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Recovering Elements in Historical Archaeology: The use of Soil Chemical Analysis for Overcoming the Effects of Post-Depositional Plowing

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RECOVERING ELEMENTS IN HISTORICAL ARCHAEOLOGY: THE USE OF SOIL CHEMICAL ANALYSIS FOR OVERCOMING THE EFFECTS OF POST-DEPOSITIONAL PLOWING

A Thesis
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In Partial Fulfillment
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Master of Arts

by
Lisa E. Fischer
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APPROVAL SHEET

This thesis is submitted in partial fulfillment of

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ABSTRACT

The purpose of this research is to demonstrate the benefits of soil chemical analysis for historical archaeological research on plowed sites. The premise of soil chemical analysis is that humans affect the soil chemistry of any area that is inhabited extensively and that those changes may last in the archaeological record for a long time. Thus, a soil chemical study can help elucidate aspects of spatial usage and organization, especially on sites for which these issues are more difficult to study because of post-depositional plowing.

Although soil chemical analysis has been incorporated into a few historical archaeological studies, no guidelines for a soil chemical study have ever been published. This thesis provides a framework in which to apply soil chemical analysis to the study of a plowed archaeological site. The many issues that need to be considered by historical archaeologists in implementing a soil chemical study are enumerated. In addition, a possible approach to the research, including soil collection strategies, analysis of samples and interpretation of data, is discussed.

The application of soil chemical analysis to a plowed historic site is further discussed with the case study of the Poplar Forest Quarter Site. The soil chemical analysis of the slave quarter at Poplar Forest applied a similar approach to that discussed in the framework. The soil chemical research at the Poplar Forest Quarter Site clearly demonstrates the utility of this approach as the data clearly enhanced and improved the interpretation of the site.

This research clearly shows that soil chemical analysis could have great benefits for the examination of spatial issues on plowed historic sites. However, further research and more studies need to be conducted before it will reach its full potential for historical archaeology.

RECOVERING ELEMENTS IN HISTORICAL ARCHAEOLOGY: THE USE OF SOIL CHEMICAL ANALYSIS FOR OVERCOMING THE EFFECTS OF POST-DEPOSITIONAL PLOWING

CHAPTER I

INTRODUCTION

Post-depositional plowing, a common hindrance faced by many historical archaeologists, creates a uniform deposit of mixed soil and cultural materials on an archaeological site. Although the effect of plowing on the integrity of archaeological sites is considerable, it is not significant enough to discourage the excavation of such sites, especially because so many have been impacted in this way. Rather, archaeologists are forced to devise creative methods for overcoming the effects of the plow to address specific research questions. Both landscape and space have become critical issues of interest within historical archaeology, but they are also, perhaps, two of the research areas most impacted by post-depositional plowing. Evidence of landscape and space can take on a multiplicity of forms but many are ephemeral, meaning that they can be easily distorted or destroyed by the plow.

This thesis will demonstrate that soil chemical analysis, which involves the examination and interpretation of elemental distributions across a site, is an effective method for overcoming the impediment of post-depositional plowing and is one of the best interpretive tools currently available for addressing questions of landscape and space on plowed sites. While issues of landscape and space may be partially addressed by other archaeological evidence, soil chemical data provide a new and unique type of information that can present a more complete picture of spatial patterning. However, no thorough discussion of the many pertinent issues that must be considered in the application of soil chemical analysis to historical sites has ever been published. Consequently, many historical archaeologists are simply unaware of how to approach this type of research. Therefore, this thesis will present a framework and outline the important considerations for approaching soil chemical analysis on plowed sites so that historical archaeologists may begin to incorporate the technique into their research.

The premise of soil chemical analysis is that human occupations impact the soil chemistry of inhabited areas significantly enough that traces of these changes can be detected in the soil, even long after the occupation has ended. These alterations to the soil chemistry may be indicative of a variety of spatial phenomena, including the layout of buildings, activity areas, the organization of yards, and the deposition of trash, all of which speak to one issue: past usages of spaces. With the importance of landscape and space to historical archaeological analysis, the problem that post-depositional plowing presents for the examination of such issues is obvious. Luckily, evidence suggests that elemental distributions, unlike some other types of archaeological evidence, are little affected by plowing, so that even after the artifactual or feature evidence of these human activities has been disturbed, these elemental signatures may survive relatively intact (Pogue 1988:1-2). Therefore, the careful collection and analysis of plowed anthrosols, or soils whose characteristics have been modified either directly or indirectly by people, has the potential to reveal spatial data that may not be available in any other form. Consequently, soil chemical analysis should be considered for incorporation into the research designs of *all* plowed historical sites.

Defining Landscape and Space

Because landscapes and spaces are ubiquitous and diverse, defining all-encompassing concepts for use in anthropological analysis is challenging. Although the term landscape originated during the late sixteenth century as a descriptor for the subject of paintings (Hirsch 1995:2), it has clearly evolved into something much more complex and layered in meaning within the English language. In everyday usage, landscape can be used in a multiplicity of ways, ranging from its original sense for works of art to components of the physical world. In the latter sense, landscape is commonly defined as consisting of two elements, parts of the physical world that are "natural" and those that are man-made. The dichotomy inherent in this definition is problematic for anthropologists, however, as the placement of different pieces of the landscape into either of these categories is culturally-determined rather than inherent in "nature" (Knapp and Ashmore 1999:2; Hood 1996:122). Furthermore, non-Western cultures might not even chose to define the physical world in terms of the same categories. Consequently, it has been argued that the notion of landscape is a Western concept, not universally found in all cultural groups, and therefore its application to the archaeological studies of non-Western cultures should be scrutinized (Thomas 1995:20). While landscape as used in the English language may not be a universal idea, anthropologists can overcome this by defining it as an anthropological term that encompasses all cultural expressions of the concept.

Many social scientists analyzing landscapes, in fact, have proffered the definitions that guided their research. J.B. Jackson, for instance, defines landscape as "a composition of man-made or man-modified spaces to serve as infrastructure or background for our collective existence" (cited in Nye 1999:3). Geographer Pierce Lewis suggests that cultural landscape be defined as "everything that humans do to the natural earth for whatever purpose but most commonly for material profit, aesthetic pleasure, spiritual fulfillment, personal comfort, or community safety" (1993:116). In contrast to Jackson's and Lewis's rather concise definitions, archaeologist John Barrett provides a much longer description of the concept; it is:

> the entire surface over which people moved and within which they congregated. That surface was given meaning as people acted upon the world within the context of the various demands and obligations which acted upon them. Such actions took place within a certain *tempo* and at certain *locales*. Thus landscape, its form constructed from natural and artificial features, became a culturally meaningful resource through its routine occupancy. (cited in Knapp and Ashmore 1999:6-7)

Paul Groth, a cultural landscape historian offers a better definition of landscape and the one that with a slight modification will be used for the purposes of this research; Groth envisions *landscape* to be "the [cultural] interaction of people and place: a social group and its spaces, particularly the spaces to which the group belongs and from which its members derives some part of their shared identity" (1997:1).

Clearly the concept of space is critical to landscape, especially as defined by Groth. In this sense spaces can be viewed as the building blocks of landscapes. James Deetz also emphasizes the importance of space to archaeology as it, along with time and form, are the three dimensions ingrained in all archaeological evidence (1977:64). However, despite the fact that archaeologists commonly use the term space, they rarely define it. Charles Orser, in his book *A Historical Archaeology of the Modern World*, defines space to be "the physical reality of where thing are not located" (1996:136). However, this concept of space is impractical for the discipline of archaeology, which seeks to examine material culture, not nothingness (Tilley 1994:9). Consequently, a usable definition of space for historical archaeologists must incorporate both the material and culture. Christopher Tilley, in *The Phenomenology of Landscape*, offers an in-depth discussion on the meaning of space (1994:9-17). Although he does not provide a concise definition of space, the concepts can be distilled into the following definition, which will be used for this research; *space* is the culturally-dictated material manifestation of relations between objects and/or loci (Tilley 1994:17).

The Importance of Landscape and Space

Landscapes, which are omnipresent, are infused with cultural messages, some blatantly obvious and some heavily encrypted. Geographer Pierce Lewis (1993) compares a landscape to a "cultural autobiography." Although the text of landscape, he argues, is challenging to read, incomplete, and always being rewritten, it is an integral part of culture: "Cultural landscape has many of the qualities of a gigantic palimpsest, a huge ragged informal document written by a host of people with various levels of literacy, repeatedly erased and amended by people with different motives and different tools at their disposal" (Lewis 1993:116). Furthermore, landscapes often contain messages not found in other sources, making them important reservoirs of cultural information (Lewis 1993:116-118). Consequently, any complete anthropological study should attempt to read and decipher the text of the landscape, and archaeology, which is already intimately intertwined with the physical world, should be no exception.

Over the past fifteen years, historical archaeologists have become increasingly aware of how examining landscapes and spaces can elucidate aspects of past cultures, ranging from gender roles to issues of race, power and class. In fact, more and more historical archaeological studies have begun to address questions of landscape and space, and several volumes have been devoted specifically to the examination of past historical landscapes (Kelso and Most 1990; Miller and Gleason 1994b; Yamin and Metheny 1996; Ashmore and Knapp 1999; Ucko and Layton 1999). Furthermore, over the past decade and a half, more and more conference sessions at archaeological and anthropological meetings have been dedicated entirely to papers on archaeological analyses of landscapes and spaces. Unequivocally, all of this research signifies that questions of landscape and space are beginning to assume a fundamental and deserved role within historical archaeology.

The evolution of the role that landscape has played in archaeology is indicative of larger theoretical issues within the discipline. Knapp and Ashmore (1999) argue that even though landscape analysis has been incorporated into archaeological research for many years, its interpretive role has changed. At first, landscape was used simply as a model to provide a backdrop in which to place archaeological findings. Thus, landscape information added color to the picture of the past, but did not inform the interpretation. As new theoretical approaches have begun to infuse archaeological thinking, however, the cultural information provided by past landscapes has become more valued. For example, in an economic approach espoused by critical archaeologists, landscape is metamorphasized into a tool which provides "resources, refuge and risks," meaning that it becomes inextricably linked to the interpretation (Knapp and Ashmore 1999:1). Symbolic archaeology, another important theoretical viewpoint, focuses on the inherent symbolic nature of landscape: "landscape is an entity that exists by virtue of its being perceived, experienced and contextualized by people" (Knapp and Ashmore 1999:1). Thus, landscape has become a critical concept in archaeology.

Landscape and space, which are intimately intertwined, are complex phenomena that are not only integral to culture, but also reflective of culture. Landscape "physically embodies the history, structure, and contexts of human behavior....Any understandings of the physical landscape, therefore, cannot be separated from the culture of the people who utilize it" (Hood 1996:121). In their daily lives, people move through these landscapes and spaces and in doing so negotiate hierarchies of class, ethnicity, race and gender (Delle 1998:8). Spaces frame people's perceptions of the world in which they live. In turn, spaces are manipulated so as to reflect an order dictated by cultural ideas. Through this process of ordering, spaces and landscapes are encoded with cultural messages, some of which can be perceived consciously but many of which are read unconsciously.

The significance of examining landscapes using archaeology is emphasized in the model of landscape as artifact:

> Landscapes are particularly powerful symbolic artifacts because they are three-dimensional spaces, which unlike portable artifacts, are volumes literally entered into and experienced. Space is not simply viewed, held, or worn; it is enacted by being within and moving through it. A landscape, through the structure of its space, directs what one sees and how one moves." (Kryder-Reid 1994:133)

Unlike portable artifacts, however, historical landscapes possess nebulous boundaries creating a challenge in defining the exact subject of study. Because it is impossible to know or study a past landscape in its entirety, archaeologists must study landscapes by examining the use and organization of smaller spaces while appreciating that these pieces were once parts of larger frameworks. Even though reducing a landscape into individual components is problematic, this unfortunately represents the only manageable way for archaeologists to begin. The examination of these smaller pieces allows historical archaeologists to assess and manipulate more manageable units, but as more and more of these patchwork spaces are analyzed, the segments will begin to merge, filling out the picture of larger historical landscapes.

Finding Landscape and Space in the Archaeological Record

Although landscapes are artifacts, unearthing them is far more complicated than recovering portable artifacts. Studying spatial evidence in the archaeological record involves the synthesis of many types of data to begin to understand how spaces were used and landscapes were constructed. In the past, historical archaeological studies have focused much attention on the excavation and analysis of individual buildings, often ignoring or missing other types of evidence that also illuminate spatial concepts. This is not, however, a criticism of the development of excavation techniques for buildings. Many crucial improvements in the archaeological study of structures, especially in the excavation of earthfast buildings, have been important to the study of spaces and landscapes. It is important, however, to acknowledge that landscape and space are not just about buildings, but also about how spaces around buildings were organized, how people moved through them, and the cultural messages they contained.

Many historical archaeological analyses have begun to progress from the overemphasis on individual buildings to more generalized interpretations of spaces. Spaces take on myriad forms, such as yards, lots, formal settings, gardens, fields, and activity areas, all of which begin to elucidate past landscapes. While arguments can be presented supporting the analysis of each of these types of spaces, Barbara Heath and

Amber Bennett argue the importance of analyzing yards for the cultural information that they contain about slave life:

> While yards cannot be studied independently of the houses they surround...it is time to develop tools and to frame questions that take advantage of the unique perspective these external spaces have to offer. Archaeologists must learn to read multiple messages enslaved men and women sought to express in their yards since the study of these spaces provides information about past lives which can be obtained nowhere else. (2000:38)

Similar arguments can be made for the many other types of spatial features, highlighting the important information that they hold. In moving away from the emphasis on individual buildings, the discipline of historical archaeology has begun to reframe research questions, to seek new excavation strategies, and to find additional ways to understand and interpret landscape and space.

Entire volumes could be devoted to how spatial evidence manifests itself in the archaeological record. While each site will have its own considerations, archaeological evidence of spaces can come in many forms, ranging from small artifacts and ecofacts to large aggregations of associated features. Artifacts and how they are distributed can elucidate issues ranging from types of activities and where they were taking place to the boundaries and maintenance of spaces. Ecofacts shed light on the environment, from types of vegetation and where plants were being grown to climatic issues. Major categories of spatial features could include buildings, both with brick foundations and those that were earthfast, as well as fence lines, boundary ditches, trash pits, garden beds, and roads, just to name a few. Most archaeological data will illuminate space and landscape in some way and if these issues were not important to historical archaeologists, then the excavation process would not be so focused on the careful recording of feature and artifact positions.

The Plowzone Problem

As has been demonstrated, the archaeological recovery of spatial data is directly tied to locus, something that is forever altered by post-depositional plowing. The plow can displace artifacts, destroy ecofacts, and decapitate some features while expunging all evidence of others. However, plowing does not eradicate all of the cultural data, meaning that plowed sites can still be investigated. Because so many sites in the United States have been plowed, archaeologists are forced to study them and must adopt a variety of approaches in dealing with this type of disturbance.

In the past, some archaeologists considered plowzone to be of little use in understanding an archaeological site and it was frequently removed quickly to expose what damaged but intact features remained. However, over the past twenty-five years, more and more historical archaeologists have begun to note the fault in this approach and some have attempted to study the effects of post-depositional plowing on archaeological sites (for instance, Roper 1976; Lewarch and O'Brien 1981; Odell and Cowan 1987; Riordan 1988; Custer 1992). After all, if the plow cut through all of the occupation layers of the site, then it will contain the majority of the site information, albeit in a disturbed context. By only examining the features that cut deep enough into subsoil so as to survive the plow, an incomplete picture of the site is provided and much important information is potentially missed.

In questioning whether plowzone should in fact be studied, archaeologists began to examine the magnitude of artifact movement caused by plowing. Some of these studies suggested that, contrary to popular opinion, artifacts were not carried long horizontal distances by plowing; as a result, the controlled collection of artifacts from the plowzone could be meaningful for site interpretations as their general depositional loci could still be understood (Roper 1976). While one study insinuated that size does not affect how far an artifact is moved by the plow (Odell and Cowan 1987:473-474), another study suggested otherwise by indicating that larger artifacts are more likely to be carried further than smaller ones (Riordan 1988:4). These apparently contradictory studies clearly demonstrate the need for continued research on the effects of post-depositional plowing on archaeological sites.

In light of all of these studies, however, many archaeologists have come to regard the collection of plowzone artifacts as beneficial: "While specific, point provenience has been lost on plow zone materials, the overall pattern of the site will be preserved....The plow zone data can provide important behavioral insights on the site's occupants. The [artifactual] data are not 'ruined'; they are slightly out of focus" (Riordan 1988:4). Consequently, historical archaeologists have argued that the recovery of artifacts from the plowzone should be incorporated into the research designs of plowed sites (King and Miller 1987:37; Riordan 1988:4).

While the minimal movement of artifacts by the plow has been clearly demonstrated, artifact distributions are not the only type of information needed for spatial analysis. Besides the examination of artifact transport by the plow, little effort has been applied to studying other ways in which plowzone may be used to inform archaeological interpretations. For research questions that are independent of artifacts or only partially artifact-dependent, plowed sites are still problematic. If retrieving artifacts from the plowzone is valuable, might it not contain other types of equally-useful information? In fact, evidence strongly suggests that elemental distributions in the soil are little affected by plowing and may be able to help answer many archaeological questions, especially those pertaining to the use of spaces (Pogue 1988:1-2).

Soil Chemical Analysis

When investigating plowed sites, archaeologists must expand their repertoires to include approaches not traditionally employed for other sites and the technique of soil chemical analysis is one such method. The careful examination of specific elements and their distributions within the soil can potentially provide information about spatial patterns not necessarily found in other ways. Thus, soil chemical analysis may help historical archaeologists to overcome the impediment of post-depositional plowing to answer research questions that are not artifact-dependent. Although in its infancy as an archaeological technique, soil chemical analysis, with further research and continued use, could develop into a powerful interpretive tool for historical archaeologists.

Over the past seventy-five years, archaeologists have applied the technique of soil chemical analysis to archaeological research questions in a variety of ways. Originally, soil chemical analysis, and specifically the examination of phosphate levels, was used as a survey method, the premise being that elevated phosphorous, indicative of waste and trash deposition, demarcated the presence of sites without extensive digging (Bethell and Máté 1989: 1-2). More recently, however, archaeologists have become more aware of the potential of soil chemical analysis as an interpretive method. After all, if human occupation raises phosphorous levels, people must significantly alter the overall soil chemistry of any inhabited area. Although micro-environmental factors may also affect a site's soil chemistry, humanly-induced changes can be so significant that their traces may survive for hundreds, and perhaps thousands of years. While many historical archaeologists do collect soil during the excavation process, the samples are often taken out of a sense of obligation rather than in accordance with a research design incorporating soil analysis. If soil samples are taken for specific research reasons, frequently they are for the examination of phytoliths or pollen, rather than the distribution of elements. However, for soil chemical analysis to realize its full potential for historical archaeology, the approach must be expanded by including it in the research designs of many plowed sites.

The Science of Soil Chemistry

Although soil chemistry is an extremely complex phenomenon, historical archaeologists possessing some understanding of the pertinent issues can successfully apply soil chemical analysis to archaeological sites. While entire volumes could be devoted to soil and soil chemistry, certain aspects such as the elements, how they are held in the soil and the determination of elemental levels in the soil, have direct bearing on the application of soil chemical analysis to archaeological research. In order for the technique to be used effectively, archaeologists must grasp these issues well enough to make informed decisions from an archaeological perspective.

Soil chemical analysis seeks to examine patterns of elemental distributions across an archaeological site. *Elements* are pure substances that serve as the basic building blocks of all natural matter on earth, including soils. They cannot be broken down by ordinary chemical reactions, nor can they be created by chemical union (Weast and Astle 1982:F-90). All soils contain elements and prior to all human occupation, soil could have been considered *unenhanced*, or exhibiting elemental levels reflective only of natural processes. Through habitation, however, people both contribute to and remove elements from the soil through a variety of processes, such as waste deposition, penning of animals, building construction, and vegetation removal. As these processes are repeated, certain elements can be concentrated in the soil while others are depleted, thereby altering the soil chemistry substantially. Consequently, after an area is used significantly by people, the soil must be considered permanently *enhanced*, or exhibiting elemental levels reflective of human activity, as alterations to soil chemistry induced by people can be apparent long after an occupation has ended.

The soil chemical analysis of archaeological sites has traditionally focused on three or four elements: phosphorous, calcium, potassium and sometimes magnesium. Phosphorous, which is found in human and animal tissues and waste products as well as foodstuffs, has been linked to trash middens, privies, animal pens, and food processing areas. Elevated calcium, found in bone and shell, can be indicative of trash middens, food processing areas, and shell walkways. Potassium, which is common in wood and its ash, can indicate hearth areas, burned buildings and the disposal of fireplace sweepings. Magnesium, which has been tentatively connected to burning (Konrad *et al.* 1983:24), could indicate hearths and burned buildings.

Elements, whether naturally-occurring or humanly-introduced, can be held in the soil in different ways. Soil is a medium for plant growth and it provides nutrients in the form of elements. Thus, some of each element necessary for plant development must be in the soil in a form that plants can easily extract. The easily-extractable or *available* amount of an element consists of the labile, or loosely-bound form, as well as the small portion of the element already in solution (Eidt 1977:1328). Soil, however, will also bind up portions of each element more tightly into a form commonly referred to as *unavailable*, indicating that it is not accessible to plants.

The ratio of the available to unavailable forms of an element will directly affect the determination of the elemental level of a soil sample. The actual soil analysis employs reagents to extract the element or elements being examined. The choice of reagents, however, will affect how much of the available and more importantly, the unavailable form of the element is released and therefore detectable by the instrument assessing the soil. Therefore, the same soil sample when tested using different reagents could have completely different elemental levels. Consequently, archaeologists must understand the variety of approaches to the soil analysis so that results most reflective of a site's previous human activity are obtained.

For a technique that appears to have such potential benefits for archaeological research, soil chemical analysis is underutilized in historical archaeology. While this may be related to a variety of factors, one of the main reasons is the lack of a synthesizing analysis that examines the technique and how to use it to investigate plowed sites. Consequently, this thesis will seek to explore the potential role of soil chemical analysis in historical archaeology. Using the research from the soil chemical analysis of the Poplar Forest Quarter Site along with many of the published studies of archaeological sites using soil chemical data, a variety of questions about its application to plowed historical sites will be explored: What is soil chemical analysis and how can it best be used for historical archaeology? What are the elements examined and their possible interpretations within the archaeological record? What are the kinds of sites for which it can and cannot be used? What types of research questions can it help to answer? How can it be incorporated into a site's research design? How should archaeologists best approach soil sampling and collection? How are soil chemical data analyzed and interpreted? While these are just a few of the many questions that need to be considered by historical archaeologists, they will provide a starting point for making soil chemical analysis a valuable technique for historical archaeological research.

CHAPTER II

THE DEVELOPMENT OF SOIL CHEMCIAL ANALYSIS

The analysis of soil chemistry for archaeological research is not new to the discipline, but the particular methods being employed and research questions being explored have evolved and broadened over the decades. An examination of archaeological investigations that have incorporated soil chemical data will demonstrate the development and the evolution of the technique over the past one-hundred years. Although the first soil chemistry studies would be considered simplistic by today's standards, they laid the foundations for future archaeologists to incorporate soil chemical data into their site interpretations. While recent soil chemical studies demonstrate how far the technique has progressed since the earliest phosphate studies, soil chemical analysis is clearly still in its infancy as an archaeological method. Archaeologists must continue to incorporate soil chemical data into their research in order for the technique to improve so that its full potential may be realized one day.

The Importance of Phosphates

The first soil chemical studies in archaeology centered around the detection of the element phosphorous and what its presence in the soil might indicate about the former locations of human settlements. The early focus on phosphates, however, is not surprising; because phosphorous is in both food and waste products, people add significant amounts of it to the soil in any inhabited area. The advantage of phosphorous over other elements that might be distributed by people is that it is bound up quickly, remaining relatively immobile in the soil for long periods of time, even up to 10,000 years (Bethell and Máté 1989:9; Konrad *et al.* 1983:14). In 1911, Hughes, while working in Egypt, was the first person to observe the connection between phosphate concentrations and human settlements, but its potential for archaeology was not considered until the mid-1920s (Bethell and Máté 1989:1).

Olof Arrhenius, a Swedish agronomist, was one of the first to apply phosphate analysis to the problem of locating archaeological sites. In the process of examining soils for agricultural purposes, he realized that phosphorous accumulated in the soil in areas of human habitation. This insight led him to conclude that elevated phosphorous levels could indicate the former locations of human settlements lacking observable above-ground remains (Bethell and Máté 1989:1-2). In 1926, Arrhenius tested phosphorous levels around the Kagghamra Estate in Sweden and determined that areas exhibiting concentrated phosphorous had been Viking settlements (Arrhenius 1963:122). Throughout his life, Arrhenius continued collecting soil samples in an effort to study patterns in the distribution of phosphorous around Southern Sweden. By the end of his career, he had amassed hundreds of thousands of samples from Sweden and even broadened his focus to examine several prehistoric sites in the United States (Cook and Heizer 1965:1; Arrhenius 1963).

In the late 1930s and early 1940s, Walter Lorch, a German scientist, also examined ways to facilitate the application of phosphate analysis to archaeology. He developed a method for a phosphate field spot test that allowed for an immediate understanding of the archaeological potential of an area without taking samples back to a laboratory for processing. Unlike Arrhenius, he also attempted to examine how variations in anomalous phosphate concentrations might be indicative of different types of settlements (Bethell and Máté 1989: 1-2). While neither Lorch nor Arrhenius ever really considered other elements that might be connected to human settlements besides phosphorous, their work laid the foundations for future soil chemical studies in archaeology.

The Introduction of Soil Chemical Analysis to American Archaeology

Knowledge of the potential of phosphate analysis for archaeological studies spread slowly, most likely because the works of Arrhenius and Lorch were not easily accessible (Bethell and Máté 1989:2). American archaeologists did not begin using phosphate analysis on archaeological soils until the 1950s. These American pioneers built on the research of Arrhenius and Lorch and applied soil chemistry concepts to the analysis of a variety of prehistoric sites around the country. Some of the most important of these studies sought not only to identify the presence of archaeological sites, but also to examine the information provided by the soil chemical data about the sites themselves.

One of the first archaeological soil chemistry studies in the United States examined the soil of an Adena Mound and the "natural" soil around it (Solecki 1951). Ralph Solecki argued that because of the deposition of bone, the soil of an intensively-occupied site might contain as much as fifty times the proportion of phosphate as compared to the soil of an uninhabited area. In order to prove his hypothesis, Solecki collected soil samples from known burials, suspected burials, and layers, all from within the mound, as well as the "sterile" soil around it. Because the supposed graves exhibited elevated phosphorous comparable to the known interments, the author concluded that all the features were burials.

In another important study from the same year, H.J. Lutz (1951) examined the soil chemistry around several archaeological sites in Alaska. Lutz compared soil samples from two known ancient village sites to soil from adjacent forested areas, which he considered to be "natural." Unlike Solecki, Lutz expanded the elements examined to include not only readily-soluble phosphorous, but also exchangeable calcium, potassium and nitrogen. The results showed that one site had phosphorous levels 50-times higher than the adjacent forest and the other had levels 175-times higher. Even though the ratios were not nearly as great, the other three elements examined were also elevated for the site samples suggesting that human occupation impacts the overall soil chemistry of an inhabited area.

In the late 1950s, Eugene Dietz (1957) adopted a similar approach to those used by Solecki and Lutz. Dietz collected soil samples from a known Native American site and from a similar area thought to have been uninhabited, or unenhanced, in order to compare the two. Dietz's method, however, differed from his predecessors in that he collected samples at five-foot intervals across a grid and generated distributional maps of the available phosphorous. He determined that both the enhanced and the unenhanced areas exhibited variations in their phosphorous distributions, but the degree of variation for the known archaeological site was greater. Furthermore, Dietz suggested that some of the anomalies in the phosphorous patterns for the site could demarcate the locations of structures.

In the early 1960s, J.M. Cruxent (1962) re-examined the features known as the Texas Street hearths in an attempt to end the debate surrounding their creation. The previous excavator, George Carter, believed these features to be of human origin, but Cruxent concluded otherwise based on his examination of their phosphate levels. Cruxent took five samples, three from within the features and two "control" samples from the soil surrounding them. The results indicated little variation in the phosphate levels for all of the samples suggesting to Cruxent that none of the soils had been greatly influenced by human activity. While the method and conclusions in this study might be considered problematic by today's standards, Cruxent was one of the first archaeologists to attempt to answer a specific archaeological question with soil chemical data.

The Rise of Processual Archaeology

During the 1960s, more archaeologists were introduced to the potential of soil chemical analysis as an archaeological tool. An increased interest in the technique arose out of the growth of the "New Archaeology," whose emphasis on a scientific approach provided a backdrop for archaeologists to consider the method's benefits for their research (Bethell and Máté 1989:2). Soil chemical analysis accorded archaeologists a new and unique data set that provided information about a site not necessarily found in other ways. Furthermore, this data set lent itself well to testing hypotheses, an important tenet of any scientific approach.

One of the most influential works to examine the use of soil chemical analysis for archaeological research was published as the growth of processual archaeology was beginning. Sherburne Cook and Robert Heizer's book entitled *Studies on the Chemical*

Analysis of Archaeological Sites (1965) provided the first widely-available analysis of the use of soil chemical data for understanding and interpreting archaeological sites. Cook and Heizer were the first archaeologists to attempt to quantify the effect that human habitation has on soil chemistry and to discuss how archaeologists might use this information to learn more during the excavation process. Although Cook and Heizer only consider a small part of the human impact on soil, they synthesized many issues that had never been discussed before.

Cook and Heizer's book, which is organized into three sections, begins with an examination of the theoretical elemental contributions added by human habitation to the soil. The authors present statistics on the levels of phosphorous, calcium and nitrogen found in human and animal waste and suggest how much of each of these elements should be added to the soil by a specific-sized population over the course of a year. While they acknowledge the fact that these elements will be redistributed throughout the soil over time, they conclude that at least some of the concentrations, especially phosphorous ones, will be retained by the soil after a significant occupation. Cook and Heizer surmise that nitrogen and calcium are not as resilient as phosphorous, but should still be examined (Cook and Heizer 1965: 4-20). Although the authors overlook many of the other ways humans can influence soil chemistry, both in terms of additional elements and activities not discussed, their conclusion that humans significantly alter the soil chemistry in any intensively-inhabited area in which they live remains valid.

After establishing that human occupation affects soil chemistry, the authors sought to examine how soil chemical data could be incorporated into archaeological research. For the collection of soil samples, they advocated a two-part strategy that involves taking surface samples across a grid, both "on" and "off" site, as well as vertical samples down a profile. The elemental levels from the samples can be examined both absolutely and relatively and then graphed to look for patterns and anomalies (Cook and Heizer 1965:20-28). Although they did not discuss much about how soil chemical results can be incorporated into site interpretations, they concluded with several different case studies involving sites in California and Mexico to illustrate their method (Cook and Heizer 1965:29-95). While Cook and Heizer's approach is simplistic in that it only focuses on a few elements and does not emphasize the overall site interpretation, it was revolutionary at the time and can be refined for use on archaeological sites today.

The Development of the Field Spot Test

The influence of processual thinking continued into the 1970s as the technique of soil chemical analysis became even more systematic in its approach. Outside of archaeology, great strides were made in the field of soil analysis, leading to developments that would improve the application of soil chemical analysis to archaeology. At this time, archaeologists also began to realize that soil chemical data could enhance site interpretations both alone, but more importantly in conjunction with other types of archaeological evidence (Bethell and Máté 1989:2-3).

One of the most revolutionary developments for soil chemical analysis was the refinement of the field spot test for phosphates. While field spot tests were being used as early as the 1930s, an accurate method for administering them was not available until the 1970s. While these tests provide relative rather than absolute results, they enable archaeologists to assess phosphate distributions in the field, thereby saving time and money. Consequently, archaeologists were now able to use phosphate data to help them further refine their research designs and areas of study while in the preliminary stages of excavation.

In the 1970s, Robert Eidt (1973; 1977) developed a unique and accurate field spot test for phosphates. Eidt detailed a specific process and reagents that would produce a color change on filter paper indicating the relative amount of available phosphorous present in a sample. One advantage of Eidt's method over previous field spot tests was that the reaction was stopped after a set period of time, allowing for a much easier comparison of the relative amounts. Eidt cautioned, however, that the results could be affected by other factors, including sample size, color perception, and temperature and that the test could only detect available phosphorous, making it impossible to distinguish anthrosols from soils naturally high in phosphorous. Nevertheless, Eidt's field spot test allowed archaeologists for the first time to incorporate accurate relative phosphate testing into archaeological studies with immediate results.

Fractionation

Another revolutionary development in soil chemical analysis, the application of fractionation, offered archaeologists a unique way to study phosphorus distributions. Fractionation is a process that quantifies the percentage of each type of phosphorous present in a sample. Fraction I accounts for the easily-extractable phosphorous, Fraction II is all the tightly-bound or occluded iron and aluminum phosphates, and Fraction III consists of tightly-bound calcium phosphates (Eidt 1985:181). S.C. Chang and M.C. Jackson (1957) were two of the first soil scientists to consider the use of fractionation for archaeology. They argued that the separation of phosphorous into fractions revealed which soils exhibited naturally occurring phosphorous and which contained humanly-introduced phosphorous. Furthermore, they believed a comparison of fraction patterns from samples could indicate the relative dates of different sites. In the 1970s, William Woods (1977) argued that fractionation provided more information for archaeologists than either available phosphorous or total phosphorous because the three different fractions typically come from different sources. As a result, Woods examined phosphate fractions and was able to determine the functions of different site areas, ranging from residential to ceremonial, based on the patterns.

In the 1980s, Robert Eidt (1985) continued working with fractionation and its application to archaeology. He provided archaeologists with an explicit method for the fractionation process (Eidt 1985:183-185). Furthermore, in order to assess whether differing land use created different fraction patterns, Eidt collected samples from places whose previous uses were known, including farmland, forested and residential areas. He compared the fraction patterns for each type of sample and found that areas that had been used in analogous ways exhibited similar patterns. He concluded that the fraction patterns from archaeological samples could be compared against soils from areas of known function to elucidate past land use (Eidt 1985:181-183). While no studies of American historical sites using phosphate fractionation have been published to date, a recent study in Portugal examined the application of some of Eidt's theories (Lillios 1992). Research on soils from Agroal suggested that phosphate fraction patterns do provide evidence of former land use and that the ratio of Fraction II to Fraction I was moderately successful at providing relative site dates.

Soil Chemical Analysis in American Historical Archaeology

The first application of soil chemical analysis to historical archaeology in the United States occurred in the 1970s. The American Bicentennial invigorated a national interest in history and consequently in historical archaeology resulting in increased funding for the discipline. Innovative research on new techniques, especially those that can require significant budgets, suddenly became possible for many sites. Not surprisingly, it was in this context that the first large scale soil chemical analysis of an historical site was conducted.

St. John's

The first soil chemical study undertaken in historical archaeology examined the soil of the St. John's site, a seventeenth-century plantation homelot in St. Mary's City, Maryland. Robert Keeler's dissertation entitled "The Homelot on the Seventeenth-Century Chesapeake Tidewater Frontier" (1978) discusses the archaeological study, which had goals of advancing both the understanding of the seventeenth century and the methods of historical archaeology. Keeler assessed the St. John's site from the perspective of a frontier cultural system. Within this context, the research focused not only on how archaeological and documentary data could be blended, but also on how artifact and soil chemical analyses could be incorporated to further the interpretation of the site.

The soil chemical analysis for St. John's was conducted in a systematic manner. Soil samples were collected from the plowzone and from "culturally significant" features. The samples were analyzed at the Soil Testing Lab at the University of Maryland for the available levels of inorganic phosphates, potash, and calcium. These chemical species were chosen because of their usual inclusion in agricultural testing, but cost prohibited examining any others (Keeler 1978:26-31).

Based on both the soil chemical and artifact distributions, certain facets of how the yard space was used and organized became apparent. For instance around the house, peaks in the elemental and artifact distributions provided strong evidence for the location of doorways where waste was being tossed out into the yard. Interestingly, variations in the distributions of phosphorous, calcium and some types of artifacts, particularly white clay tobacco pipes, suggest that the location of the door out into the back yard may have changed at some point during the occupation. The yard area behind the hall exhibited artifact concentrations as well as elevated elemental levels except for potassium, suggesting that this was a midden used for general trash but not fireplace sweepings which are generally high in potassium. In contrast, the part of the back yard between the house and the kitchen seems to have been kept relatively clean as indicated by the lack of artifacts and the low elemental levels. The kitchen area exhibited elevated potash, most likely from the deposition of fireplace ash, and to the east of the kitchen, few artifacts and a concentration of phosphorous, possibly from manure, suggested the location of an animal pen. Around the perimeter of the fenced-in yard, peaks in the elemental and artifact patterns delineated the placement of two gates. High calcium levels in the middle of both gates indicate that oyster shell paths led out of the enclave (Keeler 1978:65-74).

Although the application of soil chemical analysis was not the central focus of the research at St. John's, the use of this type of data for the interpretation of an historical site was groundbreaking. This study applied an explicit method for the collection and analysis of soil samples, including those from plowed strata, at a time when many archaeologists disregarded the plowzone altogether. Moreover, the soil chemical data enhanced the interpretation of the site in ways not possible simply using the artifacts and features. The research at St. John's not only made historical archaeologists aware of the potential of soil chemical analysis, but created a useable framework for the incorporation of soil chemical analysis into archaeological research on plowed sites.

New Windsor Cantonment

In the early 1980s, soil chemical analysis was incorporated into the research design for the archaeology of the New Windsor Cantonment in New York (Sopko 1983). Archaeologists were interested in evaluating the site where the American Continental Army camped during the winter of 1782-83 with minimal impact on its overall archaeological integrity. In addition to soil chemical analysis, the research design also included a geophysical study and shovel testing, all focusing on a specific portion of the site. The geophysical assessment, which consisted of both a magnetic survey and ground penetrating radar, located several hearth areas and showed a lack of middens and sheet refuse among the huts (Sopko 1983:24).

The archaeologists hoped that the soil chemical data would identify the activity areas, and separate the "occupation and activity" from the "historically unoccupied" sections of the site. Ninety-three soil samples were collected and classified by feature type or as non-feature, for samples taken from between the huts and in the parade ground. The samples were analyzed for pH, phosphate, calcium and potassium, but the types of testing and the methods used were not discussed. A statistical tool, the "student" t-test, which assesses whether two subsamples most likely came from the same or different populations, was employed to examine whether the feature samples differed from the non-feature samples. The results suggested that the variation between the two groups was "significantly different" for phosphate and calcium but not for pH and potassium (Sopko 1983:25-26).

Based on the statistical analysis, the researchers chose to investigate further the phosphate and calcium distributions in the vicinity of two previously-identified structures, a hut and a kitchen. More soil samples were collected from in and around the hut at ten-foot intervals and the kitchen at five-foot intervals. The phosphate and calcium levels for these samples were mapped and analyzed in conjunction with the geophysical data. The analysis delineated the approximate boundaries of the hut, identified the hut's type based on the internal layout of bunks, and assessed the activity areas in and around the building. The soil chemical patterns from the kitchen were similar to the those from the hut area suggesting that the kitchen area may also have been inhabited (Sopko 1983:26-29).

The soil chemical study of the New Windsor Cantonment highlights some of the potential benefits of soil chemical analysis to archaeological research. Much of the information about the site was learned with minimal excavation, thereby protecting the non-renewable archaeological record for future generations. In addition, much of the evidence provided by the soil chemical data probably would not have been obtained even with the most thorough of excavations. While a full-scale excavation could have delineated the structures, it is doubtful that the features and artifacts alone could have provided as much information about the structures' internal layouts and uses.

While the research at New Windsor Cantonment indicates the benefits of conducting a soil chemical study, it also highlights some of the problems commonly found in published soil chemical studies in historical archaeology. One major problem is the lack of details pertaining to the soil analysis itself. Sopko does not discuss the method used for the analysis or the specifics of the elements examined, leaving the reader without a foundation for evaluating the results or conducting a similar study.

The other major problem with the research is in the assessment of which elements provided significant results. Sopko posits that "if the soil chemical content of the features was significantly different from the soil chemical content of the historically unoccupied areas without features, then the soil chemistry could be used to identify and delineate features" (Sopko 1983:25). He uses the "student" t-test to attempt to define the difference between these two groups. Although use of the "student" t-test for assessing soil chemical data can be quite useful, Sopko's choice of sample groups is problematic. The samples from the group representing the "historically unoccupied areas without features" were still collected from within the site boundaries meaning that they are not necessarily unenhanced. While Sopko does not specify whether the non-feature samples were taken from subsoil, research at the Poplar Forest Quarter, which will be discussed in Chapter V, clearly indicates that subsoil within the site can become enhanced, especially in the case of elements prone to leaching, such as potassium. Although the results of the "student" t-test clearly indicate differences between the habitation and exercise areas in terms of calcium and phosphorous, potassium cannot be dismissed as an indicator of human activity and its distribution potentially could have provided important information about the site.

The Wilson-Slack Site

Another important soil chemical study examined the Wilson-Slack site in Delaware (Custer *et al.* 1986). This site was the location of a nineteenth- and early twentieth-century farm and blacksmith shop. Using oral history and documentary evidence, archaeologists obtained a detailed picture of the site's previous activities and their locations in order to compare the patterns of soil chemical distributions within known activity areas. Prior to the testing, archaeologists predicted what the elemental signatures for the different parts of the site should be based on the activities and events that had occurred. Archaeologists then collected soil samples from the horizon just below the humus during the excavation of shovel test pits at five-foot intervals across a grid. The samples were analyzed at the University of Delaware College of Agriculture Soils Laboratory for calcium, phosphorous, magnesium, potassium, and pH (Custer *et al.* 1986:89-93).

When the actual soil data were compared to the hypothetical patterns, the amount of correlation varied for different parts of the site. For instance, increased phosphorous levels did coincide with the former location of the gristmill and a trash midden near the house as expected. A rapid decrease in the phosphorous levels also delineated the position of a fence line known to have separated the domestic enclave from the industrial area. However, the animal pen did not exhibit elevated phosphorous from the manure, contrary to expectations. Two other elements examined, calcium and magnesium, seemed to correlate not only with each other, but also with a modern road disturbance and the location of the destroyed grist mill. In the area where a building had burned, the authors expected elevated potassium from the burned wood, but this was not the case even though potassium levels differed for the domestic and the work spaces. The garden area was expected to exhibit an elevated pH due to liming, but this area was not more alkaline than other unlimed areas. The authors concluded that liming may not increase the pH as much as expected or that more acidic, organic fertilizing agents were used. Based on the results, the authors conclude that the correlation between specific elemental signatures and known activity areas was not as strong as expected (Custer *et al.* 1986:90-93).

The Wilson-Slack study adopts a unique approach to evaluate the effectiveness of soil chemical analysis in detecting evidence of prior activities and events on archaeological sites. The authors' assessment of soil data from known activity areas focuses only on the traditional elements examined by archaeologists but does highlight some of the technique's strengths and weaknesses. Undeniably, some of the results did correlate with the authors' expectations based on the site's history. Each element did appear to correlate with some past activity or event even if not all of the connections were expected, clearly indicating the need to continue examining the meanings of different elemental signatures in the soil rather than abandoning the technique. Because soil is a dynamic entity, many soil studies will be required before the human impact on the distribution of elements within soil will be fully understood.

The authors conclude by questioning the validity of soil chemical analysis as an archaeological tool, but a careful examination of their research design suggests several factors that may have affected the results, possibly creating the discrepancies between the expected and actual patterns. For instance, the authors' expected patterns should be scrutinized because they may not be correct assessments of what the elemental levels should be. Furthermore, some of the unexpected results could, in fact, disclose aspects of the site's history of which the authors are unaware because even though documentary and oral histories provide much information, they are never complete.

Another problematic facet of the research is that the samples were collected from the soil just below the humus, but it is unclear as to whether this soil is specifically linked to the occupation of the site. Perhaps the collection of samples from a lower point in the soil profile might have provided results that were more in accordance with expectations. The third problem with this study is that the authors distilled the results from three-hundred soil samples into sweeping generalizations about large areas. Although maps of the distribution of each element are provided, the contour intervals are quite large and the maps are quite small, thereby masking the nuances of the patterns. A more detailed examination of the data from specific parts of the site might have highlighted aspects of the activities or events sought that are glossed over when examined from such a general perspective.

Forts Kaskaskia and de Chartres

John Weymouth and William Woods (1985), in their article entitled "Combined Magnetic and Chemical Surveys of Forts Kaskaskia and de Chartres Number I, Illinois," discuss the examination of two sites that were analyzed with minimally-invasive archaeological testing. To study the sites without damaging their archaeological integrity, they employed two analytical methods, soil chemical analysis and magnetic surveying, allowing for a more accurate interpretation of the sites than either one would have alone. At Fort de Chartres Number I, the goal was to use both data sets to define the site's and the fort's boundaries. In contrast, the examination of Fort Kaskaskia focused on more detailed aspects of the site, seeking to examine the fort's interior layout.

At Fort de Chartres Number I, the soil chemical method for identifying the site boundaries focused on the analysis and comparison of samples collected by coring. Archaeologists obtained soils from beneath the plowzone at one-meter intervals along transects spaced ten meters apart. All of the samples were analyzed for phosphates and based on these results, forty-six of them were chosen for more detailed chemical work-ups, including phosphate fractionation and determination of pH, calcium, magnesium, potassium, iron, zinc, and copper. The soil chemical data in conjunction with the results of the magnetic survey denoted the location of the walls and a possible bastion, all of which correlated with the potential fort boundaries previously-identified in an aerial photograph. Several years later in 1983, subsequent archaeological testing uncovered features confirming the location of the fort's external structure as identified by the soil chemical and magnetic research (Weymouth and Woods 1985:22-28,35).

Because the site's boundaries had been previously identified at Fort Kaskaskia, the approach to the soil chemical analysis was slightly different than that used at Fort de Chartres Number I. Soil samples from the fort's interior were collected by coring at ten-meter intervals along two orthogonal transects as well as coring at five additional locations thought to be possible feature areas. The samples were analyzed for pH and qualitatively for phosphates. As with Fort de Chartres Number I, some of the original samples were chosen for further analysis, consisting of the quantitative levels of phosphate, calcium, and potassium. The magnetic and elemental results suggested the location of one structure, but indicated minimal activity in much of the rest of the fort.

Using evidence from previous archaeologically testing of the fort and the new data, the authors concluded that other than the structure identified, the fort contains little of archaeological interest (Weymouth and Woods 1985:28-34).

The methods applied at Forts de Chartres Number I and Kaskaskia are an interesting combination of soil chemical analysis and geophysical testing with little archaeological excavation. The major benefit of this approach is that it provides information, but leaves the majority of the archaeological record intact for future research. Interestingly, Weymouth and Woods ignored the plowzone, instead choosing to sample the soil underneath it. While it is unclear as to whether the samples were from subsoil, testing the plowzone might have provided valuable results. Even though soil chemical analysis can be expensive, the authors conclude that the collection and analysis of the samples were more cost effective than paying a field crew to shovel test the same area (Weymouth and Woods 1985:35). While field excavation will never be abandoned, Weymouth and Woods present an approach that can be considered in the future for other sites where limited excavation is desirable.

The King's Reach Site

In the late 1980s, Dennis Pogue (1988), building on Keeler's work at St. John's, conducted a soil chemical study of the King's Reach Site, a late seventeenth- and early eighteenth-century plantation in Maryland. Pogue argues that elements, like artifacts, are displaced little by plowing. Therefore, the systematic collection and analysis of plowzone soil samples could be quite informative. At King's Reach, archaeologists collected 144 plowzone samples, most of which were taken at two-meter intervals across the core of the site. The samples were analyzed for phosphorous, calcium, potassium, and magnesium (Pogue1988:2,5).

An examination of the elemental and artifact distributions provided a detailed picture of how the King's Reach site was used and organized. For instance, concentrations of phosphorous, most likely from the deposition of waste, were found within the house in association with the cellars and several of the doorways. Although the yard exhibited some areas of elevated phosphorous, the lack of a significant concentration in the yard led Pogue to conclude that the animal pens were outside the tested area. Calcium, which was elevated both within the house and in several areas of the yard, was also found to be indicative of trash deposition as it correlated with the distribution of tobacco pipes. The potassium pattern, however, differed from both the phosphorous and calcium distributions in that it was concentrated primarily outside of the boundary fence forming a band around the site. Because of potassium's presence in wood and its ash, this band was most likely created by the disposal of fireplace ash around the perimeter of the yard. In contrast to the other three elements, the magnesium concentrations did not present an easily-interpretable pattern as the main accumulation of it was in the midden behind the house. Furthermore it did not correlate with potassium, which would have been expected if it is connected to burning, as has been speculated. The author concluded that the soil chemical data helped to refine the interpretation of the homelot in conjunction with the other archaeological evidence and that this type of research provides a valuable method for spatial analysis on a plowed site (Pogue 1988:8-13).

The research at King's Reach provides a thorough approach to the application of soil chemical analysis for historical archaeologists. Pogue has clearly demonstrated that the systematic collection of plowzone samples across a grid can reveal subtle yet informative variations in the elemental distribution patterns elucidating the organization and use of space, even if a site has been plowed. While more research regarding the interpretation of elements is necessary, Pogue's framework should be emulated by other historical archaeologists in order to provide comparative studies that will further the technique.

Given how few historical archaeological studies emphasizing the use of soil chemical data have been published, many archaeologists may not be aware of the benefits that this technique has to offer. While some archaeologists are conducting soil chemical studies of sites, they are not published and in some cases not even obviously incorporated into site analyses. As archaeologists begin to use the technique, the dissemination of information, including research questions, strategies used, problems encountered and interpretations of results, is extremely important. Thus, a comprehensive examination of soil chemical analysis, the goal of this thesis, is necessary to ensure that archaeological studies can build on previous works and enhance the technique.

CHAPTER III

THE TECHNIQUE OF SOIL CHEMICAL ANALYSIS

Historical archaeologists do not universally understand the myriad ways in which soil analysis can be incorporated into archaeological research. As a result, soil samples are frequently collected out of a sense of obligation, with little forethought as to how they will enhance a site's interpretation. Consequently, many soil samples sit on the shelves of archaeology labs, collect dust, grow mold, and may eventually be disposed of without ever having been analyzed. When soil samples are examined, it is commonly as an afterthought in response to an issue that arose during the excavation process. While the research questions may or may not be resolved in this way, the "afterthought" approach to soil analysis undermines its power for interpreting archaeological sites. In order to obtain the most information from soil and to improve site interpretations, historical archaeologists must consider the types of soil analysis available, how to incorporate them into a research design, and how to interpret soil data before the excavation process is begun.

While digging a site, historical archaeologists are constantly working with the soil, but rarely think about it and the information it may contain. Instead the common perception of excavation is to separate the unimportant particulate matter from the more important artifacts, a view applied particularly to plowzones. While artifactual information will always be central to archaeological research, archaeologists need to stop taking the soil matrix for granted and to begin considering what other evidence it may hold. Therefore, archaeologists must possess an understanding of soil processes, how they work and how to use the soil to their advantage.

The Soil Environment

Despite its surface appearance, soil is a dynamic entity. It is constantly undergoing change at the hands of physical and chemical processes that may or may not be visible to the naked eye. One way to define *soil* is as "a complex natural material derived from decomposed rocks and organic materials...[that] serves as a medium for plant growth by providing nutrients, moisture, and anchorage for plants" (Ankerman and Large n.d.:3). This relatively general definition would encompass most deposits of material sitting on top of bedrock.

Some soil scientists, however, draw a distinction between soils and sediments (for instance, Shackley 1975). Myra Shackley defines a sediment to be "a collection of mineral or rock particles which have been weathered or eroded from their primary source and redeposited elsewhere" (Shackley 1975:1). In contrast, Shackley defines a soil as "a deposit which has been weathered and altered *in situ* to such a point that a vertical section taken through it will show some interior zonation, a division into horizons which are the result of the movement through the profile of certain constituents" (Shackley 1975:3). With this distinction, some archaeological strata may be sediments rather than soils.

While the debate over the definition of a soil is best left to soil scientists, it is important for archaeologists to understand the potential differences in the usages of these terms.[1]

Pedogenesis is the process by which soils are created. The five main factors affecting soil development are parent material, climate, living organisms, topography, and time (Ankerman and Large n.d.:3). Soil particles of a parent material become altered because of the process of weathering. Physical weathering, such as wind, moving water and freezing and thawing, involves the break down of the parent material without alteration of its basic makeup. In contrast, chemical weathering, which can encompass reactions with water, oxygen, and carbon dioxide, results in changes to the composition of the parent material. The types and amount of weathering leading to the creation of a soil will depend upon environmental factors, especially rainfall and temperature (Water 1992:16-19). In addition, biological factors can weather the soil both physically and chemically (Montgomery 1992:236). Thus, after archaeological soils are deposited, they may still be undergoing changes even long after they are buried.

Weathering induces size and shape changes in the particulate matter of the soil matrix. Soils and sediments are often classified using such terms as loam, sand, silt, and clay, all of which refer to the size of the particles. According to the Wentworth Scale, a clay has a diameter of less then 0.0039 mm, a silt has a diameter between 0.0039 mm and 0.0625 mm, a sand has a diameter between 0.0625 mm and 2 mm, and a gravel is anything greater than 2 mm (Water 1992:21). A loam is roughly equal parts of sand, silt and clay. For soils that exhibit varying amounts of differently-sized particles, the terms

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[1] For the purposes of this thesis, a distinction between soils and sediments will be drawn when necessary. However, the term soil will be used in most cases when discussing abstract situations. If the information applies to a soil, then it also applies to a sediment unless otherwise noted.

can be combined to create the most representative description. Soil particles will also exhibit different morphologies, which can be described using such terms as platy, prismatic, columnar, blocky, and angular, and possess varying surface textures, ranging from unworn to worn and glossy to dull (Shackley 1975:44-53). Thus, by studying a soil or sediment's characteristics, clues to how it has been weathered may be apparent.

As soils undergo weathering, a structure, consisting of horizons, or layers, develops. A typical soil profile may have three horizons, referred to by the letters A, B and C. The A horizon is the uppermost soil and is the zone of leaching because water movement down through the soil carries elements out of this horizon and into the lower one. Because this horizon is closest to the surface, it is subjected to the most weathering and usually contains humified organic material. Under the A Horizon is usually the B Horizon, the zone of accumulation. This horizon, which is quite often the subsoil for archaeologists, is where the leached elements from the A horizon collect. The C Horizon, under the B Horizon, consists of broken-up bedrock that has been least affected by weathering agents and sits directly on top of the R horizon, or unweathered bedrock. Another common layer, the O horizon, is decomposing plant material found on the surface. The horizons can also be modified with subscripts pertaining to their specific characteristics, such as p for plowed and g for gleyed (Ankerman and Large n.d.:3-4; Montgomery 1992:236-7; Easterbrook 1993:46-7).

Soils are primarily composed of mineral particles made up of elements and compounds. As has been noted, weathering can affect the composition of soil, both in terms of the elements and compounds present, as well as how they are distributed in the soil profile. Plants are dependent on their ability to extract certain nutritive elements from the soil to survive. Because natural activities could easily upset a soil's balance by depleting elements important to plant life, many elements are kept in check by cycles. Soil cycles involve natural processes whereby an element is being added to the soil by some processes while at the same time being removed by others. The additive part of these cycles will vary from element to element and can occur through many different means, including deposition of organic waste, microbial action, and atmospheric deposition. The possible ways in which elements are withdrawn from the soil will also depend on the element, but can occur through plant uptake, leaching and atmospheric absorption. Assuming no major disruptions, such as those frequently created by people, these natural cycles can keep a soil's elemental levels fairly stable.

The Impact of Humans on Soils

Humans are, perhaps, the most disruptive force that can impact and alter soil chemistry. In contrast to the many natural weathering agents that are relatively slow and constant, humans can transform the properties of soil swiftly and significantly. Through intensive occupation and agriculture, people almost always alter a soils natural properties, usually without even being aware of it. Although natural processes may slowly correct elemental concentrations and deficiencies, these humanly-induced changes to the soil are often long lasting because they are so significant (Cook and Heizer 1965:96; Proudfoot 1976:93; Eidt 1985:155).

Human effects on the soil, like weathering processes, can be divided into two categories, physical and chemical. Physical changes are caused by human actions that move the soil around or alter its structure, drainage, or texture (Eidt 1985:169-70).

Examples of such activities would include bulldozing, deforestation, dam building and agriculture. These physical modifications brought about by humans, however, often induce chemical alterations, evidence of which may survive in the soil longer than the original physical changes (Eidt 1985:155-156).

Chemical changes, whether directly or indirectly caused by people, can be divided into five major categories. These include changes to the macro- and micro-nutrient levels, organic matter levels, oxidation-reduction characteristics, and soil pH as well as the introduction of contaminants (Eidt 1985:156-169). A few examples of human activities that can create chemical changes would include fertilizer application, waste deposition, penning animals, and industrial activity.

Because human habitation has such a profound effect on the soil of an area, archaeological soils possess unique characteristics that are crucial to the understanding of a given site. An *anthrosol* is a soil "whose features have been altered by human activities" (Eidt 1985:155). Anthrosols can be further subdivided into *anthropogenic* soils, which are anthrosols intentionally modified by humans, and *anthropic* soils, or those soils unintentionally altered by people.

Types of Soil Analysis

Besides containing artifacts, anthrosols can also be repositories of minute clues about past lifeways and landscapes. Unlike with artifact recovery, however, the soil cannot simply be screened to retrieve these tiny traces of evidence; rather, to study the information contained within the soil matrix, samples must be collected in a controlled manner and processed in a special lab. Determining the most appropriate approach to soil analysis and the best way to analyze samples will depend upon the types of information desired and the research questions being studied.

Many of the varieties of soil analysis focus on environmental questions. Phytolith analysis, palynology, and macrobotanical studies all involve the collection of soil samples to find evidence of former plant life that has been trapped in the soil matrix. Because individual plants leave behind different types of remains, many studies employ more than one variety of analysis, if not many, to achieve the most comprehensive data set possible. Since environments are not static, vegetation can change over time and all of these approaches can provide a more complete picture of a site's former plant life. Moreover, garden archaeology, which is impossible without soil analysis, has become an important sub-discipline within historical archaeology (for example, see Brown and Samford 1990; Miller and Gleason 1994a; Beaudry 1996).

Phytolith analysis focuses on the identification of minute silica casts produced by many plants. Phytoliths are mineral particles "formed in plants when hydrated silicon dioxide precipitates out and is deposited along cell walls and intercellular spaces where it forms a hard, durable opaline cast" (Fisher and Kelso 1987:30). When plant tissue decays, it releases its phytoliths into the soil where they may remain for long periods of time. In order to recover phytoliths from the soil, samples are collected from archaeologically-relevant deposits. In a laboratory facility, the soil particles and any other organic matter are extracted using physical and chemical methods, leaving behind the microscopic silica casts. By comparing them to previously-identified phytoliths, the archaeological specimens can be attributed to a family and sometimes even a genus or species. One of the main drawbacks of phytolith analysis is that not all plants produce these silica casts. For instance, grasses are more likely to make phytoliths than trees. Therefore, to obtain the most complete view of a site's past environment, phytolith data must be supplemented with other forms of environmental analysis (for further discussion of phytolith analysis in historical archaeology, see Fisher and Kelso 1987; Rovner 1990).

Another environmental soil analysis, palynology, focuses on the recovery of pollen from discrete archaeological contexts. Because of the wind-borne nature of pollen, soil sampling for palynology must be done carefully to avoid contamination by modern particles. Once the samples have been collected, the pollen grains present in the samples are extracted from the other particulate matter and identified under magnification, much the same way phytoliths are. The results are usually presented in terms of the percentage that each pollen type represents out of the entire sample. As with phytoliths, however, not all plants produce pollen, meaning that palynology will favor the recovery of certain varieties, possibly presenting a biased picture of the vegetation. Phytoliths, because of their durable quality, are also more likely to survive archaeologically than pollen, potentially skewing the data even more (for further discussion of the use of palynology in historical archaeology, see Schoenwetter 1990).

In addition to phytolith analysis and palynology, past plant life of a site can be studied using macrobotanical remains. Flotation, a method that employs water to separate and remove soil particles from anything else that is present, is the most common way to retrieve small items that might be missed during the normal screening process. If seeds are recovered, they can be identified using a comparative collection. However, special care must be given to determining the age of the seeds and the integrity of their contexts since seeds can migrate through the soil profile easily. In fact, it has been argued that although charred seeds found in sealed contexts are historical, the interpretation of uncharred seeds as such must be done with care (Miller 1989:50) (for further information on the use of macrobotanical remains in historical archaeology, see Miller 1989).

In contrast to the environmental soil analyses that focus on remains trapped in the soil, particle analysis examines the physical attributes of the soil itself. Characteristics of a soil's structure and composition can shed light on a its creation and deposition. Particle analysis can be broken down into two basic types, ones in which the particle orientation is important and ones in which it is not. The examination of the micromorphology of soil thin sections is one variety of particle analysis in which the particles' relationships are retained. Thin sections of soil profiles are examined under a microscope for the density and spatial arrangements of the particles, both of which can elucidate the formation processes that created a soil deposit.

Examples of particle analysis in which the orientation is unimportant would include morphology and size analyses. An examination of particle morphology involves studying the characteristics, such as shape, roundness, sphericity, and surface texture, of individual soil grains. Particle-size analysis involves breaking down the soil into its component particles, resulting in the percentages of sand, silt, clay and gravel present. One method for determining how much of each sized particle is present is to spin the sample in water, measuring how much settles out at specific time intervals. By classifying a soil's attributes in these ways, information about its origin and the weathering processes it has undergone can be inferred (for further discussions of particle analyses, see Shackley 1975; Evans 1985; Courty *et al.* 1989; Water 1992).

The Premises of Soil Chemical Analysis

While the varieties of soil analysis discussed so far have focused primarily on the remnants of natural phenomena, soil chemical analysis seeks to examine the effects that humans have on the soil. In the process of working and ordering their landscapes, people will alter, both intentionally and unintentionally, the soil chemistry. Although humanly-induced physical changes to anthrosols are frequently more apparent on the surface, chemical changes brought about by human activities tend to be more extreme and longer-lasting (Eidt 1985:155-156). Thus, by systematically examining the soil chemistry of a known site, archaeologists can look for evidence of these humanly-induced changes in order to study past lifeways, activities and uses of spaces.

Cook and Heizer (1965) attempted to quantify the human impact on the soil by considering the amounts of nitrogen, phosphorous and calcium that should be deposited by one-hundred people and their animals living on two acres. An analysis of the amounts of these elements contained in human and animal tissues and waste suggests that this population would contribute roughly 904 pounds per acre of nitrogen, 133 pounds per acre of phosphorous and 59 pounds per acre of calcium into the soil over the course of a year (Cook and Heizer 1965:8-9). These figures only reflect the approximate deposition of organic waste, so the figures could be even higher if other activities are adding these elements. The authors conclude that "even though it is well recognized that chemical and biological changes plus vertical movements in the soil do not permit a linear accumulation through extended periods of time, nevertheless the residual quantity detectable chemically at the surface must reach significant values" (Cook and Heizer 1965:9). While smaller populations will clearly contribute less to the soil, they will most likely inhabit smaller areas and still could have a significant impact on the soil chemistry with long occupations.

Most of the intentional modifications to soil chemistry are related to farming. Since the development of agriculture, people have been working with the land to make it produce the kinds of foods desired and in the amounts necessary to survive. As land is farmed intensively, the soil's nutrients are depleted, thereby decreasing its ability to sustain plant life. The addition of fertilizers is intended to replace lost elements to ensure continued plant growth. The recent applications of lime, manure, potash, and modern engineered fertilizers would all be detectable with an examination of elemental levels in the soil.

Many of the ways that people impact soil chemistry are unintentional. For example, the repeated deposition of trash in a midden will concentrate certain elements in the surrounding soil as the waste breaks down. The creation of animal pens or designating an area for a specific activity, such as food processing, food preparation, or a trade, can also have the same effect (Cook and Heizer 1965:4; Eidt 1985:156-157). Through the construction of buildings, protected pockets of soil are created underneath, preventing many of the natural processes, such as rain and wind, from redistributing elevated elements (Middleton and Price 1996:681). Removing vegetation, either through harvesting or clearing land, will impact the soil's elemental composition, but negatively, as nutrient-rich plants are removed (Eidt 1985:156).

The Effect of Plowing on Soil Chemistry

Given the effect that humans have on the soil, a logical assumption might be that plowing will also significantly affect the soil chemistry. However, evidence suggests the contrary: elemental concentrations do not appear to be dispersed, or even altered considerably by post-depositional plowing. Dennis Pogue (1988), based on his research at King's Reach, argues that like artifacts which are only slightly displaced by plowing, elemental residues are little affected by soil tillage. Furthermore, the plow can damage or even destroy certain types of fragile artifacts/ecofacts, such as bone, shell, and wood, and the only traces of them that may remain are elemental concentrations. Therefore, the analysis of the distribution of elements in the plowzone can provide evidence that might not be found in any other form (Pogue 1988:1-2).

The only potentially significant effect on soil chemistry caused by the use of a site as an agricultural field is the application of fertilizer. While this may enhance certain elements in the soil, it does not appear to mask humanly-induced concentrations. At both St. John's (Keeler 1978) and King's Reach (Pogue 1988) interpretable patterns of elements were found in their respective plowzones, which almost certainly were subjected to the application of fertilizers at some point during their use. Most likely, fertilizers do not hide these signatures because they are applied to the soil in a relatively uniform manner, unlike the introduction of elements by humans. The one precaution, however, when examining a plowzone is that the absolute elemental levels cannot be compared against non-plowed strata because of the possibility that they have been affected by fertilizing agents. However, the comparison of non-plowed strata to the plowzone is not a problem if the absolute levels of the elements are standardized. All in all, the evidence suggests that the examination of the elemental distributions in the plowzone can be extremely informative, as plowing does not spread or obscure humanly-induced concentrations.

The Elements and their Meanings

Clearly, the key to using soil chemical analysis for the investigation of plowed archaeological sites is the ability to interpret the meanings of different elements and their distributional patterns. However, this is also the aspect of soil chemical analysis that needs the most further research as the meanings of some elements are less than proven while others have yet to be determined. Dennis Pogue suggests that few authors provide enough valid sources to support their assumptions about the meanings of specific elements (Pogue 1988:3). While Pogue's observation is certainly not unfounded, the only way to rectify this problem is to continue using soil chemical analysis for archaeological research until the meanings are more clearly understood. Although soil chemical data from different sites can never be directly compared (Cornwall 1960:282), their distributional patterns can be and it is similarities in these distributions that will elucidate how they should be interpreted

Several archaeologists have, in fact, attempted to test some hypotheses about how humans impact the soil and how archaeologists can use this information to interpret sites. William Middleton and Douglas Price (1996) conducted an examination of the methods and interpretation of soil chemical data by doing an ethnoarchaeological study in which the elemental patterns from a modern site and two archaeological sites of different time periods were compared. Their approach involved the collection of "contemporary control samples" of undisturbed soils that would have been on the surface during the sites' occupations. The samples from the modern site suggested that calcium, sodium, and strontium were "particularly good indicators of human activity" and cooking and general occupation each had their own identifiable elemental signatures (Middleton and Price 1996:677-678). By comparing the modern site to the archaeological sites, they determined that the intensity of the elemental signatures of the archaeological sites may have diminished slightly, but that "the archaeological chemical residues…remain distinct and detectable" (Middleton and Price 1996:679). Therefore, this study demonstrated not only that people create distinct elemental signatures in the soil through habitation, but that these signatures, which may weaken with time, can still be apparent long after the occupation has ended.

In order to undertake a soil chemical study for archaeology, it is necessary to have an understanding of the elements to examine and what their anomalous values might mean within an archaeological context. Three criteria must be met for an element to have potential applications to archaeological research:

> First, human activity must alter the natural concentration of this element across the site. Secondly, this influence must be readily apparent in comparison with the natural background concentrations and variability of the element. Thirdly, any alteration needs to be fixed in the soil in a persistent form so as to ensure a lasting record of human occupation. (Entwistle *et al.* 1998:53)

This third requirement, the ability of a humanly-introduced element to be retained in the soil for long periods, is, perhaps, the most difficult to satisfy. Because of soil's natural tendency to redistribute certain elements over time, they may not remain concentrated. Nitrogen and sodium are two such elements; they are connected to human occupation, but they are so mobile, leaching down the profile or being removed quickly by other agents, that they do not remain elevated in the soil for long (Cook and Heizer 1965:18; Middleton and Price 1996:681).

In the past, archaeological research has focused on the same three or four elements: phosphorous, calcium, potassium, and sometimes magnesium. These macro-elements, the available form of which are commonly assessed as part of agricultural soil testing packages, are relatively easy and inexpensive to study. Agricultural testing also will frequently report levels of specific micro-elements, such as boron, copper, iron, manganese, molybdenum and zinc, none of which have received much attention from archaeologists. Archaeological research has also begun to investigate the potential of rarer elements that, perhaps, meet the three criteria better than some of the ones traditionally studied. Because this technique is still in its infancy, further research will surely identify more elements suited for archaeological study, as well as refine current understandings of elements already examined. Furthermore, future research should also elucidate the meanings of elemental signatures, or specific combinations of concentrated elements.

Phosphorous (P)

Phosphorous, which is commonly found in the soil as a phosphate ion, is the most studied element for archaeological research. Phosphorous is a necessary element in all living things as it is "an essential ingredient in all cell protoplasm, nervous tissue, and bones" (Weast and Astle 1982:B-30) and plays an important role in energy transfer and metabolic processes (Ankerman and Large n.d.:120). Consequently, phosphorous is found in all *organics*, or materials derived from living organisms, including human and animal tissue, waste products and plant materials. Because people use, produce and discard so many sources of phosphate, phosphorus must collect in areas where these materials are being used and deposited. Over time, the addition of phosphorous in such quantities will create phosphate concentrations.

Most phosphorous, once it enters the soil, binds up quickly with other ions into an inorganic form not available to plants. Thus, phosphorous is rendered relatively immobile, an ideal characteristic for archaeological investigation because it can remain in the soil for long periods of time without being particularly susceptible to plant uptake or leaching (Bethell and Máté 1989:5-9; Ankerman and Large n.d.:23). Phosphorous's relative immobility, however, also affects phosphate analysis because agricultural testing only assesses the available phosphorous accessible to plants, rather than the total levels in the soil. Some archaeologists warn that total phosphorous will provide a much more accurate picture of the phosphorous distribution for archaeological sites and therefore is the preferable method of analysis (Bethell and Máté 1989:6; Herz and Garrison 1998:184).

Elevated phosphorous levels can be found in association with many different types of features. For instance, the soil of privies and places where the contents of chamber pots were routinely disposed of will be high in phosphorous due to the element's presence in human waste. Animal excreta, which are also high in phosphorous, build up in animal pens, the interior of which will also exhibit elevated phosphate. Manure was a common fertilizing agent, so gardens or fields where it has been applied to increase soil fertility may also exhibit high phosphate levels. Burials are another type of feature that should contain significant amounts of phosphorous as it is present in human and animal tissues, including bone. Furthermore, animal butchering, food processing and preparation areas would all be subjected to increased phosphorous deposition. One of the most common features marked by high phosphorous values are areas of general trash deposition, whether in a midden, trash pit, or as general surface scatter (Cook and Heizer 1965:4; Proudfoot 1976:93-4; Pogue 1988:2-4).

Calcium (Ca)

Another important element for archaeologists to examine is calcium. Calcium is an important building block of bone, teeth, shell, and leaves (Weast and Astle 1982:B-9-B-10) and therefore is present in human and animal tissues, and waste products as well as plants. Agricultural lime, which can be made from bone or shell, is essentially calcium oxide and is applied specifically to soil to raise the pH. Another significant source of calcium is wood and its ash. Calcium, like phosphorous, is relatively immobile and may also remain elevated for long periods of time (Pogue 1988:3; Ankerman and Large n.d.:59-61).

As calcium is found in many materials used and discarded by humans, its distribution across a site can be indicative of many different activities. Elevated calcium levels may reflect the disposal of bone and organic waste, as might be seen in trash middens, privies, burials, and food preparation/processing areas. For instance, at King's Reach, calcium was found to correlate with the distribution of pipe stems, which reflects the connection between calcium and trash deposition (Pogue 1988:9). Elevated calcium can also denote the former location of shell or marl walkways as was found at St. John's where the element peaked in the middle of two gates and on the side of the kitchen suggesting the use of oyster shell paving material in these areas (Keeler 1978:67,70-71).

In garden features and agricultural fields, elevated calcium can indicate the prior application of lime. Archaeological work on gardens at Leigh Park in England showed increased calcium in the Dutch Garden suggesting that the beds had been limed (Currie 1995:231). Elevated calcium levels can also be indicative of the deposition of significant amounts of mortar (Custer *et al.* 1986:90-1) and may be found in association with hearth areas.

Potassium (K)

Potassium, the third element commonly examined by archaeologists, is essential to plant growth (Weast and Astle 1982:B-32) as it plays an important role in protein synthesis, carbohydrate translocation and enzyme activation (Ankerman and Large n.d.:120). Consequently, potassium is found in wood and other plant parts. Unlike phosphorous and calcium, potassium is a little more mobile in the soil meaning that accumulated potassium may disperse over time. As a result, the survival of potassium concentrations in the soil may depend upon environmental factors (Pogue 1988:9). The likelihood of potassium leaching is also dependent upon soil texture as it is relatively immobile in fine and medium grained soils, but prone to leaching in sandy and organic soils (Ankerman and Large n.d.:44). However, the main consequence of potassium's potential mobility is that a lack of potassium cannot necessarily be interpreted as negative evidence, but potassium in concentration may reflect past human activity.

Despite potassium's mobility, its depositional pattern may be quite revealing and should be examined for anomalies. Because of potassium's presence in wood, elevated potassium levels can be indicative of hearths, places where wood has decomposed, and ash dumping. The soil data from King's Reach revealed elevated potassium in a band encircling the plantation's core, suggesting the deposition of fireplace ash along a fence around the perimeter of the property. At King's Reach, potassium concentrations were also present just outside several doorways (Pogue 1988:9) and at St. John's it was concentrated around the kitchen (Keeler 1978:67). Evidence from Middleton and Price's ethnoarchaeological study also suggests that potassium is associated with burning (1996:677-678). Although the potassium data from the Wilson-Slack site were less clear because the area where a small wooden outbuilding had burned was not potassium-rich (Custer *et al.* 1986:93), the general evidence suggests that, in many cases, potassium concentrations serve as good indicators of the prior deposition of wood and wood ash.

Magnesium (Mg)

Although less commonly examined than phosphorous, calcium, and potassium, magnesium is another element that is studied archaeologically. Like potassium, magnesium is relatively mobile and its retention by the soil may partially depend upon environmental factors (Pogue 1988:3). When it is present at anomalous levels, its exact meaning within an archaeological context is still less than proven. Magnesium is important for plants and animals and is a constituent of chlorophyll (Weast and Astle 1982:B-24). However, Konrad *et al.* based on their work at Munsungun Lake in Maine suggest a connection between the element magnesium and hearth areas:

> The best support of use of Mg analysis in identifying hearth locations originates at the historic component...where extreme Mg anomalies are associated with the stone hearth and probable ash dumps of a cabin....High anomalies of Mg associated with similarly high values of Ca and P also produced hearth features near the baseline of the prehistoric component. (1983:24)

This has led to the hypothesis that magnesium may build up in areas of the soil where burning has occurred (Pogue 1988:3). However, if magnesium is indicative of burning, the chemical explanation for this is unclear. Middleton and Price's ethnoarchaeological analysis suggests that on the modern site magnesium did correlate with burning. On the archaeological sites examined by Middleton and Price, however, magnesium was found to coincide with food preparation areas (1996:677-8,681).

Other Elements

Over the past decade, a few archaeologists, hoping to further soil chemical analysis, have begun to broaden their approaches to include elements not commonly investigated. Jane Entwistle *et al.* in their article entitled "Multi-Element Analysis of Soils from Scottish Historical Sites: Interpreting Land-Use History Through the Physical and Geochemical Analysis of Soil" (1998) outline many new potential elements for archaeologists to consider. For instance, the Clachan site exhibited elevated levels of cesium (Cs) and rubidium (Rb), both of which appear to correlate with human occupation. Although no human activities are known specifically to produce or use either of these elements, evidence suggests that cesium becomes concentrated in plant tissues. Therefore, elevated cesium levels could be indicative of food processing, food storage, and trash deposition. Cesium, however, provides an advantage over potassium because, unlike potassium, it is relatively immobile once it enters the soil. Therefore, cesium concentrations are more likely to persist than potassium ones (Entwistle *et al.* 1998:64).

Strontium (Sr) is another element that appears to correlate with human activity. Entwistle *et al.* discovered elevated strontium, an element found in shell, in an agricultural field perhaps indicating the prior application of shell sand fertilizer. Furthermore, strontium, which is more resistant to leaching than calcium, produced a more distinctive distributional pattern than calcium (Entwistle *et al.* 1998:65).

Middleton and Price's ethnoarchaeological study found that strontium was one of several "particularly good indicators of human activity" and appeared to accumulate in covered, enclosed spaces such as under buildings (1996:677-8).

Other elements, such as Thorium (Th), which happens to be relatively immobile, exhibited enriched levels in the occupation areas of the site, but their presence could not be clearly correlated with a specific human activity. Barium (Ba), Lanthanum (La), Cerium (Ce) and Praseodymium (Pr) also were elevated and interpreted to be indicative of human occupation and could correlate with trash deposition. Barium is found in ashes of different materials, including wood and bone, and in shell while the other three elements are contained in small amounts in bone and teeth (Entwistle *et al.* 1998:64). While more studies should be done to investigate the presence of all these elements and how they can be interpreted on other sites, they appear promising for future soil chemical analyses.

Another avenue for the study of elements would be some of the more common trace elements. Archaeologists who use basic soil testing packages at agricultural labs frequently receive information on the presence of some trace elements, such as boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) in addition to the four macro-elements. For instance, research at the Poplar Forest Quarter Site, which will be discussed in Chapter V, suggests that both boron and zinc may be related to general trash deposition as they were distributed similarly to calcium. While the potential meanings of specific trace element concentrations have not received much attention, they could, with further research, have much new information to offer for historical archaeological studies.

Soil chemical analysis, when carefully conducted, can provide significant amounts of information about anthrosols, even when they have been plowed. Although soil is a dynamic entity, the human impact on soil chemistry created by habitation can be so great that it can be detected long after the occupation is over. While each element behaves differently and will have a different distribution in the soil, some, such as phosphorous, calcium, potassium, and strontium, are clearly connected to human activities. Other elements also have the potential for revealing connections to human occupation and as further research is conducted, the interpretation of elements and signatures will definitely improve.

CHAPTER IV

CONDUCTING A SOIL CHEMICAL STUDY

The key to conducting a successful soil chemical study for historical archaeology is careful planning, from the research questions and sampling strategies to the soil analysis and the interpretation of the data. Although incorporating soil chemical analysis into archaeological research is certainly complicated, it is no more complex than many other aspects of excavation. However, the only way to ensure consistent and interpretable results is to consider a variety of issues before the excavation is even begun, so that appropriate strategies targeting site-specific research needs can be devised.

Guidelines for historical archaeologists to use in planning a soil chemical study of a plowed historical site, however, have never been published. Consequently, many historical archaeologists are unaware of the important considerations that are necessary in planning a soil chemical study. Therefore, historical archaeology would benefit greatly from a discussion of potential issues involved in the incorporation of soil chemical data into archaeological research and this chapter will present guidelines for how to approach the elemental analysis of plowed sites. As many valid approaches exist, it would be impossible to provide an exhaustive discussion of all possible issues and methods related to soil chemical analysis. However, this chapter will provide a framework that could generally be adopted on many historical sites so archaeologists will not only realize the potential benefits of soil chemical data, but hopefully will begin examining elemental distributions as part of their own research.

Determining Applicability to a Site

When considering the use of soil chemical data for an historical archaeological study, three questions, two theoretical and one practical, must be considered: Will soil chemical data help to answer questions put forth in the research design and enhance the interpretation of the site? Should the type and the conditions of the site permit the reasonable recovery and interpretation of soil chemical data? Is there enough funding available to cover the cost of the desired analyses? If the answer to all three of these questions is yes, then a strategy for soil chemical analysis should be designed and incorporated into the site research plan.

Answering the first question, will soil chemical data help to answer questions put forth in the research design and enhance the interpretation of the site, will obviously depend on the characteristics of each site. Soil chemical analysis, however, can examine a variety of issues pertaining to landscapes, spaces and activities. Given the recent trends in historical archaeology, it is difficult to imagine too many sites for which one or more of these issues are not being investigated. As to whether soil chemical data will enhance the interpretation, some speculation may be necessary; prior to starting the excavation, predicting how a site will excavate, the types of evidence that will be necessary, and how the soil chemistry will behave are impossible, but an educated guess about the potential utility of soil chemical data can be made. However, if a site has been plowed or suffered another large-scale disturbance, soil chemical analysis should, in most cases, be beneficial as the other data have been damaged. Consequently, the elemental patterns may reveal information not found in other ways (Pogue 1988:1-2).

In contemplating the second question regarding the type and condition of the site, several factors should be considered. First of all, how much unrelated activity has occurred in the vicinity of the site? Is this a site that has had multiple, discrete occupations? If a considerable amount of unassociated activity has transpired, such as with urban archaeology, then soil chemical analysis may not be an appropriate archaeological approach. Unlike artifacts, separating elements recovered from disturbed contexts temporally is nearly impossible. Therefore, this technique should, in most cases, only be employed on sites that have had one major occupation. However, this should not preclude sites that have been inhabited for long periods of time by the same general group of people. In fact, brief occupations, especially by small populations, may not alter the soil chemistry significantly enough to be detectable long afterward. Therefore, the larger the population and/or the longer the occupation, the more affected the soil chemistry is likely to be and therefore the more visible in the patterns of elemental distributions.

The final question, which concerns budgetary issues, is the most practical part of the decision about whether to use soil chemical analysis. Although it is impossible to predict how much it will cost before designing the research plan, approximations can be made based on a series of factors, including the potential number of samples and type or types of soil analysis desired. The number of samples will be determined by the size of the site, the plowzone sampling interval and other additional samples that might be examined. Because only having a few samples analyzed is likely to provide little useful information without other comparative data, any research plan should call for the analysis of a significant number of samples (Cavanagh *et al.* 1988:67). How the samples are analyzed will also influence the potential cost. Basic agricultural testing will start at about $7.00 per sample while more detailed analyses could cost $50.00 or more per sample. While some labs may offer discounts for bulk samples, a minimum budget of $1000 and preferably more, should be available for the soil analysis.[1]

Incorporating Soil Chemical Analysis into a Research Design

Planning the approach to soil chemical analysis early on in the excavation, preferably even before trowel is put to ground, is the best way to ensure a successful study. Because this technique requires consistency, from how samples are collected to how they are analyzed, the only way to guarantee that everything is done in a similar manner is to develop a strategy that is implemented from the start. In addition, because archaeology is a destructive process, collecting more samples at a later date is all but impossible. Therefore, it is crucial to know from what and where samples need to be taken prior to the start of excavation.

When investigating a site whose characteristics warrant the use of soil chemical analysis, archaeologists must consider a variety of issues, first and foremost being what questions will be answered with soil chemical data. Although research questions will always be site specific, soil chemical data can address a variety of spatial issues concerning how sites were used and organized: How were buildings laid out? Where were the doors, chimneys, and other important components? Where and how was trash

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[1] While soil chemical studies rarely discuss budgets, Weymouth and Woods in their 1980 study of Fort de Chartres Number I spent approximately $800 on the analysis of the soils (1985:35).

disposed of? How were "outdoor" spaces divided and organized? Where was food processed and prepared? Were there gardens or animal pens? Is there any evidence of industrial activity? While these are a few general examples of the many questions that may be examined using soil chemical analysis, they clearly demonstrate the range of issues that can be considered when designing the research approach.

The other main aspect of developing the research design is to decide upon an appropriate collection strategy, including what, where, and how samples will be taken. The more specific and systematic the collection approach is, the more consistent the process and, therefore, the results will be. The best way to maintain uniformity would be for one individual to collect all of the samples, but this is impractical for most archaeological excavations. Therefore, each excavator *must* be familiar with the collection strategy to ensure its implementation in the most consistent fashion possible.

Deciding what soils should be sampled will be determined by the research questions and the characteristics of the site. The most important component in the soil chemical analysis of a plowed site is the plowzone, which should be sampled at regular intervals across a grid. Additionally, other stratum samples, including non-plowed layers or subsoil[2], may be sampled if the data could target specific research questions. Stratum samples may also be augmented with the collection of feature samples. Some archaeologists already collect feature samples although they frequently do so without a specific research plan for the specimens. The analysis of random features, however, will most likely provide little interpretive information unless in the context of a larger plowzone study that can provide comparative data for understanding the elemental levels

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[2] See Chapter V for a discussion of the potential benefits of collecting subsoil samples.

found in the feature soils. Consequently, if, after the collection of plowzone samples, questions arise during the excavation of specific features, such as what a feature was used for, how it was created, or what was deposited within it, collecting a soil sample or samples is certainly warranted. The results from these feature samples can be standardized and then compared to the other samples taken to look for positive evidence, or soils exhibiting unusually high elemental levels. Unless a large number of feature samples spanning the range of feature types on the site are collected and analyzed, feature samples can never be examined for negative evidence, or unusually low elemental levels, because they can only be compared against other samples that may have been subjected to different post-depositional factors.

One study that did successfully rely upon the study of feature samples was the examination of the Utz Site, a prehistoric site in Missouri occupied from approximately 1550-1700 (Van der Merwe and Stein 1972). This study sought to examine whether postmolds and rodent burrows each had distinctive elemental signatures. The authors of the study adopted a unique approach and collected over one-hundred soil samples, including not only soil from the features but also from adjacent non-feature soils. The side-by-side samples were examined and it was found that postmolds had higher phosphate levels but lower magnesium levels as compared to the adjacent soils. The rodent burrows, however, frequently had lower phosphate levels but higher magnesium levels in comparison to the surrounding soil. The authors were able to create a formula that correctly identified forty-five out of forty-seven postmolds based on their elemental signatures. While identifying postmolds on historical sites using soil chemistry would be unnecessary, the approach demonstrated is quite intriguing as it suggests that soil chemical analysis of features, when approached in a systematic and large enough manner, can answer specific research questions.

After determining the types of soil to be sampled, the next step is to decide from where those samples should be taken. For any stratum, whether plowzone, a non-plowed layer, or subsoil, samples should be collected at regular intervals across a grid. The sampling interval for the collection of stratum samples will directly affect the amount of detail present in the distributional patterns and consequently the understanding of the site: "as with any spatial sampling program, the size of the interval between soil samples remains a crucial determinant of the validity of the results" (Pogue 1988:13). Thus, large sampling intervals may indicate general elemental patterns but will not evoke any of the finer details of the distribution. However, too small an interval, unless dictated by a specific research need, may provide too much detail, thereby obscuring the overall pattern.

While predicting exactly what a site will look like is impossible, the general characteristics expected can be used to focus the sample interval. For instance, in the excavation of structures, collecting soils from both inside and outside buildings is critical to being able to interpret their layout. Therefore, the sample interval should be smaller than the size of any buildings likely to be encountered. Other characteristics of the site, such as its total size and research questions being asked may also influence the sample interval. Table 1 provides a range of sampling strategies employed on historical sites in the United States.

TABLE 1: EXAMPLES OF SOIL SAMPLE COLLECTION METHODS

Site	Interval	Layout	Layer Type	Number Collected
Fort de Chartres Number I[3]	1 m.	Transects, 10 m. apart	Sub Plowzone	404
Fort Kaskaskia[4]	10 m.	2 Orthogonal Transects and 5 other areas	Strata at varying depths	90
King's Reach[5]	2 m.	Grid	Plowzone	144
New Windsor Cantonment[6]	Hut: 10ft. Kitchen: 5 ft.	Grid	Unspecified	Hut: 20 Kitchen: 16
St. John's[7]	Unclear	Grid? Not entirely clear	Plowzone	Not mentioned
Wilson-Slack Site[8]	5 ft.	Grid	Below Humus	300+

Perhaps the easiest way to choose the sampling interval is based upon the size of the excavation unit. Taking one sample per square requires no measuring because the grid is already established and excavators are less likely to forget to collect samples if done every time. Both one-meter and five-foot excavation units are common on historical sites and are appropriate sampling intervals. Sample intervals of this size allow more control over what is examined as the interval may be increased, if necessary, simply by not analyzing all the samples. Starting with a relatively small interval, such as these, should allow for detailed distributions, even if questions arise during the excavation or after it is finished.

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[3] Weymouth and Woods 1985:23.
[4] Weymouth and Woods 1985:18.
[5] Pogue 1988:5.
[6] Sopko 1983:26-7.
[7] Keeler 1978:22-32.
[8] Custer *et al.* 1986:90.

The last step in creating the sampling strategy is to determine from where within each unit the stratum samples will be taken. In order to maintain the proper interval, samples should be removed from similar places, both horizontally and vertically. For the horizontal location, either the center or a particular corner should be chosen, although the position should be shifted slightly and noted if a feature is encountered. Standardizing the vertical placement of samples is harder since predicting exactly when the bottom of a stratum will be reached is difficult. Samples should not be taken too close to the bottom or top of the stratum, as the goal is to sample the plowed soil nearest to where the occupation layers had been.

Collection of Soil Samples

All soil samples should be collected in a controlled and consistent manner to ensure the most accurate results possible. While different labs may require different amounts of soil, two cups should be enough for each sample in most cases. Typically archaeological samples are collected by scraping the soil with a trowel, but an auger or coring tube may also be used as long as they are stainless steel or chrome plated to avoid the introduction of trace elements. Archaeological soil samples can also be contaminated by packaging containers in which samples are placed (Ankerman and Large n.d.:86; A & L Reference Guide: Soil Sampling n.d.), so plastic bags or the containers supplied by the soil lab are best. Additionally, all equipment should be free of other soils prior to obtaining the sample, again, to prevent contamination.

Another possible approach to soil chemical analysis involves the collection of samples with minimal excavation, the strategy adopted at Forts de Chartres Number I and

Kaskaskia (Weymouth and Woods 1985). The advantage of this approach is that soil elemental distributions can be analyzed, but the site remains relatively intact for future generations. With this approach a coring tube or auger is inserted into the soil at the appropriate intervals until the correct stratum is reached. Some care, however, must be taken to ensure that the correct layer is, in fact, sampled every time. The rest of the analysis can then be conducted as it would be for any other archaeological site.

Many scientific experiments employ a control sample or samples, in order to establish the typical unenhanced levels so that change in the affected specimens is more visible. A "contemporary control sample," as defined by Middleton and Price is an unenhanced but stratigraphically equivalent soil, such as a buried A horizon (1996:674). Many archaeologists using soil chemical analysis strongly advocate the collection of control samples to provide some idea about what the "natural" levels should be (Cook and Heizer 1965:16; Miller and Gleason 1994a:31). Many archaeological studies have attempted to compare data against a "control" (for example, Dietz 1957; Moore and Denton 1988; Middleton and Price 1996).

Although obtaining control samples would be ideal, within the framework of soil chemical analysis on historical archaeological sites, it is, in most cases, completely unrealistic. Just as there are not "natural" landscapes, there are not "natural" soils either, as most land in the United States has been inhabited, farmed or generally affected by humans. Therefore, searching for soil that has only been "minimally-enhanced" could involve as much excavation as is necessary to dig the site. Therefore, if a minimally-enhanced, stratigraphically-equivalent soil presents itself, it can be sampled for comparison, but the use of a true control sample for soil chemical analysis within historical archaeology is impossible.

Analysis of Soil Samples

One of the largest debates concerning the use of soil chemical analysis for archaeological research centers around what is considered to be the most appropriate type of analysis, especially for the examination of phosphorous. Because phosphorous binds up tightly and much of it is not present in the soil in a form obtainable to plants, agricultural testing procedures are liable only to extract and report available amounts. Therefore, many archaeologists consider the examination of available phosphorous to be problematic because, they argue, the data do no present the complete picture (Bethell and Máté 1989:6; Miller and Gleason 1994a:29; Herz and Garrison 1998:182). Herz and Garrison claim, in fact, that:

> the amount of labile P in a soil depends on many variables, none of which are related to archaeology, for example, soil water, soil textures and structure and extraction of different amounts of P from the soil by different plants. The determination of available P in soil correlates only with the fertility of the soil and is controlled by modern conditions. (1998:182)

Evidence, however, suggests that the relationship between available phosphorous and the modern conditions might not be as simple as Herz and Garrison suggest. Eidt contends that available phosphorous in the soil is difficult to assess because simulating plants' abilities using extracting agents has not been perfected (1977:1328). Proudfoot argues that different extractants can produce highly variable results (1976:95) suggesting that if different labs use differing extracting agents the supposed "available" levels could differ. In fact, Middleton and Price claim that any extractant stronger than dilute hydrochloric acid releases too much of the tightly-bound phosphorous, which only provides information about the parent material, rather than the anthropogenic nature of the soil (1996:675).

Examinations of different soils also indicate the complexity of assessing phosphate levels. For instance, agricultural testing of soils from the Poplar Forest Quarter Site, which will be discussed further in Chapter V, provided mixed results for phosphorous. Phosphorous was extracted using diluted hydrochloric and sulfuric acids and the plowzone, layer and subsoil samples showed little variation except in a few, importantly-located samples. However, samples taken from root cellar fill, which should exhibit elevated phosphorous because of the storage and deposition of food and other organics, were extremely elevated; in fact, three out of the four root cellar samples had standard scores above five meaning that the phosphorous levels were more than five times the standard deviation above the mean of all the site samples. These extremely elevated levels within the root cellars cannot possibly be entirely the result of modern conditions as Herz and Garrison suggest and clearly indicate anthropogenic enhancement. Furthermore, Conway (1983), in research on a Romano-British site, compared extractable to total phosphorous and found that they exhibited similar distributions, but that the total phosphorous pattern was more detailed. He concluded that extractable phosphorous is "a less sensitive indicator of the original deposition pattern," but that it did still reveal the general distribution (Conway 1983:123).

Many of the soil chemical studies of historical archaeological sites fail to provide enough detail about the testing of the soil to determine the exact type of phosphorous extracted. The lack of information about the testing is problematic because evaluating the phosphorous distributions is impossible without knowing the type of phosphorous that has been examined. Furthermore, it makes it difficult to explore which types of phosphorous are providing historical archaeologists with the best results and suggests that many historical archaeologists are not aware of the issues concerning the analysis of phosphorous.

TABLE 2: APPROACHES TO THE ANALYSIS OF PHOSPHOROUS

Site	Soil Testing Lab	Type of Phosphorous Testing	Phosphorous Results
Fort de Chartres Number I[9]	Rock River Laboratory, Wisconsin	Sequential Fractionation	one of the elements of "greatest interpretive significance"
Fort Kaskaskia[10]	Rock River Laboratory	Unclear: possibly same as Fort de Chartres	generally high, much of which was for natural reasons
King's Reach[11]	University of Maryland	Unclear	seemed to generally correlate with organic refuse
New Windsor Cantonment[12]	Not Mentioned	Unclear	interpreted to exhibit significant variation
St. John's[13]	University of Maryland	Available	interpreted to exhibit significant variation
Wilson-Slack Site[14]	University of Delaware College of Agricultural Soils Laboratory	Unclear	provided mixed results—high in some places but not in others as expected

Choosing whether to test for available or total phosphorous may have to be made in consultation with a soils lab familiar with the local environment or may require some

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[9] Weymouth and Woods 1985:23,36.
[10] Weymouth and Woods 1985:34,36.
[11] Pogue 1988:3,8-9.
[12] Sopko 1983:29.
[13] Keeler 1978:29.
[14] Custer *et al.* 1986:90,94.

pretesting of samples to determine which provides the best results. Perhaps the conclusion to draw is that neither approach is best and that fractionation might be preferable as it could potentially distinguish between humanly-introduced and naturally-occurring phosphorous (Woods 1977; Eidt 1985). However, both fractionation and total testing are more expensive than available testing, so these detailed analyses may, in many cases, not be worth the additional cost.

With an understanding of the issues debated in the analysis of phosphorous, finding a lab that will perform the desired analyses is the next step. Archaeologists who are still unsure as to the type of analyses desired may be best served by finding a soils lab that is willing to advise on the special requirements involved in the analysis of archaeological specimens. There are privately-run soils testing labs around the country, but many states also have state-run labs that provide analysis for farmers. Private labs may offer more variety in the types of analysis, but state-run labs may be cheaper because the soil testing package is preset and done frequently. However, looking into both types of labs should provide options in the types of analysis and the costs.

One example of a state-run lab is the Virginia Tech Soil Testing and Plant Analysis Laboratory in Blacksburg. Virginia residents who wish to have samples analyzed at Virginia Tech contact their county extension agent who provides the necessary paperwork and half-pint sample boxes. Routine testing at Virginia Tech costs \$7.00 per sample in-state or \$10.50 out-of-state and provides the levels of Phosphorous, Potassium, Calcium, Magnesium, Zinc, Manganese, Copper, Iron, and Boron as well as the pH. Upon arriving at the lab, each sample is dried and crushed. Then, a subsample is measured out for the pH testing which involves the addition of distilled water before assessment with a pH probe. Determining the elemental levels involves a slightly more complicated process. An extracting solution consisting of hydrochloric and sulfuric acids diluted in deionized water is added to another subsample creating a soil solution. The solution is then shaken and filtered before being transferred to a tray for the analysis. The analysis is conducted using an Inductively Coupled Plasma Spectrometer which provides the readings for each element tested from the same subsample. The resulting levels are then calculated based on the readings into either pounds per acre for Phosphorous, Calcium, Potassium and Magnesium or parts per million for the remaining trace elements (Donohue and Heckendorn 1994).

In comparison, the private A & L Agricultural Laboratory has labs spread around the country, including one located in Richmond, Virginia. They offer a more extensive and varied list of testing methods that can be performed. While they have basic soil testing packages, similar to the ones performed by the Virginia Tech lab, they also offer more detailed analyses, including tests that provide total elemental levels. The fee structures for basic testing packages are more complex, but an equivalent testing package to Virginia Tech's would be significantly more expensive. The cost for analysis of total levels is $8.00 for every element requested in addition to a $10.00 digestion fee.[15] However, the price listing also suggests that discounts may be offered for large numbers of samples and that flexibility is available for packages not listed (A & L Eastern Agricultural Laboratories, Inc. Schedule of Fees 1989).

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[15] These prices were available in the late 1990s and could have changed slightly since then.

Analysis and Interpretation of Data

Once the data are returned, the analysis and interpretation of the results can begin. Soil analysis results may at first appear to be nothing more than a list of numbers on a piece of paper. For each sample, a variety of elements may have been examined and there should be significant variation between different elements within the same sample. While many approaches can be used to understand the meaning of the data, several easily-applied techniques will be discussed. Although many of the aspects of data analysis will be determined by a site's characteristics, some approaches that have been successfully used on historical sites will be explored. Table 3 illustrates examples of statistical tools and mapping methods used for soil chemical data analysis on historical sites.

TABLE 3: APPROACHES TO DATA ANALYSIS

Site	Statistical Tools Used	Interpretive Tools Used
Fort de Chartres Number I[16]	None mentioned	Distribution Maps of absolute levels
Fort Kaskaskia[17]	None mentioned	None—sample interval too great for mapping
King's Reach[18]	None mentioned	Distribution Maps of absolute levels
New Windsor Cantonment[19]	"Student" t-test	Histograms comparing levels of feature to non-feature areas and Distribution maps of absolute levels
St. John's[20]	Mean, Standard Deviation (s), Pearson's Coefficient of Skewness	Distribution Maps of standard units in relation to the mean
Wilson-Slack Site[21]	Indices, but not discussed	Distribution Maps of indices

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[16] Weymouth and Woods 1985:28.
[17] Weymouth and Woods 1985:34.
[18] Pogue 1988:10-12.
[19] Sopko 1983:26-27.
[20] Keeler 1977.

Assessing the elemental levels and variation within the samples will only be clear with some statistical calculations. Each statistic should be determined for the entire group of samples. Additionally, the same statistics should also be calculated for the major sub-groups, such as the plowzone. In order to characterize the central values of the group, the mean (X), or the average of all of the elemental levels, the median, or the mid-point of the distribution, and, if desired, the mode, or the most commonly occurring elemental level, should be determined.[22] In order to assess the variation within the entire group, the standard deviation (s), which is essentially an average of how much scores differ from the mean, should also be calculated. Within a sample, typically two-thirds of the groups will be within one standard deviation of the mean.

A fifth statistical tool, a z or standard score, does not characterize the group of samples, but rather represents an individual score in relation to the mean and standard deviation of its group. The z score, which is essentially a representation of an absolute score in standard deviation units, is calculated by subtracting the mean from an absolute score and dividing the result by the standard deviation. Thus, the z score not only provides an idea of how certain levels within the same group compare to each other, but also allows for comparison of scores in different groups, something impossible with absolute levels.

Feature samples, if analyzed, are problematic to study because they are more random than stratum samples taken across a grid. If a few "important" feature samples are analyzed, they can only be examined for positive evidence, or unusually high

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[21] Custer *et al.* 1986:92.

[22] Most of the statistics discussed can be calculated easily using a computer program, such as *Microsoft Excel*. For further descriptions or the exact formulae for any of these statistics, consult a statistics text.

elemental levels as compared to the entire set of samples. Negative evidence, or low levels, cannot be interpreted for feature samples because they are compared against the entire sample group, which could contain specimens subjected to varying post-depositional factors. Consequently, determining whether a feature sample exhibits a low elemental level because of relatively little human enhancement or appears low because the other samples all exhibit post-depositional enrichment is impossible. Calculating z scores for the features as their own subgroup may be done as long as it is clear that these features may *not* represent the entire population of feature samples.

For any type of stratum sample, including the plowzone, depicting the distribution of the elemental levels in relation to their site location is extremely important. By mapping the distributions, anomalous values, not just for one sample but for groups of adjacent samples, will be revealed, thereby demarcating concentrations and areas of minimal enhancement. The visual depiction of the values, either in absolute levels or in terms of the z scores, allows for much easier interpretation of how elemental patterns relate to the site's features.

In order to picture the distribution of individual elements across a site, it is necessary to map them in some way. A low-tech mapping method is to color-code grid squares on a site map according to each unit's distance above or below the mean. In this way, higher values will take on similar colors as will lower values. Using a computer, the data can be mapped using a distribution program, such as *Surfer*, a program commonly used in archaeology. *Surfer* produces contour maps that indicate the peaks and valleys of the distributions. The maps, however they are generated, are then assessed for how the elemental levels relate to the features of the site. With an understanding of the potential meanings of each element, interpreting the elemental distributions for the site is possible.

While many ways to approach the chemical analysis of soils exist, the most important aspect of the research is to plan the study ahead of time. Soil chemical analysis does not lend itself to being incorporated into archaeological research in the middle or at the end of a project. When carefully planned, soil chemical analysis is a powerful tool, especially in the analysis of landscape and spatial issues on plowed sites. As further research is done on the chemical analysis of soils on historical sites, undoubtedly new and innovative approaches will be developed to further the technique's application to archaeological research.

CHAPTER V

SOIL CHEMICAL ANALYSIS AT THE QUARTER SITE

Recent work at the Poplar Forest Quarter site illustrates the benefits of soil chemical analysis for the interpretation of a plowed archaeological site. Soil chemical analysis had never been employed previously for the examination of an archaeological site at Poplar Forest, so knowing how best to approach the research and how well it would work were uncertain. However, after the first excavation season at the Quarter Site, it was evident that the plow disturbance to approximately two-thirds of the site would hinder the understanding of certain facets of slave life, especially the organization and use of space. Although the examination of the Quarter site's soil chemistry was a learning experience, in the end the soil chemical data strengthened and enhanced the interpretation of slave life.

Poplar Forest

Poplar Forest, located in Bedford County, Virginia, was once a sprawling plantation owned by Thomas Jefferson. Jefferson inherited the property, named for the tulip poplars dotting the landscape, when his feather-in-law, John Wayles, a land speculator and entrepreneur, died in 1773. A working plantation at the time Jefferson acquired it, Poplar Forest was located ninety miles, or a 2.5 to 3 day ride south of his better-known home Monticello (Chambers 1993:x). During his visits to Poplar Forest in the eighteenth century, Jefferson likely stayed in the home of the overseer as he had to yet to develop the property. Jefferson also wrote most of *Notes on the State of Virginia* while staying at Poplar Forest to avoid capture by the British Troops in 1781. In 1806, Jefferson began constructing an octagonal brick villa that would become the core of his retreat. By making his house the center of an ordered landscape, Jefferson incorporated visions of his ideals, not only into the buildings but also into the rest of the plantation. After the completion of the house, Jefferson visited Poplar Forest as often as possible, frequently with one or more of his children or grandchildren. Upon Jefferson's death in 1826, the property passed to his grandson, Francis Eppes, who sold the property in 1828 (for a detailed history of Poplar Forest, see Chambers 1993).

In 1989, under the auspices of The Corporation for Thomas Jefferson's Poplar Forest, archaeologists began investigating the property in preparation for the restoration of both the house and the landscape. Although the plantation was almost 5000 acres at the time Jefferson inherited it, today the Corporation only owns the approximately 500-acre core, including Jefferson's octagonal house. The first archaeological assessments and excavations focused on the house and the grounds immediately surrounding it, as this was the first area to be restored. However, as the restoration of Jefferson's octagonal villa progressed, the archaeological work expanded to examine other parts of the property.

The Quarter Site

In 1993, archaeologists shifted their attention away from the main house to test a sloped-area along the current eastern property line in preparation for planting a row of trees. In order to ensure that no important archaeological remains would be disturbed, archaeologists dug a series of test pits in the area to be impacted. Surprisingly, on the rather inhospitable slope, the shovel testing unearthed late eighteenth- and early nineteenth-century artifacts in the plowzone and exposed several features. To assess the context of these findings, a larger excavation unit was opened up, revealing that one of the shovel test pits had uncovered a root cellar, an indication that archaeologists had probably stumbled upon a slave quarter. The excavations were expanded and continued until the site's completion in 1996 by which point archaeologists had uncovered evidence of three structures, various landscape features and thousands of artifacts, all of which helped to elucidate life in this previously-unknown quarter (for an in-depth analysis of the Quarter Site, see Heath 1999).

Structure I, the first building uncovered, was a two-room 25' by 15' wooden cabin sitting diagonally across the middle of the slope (see Figure 1). The archaeological remains of the building consisted of various postholes, three at the corners and many more irregularly placed along the perimeter and interior dividing wall. The lack of a posthole at the northwest corner suggests that it must have been supported by a stone pier to level out the cabin. Each room had a rectangular root cellar, one of which had been filled in and re-dug during the house's occupation.

Slightly to the east and north of Structure I sat Structure II, a thirteen-foot square building straddling the current property line. Although no postholes were associated with the structure, a large rounded pit, containing two distinct fills, was the remains of a worn floor surface. Dug into this floor was a small, round pit filled almost entirely with ash upon which a flat stone had been placed, as if to seal it. Because the clay soil did not

FIGURE 1: THE QUARTER SITE

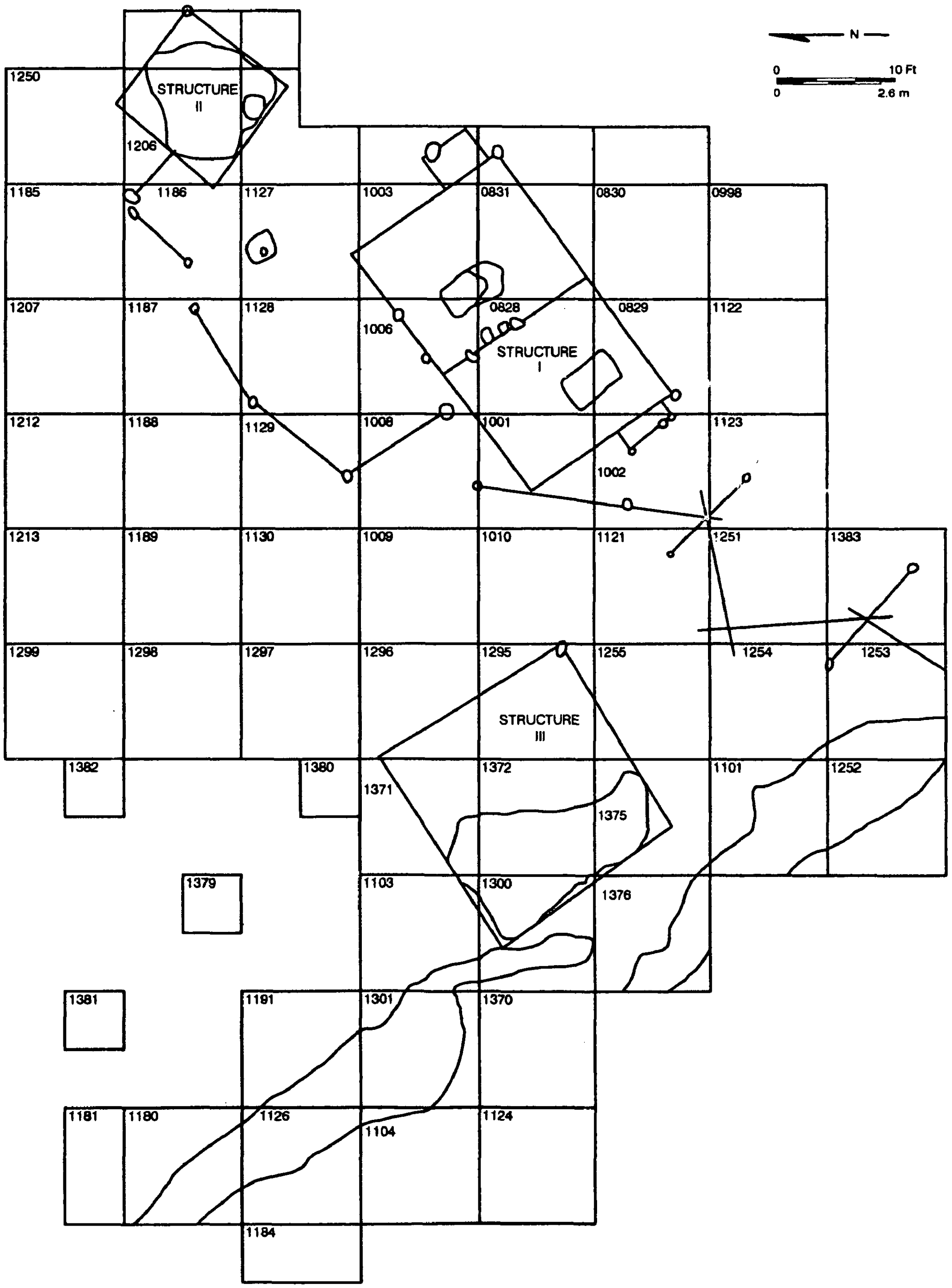

exhibit signs of having been burned or exposed to heat, the source of the ash remains unclear. The size of the building and the presence of significant amounts of ash and charcoal in its fill suggest that it was originally an outbuilding. However, the significant number of domestic artifacts also recovered indicate that the building was inhabited during part or all of its existence.

On the west side of Structure I on a relatively steep part of the slope, evidence of a third structure was uncovered. Structure III was a square building, measuring 18.5 feet per side, and, like Structure I, was also supported by a combination of posts and stone piers. Erected on top of an earlier erosional ditch, the structure's location was apparent because of a dark, artifact-rich fill that had settled into a construction pit under the building. Around the building's south and west exteriors was a stone paving surface. The artifacts recovered around the building suggest that Structure III may have been constructed later and/or occupied longer than either of the other two buildings (Heath 1999:41).

In addition to the three structures, evidence of a garden and several fence lines also indicate how the Quarter was organized. The fenced-in garden, which was in the southeast corner of the excavation area, was behind Structure I and could have been used by the Quarter's occupants or, perhaps, the overseer and his family. According to an eighteenth-century map, the overseer's house appears to have been located southeast of the site in an area that is not currently owned by the Corporation (Heath 1999:6). Several fence lines also dotted the landscape of the quarter. One enclosed the east front of Structure I and extended uphill to Structure II to create a small fenced-in front yard. A snake fence began at the northwest corner of Structure I and meandered to the south past

Structure III. A fourth fence, marking the western perimeter of the Quarter, may have run north to south on the west side of Structure III.

During the years of excavation, approximately 20,000 artifacts were recovered. The artifacts, all elucidating slave life in the Quarter, ranged from ceramics, glass and nails to fragments of unusual stone smoking pipes. The TPQs of the artifacts recovered and the predominance of pearlware indicate that the Quarter Site was inhabited during the last decade of the eighteenth century and first decade of the nineteenth. Therefore, the Quarter was in use primarily when Poplar Forest was a working plantation before Jefferson began construction on the main house. Thus, these slaves, although under the supervision of an overseer, were living in a primarily-slave community. Therefore, the site offered an important opportunity to examine how slaves were able to create their lives, and as is the focus of this study, their landscapes and spaces. The slave quarter was most likely dismantled and the slaves moved elsewhere in 1812 when Jefferson ordered the erection of the Curtilage Fence. The fence, which would have passed through or very near to the Quarter Site, encircled the sixty-one-acre core of the plantation (Heath 1999:65).

Research Design for the Soil Chemical Study[1]

Because the landscape of Poplar Forest had been a focal point of archaeological excavations from the beginning, an examination of the physical world of the Quarter became an essential part of the site's research design. To study how the slaves lived, it

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[1] The following discussion of the soil chemical analysis of the Poplar Forest Quarter Site was previously discussed in Fischer 1996. This chapter contains more statistical information and examines a few issues not discussed in the original report. However, many of the conclusions remain the same.

was crucial not just to identify structures, but also to examine how those buildings were tied to each other, how spaces were used and organized, and thus how the slaves created their community. When approaching this site, several landscape and spatial questions were integral to the research: How were individual buildings laid out? Where were the doors and chimneys and how were the buildings used? How were the spaces between buildings used and organized? What kinds of activities were going on in the quarter and were there specialized areas designated for these activities?

Although many of the research questions could be partially answered with artifacts and features, these types of evidence might not necessarily provide the whole picture because much of the site had been subjected to post-depositional plowing. For the eastern two-thirds of the site, plowing had disturbed any occupational strata, displacing the majority of the artifacts and removing the tops of surviving features. The nineteenth-century plowing had ended, however, approximately in the middle of Structure III meaning that the building had differential stratigraphy for each half, severely complicating its interpretation. Given the ephemeral nature of the site's surviving remains, it was impossible to know how many other features or pieces of evidence had been eradicated altogether by the plow.

To overcome these challenges in the exploration of the site's research questions, the archaeological approach centered around the careful excavation of the plowzone. However, at the end of the first field season, archaeologists decided to scrutinize the plowzone even more by adopting a less common method for the analysis of plowed sites, soil chemical analysis. An explicit research plan, involving the collection of plowzone, non-plowed layer, subsoil, and feature samples, was devised and implemented at the start of the second field season in the hope that the unique nature of soil chemical data would provide information about the site not found in other ways.

Sampling Methodology

The potential importance of soil chemical data for understanding the Quarter Site was not realized, unfortunately, until after the first field season had been completed. In 1993, nine excavations units, comprising a 30' by 30' area, were dug revealing most of Structure I including the root cellars and much of the building's perimeter. During this excavation season, the research plan only called for the collection of soil from potentially-important features, such as the root cellars. Consequently, no plowzone samples were taken.

In 1994, archaeologists returned to the Quarter Site with a firmer research strategy involving the systematic collection of plowzone and layer soil samples in addition to the feature samples already being taken. The stratum sampling interval chosen was ten feet based on the size of the excavation units. The collection procedure for the plowzone samples was for the excavator, at some point during the excavation of the fourth quadrant of each unit, to fill an appropriately-labeled plastic bag with 250 milliliters of freshly scraped soil using a clean trowel. Because the western third of the site had not been subjected to nineteenth-century plowing, the typical soil profile in each unit was more variable, the stratigraphy consisting of topsoil, one to three layers, and subsoil. With the exception of topsoil, each layer was sampled in much the same way as the plowzone, by collecting 250 milliliters of soil from the fourth quadrant of each unit during the excavation process. When non-modern features were excavated, 250 milliliters of soil was also saved. For complex features, such as the fills associated with the structures, samples were taken to capture the horizontal and vertical variation within these features.

In order to assess the "normal" elemental levels found in the site's Virginia-piedmont clay, an attempt was made to collect "control" samples for comparative purposes. The original strategy for the collection of the controls involved taking soil samples approximately 0.5' into the subsoil at various locations around the site. However, the analysis of these potential control samples indicated that they were not unenhanced; rather, being from the B-horizon or zone of leaching, the subsoil samples had been the beneficiary of many elements leaching downward from the occupation layers. Although the elemental levels indicated that these subsoil samples could not be used as controls, they suggested that subsoil might be informative. Thus, the examination of subsoil could provide archaeologists with a potential way to assess the soil chemistry of the portion of the site for which plowzone samples had not been taken. Consequently, more subsoil, both from the nine units lacking plowzone samples and several other areas of interest that had been previously sampled, was collected. The subsoil sampling was performed in a much more consistent manner than any of the other stratum samples as most of them were taken in a two-day period by the same individual. The collection procedure for the subsoil samples involved a thorough cleaning, removing at least several tenths of an inch from the center of each designated fourth quadrant, before the requisite 250 milliliters of soil was removed and placed into an appropriately-labeled plastic bag.

A final effort to obtain a "control" sample was made during an archaeological survey of the property. Finding an area that had not been subjected to human occupation or plowing on the plantation was virtually impossible. However, subsoil was collected from the bottom of a "sterile" test pit located in a copse of trees on the western edge of the site. Although this area revealed little evidence of habitation and few artifacts, it may have been plowed in the eighteenth century. Most of the elemental levels from this sample, except for potassium, manganese, and iron, were lower than the means for the rest of the site samples (see Appendix A, Table 5). The elevated potassium, however, could be explained by the fact that this area is wooded. Although this sample appeared to exhibit minimal human enhancement, it may only be considered a guide rather than a true control sample, an impossibility in the examination of archaeological soils on historical sites.

Analysis of the Samples

During the excavation process, over one-thousand soil samples were collected, but in order to best answer the questions outlined in the research design within the budget, 116 samples were chosen for analysis. Table 4 provides the distribution of samples analyzed, which included all of the plowzone, layer and subsoil samples taken. In addition, samples from several important features, and samples from several intriguing but unidentified features were also examined. All of the soil was sent in one of three batches to the Virginia Tech Soil Testing Laboratory in Blacksburg. For shipping, each chosen sample was transferred from its plastic bag into a cardboard box provided by the Bedford County Extension Agency. Because the boxes were smaller than the samples collected, each bag was shaken before approximately two-thirds of it was poured into a box. Upon arrival at Virginia Tech, the samples were analyzed according to the method described in Chapter IV. In addition to the pH, the elements determined, all commonly examined for agricultural purposes, included available phosphorous (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Zinc (Zn), Manganese (Mn), Copper (Cu), Iron (Fe) and Boron (B) (Donohue and Heckendorn 1994). A sheet was provided with the results for each sample with phosphorous, calcium, potassium, and magnesium reported in pounds per acre and the remaining microelemental levels reported in parts per million.

TABLE 4: DISTRIBUTION OF QUARTER SITE SOIL SAMPLES

Sample Type	Number of Samples Analyzed
Plowzone	37
Historic Layers	30
Subsoil	25
Feature	23
“Sterile” Subsoil	1

Analysis of Results

To assess and interpret the data, several statistical tools were used. The means, medians, modes, and standard deviations for the entire group of samples, excluding the off-site “sterile” sample, were calculated using *Microsoft Excel* (see Appendix A, Table 5). These same statistics were also calculated for the important sub-groups, including the plowzone, layer, subsoil, and feature samples (see Appendix B, Tables 6, 7, 8 and 9). These four groups were examined separately because each may have been impacted slightly differently by post-depositional factors related to human activities and their locations within the soil profile. However, the feature sub-group data are provided only for examination, but were not factored into the site analysis. As discussed in Chapter IV, the feature group may not be representative of the entire feature sample population.

Therefore, the features were only analyzed in terms of their relationship to the entire group of soil samples.

To aid in the comparison of elemental levels between the groups, however, each absolute value was converted into a z score. Z scores, or standard scores, were calculated in relation to the mean and standard deviation of the sub-group to which a sample belonged, as well as in terms of the mean and standard deviation of the entire sample group. Z scores represent an absolute reading in standard deviation units above or below the mean. Consequently, a raw score equal to the sample mean will have a z score of zero. Positive z scores indicate that an absolute level was greater than the sample mean while a negative z score shows that a raw score was below the mean. Thus, the larger the z score, whether positive or negative, the more extreme the absolute elemental level was as compared to its group. Approximately two-thirds of the sample group will fall within one standard deviation of the group's average, meaning that z scores greater than 1.00 and less -1.00 can be considered anomalous.

To examine the elemental patterns, two different approaches were used to simulate the elemental distributions across the site. For the purposes of mapping the data, the assumption was made that the interval between samples was ten feet and that each sample corresponded to the central point of quadrant four of its unit. The simplest mapping approach was to color-code each unit on a site map based on its z score. Thus, the high points and low points for each element were demarcated by similar colors and could be examined in relation to the features of the site. Therefore, a visual inspection of the data was possible without subjecting it to the interpolation necessary for a computer-generated plot, such as *Surfer*. The maps of subsoil distributions for phosphorous, calcium, potassium, and magnesium are of this color-coded variety because the samples were not taken at regular intervals across the entire site grid (see Appendix C, Figures 5, 9, 13 and 17). The plowzone and other layer data were entered into *Surfer* to create contour maps of the distributions as these strata were sampled at regular intervals across the entire site (see Appendix C for all of the distribution maps and more information on the mapping strategies).

Because of the problematic site stratigraphy, decisions had to be made about how to approach the mapping and analysis of the western part of the site, especially because the stratigraphy was not equivalent within each unit. In units with three layers, the uppermost strata probably postdated the site and therefore its elemental levels were not related to site patterns. The lowest layer in the multi-layer units was most likely the remnants of a pre-occupation plowzone, which may be the closest approximation of a living surface. The overall complexity of the stratigraphy, however, made it difficult to interpret the distribution patterns within the layers because of the lack of contiguous, intact strata. Therefore, two maps were created for each element for the western part of the site. The "layer above subsoil" maps indicate the elemental levels for each stratum directly on top of subsoil. Additionally, a second map for the "middle layer" was generated in which the upper layer levels were used for units with one or two strata and the middle layer was used for units with three strata. However, the general elemental patterns for these two types of maps appear relatively similar (see Appendix C, Figures 4, 8, 12 and 16).

Distributional Patterns

To understand and interpret the soil chemical data recovered from the Quarter Site, the distributional maps need to be examined. By studying the distributions of the different elements as well as the general artifact scatter in relation to the known features of the site, patterns begin to emerge. With an understanding of the meanings of the different elements, these complex patterns suggest information about the locations of doorways, hearths, and trash deposition as well as how the slaves used and organized different parts of their quarter. While some of this information could have been hypothesized based on the artifact distribution or site features, the elemental data were able to provide independent proof for these suspected interpretations. Furthermore, the elemental data also imparted other information about the site not apparent in any of the other archaeological evidence.

Artifacts

The general distribution of artifacts around the Quarter Site exhibited a definite pattern (see Appendix C, Figure 2). The artifacts, which were mapped according to the number present in all of the layers within each ten-foot excavation unit, congregated in the plowzone on the north side of the site. One large concentration of artifacts extended out from the picket fence enclosing the yard between Structures I and II and indicated the primary trash midden for these two buildings. The quantity of artifacts gradually decreased to the south and was relatively low on the south side of Structure I. In contrast, the area in and around Structure III contained many artifacts, most likely related to trash collecting under the building. The residents of Structure III also appear to have developed their own midden, which extended from the north side and northwest corner of the building, down slope to the west.

Phosphorous

The phosphorous levels around the site were generally quite low, most likely symptomatic of the use of agricultural testing to approximate the available rather than the total phosphorous in the soil. However, the phosphorous distribution within certain strata still revealed several important areas of interest. For instance, the distribution of phosphorous in the plowzone indicated two contained but important concentrations (see Appendix C, Figure 3). Off the west corner of Structure I, just beyond the start of the snake fence, the plowzone phosphorous was extremely elevated (z score: 5.61). Although the surrounding squares for which samples were taken were also slightly elevated in comparison to the rest of the plowzone, the phosphorous peak was quite sharp suggesting that this area had received at one time the concentrated deposition of organic waste, such as the contents of chamber pots. The location of this phosphorus peak clearly indicated that a door led out of the west room of Structure I along the north wall. The slaves must have exited the cabin through this door routinely to deposit organic waste, perhaps in a shallow pit that has since been plowed away.

The plowzone distribution also revealed a lesser phosphorous concentration south of Structure I in the corner of the excavation area (z score: 1.31). This part of the site, which was relatively devoid of artifacts (see Appendix C, Figure 2), exhibited many irregular planting holes, most likely from its use as a garden. Although this garden could have been planted and used by the slaves or the nearby overseer, the interpretation of this area as such is strengthened by the phosphate enrichment, probably indicative of the previous application of manure or other organic fertilizing agents to enhance the soil.

The phosphorous patterns for the western strata are more difficult to interpret than the plowzone distribution (see Appendix C, Figure 4). In both the "middle layer" and the "layer above subsoil" distributions, one peak was apparent under Structure III where the stratified soils abut the plowed portion of the site. This peak was most likely caused by the collection of refuse under the building during its use. An even more intriguing phosphorous concentration, seen only in the "middle layer," is found on the extreme western portion of the site, down slope of Structure III. Near the Structure III trash midden, this phosphorous peak may, like the phosphate concentration outside of the door of Structure I, be indicative of the deposition of organic waste a few paces from building's main access.

In contrast to the plowzone and layer distributions, the subsoil exhibited little phosphorous variation, even for the few units whose upper strata were elevated (see Appendix C, Figure 5). The low phosphorous levels for the subsoil samples, however, are not surprising because of phosphorous's resistance to leaching. Furthermore, the soil testing method, which only allowed for the extraction of the available phosphorous, may also have contributed to the low subsoil levels. Because of the lack of phosphorous variation within the subsoil, the original patterns immediately around Structure I remain unknown.

Calcium

Calcium, which was concentrated in several key locations, exhibited a different distributional pattern than phosphorous. For instance, north of the fenced-in yard between Structures I and II, the plowzone calcium levels were generally elevated (z scores: -0.07 to 1.67). The calcium-enriched soil together with the artifact concentration in this area indicated that the slaves living in Structures I and II deposited much of their general refuse in a now-plowed surface midden (see Appendix C, Figure 2 and 7). The interior of the fenced-in yard also exhibited slightly elevated calcium levels, especially in the vicinity of Structure II. This fenced-in front yard is believed to have been used for food processing and preparation, an interpretation supported by the enriched calcium in the soil and by the presence of several unexplained features that could have been linked to these activities. Although the calcium distribution did not clearly demarcate the eastern door on the north wall of Structure I, one must have existed providing the only egress from the building into the fenced-in front yard. However, the calcium did indicate that the slaves made some effort to keep the fenced-in yard clean, especially in front of the door, as the levels increased toward the fence. Furthermore, within the fenced-in yard between Structures I and II, the calcium levels also decreased rapidly to the east. A similar decline was also apparent in the artifact and other elemental distributions, all suggesting the presence of a barrier between the two structures. Although the divider was not obvious archaeologically, the distributional patterns indicated that the front yard was entirely enclosed. Two particular units along the picket fence exhibited calcium accumulation suggesting the most likely location of a gate from where the slaves exited the yard and from they threw their refuse into the midden.

Not surprisingly, the calcium levels were also greatly enhanced to the west of Structure I just beyond the start of the snake fence. The plowzone unit containing the most calcium (z score: 1.59) was the same one that exhibited the large, defined phosphorous peak, further demonstrating the previous deposition of significant amounts of organic waste in this area. In contrast to the phosphorous distribution, all of the units on the south side of Structure I exhibited calcium levels well below the plowzone mean although the levels began to increase slightly toward the west.

In contrast to the plowzone calcium patterns, the distribution of calcium in the layer samples from the western part of the site was more difficult to interpret (see Appendix C, Figure 8). Calcium was elevated in the layer above subsoil under Structure III in a concentration extending to the north and along the west wall of the building. However, the calcium was relatively low down slope to the west of the cabin as only a few units were even above the layer mean. Given the concentration of artifacts in this area (see Appendix C, Figure 2), higher calcium levels might have been expected. The relatively low elemental levels, however, could indicate that the Structure III midden was smaller than the excavated artifact concentration and that many of the artifacts were carried down slope over time by erosion. To the north of Structure III, in an area only excavated in a checkerboard fashion, calcium was also elevated, possibly from the up-slope midden.

Unlike phosphorous, the general calcium patterns in the plowzone and layers were mostly replicated in the subsoil (see Appendix C, Figure 9). For instance, the general subsoil levels were elevated outside of the fenced-in yard and just outside the snake fence on the west side of Structure I, both concentrations of which were present in the plowzone. In and around Structure I, where no plowzone samples were taken, the subsoil calcium levels were very low in the southeast of the 30' x 30' area and increased gradually toward the northwest corner. Because the calcium both in the plowzone and subsoil was relatively unenhanced on the south side of the building, the distributional pattern further supports the interpretation that the building only had two doorways, both on the north wall. The soil in the vicinity of Structures II and III exhibited above-average calcium levels, especially on the west side of Structure III (z score: 1.78).

Potassium

Potassium, which is associated with wood and its ash, was distributed differently than either phosphorous or calcium. The north side of the site, which exhibited concentrated calcium, had only average potassium levels, with some units slightly higher than the plowzone mean and some slightly lower (see Appendix C, Figure 11). Potassium, however, was more concentrated within the enclosed yard on the north face of the cabin, most likely from the cooking activities and possibly the removal of fireplace ashes from Structure I through this yard. Like calcium, the potassium levels within the yard decreased toward the east between Structures I and II, again indicating the presence of a barrier that enclosed the work space entirely. In stark contrast to the elevated phosphorous and calcium, the areas just outside of the west door of Structure I and the snake fence were quite low in potassium (z score: -1.18). Down slope of Structure I, however, the potassium increased in association with Structure III, including both the northeast corner and east side of the building, helping to narrow down the location of its chimney and hearth (z scores : 0.47 to 2.03). The garden area on the south side of Structure I also exhibited potassium enrichment possibly suggesting the deposition of wood ash in the garden.

In examining the west side of the site, the distribution of potassium both in the "middle layer" and in the "layer above subsoil" appear similar (see Appendix C, Figure

12). The greatest concentration of potassium was in the northwest corner of the site, an area that exhibited little elemental enrichment for either phosphorous or calcium. This potassium concentration may suggest that the slaves living in Structure III disposed of their fireplace ash downhill away from the majority of other waste and activities or it could relate to the modern trees growing nearby.

The potassium pattern in subsoil was similar to that seen in the strata above but, like the upper strata, contrasted to the subsoil phosphorous and calcium distributions (see Appendix C, Figure 13). However, the subsoil potassium mean was slightly higher than that of the plowzone and much higher than the potassium mean for the other layers, most likely because of potassium's propensity for leaching. The potassium levels in the subsoil around Structure I were extremely high and all but one of the units containing the building were above the subsoil mean for potassium (z scores: -0.09 to 1.49). The area of potassium concentration included almost all of the house and excavated area south of it, extending to the garden. The elevated potassium inside Structure I could be indicative of repeated sweeping causing the fireplace ashes to fall through the floorboards. Within the area around Structure I, two mini-peaks were present, one close to the southeastern corner of the house along the southern wall and one at the southwestern corner of the house that continued toward the garden. Portions of the gable ends of the house were included within these high potassium peaks as was much of Structure I's south wall. In light of the potassium distribution, small irregular postholes along each gable end, but off center to the south, suggest the location of the chimneys. The subsoil potassium distribution, like the plowzone pattern, also hinted that fireplace ashes may have been spread on the garden from time to time.

Definitively locating the chimney for Structure III was more difficult although its location can be narrowed down to one of two walls. Unlike Structure I, no postholes existed around the building to suggest the former location of the wooden chimney. The largest plowzone potassium peak occurred underneath Structure III close to the center of the southeast wall. However, the exact location of this potassium peaks was dictated by the sampling interval as only one sample was taken from inside the building. Both the plowzone and the subsoil exhibited enriched potassium along the entire northeast wall of the structure. Based on the potassium distribution and the southeast wall's proximity to the snake fence, the chimney was most likely located on the northeast wall.

Magnesium

Of all of the elements commonly examined for soil chemical studies of archaeological sites, the interpretation of magnesium as being connected to burning is the most tenuous. The distribution of magnesium at the Quarter Site is puzzling (see Appendix C, Figures 15-18). Magnesium, exhibiting a similar pattern to calcium, was somewhat concentrated north of the fenced-in yard in the vicinity of the general surface midden. Magnesium was also elevated at the corner of Structure I, possibly related to the nearby hearth. However, a similar peak would have been expected near the building's other hearth, but none was present. Further complicating the situation was the fact that the area around the most likely location of Structure III's hearth also exhibited elevated magnesium. Consequently, the magnesium distribution at the Quarter Site only indicated that the link between magnesium and burning needs to be further investigated.

Other Elements

Although the meanings and potential archaeological uses of other elements are unclear, the distributions of the trace elements provided are worth examining to see if any of their patterns might relate to the site's activities. While the exact meanings of these elements may not be known, if their distributions suggested some connection to the site's features, then this would raise the possibility that they could be indicative of the prior human activity. The focus of the research clearly should not be on the unknown elements, but quickly analyzing their distributions may present potential patterns that could be examined in the future.

The patterns of boron, zinc, and to a lesser extent manganese all could potentially be connected to the slave activities at the Quarter Site. Boron's distribution was similar to that of calcium and may suggest some connection to food processing, preparation, and refuse disposal (see Appendix C, Figure 20). Boron was generally elevated within the fenced-in yard and peaked just outside the gate. Like the other elements, it too decreased rapidly in the area between Structures I and II again supporting the location of a barrier in this vicinity. In addition, a second boron peak, apparent outside of the start of the snake fence near the phosphorous and calcium peaks, extended down toward Structure III.

Like boron, the relative distribution of zinc could be associated with the occupation as its overall pattern was similar to calcium's (see Appendix C, Figure 19). The largest concentrations of zinc were found in the plowed surface midden, north of the fenced-in yard. In addition, the zinc, like phosphorous and calcium, peaked just beyond Structure I's northwest door at the start of the snake fence. However, several other zinc concentrations, including one on the south side between Structure I and the garden, were less explicable in terms of their potential connections to human activity.

The manganese distribution also could be indicative of past human activity at the site, though its pattern is less convincing than those of boron and zinc (see Appendix C, Figure 21). Manganese was concentrated on the north side of the site, extending south toward Structure III. However, it was much lower around the picket fence and in the midden area to the north, which generally exhibited elevated levels of elements associated with the general deposition of waste. Manganese also peaked around Structure II and the west side of Structure I near the snake fence.

Neither iron, copper, nor pH exhibited distributions that appeared to relate to the slave activity at the Quarter Site. The iron levels were generally low on the north side of the site and higher for the southern portion of the site, but if this is meaningful it is unclear as to why (see Appendix C, Figure 23). While it has been suggested that iron may accumulate around features, such as pits, postholes, and trenches (Lambert 1997:41), the general pattern did not suggest a relationship to the known areas of high activity at the Quarter Site. Like iron, the copper distribution also presented little apparent correlation to the site's activities (see Appendix C, Figure 22). The copper distribution was relatively even with one exception, a large peak approximately ten feet outside of the gate in the picket fence (z score: 4.11). However, this aberration could be the result of modern conditions or causes. The pH distribution exhibited little variation and did not suggest any connection to the human occupation (see Appendix C, Figure 24).

Features

Although many feature samples were collected throughout the excavation, only a few were chosen for analysis because of budgetary considerations. Consequently, only important features, such as those related to the structures, as well as several unidentified but intriguing features were examined. Because these samples are not representative of all the site features, they can only be compared to the entire sample group, rather than the feature sub-group as discussed in Chapter IV. Thus, low elemental levels cannot be considered negative evidence, but concentrations can potentially be linked to cultural activities.

The root cellars associated with Structure I all exhibited relatively high phosphorous and calcium levels. In comparison to the entire group of samples, the southwestern root cellar's fill was extremely elevated in phosphorous and calcium (phosphorous z scores : 5.43 to 5.73; calcium z scores: all 2.26). Even though the root cellar sample from the northeastern room was not nearly as elevated, it was still well above the site mean (phosphorous z score: 1.99; calcium z score: 2.26). These levels are consistent with the storage and deposition of organics, such as foodstuffs. In contrast, the potassium and magnesium levels varied slightly among the root cellar samples, but were generally average to below average (potassium z scores: -0.63 to 0.66; magnesium z scores: -.68 to -1.57). Perhaps not surprisingly, zinc and boron, both of which had similar distributional patterns to calcium, were also elevated within the cellars (zinc z scores : 0.64 to 2.75; boron z scores : 0.21 to 4.19) again suggesting the need to explore these two elements further.

Of all of the aspects of the Quarter Site, Structure II is, perhaps, the most enigmatic. The building's location along the current property line prevented the exploration of its eastern perimeter. The doorway may have been along the north wall, like the other buildings, exiting just to the northeast of the picket fence. This location would have provided the slaves with the easiest access to both the midden and the fenced-in yard. However, the calcium levels were only slightly above average in this area and with no information from the east half of the building, knowing the door's location conclusively is impossible.

The primary interpretive soil samples from Structure II came from the floor fill, including two from each of two fill layers, and one from the ash pit. Based on the evidence collected during the excavation, the fill layers and the plowzone should have exhibited certain elemental signatures. Although the calcium levels were generally elevated (z scores: 0.92 to 2.26) as would have been expected from the bone deposition, most of the other elements were not significantly enriched except, surprisingly, manganese (z scores: 0.49 to 1.88). The potassium levels should have been high based on the large amount of charcoal and ash scattered throughout the fill. However, the fill layers were all well below the site mean (z scores: -0.65 to -1.17) as was the pit that had been almost solidly filled with ash (z score: -0.63). Although no conclusion can be drawn from this negative evidence, one possible question to explore would be whether the greenish material is definitely wood ash, something only assessable with further analysis.

Even ignoring the problematic potassium results, trying to understand Structure II itself was still difficult. The phosphorous and calcium levels as well as the bone distribution in the fill layers all suggested that more refuse was deposited in the southern end of the building near the ash pit than in the northern half where the door may have been located. Although no logical explanation for why one half was kept cleaner is obvious, this pattern could have been related to the structure's dual function as a habitation and work area.

Six soil samples associated with Structure III were also analyzed: two from the uppermost fill layer, two from a small pit underneath, and two related to the stone paving. The stratigraphy suggested that the stone paving, which extended around the south and west exteriors, was made to cross an older erosional ditch that had developed before the building's construction. Although two samples were collected from the distinct soil layers sitting on top of and among the paving stones, the remainder of the paving surface was not excavated. For the two samples from the fill that collected under Structure III, the elemental levels were generally higher than the site mean, but not extremely elevated (phosphorous z scores: -0.24 to 0.01; potassium z scores: 0.17 to 0.73; calcium z scores: 0.48 to 1.70). In contrast, the small pit, whose fill was virtually identical to that found under the building, exhibited above average phosphorous (z scores: 0.47 to 0.98) and calcium (z scores: all 2.26), but low potassium (z scores: -0.8 to -0.85). Perhaps the most interesting samples were the ones taken from within the stone paving. Not only did they exhibit high phosphorous (z scores: 0.57 to 2.29) and calcium (z scores: all 2.26) but also extremely elevated boron (z scores: 5.41 to 6.94) and one sample had elevated zinc (z score: 2.47). This specific signature resembled that seen in the root cellars and may suggest that the stone paving was used as a food processing area at one time.

As for the other features examined, the soil chemical data did not provide much new or interpretable evidence. The erosional ditches were generally below average for the elements. However, this is not surprising given that these features were mostly filled in prior to the site's occupation. As for the three unidentified features examined, little new evidence about their functions came to light. Feature 1004B, which was located in the vicinity of Structure I, contained a significant amount of potassium (z score: 1.44), perhaps suggesting a relationship to fire or the deposition of wood ash. The other two unidentified features were generally average, but were not any more interpretable based upon the soil chemical data than they had been in the field.

Interpreting the Quarter Site with Soil Chemical Data

The soil chemical information at the Poplar Forest Quarter Site has clearly enhanced the understanding of the site. Without the data, the locations of the structures' doors and hearths might have been suspected, but could not have been easily proven. Furthermore, the elemental distributions elucidated the activities going on in some parts of the Quarter. On the north side of Structure I was an enclosed yard where much of the outside food preparation activities occurred. Beyond the fenced yard was the general trash midden. The refuse appears to have been tossed down slope from both the doorway of Structure II and the gate in the fenced yard. In addition, waste was being concentrated in a small area just beyond the start of the snake fence outside of the western door of Structure I. The garden was located on the south side of the Quarter, most likely near the overseer's house.

While the interpretation of life at the quarter is complex and has been discussed thoroughly in Barbara Heath's book *Hidden Lives: The Archaeology of Slave Life at Thomas Jefferson's Poplar Forest* (1999), the soil chemical data have clearly improved the understanding of how the Quarter was used and how the slaves moved through their world on a daily basis. While many facets of the interpretation have been impacted by the soil chemical analysis, one particular aspect clearly illustrates how the soil chemical evidence improved the understanding of slave life at the site. Much of the activity was occurring on the north side of the structures according to the elemental patterns. Barbara Heath describes the slaves' use of the small yard on the north side of Structure I:

> Slaves chose to locate this yard on the side of the house facing away from the mansion or overseer's house. This plan allowed them space, air, and light to work in, elements lacking within the dark crowded buildings. At the same time, the placement of the yard afforded them the freedom to socialize and relax away form the watchful eyes of the overseer and his family. (1999:44)

In addition, the doorways on all three Structures faced north, again most likely not a coincidence, as this would have shielded the slaves' comings and goings from the nearby overseer.

James Delle (1998) in his examination of Jamaican coffee plantations illustrates the interplay of power in the layout of the plantations. He discusses the power of surveillance in the context of one plantation, Clydesdale:

> By locating the overseer's house in such a way that the overseer could be surveying the village and works from the veranda, or even by gazing out of one of the house's windows, the workers could never be entirely sure whether they were being watched. The purpose behind the construction of this spatiality was the construction of discipline in the work force; the logic of the panopticon dictated that the workers would cooperate if they thought they were being watched. (Delle 1998:159,161)

However, Delle argues that the slaves thwarted the spatialities of control with their own spatialities of resistance (1998:161,163). Applying such a model to the Quarter Site, the archaeological evidence, especially the soil chemical data, illuminated one of the ways in which these slaves exercised their spatiality of resistance: in choosing to face all of their buildings away from the overseer and to engage in the majority of their activities on the north side of the buildings, the slaves were deliberately circumventing the overseer's ability to watch them and thereby assuming some control over their own lives.

CHAPTER 6

CONCLUSION

Research questions centering on landscapes and spaces have become integral to the archaeological analysis of most historical sites. The critical roles assumed by landscape and space, however, are certainly deserved at they are integral to culture and can provide cultural information not transmitted in other forms. However, spatial evidence in the archaeological record is frequently ephemeral and difficult to interpret, even on sites with relatively intact stratigraphy. For sites that have suffered post-depositional plowing, assessing or even finding traces of spatial evidence is even more challenging. Soil chemical analysis, however, affords historical archaeologists a new and unique data set that may provide information about past uses and organization of spaces not recovered in other ways, thus helping to overcome the effects of post-depositional plowing.

Soil chemical analysis is clearly a technique that can enhance and improve archaeological excavation and the interpretation of plowed sites. Although the research designs for plowed sites include the careful collection of artifacts from the plowzone more often than not, historical archaeologists have yet to examine consistently other types of evidence contained in the plowzone. Historical archaeologists *must* begin to change the prevailing perception that the plowzone is nothing more than a disturbed layer containing artifacts by incorporating soil chemical analysis into the research designs for *all* plowed sites that meet the technique's applicability criteria. Because archaeology is a destructive process, historical archaeologists are, perhaps, being slightly irresponsible in not at least considering the use of soil chemical analysis and the valuable information that it can provide for excavations of plowed sites.

As has been discussed, the recent soil chemical study of the Poplar Forest Quarter Site as well as the studies at St. John's (Keeler 1978), New Windsor Cantonment (Sopko 1983), Forts de Chartres Number I and Kaskaskia (Weymouth and Woods 1985), and King's Reach (Pogue 1988) all indicate how elemental distributions can shape and improve site interpretations. For instance, the elemental patterns at the Quarter Site elucidated the layout of buildings as well as how the slaves used and organized spaces within the quarter. From this detailed picture emerges the slaves' subtle use of space to assert some control over their situation by shielding their activities, and thus providing some degree of privacy from the prying eyes of the overseer (Heath 1999:44). Unequivocally, the interpretation of the Quarter Site, as well as most of the other sites discussed, would not have been as refined without the systematic analyses of the elemental distributions in the soil.

Given the clear benefits of soil chemical analysis, a variety of reasons are needed to explain why more historical archaeological studies are not incorporating the technique. While theoretical ideas and models grow and change, methodological approaches to the excavation of historical sites frequently rely on tried and true techniques. While using proven methods is not problematic in any way, many archaeologists only seek new and/or other methods and techniques when a challenge arises during the excavation process. Soil chemical analysis, however, cannot be assimilated into archaeological research in the middle of a project as it requires careful planning from the start in order to be most beneficial. Collection strategies and approaches to the analysis must be consistent and target specific research questions. Historical archaeologists may also be discouraged from using soil chemical analysis based on the cost. Although soil analysis is clearly expensive, in comparison to the overall site budget for a large-scale excavation, the costs should be relatively low. The small amount of money spent on the analysis of samples, however, can pay huge dividends in terms of the information provided.

The most likely reason, however, for so few historical archaeologists contemplating the use of soil chemical analysis within the research designs of plowed sites is a lack of information. The major goal of this research was to present many of the issues that historical archaeologists need to consider and understand so that soil chemical analysis can be implemented more easily into archaeological analysis. Because a general treatise on the use of soil chemical analysis in historical archaeology has never been published, historical archaeologists may simply be unaware of the technique's benefits and the relative ease with which elemental data can be collected and assessed. Because the technique requires a planned, systematic approach, archaeologists must thoroughly understand the pertinent issues, such as how to incorporate it into the research design, how samples should be collected and analyzed, how the data can be interpreted, and the potential meanings of particular elements. Without this background information, the process of soil analysis may seem daunting and best left to specialists. However, the process is certainly no more complex than most other aspects of excavation and is certainly possible within most excavation approaches.

The lack of information concerning the application of soil chemical analysis to historical archaeological research highlights a common problem within the discipline, the lack of published or shared information pertaining to critical issues, especially methodological ones. Information about the strengths and weaknesses of archaeological methods must be shared and discussed for these approaches to be able to evolve and for archaeologists to receive the most benefit from them. For continued research into the chemical analysis of archaeological soils to enrich the discipline, archaeologists must begin publishing and discussing their findings, the problems encountered, and appropriate ways to approach the analysis. With expanded discussions, more and more archaeologists will become aware of the potential benefits of soil chemical analysis, especially in the examination of plowed sites, and may be more willing to apply it to their own research. Without a dialogue concerning the many facets of soil chemical analysis, the technique can never reach its full potential for historical archaeological research.

In order for a discussion on soil chemical analysis to occur, archaeologists must begin incorporating it into their projects in varying ways. For soil chemical analysis to become a truly viable technique, as it certainly could, more systematic research into all aspects of the technique must be carried out. As more studies are conducted, a body of comparative data, something that the field is currently lacking, will develop. Through the analysis of this comparative evidence, patterns will emerge, not only helping to refine interpretations of individual sites but also understandings of the technique. Although this research is likely to identify benefits as well as problems in studying elemental distributions, the identification of the technique's strengths and weaknesses will only improve its application as part of archaeological analysis.

Research into soil chemical analysis is already suggesting many new areas to explore as well as current ideas to reevaluate and revise. For instance, the refinement of the meanings of particular elements as well as the expansion of the common elements usually examined seem quite possible. The research at the Poplar Forest Quarter Site suggested that in addition to the traditional elements, boron and zinc might present potentially important results and should be examined in future studies. Recent examinations focusing on rarer elements (Entwistle *et al.* 1998) have also suggested that a wide variety of other elements may have archaeological significance and the key for the future will be to determine which also possess the best characteristics for archaeological analysis. The only way to begin to understand the meanings of all of these elements is for soil studies to be performed on a variety of different historical sites, from different time periods, in different regions, with different types of soils, taking different approaches. Once enough studies have been done, patterns in the distributions of different elements, which have been strongly hinted at in previous research, will become clearer and more understood. As these patterns emerge, they will, in turn, expand the potential research questions that can be explored with soil chemical data.

Further research and soil chemical studies will also develop new approaches to the analysis and interpretation of the data. New collection strategies can be developed, ones that provide flexibility but still target specific research questions. The research at the Poplar Forest Quarter Site, for instance, suggested that perhaps a ten-foot sampling interval was too large to access some of the finer nuances of the distribution, especially in relation to the buildings. For that reason, the collection of soils from other sites at Poplar Forest has been reduced to five feet, quadrupling the number of samples collected but hopefully allowing archaeologists more choice in which samples are analyzed even after the project has ended. The soil analysis of the Quarter Site also suggested the potential benefits of subsoil sampling, a strategy that has yet to be explored for other sites or other types of subsoil. However, if subsoil samples can be informative, at least for particular elements, this has potentially beneficial repercussions for disturbed sites whose only remnants are found in the subsoil.

Another area to explore is the debate over the most appropriate types of soil analysis. Comparisons of the results of different analyses, such as the study performed by Conway (1983), would be one way to assess whether the more detailed types of soil analysis provide enough new information to justify the added cost. In turn, as the information provided by the different types of soil analysis becomes clearer, it will also strengthen the understanding of the behavior and meanings of particular elements.

Great research potential also exists within the area of data analysis. Most of the approaches used to date have involved simple statistical manipulations or none at all. In the future, the use of other statistical methods should be explored to determine whether other approaches might be more informative. In addition, other ways to visually represent the elemental distributions should be tried to find approaches that best illuminate the elemental relationships to site features.

The amount of research potential in the area of the application of soil chemical analysis to historical archaeology is clearly great, but it also highlights the fact that that use of the technique as an interpretive tool is still in its infancy. With each study done, more is learned about how to conduct the research, how to analyze the data, and the kinds of information revealed. The key to realizing the potential of this technique as an important research tool for historical archaeologists is to continue conducting this type of research and sharing the results. Without continued study of the potential uses and approaches to soil chemical analysis to historical archaeology, the discipline will be missing out.

APPENDIX A

QUARTER SITE SOIL DATA

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**P**	***P***	**K**	***K***	**Ca**	***Ca***	**Mg**	***Mg***
		(lb/A)	*Z Score*	**(lb/A)**	*Z Score*	**(lb/A)**	*Z Score*	**(lb/A)**	*Z Score*
829C	Structure I: Root Cellar	114	5.43	202	0.66	2400	2.26	125	-0.68
829E	Structure I: Root Cellar	120	5.73	148	-0.25	2400	2.26	101	-1.27
829F	Structure I: Root Cellar	120	5.73	173	0.17	2400	2.26	120	-0.81
998A/4	Plowzone	10	0.17	206	0.73	1320	-0.25	158	0.13
1003D	Structure I: Root Cellar	46	1.99	126	-0.63	2400	2.26	89	-1.57
1004B	Unidentified Feature	1	-0.29	248	1.44	1032	-0.91	142	-0.26
1009A/4	Plowzone	32	1.28	129	-0.58	2112	1.59	223	1.73
1010A/4	Plowzone	6	-0.04	119	-0.75	1632	0.48	163	0.25
1101B	Trench	2	-0.24	228	1.10	1488	0.14	226	1.80
1103A/4	Layer	2	-0.24	126	-0.63	1392	-0.08	139	-0.34
1103K/4	Layer	1	-0.29	135	-0.47	1488	0.14	94	-1.44
1103M/4	Layer	1	-0.29	113	-0.85	1512	0.20	94	-1.44
1104A/4	Layer	5	-0.09	126	-0.63	1128	-0.69	146	-0.17
1104B/4	Layer	2	-0.24	62	-1.71	1248	-0.41	118	-0.85
1121A/4	Plowzone	1	-0.29	164	0.02	1464	0.09	156	0.08
1122A/4	Plowzone	1	-0.29	202	0.66	1104	-0.75	161	0.20
1123A/4	Plowzone	2	-0.24	271	1.83	1440	0.03	190	0.92
1124A/4	Layer	2	-0.24	157	-0.10	1248	-0.41	173	0.50
1124B/4	Layer	2	-0.24	100	-1.07	1008	-0.97	161	0.20
1126A/4	Layer	5	-0.09	202	0.66	1128	-0.69	175	0.55
1126B/4	Layer	2	-0.24	170	0.12	984	-1.03	144	-0.22
1127A/4	Plowzone	1	-0.29	186	0.39	1056	-0.86	139	-0.34
1127D	Unidentified Feature	2	-0.24	202	0.66	1728	0.70	163	0.25
1127JJ	Unidentified Feature	2	-0.24	106	-0.97	2040	1.43	182	0.72
1128A/4	Plowzone	3	-0.19	232	1.17	1464	0.09	146	-0.17
1129A/4	Plowzone	1	-0.29	248	1.44	1560	0.31	180	0.67
1130A/4	Plowzone	4	-0.14	154	-0.15	1680	0.59	178	0.62
1180A/4	Layer	2	-0.24	180	0.29	1080	-0.80	137	-0.39
1180B/4	Layer	1	-0.29	206	0.73	1056	-0.86	127	-0.63
1180D	Trench	1	-0.29	59	-1.76	1152	-0.64	79	-1.81
1181A/4	Layer	1	-0.29	145	-0.30	1080	-0.80	149	-0.09
1181B/4	Layer	1	-0.29	145	-0.30	1008	-0.97	137	-0.39
1184A/4	Layer	1	-0.29	170	0.12	1008	-0.97	142	-0.26
1184B/4	Layer	1	-0.29	122	-0.69	1344	-0.19	146	-0.17
1185A/4	Plowzone	1	-0.29	157	-0.10	1704	0.65	187	0.84
1186A/4	Plowzone	3	-0.19	212	0.83	1776	0.81	182	0.72
1187A/4	Plowzone	2	-0.24	167	0.07	1848	0.98	187	0.84
1188A/4	Plowzone	2	-0.24	167	0.07	1944	1.20	180	0.67
1189A/4	Plowzone	4	-0.14	196	0.56	1824	0.92	209	1.38
1191A/2	Layer	2	-0.24	151	-0.20	1248	-0.41	154	0.03
1191B/2	Layer	2	-0.24	167	0.07	1152	-0.64	146	-0.17
1191E/2	Layer	1	-0.29	138	-0.42	1248	-0.41	139	-0.34
1206A/4	Plowzone	2	-0.24	170	0.12	1704	0.65	149	-0.09
1206B/1	Structure II	1	-0.29	122	-0.69	1824	0.92	113	-0.98

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**P**	***P***	**K**	***K***	**Ca**	***Ca***	**Mg**	***Mg***
		(lb/A)	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***
1206B/3	Structure II	15	*0.42*	94	*-1.17*	2328	*2.10*	96	*-1.40*
1206C/1	Structure II	5	*-0.09*	103	*-1.02*	2280	*1.98*	106	*-1.15*
1206C/3	Structure II	6	*-0.04*	113	*-0.85*	2400	*2.26*	84	*-1.69*
1206D	Structure II	2	*-0.24*	126	*-0.63*	1872	*1.04*	67	*-2.11*
1207B/4	Plowzone	2	*-0.24*	225	*1.05*	1968	*1.26*	223	*1.73*
1212A/4	Plowzone	2	*-0.24*	190	*0.46*	1728	*0.70*	190	*0.92*
1213A/4	Plowzone	2	*-0.24*	141	*-0.37*	1512	*0.20*	173	*0.50*
1250A/4	Plowzone	1	*-0.29*	100	*-1.07*	1368	*-0.13*	149	*-0.09*
1251A/4	Plowzone	2	*-0.24*	135	*-0.47*	1344	*-0.19*	144	*-0.22*
SB1251A/4	Plowzone	2	*-0.24*	170	*0.12*	1512	*0.20*	170	*0.42*
1252A/4	Plowzone	3	*-0.19*	196	*0.56*	1752	*0.76*	240	*2.14*
1253B/4	Plowzone	2	*-0.24*	161	*-0.03*	1584	*0.37*	216	*1.55*
1254A/4	Plowzone	1	*-0.29*	103	*-1.02*	1224	*-0.47*	137	*-0.39*
1255A/4	Plowzone	3	*-0.19*	151	*-0.20*	1536	*0.26*	190	*0.92*
1295A/4	Plowzone	2	*-0.24*	245	*1.39*	1488	*0.14*	202	*1.21*
1296A/4	Plowzone	4	*-0.14*	212	*0.83*	1608	*0.42*	235	*2.02*
1297A/4	Plowzone	3	*-0.19*	126	*-0.63*	1440	*0.03*	211	*1.43*
1298A/4	Plowzone	2	*-0.24*	196	*0.56*	1392	*-0.08*	235	*2.02*
1299A/4	Plowzone	2	*-0.24*	222	*1.00*	1608	*0.42*	240	*2.14*
1300A/4	Layer	2	*-0.24*	145	*-0.30*	1392	*-0.08*	134	*-0.46*
DB1300A/4	Layer	2	*-0.24*	170	*0.12*	1392	*-0.08*	178	*0.62*
1301A/4	Layer	2	*-0.24*	126	*-0.63*	960	*-1.08*	151	*-0.04*
1301E	Trench	1	*-0.29*	72	*-1.54*	1176	*-0.58*	108	*-1.10*
1301F	Trench	1	*-0.29*	122	*-0.69*	1200	*-0.52*	86	*-1.64*
1370A/4	Layer	3	*-0.19*	132	*-0.52*	1032	*-0.91*	166	*0.33*
1370B/4	Layer	2	*-0.24*	88	*-1.27*	936	*-1.14*	139	*-0.34*
1370C/4	Layer	1	*-0.29*	116	*-0.80*	960	*-1.08*	178	*0.62*
1371A/4	Plowzone	2	*-0.24*	222	*1.00*	1224	*-0.47*	178	*0.62*
1372A/4	Plowzone	3	*-0.19*	277	*1.93*	1560	*0.31*	230	*1.90*
1372D/2	Structure III	2	*-0.24*	173	*0.17*	1632	*0.48*	91	*-1.52*
1372D/3	Structure III	7	*0.01*	206	*0.73*	2160	*1.70*	110	*-1.05*
1372E/2	Structure III	16	*0.47*	116	*-0.80*	2400	*2.26*	77	*-1.86*
1372F/2	Structure III	26	*0.98*	113	*-0.85*	2400	*2.26*	70	*-2.03*
1372G/1	Layer	4	*-0.14*	116	*-0.80*	1704	*0.65*	77	*-1.86*
1372H/3	Structure III	18	*0.57*	78	*-1.44*	2400	*2.26*	77	*-1.86*
1372R/3	Structure III	52	*2.29*	173	*0.17*	2400	*2.26*	103	*-1.22*
1372QQ	Trench	1	*-0.29*	126	*-0.63*	1536	*0.26*	91	*-1.52*
1375A/4	Plowzone	2	*-0.24*	167	*0.07*	1128	*-0.69*	163	*0.25*
1375S	Layer	2	*-0.24*	88	*-1.27*	1272	*-0.36*	168	*0.37*
1376A/4	Layer	2	*-0.24*	113	*-0.85*	1272	*-0.36*	180	*0.67*
1376E/1	Layer	2	*-0.24*	100	*-1.07*	936	*-1.14*	154	*0.03*
1379A/4	Layer	1	*-0.29*	190	*0.46*	1272	*-0.36*	185	*0.79*
1380A/4	Plowzone	3	*-0.19*	170	*0.12*	1248	*-0.41*	202	*1.21*
1381A/4	Layer	1	*-0.29*	186	*0.39*	1032	*-0.91*	146	*-0.17*

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**P**	***P***	K	***K***	Ca	***Ca***	**Mg**	***Mg***
		(lb/A)	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***
1382A/4	Plowzone	2	*-0.24*	190	*0.46*	1248	*-0.41*	233	*1.97*
1383A/4	Plowzone	2	*-0.24*	129	*-0.58*	1512	*0.20*	173	*0.50*
SU828/4	Subsoil	1	*-0.29*	238	*1.27*	1080	*-0.80*	132	*-0.51*
SU829/4	Subsoil	1	*-0.29*	297	*2.27*	816	*-1.42*	161	*0.20*
SU830/4	Subsoil	1	*-0.29*	238	*1.27*	840	*-1.36*	132	*-0.51*
SU831/4	Subsoil	1	*-0.29*	267	*1.76*	1008	*-0.97*	202	*1.21*
SU998/4	Subsoil	1	*-0.29*	314	*2.56*	888	*-1.25*	199	*1.14*
SU1001/4	Subsoil	1	*-0.29*	202	*0.66*	1128	*-0.69*	142	*-0.26*
SU1002/4	Subsoil	2	*-0.24*	271	*1.83*	1080	*-0.80*	144	*-0.22*
SU1003/4	Subsoil	1	*-0.29*	258	*1.61*	840	*-1.36*	130	*-0.56*
SU1006/4	Subsoil	1	*-0.29*	238	*1.27*	984	*-1.03*	132	*-0.51*
SU1008/4	Subsoil	2	*-0.24*	177	*0.24*	1152	*-0.64*	154	*0.03*
SU1009/4	Subsoil	1	*-0.29*	44	*-2.02*	1224	*-0.47*	187	*0.84*
SU1121/4	Subsoil	1	*-0.29*	135	*-0.47*	1104	*-0.75*	151	*-0.04*
SU1124/4	Subsoil	2	*-0.24*	122	*-0.69*	816	*-1.42*	156	*0.08*
SU1127/4	Subsoil	1	*-0.29*	157	*-0.10*	960	*-1.08*	149	*-0.09*
SU1181/4	Subsoil	1	*-0.29*	78	*-1.44*	936	*-1.14*	139	*-0.34*
SU1188/4	Subsoil	1	*-0.29*	56	*-1.81*	1344	*-0.19*	142	*-0.26*
SU1206/4	Subsoil	1	*-0.29*	50	*-1.91*	1344	*-0.19*	130	*-0.56*
SU1207/4	Subsoil	1	*-0.29*	154	*-0.15*	1248	*-0.41*	144	*-0.22*
SU1295/4	Subsoil	1	*-0.29*	314	*2.56*	984	*-1.03*	182	*0.72*
SU1299/4	Subsoil	2	*-0.24*	196	*0.56*	1008	*-0.97*	127	*-0.63*
SU1300/4	Subsoil	2	*-0.24*	94	*-1.17*	1368	*-0.13*	118	*-0.85*
SU1371/4	Subsoil	1	*-0.29*	264	*1.71*	1152	*-0.64*	130	*-0.56*
SU1372/4	Subsoil	1	*-0.29*	232	*1.17*	1224	*-0.47*	137	*-0.39*
SU1375/4	Subsoil	1	*-0.29*	154	*-0.15*	1128	*-0.69*	166	*0.33*
SU1383/4	Subsoil	2	*-0.24*	69	*-1.59*	1128	*-0.69*	178	*0.62*
Statistical Totals:									
Mean		6.7		163.0		1425.8		152.8	
Median		2.0		157.0		1344.0		149.0	
Mode		1.0		126.0		2400.0		139.0	
Standard Deviation (s)		19.8		59.0		430.6		40.7	
Unenhanced?	Subsoil	1		238		936		142	

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**Zn**	***Zn***	**Mn**	***Mn***	**Cu**	***Cu***	**Fe**	***Fe***
		(ppm)	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***
829C	Structure I: Root Cellar	3.1	2.75	9.2	0.20	4.5	3.77	5.1	-0.66
829E	Structure I: Root Cellar	2.1	1.35	7.9	-0.14	1.4	0.33	5.6	-0.41
829F	Structure I: Root Cellar	2.8	2.33	9.6	0.31	1.2	0.11	4.2	-1.10
998A/4	Plowzone	1.1	-0.06	5.5	-0.78	1.0	-0.11	4.9	-0.76
1003D	Structure I: Root Cellar	1.6	0.64	8.8	0.10	0.8	-0.34	2.8	-1.79
1004B	Unidentified Feature	0.4	-1.04	8.3	-0.04	1.1	0.00	9.7	1.60
1009A/4	Plowzone	2.6	2.05	10.1	0.44	0.9	-0.22	5.6	-0.41
1010A/4	Plowzone	1.3	0.22	6.9	-0.41	1.0	-0.11	4.2	-1.10
1101B	Trench	1.9	1.07	3.7	-1.26	0.6	-0.56	8.8	1.16
1103A/4	Layer	1.5	0.50	16.1	2.04	1.8	0.77	5.6	-0.41
1103K/4	Layer	0.9	-0.34	13.5	1.35	1.1	0.00	4.7	-0.86
1103M/4	Layer	0.8	-0.48	13.1	1.24	1.0	-0.11	5.0	-0.71
1104A/4	Layer	1.9	1.07	9.1	0.18	1.1	0.00	6.8	0.18
1104B/4	Layer	0.9	-0.34	7.8	-0.17	1.2	0.11	5.3	-0.56
1121A/4	Plowzone	1.0	-0.20	7.6	-0.22	1.1	0.00	5.1	-0.66
1122A/4	Plowzone	0.8	-0.48	4.7	-1.00	1.1	0.00	4.8	-0.81
1123A/4	Plowzone	2.6	2.05	8.6	0.04	1.2	0.11	6.3	-0.07
1124A/4	Layer	0.9	-0.34	3.5	-1.32	0.8	-0.34	7.6	0.57
1124B/4	Layer	0.4	-1.04	4.3	-1.10	0.7	-0.45	8.0	0.77
1126A/4	Layer	2.4	1.77	16.1	2.04	1.2	0.11	7.6	0.57
1126B/4	Layer	0.9	-0.34	11.8	0.89	1.2	0.11	5.9	-0.27
1127A/4	Plowzone	0.9	-0.34	4.7	-1.00	1.1	0.00	4.7	-0.86
1127D	Unidentified Feature	1.3	0.22	11.6	0.84	1.1	0.00	4.5	-0.96
1127JJ	Unidentified Feature	1.3	0.22	10.9	0.65	1.2	0.11	4.1	-1.15
1128A/4	Plowzone	0.9	-0.34	6.5	-0.52	0.9	-0.22	3.7	-1.35
1129A/4	Plowzone	1.2	0.08	6	-0.65	1.1	0.00	4.4	-1.00
1130A/4	Plowzone	1.2	0.08	5.5	-0.78	1.1	0.00	3.9	-1.25
1180A/4	Layer	1.2	0.08	9.8	0.36	1.7	0.66	7.3	0.42
1180B/4	Layer	0.8	-0.48	8.7	0.07	1.2	0.11	5.6	-0.41
1180D	Trench	0.5	-0.90	10.6	0.57	1.2	0.11	5.4	-0.51
1181A/4	Layer	1.8	0.93	8.5	0.02	1.3	0.22	7.3	0.42
1181B/4	Layer	0.9	-0.34	8.4	-0.01	1.2	0.11	6.2	-0.12
1184A/4	Layer	0.6	-0.76	12.1	0.97	1.2	0.11	5.3	-0.56
1184B/4	Layer	0.5	-0.90	9.0	0.15	1.1	0.00	5.1	-0.66
1185A/4	Plowzone	1.3	0.22	4.9	-0.94	1.0	-0.11	3.3	-1.55
1186A/4	Plowzone	1.6	0.64	8.2	-0.06	1.1	0.00	3.9	-1.25
1187A/4	Plowzone	1.6	0.64	5.9	-0.68	1.4	0.33	3.7	-1.35
1188A/4	Plowzone	1.1	-0.06	4.7	-1.00	1.0	-0.11	3.3	-1.55
1189A/4	Plowzone	2.2	1.49	10.1	0.44	1.1	0.00	5.5	-0.46
1191A/2	Layer	1.5	0.50	9.3	0.23	1.2	0.11	8.0	0.77
1191B/2	Layer	1.1	-0.06	9.0	0.15	1.2	0.11	7.2	0.37
1191E/2	Layer	0.7	-0.62	9.9	0.39	1.1	0.00	5.2	-0.61
1206A/4	Plowzone	1.5	0.50	13.7	1.40	0.9	-0.22	4.3	-1.05
1206B/1	Structure II	1.2	0.08	13.5	1.35	1.2	0.11	4.9	-0.76

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**Zn**	***Zn***	**Mn**	***Mn***	**Cu**	***Cu***	**Fe**	***Fe***
		(ppm)	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***
1206B/3	Structure II	1.6	0.64	14.9	1.72	1.2	0.11	5.2	-0.61
1206C/1	Structure II	1.4	0.36	15.5	1.88	3.0	2.10	6.4	-0.02
1206C/3	Structure II	1.5	0.50	10.3	0.49	1.8	0.77	7.8	0.67
1206D	Structure II	0.6	-0.76	11.0	0.68	1.0	-0.11	8.5	1.01
1207B/4	Plowzone	2.0	1.21	5.2	-0.86	1.9	0.88	3.5	-1.45
1212A/4	Plowzone	1.8	0.93	13.4	1.32	0.7	-0.45	4.4	-1.00
1213A/4	Plowzone	1.7	0.79	12.6	1.11	0.8	-0.34	6.1	-0.17
1250A/4	Plowzone	1.0	-0.20	11.0	0.68	0.8	-0.34	4.3	-1.05
1251A/4	Plowzone	1.1	-0.06	10.4	0.52	0.8	-0.34	7.4	0.47
SB1251A/4	Plowzone	1.2	0.08	10.2	0.47	1.0	-0.11	6.8	0.18
1252A/4	Plowzone	1.5	0.50	3.6	-1.29	0.6	-0.56	9.3	1.41
1253B/4	Plowzone	1.4	0.36	4.2	-1.13	0.8	-0.34	9.6	1.55
1254A/4	Plowzone	1.0	-0.20	8.9	0.12	1.0	-0.11	7.1	0.32
1255A/4	Plowzone	2.0	1.21	10.0	0.42	1.1	0.00	10.2	1.85
1295A/4	Plowzone	1.4	0.36	11.3	0.76	0.9	-0.22	5.0	-0.71
1296A/4	Plowzone	1.8	0.93	12.3	1.03	0.9	-0.22	4.5	-0.96
1297A/4	Plowzone	1.6	0.64	13.5	1.35	1.0	-0.11	5.5	-0.46
1298A/4	Plowzone	2.2	1.49	16.1	2.04	1.0	-0.11	7.9	0.72
1299A/4	Plowzone	2.0	1.21	13.4	1.32	0.7	-0.45	6.5	0.03
1300A/4	Layer	1.3	0.22	16.1	2.04	2.0	1.00	5.2	-0.61
DB1300A/4	Layer	3.3	3.04	12.3	1.03	2.9	1.99	6.0	-0.22
1301A/4	Layer	1.7	0.79	13.5	1.35	1.5	0.44	9.3	1.41
1301E	Trench	0.5	-0.90	5.9	-0.68	0.8	-0.34	6.2	-0.12
1301F	Trench	0.5	-0.90	12.2	1.00	0.8	-0.34	5.7	-0.36
1370A/4	Layer	2.2	1.49	9.5	0.28	9.0	8.76	11.6	2.54
1370B/4	Layer	0.6	-0.76	5.2	-0.86	1.0	-0.11	7.4	0.47
1370C/4	Layer	0.6	-0.76	4.3	-1.10	0.9	-0.22	8.5	1.01
1371A/4	Plowzone	1.2	0.08	12.5	1.08	0.8	-0.34	5.3	-0.56
1372A/4	Plowzone	2	1.21	13.3	1.29	0.8	-0.34	6.0	-0.22
1372D/2	Structure III	1.3	0.22	14.4	1.59	1.1	0.00	5.6	-0.41
1372D/3	Structure III	1.8	0.93	11.5	0.81	1.6	0.55	3.9	-1.25
1372E/2	Structure III	2.1	1.35	14.8	1.69	1.0	-0.11	4.6	-0.91
1372F/2	Structure III	1.6	0.64	14.4	1.59	1.0	-0.11	4.4	-1.00
1372G/1	Layer	1.0	-0.20	10.2	0.47	1.0	-0.11	7.0	0.27
1372H/3	Structure III	0.4	-1.04	0.5	-2.12	0.1	-1.11	1.2	-2.58
1372R/3	Structure III	2.9	2.47	10.4	0.52	0.8	-0.34	2.1	-2.14
1372QQ	Trench	0.8	-0.48	9.0	0.15	0.9	-0.22	5.5	-0.46
1375A/4	Plowzone	1.3	0.22	9.7	0.34	0.8	-0.34	6.9	0.23
1375S	Layer	0.6	-0.76	4.6	-1.02	0.8	-0.34	6.5	0.03
1376A/4	Layer	1.7	0.79	6.6	-0.49	0.7	-0.45	13.2	3.32
1376E/1	Layer	0.4	-1.04	5.2	-0.86	0.8	-0.34	6.8	0.18
1379A/4	Layer	0.8	-0.48	8.4	-0.01	0.9	-0.22	6.1	-0.17
1380A/4	Plowzone	1.4	0.36	10.8	0.63	0.9	-0.22	7.0	0.27
1381A/4	Layer	0.5	-0.90	7.2	-0.33	1.0	-0.11	6.1	-0.17

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**Zn**	***Zn***	**Mn**	***Mn***	**Cu**	***Cu***	**Fe**	***Fe***
		(ppm)	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***
1382A/4	Plowzone	1.2	*0.08*	10.5	*0.55*	1.0	*-0.11*	5.8	*-0.32*
1383A/4	Plowzone	1.4	*0.36*	4.9	*-0.94*	0.7	*-0.45*	6.5	*0.03*
SU828/4	Subsoil	0.4	*-1.04*	1.9	*-1.74*	0.6	*-0.56*	10.0	*1.75*
SU829/4	Subsoil	0.3	*-1.18*	4.6	*-1.02*	0.7	*-0.45*	8.2	*0.86*
SU830/4	Subsoil	0.3	*-1.18*	2.7	*-1.53*	0.5	*-0.67*	9.0	*1.26*
SU831/4	Subsoil	0.4	*-1.04*	3.9	*-1.21*	0.6	*-0.56*	10.2	*1.85*
SU998/4	Subsoil	0.5	*-0.90*	2.8	*-1.50*	0.7	*-0.45*	8.5	*1.01*
SU1001/4	Subsoil	0.3	*-1.18*	6.5	*-0.52*	0.8	*-0.34*	8.7	*1.11*
SU1002/4	Subsoil	0.4	*-1.04*	5.7	*-0.73*	0.8	*-0.34*	9.4	*1.46*
SU1003/4	Subsoil	0.3	*-1.18*	4.5	*-1.05*	0.6	*-0.56*	9.6	*1.55*
SU1006/4	Subsoil	0.3	*-1.18*	4.2	*-1.13*	0.6	*-0.56*	8.3	*0.91*
SU1008/4	Subsoil	0.3	*-1.18*	5.8	*-0.70*	0.8	*-0.34*	7.6	*0.57*
SU1009/4	Subsoil	0.4	*-1.04*	6.2	*-0.60*	0.7	*-0.45*	7.0	*0.27*
SU1121/4	Subsoil	0.3	*-1.18*	6.5	*-0.52*	0.8	*-0.34*	7.7	*0.62*
SU1124/4	Subsoil	0.2	*-1.32*	3.1	*-1.42*	0.5	*-0.67*	8.6	*1.06*
SU1127/4	Subsoil	0.3	*-1.18*	4.8	*-0.97*	0.7	*-0.45*	7.6	*0.57*
SU1181/4	Subsoil	0.3	*-1.18*	4.2	*-1.13*	0.5	*-0.67*	8.0	*0.77*
SU1188/4	Subsoil	0.6	*-0.76*	3.3	*-1.37*	0.9	*-0.22*	9.1	*1.31*
SU1206/4	Subsoil	0.3	*-1.18*	4.6	*-1.02*	0.8	*-0.34*	9.6	*1.55*
SU1207/4	Subsoil	0.4	*-1.04*	7.0	*-0.38*	0.9	*-0.22*	7.2	*0.37*
SU1295/4	Subsoil	0.3	*-1.18*	6.6	*-0.49*	0.7	*-0.45*	6.8	*0.18*
SU1299/4	Subsoil	0.3	*-1.18*	3.9	*-1.21*	0.7	*-0.45*	8.3	*0.91*
SU1300/4	Subsoil	0.3	*-1.18*	5.3	*-0.84*	0.7	*-0.45*	5.7	*-0.36*
SU1371/4	Subsoil	0.4	*-1.04*	6.0	*-0.65*	0.8	*-0.34*	7.8	*0.67*
SU1372/4	Subsoil	0.3	*-1.18*	5.7	*-0.73*	0.8	*-0.34*	6.3	*-0.07*
SU1375/4	Subsoil	0.3	*-1.18*	3.7	*-1.26*	0.7	*-0.45*	7.5	*0.52*
SU1383/4	Subsoil	0.4	*-1.04*	3.9	*-1.21*	0.7	*-0.45*	7.3	*0.42*
Statistical Totals:									
Mean		1.14		8.44		1.10		6.44	
Median		1.10		8.50		1.00		6.20	
Mode		0.30		16.10		0.80		5.60	
Standard Deviation (s)		0.71		3.75		0.90		2.03	
Unenhanced?	Subsoil	0.3		9.0		0.8		10.8	

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**B**	***B***	**pH**	***pH***
		(ppm)	***Z Score***		***Z Score***
829C	Structure I: Root Cellar	0.5	*0.21*	5.9	*0.44*
829E	Structure I: Root Cellar	0.7	*0.82*	5.9	*0.44*
829F	Structure I: Root Cellar	0.8	*1.13*	6.1	*0.80*
998A/4	Plowzone	0.4	*-0.10*	5.5	*-0.28*
1003D	Structure I: Root Cellar	1.8	*4.19*	7.9	*4.02*
1004B	Unidentified Feature	0.3	*-0.40*	5.8	*0.26*
1009A/4	Plowzone	0.6	*0.52*	5.2	*-0.81*
1010A/4	Plowzone	0.4	*-0.10*	5.4	*-0.45*
1101B	Trench	0.5	*0.21*	5.3	*-0.63*
1103A/4	Layer	0.4	*-0.10*	5.4	*-0.45*
1103K/4	Layer	0.3	*-0.40*	5.7	*0.08*
1103M/4	Layer	0.4	*-0.10*	5.8	*0.26*
1104A/4	Layer	0.4	*-0.10*	5	*-1.17*
1104B/4	Layer	0.3	*-0.40*	5.4	*-0.45*
1121A/4	Plowzone	0.4	*-0.10*	5.2	*-0.81*
1122A/4	Plowzone	0.4	*-0.10*	5.2	*-0.81*
1123A/4	Plowzone	0.5	*0.21*	5.1	*-0.99*
1124A/4	Layer	0.4	*-0.10*	5.5	*-0.28*
1124B/4	Layer	0.2	*-0.71*	5.8	*0.26*
1126A/4	Layer	0.4	*-0.10*	4.4	*-2.25*
1126B/4	Layer	0.3	*-0.40*	4.9	*-1.35*
1127A/4	Plowzone	0.4	*-0.10*	5.3	*-0.63*
1127D	Unidentified Feature	0.4	*-0.10*	5.3	*-0.63*
1127JJ	Unidentified Feature	0.4	*-0.10*	5.4	*-0.45*
1128A/4	Plowzone	0.5	*0.21*	5.7	*0.08*
1129A/4	Plowzone	0.4	*-0.10*	5.7	*0.08*
1130A/4	Plowzone	0.5	*0.21*	5.4	*-0.45*
1180A/4	Layer	0.4	*-0.10*	5.2	*-0.81*
1180B/4	Layer	0.3	*-0.40*	5.5	*-0.28*
1180D	Trench	0.2	*-0.71*	5.5	*-0.28*
1181A/4	Layer	0.4	*-0.10*	5.1	*-0.99*
1181B/4	Layer	0.4	*-0.10*	5.3	*-0.63*
1184A/4	Layer	0.3	*-0.40*	4.8	*-1.53*
1184B/4	Layer	0.3	*-0.40*	5.4	*-0.45*
1185A/4	Plowzone	0.4	*-0.10*	5.7	*0.08*
1186A/4	Plowzone	0.5	*0.21*	5.3	*-0.63*
1187A/4	Plowzone	0.5	*0.21*	5.6	*-0.10*
1188A/4	Plowzone	0.5	*0.21*	5.8	*0.26*
1189A/4	Plowzone	0.5	*0.21*	5.2	*-0.81*
1191A/2	Layer	0.4	*-0.10*	5.2	*-0.81*
1191B/2	Layer	0.4	*-0.10*	5.2	*-0.81*
1191E/2	Layer	0.3	*-0.40*	5.6	*-0.10*
1206A/4	Plowzone	0.4	*-0.10*	5.6	*-0.10*
1206B/1	Structure II	0.4	*-0.10*	5.8	*0.26*

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**B**	***B***	**pH**	***pH***
		(ppm)	***Z Score***		***Z Score***
1206B/3	Structure II	0.4	*-0.10*	6.0	*0.62*
1206C/1	Structure II	0.5	*0.21*	6.4	*1.34*
1206C/3	Structure II	0.8	*1.13*	7.1	*2.59*
1206D	Structure II	0.6	*0.52*	7.1	*2.59*
1207B/4	Plowzone	0.6	*0.52*	5.8	*0.26*
1212A/4	Plowzone	0.4	*-0.10*	5.2	*-0.81*
1213A/4	Plowzone	0.4	*-0.10*	5.2	*-0.81*
1250A/4	Plowzone	0.4	*-0.10*	5.9	*0.44*
1251A/4	Plowzone	0.4	*-0.10*	5.4	*-0.45*
SB1251A/4	Plowzone	0.5	*0.21*	5.0	*-1.17*
1252A/4	Plowzone	0.5	*0.21*	5.4	*-0.45*
1253B/4	Plowzone	0.4	*-0.10*	5.7	*0.08*
1254A/4	Plowzone	0.3	*-0.40*	5.4	*-0.45*
1255A/4	Plowzone	0.5	*0.21*	5.0	*-1.17*
1295A/4	Plowzone	0.5	*0.21*	5.4	*-0.45*
1296A/4	Plowzone	0.6	*0.52*	5.4	*-0.45*
1297A/4	Plowzone	0.4	*-0.10*	5.4	*-0.45*
1298A/4	Plowzone	0.4	*-0.10*	5.0	*-1.17*
1299A/4	Plowzone	0.5	*0.21*	5.2	*-0.81*
1300A/4	Layer	0.3	*-0.40*	5.3	*-0.63*
DB1300A/4	Layer	0.4	*-0.10*	4.9	*-1.35*
1301A/4	Layer	0.3	*-0.40*	4.9	*-1.35*
1301E	Trench	0.2	*-0.71*	5.8	*0.26*
1301F	Trench	0.3	*-0.40*	6	*0.62*
1370A/4	Layer	0.3	*-0.40*	4.9	*-1.35*
1370B/4	Layer	0.2	*-0.71*	5.3	*-0.63*
1370C/4	Layer	0.2	*-0.71*	5.5	*-0.28*
1371A/4	Plowzone	0.4	*-0.10*	6.1	*0.80*
1372A/4	Plowzone	0.4	*-0.10*	5.3	*-0.63*
1372D/2	Structure III	0.4	*-0.10*	6	*0.62*
1372D/3	Structure III	0.4	*-0.10*	5.9	*0.44*
1372E/2	Structure III	0.6	*0.52*	6.5	*1.52*
1372F/2	Structure III	0.7	*0.82*	6.4	*1.34*
1372G/1	Layer	0.4	*-0.10*	6	*0.62*
1372H/3	Structure III	2.7	*6.94*	7.8	*3.84*
1372R/3	Structure III	2.2	*5.41*	7.4	*3.13*
1372QQ	Trench	0.4	*-0.10*	6.3	*1.16*
1375A/4	Plowzone	0.3	*-0.40*	5.5	*-0.28*
1375S	Layer	0.3	*-0.40*	5.5	*-0.28*
1376A/4	Layer	0.4	*-0.10*	5.3	*-0.63*
1376E/1	Layer	0.3	*-0.40*	5.5	*-0.28*
1379A/4	Layer	0.3	*-0.40*	5.2	*-0.81*
1380A/4	Plowzone	0.3	*-0.40*	5.2	*-0.81*
1381A/4	Layer	0.3	*-0.40*	5.6	*-0.10*

TABLE 5: QUARTER SITE DATA

Provenience	**Sample Type**	**B**	***B***	**pH**	***pH***
		(ppm)	***Z Score***		***Z Score***
1382A/4	Plowzone	0.4	*-0.10*	5	*-1.17*
1383A/4	Plowzone	0.6	*0.52*	5.5	*-0.28*
SU828/4	Subsoil	0.3	*-0.40*	5.8	*0.26*
SU829/4	Subsoil	0.2	*-0.71*	5.7	*0.08*
SU830/4	Subsoil	0.3	*-0.40*	5.8	*0.26*
SU831/4	Subsoil	0.3	*-0.40*	5.7	*0.08*
SU998/4	Subsoil	0.4	*-0.10*	6.3	*1.16*
SU1001/4	Subsoil	0.3	*-0.40*	5.6	*-0.10*
SU1002/4	Subsoil	0.3	*-0.40*	5.7	*0.08*
SU1003/4	Subsoil	0.2	*-0.71*	5.8	*0.26*
SU1006/4	Subsoil	0.3	*-0.40*	5.7	*0.08*
SU1008/4	Subsoil	0.3	*-0.40*	5.9	*0.44*
SU1009/4	Subsoil	0.3	*-0.40*	6.0	*0.62*
SU1121/4	Subsoil	0.3	*-0.40*	6.1	*0.80*
SU1124/4	Subsoil	0.1	*-1.01*	6.1	*0.80*
SU1127/4	Subsoil	0.3	*-0.40*	5.5	*-0.28*
SU1181/4	Subsoil	0.1	*-1.01*	5.7	*0.08*
SU1188/4	Subsoil	0.4	*-0.10*	6.7	*1.87*
SU1206/4	Subsoil	0.3	*-0.40*	6.3	*1.16*
SU1207/4	Subsoil	0.3	*-0.40*	6.0	*0.62*
SU1295/4	Subsoil	0.3	*-0.40*	5.7	*0.08*
SU1299/4	Subsoil	0.2	*-0.71*	5.9	*0.44*
SU1300/4	Subsoil	0.3	*-0.40*	5.9	*0.44*
SU1371/4	Subsoil	0.2	*-0.71*	5.9	*0.44*
SU1372/4	Subsoil	0.3	*-0.40*	6.1	*0.80*
SU1375/4	Subsoil	0.3	*-0.40*	5.8	*0.26*
SU1383/4	Subsoil	0.3	*-0.40*	5.9	*0.44*
Statistical Totals:					
Mean		0.43		5.65	
Median		0.40		5.60	
Mode		0.40		5.20	
Standard Deviation (s)		0.33		0.56	
Unenhanced?	Subsoil	0.2		6.1	

APPENDIX B

QUARTER SITE SOIL DATA BY SAMPLE TYPE

TABLE 6: QUARTER SITE PLOWZONE DATA

Provenience	**P**	***P***	**K**	***K***	**Ca**	***Ca***	**Mg**	***Mg***	**Zn**	***Zn***
	(lb/A)	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***	**(ppm)**	***Z Score***
998A/4	10	*1.31*	206	*0.56*	1320	*-0.85*	158	*-0.93*	1.1	*-0.84*
1009A/4	32	*5.61*	129	*-1.18*	2112	*2.35*	223	*1.15*	2.6	*2.40*
1010A/4	6	*0.53*	119	*-1.41*	1632	*0.41*	163	*-0.77*	1.3	*-0.41*
1121A/4	1	*-0.45*	164	*-0.39*	1464	*-0.27*	156	*-1.00*	1.0	*-1.06*
1122A/4	1	*-0.45*	202	*0.47*	1104	*-1.72*	161	*-0.84*	0.8	*-1.49*
1123A/4	2	*-0.25*	271	*2.03*	1440	*-0.36*	190	*0.09*	2.6	*2.40*
1127A/4	1	*-0.45*	186	*0.11*	1056	*-1.91*	139	*-1.54*	0.9	*-1.27*
1128A/4	3	*-0.06*	232	*1.15*	1464	*-0.27*	146	*-1.32*	0.9	*-1.27*
1129A/4	1	*-0.45*	248	*1.51*	1560	*0.12*	180	*-0.23*	1.2	*-0.63*
1130A/4	4	*0.14*	154	*-0.62*	1680	*0.60*	178	*-0.29*	1.2	*-0.63*
1185A/4	1	*-0.45*	157	*-0.55*	1704	*0.70*	187	*0.00*	1.3	*-0.41*
1186A/4	3	*-0.06*	212	*0.70*	1776	*0.99*	182	*-0.16*	1.6	*0.24*
1187A/4	2	*-0.25*	167	*-0.32*	1848	*1.28*	187	*0.00*	1.6	*0.24*
1188A/4	2	*-0.25*	167	*-0.32*	1944	*1.67*	180	*-0.23*	1.1	*-0.84*
1189A/4	4	*0.14*	196	*0.33*	1824	*1.18*	209	*0.70*	2.2	*1.54*
1206A/4	2	*-0.25*	170	*-0.26*	1704	*0.70*	149	*-1.22*	1.5	*0.02*
1207B/4	2	*-0.25*	225	*0.99*	1968	*1.77*	223	*1.15*	2.0	*1.10*
1212A/4	2	*-0.25*	190	*0.20*	1728	*0.80*	190	*0.09*	1.8	*0.67*
1213A/4	2	*-0.25*	141	*-0.91*	1512	*-0.07*	173	*-0.45*	1.7	*0.46*
1250A/4	1	*-0.45*	100	*-1.84*	1368	*-0.65*	149	*-1.22*	1.0	*-1.06*
1251A/4	2	*-0.25*	135	*-1.05*	1344	*-0.75*	144	*-1.38*	1.1	*-0.84*
SB1251A/4	2	*-0.25*	170	*-0.26*	1512	*-0.07*	170	*-0.55*	1.2	*-0.63*
1252A/4	3	*-0.06*	196	*0.33*	1752	*0.89*	240	*1.70*	1.5	*0.02*
1253B/4	2	*-0.25*	161	*-0.46*	1584	*0.22*	216	*0.93*	1.4	*-0.19*
1254A/4	1	*-0.45*	103	*-1.77*	1224	*-1.23*	137	*-1.61*	1.0	*-1.06*
1255A/4	3	*-0.06*	151	*-0.69*	1536	*0.02*	190	*0.09*	2.0	*1.10*
1295A/4	2	*-0.25*	245	*1.44*	1488	*-0.17*	202	*0.48*	1.4	*-0.19*
1296A/4	4	*0.14*	212	*0.70*	1608	*0.31*	235	*1.54*	1.8	*0.67*
1297A/4	3	*-0.06*	126	*-1.25*	1440	*-0.36*	211	*0.77*	1.6	*0.24*
1298A/4	2	*-0.25*	196	*0.33*	1392	*-0.56*	235	*1.54*	2.2	*1.54*
1299A/4	2	*-0.25*	222	*0.92*	1608	*0.31*	240	*1.70*	2.0	*1.10*
1371A/4	2	*-0.25*	222	*0.92*	1224	*-1.23*	178	*-0.29*	1.2	*-0.63*
1372A/4	3	*-0.06*	277	*2.17*	1560	*0.12*	230	*1.38*	2.0	*1.10*
1375A/4	2	*-0.25*	167	*-0.32*	1128	*-1.62*	163	*-0.77*	1.3	*-0.41*
1380A/4	3	*-0.06*	170	*-0.26*	1248	*-1.14*	202	*0.48*	1.4	*-0.19*
1382A/4	2	*-0.25*	190	*0.20*	1248	*-1.14*	233	*1.47*	1.2	*-0.63*
1383A/4	2	*-0.25*	129	*-1.18*	1512	*-0.07*	173	*-0.45*	1.4	*-0.19*
Statistical Totals:										
Mean	3.3		181.3		1530.2		187.1		1.49	
Median	2.0		170.0		1512.0		182.0		1.40	
Mode	2.0		167.0		1512.0		190.0		1.20	
Standard Deviation (s)	5.1		44.1		248.0		31.2		0.46	

TABLE 6: QUARTER SITE PLOWZONE DATA

Provenience	**Mn**	***Mn***	**Cu**	***Cu***	**Fe**	***Fe***	**B**	***B***	**pH**	***pH***
	(ppm)	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***		***Z Score***
998A/4	5.5	*-1.01*	1.0	*0.12*	4.9	*-0.40*	0.4	*-0.57*	5.5	*0.36*
1009A/4	10.1	*0.33*	0.9	*-0.32*	5.6	*0.00*	0.6	*1.92*	5.2	*-0.75*
1010A/4	6.9	*-0.60*	1.0	*0.12*	4.2	*-0.80*	0.4	*-0.57*	5.4	*-0.01*
1121A/4	7.6	*-0.40*	1.1	*0.56*	5.1	*-0.29*	0.4	*-0.57*	5.2	*-0.75*
1122A/4	4.7	*-1.25*	1.1	*0.56*	4.8	*-0.46*	0.4	*-0.57*	5.2	*-0.75*
1123A/4	8.6	*-0.10*	1.2	*1.01*	6.3	*0.40*	0.5	*0.67*	5.1	*-1.12*
1127A/4	4.7	*-1.25*	1.1	*0.56*	4.7	*-0.52*	0.4	*-0.57*	5.3	*-0.38*
1128A/4	6.5	*-0.72*	0.9	*-0.32*	3.7	*-1.09*	0.5	*0.67*	5.7	*1.10*
1129A/4	6	*-0.87*	1.1	*0.56*	4.4	*-0.69*	0.4	*-0.57*	5.7	*1.10*
1130A/4	5.5	*-1.01*	1.1	*0.56*	3.9	*-0.98*	0.5	*0.67*	5.4	*-0.01*
1185A/4	4.9	*-1.19*	1	*0.12*	3.3	*-1.32*	0.4	*-0.57*	5.7	*1.10*
1186A/4	8.2	*-0.22*	1.1	*0.56*	3.9	*-0.98*	0.5	*0.67*	5.3	*-0.38*
1187A/4	5.9	*-0.89*	1.4	*1.89*	3.7	*-1.09*	0.5	*0.67*	5.6	*0.73*
1188A/4	4.7	*-1.25*	1	*0.12*	3.3	*-1.32*	0.5	*0.67*	5.8	*1.48*
1189A/4	10.1	*0.33*	1.1	*0.56*	5.5	*-0.06*	0.5	*0.67*	5.2	*-0.75*
1206A/4	13.7	*1.39*	0.9	*-0.32*	4.3	*-0.75*	0.4	*-0.57*	5.6	*0.73*
1207B/4	5.2	*-1.10*	1.9	*4.11*	3.5	*-1.20*	0.6	*1.92*	5.8	*1.48*
1212A/4	13.4	*1.30*	0.7	*-1.21*	4.4	*-0.69*	0.4	*-0.57*	5.2	*-0.75*
1213A/4	12.6	*1.07*	0.8	*-0.77*	6.1	*0.29*	0.4	*-0.57*	5.2	*-0.75*
1250A/4	11.0	*0.60*	0.8	*-0.77*	4.3	*-0.75*	0.4	*-0.57*	5.9	*1.85*
1251A/4	10.4	*0.42*	0.8	*-0.77*	7.4	*1.03*	0.4	*-0.57*	5.4	*-0.01*
SB1251A/4	10.2	*0.36*	1.0	*0.12*	6.8	*0.69*	0.5	*0.67*	5.0	*-1.50*
1252A/4	3.6	*-1.57*	0.6	*-1.65*	9.3	*2.12*	0.5	*0.67*	5.4	*-0.01*
1253B/4	4.2	*-1.39*	0.8	*-0.77*	9.6	*2.29*	0.4	*-0.57*	5.7	*1.10*
1254A/4	8.9	*-0.02*	1.0	*0.12*	7.1	*0.86*	0.3	*-1.82*	5.4	*-0.01*
1255A/4	10.0	*0.31*	1.1	*0.56*	10.2	*2.64*	0.5	*0.67*	5.0	*-1.50*
1295A/4	11.3	*0.69*	0.9	*-0.32*	5.0	*-0.34*	0.5	*0.67*	5.4	*-0.01*
1296A/4	12.3	*0.98*	0.9	*-0.32*	4.5	*-0.63*	0.6	*1.92*	5.4	*-0.01*
1297A/4	13.5	*1.33*	1.0	*0.12*	5.5	*-0.06*	0.4	*-0.57*	5.4	*-0.01*
1298A/4	16.1	*2.09*	1.0	*0.12*	7.9	*1.32*	0.4	*-0.57*	5.0	*-1.50*
1299A/4	13.4	*1.30*	0.7	*-1.21*	6.5	*0.52*	0.5	*0.67*	5.2	*-0.75*
1371A/4	12.5	*1.04*	0.8	*-0.77*	5.3	*-0.17*	0.4	*-0.57*	6.1	*2.59*
1372A/4	13.3	*1.27*	0.8	*-0.77*	6.0	*0.23*	0.4	*-0.57*	5.3	*-0.38*
1375A/4	9.7	*0.22*	0.8	*-0.77*	6.9	*0.75*	0.3	*-1.82*	5.5	*0.36*
1380A/4	10.8	*0.54*	0.9	*-0.32*	7.0	*0.80*	0.3	*-1.82*	5.2	*-0.75*
1382A/4	10.5	*0.45*	1.0	*0.12*	5.8	*0.11*	0.4	*-0.57*	5	*-1.50*
1383A/4	4.9	*-1.19*	0.7	*-1.21*	6.5	*0.52*	0.6	*1.92*	5.5	*0.36*
Statistical Totals:										
Mean	8.96		0.97		5.60		0.45		5.40	
Median	9.70		1.00		5.30		0.40		5.40	
Mode	4.70		1.00		3.70		0.40		5.20	
Standard Deviation (s)	3.42		0.23		1.74		0.08		0.27	

TABLE 7: QUARTER SITE LAYER DATA

Provenience	**P**	***P***	**K**	***K***	**Ca**	***Ca***	**Mg**	***Mg***	**Zn**	***Zn***
	(lb/A)	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***	**(ppm)**	***Z Score***
1103A/4	2	0.06	126	-0.38	1392	1.06	139	-0.27	1.5	0.52
1103K/4	1	-0.86	135	-0.13	1488	1.55	94	-2.01	0.9	-0.37
1103M/4	1	-0.86	113	-0.75	1512	1.67	94	-2.01	0.8	-0.51
1104A/4	5	2.84	126	-0.38	1128	-0.29	146	0.00	1.9	1.12
1104B/4	2	0.06	62	-2.18	1248	0.33	118	-1.08	0.9	-0.37
1124A/4	2	0.06	157	0.49	1248	0.33	173	1.05	0.9	-0.37
1124B/4	2	0.06	100	-1.11	1008	-0.90	161	0.58	0.4	-1.11
1126A/4	5	2.84	202	1.76	1128	-0.29	175	1.13	2.4	1.86
1126B/4	2	0.06	170	0.86	984	-1.02	144	-0.07	0.9	-0.37
1180A/4	2	0.06	180	1.14	1080	-0.53	137	-0.34	1.2	0.08
1180B/4	1	-0.86	206	1.87	1056	-0.65	127	-0.73	0.8	-0.51
11814/4	1	-0.86	145	0.15	1080	-0.53	149	0.12	1.8	0.97
1181B/4	1	-0.86	145	0.15	1008	-0.90	137	-0.34	0.9	-0.37
1184A/4	1	-0.86	170	0.86	1008	-0.90	142	-0.15	0.6	-0.81
1184B/4	1	-0.86	122	-0.49	1344	0.82	146	0.00	0.5	-0.96
1191A/2	2	0.06	151	0.32	1248	0.33	154	0.31	1.5	0.52
1191B/2	2	0.06	167	0.77	1152	-0.16	146	0.00	1.1	-0.07
1191E/2	1	-0.86	138	-0.04	1248	0.33	139	-0.27	0.7	-0.66
1300A/4	2	0.06	145	0.15	1392	1.06	134	-0.46	1.3	0.23
DB1300A/4	2	0.06	170	0.86	1392	1.06	178	1.24	3.3	3.19
1301A/4	2	0.06	126	-0.38	960	-1.14	151	0.20	1.7	0.82
1370A/4	3	0.99	132	-0.21	1032	-0.78	166	0.78	2.2	1.56
1370B/4	2	0.06	88	-1.45	936	-1.27	139	-0.27	0.6	-0.81
1370C/4	1	-0.86	116	-0.66	960	-1.14	178	1.24	0.6	-0.81
1372G/1	4	1.91	116	-0.66	1704	2.65	77	-2.67	1.0	-0.22
1375S	2	0.06	88	-1.45	1272	0.45	168	0.86	0.6	-0.81
1376A/4	2	0.06	113	-0.75	1272	0.45	180	1.32	1.7	0.82
1376E/1	2	0.06	100	-1.11	936	-1.27	154	0.31	0.4	-1.11
1379A/4	1	-0.86	190	1.42	1272	0.45	185	1.51	0.8	-0.51
1381A/4	1	-0.86	186	1.31	1032	-0.78	146	0.00	0.5	-0.96
Statistical Totals:										
Mean	1.9		139.5		1184.0		145.9		1.15	
Median	2.0		136.5		1140.0		146.0		0.90	
Mode	2.0		126.0		1248.0		146.0		0.90	
Standard Deviation (s)	1.1		35.5		195.9		25.8		0.68	

TABLE 7: QUARTER SITE LAYER DATA

Provenience	**Mn**	***Mn***	**Cu**	***Cu***	**Fe**	***Fe***	**B**	***B***	**pH**	***pH***
	(ppm)	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***		***Z Score***
1103A/4	16.1	*1.87*	1.8	*0.23*	5.6	*-0.69*	0.4	*1.01*	5.4	*0.28*
1103K/4	13.5	*1.14*	1.1	*-0.24*	4.7	*-1.17*	0.3	*-0.50*	5.7	*1.15*
1103M/4	13.1	*1.03*	1.0	*-0.31*	5.0	*-1.01*	0.4	*1.01*	5.8	*1.44*
1104A/4	9.1	*-0.09*	1.1	*-0.24*	6.8	*-0.06*	0.4	*1.01*	5.0	*-0.88*
1104B/4	7.8	*-0.46*	1.2	*-0.17*	5.3	*-0.85*	0.3	*-0.50*	5.4	*0.28*
1124A/4	3.5	*-1.67*	0.8	*-0.44*	7.6	*0.36*	0.4	*1.01*	5.5	*0.57*
1124B/4	4.3	*-1.44*	0.7	*-0.51*	8.0	*0.57*	0.2	*-2.02*	5.8	*1.44*
1126A/4	16.1	*1.87*	1.2	*-0.17*	7.6	*0.36*	0.4	*1.01*	4.4	*-2.63*
1126B/4	11.8	*0.66*	1.2	*-0.17*	5.9	*-0.54*	0.3	*-0.50*	4.9	*-1.17*
1180A/4	9.8	*0.10*	1.7	*0.16*	7.3	*0.20*	0.4	*1.01*	5.2	*-0.30*
1180B/4	8.7	*-0.21*	1.2	*-0.17*	5.6	*-0.69*	0.3	*-0.50*	5.5	*0.57*
11814/4	8.5	*-0.26*	1.3	*-0.11*	7.3	*0.20*	0.4	*1.01*	5.1	*-0.59*
1181B/4	8.4	*-0.29*	1.2	*-0.17*	6.2	*-0.38*	0.4	*1.01*	5.3	*-0.01*
1184A/4	12.1	*0.75*	1.2	*-0.17*	5.3	*-0.85*	0.3	*-0.50*	4.8	*-1.46*
1184B/4	9.0	*-0.12*	1.1	*-0.24*	5.1	*-0.96*	0.3	*-0.50*	5.4	*0.28*
1191A/2	9.3	*-0.04*	1.2	*-0.17*	8.0	*0.57*	0.4	*1.01*	5.2	*-0.30*
1191B/2	9.0	*-0.12*	1.2	*-0.17*	7.2	*0.15*	0.4	*1.01*	5.2	*-0.30*
1191E/2	9.9	*0.13*	1.1	*-0.24*	5.2	*-0.91*	0.3	*-0.50*	5.6	*0.86*
1300A/4	16.1	*1.87*	2.0	*0.36*	5.2	*-0.91*	0.3	*-0.50*	5.3	*-0.01*
DB1300A/4	12.3	*0.80*	2.9	*0.97*	6.0	*-0.48*	0.4	*1.01*	4.9	*-1.17*
1301A/4	13.5	*1.14*	1.5	*0.03*	9.3	*1.26*	0.3	*-0.50*	4.9	*-1.17*
1370A/4	9.5	*0.02*	9.0	*5.06*	11.6	*2.48*	0.3	*-0.50*	4.9	*-1.17*
1370B/4	5.2	*-1.19*	1.0	*-0.31*	7.4	*0.26*	0.2	*-2.02*	5.3	*-0.01*
1370C/4	4.3	*-1.44*	0.9	*-0.38*	8.5	*0.84*	0.2	*-2.02*	5.5	*0.57*
1372G/1	10.2	*0.21*	1.0	*-0.31*	7.0	*0.05*	0.4	*1.01*	6.0	*2.03*
1375S	4.6	*-1.36*	0.8	*-0.44*	6.5	*-0.22*	0.3	*-0.50*	5.5	*0.57*
1376A/4	6.6	*-0.80*	0.7	*-0.51*	13.2	*3.32*	0.4	*1.01*	5.3	*-0.01*
1376E/1	5.2	*-1.19*	0.8	*-0.44*	6.8	*-0.06*	0.3	*-0.50*	5.5	*0.57*
1379A/4	8.4	*-0.29*	0.9	*-0.38*	6.1	*-0.43*	0.3	*-0.50*	5.2	*-0.30*
1381A/4	7.2	*-0.63*	1.0	*-0.31*	6.1	*-0.43*	0.3	*-0.50*	5.6	*0.86*
Statistical Totals:										
Mean	9.44		1.46		6.91		0.33		5.30	
Median	9.05		1.15		6.65		0.30		5.30	
Mode	16.10		1.20		5.60		0.30		5.50	
Standard Deviation (s)	3.57		1.49		1.89		0.07		0.34	

TABLE 8: QUARTER SITE SUBSOIL DATA

Provenience	**P**	***P***	**K**	***K***	**Ca**	***Ca***	**Mg**	***Mg***	**Zn**	***Zn***
	(lb/A)	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***	**(lb/A)**	***Z Score***	**(ppm)**	***Z Score***
SU828/4	1	*-0.55*	238	*0.62*	1080	*0.05*	132	*-0.80*	0.4	*0.68*
SU829/4	1	*-0.55*	297	*1.30*	816	*-1.54*	161	*0.45*	0.3	*-0.54*
SU830/4	1	*-0.55*	238	*0.62*	840	*-1.39*	132	*-0.80*	0.3	*-0.54*
SU831/4	1	*-0.55*	267	*0.95*	1008	*-0.38*	202	*2.22*	0.4	*0.68*
SU998/4	1	*-0.55*	314	*1.49*	888	*-1.10*	199	*2.09*	0.5	*1.90*
SU1001/4	1	*-0.55*	202	*0.20*	1128	*0.34*	142	*-0.37*	0.3	*-0.54*
SU1002/4	2	*1.74*	271	*1.00*	1080	*0.05*	144	*-0.28*	0.4	*0.68*
SU1003/4	1	*-0.55*	258	*0.85*	840	*-1.39*	130	*-0.89*	0.3	*-0.54*
SU1006/4	1	*-0.55*	238	*0.62*	984	*-0.53*	132	*-0.80*	0.3	*-0.54*
SU1008/4	2	*1.74*	177	*-0.09*	1152	*0.49*	154	*0.15*	0.3	*-0.54*
SU1009/4	1	*-0.55*	44	*-1.63*	1224	*0.92*	187	*1.57*	0.4	*0.68*
SU1121/4	1	*-0.55*	135	*-0.58*	1104	*0.20*	151	*0.02*	0.3	*-0.54*
SU1124/4	2	*1.74*	122	*-0.73*	816	*-1.54*	156	*0.23*	0.2	*-1.75*
SU1127/4	1	*-0.55*	157	*-0.32*	960	*-0.67*	149	*-0.07*	0.3	*-0.54*
SU1181/4	1	*-0.55*	78	*-1.23*	936	*-0.81*	139	*-0.50*	0.3	*-0.54*
SU1188/4	1	*-0.55*	56	*-1.49*	1344	*1.64*	142	*-0.37*	0.6	*3.12*
SU1206/4	1	*-0.55*	50	*-1.56*	1344	*1.64*	130	*-0.89*	0.3	*-0.54*
SU1207/4	1	*-0.55*	154	*-0.36*	1248	*1.06*	144	*-0.28*	0.4	*0.68*
SU1295/4	1	*-0.55*	314	*1.49*	984	*-0.53*	182	*1.36*	0.3	*-0.54*
SU1299/4	2	*1.74*	196	*0.13*	1008	*-0.38*	127	*-1.02*	0.3	*-0.54*
SU1300/4	2	*1.74*	94	*-1.05*	1368	*1.78*	118	*-1.40*	0.3	*-0.54*
SU1371/4	1	*-0.55*	264	*0.92*	1152	*0.49*	130	*-0.89*	0.4	*0.68*
SU1372/4	1	*-0.55*	232	*0.55*	1224	*0.92*	137	*-0.58*	0.3	*-0.54*
SU1375/4	1	*-0.55*	154	*-0.36*	1128	*0.34*	166	*0.67*	0.3	*-0.54*
SU1383/4	2	*1.74*	69	*-1.34*	1128	*0.34*	178	*1.18*	0.4	*0.68*
Statistical Totals:										
Mean	1.2		184.8		1071.4		150.6		0.34	
Median	1.0		196.0		1080.0		144.0		0.30	
Mode	1.0		238.0		1128.0		132.0		0.30	
Standard Deviation (s)	0.4		86.5		166.3		23.2		0.08	

TABLE 8: QUARTER SITE SUBSOIL DATA

Provenience	**Mn**	***Mn***	**Cu**	***Cu***	**Fe**	***Fe***	**B**	***B***	**pH**	***pH***
	(ppm)	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***		***Z Score***
SU828/4	1.9	*-2.01*	0.6	*-0.92*	10.0	*1.61*	0.3	*0.33*	5.8	*-0.40*
SU829/4	4.6	*-0.07*	0.7	*-0.04*	8.2	*0.04*	0.2	*-1.05*	5.7	*-0.78*
SU830/4	2.7	*-1.44*	0.5	*-1.80*	9.0	*0.74*	0.3	*0.33*	5.8	*-0.40*
SU831/4	3.9	*-0.57*	0.6	*-0.92*	10.2	*1.79*	0.3	*0.33*	5.7	*-0.78*
SU998/4	2.8	*-1.36*	0.7	*-0.04*	8.5	*0.30*	0.4	*1.71*	6.3	*1.52*
SU1001/4	6.5	*1.30*	0.8	*0.85*	8.7	*0.47*	0.3	*0.33*	5.6	*-1.17*
SU1002/4	5.7	*0.72*	0.8	*0.85*	9.4	*1.09*	0.3	*0.33*	5.7	*-0.78*
SU1003/4	4.5	*-0.14*	0.6	*-0.92*	9.6	*1.26*	0.2	*-1.05*	5.8	*-0.40*
SU1006/4	4.2	*-0.36*	0.6	*-0.92*	8.3	*0.12*	0.3	*0.33*	5.7	*-0.78*
SU1008/4	5.8	*0.79*	0.8	*0.85*	7.6	*-0.49*	0.3	*0.33*	5.9	*-0.02*
SU1009/4	6.2	*1.08*	0.7	*-0.04*	7.0	*-1.02*	0.3	*0.33*	6.0	*0.37*
SU1121/4	6.5	*1.30*	0.8	*0.85*	7.7	*-0.40*	0.3	*0.33*	6.1	*0.75*
SU1124/4	3.1	*-1.15*	0.5	*-1.80*	8.6	*0.39*	0.1	*-2.43*	6.1	*0.75*
SU1127/4	4.8	*0.07*	0.7	*-0.04*	7.6	*-0.49*	0.3	*0.33*	5.5	*-1.55*
SU1181/4	4.2	*-0.36*	0.5	*-1.80*	8.0	*-0.14*	0.1	*-2.43*	5.7	*-0.78*
SU1188/4	3.3	*-1.00*	0.9	*1.73*	9.1	*0.82*	0.4	*1.71*	6.7	*3.05*
SU1206/4	4.6	*-0.07*	0.8	*0.85*	9.6	*1.26*	0.3	*0.33*	6.3	*1.52*
SU1207/4	7.0	*1.66*	0.9	*1.73*	7.2	*-0.84*	0.3	*0.33*	6.0	*0.37*
SU1295/4	6.6	*1.37*	0.7	*-0.04*	6.8	*-1.19*	0.3	*0.33*	5.7	*-0.78*
SU1299/4	3.9	*-0.57*	0.7	*-0.04*	8.3	*0.12*	0.2	*-1.05*	5.9	*-0.02*
SU1300/4	5.3	*0.43*	0.7	*-0.04*	5.7	*-2.16*	0.3	*0.33*	5.9	*-0.02*
SU1371/4	6.0	*0.94*	0.8	*0.85*	7.8	*-0.32*	0.2	*-1.05*	5.9	*-0.02*
SU1372/4	5.7	*0.72*	0.8	*0.85*	6.3	*-1.63*	0.3	*0.33*	6.1	*0.75*
SU1375/4	3.7	*-0.72*	0.7	*-0.04*	7.5	*-0.58*	0.3	*0.33*	5.8	*-0.40*
SU1383/4	3.9	*-0.57*	0.7	*-0.04*	7.3	*-0.75*	0.3	*0.33*	5.9	*-0.02*
Statistical Totals:										
Mean	4.70		0.70		8.16		0.28		5.90	
Median	4.60		0.70		8.20		0.30		5.90	
Mode	3.90		0.70		9.60		0.30		5.70	
Standard Deviation (s)	1.39		0.11		1.14		0.07		0.26	

TABLE 9: QUARTER SITE FEATURE DATA

Provenience	Sample Type	P	*P*	K	*K*	Ca	*Ca*	Mg	*Mg*
		(lb/A)	*Z Score*	(lb/A)	*Z Score*	(lb/A)	*Z Score*	(lb/A)	*Z Score*
829C	Structure I: Root Cellar	114	*2.26*	202	1.20	2400	0.90	125	0.42
829E	Structure I: Root Cellar	120	*2.41*	148	0.15	2400	0.90	101	-0.21
829F	Structure I: Root Cellar	120	*2.41*	173	0.64	2400	0.90	120	0.29
1003D	Structure I: Root Cellar	46	*0.55*	126	-0.28	2400	0.90	89	-0.52
1004B	Unidentified Feature	1	*-0.59*	248	2.10	1032	-1.88	142	0.86
1101B	Trench	2	*-0.57*	228	1.71	1488	-0.96	226	3.06
1127D	Unidentified Feature	2	*-0.57*	202	1.20	1728	-0.47	163	1.41
1127JJ	Unidentified Feature	2	*-0.57*	106	-0.67	2040	0.17	182	1.91
1180D	Trench	1	*-0.59*	59	-1.59	1152	-1.64	79	-0.78
1206B/1	Structure II	1	*-0.59*	122	-0.36	1824	-0.27	113	0.11
1206B/3	Structure II	15	*-0.24*	94	-0.91	2328	0.75	96	-0.34
1206C/1	Structure II	5	*-0.49*	103	-0.73	2280	0.65	106	-0.08
1206C/3	Structure II	6	*-0.46*	113	-0.53	2400	0.90	84	-0.65
1206D	Structure II	2	*-0.57*	126	-0.28	1872	-0.18	67	-1.10
1301E	Trench	1	*-0.59*	72	-1.34	1176	-1.59	108	-0.03
1301F	Trench	1	*-0.59*	122	-0.36	1200	-1.54	86	-0.60
1372D/2	Structure III	2	*-0.57*	173	0.64	1632	-0.66	91	-0.47
1372D/3	Structure III	7	*-0.44*	206	1.28	2160	0.41	110	0.03
1372E/2	Structure III	16	*-0.21*	116	-0.48	2400	0.90	77	-0.84
1372F/2	Structure III	26	*0.04*	113	-0.53	2400	0.90	70	-1.02
1372H/3	Structure III: Stone Paving	18	*-0.16*	78	-1.22	2400	0.90	77	-0.84
1372QQ	Trench	1	*-0.59*	126	-0.28	1536	-0.86	91	-0.47
1372R/3	Structure III: Stone Paving	52	*0.70*	173	0.64	2400	0.90	103	-0.16
Statistical Totals:									
Mean		24		140		1959		109	
Median		5		126		2160		101	
Mode		1		173		2400		91	
Standard Deviation (s)		40		51		492		38	

TABLE 9: QUARTER SITE FEATURE DATA

Provenience	**Sample Type**	**Zn**	***Zn***	**Mn**	***Mn***	**Cu**	***Cu***
		(ppm)	***Z Score***	**(ppm)**	***Z Score***	**(ppm)**	***Z Score***
829C	Structure I: Root Cellar	3.1	2.07	9.2	-0.32	4.5	3.67
829E	Structure I: Root Cellar	2.1	0.82	7.9	-0.68	1.4	0.14
829F	Structure I: Root Cellar	2.8	1.70	9.6	-0.22	1.2	-0.09
1003D	Structure I: Root Cellar	1.6	0.20	8.8	-0.43	0.8	-0.54
1004B	Unidentified Feature	0.4	-1.30	8.3	-0.57	1.1	-0.20
1101B	Trench	1.9	0.57	3.7	-1.83	0.6	-0.77
1127D	Unidentified Feature	1.3	-0.18	11.6	0.33	1.1	-0.20
1127JJ	Unidentified Feature	1.3	-0.18	10.9	0.14	1.2	-0.09
1180D	Trench	0.5	-1.18	10.6	0.06	1.2	-0.09
1206B/1	Structure II	1.2	-0.30	13.5	0.85	1.2	-0.09
1206B/3	Structure II	1.6	0.20	14.9	1.23	1.2	-0.09
1206C/1	Structure II	1.4	-0.05	15.5	1.40	3.0	1.96
1206C/3	Structure II	1.5	0.07	10.3	-0.02	1.8	0.59
1206D	Structure II	0.6	-1.05	11.0	0.17	1.0	-0.32
1301E	Trench	0.5	-1.18	5.9	-1.23	0.8	-0.54
1301F	Trench	0.5	-1.18	12.2	0.50	0.8	-0.54
1372D/2	Structure III	1.3	-0.18	14.4	1.10	1.1	-0.20
1372D/3	Structure III	1.8	0.45	11.5	0.30	1.6	0.37
1372E/2	Structure III	2.1	0.82	14.8	1.21	1.0	-0.32
1372F/2	Structure III	1.6	0.20	14.4	1.10	1.0	-0.32
1372H/3	Structure III: Stone Paving	0.4	-1.30	0.5	-2.70	0.1	-1.34
1372QQ	Trench	0.8	-0.80	9.0	-0.38	0.9	-0.43
1372R/3	Structure III: Stone Paving	2.9	1.82	10.4	0.00	0.8	-0.54
Statistical Totals:							
Mean		1.4		10.4		1.3	
Median		1.4		10.6		1.1	
Mode		1.6		14.4		1.2	
Standard Deviation (s)		0.8		3.7		0.9	

TABLE 9: QUARTER SITE FEATURE DATA

Provenience	**Sample Type**	**Fe**	***Fe***	**B**	***B***	**pH**	***pH***
		(ppm)	***Z Score***	**(ppm)**	***Z Score***		***Z Score***
829C	Structure I: Root Cellar	5.1	-0.11	0.5	-0.32	5.9	-0.46
829E	Structure I: Root Cellar	5.6	0.14	0.7	-0.01	5.9	-0.46
829F	Structure I: Root Cellar	4.2	-0.55	0.8	0.15	6.1	-0.19
1003D	Structure I: Root Cellar	2.8	-1.24	1.8	1.71	7.9	2.22
1004B	Unidentified Feature	9.7	2.16	0.3	-0.63	5.8	-0.59
1101B	Trench	8.8	1.72	0.5	-0.32	5.3	-1.26
1127D	Unidentified Feature	4.5	-0.40	0.4	-0.47	5.3	-1.26
1127JJ	Unidentified Feature	4.1	-0.60	0.4	-0.47	5.4	-1.13
1180D	Trench	5.4	0.04	0.2	-0.79	5.5	-1.00
1206B/1	Structure II	4.9	-0.20	0.4	-0.47	5.8	-0.59
1206B/3	Structure II	5.2	-0.06	0.4	-0.47	6.0	-0.33
1206C/1	Structure II	6.4	0.54	0.5	-0.32	6.4	0.21
1206C/3	Structure II	7.8	1.23	0.8	0.15	7.1	1.15
1206D	Structure II	8.5	1.57	0.6	-0.16	7.1	1.15
1301E	Trench	6.2	0.44	0.2	-0.79	5.8	-0.59
1301F	Trench	5.7	0.19	0.3	-0.63	6	-0.33
1372D/2	Structure III	5.6	0.14	0.4	-0.47	6.0	-0.33
1372D/3	Structure III	3.9	-0.70	0.4	-0.47	5.9	-0.46
1372E/2	Structure III	4.6	-0.35	0.6	-0.16	6.5	0.34
1372F/2	Structure III	4.4	-0.45	0.7	-0.01	6.4	0.21
1372H/3	Structure III: Stone Paving	1.2	-2.03	2.7	3.11	7.8	2.08
1372QQ	Trench	5.5	0.09	0.4	-0.47	6.3	0.08
1372R/3	Structure III: Stone Paving	2.1	-1.58	2.2	2.33	7.4	1.55
Statistical Totals:							
Mean		5.3		0.7		6.2	
Median		5.2		0.5		6.0	
Mode		5.6		0.4		5.9	
Standard Deviation (s)		2.0		0.6		0.7	

APPENDIX C

QUARTER SITE ARTIFACT AND ELEMENTAL DISTRIBUTION MAPS

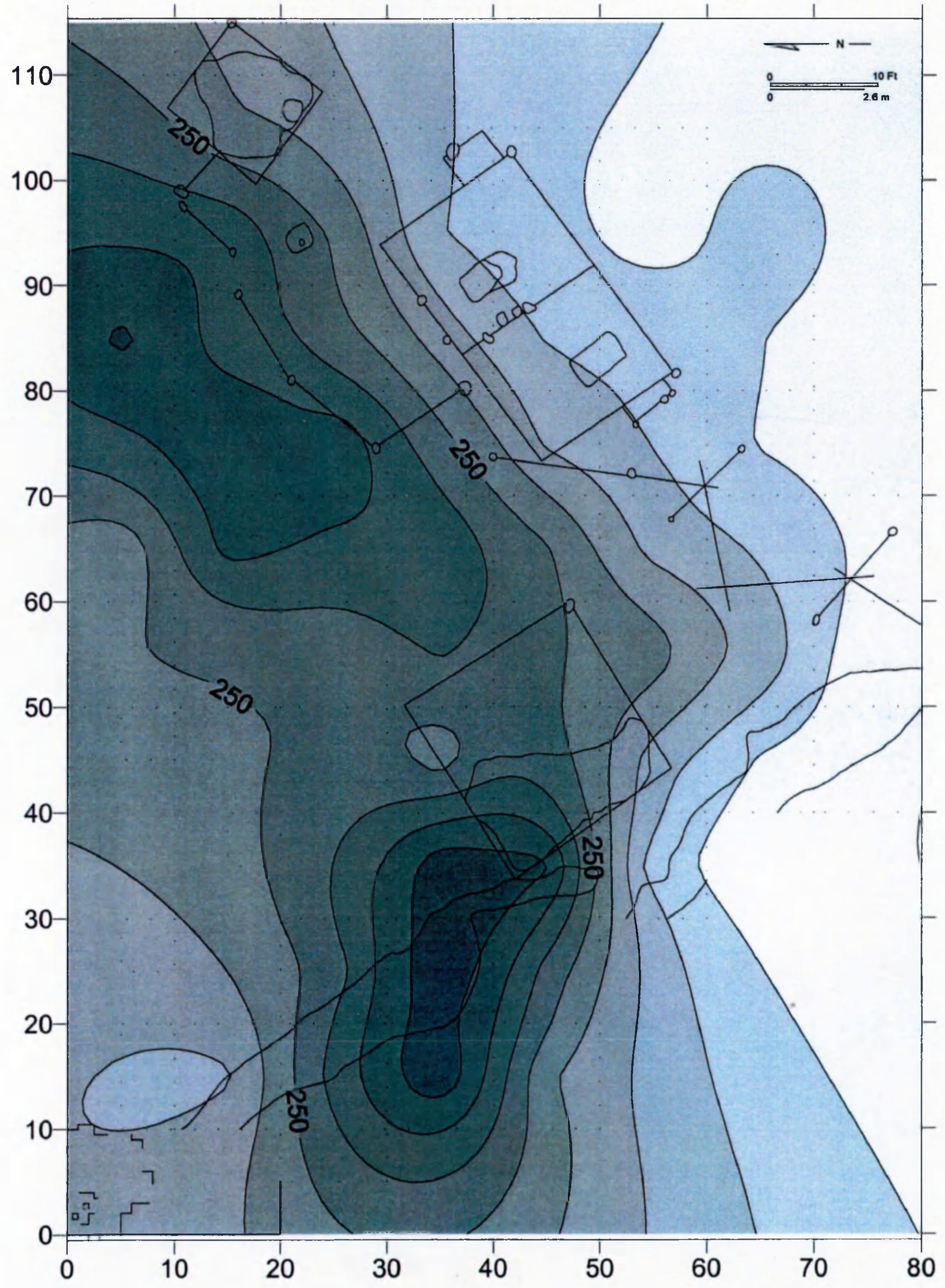
The following distribution maps are intended to illustrate the general patterns of the soil and artifact data at the Poplar Forest Quarter Site. Most of the maps were generated using the computer program *Surfer* to create contour maps. The elemental data were inputted into *Surfer* by assigning the absolute value or the z score to the central point of the fourth quadrant from which the sample was taken. The artifacts were mapped by inputting the total number of artifacts collected, excluding artifacts that were weighed, from each ten-foot square to the central point of the excavation unit.

"Relative distribution" *Surfer* maps are provided for each element as well as the pH. These ten maps are intended to provide the general pattern of the distributions of each element using the *z scores*. Because of the problematic stratigraphy and lack of a comparable sampling unit across the entire site, these maps are only meant to convey the general pattern. They depict a combination of plowzone, layer above subsoil as well as subsoil z scores. The z scores for the plowzone and layers above subsoil were used except for the nine units lacking plowzone samples, for which the subsoil z scores were used.

Individual plowzone, middle layer and layer above subsoil *Surfer* distribution maps for phosphorous, calcium, potassium and magnesium are also provided as these distributions need to be thoroughly understood. These maps are all generated from the *absolute* elemental levels. These maps are appropriately blanked so that only areas with samples are colored on the map. Although the phosphorous, calcium, potassium, and magnesium relative distribution maps, as described above, are not referred to in the text, they are included to demonstrate how the *Surfer* maps generated from raw data and those generated from z scores compare to each other.

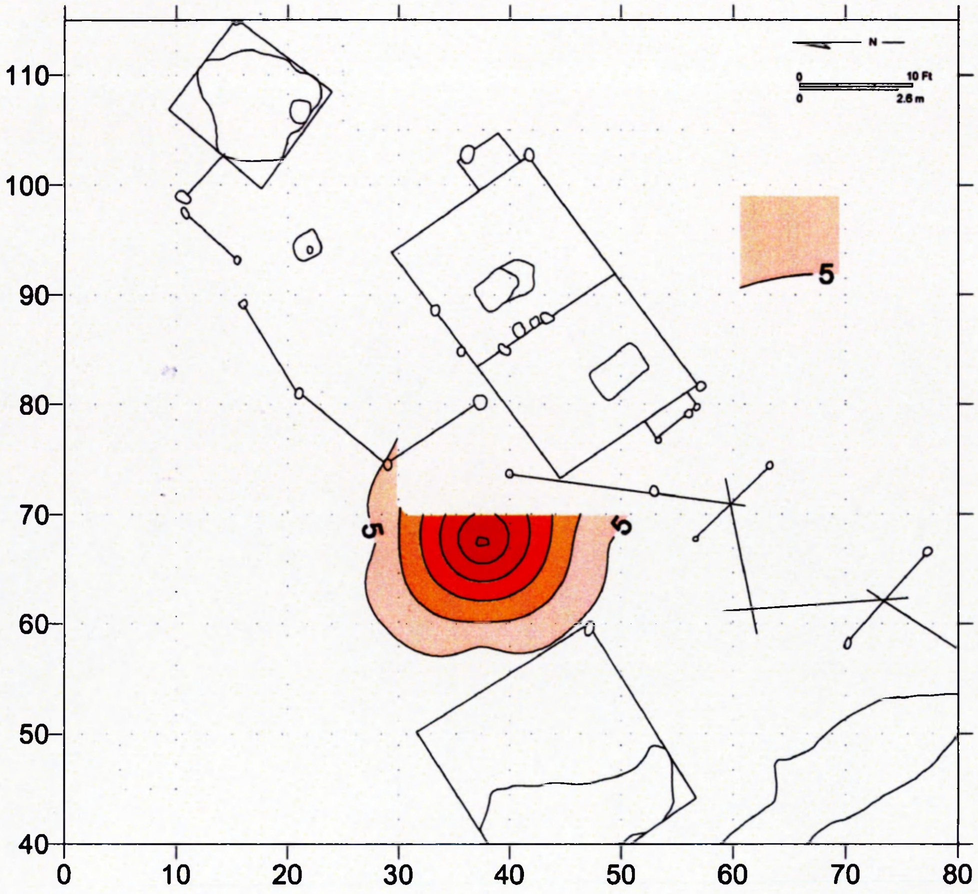
Subsoil maps are also provided for phosphorous, calcium, potassium and magnesium. Because of the irregular distribution of the subsoil samples, the maps are color-coded maps of z-scores rather than *Surfer* maps.

FIGURE 2: DISTRIBUTION OF ARTIFACTS IN STRATA



Contour Interval = 50 artifacts

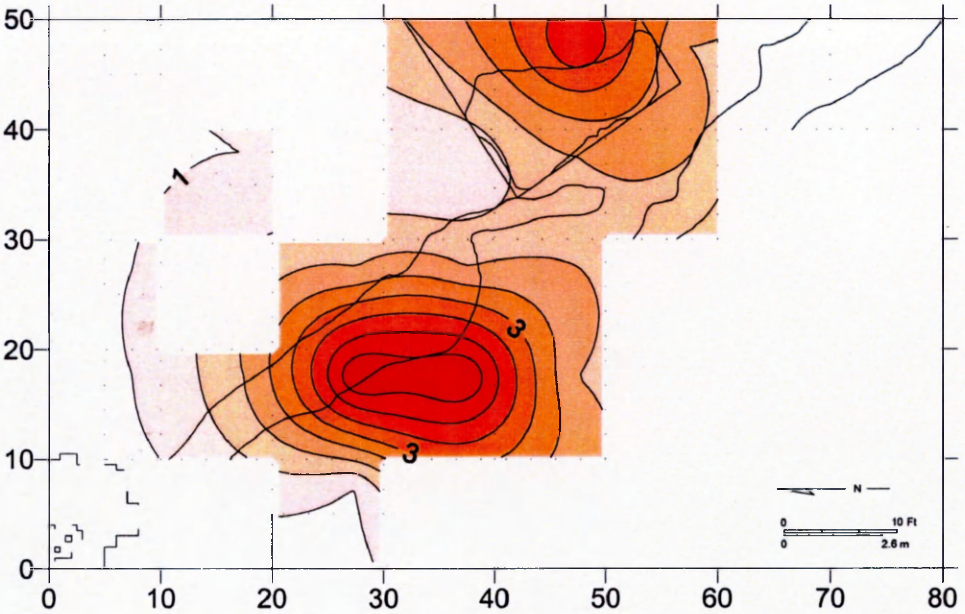
FIGURE 3: PHOSPHOROUS IN PLOWZONE



Contour Interval = 5 lb/A

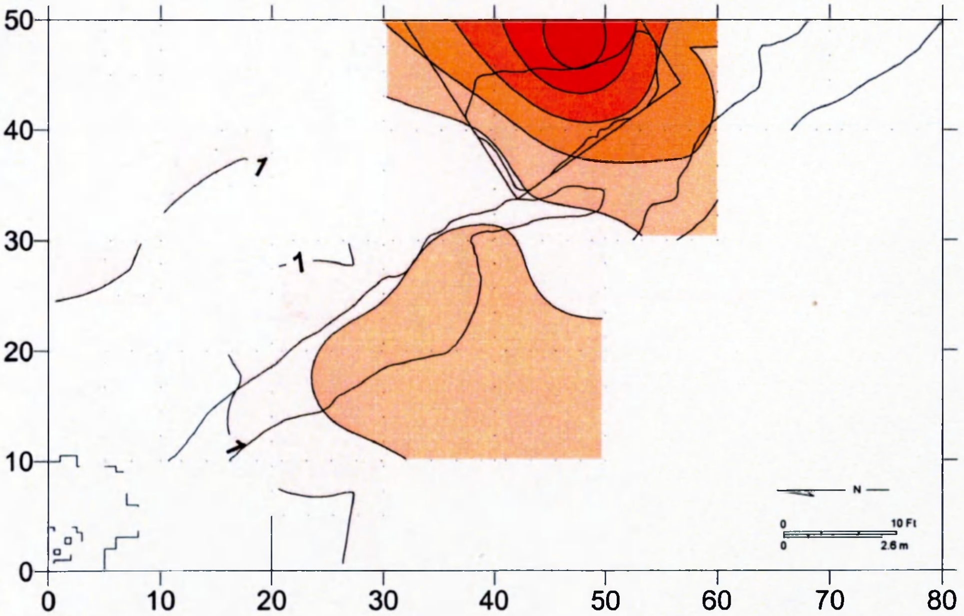
FIGURE 4: PHOSPHOROUS IN LAYERS

PHOSPHOROUS IN MIDDLE LAYER



Contour Interval = 5 lb/A

PHOSPHOROUS IN LAYER ABOVE SUBSOIL



Contour Interval = 0.5 lb/A

FIGURE 5: PHOSPHORUS IN SUBSOIL

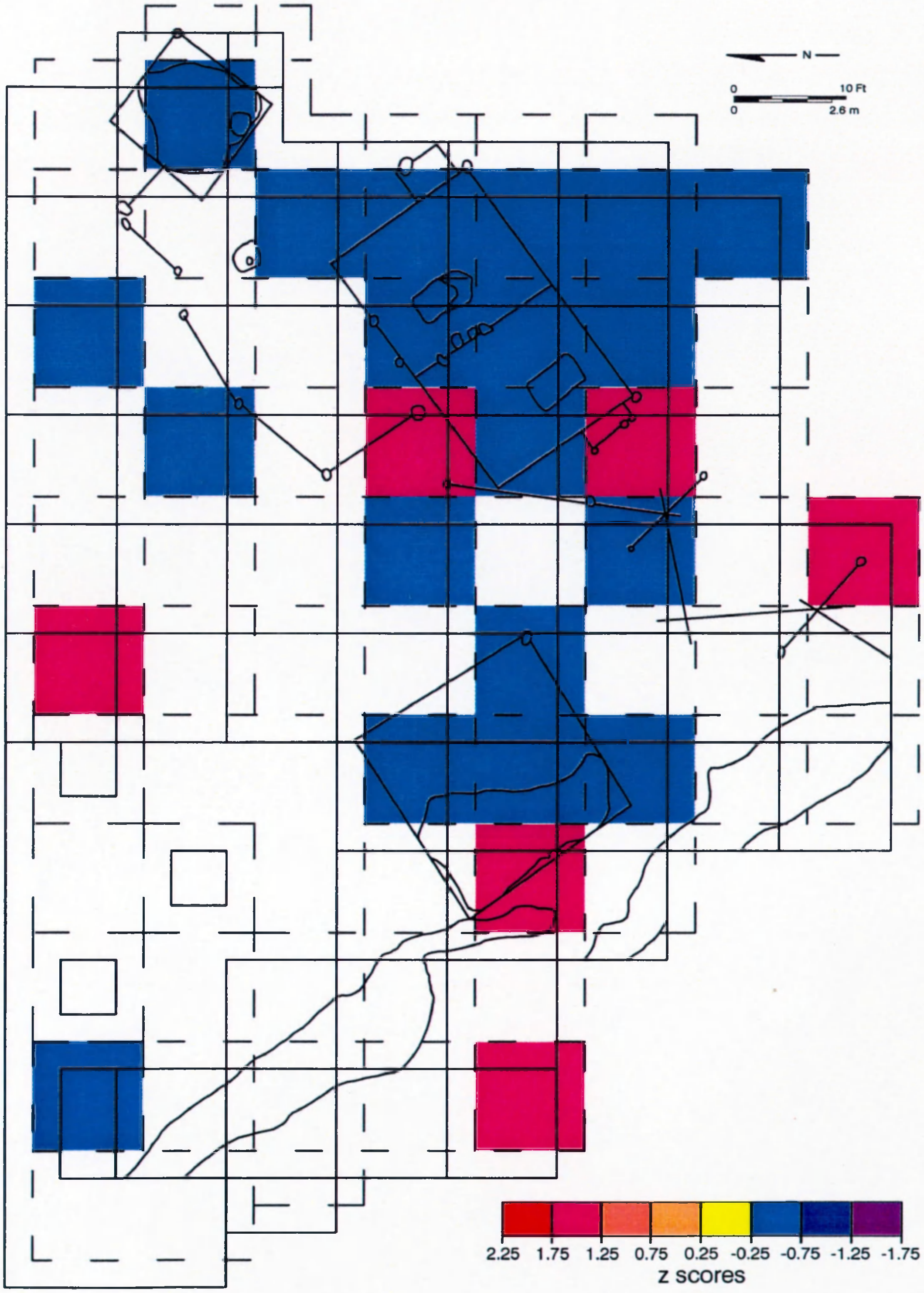
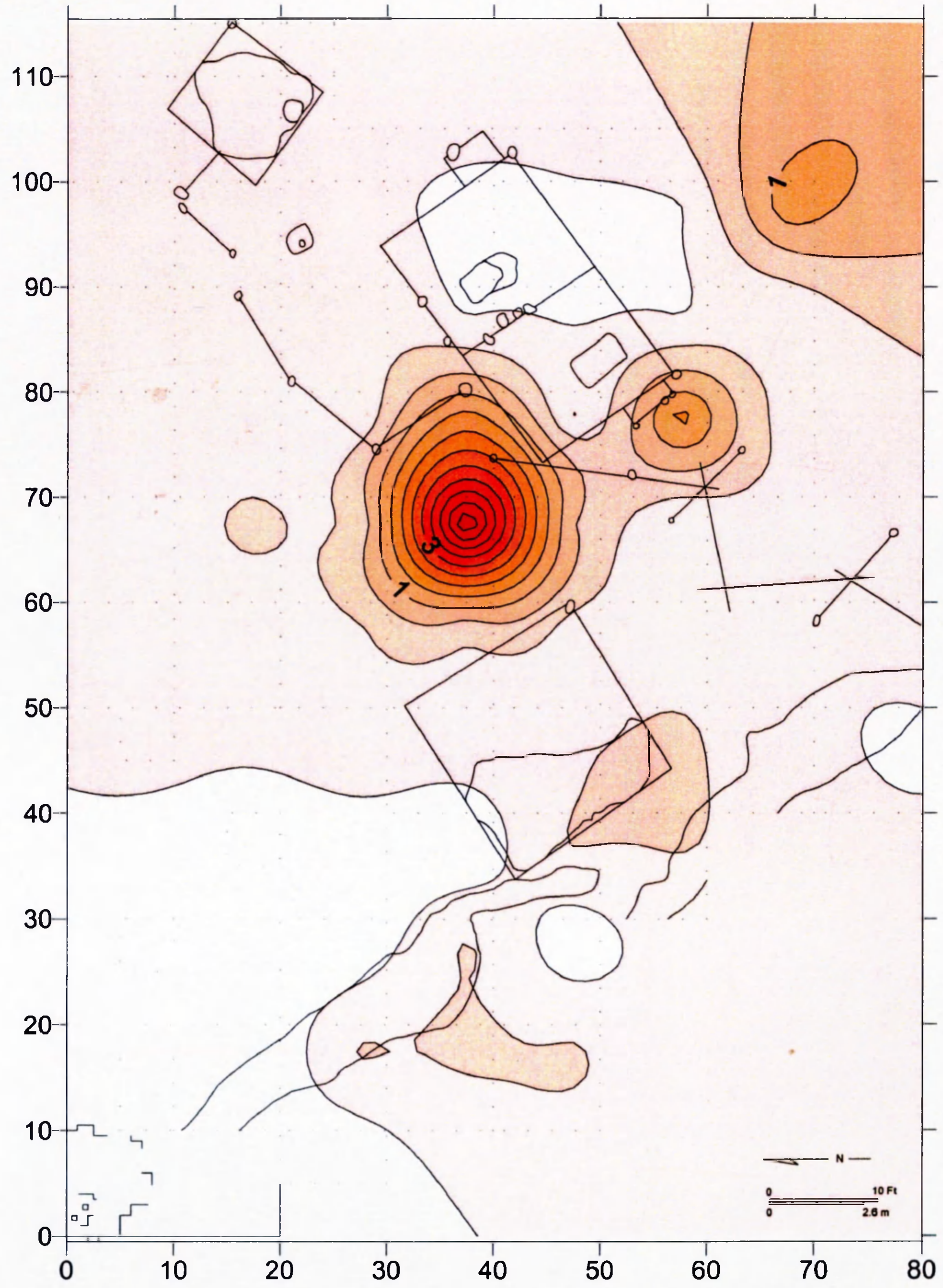
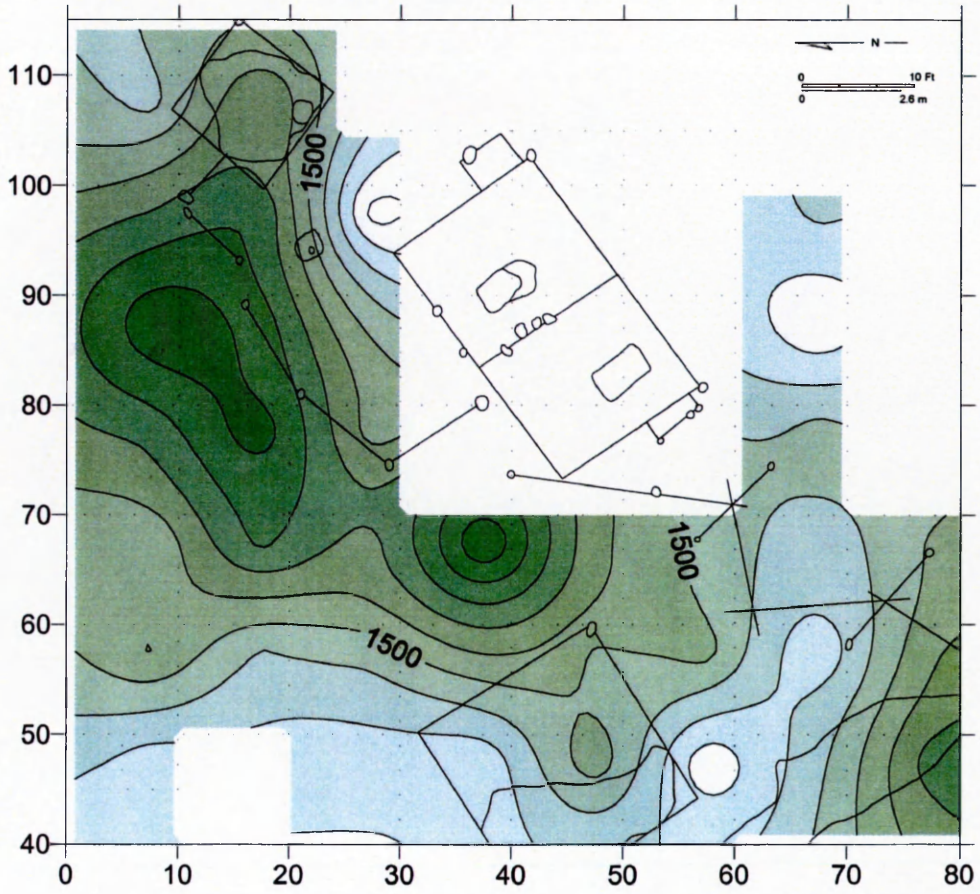


FIGURE 6: RELATIVE PHOSPHOROUS DISTRIBUTION



Contour Interval = 0.5 (z score units)

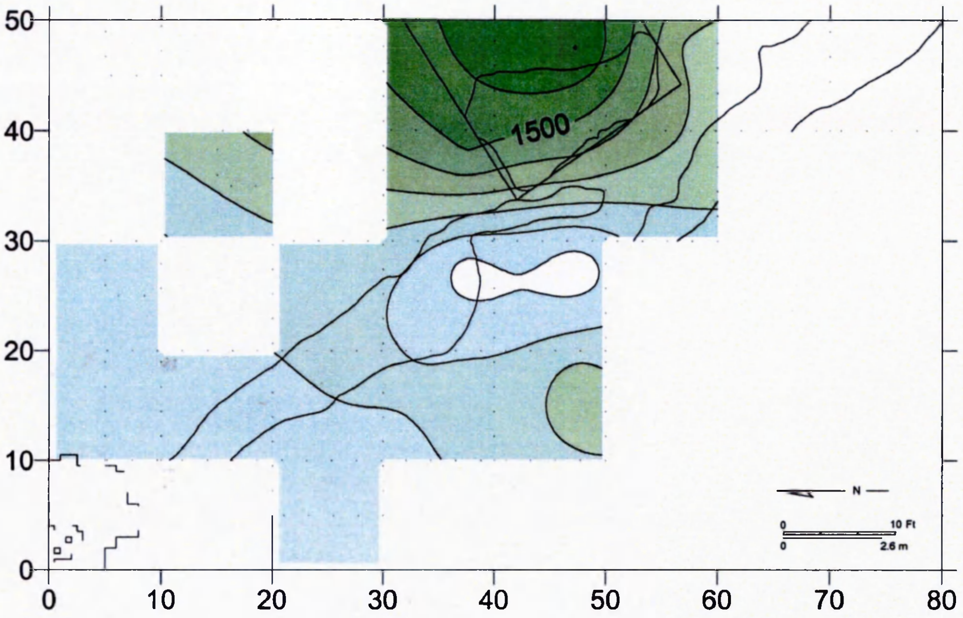
FIGURE 7: CALCIUM IN PLOWZONE



Contour Interval = 100 lb/A

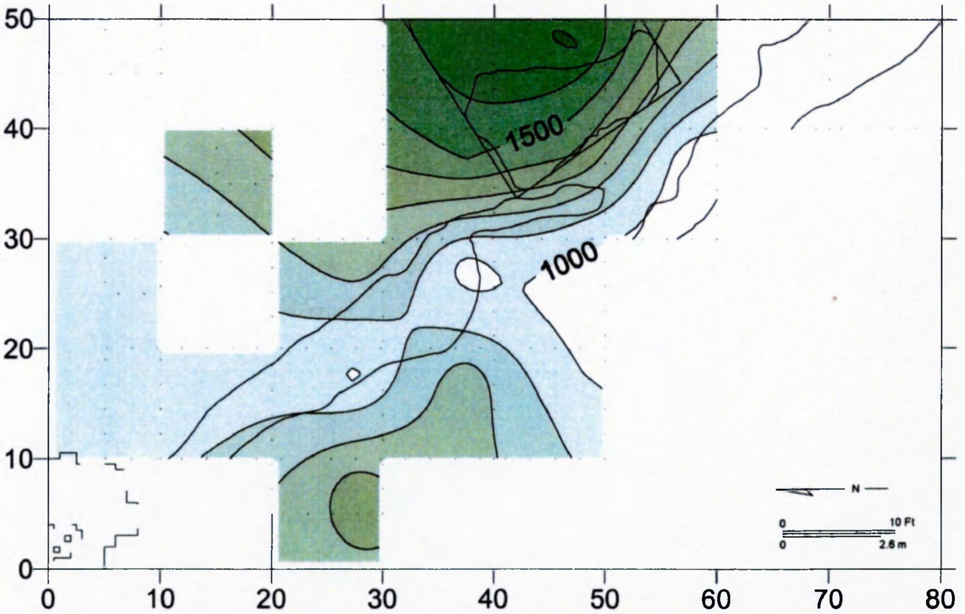
FIGURE 8: CALCIUM IN LAYERS

CALCIUM IN MIDDLE LAYER



Contour Interval = 100 lb/A

CALCIUM IN LAYER ABOVE SUBSOIL



Contour Interval = 100 lb/A

FIGURE 9: CALCIUM IN SUBSOIL

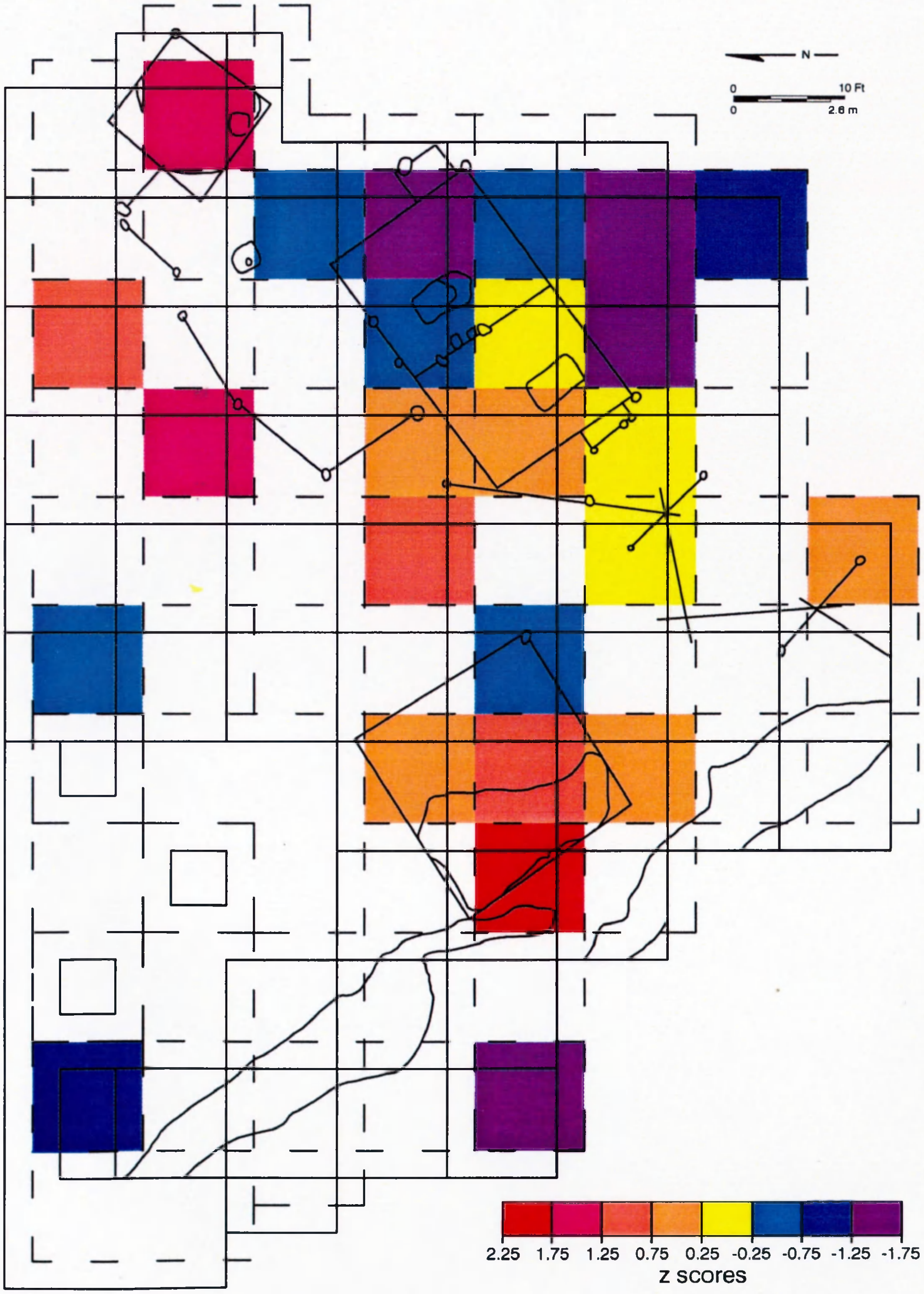
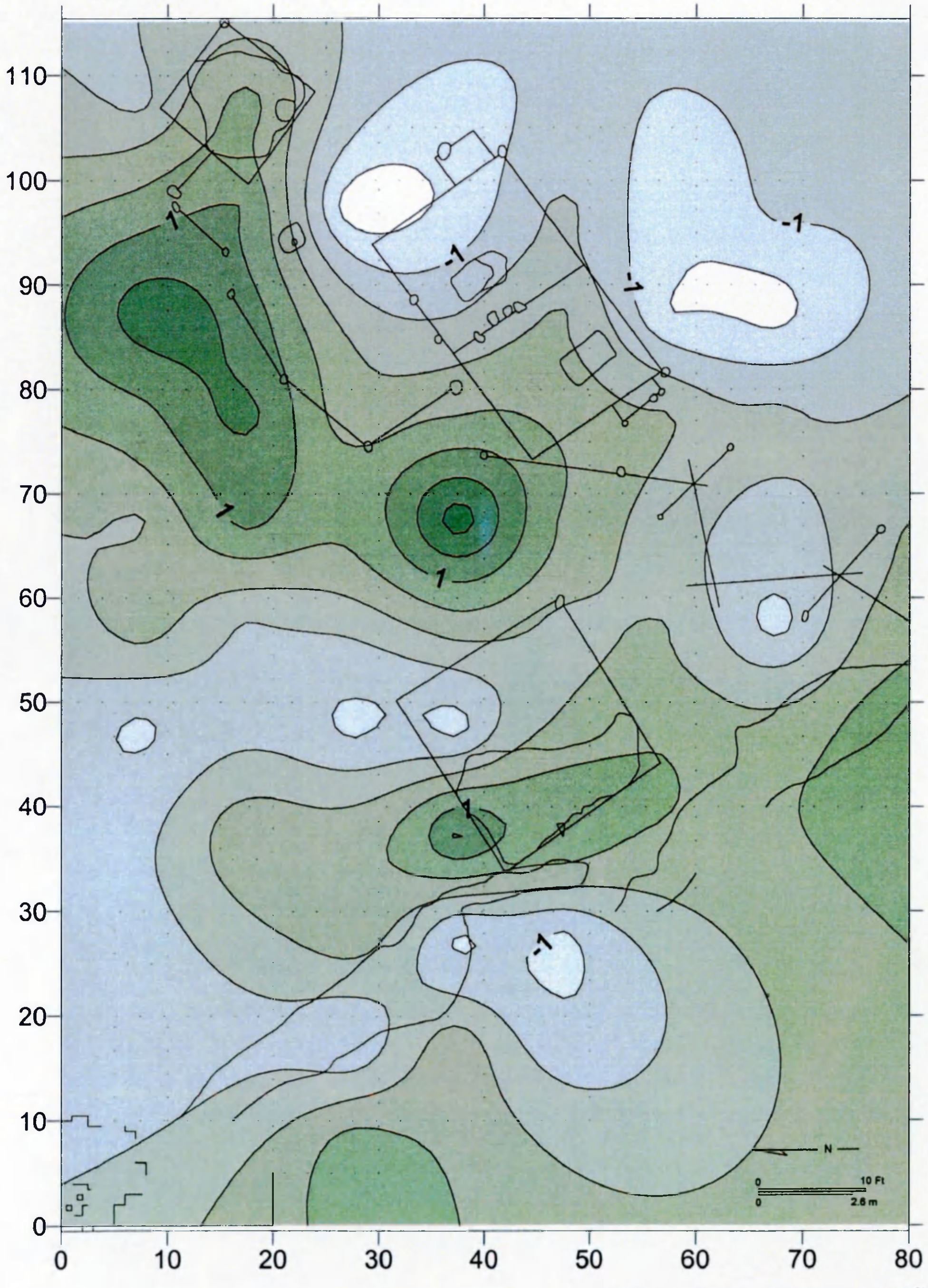
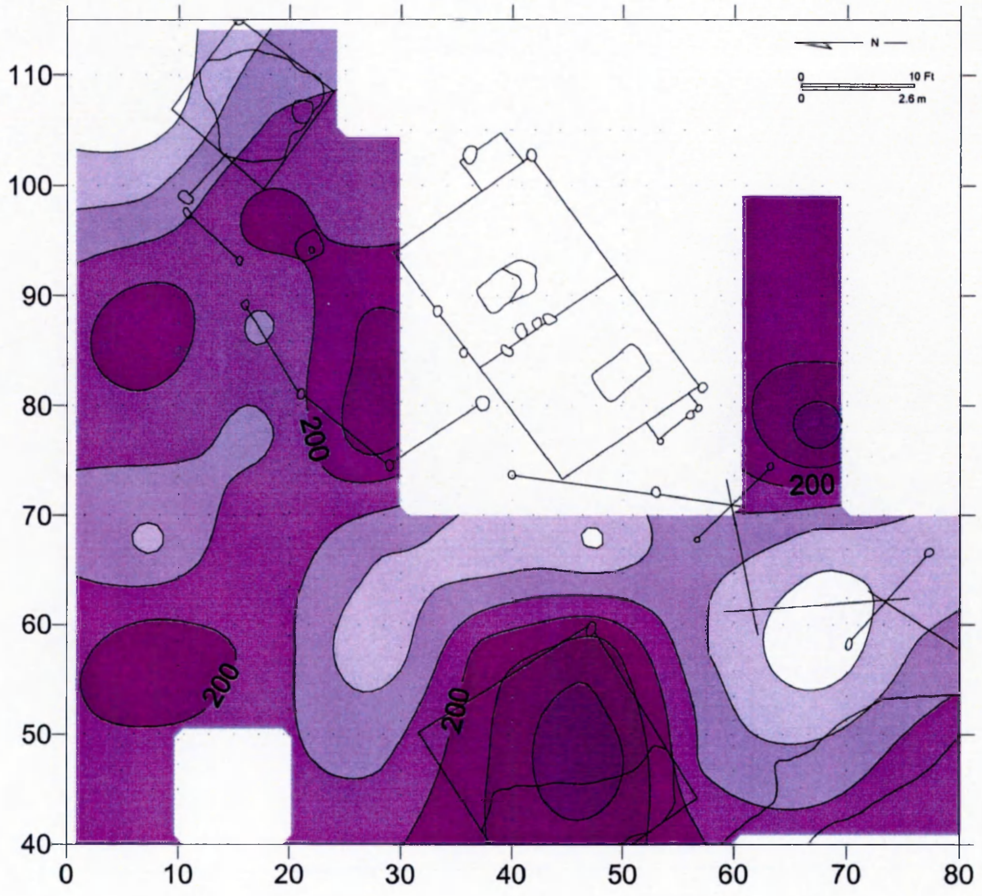


FIGURE 10: RELATIVE CALCIUM DISTRIBUTION



Contour Interval = 0.5 (z score units)

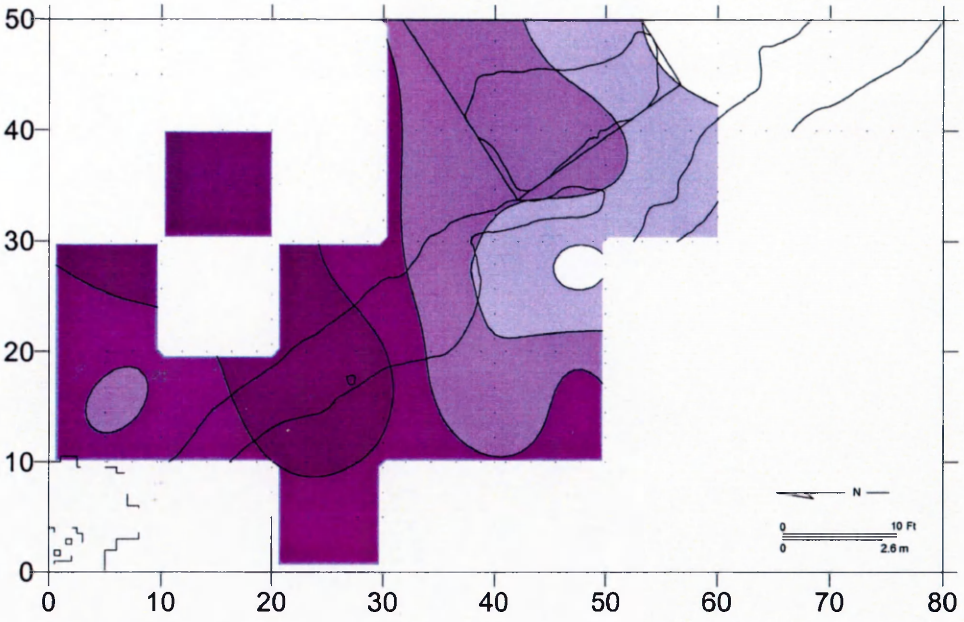
FIGURE 11: POTASSIUM IN PLOWZONE



Contour Interval = 25 lb/A

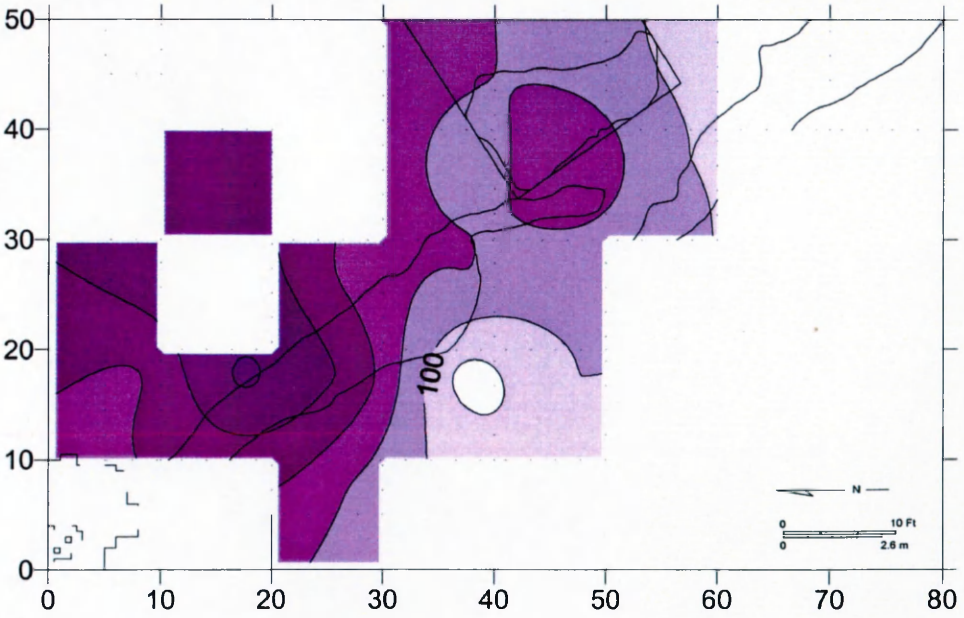
FIGURE 12: POTASSIUM IN LAYERS

POTASSIUM IN MIDDLE LAYER



Contour Interval = 25 lb/A

POTASSIUM IN LAYER ABOVE SUBSOIL



Contour Interval = 25 lb/A

FIGURE 13: POTASSIUM IN SUBSOIL

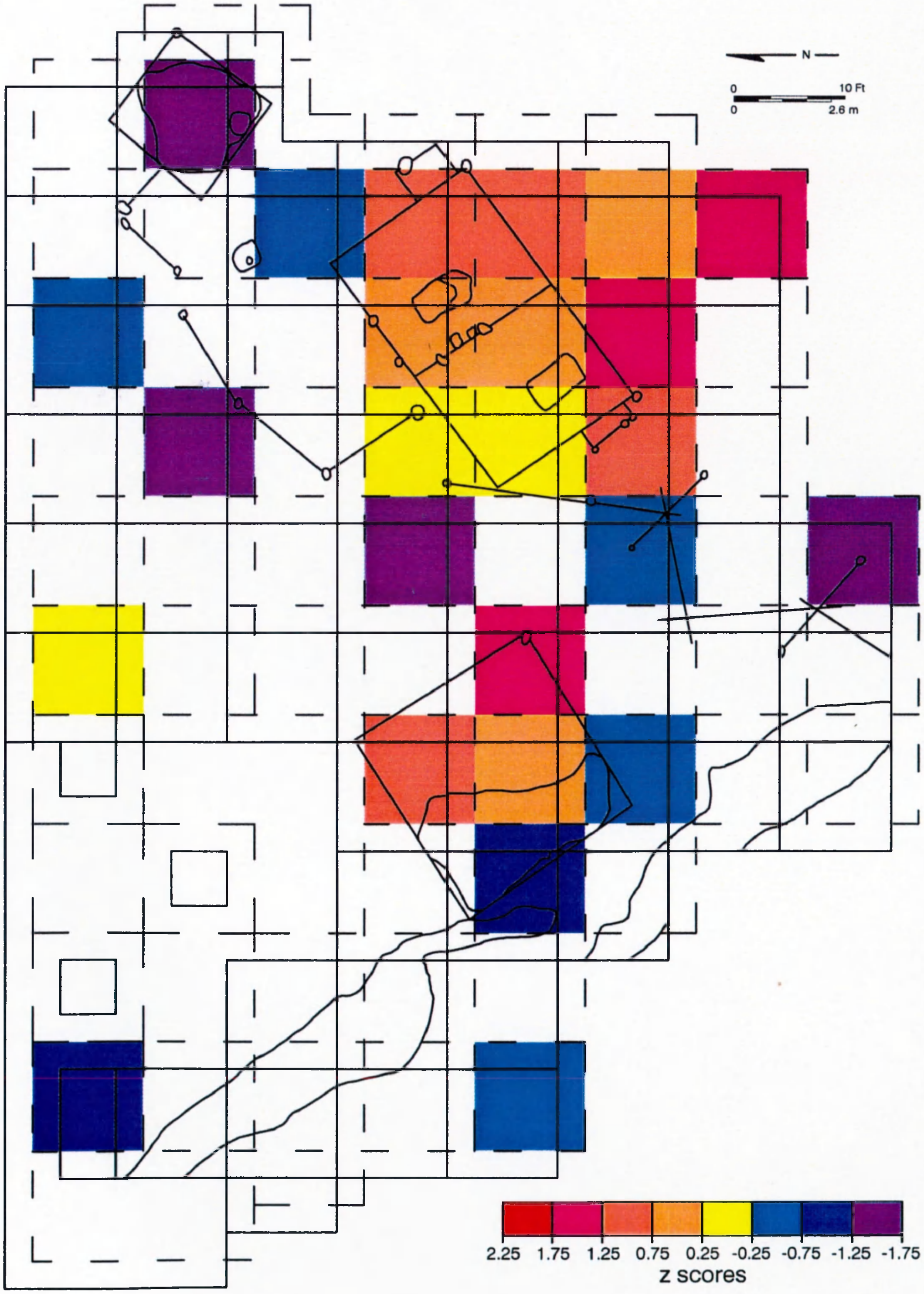
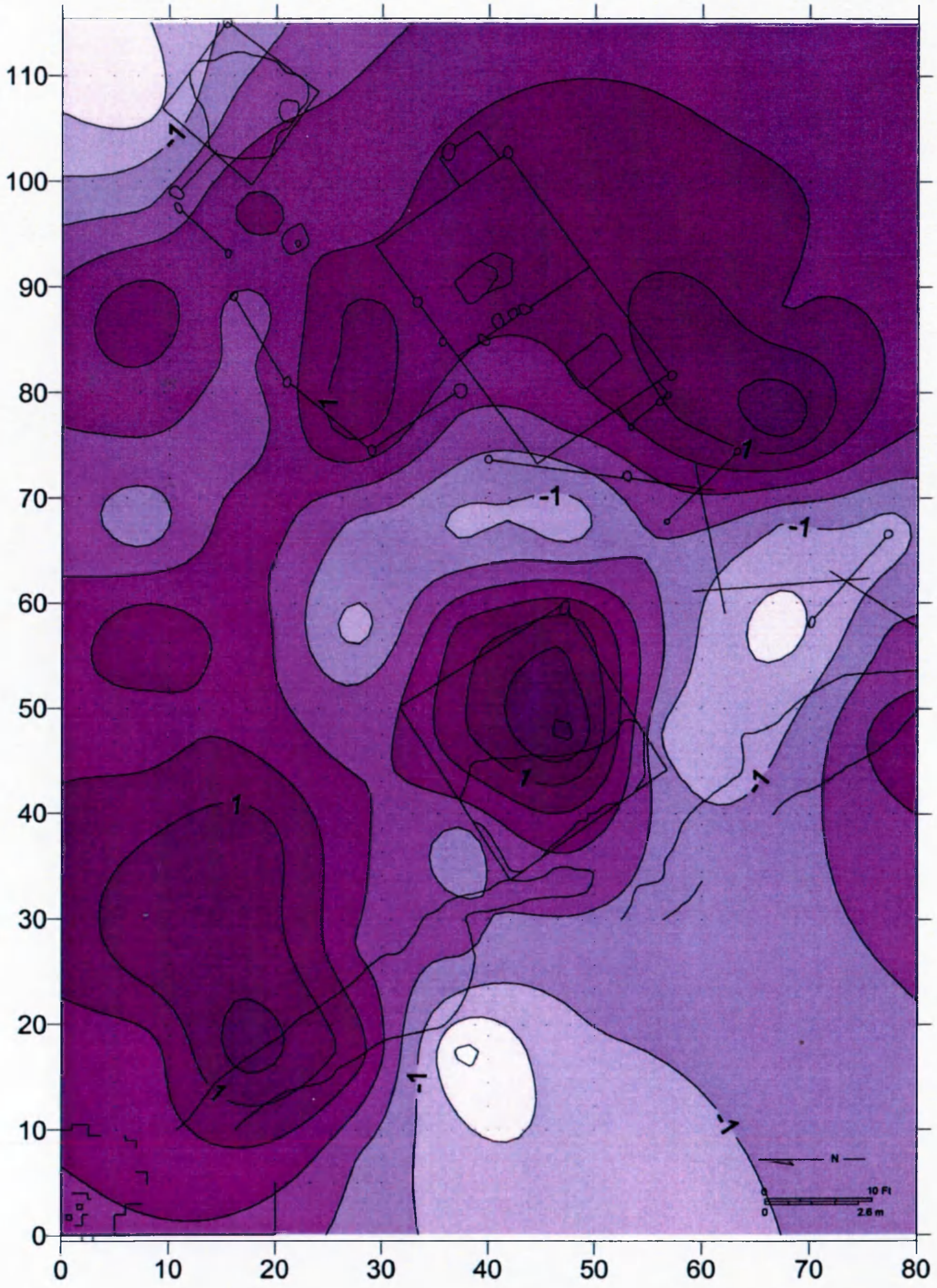
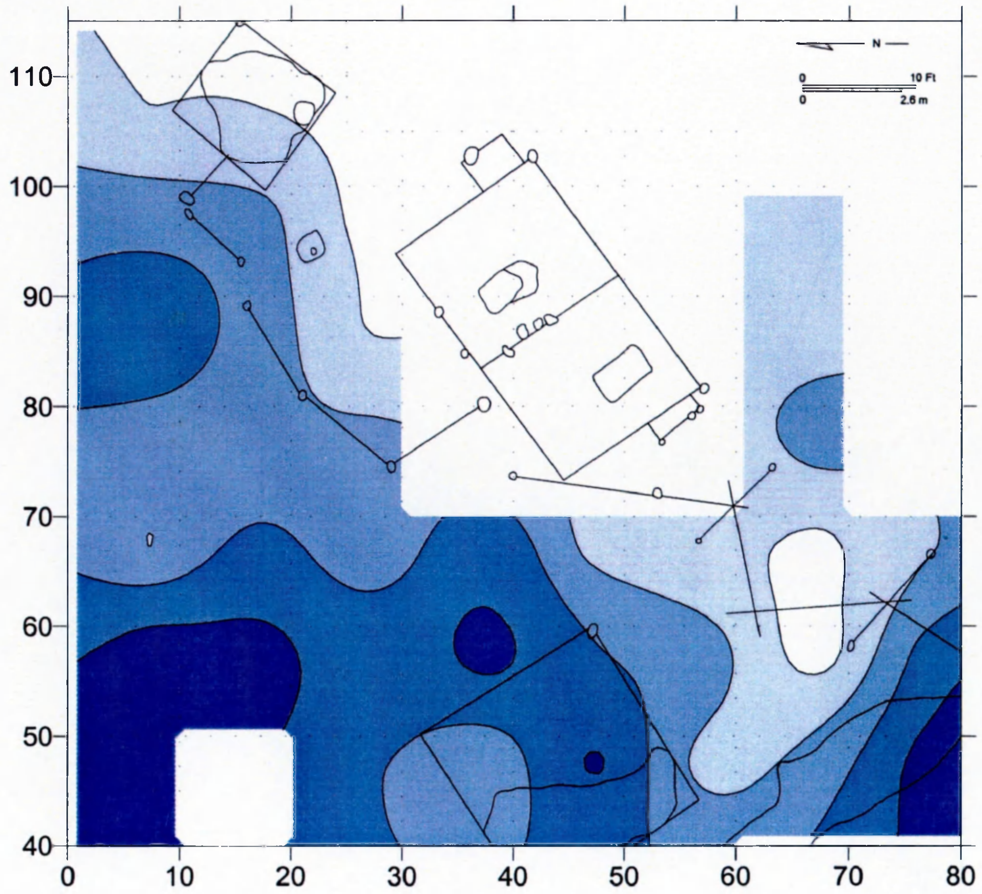


FIGURE 14: RELATIVE POTASSIUM DISTRIBUTION



Contour Interval = 0.5 (z score units)

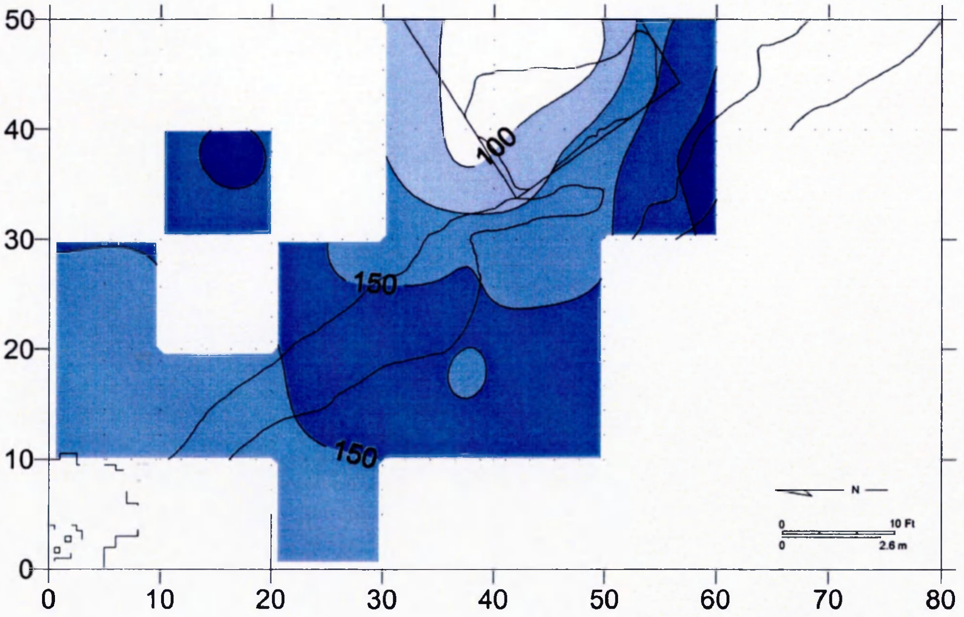
FIGURE 15: MAGNESIUM IN PLOWZONE



Contour Interval = 25 lb/A

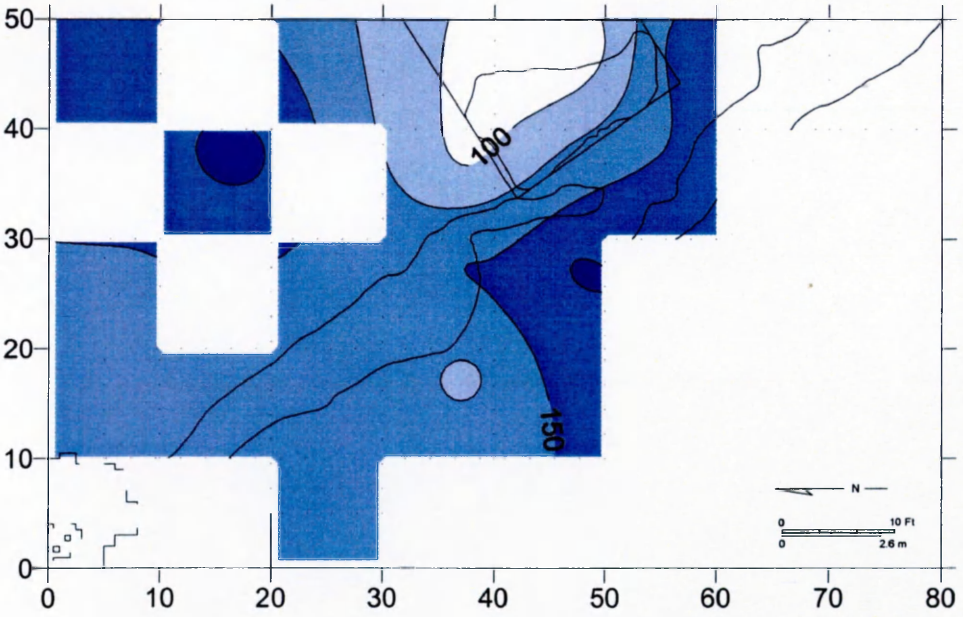
FIGURE 16: MAGNESIUM IN LAYERS

MAGNESIUM IN MIDDLE LAYER



Contour Interval = 25 lb/A

MAGNESIUM IN LAYER ABOVE SUBSOIL



Contour Interval = 25 lb/A

FIGURE 17: MAGNESIUM IN SUBSOIL

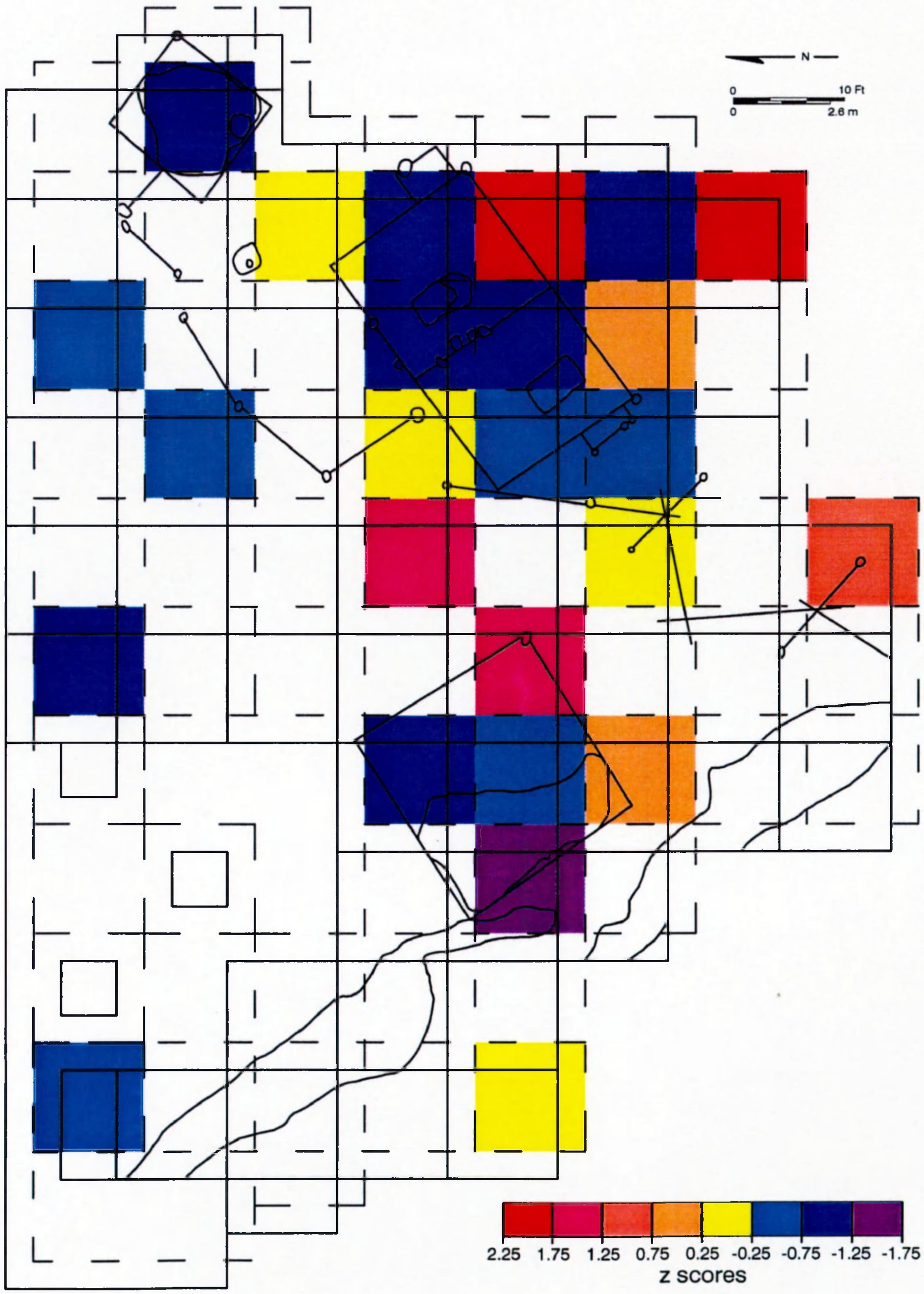
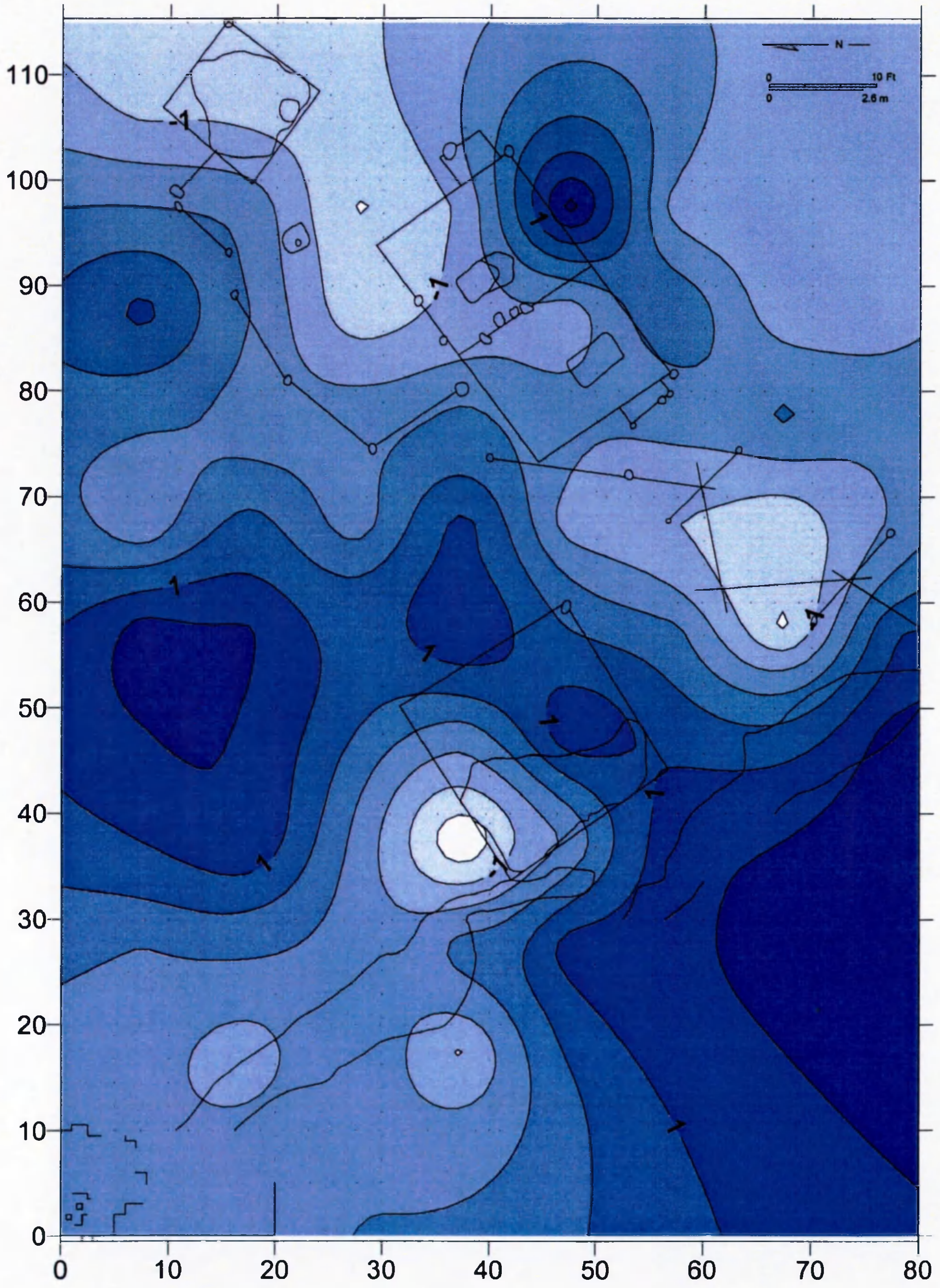
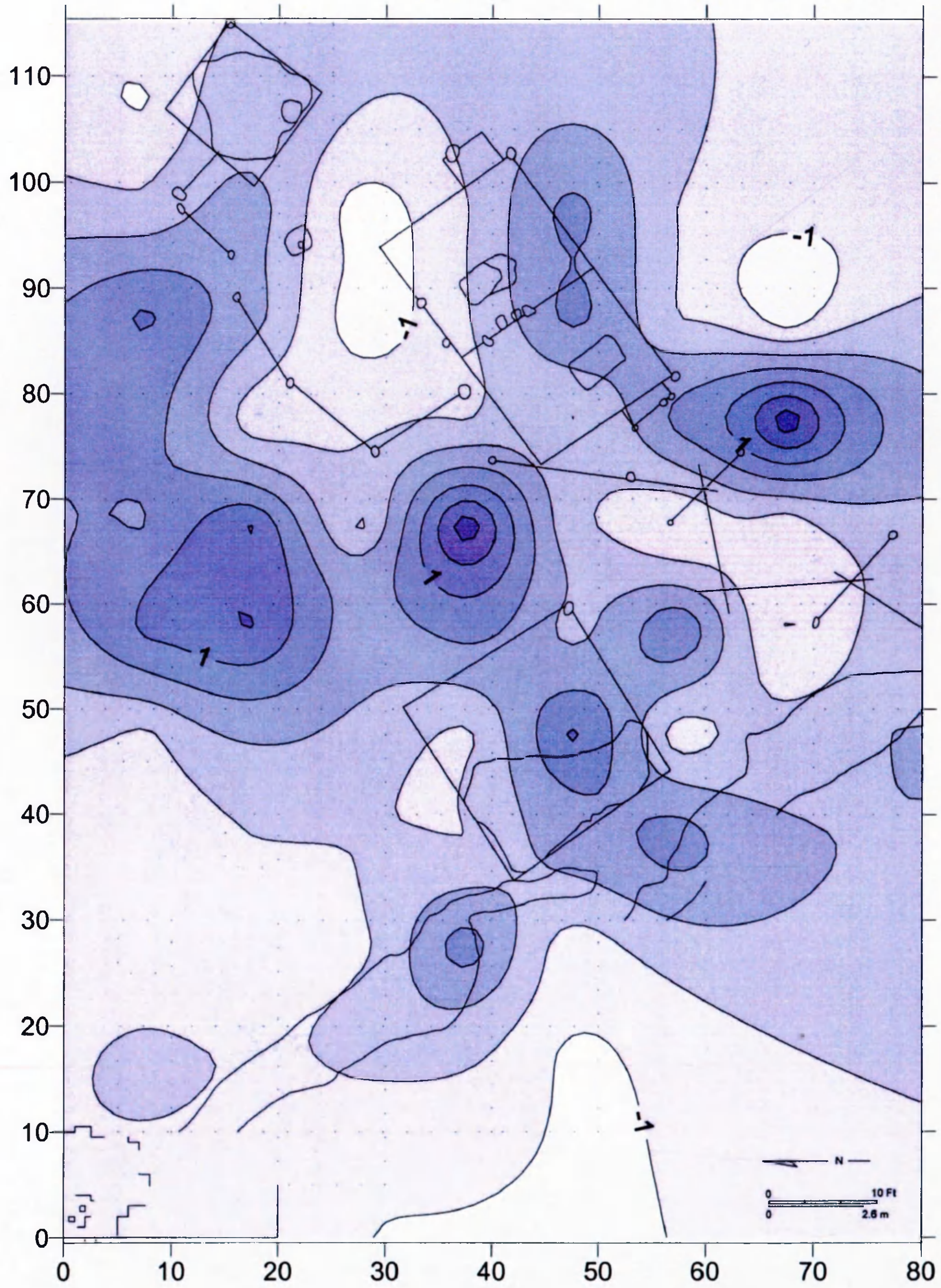


FIGURE 18: RELATIVE MAGNESIUM DISTRIBUTION



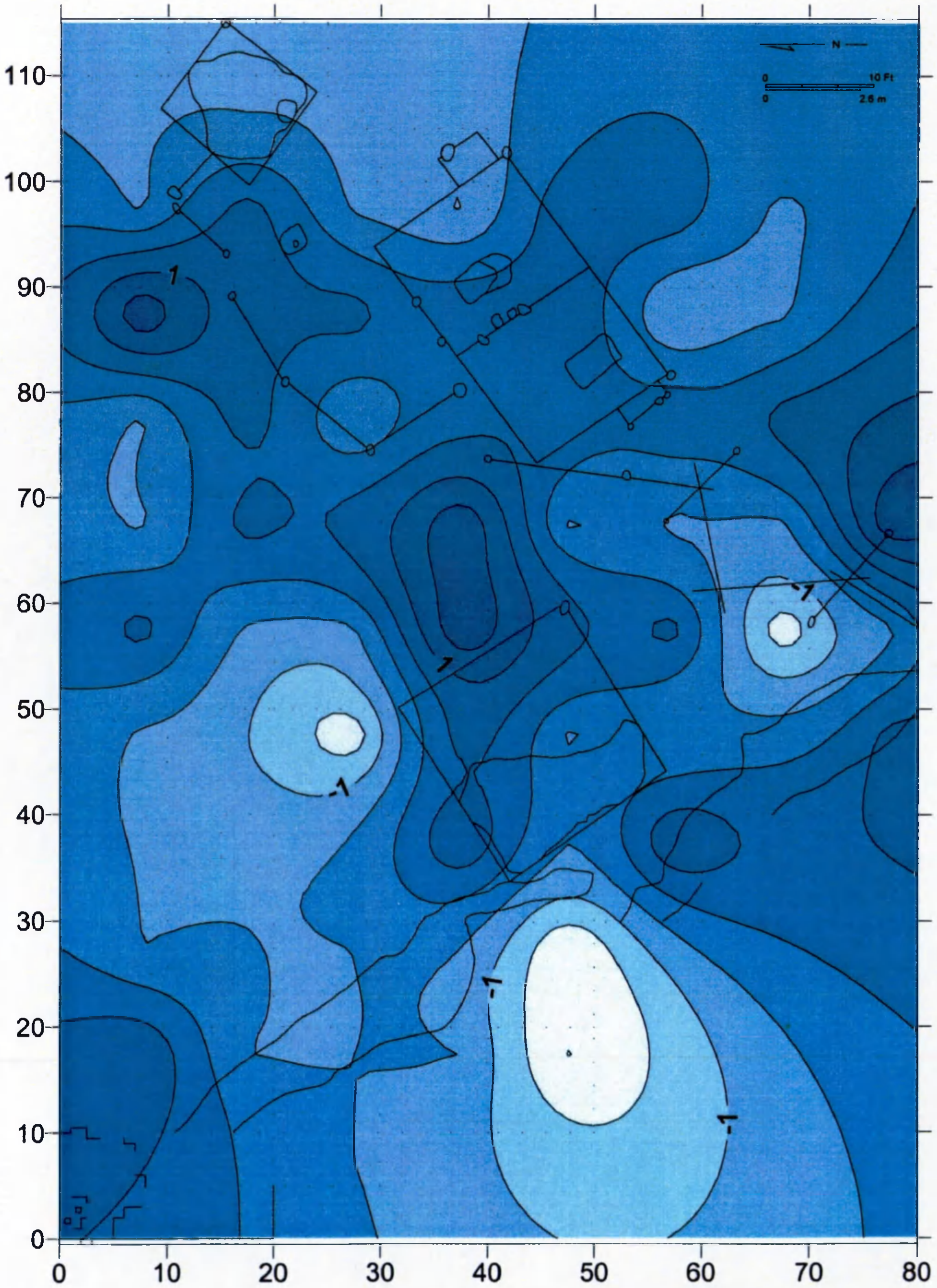
Contour Interval = 0.5 (z score units)

FIGURE 19: RELATIVE ZINC DISTRIBUTION



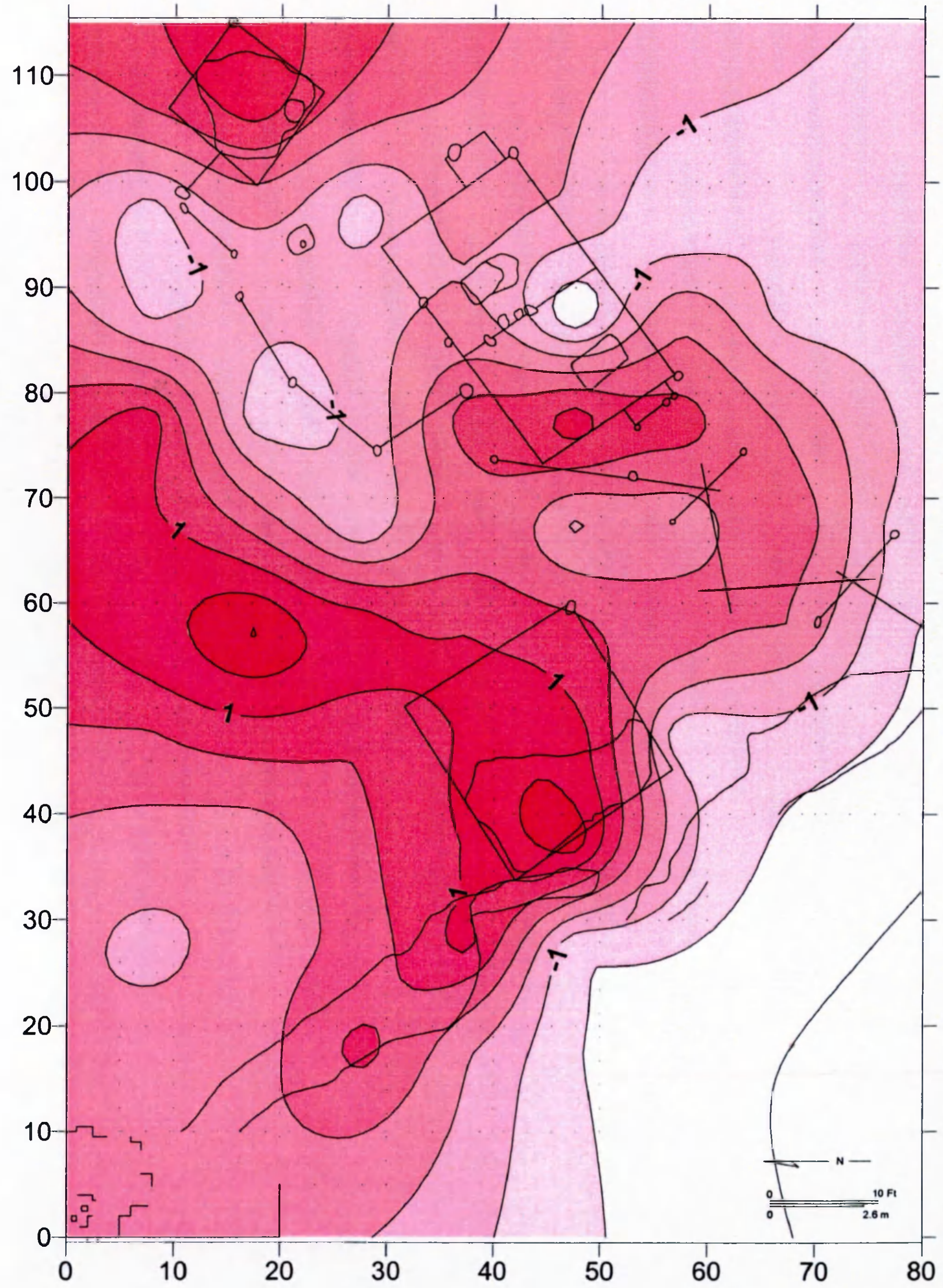
Contour Interval = 0.5 (z score units)

FIGURE 20: RELATIVE BORON DISTRIBUTION



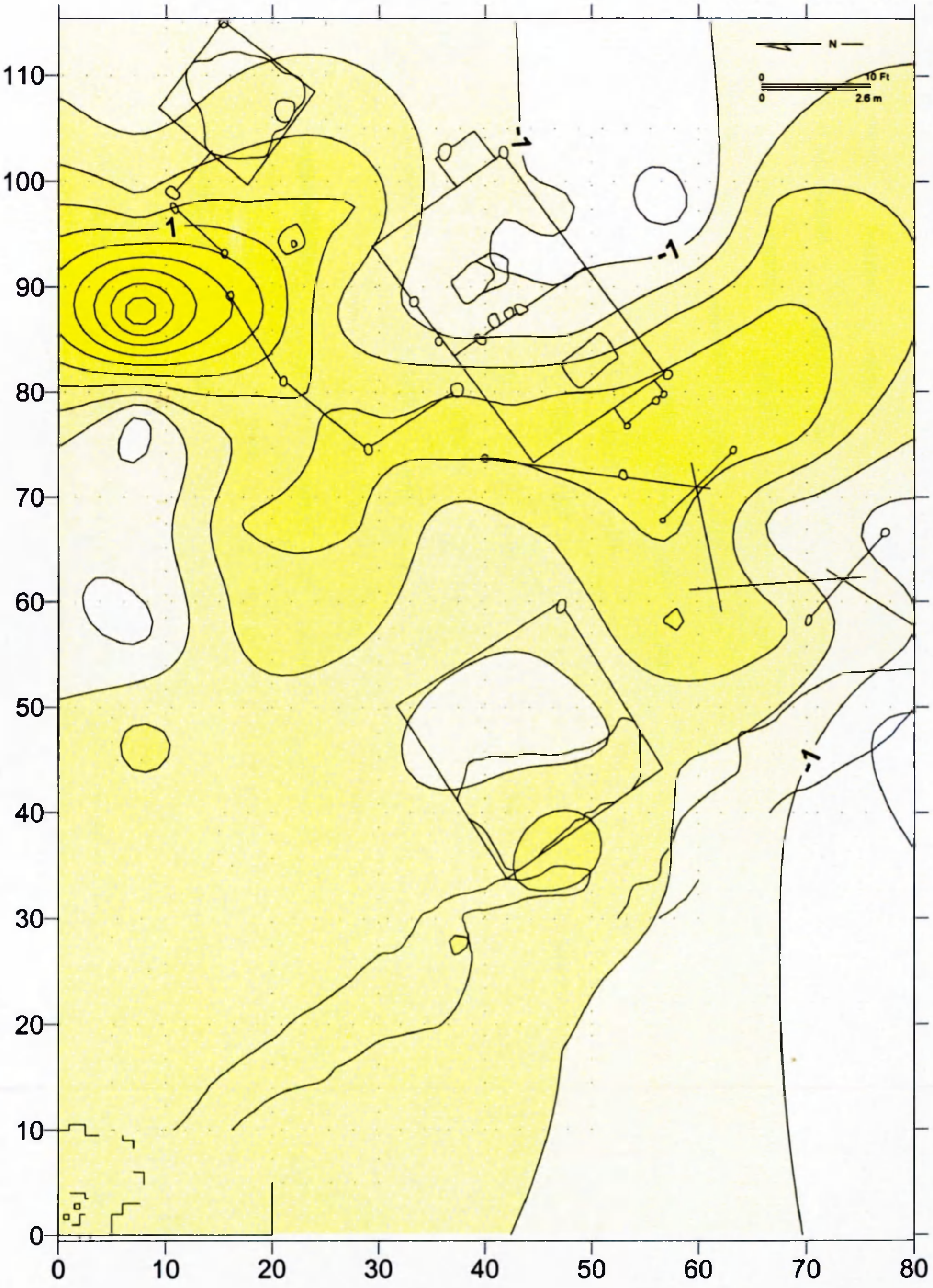
Contour Interval = 0.5 (z score units)

FIGURE 21: RELATIVE MANGANESE DISTRIBUTION



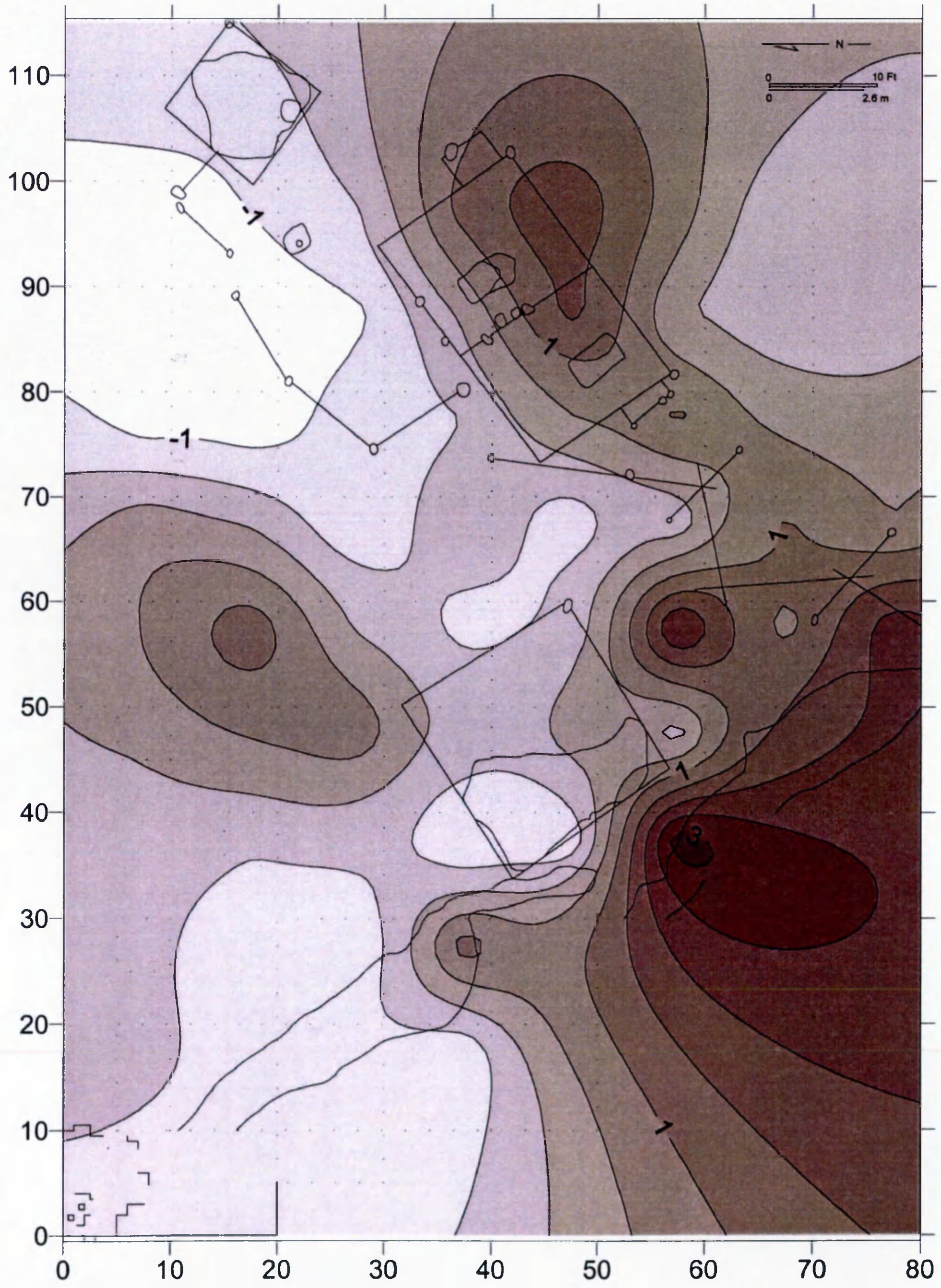
Contour Interval = 0.5 (z score units)

FIGURE 22: RELATIVE COPPER DISTRIBUTION



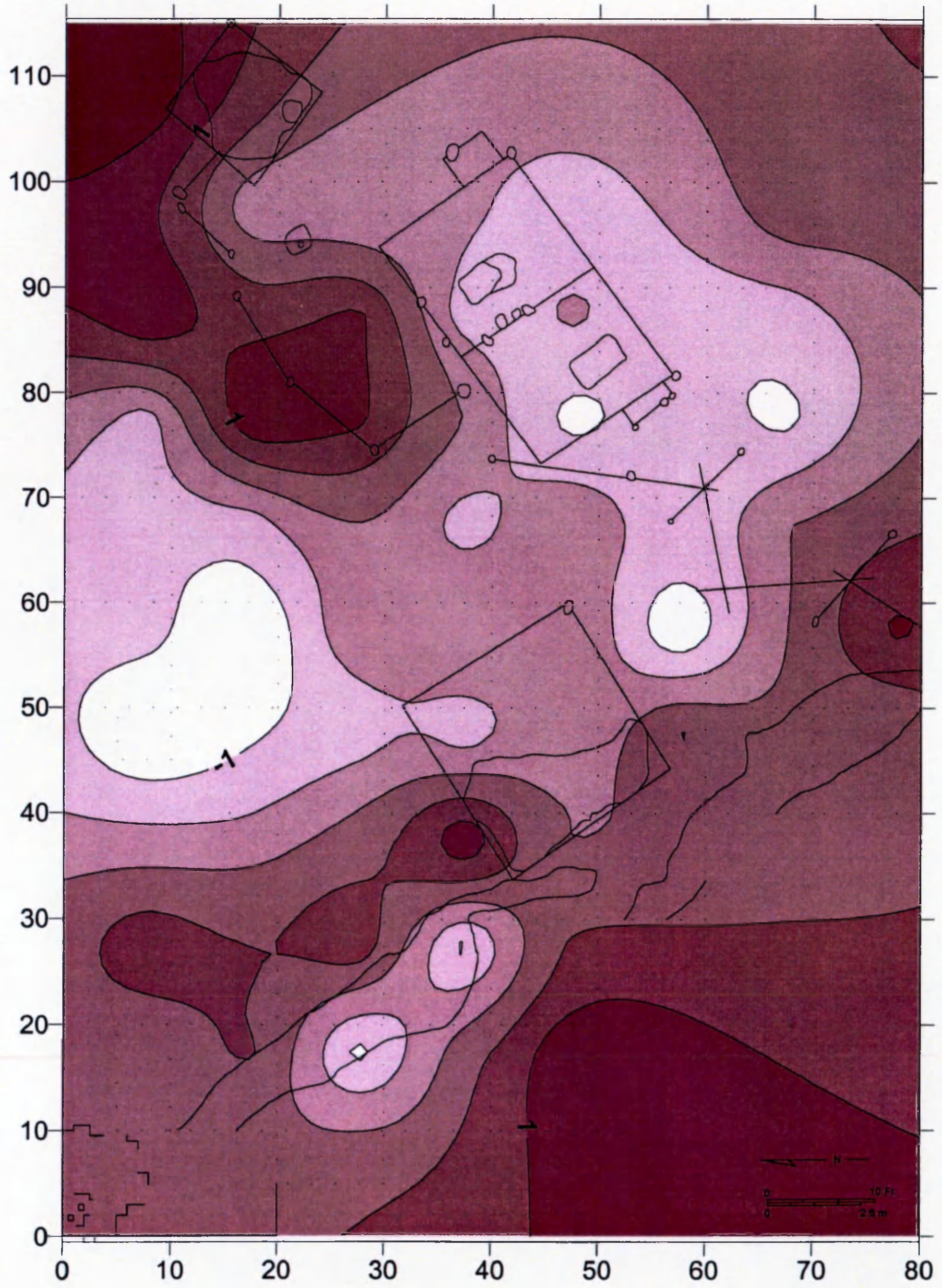
Contour Interval = 0.5 (z score units)

FIGURE 23: RELATIVE IRON DISTRIBUTION



Contour Interval = 0.5 (z score units)

FIGURE 24: RELATIVE pH DISTRIBUTION



Contour Interval = 0.5 (z score units)

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