that bioturbation created it (Fig. 5). Similarly, the Sangamon Soil at Moses Pit contains a subtle stone-line in the AE and E horizons but nowhere else in the profile, indicating that bioturbation created this stone-line (Fig. 6).

Pebbles are concentrated into a subtle stone-line in E and upper Bt horizons of the Sangamon Soil at Thebes indicating that it was created by bioturbation (Fig. 7). The Sangamon Soil at Vicksburg contains one subtle stone-line in the lower E(C2) horizons and another subtle stone-line in the 2Btlb horizon (Fig. 8). Bioturbation may have created the first stone-line. If a period of episodic upbuilding occurred after the first stone line was created, the zone of dominant bioturbation would have shifted upward causing it to be "left behind." Subsequently, the second horizon stone-line may have formed as a result of bioturbation after the period of upbuilding but before the Sangamon Soil was buried.

CONCLUSIONS

Many of the suspected gastroliths can be safely inferred to be gastroliths. The recovery of former gastroliths from the Rocky Run site illustrates that former gastroliths are present at upland archaeological sites surrounded by deep loessal soils. If former gastroliths are recovered at similar archaeological sites, they may be used to indicate the location of living surfaces. In addition, their numbers may be used to estimate the importance of gastroliths to the inhabitants' dietary intake.

The apparent concentration of predominantly former gastroliths into subtle stone-lines in the Farmdale and Sangamon Soils at Moses Pit, and in the Sangamon Soil at Moses Pit, Thebes, and Vicksburg
FIG. 5. The percent coarse fraction found in the Farmdale Soil at Moses Pit.

FIG. 6. The percent coarse fraction found in the Sangamon Soil at Moses Pit.

FIG. 7. The percent coarse fraction found in the Sangamon Soil at Thebes.

FIG. 8. The percent coarse fraction found in the Sangamon Soil at Vicksburg. The horizon designations are borrowed from Miller et al., (1984).
indicates that bioturbation can conceivably create stone-lines in upland loess-derived soils, given enough time. Logically then, bioturbation must be a viable process in creating stone-lines in all soils that contain stones.

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Bioturbation to Bulldozers: The Myth of Undisturbed Sites and Its Implications in Cultural Resource Studies

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One of the most important goals of archaeology, one which serves to set our discipline apart from other social sciences, is the goal of gaining insights into human behavior through the methodology of recognizing and interpreting patterns and associations in the placement of artifacts and features in archaeological sites. Unfortunately, archaeological sites and the artifacts within them are subject to a myriad of forces that can alter or destroy that patterning. With increasing age, the effect of these forces is compounded and aggravated. Hester, Heizer, and Graham, in a near poetic passage in their widely used textbook, Field Methods in Archaeology (1975), state: "Time, weather, and vandals have eliminated so much evidence at many sites that perceptiveness, imagination, and ingenuity are all necessary to get the merest hints of things once obvious, to recognize the subtle residues of once-living cultures." We are now starting to have a greater understanding of what some of these forces are and how to recognize their effects on the archaeological record.

Discussions of "site formation processes" (Schiffer, 1976) have become common, but training to recognize these processes is often informal and non-structured. Most of the concern with site formation and site disturbance processes and their effects is focused upon the excavation phase of archaeological research. It is my contention that it needs to be considered much earlier in the process, particularly in cases where historic preservation and archaeology intersect.

An important part of field training in archaeology consists of teaching future archaeologists to recognize features in the soil and to distinguish those which are the result of natural actions from those which are the result of cultural actions. But most field schools must concentrate on work at one site for an entire field season or more, and no one site is likely to present a student with the range of experiences one will encounter as a professional.

Archaeological site survey is not routinely included as part of field schools. When treated at all, it is usually relegated to a single lecture or a field trip on a rainy day. If a student is lucky, he or she may get to work on a survey that an institution or individual faculty member has contracted to perform. If the student is even more fortunate, a regional survey, usually an effort to locate sites suitable for future field schools, may be included in the school's archaeological program. What is generally not covered in the classroom or in field schools is the art and science of how to recognize the types of actions that have helped shape the post-depositional environment of archaeological sites.

In the early 1970s, three events happened that have drastically changed the archaeological profession in the United States: passage of the Archaeological and Historic Preservation Act (Public Law 93-291, 16 U.S.C. 469); the publication of federal regulations (36 CFR 800) for compliance with the National Historic Preservation Act of 1966 (Public Law 89-665, as amended, 16 U.S.C. 470); and the implementation of the National Environmental Policy Act of 1969 (Public Law 91-190, 42 U.S.C. 4332). Since that time archaeological survey work has become a major part of the archaeological research done in this country. Surveys to identify cultural resources have become the cornerstone of what has been labeled Cultural Resource Management (CRM). In North Carolina alone, over 1,700 archaeological reports were generated in the decade from 1975 to 1985 (Mathis, 1988), almost all the result of CRM "compliance" surveys. Although federal regulations may soon change, in the past two decades, nonacademic CRM has been the growth sector of the discipline. The number of non-academic archaeologists currently employed in the U.S. probably exceeds the number in university departments. Many university archaeologists also engage in CRM archaeology either full time or part time, and a number of academic departments have non-teaching faculty positions expressly set up to run CRM contract programs.

CULTURAL RESOURCE MANAGEMENT

The term cultural resource management (CRM) is used here to denote historic preservation archaeology, or archaeology done under the authority of Section 106 or Section 110 of the National Historic Preservation Act (NHPA). Archaeological studies conducted under other federal, state, and even local statutes can also be considered CRM archaeology, but the NHPA is the primary legislative authority for historic preservation in the United States, covering archaeological sites as well as historical and architecturally significant properties. The NHPA has grown out of a public concern for the
loss and destruction of historically important properties, including archaeological sites.

The goal of CRM archaeology is to preserve significant archaeological sites, either through actual site conservation and in situ preservation or by recovery and preservation of the archaeological data in the site (King et al., 1977). However, it is neither possible nor particularly desirable to extend this level of protection to all archaeological sites. The federal agency responsible for funding, approving or licensing the project is required only to consider what effects that project will have on properties or sites that are on or eligible for listing on the National Register of Historic Places. Federal regulations (36CFR66) enumerate the criteria for such listing. Additional guidelines have been issued and several journal articles have appeared in the literature in an attempt to define national standards for "significant" archaeological resources (Barnes et al., 1980; Department of Interior, 1977, 1983, 1988, 1990, 1993; see also Glassow, 1977; Sharrock and Grayson, 1979).

Cultural Resource Management archaeology is usually initiated by specific government funded or licensed construction projects such as dam construction, road and utility projects, or urban renewal projects, all of which fall under Section 106 of the National Historic Preservation Act, or by an agency that controls federal lands which require an inventory of historic properties under Section 110 of the act. In this sense it is project oriented, rather than problem oriented.

At the heart of the NHPA procedures (known as the "106 process") to consider project impacts on significant archaeological sites, is the requirement to "locate and evaluate" all sites in the project study area. Studies that have been done concerning pedological and other factors affecting site formation and disturbance are of particular importance to archaeologists seeking to identify sites that would meet National Register eligibility. Those of us either actively engaged in CRM work or in teaching students who will be employed to conduct CRM identification and evaluation surveys could benefit from additional knowledge and awareness of these factors.

SITE DISTURBANCE PROCESSES

Geomorphology is the study of geological and physical factors that shape the landscape. Pedology is the study of soils and soil formation. The inclusion of these sciences within archaeology in recent years has led to the use of terms like geoarchaeology and pedoarchaeology. Although there are objections to both these terms, their usage is spreading in the profession. For the purposes of this paper, I use the phase "site disturbance processes" to include pedologic and geomorphologic actions that impinge upon archaeological sites.

The range of potential mechanical and biological actions that have affected archaeological sites is almost unlimited. It is probably more prudent to assume that a particular site has been disturbed than to assume the opposite. I am always skeptical of survey reports that refer to "apparently undisturbed deposits" or "undisturbed" archaeological sites. The amount of disturbance to artifact distributions and patterns varies with different circumstances, but any site exposed to the vagaries of nature is going to be changed or disturbed in some way. Even materials contained in features and other "sealed contexts" are often subjected to such common actions as root penetration and the burrowing of animals and insects. At the level of the archaeological survey, site disturbance processes are not always obvious.

Although archaeologists have always been aware of at least some of these factors and occasional articles on the subject can be found in the professional literature prior to 1970 (e.g., Ascher, 1961; Duffield, 1970; Hawley, 1937; Hayden, 1965), it was not until the late 1970s that articles and reports discussing a wide range of pedoturbation factors appeared in the archaeological literature. The article by Wood and Johnson first published in Advances in Archaeological Method and Theory in 1978 is an excellent review of site disturbance processes, citing literature of soil scientists, foresters, zoologists, geologists, geographers, and engineers (Wood and Johnson, 1978). Using research published in these non-archaeological sciences, as well as the archaeological literature, Wood and Johnson explained the actions and the archaeological implications of soil bioturbation by ants, earthworms, rodents, root action and tree tip-ups. They discuss the effects of swelling and shrinking clays, water transport, freeze-thaw, wind deflation, crystallization, and even seismic activity. The only major omission in Wood and Johnson's article was the work done by Walter Lyford at Harvard Forest in the early 1960s (Lyford, 1963; Lyford and MacLean, 1966), but similar research studies are cited. Wood and Johnson did not discuss the effects that human actions in the historical past have had on soils and on archaeological sites, but those effects can be dramatic and their impact must also be considered.

For a discipline that deals so much with soil, archaeology has been rather slow to learn how complex soil really is. But this has begun to change in the last 15 years, and geomorphologists and soil scientists are increasingly consulted on major excavation projects. Sponsoring agencies have recognized the value of these special analyses and have become more receptive to funding them. At least one university program on historic preservation (at the University of Nevada, Reno) has added geomorphology to the curriculum. The success of the International Conference on Pedo-Archaeology is evidence of the increasing realization of the importance of soils, soil formation, geomorphology,
BIOTURBATION TO BULLDOZERS

and site disturbance processes in archaeology. In doing site surveys, however, the investigator is limited in the amount of subsurface information available and must often concentrate on surface indications and small test units to assess the amount of disturbance to the "natural" landscape.

Trying to quantify these disturbance processes, however, is extremely difficult. For example, tree tip-ups leave a characteristic mound and pit topography on the landscape. This is particularly noticeable following a major episode of trees being uprooted such as occurs during large storms. The cratersed ground surface slowly recovers from such major episodes, and the rate of recovery can be measured over time, but a number of new tree falls will occur in the interim period. Lyford attempted to study the rate of episodic soil churning resulting from tree tip-ups by using historical data on storm paths and observations on storm effects on tree fall at Harvard Forest (Lyford, 1963).

SURVEY CONSIDERATIONS

When conducting archaeological surveys for historic preservation or environmental compliance studies, the investigator must consider a vast number of factors that will affect the success of the study, from the type of soils in the project area to historical land-use patterns. One aspect of land use we have perhaps tended to overemphasize is the effects of modern agriculture (cultivation) on sites. This is not to belittle those impacts. Stanley Trumble's classic study, "Man-induced Soil Erosion on the Southern Piedmont" (1974) and Jim Scholtz's quantification of site destruction in eastern Arkansas (Scholtz, 1968) have long ago documented these effects in the southeast.

But with so much land being taken out of agricultural production in the recent past, it is sometimes easy to overlook the fact that the land was once subjected to cultivation, erosion, slope terracing, drainage, etc., all of which altered the "natural" landscape. There is a tendency to assume that land that has not been cultivated recently has somehow escaped cultural alteration. In the eastern United States, with notable exceptions such as the Joyce Kilmer Memorial Forest in North Carolina, every acre of dry land (and even a large amount of wetlands) has been altered by some human action in the last 250 years. If it was not cultivated, it was timbered (and usually it was both). Logging not only has direct impacts of logging trails, camps, work areas, and rail lines, but can cause indirect impacts with enormous consequences. Clear-cutting the southern forests led to massive flooding and erosion in the late nineteenth and early twentieth centuries. Scars on the landscape from this era can still be detected in many places.

The Euro-American search for exploitable mineral resources also led to extensive land alteration in many places. For example, western Pennsylvania was once a forest of oil rigs which have now disappeared but which certainly altered the landscape and doubtlessly also affected prehistoric sites. Large tracts of the Piedmont were mined by various methods (including hydraulic) in the nineteenth and early twentieth centuries.

Now, much of the industry of our forefathers is easy to overlook in the present terrain of pastures, fields, woods and suburban shopping malls of eastern North America. However, historic period land use has often been the dominant process in shaping the modern landscape and the modern soils.

It is the task of the survey archaeologist to be aware of and document these types of land impacts as well as natural impacts such as tree tip-ups or "tree throw." The "mound and pit" micro-relief caused by tree tip-ups and other types of bioturbation (fire ant colonies, animal burrows, etc.) are discernible from surface indications. Old road beds, terraces, erosional gullies, and "borrow" areas may or may not be very easily discernible. In order to adequately recognize and evaluate all these impacts, archaeologists should not only be familiar with the various processes of pedoturbation, but should be thoroughly aware of the historic background of the area.

So where does this leave us in trying to "locate and identify" sites that are "significant"? Considering the multitude of forces that demonstrate that the second law of thermodynamics is very much at work on our sites, one might infer that all archaeological sites are disturbed to the point that the cultural patterns supposedly reflected in the original deposition of artifacts and features are no longer discernible or meaningful.

It is important to remember, however, that many of the same actions that destroy the context of some sites serve to protect other sites by burying them under colluvial, eolian, or alluvial deposits. Slope terracing has been thought of as a site-destructive process, but it can be, at least in some cases (John Davis, personal communication), just the opposite, preserving subplowzone features. Indeed, many of the historic period activities (such as mining, milling, logging, and even general urban construction) that have damaged or destroyed prehistoric sites have, in turn, left historic sites that may be significant on the local, regional, or even national level. All of these actions have to be evaluated at some level during an archaeological survey.

In evaluating any site for Section 106 purposes, the questions that have to be asked are: "What are the qualities that make that site eligible for the National Register of Historic Places?"; "Does the site still contain those qualities?"; and, "Will the proposed action affect or alter those qualities?".

INTEGRITY OF ARCHAEOLOGICAL RECORD

All archaeologists should be concerned about the integrity of the archaeological record and the decisions,
evaluations, and judgments that are being made about the finite resource of archaeological sites. At the same time, we must remember that as archaeologists we have no inherent rights to, or demonstrated proprietary interests in, any archaeological site, despite ninety years of legislation aimed at archaeological protection and conservation. In fact, a recent suggestion to the contrary, made in regard to the Poverty Point Site (Gibson and Saunders, 1993), brought criticism from letter writers in a subsequent issue of the SAA Bulletin (Fenn, 1994; Hanson, 1994).

Archaeological survey work is difficult under the best circumstances. It requires physical stamina, keen powers of observation, and a good deal of common sense. When done for historic preservation studies, it normally requires that sites not only be found and recorded, but that a judgment on the site’s research value be made, and often these evaluations have to be based upon surface data and very limited subsurface testing. The archaeologist must determine if a site is the result of primary or secondary deposition and what the potential is for organic and feature preservation.

As a practical matter it is seldom possible to conduct major testing of all survey areas to answer these questions or to carry out the mechanical testing necessary to record deeply buried sites. Therefore, it is important to gain all the information we can on the history, geomorphology, and soils of the area. The more we understand about pedological and geomorphological processes and their effects on archaeological sites, the better we will be at evaluating the archaeological record and making informed decisions about preservation and data recovery options. In fact, this information is important in determining whether a survey of a particular project area is warranted in the first place.

Once a survey is completed and sites are located, this type of information is crucial in the evaluation of sites for cultural resource management. At some level these factors affect the recording and eventual evaluation of sites. In a CRM survey four mistakes can happen: (1) significant sites are not recorded at all; (2) significant sites are recorded as non-significant sites; (3) insignificant sites are recorded as significant; or (4) insignificant sites are not recorded.

Only the last case may be inconsequential. In the first two instances, a good site is either not recognized by the surveyors or is misjudged in the evaluation, and may therefore be inadvertently destroyed, or at least "adversely affected." In the third case, time, effort, and money (possibly your tax money) may be ill spent on a site that has little or no real research value.

Remembering what Hester, Heizer, and Graham so eloquently stated long ago, knowledge of site disturbance factors and site-specific geomorphology is one tool that CRM archaeologists must use if we are to have the "perceptiveness, imagination, and ingenuity... to recognize the subtle residues of once-living cultures."

REFERENCES


Evidence for Subsurface Translocation of Ceramic Artifacts in a Vertisol in Eastern Crete, Greece

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A team of soil and biological scientists from the University of Tennessee and the College of Southeastern Europe worked in cooperation with archaeologists from the Kavousi Project in Eastern Crete, Greece. The Kavousi Project, an archaeological expedition sponsored by the American School of Classical Studies in Athens, Greece, focused on excavations in the Late Bronze Age/Early Iron Age sites of Vronda and Kastro on the southern aspects of the Siteia Range in Eastern Crete. Soil studies conducted in cooperation with the Kavousi Project focused on locating, describing, and characterizing depositional basins in order to understand the dynamics of landscape development over time. One such depositional basin was located in the northern coastal hills northwest of the present village of Kavousi. This landform consisted of a large sinkhole with an alluvial fill of considerable depth. Artifacts were noted in the profile walls of an excavated borrow pit. It was believed that these artifact assemblages would help to establish the time during which the surface of the alluvial landscape was stable and to estimate the amount of sediment deposition that would have occurred between the depositions of these assemblages.

Artifacts were encountered in the profile of the borrow pit from 30 to 110 cm below the surface. These artifacts, which consisted of ceramic sherds dating to the Middle Minoan Period (2000-1550 B.C.), were found on the surface of the alluvium. Upon identification of these ceramic sherds, the investigation learned that the buried ceramic sherds were from the Middle Minoan Period as well. Soil morphological features such as deep vertical cracks extending from the surface, intersecting slickensides, and a high clay content were described. It was surmised that this soil unit was a Vertisol and the artifacts may have been "redeposited" as a result of the opening and closing of the vertical cracks by the shrink-swell activity of this Vertisol.

A Chromic Haplooxerert was investigated in cooperation with a soil survey of the Kavousi Archaeological Expedition near the village of Kavousi in Eastern Crete, Greece. This Vertisol was found in a sinkhole formed in Triassic age dolomite in a coastal hill range on the Bay of Mirabello. The Vertisol developed in low energy deposits, and parent material was derived from the "terra rossa" soils (Lithic Ruptic Xerofertal and Lithic Ruptic Xerofertal) of the surrounding uplands. A Middle Minoan Period (2000 to 1550 B.C.) archaeological ceramic deposit was located on the surface of this soil. Ceramics dating to the same period were discovered in the profile between the depths of 30 and 110 cm. The soil profile was described and sampled. Soil samples were subjected to particle size, total carbon, organic carbon, and extractable metals analyses to examine the possibility of discontinuities and buried soil horizons as an explanation for the appearance of artifacts deep in the profile. X-ray diffraction analysis was performed to identify the clay minerals in the profile. Vertical cracks of 1 cm in width or more were observed in the profile from the surface to 170 cm in depth. The majority of the intersecting slickensides were observed at 110 cm, but some slickensides were recorded at a depth of 200 cm. Particle size analysis showed no discernible discontinuities associated with the pottery. There was a increase in clay content from 50.3% in the surface to 68.0% at the base of the profile. Carbon increased at 140 cm below the surface, but no discernible increase at the depths of the pottery fragments. Extractable element analyses showed a gradual decrease of Ba and Mn from the surface to the base of the profile indicating an absence of buried surfaces. Clay mineral analysis revealed the predominant clay-sized minerals to be illite, kaolinite, and quartz. This evidence indicated that the ceramic artifacts had been translocated from the surface of the landform to as far as 110 cm into the profile due to the shrink-swell of Vertisol pedogenesis. The primary driving force behind the vertic morphology is the seasonal wet and dry conditions indicative of the xeric climate of the eastern Mediterranean.
The objective of this study was to determine if there were evidence for buried soils and/or discontinuities in the soil profile that would explain the presence of artifacts deep in the soil profile. A number of techniques were employed to determine the presence of discontinuities. Soil descriptions were made to note any changes in the soil morphology of the pedon. Soil samples were collected from the pedon for particle size, carbon, and extractable element analyses. Particle size analysis was used to note changes in the particle size distribution with depth where variability in particle size distribution would characterize changes in the lithology (e.g., the presence of stone lines or multisequel argillic horizons) and would locate discontinuities. Carbon analyses were used to determine if buried soil surfaces were present in this pedon. Buried soils can be identified by increases in organic carbon and decreases in inorganic carbon due to recycling of organic materials and leaching of carbonates at a soil surface. Extractable element analyses were performed to denote changes in the distribution of metals in the profile and to help in locating buried surfaces where such metals as Ba and Mn and non-metals such as P would be concentrated. By observing these changes in the soil profile and correlating them with the buried artifacts, the presence of buried surfaces associated with these artifacts was determined. If no discontinuities were found, it could be determined that the artifacts were translocated and not in their original depositional context.

**BACKGROUND**

Vertisols form on a wide variety of parent materials in a number of climates. Vertisol parent materials can include basaltic intrusions, calcareous rocks, gneisses, sandstones, shale, gabbro, diabase, dolerite, serpentines, volcanic ash rich in feldspars, marine and lagoonal clays, and alluvium. The climatic conditions for Vertisol formation are also quite variable, but generally there needs to be some seasonality of precipitation leading to episodes of wetting and drying of the profile (Ahmad, 1983; Soil Survey Staff, 1975). Ahmad outlined some of the more common aspects of the Vertisol profile:

Some of the outstanding features of the profile are the development of minimal horizon differentiation due to pedoturbation, high clay content, pronounced changes in volume with changes in water content resulting in deep, wide cracks in the dry seasons, and very plastic and sticky soil consistency when wet. The profile has a high bulk density when dry and very low hydraulic conductivity when wet, and when it dries some subsidence occurs and cracks develop. As a result of internal stresses due to overburden pressure and swelling and shrinking of the subsoil, a peculiar type of wedge-shaped platy structure develops in which the peds have greater horizontal dimensions than vertical. The upper and lower-ped surfaces instead of being parallel, are inclined away from each other at 20-30°, forming wedges. The particular type of orientation of the clay on the ped surfaces due to stress is known as "slickensides." The physical behavior of Vertisols commonly results in "gilgai" microrelief which consists of slight depressions and mounds, in an irregular pattern or ridges and valleys oriented normal to the slope gradient (Ahmad, 1983:92).

Other features that are common to Vertisols include a high cation exchange capacity, montmorillonite as the dominant clay mineral, low organic matter content, and a dark color. These soils are usually found at an elevation less than 1000 m AMSL and on slopes of less than 5%. One of the major characteristics of Vertisols is the self-swallowing aspect of the profile. Shrink and swell conditions tend to cycle materials from the surface into the interior of the profile through the vertical cracks that extend from the surface. This process has been termed "pedoturbation" and is described as follows:

In Vertisols there are two main causes of pedoturbation and development of slickensides. One is the effect of swelling pressures upon wetting and the resolution of horizontal and vertical stress components. The other is the "self-swallowing" concept in which surficial soil material is continuously being incorporated into the subsoil through stress cracks, thus increasing the volume of subsoil material at depth. If some of the main stress cracks are semi-permanent as evidence suggests, the continuous loss of surface soil at the locations in dry seasons and the heaving which occurs in the wet season due to swelling would eventually lead to the development of gilgai micro-relief. Swelling pressures at depths below the depth of cracking are not as easily resolved by soil heaving due to greater overburden pressure and in most cases, the formation of slickenside features must be related to lateral swelling pressures which exceed the shear strength of the soils under overburden-pressure confinement (Ahmad, 1983:112).

The vertical movement of artifacts through a soil profile has been documented in other archaeological studies. Wood and Johnson (1978) identified a number of disturbance processes, based on the evolution model of pedogenesis (Johnson and Watson-Stegner, 1987), which would tend to redistribute artifacts, thus blurring the archaeological context. One of the processes to which Wood and Johnson (1978) refer is directly related to the shrink-swell properties of Vertisols and soils with vertic morphology, which was termed "argilliturbation." Hofman (1986) documented vertical movement of artifacts, by refitting analysis, in Holocene alluvium of the Duck River in Middle Tennessee. Hofman noted a 40% clay content and massive vertical cracks that extended from the surface to 2 m into the profile. Although a Vertisol was not
described, the observations were consistent of soils with vertic morphology.

SITE SETTING

The Vertisol was located in the coastal hills of the Bay of Mirabello in Eastern Crete, and is referenced as the Kavousi 3 pedon (Figs. 1 and 2). The site was a sinkhole formed in Triassic age dolomite of the Tripolitza series and located approximately 2 km west of the present village of Kavousi at 35°50'08" E Long., 35°07'37" N Lat. Dimensions of the alluvial fill in the sinkhole were approximately 280 m north to south and 410 m east to west, and it was roughly triangular in shape. The sinkhole had an outlet to the west into the Bay of Mirabello, and the pedon was slightly less than 100 m AMSL in elevation. Alluvium in the sinkhole was red, stone-free, and fine-textured. A borrow pit was placed in the center of the sinkhole, and a maximum depth to bedrock was noted at approximately 5 m below the surface.

The climate of Kavousi is typical of the Mediterranean area and is considered one of the drier areas of Crete. Precipitation is restricted primarily to the months from September until May with the highest precipitation occurring in December and January. Rainfall is rare between the months of May and August. Average rainfall in Ierapetra, a village approximately 7 km to the south at sea level, is 380 mm yr⁻¹. Mean monthly temperatures for Ierapetra are 13.2° C in January and 27.2° C in August (Zohary and Orshan, 1965). Figure 3 shows the temperature and precipitation averages of selected months for the city of Iraklio, Crete.

Archaeological sites that are contemporaneous with the artifacts found in the Kavousi 3 pedon include a number of Middle Minoan and Late Minoan Period (1900-1450 B.C.) sites. Middle Minoan to Late Minoan I sites are located at Pseira (an island 6 km north of Kavousi 3), Vasiliki (a village 5 km south of Kavousi 3), and Gournia (an archaeological site 5 km west of Kavousi 3). The archaeological sites in the Kavousi study area of Vronda and Kastro were inhabited during the Late Minoan IIIC and Protogeometric Periods (1100-900 B.C.) and probably did not contribute to the artifact assemblage found in the sinkhole.

METHODOLOGY

Field Methods

The sinkhole at Kavousi 3 was located during a soils mapping reconnaissance. A borrow pit approximately 50 x 50 m had been placed in the center of the alluvial deposit of the sinkhole by a local brick-making company. Two continuous profiles with a north- and an east-facing aspect had been exposed. The profiles had 3 m of exposure in places from the surface downward.

A 1-m profile section of the east-facing exposure was selected for sampling purposes. This pedon was sampled and described according to methods outlined in the Soil Survey Manual (Soil Survey Staff, 1984). Artifacts located in a 1-m section of the described profile were mapped in situ with the relative depth and orientation of the ceramic sherds noted (Fig. 4).

Laboratory Methods

The soil samples were air dried and ground to pass a 10-mesh sieve (2.00 mm limiting diameter). The fraction >2.00 mm was collected and weighed. The fraction ≤2.00 mm was quartered, and one-quarter was ground to 60 mesh and finer.

Total carbon content for each sample was determined using a LECO CR-12 carbon analyzer on the ≤60-mesh portion of the sample. Each sample was tested with 1 M HCl for the presence of inorganic carbon (CO₃²⁻). The organic carbon content in each sample was determined by use of the Walkley-Black method (Nelson and Somers, 1986).

A particle size analysis was performed on all samples using a combination of sand sieving and sedimentation techniques as outlined in Gee and Bauder (1986). Samples with ≥1.0% organic carbon were pretreated with a 30% H₂O₂ solution, and samples that reacted to 1 M HCl were treated with a 1 M Na-acetate solution buffered at pH 4.5. Approximately 10 g of the <2.00-mm fraction of each sample were dispersed in a Na-hexametaphosphate/Na-carbonate solution, and the sand-size fraction of each sample was separated from the smaller fractions by wet sieving. The remaining silt- and clay-size fractions of each sample were retained in a 1000-ml capacity sedimentation cylinder and placed in a water bath. Pipette analysis was performed on these samples to determine their silt (50-2 μm) and clay (<2 μm) fractions.

Elemental analyses were performed with the aid of a Thermo Jarrel Ash Model 61 Inductively Coupled Argon Plasma Atomic Emission Spectrometer (ICP–AES), which has the capacity to analyze 26 different elements simultaneously. Extractable element analysis was performed by using approximately 2 g of the <2-mm fraction of the soil sample. This sample was extracted with a 5:1 HCl:HNO₃ solution adjusted to 0.75 M according to a procedure outlined in Lewis et al. (1994).

Extractable elements were used to document the presence of buried surfaces in the pedon. Elements such as Mn, Cu, and Zn are common plant nutrients. Barium and Sr can be extracted from the soil solution by mass flow or diffusion into root cells and recycled by leaf, root, and other plant tissues. These metals can be retained in the surface of a soil by processes such as adsorption onto clay mineral surfaces, adsorption by organic matter, and complexation by residual organic compounds. Non-metals, such as P, are major
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FIG. 1. Plan of the Kavousi area including the Vronda and Kastro archaeological sites and the Kavousi study pedons. Kavousi 3 is located in the center of the drawing.
FIG. 2. View of the sinkhole at Kavousi 3 with the outlet to the sea at the far left, facing north.

FIG. 3. Mean Air Temperature (°C) and Mean Precipitation (mm) for selected months for Iraklio, Crete, Greece. Source: Mariolopoulos (1961).
components of organic materials and can be concentrated in the soil system where organic materials are located, primarily in the surfaces.

Clay mineralogy was analyzed on samples in the mineralogical control section of the soil pedon. Samples of clay were collected in the particle size analysis procedure. Each clay sample was split, and one part was saturated with KCl solution and the other part was saturated with MgCl₂ solution. Both samples were treated with Na-citrate-dithionite to remove the iron oxides. The clay samples were subjected to a filter peel technique and placed on a glass slide according to a procedure outlined by Drever (1973). The K-saturated slides were subjected to air-dry, 105°C, 300°C, and 550°C treatments. The Mg-saturated slides were subjected to air-dry and ethylene-glycol treatments. X-ray diffraction analysis was performed on a Scintag XDS 2000 X-ray diffractometer at the Oak Ridge National Laboratory in a procedure outlined by Whitig and Allardice (1982).

RESULTS

The soil morphology at Kavousi 3 represented a profile of deep alluvium (Table 1, Fig. 5). Some of the more notable aspects of the soil morphology were the vertic properties associated with this soil. The texture of the entire profile was clay, and the colors were dark red and red ranging from 2.5YR 3/6 to 2.5YR 4/6. The profile exhibited stress cutans or slickensides from 40 to 200 cm below the surface in the Bss horizons (Fig. 6). The peds were subangular blocky to prismatic in structure, and the dry consistence ranged from friable in the surface to very firm at a depth of 200 cm. The Bk horizon (200-210+ cm) was distinguished from the rest of the profile by the presence of common fine and medium carbonate nodules in the matrix. The moist color was a 10R 4/6 (light red) with a moderate, coarse subangular blocky structure, and a friable moist consistence. There was evidence of clay flows between the carbonate nodules which formed by flocculation of clays in the Bk horizon due to high cation concentrations. Field tests with 1 M HCl showed that this was the only horizon in the profile that exhibited a reaction to the acid.
Some of the chemical characteristics from Kavousi 3 aided in the interpretation of the soil morphology (Fig. 7). Organic carbon exhibits a decrease from 1.26% at the surface to 0.19% at 210 cm below the surface, with two minor peaks at 80-100 cm and 160-180 cm. The distribution of inorganic carbon (total carbon - organic carbon) exhibited a somewhat irregular pattern from the surface to 180 cm in depth (mean = 0.09%), but increased to 0.22% at 180-200 cm and to 2.48% at 200-210 cm. This pattern was interpreted as the precipitation of carbonates above the capillary fringe of a water table, perhaps due to some evapotranspiration during the dry season.

An examination of the particle size distributions showed that most of the profile was homogeneous (Fig. 8). The clay content increased from 50.3 to 58.6% from the surface to the Bw horizon. There was also a decrease in sand content from 14.5 to 11.9% as well, and the sand content decreased to 8.8% at 200 cm and again to 3.3% at 210 cm. There was an increase in clay from 62.9% at 200 cm to 68.0% at 210 cm. This increase in clay content over a short distance could be ascribed to the flocculation of clay due to an increase in exchangeable cations.

Extractable element distributions did not identify any discontinuities that may be represented by artifact locations (Fig. 9). Most of the extractable elements that were analyzed had their greatest concentrations at the surface and gradually decreased with depth. Extractable Mn decreased from 394 mg kg⁻¹ in the Bk horizon with two lesser peaks at 80-100 cm and 160-180 cm. Extractable P was only detectable in the surface horizon at 3.00 mg kg⁻¹, which indicated that biological activity was restricted to the surface. Extractable Ba was more concentrated in the upper part of the pedon (0-120 cm) with values ranging from 77.6 to 73.0 mg kg⁻¹. The lower part of the pedon (120-210 cm) had extractable Ba values that ranged from 68.7 to 35.8 mg kg⁻¹. This relationship indicated that the surface material containing some residual organic material was being recycled in the upper 120 cm of the profile, which was the depth of the major slickensides. The clay mineral analysis performed on the Bss2 horizon (100-120 cm) showed the horizon had no expandable clay minerals (Fig. 10). A comparison of the K saturated air-dried and the K saturated 550°C treatments showed kaolinite to be present at 7.2 Å and 3.54 Å because these peaks disappear as kaolinite is destroyed at 550°C. A comparison between the Mg saturated air-dried and Mg saturated ethylene-glycol treatments showed that an illite peak at 10.0 Å did not increase and therefore, did not expand upon glycolation. This was unusual for a Vertisol since most reported Vertisols have at least some expandable minerals (Ahmad, 1983). The remaining X-ray diffraction peaks were an illite peak at 5.0 Å and a quartz peak at 3.34 Å. Therefore, kaolinite and illite were the major clay minerals in the control section of this Vertisol.

**DISCUSSION**

Artifact lines mapped in profile have been used to indicate buried surfaces and paleosols in archaeological studies (Turner et al., 1982; Turner and Klippe, 1989). This principle is consistent with the development of stone lines, which are recognized as evidence of buried surfaces in a profile (Rube, 1959). Artifacts that have been recognized as having been translocated in a profile are generally not associated with the development of discrete artifact lines in profile (Cahen and Moeyersons, 1977; Hofman, 1986). In the case of the pedon at Kavousi 3, there seemed to be a development of artifact lines as a function of the translocation of these artifacts by argilliturbation (Wood and Johnson, 1978). The artifact line at 30 cm below the surface correlated with the base of a plow zone in the alluvium of the sinkhole.
FIG. 6. Slickensides from the Kavousi 3 pedon at 110 cm below the surface.

FIG. 7. Distribution of inorganic and organic carbon vs. depth for the Kavousi 3 soil pedon.

FIG. 8. Distribution of gravel, sand, silt, and clay, as determined by particle size analysis, vs. depth for the Kavousi 3 soil pedon.
Perhaps the extent of the vertical cracking was interrupted by this activity, and the 30-cm depth represented the depth to which the continuous cracking was disturbed. The depths of the artifacts at 110 cm conformed to the depth of the wedge-shaped aggregates with fluted slickensides that were oriented at an approximate 45° angle. This artifact distribution could be explained by the depth to which straight vertical cracking existed between the surface and the subsoil. Although vertical cracks at least 1 cm wide were noted to a depth of 170 cm, these wedges may have provided an obstacle limiting the depth of artifact translocation.

The Vertisol at Kavousi 3 had most of the characteristics common to Vertisols. The clay content was sufficiently high, the relief was relatively level, the climate had distinct wet and dry seasons, and the profile exhibited vertic morphology. The main difference between this profile and most Vertisols was the absence of smectites in the clay mineral suite. Ahmad (1983) noted that Vertisols formed in alluvium had a mineralogy abundant in illite. Ahmad (1983) also noted that continental Vertisols in Australia commonly had higher kaolinite contents than smectite. D’Hoore (1968) did report that several African Vertisols had low swelling clay contents, but were high in amorphous gels of Al₂O₃ and SiO₂ in the clay fraction. Usually the non-crystalline content of Vertisols is less than 20% of the clay-size fraction (Ahmad, 1983). Although it was not tested for these components, the Vertisol at Kavousi 3 may reflect this composition as well.

The presence of Middle Minoan Period artifacts on the surface of the Kavousi 3 pedon, and the evidence that Middle Minoan artifacts had moved through the profile, indicated that the surface of this alluvium was stable at least 4000 yr B.P. (Fig. 11). The questions that remain are when did the sediments in this sinkhole accumulate, and by what mechanism did they accumulate? The parent material for the alluvium was derived from the terra rossa soils (Lithic Ruptic Xerochreptic Rhodoxeralfs and Lithic Ruptic Rhodic Xerochrepts) of the surrounding basin. Davidson (1980) noted that the terra rossa soils may be relict in origin and a product of the climate of the last glacial period. The fineness of the sediments in the sinkhole reflected a depositional regime that was of relatively low energy, such as in a slackwater environment. It is possible that this was a Pleistocene or Early Holocene lake, and these sediments represent a lacustrine environment. Pluvial conditions have been reported in the areas of the Levant and North Africa (Farrand, 1971). Ritchie et al. (1985) reported on pluvial conditions in north-west Sudan between 8900 and 4900 yr B.P. Bertolani-Marchetti (1985), through paleovegetation reconstruction, suggested that these pluvial conditions could have been in place in the eastern Mediterranean during the Late Pleistocene. Pluvial conditions can be explained by the southward shift of the Mediterranean winter rain belt during the last glacial episode. The sinkhole at Kavousi 3 may represent a Late Pleistocene/Early Holocene lake in this part of Crete and stand as a relic of a previous climatic regime.

CONCLUSION

The appearance of artifacts between the depths of 30 and 110 cm in a profile could have been explained as the presence of living surfaces with deposition of artifacts and their subsequent burial. However, field observations and laboratory analyses from this pedon indicated a lack of evidence of buried surfaces to correlate with these artifact distributions. An artifact line at 30 cm below the surface indicated the base of a plow layer at the site. The distribution of artifacts to a depth of 110 cm was related to the vertic morphology of the pedon. Artifacts on the surface of the pedon were incorporated into the profile during the summer months when the extent of the cracks from the surface downward were the greatest. Movement of artifacts through the profile was dependent upon the limiting diameter of the artifact and the morphology of the vertical cracks. The shrink-swell properties of this Vertisol were determined to be a function of the Mediterranean or xeric climate where the episodes of wet conditions fall between episodes of very dry conditions, rather than a function of the shrink-swell
FIG. 10. X-ray diffractograms of a clay sample from the Bss2 horizon (100-120 cm) of the Kavousi 3 soil pedon.

FIG. 11. Minoan-age ceramic fragments on the surface of the Kavousi 3 pedon. Note proximity of artifact to vertical cracks.
properties of the clays. It is concluded that artifacts in a Vertisol can move a considerable distance through a soil profile from their original depositional context.

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Variable Artifact Displacement and Replacement in a Holocene Eolian Feature

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During July and August 1992, a primarily Middle Holocene archaeological site was excavated in north-central South Carolina about 97 km southeast of Charlotte, North Carolina. The west side of the site is an eolian blowout. Guilford, dated at 5300 yr B.P., and millennium-earlier Morrow Mountain components were found buried under the east side of the eolian feature. The eolian feature appears to have stabilized by 3500 yr B.P. (see Tanner 1980 for discussion of eolian non-dune topographic features). Other such eolian features appear to have been reported in the archaeological literature of the region. Analysis of artifact distributions in various parts of the feature revealed variable downward displacement of artifacts depending on sediment grain size and artifact size. The least displacement is evident in the areas of coarsest sediment grain size. Artifacts larger than 5 cm appear to be stable while artifacts smaller than 5 cm are progressively more prone to downward displacement. We propose an algorithm to replace artifacts to their original positions in the sediment column.

The question of bioturbation and the disturbance it brings to archaeological sites is clearly a topic that requires more attention than it has been given in the past. Archaeologists have long recognized bioturbation as a fact but given only passing attention to its implications for interpreting archaeological site patterns.

Copperhead Hollow (38CT58) in north-central South Carolina, is located on a sand body believed to have been an active eolian feature during the Middle Holocene (Gunn and Foss, 1992; Gunn and Wilson, 1993). Not a true dune, it possesses a blowout on the west and approximately a meter of eolian deposition on the east. Sediment characterization revealed variable sediment grain size in different parts of the site. Artifact analysis indicated variable rates of descent, also inhomogenously distributed over the site. The question that arises in this dynamic context is whether the tediously excavated, presumed occupations floors are truley meaningful in terms of activity loci.

In this paper we attempt to take advantage of some of the variability within the site to suggest possible differences in the characteristics of bioturbation within varying sediment and artifact size domains. The paper is only exploratory. It supports the contention that artifact displacement is a more complicated process than implied by the linear formulations developed to date. It does not attempt to explore a broad range of conditions. The sediments at Copperhead Hollow are loamy to clayey sands. Silts and clays have long been understood to have their own bioturbation characteristics. The paper attempts to describe in a general fashion the characteristics of bioturbation on one sand hill. It should be treated as a case study in a range of depositional environments. It is not an attempt to develop a unified framework for bioturbation of archaeological sites such as that undertaken by Johnson (1992). It is rather an effort to suggest some of the multidimensional factors accounting for at least a half-dozen variables including space, depth, time, artifact size, sediment grain size, and biotic community contributions such as the size of animals during varying climatic conditions.

PHYSIOGRAPHY

Copperhead Hollow (38CT58) lies at the interface of the Piedmont and the Sand Hills segment of the inner Coastal Plain physiographic province just to the southeast of the Fall Line (Fig. 1). The Fall Line marks a transition zone about 8-16 km in width separating the rolling hills and valleys of the Piedmont from the nearby flat Coastal Plain (Fenneman, 1938:39). Immediately to the southeast of the Fall Line is a zone of relatively high sand hills that form interfluvial uplands (Cooke 1936). The Sand Hills vary from 32-64 km in width and consist of unconsolidated coarse and fine sands, bisected by numerous rivers originating in the Piedmont and mountains, and draining through the Coastal Plain into the Atlantic Ocean. The hills frequently overlook low-lying areas and may rise to 61 m above floodplains and valley bottoms (Cooke 1936; Fenneman 1938).
FIG. 1. Map of Fall Line showing sites in the region.

FIG. 2. Project location map.
The South Carolina Sand Hills exhibit much physiographic variability. Cooke (1936) divided the Sand Hills into the Aiken Plateau, the Congaree Sand Hills, the Richland Sand Hills, and the High Hills of the Santee. The Richland Red Hills and the High Hills of the Santee are small in size and morphologically similar. Colquhoun (1965) has grouped these two formations into the "Red Sand Hills." He places the Aiken Plateau and Congaree Sand Hills into the "White Sand Hills." Environmentally, the Red Sand Hills exhibit a more mesic climate and the White Sand Hills a more xeric climate. The Red Sand Hills support a mixed hardwood and pine forest, in part attributed to the higher clay content in their soils. The zone of clay accumulation is denser and situated nearer to the ground surface and inhibits downward percolation of moisture resulting in a higher subsurface water table. As a result, a floral regime similar to that of the Piedmont can be found in the Red Sand Hills. The White Sand Hills are comprised of soils exhibiting lesser amounts of clay that results in increased permeability and a lower and seasonally short-lived subsurface water table. Thus, the White Sand Hills are dominated by a more xeric floral regime of pines and several species of scrub oak.

Copperhead Hollow is located in the Red Sand Hills. Cable and Cantley (1979) reviewed the environmental diversity and the biotic potential of the Red and White Sand Hills. Their assessment revealed that a much more environmentally diverse setting exists in the Red Sand Hills than in the White Sand Hills to the northeast of the site. However, the project did not result in generation of comparative data from the Red Sand Hills. Thus, the potential variation in the prehistoric occupation and utilization between these topographic features could not be assessed. Clarification and refinement of any potential differentiation of occupation and exploitation of resources between these rests upon expanding the archaeological data base for the region.

SITE LOCATION

Copperhead Hollow is located east of Jefferson, South Carolina, in the Fork Creek drainage, a tributary of the Lynches River (Fig. 2). Fork Creek and Lynches River join 6.3 km below the site. It is situated on a sandhill next to a spring and immediately west of the intersection of Road S-43 and the unpaved Hopewell Cemetery access road. The sandhill was formerly cultivated, but since 1990 has been fallow and overgrown with weeds (Roberts, 1991). It measures 49.8 x 65 m (0.80 acres). The elevation ranges from 139 to 146 m above mean sea level (AMSL).

Cultural materials recovered from the site are attributed primarily to Middle and Late Archaic periods, although artifacts from all periods from Paleoindian to historic are present. Based on survey, testing, and data recovery excavations, the density of the artifact scatter and range of artifact types recovered from the site suggested short-term, repeated, seasonal habitation and exploitation of locally occurring upland resources (Cable and Cantley, 1979; Gunn and Wilson, 1993; Trinkley and Tippett, 1979). Historic plowing of the site affected its depositional integrity. Several test trenches excavated at the site by Trinkley and Tippett did not result in the exposure or identification of any archaeological features, but did reveal that plowing had extended into the subsoil in places. One quartz flake was recovered from a depth of 50 cm. The assemblage also included fire-cracked rock (Roberts, 1991), suggesting that hearth features might be present. Extensive data recovery excavations (Gunn and Wilson, 1993) revealed numerous hearth features marked by fire-cracked rock, as well as a broad range of other Archaic period artifacts in substantial quantities.

GEOLOGY

Copperhead Hollow is in the geological region known as the Carolina Slate Belt. As many researchers have noted, this historical label does not reflect the actual bedrock composition in the region as slate is actually not that common (Cable and Cantley, 1979).

One of the most important materials for the prehistoric occupants of the region was the Morrow Mountain rhyolite, which is "a dark-gray to black, porphyritic rhyolite usually showing excellent flow foliation" (Conley and Bain, 1965:132; Daniel, 1992, 1994). Abundant outcrops of this rhyolite (and known prehistoric quarries) are located north of the project in Morrow Mountain State Park in North Carolina, and this material is common in assemblages throughout the region. In their survey report for the S.C. 151 widening project, Cable and Cantley (1979:14) reported that related flow-banded rhyolites can be found in numerous locations along the Lynches River, which is west of Copperhead Hollow.

At Copperhead Hollow, exploratory drilling by others has documented that the site rests on 12 m of sand, that is underlain by low-grade gold ore (B. Ingram, personal communication 1992). There is also a major working gold mine immediately west of Jefferson.

SOIL MORPHOLOGY

No Soil Conservation Service soils report exists for Chesterfield County, South Carolina. A general soils map of South Carolina (Smith and Hallbick, 1979)
indicates that the project area and the better part of Chesterfield County is in the Lakeland-Fuquay-Troupe soil association. These are soils that form on sloping uplands and are underlain with sandy and loamy sediments. In the nearby Black Creek drainage to the northeast is the Norfolk-Cox-Wagram soil association. These soils form in level to sloping uplands with loamy and clayey sediments. The important differences between the two soils is greater permeability in the project area Lakeland-Fuquay-Troupe series, and consequent higher permeability and poorer crop suitability.

Several aspects of the soils and geomorphology helped define the environmental character of the site. A graying of the profile in test unit (TU) 4 (Fig. 3) toward the bottom of the surficial sediments (B zone) indicated oxidation of iron and that the soil had been in place for some time. It also indicated that there was a perched water table under the site at one time. The compact strata below 1 m are pedologically very well developed and probably have been in place for at least 0.5 million years.

The geological material forming the parent material for the soils were eolian sands overlying Coastal Plain sediments. The soils were characterized by very sandy sediments overlying a paleosol Bt horizon that had developed in the Coastal Plain sediments. Soils developing in the eolian sediment showed minimal pedological weathering characteristics. A weaker color Bw is present in the upper very sandy materials in all profiles described. The slightly browner color compared to the C horizon in the same profile is the result of translocation of iron from A to the Bw horizon. The Bw does not qualify for a diagnostic horizon such as a cambic or spodic. In some soil surveys in this region, the very sandy soils overlaying the Bt is considered simply an over-thickened E horizon (leached zone). However, it is believed in this case that the very sandy sediment is a distinct stratum from the underlying paleosol Bt horizon.

The paleosol Bt horizon was encountered at depths ranging from 48 to 149 cm. The depths depended on the thickness of the overlying sands that seemed to respond to landscape position; the sands seemed to thin in a western direction (Fig. 4). The characteristics of the paleosol Bt horizon include: sandy loam to sandy clay loam texture; reticulate mottling with colors ranging from red (2.5YR 4/8), yellowish brown (10YR 5/6), to gray (10YR 6/1); moderate, medium subangular blocky structure; and abundant clay bridging between soil separates. Clay bridging and coatings provide evidence of translocation of clay and is common in argillic horizons.

The mottling occurring above the paleosol (2Bt horizon) in some profiles results from water moving slowly through the more clayey horizon; this results in more reducing conditions in horizons above the argillic stratum and leads to the iron becoming mobile and developing mottles. Lamellae were noted in profile 4 (S92SC4 TU 3); the lamellae were thin (1-2 mm) and nearly continuous. This may have resulted from water being slowed by the paleosol and depositing of the finer particles and some iron in solution.

The sediment analyses have direct bearing on the climate during the Middle Archaic phases of occupation. The hollowed-out west side of the site was determined to be a sand blowout. The Guilford and Morrow Mountain components were on the lee or east side of the dune and thus were buried. The Guilford component appears to be more deeply buried on the northeast part of the site. This implies that the prevailing winds were from the southwest (235°) during the Guiford phase (ca. 5000-5500 yr B.P.). During the earlier Morrow Mountain phase (5500-7500 yr B.P.), when occupation concentrated in the southeast part of the site, the winds were more from the northwest (320°). That the site was an active sand eolian feature during the Middle Holocene suggests that the upland area was essentially denuded of vegetation during these two Middle Holocene (7500-4500 yr B.P.) phases. Pollen analysis (see below) hints that the Middle Holocene was relatively dry. The evidence from this site indicates that it was extremely dry. (The possibility of anthropogenic contribution cannot be discounted.) The same dune-site relationship appears, by our interpretation, to be duplicated at site 38LX5 (Anderson, 1979) with a similar relationship between blowout and buried Morrow Mountain component.

The conditions encountered at Copperhead Hollow imply that indications of increased moisture during the Middle Holocene, such as that observed at Gregg Shoals on the Savannah River (Tippitt and Marquardt, 1984), were confined to riverine environments and thus had origins in headwaters in the mountains, while surrounding uplands of the Piedmont and Sandhills were desiccated by a local dearth of precipitation (see Gunn and Wilson 1993 for a model of this condition).

**EOLIAN FEATURES**

The possibility of active sand features in the Middle Holocene, and the open upland vegetation implied by it, opens an important question relative to global climate. Since the Middle Holocene was a globally warm period, it is generally presumed that some areas of the world were drier. It is also well documented that some parts of the world were moister; the Sahara Desert, for example, spawned some of the earliest agriculture during this time (see Schneider and Londer 1984 for an extensive review). Therefore, it cannot be taken for granted that South Carolina was dry. In fact, some data have been interpreted to mean that it was moister (Tippitt and Marquardt, 1984). The
FIG. 3. Profile of TU4 geological test unit.

FIG. 4. Cross section showing the thickness of eolian sands from TU 8 to TU 4.
two rivers model offered elsewhere (Gunn and Wilson, 1993) is an attempt in part to reconcile the positions of those who suggest a moist Middle Holocene with those who view it as having been dry.

There are lines of evidence that indicate dry conditions in the uplands of the Coastal Plain during the Middle Holocene. Brakenridge (1980) interpreted the general increase in sedimentation in southeastern rivers during the Middle Holocene to be indicative of a drier upland environment. At White Pond, Watts (1980) found evidence for a Middle Holocene low water horizon which may have interrupted the deposition of pollen. This negative evidence does not make a strong argument for a Middle Holocene drought. However, geologists have found active dunes in the Cape Fear River valley that they date to 7700 to 5720 yr B.P. The Middle Holocene dunes have been clearly distinguished from earlier Pleistocene dunes (Soller and Mills, 1991).

An archaeological site that appears to support a sand dune interpretation similar to that of Copperhead Hollow is 38LX5 (Anderson, 1979). The site is on a sandhill southeast of Columbia, South Carolina. Morrow Mountain levels were found under sand. A radiocarbon date of 5477 ± 170 yr B.P. was obtained for the Morrow Mountain levels. Maps of sites 38LX5 and Copperhead Hollow are juxtaposed in Figure 5 showing that the orientations of the blowout, dune, and buried Morrow Mountain components are similar at the two sites. The Guilford and Morrow Mountain components were on the lee or east side of the dune and thus were buried.

Although Copperhead Hollow was apparently still an active sand dune during the Guilford phase, the sediments of the site convey the impression that it was a less active sand dune during the later occupation. Guilford points are distributed more or less evenly over the site rather than being limited to restricted areas as was Morrow Mountain. The tool kit is more of an opportunistic assemblage rather than the carefully constructed curated assemblage of the Morrow Mountain phase. This suggests a somewhat moister and more stable environment, though still open enough to prevent stabilization of the dune. If this impression is correct, it suggests a slightly varied general climatic circumstance. Sassaman et al. (1990:22, 26) attribute a climatic change at this time to final stabilization of post-Pleistocene sea-level rise and the development of the coastal estuarine environment that supplies evaporated moisture to the Coastal Plain. There was also an episode of Middle Holocene cooling of about 200 years at that time, probably associated with global-scale volcanism.

**CLIMATE AND PALEOENVIRONMENT**

Recent reconstructions of climatic conditions during the last 25,000 years strongly suggest that numerous shifts have occurred that have affected the composition of both plant and animal assemblages at the site and in surrounding regions. Several researchers including Whitehead (1965, 1973) and Watts (1979, 1980) have described a palynological record for the region. One of the more important palynological locations, White Pond (Watts, 1979, 1980), is located 64 km southwest of the site. The palynological record exhibits changing floral composition from which they have inferred contemporaneous faunal and climatic changes from the late Pleistocene until the present day. Whitehead has identified and described three major periods including the 1) Full Glacial (ca. 25,000-15,000 yr B.P.), 2) Late Glacial (ca. 15,000-10,000 yr B.P.), and 3) Post-Glacial (ca. 10,000 yr B.P.-present). He presents a reconstruction for the southeastern Coastal Plain in which a boreal (spruce and pine) forest of the Full Glacial period is replaced by a northern hardwoods (hemlock dominated) forest in the Late Glacial period. The northern hardwoods forest in turn is replaced by a deciduous forest mixed with pines in the Post-Glacial period (post-Pleistocene or Holocene).

Interpreting the pollen column derived from White Pond, South Carolina, Watts (1979, 1980) has arrived at similar conclusions. In the early post-Pleistocene or early Holocene, Watts documented the presence of a forest dominated by oak and hickory. He finds that the Full Glacial period boreal forest was replaced rapidly in the Late Glacial period by deciduous dominated forest cover and that the Late Glacial period forest became dominated by oak and hickory by 9500 B.P., or in the very early portion of the Holocene. High frequencies of shrub plant macrofossils appear about 7000 yr B.P. indicating low and unstable lake levels. This suggests a Middle Holocene hiatus in the pollen record. Watts (1979:269) reconstructs the Middle Holocene vegetation as that of a "hot and dry oak forest." Wetter conditions returned by the Late Archaic period.

The earliest European settlers reported that large stands of yellow pine, including longleaf pine, were present in the oak-hickory forests of the Piedmont. It is not known at this time if the large stands of yellow pine were products of natural forces or the result of Indian hunting methods that utilized fire to drive and concentrate game.

Climatological studies over the past few decades have shown that important changes occur over much shorter intervals than the well-understood Pleistocene-Holocene transition (Denton and Karlen 1973; Williams and Wigley 1983). Tanner (1993) has found evidence of sea-level stands between 7000-6000 yr B.P. that are probably relevant to moisture conditions in the study area. At the same time, it has become increasingly apparent that changes at annual and decadal time scales are important to human adaptations (see Anderson et al., 1995).

The work of Stahle et al. (1991) on bald cypress tree rings along the Atlantic slope has now provided an annual climatic chronology to A.D. 365 on the Black
FIG. 5. Topographic maps of 38CT38 (left) and 38LX5 (right), showing prevailing wind directions.
River in North Carolina 177 km to the east, and to A.D. 1001 in Four Hole Swamp Creek in South Carolina 161 km to the south.

The contemporary climate in Chesterfield County is characterized by long, hot summers and short, cool winters. Frost-free days average 221, extending from late March through early November. The average annual temperature is 60.9°F. High temperatures in the summer average 89.7°F or slightly higher, but rarely exceed 100°F. The average annual rainfall is 60.9 cm. Rainfall in the summer months comes primarily in the form of intermittent afternoon showers and thunder-showers, which is normally adequate for all crops. July is the wettest month, registering an average of 12.6 cm. The driest month is November, with an average of 6.9 cm (Epperson, 1971).

**OCCUPATION FLOORS**

A consistent and widespread occupation floor was identified at about 30 cm below the surface in several units of the excavation. A prismatic blade and a scraper on a crest blade were found in TU 6, several flakes were recovered from TU 7, and flakes and a teardrop scraper were found in TU 5. The tool inventory in the lower levels hints at a very thinly spread Early Archaic or Paleoindian floor. The greatest vertical concentration of artifacts appeared directly under the plow zone in level 2. Of first importance is the question of whether the floors represent discrete occupations, phantom floors recovered from a matrix homogenized by bioturbation, or something in between perfectly preserved or totally homogenized deposits.

Initial exploration of artifact densities on occupation floors was prepared by mapping two of TU 5's occupation floors. Figure 6 shows TU 5 as seen from the northwest. Floor 2.2 (immediately below the plow zone, Fig. 6 top) and floor 4.1 (about 20 cm below the plow zone, Fig. 6 bottom) are displayed as column diagrams in this format. Both floors were associated with Morrow Mountain components. The column graphs are based on field bag weights; thus, they represent the total artifacts from units. Comparison of the two floors shows that the horizontal location of clusters varies between levels. Of the alternative hypotheses, deposition or displacement, the distributions observed in this graphic test support the buried alternative, since artifact displacement would produce homogenous distributions of clusters on successively deeper floors.

While this test may not provide definitive determination of the validity of the floors, it does suggest that at least in the more stable areas of the site, a study of the artifact distributions as occupations floors would be useful. The conclusion was also supported by studies of fire-cracked rock size and displacement velocity discussed below.

Areas were selected for occupation floor study that were associated with radiocarbon dates and had relatively large areas of excavated material. The levels were excavated in approximately 5-cm cuts under the presumption that typical root disturbance would move artifacts up or down about 2 cm, and that a 5-cm cut targeted on a vertical concentration of artifacts would recover artifacts across the span of the vertical disturbance (Gunn and Brown, 1982). After analyzing the potential for artifact movement, however, it was decided to conflate vertically adjacent 5-cm levels onto a single map representing 10 cm of excavation thickness. This was done on the theory that less harm would be done by adding extraneous information to a floor than by missing parts of them due to displacement. Since an occupation floor is a palimpsest unless only one occupation is captured in an excavation level, interpretation consists of discerning order in the midst of noise. Loss of information is therefore a more detrimental issue than gaining noise.

**Floor 4-2**

Floor 4-2 (Fig. 7) is in a primarily Guilford area of the site, and no Morrow Mountain points were found. Feature 10, from which the 5350 ± 60 yr B.P. date was taken, is a concentration of fire-cracked rock in the east part of TU 4. The density of artifacts in TU 4 is low relative to other test units. This no doubt reflects its mapping indicates that there is no notable increase in artifact density in any direction within the unit. Three stains along the north wall of the unit are the remains of trees. The absence of artifacts around the trees might indicate that they were present when the site was occupied, although this is somewhat adverse to the general interpretations of denuded uplands put forth above, and disagrees with the dating of tree roots in other units that provide much later dates. Nevertheless, the tree roots without artifacts in this unit are distinct from tree roots in the other mapped units. Since this unit would have been farthest downhill, it is the most likely place for trees to have grown. The deep sounding in the east part of TU 4 identified evidence for a perched water table, so the location may have been especially well suited for sustaining arboreal vegetation in an otherwise shrub grassland.

**Floor 5-2**

Floor 5-2 (Fig. 8) is in a primarily Morrow Mountain area of the site, though there was a thin horizon of Guilford points in the uppermost areas between plow scars. The floor contained numerous clusters of artifacts of highly variable density. Feature
FIG. 6. Test Unit 5, Occupation Floor 2.2 (top) and Floor 4.1 (bottom).
FIG. 7. Test Unit 4, Occupation Floor 2 containing Feature 10.
FIG. 8. Test Unit 5, Occupation Floor 2 containing Features 3A and 3B.
3 is a tree root or pair of tree roots; Feature 3a was dated to 3490 ± 60 yr B.P. The floor is relatively free of tree roots; in the case of Feature 3, there are some artifacts above the roots. Artifacts in this floor are concentrated in a diagonal band across the units from east to west. This band roughly parallels the ridge crest at the center of the site. An extremely dense concentration of flakes was found in the east end of the unit, indicating a workshop area.

Floor 6-2

Floor 6-2 (Fig. 9) is in a predominantly Guilford area of the site; only one Morrow Mountain point was found in the plow zone. The floor contained a moderate concentration of artifacts. All of the tree stains have artifacts on top of them, including Feature 16 which was dated to 3790 ± 60 yr B.P. There are clusters of artifacts, rather than a uniform spread as in TU 4. With one exception, tools fall within clusters of flakes. Features 4, 6, and 16 have distinct clusters of fire-cracked rock above the tree roots.

SITE FORMATION PROCESSES

Very soon after excavations started at Copperhead Hollow, it became evident that it was an important Middle Holocene activity locus. Not immediately apparent was the structure of the site being recovered. Why, for example, did the west side of the site appear to be heavily eroded, interbedded with pebbles, and with only thin deposits over the substrata sediment? This contrasted with the east side of the site that was much thicker, demonstrated no apparent erosion of surficial sediments, exhibited less concentration of pebbles, and possessed a distinctly Middle Holocene cultural character.

Archaeologists visiting the site suggested Michie's (1990) research on displacement of artifacts through sandy sediments. On the other hand, the project pedologist (Foss) pointed out that the site appeared to be a stabilized eolian sand feature, with the western sector representing the windward blowout, and the east site the leeward side of the dune. The implications of these two models of site formation were evident soon enough to implement excavation and analytical strategies to test the displacement and dune models as alternative site formation hypotheses.

Post-Depositional Processes: Up, Down, Around

There are several forces that tend to move artifacts both up and down as well as laterally in sites during the depositional and post-deposition eras of its duration.

The most readily conceived forces that move material up in the sediment column are human, most commonly accidental upward movement of diagnostics by excavation of features. An example is the movement of Middle Woodland ceramics up into Mississippian levels at the Sellers Site (Gunn, 1992) on the floodplain of the Hiwassee River valley of western North Carolina. In this case, the Mississippian levels were clearly distinguishable from Middle Woodland levels because they contained both Mississippian and Middle Woodland sherds, while the Middle Woodland levels contained only Middle Woodland sherds and Late Archaic levels contained only appropriate Archaic diagnostics. Also, the features that resulted in the upward movement of artifacts were clearly visible.

Another process that moves materials upward is intentional mining of ancestral deposits for raw and not-so-rare material. Gould (1980) observed this among Australian aboriginals. While traveling with a group of aboriginals, Gould was told that rockshearts were good places to acquire tools, and the person proceeded to enter a rockshelet and excavate said material for his use. Sassaman et al. (1990) believe that scavenging lithics was a regular part of Early Woodland resource acquisition in the Savannah River valley. The process appears to reflect resource scarcity due to the reduction of range. It also reflects geomorphic factors (e.g., the general landscape stability of the Early Woodland that left Late Archaic artifacts exposed to be scavenged from the surface).

A third upward process is related to the size and utility of large artifacts (Baker, 1978). Any archaeologist who has performed a survey has had the experience of finding a single large artifact in the grass that led to the discovery of a site. Examples are the Moccasin Confluence site in the Edwards Plateau area of Texas (Gunn and Kerr, 1986), and the Dixie Recycling site in Hancock County, Georgia (Gunn and Repass, 1991), both found by metates on the surface. The reason for this process appears to be that large artifacts such as metates are too cumbersome to transport, but also large enough that they are unlikely to be buried by single overbank flood events, bioturbation, and colluviation. Thus, they are curated with each visit over thousands of years until they are fully expended and useless; then they are finally discarded and become buried with the passage of time.

Forces that move artifacts downward are equally varied. Bioturbation by animals is probably the most prevalent. In this process, the sediments are moved up, rather than the artifacts. This results in a net downward displacement of the artifacts relative to the surface. An example is the early and late Holocene Eagle Hill II site in west-central Louisiana (Gunn and Brown, 1982). Crayfish inhabit the sandy tops of the Kisachie Wold that crosses central Louisiana from east to west. The sandy surficial sediments are underlain by tertiary nearshore lake sediments; these are heavily weathered, with resultant downward migration of clay-sized particles. This increases the impermeability of the clay bedrock and provides for perched water tables under the sandy surface sediments. Crayfish excavate nearly vertical
FIG. 9. Test Unit 6, Occupation Floor 2.1 containing Feature 16.
burrows from the surface to the water table. They apparently are unable to remove the larger sediments, including artifacts, out of the burrow, and thus carry them downward with them. This results in caches of flakes at the bottoms of the burrows. During the excavation of Eagle Hill II, such caches were identified and eliminated from the occupation floor analysis. As documented by Johnson (1992), mammals larger than crayfish move flakes up rather than down. Thus, the effect of the process depends on the size of the disturber.

In addition to the up and down forces, there are also random forces. Plant roots tend to follow nutrient-rich occupation floors. The result of this growth is the displacement of artifacts either up or down a centimeter or two depending on the size of the root. Most of these roots tend to be about 2 cm in diameter, although larger specimens can be found. Thus, as a mean figure, artifacts would be displaced up or down 2 cm by a root passage event. When excavating, this author attempted to remove soil in approximately 5-cm cuts, adjusting the vertical position of the level so that the cut brackets a vertical peak in artifact frequencies. This peak presumably represents an occupation floor and the 

± 2 cm displacement of occupation floor debris. The artifacts gathered in a 5-cm cut are then analyzed as a unit under the presumption that they represent a coherent occupational discard pattern.

In addition to vertical movements of artifacts, there is also lateral displacement. At Copperhead Hollow, fire-cracked rock concentrations were found that appeared to be over tree roots. This suggested that the tree roots were being used as fuel for cooking fires. Upon dating the tree roots, however, it was found that they were about 1500 years younger (3490 ± 70 and 3790 ± 60 yr B.P.) than the Guilford levels they were presumed to lie within. In fact, a collagen date derived from bone fragments found in an equivalent fire-cracked rock concentration produced the reasonable Guilford date of 5350 ± 60 yr B.P. This suggests that the trees grew up through the Guilford hearths approximately 1000 years after the use and burial of the hearths. The fire-cracked rock was displaced upward and outward by the tree tap root as it grew in circumference. Then, as the top of the tree died and the root was burned, the fire-cracked rock returned to a location closer to its origin. This hypothesis could be tested using magnetic resonance because the rocks would have been heated at two significantly different times.

Previous Research

Site formation processes have been a subject of concern to American archaeologists at least since the 1920s when investigators such as Kidder (1924) and Deuel (1935) began to realize the potential of site stratigraphy to resolve cultural chronology. Coe (1964) made major contributions to the understanding of site formation by applying floodplain geomorphology. Upland colluvial geomorphology also lends considerable insight to site formation (Gunn and Brown, 1982; Gunn and Poplin, 1991). Beginning in the 1960s, intrastratigraphic structure of deposits benefited from attributions of various site formation processes to different natural and cultural forces (Schiffer, 1976).

The issue of post-depositional reworking of site deposits and the resultant movement of artifacts has been given increased attention during the last decade. Johnson (1992) reports that Charles Darwin may have been the first scientist to report on bioturbation. Several individuals published reports on the topic in the late 1980s. Interest in the subject then lapsed until the mid-twentieth century. The powerful effects of very small animals on the upper 30.5 cm, or turbidity zone (Michie, 1983:45), of sediments appear to have come to archaeologists' attention first. Termites are the most powerful earth movers in the tropics (Caillen and Moeyersons, 1977), while lowly worms and ants churn the soil in the northern temperate forests of North America (Stein, 1983; Thomas and Robinson, 1983; Wood and Johnson, 1978). On the Atlantic slope, Michie (1990:30) suggests "moles, earthworms, bees, frogs, ants, grubs, and other species that burrow" are responsible for moving large quantities of earth. Researchers have demonstrated in several climatic and physiographic settings that, in some depositional environments, the archaeological chronology of sediments can be accounted for by statistical analysis of the depths of temporally diagnostic artifacts (Michie 1983; Thomas and Robinson 1983; Cassedy 1984) better than by microstratigraphic excavation analysis. Typical artifact profiles indicate that over the course of the Holocene, artifacts have descended through the soils at variable rates depending on the forces moving them. At least one of these forces, gravity, imposes a systematic downward trajectory over time. Other forces, such as tree falls, exert random directions of movement, both vertically and laterally. Michie (1990:31) notes that intrinsic characteristics of artifacts such as size may influence the movement trajectory.

A useful concept to emerge from studies of artifact post-depositional movement is a concept of velocity. Velocity is greatest in the turbidity zone, or A soil horizon. It varies with the dominant sediment grain size. Thomas and Robinson (1983) suggest that the tendency for bioturbation to move soil-sized particles upward through animal action results in the displacement of artifacts into the A zone in less than a century. Michie made extensive studies of displacement velocity in sandy sediments. For example, he suggests that the bulk of Middle Archaic artifacts should be found between 36 and 46 cm below the surface in South Carolina (Michie, 1990:44).
ARTIFACT SIZE AND DISPLACEMENT AT COPPERHEAD HOLLOW

In the interest of expanding the window of observation on displacement velocity, this study undertakes analysis of the effects of artifact size on movement. Copperhead Hollow is similar in many respects to the Open Area site (38GE261) studied by Michie (1983, 1990). It is composed of sandy sediments. It is located on an essentially convex surface. The surficial sand deposit is about a meter thick and contains layers of pebbles in the lower strata. Being located on the edge of the Piedmont at 140 m AMSL, it also has important differences from Michie's Coastal Zone site. It is underlain by a tough clayey sand substratum that supports a short-term perched water table. The substrate is heavily weathered, mottled, and consolidated. This stratum is thought to be at least 0.5 million years old. The surface sand is asymmetrically distributed across the site from west to east. On the west, the sands are thinner and the topography has a bowl-shaped appearance. The sands are thicker on the east, and appear to be in a dome-shaped eolian deposit. The landform is interpreted to be a stabilized sand dune. The thick eastern deposit contains nearly exclusively Middle Holocene artifacts. This suggests that the sand dune was active during the Middle Holocene.

Fire-cracked rock (FCR) was chosen as the vehicle by which to study the effects of size on displacement velocity. While FCR does not offer the apparent temporal clues of diagnostics, the great numbers of FCR specimens provide vertical statistical distributions that may supply similar information. It is abundant and scattered more or less evenly over most sectors of the site. It also seems that the FCR presents a relatively random shape that might standardize the dynamics of movement in a statistical sense. Some of the imponderables that should eventually be given consideration are the processes that break up the FCR. Does this fracturing, for example, mostly occur during use, or due to post-use moisture and soil mechanics such as freeze-thaw? Presumably the size effect is a factor in FCR destruction dynamics.

A plot of the FCR frequencies by level for the entire site shows distinctly different vertical frequency distributions for the various size grades (Fig. 10). The following observations are offered, and the interpretations that follow are suggested as possible but not definitive explanations of the distributions.

1). Size grades above 4 cm are confined to the upper 50 cm of the deposits. This is also the extreme depth of tools of similar size and could represent occupied strata.
2). Each size grade below 4 cm extends deeper than its immediately larger counterpart. Each smaller size grade extends 10 cm below the next larger class.
3). The 2-cm fraction (1-2 cm) and the 3-cm fraction both have secondary peaks in the lower levels. The 2-cm fraction peaks across two levels between 60 and 70 cm below the surface. The 3-cm fraction peaks at a lesser depth of around 50-60 cm.
4). In the plow zone, level 1, there are slight increases in the frequencies of all fractions up to 5 cm. The frequency of the 5-7 cm fraction decreases in the plow zone.
5). The 3-cm fraction (2-3 cm diameter) is most frequent of all fractions in the plow zone and level 2. The difference between 2- and 3-cm frequencies does not appear to be very high in the graphic; however, the scale is logarithmic, so differences are numerically greater than they appear graphically.

The following interpretation is suggested: Since 3-cm rocks are the most frequent, they are the size at which FCR was no longer regarded as usable. The 2-3 cm size grade is the size utility limit for FCR, and thus the size at which it accumulates in highest frequency; anything larger will be further reduced by further use. Stratigraphically this amounts to upward recycling as discussed above. Usable rocks were in the range of 5-10+ cm range, and thus are fewer in number.

Rocks below 4 cm in size are downwardly mobile since they extend below what appears to be the occupation zones represented by the more stable large artifacts. Each 1-cm decrease in size appears to increase the rate of displacement by 10 cm over the period of residence. Assuming that the occupations in levels 2 and 3 are the source of the rocks, the period of displacement is assumed to be between 5300 yr B.P. (young Guilford, this site) and 7600 yr B.P. (old Morrow Mountain, Rae's Creek). If the secondary peaks in the 2- and 3-cm classes are taken to be derived from occupation levels 2 and 3, then displacement velocities can be calculated for the 2- and 3-cm fractions.

The 2-cm fraction secondary peak spans two levels, 6 and 7, as does the upper occupation. If level 2 is taken to be the source of the FCR found in level 6, then the mobile portion of the 2-cm fraction descended 40 cm in a minimum of 5300 radiocarbon years, or 6100 calendar years. The calendar rate of displacement, then, is 6.56 cm per 1000 years (40 cm per 6100 years). If level 3 is taken to be the source of the FCR found in the secondary peak in level 7, then the mobile portion of the 2-cm fraction descended 40 cm in a maximum of 7600 radiocarbon years, or 8400 calendar years. The calendar rate of displacement, then, is 4.76 cm per 1000 years (40 cm per 8400 years). Michie (1990) suggests that there is a reduced rate of displacement with depth. Presumably there is a curvilinear function that fits the two rates calculated here.

The 3-cm fraction only has one secondary peak in level 5 (approximately 50-60 cm). If level 2 is taken as the source of the 3-cm FCR in level 5, then the 3 cm fraction was lowered 30 cm in 6100 calendar years, a rate of 4.92 cm per 1000 years. The lesser rate
calculated from level 3 is 30 cm in 8400 calendar years, a rate of 3.70 cm per 1000 years.

The differences in displacement rates based on size for the two smallest fractions indicate that a reduction of 1 cm in size increases displacement rates an average of 1.41 cm per 1000 years. If the displacement rate relationship to size were a linear system, which there is no assurance at this point it is not, then displacement rates would drop to zero at an artifact size of 6 cm in this particular depositional environment.

Other observations on the distribution indicate potentially important alterations of the FCR assemblage: 1) diagnostics, which universally fall in the greater than 3-cm range, are limited to levels 2 and 3, about 20-30 cm and 30-40 cm. This is approximately the same depth range as the FCR assemblage greater than 4 cm which appears to have remained in place, or nearly so; 2) for most size grades, there are slightly more specimens in the plow zone than in the first sub-plow zone level. The exceptions are the 7-cm and 9-cm rocks, which decrease in frequency from the sub-plow zone level to the plow zone (could this reflect farmers throwing larger rocks out of the field?); and 3) there is nothing immediately apparent in this approach that indicates how the standard deviation of displacement changes with time.

What are the implications of this analysis for the investigation of the presumed living floors? For one, it suggests that artifacts that are smaller than 2 cm (.79 or 3/4 inch) should be treated apart from the larger artifacts that may be more in place. Smaller artifacts will be in downward tangent, and have to be treated in another fashion than straightforward mapping, as normally practiced. It further suggests that larger artifacts, which include the range of sizes within which dart points, but not arrow points, fall, provide more reliable temporo-spatial indicators than smaller artifacts, especially with regard to vertical provenience.

*Horizontal Variance in Vertical Displacement*

An examination of the distribution of displacement velocities by excavation units indicates that displacement rates are related to sediment grain size. The southeast part of the site located at the lee axis of the eolian feature has the coarsest grain size. In this area, TU 15 registered medium sand and TU 5 coarse sand. These units also have the lowest downward displacement rates (Fig. 11). In something of a semicircle around TUs 5 and 15 to the west are units that were found to be of finer grain sizes, TU 2 silty loam, TU 6 loamy sand and TU 4 loamy coarse sand. Finally on the windward axis of the eolian feature is TU 1 that is in clayey sand. Comparing the grain sizes with the size frequency diagrams suggests that velocity increases inversely with grain size. The smaller the grain size, the more rapid the artifact descent.
FIG. 11. Verticle displacement increases as grain size decreases across the site.
Arguments for and against Displacement at Copperhead Hollow

Michie (1990, 1992) has observed a consistency of depths of artifacts in upland sites with sandy sediments. The artifacts generally reflect expected chronological order. Given the resemblance between Copperhead Hollow and Michie's sites, it cannot be taken for granted that the site contains buried and unmoved occupation floors. This is particularly the case, given that it has been demonstrated that at least some artifact size classes appear to be downwardly mobile. A viable alternative hypothesis to undisturbed Holocene occupation floors is the contention that all artifacts represent occupation on a Pleistocene eolian surface and that they were lowered to their present positions by bioturbation and gravity. On the other hand, it is clear from the many examples of bioturbation offered at the 1992 Conference on Bioturbation and Gravity, that environments and sites vary significantly in the amount of bioturbation to which they are subjected. It cannot be assumed that all sites are biologically disturbed in equal degree.

In the case of Copperhead Hollow, internal evidence seems to indicate that smaller artifacts were downwardly mobile. There is equally compelling evidence that large artifacts were to some degree more stable. Probably the most notable evidence for stability is that the Morrow Mountain and Guilford diagnostics were found buried within the sand dune, while earlier and later artifacts were located on the surface around it. With the exception of the two Hardaways and a Palmer, no other points were found buried in the occupation zones. On the surface outside of the buried occupation zones, older points (Palmers and Kirks) and younger points (Guilford, Thelma) were found in relatively higher frequencies. This argues against displacement of the whole Holocene suite of artifacts as a unit. If the antecedent and following groups were on the site, why are not their diagnostics interspersed with the Middle Archaic points in more equal numbers? More specifically, this parallels the geomorphological suggestions that the site was an active sand dune during Morrow Mountain and Guilford times, and that those occupations were buried by eolian action. The bone collagen accelerator date in the Guilford horizon provides supporting evidence. It probably also argues that the small fragments of calcined bone were protected from movement by the greater size of surrounding FCR fragments. It is also potentially important that the dune coincides with a period of global warming, one that suggests a Holocene rather than Pleistocene date for the dune.

An important question is whether the depth of artifacts at Copperhead Hollow corresponds to Michie's (1990) suggested displacement rates. The exact depth of Middle Archaic artifacts is difficult to evaluate because of the variable thickness of the plow zone. This variation is presumed to reflect some lateral sediment removal through sheet wash and horse plowing, which tends to move topsoil toward the outer edge of a field (Gunn, 1992).

For the data on location and size of artifacts to be amenable to treatment by linear regression, it needs to
be as simple as possible, that is, expressed in as few measurements as possible, and it needs to conform to the linear data format assumed in regression analysis.

The location of artifacts can be reduced to two measurements because of the circular nature of the dune, distance and depth. Because of the circular structure, it is possible to simplify the two dimensional, or x and y, horizontal spatial relationships to a simple distance measurement from the central coarse sand core of the sand body to the TUs. This effectively moves the units from their original locations as in Figure 12a, folding them through B to align them on a single horizontal spatial coordinate spaced from the center of the dune as in Figure 12c. A simplifying assumption for the linear model is that artifact descent is a simple linear function of distance from the center of the dune. At the center of the dune the lowering effect is .00. At the margin of the dune the lowering effect is a maximum, or 1.00. Geometrically this describes a simple conical with .00 at the center of the cone or dune, and 1.00 at the margin of the dune.

Depth is coded in centimeters from the surface. Since the site was recorded in 10-cm levels for the most part, artifact depths must be dealt with in 10-cm increments. Ideally each artifact would have a vertical coordinate in centimeters.

Grain size can be coded on a ordinal scale from .005 mm = clayey sand, .05 mm = loamy sand, .5 mm = medium sand, and 1.0 mm = coarse sand.

It is also clear that the velocity of descent varies with the size of the artifacts. Artifacts smaller than 5 cm appear to move rapidly downward. Artifacts larger than 5 cm move slowly, not at all, or perhaps randomly and they show no readily evident movement.

These four spatial and sediment matrix characteristics of artifacts can in theory be used to undo or cancel downward displacement. To restore artifacts to their theoretical original depth, a function or relationship among the characteristics is needed that will simultaneously removed the effects of grain size, artifact size, and distance from the depth of the artifact.

FIG. 12. Folding space to reduce the number of space variables.
New depth = a - (bd + cd)*Old depth + e,

where:
- a = constant
- b = maximum displacement due to grain size (obtained by inspection of size frequency diagrams between units)
- c = maximum displacement due to artifact size (obtained by inspection of size frequency diagrams within units)
- d = proportion of distance from dune center (0.0) to dune margin (1.00). This is obtained by dividing distance from dune center by the distance to the dune margin.
- e = an error factor.

Estimates of the factors from inspection of the size frequency diagrams indicates that 40 cm approximates the value of b. This value effectively corrects for the increase in velocity along the grain size decline distance away from the center of the dune. This is based on the apparent increase in rate of descent from less than 10 cm at the center of the dune (TUs 5 and 15) on the lee axis, to 40 cm on the windward axis (TU 1). This is detected by looking for kick-ups in the smaller size frequency profiles. Thus, on the dune center, the function will move an artifact up 0 cm, but on the west it will move it up 40 cm.

A similar approximation of c is 7-15 cm. It is based on the differing rates of descent within units according to the size of the artifacts. Various of the size frequency diagrams suggest that 2-cm artifacts are moving downward about 15 cm faster than 3-cm artifacts. Conversely, 3 cm artifacts are moving downward 7 cm faster than 4-cm artifacts. Thus the function will move 2-cm artifacts upward 15 cm while 3-cm artifacts will only be moved 7 cm.

These quantities could be estimated more systematically by regression analysis, and thus this presentation should remain purely a crude example of a possible approach. More refined approaches could include more complex, higher order trend surface analyses, and completely non-linear methods. It should also be kept in mind that this semi-conical configuration is unique to this site and possibly a few others; each site will have a unique set of circumstances requiring a unique artifact replacement formulation. Finally, this site is composed of a fundamentally sand matrix. Commentary from colleagues gathered in conversation suggests that other sediment grain sizes, especially clays, may have fundamentally different artifact displacement processes. Consider for example, the cracking and swelling of montmorillonite clays.

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Prehistory and Holocene Floodplain Evolution along the Inner Coastal Plain of Virginia: A Case Study from the Chickahominy Drainage

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The role of landscape dynamics for understanding prehistoric site location and preservation has been demonstrated in a variety of environmental zones across the Middle Atlantic and Southeastern United States (Anderson, 1991, 1995; Carbone 1976; Cavallo and Joyce 1986; Morse and Morse 1983; Schuldenrein 1996). Typically continental floodplains and alluvial basins contain the deepest and most prolific records of site activity and sediment storage, since such settings were both repeatedly attractive to prehistoric groups and subject to the rapid alluviation that seals in evidence of cultural activity (Gladfelter, 1985). No less significant for prehistory, however, are coastal plains whose locations at the margins of brackish, freshwater, and marine eco-zones accounted for an even broader range of resource environments than those available in interior provinces. The complexities of coastal plain geomorphology and in particular landscapes whose evolution must be reconstructed through lateral rather than vertical sequences, is reflected in fewer models of linked landscape and prehistoric succession (although see Johnson and Stright 1992; Kraft 1985).

The present study explores changing patterns of landscape development, sedimentation, and occupation along the Chickahominy River floodplain in east-central Virginia. The project area spans the transitional terrain—the Fall Zone—between the Piedmont and Inner Coastal Plain, thus affording an example of Late Quaternary geomorphic dynamism across surfaces that were differentially constructed by both marine and terrigenous sedimentation. Preservation of prehistoric Woodland and Archaic cultural horizons within these sediments and on discrete alluvial landforms indexes the variability in occupational environments over the bulk of Holocene time.

BACKGROUND AND OBJECTIVES

Four prehistoric sites were examined over a 25-km (15.7-mi) span of the Chickahominy River between Richmond and the Atlantic tidal margins. Sites 44HN202 and 44HN204 preserved the most extensive and intact archeological remains and form the basis of this study. Two additional sites, 44HN203, 3 km (1.9 mi) upstream of 44HN204/204, and 44NK173, 18 km (11 mi) downstream, were also investigated; these extended the physiographic reach of the study area from the perimeter of the Coastal Plain Uplands into the estuarine flats (Blanton et al., 1993 a,b). Landform elevations range from ca. 20 m (75 ft) at sites 44HN202, 44HN203, and 44HN204 to ca. 3 m (10 ft) at 44NK173. Tidal activity is pronounced only at the latter site where extensive brackish sedimentation is registered by 1 to 2 m accumulations of organic silts and sands (Blanton et al., 1993 b).

Sites 44HN202 and 44HN204 occupy paired first terrace (T-1b) landforms at the confluence of an unnamed first order tributary to the Chickahominy River (Fig. 1). A second terrace bench (T-1a), 1 to 2 m lower in elevation, is inset against the higher surfaces. The T-1a is morphologically and genetically related to the higher T-1b and is a younger landform. The archeological stratigraphy preserves shallow but stratified Middle Archaic through Woodland components in the T-1b (44HN202, 44HN204) and only Woodland materials in the T-1a (44HN202). Collectively, the T-1 surfaces are about 3 m above the levels of the active floodplain (T-0). Vertical columns of both sites preserve elements of the alluvial histories of the trunk stream and the tributary fills.

Primary objectives of the investigations included the following:

1). Development of an alluvial and soil stratigraphy;

2). Reconstruction of sedimentary environments associated with the archeological deposits;

3). Formulation of a working model of landscape chronology, evolution and site formation; and

4). Outlines of landscape-based settlement strategies for given prehistoric periods.
FIG. 1. Project geomorphic map.
The potential for environmental reconstruction was facilitated first, by the preservation of artifacts in discrete stream sediments of Middle-Late Holocene age; and second, by the relationship between Holocene stream activity and sea-level change. The site settings breaching the critical Coastal Plain to continental transition afford a unique opportunity to superpose the changing dynamics of stream activity and landform evolution against contemporary models of Middle to Late Holocene sea-level rise. In recent years, models of continuous Holocene transgression along the Atlantic Coast have been questioned and hypotheses advocating periodic regressions (or "pulses") have been advanced (Dionne, 1988; Gayes et al., 1992). Data in support for the latter come from prehistoric settlement patterns along Coastal Plain streams that implicate systematic relationships between periods of occupation, base level changes, and terrace chronologies (Brooks and Sassaman, 1990). The lateral migrations of channels and floodplains that widen progressively downstream towards littoral zones have differentially built up, buried, and eroded landforms that once supported prehistoric peoples. Time-transgressive trends in the transformation of Holocene floodplains may be diagnostic for modeling site-landscape correlations across continental (riverine) and marine (coastal plain) environments (Brooks and Sassaman, 1990; Johnson and Stright, 1992; Kraft, 1985; Young et al., 1992).

Sites 44HN202 and 44HN204 contained artifacts ranging from the Early Archaic through historic periods. Over the course of this time, post-Pleistocene sea-level rises first rose dramatically then slowed, presumably reaching threshold levels of stability between 6000 and 4000 years ago (Bloom, 1983; Fairbridge, 1992). Along the southeastern Atlantic Coast a highstand of relative sea level around 4200 yr B.P. has been suggested (Colquhoun and Brooks, 1986; DePratter and Howard, 1981; Gayes et al., 1992). This would argue for incursions of marine sediments into presently continental drainages and would have serious implications for prehistory. Evidence from both the geomorphic and archaeological records argues for progressively rising shorelines, as oceanic levels oscillated within a 1-3 m range. Of unique interest are the effects of progressive stability and oscillating base levels in the Middle-Late Holocene, as the Archaic and Woodland peoples occupied discrete terraces flanking one of the major streams debouching onto the Middle Atlantic Coastal Plain.

GEOMORPHOLOGY ALONG THE CHICKAHOMINY RIVER

The Chickahominy River follows an increasingly meandering downstream course from northwest to southeast (Fig. 1). Stream sinuosity—the magnitude of meandering as measured by the channel to valley length ratio (Schumm, 1977)—increases prominently downstream, because of the diminished gradient of the stream and a consequent widening of the floodplain. The width of the alluvial valley is at a minimum of 1.6 km (1 mi) at 44HN203 and expands to over 4.5 km (2.8 mi) at the tidal margins. Channel course is nearly straight at 44HN203, forms broadly arcuate swings 10 km (6.3 miles) south of 44HN202, and then rapidly emerges in a series of goose neck meanders upstream of Mountcastle, due west of 44NK173 (Fig. 1).

The major occupations of 44HN202 and 44HN204 are on the upper first terrace (T-1b) surface. Elevations of the two sites range between 21-23 m (70-75 ft) AMSL, typically 3 m (10 ft) above the Chickahominy channel (Fig. 1). Field relations suggest that channel migration and deepening sedimentation resulted in seasonal inundations of the lower T-1a. In places the T-1a is indistinguishable from the present alluvial surface (T-0). However, the T-1b is sufficiently above the 10-year flood levels and is rarely under water.

The T-0, T-1a, and T-1b all have been formally mapped as "undifferentiated Quaternary alluvium" ("Qal" in Mixon et al., 1989), although it is widely recognized that the alluvial fills transported onto the Coastal Plain are of Holocene age. Pleistocene and earlier sediments underlie considerably higher terraces (see "Qsh" and "Tc" formations in Fig. 1). They are built of coarser gravels and sands and feature generally paler colors; these sediments intergrade with post-Pleistocene deposits in the direction of tributary streamflow. Near 44HN202 and 44HN204 terrace formations flanking the "Qal" are mapped as the Chesapeake Group, Pliocene/Miocene fine to coarse quartzose sands, silts and clays containing abundant marine fossil fragments (Fig. 1; Mixon et al., 1989).

The most recent soil and landform chronosequence has isolated surficial deposits by elevation (Daniels and Onuschak, 1974; Howard et al., 1993). By these criteria the alluvium near the tidal zone (i.e., at 44NK173) is considered a Holocene alluvial fill (<5000 B.P.) that weathers to a young Entisol or Inceptisol. The Pliocene/Miocene 40-70 m terraces near 44HN202 and 44HN204 form Typic Paleudults differentiated by strongly developed clay argillic horizons (5YR-2.5YR colors) (Howard et al., 1993:Table 1). As discussed below, eroded exposures of the argillic clays were recognized as the basal weathered soils at depths in excess of 1.5 m at the archaeological sites.

Despite the recent updating of the alluvial soil chronosequence, there are no formal Holocene stratigraphic markers for the Inner Coastal Plain. Accordingly, Howard et al. (1993) do not recognize diagnostic fills spanning the Middle Pliocene to Middle Holocene. Comprehensive stratigraphies postdating the Middle Holocene are also lacking. The only baselines for reconstructing post-Pleistocene events derive from broad and regional studies of Atlantic Ocean postglacial sea-level rise (Colquhoun and
PREHISTORIC LANDSCAPES OF THE UPPER CHICKAHOMINY RIVER

Limited paleoenvironmental and archeological work has been undertaken along the James and Chickahominy rivers near the Fall Line. At the mouth of Four Mile Creek, flanking the James, sediment cores preserved a sequence of middle to late Holocene conditions (Mouer et al., 1986:48-52). Pleistocene and early Holocene sediments appear to have been truncated by stream scour. Core profiles indicate rapid infilling of fines and evolution of an embayment between 6000 and 4000 B.P. Slower rates of sea-level rise were demonstrated between 4000 and 2000 B.P., by which time pollen records point to the displacement of riverine settings by wetlands. Renewed alluviation is signalled by coarser grain sizes in horizons dated between 2000 and 1000 B.P., after which slower sedimentation resumed. Significantly, cultural deposits were preserved within aeolian sediments (Mouer et al., 1986:50-51) that capped stream terraces 4–12 m above the present James River. At the highest site a complete Woodland sequence is contained within deflated silts. At lower elevations stratified Late Archaic materials are separated from an intact Woodland component by 0.5 m of sterile sediment. The suspected source for the wind-transported sediment is relic fluvial features such as point and channel bars.

Immediately upstream from the project sites, the Pony Pasture Site (44HE313) occupies a low terrace of the Chickahominy floodplain (McLearen, 1987:236-284). Here, well-stratified cultural sediments began to accumulate above coarse channel sands around 5000 B.P. The fine sands and silts of the upper sequence contain Late Archaic Halifaxes and Savannah River, capped by Middle–Late Woodland artifacts and features in classic vertical, overbank stratigraphy. This geoarchaeological context is most analogous to that of 44HN202 and 44HN204.

Archaeological researchers in the northern Middle Atlantic region have called attention to accelerated sedimentation rates during the Middle Holocene (ca. 5000–3000 B.P.) (see discussion in Custer, 1984, 1986). In most cases, however, deposition is attributed to aeolian processes associated with the more xeric climates of the regional Altithermal. Stevens (1991:195-197) has proposed a "fluvial response model" rather than simple environmental dessication to account for emergence of wind-blown sediment packages. The paradigm is rooted in the relationship between reduced channel gradient and sea-level rise. Sources of the aeolian sediment were widening, silt-filled basins at the mouths of aggrading stream embayments. Fines were subsequently deflated onto flanking stream terraces. This explanation is a more regional construct merging local landform relations and stratigraphies.

Both the fluvial- and aeolian-based paradigms call attention to threshold environmental changes after 5000 B.P. and the onset of the Middle Holocene. Sea-level fluctuation was a dominant factor affecting channel dynamics and littoral process, thereby having critical implications for realignments of resource environments and archaeological settlement.

GEOARCHAEOLOGICAL RESEARCH

Field observations at sites 44HN202 and 44HN204 were supplemented by a radiocarbon chronology and detailed geochemical and sedimentological analysis. Geomorphic events recorded within the three terrace sequences (T-0, T-1a, and T-1b) were of significant magnitude to permit assignment of "landform-sediment packages" distinctive to particular cultural periods. The data assembled from each stage of investigation are summarized below.

Field Observations

As noted, close-interval topographic mapping and variation in terrain texture isolated the undulating floodplain (T-0) from abruptly offset first terraces (T-1a, T-1b). Continuity of extensive alluvial faces and soil horizons confirmed that the terrace history of the T-1b was tied to both regional drainage and climatic trends. More localized sediment packages and abrupt bedding structures showed that the T-1a was constructed by periodic sediment contributions from feeder channels.

Figure 2 depicts the relations between primary site landforms, and depositional and soil stratigraphic units. Stratigraphic observations extended to 2.1 m, at which depth water table was encountered. Three radiocarbon dates were obtained for the richest cultural levels; all articulated with discrete archaeological components.

The two sites flank a perennial second-order stream emptying into the Chickahominy River from the north (Fig. 1). The Chickahominy floodplain (T-0) is at least seasonally inundated, since the extent of marshland vegetation extends up to the 18-m (60-ft) contour, encroaching onto the edge of the higher site terrace (T-1b). The artifact concentrations and the most extensive occupational surfaces are on the T-1b. These are "paired surfaces," or broad alluvial landforms that were incised by the feeder channel during the same Holocene geomorphic cycle. On both sides of the channel, the T-1b preserves the same sets of buried surfaces and soils (Fig. 2). These included two weak to moderately developed soils ("Bw" and "2Bt") and one well-developed Argillic paleosol ("3Bt") that is of pre-Holocene age.
The T-1b is offset 2-3 m from the T-0 surface and ±1 m from the T-1a. The T-1a is a considerably narrower landform than the T-1b, effectively a semi-continuous ridge that can be traced upstream into the feeder drainage and downstream onto the Chickahominy floodplain (T-0), where it is preserved as a series of discontinuous, ellipsoidal ridges; in places it grades laterally into the T-0. Observations of sediment texture and structure at T-1a outcrops revealed granular, moderately bedded coarse to medium sands indistinguishable from the channel sands and point bars of the T-0. This suggests that the same body of sediment has been periodically reworked along the Chickahominy and its tributaries since the T-1a was laid down. The landform configuration and sedimentology underscore the channel’s extensive migrations across the Chickahominy floodplain. At site 44HN202 Woodland artifacts occur in the upper levels of the T-1a.

Tables 1 and 2 summarize the general field stratigraphy at both sites. Figure 2 illustrates that the soil chronology is broadly the same across the T-1b landform with both sites preserving complex "Ap-Bw-Cox-2Bt-2Cox" profiles. Variability generally reflects either differential degrees of subsoil weathering or minor differences in parent material texture. For example, the thickness of the "2Bt" is greater at 44HN202 (30 cm vs. 15 cm at 44HN204) and the general grain size distributions for all horizons is coarser. The "2Bt" is not substantially better developed than the higher "Bw," although its hue is redder. 44HN202 is also capped by an "A1" horizon indicative of the contemporary forest cover, which is missing at 44HN202.

More significant, however, is the general homogeneity in depositional suites and weathering, and the synchronicity between site sequences. Both demonstrate at least three discrete depositional cycles capped by soils that grade progressively weaker up the profile (i.e., from the firmly structured basal argillic "3Bt" horizons to the uppermost, loosely structured and marginally rubefied "Bw"). Stratigraphic consistency is paralleled by synchronous trends in the cultural successions at both sites (see below).

At the base of the sequence, the lowermost horizon is a deeply weathered Argillic paleosol ("3Bt") (Tables 1 and 2), which, because of its depth (>2.5 m.b.s.) and proximity to water table, was exposed only in isolated excavation units at 44HN202. The paleosol was not identified anywhere at 44HN204. It is the top of the deepest paleosol in the project area and is fully 1 m below the levels of the deepest Early-Middle Archaic artifact horizons.
### TABLE 1

<table>
<thead>
<tr>
<th>Landform</th>
<th>Soil Horizon</th>
<th>Depth (cm)</th>
<th>Color</th>
<th>Texture</th>
<th>Structure</th>
<th>Motting</th>
<th>Stoniness</th>
<th>Roots</th>
<th>Fe/Mn</th>
<th>Boundary</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1a, T-1b</td>
<td>A</td>
<td>0-5</td>
<td>10YR 2/2</td>
<td>Silty medium sands</td>
<td>Granular</td>
<td>NA</td>
<td>L</td>
<td>H</td>
<td>NA</td>
<td>Clear, smooth</td>
<td>Forested muck soil; preserved organic mat; with macro-organisms; weak to moderately compacted; highly acidic; actively degrading; isolated artifacts</td>
</tr>
<tr>
<td>T-1a, T-1b</td>
<td>Apb</td>
<td>5-28</td>
<td>10YR 4/3, 2.5Y 4/2</td>
<td>Silty medium sands</td>
<td>Weak subangular blocky</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>L</td>
<td>Abrupt, smooth</td>
<td>Bended slope-zone, irregularly channeled; heterogeneous colors and structural matrices; friable; dense artifact concentrations in upper half (Middle Woodland)</td>
</tr>
<tr>
<td>T-1a, T-1b</td>
<td>Bw</td>
<td>28-52</td>
<td>10YR 4/6</td>
<td>Silty medium sands</td>
<td>Weak subangular blocky</td>
<td>M</td>
<td>L</td>
<td>M</td>
<td>L</td>
<td>Gradual, smooth</td>
<td>Heterogeneous colors and structural matrices; friable; dense artifact concentrations in upper half (Middle Woodland)</td>
</tr>
<tr>
<td>T-1b</td>
<td>Coa/Cu</td>
<td>48-90</td>
<td>10YR 5/8, 10YR 6/8</td>
<td>Medium sands, pebbles</td>
<td>Granular</td>
<td>M-H</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>Clear, smooth</td>
<td>Moderately sorted medium-sands; poorly sorted; lateral, vertical interdigitation between &quot;Coa&quot; and &quot;Cu&quot; depending on slope and drainage; bimodal artifact distribution (peak at BC horizon interface), with Middle &amp; Late Archaic components</td>
</tr>
<tr>
<td>T-1b</td>
<td>2B</td>
<td>90-120</td>
<td>7.5YR 4/6 (also lamellae)</td>
<td>Clay enriched medium sands, pebbles</td>
<td>Weak subangular blocky</td>
<td>H</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>Clear, smooth</td>
<td>Moderately sorted medium-sands; poorly sorted; lateral, vertical interdigitation between &quot;Coa&quot; and &quot;Cu&quot; depending on slope and drainage; bimodal artifact distribution (peak at BC horizon interface), with Middle &amp; Late Archaic components</td>
</tr>
<tr>
<td>T-1b</td>
<td>2 Cox</td>
<td>128-225</td>
<td>10YR 4/6, 2.5Y 7/4 (lamellae)</td>
<td>Coarse sands</td>
<td>Granular with weakly bedded lamellae</td>
<td>H</td>
<td>M-H</td>
<td>L</td>
<td>L</td>
<td>Abrupt, smooth</td>
<td>Moderately sorted channel sands; very friable with reduced compaction; Fe++ streaks &amp; stains (7.5 YR 4/6) more concentrated and thicker base</td>
</tr>
<tr>
<td>T-1b</td>
<td>3B</td>
<td>&gt;225</td>
<td>7.5 YR 6/8</td>
<td>Coarse sandy clay</td>
<td>Angular blocky</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>H</td>
<td>NA</td>
<td>Moderately sorted channel sands; very friable with reduced compaction; Fe++ streaks &amp; stains (7.5 YR 4/6) more concentrated and thicker base</td>
</tr>
</tbody>
</table>

### TABLE 2

<table>
<thead>
<tr>
<th>Landform</th>
<th>Soil Horizon</th>
<th>Depth (cm)</th>
<th>Color</th>
<th>Texture</th>
<th>Structure</th>
<th>Motting</th>
<th>Stoniness</th>
<th>Roots</th>
<th>Fe/Mn</th>
<th>Boundary</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1a, T-1b</td>
<td>Ap</td>
<td>0-28</td>
<td>10YR 3/3</td>
<td>Coarse-medium sands</td>
<td>Granular to weak subangular blocky</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>NA</td>
<td>Abrupt, wavy</td>
<td>Moderately well sorted; &gt;50% quartz; very friable; decomposing pine needles &amp; fleshy roots provide coherence to root mat (root density=30%); high Woodland artifact concentrations</td>
</tr>
<tr>
<td>T-1a, T-1b</td>
<td>Bw</td>
<td>28-40</td>
<td>10 YR 6/8</td>
<td>Silty medium sands</td>
<td>Firm subangular blocky to medium angular blocky</td>
<td>H</td>
<td>L</td>
<td>M</td>
<td>L</td>
<td>Gradual, smooth</td>
<td>Weakly moderately structured; abundant, dense root system; concentrated micro-organisms; thinning upward sequence; subsoil; friable, but extensive horizon that spans site; artifact densities increase with depth; Terminal &amp; Late Archaic: 1570 to 120 B.P.</td>
</tr>
<tr>
<td>T-1b</td>
<td>Coa</td>
<td>48-70</td>
<td>10YR 6/6</td>
<td>Coarse-medium sands, pebbles</td>
<td>Granular</td>
<td>M-H</td>
<td>H</td>
<td>L</td>
<td>M</td>
<td>Clear, wavy</td>
<td>Coarse sand form base of fining upward sequence; very friable; lower pebbles are rounded, abraded (10-15 mm); striations interspersed in lower 10 cm; artifact densities diminish to base; Middle &amp; Late Archaic: 2870 to 160 B.P. (top) 4780 to 280 B.P. (middle)</td>
</tr>
<tr>
<td>T-1b</td>
<td>2B</td>
<td>70-85</td>
<td>7.5YR 6/6</td>
<td>Clay enriched coarse sands with pebbles</td>
<td>Weak subangular blocky to angular blocky</td>
<td>M-H</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>Gradual, smooth</td>
<td>Moderately sorted channel sands; very friable with reduced compaction; Fe++ streaking (10YR 4/6) increases to base (30% of ped faces); no artifacts</td>
</tr>
<tr>
<td>T-1a, T-1b</td>
<td>2 Coa</td>
<td>85&gt;100</td>
<td>10YR 7/6</td>
<td>Clayey-medium sands</td>
<td>Granular</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>NA</td>
<td>Moderately sorted channel sands; very friable with reduced compaction; Fe++ streaking (10YR 4/6) increases to base (30% of ped faces); no artifacts</td>
</tr>
</tbody>
</table>
Radiocarbon Chronology

Archeological features are intrusive into the "Cox" at site 44HN204. Here a date of 2870 ± 160 yr B.P. (Beta-54855) was obtained from Feature 14 near the top of the horizon and a second determination of 4780 ± 280 yr B.P. (Beta-54856) was taken from Feature 16, 10 cm below that level. Both features are associated with the occupation preserved in the overlying "Bw" horizon.

At both sites, artifact densities are minimal at the top and increase towards the middle of the "Cox"; this underscores the sealed context of Late and Terminal Archaic components. A date of 1570 ± 120 yr B.P. (Beta-54857) was obtained from charcoal associated with upper levels of the horizon at 44HN204. Limited vertical accumulation implies the intrusion of Middle Woodland materials into older Archaic sediments. It is equally possible that a compressed stratigraphy is preserved in the "Bw" horizon, the result of cumulative soil development.

Geochemistry and Sedimentology

Sedimentological analysis involved dry sieving for the sand fraction, and the hydrometer method for separation of the sand, silt, and clay fractions. Particular emphasis was placed on the sand fraction analysis due to the dominance of sands of all ranges in depositional and archaeologically enriched matrices. Parameters of sorting (So), skewness (Sk), and kurtosis (Kg) were calculated (after Folk, 1974) to compare trends in sedimentation within and between 44HN202 and 44HN204.

A battery of quantitative geochemical tests were applied to the samples to obtain signatures of regional Spodosol weathering and/or disaggregation of cultural residues. The elements, or ions, tested to identify anthropogenic additions to the profile included potassium (K) and phosphorous (P). The most common archaeological residues isolated by these ion tests are bone, wood ash, excreta, and animal meat and tubers (Cook and Heizer 1965; Anderson and Schuldenrein 1985; Kolb et al., 1990). To examine the degree of weathering in the three soil ("B") horizons, relative concentrations of mobile iron (Fe) were measured along with organic matter (OM) and pH. Covarying trends can help to determine if vertical changes in the profile are attributable to soil forming processes, human inputs into the sediments, or combinations of pedogenic and anthropogenic transformations to the matrix.

Finally, to register anthropogenic contributions independently, vertical artifact frequency data were plotted against the sedimentological and geochemical parameters. Artifact counts were obtained from the lithic analysis at select excavation units and summed by excavation levels prior to inclusion in the composite analyses.

In this study, geochemical testing methods followed procedures outlined in Liegel et al. (1980). Results of the soil and sediment analysis for representative site stratigraphic columns for 44HN202 and 44HN204 are illustrated in Figures 3 and 4. Samples were taken for all major soil and depositional units except the basal "3Bt" horizon which was clearly pre-Holocene and antedated the occupations. Column depths extended to 1.5 m for 44HN202 and 1.0 m for 44HN204.

Beginning with the granulometric data, the graphs show that for both sites the overwhelmingly dominant fraction is sands; these account for >80% of the matrix population. Within the sand fraction, the medium-fine size grade exceeds 50% of the total distribution at both sites. 44HN204 averages on the order of 5% higher concentrations of fines (clays, silts) than 44HN202. There is only incremental variability between horizons. Both clay and silt frequencies increase slightly near the base of the "2Bt" at both sites (5-8%), indicating illuviation. Silt percentages at 44HN204 rise somewhat at the "Bw"/"Cox" interface as artifact concentrations increase.

Somewhat more pronounced and diagnostic vertical trends are registered by the grain size parameters. Generally, the mean grain sizes (Mz) for each site column are consistent with depth, clustering in the medium sand range at 44HN202 (Fig. 3) and in the fine sand fraction at 44HN204 (Fig. 4). Limited weathering, signified by slightly elevated concentrations of fines, are again registered by small bulges in the "2Bt" in both profiles. Variability in the degree of sorting (So) index is a more telling index of change. At 44HN202 a low value, corresponding to optimal relative sorting, was obtained for the "2Cox", since this is the parent material containing the coarsest, best sorted, high-energy stream sands. Precisely the opposite trend—poor sorting (high So value)—was noted for 44HN204, probably because an oxidized sample containing settling ferric clays was selected. So values on the order of 2.0 are indicative of illuviation, since they occur in the "2Bt" (at both sites), a horizon devoid of artifacts and clearly weathered. So values between 1.5 and 2.0 appear to be related to artifact horizons and the more limited weathering in the "Bw."

For both profiles, skewness values (Sk) or the measure of asymmetry in the overall grain size distribution, fall between 0.3 and 0.7. This range characterizes strongly fine skewed distributions (Folk, 1974). Kurtosis (Kg) indexes the ratio between sorting in the tails and in the central parts of the distribution. Kg values for both profiles are between 2.2 and 3.5; they are strongly leptokurtic, signifying a major departure from the normal sorting in the central portion of the curve. To assess changes in sedimentary environment, the Sk and Kg values are best applied to unweathered or weakly weathered (i.e., non-pedogenic) horizons, where they measure changes in the floodplain.
FIG. 4. Stratigraphy and soil sediment analysis: 44 HN 204.
and/or occupation settings. Thus, the "Bt" horizons should be eliminated from comprehensive comparisons. For the "Bw," "Cox," and "2Cox," Sk values remain in the original (0.3-0.7) ranges while only the most leptokurtic values are eliminated (i.e., from the "2Bt" at 44HN204). Even with the elimination of the "Bt," fineskewed, leptokurtic trends exemplify the site profiles. Folk (1974:7) notes that such trends are characteristic of sediments derived from "multiple sources". Comparison of the Sk and Kg trends with artifact distribution data (compare Figs. 3 and 4) shows that in non-pedogenic horizons the most finely skewed and leptokurtic sediments (Sk=0.5; Kg=2.4) are associated with zones of highest artifact frequency. These data indicate that the major body of river-derived sands mixed with fines from the local setting, here perhaps the products of deflation or disaggregation of residues associated with human activity on the T-1b.

Geochemical analysis revealed relatively high concentrations of organic matter (OM) throughout the "Bw," extending well into the "Cox." At 44HN202 bimodal peaks of OM (Fig. 3) coincide with the transition to the parent material in both the upper and lower soils ("Bw-Cox" and "2Bt-2Cox" successions). At 44HN204 high OM levels are preserved in the upper soil only. These trends demonstrate either mobilization or primary incorporation of organics well into the unweathered substrate. Levels of pH do not vary significantly but are generally more acidic at 44HN204. Total phosphorous (P) levels are expectedly elevated in the "Apb" horizon, where they may measure disturbed anthropogenic signatures as well as introduction of chemical additives for historic agriculture. In the substrate of 44HN204, P concentrations remain comparatively high in the "Bw" (4.5 ppm), the major Transitional Archaic occupation horizon. Below this horizon, however, both sites feature low concentrations and do not isolate levels of occupation activity from the undifferentiated alluvium or soils. Most striking, however, is the considerable variability within the mobile iron (Fe) profiles. Conflicting trends offset the "B" horizons at both sites, with peak concentrations paralleling the development of both the Cambic and Argillitic paleosol at 44HN204 and minimal levels characteristic of the "2Bt" at 44HN202. In this case, it is probable that iron mobility was more affected by groundwater and/or the porosity of the coarse sands rather than soil formation. Thus, high iron concentrations within the underlying "2Cox" represent formation of iron-enriched lamellae below the primary argillic horizon (see discussion in Larsen and Schudlenrein, 1990).

The last columns of Figures 3 and 4 highlight artifact density curves that are polymodal. At 44HN202 frequencies are highest for the disturbed "Ap" horizons. For the more significant, sealed contexts the Late/Transitional Archaic artifact concentrations are prominent in the upper "Bw" and a second bulge is notable at the "Bw/Cox" interface; concentrations diminish with depth in the "Cox." Similarly, at 44HN204 artifact richness is highest in the "Ap," a second concentration is evident at the "Bw/Cox" contact, and only isolated artifacts are present in the parent material.

Taken together, the composite site profiles reinforce a series of positive correlations between higher artifact densities, increased organic matter (OM) and phosphorous (P) values, generally elevated iron (Fe) levels and vertical trends in some of the grain size parameters. Artifact frequency appears to be linked to finer mean grain sizes (Mz) and fine-skewed grain size distributions, especially at 44HN202. At the approximate levels of the artifact horizon, kurtosis (Kg) values are highest due to the introduction of silt- and clay-sized particles through soil formation and/or local redeposition perhaps linked to human activity. Geochemical signatures diagnostic of anthropogenic activity are mirrored by high artifact frequencies. Measures of soil formation, mobile iron (Fe) concentrations, also vary with artifact frequency since intensity of occupation can be expected to be associated with the soils of a formerly stable surface.

**ARCHAEOLOGICAL STRATIGRAPHY**

The 21-23 m surface of the T-1b sealed in the primary archaeological occupations for both sites (Fig. 2). In general, the artifact concentrations were housed in the upper 90 cm at 44HN202. Middle Archaic through Late and Transitional Archaic components were vertically stratified, while the plow zone ("Apb") contained a mixed Woodland assemblage. A more compressed (up to 60 cm) but similar sequence was identified at 44HN204; here, however, some Woodland materials were sealed within the substrate ("Bw" soil horizon).

Artifact assemblages at both sites were generally confined within the "Apb-Bw-Cox" epipedon. Reduced concentrations of cultural materials extend well into the "Cox" and at 44HN202 into the "2Bt" horizon. Entrainment of cultural materials in the pebbly, coarser sands is not uncommon (i.e., "2Cox" horizon), although isolated artifacts and not intact assemblages are more typical. The soil-sediment "packages" preserving archaeologically stratified deposits are virtually the same at both sites and indicate that preservation conditions are largely analogous.

The stratification of the cultural materials is consistent between the two sites and mirrors developments in the soil and sediment sequences. Thus the basal Early/Middle Archaic occupation are associated with the "Cox" horizon; Late Archaic and Transitional components are preserved within the "Bw"; and Woodland materials are either intrusive or weakly preserved in the upper "Bw" and more concentrated in the "Apb."
Inspections of all exposed excavation units at the two sites disclosed the presence of a weakly developed, but discrete "Bw" (Cambic) soil horizon. It served as a critical marker horizon to differentiate first, the zone of highest artifact density and second, the uppermost intact soil which spanned the T-1b and T-1a landforms at the interface of the Transitional Archaic and Woodland horizons. Woodland materials were densest on the T-1a while Archaic horizons were exclusively within the T-1b. The stratification of the Woodland materials overlying Archaic artifacts at the interface of the "plow zone" ("Apb" horizon) and the "Bw" underscores the stability of the T-1b surface. At both sites Terminal Archaic artifacts are in sealed context at depths >0.4 m and in association with the Cambic horizon. Woodland artifacts may be associated with the uppermost 5-10 cm of that soil.

Significantly, on the lower T-1a surface exclusively Woodland assemblages were identified by the archaeologists. This landform was not as intensively investigated geomorphically, since profiles disclosed generally weaker and shallower variants of the profiles registered on the T-1b. There was also more diffuse articulation of strata and soil horizons with artifact assemblages. The most representative soil-stratigraphy for the T-1a is contained at 44HN202 where the "Apb-Bw" solum grades down from the T-1b surface. Artifact clusters are differentially preserved in the substrate.

On a larger scale, the archaeological stratigraphy spanning the lower Chickahominy drainage from the inner Coastal Plain to the estuary revealed consistent, coeval sedimentation and preservation trends. These are depicted schematically in Figure 5. Note that 44NK173 accentuates the alluvial stratigraphy at the estuarine location.

All four sites considered in the study (44HN203 and 44NK173 in addition to 44HN202/204) contained multicomponent occupations preserved in analogous soil-sediment suites; all sequences contained stratified—albeit weakly—Kirk through Woodland components. Aligned in a downstream direction, soil-sediment accumulations grade progressively thicker above the levels of the basal, culturally sterile Holocene deposits. Capping the Kirk horizons, sediment thicknesses range from 45 cm at the upstream end.
provinces. Conversely, surfaces the length of many Coastal Plain drainages in stabilization on the upstream drainages was promoted stripped and modified downstream landforms. Extensive sites are found along even slightly elevated alluvial sediment and lateral constriction of the T-la terrace. These reinforcing trends acted to sustain and expand occupational surfaces upstream (near 44HN202/204) while erosion and tidal oscillations stripped and modified downstream landforms.

While 15 cm of Woodland sediment are preserved at 44HN203, given the accepted sedimentation gradients for the upstream and downstream ends, an expected rate of 28.2 would be projected for 44NK173. The true figure represents a reduction of 30%. The discrepancies in these values are consistent with high frequency inundations along the tidal margins and periodic stripping of the occupation horizons. Conversely, stabilization on the upstream drainages was promoted by creation of a new base level, net aggradation of alluvial sediment and lateral constriction of the T-1a (Woodland) terrace. These reinforcing trends acted to sustain and expand occupational surfaces upstream (near 44HN202/204) while erosion and tidal oscillations stripped and modified downstream landforms.

In contrast, for the earlier, Late Archaic surfaces (T-1b), broad stabilization was characteristic the length of the drainage. This was in response to the dramatic fall-off in sea-level rise along the Coastal Plain between 6000-5000 yr B.P. which resulted in threshold levels and adjustments to prevalent base levels. Accordingly, extensive sites are found along even slightly elevated surfaces the length of many Coastal Plain drainages in the Middle Atlantic and Southeastern physiographic provinces.

General trends may be summarized as follows:

1). Above the disconformity marking the transition from rapid deposition to overbank accretion cultural materials become key components of sediment packages. Typically finer grade, more massive and poorly bedded matrices are characteristic. The first, ephemeral evidence of occupation dates to the Early Archaic, Kirk phase (9000 yr B.P.), but denser assemblages are dated about 5000 yr B.P. (Halifax/Brewerton).

2). Bimodal distributions in artifact density are characteristic of vertically stratified columns. These are most typical along the T-1b, where Late Archaic assemblages are separated from Woodland feature and artifact clusters by variable thicknesses of sterile alluvium and/or by buried soils.

3). A Holocene alluvial landscape chronology is implicated by lateral and vertical zonation of temporally diagnostic artifact assemblages. Woodland materials occur on both T-1a and T-1b landforms within 0.5 m of the surface. Late Archaic deposits are always associated with the T-1b and below buried Woodland surfaces.

The interdependence of the archaeological and geomorphological records is discussed below.

HOLOCENE LANDSCAPE HISTORY ALONG THE LOWER CHICKAHOMINY

The Continental Record

Table 3 is a model of the Holocene landscape history bridging soil stratigraphies, cultural and alluvial sediments, and occupation chronology. Four discrete geomorphic cycles are defined based on phases of floodplain sedimentation (the "Cox/Cu" horizons), soil formation and landscape stability ("Ap," "Bt," and "Bw" horizons), and subsequent erosion (emergence of raised T-1b and T-1a surfaces). Each successive cycle was initiated by aggradation of a new series of floodplain sands. In contrast to fluvial regimes in more continental riverine settings such as the Piedmont, Coastal Plain stream cycles are characterized by subdued vertical incision. The graded relief of the flood basin promotes lateral migration and mitigates against pronounced downcutting. Instead, periodic reworking of channel sediments is typical and the T-1a and T-1b landforms represent meta-stable surfaces, more elevated than the surrounding terrain and laterally removed from the primary flooding axes. For these reasons the landforms were repeatedly occupied. However, since the landforms remained within the general floodbelt for most of the Holocene, the occupations were either short-term or poorly preserved. In either case, the evidence for protracted habitation is missing.

Collectively, the sites house >2 m stratigraphic sequences, characterized by two separate cycles of floodplain aggradation above a pre-Pleistocene soil ("3Bt"). The composite stratigraphy is not intact in any single profile because of differential preservation of only select landscape remnants in the dynamic floodplain environment. Still a comprehensive reconstruction is facilitated through examination of the landform distributions and stratigraphy.

Beginning at the base of the sequence, Cycle I (Plio-Pleistocene?) identifies a major disconformity signaling erosion of oldest soils in the project area ("3Bt"). The antiquity of the horizon cannot be firmly dated, but field and laboratory data attest to regional weathering that conforms most nearly to descriptions of weathered argillaceous clays recently classified as Pliocene-Miocene Paleudults (Howard et al., 1993). The limited

(44HN203), to 65 cm several km downstream (44HN202/204), to a maximum of 85 cm near the tidal margins at 44NK173; sedimentation rates are nearly twice as great (1.88) on the downstream as at the upstream end. Differential aggradation rates mirror variability in topography and more significantly the increased accumulations of sands shoreward. These trends appear to be consistent with burial depths for all cultural components except the Woodland which are shallowest on the downstream end. Less than 20 cm of Woodland deposition are registered at 44NK173. While 15 cm of Woodland sediment are preserved at 44HN203, given the accepted sedimentation gradients for the upstream and downstream ends, an expected rate of 28.2 would be projected for 44NK173. The true figure represents a reduction of 30%. The discrepancies in these values are consistent with high frequency inundations along the tidal margins and periodic stripping of the occupation horizons. Conversely, stabilization on the upstream drainages was promoted by creation of a new base level, net aggradation of alluvial sediment and lateral constriction of the T-1a (Woodland) terrace. These reinforcing trends acted to sustain and expand occupational surfaces upstream (near 44HN202/204) while erosion and tidal oscillations stripped and modified downstream landforms.

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TABLE 3
Landscape Chronology and Prehistoric Occupations/Correlations

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Soil Horizon</th>
<th>Cultural Component/Time Range</th>
<th>Soil-Sediment Matrix/Artifact Context</th>
<th>Landscape Developments</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV</td>
<td>A-Apb</td>
<td>Historic/Middle Woodland (2500 B.P.-A.D. 1950)</td>
<td>Contemporary T-1b surfaces seal in historic plow zones; late prehistoric artifact contexts compromised by plowing, pedo- and bioturbation; largely disturbed Woodland occupations on T-1a and T-1b surfaces.</td>
<td>Stabilization of T-1b, while T-1a actively aggrades. Incremental buildup of T-1b by contemporary land use activities. Alluviation rates on T-1a diminished over past 200-300 years.</td>
</tr>
<tr>
<td>II</td>
<td>Bw-Cox/Cu</td>
<td>Middle-Late Archaic /Terminal Archaic-Late Woodland (6000-1500 B.P.)</td>
<td>Weak Cambic paleosol preserves broad range of occupations (T-1b only); most are weakly separated; no evidence for occupation floors (variable vertical artifact displacement); stable surfaces on T-1b, minimal occupation on T-1a.</td>
<td>On T-1b, lateral accretion regime gives way to overbanking; umidic soil caps silt loam; stability of T-1b. Subsequently, Chickahominy base level oscillates 1-2 m; T-1b above flood levels by c.2500 B.P. when stream is incised and T-1a actively aggrades</td>
</tr>
<tr>
<td>O</td>
<td>2Bt-2Cox</td>
<td>Early Archaic (?)(&gt;10,000-6000 B.P.)</td>
<td>Weak Argillic paleosol developed in uppermost channel deposits (poorly sorted pebbly coarse sands) (T-1b only); isolated artifacts</td>
<td>Initial cycle of post-Pleistocene lateral accretion as sea level rises; consistent reworking of generally uniform channel deposits across broad floodplain; prominent braided stream channels and overflow chutes</td>
</tr>
<tr>
<td>I</td>
<td>3Bt</td>
<td>(Plio-Pleistocene) (?)(&lt;10,000 B.P.)</td>
<td>Firm Argillic paleosol developed over pre-Pleistocene marine terrace; exposed only on eastern limits of 44HN202; no artifacts</td>
<td>Forms erosional surface that was incised and overridden by realigned Pleistocene and (possibly) early Holocene streams</td>
</tr>
</tbody>
</table>

The horizontal distribution of the Pliocene-Miocene soil, and the relatively minimal aggradation up to the Early Holocene and Early-Middle Archaic levels (on the order of only 1.2 m) bespeaks considerable surface stripping in post-Pleistocene times. The most recent map of alluvial landforms in central Virginia is conspicuous for its absence of Pleistocene features for any stream systems tributary to the regional trunk feeder, the James River (Howard et al., 1993). This suggests a complete overhauling of the drainage network of the Inner Coastal Plain prior to the early Holocene. After that time the Chickahominy floodplain and terrace system preserve a comprehensive sequence.

Cycle II (10,000-6000 B.P.) introduces the earliest Holocene landform (T-1b only). Its deposits are typically bedload and channel sediments consisting of fine gravels and coarse-medium sands. The cross section illustrates mobilization of substantial quantities of sediment, given the depth and extent of undifferentiated coarse sands (Fig. 2); analogous sections were observed at several locations in site proximity. An initial phase of incision is demonstrated at 44HN202 where apparent downcutting into the paleosol ("3Bt") may be evidence for entrenchment of a new channel, possibly during the Pleistocene/Holocene transition. That channel is primarily aligned with the tributary stream, which spilled into the mouth of the Chickahominy River downstream during the early Holocene.

Following incision of the tributary and erosion of the Plio-Miocene fills a realigned early Holocene Chickahominy channel emerged in response to rapid encroachment of the Atlantic shoreline. For the Atlantic Coast generally, sea level rises on the order of 10-20 m have been estimated between 10,000-6000 B.P. (Bloom, 1983; Kraft, 1985). Landward encroachment of the margins of the Chickahominy estuary would have filled up the former drainage mouth with sands that graded the floodplain in an upstream direction. This is demonstrated by progressively higher buildups of sediment in a downstream direction (compare thicknesses of equivalent strata at 44NK173 and 44HN202 and 204 in Fig. 5). As the river debouched onto the Coastal Plain, it traversed a widening, broad but shallow channel floor infilled with coarse sands that were periodically reworked. A network of braided channels probably emerged at this time. The general trend of stream evolution was to systemic lateral migration rather than cutting and filling. The raised landforms, on which the archaeological sites were situated, emerged initially by lateral accretion. These were effectively point bars. Subsequently their surfaces were built up by fining-upward suites and were eventually stabilized by
overbanking of fines and formation of a soil ("2Bt"). Periodicity of channel shifts was high, such that only isolated sites or artifact assemblages would have been preserved on channel margins. Large-scale sedimentation (the product of base level rises) and lateral channel swings would have buried and/or eroded most of the sites. The "2Bt" soil represents the period of most extensive surface stability. On a larger scale, it marks the end of the early Holocene cycle of continuous, rapid sea-level rise. Subsequently, base levels everywhere along the Atlantic Coast oscillated to within several meters of their present positions.

Cycle III (6000-1500 yr B.P.) is marked by a new round of stream migration, channel stabilization and soil formation. More compressed stratigraphies at the top of the T-1b implicated reduced sedimentation rates and, by extension, diminished stream dynamism and perhaps more limited channel migration. A raised floodplain-terrace topography emerged 1-2 m above floodstage, probably between 6000-4000 yr B.P. The overarching pattern of landform evolution echoed that of the preceding cycle and the most attractive, intensely occupied habitats were the T-1b outcrops above annual bankfull levels. The latter phases of the cycle are marked by initial construction of the T-1a landform. Thus two discrete landforms (T-1b, T-1a) were occupied between 2500 and 1500 yr B.P. and highlight the best differentiated landscape locally. A partial explanation for the optimal occupation environments lies in shorter term but more frequent transgressions and regressions of the coastline. These would have produced brackish and aquatic habitats along the Chickahominy which sustained braided channels that migrated laterally in sandy infilled flood basins. Prehistoric materials are scant to nonexistent and invariably out of context.

At the onset of Cycle II (10,000-6000 yr B.P.), actively transgressing shorelines at the onset of the Holocene resulted in base level rises on the order of 5-10 m/millennium (Kraft, 1985). These produced graded floodplains in interior drainages such as the Chickahominy basin. The fluvial regime of the trunk stream featured periodic lateral channel shifts followed by overbanking, soil formation, and a new cycle of channel and floodplain migration. These developments are registered by the basal soil-sediment "packages" exposed on the T-1b. Artifact counts are slightly higher in these levels but evidence for intact assemblages remains marginal. Near the end of the period, rates of sea-level rise slowed dramatically and nearshore sedimentation and catastrophic realignments of near-shore landscapes were dominant.

By Cycle III (6000-1500 yr B.P.) base levels were oscillating since sea level was no longer rising uniformly. The T-1b evolved into a stabilized surface by the end of this cycle. By 2500 yr B.P. the T-1a began aggrading as tributary systems created riparian landscapes along the margins of the primary drainage. Less turbulent Chickahominy stream flow reduced the frequency of former T-1b flooding. The period between 2500-1500 yr B.P. was marked by landscape expansion and growing attractiveness of former flood basin tracts as both the T-1a and T-1b sustained elevated surfaces.

These time-transgressive developments are mirrored in an archaeological record that becomes progressively richer and more complex stratigraphically, first vertically (to the top of the T-1b sequence) and then laterally (across the T-1b and T-1a surfaces). Thus, assemblage integrity was initially demonstrated for the

Synthesis of Continental and Marine Landscape Records

An overview of the cyclic model of landscape evolution and human occupation presented above (Table 3) isolates several turning points offsetting intervals of optimal occupation and environmental stability from periods of dynamic landscape change and marginal archaeological records. These may be assessed against the backdrop of the littoral record and models of Holocene sea-level oscillations for the Middle Atlantic coast. The turning points are 10,000 yr B.P., 6000 yr B.P., and 2500-1500 yr B.P. corresponding to the ends of cycles I, II, and III respectively.

Beginning with Cycle I (>10,000 yr B.P.), actively transgressing shorelines at the onset of the Holocene resulted in base level rises on the order of 5-10 m/millennium (Kraft, 1985). These produced graded floodplains in interior drainages such as the Chickahominy which sustained braided channels that migrated laterally in sandy infilled flood basins. Prehistoric materials are scant to nonexistent and invariably out of context.

At the onset of Cycle II (10,000-6000 yr B.P.) systemic stream adjustments to elevated base levels initiated the present landscapes and hydrographic networks of the Chickahominy basin. The fluvial regime of the trunk stream featured periodic lateral channel shifts followed by overbanking, soil formation, and a new cycle of channel and floodplain migration. These developments are registered by the basal soil-sediment "packages" exposed on the T-1b. Artifact counts are slightly higher in these levels but evidence for intact assemblages remains marginal. Near the end of the period, rates of sea-level rise slowed dramatically and nearshore sedimentation and catastrophic realignments of near-shore landscapes were dominant.

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Late Archaic, became more widespread for the Terminal Archaic components, and was most extensive for the Woodland period. Coeval trends of better preserved, more extensive archaeological assemblages correspond to increased availability of prime floodplain tracts, diminished flooding, and limited periodicity and magnitude of sea-level transgression.

MODELING MAN-LAND RELATIONSHIPS ALONG THE CHICKAHOMINY

The cyclical reconstruction of landscape transformation facilitates a drainage-wide model of human adaptation driven, in part, by environmental change. Periodicity in landscape change is mirrored in patterned occupational successions over the course of Holocene prehistory in the Chickahominy River valley. The model advanced below is organized chronologically (Fig. 6). Note that the cycles of landscape and geomorphic dynamism are not necessarily in phase with major periods of cultural change, because human adaptive transformations reflect influences above and beyond ecological overhauls.

Period I (prior to 6000 yr B.P.)

The archaeological evidence of this period is as diffuse along the Chickahominy as everywhere in the Middle Atlantic; settlement data are incorporated from a variety of locales in east-central Virginia. Central to any settlement model is the 10-15 m depression of base levels which had ramifications for continental settlement location and preservation. Higher gradients of interior streams encouraged more dynamic stream flow. The Chickahominy floodplain was very active and experienced relatively frequent channel shifts between the ancient, well-established terraces (Fig. 6). Rather than mature floodplain forests, unvegetated bars and shoals might have been typical (Stevens, 1991) and the extent of expansive wetlands was limited.

Human habitation along the Chickahominy would have focused on upland landforms. These consisted of

FIG. 6. Schematic views of Holocene landform evolution.
the ancient marine and fluvial terraces, which define the current floodplain. These landforms were stable and supported mature forests. Results of a transect survey over the James-Chickahominy divide verified that sites from this period cluster along these higher elevations (Blanton et al., 1992). The presence of occasional, isolated Early-Middle Archaic artifacts at the Chickahominy sites indicates some ephemeral use of the area. Activities were probably limited to brief forays and precluded establishment of longer-term, established camps. It is possible that ephemeral settlements were scoured away by turbulent, early Holocene channeling. The floodplain and its flanking basins constituted limited habitats prior to about 5500 B.P.

The archaeological potential of the Chickahominy floodplain for sites predating about 5000 B.P. is limited. The active fluvial environment would have been unlikely to propagate site preservation; individual site structures were rudimentary and site densities were generally low.

**Period II (6000-2500 yr B.P.)**

This period marks the onset of relative stability of the riparian landscape and its subsequent maturation to contemporary configurations. The key environmental factor acting on the landscape was long-term slowing of marine transgression. As the rate of sea-level rise declined and stabilized to within ±6-8 m of the present shoreline between 6000-5000 yr B.P., stream gradients were lowered. Channel flow became restricted within more confined flood belts. In turn, the more static floodplains became vegetated. When steady state was reached, inland alluvial basins began to evolve and zonation of aquatic biomes was highly diversified. Over the longer term, sinuous channel regimes were displaced by migrating, laterally accreting flows and eventually by overbanking, entrenched channels (see Fig. 6). The progression to successively lower energy stream environments resulted in the alignment of the prehistoric sites with their respective stream landforms. At older sites 44HN203 and 44NK173 landforms are former point bars, while at 44HN202/204 occupations occurred on lower alluvial terraces.

The ramifications of landscape stabilization for human utilization of the region were significant. Emerging alluvial terraces and floodplain segments constituted newly opened settlement loci. More importantly these locations were proximal to floodplain resources including wetland and aquatic faunal and floral species. With the channelization of streams the threat of flooding was minimized.

Archaeologically the proliferation of cultural loci and higher density site finds mirrors these trends. While Middle and Early Archaic artifacts are typically diffuse and are too infrequent to assign to discrete landform components, by upper Late Archaic (Halifax/Brewerton) times occupation horizons coincide with discrete alluvial facies (fine sands and silts characteristic of upward-fining lateral accretion sequences; lamellae are also characteristic). By the terminal Late Archaic, overbank sediments were more prolific, as were Cambic soil profiles; recurrent occupation of stable surfaces was typical. These patterned soil-sediment and archaeological associations underscore the systematic distribution of sites along the Chickahominy by 2500 B.P.

The prominence of Halifax/Brewerton components at the sites underscores dominant selection of “riverine” locales at this time. Accordingly, models linking these components to upland settings need to be reconsidered (Mouer et al., 1990; Pullins and Schuldenrein, 1993a, 1993b). Spatial and stratified data converge around a wide-ranging pattern of foraging by these groups. Subsistence rounds would be keyed to riverine resources regularly. The creation of the environments described probably contributed to this shift and promoted gravitation to broadly zoned, yet stabilized subsistence areas during the terminal Late Archaic. Progressive Late Archaic emphasis on wetland/estuarine resources coincides with the stabilization of sea level. Large habitation sites on or near floodplains constitute the major evidence. Part of the attraction of these environments might have been the increased ease and necessity of water travel as stream courses became more dependable and semi-permanent wetlands evolved as more prominent elements of the resource environment.

Sites dating to this period should be plentiful in the area. As increased numbers of sites are discovered, their locations will probably be linked to the expansion of wetlands.

**Period III (2500-350 yr B.P.)**

This period is marked by continued maturation of the floodplain environment. Consequently there were fewer wholesale modifications to the alluvial biome. Nevertheless static configurations of aquatic habitats have important implications for human settlement. First, ongoing reductions in sea-level rise perpetuated a steady state in interior settings heretofore unknown. Second, a renewed phase of stabilization of near-shore environments occurred about 2000 yr B.P. Evidence comes from geological probes demonstrating formation of fringing marshes at this time in proximity of present baymouths of the James River network (Finkelstein and Hardaway, 1988).

Along the Chickahominy River, landform construction proceeded by limited lateral accretion and overbanking at floodplain margins. Most prominent are the embankments of the T-1b along the small tributary stream at 44HN202/44HN204, and ongoing overbank deposition. Presumably, the even lower stream gradients would have promoted extensive wetland
development, just as the marshes were formed toward the outer Coastal Plain.

Settlement of these lower terrace areas began during the Middle Woodland, probably soon after they were forested. Analogous patterns have been observed elsewhere in the area and are generally attributed to the increasing emphasis placed on the expansion of wetland floral communities and specifically the availability of native starchy seed plants. It is probable that the exploitation of specific wetland flora was perpetuated by increased population pressure during Woodland times.

Sites of this age should be among the most common in the area. An emphasis should be placed on refining the timing of occupations in the river bottom relative to larger-scale changes in stream gradient and effective climate.

Period IV (post-350 yr B.P.)

This period essentially accounts for the effects of Euro-American settlement on the natural environment. Sea level did not remain stagnant and the rate of rise over the past three or four centuries may be on the order of about 30 cm/century. A shift of this magnitude has obvious implications for stream gradient changes, along with the farther reaching effects of accelerated sediment yield. The latter results from agricultural exhaustion and dispersal of topsoils and large-scale modifications of surface covers by contemporary landscaping and reclamation.

Culturally induced changes are related almost entirely to land clearance and farming practices that began with Euro-American settlement in the seventeenth century and only accelerated with time. Severe erosion affected in the loss of tremendous amounts of soil that was ultimately transported in stream loads and deposited as alluvium in bottomlands. Progressive and exponentially accelerated deposition choked many stream courses which were formerly free-flowing, thus creating new aquatic habitats. Subsequent efforts to control hydrographic balances included channel diversion and creation of new farmland and access for timber harvest. More recently causeways for roads have been constructed that further impede regulated stream flow of the river and its tributaries.

The overall effects of successive layers of landscaping and large-scale soil-sediment mobilization has been alteration of the natural landscape to a degree that reconstruction of past conditions is precluded in all but select segments of the general landscape.

REGIONAL CORRELATIONS

To date, the most ambitious efforts linking Coastal Plain Holocene chronologies and archaeological sequences have been applied to estuarine environments in the Northeast and upper Middle Atlantic regions (Brennan, 1977; Kraft, 1977, 1985; Ritchie, 1981; Sanger and Belknap, 1987; Wyatt, 1977; Young et al. 1992). Reconstructions for the South Carolina Inner Coastal Plain are being advanced by Colquhoun (1967, 1969) and co-workers (see Colquhoun and Brooks, 1986, 1987). These are producing baseline sequences for gauging regional relationships between coastline movements, sea-level changes, and fluvial adjustments along interior valleys.

The most comprehensive interdisciplinary effort is a stratified Archaic sequence embedded in stream terrace deposits of the Inner Coastal Plain segment of the Savannah River, South Carolina (Brooks and Sassaman, 1990), 600 km (380 miles) south of the Chickahominy. The principal conclusion of that study is that Archaic occupations were situated on former point bars that emerged initially through lateral migrations of braided streams. Progressive build up of the point bars was reinforced by overbanking as channel geometry stabilized. Significantly, the setting of the key archaeological site, Pen Point (38BR383), is nearly identical to that of 44HN202/204, positioned at the confluence of the Savannah with a tributary stream. The archaeological sequence, while considerably richer than that of the Chickahominy sites, is preserved in analogous pedo-sedimentary contexts. A complete Archaic chronology—Dalton to Savannah River phases (10,000-3500 yr B.P.)—is contained in >1.0 m of weakly stratified medium-coarse sands, separated by a Cambic soil ("Bw" horizon)(Brooks and Sassaman, 1990:Fig. 5). The only difference in occupational history between Pen Point and the Chickahominy sites is the minimal evidence for Woodland presence at the former. At Pen Point a single landform, a stabilized point bar, sustained all occupations until 4000 B.P., after which overbank deposition resulted in low-level occupations and a shift in stream course sufficiently distant from the river that the site’s logistical advantages had disappeared (Brooks and Sassaman, 1990: 189).

Figure 7 superposes the landform chronology and key soil units at 44HN202/44HN204 with the Pen Point sequence (Brooks and Sassaman, 1990) and the sea-level curve generated from a series of geological and archaeological indicators on the South Carolina coastal plain (Colquhoun and Brooks, 1986). The data indicate that for parallel periods general sedimentation rates along the Savannah River at Pen Point are approximately twice those for the Chickahominy. General differences in sedimentation magnitude between the drainages are functions of the sizes of local drainage nets as well as independent geomorphic and hydrographic controls acting on the individual fluvial systems. It is striking, however, that for each drainage the vertical profiles and the composition of the soil-sediment "packages" display similar vertical trends. For both the Pen Point and Chickahominy sequences the following are noted:
FIG. 7. Sea-level change and Holocene geomorphic cycles.

1). The first major occupations, the Early-Middle Archaic at both sites, culminate at the top of the thickest post-Pleistocene fluvial depositions between 10,000-6000 yr B.P.; this period registers the end of rapid sea-level rise and earliest Holocene surface stabilization (i.e., the "2Bt" horizon at Chickahominy);

2). A period of intense occupation at both sites occurs around Late Archaic times, 4000 yr B.P., co-incident with a peak in a rapidly oscillating sea-level curve and high artifact densities ("Cox/Cu" horizons);

3). Covarying changes in stream flow, sedimentation, sea-level periodicity and occupational intensity occurred after 4000 B.P. At Pen Point there is more limited Late Archaic occupation as stream migration forced the channel away from the location of the earlier Archaic habitation. Along the Chickahominy, intense human activity begins around this time. Occupation here peaked between 4000 and 2500 yr B.P. when the initiation of terrace aggradation (T-1a) promoted diverse occupation across two surfaces of the tributary and the main channel. The "Bw" spanning the stable Terminal Archaic surface at the Chickahominy sites is absent at Pen Point.

4). More diverse fluvial environments emerged after 2500 yr B.P. marked by abandonment of the Archaic locus at Pen Point and broad, intermittent Woodland settlement at Chickahominy (differentiated T-1a, T-1b surfaces).

On a larger scale, these trends are mirrored in many regions of the Middle Atlantic and Northeast Atlantic coast. Geological research is demonstrating high degrees of ecological differentiation in near shore as well as riparian environments at turning points in the sea-level curve around 6000 yr B.P. and 2500-1500 yr B.P. (Cycle II/III and III/IV transitions respectively in Fig. 7) (Bloom, 1983; Kraft, 1985). These resulted in the initiation of adaptive strategies as aboriginal populations became sensitized to shifting landscape and meso-environmental configurations, especially in the pivotal Woodland period (Ritchie, 1981).

CONCLUSIONS

The investigations reported at alluvial terrace sites along the Chickahominy River produced a general model of landscape evolution linking archaeological deposits to changes in stream dynamics and Holocene sea-level change for the Inner Coastal Plain of Virginia. The major interpretations may be summarized as follows:

1). The extensive stabilization of Late Archaic surfaces across the portion of the floodplain examined suggests that the most dynamic changes in sea-level rise had taken place by 6000 years ago. Subsequently incremental rises were
characteristic and did not have as dramatic ecological and settlement ramifications.

2). Stream regimes were cyclic and were initiated in early Holocene sandy floodplains whose origins are traced to upstream encroachment of coastal deposits as sea level rose. Subsequently four discrete cycles of floodplain development are identified, tied to changes in sea level. Turning points are identified at 10,000 B.P., 6000 B.P., and 2500-1500 B.P.

3). Each cycle was generated by emergence of high to moderate energy fluvial regimes that became progressively more subdued and stable. The end of a cycle coincided with peak occupation.

4). For the duration of the Holocene, occupation environments emerged in point bars built up by braided channels. The point bars were fashioned by lateral accretion and were incrementally fortified by overbanking, eventually capped by soils. Subsequently, stabilized surfaces were eroded and channels migrated. This pattern diminished in intensity through time.

5). Three soils are in evidence, two of which are linked to discrete occupations: Middle-Late Archaic ("2Br") dated to 6000-5000 B.P. and Terminal Archaic-Woodland ("Bw") around 2500-1500 B.P. The former soil is associated with an extensive Archaic period terrace, T-1b. The second soil spans two surfaces, T-1b, and the younger, T-1a.

6). The disposition of Woodland artifacts on surfaces lower than the Archaic suggests that by 2500 B.P. a steady state was reached in the rate of sea-level rise. At this time, complex alluvial settings emerged that were ecologically and topographically differentiated.

7). The aforementioned site-landform correlations coupled with drainage-wide observations of landscape morphology indicate that Woodland surfaces may tend to be better preserved in upstream locations, while Archaic surfaces are extensive throughout.

8). Covarying trends in archaeological, stratigraphic, and landscape records at the Chickahominy sites have analogues elsewhere across the Southeast and Middle Atlantic regions. Correspondences between site preservation, stream-terrace stratigraphy and sea-level chronology along the Atlantic coastline remain to be explored in more systematic fashion.

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Soil Moisture Environments Of Pre-Columbian Agricultural Terraces And Settlement, Rio Gavilan, Chihuahua, Mexico

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Man as a modifier of his environment and as an agent of landscape change can be well exemplified by the traditional farmers of Mexico, who have devised and used a variety of successful techniques to improve the agricultural productivity of marginal environments. Past and present Mexican farmers, for example, utilized chinampa agriculture, drained field agriculture, and agricultural terracing. In the marginal mountain environment of the northern Mexican states of Sonora and Chihuahua, a particularly widespread human modification of the land—Pre-Columbian terracing—has been noted by travelers, environmentalists, and archaeologists and studied over the last thirty years by geographers, geologists, and soil scientists. How one area of this terracing relates to soil moisture and to prehistoric settlement is the subject of this paper.

Agricultural terraces of the Casas Grandes archaeological zone, locally known as trincheras, have been investigated by the Department of Geography, University of Denver, in field studies since the mid-1960s. Early studies defined the phenomena and their distribution (Herold, 1965; Howard and Griffiths, 1966; Schmidt and Gerald, 1988). An especially well-developed terraced area was selected in 1968 for more detailed study of the association between the terraces and prehistoric occupation structures probably dating A.D. 1060-1430 (Luebben et al., 1986). Studies continuing since 1988 have focused on the soil moisture environments of various types of terraces and terrace systems (Herold and Miller, 1993). The present paper reviews the components and methodology of study and relates the soil-water results to the areas of soil available for crop production and to the prehistoric population as indicated by nearby ruins.

THE STUDY AREA

The Rio Gavilan study area is located 75 km southwest of Nuevo Casas Grandes, within the Sierra Madre Occidental, at an elevation of 1600-1750 m. The 15 km² area (defined in Herold, 1965) lies at the confluence of the Rio Gavilan and the Rio Gavilan Norte, which are upper tributaries of the Rio Bavispe. Within this area, three separate sample areas were established and all terraces in each area were mapped. Two of these sample areas were studied for soil moisture.

The Rio Gavilan area is one of numerous north-tending structural depressions found in the mountain mass. On both the east and west sides, highlands rise to 2400 m. The bedrock consists of lava flows and tuffs. The terrain is composed of mesas dissected by numerous steep sided valleys 100-300 m deep. Thin soils are found on the mesa surfaces and gently sloping areas. On the valley floors, thicker but discontinuous alluvial deposits extend up to 200 m away from the streams.

The climate can be classified as subtropical. A well-pronounced late spring to early summer drought typically occurs. The average annual precipitation is 600-650 mm with 60-70% falling from early July through October. The mean July temperature is 22°C; while the mean January temperature is 5°C. Frosts may occur until May and the average frost-free period is 180 days. Lateness of frosts and summer rains presents particular hazards to crop production.

The vegetation is open woodland of oak and pine. Undercover of gramma grasses and weedy annuals is characteristically dry until the rains come in early July.

ARCHAEOLOGY

Prehistoric settlements of the Rio Gavilan are culturally affiliated with the Casas Grandes culture, which was centered at the Pueblo of Paquime, located near the modern town of Nuevo Casas Grandes. This culture is generally considered to have strong ties with traditions of both Central Mexican and Southwestern United States.

Within one 6 km² sample area (as shown in Fig. 1), the remains of 46 prehistoric stone sites included 10 small permanently occupied sites and 26 special-use structures, such as field houses, forts, and lookout posts. The Whetten site, a small house of 8-10 rooms, was partially excavated (Luebben et al., 1986). Pottery excavated here and from nearby sites, dating...
Rio Gavilan Study Area
Archaeological Features
and Terrace Systems

FIG. 1. Rio Gavilan study area archaeological features and terrace systems.
A.D. 1060-1205, and a radiocarbon date of A.D. 1190 ± 100 years place these sites within the Buena Fe phase in the Medio period of the Casas Grandes chronology.

TERRACES

The most common type of terrace in the area, called a cross-channel terrace, is formed by construction of a rock wall, or dam, perpendicularly across a drainage course (Fig. 2). In valleys of variable depth and width, earth terraces are formed behind and above series of rock dams which progress along the drainage in step-wise manner. They are almost always arranged in series, with an interval of 7-15 m. Cross-channel walls invariably rest directly on bed rock.

Less than 10% of the Rio Gavilan terraces are sideslope terraces, which parallel the contour of the terrain. They share many constructional features with cross-channel terraces, however, they tend to be lower in height (6-8 dm) and longer (16-20 m) than cross-channel terraces.

Mesatop linear borders are often found in isolated clusters of 5-15 terraces. They are low, usually under 4 dm high, but may extend to a length of 30 m or more. No linear border terraces were sampled for soil moisture within the Whetten site terrace system, but this type was sampled for soil moisture at another site 1.2 km north.

Particularly important for soil moisture analysis is the system of 233 terraces adjacent to the Whetten Pueblo as shown by Fig. 3. (Luebben et al., 1986).

Here, individual terraces vary in size from 6-400 m² and from 3 dm to 2 m high. The total terrace surface is 36,076 m², or just over 3.6 ha.

Donkin (1979), in his study of terracing in the New World, considers all terraces similar to those in the Gavilan study area to be agricultural in purpose. For farmers, terraces provide level surfaces and deep soils in steeply sloping areas as well as increased soil depth in gently sloping areas. Terraces usually occur in areas with seasonal drought.

On the other hand, Di Peso (1974), in his study of the Casas Grandes archaeological area, minimizes the agricultural function of terraces. He states that "It can be postulated that they were not all designed as planting areas, but rather as integral parts of a widespread up slope system that was created to protect lower valley floodplains" (Di Peso, 1974:337). He further states,

The up slope proportion was controlled by at least five types of stone-walled checks, designed in the Buena Fe phase to take the violence out of thunder storm runoff. Many feel that there must be a direct connection between the demographic rise of the Casas Grandes population and the building of the water-soil conservation system, and it is here assumed that the valley people moved westward into the mountains in part to assist in its construction and maintenance (Di Peso, 1974:340).

This is an intriguing hypothesis. However, even though terraces undoubtedly entered into local reduction of soil erosion by controlling runoff and
THE WHETTEN SITE
And
ADJACENT TERRACES

FIG. 3. The Whetten site and adjacent terraces.

protecting adjacent fields from destruction, to extend this importance to a regional level is exaggerated. These terraces, admittedly well built and consisting of at least four types, nevertheless were constructed piecemeal by single families or groups of families. Their maintenance would involve cooperation at a level no higher than a village community—precisely the type of settlement found within the study area.

TERRACE SOIL MOISTURE ANALYSIS

Soil moisture varies in the soil behind the various types of stone terrace walls, i.e., in cross-channel dam alluvium, in side-slope terrace alluvium, and in alluvium trapped above low linear borders on gently sloping uplands.

Soils were sampled with an auger, under both maximum wet and dry conditions. Measurements of differences in water content, water retention pressure, and volume weight were obtained for consecutive decimeter depth increments of the various soil profiles. These measurements were used to determine quantities of water adsorbed as films to the surfaces of soil particles at various levels of water retention pressure.

Void water capacity was determined from volume weight values. Quantities of water were reported as mm/dm of depth, which permits comparison with rainfall reported in mm. The relative permeability of the various depth increments was defined from the ratio between void capacity and water retained at 200 g/cm² of retention pressure, or a pF of 2.30. Retention pressure reported as pF, is the log of the retention pressure in g/cm². The resulting linear relationships, between water content (w) and pF, were used to determine quantities of water available to plants as consecutive molecular thicknesses of water are desorbed and levels of retention pressure double. The level of pF increases by 0.301, the log of 2, as levels of retention pressure double. Quantities of water adsorbed by the soil and available to plants, within each retention pressure range as it doubles, are a major factor in determining the kinds of crops that could be produced.

TERRACE TYPE AND SOIL-WATER RELATIONS

Techniques used to define water relations of various alluvium (naturally occurring alluvium, side-
slope terraces, cross-channel terraces, and low terraces on gently sloping mesas) were described by Herold and Miller at the 1992 conference on Pedo-Archeology (Herold and Miller, 1993). Soils were sampled to contact with rock on still-functional terraces, under maximum wet and dry conditions. Quantities of water available for desorption from the various soils were defined.

Amounts of water desorbed from each soil, as the retention pressure doubles from maximum to minimum levels of storage, were defined through a graphic modeling. Amounts of water available from each retention pressure range were multiplied by the maximum pressure achieved. These values were then totaled to define the average grams per square centimeter of retention pressure that must be overcome to desorb the water stored between maximum and minimum levels of storage.

Quantities of water desorbed varied from 98 mm from stream-side alluvium, to 127 mm from side-slope terraces, to 139 mm from upland terraces. This indicates that side-slope and upland terraces receive supplemental water in excess of rainfall. This would enhance the capability of these sites for crop production.

The cross-channel terrace where measurements were obtained was still intact because of location near the head of the drainage channel. (The terraces above it were also intact.) Water was seeping from the base of this 2-m high terrace. Computations indicate 320 mm of water present between maximum and minimum levels of storage. There was evidence of wetting from the surface to a depth of 50 cm. As with the upland and side-slope terraces under these conditions, maximum wetness was within the field capacity range of water retention pressure—between 100-200 g/cm².

There was evidence in the cross-channel terrace of capillary rise of water upward almost to the base of the soil wetted from the surface. This resulted in a total of 320 mm of water present between maximum and minimum levels of storage. As a result of capillary rise, approximately 190 mm of water in excess of the 130 mm derived from the surface was present. Thus, considerable quantities of water are available at lower levels of water retention pressure. This accounts for an average of only 10,660 g/mm of water desorbed from the cross-channel terrace as compared to 19,480 g/mm from the upland terrace, 20,010 g/mm from the side-slope terraces and 35,900 g/mm from stream-side alluvium.

On the basis of this evidence, cross-channel terraces provide the most productive environment for plant production. The most water-demanding crops can be planted there. Less-demanding short season crops can be planted on upland and side-slope terraces. Stream-side alluvium is the least productive, since it depends only on water derived from snow or rain falling on the surface.

Rainfall and soil moisture measurements for the summer of 1964 (Herold, 1965) indicate that 135 mm of rain fell in large enough increments to penetrate the soil. This occurred during July, following the spring drought, when growth was just starting. Such a regime permitted water to accumulate in the soil with a minimum of depletion. Maximum water measurements made in 1991 were obtained under similar conditions. Water derived from snow melt was not measured. However, since 30% of the average annual precipitation of about 600 mm falls in winter, up to 180 mm could be derived from snow melt and winter rains. When this occurs, long season crops can be planted in the deeper terrace soils at the start of the frost-free period and will probably survive until the soils are recharged by summer rains.

**TERRACE SURFACE, ARABLE LAND, AND SETTLEMENT**

Within a 1.5-km radius of the Whetten Pueblo, 21 intensively terraced areas, 11 limited terrace areas and 10 occupation sites were located (see Fig. 1).

The best developed terracing, by far, is the system of 233 terraces adjacent to Whetten Pueblo, described previously. A total terrace surface of 36,076 m², or somewhat over 3.6 ha, is formed. In addition, in the immediate vicinity of the pueblo there are 2.5 ha of arable alluvial soil not in terraces, which consists of at least two decimeters of fine alluvium deposited over the underlying rocky alluvium. Thus a total of slightly more than 6 ha of land are available for cultivation adjacent to the pueblo.

The Whetten Pueblo's 8-10 rooms probably housed one or two extended families with a maximum population of 20 persons. This settlement probably was sustained by crops produced on the approximately 6 ha of arable land, both terraced and non-terraced in the immediate vicinity of the settlement (see Fig. 3).

The remaining 20 intensely-terraced localities each contain considerably less terrace surface than the Whetten Pueblo terrace system. Their total area was determined to be slightly over 62 ha. However, large-scale mapping of terrace height, length, and plot size in three sample areas indicates that only 8.7-12.9% of any one intensive terrace system is terrace surface per se. Thus, intensive terrace surface outside the Whetten system totals 5.4-8.0 ha. An additional 11 terrace systems where terraces were both limited in size and density are suggested to add only 1-1.5 ha. That nine permanent occupation sites (other than Whetten Pueblo) shared 6.4-9.5 ha of terrace surface contrasts sharply with the Whetten Pueblo's sole control of 3.6 ha of arable terraced land.

Palerm (1966), in a study based on ethnographic research in Mexico, suggests the following arable land requirements per Mexican family for various cultivation techniques:
1). Slash-and-burn requires 1.5 ha under cultivation, with a reserve of 10.5 ha.

2). Fallow-and-fertilize requires 2.5 ha under cultivation, with a reserve of 4 ha.

3). Irrigation requires .86 ha under continuous cultivation.

The degree or intensity of utilization of the 6 ha of arable land adjacent to the Whetten site meets conditions of both the fallow-and-fertilize technique and the irrigation technique. The 2.5 ha of naturally occurring alluvium accumulated to a depth of 2 dm receives water primarily from rainfall and resembles the land under the fallow-and-fertilize technique. The remaining 3.6 ha of alluvium accumulated behind structures cross-channel and side-slope terrace receive run-in water to such an extent that they can be considered partially irrigated in Palerm's third type.

However, the extent of terracing adjacent to the Whetten site appears unrepresentative—exceptionally larger than other terrace systems within the immediate vicinity. Thus, the conclusions must be drawn that, while terracing in the Rio Gavilan area is a very important feature of the cultural landscape and creates hydrographic environments demonstrably increasing the water content of the associated soil, yet terraces probably did not fully provide required land for cultivation for all of the eleventh-to-thirteenth-century occupants. In addition to the cross-channel and side-slope terrace plots, the thin soils of the mesatops both within and outside terrace control and the limited area of alluvial soils adjacent to the permanent streams were vitally needed for cultivation.

In a recent evaluation of Pre-Columbian canal irrigation at Casas Grandes, Doolittle (1993:149) in closing states,

Although the terrace check dams, and linear borders, all known generically in Spanish as trincheras, found in the upper portions of the drainage basin were undoubtedly important, the combined total of all the land area they encompassed, that which could have been under cultivation at any one time, pales in comparison to what must have been thousands of hectares irrigated on the floodplain.

Doolittle's call for archaeological search and investigation of irrigation structures throughout the Rio Casas Grandes drainage basin appears justified from the Rio Gavilan studies.

While there is controversy over the dating of the Buena Fe Phase, it was at that time that irrigation canals were first used at Paquime (Di Peso, 1974). It is intriguing to speculate that simple ephemeral water-diversion structures may have been simultaneously constructed by eleventh- to thirteenth-century Gavilan settlers to irrigate low-lying stream-side alluvial fields. Examples of this simple system to irrigate small fields of corn can be seen today in the Sierra Madre Occidental. Such supplements to prehistoric terraced fields would have been highly desirable, as this study has established, yet thus far their remnants remain undocumented.

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Field and laboratory work were performed on the soils of Caracol, Belize, a major site of the Maya of the Classic Period. Previous work has been published on the soils in the stone-walled terraces. The objective of this research was to characterize the modern soils in order to find clues to ancient Mayan agricultural and engineering practices.

In a depression at the base of a series of terraces, I found a thick, very dark gray clay soil which is well supplied with bases and contains the highest total P of any soil examined. This suggests that soil amendments made on the terraced soil contributed to this accumulation. I investigated two highly calcareous, non-terraced soils. One soil occurs on a steep slope (20-25%) northwest of Caracol’s epicenter and is loamy throughout. It is well supplied with extractable P and other macro- and micronutrients. Calcium carbonate equivalence (CCE) ranges from 57 to 78%. Ten kilometers northeast of the Central Plaza I found a large area of non-terraced soils occurring on relatively flat slopes (3-4%). While these soils are fertile and may have been farmed by the ancient Maya, no settlements occur nearby as in areas which are extensively terraced. The high CCE may cause micronutrient deficiencies and P fixation, but soil tests indicate that these nutrients are adequate to marginal.

I conclude that the ancient Maya probably added amendments to the thin, terraced clayey soils of the hillsides and that they farmed large areas of flatter unterraced soils and, presumably, maintained their fertility.

During the classic Maya Period, Caracol, Belize was one of the largest cities and polities in the Southern lowlands of Central America. An area of approximately 100 km², including the city of Caracol, was occupied by about 100,000 persons (Chase and Chase, 1987). Although the extent of external trade is not well established, we think that most food production occurred within a 400-km² area. This estimate is based on the length of the causeways, presence of terraced fields, and distances that seem reasonable for hauling large quantities of food.

Since soils are basic to most agricultural production we must consider their nature and properties to understand the food support system. Soils are used for other purposes, such as engineering, i.e., support for buildings, roads and other structures. This study of the soils at Caracol was undertaken to measure the effect of ancient agricultural practices on modern soils, to better understand the fertility of present day soils in order to make assumptions concerning fertility of ancient soils, and thus, the food production capacity of these soils, and to investigate how the ancient Maya manipulated soils for agricultural and engineering purposes.

Many early students of the ancient Mesoamerican Maya assumed that “slash and burn” shifting agriculture was widely practiced as is largely the case with modern small farmers in this area (Morely, 1968). More recent studies (Donkin, 1979; Dunning, 1993; Harrison and Turner, 1978; Pohl, 1985) point out that intensive agriculture practices such as raised beds in wetlands (or drainage systems), terraces and fertilization, were employed. The necessity for more intensive agriculture than slash and burn can be deducted by carrying capacity studies and recent population estimates of the early Maya sites.

During the Classic Maya period in Caracol, Belize, the Maya constructed extensive stone-walled terraces on the rolling hills, presumably to conserve soil and water and intensify agriculture. Soils in these terraces are thin, clayey (smectite), and reasonably well supplied with plant nutrients (Coultas et al., 1993).

The climate at Caracol is warm, humid, and tropical, with approximately 1.8 m of rainfall per annum. There is a distinct dry season which usually occurs from January through May. Elevation ranges from 500 to 600 m and the topography is karstic. The limestone which underlies this region is relatively pure calcite. There are no perennial streams within 20 km of the Central Plaza, and ground water occurs at a depth of over 100 m. Vegetation is composed of a dense, non-deciduous, broad-leafed forest, with a closed canopy. Numerous palm trees occur in the area.

**METHODS AND MATERIALS**

Soils were examined by auger along several ancient causeways, and the modern road entering the site from the east and northeast. Subsequently, we dug pits, examined, described, and sampled soils following procedures of the Soil Survey Manual (Soil Survey Staff, 1981). The following determinations were performed on some horizons of all soils: pH in 1:1 water and 1:2.5 KCl, where appropriate. (Jackson, 1958), total N (Bremner, 1985), organic C (Jackson,
RESULTS AND DISCUSSION

The soil in the depression at the base of the terraces (bajo) has a thin organic layer at the surface (Table 1). Below, soil texture is clay to at least 160 cm. The matrix color ranges from black at the surface to dark gray with depth. Red and reddish-brown mottles are common from 0 to 160 cm, indicating imperfect drainage and a fluctuating water table which occurs at 0.5 HCl and back-titrating with NaOH (Soil Survey Staff, 1972).

Particle size was determined after destruction of organic matter with H2O2 using the pipette method (Day, 1965). Mineralogy of the 2 micron and finer clay fraction was determined by X-ray diffraction instrument (Cu-K alpha radiation [Whittig, 1985]).

The non-terraced, relatively flat soil we examined is located approximately 10 km N-NE of Caracol's epicenter, occurs on a low slope (4%), and is extensive in area. Although it is difficult to be certain (because of the dense vegetation), the soil occurs in a saddle in a relatively high position. A thin organic horizon overlies a very dark gray-brown and dark grey-brown A horizon, which is calcareous and has a silty clay and silty clay loam texture (Table 1). We found frequent pottery sherd and one obsidian chip in the surficial layers. The soil becomes more calcareous and lower in clay below the AC horizon. The boundary between the lower AC and C horizon is clear to abrupt and wavy to irregular in topography. This soil contains more organic C at the surface than any soil examined and has a higher CCE percentage than the steep hillside soil. The sequence of horizons, the high CCE, and the wavy to irregular topography of the lower A, AC and upper C horizons are similar in the two calcareous soils. The flatter soil has a thinner solum and the A horizon is much higher in clay than the steep hillside soil, however.

Soil reaction is neutral to alkaline in the two soils developed in highly calcareous material. The soil in the bajo is moderately to strongly acidic. The C:N ratio of these soils is relatively narrow compared with the terraced soils, suggesting more microbiological activity. All soils have a relatively high organic C content at the surface that decreases gradually with depth. Total P in the steeply sloping hillside soil ranges from 810 mg/kg at the surface to 420 mg/kg at 84-104 cm. This is similar to the levels and distribution of P in the terraced soils. Total P in the bajo soil ranges from 1510 mg/kg at the surface to 840 mg/kg in the subsoil. Extractable P is higher in both the bajo and hillside soil than in the terraced soils, suggesting movement of available P from the upland to the bajo and applications of P-containing amendments to the upland soils. Salinity is not a problem with any soil examined as indicated by conductivity measurements (Table 3).

Most macro- and micronutrients are in adequate supply for most agronomic crops in all soils examined (Table 4). Zinc is limited in the hillcrest soil, except in the 0-8 cm layer.

Except for the organic horizon (0-5 cm) of the bajo soil, particle-size content and distribution is similar to the terraced soils (Table 2). The clay mineralogy of the bajo soil is also similar to the terraced soils. The hillcrest soil has a loamy texture with silt being the predominant particle size (Table 2). The sand content is higher than in any other soil examined and the clay content is lowest. Calcium carbonate equivalence is high at the surface, increases to 66 cm, and then decreases slightly. Clay mineralogy is predominantly smectite (calcite was destroyed in sample preparation). The relatively flat soil has intermediate levels of clay in the upper solum and loamy material in the C (similar to that in the hillcrest soil). Although clay mineralogy was not determined we assume the smectite predominates.

The hillcrest soil and the relatively flat soil pose some intriguing questions concerning origin and genesis. While the terraced soils are associated with the bajo soil in a fashion that could be predicted by topography, such is not the case with the other 2 soils. From this and numerous other excavations it appears that this deep calcareous, loamy material is common around the Central Plaza and adjoining building sites in hillcrest positions. This is not what one would expect from factors of soil formation. Over a rolling limestone surface I would expect thinner soils on the steeper hillside and hillcrests, unless silty materials were blown in and differentially deposited on the high surfaces (this is a common phenomenon in Western Iowa where silty loess caps the glacial till). This mode
### TABLE 1
**Description of Three Soils at Caracol, Belize**

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<thead>
<tr>
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<th>Depth (cm)</th>
<th>Munsell Color (moist)</th>
<th>Texture</th>
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<td>f gr</td>
<td>fr</td>
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<td>wk sbk</td>
<td>v sticky</td>
<td>occ f, med roots</td>
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<td>v dk gr 2.5Y 3/0-4/0</td>
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<td>occ f, med roots</td>
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<td>81-160</td>
<td>dk gr matrix</td>
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<td>l</td>
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<td>8-23</td>
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<td>l</td>
<td>gran</td>
<td>fr</td>
<td>occ ls grav</td>
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<td>23-41</td>
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<td>occ roots, wvy bdry</td>
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<td>l</td>
<td>gran</td>
<td>fr</td>
<td>freq ls grav</td>
</tr>
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<td>66-84</td>
<td>br 10YR 4/3</td>
<td>sil</td>
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<td>84-104</td>
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<td>l</td>
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<td>sicl</td>
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<td>calcareous, med roots</td>
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<td>39-47</td>
<td>gr br &amp; lt gr br mixed</td>
<td>sic</td>
<td>wk sbk</td>
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**Abbreviations:**
c - clay; sic = silty clay; l = loam; silt = silt loam; sicl = silty clay loam; mot = mottled; v = very, dk = dark; gr = gray; br = brown; pk = pink; ry = reddish-yellow; lt = light; f = fine; gran = granular; w = weak; sbk = subangular blocky; mass = massive; grn = grained; fr = friable; ls = limestone; grav = gravel; wvy = wavy; bdry = boundary; abund = abundant; occ = occasional; los = loose; org = organic; est = estimate
TABLE 2
Particle-size Analysis and Clay Mineralogy of Three Soils at Caracol, Belize

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>% Sand</th>
<th>% Silt</th>
<th>% Clay</th>
<th>Texture</th>
<th>% Smectite</th>
<th>% Kaolin</th>
<th>% Quartz</th>
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<tr>
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<tr>
<td>66-84</td>
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Abbreviations: 1 = loam; sil = sIL; est = estimate; org = organic; clay mineralogy: 1 = >75%; 2 = 1-25%; 0 = none
*clay samples treated with acid before X-ray, thus, the calcite clays which were probably in the sample were destroyed.

TABLE 3
Some Physical and Chemical Properties of Three Soils at Caracol, Belize

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>pH H2O</th>
<th>pH KCl</th>
<th>Organic C%</th>
<th>Total N %</th>
<th>Total P mg/kg</th>
<th>*Extract P mg/kg</th>
<th>Elect. Conduct. mmmhos/cm</th>
<th>CCE %</th>
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*Mehlich 3 extractant used with acidic depressional soil; ammonium bicarbonate DTPA extractant used for calcareous sloping soil. vh = very high; h = high; m = medium; l = low for agronomic crops; CCE = calcium carbonate equivalence
SOILS OF CARACOL, BELIZE

TABLE 4
Some Extractable Macro- and Micronutrients from Three Soils at Caracol, Belize

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Mo</th>
<th>Zn</th>
<th>B</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
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<tr>
<td>5-0</td>
<td>8591h</td>
<td>407vh</td>
<td>314vh</td>
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<td></td>
</tr>
<tr>
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<td>0.5</td>
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<td>0.3</td>
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<td>7.2h</td>
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<td>0.3</td>
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<tr>
<td>66-84</td>
<td>62m</td>
<td>0.5m</td>
<td>0.41</td>
<td>0.3</td>
<td>0.9h</td>
<td>6.2h</td>
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<tr>
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<td>421h</td>
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<td>0.41</td>
<td>0.3</td>
<td>3.2h</td>
<td>3.21</td>
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<td>Relatively flat soil</td>
<td></td>
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<td>4-0</td>
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<td>0.21</td>
<td>1.4m</td>
<td>0.4</td>
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<td>6.4h</td>
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<tr>
<td>0-15</td>
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<td>0.1</td>
<td>8.3h</td>
<td>10.0h</td>
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</table>

*Mehlich 3 extractant used with depressional soil and reported as mg/dm³.
Ammonium bicarbonate EDTA extractant used with steep hillside soil and flat soil (calcareous), and reported as mg/kg.
Abbreviations: vh = very high; h = high; m = medium; l = low for agronomic crops.

of deposition is not possible when one considers the fact that there are large limestone rocks (and smaller quartz stones) interspersed in the loamy matrix.

Perhaps the soil on the hillcrest is developing in materials deposited by the ancient Maya to improve drainage and the stability of the soil for the support of structures. Others have reported that the Maya mined "sascab" for road building and other purposes (Ishphording and Wilson, 1973). While this calcareous material is not sascab (the highly calcareous material found under caprock formations) it could serve similar purposes.

These calcareous deposits are relatively common and several have recently been excavated for road-building material. These deposits rest on an irregular hard limestone surface near ridgecrests, often facing in a westerly direction. The position of the hillcrest soil is illustrated in Figure 1. This silt occurs on an 18 to 25% convex slope facing west. There is an abrupt boundary between the thin dark gray-brown clay soil and the thick loamy calcareous soil, both at the ridgecrest and where the slope flattens to 8 to 10%. Stone-walled terraces occur shortly after the slope flattens. Laterally, the calcareous soil extends an estimated 200 m in a N-S direction.

I think that these (both the steeply sloping hillcrest and the relatively flat calcareous soil) are relatively fresh (young) deposits because of their high CCE. Some downward movement of Ca/Mg carbonates has occurred in the soil surface. With fairly well distributed rainfall (January - April dry season) of over 1.5 m, I would expect at least this much leaching within a millennium.

SUMMARY AND CONCLUSIONS

All soils examined are relatively young and unweathered as indicated by the high content of smectic clay, the high content of bases, and the lack of significant morphological development. There has been no clay translocation in the soils. Horizon boundaries are gradual (except at the rock-soil or AC-C interface) and smooth in the soils on the terraces and in the bajo.

In the hillcrest and other calcareous soils with low slopes, the boundary between the AC and the C horizon is clear and wavy, suggesting some disturbance. Perhaps windthrow of trees has caused this pedoturbation.

What has been the effect of ancient agriculture on modern soils at Caracol? Certainly the terraces have been effective in slowing erosion and, presumably, conserving moisture. Rocks have been culled from the interterrace soil for the construction of the terrace and possibly for other structures. The surface horizons are higher in available plant nutrients than the subsoil. Whether this is due to fertilizer applications by the ancient Maya or natural bio-accumulation is a moot question. Elevated P levels are sometimes used by archaeologists as an indicator of ancient intensive agriculture, or at least habitation (Dunning, 1993), but we can conclude little from these data. We are of the opinion that the fractionating P compounds following
FIG 1. Slope, direction, and soils across a ridgecrest along NW Causeway, showing position of steeply sloping calcareous soil.

Chang and Jackson's (1957) procedures will yield few clues concerning very ancient agricultural practices, but since we found high total P levels in the bajo which received runoff from the terraces, this procedure needs testing at this site. Sandor et al. (1986) found that total P and most P fractions were reduced by cropping between A.D. 1000 and 1150 on terraced soils in southwestern New Mexico. Total P levels and P fractions vary considerably due to differences in parent material and other factors of soil formation. Sandor and Eash (1991) found that total P level in volcanic ash in Peru range from less than 100 to around 1900 mg P/kg soil.

The hillcrest soil has a mollic surface, friable granular structure, and qualifies as a Mollisol (Calcudoll). The bajo soil has a thick dark-colored surface horizon which probably was a high base status. Since the aggregates would likely be very firm when dry, I can not class it as a Mollisol, and since it has neither slickensides nor significant cracking (permanently wet) it is not a Vertisol. I classify it as an Inceptisol (Humaquept). The calcareous soil on low slopes I classify as a Calciudoll.

We can conclude, then, that these were reasonably productive soils for the ancient Maya. They may have enhanced their productivity with compost of plant and animal wastes, and we have some evidence for this. They protected the soil from destructive erosion and conserved water with the construction of stone terraces. They had large areas of non-terraced, non-stony soils available to them which were easier to work (cultivate) and probably more productive than the terraced soils.

ACKNOWLEDGMENTS

I want to thank Drs. Arlen Chase and Mary Collins for assistance with field and laboratory work and for their helpful comments in manuscript preparation. A longer version of this paper may be found in: D. Z. Chase and A. F. Chase, Eds. Studies in the Archeology of Caracol, Belize, Monograph 7, Pre-Columbian Art Research Institute of San Francisco, 1994, pp. 21-23.

REFERENCES


Pedo-Archaeology of the Mammoth Meadow Fan/Terrace Workshop Site in Southwestern Montana

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Pedological studies of the Mammoth Meadow fan/terrace were conducted as a part of an interdisciplinary investigation of archaeological site 24BE559 in extreme southwestern Montana. The fan/terrace contains a deeply stratified, intact record of human occupation from the late Pleistocene to European contact. Soil science has provided information for defining stratigraphic discontinuities, possible sources of sediments and their modes of deposition, post-depositional modifications, and both a theoretical and operational basis for dispersing fine earth in order to recover hair and other small organic remains.

Field and laboratory investigations have been underway since 1986 at the Everson Creek-Black Canyon (ECBC) Quarry Workshop Complex in extreme southwestern Montana by the Center For the Study of the First Americans (Bonnichsen et al., 1992). The Mammoth Meadow Fan/Terrace (24BE559) locus, which is the focus of this paper, is a part of the ECBC complex. The ECBC investigation is being carried out by an interdisciplinary team of scientists that includes archaeologists, climatologists, geologists, geophysicists, pedologists, molecular biologists, and a large group of students and lay volunteers.

The ECBC complex lies about 7 km east of the Continental Divide at an elevation of approximately 2100 m. It is located on the east slope of the Beaverhead Mountains in the Bitterroot Range near the northern end of the Basin and Range Province of the western United States. The ECBC quarry-workshop site is located on a band of Tertiary valley-fill sediments that were impregnated with siliceous hydrothermal solutions during the early to mid-Tertiary. The original valley-fill sediments range in texture from conglomerates through fine sands and silts, to freshwater limestone. The impregnated area is approximately 5 km long and 3 km wide. The original constituents were partly to completely replaced by silica, so that the rock is now composed almost entirely of the minerals opal and chalcedony. The area was glaciated in the early to mid-Pleistocene. The landscape within the ECBC is pocked with hundreds of small quarries. Humans excavated and brought vast quantities of suitable chalcedony from these quarries to the Mammoth Meadow workshop site for use in making tools. The Mammoth Meadow fan/terrace lies within the ECBC along South Fork Everson Creek at the confluence of the creek and two small, intermittent drainageways.

METHODS

Excavations at Mammoth Meadow I showed that the fan/terrace is a deeply stratified archaeological site (Fig. 1). Project staff then developed a sequential excavation strategy designed to expose essential site formation data for the fan/terrace with the minimum possible disturbance.

Representative vertical profiles of trench and pit walls were described and sampled using standard pedological methods (Guthrie and Witty, 1982; Soil Survey Staff, 1981) of the National Cooperative Soil Survey. Then the morphology of all walls was mapped by extrapolation from the units defined and described at key representative profiles.

Routine laboratory analyses of the <2 mm fractions of samples from all horizons and subhorizons from selected profiles were carried out to determine: pH, organic C, CaCO₃, exchangeable K; amounts of a suite of 23 elements were determined following extraction...
with boiling nitric/perchloric acid using an ICP spectrophotometer (Schulte et al., 1987). Particle size distribution was determined using the hydrometer method (Gee and Bauder, 1986). Mineralogy of clay-size fractions of selected samples was determined using the method of Klages and Montagne (1985). Lithology and quantitative distribution of gravels, stones, cobbles and boulders were determined at selected locations.

Results of field and laboratory studies were interpreted by an iterative process of drawing and testing alternative inferences, from which the most probable explanations were developed. Interdisciplinary perspectives were particularly helpful in development of these inferences about the events and processes that occurred at and helped to create this site. The results given here are only a part of the array of data amassed from the investigation.

RESULTS

Overall Stratigraphy of the Fan/Terrace

Figure 2 shows a cross section of the Mammoth Meadow fan/terrace along line A-A' in Figure 1, with the large and variable array of pedologic and lithologic units grouped into 10 Major Stratigraphic Units. Figure 3 is a schematic profile of the west wall of archaeological pit Mammoth Meadow II. Table 1 summarizes the detailed morphology of the west wall of Mammoth Meadow II, a stratigraphically and pedologically complex location near the middle of the fan/terrace; Figures 4 and 5 show depth distribution of organic C and particle size distribution, respectively, at the same location. From these and similar data at other locations on the fan/terrace, we have developed an understanding of the forces and events that have operated there since the late Pleistocene. Our current understanding of how they have shaped this landform is summarized below.

The varied array of pedologic horizons and other strata in the fan/terrace were grouped into 10 Major Stratigraphic Units, (Fig. 2), as a means of understanding its complex origins and structure. Criteria for the grouping include the following: color, structure of peds if present, content of organic C, texture and textural discontinuities, mineral content, and kinds and amounts of coarse clasts. All Major Stratigraphic Units except VII and X, the basal units that have been little studied, contain two or more pedologic horizons or subhorizons, and/or stratigraphic units that do not show evidence of significant pedologic modification.

Major Unit X, the oldest deposit on the site, is a stream terrace (Fig. 2). The terrace surface excavated to date has an elevation of 2091.5 meters above sea level at meter 40, and slopes upward to the west. At
Trench 5, 67 m west of the Reference Point, its elevation is 2092.8 m. This terrace consists of very poorly sorted boulders (up to 1 m diameter), stones, cobbles, gravels and sands.

A stratum of clayey sediments (Major Unit IX, Fig. 2) lies above the fluvial deposits. It consists of a clay-textured matrix with abundant cobbles and stones 20 to 40 cm in diameter in its lower portion. Gravels and coarse sand are almost absent. In places the cobbles and stones occupy 75% of the volume of the lower portion of the stratum. This stratum lies directly on and is interbedded with the fluvial terrace deposit, but ranges considerably in thickness. A distinguishing mineralogical characteristic of the fine-earth fraction of the stratum is its low contents of total K (2400-2850 mg/kg), Mn (~300 mg/kg), and Zn (40-65 mg/kg), as compared to other deposits at the site having a similar texture.

Major Unit VIII, a discontinuous stratum of slopewash, was exposed in Trench 5 between the low-K clay, Major Unit IX, and the overlying paleosol, Major Unit V. Small deposits of Glacier Peak volcanic ash, 11,200 yr B.P. (McDaniel, personal communication, 1993), occur in its upper surface.

Major Unit VII is a fluvial deposit of sand, gravel, cobbles, and stones that is weakly stratified and poorly sorted. It lies at an elevation of 2090 m, approximately the elevation of the bed of South Fork Everson Creek at this location. The deposit extends westward about 35-40 m from the Reference Point with little change in elevation. Its steep boundary with Major Unit X appears to be a terrace escarpment, with Major Unit VII having been formed after the partial erosion of Major Units IX and X.

Major Unit VI consists of a variable array of clayey and silty materials with inclusions of gravels and occasional cobbles and stones. The fine-textured sediments contain notably more total K (5500 mg/kg) than the clay of Major Unit IX. Low-chroma colors and mottles reflect the effects of the aquic moisture regime.
in this part of the fan/terrace.

Major Unit V, a prominent paleosol, extends the length of the fan/terrace. Its upper portions generally contain a concentrated assemblage of stone tools and debitage. The paleosol ranges from 10 to approximately 100 cm in thickness. In a few places artifacts and debitage occupy as much as 80% of the volume of the horizon. The textures of the paleosol are silty clay, clay loam and silty clay loam. The paleosol is massive, darker in color, and more compact than materials of similar textures above and below it. At Trench 5 (Fig. 2) it is separated from the basal fluvial surface, Major Unit X, by more than 1 m of intervening deposits; at Mammoth Meadow II the base of the horizon is 70 cm above the top of the same fluvial surface; whereas, at Mammoth Meadow I (MMI), it lies from 0 to 15 cm above the top of the fluvial surface of the lower, younger terrace, Major Unit VII.

Major Unit IV is predominantly clayey and silty in texture, lacks pronounced characteristics of soil development such as coated ped surfaces, and contains less gravel than Major Unit VI below it. Major Units IV and VI both appear to consist of redeposited materials from the higher elevations of the fan.

Major Unit III delineates a stratified deposit of slopewash, colluvium, and loess with paleosols, that extends downslope from the boundary of the fan with the uplands, ending approximately 40 m from the reference corner at MM I. These deposits, which are thicker and more complex upslope, were sampled and described in detail at MM II. Table 1 gives the individual strata and pedogenic horizons that constitute this array of materials (Major Unit III) as horizons 3C through 7C, inclusive. Figure 5 shows the wide range in particle size distribution among them.

In most of the fan, two paleosols (Major Unit II) lie between the contemporary soil (Major Unit I) and underlying deposits. The paleosols have a strong prismatic structure, prominent pressure films on most ped surfaces and an abrupt upper boundary. The contemporary soils (Major Unit I) are thick, black and silty. They increase in thickness and in organic C content from the head to the toe of the fan.

Pedological Processes and Results

The archaeological excavation known as Mammoth Meadow II, located at the mid-point of the fan/terrace, illustrates the results of both local-scale and global-scale processes. Figure 3 gives a schematic representation of the profile, including the relationship of pedologic horizons and subhorizons and other strata to the Major Stratigraphic Units present there. It shows the horizons from which hair has been recovered by dispersion, floatation and screening (Beatty and Bonnichsen, 1994). Table 1 summarizes the morphological properties of the profile shown schematically in Figure 3. Figure 4 shows the depth distribution of organic carbon for the same profile, and Figure 5 shows particle size distribution.

These figures and table show that the section includes a contemporary soil approximately 1.1 m thick, and three buried paleosols interspersed among diverse deposits that show no significant evidence of pedologic development. The entire profile has pH values near neutrality; free carbonates are absent (although they occur occasionally in low concentrations in other parts of the fan/terrace).

The entire upper solum and the uppermost paleosol (2Ab and 2Bb) have the characteristics of loessial deposits in which organic matter has accumulated by pedogenic, and probably anthropogenic processes, and in which structural peds have become moderately and strongly developed. Some peds have continuous films. Thin sections show that these films are not due to translocation of clay, but are likely to be pressure films. This observation is consistent with the mineralogy of the clay fraction, which is predominantly smectite (Turner et al., 1991).

Below the 2Ab-2Bb solum, horizons 3C through 5C constitute the upper part of a series of deposits that we interpret to have been formed from slopewash from the adjacent uplands. This slopewash was deposited over the fan during the mid-Holocene. Horizon 7C is also a slopewash deposit, but it is separated from the slopewash deposits above by a very weakly developed paleosol, horizon 6Ab. The silty clay loam texture, essential absence of gravel, and higher content of organic C (Fig. 4) than the overlying or underlying strata, and the darker colors, all help to define this thin, weak, paleosolic A horizon.

The stratigraphic position of the series of slopewash deposits and weak paleosol included within them relate well to the modeled climate of the mid-Holocene for this site. At 6000 yr B.P., the lower-than-present precipitation and significantly higher-than-present summer and early fall temperatures would have supported only very sparse vegetative cover that might be expected to allow any strong rainfall events to cause severe erosion on the adjacent uplands and deposition of the poorly sorted sediments in the runoff on the fan.

Horizons 8Ab1 and 8Ab2 are a thicker, more prominent paleosol than horizon 6Ab. This paleosol extends the length of the fan/terrace, although it varies considerably in thickness. In addition to its distinctive dark colors and clayey textures, it contains a prominent band of chaledony flakes that we have named the Cody Living Floor. There is occasional evidence of solifluction; and thin sections show its pore distribution to have been affected by frost. A C14 date of 8226 ± 85 yr B.P. from this paleosol at this pit accords with both the archaeological specimens that are so abundant; and the frost-affected pore distribution accords with the modeled climate of that time, in which winter temperatures were several degrees C below those at present. Mineralogy of the clay fraction is predomin-
## TABLE I
Morphological Description of Soils and Sediments, Mammoth Meadow II

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<tr>
<th>Horizon</th>
<th>Depth below datum (cm)</th>
<th>Color</th>
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1 nomenclature as per Soil Survey Staff (1981).
FIG. 3. Profile of the west wall of Mammoth Meadow II.
FIG. 4. Depth distribution of organic carbon, Mammoth Meadow II.

FIG. 5. Particle size distribution, fine-earth fraction, Mammoth Meadow II.
nantly vermiculitic, indicating a different source for this loess than for those that comprise the contemporary soil above, since micromorphological evidence shows essentially no pedogenesis or translocation of clays in the profile. Total K content of 4800 mg/kg supports the vermiculitic nature of the clay fraction.

Horizons 9C1 and 9C2 consist of very cobbly, massive clay that is considerably lighter in color and lower in organic C than the overlying 8Ab2. Total potassium is 2850 mg/kg in the 9C1 and 2400 mg/kg in the 9C2. Below horizon 9C2 there is a gradual transition to poorly sorted, fluvial deposits that form the surface of the older, higher stream terrace, Major Stratigraphic Unit X.

Since soils are the product of the soil-forming factors climate, relief, and biologic forces acting upon parent materials through time, the presence of numerous paleosols in the fan/terrace and the need to know how climate changes may have affected human occupation led to investigation of past climates and the times during which they existed.

**Paleoclimates**

Paleoclimate models show striking changes in climates at the site and surrounding region from the late Pleistocene to the present. J. Kutzbach and P. Behling (personal communications, 1994 and 1995) graciously provided data from four cells of the COHMAP Community Climatic Model (Wright et al., 1993) that surround the ECBC site, from which we derived the information given below.

At 16,000 yr B.P., monthly temperatures are modelled to have been 4 to 15°C below monthly averages at present. At 14,000 yr B.P., increases in summer solar insolation caused monthly average temperatures during July and August to approximate those at present, while average temperatures for other months remained 2 to 8°C below present levels. At 11,000 yr B.P. average monthly temperatures from July through October were 2 to 5°C warmer than for the same months at present; winter temperatures were 2 to 5°C below those for the same months at present. At 6000 yr B.P. temperatures for July, August, September and October were warmer by 3 to 5°C than at present, and temperatures for January, February and June were slightly colder than at present. Average temperatures for other months were less than 1°C different from those at present.

Modeled precipitation change during the 14,000 yr B.P.-to-present interval is similarly shown to have been substantial. A model by Bryson (personal communication, 1994 and 1995) that uses somewhat different algorithms than those used by COHMAP shows precipitation at 14,000 yr B.P. to be approximately 170 mm/yr; at 11,000 to 8500 yr B.P. to be 230-280 mm/yr; and from 7000 yr B.P. to the present precipitation has ranged from 300 to 390 mm/yr. Current average precipitation at Mammoth Meadow is approximately 350 mm/yr. The COHMAP model shows a similar pattern of much lower precipitation in the late Pleistocene and early Holocene.

This pattern of changes in modeled temperatures and precipitation during the climatic transition from late-glacial to present conditions offers insights into the changing environments that led to the series of deposition-erosion events that left the array of deposits shown in Figure 2.

COHMAP models of wind velocity and vectors (Kutzbach and Behling, personal communications 1994 and 1995) show substantial anomalies from present velocities and vectors during the climatic transitions from late-glacial to present conditions. The combination of much lower precipitation, higher-than-present summer temperatures and alterations in wind velocities and vectors offer strong evidence to support the presence of multiple loess deposits from different source areas, and the deposits of very poorly sorted slopewash that form substantial parts of Mammoth Meadow fan/terrace. During some of the >11,200-yr interval, there were periods when surfaces were sufficiently stable for soils to form. The modeled climate data indicate that these soils were likely to have formed under conditions of much lower precipitation and much lower winter temperatures than those prevailing now.

**Hair Recovery**

Principles used in soil dispersion (Gee and Bauder, 1986) for many decades were adapted to field conditions and used to enhance the recovery of hair from sediments excavated at the site (Beatty and Bonnichsen, 1994). Both naturally shed human and animal hair were recovered from sediments at several levels in the fan/terrace. Hair offers the possibility of recovering and multiplying DNA for studies of genetic relationships among ancient humans and ancient animals.

**CONCLUSIONS**

From the results given above, and from other data from Mammoth Meadow and other locations in and on the fan/terrace, we have developed the following conclusions regarding site formation processes and results at Mammoth Meadow.

1. High-velocity stream flows deposited coarse, poorly-sorted outwash in the valley of South Fork Everson Creek. Humans occupied the surface and made stone tools from raw materials collected from the stream deposits. They shed hair which has remained to the present time.

2. Fine-textured eolian sediments, with low amounts of total potassium, manganese and zinc relative to overlying sediments, covered the
environments, forces, and processes that existed during the time that humans have used Mammoth Meadow and the entire ECBC site. Our current understanding is a result of integrating data and insights from: archaeology, molecular biology, climatology (including climate modeling), geology (including geomorphology), paleontology, pedology, and other fields of science. It is important to keep this broad-based interdisciplinary approach in mind when considering the contributions of pedology to this ongoing investigation.

Within this context, pedology has:

1) Provided both a conceptual and an operational basis for delineating horizons and other strata in a deep, complex site.

2) Provided a host of relevant chemical analyses that have been important to the process of delineating and characterizing the numerous deposits.

3) Given a basis for identifying and characterizing a series of paleosols that mark intervals of relatively stable, older, buried surfaces. With further analyses of the archaeological record and dating of the paleosols the pedological information may prove extremely useful to understanding the succession of human activities at the site.

4) Jointly with geology, geomorphology, and climatology, pedology has delineated the stratigraphy and developmental processes for the Mammoth Meadow fan/terrace and nearby areas given above.

5) Provided a basis for understanding post-depositional modifications such as leaching of carbonates, development of mottling, and organic matter accumulation patterns in the fan/terrace.

6) Provided a theoretical basis for dispersing sediments excavated at the site for elutriation and screening to recover hair and other organic remains.

7) Helped us to characterize depositional environments including temperatures, moisture regimes and movements, reduction-oxidation regimes, and possible environmental modifications of hair and other organic remains through time.

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Considerations About Fragipans of the Eastern United States

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Identification and use of adequate techniques in the excavation through layers of fragipans during the exploration of archaeological sites is of interest. Fragipans can cause costly delays in exploration programs when they are found unexpectedly. The difficulty of excavation (the "F" factor) can reach a value of 5 or higher when compared with that of a well developed "B" horizon. Development of these layers ranges over a continuum, from incipient to very well developed as functions of age, parent material, moisture regime in the soil and landscape position. Adequate excavation techniques can reduce the difficulty of their removal. Formation of lightly developed fragipans ("F" factor of 2) would represent 2000 to 5000 years. A well-developed fragipan would take 6000 to 10,000 years to develop, and usually should be assigned a factor of 3 or 4 in excavation difficulty. Very well developed ones would take more than 10,000 years to develop, their excavation difficulty is over 5, and usually requires a pickax.

Factors that should alert to the probable existence of an incipient to moderately developed fragipan are: strong, coarse prismatic structure; high density; silty clay texture; mottles; extremely firm consistence (under thumb and finger pressure at conditions between dryness and field moisture capacity); pH between 6.5 and 6.8, indicative that the firmness is not due to the presence of carbonates (Table 2).

DEFINITION AND CHARACTERIZATION OF FRAGIPANS

Fragipans are part of a family of indurated soils (Table 1). Induration can develop a long time after the parent material has been emplaced. The definition by Buol et al. (1981) indicates that they are: "Subsoil layers of high bulk density, brittle when moist, very hard when dry" and that a fragipan "does not soften on wetting, but can be broken in the hand. Air-dry fragments slake when immersed in water"; it "may qualify as A2, B or C, in toto or in part."

Factors that should alert to the existence of an incipient to moderately developed fragipan are: strong, coarse prismatic structure; high density; silty clay texture; mottles; extremely firm consistence (under thumb and finger pressure at conditions between dryness and field moisture capacity); pH between 6.5 and 6.8, indicative that the firmness is not due to the presence of carbonates (Table 2).

GENETIC ASSOCIATIONS

Fragipans are usually found associated with either of two soil groups:

1). Ultisols: formation of clay in situ [?]; albic and argillic horizons; no carbonates; poor drainage; abundant rainfall, long frost-free seasons. South of glacial border; edges of depressions [?].

2). Spodozols (below spodic horizon): bulk dry density to 1.92 g/cc; silica, Al, or illite, as light reversible cement; very good packing. Vesicular, platy, or prismatic structure. Repeated freezing front through it [?]. Barrier to root growth and water flow.

TABLE 1

The Family of Indurated Soils

1. Hard caliche
2. Plinthite (Fe, O)
3. Siliceous duricrust (Si, O)
4. Tropical "Tosca" (Si, Fe, O)
5. Fragipans

TABLE 2

Characteristics of Fragipans

1. Coarse, prismatic structure
2. High density
3. Silty clay texture
4. Extremely firm consistency
5. pH of 6.5-6.8; low B saturation
6. Mottles, red to grey
7. Red, brown, grey color
AGE, DEVELOPMENT, AND DIFFICULTY OF EXCAVATION OF FRAGIPANS

Development of these layers ranges over a continuum, from incipient to very well developed; as a function of age; parent material; moisture regime in the soil; and landscape position. The difficulty of excavation (the "F" factor) can reach a value of 5 or higher when compared with that of a well developed "B" horizon (John Foss, personal communication; Table 3).

Formation of lightly developed fragipans (soils that crumble easily under light pressure), with "F" factors of 1 to 1-1/2, is estimated to require 1000 to 2000 years in the Eastern United States. Moderately developed fragipans ("F" factor of 2) would represent 2000 to 5000 years. A well-developed fragipan would take 6000 to 10,000 years to develop, and usually should be assigned a factor of 3 or 4 in excavation difficulty. Very well developed ones would take more than 10,000 years to develop, their excavation difficulty is over 5, and it usually requires a pickax. It is important to maintain original moisture levels in the excavation surfaces, as once fragipans become dry they do not reabsorb moisture easily.

Fragipans develop gradually and one may find them at various stages of development, from incipient to very well developed. Sometimes it is necessary to attempt to estimate the time that it will take to carry out archaeological excavations in fragipans. An attempt to break down the continuum into classes that can be differentiated in the field, with the aid of a hand auger is indicated in tabular form below (Table 3). The table is empirical, developed on the basis of experience in the Eastern United States. Data are based on personal communications by John E. Foss, University of Tennessee, Knoxville (1993); William Gardner, Catholic University of America (1993); and Kurt Carr, Pennsylvania State Archeologist (1993). The "F" factor represents the estimated difficulty by ordinary spade and trowel methods, as compared with a well developed "B" horizon of similar thickness.

<table>
<thead>
<tr>
<th>Age (yrs B.P.)</th>
<th>&quot;F&quot; Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000-2000</td>
<td>1-1.5</td>
<td>lightly developed</td>
</tr>
<tr>
<td>2000-5000</td>
<td>2.0-2.5</td>
<td>moderately developed</td>
</tr>
<tr>
<td>5000-10,000</td>
<td>3.0-4.0</td>
<td>well developed</td>
</tr>
<tr>
<td>10,000+</td>
<td>5+</td>
<td>very well developed</td>
</tr>
</tbody>
</table>

FRAGIPANS AND CULTURAL STRATIGRAPHY

The hardness of fragipans may lead investigators to assume that the sediments that compose them are pre-Paleindian in age. In the Eastern United States this would usually mean the end of the excavation. The assumption is not always correct, however, and Table 4 below illustrates this point. It is based on a report by Carbone (1977) on a stratified, Paleoindian-Middle Archaic site (the Fifty site, 44WR50) in which a well developed fragipan was encountered.

Table 5 below, based on Carbone's (1977) report reveals that textural data (i.e., grain size) by itself is not a sufficient criterion to determine where a fragipan exists, or where it would develop. This has some interesting implications in relation to the genesis of these soil horizons.

<table>
<thead>
<tr>
<th>Age Projectile Depth</th>
<th>Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2</td>
<td>6-25</td>
</tr>
<tr>
<td>B2</td>
<td>7-25</td>
</tr>
<tr>
<td>IIIB2t</td>
<td>14-37</td>
</tr>
<tr>
<td>IIIB2t</td>
<td>25-41</td>
</tr>
<tr>
<td>Clovis</td>
<td>32-41</td>
</tr>
<tr>
<td>barren IIIB2t</td>
<td>41-70</td>
</tr>
</tbody>
</table>

Note: x indicates fragipan

<table>
<thead>
<tr>
<th>Depth (inches)</th>
<th>Horizon</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6</td>
<td>Ap</td>
<td>25.8</td>
<td>51.5</td>
<td>19.8</td>
</tr>
<tr>
<td>6-14</td>
<td>B21t</td>
<td>21.7</td>
<td>48.5</td>
<td>26.1</td>
</tr>
<tr>
<td>14-19</td>
<td>B22t</td>
<td>24.5</td>
<td>46.3</td>
<td>26.4</td>
</tr>
<tr>
<td>19-25</td>
<td>B23t</td>
<td>29.7</td>
<td>42.3</td>
<td>27.3</td>
</tr>
<tr>
<td>25-32</td>
<td>IIIB3</td>
<td>34.4</td>
<td>38.7</td>
<td>24.6</td>
</tr>
<tr>
<td>32-41</td>
<td>IIIBx</td>
<td>26.5</td>
<td>40.4</td>
<td>28.7</td>
</tr>
<tr>
<td>41-50</td>
<td>IIIB21t</td>
<td>23.9</td>
<td>41.5</td>
<td>34.6</td>
</tr>
<tr>
<td>50-60</td>
<td>IIIB22t</td>
<td>15.7</td>
<td>41.5</td>
<td>42.8</td>
</tr>
<tr>
<td>60-70</td>
<td>IIIB23t</td>
<td>12.0</td>
<td>40.3</td>
<td>47.7</td>
</tr>
</tbody>
</table>
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The Nahanada site lies on a sandy, washover, and eolian landform within Maine's strike-parallel coastal compartment. Investigation of geologic context, stratigraphy, and geochemistry at the Nahanada site has yielded evidence for long-term, intensive and extensive use of the locality. Ongoing pedological developments affecting the Nahanada site landform have strongly influenced the resultant archaeological record morphology. For example, many cultural features were marked by localized Spodosol soil development, while the widespread E horizon of the buried paleosol had largely been destroyed by multiple human occupations. Other stratigraphic disturbances resulted from a combination of natural and anthropogenic processes. Archaeological remains such as bone, shell-tempered ceramics, and rhyolitic lithics were differentially preserved across the site landform. Despite complex Nahanada site geology and pedology, the archaeological record morphology exhibits Spodosol formation influences on cultural remains similar to those occurring on many other northeastern archaeological sites.

In 1977, avocational archaeologist Dick Doyle informed state authorities about an endangered coastal site (Fig. 1) at Pemaquid Beach in Bristol, Maine (Sanger et al., 1983). Relatively rare seventeenth-century artifacts were rapidly eroding out of a feature at the scarped edge of a probable eolian landform. Alerted to the possibility that this site could conceivably address questions concerning Native American lifeways in the early contact period, a team of University of Maine archaeologists (under the direction of David Sanger) undertook salvage excavations in the early 1980s (Fig. 2). Artifacts that have been retrieved from the Pemaquid Beach locality by collectors and archaeologists date from approximately 5000 yr B.P. to the present. Cultural materials encountered during salvage excavations were attributed to a somewhat more restricted time period (Birnie, n.d.; Bradley, 1980; Petersen, 1992, 1983; Sanger et al., 1983). In addition, archaeological remains recovered included remarkably well-preserved faunal material (Fig. 3) for an apparently acidic, non-shell midden site (Spiess, 1982, 1980). The early 1980s excavations resulted in a National Register of Historic Places designation for the Nahanada site; this site probably marks the locality where early explorer George Weymouth captured Native Americans (including Nahanada) in 1605 and returned with them to England (Sanger et al., 1983).

At the conclusion of the early 1980s salvage excavations, the geoarchaeological context of the Nahanada site appeared somewhat confusing. How did the landform originate? Were archaeological remains recovered during excavations in primary or secondary deposits? What time periods and which cultures are actually represented at the Nahanada site or in the Pemaquid Beach locality? What mechanisms preserved faunal remains in what appears to be a natural forest Spodosol? Native American contact period sites...
FIG. 2. Overview of a 1980s University of Maine archaeological crew excavating on the Nahanada site Paleo-dune. Note scarped edge of landform.

FIG. 3. Deer mandible in 1980s excavation unit S18W43 exemplifying the well-preserved faunal material occasionally excavated from the inflated Unit III (Ab) Paleo-dune context at the Nahanada site.
enabling a glance at seventeenth-century lifeways comprise a critical Maine resource (Grumet, 1992). A key research issue at this coastal site concerns potential for exploring shifts in marine adaptation through time (e.g., Sanger, 1988, 1982; Sanger and Belknap, 1987), particularly changes in adaptive strategies resulting from increasing contact with Europeans. In addition to providing models facilitating assessment of the Nahanada site context, the geoarchaeological processes discussed here also apply to other coastal sites, eolian landforms, Spodosol environments, anthropogenic geochemical research, and the preservation of archaeological materials (Callum, 1994).

The archaeology, geology, and pedology of adjacent landforms (i.e., "the ridge," "terrace/alluvial," and "modern dune/washover" geomorphic units) were contrasted with the Nahanada site "paleo-dune" (Fig. 4) following topographic mapping of the research area (nomencalure assigned on the basis of geomorphic attributes). Geoarchaeological investigation focused on extensive shovel testing of these four geomorphic units in order to examine stratigraphic profiles. Geochemical samples were extracted at 5-cm intervals from over 70 shovel-test columns. Analysis of archived 1987s paleo-dune block excavation records supplemented gathering of new geoarchaeological data. Both recently retrieved (shovel-test columns) and previously curated (block excavation) samples were analyzed for anthropogenic indicators such as pH, qualitative P (phosphate), O.M. (organic matter), CaCO₃ (calcium carbonate), and visible shell. In addition, a limited number of column and feature samples were investigated for exchangeable Ca (calcium), phosphate fractions, and Hg (mercury). Stacking and contrasting transparent overlays of isopoll concentration maps of specific geological and pedological horizons was employed as a method for isolating broad patterns possibly attributable to anthropogenic signature(s). Geoarchaeological isopoll maps were subsequently compared to archaeological data, including artifact distribution, artifact chronology, presence of features, and cultural material preservation.

Pemaquid Beach paleogeographic parameters controlled paleo-dune transformation processes (Callum, 1994; Young et al., 1992). Sandy beaches like the one at Pemaquid are rare (Nelson and Fink, 1980) in Maine's strike-parallel (bedrock strike-aligned valleys accentuated by glacial scouring) coastal compartment (Kelley, 1987). This coastal compartment (Fig. 1) is typically characterized by rocky, jutting headlands that have been stripped of sediment and narrow embayments, where, except for the upper estuaries, few sedimentary sequences have been preserved (Kelley, 1987). Differential erosion of the regional metamorphic bedrock has led to the development of pronounced headlands and embayments that trend parallel to the strike of the regional metamorphosed bedrock. The evolution of Johns Bay in the face of rising sea level (Belknap et al., 1989; Kelley et al., 1992) (Fig. 5) directly relates to the strike-parallel nature of regional bedrock. At Pemaquid Beach, linear bedrock ridges (Fig. 6) have temporarily protected sediments from erosion driven by the rising sea level (Young et al., 1992).

Geomorphology and grain size analysis (Callum, 1994; Hancock, n.d.) suggests that the extant "paleo-dune" was largely built during storm-driven washover episodes operating between 3200 and 2000 yr B.P. Earlier cultural sites may have been located on similar receding landforms lying along the freshwater stream. As people moved incrementally inland in the face of rising sea levels, a type of horizontal site stratification developed (Figure 7). Such postulated former archaeological sites may have been horizontally-stratified on a series of "shingled" landforms (Young et al., 1992). As these former archaeological sites eroded, they supplied lithic artifacts to subaqueous sedimentary deposits in John's Bay. In Pemaquid Beach's swash-aligned system (i.e., characterized by seasonal off-shore to on-shore sediment cycling rather than along-shore transport of sediments), storm overwash episodes may have contributed artifacts to the modern dune/washover with other coarse sediments. By analogy, isolated early artifacts in the central component of the paleo-dune, or resting on the paleosol surface of the paleo-dune, may have also derived from storm-driven overwash episodes.

After approximately 2000 yr B.P., perhaps as the paleo-dune gained in height or the configuration of the beach changed, episodic washover construction of what is now the area of the archaeological site became infrequent. Paleo-dune landform stabilization at this time led to development of a well-expressed Spodosol (Fig. 8: Unit V and lower Unit III), the surface of which was available for human occupation. In the 1600s, the advancing shoreface once again resulted in destabilization of the northeastern end of the paleo-dune. Humans may have accentuated natural eolian activity during this time period by dev egetation (e.g., foot traffic, intentional or accidental fire, firewood gathering) of the paleo-dune scarp. As a result, the Spodosol organic horizon became inflated by a series of thin, laterally limited, white and black eolian lenses (Fig. 8: inflated Unit III and the Unit II lenses) at the northeastern end of the paleo-dune. Pathways for deposition of Unit II (2C) eolian deposition appear bidirectional: dark sediment arrived from a probable eroding site at the scarped edge of the paleo-dune while white, unaltered beach sand was probably supplied by along-shore transport processes. Sandshadows associated with topographic depressions and/or rocks allowed elucidation of eolian sand lens transport directions (Fig. 9). The rest of the paleo-dune maintained a relic landform surface during this time period. Despite their limited lateral extent, eolian lenses (i.e., Unit III [Ab inflated], Unit II [2C] and in lower Unit I) form critical stratigraphic markers at the Nahanada site. Regular
truncations of one or more of Unit II (2C) lenses enabled initial laboratory isolation of features not previously designated during fieldwork (e.g., Fig. 10 and 11). During the 19th and 20th centuries, the scope of eolian activity, driven by further sea-level rise, broadened beyond the northeastern end of the paleo-dune with the widespread deposition of Unit I (Fig. 8).

Presence of stratified, in situ features provided critical time depth to the Nahanada site analyses. These features imply that despite the possible overwash events and eolian activity, the surface of the landform was conducive to human occupation. Types and extent of post-depositional disturbances were assessed by examination of pedological, archaeological, and geological criteria. Many features were marked by localized Spodosol formation (e.g., Feature 36 in Fig. 9 and Feature 29 in Fig. 10). In contrast, the E horizon related to the buried Spodosol was destroyed (e.g., absence of Unit IV in Fig. 8) in heavily occupied areas of the site (e.g., the northeastern end of the paleo-dune). The stratigraphic integrity of Unit II lenses suggests less post-depositional disturbance (e.g., bioturbation, occupational trampling) after deposition of these younger sediments. The existence of cryoturbation and other disturbances which may differentially affect artifact placements meant that feature or stratigraphic assemblages were a preferred data set over isolated artifacts.
FIG. 6. Paleogeography of Johns Bay and Pemaquid Beach at 11,000, 9500, and 5000 yr. B.P. (modified from Young et al., 1992). Long narrow estuaries like Johns Bay are typical of those in the strike-parallel coastal compartment. Note linear bedrock protecting sandy deposits during the latter two time periods.

FIG. 7. Paleogeography of the Nahanada locality from 3200 to 900 yr. B.P. (modified from Young et al., 1992).
Approximately 50 features, general middens, disturbances, and specific loci were identified by means of stratigraphic relationships, localized Spodosol soil development, and cultural material concentrations. Cultural chronology was established by artifact assemblage dating. In situ features ranged from Ceramic Period 2-3 (2150-1350 yr B.P.) to the present. The majority of features date to the third quarter of the seventeenth century. The current Nahanada site comprises only the remaining portion of a formerly more extensive landform (or shingled landforms). The apparent absence of an early 1600s contact presence may be due to erosion of such remains along with earlier prehistoric features, this component may be currently unexcavated, or it may be "archaeologically invisible." The possibility that an early contact presence is yet unexcavated or archaeologically invisible is highly likely. Historic documentation (Bradley, 1980; Sanger et al., 1983) suggests that this locality is indeed the Nahanada site and an overwhelming amount of archaeological evidence does attest to long-term occupation at Pemaquid Beach extending from prehistory into the late contact period. Archaeological invisibility might have easily have resulted if relatively rare, early contact trade items were not deposited in features currently interpreted as late prehistoric. Despite differential preservation of the paleo-dune landform, it is clear that intensive occupations occurred during the 1650-1675 time period, with landform use becoming more sporadic later in time. Cultural activity increases again in the twentieth century.

Cultural affiliation is less clear than geoarchaeological contexts. Earliest occupations are undoubtedly Native American. The intensive 1650-1675 occupations are characterized by presence of domesticated faunal remains, absence of traditional Euro-American structures, and features which appear similar to earlier prehistoric ones. Bradley (1980) concluded that the locality would have been of little use to European colonists, but is nicely situated (i.e., close to the European Fort Pemaquid) for a Native American trading encampment. Nahanada site artifacts from 1650-1675 occupations would be unusual if this were a Euro-American site of that time period. For example, period glass and ceramics, except for beads and pipes, are rare. Pipe stems are largely absent and pipe bowls are mostly decorated types. Most nails have not been clinched. European lithic materials (i.e., flint) have been worked by traditional Native American technology. "Prehistoric" ceramics (CP 6/7, especially...
FIG. 9. Sandshadow evidence from S16W41.5. Note thicker Unit II (2C) white lens in the north side (lee) of a paleo-topographic depression caused by Features 35, 36 and Disturbance 3. Wind is from Grid South (Magnetic SE).
FIG. 10. Features 1 (photo right) and 20 (photo left) do not truncate Unit II (2C) in S17W33.

FIG. 11. Feature 2 truncates Unit (2C) in S17W42.5-43.5.
CP 7) may have been in continuous use during this time, as they are associated with specific features (e.g., Feature 2) dating to the third quarter of the seventeenth century. These third quarter of the seventeenth-century occupations can be safely designated “contact” in the sense that European items were gradually incorporated into an existing Native American culture. As suggested by the proximity of the Nahanada site to the European settlement, existence of European trade goods, and plentiful domesticated faunal remains, close ties were probably maintained with Fort Pemaquid during this time period (cf. DePaoli, 1994). Later feature affiliation is ambiguous. Feature style changed little, and historic evidence suggests continuing use of the locality throughout the eighteenth and nineteenth centuries, perhaps by Native Americans. Modern twentieth-century use is associated with the Bristol Town Beach. Of the uneroded contexts, the preserved portion of the 1650-1675 occupations contributes excellent information regarding Native American adaptation to European colonization during the late contact period.

Early historic remains were largely distributed along the scarped edge of the paleo-dune, with a strong focus at the northeastern end of the landform (Fig. 12). All archaeological materials reside in variable geochemical contexts. Across the paleo-dune landform, pH varies dramatically from 3.7 to 7.3. Comparison to other geomorphic units in the research area shows that Spodosol pH is ordinarily acidic (e.g., Hedstrom, 1987). In the buried Spodosol B horizon (Unit V) multiple cultural occupations increased pH to 6.8, or almost neutral, especially at the northeastern end of the paleo-dune (Fig. 13). The %O.M. by LOI (loss-on-ignition) also ranges widely, but artifacts are associated with minimal O.M.. Minimal %O.M. in cultural areas suggests that human activities disturbed the natural forest organic horizon. This conclusion confirms the interpretation based on the absence of a general E horizon. Qualitative P tests (by a modification of methodology proposed by Eidt, 1984) exhibit high, widespread P in the illuvial Unit V (Bb) horizon (Fig. 14) but variable patterns in overlying horizons (e.g., Fig. 15: Unit I or 1C). Phosphate is tightly bound in Spodosols, making it a reliable long-lived indicator. Thus, widespread, shifting qualitative P anomalies through various horizons indicate the long-term, variable utilization of the entire landform throughout prehistoric or historic times. The conspicuous macro-environmental shifts in geochemistry marked by almost neutral pH, minimal O.M., and high P appear related to the intensive 1650-1675 occupation. Subtle anthropogenic geochemistry, characterized solely by P anomalies in the B horizon, are probably associated with prehistoric occupations. In this dynamic system, immediate geochemical effects of cultural occupation (e.g., easily decomposed waste like fire-hearth ash, food-processing) quickly achieved equilibrium. During an intermediate time period, dissolution of more basic-rich archaeological materials (e.g., shell, shell-tempered ceramics, rhyolitic lithics, bone) steadily contributed Ca to site sediments. Over longer time periods, after sources of Ca abated and site sediment geochemistry once again largely achieved equilibrium, only traces of P-rich materials (e.g., bone) remained as an anthropogenic marker.

Because this was a multi-occupational site, P fractionation (cf. Eidt, 1984; Lillios, 1992) was a useful anthropogenic and antiquity indicator. Other anthropogenic indicators (e.g., qualitative P, O.M. by LOI, and exchangeable Ca) provided additional information, although a more quantitative method of determining P is recommended for future investigations (e.g., Bethell and Mate, 1989). Determination of Ca by LOI was also not as successful as hoped and other methods are recommended. Geochemical indicator analyses did serve to confirm most hypotheses generated during other geoarchaeological research (e.g., localized spodic development associated with features). Several new directions for geoarchaeological research were suggested; geochemistry has proven invaluable at the Nahanada site.

Most significantly, geochemical results demonstrated that the preservational context at the Nahanada site varied dramatically within a few centimeters vertically and over a few meters (m) laterally. For example, analyses showed that bone, rhyolitic lithics, and shell-tempered ceramics, despite almost neutral pH in places, were best preserved in limited feature microenvironments. Existence of anthropogenic shell lenses appeared especially critical. Of unburned bone in equivalent pH situations, the relatively young seventeenth-century bone was better preserved than prehistoric counterparts. Thus, seasonality studies (i.e., Hancock, 1982; Spiess, 1980) at the Nahanada site have largely focused on faunal material (e.g., bones and shell) associated with the third quarter of the seventeenth-century occupations. Depending on interaction between pH, bone antiquity, and perhaps bone density factors (e.g., Knight, 1985), the Nahanada site faunal record actually consisted of a few well-preserved elements (e.g., Fig. 3) in a background of diagenetically altered fragments. Determination of the nature of marine adaptation in this type of multicomponent, taphonomically altered faunal record could prove problematic. Attempt at analysis of mercury as an indicator of cultural focus on aquatic ecosystems yielded ambiguous results. More conclusive work on the potential of Hg as an anthropogenic indicator is required. In order to determine the nature of cultural adaptation to marine ecosystems versus emphasis on terrestrial or domesticated species at the Nahanada site, the faunal record itself should be synthesized. This geoarchaeological research has demonstrated that archaeological materials have been subjected to differential geochemical processes that varied across the paleo-dune landform through time. Further analyses of the
FIG. 12. Presence (1)/absence (0) isopoll map of distribution of early historic artifacts on the paleo-dune. Note concentration to the northeast end of the paleo-dune.

FIG. 13. Isopoll map of pH the paleo-dune Unit V (Bb) horizon. Note higher pH readings to the northeast end of the paleo-dune.
FIG. 14. Qualitative P isopoll map of paleo-dune Unit V (Bb) horizon. Note widespread, high P values over the entire landform.

FIG. 15. Qualitative P isopoll map of paleo-dune Unit I (1C) horizon. In contrast to Figure 14, note variable P values across the landform.
resultant archaeological record morphology at the Nahanada site should emphasize differential geographical environments, stratified feature contexts, and variable anthropogenic chemistry.

Despite complex geoastronomical contexts, this endangered coastal landform affords a unique look at Native American lifeways, especially during the third quarter of the seventeenth century (and possibly of yet unexcavated earlier contact period assemblages). Refinement of knowledge concerning the early contact period at the Nahanada site awaits secure dating of feature and geoarchaeological contexts, possible future assemblage or geochemical techniques (e.g., phosphate investigation of this significant site.

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A Conceptual Methodology for Studying the Geoarchaeology of Fluvial Systems

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This paper presents a methodology for studying the geoarchaeology of fluvial systems. It is called geoarchaeology because it is an approach to the past that focuses upon the geomorphological context of artifacts (Gladfelter, 1981, 345) and it applies geological principles and techniques to the solution of archaeological problems (Rapp and Gifford, 1989) relating to fluvial processes. Its application to fluvial systems in two different geomorphic environments, the Oklawaha River in Florida and the Earn River valley in Scotland will be considered. In these different environmental settings, the geoarchaeological approach makes use of different kinds of evidence available to it. Geomorphology and soil related evidence are most effective and applicable tools for integrating with traditional forms of archaeological research in fluvial systems everywhere.

Geoarchaeology, the approach advocated here for studying fluvial systems, can be applied to any fluvially associated landscape. From the Oklawaha River Survey in Florida, there is evidence to suggest that site distribution and density patterns will be altered by inclusion of archaeological data derived from this approach. As you read this paper, consider the potential for sites of this nature in your own research areas. Through conceptualization and application of this approach to the geoarchaeology of fluvial systems, the arbitrary land/water interface can effectively be erased from research areas and rivers can be viewed not as permanent and unmoving barriers, but as significant and dynamic components of the archaeological landscape.

WHY FLUVIAL ENVIRONMENTS?

In 1990, 90 percent of the world's population was living on 10 percent of its landmass. That 10 percent landmass primarily consists of riverine and coastal environments. There is a high probability, therefore, that fluvial systems will contain a large proportion of the archaeological record. However, we must consider whether prehistoric and historic peoples' interaction in river environments has been consistent with modern usage of river systems. For this purpose, we are assuming that modern (and past) human interaction in fluvial systems is based upon our biological need for fresh water, the ecosystem's rich natural resources, its greater agricultural potential and more efficient means of transportation (see Johnstone, 1980; McGrail, 1987 Milanch and Fairbanks, 1980; Webb and Martin, 1974).

Rivers also enhance the fertility of the earth as they move across and through its surface. Through the equally destructive processes of lateral migration and vertical accretion, rivers provide natural forms of erosion or excavation. Their reaches spread across the terrestrial landscape like branches of a tree. In this form, running water is the most important of all the processes that fashion the landscape (Judson, 1982). However, a fluvial system's ability to affect archaeological sites and to influence the ways in which their distribution and density patterns are interpreted in the landscape are perhaps not so well recognized by archaeologists.

When considering archaeological sites in fluvial settings, it is necessary to understand the natural processes at work before attempting to locate, record, and interpret archaeological sites within them. These are complex systems with varying degrees of dependence on too many geomorphological and ecological factors to describe in this brief paper (see Gregory, 1987; Schumm, 1977; Selby, 1985). The critical and immediate variables affecting fluvial landscape development, however, are ground cover, runoff and sediment supply. The ultimate variables are climate and human intervention (Butzer, 1971).

THE APPROACH

A geoarchaeological methodology provides the appropriate format for understanding the dynamics of fluvial processes on archaeological sites. Geoarchaeologists are concerned with the relationship between the geological setting of a region and settlement location, the nature of the site-forming processes, the recognition of activity areas in archaeological sites, the role played by geological processes in distorting or preserving that archaeological record, and the dynamic relationship between people and the earth (Hassen, 1979, 267). Rather than a repertoire of techniques, geoarchaeology is first and foremost a conceptual approach (Butzer, 1982, 36).

The approach presented in this paper is a five step process. When considering a river basin for archaeological analysis, begin by obtaining information
on the geology of the region, both solid and drift. It is necessary to determine what are the primary geomorphic processes creating the soils and the landscape and therefore affecting the archaeological sites contained therein. If these are processes which are not familiar to you, go back and relearn the basic principles of geology concerned with these unfamiliar processes. For instance, the glaciated landscape of Scotland was utterly foreign to me, an untravelled native Floridian born on a Miocene beach ridge. I was required to relearn basic geological theory about glaciation and its effect on the landscape. Geologic and geomorphologic information will assist the archaeologist’s understanding of parent materials, origin of soils and landforms in the basin and in archaeological contexts.

The second step requires analysis of the existing body of data available from government agencies on the archaeological resources previously known in the study area. This is not always as straightforward as it might seem. There are many factors affecting the quality and usefulness of preexisting archaeological databases—standardization of terminology among users, change in database function through time, change in our interpretation of a region’s cultural history over time, and inconsistent reports, to name a few. Bias in the data collection strategies can also be potentially difficult to overcome. At a minimum, these problems must be identified and corrected, where possible.

Other sources of evidence for archaeological information can also be sought at this stage including but not limited to academic literature searches, oral interviews, and historical documentation. As with the geology in step one, if the cultural history of the area under investigation is unfamiliar, seek the basic and accepted archaeological information available on the populations inhabiting the river basin through time.

Integration of the first two steps begins in step three. Once a database of archaeological site types and their attributes is obtained for the research basin, step three involves generation of a project archaeological database corrected from the source database for inconsistencies and nonstandard terminology and expanded to include relevant geomorphological fields such as soils, vegetation, and landform. Oftentimes, in archaeological databases where these fields already exist, archaeologists incorrectly use terms from the natural sciences. This can be overcome by adopting natural science standards in these fields and assigning each archaeological site in the database with the correct geomorphic information available from the natural science sources.

Once the database is in order and step three is complete, the researcher must query the database regarding the relationship of sites to soils and landforms, and look for any other outstanding relationships that begin to emerge from the data. In step four, the very nature of the preexisting database and its biases may seem to create relationships that may or may not exist. Future research might be aimed at determining the precise nature of those relationships. But one point should become clear in step four—there is value in understanding the natural and physical geomorphic processes of fluvial activity in river basin research. It highlights the gaps that exist in the archaeological record of river basins and establishes possible relationships between sites and associated landforms or geomorphologies.

At this point, given that each river will have a different geology, cultural history, and archaeological database, there are numerous forms of evidence that will begin to emerge. The task in step four is to remain flexible enough within the approach to recognize the differing forms of evidence that do emerge and to follow those up in future research. The evidence will lead you in different directions depending upon the parameters established in steps one through three. Examination of the two case studies will illustrate this feature of the approach and will be discussed more fully in the conclusion.

In the fifth and final stage, field projects are developed and executed in the river basin to test hypothesis generated from the desk-based research described in steps one through four. It is likely that initial survey work will be needed to identify and record previously unrecorded sites in submerged and frequently flooded portions of the river system. These surveys are necessary in order to obtain data on actively eroding archaeological sites and to augment the conventional forms of survey traditionally undertaken on higher elevations of well-drained soils.

Future excavation or research projects on specific sites within a fluvial system will require interdisciplinary teams of coordinated researchers to grasp the site’s full potential. Geoarchaeological project directors must be conscious of the demands of multidisciplinary research. Interdisciplinary teams require good communication skills among members, pre-planning stages that allow effective exchange of project needs and individual objectives, and adequate report dissemination after the project is complete. Although demanding, the results of such research is potentially beneficial to all concerned.

**THE CASE STUDIES**

Application of the approach to contrasting fluvial systems in the Oklawaha and Earn Rivers of Florida and Scotland, respectively, will serve as our case studies (Figs. 1 and 2). First, each system’s predominant geomorphologic character and climatic conditions are described. The approach next allows for the inclusion of pre-existing archaeological data into the developing geomorphological framework. Finally, application of the geoarchaeological approach upon fluvial systems with different geologies, land-use
FIG. 1. Map of Florida, showing the St. Johns River and its tributary, the Oklawaha, and significant archaeological sites.

FIG. 2. The Tay River and Earn River valleys of Scotland.
histories and archaeological databases provides a broad range of geoarchaeological evidence. When working in different fluvial systems, a multidisciplinary approach such as geoarchaeology is well suited to cope with the varied forms of evidence encountered. I now illustrate the application of the geoarchaeological approach by describing studies of the Earn and Oklawaha Rivers.

The Florida Example: The Oklawaha River Survey (ORS)

A large portion of the southeastern United States is underlain by a porous limestone formation from the Eocene known as the Floridan aquifer (Lane, 1986). Chemical and physical weathering of this marine succession results in karstic topography which characterizes Florida and its coastline. Florida emerged from the sea during the Eocene and was formed as a lateral series of beach ridges running parallel to the sea margin (White, 1970). As a result, soils in Florida are composed of 90% sand fraction. Along its 483-km course, the St. Johns River changes in elevation by only 8.2 m (27 ft) giving it one of the flattest river catchments in the world (FDNR, 1989).

Florida's climate is classified as humid subtropic. Due to its location on the eastern shore of the North American continent, winters are mild (coldest month 2-10°C), summers hot (warmest months 23-30°C), with a long growing season of 7 to 12 months. There is no snow cover although moisture is abundant all year round particularly during the summer months.

There are many ways of locating archaeological sites in Florida's fluvial systems, some of which are traceable from research in other areas of North America. In New Mexico, for example, there is evidence to suggest a strong positive correlation between well-drained soils in close proximity to water and the existence of archaeological sites (Wood, 1978). In Florida, location of archaeological sites in fluvial settings can be similarly related to specific well-drained soils more easily identified by their corresponding vegetation (SWCS, 1989).

Another potential source of evidence rather more unique for locating sites in Florida's fluvial environments is river diver information. Sport divers have been entering Florida rivers to collect archaeological and palaeontological material since the 1960s. After thirty years of observation, without much recording of finds, river divers are now cooperating with professionals and providing information about the impact of fluvial activity on archaeological sites (Denson and Dunbar, 1992).

In Florida's fluvial systems, the issue has been to determine how changing sea levels and river shifts might have affected archaeological sites and their distribution and density patterns in the landscape. Another concern is how to identify sites that have been affected by such shifts and those that might be affected in the future. In 1991, the Oklawaha River Survey was initiated as a pilot project to answer these questions (Denson, 1992). A 15-km portion of the Oklawaha River was selected for underwater survey although the original terrestrial study area comprised a 31-km contiguous river segment. The crew consisted of six underwater field archaeologists, a consulting soil scientist, an archaeobotanical specialist, a palaeontologist, a conservator, and a host of volunteers with wide-ranging skills and abilities.

The pilot project apportioned the river into 18 one-half-mile sectors. Within each sector, three units were visually inspected using underwater archaeological survey techniques designed by archaeologists in cooperation with river divers to meet the local river diving conditions. Two eroding river margins and one straight section connecting two meanders (to act as a control) were inspected in each sector. Once an eroding unit or a "straightaway" had been selected for inspection, a subsurface reconnaissance of the river channel was carried out.

Using this method of survey, 11 new sites were discovered during the three-week field survey (Fig. 3). When cultural materials or bone beds were located, the diving survey team released a buoy to the surface and followed the scatter along the river bed. At the upstream terminus of any such scatter, a 5-m-square grid was placed using pre-set 5-m lines to ease the problem of setting a 5 x 5-m grid squarely in low visibility diving conditions. In cases where the scatter exceeded the 5 x 5-m grid area, a baseline was appropriately positioned to allow collection along either side of the baseline in meter units.

At most sites, surface collection was the accepted collection strategy. However, hand fanning to a depth no greater than 20 cm was utilized in some cases. Terrestrial test pits were placed along the river margins where dry ground lay parallel to an underwater site to determine the distribution of materials across the land/water interface. Likewise, when land crews identified terrestrial sites through surface inspection of land parallel to the river, an underwater survey of the associated river bottom was undertaken.

Soil samples were taken in areas both wet and dry to aid in determining the geomorphological processes affecting the Oklawaha River landscape and in reconstructing its depositional environment. Post-survey soil analysis for particle size, pH, organic carbon and total phosphorus were employed to identify human activity as well as geomorphic ones. Changes in parent materials were associated with buried land surfaces indicating periods of downslope migration of sediments and archaeological deposits into the low-lying areas adjacent to the high bluffs. Total phosphorus was a useful indicator of the original range and extent of prehistoric shell mounds that had been partially eroded by river migration.
FIG. 3. Oklawaha River study area, showing sites identified during river survey.
Ten of the 11 newly recorded sites were located in the eroding margins of the river. One site located in a straight section connecting two meanders was uncovered by deflected current from a fallen tree across the river's course. Evidence from river divers and observations made during the pilot project have suggested that the majority of destruction to archaeological sites in the study area occurs on the outer bends of meanders, where erosion of the terrestrial landscape is the greatest.

Prior to the fieldwork, assessment of the previously known archaeological sites in the 19 mile study area showed that 54 sites were recorded in the State's archaeological master site file. The Master Site File indicated that the majority were prehistoric and characterized as lithic scatters, artifact scatters, middens, and mounds. The pre-1970s surveys emphasized prehistoric sites, particularly middens, mounds, and lithic scatters. The post-1970s pattern of recorded sites shifted toward historic refuse and artifact scatter sites as well as industrial and special purpose sites such as moonshine stills and turpentine stations. This may be, in part, attributed to the developing impact-oriented nature of government policy on archaeological survey of federal lands (Denson and Ellis, 1991).

A pilot project database was set up to include not only information on the site type and cultural components, but also geophysical data, associated soil seres, landform and physiography for each site in the study area. The additional geo-data are not systematically included in the Master Site File nor are they standardized when they do appear (Denson and Ellis, 1992). However, they are included here because they constitute a form of evidence which comes to light when utilizing a geoarchaeological approach to locating archaeological sites in fluvioglacial systems.

Sites situated in terra ciea muck, a highly decomposed, organic soil usually associated with wet or moist low energy environments were useful to examine because they offer good preservation of archaeological material and indicate some association with the river's past regime. Only eleven such sites were known prior to the ORS. During the underwater survey, an additional 6 were discovered, realizing a sixty percent increase in prehistoric sites identified in terra ciea muck.

By cultural affiliation, one-half of the newly recorded sites were prehistoric and the other 50 percent were multicomponent sites. If the results are weighted for the shorter length of river surveyed (15 km; 11 sites) compared with the total terrestrial study area length (31 km; 54 sites), then it is estimated that 40.7% more sites could have been identified in the Oklawaha River study area than had been previously discovered by conventional survey methods alone.

The Scotland Example: The Earn River Valley

The predominant geomorphologic activity which affected the Scottish landscape was glaciation during the Pleistocene. Scotland's climate is humid temperate and it displays more seasonality than that of Florida. Moreover, located on the western margin of the European continent in a maritime context, its winters are cool (coldest month 2-10° C), summers are warm (warmest month 15-19° C), and the growing season lasts five to ten months. In the Earn Valley, there is snow fall but no durable cover. The boreal forest soils of Scotland are dominated by chemical weathering although frost weathering and freeze-thaw processes act to open up the rock bodies.

The Earn River is situated in the Midland Valley, an ancient rift valley or graben bounded to the north by the Highland Boundary Fault and to the south by the Southern Upland Fault (Cameron and Stephenson, 1985). The basin was established in the Tertiary and overlies Upper and Lower Devonian sandstones bounded on either side by abruptly rising volcanic hills composed of andesitic and basaltic lavas and pyroclastic rocks. Pleistocene glaciations, however, eroded the bedrock and deposited tills and marine sediments of sand, silt and clay (Armstrong et al., 1985).

The Midland Valley was free from ice shortly after 13,000 B.P. when fluvioglacial activity in the area declined. Relative sea-level studies since deglaciation have been extensively undertaken in the Forth and Tay valleys (see Browne, 1980; Cullingford et al., 1980; Morrison et al., 1981; Paterson et al., 1981; Sissons et al., 1965). The most obvious Late-Glacial shoreline is the Main Perth Shoreline dating to 13,500 yr B.P. Other late glacial shorelines have been identified by Cullingford (1977) and termed the Lower Perth shorelines. The formation of these raised shorelines is best viewed in terms of an interplay between isostatic uplift and eustatic rise of sea level, major shorelines having been formed when the latter kept pace with the former. Cullingford (1977, 31) has estimated total uplift in the Earn Valley since deglaciation to be an astonishing 90-95 m.

There are remnants of later shorelines in the Earn Valley as well. The High, Main and Low Buried beaches are associated with a rather quick series of sea-level changes spanning the Late Glacial into the Post-Glacial period. During the Flandrian, evidence of terracing occurs in the estuarine deposits with subaereal peat beds resulting from variable sea levels between 9,000-7000 yr BP. Overlying the Sub-Carse Peat is a estuarine deposit of Carse Clay associated with rising sea levels.

There are many forms of evidence to aid in location of archaeological sites in fluvioglacial environments like the Earn River Valley in Scotland. Historic maps provide one source. Physical comparison of the first series Ordnance Survey maps produced in 1866 with more recent O.S. maps were used to locate and identify meandering river courses in the Scottish landscape. The Earn River, a lower tributary of the River Tay, was
selected due to its meandering nature identified in early historic maps. Some meanders were shown to migrate between 30.5 and 91 km downstream in the last century.

The Earn study area is defined as that portion of the Earn River valley from Creiff to its confluence with the River Tay, approximately 61 km. The most prominent course changes, however, have occurred east of Dunning, the point identified by Cullingford (1977) but disputed by Browne (1980) on where the ice margin lay in the Earn valley while the Main Perth Shoreline was forming.

Another source of evidence for archaeological sites in the Earn River valley was supplied by the National Monuments Record Office (NMR), a department of the Royal Commission on Ancient and Historic Monuments of Scotland. It maintains the archaeological data presently known in all of Scotland including the Earn study area. The location and description fields were lifted directly from the 206 NMR files relating to known sites.

Additional fields were added to the database to account for the observations made in Florida concerning erosion and its affect on archaeological deposits. An indicator field was used to define whether the site was indicative of where the river had been in the past. For instance, all river finds described as such were indicated true for position of the river in the past. All sites relevant to river activity, like bridges, harbours and quays were also indicated true.

The most intriguing site type marked true as indicators of erosion were sites clearly missing portions of their features as a direct result of river action. This was the case, in particular with the Roman camps of approximate known dates which were once rectangular in plan and are now missing parts of their circuits due to the process of fluvial erosion or lateral migration of the river’s channel (Fig. 4).

In addition to the NMR fields and the subjective fields indicating fluvial erosion activity, two soil fields were created. In the Earn River valley, it was useful to distinguish parent materials between the fluvial terrace formations and the fluvioglacial deposits. This was an effective form of evidence for discovering relationships between the soils, the terraces and the archaeological sites previously known in the Earn study area.

The last field was marked for aerial photography and was added to the archaeological database only after it became apparent that sites known from aerial photography comprised greater than 50% of the archaeological record kept by the NMR. This form of archaeological evidence was abundant in the Scottish environment. One-hundred-ten out of 206 sites were identified by aerial photography alone in the Earn study area. Of those 206 known sites, 58 were identified in the modern floodplain, 8 in the first terrace, 71 in the second terrace deposits, 15 in the fluvioglacial terraces and moraine deposits, 29 in the Old Red Sandstone tills, and 25 in tills derived from igneous rocks.

Interestingly, 73% of all sites identified by aerial photography only were located in the second terrace deposit. I am not certain why this bias in the archaeological record occurs. Is it based on the differential effectiveness of aerial photography in soils of varying moisture content? Are aerial survey crews concentrating on these deposits because they get the best results there? Or is this pattern an accurate representation of site location strategy in the Earn River valley’s archaeological record? More work is needed to investigate these, as yet, unanswered questions.
CONCLUSION

That the geoarchaeological approach can be applied with good success to fluvial systems in regions as diverse as Florida and Scotland exemplifies its flexibility as a conceptual methodology. It allows different types of evidence to be used for predicting the locations of archaeological sites within fluvial landscapes as well as the processes that affect them. Initially, similar categories of evidence, for instance, the geology, archaeology, and history are considered for each area.

In Florida, the karstic nature of the topography and the predominance of sand-size particles makes specific soil types and their corresponding vegetation useable as indicators of river shift (i.e., terra ceia muck) or of the potential presence of archaeological sites (i.e., well-drained soils in good proximity to water). This represents a form of evidence identified in Florida by application of geoarchaeology to the archaeology of its fluvial system. Additional and complementary forms of evidence come from examination of preexisting archaeological information supplied from the State's Master Site File office on known sites in the study area. Biases can be identified and possibly linked to compliance-based archaeological surveys on federally owned lands, in this instance.

River diver information, a regionally specific form of evidence used for locating archaeological sites, is characteristic of the Florida example. From this information source, actively eroding river margins were identified through a survey that was designed and successfully carried out to locate and record affected sites. The nature and rates of erosion affecting these archaeological sites in the Oklawaha River are now being identified and quantified. A working hypothesis on the effect of river erosion on archaeological sites has been developed and future investigations will continue to collect data on geomorphic processes affecting sites and to identify any new forms of evidence that arise from this methodology.

There are drawbacks associated with the application of geoarchaeology to fluvial systems. First, because of its multidisciplinary nature, organizing and mounting an appropriate project crew can be both expensive and difficult. No single archaeologist can be expected to make multidisciplinary field observations as sufficiently as a selected team of professional researchers. Thus, this approach is heavily dependent on multidisciplinary teams. Likewise, the most difficult part of any multidisciplinary project is establishing and maintaining communication and interaction among the different players throughout the planning, development and implementation stages. First, the archaeologist's goals and objectives must be communicated to the other researchers in a timely fashion so that an effective research design can be created and carried out with the utmost of financial efficiency and feedback. Input from all disciplines at the planning stage should improve the effectiveness of the project and the quality of the archaeological data extracted during the field work.

In Scotland, the glaciated landscape and resulting isostatic uplift of the land and eustatic effects of the sea dictate that more work is needed in the Earn valley before any field work can commence. Future work in the Earn River valley will be directed at quantifying the rate of erosion at the eroding Roman sites using the full range of evidence available. Further geomorphic data including soils and terracing along with archaeological data from other historic maps, such as Roy's Map, and aerial photos, terrestrial surveys, and river finds will further be considered. It is anticipated that some underwater survey utilizing geophysical methods of investigation combined with visual survey techniques, similar to those carried out in the Oklawaha River, will be developed and implemented.

Extensive terracing and deposition of marine and estuarine sediments in the Earn valley during the Late Devensian and Flandrian demands that these processes and resulting landforms be identified and understood before attempting any interpretation of site distribution and density patterns in the Earn valley's archaeological record. The Florida example has proved that careful examination of a fluvial system and the archaeological sites they may contain can change our knowledge about its past and the human activity taking place within the fluvial landscape. Geoarchaeology is presented in this paper as a most effective methodology, although costly and not without drawbacks, for studying the archaeology of fluvial systems.

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Application of the Newly Developed OCR Dating Procedure in Pedo-Archaeological Studies

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The Archaeology Consulting Team has developed a new dating procedure based on the biochemical degradation of organic carbon. This procedure, termed the "Oxidizable Carbon Ratio" or OCR, produces age estimates comparable to 14C age estimates. The OCR and 14C age estimating procedures are compared demonstrating the applicability of the OCR procedure for dating archaeological features. Originally the OCR procedure was developed to provide age estimates for archaeological cultural features containing charcoal. Ongoing research by the Archaeology Consulting Team demonstrates a broader application for this procedure. The OCR procedure is used to determine forest fire sequences and probable forest community composition, and to establish the age of buriedPaleosols and former riverbank surfaces.

THE OCR PROCEDURE

The interdependent dynamics of climate, biota, relief, parent material, and time affect the evolution of soils (Jenny, 1941) and archaeological materials within the soil. Chemical analyses of archaeological charcoal deposits (i.e., cooking hearths, refuse pits, and post molds) demonstrate that charcoal is also subject to environmental degradation, and changes through time (Frink, 1992). The "Oxidizable Carbon Ratio," or OCR procedure, describes this change by simple chemical carbon analyses. These analyses determine the ratio of total carbon to readily oxidizable carbon, and environmental factors influencing the rate of biochemical degradation of the charcoal.

Rainfall and temperature affect soil development. Soil pH decreases with increased rainfall, indicating that the extent of leaching and organic decomposition decreases. Concurrently, the depth to leached carbonates in the soil increases. Nitrogen content increases, indicating the degree of organic decomposition in the soil. Clay content increases, reflecting the leaching and mineral decomposition in the soil (Jenny, 1941). In addition, for every 10° C rise in temperature, the rate of chemical reactions increases by a factor of 2 to 3 (Van't Hoff, 1884).

Soil depth and texture affect the rate of oxygen diffusion into the soil, and thus the growth rate and depth of root development (Stolzy et al., 1961). As the depth increases, oxygen and root growth decrease. Coarse-textured soils have a higher rate of oxygen diffusion, with a corresponding increase in the rate and depth of root growth.

Nutrients available to plants and soil microorganisms are at first dependent on the parent material, but influenced by the biological community (Jenny, 1958). Soil pH affects both chemical and biological processes in the soil. And, the factor of time affects the rate and the duration of biochemical processes (Jenny, 1941).

METHODS

Soil samples of at least 100 g are air dried prior to analyses. The samples should be air dried as soon after excavation as possible to arrest biochemical activity.

Soil texture is determined by dry screening, with the mean texture calculated by the percent weight of each fraction as determined by USDA standard mesh screen sizes. Arbitrary values ranging from 1 (clay) through 7 (very coarse sand) are assigned to each soil fraction, and the mean average weight is calculated for each sample. Soil pH is determined from a 1:1 soil:water paste. The total carbon is determined by the Ball Loss on Ignition procedure (Ball, 1964), and the readily oxidizable carbon is determined by the Walkley-Black wet combustion procedure (Walkley, 1935; Walkley and Black, 1934). As the object of analysis is charcoal, the results of the carbon analyses are not converted to their equivalent organic matter.

Data for the mean annual temperature and rainfall are based on National Oceanic and Atmospheric Administration (NOAA) Narrative Summaries for the period of 1941 to 1975 (Ruffner, 1978). The mean annual rainfall is expressed in centimeters per year, and the mean annual temperature is expressed in degrees Fahrenheit. The Fahrenheit scale is employed to accommodate pergelic and cryic soils, where mean temperature expressed in degrees centigrade would require negative numbers, needlessly complicating the computations.

Other factors affecting the oxidizability of the carbonized organic matter, as yet unidentified, are subsumed within a calculated factor determined by the following formula:
Solving this equation for TIME, expressed as OCRDATE, yields a formula for calculating an age estimate of the carbonized organic matter.

\[
\text{OCRDATE} = \frac{\text{OCR} \times \text{DEPTH} \times \text{MEAN TEMP.} \times \text{MEAN RAINFALL}}{\text{MEAN TEXTURE} \times (\text{P}\mathbf{H})^{1/2} \times (\%\text{CARBON})^{1/2} \times \text{TIME}}
\]

The dynamic systems formula provides a means of measuring the site specific rate of biochemical decay of charcoal in terms of its chronometric age. Thus, the OCR is a new method to interpret change in charcoal, and provides accurate and precise age estimate of the charcoal.

The Current Database

While most of the current OCR data comes from samples obtained in New England, archaeological charcoal samples from New York, Pennsylvania, Ohio, West Virginia, and from the country of Somalia in East Africa are included in the OCR database (Fig. 1). The samples in this database represent a wide range of climatic settings including semiarid to subartic, and a variety of landforms including stratified riverbanks, open-air surface, and sub-plow zones. The samples cover a time span ranging from one year to 14,000 years ago. The OCR procedure accounts for site specific environmental factors of temperature, rainfall, carbon concentration, depth below surface, soil reactivity (pH), soil texture, and time.

Excluding samples affected by improper storage conditions, the OCRDATE age estimates demonstrate a strong correlation \((r = 0.98, \text{s.e.} = 0.03)\) with documented events and 14C age estimates (Frink, 1994) (Fig. 2). A similar correlation is evident between the OCRDATE age estimate and the expected age of samples based entirely on temporally diagnostic cultural artifacts (Fig. 3). Accurate and precise age estimates evident in this database demonstrate the successful application of the OCR procedure (Frink, 1992, 1994, 1995).

**COMPARING THE OCRDATE AND RADIOCARBON AGE ESTIMATE PROCEDURES FOR ARCHAEOLOGICAL FEATURES**

The Archaeology Consulting Team developed the OCR procedure to analyze charcoal within a biochemically active, aerobic soil context. Radiocarbon dating procedures measure the isotopic ratio of a wide range of carbon-containing material within various contexts. The environmental context of a carbon sample may introduce certain errors influencing the interpretability of the radiocarbon date estimate. However, specific environmental conditions must be met before the results of the OCR procedure are valid. The principal assumption behind the OCR procedure is that the phenomena being measured are oxygen dependent biochemical processes in soil that cause a change in the relative oxidizability of the charcoal carbon. Deep riverine soils, which undergo multiple episodes of reduction and oxidation due to fluctuating water table levels, have been shown to severely affect the OCR procedure. Environmental barriers to oxygen diffusion in the soil, such as large capping stones or pavement, and barriers to solar radiation and rainfall, such as rock shelters, have an incalculable effect on the rate of biochemical change on the charcoal carbon.

The relative accuracy and precision of radiocarbon date estimates are the product of a number of factors, including the recent phenomena of the Suess and Atomic Bomb Effects. In combination with the de Vries Effect, which has been particularly pronounced since the mid-seventeenth century, these factors render radiocarbon date estimates of recent events virtually meaningless. Statistically, radiocarbon date estimates of 300 years or less before present are reported simply as "modern" (Taylor, 1987).

The relative precision of the OCRDATE estimate is statistically linear. The estimated error for the OCRDATE estimate is 3%. For example, the expected precision of the OCRDATE estimate from a 100-year-old fire is ±3 years, whereas the precision for a sample 10,000 years old is ±300 years. The precision of the OCR procedure with recent samples makes the OCR procedure more appropriate than radiocarbon dating for use on late Native American and all European American sites.

The two procedures also differ in terms of the relationship between the sample being analyzed and the specific event being dated. This relationship is commonly referred to as the "presample-growth error." Radiocarbon analysis measures the date of 14C absorption by a living organism. The specific event that the archaeologist seeks to date is the carbonization of wood during its use. The average life span of tree species generally range from less than 100 years to over 400 years. Thus, the "presample-growth error" could be several hundred years. In most archaeological features, the excavated sample consists of many small pieces of charcoal representing several pieces of wood. The "presample-growth error" is not likely to be the same for all pieces of wood in the sample submitted for radiocarbon analysis. In contrast, the OCR procedure measures change in the readily oxidizable portion of charcoal from the time of carbonization. With the OCR procedure, the relationship between the analyzed sample and the specific event being dated is clear.

Another common problem with radiocarbon analysis has been the lack of charcoal in sufficient quantity and size in archaeological deposits. Recent advances in physics, specifically the development of Accelerator Mass Spectrometry (AMS), have provided
FIG. 1. Locations of soil samples used in this study.
FIG. 2. Correlation between Oxidizable Carbon Ratio age estimates and known dates from earlier studies (Frink, 1994).

FIG. 3. Correlation between calculated OCR DATE and expected age estimates based on artifact typologies.
a means to obtain accurate and precise radiocarbon date estimates from very small samples. However, AMS costs more than twice that of standard decay counting procedures. A sample submitted for analysis by the OCR procedure consists of a mineral soil matrix and carbon particles. The size of the charcoal is consequential, as the soil sample is ground to pass through a 2-mm meshed screen. The OCR date estimates are accurate and precise with soil samples containing as little as 0.5% total carbon. The cost per sample for the OCR procedure is roughly one-fifth that of the standard decay counting procedure and one-eleventh the cost of the AMS procedure.

NEW APPLICATIONS OF THE OCR PROCEDURE

As we continue to build the database for OCRDATE age estimates on archaeological carbon features, the Archaeology Consulting Team is conducting studies expanding the application of the OCR procedure. In addition to the dating of archaeological features, we are reconstructing former forest fire sequences and former forest communities, and establishing age estimates of specific landforms including paleosols and buried riverbank soils. These studies provide a more inclusive context for specific archaeological sites.

Forest Environmental Reconstructions

Beginning in 1992, we have been collecting samples of rootburns from northwestern Vermont during Phase I archaeological site identification studies (Fig. 4). Our environmental models of forest community reconstructions, developed for previous studies, predict that a pine-hemlock-oak forest community would have been best adapted to the late Pleistocene sandy deltaic outwash deposits located near the mouths of major rivers (Frink and Baker, 1992). We predict that Native American use of this forest community would consist primarily of two different seasonal resource extraction site types. Native American use of the mature forest community would focus on the mast harvest of nuts, and seeds, and the wide range of fauna that seasonally feeds on this resource. Due to the regenerative cycles resulting from frequent severe forest fires characteristic of this forest community, we predict a second extraction camp type focused on summer berries and nuts common in the early immature stages of this forest community.

We obtained OCRDATE age estimates and tree species identifications for each root burn sample. The OCRDATE age estimates provide a history of forest fire periodicity within the study area for the past 2000 years. The calculated 87-year cycle indicated by the grouping of OCRDATE age estimates is consistent with fire cycles found in a pine-hemlock-oak dominated forest.

Identification of the tree species provides corroborating evidence, with white pine (Pinus strobus) comprising 67%, hemlock (Tsuga canadensis) 28% and unidentified coniferous softwoods 6% of the sample (Frink et al., 1993).

Despite the small sample size, a comparison between the age estimates of cultural features found within the study areas and the calculated episodes of major, regenerative forest fires supports our predicted pattern of Native American resource extraction strategies based on forest maturity.

Dating Paleosols under Loess Cappings

Soil samples from two stratigraphically complex excavations in Ohio were analyzed by the Archaeology Consulting Team to determine the probable ages of individual soil horizons. Each soil column consisted of a plowzone (Ap-horizon) and one or more argillic (Bt) horizons formed in post-Pleistocene loess. A paleosol and Pleistocene gravels underlay the loess capping (Callum, 1993). Although we originally developed the OCR procedure to analyze charcoal, pedogenic studies using 14C analysis suggest similarities between the biodegradation of charcoal and the more resistant organic matter normally found in soils.

Like charcoal, relatively stable humic material undergoes degradation through time due to environmental influences. Following fractionation procedures to separate the humic acids, radiocarbon analysis is conducted to obtain an age estimate representing the "mean residence time" (MRT) of the soil humus. Pedogenically active soils are constantly enriched with new humic material, while concurrent biochemical degradation and leaching remove older humic material from the soil (Stein, 1992). The "MRT" represents the mean age of all the humic material residing in the sampled soil horizon at the time of analysis (Sharpenseel, 1971). Our studies demonstrate a strong correlation between the OCRDATE estimate and the expected age of the Ohio soil horizons (Fig. 5). As with radiocarbon date estimates of soil humic acids, the OCRDATE age estimates represent a mean, not absolute, age of organic matter contained within the sampled pedogenic horizons (Frink, 1995).

Determination of Pedogenic vs. Depositional Soil Horizons and Their Age in Riverine Soils

Recently, we analyzed soil samples from a riverbank terrace along the upper Connecticut River valley in eastern Vermont. Total soil carbon was used to differentiate between buried, formerly pedogenic horizons suitable for human habitation, and depositional horizons subject to flooding. The "MRT" of the soil humus was calculated for each soil stratum using the OCRDATE procedure (Fig. 6). Cultural artifacts recovered by the Archaeology Consulting Team pro-

APPLICATION OF OCR DATING IN PEDO-ARCHAEOLOGY
PAST FOREST FIRE EPISODES IN PINE-HEMLOCK-OAK FORESTS, NORTHWEST CHITTENDEN COUNTY, VERMONT

FIG. 4. Sample locations and OCR data from paleoenvironmental study depicting the episodes of major forest fires and dated archaeological sites.
provided corroborating temporal data for this riverbank soil study.

We expect riverbank deposits, which are cumulative soil composed of a mixture of sediments and organic matter from upstream, to have a "MRT" significantly older than adjacent stable pedogenically active horizons. A stable, formerly pedogenically active, soil solum (cumlic) will be enriched with younger organic carbon resulting in a "MRT" significantly younger than the stratum immediately above and below it (Stein, 1992). However, the influence of the originally deposited organic matter will be reflected in an older than expected "MRT" age estimate for the stable pedogenic soil strata (Ferring, 1992). Archaeological sensitivity of the defined soil horizons are thus ascribed a *terminus post quem*, or a time after which cultural habitation would be possible (Frink and Baker, 1994).

**CONCLUSION**

The OCR\_DATE age estimates for archaeological features, root burns, paleosols and buried riverbank soil horizons demonstrate strong correlations with expected age estimates based on 14C data, documented events, or temporally diagnostic artifacts. As such, the OCR\_DATE estimates can be used as an independent check or replacement of existing dating procedures, including radiocarbon analysis and artifact typologies. The low cost of the OCR procedure facilitates the testing of a number of samples, either from within one feature or from several features. Compound or turbated features can be dissected and analyzed for those parts having the most archaeological integrity. As an independent dating procedure, the OCR offers accuracy and precision in results, significant cost savings per sample, and meaningful age estimates for both archaeological
FIG. 6. Soil profiles and OCR data from riverbank study correlating OCR\text{DATE} estimates and artifact age ranges.
features, and the landforms which are the context of the archaeological site.

REFERENCES


