University of Southampton, 2004

FACULTY OF ARTS

DEPARTMENT OF ARCHAEOLOGY

SOIL AND ARTIFACT MODELING USING ESRI ARCSCENE

by Christian A. Maire

A dissertation submitted in partial fulfillment of the requirements for
MSc Archaeological Computing (Spatial Technologies)
by instructional course.

Table of Contents

Table of Figures

Acknowledgements

I would like to thank Robins Air Force Base (RAFB) and its Environmental Management (EM) division for allowing me to use their archaeological and geographic data for this project, not to mention their facilities. I would especially like to thank Bob Sargent for granting this permission. My thanks also go out to RAFB archaeologists Larry Abbott and Stephen Hammack for their valuable assistance and support in this project. Larry's expertise and insight regarding the soils on the site were extremely helpful in producing a useful soil database and model.

Additionally, I thank Ellis Environmental Group, LC for their help in assembling their archaeological data, as well as lending me their facilities. Particularly I thank Carol Moldoveanu for her assistance in arranging my visits to Warner Robins and helping make this project possible.

I heartfully thank my mother and father for their unending support throughout my life that made it possible for me to follow my dreams. Many thanks to my new wife, Mary, for letting me spend our last year of courtship far away in England.

Finally, I thank all those at the University of Southampton for their support through all stages of this Master's dissertation: Dr. David Wheatley, my course coordinator, for giving me guidance in the planning and execution of this project, Dr. Marcos Llobera for taking so much time in helping me through some of the most challenging parts of my work, Dr. Graeme Earl for being there when things got frustrating, and Timothy Sly for keeping the computers working and installing the multitude of software I requested.

Oh, and special thanks to all my fellow students who helped me not go entirely insane.

Abstract

A prehistoric site, designated 9Ht46, is used to explore the possibilities of using ESRI ArcGIS for soil modeling and artifact analysis. The site was occupied during the Early, Middle and Late Archaic periods, the Early Woodland period, and possibly later. Soil data was collected during archaeological survey of the site using scissor posthole diggers. Soil horizons were combined into model layers. Data was processed using Microsoft Access and Visual Basic for Applications (VBA). Interpolation of layer thickness was performed by means of kriging, and the results used to produce digital elevation models (DEMs) of the model layers. The soil landscape was then visualized in three dimensions using ESRI ArcScene. Total artifact distributions and distributions for each layer were draped onto the layers of the model to investigate site-wide patterns and relationships between artifact concentrations and soil and landscape features. Despite some difficulties with the dataset, the model was successful and helped to address several research questions regarding the soils and artifact density patterns on the site.

Chapter 1. Introduction

Georgia, along with the southeastern United States in general, played an important role in the prehistoric developments of the New World. Some of the earliest pottery in the Americas, fiber-tempered ceramics, appears in the coastal plain of Georgia and South Carolina. There are also many ceremonial mound sites, including effigy mounds, in Georgia and the rest of the Southeast. Much is known already about recent prehistory and the effects of European contact on Mississippian societies in Georgia.

However, there are many unanswered questions regarding particular aspects and periods of Georgia archaeology. In Georgia's Coastal Plain region, there are unexplained gaps in the archaeological record, particularly in the period known as the Middle Archaic. Also, paleoclimate is a point of contention in Georgia, especially for this period. Different researchers have argued for a wide range of climates, from very wet to very dry.

This study focuses on an upland site situated on the edge of the Coastal Plain. The site is currently known only by its Georgia site file designation of 9Ht46. Survey and testing on the site recovered artifacts from a number of periods ranging from the Early Archaic to the Woodland period, including a small representation of the Middle Archaic. The soils on the site are complex and were difficult to interpret during fieldwork. However, they hint at dry climate conditions causing vegetation to recede, resulting in erosion in portions of the site (Larry Abbott, personal communication).

The site is situated on Robins Air Force Base (RAFB) in Warner Robins, Georgia. The RAFB, like all federal installations in the United States, has a mandate to protect cultural resources on its property. To this end, the base has for many years been conducting archaeological surveys of all developable land within its boundaries. 9Ht46 was discovered in the 1980's during one of these surveys, and has recently undergone thorough sampling using scissor posthole diggers and hand augers. Soil profile data and interpretations were collected for each posthole excavation.

It is the aim of this study to use the soil profile and artifact data collected to produce a soil model of the site, to be displayed and manipulated in three dimensions. It is hoped that such a model may answer questions regarding the paleoclimatology and soil deposition on the site. The model should as well as shed some light on possible disturbances of archaeological components. In order to explore artifact distributions and their relation to the soil landscape, artifact distributions will be modeled and displayed as part of the soil model.

The proposed method for interpolating soil horizons and layers is kriging. This is a geostatistical technique commonly used in soil science for modeling soil attributes. The efficacy of kriging for interpolating soil thickness will be assessed, as will its robustness when applied to highly variable soils.

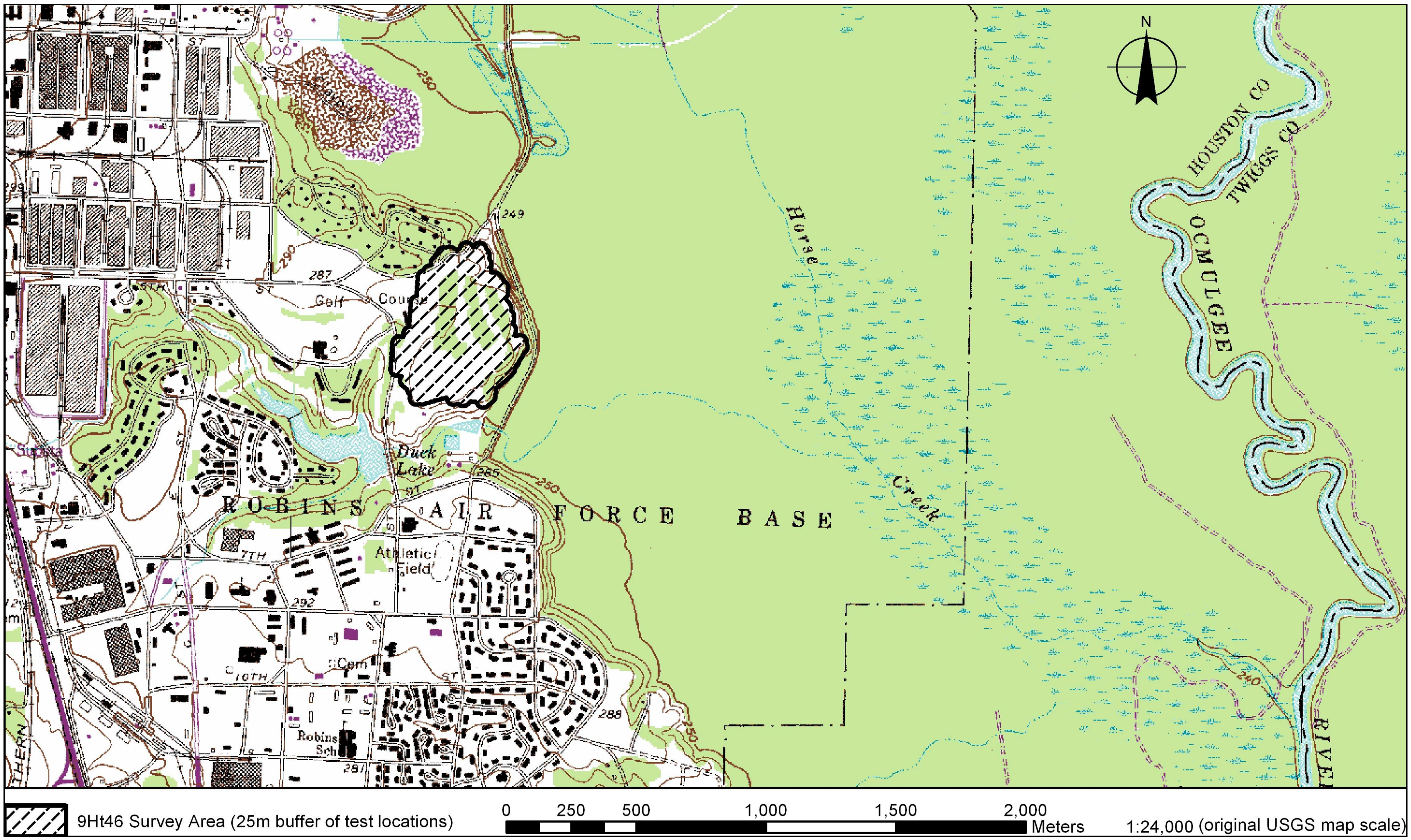


Figure 1-1: USGS quad map (USGS 1985) portion, showing the survey area in relation to the surrounding landscape and the Ocmulgee River

Chapter 2. Site background

2.1. Brief review of Georgia archaeology

2.1.1. The Paleoindian period (11,500 – 10,000 B.P.)

The earliest occupation of Georgia is thought to have been between 11,500 and 11,000 years ago. As the Pleistocene waned, many large mammals began to die off, and their complete extinction appears to have occurred concurrently with the widespread settlement of the Americas, possibly resulting from human hunting and burning activities. While in Northern Georgia the previous spruce pine boreal forest gave way to hardwood forest, south of Macon hardwood forest already was in place, and may have been through the entire glacial period (Anderson, Ledbetter, & O'Steen 1990:4).

The Paleoindian period has been divided into three subperiods. The Early Paleoindian (11,500 – 11,000 B.P.) is characterized by large, thick fluted points, such as Clovis. The Middle Paleoindian (11,000 – 10,500 B.P.) features smaller fluted and unfluted lanceolate points with constricting hafts. The predominant tool of the Late Paleoindian (10,500 – 10,000 B.P.) is the Dalton type, with a lanceolate blade outline and concave base. In Georgia, Paleoindian sites are typically rather small, and most evidence of the Paleoindian occupation of Georgia has consisted of surface finds (Anderson 2003, Anderson et al. 1994).

People of the Paleoindian period participated in a pioneering human ecosystem, exhibiting high mobility over a large territory. While edible vegetation was sparse, large game was abundant and provided the main source of food for the Paleoindians. As the period waned, there is evidence of more regionally based movement patterns, and by the end of the Paleoindian period the shift toward a foraging ecosystem had probably already begun (Stoltman & Baerreis 1984:253-54).

2.1.2. The Archaic period (10,000 – 3,000 B.P.)

The Archaic is the longest period in Georgia archaeology, yet in the Coastal Plain, Archaic sites are relatively rare. As of 1994, the Coastal Plain and Coastal Zone, despite encompassing almost two-thirds of the State of Georgia, accounted for less than one fourth of Archaic sites in the Georgia state archeological site files. This paucity may reflect a survey bias or a decreased detectability of these sites (Eliott & Sassaman

1995:1). There is evidence that climatic changes during the Holocene resulted in more localized availability of resources. Some researchers have suggested that the low number of Middle Archaic sites in the Coastal Plain reflects either a resulting increase in sedentism or an avoidance of conditions that would hamper mobility. The latter would help to explain the apparent preference for the more homogeneous Piedmont province. (Eliott & Sassaman 1995:12).

The archaeological record of the Archaic in the Southeast demonstrates a transition from the high-mobility settlement pattern of the Paleoindian period to more localized and homogenous areas of occupation. The Archaic is typically subdivided into the Early (10,000 to 8,000 B.P.), Middle (8,000 to 5,000 B.P.), and Late (5,000 to 3,000 B.P.) Archaic. Early Archaic sites are small, short term seasonal camps, and indicate a high level of mobility. Middle Archaic sites are also short term and equally low in artifact density. However, Middle Archaic people appear to have constrained themselves to distinct physiographic provinces more than their Early Archaic counterparts. Late Archaic social organization saw an increase in complexity, and was characterized by larger social networks and seasonal gatherings for trade, subsistence, and ceremonial purposes (Benson 1995).

The Middle Holocene climactic optimum, also called the Altithermal, had profound climatological effects on most of North America. There are, however, greatly divergent opinions on the extent to which the Holocene Altithermal affected the climate of the Georgia Coastal Plain. Some researchers have suggested there were extensive droughts, some lasting as long as 500 years (Kane & Keeton 1998). Others have suggested that there is no data to conclusively suggest any climatic change at all during the Middle Holocene, and that the prehistoric climate was much like the present (Eliott & Sassaman 1995:13). Leigh and Feeney (1995) suggested in their study of large paleochannels in Southeast Georgia that the late Pleistocene to middle Holocene climate was significantly wetter than modern conditions.

In the Georgia Late Archaic, significant developments include intensified settlement of riverine locations, the first appreciable exploitation of shellfish, the production of soapstone vessels, diversification of ground stone technology and the introduction of pottery. While Georgia and the Carolinas were approximately 1,000 years behind the rest of the Southeast in most of these developments, the fiber-tempered pottery in the area was some of the first in North America. Still, its use remained limited during at least the first thousand years after its introduction, and did not see widespread use until about 3,000 B.P. (Eliott & Sassaman 1995).

2.1.3. The Woodland period (3,000 – 1,100 B.P.)

The Woodland Period in the North America is in most ways a continuation of developments already in progress in the Late Archaic. Its major distinction from its predecessor is the widespread use of pottery, although we have already established that at least limited pottery utilization predates the Early Woodland in the Southeast. In most of North America the initial appearance of pottery is considered diagnostic of this period, although not all Woodland sites necessarily contain ceramics (Brown 1986:599-605).

Fiber-tempered pottery persists into the initial Woodland, through it is only with the appearance of the Deptford ceramic tradition that a trend toward less egalitarian social practices begins to emerge. Deptford pottery is associated with the Yent ceremonial complex, a cultural tradition related to the Hopewellian culture that dominated much of the eastern United States. Deptford ceramics and evidence of the Yent complex are found predominantly along the coast in Georgia, and to a much lesser degree along the rivers of the upper Coastal Plain. Deptford mound sites are especially limited to the coastal regions. Because of limited archaeological survey coverage of the upper Coastal Plain, it is not yet clear whether this reflects a more seasonal occupation of the interior or merely a survey bias (Steinen 1995:31-33).

The Middle Woodland period in the upper Coastal Plain is much better understood, and is dominated by the Swift Creek culture and ceramic tradition. Earthen mounds from this culture are found throughout the Coastal Plain, and the type site for the period is located southeast of Macon, Georgia, not far from the Robins Air Force Base and 9Ht46. Swift Creek material culture is typified by a distinct mound-building tradition and use pattern, as well as an intricate pottery decoration style (Jefferies 1994).

However, it is the transition from Early to Late Swift Creek that represents a major change, more so than that from Archaic to Woodland. It appears that Late Swift Creek represents socio-political developments that would culminate in a chiefdom-level society. There is an increase in middens, and mounds increase in number and complexity. Steinen (1995) argues that, at least in the exceptionally socio-politically complex site of Kolomoki, there was also an adoption of maize horticulture.

The Late Woodland in the Georgia Coastal Plain appears to be a continuation of developments in Late Swift Creek, during what is called the Weeden Island period. The increase in ceremonialism and elaboration of artistic styles persists until the end of the Weeden Island period, when a dramatic change in settlement pattern occurred. Although population continues to increase, there is a marked decentralization at this point. A preferential selection of locations with rich soils emerges, with a concurrent decrease in mound size and apparent ceremonial authority. This is in contrast to coastal and Piedmont sites, where civic centers and mound-building continue (Steinen 1995).

2.1.4. The Mississippi period (1,100 B.P. – 500 B.P.)

The term 'Mississippian' refers to a cultural phenomenon in the Eastern Woodland characterized by the construction of large ceremonial mounds and intensive agricultural system based on corn, beans and squash. This period saw the development of complex chiefdom societies and occupational specialization. The Mississippian cultures practiced regional variants of an area-wide belief system that appears in the archaeological record as widespread iconographic themes. The period ended shortly after the settlement of Europeans in North America.

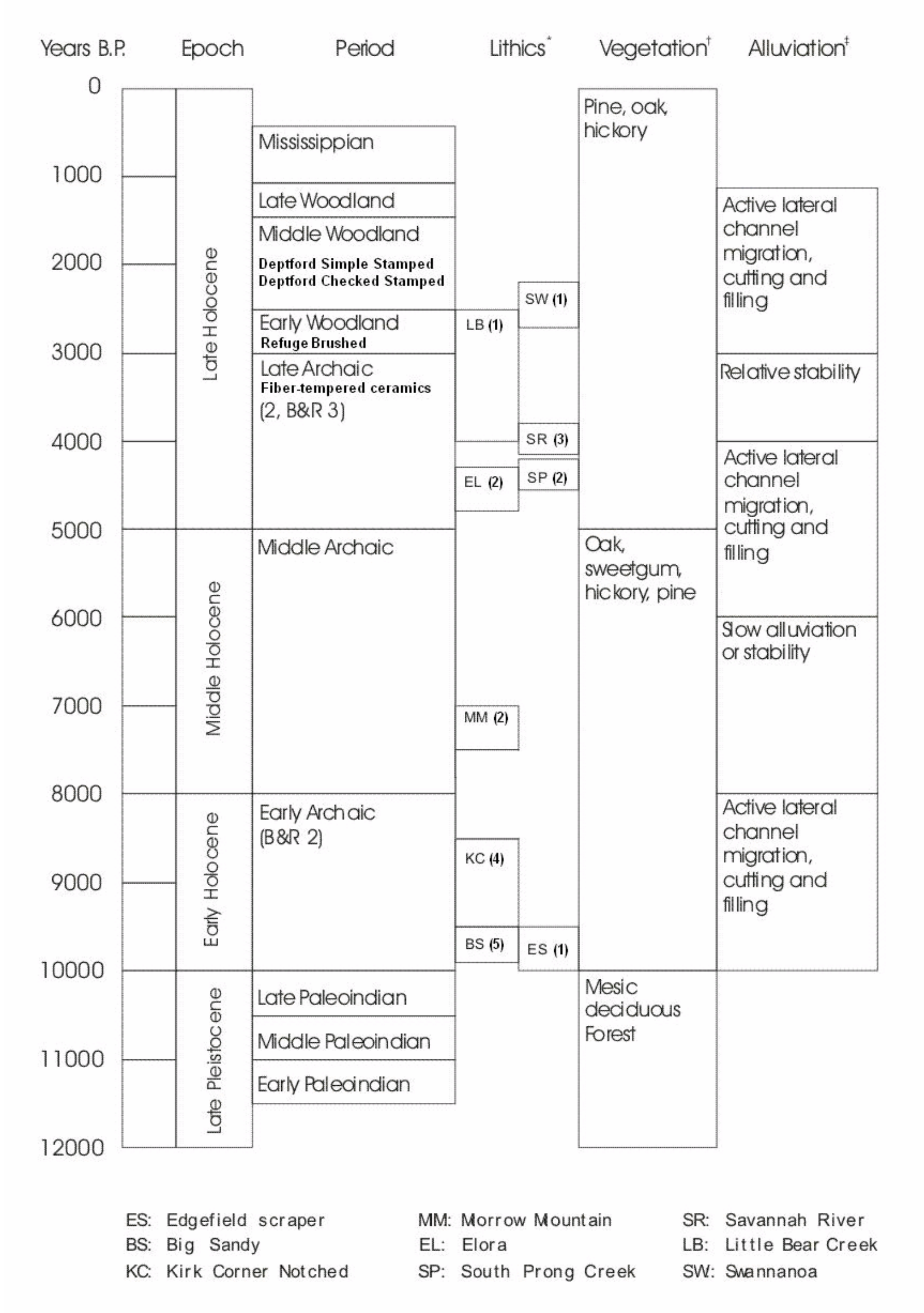


Figure 2-1: Prehistoric chronology of Georgia and the Southeast. *Georgia lithic tool typologies and quantities found on 9Ht46 (Whatley 2002). †Pollen stratigraphy of the Coastal Plain (Davis 1984:172-73). ‡ Generalized regional alluvial chronology of the Eastern Woodlands (Knox 1984). Created by Christian Maire, modified by Larry Abbott to accommodate recent artifact reinterpretations.

2.2. Physiography & geology

9Ht46 is located in the Fort Valley Plateau physiographic district, within the Fall Line Hills that mark the beginning of the Coastal Plain. About 25 kilometers north of the site is the Fall Line, which marks the Mezozoic oceanic shoreline, separating the sedimentary bedrocks of the Coastal Plain from the crystalline bedrocks of the Piedmont to the North. The Fall Line is named for the waterfalls that are found along it, which act as a barrier in river navigation between the two physiographic regions (Duncan 2003).

The Fall Line physiographic district consists of Piedmont igneous and metamorphic rocks covered by a mantle of the Cretaceous to Holocene sedimentary ocean deposits that make up the Coastal Plain. Chert deposits in the Coastal Plain are found primarily in these sedimentary deposits, specifically Oligocene and Eocene deposits in the upper to middle Coastal Plain (Eliott & Sassaman 1995:8-11).

The 9Ht46 site itself is located on a Providence Sand geological formation (Georgia Geologic Survey 1999), at the edge of a bluff overlooking the floodplain of the Oculmulgee River. The bluff itself represents at least two meanders of the river. The floodplain is mainly composed of wetlands, and is home to abundance of wildlife, including black bear, white-tailed deer, coyotes, beaver, alligators, and feral hogs. The last of these is an introduced species and would not have been present prior to European occupation (Abbott 2003:17-18).

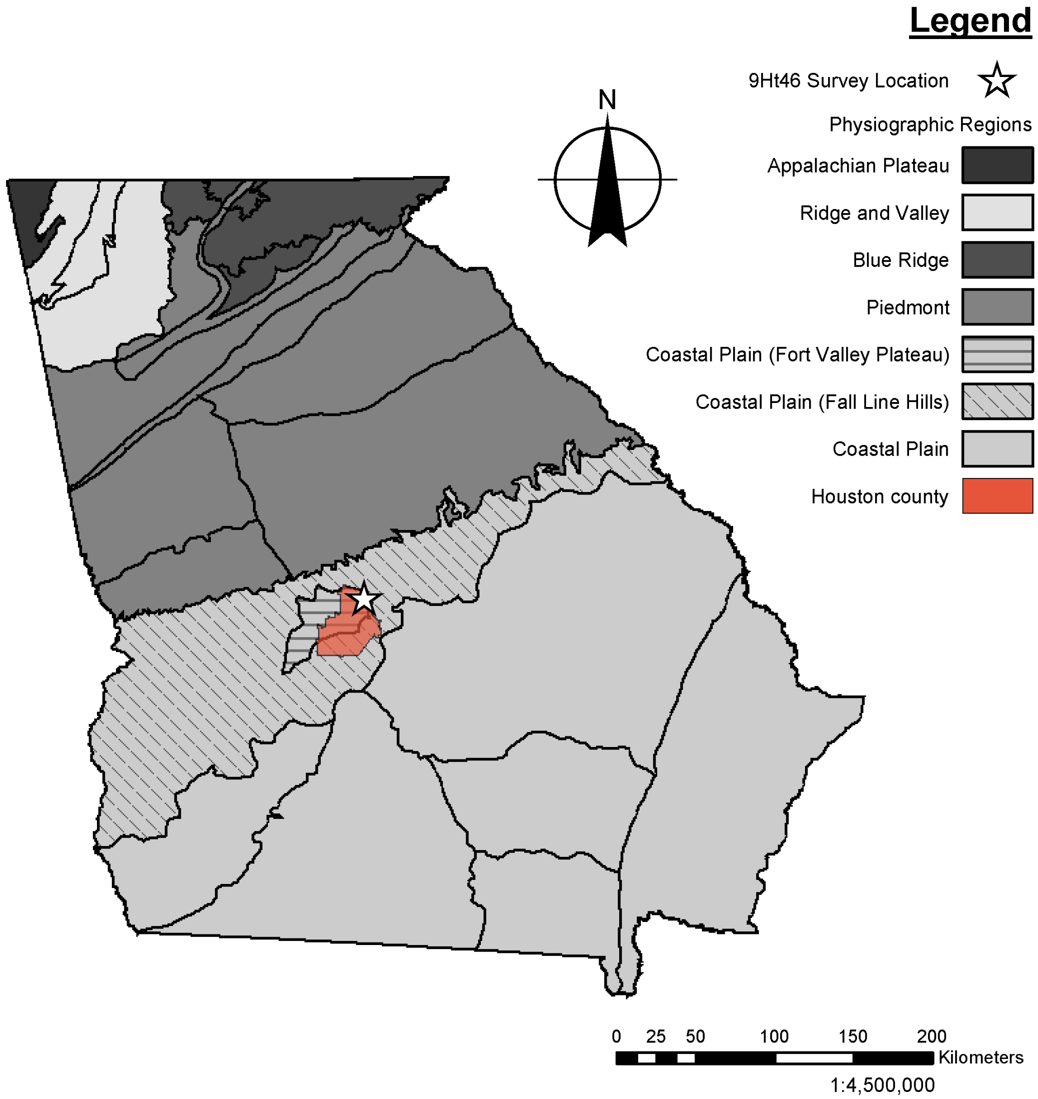


Figure 2-2: The physiographic regions and some districts of Georgia (Data source: Georgia Geologic Survey 1996)

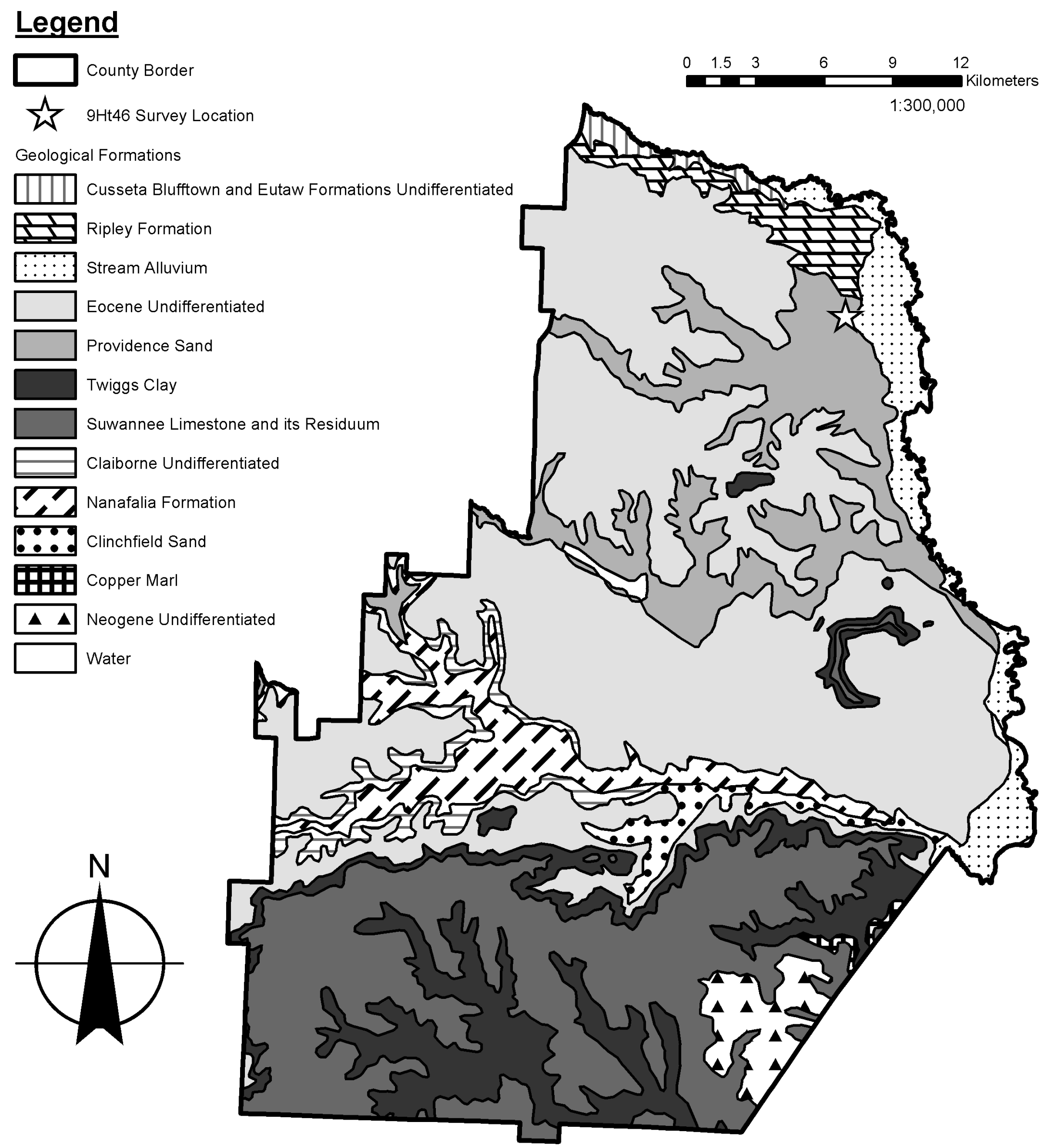


Figure 2-3: Geological formations in Houston County, Georgia (Data source: Georgia Geologic Survey 1999)

2.3. Early surveys at 9Ht46

The site 9Ht46 was first investigated by Dennis Blanton and Mary Reed (1987) during a base-wide archaeological survey. They reported a large site, designated by them as Site 23, located on the golf course, along the bluff edge overlooking the floodplain of the Ocmulgee River. Because of an erroneous assumption that all landscaped portions of the golf course were disturbed, only the wooded areas separating the fairways and along the bluff edge were surveyed. Forty-five test pits were dug, thirty-three of which produced archaeological material. Blanton and Reed identified three major concentrations of artifacts: one at an elevated area overlooking what is now the 5th teebox, one at the southern end of the bluff edge, and the largest surrounding what is now the 5th green.

Artifacts recovered from the 1987 survey suggested at least three temporal components. Three lithic tools identified as Early Archaic were uncovered from the 5th green area and the southern end of the site. Some Late Archaic material was discovered on the surface at the north end of the site. A third component is evidenced by the presence of undecorated sand-tempered pottery, probably from the Woodland period.

In the 1990s, material was recovered from the surface collections on the site. Unfortunately, no spatial data exists for these artifacts. Diagnostic artifacts include two Early Archaic Kirk Corner-Notched points, an Early Archaic Edgefield Scraper, a Middle Archaic Stanly point, and a biface identified as a Larel Mountain point.

2.4. Recent surveys

The first stratigraphically controlled excavation on 9Ht46 for which there is reliable spatial data was a small survey by Larry Abbott (2000) outside the Pine Oaks Golf Course maintenance shed, at the southwest corner of the currently-defined site area, adjacent to the 6th fairway and the driving range. This and all subsequent surveys compose the data source for the current study. Twelve holes were excavated using 15cm-diameter scissor posthole diggers on a ten-meter interval grid. Modern fill dirt was excavated as a single stratigraphic unit, as was the plowzone. Further excavation was done in 10-centimeter levels below surface, generally until the Bt soil horizon or the paleosol was penetrated. If excavation depth exceeded the length of the posthole digger, excavation was continued with an extendible hand auger. Four artifacts were encountered, all of them non-diagnostic lithic debitage.

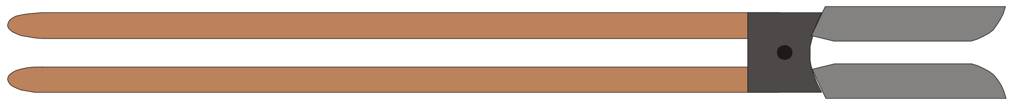


Figure 2-4: Example of a scissor posthole digger.

The next investigation of the site occurred during a survey of the golf course's 18 greens by Abbott and Hoffman (2001). Postholes were dug at a twenty-meter interval, which was reduced to ten meters around holes that produced cultural material. Again, fill and plowzone were kept as separate stratigraphic units, and holes were excavated in ten-centimeter levels below surface. Texture, Munsell (1975) soil colour other soil features were recorded on a soil profile form, and each level was screened using a 6.35mm (1/4 inch) mesh. Artifacts associated with 9Ht46 were discovered under the 1st, 2nd, 3rd, and 5th greens.

Abbott and Hoffman (2002) performed another twenty-meter interval posthole survey of the driving range, using the same methodology as the 2001 greens survey. Relatively sparse cultural material was encountered in the western portion of the survey.

The remaining site area was tested during a 2003 survey of the first six fairways. Posthole tests were dug using the same methodology as the previous two surveys. The results of the posthole survey were used to select locations for ten 1-meter x ½-meter and seven 1-meter x 1-meter test units. The report for this survey has not yet been completed.

Additional artifacts have been recovered during monitoring of trenching during golf course renovations. Several of these are diagnostic tools, but no vertical stratigraphy could be preserved, and only approximate horizontal spatial locations could be recorded.

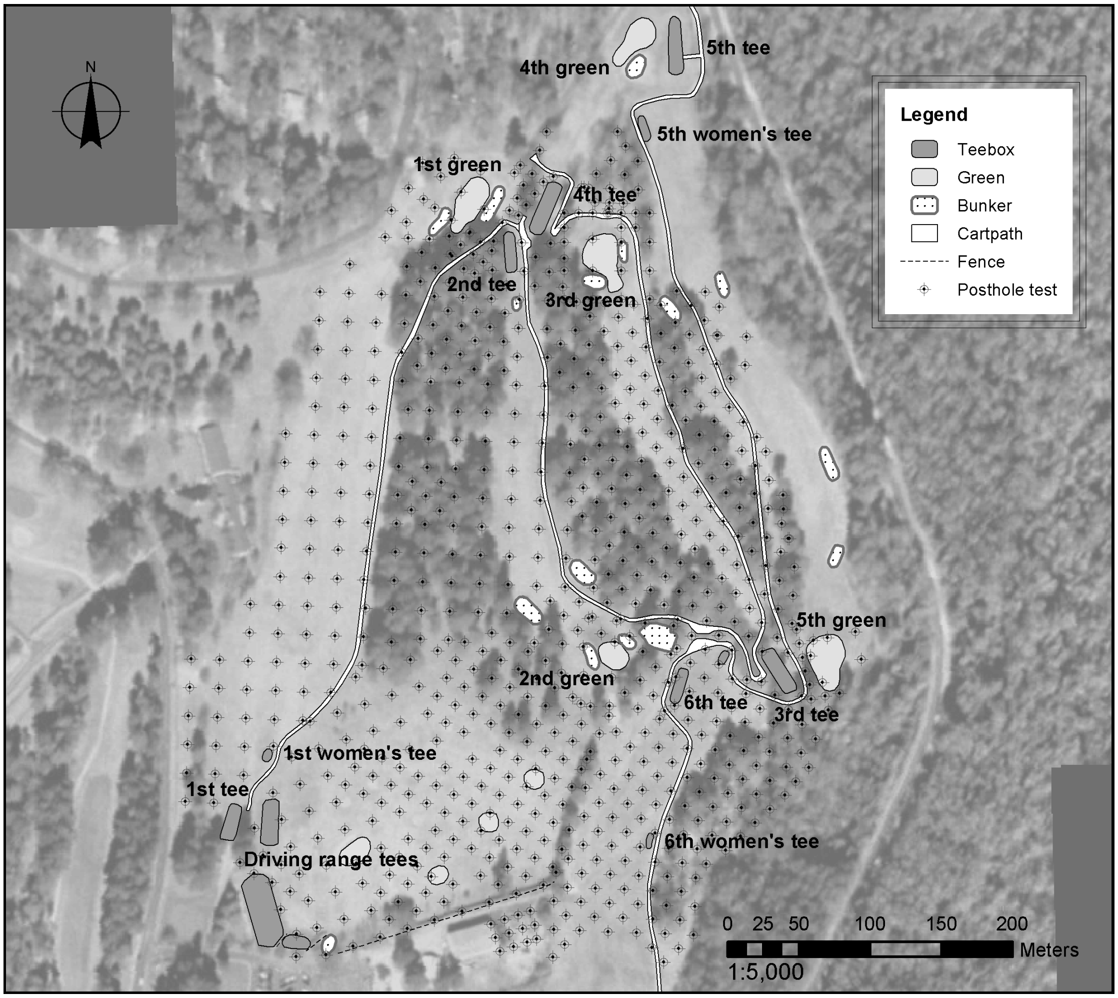


Figure 2-5: Posthole test locations and golf course features

Chapter 3. Data collection and initial processing

Data was collected from a variety of sources, in different scales and coordinate systems. Most large-scale data was collected for illustrative purposes only. Data used for analysis was at an intra-site scale. The primary coordinate system used was Georgia State Plane West coordinates, using the 1987 datum. This is the preferred coordinate system for current archaeology on the Robins Air Force Base. Some data collected from external sources was in UTM coordinates. However, most output data was produced using the Georgia State Plane system.

Both feet and meters are used in this report. The commonly used measurement system for prehistoric archaeology in the United States is metric. Therefore, the archaeological data collected on the site is in metric. However, most externally collected GIS data is in imperial units, and the Georgia State Plane coordinate system is based in feet. ArcGIS converts coordinate systems and measurement units fluidly, and therefore this mixing of measurement units did not pose any known problems.

3.1. Aerial photos and surface feature data

Two colour, one-foot cell size aerial photos covering the survey area were used as a reference for georectification of other layers and for the digitization of the golf course features. These are property of the U.S. Air Force and could not be included in this report or the attached data CD, and were therefore not used in any of the illustrations.

For illustration purposes two publicly available black and white, one meter cell size aerial photos were obtained from Microsoft's Terraserver website (www.terraserver.microsoft.com). Using Autodesk Map and Raster Design, these were imported with a coordinate transform into Georgia State Plane coordinates, merged and saved as a single TIFF image with a new world file.

The U.S. Air Force colour aerial photos were used to digitize surface features of the golf course using AutoDesk Map. These were then saved as separate polygon shapefiles for golf course greens, tees, bunkers and cart paths, and a polyline shapefile for several fences along the driving range.

A digital raster graphic (DRG) of the United States Geological Survey (USGS) Warner Robins SE 1:24,000 quad sheet map (USGS 1985) was obtained from the GIS Data Depot (http://data.geocomm.com) website. This was included for illustration purposes only, and because it is required for the submittal of a National Register of Historic Places (NRHP) recommendation.

3.2. Excavation data

3.2.1. Posthole test digitization

Posthole tests had been mapped on a series of sketch maps on graph paper, with each grid square representing one square meter. Their location on the sketch map was marked in arbitrary relative coordinates based on triangulated tape measurements made in the field. When hole placements were offset because of obstacles, the new posthole locations were marked appropriately on the sketch map. The distance of nearby features, including cart paths, roads and bunkers, were measured and used to place those features on the maps.

These sketch maps had been produced in the field, and had been exposed to months of heat, dust and moisture. This resulted in warping, which it was necessary to correct. All sketch maps of the fairway survey were scanned using a Microtek Slimscan C6 USB scanner at 300 dpi.

The arbitrary grid coordinates of each hole were recorded in a csv (comma separated values) file and displayed as x,y data in ESRI ArcMap. This was subsequently exported as a shapefile and imported into AutoDesk Map. Each sketch map image was imported into Map and corrected using polynomial rubbersheeting, matching a well-distributed sample of grid locations on the sketch map with their corresponding positions on the regular arbitrary grid using snapping. Grid locations along the empty margins of each sketch map were georeferenced by entering the arbitrary grid coordinates by hand. Where there was overlap between sketch maps, images were cropped in order to make all points and map features visible.

Figure 3-1: The composite site sketch map of the fairway survey, corrected and spliced in AutoCAD Map

The result was a composite sketch map of the entire site, georectified to the arbitrary grid laid out in the field. The images were merged and saved as a single jpeg. This was then imported into ArcMap and georeferenced to the high-resolution U.S. Air Force aerial photos in 1987 Georgia State Plane West coordinates using an affine transformation. Features on the sketch map that could be matched on the high-quality aerial photo were used as control points. Since GPS data was not available for posthole test locations, this was the most accurate method possible. The result was acceptably accurate for the purposes of this study.

Once the map was georeferenced, the posthole test locations were digitized in ArcMap. The posthole test locations from the greens survey had been georeferenced previously, so these coordinates were merged with the digitized data in the final feature class. One sketch map from the driving range had not been scanned during data collection, and this was received by fax. Because of the poor quality and inherent distortion in the fax, a proper georectification was not attempted. Instead, this map was georeferenced using an affine transformation and used as a guide for the triangulation of the new points from already digitized driving range survey points. This was done using the direction-distance and distance-distance digitization tools in ArcMap.

3.2.2. Test unit digitization

Test unit locations were determined by their location on the sketch maps. These locations were cross-checked against the assigned arbitrary grid coordinate and the test unit profile sketches, and any discrepancies were corrected. Test unit polygon features were digitized as 1m x 1m squares and 1m x 0.5m rectangles, aligned to the posthole feature grid, using the same coordinate system. Test unit point features were digitized at the center of the polygon feature.

3.3. Elevation data

A shapefile containing one foot (30.48 cm) interval vector contour data was obtained from the Robins Air Force Base official GIS. No spot height data was available. The shapefile was “clipped” so as only to include elevation data for a reduced area surrounding the survey area. This contour data was converted into an ESRI coverage and used to produce two digital elevation models (DEMs) in ARCInfo’s TOPOGRID tool, graphical user interface (GUI) for TOPOGRID. A DEM with a 5 foot cell size was generated for the purpose of visualizing the site area and topographic features surrounding the site. A second DEM was generated strictly for the area surveyed, with a cell size of 1 foot. This DEM was created as a surface from which to derive base elevations for the posthole tests. The input shapefile and output DEMs are both in 1983 Georgia State Plane West coordinates.

There are few interpolation algorithms that are specifically designed to process contour data, despite this being the most common source of elevation data. Among those that do, a ubiquitous problem is "stepping" occurring at the locations of contour lines, creating a somewhat unrealistic slope. TOPOGRID was selected because it has performed well in comparative tests (Briggs 1974), although Gousie & Franklin (2003) have recently been developing a new technique incorporating the computation of intermediate contour lines and Gaussian smoothing that has proved superior to TOPOGRID in preliminary tests.

For both DEMs, a tolerance parameter of 0.5 was used, according to the program's documentation (ESRI 2003), which states that the tolerance should be set to one half of the contour interval. Several values were tested for the number of iterations in the production of the 1-foot DEM, namely 20, 40 and 60, in addition to the default value of 30. The quality of the output was evaluated qualitatively using hillshade analysis.

At 20 iterations, bizarre artifacts were encountered that had no obvious source in the input contour data. At 60 iterations, the "stepping" artifacts become more severe. At 30 and 40 iterations, artifacts differed in nature but not in amount. The default of 30 iterations was selected for the final DEM.

In order to derive elevations for each posthole test, the GRIDSPOT script available on the ESRI ArcScripts website (http://arcscripts.esri.com/) was used to add the cell value of the 1-foot cell size DEM as an attribute value in the posthole shapefile. Elevations in meters were calculated in an additional attribute field. This shapefile was later converted into a 3D point feature class in the project geodatabase, again using the 1 foot DEM as an elevation source.

3.4. Artifact data

Prior to the current study, most of the artifacts from the posthole surveys had been cataloged. Those that had not been were identified, measured, and entered directly into the project database. The rest of artifacts from the survey of the fairways had been recorded in an Excel spreadsheet. This data was cleaned and transformed to match the format of the Access 'Artifacts' table before being imported. Artifact data from the surveys of the greens and driving range had been stored in Word tables. These were copied into Excel, cleaned, transformed, and imported into Access. The results from all surveys were stored in the same table, as they could be later differentiated by their posthole ID prefix and corresponding excavation date.

No artifacts from any of the 17 test units had been previously cataloged. These were cataloged as part of the current study, in part to produce a complete record of diagnostic and semi-diagnostic artifacts on the site to assist in chronological interpretations. Also, the locations of diagnostic material could be related to the results of the soil model analysis. All data on test unit artifacts, diagnostic or otherwise, were stored in a separate 'TU_Artifacts' table.

Diagnostic and semi-diagnostic artifacts from construction monitoring and surface collection in the site area were also cataloged and measured. These were stored in a separate table in the database reserved for artifacts found with no specific context. Full metrics and further data specific to small finds were stored in yet another table that was linked to all three of the tables for posthole, test unit and non-contextual finds. For full details, see Chapter 5 of this report.

Most diagnostic lithic artifacts were identified, either in person or through photos and metric data, by John Whatley, a leading projectile point expert in the state of Georgia. While few large ceramic sherds were found, those that were considered distinctive were reviewed by Frankie Snow, a specialist in Georgia prehistoric ceramics.

3.5. Soils data

3.5.1. Soil surveys

County-wide vector soil survey data was obtained from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database, available online at http://www.ncgc.nrcs.usda.gov/ in shapefile format. This is a 1:12,000-scale digital copy of an unpublished 2001 minor revision of the published 1:15,840-scale Houston County soil survey (Woods 1967).

A separate soil survey was done for Robins Air Force Base by the NRCS (1989), though a digital copy of the soil map could not be obtained. The printed map was scanned and georectified for reference purposes, and it was found that while the soil classifications of the two surveys differ, their boundaries are the same. Therefore, it was not digitized.

3.5.2. Soil profile data storage

During posthole surveys, soil profiles were recorded on specially designated forms. Soil colour, texture, pebbliness and other characteristics were recorded for each ten-centimeter level, and transitions within each level were approximated from observed relative soil volumes within the screen. When a soil transition was relatively abrupt, typically between distinct soil horizons, a line was drawn to indicate the approximate depth of the transition. Once a posthole test was completed, soil horizon interpretations were made when possible.

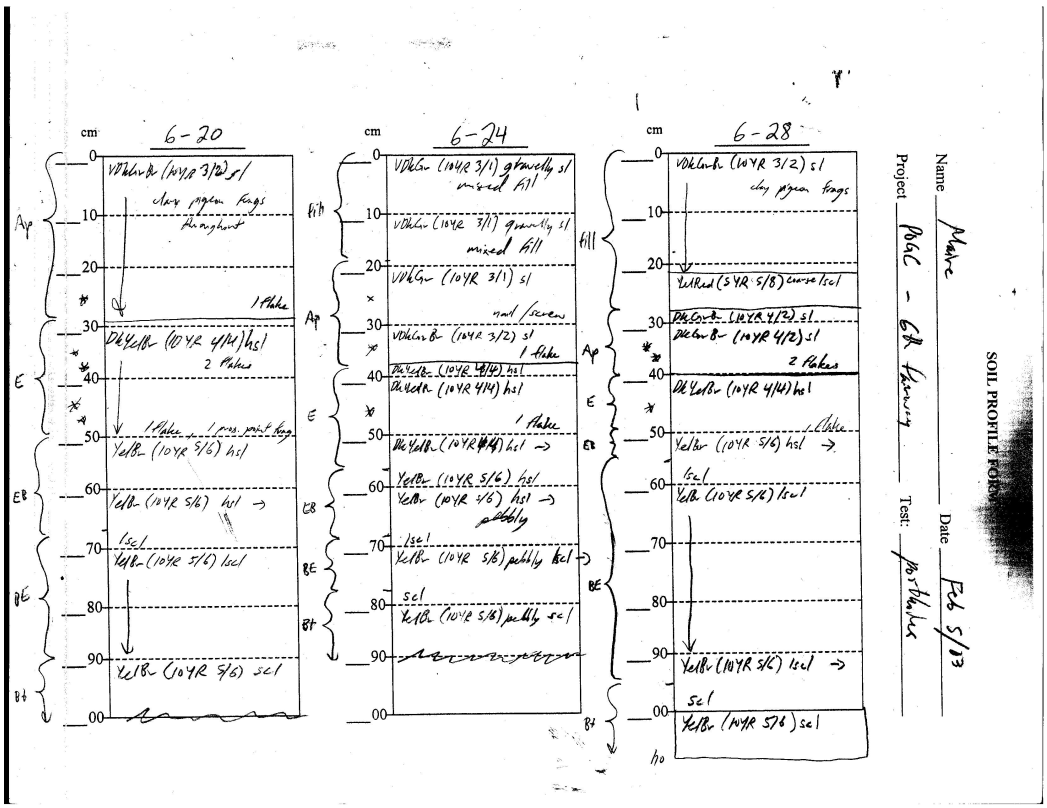


Figure 3-2: One of the approx. 250 soil profile sheets.

These soil profile forms were scanned, cropped and saved as individual profiles, with filenames following a naming convention of “[fairway]-[posthole].jpg”. This was done to ease data entry by displaying the image in the Access database profile form by means of a small Visual Basic for Applications (VBA) script (See Appendix A2.1). Also, subtleties in the recording of the paper forms give insight into the profile that could not otherwise be embedded in the database. These images were also used to compare profiles in the spatial database using a similar VBA script.

A thorough description of the database structure can be found in Chapter 5 of this report. Soil profile data was broken into two main tables. The parent table contains data about the entire posthole test, including the excavator, data of excavation, posthole number and whether it should be excluded from analysis. The child table held records for each unique depth range in the profile. Modern fill was given a single depth range, and no descriptive data such as colour or texture was entered. Each record contains the posthole number, a soil horizon interpretation, the "certainty" of that interpretation, and an upper and lower limit for the depth range. In addition, each record contained descriptive information about the depth range. If any of these descriptive characteristics changed through the profile, a new record was created to represent the new set of characteristics. These characteristics consist of soil disturbance, Munsell (1975) colour, dryness, texture, pebbliness, mottling, and presence of concretions, charcoal and burned earth. Therefore, soil horizons could be subdivided into several records if, for example, their pebbliness or colour changed with depth. These could be then recombined using database queries, when necessary.

3.6. Other GIS data

3.6.1. Environmental data

State-wide 1:500,000 geologic and 1:2,000,000 physiographic ESRI coverages produced by the United States Geological Survey (USGS) were obtained from the Georgia GIS Clearinghouse, on-line at https://gis1.state.ga.us/. This data was used to situate the site within a physiographic and geologic context, and a subset of the geologic coverage was created to show the geology of Houston county specifically.

State-wide 1:24,000 USGS shapefiles of the lakes and rivers in Georgia were also obtained from the Georgia GIS Clearinghouse. Although these were not explicitly used for the current project, they are included on the data CD included with this dissertation.

3.6.2. Infrastructure and political data

A 1:24,000 Georgia county boundary polygon coverage, created by the Georgia Department of Community Affairs, and a 1:24,000 Houston county road coverage, produced by the Georgia Department of Transportation, were obtained from the Georgia GIS Clearinghouse. They were not explicitly used in this project, but are included on the attached data CD.

1:1,000,000 city polygon and point coverages of Georgia were obtained from The GIS Data Depot. This data was produced by ESRI, and is a subset of the Digital Chart of the World. They were not explicitly used in this project, but are included on the attached data CD.

Chapter 4. Soils

Soil is defined in the USDA Soil Taxonomy (Soil Survey Staff 1999:9) as:

> …a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment.

This definition is derived from a view of soils not as simply weathered rock, as it is perceived in some disciplines, but as an independent, organized natural body whose morphology is determined by a combination of environmental factors. In soil science, soil state is considered to be a function of five "state factors" (Gerrard 1981:1-4). Although there have been a number of equations developed to represent this relationship, most are variations of Jenny's (1941) state factor equation:

$$S = f(cl, o, r, p, t, \ldots)$$

This means simply that soil property is a function of climate, organisms, relief, parent material and time since the start of soil formation.

Horizontal variation of soils is described in soil maps, in which soil survey results are used to estimate the extent of soil individuals, or contiguous areas that can be associated with a single soil series (Fanning & Fanning 1989:165-69). Vertically, soils divided into roughly horizontal layers that differ from the layer above and below, called horizons. Horizons are described by their colour, texture, structure, consistence, and the nature of the boundaries between them.

4.1. Soil Horizons

4.1.1. Master Horizons

In the United States, the main guides for horizon nomenclature are the USDA's Keys to Soil Taxonomy (Soil Survey Staff 2003) and Soil Survey Manual (Soil Survey Staff 1993). Horizons are classified into seven master horizons, usually occurring in the following order in any one distinct soil or buried soil:

O: Organic animal and plant litter, usually found at the ground surface

A: Mineral horizon with high organic content from root decomposition or farming

E: Lighter-coloured horizon leached of clay, iron or aluminium

B: Chemically altered mineral horizon that has formed underground

C: Non-bedrock mineral layer with little alteration from soil-forming processes

R: Hard bedrock and soil material within cracks of bedrock

W: Layers of water, frozen or liquid

4.1.2. Transitional Horizons

There are often layers within the soil that lie between these master horizons and share characteristics of both the overlying and underlying master horizons. These are considered transitional horizons and are symbolized by a combination of the two master horizon letter designations, in which the letter of the dominant master horizon appears first. For example, a soil profile may include an E, EB, BE, and B horizon. The EB horizon will share more characteristics of the E horizon, whereas the BE horizon will be more like the B horizon.

4.1.3. Subordinate distinctions

The upper-case horizon designation may be followed by one or more lower-case letters describing specific soil characteristics. Those used in the current surveys are:

g: Strong gleying, or light colour due to at least partial absence of ferrous iron

p: Cultivation disturbance, typically plowing, that mixes surface horizons

t: Accumulation of silicate clay on ped or particle surfaces

w: B horizon that has developed colour or structure different from the A or C

If there are subdivisions within the horizon, this can be described with a number suffix, such as EB1 and EB2. Soil discontinuities that suggest a different genesis are indicated by a number prefix. If two horizons exist that are considered equivalent but are divided by an unlike horizon, the designation of the second occurrence is followed by a prime ('). This often occurs when a new horizon is formed within an existing horizon.

4.2. Soil Classification

Globally, soils are divided into 10 major orders: Entisols, Vertisols, Inceptisols, Aridisols, Mollisols, Spodosols, Alfisols, Ultisols, Oxisols and Histosols. Georgia is almost entirely dominated by Ultisols, and non-coastal Georgia specifically the Udult suborder (Fanning & Fanning 1989:218-20). This is the predominant soil type on the upland landscape of Robins Air Force Base and on the site itself. Also present on part of the site is an upland Inceptisol.

4.2.1. Ultisols and Udults

Almost all Ultisols form in acidic parent materials. Udults have a deep water table, and dry periods are of short duration. All Ultisols exhibit an increase in clay content with increased depth. Well drained Ultisols, such as that on 9Ht46, have distinct, light-coloured E horizons and reddish argillic or kandic horizons. These horizons differ somewhat in their definition, but both are characterized by a significant increase in clay content and are usually recognized as Bt horizons. The predominant theory for the origin of increased clay in the Bt horizon is the decay and downward transport of clays within the profile (Buol et al. 2003:339-347). Ultisols are typically pre-Holocene in age (Ruhe 1984:24)

Abbott (personal communication) has argued that clays may at least in part have been deposited during the stabilization of landscapes of the late Pleistocene. As dust settled, fine-grained materials such as clay would have been the last aeolian deposit. He correlates this with the base-wide paucity of artifacts in the Bt horizon, and general absence of cultural material in deeper horizons.

4.2.2. Inceptisols

Inceptisols are weakly developed soils that can be formed by a wide variety of pedogenic processes, although all exhibit leaching. Inceptisols may develop a cambic horizon, but lack features of a mature soil. Cambic horizons are fine-textured with a developed structure and weak colour alteration. These horizons are often recognized as Bg or Bw horizons. On the current site, this horizon has been notated as Bw. Kandic or argillic horizons are not present (Buol et al. 2003:293-300). Inceptisol are described as being "youthful" or immature in their profile development, but this does not always imply the same of their actual chronological age (Fanning & Fanning 1989). Still, they are typically Holocene in age (Ruhe 1984:20).

4.3. Soil Evolution

Johnson and Watson-Stegner (1990) have developed a model of soil evolution that they have also used to explain the transport and burial of artifacts. The model is expressed as:

$$S = f(P,R)$$

Where S is soil, and P and R represent progressive and regressive pedogenesis. Progressive pedogenesis refers to processes that advance soil evolution. These are horizonation, developmental upbuilding and soil deepening. Horizonation is a catch-term for the suite of physical and chemical processes that form soil horizons. Developmental upbuilding refers to deposition slow enough to allow pedogenic assimilation of the new material. Soil deepening is the extension of the lower extent of the soil profile into subjacent unweathered material through leaching and weathering.

Regressive pedogenesis refers to processes that hinder or reverse soil development. These are haploidization, retardant upbuilding, and soil removals. Haploidization refers to processes that simplify and/or rejuvenate the soil profile, such as soil mixing. Retardant upbuilding is accelerated deposition that prevents horizon differentiation or deepening. Soil removal is the erosion or other removal of soil that exceeds the rate of deposition.

Soils may in their lifetime be dominated by progressive or regressive pedogenesis, but most experience the effects of both during their development. In a stable progressive depositional environment, artifact lines may be relatively intact. These represent an occupational surface buried through sediment deposition and faunal activity. In a regressive environment, artifacts may be vertically displaced by haploidization and/or horizontally displaced by soil removal.

4.4. The site landscape

The site consists mainly of an upland Ultisol resting on reddened paleosol, at the edge of a bluff overlooking the wetland floodplain of the Ocmulgee River. The eastern bluff represents two episodes of river meandering. The steeper slope of the southern meander suggests it is more recent (see Figure 4-1). However, during construction, soil was removed from the 5th fairway and pushed off the bluff edge. The sharp linear slope about 50 meters west of the bluff edge shows where soil was removed. This activity may have obscured the natural slope of the bluff edge. It also served to truncate the entire upper soil along a significant length of the bluff edge, along with any cultural material within it. With the exception of this area, most of the site exhibited an intact plowzone. Therefore, golf course construction did not significantly affect the subsoil components in the rest of the site.

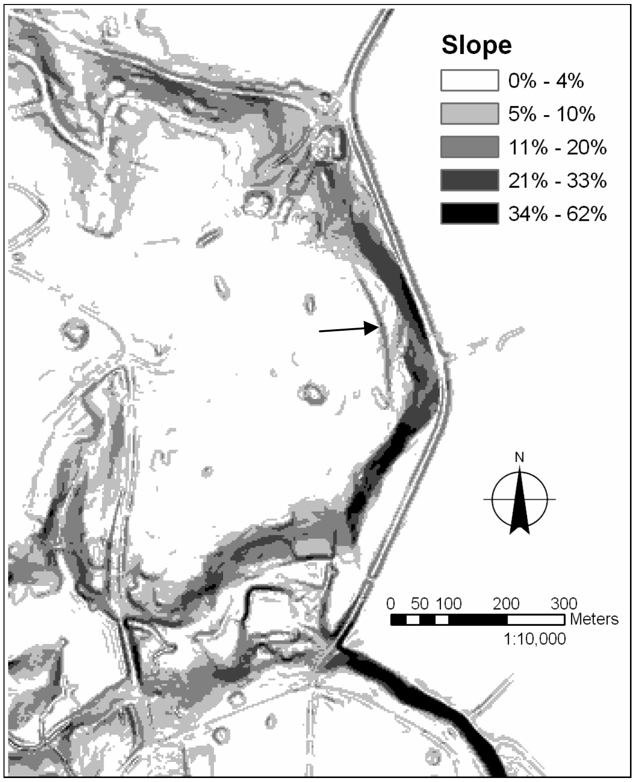


Figure 4-1: Slope diagram of the site area (arrow points to strip where soil was removed).

The northern portion of the site saw significant erosion during the Holocene. The northeastern portion of the survey area is dominated by a reddened Inceptisol, characterized by its colour, its lower clay content, and layers of gravel indicating erosional deposition. The typical profile for this soil is Ap-E-EB-BE-Bw-BC underlain by a reddened paleosol, though in many cases the E horizon and a portion of the EB have been assimilated into the plowzone. The upper portion of the profile, roughly the E and EB horizons, represents late Holocene deposition in a more stable, progressive environment. Therefore, components in this portion of the profile may have remained intact. However, the transition in the profile to a state of progressive pedogenesis is not always clear, and may vary across the soil landscape.

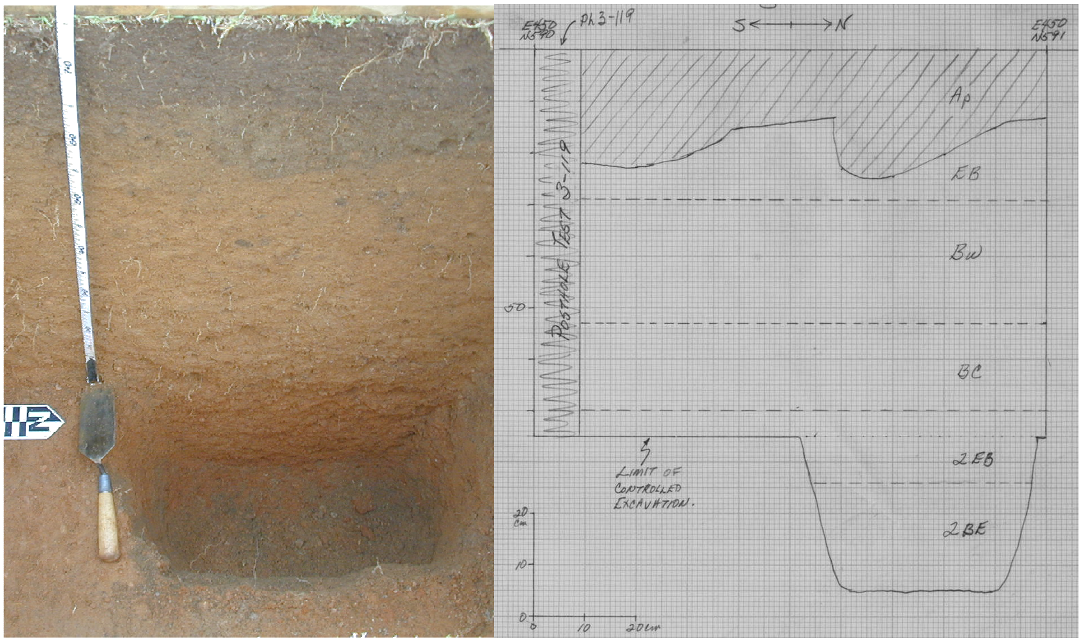


Figure 4-2: Profile of Test Unit 15, exhibiting an upland Inceptisol overlying a reddened paleosol

The rest of the survey area is dominated by an Ultisol. Here the typical profile is Ap-E-EB-BE-Bt, underlain by the same reddened paleosol. There is evidence of rilling around the area of the Inceptisol, and overthickened profiles in areas suggest rapid deposition causing retardant upbuilding, which acted to blur the distinctions between the E, EB and BE horizons. The E and EB horizons appear in most cases to roughly correspond temporally to their counterparts in the Inceptisol profile.

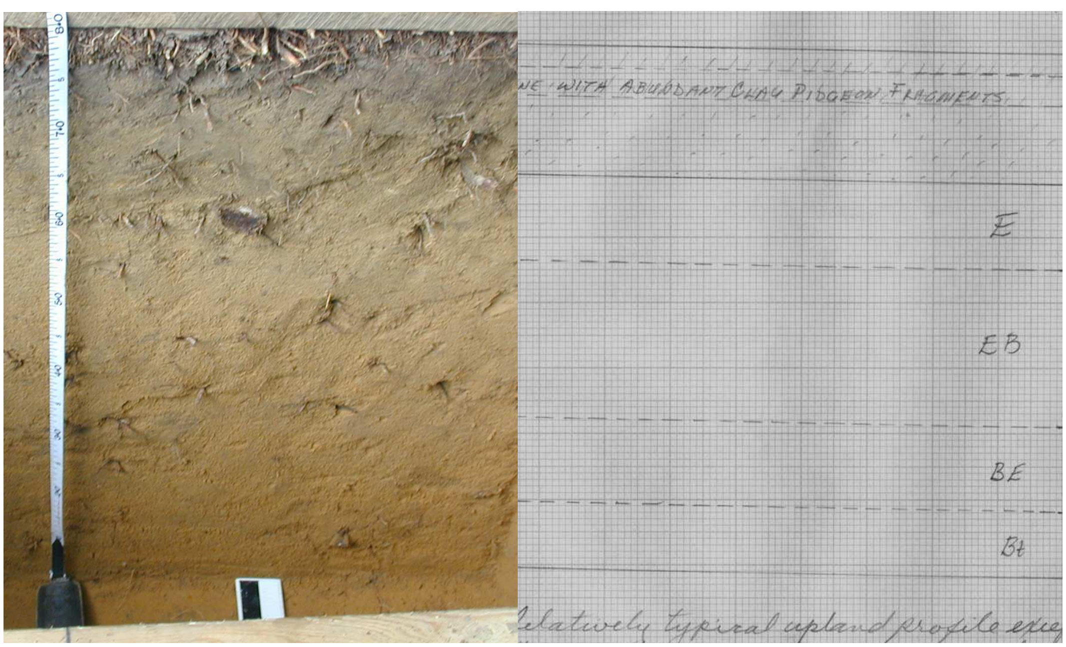


Figure 4-3: Profile of Test Unit 12, exhibiting a typical upland Ultisol profile

Chapter 5. The project database

In order to store, display, analyze and manipulate soil and artifact, and to produce output suitable for introduction into ArcGIS, it was necessary to design and populate a new relational database in Microsoft Access. The database was not designed to be extendable to other sites, nor to become a multi-user database for use beyond the current project. Its sole purpose was to support the analysis required in the present study.

The project database stores soil data from the posthole tests of all the 9Ht46 site area archaeological surveys since the Pine Oaks Golf Course maintenance shed survey in 2000 (Abbott 2000). It also stores complete artifact data from all the aforementioned posthole surveys, as well as complete artifact data from all seventeen test units. Also included are diagnostic artifacts found outside of the stratigraphically controlled surveys, as well as detailed data on all small finds. The database was made into a geodatabase, storing point and polygon feature class data from the posthole surveys and test units.

Table and attribute metadata can be found in the geodatabase's ESRI XML metadata.

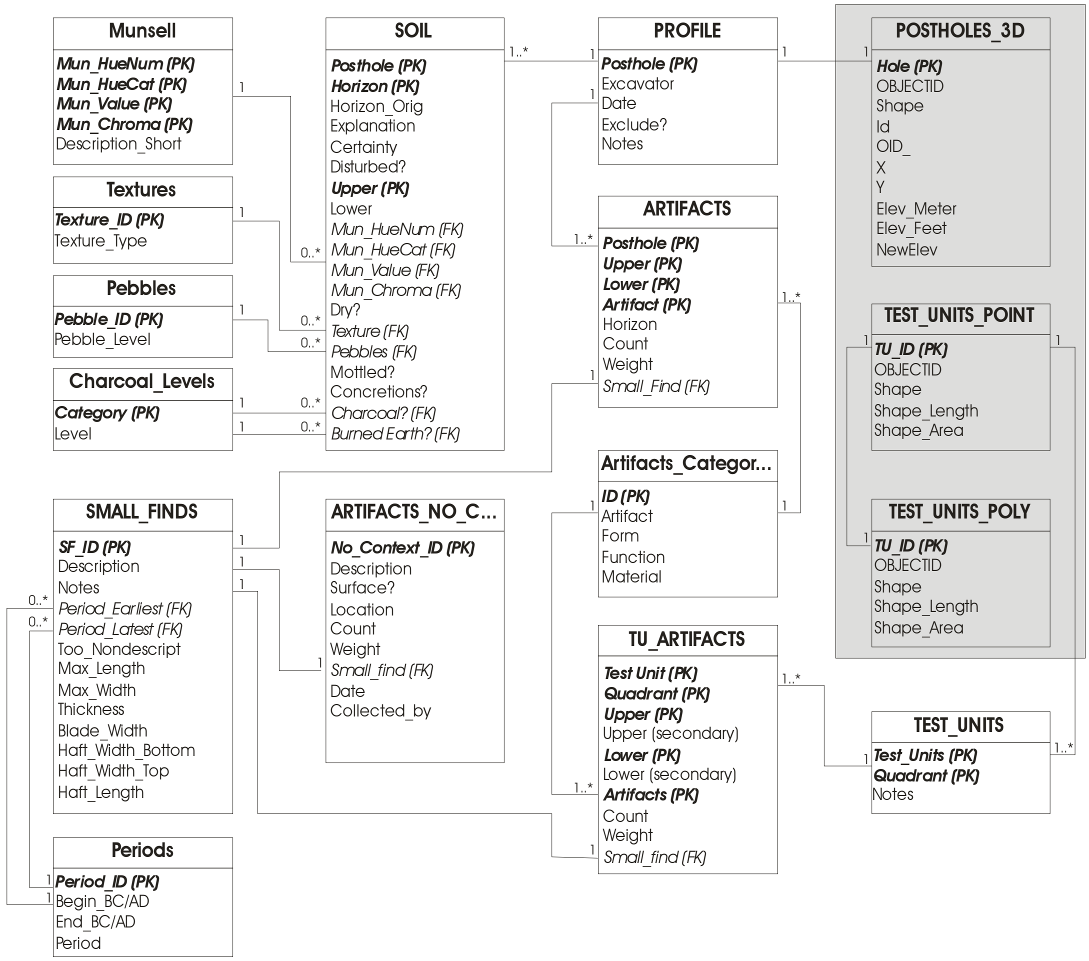


Figure 5-1: Entity relationship diagram of the project database. The grey area represents the ESRI geodatabase. (PK = primary key, multiple PK = composite key, FK = foreign key)

5.1. Database tables

5.1.1. The 'Profile' table and 'Soil' subtable

The 'Profile' table holds general data unique to each posthole, including the posthole number, excavator initials, excavation date, and notes. It also includes a Boolean field to specify if the posthole should be excluded from the soil interpolation.

The 'Soil' table contains descriptive data about each morphologically distinct 'layer' in the profile. The word 'layer' is used hesitantly, because the records do not represent actual layers in an archaeological sense, merely qualitative changes in the soil that are often quite transitional in nature. This data structure allows the soil attributes to be consolidated to analyze the vertical distribution of those attributes.

The ‘Soil’ table is made up of the posthole number, the original soil horizon designation, the final horizon designation, a ‘certainty’ indicator, the depths of the beginning and end of the layer as estimated from visual inspection of the soil profile sheets, the Munsell (1975) hue, value and chroma, a Boolean indicator for dry colour readings, the soil texture, pebbliness, Boolean fields for presence of mottles and concretions, and fields for amount of burned earth and charcoal.

The ‘certainty’ field was introduced in order to track certainty of and changes to the original horizon designation. No change is indicated by ‘3’. If the interpretation on the soil profile form was followed by a question mark, the value is ‘2’. A value of ‘1’ indicates that the interpretation was altered during the error-checking phase of this study (refer to section 7.2). If no interpretation was made on the original form, the value is ‘0’.

Later in the study, an additional Boolean field was added to indicate whether the layer belonged to the Inceptisol, as discussed in section 7.4.

5.1.2. Geodatabase tables

These are geodatabase tables for the ESRI point feature class on the posthole test locations. ‘Postholes_3d’ contains an attribute field for the posthole number, as well as attributes calculated in ArcMap, including the X and Y coordinates, the surface elevation in feet at two scales of precision, and the surface elevation in meters calculated from the two-decimal precision foot elevation.

The ‘Test_Units_Point’ and ‘Test_Units_Poly’ and the point and polygon feature classes for the test unit locations, respectively. The point table contains X and Y coordinates, and a two-decimal precision elevation in feet.

By storing these feature classes in the Access database, queries can incorporate locational data without requiring such data to be duplicated between the GIS and the relational database.

5.1.3. Artifact tables

The ‘Artifact’ table stores artifact data for the posthole tests. Each row represents a particular artifact type from a particular posthole excavation level. It contains fields for a posthole number, an upper and lower limit of excavation, artifact description, artifact count, total weight, and small find ID. There is also a ‘Horizon’ field which contains any horizon information written on the artifact bag. This is for reference only, and cannot be relied upon as interpretations during excavation were less informed that the full interpretation following the posthole excavation. Horizon position is determined by queries comparing the depth ranges of the excavation levels with the depth ranges in the 'Soil' table

Artifact descriptions were not indexed, but the field was made a combo box which returned a DISTICT query on itself, such that all values entered previously can be chosen and will autofill once typing begins. As the author was the sole user of the database, this was sufficient for the purposes of the database.

The 'TU_Artifacts' table is a subtable of the 'Test_Units' table, which stores data specific to each test unit quadrant, specifically the test unit number, the quadrant (or fill / plowzone context), and a notes field. The 'TU_Artifact' table has fields for the test unit number, quadrant, upper and lower excavation limits (and secondary limits if the level was not of uniform depth), the artifact type or "No Material", artifact count and weight, and a small finds ID.

For artifacts that were found during surface collection or construction monitoring, a separate table called 'Artifacts_No_Context' was created. This assigned an automatically generated integer ID, and stored data about the description, location, count, weight, collection date, collector initials, small find number, and a Boolean field indicating if the artifact was collected from the surface.

The 'Small_Finds' table is a special table related to the above three tables through the automatically generated small find number. Duplication between the three parent tables is prevented via a custom VBA script discussed in section 5.2.1 and appendix section A2.4. The table stores data that is only required for small finds. It contains a description field which defaults to the parent table description when a new record is created using the aforementioned VBA script from one of the artifact forms. This allows a more extended description to be included if desired. The 'Notes' field stores additional information, such as the identifications made by consulted specialists.

If at least a tentative period identification can be made, this can be stored in the 'Period_Earliest' and Period_Latest' fields as a two letter ID code. If, for example, a projectile point was identified as being Archaic, but was too nondescript to identify a subperiod, this could be recorded as an earliest period of Early Archaic ("EA") and a latest period of Late Archaic (“LA”). A Boolean field indicates if the period range identified was tentative or relatively certain. In the example above, the range indicated could be considered certain.

The rest of the fields store metrics where applicable. These are maximum length, width and thickness, blade width, bottom and top haft width, and haft length.

5.1.4. Reclassing tables

Two tables were created for the purposes of recategorizing and indexing data from another table. The first of these is the ‘Horizon_ID’ table. This contains a field that stores all of the horizons specified in the ‘Soil’ table. Another field ranks the horizons according to the order in which they occur through the entire site. A third field at first grouped horizon classifications that effectively described the same horizon, but was later generalized to group horizons into the layers for the soil model.

The second reclassing table is the ‘Artifact_Categorize’ table. This table was created after all artifact data had been entered, and is a list of all artifact descriptions that occur in any of the artifact tables. There are three categorization fields: ‘Form’, ‘Function’ and ‘Material’. These were created to allow the investigation of spatial patterns of different types of artifacts over the site area. The classifications are somewhat arbitrary and are only experimental. They should not be considered a theoretically sound, formal classification system.

5.1.5. Supporting tables

The ‘Charcoal_Levels’ table actually populates the drop-down selection of the charcoal and burned earth fields in the ‘Soil’ table. The values are “None”, “Little”, “Common” and “Abundant”.

The ‘Munsell’ table is an index of text descriptions associated with the Munsell soil colours as defined in the Munsell Soil Color Charts (1975). This was not completed because it was not needed for the study, and because of lack of access to a Munsell chart.

The ‘Pebbles’ table populates the corresponding field in the ‘Soil’ table. The values are “somewhat pebbly”, “pebbly”, “very pebbly”, “gravelly”, and “very gravelly”.

The ‘Periods’ table defines the descriptions of the Period IDs used in the ‘Small_Finds’ table, as well as beginning and ending dates for each subperiod. However, this table was not referred to in any queries.

‘Textures’ is an index of the soil texture short descriptions that populates the drop-down selection in the ‘Soil’ table. It also includes the full text description of the texture. The naming convention for soil textures is in part derived from the USDA Field Book for Describing and Sampling Soils (Schoenberger et al. 1998).

5.2. Forms

5.2.1. The ‘Profile’ form

This form displays the ‘Profile’, ‘Soil’ and ‘Artifact’ data for each posthole. It also contains an image control that displays a scanned image of the original soil profile form, to ease data entry and to provide a reference to the original data. Also, subtleties in the filling out of a profile form can be informative, though impossible to capture in a tabular format. This image was loaded using a VBA script described in section A2.1 of the appendix.

Another custom-made VBA script, attached to a button control in the ‘Artifacts’ subform, provides a link to the ‘Small_Finds’ form (see appendix section A2.4). If the artifact record is already assigned a small find number, the corresponding small finds record is opened. If not, a new small finds record is recorded, and the new small find number is automatically entered into the ‘Artifacts’ subform. The ‘Description’ field if the small finds record is given an initial value equal to that in the ‘Artifacts’ subform.

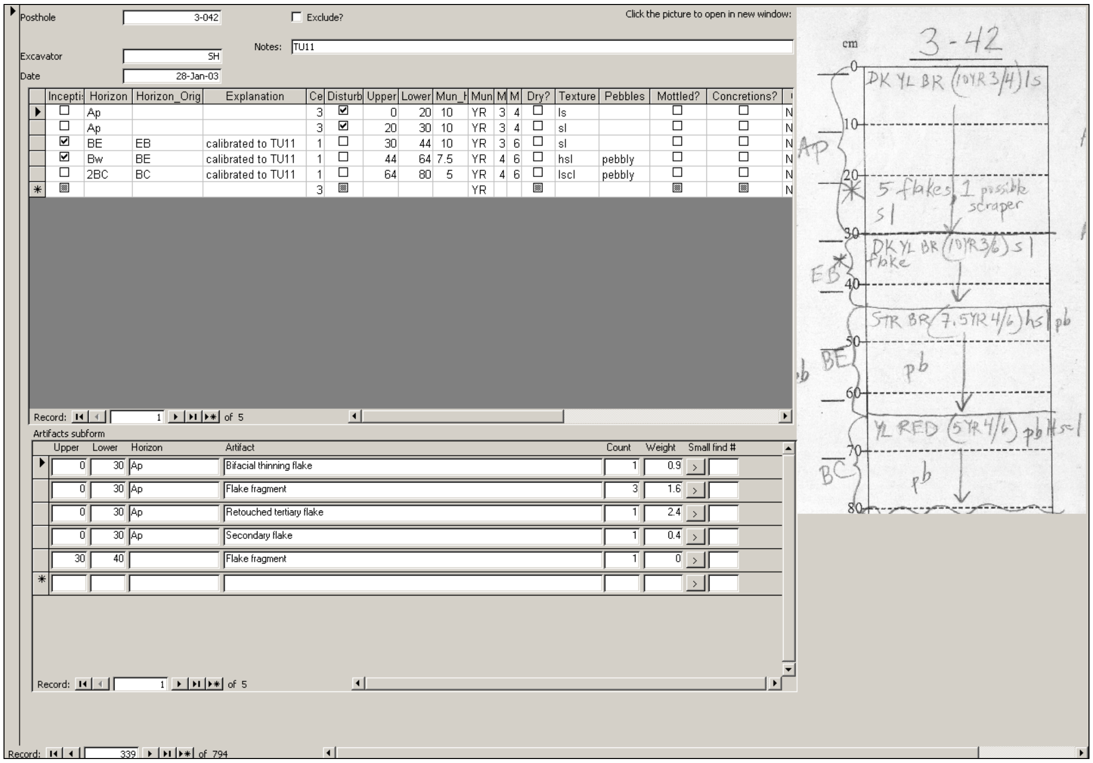


Figure 5-2: The 'Profile' form of the Access database

5.2.2. The 'Test_Units' form

This form displays data from the 'Test_Units' table and the 'TU_Artifacts' subtable. The artifact subform has a button control for each artifact record that uses the same 'Small Finds link' VBA script described in section 5.2.1 and appendix section A2.4. Another button control in the 'Test_Units' main form provides a link to the scanned test unit profile sketch, as described in appendix section A2.5.

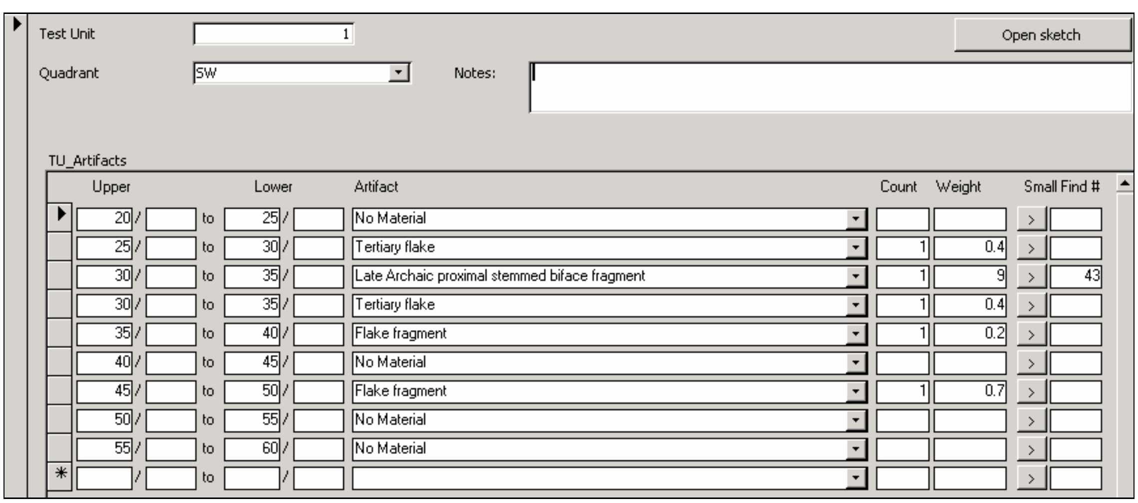


Figure 5-3: The 'Test_Units' form.

5.2.3. The ‘Artifacts_No_Context’ form

This is a simple one-table form that displays data from the ‘Artifacts_No_Context’ table. It also includes a button control that initiates the ‘Small Finds link’ VBA script described in section 5.2.1 and appendix section A2.4.

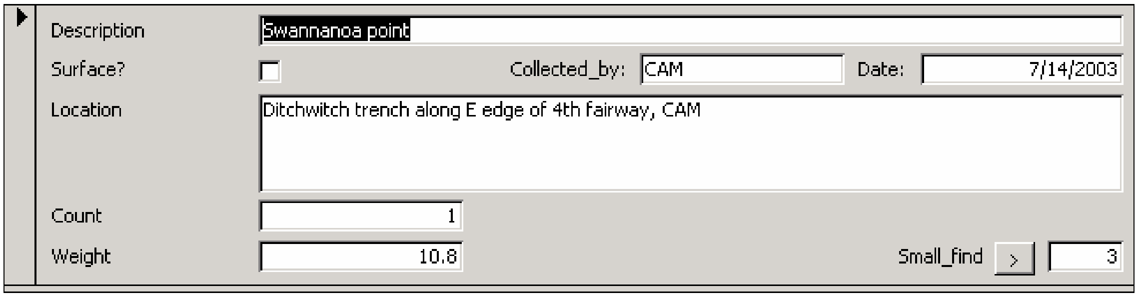

Description: Swannanoa point
Surface? Collected_by: CAM Date: 7/14/2003
Location: Ditchwitch trench along E edge of 4th fairway, CAM
Count: 1
Weight: 10.8 Small_find > 3

Figure 5-4: The 'Artifacts_No_Context' table.

5.2.4. The ‘Small_Finds’ form

The ‘Small_Finds’ form is another one-table form that displays data from the table by the same name. One enhancement that could be made to this form would be a VBA script to link back to the current record’s parent record in the appropriate artifact form.

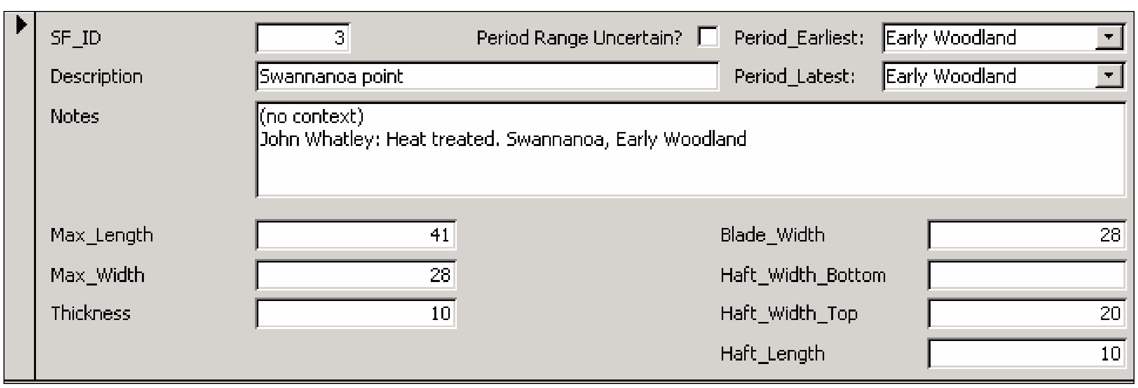

SF_ID: 3 Period Range Uncertain? Period_Earliest: Early Woodland
Description: Swannanoa point Period_Latest: Early Woodland
Notes: (no context)
John Whatley: Heat treated. Swannanoa, Early Woodland
Max_Length: 41 Blade_Width: 28
Max_Width: 28 Haft_Width_Bottom:
Thickness: 10 Haft_Width_Top: 20
Haft_Length: 10

Figure 5-5: The 'Small_Finds' form (artifact is the same as in Figure 5-4.)

Chapter 6. Interpolation Techniques

Interpolation is the estimation of values of a variable at unknown locations based on locations for which values are known, using a mathematical algorithm. Some techniques use simple linear equations to approximate values, while others are quite complex. All are based on Tobler's First Law of Geography, which states that "everything is related to everything else, but near things are more related than distant things" (Tobler 1970).

There are a multitude of interpolation algorithms, and a review of all possible methods is beyond the scope of this paper. There is little agreement on what methods are best, and the choice of which to use is largely dependent on the specific needs of the researcher. The methods used here are Inverse Distance Weighting and Universal Kriging.

6.1. Inverse Distance Weighted Interpolation

Inverse Distance Weighted, or IDW, interpolation is a relatively simple technique commonly used by archaeologists. Despite its simplicity, it has been shown in several cases to be as good as or better than more sophisticated algorithms (see Zimmerman et al. 1999:376 for a review).

In IDW, the value of an unknown point is predicted using neighboring known points, based on the assumption that the unknown point will more closely resemble near points. Known points are weighted in inverse proportion to their distance from the unknown point. As such, points differ from each other in a linear fashion as a direct function of distance. The square roots of the distance of the unknown point to each known point are averaged, producing a predicted value for the unknown point. The final equation is:

$$\hat{z}(x) = \frac{\sum_{i=1}^{n} \sqrt{d_{ij}}\, z(x_i)}{\sum_{i=1}^{n} \sqrt{d_{ij}}}$$

where $\hat{z}(x)$ is the interpolated value at the unknown point, $z(x_i)$ is the known value at location $\boldsymbol{i}$, $\sqrt{d_{ij}}$ is the distance from the unknown point to location $\boldsymbol{i}$, and $\boldsymbol{n}$ is the number of known sample points.

IDW is not an exact interpolator. In other words, it "smoothes" the interpolated surface such that the predicted surface does not pass through the known points. The degree of smoothing is controlled by the number of neighbors used in the prediction. The more neighbors incorporated in the calculation, the greater the difference between the actual known value at a location and the predicted value at the same location (Wheatley & Gillings 2002:193-95).

6.2. Kriging

Kriging is a set of sophisticated interpolation techniques that are the most prolific contribution of geostatistics. The field of geostatistics was developed because of the failure of most classical statistical methods in dealing with spatial variables. Although the original application of kriging techniques was in the mining industry, it is now used by most disciplines that deal with variables that vary with some degree of continuity over space. Archaeology remains an exception, as archaeologists have tended to shy away from its use. Notable exceptions are Zubrow & Harbaugh's (1978) study of the applications of kriging in predictive modeling, Ebert's (1998, 2002) application of kriging techniques for mapping bulk struck flint distributions from fieldwalking, and two recent case studies conducted by Lloyd & Atkinson (2004).

Unlike IDW, kriging does not assume that the variation between two points is linear. It attempts to determine a function that explains the nature of the variation between points based on the spatial relationship between known points, and then uses this function to predict unknown points.

6.2.1. Regionalized variable theory

In geostatistics, spatial variation is conceptually divided into a deterministic or structural component and a random component (Lloyd & Atkinson 2004). The structural component is widely referred to as the spatial trend. The random component can be further divided into a random spatially correlated element and a random noise element. This is called *regionalized variable theory*. While the structural component can be predicted, the random noise component by definition cannot. The combination of all three components accounts for variation in the real world. Random error accounts for the discrepancy between predicted and actual values (Wheatley & Gillings 2002:193-95).

6.2.2. The semi-variogram

The semivariogram, also referred to simply as the variogram, is central to kriging and geostatistics in general. It is based on the semivariance, which is half the total difference between a point $\mathbf{Z_{(x)}}$, and all other points $\mathbf{Z_{(x+h)}}$, where **h** is a vector, known as the lag, representing a given distance. The semivariance is expressed mathematically as:

$$\gamma(h) = \frac{1}{2N(h)}[Z_{(x)} - Z_{(x+h)}]$$

The semivariogram is a scatter plot of the semivariance, on the x-axis, against the lag, on the y-axis. It displays the degree of variation as a function of distance between points. A mathematical model is then 'fitted' to the scatter plot to describe the pattern of spatial variation in the same way as a regression line. This typically appears on the semivariogram as a curved line. In a standard semivariogram, this line begins at the origin, meaning that the values of two points with a distance of zero will have the same value. In some cases this is not true, most notably when there is a certain degree of measurement error. Therefore, a nugget effect may be incorporated into the semivariogram model so that the line representing the model intersects the y-axis above the origin. A nugget value is also used to represent variance at a smaller scale than the sampling interval. Still, when a nugget is used kriging acts like a smoothing interpolator rather than an exact interpolator (Kies et al. 2002).

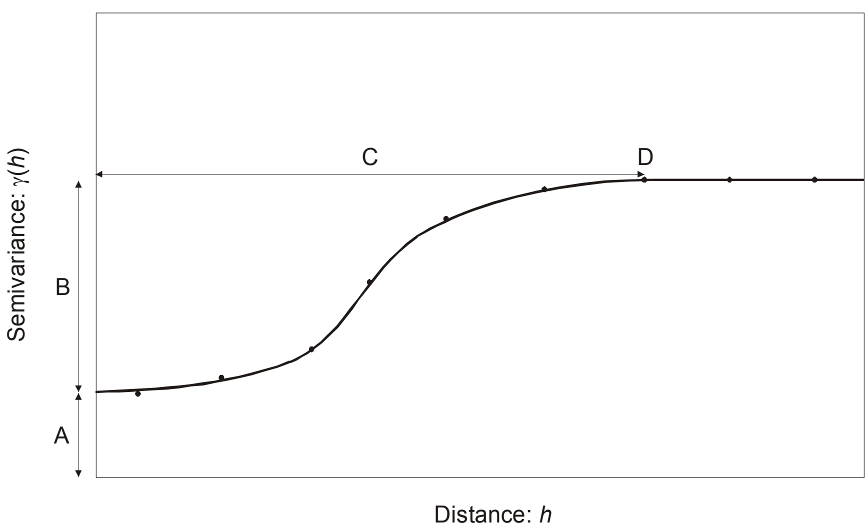


Figure 6-1: The components of a semivariogram: (A) the nugget, (B) the structured component, (C) the range, and (D) the sill

The point at which the semivariance reaches its maximum value is called the sill. This value is the sum of the nugget, and the structured component. If there is no nugget, it is equivalent to the structured component. The sill is only present in bounded models. Unbounded models, such as linear and logarithmic models, continue to increase in semnivariance to an infinite distance. The lag at which the sill is reached is called the range. In most mathematical models, sample pairs that are further apart than the range distance have an equal semivariance, represented by the ‘flat line’ in the semivariogram model. Essentially, this means that points sample points at a greater distance than the lag are unrelated and are given a weight of zero when estimating the value of an unknown point.

When there is a significant directional influence on semivariance, i.e. sample points are more similar in a particular direction, than an anisotropic model can be used. In this case, variograms are produced using only points aligned in varying directions, usually at 0, 45, 90 and 135 degrees. If the data exhibits anisotropy, the shape of the semivariogram will be different depending on its direction (Ebert 2002, Lloyd & Atkinson 2004, Zubrow & Harbaugh 1978).

6.2.3. Kriging

In kriging, the semivariogram model is used to weight the sample points when estimating the value of an unknown point. Therefore, the weighting is dependent not solely on linear distance, as in IDW, but on the nature of the spatial relationship across the sampling area. Values at sample locations near to the point to be estimated still carry less weight than those further away, but the weighting is dependent on the shape of the semivariogram model.

Like in IDW, weighted values are only calculated from sample points within a predefined neighborhood. Generally, homogeneous datasets may benefit from a larger neighborhood, but more locally variable datasets should be interpolated with a relatively small neighborhood. Cross-validation, described below, can help in selecting appropriate size of neighborhood. The neighborhood may be defined by a fixed search radius, a maximum and minimum number of sample points, or a combination of the two.

The mathematically model of the semivariogram is essentially a combination of three equations. The nugget, when present, is used to describe the model in the case of a lag of zero. In bounded models, another equation describes the model when the lag is greater than the range. The core equation describes the behaviour of the model when the lag is greater than zero but less than the range.

The shape of the semivariogram influences how rapidly and at what distance similarity of points tends to decline as they compared at greater distances. A relatively flat curve would suggest a fairly uniform distribution, in which data points at increasing distances tend to remain similar in value. On the other hand, in a model in which semivariance increases steeply with distance, values tend to vary locally. In a model in which semivariance remains relatively stable at short distances but increases sharply at larger distances, such as in Figure 6-1, values tend to be similar within local regions but exhibit a high degree of variance globally (Ebert 2002).

6.2.4. Cross-validation

Of course, the shape of the model depends greatly on the mathematical model used to represent the semivariogram. The accuracy of kriging estimates also is largely influenced by this choice. While models were fitted by eye earlier in the history of geostatistics, and sometimes still are, this technique requires a high degree of expertise and is arguably less accurate than a mathematical method. Cross-validation using least squares is the most recommended method for model fitting (Oliver, Webster, & Gerrard 1989), and is the method used here.

In cross-validation, the kriging formula is used to estimate values at known sample locations, omitting the value of the cross-validated point from the calculation. The difference between the observed value and the estimated value at that point is the actual deviation between the model's estimate and the observed reality. This is repeated for all sample locations in the dataset (Ebert 2002).

Predicted and actual values can be plotted against each other and displayed as a regression line, as they are in ArcGIS Geostatistical Analyst. If there is little error, the regression line will approach a 1:1 line, where values for each axis will be equal. As error increases, the line will divert from the 1:1 line (see Figure 6-2).

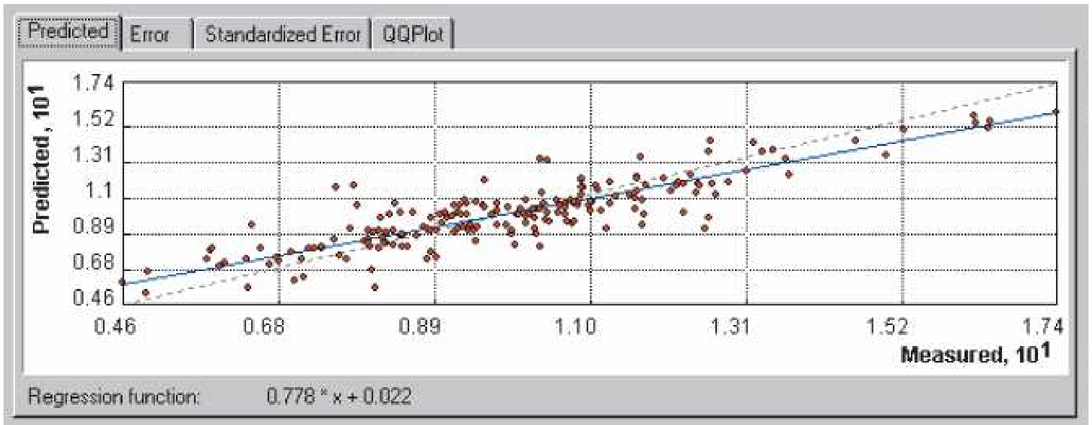


Figure 6-2: Predicted error plot in ArcGIS Geostatistical Analyst (from Johnston et al. 2001)

ArcGIS also provides several error statistics for cross-validation. If the standardized mean predicted error is close to zero, prediction errors are centered on the measurement values, i.e. unbiased. The root-mean-square prediction error is an indication of how close the predicted values are to the measured values, and should be as small as possible. The root-mean-squared standardized error is an indication of whether estimated values are being over- or underestimated by the model. If the measure is greater than one, values are being overestimated, while if it is less than one, values are being underestimated (Johnston et al. 2001:189-91).

Cross-validation can be repeated with several models, with and without anisotropy, and with differing search neighborhoods, in order to aid in the selection of the most appropriate parameters for estimating the final interpolation surface. It should, however, be noted that cross-validation only tells us how well the model fits to the values already known, which are the basis for the model in the first place! Since these values are hoped to be representative of the entire survey area, it is assumed that the cross-validation error approximates the real error. Nothing short of field-checking the model can verify the actual validity of the mode

Chapter 7. The soil model

The relatively smooth modern surficial landscape of the site belies the severe topography of the soils beneath. In some areas, especially outside areas of high artifact density, the soils clearly resemble the upland Ultisol common throughout most of the Robins Air Force Base. In other areas this typical profile is again found, but with greatly overthickened horizons. In many cases the transition from normal to overthickened is quite abrupt. The northeastern quarter of the site is dominated by a younger Inceptisol resting directly on the red paleosol that presumably underlies the entire site.

It is hoped that visualizing these phenomena in a three-dimensional model would help to make their meaning clearer, and allow the user to inspect the soil landscape in a more intuitive format than a stack of soil profile forms or even a series of fence diagrams.

7.1. Software considerations

Traditionally, two-dimensional maps or GIS layers have been used to represent soil and landscape patterns. This is still the most common method for displaying soil data, despite the fact that soils exhibit complexity that can only be described in three dimensions. Studies that attempt to represent soils in three dimensions using quantitative methods are rare, and will be reviewed below.

After considering several software platforms for producing a soil model in three dimensions, ESRI ArcGIS, GRASS GIS, and VRML stood out as the most appropriate solutions. After weighing their strengths and weaknesses, as well as considering the scope and time frame of the current project, it was decided that ArcGIS would be the best choice for producing the desired results.

It should be noted that another promising application that was not considered due to time and software constraints is Intergraph's Voxel Analyst. This program supports true 3D interpolation and visualization. It is, however, dated and no longer supported by Intergraph. It also does not function on Windows 2000 or XP platforms. Voxel Analyst is currently available free of charge at: ftp://ftp.intergraph.com/gis/fixes/voxel202.zip.

7.1.1. VRML

Complex soil models have been produced in VRML by several researchers. The advantage of VRML is that it produces true 3D objects. The possibilities for computation and manipulation are open-ended, since the software is essentially built from scratch by the developer. However, this also means there is a significant time investment, not including the time required to learn VRML programming.

Sabine Grunwald has spearheaded several projects (Grunwald & Barak 2001, Grunwald & Barak 2003, Grunwald et al. 2001) using object-oriented VRML programming to produce polyhedron and voxel-based interactive soil models, neatly displaying soil horizons as well as other three-dimensional variables. The results of some of her work can be viewed at: http://grunwald.ifas.ufl.edu. The soil landscapes used in their models were more complex than those used in other studies, and the outcome is the closest to the goals of the current project. Their core data structure is also very similar to that of the present study.

However, as promising as VRML technology is for such application, the time required to complete such a project is beyond that available for the current study, especially given no prior knowledge of VRML programming. X3D is a technology currently under development which promises to replace VRML. It is recommended that researchers with similar goals consider its application in their work.

7.1.2. GRASS GIS

GRASS has the advantage of being a true 3D GIS, employing voxel technology. It is also open-source, opening up the possibilities for analysis to the imagination and programming abilities of the developer. Unlike VRML, the basic GIS infrastructure already exists in GRASS, and does not need to be built from scratch. 3D interpolation algorithms for inverse distance weighting (s.vol.idw) and regularized spline with tension (s.vol.rst) are built in to the software package of GRASS. GRASS also includes a 3D viewer based on the OpenGL graphics engine.

Masumoto et al (2004) used GRASS to interpolate geologic surfaces, using custom-developed rules to control the interpreted stratigraphy where surfaces intersected. These surfaces were then used to generate volumes to a specified depth. Since in the current model there are numerous cases of intersecting horizons and layers, this technique is promising. However, the bottom of the volumetric model would need to be defined by the extents of excavation, not a horizontal arbitrary depth.

In a very interesting study, Ameskamp & Lamp (1998) used fuzzy, continuous soil classification to produce three-dimensional volumetric soil models in GRASS using aerial photo data coupled with soil survey expertise. This is an admittedly low-precision but still highly efficient method. The approach is worth noting, but not applicable to the current study, which uses higher resolution, quantitative primary data.

A study by Suwanwiwattana et al (2001) makes use the 3D volumetric interpolation capabilities of GRASS to produce a model based on soil boring data from Bangkok. Their approach uses borehole data to produce 2½-D isosurfaces of horizon boundaries. These are then visualized in three dimensions. However, the interpolation method used was spline with tension, which resulted in a very blocky-looking model.

While more user-friendly than VRML and equally open-ended, GRASS is UNIX-based and does not function fully when run in an emulated environment on the Windows interface. It also has a high learning curve relative to other GIS applications. While the software is well-suited to soil modeling, it was decided that a GRASS-based model was also beyond the scope of the current study.

7.1.3. ESRI ArcGIS & ArcScene

Mendonça Santos et al (2000) produced a soil model using ArcINFO coupled with several other software packages. Their approach was to produce DEMs from TINs of each soil horizon, generated using soil coring data that included horizon depth and thickness. However, their 3D soil volume model was produced using a modified version of Király's Fen Codes program (described in Bouzelboudjen & Kimmeier 1998). While this method normally employs geostatistical interpolation techniques, their final model is visibly TIN-based. TINs have the advantage of being simple to work with, but they do not attempt to recreate a semblance of the original landscape.

A third-party extension that was not available for the current project, and also not known about until late in the project's execution, is EQUIS for ArcGIS. Weaver, Bate & Autio (2003) have demonstrated its efficacy in managing borehole data and producing fence diagrams. However, that is not the final aim of the current project, and these tasks was accomplished using the custom Access database described in Chapter 5 and the custom

VBA fence diagram tool described in section 7.3. While EQUIS can assist in producing solid models, additional processing with other software packages is necessary.

ArcGIS was chosen as the central software application for soil and artifact modeling. While it cannot produce true 3D volumetric models, the goal of this project is a visually interpretable model, and this can be accomplished using ArcScene. The author's familiarity with ArcGIS and the ability to integrate Microsoft Access databases and custom Visual Basic scripts place an ArcGIS-based project within the scope of this dissertation.

7.2. Error-checking and preliminary inspection

The soil interpretations from the field exhibited discrepancies that had to be resolved before the data could be used for interpolation. This data had been recorded in multiple surveys spanning several years, by individuals with differing expertise in soils. Also, portions of the site had very confusing soils, which were not readily interpretable during the survey. It was necessary to thoroughly inspect the horizon designations to ensure agreement between neighboring soil profiles, especially where surveys overlapped.

Morphological attributes of groups of neighboring profiles had to be compared, ensuring that these corresponded with sensible agreements in interpretation. Where there was not an agreement between interpretations, transects of profiles had to be viewed in order to determine if this represented a genuine soil transition. Also, it was necessary to consider the relative elevations of soil profiles to compare the relative vertical position of soil horizons.

7.3. The 'Draw Profiles' VBA tool

To this end, a tool was produced using a VBA form to draw the profiles of postholes selected in ArcMap. To use the tool, the user selects the postholes of interest, often in clusters or transects, and presses a custom button that initiates the tool. A connection is established from ArcGIS to the Access database and attribute data on the selected postholes is stored in the random-access memory (RAM). This is done by looping through all selected features in the selected layer in ArcMap and querying their attributes from the Access database using dynamically produced SQL statements.

Each "layer" in the 'Soil' table is then drawn using VBA form labels. These are vertically sized to scale, and all profiles are aligned according to their relative elevations. The soil description appears in the rectangle representing each layer, and the soil texture and hue are symbolized again by the label's border and background colours, respectively. The width, spacing, vertical scaling and vertical offset can be adjusted by changing the default values in the text boxes at the top of the form.

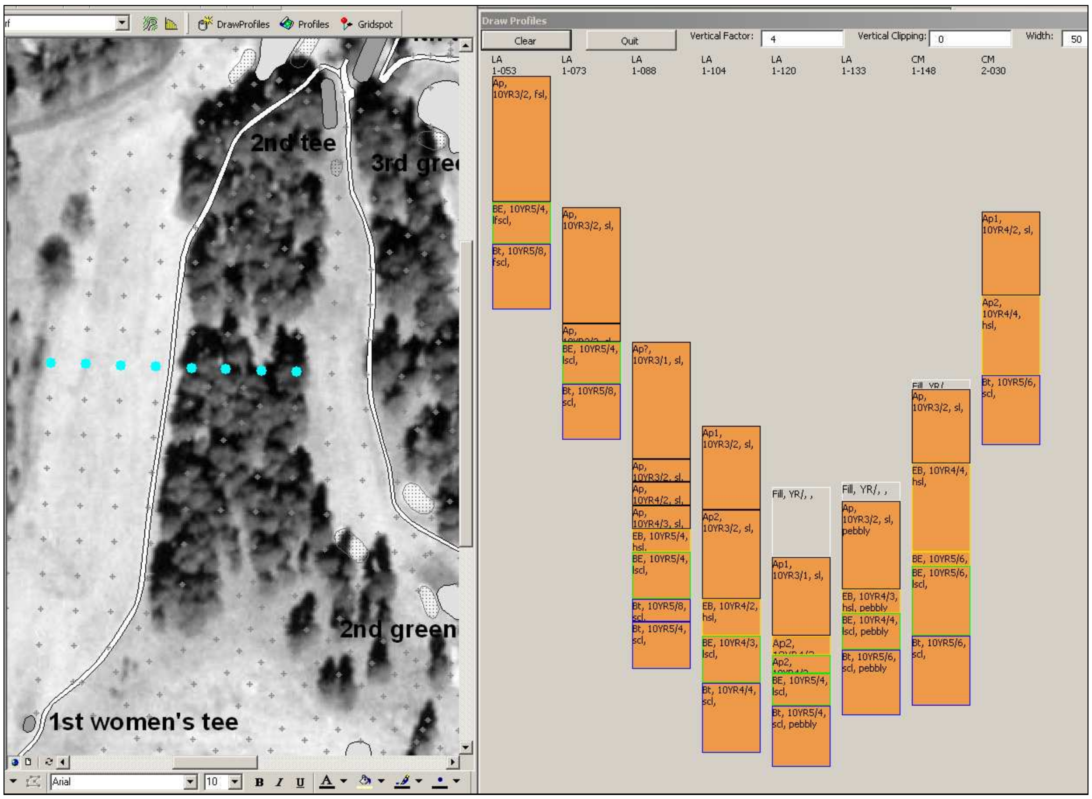


Figure 7-1: The 'Draw Profiles' tool

By colour-coding these two important soil attributes, similar soil layers could be noticed at a glance and their similarity checked upon closer examination of their properties. This was essential for inspecting such a large and spatially complex dataset. Many errors or differences in interpretation were made immediately obvious, while true soil transitions could be investigated. A thorough investigation of all survey points followed. Profiles were compared in clusters and unusual or uninterpreted profiles were cross-checked against all their neighboring profiles. Profiles were also compared in transects to determine whether and how profile interpretations should be corrected, and to investigate large-scale soil transitions.

If a correction needed to be made, its record was revised in the Access database and the profile was refreshed. Since the profile display script derives its data from the database directly, this provided instant feedback and verification of corrections.

Future improvements to the tool could be an absolute scale along the left edge, and automatic vertical scaling in cases when the default value causes the diagrams to extend below the lower limits of the display. Also, the tool was designed for a dual-screen display at a fixed resolution. If the tool were to be modified in the future to allow more universal usage, the ability to resize the tool to accommodate other displays would be necessary. The tool in its current form was designed for utilitarian purposes only, and therefore time constraints did not allow less immediately functional features to be included.

7.4. Reclassing soil data

Soil profile data in the database was stored in two tables: a master table containing general posthole information, and a subtable with a record for each morphologically distinct "layer" in the soil profile, and columns storing the layer's morphological characteristics.

This data format is useful for viewing descriptive soil data and identifying potential errors, but the data needed to be transformed for the purposes of modeling. The modeling input needed to be a single table with a row for each posthole and columns storing the elevation or thickness of each modeled soil layer. In order to be useful, the soils needed to be modeled as aggregated horizons or soil layers.

First, an order had to be defined for soil horizons found throughout the site. This was done according to the natural soil order as defined in the USDA Keys to Soil Taxonomy (Soil Survey Staff 2003). For more specific soil horizon designations that had no necessary natural order, the order observed in the field was used.

Second, the horizon data recorded in the field is arguably too complex for producing an intelligible visual display in three dimensions. Therefore, another column was included in the horizon order index table described above, defining a set of generalized horizon designations. Some horizons had been subdivided using Roman numeral suffixes (for example, Ap1 and Ap2 or BE1 and BE2) in order to recognize morphological transitions within the horizon, according to the USDA guidelines for vertical subdivision (Soil Survey Staff 2003:317). These were recombined for the purposes of modeling.

Horizons had in some cases been given letter suffixes to describe morphological attributes that differed between posthole excavations, again according to USDA guidelines (Soil Survey Staff 2003:315-17). These were also generalized to represent a single horizon. For example, in some areas the argillic Bt horizon exhibited gleying and was therefore designated Btg. However, this horizon was still associated with the Bt horizon in neighboring excavations and reflects only local anaerobic conditions, and therefore it was sensible to model this as the same horizon. In other cases where the morphological characteristic represented by the suffix represented significant and distinct depositional or developmental phenomena, these were kept separate. One such example is the Bt and Bw horizons, which are quite distinct morphologically and almost certainly differ in age.

Horizons were later consolidated into the layers that would make the final model as intelligible as possible while preserving its usefulness and accuracy. This was again done in the horizon order index table. These layers were modern fill, plowzone, the upland Inceptisol in the eastern and northern portions of the site, a consolidated layer containing the E, EB and BE horizons from the Ultisol, the Bt horizon, and the underlying paleosol.

The upper horizons of the Ultisol were grouped into one layer because of the inconsistency in their identification in the field. The boundaries between horizons were sometimes unclear, resulting from the retardant upbuilding that impeded the differentiation of soil horizons. There is a high degree of variation between relative horizon thickness between neighboring postholes, and the introduction of this kind of data into the interpolation would have significantly increased cross-validation errors. Since these horizons varied much more consistently as a group, modeling them as such made for a clearer and more accurate visualization.

The Inceptisol was modeled as one layer because of complexities and interpretation issues in its horizonation. This is due to the highly erosional nature of the Inceptisol, which resulted in differential development throughout the soil landscape. Introducing these complexities into the soil model would have resulted in questionable accuracy as well as the introduction of additional error into the interpolation.

Since the Inceptisol shared some horizon designations with the Ultisol, such as the E, EB and BE horizons, these could not be reclassed using the horizon order index table.

Instead, each layer that belonged to the Inceptisol had to be designated using a new Boolean field in the 'Soils' table. This was done by concurrently running the fence diagram display tool in ArcGIS and inspecting all candidate profiles on an individual basis.

7.5. Soil data transformation

After the lengthy process of error-checking and reclassification, the data was ready to be transformed into a format that could be introduced into ArcGIS and used as input for the soil layer interpolations. As mentioned earlier, the two-table, morphologically descriptive data format in the Access database was not conducive for display and interpolation in ArcGIS. Soil data needed to be transformed so that for each posthole test, consolidated model layers were displayed as rows, and the horizon elevations and/or thicknesses as columns.

A relatively sophisticated VBA script needed to be produced for this purpose, as SQL on its own was insufficient for this degree of data manipulation. The script transforms the data structure into the desired form and calculates the top elevation and total thickness of each of the consolidated model layers, as well as reading the coordinates of each postholes test from the feature class in the geodatabase. Deriving all classification and soil data on the fly from the Access database allows the script to run with no input from the user. When finished, the final output is saved as a comma-separated text file that can be readily displayed in ArcGIS using the included geographic coordinates.

7.6. Layer Interpolation

Rasters representing horizon thickness were interpolated using ordinary kriging. Since the sample points are located on a pseudo-regular grid, the ubiquitous grid spacing of 20 meters was a good choice of lag size (Isaaks & Srivastava 1989:146), and this was used for all layers of the model.

Since ArcGIS is not a true three-dimensional GIS, soils and soil horizons must be represented by two dimensional DEMs defining the elevations of their upper boundaries. One way to produce these DEMs would be to calculate the elevations of these boundaries by subtracting their depth from the elevation of the surface DEM. This strategy is unproblematic for relatively continuous soils, but poses serious problems for the present study.

There are soils and horizons on the site that taper out and exist in patches or only in a particular area of the site. Therefore, there are sample locations that do not define a depth (or in other terms, that define a zero depth) for particular horizons. In an elevation interpolation, considering these sample locations as values of zero would cause these points to be interpolated as a sea level elevation. The alternative of considering them as null values would cause them to be excluded from the interpolation and therefore "blurred over", instead of being correctly interpolating areas of null values.

A third possible solution would be that used by many geological modeling programs, such as Stratos by Rockware. Each horizon boundary is represented by a column, and columns are arranged in their stratigraphic order. Each borehole is represented by a row. For each row, each column contains an elevation, whether or not it exists at the particular borehole. If the horizon does not exist, the value is the same as the next deepest column. The result is that when modeled, the layer has a thickness of zero and does not appear. This works quite well in software that represents data as a solid model, but would produce confusing output in ArcGIS, which represents the data as a continuous surface.

A true 3D subsurface modeler requires a recognition tool that defines the relationships between subsurface units (Sirakov & Muge 2001:60). This can be thought of as a three-dimensional topology, which is unsupported in the current version of ArcGIS. Geologic modeling programs interpolate the contact surfaces with constraints that these surfaces may not cross. Interpolation in ArcGIS would involve a series of separate interpolations that would not informed by the concurrent interpolation of other boundaries. Also, given the relatively low resolution of the subsurface input data relative to the surface, near-surface layers such as the fill will not follow the irregularities of the surface and will be predicted at elevations higher than the surface in some areas (See Figure 7-2).

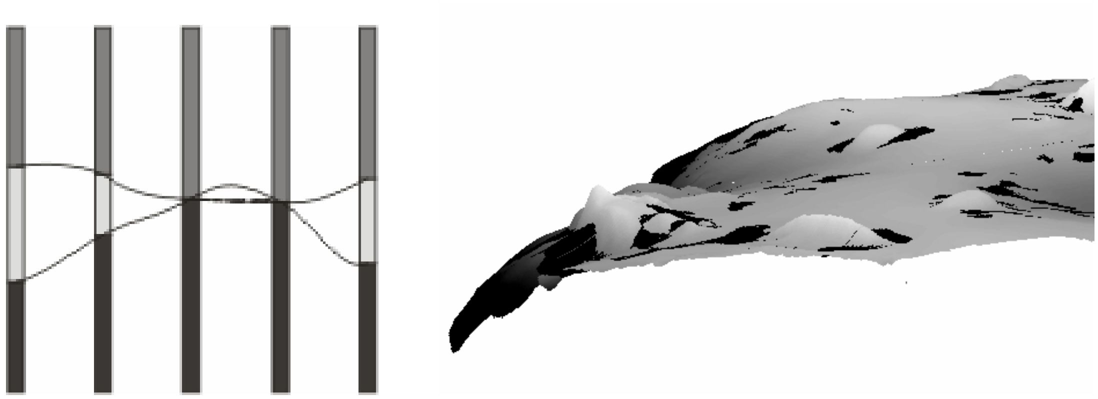


Figure 7-2: A simplified hypothetical model (left) illustrating the effects of interpolating a disappearing horizon in ArcGIS versus a solid modelling program, and the actual effects in ArcGIS (right) of interpolating the fill layer (black) based on measured elevation, independent of the contour-interpolated surface (grey).

Instead of developing a custom, rule-based interpolation mechanism, the solution chosen for the current site model relies on inferring the horizon surfaces from an interpolation of their thickness. A DEM representing the thickness of the horizon is interpolated using ordinary kriging. Sample locations in which the horizon is not present are given a value of zero. The result is that areas in which there are many sample values of zero, a continuous surface of zero (or slightly sub-zero) values is interpolated.

7.7. Interpolating the thickness rasters

Each thickness raster was produced using ordinary kriging, but the parameters and strategies used differed based on the nature of the layer. For several layers, stationarity was an issue and this will be discussed on a case-by-case basis. Unless otherwise stated, global trends were not incorporated. The Trend Analysis tool in ESRI Geostatistical Analyst calculates trends automatically. However, Isaaks & Srivastava (1989:531-32) warn against incorporating automatically generated trends if there is no qualitative reason to believe there is an actual trend. In most cases the global trend identified by ArcGIS could not be explained qualitatively, and was therefore not incorporated.

The introduction of anisotropy was also avoided in most cases. Since an omnidirectional variogram incorporates a larger number of point pairs, it is more likely to reveal the underlying structure of the data. If the structure in the variogram is clear, then anisotropy can serve to refine the interpretation of that structure. However, if the omnidirectional variogram does not reveal a clear structure, there is little sense in seeking it in a directional variogram (Isaaks & Srivastava 1989).

No nugget was incorporated for any of the thickness interpolations. The smoothing effect caused by a nugget would have caused non-zero values to be interpolated across regions of sample points with known values of zero. Although error modeling would in theory be appropriate, it was decided that restricting the edges of the layer limits was important for most accurately modeling the presence and absence of soils and soil horizons at the sample locations.

For most layers a lag size of 66 feet was used, approximating the ubiquitous 20-meter grid size of the posthole survey. When input data is arranged in a semi-regular grid, the grid spacing is usually considered a good lag spacing as well. Other lag sizes were used only when an area smaller than the entire survey area was used as input. The recommended number of lags is the greatest distance between sample points divided by the lag size, which is 16 in the case of the current survey. However, if the grid is pseudo-regular, a reduced number of lags can help to clarify the structure of the data. The effect is that the semivariogram is based on a more localized set of sample pairs (Isaaks & Srivastava 1989:146-47, Johnston et al. 2001:66).

A generally systematic method was followed in selecting the appropriate kriging parameters for each layer. An initial interpolation was conducted using a spherical semi-variogram with the appropriate lag size and number of lags as discussed above. The default interpolation searching neighborhood shape was used, with 8 neighbors per quadrant for the surface layer and 4 neighbors per quadrant for the thickness interpolations. This was repeated for reduced lag numbers, and error estimates for each were recorded and compared. Other semivariogram functions were then investigated to determine if they might better fit the data. ESRI Geostatistical Analyst supports circular, spherical, tetraspherical, pentaspherical, exponential, gaussian, rational quadratic, hole effect, K-Bessel, J-Bessel, and stable semivariogram functions.

If one of these functions appeared to produce better error estimates than the spherical model, the same process was repeated as for the spherical model. Some complex semivariograms created by combining two functions were tested, but these never produced better error results than the simple models. The error estimates for all the chosen semivariogram functions and numbers of lags were then compared. The result that produced the most optimal error estimates while producing an intuitively realistic surface was chosen as the final semivariogram model. This model was tested using different numbers of neighbors and neighborhood shapes (four or eight quadrants, cardinal or diagonal orientation). The most error-free yet qualitatively realistic parameters were selected for the final interpolation.

This study uses cross-validation to inform the selection of an ideal kriging prediction. This involves predicting error through the systematically removing of each of the sample points and using the rest of the points to predict the value of the missing point. It should be noted that this only assesses the accuracy of the prediction with regards to the known sample values. A low error result does not automatically translate into good predictive power for unsampled locations. Therefore, predictions were always subject to a "reality check" before being accepted. In some cases, the method producing the least error was not selected for the final interpolation.

All the semivariograms in this chapter were produced by Geostatistical Analyst. The x-axis represents the lag distance, in tens of feet. The y-axis represents semivariance. In the elevation model interpolation, semivariance is in feet. In the thickness interpolations, semivariances are expressed in decimeters or meters.

Kriging results were subsequently converted to a raster format. This involved resampling the model with two vertical and two horizontal predictions per 1-foot cell.

7.7.1. Surface elevation model

The surface elevation model differed from the other interpolations, since it was based on elevation values rather than thickness. The point elevations for the posthole tests that had been derived from the 1-foot DEM were interpolated in order to produce a new surface DEM. This generalized DEM was used in lieu of the original DEM for modeling purposes. Normally basing the underground elevations on the actual ground surface would be desirable, but the current site posed some special problems.

The fill layer consisted mainly of areas in which dirt had been deposited on top of the existing soil. These included the greens, teeboxes, as well as other mounds found throughout the golf course. As discussed earlier, a major advantage of interpolating the thickness of horizon boundaries rather than absolute elevation is that a surface derived from the thickness interpolation will follow the ground surface.

However, one drawback of this method is it will do so no matter how abnormal the ground surface may be. Most mounds and areas of greatest fill depth were avoided during the survey, for obvious reasons. This means that there is no data to inform the interpolator of an increase in fill thickness. Therefore, the surface resulting from the subtraction of the fill thickness raster from the DEM also displays a mound. This is obviously not the case in reality and is an artifact of the modeling strategy. Basing a DEM on only data from the sample points had the advantage of eliminating erratic effects of the surface topography that would only unnecessarily complicate the underground surfaces.

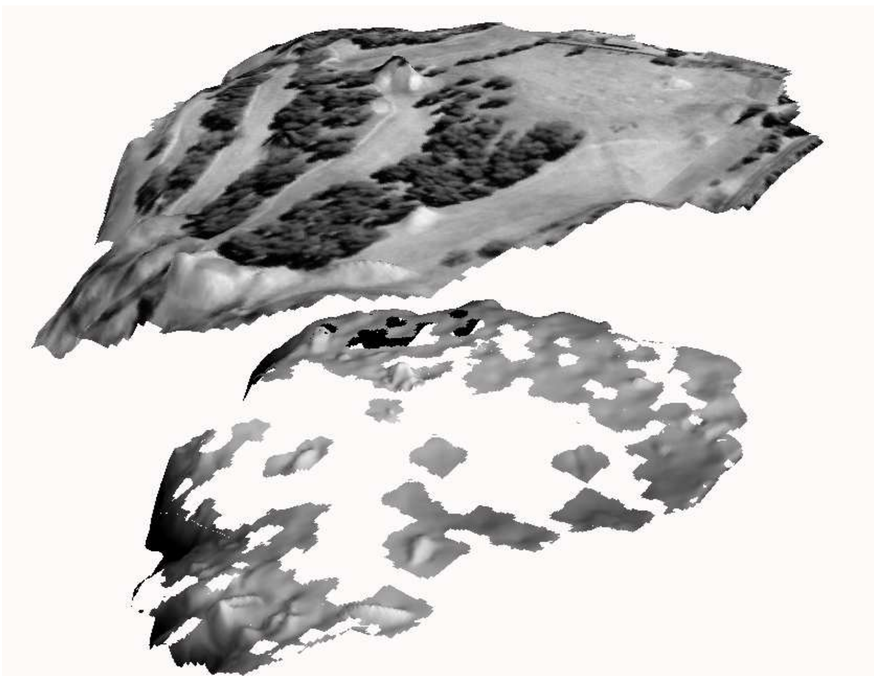


Figure 7-3: Abnormalities in the fill bottom surface (bottom) using the original contour-derived DEM (above) as a basis for subtracting an underground surface. An accurate model would not exhibit "mounds" in the natural underground surface in areas of overlying artificial fill. (vertical exaggeration 1:10, vertical offset 50 feet)

Geostatistical Analyst identified a global trend in the surface elevation, which made logical sense given the topography of the survey area. The curve of the trend suggested the incorporation of a 2nd-order polynomial global trend (See Figure 7-4). The optimal semivariogram was spherical model with 13 lags, and the optimal interpolation was produced using an eight-sector neighborhood search shape with nine neighbors per sector.

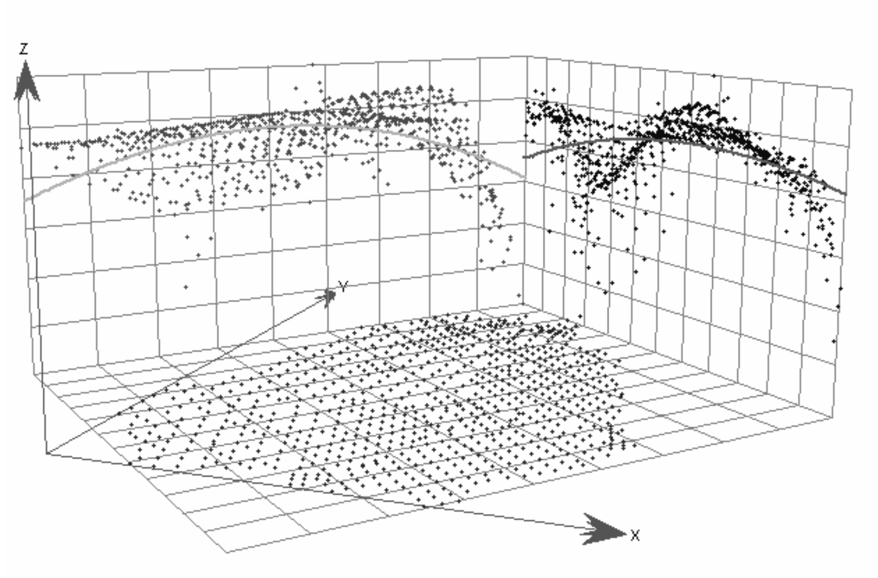


Figure 7-4: Global trend of posthole surface elevations identified by Geostatistical Analyst

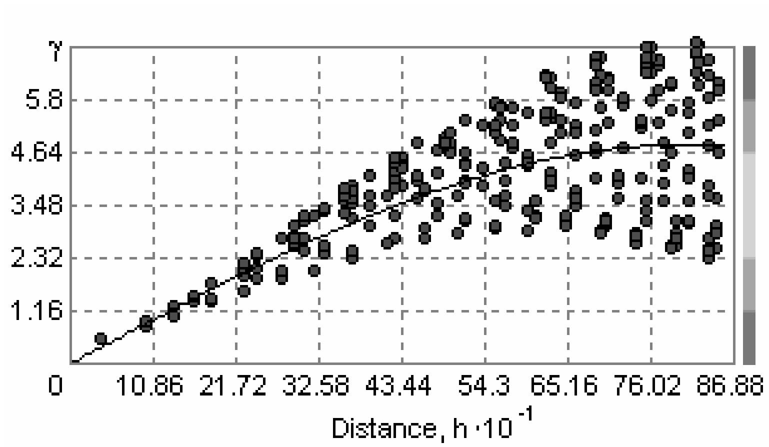


Figure 7-5: Semivariogram for the surface elevation kriging interpolation. (Partial sill: 4.8141 feet; Major range: 800.66 feet)

7.7.2. Fill thickness

The fill layer posed some special technical and theoretical problems. It is questionable whether this layer conforms to the law of stationarity. Fill dirt was encountered over a large proportion of the survey area, but large concentrations were encountered at the golf course greens. This violates the law of stationarity in the sense that similarly high values are a function of their locations and not their distance from one another. The possibility of using an alternative interpolation method was investigated, but kriging still appeared to produce the most logically sound results. Additionally, other interpolations implicitly rely on the law of stationarity, so this should not be the sole reason for abandoning the kriging method (Isaaks & Srivastava 1989:531).

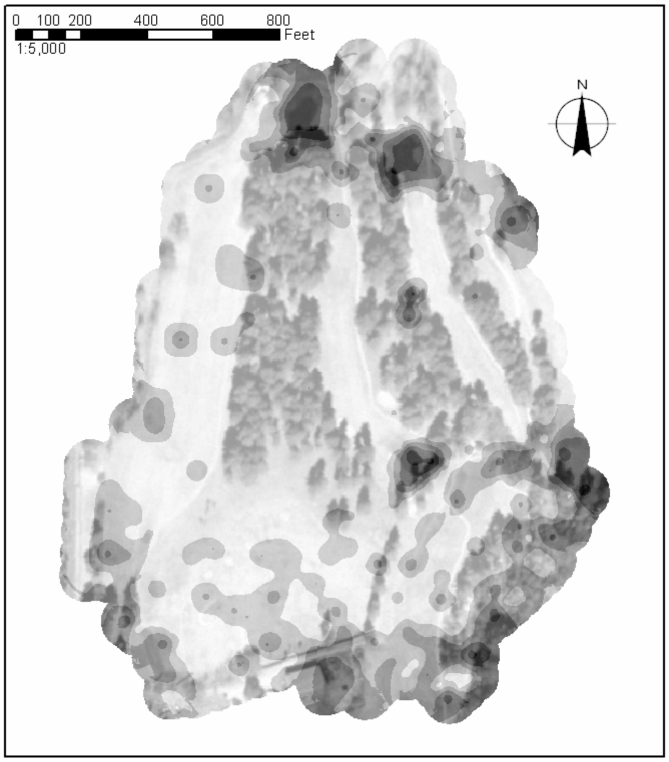


Figure 7-6: Aerial photo of survey area with darkened areas representing degree of fill thickness

An exponential semivariogram with 16 lags was chosen to represent the spatial variation of fill thickness. The final interpolation used an eight-sector neighborhood shape with more steeply than the spherical model. This means that nearer values are given more weight, making it a better model for more discontinuous datasets (Isaaks & Srivastava 1989:370-75).

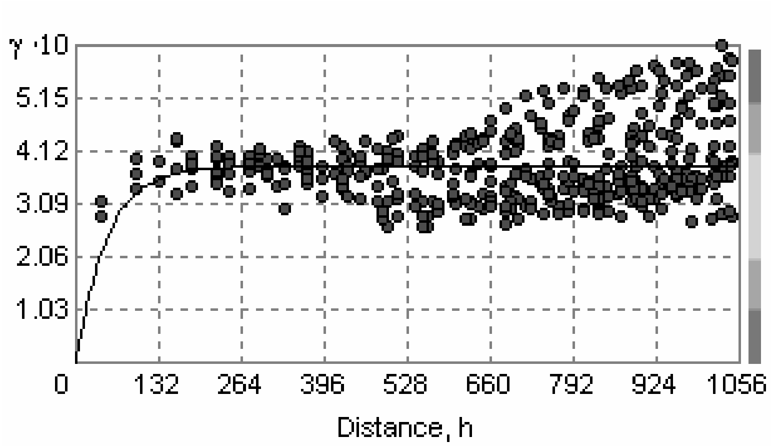


Figure 7-7: Semivariogram for the fill thickness kriging interpolation. (Partial sill: 0.38276 meters; Major range: 147.29 feet)

7.7.3. Plowzone thickness

The plowzone was relatively continuous as a whole, and present throughout the survey area. Thickness values of zero were generally found in areas of extensive construction, such as the greens and teeboxes. As a result, cross-validation produced significantly better error results than other layers. The best-fitting semivariogram was a K-Bessel model with 10 lags. An eight-sector neighborhood search shape with 9 neighbors per sector was used in the final interpolation.

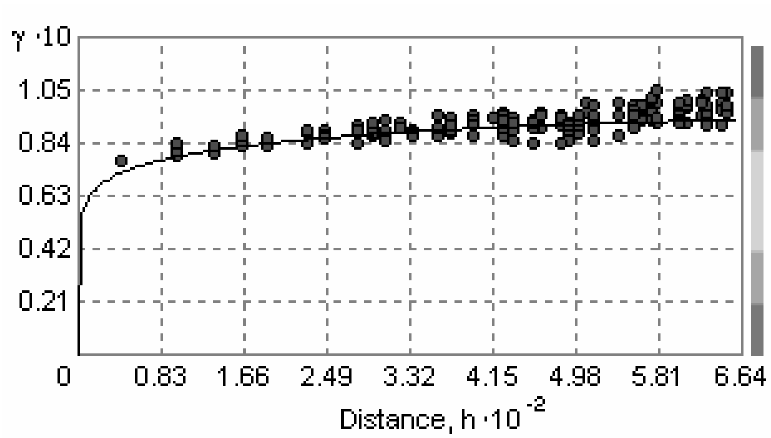


Figure 7-8: Semivariogram for the plowzone thickness kriging interpolation. (Partial sill: 0.097799 meters; Major range: 627.65 feet)

7.7.4. Inceptisol thickness

The Inceptisol only in the northeast portion of the site, therefore a constrained area was used for analysis. This was defined as all points within a 35-meter buffer from posthole locations with an Inceptisol thickness greater than zero, and several additional points to prevent erratic edge effects. Given the smaller area, the recommended number of lags for a 66-foot lag size is ten. A stable model with ten lags was found to provide the best fit. A four-quadrant neighborhood pattern was used, with four neighbors per quadrant and quadrants oriented to the cardinal directions.

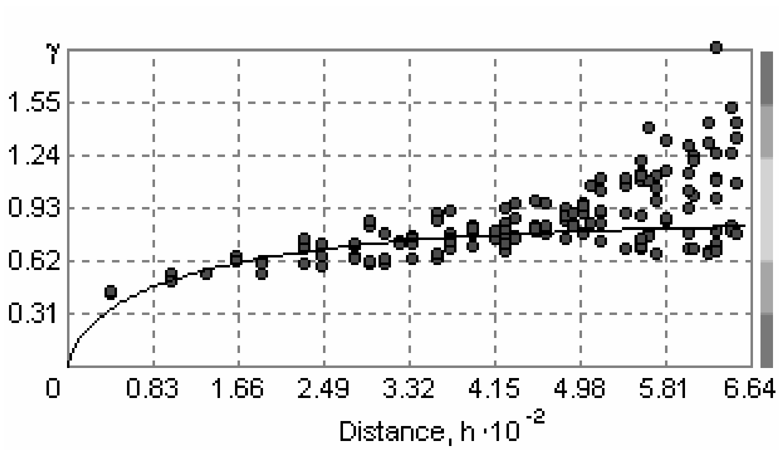


Figure 7-9: Semivariogram for the plowzone thickness kriging interpolation. (Partial sill: 0.86151 meters; Major range: 627.66 feet)

7.7.5. E/EB/BE unit thickness

This was the only thickness layer where the incorporation of a global trend was considered appropriate. There is a definite increase in E/EB/BE unit thickness progressing southward due to the overthickened upland Ultisol toward the south end on the survey area. Another minor trend exists in the east-west direction, with an increased thickness toward the middle of the area. The shape of the trend suggests the use of a second-order polynomial trend removal. A K-Bessel semi-variogram function with 10 lags produced the best cross-validation results. The ideal neighborhood search pattern was a cardinally oriented four-quadrant shape incorporating four neighbors per quadrant.

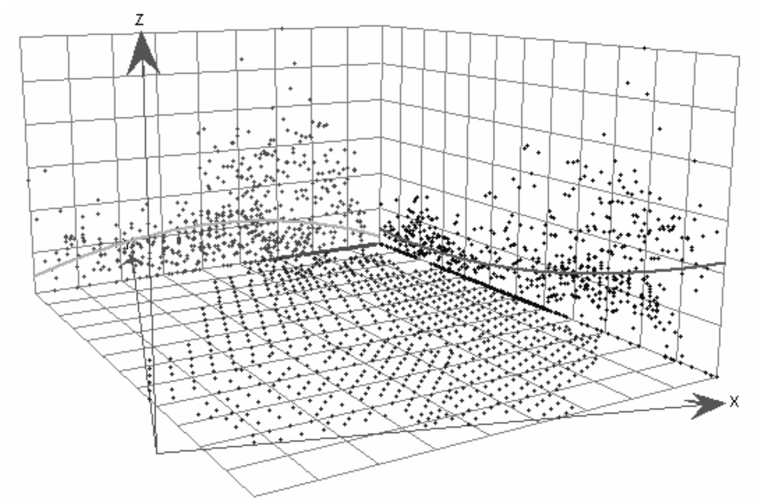


Figure 7-10: Global trend of E/EB/BE horizon unit thickness identified by Geostatistical Analyst

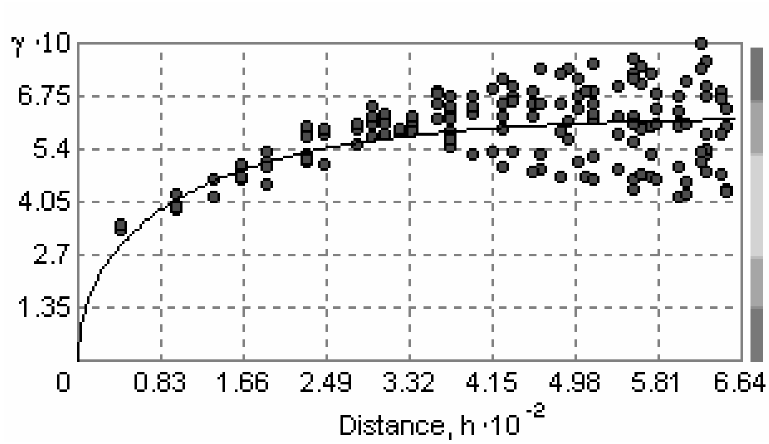


Figure 7-11: Semivariogram for the E/EB/BE horizon unit thickness kriging interpolation. (Partial sill: 0.62307 meters; Major range: 408.64 feet)

7.7.6. Bt Horizon thickness

Although this was also the case in some areas of the E/EB/BE unit, the Bt horizon was unique in that its thickness in most areas represented the limit of excavation rather than the actual thickness of the horizon. Still, the Bt had to be modeled as a thickness since it overlies the paleosol. Error in cross-validation was relatively low. The best fit resulted from a K-Bessel function with 10 lags. Cross-validation suggested an eight-sector neighborhood pattern with 14 neighbors per sector. However, this was replaced with a four-sector pattern oriented to the cardinal directions, using the same number of neighbors. The four-sector pattern produced only marginally more error, was less computationally expensive, and used a smaller search area, which made intuitive sense given the variability of the soil.

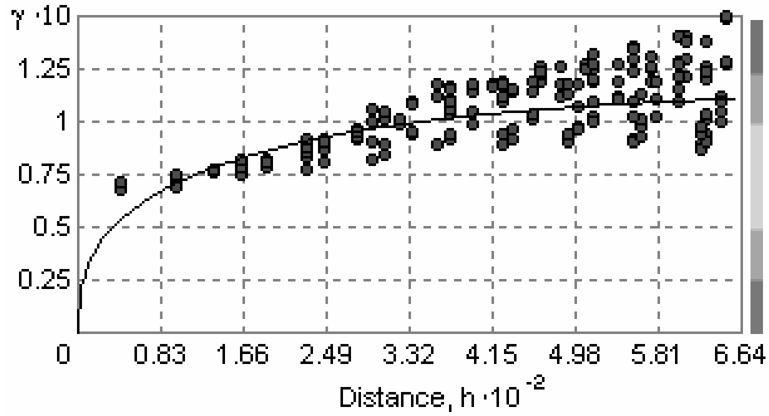


Figure 7-12: Semivariogram for the Bt horizon thickness kriging interpolation. (Partial sill: 0.11609 meters; Major range: 627.66 feet)

7.7.7. Paleosol and limit of sampling

The bottom of the paleosol was never encountered, and therefore its thickness in posthole tests is purely a function of sampling. For this reason, it did not make sense to model this layer as a thickness. Instead, a two-neighbor inverse distance weighted (IDW) interpolation was performed in order to define what would be reclassed as an approximate presence/absence raster of where the paleosol was encountered. The rest of the sampling limits were not interpolated but were calculated from the thickness rasters. This will be discussed further in the next section.

7.8. Producing the elevation surfaces

As mentioned earlier, the interpolator sometimes produced sub-zero values. These values are an artifact of the interpolator trying to produce a smooth surface. This can then be corrected using a raster calculation that sets all sub-zero values to null, since in the final model these areas should appear as "holes" in the horizon.

In some layers, there was a "spilling" effect in which the interpolator produced large areas of near-zero values, reaching zero only at the sample point. This was corrected by removing all portions of the interpolation that had a thickness value of less than one centimeter, or 0.0328 feet. This value was chosen since it also represents a reasonable detection limit in the field. Thus, the final thickness raster was produced using a raster calculation such as the following::

```
FillThickness = SetNull ([KrigingResults] < 0.0328, [KrigingResults])
```

This was done with a 25 meter buffer around all sample points used in the interpolations as an analysis mask, removing irrelevant and high-error areas from the final rasters.

An elevation for the horizon boundary can then be produced through another raster calculation that subtracts the thickness at a particular cell from the elevation of the horizon above it. Thus the bottom of the fill is defined by the thickness of the fill subtracted from the surface elevation:

FillBottom = [Surface] – [FillThickness]

In practice, the above steps can be combined, as follows:

FillBottom = SetNull([KrigingResults] <= 0.0328, [Surface] – [FillThickness])

The top of a horizon is then defined as the horizon bottom plus the horizon thickness, such as:

FillTop = [FillBottom] + [FillThickness]

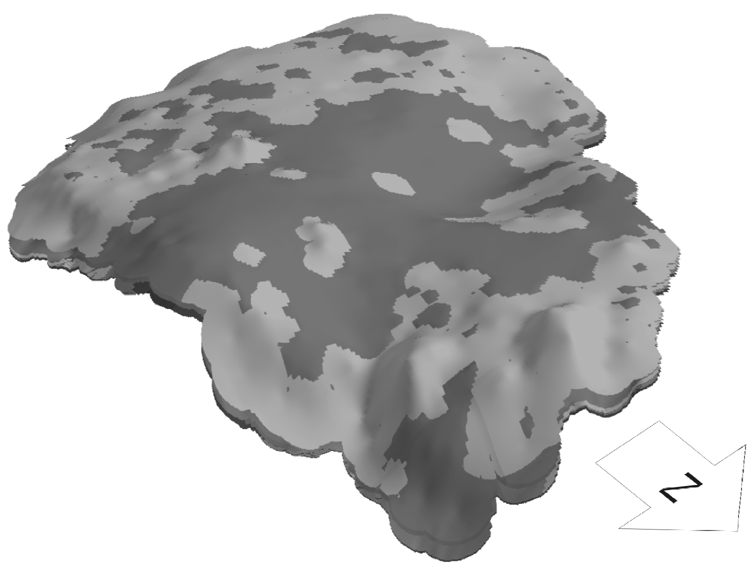


Figure 7-13: The final fill layer overlying the final plowzone layer, with vertical exaggeration.

The bottoms of subsequent horizons are calculated as the lowest overlying horizon minus the new horizon's thickness. Since raster calculator sets any cell in a calculation that has a null input as null output, these had to be converted to a very high elevation in the course of the calculation using a conditional statement. For example, the calculation for the plowzone bottom was:

PlowBottom = SetNull([PlowThickness] < 0.0328, Min([Surface], Con(IsNull([FillBottom]), 999, [FillBottom])) – [PlowThickness])

For each horizon, a similar conditional statement for the previous horizon is added to the ‘Min’ statement. The raster representing the limit of sampling is generated by a solitary ‘Min’ statement comparing the surface and all the horizons:

Bottom = Min([Surface], Con(IsNull([FillBottom]), 999, [FillBottom]), Con(IsNull([PlowBottom]), 999, [PlowBottom]), Con(IsNull([InceptBottom]), 999, [InceptBottom]), Con(IsNull([EBEBottom]), 999, [EBEBottom]), Con(IsNull([BtBottom]), 999, [BtBottom]))

The paleosol raster was generated using the same calculation, except embedded in a SetNull statement assigning a null value to all cells in the IDW paleosol presence/absence raster that have a value of zero.

All rasters were then visualized in ArcScene with vertical exaggeration, in order to investigate the underground soil landscape.

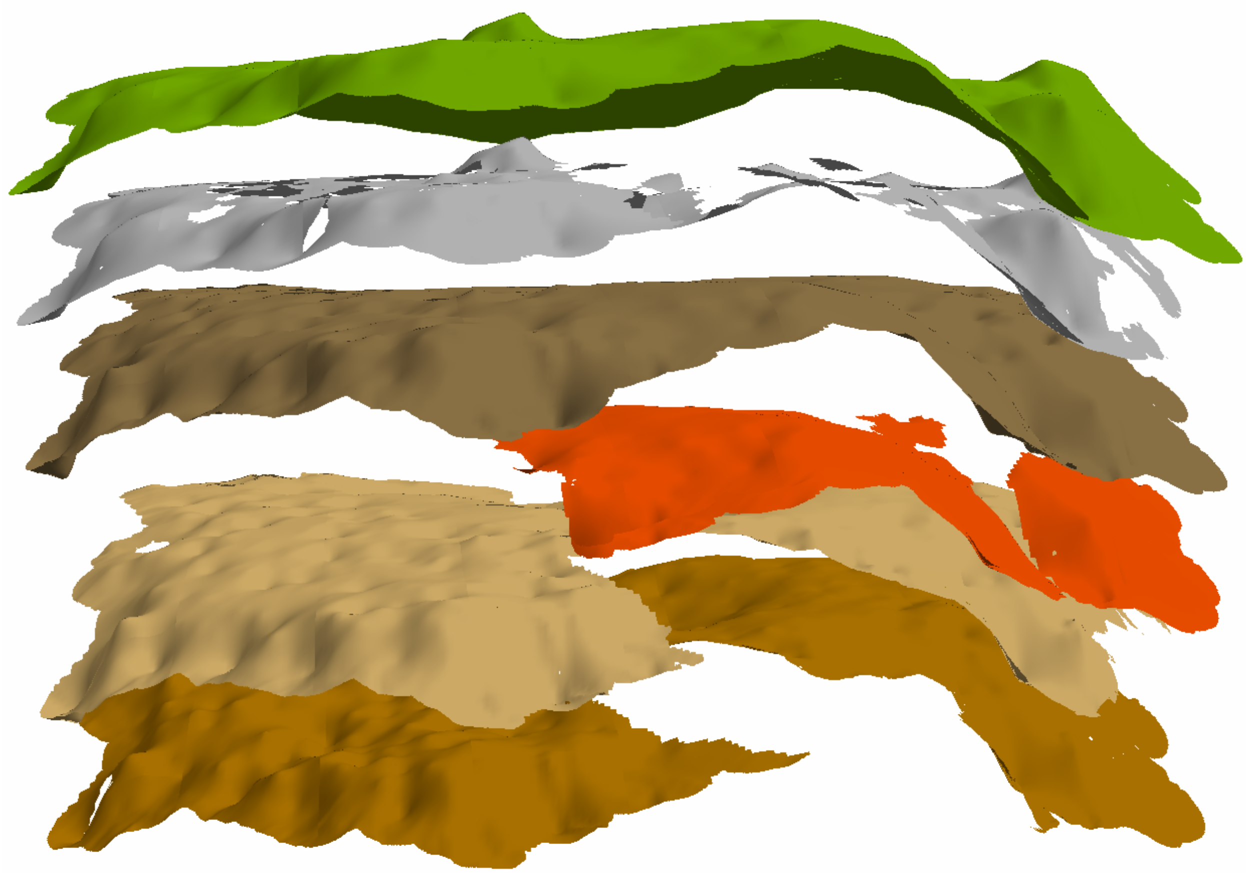


Figure 7-14: The final soil model layers , vertically exaggerated and exploded (paleosol and sampling limit not shown). From top to bottom, the ground surface (green), the fill layer (gray), the plowzone (gray-brown), the Inceptisol (red), the E/EB/BE unit (beige), and the Bt horizon (orange-brown)

Chapter 8. Analysis

8.1. The final soil model

The final model is a generalization of what the actual soil landscape may be. It can not be relied upon to make predictions at a small scale, as it is based on data that has error caused in no small part by the interpretations made in the field, as well as possible errors in their subsequent revision. Kriging itself only produces an 'average scenario', and does not itself represent a likely reality in itself. That said, large-scale patterns in the model reflect large-scale patterns in the data, and their visualization aides the interpretation of site as a whole.

8.1.1. The buried river channel

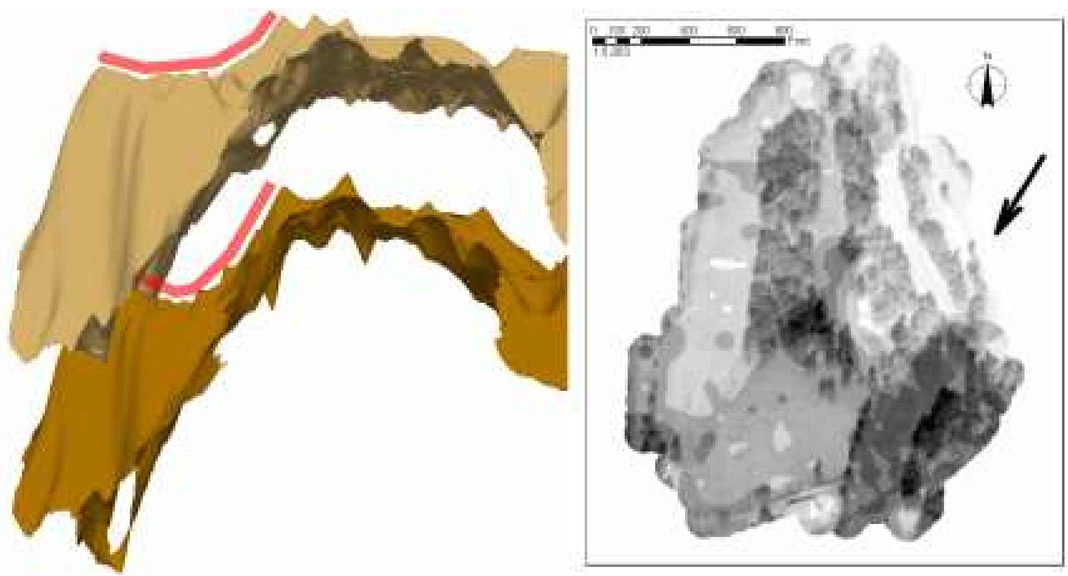


Figure 8-1: Left: Exploded view of the surfaces of the E/EB/BE unit (above) and the underlying Bt horizon (below). Right: Aerial photo of the survey area. Superimposed shading represents thickness of E/EB/BE unit. Arrow shows viewing direction in the image to left.

Figure 8-1 above shows the overthickened subsoil along the 6th fairway. It should be noted that the Bt Horizon was not always reached during excavation of some postholes in this area. Therefore, this overthickening may actually be under-expressed. While it was clear during posthole excavation that distinct overthickening occurred on the 6th fairway, the nature of the soil landscape was not clear, nor was the absolute elevation change of the Bt surface. From the model it is clear that there is a sudden drop in the Bt elevation around the edge of the sixth fairway that is much more subtly mirrored in the upper subsoil. This is interpreted as the remnants of a pre-Holocene channel of the Ocmulgee River. The 'lip' along the bluff edge exhibited unusually fine soil texture, attributable to wind-blown sediment transported from below the bluff.

8.1.2. Mid-Holocene erosion

The nature of the overthickened soil to the northeast of the buried channel is uncertain. It probably represents a smaller channel, the northeastern extents of which were eradicated during the mid-Holocene erosional event. This is indicated by its sudden termination at the edge of the Inceptisol-dominated area.

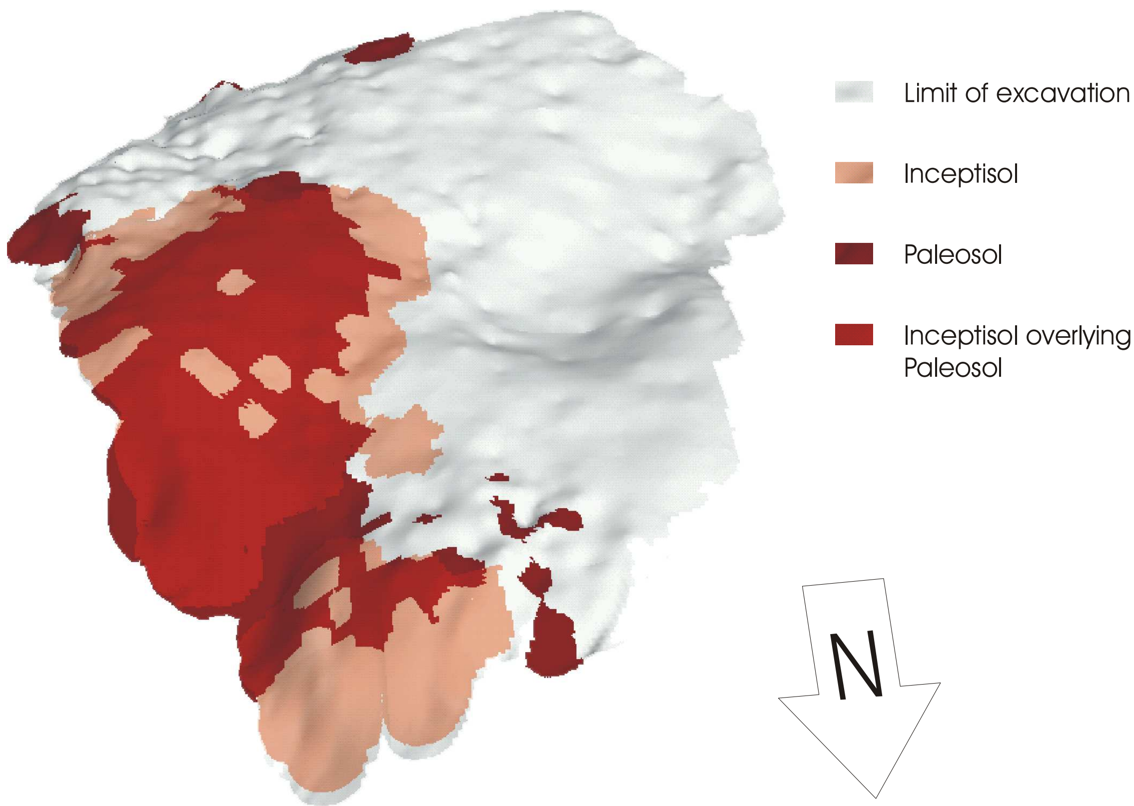


Figure 8-2: The Inceptisol (shown translucent) in relation to the underlying paleosol.

The paleosol was almost exclusively encountered when excavating in Inceptisol-dominated areas. This is clearly visible in Figure 8-2. The main reason for this is its shallow occurrence due to heavy erosion during the mid-Holocene drought. Therefore, it is likely that erosion was most severe at the highest area of the site – at the southern end of the Inceptisol – and in the drainage to the immediate north. The shallow paleosol indicates that the early-Holocene landscape would have been higher in these areas. This suggests that there was once a small hill where there is now only a small rise.

Unfortunately, this also means that archaeological components dating to or before the erosional event are probably severely disturbed in these areas.

8.2. Artifact analysis

8.2.1. Database analysis

Data was analyzed using SQL queries in Microsoft Access, and also through calculations on query results in Excel. The most important queries will be described below. Some query results were used as the basis for new GIS layers.

It was important to divide posthole artifact summaries based on whether they were derived from a fill, plowzone or subsoil context. Artifacts found in disturbed subsoil were considered to be in a secondary context and were therefore combined with the plowzone category. In a few cases, excavation layers were recorded as intersecting two contexts. In these cases, artifacts in those layers were assumed to belong in the least intact context.

A set of queries were designed in Microsoft Access to divide posthole artifacts into these three categories and generate three tables summarizing for each category the artifact totals for each posthole. From this table a shapefile was created so that artifact distributions based on context could be analyzed in the GIS.

Similarly, it was of interest to compare artifact distributions for each layer in the soil model. However, while during posthole excavation the fill, plowzone and subsoil were excavated separately, it was not possible to do the same with soil horizons. A decision had to be made about how to divide artifact totals for each layer. A number of options were considered, including taking totals of only those artifacts that were recorded in excavation layers entirely within one model layer. Alternatively, artifacts in split excavation layers could be divided based on where in the excavation layer the transition occurs. No solution was entirely satisfactory, but it was finally decided that artifacts would be attributed to any model layer that their excavation layer intersected. This meant that artifacts in split layers would be added to the totals for both model layers. However, it had the advantage of having a simple definition, namely the number of artifacts that were possibly recovered from a layer. This method allowed large-scale distribution patterns to be examined without ignoring artifacts or making unfounded assumptions based on proportions. Queries were created to make these divisions, and the results were used to create new shapefiles for these distributions.

Finally, it was desirable to examine distributions of the artifacts categories defined in the 'Artifact_Categorize' table of the database (see section 5.1.4). To this end, three queries were designed, dividing the artifact totals for each posthole into the categories based on artifact form, artifact 'function' and material. A cross-tabulation query was then designed for each of these, so that only one row exists for each posthole, and each column represents an artifact category. Each cell contains the total number of artifacts of a particular category in a particular posthole.

Summary data showed that the vast majority of artifacts recovered during posthole excavation were flake fragments (41%), tertiary flakes (29%), bifacial thinning flakes (11%) and secondary flakes (8%). All other artifact types occurred with a frequency of less than 3%. Sorted by weight, type distribution was more even. Artifact types that made up over 3% of the total artifact weight were: tertiary flakes (18%), flake fragments (16%), cores (16%), secondary flakes (12%), primary flakes (7%), biface fragments (6%), bifacial thinning flakes (6%) and block shatter (6%)

8.2.2. 2-D GIS analysis

Artifact distribution layers were produced using IDW interpolation with a limited number of neighbors to ensure that known point values, especially zero values, would be represented relatively accurately in the interpolation.

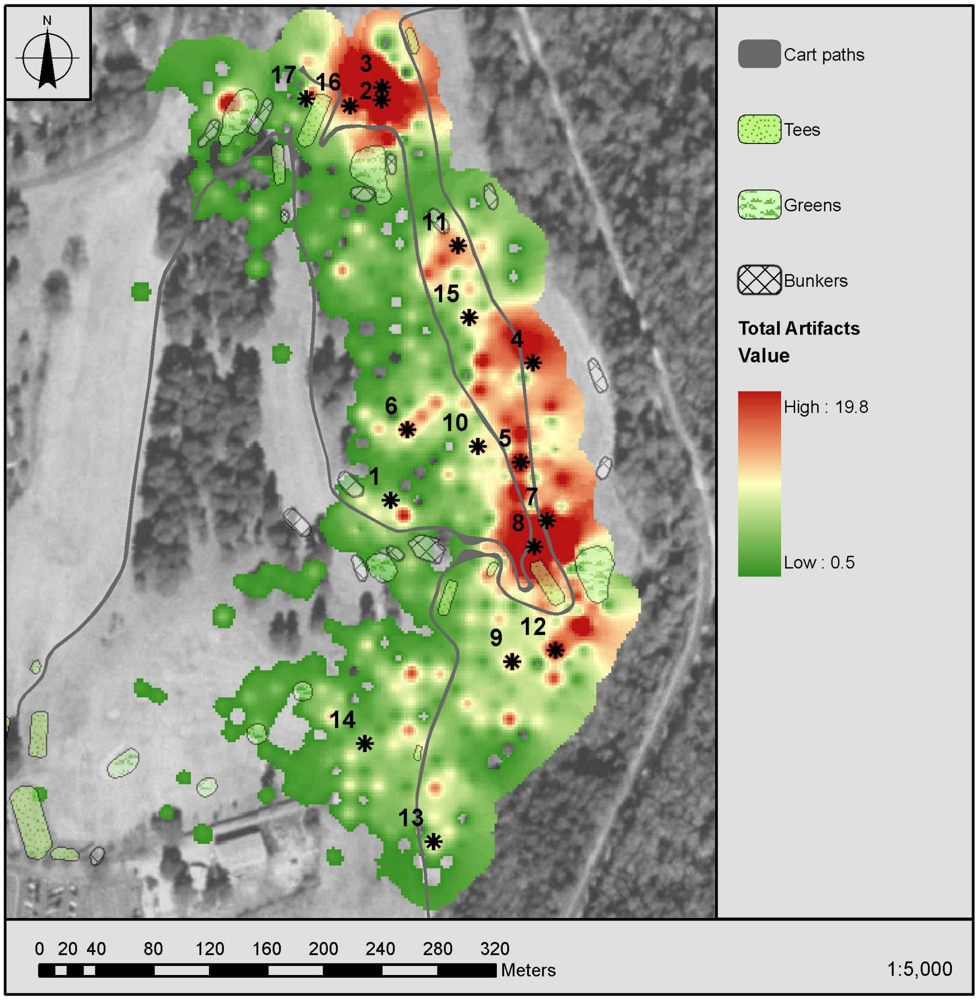


Figure 8-3: Site map showing total artifact distribution. Stars represent test unit locations.

The total artifact distribution shows that cultural material was not uniformly distributed on the site. There are two very dense concentrations: one at the northern end of the site and another north of the third tee. On the 6th fairway, at the southern end of the site, artifact distribution is less dense. This area of the site, strongly correlated with the buried river channel, probably has a fairly intact stratigraphy given its depositional history. It exhibits smaller, more localized concentrations that may represent individual occupations or activity areas. The concentration on which test unit 11 was placed was mainly present in the plowzone, but the test unit recovered a feature and a late Archaic Elora point in good context. This was within the Inceptisol, but apparently stratigraphically within soil post-dating the mid-Holocene erosional event.

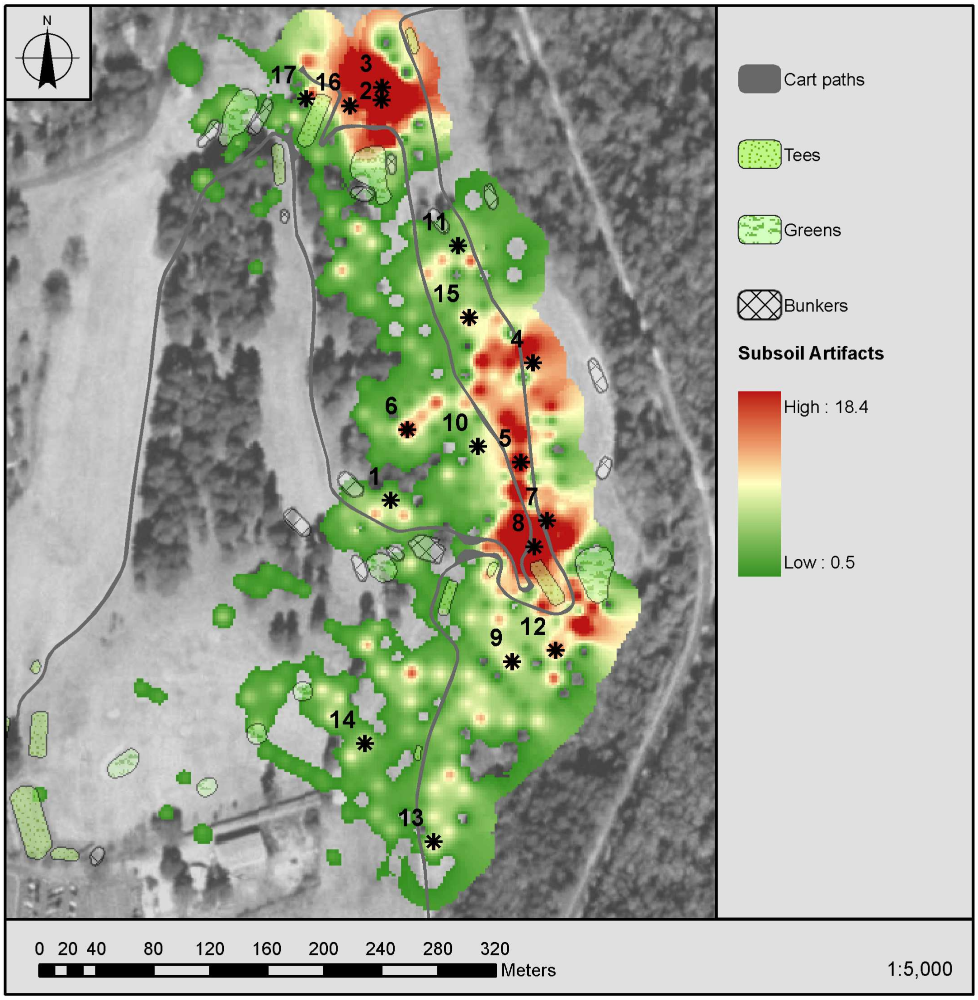


Figure 8-4: Site map showing subsoil artifact distribution. Stars represent test unit locations.

Artifact distribution in the subsoil is very similar to the total distribution, only somewhat less dispersed. This suggests that plowing did not cause major artifact relocation. The two major concentrations remain. The one at the north end is associated with the northern Inceptisol, in gravelly soils, and it is likely that many of these were transported through erosion from higher areas of the site. The southern concentration occurs on an intact Ultisol. Test units 7 and 8 exhibited good context in a normal upland profile, whereas test unit 5 was in a gravelly Inceptisol. This suggests that while there seems to be a continuous area of high artifact density along the bluff edge at the centre of the site, only the very high density cluster at the southern end of that area is fully within a good context. Test Units 7 and 8 exhibited evidence of at least one late Archaic to early Woodland component.

It is important to note that the apparent paucity of artifacts around the 5th green, southeast of the southern concentration, is most likely a result of soil removal during golf course construction. This, combined with the soil removal on much of the 5th fairway, suggests that the larger concentration making up the central third of the site extended considerably further east. Therefore the nature of the concentration as a whole, and the patterns exhibited within it, are obscured by a complete absence of data for a significant portion of the site.

8.2.3. Artifact distribution modeling in ArcScene

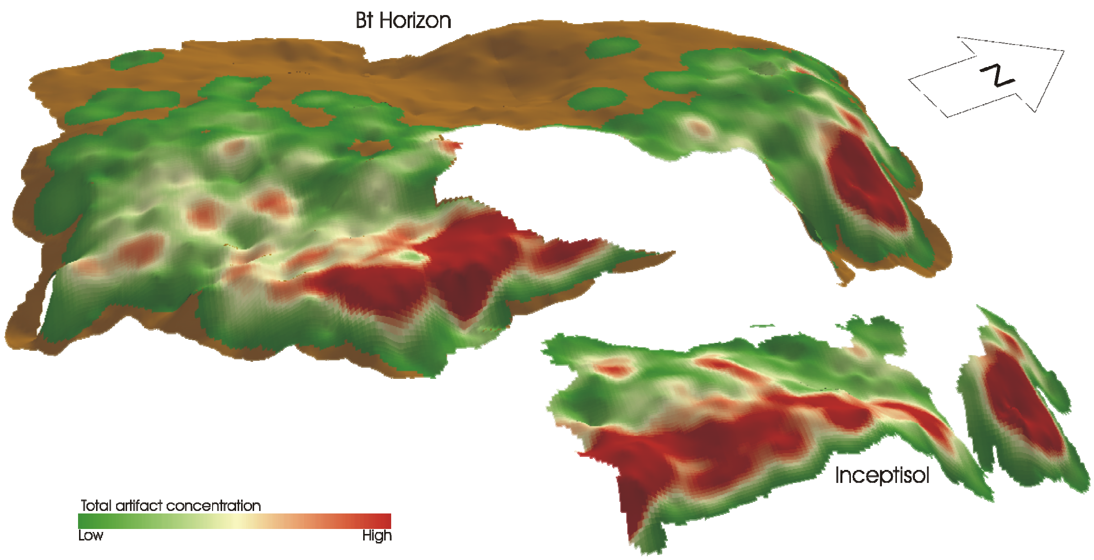


Figure 8-5: Total artifact distribution in relation to the Inceptisol (below) and the Bt horizon (above).

One concern that arose was whether the site was primarily associated with the Inceptisol, which has unclear and partially disturbed stratigraphy. Figure 8-5 above shows *total* artifact distribution in relation to the Inceptisol and the rest of the site (represented here by the Bt horizon). It is clear that while a significant proportion of the artifacts were recovered from the Inceptisol-dominated area, there are also artifact concentrations within the Ultisol, primarily on the southern portion of the site.

Of particular note is that artifacts in the Ultisol occur almost exclusively in the overthickened soils representing the pre-Holocene river channel. Whether this is a true association or a function of distance from the bluff edge is unclear. With the exception of the extreme north of the site, artifact occurrence drops off suddenly at a relatively consistent distance of approximately 500 feet (about 150 meters) from the bluff edge. This suggests that distance from the bluff edge was a primary determinant of activity location.

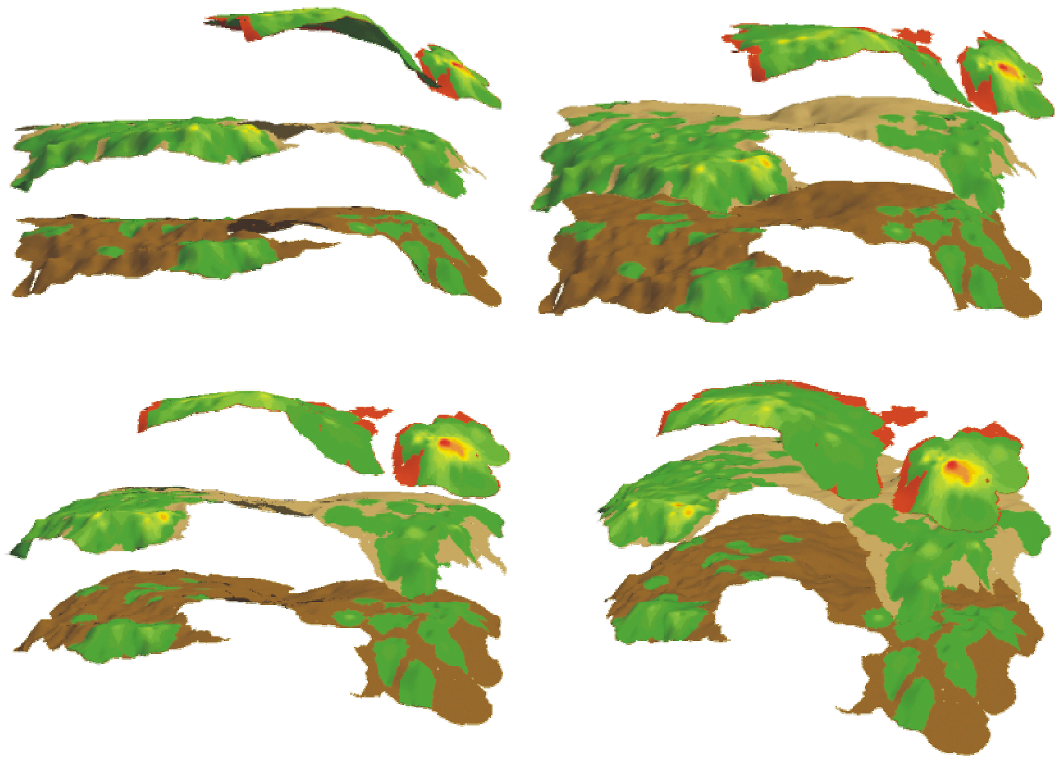


Figure 8-6: Relative artifact distribution in the three main subsoil layers (top: Inceptisol, middle: E/EB/BE, bottom: Bt), viewed from four angles. The colour scale is the same for all three layers.

Artifact distributions for each of the model layers were generated using IDW interpolation, just as those for the fill, plowzone and subsoil distributions were, using the data from section 8.2.1. The distributions were draped over their respective layers, as shown in Figure 8-6.

The distribution in the southern Inceptisol is for the most part the same as the total distribution, as it directly overlies the archaeologically sterile paleosol. Artifacts here are primarily associated with the elevated portion. Interestingly, while the surface of the Ultisol is quite flat, the Inceptisol dominates a small rise in the surface landscape. There is also a protrusion of paleosol here, which suggests that in this area was once a larger hill. This would explain the present Inceptisol and the occurrence of reddened soil in some portions of the Ultisol. Some stratigraphic inversion of diagnostic artifacts was encountered during test unit excavation. Therefore, at least in some areas, erosion was severe enough to transport large objects. For this reason, components in the southern Ultisol that precede or coincide with the mid-Holocene erosional event may in part have been contributed to by material transported from the receding hill. This could include components dating to the Middle Archaic or earlier. Existing test unit data does not appear to support or refute this hypothesis.

The northern Inceptisol partially overlies the Ultisol. The high-density artifact cluster is exclusive to the Inceptisol, but artifact occurrence at the north end is not entirely associated with this layer. Artifacts are clearly present within the Ultisol at the northern end of the site. If artifacts from this context could be related to those in the northern Inceptisol, it could identify the higher portions as a source of material in the northern artifact concentration. Unfortunately, no test units were dug in the Ultisol at the northern end of the site.

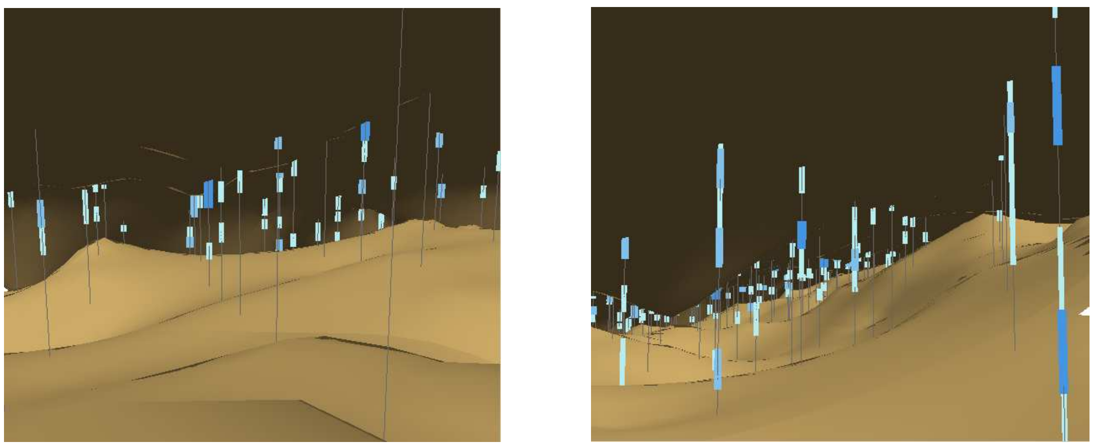


Figure 8-7: Fly-through scenes of artifact distribution within a single layer of the soil model.

Finally, Figure 8-7 illustrates an additional aspect of the soil model that is interesting but saw little practical use in the current study. A dataset was created that maintains separate records for each posthole excavation level containing archaeological material. Each record contains the level's artifact count, upper limit, and thickness. Using the extrusion feature in ArcScene, it was possible to depict the posthole results in three dimensions within the soil model. This allows the user to 'fly' inside the soil model and look for visible patterns in the artifact distribution within a particular model layer. The colour and width of each line segment represents the number of artifacts found in that level. This technique has the advantage of displaying primary data in an intuitive form. Navigation is difficult, but manageable with practice. This method of investigation, however, revealed no obvious distribution patterns in the current dataset.

Chapter 9. Conclusions

9.1. Interpretations

Most Geographic Information Systems are limited in their three-dimensional capabilities. They are only able to work with data in so-called 2½-D, displaying two-dimensional rasters in 3D space using a single attribute to define elevation. Since intra-site archaeological data is inherently three-dimensional, few intra-site studies have employed GIS for analysis (Harris & Lock 1996). This project was an attempt to explore methods for at least partially overcoming these limitations by using a layered approach utilizing posthole survey data.

The model successfully showed the variable context of the site. As was already clear during fieldwork, the far north of the site exhibits a small area of very high artifact concentration. While upper portions of the soil in this area may have been deposited under stabilized conditions, most of the profile is composed of erosional sediment forming an upland Inceptisol.

To the immediate south of this area is a strip of artifacts in stable upland Ultisol. This may represent the only surviving primary context at the northern end of the site for periods predating the erosional event. The isolated nature of this portion of the site relative to artifacts within an Ultisol context, generally more stable than the erosion-formed Inceptisols, was not recognized previously. No test units were placed there, in favour of more concentrated areas to the north and south.

The heart of the site is located on a small rise beside the 5th fairway. Distributional analysis strongly suggests that artifact density would be high on the 5th fairway, where soil was removed several decades ago during construction of the golf course. Unfortunately, that may have been the most important portion of the site, given the high association between artifact density and proximity to the bluff edge. The remaining rise appears to have been a larger hill until the middle Holocene, when dry conditions would have caused the water table to drop in elevated areas and areas near the edge of the bluff. This would have caused vegetation to recede, resulting in severe erosion. The evidence is an upland Inceptisol that shows evidence of erosion, including subsoil evidence of heavy rilling along its edges. While the soil later stabilized and cultural components post-dating this event may be intact, earlier components were heavily disturbed.

The southern portion of the site is primarily positioned on an overthickened Ultisol formed in an ancient river bend of the Ocmulgee River. Artifact density is high at the northern end of this area, just south of the Inceptisol. This concentration appears to be a continuation of that to the immediate north, but artifact density is higher here. It may be the case that artifact density on the Inceptisol has been reduced due to erosion. There is a concentration in the plowzone distribution on the drainage to the immediate north of the southern Inceptisol. This may represent a more recent component that has been assimilated into the plowzone, or it may alternatively indicate where artifacts were being transported during the erosional event.

The rest of southern portion of the site exhibits lighter overall distribution, with localized concentrations scattered across the 6^{th} fairway. Most of this area rests within an apparently stable upland Ultisol context, suggesting components may be relatively undisturbed. Despite the low incidence of artifacts relative to the rest of the site, this may represent the most important portion of the site. The localized concentrations may be individual occupations or activity areas. Unlike the bulk of the site, artifact frequency may be low enough here to not obscure single-use areas that may shed light on small-scale space usage. If future testing were to be planned, high-density posthole testing would be suggested to identify small clusters, followed by excavation of isolated clusters.

9.2. Future recommendations

The purpose of the model was to make the complexities of the site's soil visible and therefore more understandable. Unfortunately, those very complexities restricted the development process. The statistical error caused by the soil variability was enhanced by inconsistent interpretations in the field. Because of the confusing nature of the soils in some areas, soil profile interpretations were sometimes less reliable than expected. Reinterpretation was possible by using soil specialist Larry Abbott's field records as a benchmark, along with his personal guidance. However, remaining inconsistencies required the soil model to be simplified. This calls the usefulness of such soil models into question. A site with a simpler soil landscape would have made the process considerably easier, but such a site could probably be interpretable without a three-dimensional soil model.

However, the answer to a successful model may lie in sampling resolution. Arguably, the main problem with the source data is that sampling resolution was not high enough to adequately describe the high local variability of the soil. For a simple soil landscape, the sampling interval would have been sufficient for interpolating the variation between sample points. On the current site, it is indisputable that soil variability between sample points was very high in some portions of the site. This severely limits the predictive power of the interpolation. An accurate model of variability can only be achieved if sampling resolution is adjusted to limit irregularities between sample points.

Still, the model was a success for exploring site-wide patterns. The 2½-D presentation was sufficient for making the site soil landscape navigable and comprehensible. Given more time, future studies could use true 3D GIS to produce such a model. The advantage of a volumetric model would be primarily in the representation of artifact distributions, rather than actual soil description. Given soil data of high enough resolution and quality to allow confidence in local interpolation, much can be learned also by modeling artifact distribution in 3D. Three-dimensional artifact count data could be interpolated into variable density 'clouds'. Relating these artifact clouds to the soil model could identify specific cultural patterns within the soil, and even help locate individual components and occupation surfaces. Test units could then be placed to attempt to target context rather than just artifact density.

While kriging makes more informed assumptions about the nature of spatial variation, it is questionable whether it proved superior to simpler methods in this particular study. As mentioned above, soil variability was not sufficiently detected by the sampling interval. Kriging works well when local variation of attributes is low. Because of the high local variability of the soil, coupled with the insufficient sampling resolution to describe the nature of local variability, interpolated surfaces were somewhat erratic. This was also caused by the decision not to incorporate a nugget into the semivariogram model, as it caused sharp spikes where there was high local variability. However, using a nugget would have resulted in an unacceptable output, as explained in section 7.7.

Despite the issues raised above, this project helped to address several questions introduced after the site survey, and could help guide future excavations at the site. The method of interpolating soil thickness to minimize statistical error and accommodate vanishing horizons could be applied in any GIS application. By recording sample locations and soil profile data digitally in the field, much less time would be required for such a project. A more sophisticated true 3D GIS would likely produce a more useful model, however time, money and limited experience in other applications is often restrictive in such an endeavor. ESRI ArcGIS is a ubiquitous software application in archaeological GIS studies. It also incorporates data from Microsoft Access databases, to a limited degree via the user interface, and extensively using Visual Basic for Applications. This study has demonstrated the possibility of and some methods for approaching three-dimensional intrasite capabilities using these well-known and readily available technologies.

Appendix 1. Citation list

Abbott, L. R. 2000. *An archeological survey east of B-591, Pine Oaks Golf Course, Robins AFB, Georgia (unpublished report)*. Warner Robins: Ellis Environmental, LC.

—. 2003. *Cultural resources management plan: Robins Air Force Base, Houston County, Georgia*. Warner Robins, GA: Environmental Management Directorate, Robins AFB.

Abbott, L. R., and B. H. Hoffman. 2001. *An archeological assessment of the eighteen greens, Pine Oaks Golf Course, Robins Air Force Base, Houston County, Georgia (unpublished report)*. Warner Robins: Ellis Environmental, LC.

—. 2002. *An archeological survey of the 7th, 8th, 9th, 10th, 11th, and 18th Fairways, Pine Oaks Golf Course, Robins AFB, Houston County, Georgia (unpublished report)*. Warner Robins: Ellis Environmental.

Ameskamp, M., and J. Lamp. 1998. "Three-dimensional soil prediction: fuzzy rules and a GIS," in *European Soil Bureau research report no. 4*. Edited by H. e. al., pp. 361-372. Luxembourg: Office for Official Publications of the European Communities.

Anderson, D. G. 2003. Paleoindian Period: overview. *The New Georgia Encyclopedia.* Accessed July 24, 2004 at http://www.georgiaencyclopedia.org/nge/Article.jsp?id=h-810.

Anderson, D. G., J. Ledbetter, L. O'Steen, D. T. Eliott, D. Blanton, G. T. Hanson, and F. Snow. 1994. "Paleoindian and Early Archaic in the Lower Southeast: a view from Georgia," in *Ocmulgee Archaeology, 1936-1986*. Edited by D. J. Hally. Athens: University of Georgia Press.

Anderson, D. G., J. R. Ledbetter, and L. O'Steen. 1990. *Paleoindian Period archaeology of Georgia*. *University of Georgia Laboratory of Archaeology Series Report No. 28*. Athens: University of Georgia.

Benson, R. W. 1995. Quartz passports of the Morrow Mountain Middle Archaic in the Savannah River Drainage. *Early Georgia* 23(1):1-15.

Blanton, D. B., and M. B. Reed. 1987. *Archaeological testing and survey at Robins Air Force Base (unpublished report)*. Garrow & Associates, Inc.

Bouzelboudjen, M., and F. Kimmeier. 1998. GIS vector and raster database, advanced geostatistics and 3-D groundwater flow modelling in strongly heterogeneous geologic media: an integrated approach. *The eighteenth annual ESRI User Conference, San Diego, California USA, 27-31 July 1998.* Accessed August 16, 2004 at http://www.unine.ch/sig/p673.html.

Briggs, I. 1974. Machine contouring using minimum curvature. *Geophysics* 39:39-48.

Brown, J. A. 1986. "Early ceramics and culture: a review of interpretations," in *Early Woodland Archaeology*. Edited by K. B. Farnsworth and T. E. Emerson. Kampsville, IL: Center for American Archaeology Press.

Buol, S. W., R. J. Southard, R. C. Graham, and P. A. McDanial. 2003. *Soil genesis and classification*, 5th edition. Ames: Iowa State Press.

Davis, M. B. 1984. "Holocene Vegetational History of the United States," in *Late Quaternary environments of the United States, Vol. 2: the Holocene*. Edited by H. E. Wright. London: Longman Group Limited.

Duncan, M. S. 2003. Fall Line. *The New Georgia Encyclopedia.* Accessed August 30, 2004 at http://www.georgiaencyclopedia.org/nge/Article.jsp?id=h-721.

Ebert, D. 1998. *Expanding the selection of tools for spatial analysis (Master's degree thesis)*. Southampton: University of Southampton.

—. 2002. "The potential of geostatistics in the analysis of fieldwalking data," in *University of Southampton Department of Archaeology Monograph no. 3: contemporary themes in archaeological computing*. Edited by D. Wheatley, G. Earl, and S. Poppy, pp. 82-89. Oxford: Oxbow Books.

Eliott, D. T., and K. Sassaman. 1995. *Archaic period archaeology of the Georgia Coastal Plain and Coastal Zone*. *University of Georgia Laboratory of Archaeology Series Report No. 35*. Athens: University of Georgia.

ESRI. 2003. ArcObjects 8 developer help [online documentation]. Redlands, CA: Environmental Systems Research Institute, Inc. Accessed at.

Fanning, D. S., and M. C. B. Fanning. 1989. *Soil: morphology, genesis and classification*. New York: John Wiley & Sons.

Georgia Geologic Survey. 1996. GIS database: physiographic map of Georgia. Atlanta, GA: Georgia Geologic Survey. Accessed at.

—. 1999. Digital geologic map of Georgia, ver. 2. Atlanta, GA: Georgia Geologic Survey. Accessed at.

Gerrard, A. J. 1981. *Soils and landforms*. London: George, Allen & Unwin, Ltd.

Gousie, M. B., and W. R. Franklin. 2003. Constructing a DEM from grid-based data by computing intermediate contours. *Proceedings of the eleventh ACM international symposium on Advances in geographic information systems*:71-77.

Grunwald, S., and P. Barak. 2001. The use of VRML for virtual soil landscape modelling. *Journal of systems analysis, modelling and simulation (SAMS)* 41:755-776.

—. 2003. 3D geographic reconstruction and visualization techniques applied to resource management. *Transactions in GIS* 7(2):231-241.

Grunwald, S., K. McSweeney, D. J. Rooney, and B. Lowery. 2001. Soil layer models created with profile cone penetrometer data. *Geoderma* 103:181-201.

Harris, T. M., and G. Lock. 1996. "Multi-dimensional GIS: exploratory approaches to spatial and temporal relationships within archaeological stratigraphy," in *Interfacing the Past. Computer Applications and Quantitative Methods in Archaeology CAA95, Analecta Praehistorica Leidensia 28*. Edited by H. Kamermans and K. Fennema. Leiden: University of Leiden.

Isaaks, E. H., and R. M. Srivastava. 1989. *An Introduction to applied geostatistics*. Oxford: Oxford University Press.

Jefferies, R. W. 1994. "The Swift Creek site and Woodland platform mounds in the southeastern United States," in *Ocmulgee Archaeology 1936-1986*. Edited by D. J. Hally, pp. 71-83. Athens: University of Georgia Press.

Jenny, H. 1941. *Factors of soil formation: a system of quantitative pedology*. New York: McGraw-Hill.

Johnson, D. L., and D. Watson-Stegner. 1990. "The soil-evolution model as a framework for evaluating pedoturbation in archaeological site formation," in *Archaeological geology of North America*. Edited by N. P. Lasca and J. D. Donahue, pp. 541-560. Boulder, CO: Geological Society of America, Centennial Special Volume 4.

Johnston, K., J. M. Ver Hoef, K. Krivoruchko, and N. Lucas. 2001. *Using ArcGIS Geostatistical Analyst*. Redlands, CA: ESRI Press.

Kane, S., and R. Keeton. 1998. *Fort Benning: the land and the people*. Tallahassee, FL: US Army Infantry Center.

Kies, A., J. Majerus, S. Roth, and F. Tondeur. 2002. Test of geostatistical softwares with simulated and real radon data. Luxembourg: Université du Luxembourg, Laboratoire Physique des Radiations. Accessed Sept. 12, 2004 at http://www.cu.lu/lpr/papers/geostat.htm.

Knox, J. C. 1984. "Responses of river systems to Holocene climates," in *Late Quaternary environments of the United States, Vol. 2: the Holocene*. Edited by H. E. Wright. London: Longman Group Limited.

Leigh, D. S., and T. P. Feeney. 1995. Paleochannels indicating wet climate and lack of response to lower sea level, southeast Georgia. *Geology* 23(8):687-690.

Lloyd, C. D., and P. M. Atkinson. 2004. Archaeology and geostatistics. *Journal of archaeological science* 31:151-165.

Masumoto, S., V. Raghavan, T. Nemoto, and K. Shiono. 2004. Construction and Visualization of Three Dimensional Geologic Model Using GRASS GIS. *Transactions in GIS* 8:211-223.

Mendonça Santos, M. L., C. Guenat, M. Bouzelboudjen, and F. Golay. 2000. Three-dimensional GIS cartography applied to the study of the spatial variation of soil horizons in a Swiss floodplain. *Geoderma* 97(4):351-36.

Munsell. 1975. *Munsell soil color charts*. Baltimore, MA: Munsell Color Company.

Natural Resources Conservation Service. 1989. *Soil Survey of Warner Robins Air Force Base, Houston County, Georgia (unpublished report)*.

Oliver, M., R. Webster, and J. Gerrard. 1989. Geostatistics in physical geography. Part 1: theory. *Transactions of the Institute of British Geographers* (New Series), 14(3):259-269.

Ruhe, R. V. 1984. "Aspects of Holocene pedology in the United States," in *Late Quaternary environments of the United States, Vol. 2: the Holocene*. Edited by H. E. Wright, pp. 12-25. London: Longman Group Limited.

Schoenberger, P. J., D. A. Wysocki, E. C. Benham, and W. D. Broderson. 1998. *Field book for describing and sampling soils*. Lincoln, NE: Natural Resources Conservation Service, USDA, National Soil Survey Center.

Sirakov, N. M., and F. H. Muge. 2001. A system for reconstructing and visualising three-dimensional objects. *Computers and Geosciences* 27:59-69.

Soil Survey Staff. 1993. *Soil survey manual, U.S. Department of Agriculture handbook 18.* Washington: United States Department of Agriculture, Soil Conservation Service.

—. 1999. Soil Taxonomy. Washington: United States Department of Agriculture & Natural Resources Conservation Service. Accessed April 18, 2004 at ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Taxonomy/tax.pdf.

—. 2003. Keys to Soil Taxonomy. Washington: United States Department of Agriculture & Natural Resources Conservation Service. Accessed April 18, 2004 at http://soils.usda.gov/technical/classification/tax_keys/keysweb.pdf.

Steinen, K. T. 1995. *Woodland Period archaeology of the Georgia Coastal Plain*. *University of Georgia Laboratory of Archaeology Series Report No. 36*. Athens: University of Georgia.

Stoltman, J. B., and D. A. Baerreis. 1984. "The evolution of human ecosystems in the eastern United States," in *Late Quaternary environments of the United States, Vol. 2: the Holocene*. Edited by H. E. Wright, pp. 252-268. London: Longman Group Limited.

Suwanwiwattana, P., K. Chantawarangul, W. Mairaing, and P. Apaphant. 2001. "The development of geotechnical database of Bangkok subsoil using GRASS-GIS," in *Proceeding of the ACRS 2001 - 22nd Asian Conference on Remote Sensing, 5-9 November 2001*, vol. 1, pp. 643-648. Singapore.

Tobler, W. 1970. A computer model simulating urban growth in the Detroit region. *Economic Geography* 46(2):234-240.

USGS. 1985. *Warner Robins SE (1:24,000 scale quad sheet map)*. Reston, VA: United States Geological Survey.

Weaver, S. D., M. C. Bate, and R. J. Autio. 2003. EQuIS for ArcGIS: state-of-the-art environmental data management and analysis. *Environmental Expert Newsletter, July 2003.* Accessed Sept. 3, 2004 at http://www.earthsoft.com/news/articles/p594/SubsurfaceModelingwithArcGIS.htm.

Whatley, J. S. 2002. An overview of Georgia projectile points and selected cutting tools (special issue). *Early Georgia* 30(1):1-133.

Wheatley, D., and M. Gillings. 2002. *Spatial technology and archaeology: the archaeological application of GIS*. London: Taylor & Francis.

Woods, J. C. 1967. *Soil survey, Houston and Peach Counties, Georgia*. Washington: U.S. Soil Conservation Service.

Zimmerman, D., C. Pavlik, A. Ruggles, and M. P. Armstrong. 1999. An Experimental Comparison of Ordinary and Universal Kriging and Inverse Distance Weighting. *Mathematical Geology* 31(4):375-390.

Zubrow, E. B. W., and J. W. Harbaugh. 1978. "Archaeological prospecting: kriging and simulation," in *Simulation studies in archaeology*. Edited by I. Hodder, pp. 109-122. Cambridge: Cambridge University Press.

Appendix 2. VBA scripts

The requirements of the project sometimes exceeded the basic functionality of the software and existing extensions. For this reason several VBA scripts, some using ArcObjects technology, were developed in order to add critical functionality and visualization features to ArcGIS and the geodatabase. ArcObjects code was based on the standards put forth in the ArcObjects Developer Help (ESRI 2003). All code is original and developed by the author, except where noted in the script comments.

These scripts and tools were developed specifically for this project, and time was not taken to develop them much beyond a purely utilitarian state. In other words, they are all very much beta versions. Still, with some modification and an improved interface, a few could be released publicly. They also lack proper error handling, which would have to be added in a final release version.

A2.1. Soil profile form display in Access

A2.1.1. Description

It was necessary to integrate scanned copies of the soil profile forms into the Access database. First, while much detail was included in the Soil table regarding soil colour, texture, pebbliness, etc., the paper forms often contained information that could not be categorized nor adequately described in text form. Subtleties in writing or drawing could often give otherwise unrecordable insight into the meaning of the soil description.

Second, performing data entry using the paper forms was inefficient for a number of reasons. It was found that having a copy of the original form on-screen made the interpretation and recording of the form much quicker and easier. Therefore, forms were scanned and cropped into individual profiles, which were names using the same naming convention as previously defined in the database.

The VBA script was embedded in the Access 'Profile' form, and is triggered by the form's Current event, which occurs when the focus moves to a record. In practice, this occurs when the form is loaded and when switching from one record to another. The script then identifies the current path of the database and defines the path and filename of the record's image by concatenating the database path, the 'profile-scans' subdirectory, the value of the 'Posthole' field in the 'Profile' table, and the extension '.jpg'. It then sets this as the picture location and hyperlink address of the image object in the 'Profile' form. If the image is not found, both these values are made blank.

A2.1.2. Source code

```
Private Sub Form_Current()
On Error GoTo Crapout
Dim strPath As String
strPath = CurrentProject.Path & "\profile-scans\"
Image11.Picture = strPath & Posthole.Value & ".jpg"
Image11.HyperlinkAddress = strPath & Posthole.Value & ".jpg"
Exit Sub
Crapout:
Image11.Picture = ""
Image11.HyperlinkAddress = ""
End Sub
```

A2.2. Soil profile form display in ArcMap

A2.2.1. Description

This is an adaptation of the Access VBA script described above, and was developed in order to compare soil profiles adjacent to one another. This made it easier to understand the relationships between profiles and correct errors using neighboring profiles as controls. It also served as a preliminary tool for understanding the broader spatial relationships between soil profiles.

This script targets the selected layer and loops through the first four selected features. Using the same method as the Microsoft Access version of this script, it loads up to four images into the display window. Clicking anywhere within the window refreshes the display, so that the window can remain open while new sets of postholes are selected in ArcMap.

A2.2.2. Source code

```
Private Sub UserForm_Click()
LoadImages
End Sub

Private Sub imgPic1_Click()
LoadImages
End Sub

Private Sub imgPic2_Click()
LoadImages
End Sub

Private Sub imgPic3_Click()
LoadImages
End Sub

Private Sub imgPic4_Click()
LoadImages
End Sub

Private Sub UserForm_Activate()
LoadImages
End Sub

Private Sub LoadImages()
imgPic1.Picture = Nothing
imgPic2.Picture = Nothing
imgPic3.Picture = Nothing
imgPic4.Picture = Nothing
Dim pMxDoc As IMxDocument
Set pMxDoc = ThisDocument
Dim pMap As IMap
Set pMap = pMxDoc.FocusMap
Dim pLayer As IFeatureLayer
```

```
Set pLayer = pMxDoc.SelectedLayer
Dim pFS As IFeatureSelection
Set pFS = pLayer
Dim pFCursor As IFeatureCursor
pFS.SelectionSet.Search Nothing, False, pFCursor
Dim pF As IFeature
Set pF = pFCursor.NextFeature
Dim strHole As String
Dim intHyphen As Integer
Dim intFairway As Integer
Dim strPosthole As String
Dim strFilename As String
Dim strPath As String
strPath = "E:\_Southampton\Dissertation\NewGIS\Profile-scans\"
Dim intCount As Integer
intCount = 1
Dim imgTarget(1 To 4) As Image
Set imgTarget(1) = imgPic1
Set imgTarget(2) = imgPic2
Set imgTarget(3) = imgPic3
Set imgTarget(4) = imgPic4
Dim lblTarget(1 To 4) As Label
Set lblTarget(1) = lblPic1
Set lblTarget(2) = lblPic2
Set lblTarget(3) = lblPic3
Set lblTarget(4) = lblPic4
Do Until pF Is Nothing Or intCount = 5On Error GoTo Crapout:
    strHole = pF.Value(pF.Fields.FindField("Hole"))
    strFilename = strPath & strHole & ".jpg"
    imgTarget(intCount).Picture = LoadPicture(strFilename)
    'End If
Crapout:
    lblTarget(intCount).Caption = strHole
    Set pF = pFCursor.NextFeature
    intCount = intCount + 1
  Loop
  frmProfile.Repaint
End Sub
```

A2.3. Horizon data transformation and export

A2.3.1. Description

While the format used to record soil data is useful for viewing and interpreting the data as recorded in the field, it is not useful for modeling. Therefore, a script had to be developed to reorganize the data structure so that each row represents a unique posthole and horizon depths, thicknesses, and other data occur as columns.

The following script is somewhat complicated, and only a simplified description will appear here. It loops through each record in the 'Soil' table and determines the uppermost limit of each layer, using the layer definitions in the 'Horizon_ID' table. It then generates a table that displays posthole data using the structure described above. Using the surface elevations of each posthole in the geodatabase, it determines the absolute elevation of each layer as well as its thickness. It also incorporates X and Y coordinate data from the geodatabase into the final table. This table is then exported as a comma-separated value (csv) file, which is later imported into ArcGIS.

The Microsoft ADO and DAO references must be loaded in order to run this code.

A2.3.2. Source code

```
Function ProfileList()
Dim quo As String           'Double-quotes
quo = Chr(34)
Dim db As Database          'Current Database
Set db = CurrentDb()
Dim Firsttime As Boolean    'Is this the first posthole?
Firsttime = True
Dim rsPostholes As DAO.Recordset            'Select postholes that exist in the GIS and are not excluded
Set rsPostholes = db.OpenRecordset("SELECT Postholes_3d.Hole FROM Postholes_3d, PROFILE " & _
   "WHERE (((Postholes_3d.Hole)=[profile].[posthole]) AND ((PROFILE.[Exclude?])=No));")
Dim rsHorizons_ID As DAO.Recordset          'List of all horizons in order from deepest to shallowest
Set rsHorizons_ID = db.OpenRecordset("select * from Horizon_ID WHERE not isnull(Horizon_order) ORDER BY
                                                horizon_order DESC")
Dim rsCurrentElev As DAO.Recordset          'Current Horizon elevation holder
Dim sqlCurrentElev As String                'SQL statement defining current horizon elevation
Dim rsReducedHor As DAO.Recordset           'List of all general horizons
Set rsReducedHor = db.OpenRecordset("SELECT Max(Horizon_Id.Horizon_Order) AS MaxHor,
                                                Horizon_Id.Horizon_Generalize " & _
                        "FROM Horizon_Id GROUP BY Horizon_Id.Horizon_Generalize " & _
                        "ORDER BY Max(Horizon_ID.horizon_order);")
Dim rsOutput As New adodb.Recordset         'Output to be saved as csv file
With rsOutput.Fields                        'Add fields to Output
   .Append "Hole", adVarChar, 10
   .Append "Surface", adSingle
   .Append "End", adSingle
   .Append "Coor_X", adDouble
   .Append "Coor_Y", adDouble
```

```
End With
Do Until rsReducedHor.EOF                'Add fields to Output for each horizon elevation and thickness
   rsOutput.Fields.Append rsReducedHor.Fields("Horizon_generalize").Value, adSingle
   rsOutput.Fields.Append "Thick_" & rsReducedHor.Fields("Horizon_generalize").Value, adSingle
   rsReducedHor.MoveNext
Loop
rsOutput.Open                          'Open recordset
Dim rsHorizons_Cache As New adodb.Recordset 'Holds information on current posthole's horizon order, elevations,
                                                                          general horizon
With rsHorizons_Cache.Fields
   .Append "Horizon_Order", adInteger
   .Append "Horizon_Generalize", adVarChar, 10
   .Append "Elevation", adSingle
End With
rsHorizons_Cache.Open
Dim strCurrentHole As String             'Current hole
Dim sngBottom As Single
Do Until rsPostholes.EOF                 'FOR EACH POSTHOLE TEST:
   strCurrentHole = rsPostholes.Fields("Hole").Value   'Current hole
   sqlCurrentElev = "SELECT ROUND(MAX([Elev_Meter]),2) AS HorElevation, postholes_3d.X, postholes_3d.Y " & _
                "FROM postholes_3d " & _
                "GROUP BY postholes_3d.X, postholes_3d.Y, postholes_3d.Hole " & _
                "HAVING ( (postholes_3d.Hole) = " & quo & strCurrentHole & quo & ");"
   Set rsCurrentElev = db.OpenRecordset(sqlCurrentElev)    '3d surface coordinates of posthole test
   rsCurrentElev.MoveFirst
   With rsOutput                              'Write posthole 3d coordinates to Output
      .AddNew
      !Hole = strCurrentHole
      !Surface = Feet(rsCurrentElev.Fields("HorElevation").Value)
      !Coor_X = rsCurrentElev.Fields("X").Value
      !Coor_Y = rsCurrentElev.Fields("Y").Value
   End With
   rsHorizons_ID.MoveFirst
   Set rsCurrentElev = FindBottom(strCurrentHole)         'Find the bottom of the posthole test
   sngBottom = rsCurrentElev.Fields("HorElevation").Value
   rsOutput!End = Feet(sngBottom)   'Write bottom to output
   Set rsHorizons_Cache = LoadHorizons_Cache(rsHorizons_Cache, rsHorizons_ID, rsPostholes.Fields("Hole"),
                                                                          rsCurrentElev)
                                       'Get Horizon data for this hole

   Set rsOutput = FillOutput(rsOutput, rsHorizons_Cache, sngBottom)
                                       'Write horizon data to output
   rsPostholes.MoveNext                         'Go to the next posthole test
   Set rsHorizons_Cache = Clear_RS_ADO(rsHorizons_Cache)   'Clear the Horizons_Cache
Loop
Call Save_csv(db, "Horizons_Table.csv", rsOutput)          'Save to file
rsPostholes.Close                               'Close recordsets
Set rsPostholes = Nothing
rsHorizons_ID.Close
Set rsHorizons_ID = Nothing
rsCurrentElev.Close
Set rsCurrentElev = Nothing
rsOutput.Close
Set rsOutput = Nothing
Set rsHorizons_Cache = Nothing
End Function

Private Function FillOutput(rsOutput As adodb.Recordset, rsHorizons_Cache As adodb.Recordset, Bottom As Single)
                                                                          As adodb.Recordset
Dim OldElev As Single          'Elevation of previous horizon
Dim NewElev As Single           'Elevation of current horizon
Dim strField As String         'Current field
```

```
Dim sngThick As Single          'Thickness
If rsHorizons_Cache.State = 0 Then rsHorizons_Cache.Open    'If the cache isn't open, open it
rsHorizons_Cache.Sort = "Horizon_order DESC" 'Sort the Load_Horizons results by the horizon order, bottom up
OldElev = Bottom    'Compare the bottom horizon (i.e. first loop) with the bottom of the posthole test
Do Until rsHorizons_Cache.EOF   'FOR EACH POSSIBLE HORIZON:
   strField = rsHorizons_Cache.Fields("horizon_generalize")        'Current general horizon name
   NewElev = rsHorizons_Cache.Fields("Elevation")
   sngThick = (CInt(NewElev * 100) - CInt(OldElev * 100)) / 100    'Calculate thickness of current horizon
   rsOutput.Fields("Thick_" & strField) = Feet(sngThick)
   rsOutput.Fields(strField) = Feet(rsHorizons_Cache.Fields("Elevation")) 'Store horizon elevation in output
   OldElev = rsHorizons_Cache.Fields("Elevation")
   rsHorizons_Cache.MoveNext              'Move to the next possible horizon
Loop
With rsOutput
End With
Set FillOutput = rsOutput
End Function

Private Function Save_csv(db As Database, filename As String, rs As adodb.Recordset)
Dim intPos As Integer
Dim counter As Integer
counter = Len(db.Name)
Do Until counter = 0
   intPos = InStr(counter, db.Name, "\", 1)
   If intPos <> 0 Then Exit Do
   counter = counter - 1
Loop
Dim Path As String
Path = Left(db.Name, intPos) & filename
Dim fs
Set fs = CreateObject("Scripting.FileSystemObject")
If fs.FileExists(Path) Then Kill Path
Set fs = Nothing
RecordsetToText rs, Path, ","
MsgBox "Finished writing to " & Path
End Function

Private Function FindBottom(strCurrentHole) As DAO.Recordset
Dim quo As String
quo = """"
Dim sqlGetEnd(1 To 2) As String
sqlGetEnd(1) = "SELECT ROUND([Elev_Meter], 2) - Max([Lower]/100) AS HorElevation FROM Soil " & _
            "INNER JOIN Postholes_3d ON Soil.Posthole = Postholes_3d.Hole " & _
            "GROUP BY Postholes_3d.Hole, Postholes_3d.Elev_Meter " & _
            "HAVING (((Postholes_3d.Hole)=" & quo
sqlGetEnd(2) = quo & "));"
Set FindBottom = CurrentDb().OpenRecordset(sqlGetEnd(1) & strCurrentHole & sqlGetEnd(2))
End Function

Private Function LoadHorizons_Cache(rsHorizons_Cache As adodb.Recordset, _
                            rsHorizons_ID As DAO.Recordset, _
                            currentHole As String, _
                            rsCurrentElev As DAO.Recordset) As adodb.Recordset
   Dim quo As String 'double-quotes
   quo = Chr(34)
   Dim sqlCurrentElev As String          'SQL string current horizon's elevation
   Dim db As Database
   Set db = CurrentDb()                  'Current database
   Dim rsElev_Cache As DAO.Recordset       'Cache for possible horizon's elevation
   Do Until rsHorizons_ID.EOF             'Loop through all possible horizons (deepest to shallowest) and calculate
                                                                 elevation
```

```
        sqlCurrentElev = "SELECT Iif(Soil.[Inceptisol?]," & quo & "Inceptisol" & quo & ", Soil.Horizon) AS Horizon_Final, "
                                                                                  & _
              "ROUND([Elev_Meter], 2) - MIN([upper]/100) AS HorElevation " & _
              "FROM Postholes_3d INNER JOIN Soil ON Postholes_3d.Hole = Soil.Posthole " & _
              "GROUP BY Iif(Soil.[Inceptisol?]," & quo & "Inceptisol" & quo & ",Soil.Horizon), " & _
              "Postholes_3d.Hole, Postholes_3d.Elev_Meter " & _
              "HAVING (Iif(Soil.[Inceptisol?]," & quo & "Inceptisol" & quo & ",Soil.Horizon) = " & quo & _
              rsHorizons_ID.Fields("Horizon") & quo & " )" & _
              "AND ((Postholes_3d.Hole)=" & quo & currentHole & quo & ");"
        Set rsElev_Cache = db.OpenRecordset(sqlCurrentElev) 'Select the value for current possible horizon
        If rsElev_Cache.RecordCount <> 0 Then Set rsCurrentElev = rsElev_Cache
                                        'If there is a value, store it (otherwise previous value remains)
        If rsHorizons_Cache.RecordCount <> 0 Then
          If rsHorizons_ID.Fields("Horizon_Generalize") <> rsHorizons_Cache.Fields("Horizon_Generalize") Then
            rsHorizons_Cache.AddNew
          End If
        Else: rsHorizons_Cache.AddNew
        End If
        With rsHorizons_Cache   'Store horizon elevation data
          !horizon_order = rsHorizons_ID.Fields("Horizon_Order")
          !Horizon_Generalize = rsHorizons_ID.Fields("Horizon_Generalize")
          !Elevation = rsCurrentElev.Fields("HorElevation")
        End With
        rsHorizons_ID.MoveNext  'Go to the next possible horizon
      Loop
      Set LoadHorizons_Cache = rsHorizons_Cache   'Return elevations for every possible horizon
    End Function

    Public Function RecordsetToText(rs As Object, Optional FullPath _
      As String, Optional ValueDelimiter As String = " ") As Boolean
    'PURPOSE: EXPORTS DATA FROM AN ADO RECORDSET TO A TEXT FILE
    'PARAMETERS:
    'RS: Recordset to Export. Open the recordset before
    'passing it to this function
    'FullPath (Optional): FullPath of text file.
    'if not specified, the function uses app.path +
    'rs.txt
    'ValueDelmiter (Optional): String to delimiter
    'values within a row.  If not specified, an empty space
    'is used
    'RETURNS: True if successful, false if an error occurs
    'COMMENTS: Rows are delimited by a carriage return
    'This is an adaptation by Christian Maire of code available at:
    'http://www.freevbcode.com/ShowCode.asp?ID=548
    Dim sDelimiter As String
    Dim iFileNum As Integer
    Dim lFieldCount As Long
    Dim lCtr As Long
    Dim oField As adodb.field
    On Error GoTo ErrorHandler:
    If RecordSetReady(rs) = False Then Exit Function
    sDelimiter = ValueDelimiter
    iFileNum = FreeFile
    Open FullPath For Output As #iFileNum
    With rs
    lFieldCount = .Fields.Count - 1
    On Error Resume Next
    .MoveFirst
    On Error GoTo ErrorHandler
    For lCtr = 0 To lFieldCount
      Dim sNumprefix As String
      Set oField = .Fields(lCtr)
```

```
    If IsNumeric(Left(oField.Name, 1)) Then
        sNumprefix = "H_"
    Else
        sNumprefix = ""
    End If
    If FieldCanBeString(oField) Then
        If lCtr < lFieldCount Then
            Print #iFileNum, sNumprefix & oField.Name; sDelimiter;
        Else
            Print #iFileNum, sNumprefix & oField.Name
        End If
    End If
Next
.MoveFirst
Do While Not .EOF
For lCtr = 0 To lFieldCount
    Set oField = .Fields(lCtr)
    If FieldCanBeString(oField) Then
        If lCtr < lFieldCount Then
            Print #iFileNum, oField.Value & sDelimiter;
        Else
            Print #iFileNum, oField.Value
        End If
    End If
Next
.MoveNext
Loop
End With
RecordsetToText = True
ErrorHandler:
 On Error Resume Next
 Close #iFileNum
End Function

Private Function RecordSetReady(rs As Object) As Boolean
'This is an adaptation by Christian Maire of code available at:
'http://www.freevbcode.com/ShowCode.asp?ID=548
'Recordset must be opened and connected
On Error Resume Next
If rs Is Nothing Then Exit Function
If Not TypeOf rs Is adodb.Recordset Then Exit Function
If rs.State = 0 Then
    'attempt to open, requires source has populated and either
    'source or recordset has an active connection
    On Error Resume Next
    rs.Open
    If Err.Number <> 0 Then Exit Function
End If
RecordSetReady = True
End Function

Private Function FieldCanBeString(FieldObj As adodb.field) _
   As Boolean
'This is an adaptation by Christian Maire of code available at:
'http://www.freevbcode.com/ShowCode.asp?ID=548
If IsObject(FieldObj.Value) Then
     FieldCanBeString = False
Else
     'Assumes adEmpty will be converted to ""
     'Doesn't check for null value because
     'Assumes null will be converted to ""
     Select Case FieldObj.Type
```

```
        Case adBinary, adIDispatch, adIUnknown, adUserDefined
            FieldCanBeString = False
        Case Else
            FieldCanBeString = True
    End Select
End If
End Function

Private Function Clear_RS_ADO(ByRef Record_Set As adodb.Recordset) As adodb.Recordset
'This is an adaptation by Christian Maire of code available at:
'http://www.freevbcode.com/ShowCode.asp?ID=548
If Record_Set.RecordCount = 0 Then Exit Function
Record_Set.MoveFirst
    Do Until Record_Set.EOF
        Record_Set.Delete
        Record_Set.Update
        Record_Set.MoveNext
    Loop
    Set Clear_RS_ADO = Record_Set
End Function

Private Function Clear_RS_DAO(ByRef Record_Set As DAO.Recordset) As DAO.Recordset
'This is an adaptation by Christian Maire of code available at:
'http://www.freevbcode.com/ShowCode.asp?ID=548
If Record_Set Is Nothing Then Exit Function
Record_Set.MoveFirst
Do Until Record_Set.EOF
    Record_Set.Delete
    Record_Set.Update
    Record_Set.MoveNext
Loop
Set Clear_RS_DAO = Record_Set
End Function

Private Function Feet(sngInput As Single) As Single
Feet = sngInput * 3.28
End Function

Private Function Meters(sngInput As Single) As Single
Meters = sngInput / 3.28
End Function
```

A2.4. Small finds link in Microsoft Access

A2.4.1. Description

To have a single table for small finds details linked to three very different artifact tables, it was necessary to base the relevant relationships on a single key, namely ‘SF_ID’, the small finds identifier number. It was desirable to be able to both create a new small find entry and to open an existing entry from each of the three artifact forms. This was done using a VBA script. This script is initiated by a button located in all three tables beside the ‘SF_ID’ field for each artifact record. Once initiated, it first checks if there is already a small finds ID for the given artifact. If there is, it opens ‘Small_Finds”, the small finds detail form, filtered to show only the entry with the corresponding ID. If the ‘SF_ID’ field is blank, it creates a new record in the ‘Small_Finds’ form, and records the automatically generated SF_ID in the artifact form entry which initiated the script. It then fills in the ‘Description’ field of the ‘Small_Finds’ form with the description in the source artifact form, which can be subsequently changed, if necessary.

A2.4.2. Source code

```
Private Sub cmdSF_Click()
Dim intSF As Integer
Dim frmSF As Form
If IsNull(Small_find.Value) Then
   DoCmd.OpenForm "Small_Finds", , , , acFormAdd
   Set frmSF = Forms("Small_Finds")
   frmSF.Description.Value = Artifact.Value
   intSF = frmSF.SF_ID.Value
   Small_find.Value = intSF
Else
   intSF = Small_find.Value
   DoCmd.OpenForm "Small_Finds", , , "SF_ID = " & intSF
End If
End Sub
```

A2.5. Test unit sketch image link in Microsoft Access

A2.5.1. Description

This is a simple script designed to load a new target image path for the 'Open Sketch' button in the 'Test_Units' form. It is triggered by loading or changing records within the form. The end result is that by pressing the button, the image of the active record's test unit profile is opened in the computer's default image viewer.

A2.5.2. Source code

```
Private Sub Form_Current()
Dim strPath As String
strPath = CurrentProject.Path & "\profile-scans\TU_Profiles\"

Dim strFilename As String
Select Case Len(Test_Unit.Value)
   Case 1: strFilename = "TU0" & Test_Unit.Value
   Case 2: strFilename = "TU" & Test_Unit.Value
End Select
   cmdSketch.HyperlinkAddress = strPath & strFilename & ".jpg"
End Sub
```

A2.6. Fence diagram display tool in ArcMap

A2.6.1. Description

The soil profile form display in ArcMap was useful in early stages of the study, but had a number of limitations. Only four profiles could be viewed at one time, and they were not shown to scale. Their relative surface elevation was also not shown. As it was necessary in later stages to correlate horizons between neighboring profiles, this was unacceptable. Also, differences between horizons were not obvious at a glance, and many profile forms were difficult to read.

The new fence diagram tool was designed to display a large number of profiles to scale, vertically offset to reflect their relative elevations, and to show a wide variety of morphological variables in a format that could be quickly and easily assessed. Since soil texture and colour are the soil attributes most important for assessing horizon interpretations, these were made very obvious. The background colour of the profile segment reflects the Munsell (1975) hue designation, essentially reflecting a coarse scale of "redness" in the soil, while the border colour reflects the general texture of the soil. The horizon interpretation, "certainty" of that interpretation, full Munsell (1975) colour designation, specific texture description, and pebbliness are visible as text entries within each profile segment. The same text appears as a tooltip, for this segments in which the entire text may not be visible.

The form contains a large number of invisible labels. This was necessary because unlike Visual Basic, VBA does not support the creation of new controls at runtime. When the 'Draw' button is clicked, the script identifies the currently selected layer in the ArcMap document and loops through each of the selected features. It first determines the highest surface elevation of the selection set and sets this as a baseline for generating relative profile elevations. It then sets the position and vertical height of the next unused label based on the posthole surface elevation, "level" depth, and the total depth of all overlying "layers". The colours are determined by a hardcoded set of rules, the descriptive text is attached to the label, and the label is made visible. The overall width, spacing and vertical scaling of the profiles is controlled by a set of factors that can be set by the user at the top of the form, as well as a vertical offset that can be used to when a very thick fill horizon produces an impractical base elevation. The "Draw" button becomes a "Clear" button that, when pressed, resets the form.

The Microsoft ADO and DAO references must be loaded in order to run this code.

A2.6.2. Source code

```
Private Sub Quit_Click()
Unload frmDrawProfiles
End Sub

Private Sub Start_Click()
If Label1.Visible Then
   Dim intTop As Integer
   Dim intLeft As Integer
   Dim Factor As Single
   Dim Width As Integer
   Dim Spacing As Integer
   Factor = txtVFactor.Value
   Width = txtPWidth.Value
   Spacing = txtPSpacing.Value
   With frmDrawProfiles
      intTop = .Top
      intLeft = .Left
   End With
   Unload frmDrawProfiles
   Load frmDrawProfiles
   With frmDrawProfiles
      .Show
      .Top = intTop
      .Left = intLeft
   End With
      txtVFactor.Value = Factor
      txtPWidth.Value = Width
      txtPSpacing.Value = Spacing
End If
Call DrawProfiles
End Sub

Private Sub DrawProfiles()
   Start.Caption = "Clear"
   Dim pMxDoc As IMxDocument
   Set pMxDoc = ThisDocument
   Dim pMap As IMap
   Set pMap = pMxDoc.FocusMap
   Dim pLayer As IFeatureLayer
   Set pLayer = pMxDoc.SelectedLayer
   Dim pFS As IFeatureSelection
   Set pFS = pLayer
   Dim pFCursor As IFeatureCursor
   pFS.SelectionSet.Search Nothing, False, pFCursor
   Dim pF As IFeature
   Set pF = pFCursor.NextFeature
   Dim strHole As String
   Dim db As database
   Set db = OpenDatabase("9Ht46.mdb")
   Dim rsHoleData As DAO.Recordset
   Dim LayerCount As Integer, HoleCount As Integer
   LayerCount = 0
   HoleCount = 0
   Dim Factor As Single, ProfileWidth As Integer, Spacing As Integer, VClip As Single
   Factor = txtVFactor
   ProfileWidth = txtPWidth
   Spacing = txtPSpacing
   VClip = txtVClip
```

```
Dim strDescription As String
Dim strPebbles As String, strCertain As String
Dim lblBookmark As Label
Dim Depth, Thickness, AnchorXY(1 To 2) As Integer
AnchorXY(1) = 10
AnchorXY(2) = 40
Dim HighElev As Single
HighElev = GetHighestElev(db)
Dim dblColor As Double
Dim lblCurrent As Label
Do Until pF Is Nothing
  HoleCount = HoleCount + 1
  strHole = pF.Value(pF.Fields.FindField("Hole"))
  Set rsHoleData = db.OpenRecordset("SELECT [Soil].*, [PROFILE].[Excavator], [postholes_3d].[Elev_Meter] " & _
                    "FROM [Postholes_3d] " & _
                    "INNER JOIN (PROFILE INNER JOIN Soil ON PROFILE.Posthole = Soil.Posthole) " & _
                    "ON Postholes_3d.Hole = Soil.Posthole " & _
                    "WHERE ([Soil].[Posthole] = " & """" & strHole & """" & ") " & _
                    "ORDER BY [Upper]")

  Do Until rsHoleData.EOF
    Depth = Factor * (rsHoleData.Fields("Upper").Value + (HighElev - rsHoleData.Fields("Elev_Meter").Value) *
                             100)
    Thickness = Factor * (rsHoleData.Fields("lower") - rsHoleData.Fields("upper"))
    LayerCount = NewLayer(LayerCount)
    With frmDrawProfiles.Controls(LayerCount)
      .Left = AnchorXY(1)
      .Top = AnchorXY(2) + Depth - VClip
      .Height = Thickness
      .Width = ProfileWidth
      .Visible = True
      If Not IsNull(rsHoleData.Fields("Mun_HueNum")) Then
        dblColor = ChooseColour(rsHoleData.Fields("Mun_HueNum"), rsHoleData.Fields("Mun_HueCat"))
        .BackColor = dblColor
      End If
      If Not IsNull(rsHoleData.Fields("Texture")) Then
        dblColor = ChooseTexture(rsHoleData.Fields("Texture"))
        .BorderColor = dblColor
      Else
        .BorderColor = 16777215
      End If
      If Not IsNull(rsHoleData.Fields("Pebbles")) Then
        strPebbles = Catpebble(rsHoleData.Fields("Pebbles"))
      Else
        strPebbles = ""
      End If
      Select Case rsHoleData.Fields("Certainty")
        Case 0: strCertain = "(?)"
        Case 1: strCertain = "!"
        Case 2: strCertain = "?"
        Case Else: strCertain = ""
      End Select
      strDescription = rsHoleData.Fields("Horizon") & strCertain & ", " & _
            rsHoleData.Fields("Mun_HueNum") & rsHoleData.Fields("Mun_Huecat") & _
              rsHoleData.Fields("Mun_Value") & "/" & rsHoleData.Fields("Mun_Chroma") & ", " & _
            rsHoleData.Fields("Texture") & ", " & strPebbles
      .Caption = strDescription
      .ControlTipText = strDescription
    End With
    LayerCount = NewLayer(LayerCount)
    With frmDrawProfiles.Controls(LayerCount)
        .Left = AnchorXY(1)
```

```
                .Top = AnchorXY(2) - 10
                .Width = ProfileWidth
                .Height = 10
                .Visible = True
                .Caption = rsHoleData.Fields("Posthole")
                .BorderStyle = 0
            End With
            LayerCount = NewLayer(LayerCount)
            With frmDrawProfiles.Controls(LayerCount)
                .Left = AnchorXY(1)
                .Top = AnchorXY(2) - 20
                .Width = ProfileWidth
                .Height = 10
                .Visible = True
                .Caption = IIf(Not IsNull(rsHoleData.Fields("Excavator")), rsHoleData.Fields("Excavator"), "")
                .BorderStyle = 0
            End With
            rsHoleData.MoveNext
        Loop
        Set pF = pFCursor.NextFeature
        AnchorXY(1) = AnchorXY(1) + ProfileWidth + Spacing
    Loop
End Sub

Private Function NewLayer(LayerCount As Integer) As Integer
LayerCount = LayerCount + 1
Do Until Left(frmDrawProfiles.Controls(LayerCount).Name, 5) = "Label"
    LayerCount = LayerCount + 1
Loop
NewLayer = LayerCount
End Function

Private Function ChooseColour(HueNum As Single, HueCat As String) As Double
If IsNull(HueNum) Then
    ChooseColour = 16775408
    Exit Function
End If
If HueCat = "Y" Then
    ChooseColour = 5754851
    Exit Function
Else
    Select Case HueNum
        Case 2.5
            ChooseColour = 858083
        Case 5
            ChooseColour = 2500301
        Case 7.5
            ChooseColour = 221695
        Case 10
            ChooseColour = 4823790
    End Select
End If
End Function

Private Function ChooseTexture(Texture As String) As Double
Dim sl, hsl, lscl, scl, hscl As Double
sl = 197379
hsl = 55295
lscl = 60928
scl = 16711680
hscl = 9639167
Select Case Texture
```

```
    Case "sl"
        ChooseTexture = sl
    Case "fsl"
        ChooseTexture = sl
    Case "csl"
        ChooseTexture = sl
    Case "hsl"
        ChooseTexture = hsl
    Case "fhsl"
        ChooseTexture = hsl
    Case "hcsl"
        ChooseTexture = hsl
    Case "lscl"
        ChooseTexture = lscl
    Case "lfscl"
        ChooseTexture = lscl
    Case "lcscl"
        ChooseTexture = lscl
    Case "scl"
        ChooseTexture = scl
    Case "fscl"
        ChooseTexture = scl
    Case "cscl"
        ChooseTexture = scl
    Case "hscl"
        ChooseTexture = hscl
    Case "hcscl"
        ChooseTexture = hscl
    Case "hfscl"
        ChooseTexture = hscl
    Case "coscl"
        ChooseTexture = scl
    Case Else
        ChooseTexture = 16777215
End Select
End Function

Private Function GetHighestElev(db As database) As Single
Dim strWhere As String
Dim strHole As String
Dim pMxDoc As IMxDocument
Set pMxDoc = ThisDocument
Dim pMap As IMap
Set pMap = pMxDoc.FocusMap
Dim pLayer As IFeatureLayer
Set pLayer = pMxDoc.SelectedLayer
Dim pFS As IFeatureSelection
Set pFS = pLayer
Dim pFCursor As IFeatureCursor
pFS.SelectionSet.Search Nothing, False, pFCursor
Dim pF As IFeature
Set pF = pFCursor.NextFeature
Dim I As Integer
I = 0
Do Until pF Is Nothing
    strHole = pF.Value(pF.Fields.FindField("Hole"))
    If I <> 0 Then strWhere = strWhere & " OR "
    I = I + 1
    strWhere = strWhere & "(((Hole)= " & """" & strHole & """" & "))"
    Set pF = pFCursor.NextFeature
Loop
Dim rsHighElev As DAO.Recordset
```

```
Set rsHighElev = db.OpenRecordset("SELECT Max(Postholes_3d.Elev_Meter) AS MaxElev " & _
                          "FROM Postholes_3d " & _
                          "WHERE " & strWhere)
GetHighestElev = rsHighElev.Fields("MaxElev").Value
End Function

Private Function Catpebble(PebbleID As Integer) As String
Select Case PebbleID
  Case 1
    Catpebble = "s/w pebbly"
  Case 2
    Catpebble = "pebbly"
  Case 3
    Catpebble = "v. pebbly"
  Case 4
    Catpebble = "gravelly"
  Case 5
    Catpebble = "v. gravelly"
End Select
End Function
```

Appendix 3. Kriging data

A3.1. Surface elevation

A3.1.1. Model and interpolation data

Selected Method: Ordinary Kriging
Number of Points: 762
Order of Trend Removal: Second (Estimated by Global Polynomial Interpolation)
Semivariogram/Covariance:
  Model: 4.8141*Spherical(800.66)+0*Nugget
  Error modeling:
    Microstructure: 0 (100%)
Searching Neighborhood:
  Neighbors to Include: 18
  Searching Ellipse:
    Angle: 0
    Major Semiaxis: 800.66
    Minor Semiaxis: 800.66
    Angular Sectors: 8

A3.1.2. Cross-validation results

Mean: 0.003287
Root-Mean-Square: 0.3812
Average Standard Error: 0.5977
Mean Standardized: 0.001815
Root-Mean-Square Standardized: 0.6043

A3.2. Fill thickness

A3.2.1. Model and interpolation data

Selected Method: Ordinary Kriging
Number of Points: 762
Semivariogram/Covariance:
  Model: 0.38276*Exponential(147.29)
  Error modeling:
    Microstructure: 0.21221 (100%)
Searching Neighborhood:
  Neighbors to Include: 4
  Searching Ellipse:
    Angle: 0
    Major Semiaxis: 147.29
    Minor Semiaxis: 147.29
    Angular Sectors: 8

A3.2.2. Cross-validation results

Mean: -0.007992
Root-Mean-Square: 0.5335
Average Standard Error: 0.505
Mean Standardized: -0.009077
Root-Mean-Square Standardized: 1.047

A3.3. Plowzone thickness

A3.3.1. Model and interpolation data

Selected Method: Ordinary Kriging
Number of Points: 762
Semivariogram/Covariance:
  Model: 0.097799*K-Bessel(627.65,0.052455)
  Error modeling:
    Microstructure: 0.074468 (100%)
    Measurement error: 0 (0%)
Searching Neighborhood:
  Neighbors to Include: 9
  Searching Ellipse:
    Angle: 0
    Major Semiaxis: 627.65
    Minor Semiaxis: 627.65
    Angular Sectors: 8

A3.3.2. Cross-validation results

Mean: 0.0009449
Root-Mean-Square: 0.2914
Average Standard Error: 0.2799
Mean Standardized: 0.003186
Root-Mean-Square Standardized: 1.039

A3.4. Inceptisol Thickness

A3.4.1. Model and interpolation data

Selected Method: Ordinary Kriging
Number of Points: 259
Semivariogram/Covariance:
  Model: 0.87479*K-Bessel(627.66,0.21994)
  Error modeling:
    Microstructure: 0.3792 (100%)
    Measurement error: 0 (0%)

Searching Neighborhood:
  Neighbors to Include: 1
  Searching Ellipse:

Angle: 0
Major Semiaxis: 627.66
Minor Semiaxis: 627.66
Angular Sectors: 4

A3.4.2. Cross-validation results

Mean: 0.006069
Root-Mean-Square: 0.5965
Average Standard Error: 0.644
Mean Standardized: 0.00684
Root-Mean-Square Standardized: 0.9702

A3.5. E/EB/BE unit thickness

A3.5.1. Model and interpolation data

Selected Method: Ordinary Kriging
Number of Points: 762
Order of Trend Removal: Second (Estimated by Global Polynomial Interpolation)
Semivariogram/Covariance:
Model: 0.62307*K-Bessel(408.64,0.2292)
Error modeling:
Microstructure: 0.25293 (100%)
Measurement error: 0 (0%)
Searching Neighborhood:
Neighbors to Include: 4
Searching Ellipse:
Angle: 0
Major Semiaxis: 408.64
Minor Semiaxis: 408.64
Angular Sectors: 4

A3.5.2. Cross-validation results

Mean: -0.00009787
Root-Mean-Square: 0.5779
Average Standard Error: 0.5767
Mean Standardized: 0.000623
Root-Mean-Square Standardized: 1.013

A3.6. Bt horizon thickness

A3.6.1. Model and interpolation data

Selected Method: Ordinary Kriging
Number of Points: 762
Semivariogram/Covariance:
Model: 0.11609*K-Bessel(627.66,0.17819)
Error modeling:
Microstructure: 0.055932 (100%)

Measurement error: 0 (0%)
Searching Neighborhood:
Neighbors to Include: 14
Searching Ellipse:
Angle: 0
Major Semiaxis: 627.66
Minor Semiaxis: 627.66
Angular Sectors: 4

A3.6.2. Cross-validation results

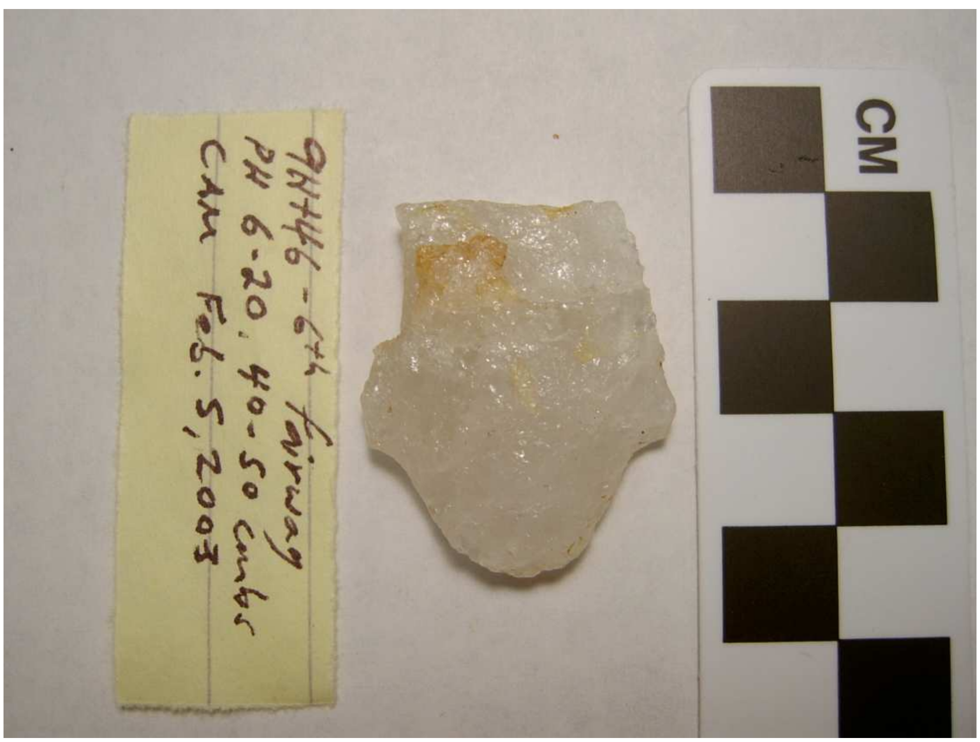
Mean: 0.001922
Root-Mean-Square: 0.2535
Average Standard Error: 0.2462
Mean Standardized: 0.004456
Root-Mean-Square Standardized: 1.043

Appendix 4. Miscellaneous images

Artifact processing and database entry.

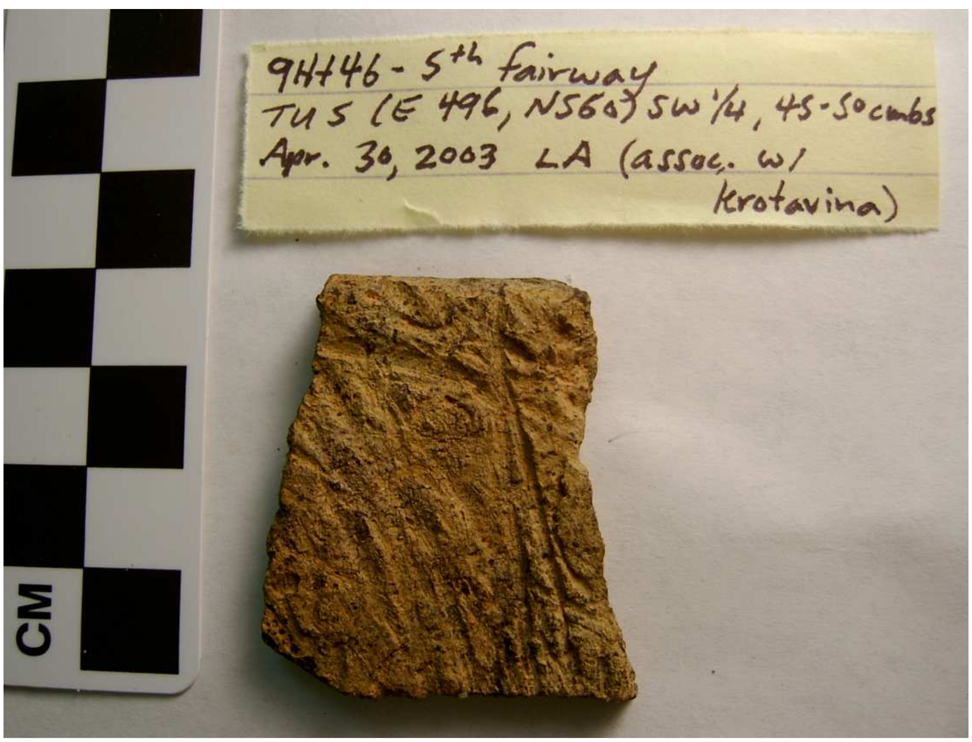
A typical test unit. The disturbed soil in the center is a backfilled posthole test.

An Early Archaic Big Sandy point.



A Middle Archaic quartz Morrow Mountain point fragment.

A Late Archaic South Prong Creek point.



An Early Woodland Refuge Brushed ceramic rimsherd.