Seeing Below the Surface with Electrical Resistivity Tomography: Exploring the Deepest Reaches of Arkansas' Tallest Prehistoric Mounds

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Seeing Below the Surface with Electrical Resistivity Tomography: Exploring the Deepest Reaches of Arkansas’ Tallest Prehistoric Mounds
Seeing Below the Surface with Electrical Resistivity Tomography: Exploring the Deepest Reaches of Arkansas’ Tallest Prehistoric Mounds

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Anthropology

by

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Despite decades of research and over a century of public interest, the most prominent features at Toltec Mounds Archeological State Park, Mound A and Mound B, remain virtually unexamined by modern archaeological techniques, and poorly understood. The tremendous scale and importance of these mounds makes most standard research methods difficult if not impossible. Electrical Resistivity Tomography, a geophysical technique rarely used in North America, was employed to survey both Mound A and Mound B, resulting in models of the subsurface that provide insights into the construction, modification and condition of the mounds.
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INTRODUCTION TO TOLTEC AND THE RESEARCH

Toltec Mounds Archeological State Park (3LN42) in south-central Arkansas is one of the largest mound complexes in the region and is home to the two tallest mounds in the state of Arkansas. The site is located beside Mound Lake, which formed from a cut off of the Arkansas River about 15 miles southeast of Little Rock and contains 18 mounds, arranged around two plazas. Though partially destroyed now, an approximately one mile long embankment and external ditch would once have enclosed three sides of the approximately 42 ha site with the fourth side being bounded by the lake. Dating to the Terminal Woodland period, the complex was probably primarily used and under construction between 700 and 1000 C.E. (Rolingson 2012).

The Late Woodland is often thought of as a period of cultural decline, with simple ceramics and less complex mortuary customs. As one of the largest monumental centers from any period in the region, Toltec is therefore somewhat of an anomaly. The peculiarity of the site does not end with its existence and great size however. Woodland mounds are expected to be low conical mounds with little formal organization. Toltec breaks with this pattern and conforms more closely with the expected pattern of Mississippian mound complexes, which frequently include large platform mounds arranged around plazas (Rolingson 1982). Even amongst large ceremonial centers with multiple mounds and plazas, Toltec is somewhat of an oddity, as in such instances the tallest mound is almost always rectangular or square, with a large platform at the top (Rolingson 1982:90). The tallest mound at Toltec, designated Mound A, is an elongated cone with a small flat surface at the top while the second tallest, Mound B, is rectangular and has a large platform surface as was confirmed by the high resolution elevation model generated during the course of this research, shown in Figure 1. It has been suggested that Mound A was at one point rectangular and has been greatly modified by erosion, and that perhaps the shape of Mound B has also been affected by years of ploughing or later additions, however with little
Figure 1: The elevation model generated for this research confirms the square shape of the mound and shows a large platform at the top.

research ever completed on the mounds these hypotheses have not been tested (Rolingson 1982:90). Regardless, the unexpected complexity and the extraordinary examples of Mississippian style structures in a clearly Woodland site, challenge the standard conception of the Late Woodland period in this region. For this reason, the mounds at Toltec have periodically elicited interest, speculation and research for nearly two centuries.

The erroneous name of Toltec Mounds stems from Gilbert Knapp, the owner of the site from around 1857 to his death in 1900 (Rolingson 1982:1). At the time the prevailing theories were that North American mounds had been built by people from Mexico; therefore Knapp named the site and surrounding community after the Toltecs.

Alternatively, the site is also known as the Knapp site, a name given to it by Cyrus Thomas in 1894 when he published the results of Edward Palmer’s excavations in five of the
mounds (Rolingson 1982:1). Even at that time Thomas noted the importance of the site, but it was not formally researched until 1966 when the University of Arkansas Museum and the Arkansas Archeological Society hosted an amateur training program excavation in Mound C. A formal research plan for the site was not created until 1976 (Rolingson 1982, 2012). The apparent lack of interest in the site by early archaeologists may be explained with a short note about the Toltec Mounds by C.B. Moore who states that he visited the mounds “but investigation was not deemed advisable, as there seemed to be no history of the discovery of artifacts in the vicinity.” (Moore 1908:557). Artifacts had been discovered in the vicinity, as Mary Eliza Knapp states in her letters to Dr. W.H. Barry that ploughing and erosion had produced “these rude relics of a prehistoric possibly an Indian race” and continues that “It was certainly a place of sepulcher for human bones rest tier up tier but mingled with those of deer and other animals. They are of great age and crumble on coming to the air.” (Rolingson 2012:14). It seems that the predominantly plain ceramics and few exotic items present at the site were not considered elaborate enough to be of interest and garner further investigation, and so the site was long left unexplored.

Following its placement on the National Register of Historic Places in 1973, and its purchase in 1975 by the Department of Parks and Tourism, a formal research plan for Toltec Mounds began to take shape (Rolingson 1982:1). All park related activities would be managed by the Department of Parks and tourism, while research would proceed under the guidance of the Arkansas Archeological Survey’s Toltec Mounds Research Station Archeologist (Rolingson 2012). Over the next thirty years, Station Archaeologist Dr. Martha Rolingson led research including multiple excavations, geophysical surveys, regional surveys and extensive processing and analysis, resulting in the establishment of the Plum Bayou culture on the basis of data collected at Toltec Mounds (Rolingson 1982, 2012). However, early in the Survey’s research efforts the large mounds were mostly left undisturbed, as it was decided that with the limited resources available it would be more productive to examine other elements of the site (Rolingson 2012). The one exception to
this came in 1979 prior to the stabilization of an erosional gully on the southern corner of Mound B by the Division of Parks, when a profile was cut on the western edge of the gully revealing 11 m of profile along the side of the mound (Rolingson 1982:37). Since this time the primary focus for Mound A and Mound B, the two largest mounds on the site, has not been in archaeological research, but rather in preservation. Therefore, despite centuries of acknowledgement of the site’s archaeological importance, and decades of professional archaeological research, the internal form and structure of Mound A and Mound B remain essentially unexplored. In her book *Toltec Mounds: Archeology of the Mound-and-Plaza Complex*, Dr. Rolingson lists the limited data on the largest mounds as one of the “biggest gaps in knowledge,” and states that this “lack of information severely hampers our overall understanding of the activities on the site.” (Rolingson 2012:3).

The lack of information about Mound A and Mound B is not a trivial problem to resolve. Mound A, the largest on the site, is a conical mound that stands approximately 15 m tall and covers an area of close to 7000 m$^2$, while Mound B, an 11.5 m tall rectangular platform mound covers more than 4000 m$^2$. The tremendous size and importance of these structures severely limits the effectiveness and feasibility of many research methods. Today limited resources continue to be a problem and the money and time required to conduct a large scale excavation of Toltec’s largest mounds would be enormous. Other considerations also render such a project untenable. The cultural, historical and archaeological importance of the mounds, and an interest in their preservation, makes such a destructive process as excavation an unreasonable method of data collection. Geophysical survey has long provided a means of addressing problems of this sort by allowing researchers to noninvasively collect data on sites that are too extensive, too difficult, or too valuable for excavation. As a result, magnetometry/gradiometry, electrical resistance/resistivity and ground penetrating radar (GPR) have become nearly standard tools in the archaeologist’s tool-kit. Unfortunately, the standard applications of these geophysical methods are not capable of penetrating to the depths required for a true exploration of any but the
near-surface features of Mounds A and B.

Therefore, to begin to resolve this problem, an alternative geophysical method known as Electrical Resistivity Tomography (ERT) or resistivity imaging, was chosen to research the mounds. A well developed method often applied to geological, engineering and hydrological problems, ERT measures the same physical properties as a standard archaeological resistivity mapping. However, while the standard method generally uses between four and eight electrodes, ERT imaging makes use of automated instruments to take measurements from dozens of electrodes and processes these much larger data sets using mathematical inversion algorithms (Papadopoulos et al. 2006). The method remains slower and more expensive than other standard archaeogeophysical methods, but is one of the only non-invasive techniques for penetrating more than a few meters below the surface. While examples of archaeological applications of ERT remain rare and its use is almost unheard of in the United States, there is a growing interest in its potential for solving specific problems as is demonstrated by the recent publication in *Archaeological Prospection* exploring a Coles Creek mound and plaza complex in southwestern Mississippi using ERT (Kassabaum et al. 2014).

Due to the limits of time and money, the window for research was restricted to a single week in March of 2013. Therefore, it was not possible to do a high resolution survey of both Mound A and Mound B, and so it became necessary to choose one as a primary research location. Both mounds were subject to investigation by Edward Palmer in late 1882 and early 1883, but the limited records of those excavations tell very little beyond the dimensions of his trenches and very rough descriptions of stratigraphy (Palmer 1990). In contrast the 1979 profile of the erosion cut on Mound B revealed five separate zones of construction with different mixtures of midden or mound fill in each (Rolingson 2012). It was hoped that evidence of these layers would also be evident in the ERT data, thereby providing a metric for comparing the geophysical results and the true stratigraphy. Furthermore, in the preliminary investigations of the site, it was proposed that Mound B
had not always been a platform mound, but perhaps was reshaped into a platform during its later construction phases (Rolingson 1982:62). In order to examine this hypothesis and utilize the most available information in the interpretation of the geophysical data, Mound B was chosen to be the primary study area for this research, while Mound A was a secondary area of less intensive study as time permitted.

Finally, following collection, cleaning and processing of the ERT data, several rectilinear anomalies were identified near the surface on the platform of Mound B. In order to further understand the context of these anomalies, in the Fall of 2013 a 20x26 meter grid was established covering the top of Mound B and surveyed using a Geophysical Survey Systems, Inc. SIR-3000 ground penetrating radar with a 200 Mhz and 400 MHz antenna, Bartington 601 dual fluxgate gradiometer and a Geoscan Research RM-15 electrical resistance meter. When combined, the ERT and other geophysical datasets allow archaeologists for the first time to begin to describe and interpret not only the previously unidentified surficial features, but also the internal structure of both Mound A and Mound B.

CULTURAL SETTING

A DISCUSSION OF TERMS

A brief discussion of the cultural and historical setting within which the Toltec Mound site was constructed and utilized is necessary for understanding the importance of the site, and is useful for the interpretation of the geophysical data. Unfortunately, archaeological terminology can occasionally be difficult to understand and manage due to the complex interweaving of time, space, and culture in the definition of periods and cultures. For these reasons, a proper examination of the context of Toltec Mounds requires first ensuring that temporal and cultural terms used in this discussion are defined for the purposes of this paper to prevent confusion. An example of one such source of confusion is the term “Late Woodland,” which Michael Nassaney (2000) notes is widely used in portions of the Eastern
Woodlands such as the midcontinental United States “where Mississippian culture developed,” but is only rarely used to describe sites in the lower Mississippi Valley.

Nassaney argues that areas less central to Mississippian development underwent a different sequence of changes and at different times than areas nearer the center of the development. Therefore, while temporally Toltec falls within the Late Woodland time period, assumptions about cultural activities believed to occur during this time period may not hold true. As a result, different terminologies have been created to describe the cultural and temporal sequence of the lower Mississippi Valley, such as the “Marksville—Baytown—Coles Creek sequence.” (Nassaney 2000). Despite the potential troubles of discussing Toltec in terms of the Late Woodland, it is still useful to discuss Toltec’s relationship to the greater Woodland Southeast and compare it to other cultures during a similar timeframe. Therefore, for the purposes of this research, the term “Late Woodland” will be used to designate the period between circa 300 and 1000 C.E, as it has been defined for the midcontinental United States by Emerson et al. (2000:p.3) in their anthology *Late Woodland Societies*. However, the term will not necessarily be forced to carry the full weight of cultural implications during this time frame as well, unless otherwise specified.

The more localized terminology discussed above is an excellent example of the intertwining of cultural, temporal and even spatial characteristics into a single designation. The Baytown and Coles Creek periods each designate specific ranges of times which overlap with the more general Late Woodland period. The Baytown period spans the years 400 to 700 C.E. while the Coles Creek period covers the years between 700 and 1000 C.E. In addition to their temporal definitions Baytown and Coles Creek are also archaeological cultures which denote specific settlement and subsistence patterns, technologies, social organizations, ceramic styles and spatial locations (Nassaney 1994). Therefore, while it is common for the term “Coles Creek” to be used throughout the Lower and Central Mississippi Valley to describe cultures between 700 and 1000 C.E, it is more appropriate to
only use this designation in the southernmost regions where the Coles Creek culture is located (Rolingson and Mainfort 2002:35). The more northern Toltec Mound site, and related sites are a part of the related, but separate, Plum Bayou culture.

At one time Toltec was identified as a part of the Coles Creek culture. This relationship, as well as its relationship to the Late Baytown and the site’s first dates, were all determined through the use of pottery (Rolingson 1982:87). By 1982, more than 90 percent of the potsherds recovered were of the type Baytown Plain. Most were simple vessels, and “Decoration, when present, is either a red film on the surface of the vessel or incision or punctation restricted to a narrow band of one or two lines on the rim and/or lip of the vessel,” and the most common variety, known as Keo, had only “a single line in the lip of the vessel.” (Rolingson 1982:87-88). This is significant because this single line is not common in the Lower Mississippi Valley, with Coles Creek culture sites more commonly having pottery with a wide rim or neck band of decoration. Similarly, the second most common decoration on the site is a new type known as Officer Punctated which has only one or two rows of punctations on the rim and is also uncommon in Coles Creek sites, while other common Coles Creek types are rare at Toltec (Rolingson 1982:88). The Plum Bayou culture is therefore distinguishable from Coles Creek largely due to its reduced frequency of decoration, and the lack of varieties common to Coles Creek sites (Rolingson 2002:57).

These distinctions continue with the combinations of decoration and red filming used on ceramics at Toltec, as well as an apparent increased interest in stone tools, with a surprisingly extensive use of quartz crystal (Rolingson 1982:89). Furthermore, the similarity between mound and submound pottery deposits appear to indicate a continuation of the local Baytown culture, rather than an intrusion by the southern Coles Creek culture who were previously believed to have built the mounds (Rolingson 1982:88). Ultimately, while it appears that the Plum Bayou culture made use of local influences, it combined elements from them in new and distinct ways, causing Rolingson to define it as a new and distinct culture. Therefore, rather than using the culturally specific term Coles
Creek to describe the primary period of construction and use of Toltec Mounds, the term “Terminal Woodland,” which Rolingson defines as the years between 700 and 1000 C.E, is more appropriate. (Rolingson 2012).

ARCHAEOLOGICAL INTEREST IN THE LATE WOODLAND

The Late Woodland archaeological period was essentially ignored by archaeologists for many years. When compared to the preceding Middle Woodland societies with extensive long-range trade networks and elaborate mound constructions, or the later Mississippian cultures with massive mound complexes such as Cahokia, and complex social interactions including institutionalized social stratification, the Terminal Woodland appeared vastly uninteresting. Nassaney (1994:45) notes that Baytown ceramics have elicited little interest in research because “the period is thought to mark a nadir in ceramic decoration and mortuary ceremonialism in the Lower Mississippi Valley.” Indeed, the persistent notion that there is little of interest to study from this period has been so powerful that it seems any discussion of Late Woodland cultures must, by necessity, begin with a discussion of Stephen Williams’ now ubiquitous evaluation of them as “Good Grey Cultures.” (Emerson et al. 2000:3). Gradually, however, this perception has begun to change.

As initial interest in the period grew, the focus was not truly the Late Woodland. Rather, researchers began to recognize the need to better understand the transition between the Middle Woodland and Mississippian Periods (Emerson et al. 2000). It seems the tacit assumption had always been that there had been a wholesale collapse in the Middle Woodland way of life, out of the ashes of which arose the great Mississippian cultures. Archeologists were beginning to recognize that the many causes and manifestations of these events, and the variations therein, remained essentially unexplored and untested. The increase in Late Woodland research, however, was only partially driven by an increased academic interest. Separate from the theoretical interest in studying the transition, an increased nation-wide emphasis on Cultural Resource Management forced
the examination of Late Woodland sites and led to a recognition of the period’s importance in its own right. By requiring researchers to record all sites encountered, Late Woodland sites were no longer systematically excluded from excavation as they were when the sites examined were determined solely by research interests (Emerson et al. 2000:3). Instead, they were documented and researched as they were discovered in the path of modern development and it rapidly became clear that sites from this “transitional” period were numerous, diverse and likely worthy of additional study.

Furthermore, while historically much research was focused on hunter-gatherer and chiefdom-level societies, in recent years researchers have recognized that understanding tribal societies, such as those in the Late Woodland, may be crucial to an understanding of the rise of political complexity and social hierarchy (Emerson et al. 2000:4). The combination of increased data from cultural resource management projects and increased theoretical interest in understanding the formation of institutionalized social inequality and complexity has created a remarkable increase in theoretical and research efforts in the Late Woodland (Emerson et al. 2000:4).

THE LATE WOODLAND

Whenever discussing the Late Woodland, it is important to realize the effects of such a long period of insufficient theoretical research. The lack of data to define cultural sequences across a region, and the lack of interest in creating and debating robust theoretical models, has led to a somewhat haphazard interpretation of the archaeology left by Late Woodland societies (Emerson et al. 2000:4). Interpretations therefore may be contradictory and greatly dependent on the theoretical foundations with which the researcher is approaching the data. Emerson et al. (2000) note that depending on the research, Late Woodland populations, interactions between communities, social complexity and inequality are each simultaneously described as both increasing and decreasing, and these trends may then be used to defend nearly whatever position is desired. In addition to theoretical differences, it
is also important to note that Late Woodland cultures were greatly variable, and so “any attempt to characterize Late Woodland societies across the entire Southeast requires gross generalizations about Native societies that were in reality historically and culturally diverse” (Nassaney 2000:717). This diversity may also help to explain the wide range of interpretations given to data from societies determined to be from the “Late Woodland.”

Despite the diversity of cultures and interpretations of the data concerning them, Emerson et al. (2000:4) suggest that it is still possible to discuss three major cultural “transformations” that occurred in many areas during or around the Late Woodland period which appear to be consistently present across much of the landscape, if not to the same degree or with the same consequences in all locations. Though not expressed equally, or at all, everywhere, these transformations do provide a larger context within which it is possible to better understand the Terminal Woodland and Toltec Mounds. The first major transformation was a marked demographic shift and change in population distribution, which is recorded as changes in settlement sizes and patterns (Emerson et al. 2000:13). This marks the end of the Middle Woodland societies and the beginning of those in the Late Woodland. The second transformation is the widespread adoption of the bow and arrow, which occurred around 600 C.E and likely had significant impacts on the dynamics of power, community interaction and population growth (Emerson et al. 2000:14-17). Each of these transformations have clearly occurred during or before the creation and use of Toltec. The third and final transformation, the increased use and dependence on maize, does not seem to have occurred at Toltec during the terminal woodland (Emerson et al. 2000; Nassaney 2000; Rolingson 2002). It is possible that maize was reserved for elite members of society, or for important occasions, and so was not widely adopted (Fritz 2002). In any case, the apparent lack of dependence on maize should not be interpreted as a lack of agricultural capability or complexity as there is evidence of widespread use and cultivation of native seeds (Fritz 1990).
In the early portion of the Middle Woodland, about 300 C.E, it seems there was a major shift in demographics. Whether that shift manifested itself through a dramatic increase or decrease in population, or simply a shift in population distribution, for example from lowlands to highlands, is debated. Indeed the answer may be somewhat dependant on the location and scale of the area studied (Emerson et al. 2000:14-17). In any case, it does appear that the American Bottom was largely abandoned near the end of the Middle Woodland, and did not begin to be re-populated until some 250 years into the Late Woodland. It has been suggested that a climactic event such as persistent increased rainfall may have caused “changes in water flow, timing of flood events, and water table level,” which may have driven societies out of the river valleys and up to higher ground (Emerson et al. 2000:14-17). The resulting shifts in subsistence and economic patterns could have contributed to the eventual collapse of the “Hopewell Interaction Sphere” and a decrease in the long distance connections and community interactions that were representative of the Middle Woodland. (Emerson et al. 2000:14-17). If such is the case, it may be possible that similar changes were occurring in the Arkansas River Valley as well.

The degree to which widespread communal interaction decreased during this time has also been the subject of some debate. While it is generally accepted that the Middle Woodland cultures had greater interaction and scope than those of the Late Woodland, there is also evidence for widespread stylistic elements in the early Late Woodland (Emerson et al. 2000:14-17). One potential explanation for these widespread similarities, even in the face of lessened interaction, is that as cultures expanded from their river-valley centers at the end of the Middle Woodland, they rapidly dispersed very similar styles to their now enlarged geographic areas (Emerson et al. 2000:14-17). As this transition occurred, settlements appear to have changed from relatively large and long-term, to much smaller and more temporary arrangements. This pattern is also reflected across the broader Southeast, though perhaps it occurred to a lesser extent here than it did in the
Midwest (Nassaney 2000).

It is partially due to these shifts that accurate estimation of the population change from the end of the Middle Woodland to the beginning of the Late Woodland is such a challenge. The shift from dense, long-term, lowland habitations to scattered, small, and temporary highland settlements makes comparisons between sites and population density very difficult (Emerson et al. 2000:14-17). The matter is further complicated by the fact that in a general movement from river-valleys to surrounding highlands, the population change will be largely dependent on where one’s research is focused. The floodplain should see a dramatic decrease in population, while the bluffs and surrounding upper valleys should see a marked increase. Therefore, the region and the scale of the study would likely determine whether population was interpreted to be increasing, decreasing, or if both river-valley and bluffs were included in the study area, perhaps roughly static.

ADOPTION OF THE BOW AND ARROW

The second major transformation to occur during the Late Woodland Period is the widespread use of the bow and arrow. It is likely that the arrowpoint, and by extension one may assume the bow and arrow, were introduced to the Mississippi Valley from outside of Arkansas, as a lack of transitional forms between dart and arrowpoints suggest the arrow was not derived from the dart (Nassaney 2000). The technology may have been available during the Middle Woodland, but it was not until sometime around 600 C.E that it was generally adopted (Emerson et al. 2000:17-18). Once it was adopted, however, its use was widespread and sudden. When examining the other transitions, it seems that they occurred later in the Central and Lower Mississippi Valley area which Nassaney (2000) refers to as the “periphery” than they did in the Midwest, which later became a core of Mississippian culture. However, this is not the case for the adoption of the bow, which suddenly arrived in the Mississippi Valley during the Baytown period, around 600 C.E, just as it did in the American Bottom (Nassaney 2000). It is not clear whether the increased
hunting capabilities or the value of the bow as a weapon against competing tribes is what
drove its rapid proliferation, but it does appear that the new technology spurred
population growth as the American Bottom and other previously abandoned regions were
suddenly reoccupied (Emerson et al. 2000:17-18). Increased use of domesticated native
crops may have further driven population expansion and helped to encourage these
populations to move back to flood plains Horton (2014). The rapid population growth,
sudden expansion back into the floodplains, potential of new weaponry for warfare, and
social implications of increased nucleation and defensive settlements makes the
introduction of the bow perhaps one of the most interesting transformations to occur
during the Late Woodland. It is vital for understanding the creation of later complexity

ADOPTION OF MAIZE

The third transformation Emerson et al. (2000:p. 18-21) identified during the Late
Woodland period is the widespread adoption and reliance on maize for the first time
around 800 or 900 C.E. Populations appear to have continued to increase wherever corn
was adopted and as settlement sizes increased, population density and social complexity
also grew (Emerson et al. 2000:18-21). Indeed at one time it was believed that the
widespread adoption of maize was synonymous with the rise of agriculture. In turn, it was
argued, there was a need to manage new large agricultural fields, food surpluses and
deficits, and utilize military strength granted through bows and arrows. This explanation
suggests that maize was a primary factor in the creation and shaping of the complex social
and political hierarchies that characterized the Mississippian period (Fritz 1990).

Archaeological data shows some critical problems with this narrative. Perhaps the
most fundamental flaw is the association of agriculture solely with the production of maize.
To the contrary, sumpweed, little barley, maygrass, chenopod, knotweed and other plants
appear to have been cultivated in the eastern woodlands for as much as two thousand of
years prior to the introduction of maize (Fritz 1990). In this sense, agriculture was hardly a new concept to the people of the eastern woodland, and it would seem difficult to describe the increase in social complexity as being resultant primarily from a need to manage new field systems (Fritz 1990). Starchy seeds likely formed a significant portion of the diets of eastern woodland peoples prior to the introduction of maize and indeed appears to have continued to do so for some time after its introduction in some locations (Fritz 2002).

Excavations at Toltec and the surrounding areas show that maize is present in the region as early as 750 C.E, but it does not appear to ever have become a primary source of food for Plum Bayou peoples (Rolingson 2002). In most instances maize dating to this period is only found in very small quantities. One exception to this is in flotation samples taken from Mound S at Toltec in the late 1980s and early 1990s, however, further evaluation and dating of these samples indicate that the increased concentration of maize resulted from an intrusive Mississippian deposit (Fritz 2002). It has been proposed that Plum Bayou people’s apparent limited use of maize may indicate that it held a particularly special symbolic or status connotation (Fritz 2002). However maize has been found in a variety of contexts throughout the region, including some small midden sites containing even more maize than the deposits at Toltec. This led Rolingson (2002) to suggest that it does not seem maize was being reserved for an elite class, or controlled through a social hierarchy. It is possible that corn was not widely adopted by the Plum Bayou people simply because it was as Fritz (2002) describes, ”a finicky crop requiring more attention and processing time than most farmers wanted to invest.”

Rather than adopting maize as a primary food source, Plum Bayou people appear to have made extensive use of various native cereal grains (Fritz 2002). The predominate type of food plant found at Toltec is a seed of unknown origins denoted simply “Type X grass.” Other grains such as little barley, and maygrass, in addition to squashes, bottle gourds, sunflower, sumpweed, thin-testa chenopod, and erect knotweed were likely also cultivated, and wild or managed oak and hickory trees provided acorns and hickory nuts, all of which
also appear to have remained fundamental elements in the people’s diets (Fritz 2002; Rolingson 2002). The ubiquity and persistence of native seeds and evidence of their agricultural production prior to and even following the introduction of maize is one of the phenomena that make Toltec such an interesting site. Far from rapidly becoming a primary food crop, maize was only nominally produced while native seeds continued to be cultivated at a much greater scale. In this case at least, it seems the model of maize as a primary driver for cultural change must be rejected. As Fritz (1990) remarks, ”there are no grounds for correlating intensification of maize agriculture with the social changes that took place at the beginning of Coles Creek and Plum Bayou cultural development.”

TOLTEC AREA SEQUENCES AND CULTURES

As previously discussed, the transitions and transformations that took place across the greater Eastern Woodland were not the same everywhere. The variations between cultural adoptions and sequences of the Arkansas Valley, central and Lower Mississippi Valley, the Midwest, and other regions of the Eastern Woodlands during the Late Woodland period make it necessary to also present the local cultures and time-frames outside of the larger context.

BAYTOWN PERIOD

Baytown period sites are quite common across central and eastern Arkansas. They are identifiable by the presence of Baytown Plain, Mulberry Creek Cord Marked and Larto Red ceramics (Nassaney 1994). Baytown Plain is the most common ceramic type by far, commonly representing more than ninety percent of all ceramics recovered from a Baytown Period site. Part of the reason for its ubiquity may be that the definition for Baytown Plain ceramics is so encompassing, including “all plain post-Tchefuncte and pre-Mississippian grog-tempered ceramics.” (Nassaney 1994:45). The Baytown Period is often thought of as a period of decline from the earlier stylistic and mortuary complexity of
the Middle Woodland. In the Central and Lower Mississippi Valley this pattern is not as clear because mortuary mounds and decorative ceramics were not common even prior to Baytown. It appears, that the shift from Middle to Late Woodland in these regions was more of a continuation of previous styles and cultures (Rolingson and Mainfort 2002:31). Mortuary mound building certainly persisted with examples such as Pinson Mounds (Rolingson and Mainfort 2002:30-31). The Baytown mound site is the largest mound site between Toltec and the Mississippi river, and is considered the type site for the Baytown culture despite relatively little research having been done there (Nassaney 1994). The use of the Toltec Mounds site began in the Late Baytown period and the foundations of the Plum Bayou Culture are rooted in the Baytown culture, but major construction on the mounds appears to have been completed primarily during the Terminal Woodland period by the Plum Bayou people (Rolingson 2002:45).

PLUM BAYOU

The Plum Bayou Culture, responsible for the construction of Toltec Mounds, gets its name from an abandoned channel of the Arkansas River now known as Mound Lake, itself named for the Toltec mounds which lie along its shore (Rolingson 2012). Between 1988 and 1990, Michael Nassaney investigated an area with a radius of 20 kilometers around Toltec in a research effort known as the Plum Bayou Survey Project. At this time he also identified a research area of approximately 100 kilometers around Toltec, which roughly aligns with the extents of relevant varieties of Coles Creek Incised ceramics (Nassaney 1994). Plum Bayou sites therefore have been identified across a wide region including portions of the Arkansas Lowlands, West Gulf Coastal Plain, Ouachita Mountains, Arkansas River Valley, Ozark Plateau, and Mississippi Alluvial Plain, though the extent of Plum Bayou activity in all of these regions is not clear (Rolingson 2002:45). These sites may be simple middens or contain single households, multiple households, multiple households with a single mound or, as in the case of Toltec, a multiple mound center (Rolingson 2002:46).
The material culture of the Plum Bayou is best described through a distinctive combination of styles used in the production of ceramics, and an increased interest in lithic technologies despite the lowland’s lack of stone sources (Rolingson 2002:56). Despite limited resources, stone is highly visible in the Plum Bayou cultural deposits. Some of these materials were acquired in the Ouchita Mountains was used, but particularly of interest is the culture’s extensive use of quartz crystals for the production of tools (Rolingson 2002:56). This use of quartz is one of the diagnostic elements of Plum Bayou culture. Plum Bayou pottery is generally simple and grog tempered, though bone or shell tempering is not unknown in the region (Nassaney 2000:181). Though decoration is rare and limited when present, diagnostic types for the Terminal Woodland include Coles Creek Incised and Officer Punctated. Also, it is not uncommon for Plum Bayou ceramics to be decorated with a red-filming (Rolingson 1982:88). This particular combination of ceramic styles is the foundation on which the archaeological culture is built and understood.

EARLY MISSISSIPPIAN

While many of the surrounding cultures saw growth, expansion, and increasing complexity following the Terminal Woodland period, the Plum Bayou culture seems to have rapidly declined and disappeared after 1000 C.E (Rolingson 2002:65). The exact reason for this collapse is not clear, but it is apparent that by 1000 C.E. mound construction at Toltec and Coy mound sites had ceased. The region was essentially abandoned until it was resettled later in the Mississippian sequence by cultures that cannot be directly connected to the creators of the mounds (Nassaney 1994).

HISTORICAL OCCUPATION AND RESEARCH

Developing an understanding of the historical occupation of Toltec Mounds and the surrounding areas is vital for understanding the current state of the structures. Farming, erosion, construction and excavation took place on all of the mounds and recognizing these
activities in the archaeological record allows the researcher to understand more of the historic life on the site, as well as determine the effects of these activities on the mounds. Only by fully understanding these effects is it possible to begin to interpret the palimpsest that occurs with the use and weathering of the site.

HISTORICAL LAND USE

The earliest documents relating to historic occupations in the area of Toltec are in reference to its Quapaw and French residents who were removed in 1833 after an 1818 treaty gave the land North of the Arkansas River to the United States government (McMullan 2001). Much of the land around the site was divided among land speculators, who apparently did not make improvements or pay taxes. The first taxes paid on the land that later became Toltec Mounds Archeological State Park were paid by William P. Officer in 1848, who resided with his wife Mary Eliza Officer and their son Eustis Feild Officer in Little Rock (Rolingson 2012). On June 21, 1851, William Officer died and left all of his land to his wife, who continued to expand her land holdings, and who’s letters are the primary source for knowledge about activities on the site during the following fifty years. (McMullan 2001).

On March 14, 1857 Mary Eliza married Gilbert Knapp, and while the family continued their residence in Little Rock they also continued to expand Lake Mound Plantation as it was now known. (Rolingson 2012). It was not until after the Civil War that a house was constructed and the Knapps themselves were at least part time residents of the site while continuing ownership of their house in Little Rock (McMullan 2001). In spite of this and the fact that in 1860 the Knapps paid taxes on 1,200 acres of land and only two slaves, Mrs. Knapp indicates in her letters that the plantation had been cultivated since soon after her acquisition of the land, even reporting harvesting “more than a bale of cotton” from one of the larger mounds (Rolingson 2012:13). The extent of the agricultural activity on the site remains unclear. It seems likely that they hired a manager, and leased slaves. Therefore the clearing and farming of the land may have been quite extensive
(Rolingson 2012). The long-term agricultural activity on the site certainly played a role in the deterioration of the mounds and other earthworks through ploughing and erosion as noted in Mrs. Knapp’s letters.

The Knapps continued to expand and diversify their farming activities. In 1874 Gilbert Knapp paid taxes on one mule, but by 1877 he owned 10 mules. Two years later in 1879 a mortgage record reports that the Knapps owned eleven mules, a gin, a store, and a corn mill, as well as corn and cotton crops (McMullan 2001; Rolingson 2012). In 1891 the Knapps landholdings had reached 1,428 acres and by this time the property included 10 houses, including one near Mound G (Rolingson 2012). With the new railroad running past the eastern end of Mound Pond in 1888, Gilbert Knapp and Eustis Officer established the town of Toltec and opened a Post Office (Rolingson 2012). It was at this time that the name Toltec was first published in relation to the site area, as it appears that Gilbert Knapp named the town in honor of those he believed had created the mounds (Jeter 1990).

Throughout the Knapp’s ownership of the Mounds it appears that Mary Eliza Knapp, known for her intellectual curiosity, was fascinated by the mounds, writing in her letters about the site in 1876, “We were attracted to the place by the immense artificial Mounds and a wall similar to our Levees about six to ten feet height enclosing 90 acres or rather coming around a half circle to the Lake bank.” (Rolingson 2012:13). Dr. William H. Barry, who was a physician in Hot Springs, forwarded a description of the site to Joseph Henry, Secretary of the Smithsonian Institution. Mrs. Knapp continued to send letters and artifacts to Joseph Henry and these letters represent the earliest available descriptions of the site (McMullan 2001).

Other researchers also began to show interest in the site. Edwin Curtiss, from the Peabody Museum of Harvard University, visited Toltec Mounds in 1879. After meeting with the Knapps in Little Rock, he continued to “Mrs. Knapp’s farm,” arranged with the man who was sharecropping the land to pull some of the cotton and “explore” the mounds with some hired help (Rolingson 2012:17). Curtiss noted that one of the mounds “had been
Tilled for many years and was somewhat worn down by constant ploughing and had yealded [sic] many things,” while some other mounds “had been ploughed level with the Surrounding bottom.” (Rolingson 2012:17). The next day a letter from Knapp arrived forbidding Curtis to dig in any of the lands that had been planted, giving him permission instead to dig in the mound that was near the quarters. Curtiss drew a map of the site, which shows the quarters near Mound G and three other adjacent small buildings, but feeling that he would not find anything of interest in Mound G, he declined to excavate (Rolingson 2012).

In 1881 Edward Palmer began his mound explorations work for the Bureau of Ethnology. On Christmas Day, 1882, Palmer and Henry J. Lewis, an African American artist from Pine Bluff made their first visit to the Knapp Mounds (Jeter 1990). After a few days of surface collections and sketches, they moved on to other locations in the region. Palmer was soon ordered to return by Cyrus Thomas and conduct excavations, which he did January 15th of 1883 (Jeter 1990). During these excavations, Palmer dug into five of the mounds on the site, including the two largest, Mound A and Mound B. This report could be quite valuable, as it provides one of the only descriptions of the stratigraphy of these two mounds. However, Palmer’s notes must be considered with caution. His initial report describes the largest mound as being 100 ft. high and nearly square, and the second as being 75 ft. tall with a prominent squarish front (Palmer 1990). Clearly these measurements are much too large to be the true dimensions of the mounds, and while it appears clear from Lewis’ sketches that Palmer was indeed correctly referring to Mound A as the largest mound, Mound A is not in fact nearly square. Palmer’s measurements were so clearly wrong that Thomas ordered him to return to the site a third time and repeat the measurements, which he did in July 1884 (Jeter 1990). Even so, his survey results were poor enough that in August of 1890 William H. Holmes from the Bureau of American Ethnology remeasured the mounds for Cyrus Thomas once more. (McMullan 2001). It was the William Holmes illustrations of the site that Thomas decided to publish in the report.
of the bureau’s mound explorations in 1894 (Rolingson 2012). Clearly, the accuracy of Palmer’s notes leaves something to be desired.

Imprecise and rough as they may be, descriptions of the stratigraphy of Mound A and Mound B are too tantalizing to ignore. In his notes he describes digging a trench in the summit of the largest mound, which he records as 8 ft square. He describes the stratigraphy of this trench saying “At first were 2 ft. of vegetable mould, in which were mixed some animal bones & pieces of pots. Then for 8 ft. was sandy loam which became so hard that at 10 ft. solid clay was struck & I could go no further.” (Palmer 1990:257). He also reports a trench from a relic hunter in the back of the mound with the same soil conditions and mentions digging his own trench in the side, “midway between the top & the base” and reports the same sandy loam (Palmer 1990:257). At the summit of Mound B, Palmer describes digging another shaft 8 ft. wide and 10 ft. deep. “At first was 2 ft. of black sticky clay. In the centre of this cut were found 2 fine crystals [...] At 2 ft. the soil changed to a yellow greasy clay which continued for 8 ft. when it became too hard to work. There were no indications of change, & nothing showing human occupation was found in this formation.” (Palmer 1990:257-258). He also reports the exterior of the mound as being composed of the same greasy clay, and that the top of the mound was “cultivated as a garden for years.” (Palmer 1990:258).

The first map of the site was drawn by Henry Lewis, and shows dwellings in the vicinity of Mound G and Mound S with fences and outbuildings apparently associated with each (Palmer 1990; Rolingson 2012). Little more is known about what structures may have existed on the site and none of the plantation buildings are labelled on the map. Palmer does mention, however, that the Knapps had a house on the property in a very contrite letter to Thomas explaining his failure to excavate at the Knapp mounds on his first trip to the site. Specifically, he describes the house at which he was staying while working as very cold, and states that “when Mr. Knapp goes to his farm he takes Survants and stops at his own house, closeing it up when he leaves it for Little Rock” (Palmer 1990:283).
Eustis Officer died on May 29th, Gilbert Knapp died August 13th of 1900 and on March 23, 1905, Mary Eliza Knapp also died. Following her death, the Lake Mound Plantation was sold by her executors to William R. McLaughlin on September 2 1907 (Rolingson 2012). McLaughlin owned a general store at the town of Toltec, and his three sons were the postmasters at the post office until it closed in 1932 (Rolingson 2012). Despite continuing to farm the land, McLaughlin did attempt to ensure the site’s preservation by deeding the land to his three granddaughters, two of whom were under-aged, and including provisions that Toltec should be protected by either the state or federal government and should only be explored under skilled supervision (Rolingson 2012). Indeed, early in the twentieth century interest in the preservation of Toltec Mounds was growing. By the mid 1930’s recommendations were submitted for giving the site National Monument Status, but they never made it out of committee (Rolingson 2012). In June of 1940 Toltec was recommended by the Arkansas State Planning Board for state acquisition and preservation as a monument and the Works Progress Administration documented the current status of the site noting that the “top of one of the mounds is still used for a garden.” (Rolingson 2012:24). Despite the recommendation by the WPA to create a state park out of a portion of the site, appropriate funding was not available and the effort failed (Rolingson 2012). Furthermore, without Mrs. Knapp’s interest, or the interest of researchers in exploring the mounds which C.B. Moore found unlikely to produce museum quality artifacts (Moore 1908), serious formal archaeological interest in the mounds languished for several decades.

While archaeological activity slowed and preservation efforts stalled, other forms of activity on the site unfortunately did not. By 1921 a road cut across the southern portion of the site, there were two houses outside the site enclosure to the east, and another inside the enclosure, just to the south of the road (Rolingson 2012). Locals also report that Mound D was used as road fill at some point, and a mule-drawn scoop was used to cut into the southeast corner of Mound B, perhaps during levee building (Rolingson 2012). There
are no documents of either of these occurrences, and stories of what was found by the mule-drawn scoop are inconsistent. Some local lore claims logs and artifacts were discovered, while others claim that nothing was found (Rolingson 2012). What is known for certain is that in 1979 the southeast corner of Mound B did have a severe erosional gully, which was stabilized by the Division of Parks at that time (Rolingson 1982).

In July, 1938, just prior to McLaughlin’s death on October 8, 1938, the Union National Bank of Little Rock sold the mortgage on the eastern portion of the site for unpaid debts and taxes (Rolingson 2012). William G. Alexander, a neighboring landowner purchased this land and grew primarily soy, also growing some rice in the 70’s, until it was purchased by Arkansas State Parks in 1975 (Rolingson 2012). During this nearly forty year period, seven aerial photographs including the site were taken by the Soil Conservation Service, one by the Corps of Engineers, and two by the Arkansas State Highway and Transportation Department, which serve to document the changes and destruction of the site (Rolingson 2012). Around 1940 a road was constructed along the Alexander side of the property boundary, and a house and outbuildings were built on the embankment. Between 1950 and 1955 an irrigation ditch and water well were installed, and by 1959 Mounds G, H, and I were intentionally levelled while the Mounds J and K also cease to be visible in the aerial photography (Rolingson 2012). Three tenant houses were built along the lake bank between 1964 and 1968. Prior to this period a borrow pit was visible to the northeast of Mound B, but sometime between the 1964 and 1968 aerial photographs this was filled in and according to local lore the remains of Mound G were used for this purpose (Rolingson 2012). The house on the embankment was also abandoned by 1968.

Following McLaughlin’s death, his son George began to sell and lease parcels of the land not sold by the bank (Rolingson 2012). In 1940 a house and outbuildings were built on Mound D and between 1943 and 1952 each of McLaughlin’s granddaughters sold off their portions of the land to T.J. and M.M. Richardson who lived in the house (Rolingson 2012). The Richardson primarily kept the land as pasture with a portion used for row
crops in the 1950’s. They also constructed a tenant house south of Mound C which was abandoned by 1958 and at some point between 1959 and 1964 they filled in a natural drainage between Mound C and Mound S, perhaps with a portion of Mound S itself (Rolingson 2012). In 1972 the Richardson sold the land to Bobby C. Jones. Jones rebuilt the house after it burned around 1973 and finally sold the property to Arkansas State Parks in 1975, by which time a small borrow pit north of Mound C had also been filled (Rolingson 2012). By the time the land was purchased by Arkansas State Parks, only the three large mounds and a faint hint of the embankment remained visible (Rolingson 2012).

In summary, the period after about 1940 and before the purchase of the site for the creation of the park in 1975 was a very destructive one for the Toltec Mound Complex. Increased construction and more intensive agriculture techniques led to the destruction of much of the embankment and ditch, while many of the mounds and other cultural features were levelled, some intentionally. Toltec Mounds was a much different site by the end of the twentieth century than it was at its beginning, despite efforts at preservation beginning as early as the late 1920s and early 1930s (Rolingson 2012). Any interpretation of the archaeology at the site therefore must be undertaken with a consideration not only of the prehistoric activity that occurred there, but also of the historic activity and destruction that occurred. It is not necessarily safe to assume that anomalies or even the forms of the structures are solely the result of one period or the other, but rather are the sum of activities at both and the erosion of as much as a thousand years.

HISTORY OF RESEARCH

Following the creation of Toltec Mounds Archeological State Park, research, preservation and the development of the park became primary goals of activity on the site. One of the first research goals was to identify and map the locations of any archaeological features visible on the ground surface, while one of the first preservation and park development goals was to cover the bare cropland with Bermuda grass (Rolingson 2012). Therefore, in
1976, the eastern portion of the site was plowed and disked, and the same was done to the western portion of the site in 1977, though with greater difficulty. This prepared the site for grass by removing rice levees and vegetation, and allowed archaeologists to systematically walk the area, mapping artifact concentrations and regions of darker soil. As a result of this effort, the locations of nine mounds and the embankment were revealed on the eastern half of the site (Rolingson 2012).

Between 1977 and 1980 major excavations were undertaken every year. In 1977 the University of Arkansas Museum and the Arkansas Archeological Survey conducted a field school on the levelled Mound D, and excavations were completed to clear the way for the new location of the county road to the south of the park (Rolingson 2012). In 1978 many new projects were undertaken, including the creation of the permanent grid, the beginning of a random sampling regimen and testing to clear the way for a new county road to the south of the site (Rolingson 2012). Furthermore, Mound D and portions of the embankment on the eastern side of the site were excavated. In 1979 further testing was done to prepare for park development efforts such as the construction of the Visitor Information Center and the construction of the board walk, and the excavation and filling of the erosion gully in Mound B (Rolingson 2012). The random sampling process also continued in 1979 and Mound E was tested for the first time.

In 1980 the first attempt was made at using geophysical techniques on the site with the use of proton magnetometry. The goal of this work was to try a new strategy for testing the site, as the random sampling process was inadequately slow and unproductive (Rolingson 2012). Excavations that year also slowed as the Visitor Center was completed and it was necessary to construct exhibits and interpretive material. Nevertheless there was still a 12 week summer excavation testing anomalies identified by the magnetometer survey. Finally, areas outside the embankment were tested to make way for the park maintenance complex (Rolingson 2012).

After these efforts the pace of excavation continued to slow as the data collected the
previous years were processed and analysed (Rolingson 2012). Field schools and training programs were still occasionally held at the site, but the research focus began to expand to the surrounding region in an effort to understand the cultural context outside of the ceremonial center in what became known as the Plum Bayou Survey Project (Rolingson 2012; Nassaney 1994). In recent years, Rolingson’s primary research efforts have been the analysis and publication of the data collected since 1975, culminating with her most recent publication *Toltec Mounds: Archeology of the Mound-and-Plaza Complex* (Rolingson 2012).

METHODOLOGY

In order to begin exploring the creation, structure, changes and damage undergone by Mound B and Mound A at Toltec, without significantly contributing to further changes or destruction, a geophysical survey was truly the only method available. To this end, an electrical resistivity tomography survey was conducted on both mounds. A single survey with a single instrument was, as usual, insufficient to offer a full interpretation, and so a secondary survey using ground penetrating radar, gradiometry, and electrical resistance was completed on the platform of Mound B. In order to better understand and interpret the datasets collected, it is useful to first discuss the theoretical background and the specific methodologies used, to better understand what features one may or may not expect to discover and interpret through this research.

THEORETICAL FOUNDATIONS OF ELECTRICAL RESISTIVITY

All materials resist the flow of electricity to varying degrees. Certain soils such as dry sands have a very high resistance, while others such as clay often have a relatively low resistance. The amount of interstitial water the soils retain has a strong effect on their resistance to electricity, and chemical properties such as the presence of free electrolytes may also have an effect (Gaffney 2003). Electrical resistance, or resistivity, surveys make use of the variation in water retention, salinity, and material resistance to electrical flow, to
identify regions with significantly different resistances from the background matrix. By mapping these variations across an area, it is hoped that resulting anomalies may be interpreted to reveal archaeological features.

Many archaeological features of interest may express variations in electrical resistance. Ditches, pits, drains and metal pipes likely will appear as low resistance anomalies either due to their collection of water, or the conductive or resistive nature of the material itself. Areas of compaction such as pathways, roads, or house floors, as well as features such as stone walls or coffins may exhibit high resistances (Gaffney 2003). It is important to note however, that a feature may not exhibit resistance variations in the same way from context to context, or even from time to time. As suggested above, a feature such as a ditch may collect more water than the surrounding matrix shortly after a rain, resulting in a relatively low resistance. However, the ditch may also aid in the draining process, and so retain less water than the surrounding matrix, resulting in a higher resistance value during a dry period. In some circumstances, a ditch, as it dries, may not even be visible to a resistance survey as there is not a contrast in the resistance between the material out of which the ditch is dug, and the ditch’s fill. Therefore, a ditch may present as either a high resistance anomaly, a low resistance anomaly, or not be present in the data at all depending on the context and the time the measurements were taken.

Another example of the variety of ways an archaeological feature may express itself in a resistance survey is demonstrated when measuring an impermeable material, which may generate a high resistance measurement under normal circumstances due to the low amounts of interstitial water. However, water pooling on the surface could alternatively result in a lower reading (Gaffney 2003). Due to these variations, when possible it is advisable to do a resistance survey on the same area under different conditions, in order to increase the likelihood of identifying anomalies which may not be visible in all conditions. Finally, it should always be remembered that any geophysical survey depends on the contrast between the target and the background physical property. If such a contrast does
not exist, it will be impossible to identify the feature from the survey.

MEASURING RESISTANCE

Instruments used to measure the electrical resistance of a material, whether it is a standard archaeological instrument such as the Geoscan RM-15 electrical resistance meter or a resistivity imaging instrument such as the Syscal Pro Switch 96 used in this research, do so by passing an electrical current, denoted $I$, through the material of interest, and measuring the voltage drop, denoted $V$, that occurs as electricity flows through the measured region. Through the use of Ohm’s law $V = IR$ it is possible to solve for resistance by

$$R = \frac{V}{I} \quad (1)$$

In a standard geophysical survey four probes, also called electrodes, are used to transmit current and measure voltage. Two of the probes are used to pass current through the ground and are designated A and B, with A representing the current source and B representing the current sink. The other two probes are then used to measure the voltage drop over a distance and are designated probes M and N (Tsourlos 1995).

These probes may be arranged on the ground surface in a nearly unlimited variety of ways, but there are several standard configurations, known as arrays, that are most common due to their properties and the ease of determining probe placement. There are two major classes of arrays. The first is comprised of those arrays that utilize all four probes in close proximity, while the other is comprised of arrays that place one or more probes in a remote location. Arrays of the first type, with all four probes near to each other are not capable of recording measurements as deep as those with remote probes. This lack of depth, however, is contrasted with their increased vertical resolution (Tsourlos 1995). Various arrays may also be better or worse when considering the signal to noise ratio, or ease of interpretation of the results. Therefore, it is important to consider the
needs of the project to properly select an appropriate array, and no single array will be best in all circumstances. There are far too many arrays and too many features of each array to provide a comprehensive discussion of them here, but it is worth examining a few properties of some of the most commonly used arrays.

Perhaps the simplest way of arranging the four electrodes is to place them in a line with equal spacing between each probe with the probes for measuring voltage placed between the probes transmitting current. This arrangement, known as a Wenner array, has a very good signal to noise ratio and ability to resolve horizontal layers. Unfortunately, the lateral resolution of the Wenner array is quite poor (Tsourlos 1995). Furthermore, the results of a survey completed with a Wenner array can be quite difficult to interpret as anomalies may be depicted in non-intuitive ways. As the array travels over a wall for instance, the outermost current probe will pass across the wall first, causing the resistance measurement to increase. Once the first voltage probe passes over the wall however, due to the geometry of the array the resistance will appear to drop quite low until the second voltage probe passes past the wall, creating a rise in the measured resistance again. This double response over a single feature can make interpretation of resistance mappings quite difficult.

The array that is most commonly used for archaeological purposes is the twin-probe array. This array places one of the current electrodes and one of the voltage electrodes, $B$ and $N$, at a great (theoretically infinite) distance from the survey area while the remaining current and voltage electrodes $A$ and $M$ are used at a set distance from each other and used to survey the area as mobile electrodes. This technique can penetrate quite deeply with narrowly spaced mobile electrodes, creating excellent horizontal resolution, but has a very poor vertical resolution (Tsourlos 1995). This makes the twin-probe array a very good array for most shallow archaeological prospection, but it is not ideal for deeper exploration.

The dipole-dipole array places the two current electrodes $A$ and $B$ a great distance from the two voltage electrodes $M$ and $N$, but keeps the current and voltage electrodes
close to their pairs. This technique allows for good depth penetration and also has quite
good horizontal and vertical resolution, however it has a very poor signal to noise ratio
(Tsourlos 1995). For these reasons, this array is very good for many deeper explorations,
except for in relatively noisy environments.

The final array to be discussed here is the pole-dipole array. This array places the
two voltage electrodes $M$ and $N$ near each other, and one current electrode, for instance $A$,
relatively nearby and in the same line. The remaining current electrode is theoretically
placed an infinite distance away. In practice this probe is located at as great a distance as
possible, to minimize error from the assumption of infinite distance. This array retains the
ability to penetrate deeply, and has a better signal to noise ratio than the dipole-dipole
array, however it does lose some horizontal resolution when compared to the dipole-dipole
array (Tsourlos 1995). The choice of array for any project therefore must reflect a balance
between depth of penetration, vertical and horizontal resolution, and the signal to noise
ratio.

Provided the spacing and orientation of the probes is kept constant and moved as a
unit across the survey area while measurements are taken at regular intervals in a process
often called resistance mapping, it is possible to simply plot the resulting data and examine
it for trends or anomalies. However, maintaining probe spacing is not always desirable,
because the spacing of the electrodes is what determines the depth of the measurements
recorded. When the spacing between electrodes is repeatedly expanded in a controlled
manner, the resulting measurements are known as a sounding, which is useful for
discovering horizontal stratigraphy. If the sounding and the mapping techniques are
combined, it is possible to produce a profile map of the survey area, which provides
information about both horizontal and vertical variation in resistance. Therefore, in order
to create models at various depths, and to even create three dimensional models of the
subsurface resistance, it is necessary to adjust the separation of the probes in the array.
Unfortunately, when this is done, it no longer makes sense to simply map the
measurements in three dimensions and try to interpret the results.

CALCULATING RESISTIVITY

When the spacing between probes or orientation of the probes with each other is changed, it is no longer possible to directly compare resistance measurements with each other because the electricity is no longer passing through the same quantity of material. To understand this problem, it is useful to imagine measuring the resistance of a small piece of iron and comparing that with the resistance of a small segment of copper wire. While iron is quite conductive, it will still have a higher resistance than that of the copper wire due to the material’s innate properties of electrical conductance. If one was to compare the resistance of the same small piece of iron to one hundred kilometers of copper wire, the small piece of iron would then have a much lower resistance, because the electricity had to travel through significantly more copper. The same concept holds true for soils. Resistance is dependent not only on the properties of the material through which it passes, but also through the quantity of that material it must traverse. Therefore, in order to make measurements with different electrode spacing and arrangement comparable, it is necessary to normalize the measurements by the distance the electricity travels through the ground. The resulting value, given in ohm-meters, is known as resistivity and is a physical property of the material measured.

In order to calculate the resistivity value of a homogeneous soil from the measured resistivity value, the geometric relationship of the probes must be taken into account using Equation 2.

\[
G = \frac{1}{2\pi} \left( \frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN} \right) \tag{2}
\]

Where AM, BM, AN, and BN are the distances between the given pairs of probes. Once the geometric factor \( G \) has been calculated, one then calculates the resistivity \( \rho \) by dividing the measured resistance \( R \) from Equation 1 by \( G \) from Equation 2 giving
\[
\rho = \frac{R}{G}
\]  
(3)

For a complete derivation of Equations 2 and 3, see the excellent work by Tsourlos (1995) *Modelling, Interpretation and Inversion of Multielectrode Resistivity Survey Data.*

It is important to note, however, that Equation 3 only gives the true resistivity \(\rho\) if the material measured is homogeneous. This is not the case in real-world surveys and the survey region would not be of interest if it was homogeneous, as the value of the survey is its ability to identify variations in resistivity values due to archaeological features. When the geometric factor is applied to measurements of inhomogeneous soils, the resulting value is known as apparent resistivity which can be understood as a calculation of the true resistivity if the soil had indeed been homogeneous (Tsourlos 1995).

A better result for interpretation would be to examine the true resistivity values themselves. Unfortunately the calculation of true resistivity in inhomogeneous soils is more complex than it is for homogeneous soils because the resistivity values themselves will affect the path taken by the electricity as it travels through the ground. Therefore, the distance travelled cannot be estimated without knowing the resistivity values, and the resistivity values cannot be calculated without knowing the distance travelled. Resolving this problem is the goal of the post processing method known as “tomography,” which will be discussed in detail below.

**TECHNIQUES USED FOR THIS RESEARCH**

A Syscal Pro Switch 96 multichannel resistivity instrument (Figure 2) was rented from Northwestern Geophysics through the support of Arkansas State Parks and the Arkansas Archeological Survey, for a week in March 2013. This instrument can control 96 separate electrodes and during a single current transmission can measure up to 10 different voltages simultaneously. In response to noisy conditions and under the expert advice of Dr. Nikos Papadopoulos, the Pole-Dipole array was selected for the purposes of this study.
Figure 2: The Syscal Pro Switch 96 is the ERT instrument that was used in this project. Photo taken by Nikos Papadopoulous and used with permission.

The primary survey area of interest, Mound B, was surveyed in forty-nine transects for a total of 2,430 electrode insertions and more than 60,100 measurements. The transects were arranged on the north-south axis and spaced at two meter intervals. Each transect began at the same southern coordinate and extended 94 to 100 meters to the north, with electrodes placed every two meters along the surface of the mound by stretching measuring tapes along each transect. It is important to remember that the depth of each measurement is determined by the spacing of the probes, and the horizontal location of the measurement is estimated as the center point between the electrodes. As greater depths are reached along a transect the center point between the electrodes shifts towards the center of the survey area. Therefore, as the instrument selects probes along the line to
increase the depth, the furthest achievable lateral position is reduced. For instance, in order to take a measurement along the periphery of the profile, it may be necessary to use the first and the second probes as the voltage electrodes. In order to measure a level deeper, however, the first and third probes must be used, thereby moving the horizontal location measured closer to the center of the profile. The measurements recorded therefore form a truncated triangular profile before topographical considerations. The resulting data was sufficient to produce a three-dimensional model of the subsurface resistivity and reconstruct some of the mound’s internal structure.

In order to account for topographic variation, a topographic survey was carried out by Tim Mulvihill, the Station Archeologist for the University of Arkansas Fort Smith Research Station for the Arkansas Archeological Survey, using a TopCon Robotic Total Station. This allowed a precise elevation model to be created for the mound and the elevations of the probes could then be extracted for the tomography procedure.

With the help of many volunteers from Toltec Mounds State Park and the University of Arkansas, and the Arkansas Archeological Society the survey of Mound B required less than the full week to complete. Therefore, in the remaining time, fifteen transects were taken across Mound A. Seven of these transects were oriented perpendicular to the lake shore, while eight were oriented parallel to it. The transects perpendicular to the shoreline were separated by 15 meters. Of the transects parallel to the lake shore, the six closest to the shore were separated by 10 meters while the final two were separated by 20 meters in order to finish the grid in the remaining time. The location and elevation of each measurement was recorded in the same manner as Mound B, and each of the transects were processed to create a series of profile reconstructions of the resistivity along each transect.

ERT DATA PROCESSING: TOMOGRAPHY

The application of the array’s geometric factor to the data collected from the inhomogeneous soil calculates the apparent resistivity. In order to model the soil’s true
resistivity, a more complex post processing procedure known at tomography is required. If one were to imagine the subsurface as a finite set of discrete, homogeneous materials, with known resistivity values, then it is possible to calculate the density of the current field through each element and thereby calculate the true geometric factor with which to correct the data collected at the ground surface. Indeed, given the resistivity value and location of each of these discrete elements, it would be possible to calculate the voltage difference, and therefore the apparent resistivity at any pair of locations within the model. This procedure is known as Forward Resistivity Modeling (FRM) and is a key element in understanding the process of tomography. Three methods have been developed to solve the FRM problem computationally, including the Resistor Network Analysis Method, the Finite Difference Method, and the Finite Element Method (Tsourlos 1995). The primary differences between these methods are rooted in how they choose to subdivide the subsurface into elements, but each method ultimately results in a system of linear equations of the form $K \ast V = F$ where $F$ describes the current source, $V$ represents the voltages, and $K$ describes the resistivity distribution throughout the model (Tsourlos 1995).

One way of understanding forward resistivity modelling is that the model seeks to find a function that maps the known resistivity on to an unknown set of voltages, i.e, the measurements that would be taken in the field. This may be expressed by in the following form:

$$f(\rho) = v$$  \hspace{1cm} (4)

Clearly, in reality the true resistivity values of the subsurface are not in fact known, as discovering these values is the goal of the processing technique. The only information available to the researcher are the current sources, and the voltages measured on the ground surface, from which the apparent resistivity can be calculated. Therefore, rather than attempting to calculate the voltage differences using the current and resistivity values as is done in the FRM problem, the researcher’s goal is to calculate the resistivity values
from the current and voltage values i.e.

\[ f^{-1}(v) = \rho \]  \hspace{1cm} (5)

This problem is known as the inverse problem, and because \( g(v) \) is non-linear, the problem cannot be solved directly (Tsourlos 1995). Furthermore, the inverse resistivity problem is ill-posed, meaning that for equation 4, very large changes in \( \rho \) can result in very small changes in the observed data \( v \). When solving the inverse problem, very small changes in \( v \) can result in very large changes to the model (Tsourlos 1995). This is especially problematic considering that any application in the real world must assume many sources of error in the observed data. Inaccuracies in the instruments, terrain model, or placement of the electrodes, will all cause errors in any dataset. Furthermore, while modeling procedures require the subsurface to be divided into discrete and homogeneous units, it is certainly not the case that each of these units will be homogeneous in reality. There is therefore error inherent in the model itself (Tsourlos 1995). Any small deviation from reality therefore could potentially result in very large variations in the model. Each of these problems must be addressed in order to possibly create a realistic and stable model of the true resistivity of the subsurface.

To address the problem of non-linearity, there are two possible solutions. The first is to make a linear approximation of \( g(v) \), and solve the system of linear equations. Alternatively one can come to a solution more accurately through iterative methods. It is this second option which will be explored here. Iterative methods make use of the solutions to the previously discussed FRM problem to arrive at an optimal solution which should closely approximate the true resistivity of the subsurface. To do this, the scheme begins with the measured dataset and a model of the resistivity distribution \( \rho_0 \). Using the forward resistivity modeling procedure on \( \rho_0 \) it is possible to calculate voltages \( v_0 \) for the model using Equation 4. The calculated voltages \( v_0 \) can then be compared to the measured dataset. In order to correct the modelled resistivity distribution to make the calculated
voltages more closely match the original dataset, it is necessary to relate the effects of each element of the model on the calculated voltages from FRM, in what is known as the sensitivity matrix or the Jacobian matrix $J$. This matrix may then be used to calculate the appropriate correction vector $d\rho$ which will improve the model. Each new resistivity estimate $\rho_{k+1}$ can therefore be calculated using Equation 6 (Papadopoulos et al. 2006).

$$\rho_{k+1} = \rho_k + d\rho_k$$

(6)

The ill-posed nature of the problem must also be addressed in $d\rho$ to arrive at a stable solution. Therefore a smoothness constraint $C$ is introduced which will produce a model that may not necessarily match the resistivity of the actual subsurface, but will hopefully produce a reasonably accurate model that will not change greatly to minor perturbations of the measured data and model parameters. The final equation for calculating each new resistivity estimate is given by Equation 7

$$\rho_{k+1} = \rho_k + [(J_k^T J_k + \lambda_k C^T C)]^{-1} J_k^T [y - F(\rho_k)]$$

(7)

where $J_k$ is the Jacobian matrix, $\lambda_k$ is the Lagrangian multiplier, $C$ is the smoothness matrix, $y$ is the measured data, and $F(\rho_k)$ is the forward modeling results (Papadopoulos et al. 2006). The entire process is then iterated until the voltages calculated through FRM are sufficiently close to the measured dataset by the specified criterion, often in the least-squares sense (Tsourlos 1995). The resulting $\rho_{final}$ represents the “best” model of the subsurface resistivity by that criterion.

DATA CLEANING IN PROSYS II VERSION 3.07.02

The first step was to do an initial “despike” of the data to remove bad data points that resulted from problems with the resistivity or poor connections to between electrodes. The raw data for each line was collected into a single file using the Prosys II software by Iris.
Instruments, and exported to a comma separated variable file so that it could be statistically analysed using the open source R software package. For Mound B, the mean Rho value was approximately 32.46 and the Rho standard deviation was approximately 87.08. Using Prosys, all data greater than three standard deviations above the mean, or less than zero was eliminated so for all data \( x \), \( 0 < x < 293.71 \). Likewise, all data with deviation values beyond 3 were eliminated. After this, 57029 out of 60121 data points remained. When the data was collected, each data point is measured three times and the standard deviation of these three measurements is given as the variable “Dev”. As an initial threshold for despiking, all measurements with a Dev of greater than 15 were also eliminated, leaving 56949 of the original 60121 data points. Finally, using the the Prosys II “Split in files...” function, each of the ERT lines was divided back into its own file.

The next step was to process each line individually using Prosys II. The data remained quite noisy, even after the initial despike and quickly a pattern began to emerge. It appears that the resistivity meter was not functioning properly and for a region estimated to be between 12 meters and 17 meters below the surface, many of the values recorded were exceedingly high or low as is shown in Figure 3. This region appeared in every profile completed on or near Mound B, and in all profiles from Mound A with the exception of those taken the last day. Therefore, it is certain that these measurements are not the result of the structure of the mounds themselves but rather a product of a problem with the instrument and therefore required elimination from the dataset. Although the loss of data was disappointing, it was not enough to seriously damage the dataset, or hamper interpretation. The most extreme values were eliminated using the “Exterminate bad data point...” function in Prosys II, which plots the values for each level and allows the researcher to eliminate data points by selecting the points to be removed. This process was repeated until the Rho pseudo-section display appeared to be free of extreme spikes. As the data was still in the initial phase of data cleaning, only points that were clearly erroneous were removed.
Figure 3: An example of a typical ERT pseudosection after an initial despiking. The missing region represents measurements where meter was malfunctioning and giving very high and low data spikes. Some bad values remain below the gap.

The final step in Prosys II was to include the topographic data for each line. Topographic data for each of the mounds had been recorded during the survey and stored in a comma separated variable format which was easily imported into R, organized into individual lines, and separated into text files to be imported by Prosys II. These elevations were used to recompute the Rho values to account for the topography using the “Insert topography...” function. Finally the cleaned and topographically corrected resistance data was exported to the RES2DINV format for inversion. This process was repeated for every line in Mound B and Mound A.
RES2DINV AND RES3DINV: FURTHER CLEANING AND INVERSION

Prior to inversion, further data cleaning was done using the “Exterminate bad datum points” function in the RES2DINV software by Geotomo Software. This function plots all data points on their levels and allows the operator to select points that are greatly outside of their expected values. Most of the bad data points had already been eliminated from previous cleaning, and this function allowed further elimination of points that may have been missed when cleaning with Prosys. Finally, the data was clean enough to attempt a first inversion.

The thickness of the first layer of the model was set to be one half the distance between the probes, for a thickness of 1 meter. This thickness was maintained throughout the depth of the profile. The model was presumed to have converged when the relative RMS error change was less than 1 percent, or after 10 iterations in order to be sure that the model had fully converged. Furthermore, to increase accuracy, the Jacobian matrix, used to calculate the changes to the model to improve its fit to the data, was recalculated after each iteration. Once all of these settings had been properly arranged the first inversion was completed for each dataset.

After the completion of the inversion it is possible to display the results in the RES2DINV software using a variety of color displays that discretized the values across 16 separate colors. This display is sufficient for an initial analysis of the quality of the inversion, but as will be described later, is not sufficient for an interpretation of the results. If the RMS error was less than 5 percent the inversion was considered satisfactory and now could be exported for further analysis and interpretation. If, on the other hand, the error was greater than this, further cleaning of the data was necessary.

Further cleaning could be completed using the “Exterminate bad datum points” function, previously described, or using the “RMS error statistics” function which displays a histogram of datum points and the amount of error they contributed to the inversion. The tool could then be used to trim only those points that contributed the most error. The
inversion and extermination process could then be repeated until the error was sufficiently low to indicate a good inversion. For the data from Mound A, collected the final day of field work, which did not have the noise due to the instrument’s error, many of these later cleaning steps were not needed as the RMS error was sufficiently low after little to no data removal. This indicates that the data points removed in these later steps were indeed increasing the error due to the noise in the instrument, and were not valid data points.

In many cases, the two-dimensional inversion of transects generates high quality models of the subsurface that are sufficient for interpretation. However, the two dimensional algorithm does not consider the three-dimensional nature of the actual structures. Therefore, cases with complex subsurface the algorithm may produce artifacts that are not truly representative of the location of interest (Papadopoulos et al. 2006). In order to accurately resolve the three dimensional nature of the ground, one may use a fully three-dimensional survey method, wherein a rectangular grid of evenly spaced electrodes are placed and the current and voltages are measured between every probe combination in the grid. Such a survey requires a great deal of time as the number of unique combinations between probes, which can be calculated from equation 8 where \( P \) is the number of probes and \( n_{\text{max}} \) is the maximum number of measurements, rapidly becomes very large (Papadopoulos et al. 2006). Given the 49x51 electrode positions used in the survey of Mound B, a fully three-dimensional survey of the mound would have required 2,499 electrodes and could have recorded more than 4.8 trillion independent measurements. A survey of this scale is not feasible with currently available technology.

\[
n_{\text{max}} = \frac{P(P - 3)(P - 2)(P - 1)}{8} \tag{8}
\]

The alternative is to collect a dense set of parallel two-dimensional transects where the transects are spaced at the same distance as the interelectrode spacing, in this case two meters. These transects can then be combined together to create a quasi-three-dimensional dataset which can be inverted by a three-dimensional inversion algorithm (Papadopoulos
et al. 2006). This process has been demonstrated on synthetic and real datasets to produce superior results to two dimensional inversion techniques (Papadopoulos et al. 2006).

Therefore, once the data from Mound B had been processed, it could be combined using the RES2DINV “Collate data into RES3DINV format” function. This collects all of the data and topography information into a single file that is readable by the Geotomo RES3DINV modeling and inversion program which was then used to construct a fully three-dimensional model. This process could not be utilized for the data collected from Mound A because for such a process to work the distance between consecutive transects should not be more than twice the spacing of the interelectrode spacing (N. G. Papadopoulos 2007). For the Mound A survey the transects were spaced between seven and ten times the interelectrode spacing. Therefore, the Mound A transects were processed using only the two dimensional inversion technique.

IMPORTING TO PARAVIEW FOR ANALYSIS AND INTERPRETATION

While the display capabilities of the Geotomo Software discussed above are sufficient for an initial look at the inverted resistivity data, they are not sufficient for a true analysis. The most important reason for this is that while the resistivity may be considered a continuous dataset, the Geotomo display is only capable of showing sixteen discrete colors. Clearly any digital display must discretize a continuous spectrum into a finite number of colors and the quantization of the data into so few colors can generate false contours leading to the interpretation of boundaries where there are none. For instance, in Figure 4 it appears that there are sharp contrasts between the low resistivity values shown in blue, and the medium ones shown in green. This is no longer the case in Figure 5 using 256 distinct colors, where it is revealed that the transition is more smooth.
Figure 4: Using 16 distinct colors, there are sharp lines dividing even subtle changes, making them appear more abrupt and robust than they truly are.
Figure 5: Using 256 distinct colors, the sharp lines from the RES2DINV model become more smoothed.
The RES2DINV visualization also makes use of a logarithmic color scale. The distribution of Resistivity data is often highly right-skewed, as it is in this case, and so a logarithmic scale is usually appropriate. In spite of this, it can be argued that a linear scale is more appropriate for this particular dataset in terms of readability and ease of interpretation.

The data collected from both Mound A and Mound B suggest a three-layer model with a highly resistant surface and base layer, and a low resistance between, implying a multi-modal distribution. The effect of a logarithmic scale on skewed data is to amplify variations at low values, which contain most of the data, while suppressing higher value variations. In this instance a logarithmic scale suppresses the variations in the second mode of the distribution which includes the highly dynamic surface layer. Therefore, as can be seen by comparing Figure 5 and Figure 6, the logarithmic scale removes some of the important interpretable detail from the surface.

![Image of Resistivity distribution](image)

Figure 6: Using 256 colors distributed on a linear color scale between 3 and 250 Ωm this image represents the color scale chosen for visualizing the ERT data from this research.

Furthermore, when the profiles are visualized using the logarithmic color scale as
shown in Figure 5 the middle layer appears to be interrupted by a high resistivity material near the center of the transect. This penetrates not only the lower layers of the mound, but also as much as seven or eight meters below the ground surface to the water table. If this were truly the case, it would be very difficult to imagine how to interpret this archaeologically. It seems much more likely that this is the result of algorithmic smoothing and corrupt data as discussed above. It is therefore desirable to suppress these anomalies, in order to prevent confusion and improve the readability of the data. Apart from the apparent intrusions the middle layer is essentially devoid of variation, perhaps due in part to the decrease in resolution with increasing depth. Any features that may have been present in this layer are likely concealed by the low resolution. Therefore, little information will be lost if the relative contrast of low values is decreased through the use of a linear rather than logarithmic scale.

The Paraview visualization shown in Figure 6 uses 256 colors and a linear scale between $3 \, \Omega m$ and $250 \, \Omega m$ and demonstrates the color scale chosen to display the data throughout the rest of this research. This scale retains the important surface variations where the data resolution is the highest. Clearly the three layer model also remains but the disruption of the middle layer is less readily apparent. There is a slightly darkened region in the middle layer of the Paraview visualization where the disruption appeared in the RES2DINV visualization. This shows the anomaly is still there, but now it appears as it should be interpreted, a shadow resulting as the algorithm attempted to smooth between the upper and lower regions of high resistivity. For a satisfactory visualization and accurate interpretation of the resistivity data, it is important to carefully choose the method of visualization. Software such as Paraview allows the user the flexibility to do so.

Finally, the three dimensional dataset produced for Mound B cannot be fully appreciated and interpreted when it is displayed as a series of either vertical or lateral slices. A fully interactive interface provided by a scientific visualisation software package allows for the rotation, slicing, contouring and other analysis methods of the dataset and is
much more useful for data exploration and interpretation. Unfortunately, ParaView does not immediately recognize the XYZ format as it is created by RES2DINV or RES3DINV. Nevertheless, it is a simple process to edit the XYZ file in a text editor and re-save it as a comma separated variable file, readable as a table by ParaView. Once the data has been successfully been imported into ParaView, the “Table to Points” filter will convert the coordinates into points, which can finally be interpolated through a Delauny Triangulation filter. This provides a fully interactive representation of the data and provides access to ParaView’s many powerful functions.

SECONDARY SURVEY

The primary goal of this portion of the project was to obtain significantly higher resolution and more diverse geophysical data of the top of Mound B in an effort to better evaluate and interpret anomalies discovered during the ERT Survey. A secondary goal was to discover anomalies in the mound’s surface that may not have been visible to the ERT survey. As is always the case with geophysics, if a contrast in the physical property measured by the instrument used does not exist, then there will be no change recorded. Therefore, while some archaeological features may maintain a resistivity value consistent with the background matrix, they may still demonstrate contrasts in the magnetic or other chemical or physical domains. The use of multiple technologies on the same area therefore provides the greatest opportunity for discovering and understanding archaeological features.

In order to address these goals three separate geophysical methods, magnetometry, ground penetrating radar, and resistance were used over a 20x26 meter region on the top of Mound B. The basic theory of these techniques is well documented in nearly any introductory geophysics textbook and so will not be given in great detail here, although a brief discussion will be useful for interpretive purposes as well as to understand why none of these methods would have been sufficient to do a complete survey of the mound’s structure.
GROUND PENETRATING RADAR

Ground penetrating radar uses an antenna to generate high-frequency radar pulses and transmit them into the ground where they propagate as waves (Conyers 2013). The amount of energy returning to the antenna is then recorded over a predetermined period of time, measured in nanoseconds, generating what is known as a trace. When a radar wave encounters a transition in the dielectric permittivity of the soil due to a physical or chemical change, some of the wave’s energy reflects back towards the antenna and upon reaching it, will be recorded as having a high amplitude in the trace. Measuring the time between the emission of the pulse and the return of the energy, and using an estimation of the speed the wave is travelling through the ground, it is possible to estimate the depth of the soil transition. A series of these traces are collected along a transect at regular intervals to create a profile known as a radargram. Furthermore, when a series of transects are made, the data can be combined to make a very high resolution three-dimensional model of the sub-surface.

GPR is exciting due to its three-dimensionality and extraordinarily high sampling rates, with traces taken as often as every centimeter. However, the instrument’s depth of penetration is limited by the conductivity of the soil. In highly conductive soils such as clays, the radar signal will be rapidly attenuated and at fairly shallow depths may not return to the antenna with sufficient energy to be measured. One method of increasing maximum measurable depth is to decrease the frequency of radar wave used in the survey (Conyers 2013). The cost of this change is a decrease in the vertical resolution of the survey, as the longer wave will pass through more material in a single period. Furthermore, in highly conductive soils a decrease in frequency may not be sufficient to greatly increase the maximum measurable depth (Conyers 2013).

The soils used to construct the mounds at Toltec have a high clay content and are highly conductive. In an effort to penetrate as deeply as possible into the mound with the hopes of confirming some of the stratigraphy displayed in the ERT data, a 200 MHz
antenna was used in addition to the 400 MHz antenna which is more standard in archaeological applications.

When using the 200 MHz antenna, a survey wheel was used to record distances and signal the radar when to collect a trace. The large antenna was then dragged across the ground with traces recorded every two centimeters, resulting in 1301 traces along the 26 meter survey transect. The entire system would then be returned to the starting line, shifted over .5 meters and then the process would begin again. In this way, forty transects were taken between the 0 point and 19.5 meters along the x-axis of the grid. The same process was repeated with the 400 MHz antenna however for this survey the smaller antenna was placed in a cart and traces were collected every centimeter, resulting in 2601 traces per transect.

MAGNETOMETRY

Unlike GPR, which is an active method in that it transmits energy into the ground and measures the response, magnetometry is a passive method which simply measures the strength of the magnetic field at the sensor’s location. In standard archaeological surveys, therefore, the data recorded is two dimensional, with no ability to measure the depth at which an anomaly occurs. Furthermore, as the strength of magnetic fields decrease at a rate of approximately \( \frac{1}{d^3} \), where \( d \) is the distance from the instrument to the target, only extremely large magnetic anomalies would be detectable at any great distance or depth. These properties make magnetometry as a method for exploring the deeper internal structure of the mounds infeasible, but the simplicity of the method and the diverse array of human activities that may be reflected in magnetism make it a powerful survey tool for archaeological features near the surface.

There are two phenomenon through which archaeological features may cause variations in the measured magnetic field, allowing their detection by magnetometry survey. The first is known as thermoremnant magnetism, and results when soil containing magnetic
minerals are heated to a sufficiently high temperature known as the Curie Point (Gaffney 2003). After reaching this temperature the iron becomes temporarily demagnetized. Upon cooling, the iron will regain its magnetism, which will be permanently aligned with the earth’s magnetic field. Archaeological features such as clay hearths or kilns that reach a high temperature are therefore likely to exhibit this kind of magnetism and may be easily recognizable (Gaffney 2003). The second phenomenon results in a magnetic susceptibility contrast, which measures the magnetism generated when the material is placed in a magnetic field. This phenomenon, often known as induced magnetism, is measurable by passive instruments such as the magnetometer because the materials are always located in the magnetic field generated by the earth (Gaffney 2003). Archaeologically, magnetic anomalies resulting from this phenomenon may occur in a variety of ways. Topsoil is frequently more magnetic and so the accumulation or removal of topsoil by human activity may result in the creation of magnetic anomalies. Furthermore, daily human activities such as farming or waste disposal may also result in an increase in magnetic susceptibility, likely due at least in part to increased microbial activity in the soil (Gaffney 2003). While a magnetometer is capable of detecting both of these magnetic phenomenon, it is not capable of distinguishing between them, but rather is only capable of measuring the strength of the field at that location. This can lead to difficulties in the interpretation of an anomaly as it may, for instance, represent either a hearth with thermoremmant magnetism, or a storage pit with a higher magnetic susceptibility and therefore induced magnetism.

Rather than using a magnetometer, the instrument used to survey the top of Mound B was a Bartington dual fluxgate gradiometer. The primary interest of a magnetic survey to an archaeologist is the variation in the magnetic field to archaeological features. However, the Earth’s magnetic field also varies through time. Therefore, the measurements taken by a single magnetometer will not be consistent from one moment to the next. One method to correct for these fluctuations and measure only for the effects of the subsurface on the magnetic field is to use a gradiometer, comprised of two magnetometers separated
by a set distance. These sensors measure the magnetic field at their respective locations, and the values are subtracted. Due to the previously discussed rapid deterioration of the strength of magnetic fields with distance, the upper sensor is primarily measuring the magnetic field of the earth, while the lower sensor is closer to the ground and therefore measures both the effects of the ground and the Earth’s fields. Subtracting these values leaves only the ground’s magnetic field, leaving only the variations that may be of interest.

Data for this project was collected in transects spaced a half meter across over the same survey area as the GPR. The instrument used, a Bartington dual fluxgate gradiometer, utilizes two gradiometers set one meter apart from each other, thereby measuring two transects simultaneously and requiring only 20 passes to collect all 40 transects for this grid.

ELECTRICAL RESISTANCE

As previously noted and described, a standard archaeological electrical resistance survey measures the exact same physical properties as does an electrical resistivity tomography survey. However, the secondary survey allowed for a much smaller area to be surveyed at a higher resolution, while forgoing the very deep measurements possible with ERT. For this new survey, the twin-probe array was chosen in which the two current probes A and B are remote probes and are placed a long, theoretically infinite, distance away. Measurements are taken between the two voltage electrodes M and N. The RM-15 Electrical Resistance Meter, by Geoscan Research, is a multiplexed meter capable of measuring between up to six voltage electrodes at once. For ease of movement and placement, the six electrodes were installed in a two meter beam such that .5, 1.0, 1.25, 1.50, 1.75, and 2.0 spaced measurements could be taken by measuring the voltage from different combinations of electrodes, and the instrument was programmed accordingly. The signal strength is determined by the distance between the remote electrodes and must be calibrated to the soils at the site. Therefore, the two remote electrodes in the twin-probe array were placed
as far away as allowed by the amount of wire available and spaced through trial and error to be approximately .85 meters apart. This ensured that the resistance values measured were within a range large enough to measure contrasts, but small enough to be acceptable to the meter. The survey area was then tested on a one meter grid, with each location recording six measurements.

DATA PROCESSING: SECONDARY SURVEY

Each of the geophysical methods used for the secondary survey require their own form of processing. The resistance maps and gradiometry data were relatively simple to post process and display using a raster capable Geographic Information System. The ground penetrating radar data required considerably more effort.

MAGNETOMETRY/GRADIOMETRY

The gradiometry was the simplest data to process. The two gradiometer’s transects are automatically organized such that readings of consecutive transects are in the proper order. Therefore the data may simply be exported and displayed as a raster file. Some processing may be needed to remove striping resulting from the instrument drifting or changes in the Earth’s magnetic field which were not entirely cancelled out through the use of a gradiometer, but this is a simple process in any raster-capable GIS program through standard de-striping techniques. Finally, the raster will have a very high sampling frequency along one axis, but only a .5 m sampling frequency along the other. In order to improve interpretability of the map, it may be useful to resample this data to a more uniform spacing. This is also easily accomplished with a GIS.

RESISTANCE

As with magnetometry, the resistance data can be displayed as raw values in a raster grid. However, there are frequently data spikes in the data from where one of the electrodes did
not make good contact with the ground surface. Usually, the instrument operator attempts to remove these spikes while in the field by re-measuring any locations that display an exceptionally high or low value. Occasionally however, the operator may not notice the error and so in post processing the data spike must be removed. This is generally done by identifying the measurement with an infeasible value and replacing it with the average of the surrounding values, or with any number of low-pass filters. As the resolution of the resistance data is quite low, it may also be useful to resample the data to a higher resolution. Though it is important to remember that this will not actually increase the resolution of the data, it will make the image appear more smooth, and perhaps may therefore be more easily interpretable.

GROUND PENETRATING RADAR

The exceedingly high resolution and three dimensionality of ground penetrating radar promises to make it an extremely powerful method, but the reality of how electromagnetic waves behave in the ground mean that post processing is almost certainly required for interpretation. Furthermore, the complexity of this behavior and tremendous size of the dataset ensures that processing methods will be similarly complex. Software for completing this processing and analysing the results are available in the form of GSSI’s RADAN software or many other proprietary software packages, but these programs were cost prohibitive for the purposes of this project. Fortunately many of the basic processing results are replicable with a computer algebra system and a GIS such as the open source software Octave and GRASS GIS.

The first and perhaps most important processing step is to generate an estimate of the speed at which the radar wave passes through the soil, as this will determine the depth which was reached by the survey. There are many methods to accomplish this when there is a feature of a known depth, however, without this knowledge it is necessary to resort to other methods. Fortunately, as the radar wave propagates into the ground, it does not
travel solely in a straight line but also expands as it propagates. Therefore, if there is a point target at a certain depth, the antenna will begin to measure this target before the antenna is directly above it. The distance along a diagonal from the antenna to the target will be larger than when the antenna has moved over the target, causing the target to be registered as deeper in the profile. As the antenna moves toward the location directly above the target it also gets closer to the target, which begins to appear closer to the surface in the profile until it finally appears at its actual location when it is directly below the antenna. The process then reverses as the antenna moves away, creating a distinctive hyperbola in the profile. By calculating the relationship between the distance from the target, and its apparent rise, it is possible to calculate the average velocity of the wave through the ground. The relationship between travel time, horizontal position of the antenna and velocity is given by equation 9, where $x$ represents the horizontal distance of the antenna from the point directly over the target, $T$ represents the travel time to the object when the antenna is at distance $x$, $T_0$ represents the travel time when the antenna is directly over the object, and $V$ represents the average velocity of the wave through the ground. (Sensors & Software Inc. 2013).

$$T = \sqrt{\frac{4x^2}{V^2} + T_0^2}$$ (9)

By converting a GPR radargram into a bitmap format using GSSI’s “RADAN to Bitmap conversion utility” and importing the image into a GIS it is possible to estimate $x$, $T$, and $T_0$ by measuring the dimensions and position of the hyperbola with respect to the ground surface. Given equation 9 and some minor arithmetic it is then possible to estimate the average velocity of the wave and convert the two-way travel times of the reflections into depths.

Unfortunately, the radargrams appeared remarkably clear of appropriate point anomalies. Of the 80 radargrams recorded between the two instruments only the radargram from the first transect of the 200 MHz antenna showed a suitable hyperbola. Ideally several
hyperbolas could have been measured, and compared within and between profiles. This would have allowed for examining any variation in velocity across the study area. Nevertheless, from the single anomaly, the velocity was estimated to be approximately 0.068 meters/nanosecond and this is the estimation of speed used for all further analysis. This velocity seems reasonable, as published tables indicate .07 meters/nanosecond as typical for silt soils, and .06 as typical for clayey soils (Davis and Annan 1989).

Much of the remaining processing is easily accomplished using a computer algebra system for numerical computation such as Octave. Before any processing can be done in Octave however, it is necessary to first get the data in a format that can be read by Octave. This is accomplished using the GSSI “RADAN to ASCII utility” which converts the data into a Tab Delimited ASCII text file, which may be read into Octave as a matrix. If this process is completed for each radargram, it is possible to create a three-dimensional matrix of all the radar data in a single block which can then be processed in parts or as a whole as desired.

As a radar wave reflects from a surface, some of its energy will be redirected towards the antenna. It is important to realize however that not all of this energy will be recorded. The wave, now travelling back towards the antenna may reflect off of higher surfaces and the antenna itself and be redirected back away from the antenna. This process often occurs between the ground surface and the antenna in what may be termed a “ringing” antenna. When first examining a radargram, one of the most noticeable characteristics is the presence of persistent horizontal banding throughout the profile. This banding, sometimes known as “wow,” results from this “ringing” or other reflections off of surface objects (Conyers 2013). Filtering this banding out of the imagery is one of the most basic and common processing steps in archaeology and is accomplished by averaging all amplitudes taken at the same time along a profile, and subtracting this average from the image (Conyers 2013). This is easily accomplished with a short script in Octave. It is important to use caution with this processing technique however, as this method will not only remove
any horizontal banding, but may also remove important data if a horizontal surface is recorded (Conyers 2013). Data was therefore examined both before and after this processing step to ensure no information was lost.

The next most conspicuous noise in the radargrams is the presence of high frequency noise at the bottom of the image. Near the surface, the radar wave is strong, so the signal to noise ratio is still quite good. At the bottom of the radargram however, the radar’s energy has mostly attenuated, and the noise is overpowering the signal. There are many possible techniques that may attempt to remove this noise, however a fairly standard image processing approach is to two-dimensionally Fourier transform the radargram and design a filter to remove the high frequency noise. The simplest filter to design is a gaussian filter, and after some trail and error for selecting appropriate values is effective at removing some of the high frequency noise. As noise is randomly added to the radargram, it is impossible to completely remove it in any context, and too strict a filtering will create a blurred image, as significant amounts of data will be removed as well. When the entire radargram is processed in this way, data is also lost in the upper section of the radargram that does not appear to require noise removal, and it will be unnecessarily blurred. Therefore, it is worthwhile to simply denoise the lower portion of the image and merge the new image with the older one.

In order to generate a horizontal view, it is also possible to generate time-slices in Octave by selecting all data at approximately the same time-depth. An envelope of 24 measurements was chosen around the desired time-depth and the maximum of the absolute amplitudes within each envelope was used to represent the amplitude at that location. Each time slice was then saved as a .mat file, which is simple to import into GRASS. The data could then be resampled to a .25 meter grid along the transect using the GRASS ”Resample using Aggregate Statistics” tool to select the maximum value within each pixel. Finally, to improve readability, the data could be resampled to a .25 meter grid perpendicular to the transect using the ”Resample Using Spline Tension” tool, and
georectified to its proper location on the site map. If this process is automated using a Python script in GRASS, it is a very simple and fast process to import many different time slices and rectify them to the same location. GRASS’s “Raster series to Volume” function can compile all of the separate raster images into a single volume, which can be exported into Paraview for three-dimensional viewing and analysis. This process allows the researcher to fully utilize the three-dimensionality of GPR data while using only the readily available open-source software. Furthermore it is easy to combine any of these processing steps to clean and investigate the data as desired.

RESULTS

MOUND B IN TWO DIMENSIONS

The Electrical Resistivity Tomography survey of Mound B yielded 49 two-dimensional profiles. Each transect began at 320 North and extended to the North. The first transect was along 416 East and the final transect was along 320 East. For ease of reference, the transect number, easting, length and number of electrodes used for each transect is included in Table 1.

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Table 1: Mound B ERT Transect Information

These transects were each processed individually and combined to create a dataset which was inverted, generating a quasi-three-dimensional model of the subsurface. Therefore each two-dimensional profile can be examined individually, and compared to slices generated from the three-dimensional model. All of the two dimensional profiles display a very similar three-layer model of sub-surface resistivity. The top layer is comprised of materials with a high resistivity, primarily between 60 and 250 $\Omega m$ and is composed of recent deposits, both geologic and anthropogenic. Away from the mound this layer is nearly always less than two meters thick and is regularly less than one, at times appearing to nearly disappear entirely. On the surface of the mound this layer can reach between three and four meters thick, but is usually between two and three. This layer is also by far the most dynamic of the three with rapid variations and high contrasts. This
increased volatility when compared to the other layers may be at least partially explained by the expected decrease in resolution with depth, that is typical of a resistivity survey. Any similar variation in deeper layers may therefore be masked by the lower resolution. The middle layer is primarily comprised of a material with a much lower resistivity, in the 3 to 60 Ωm range which is generally associated with clay deposits. This layer is generally between six and ten meters thick, though this is heightened by the mound deposits to as much as thirteen meters. Finally, the lowest layer, representing the water table, is once more composed of materials with a high resistivity, greater than 60Ωm and frequently reaching values well above 250Ωm.

The first five profiles, (transects 416 E to 408 E), are nearly indistinguishable and conform tightly to the three-layer model described above. The top layer is quite thin, while the middle layer is consistently eight to nine meters thick. The deepest layer is also most visible in these profiles as the depth of penetration is greatest off the mound. This third layer is exceedingly resistant with values reaching well above 250 to 300Ωm. These transects are well represented by Transect 3, shown in Figure 7.

Between transects five and thirteen (408 E to 392 E), the thickness of the first layer and the elevation of the surface begins to increase as the transects begin to cross the mound. This is especially the case near the center of the transects as it approaches the corner of the mound, while the ends remain much the same as previously described. The thickened surface layer is also more heterogeneous than before with more and larger patches of high and low resistance evident. The middle and deepest horizons remain relatively unchanged throughout. Transect twelve, shown in Figure 8, is representative of this set of profiles.

Beginning with transect thirteen (390 E) the same three layered structure as before persists, however the rise in elevation is no longer composed solely of high resistivity material but also includes lower resistance material in the less than 60Ωm range as shown in Figure 9. The elevation continues to rise through transect eighteen (382 E) and the
Figure 7: ERT Mound B Transect 3: This transect is representative of all of the data collected away from the mounds.

The surface layer becomes increasingly dynamic. There are multiple high resistivity intrusions into the growing middle layer, and there are some regions of the surface layer which also display low resistivity values. Finally, though still present, the deepest layer becomes less prominent in the images as the transects are now being raised by the mound and are no longer penetrating so deeply into the water table.

After transect eighteen (382 E) the summit of the mound has been reached and the elevation of the surface ceases to significantly increase. However, the surface of the mound appears to expand and then contract as the transects move across it from one corner towards the other. There continue to be many inhomogeneities near the surface and intruding into the upper elevations of the middle layer. Transect 24, shown in Figure 10, clearly shows the erosional gully and repair on the southern slope of the profile. This anomaly is visible between transects twenty-two and twenty-six. (374 E to 366 E)
Figure 8: ERT Mound B Transect 12: The high resistivity layer on the surface thickens as the mound begins to rise.

Otherwise, this transect is fairly typical of those that cross the platform at the top of the mound.

At transect thirty-one (356 E) the surface elevation begins to decrease as the transects move down the slope on the western side of the mound. Localized surface inhomogeneities persist as do apparent intrusions into the middle layer of the models by the higher resistance upper layer. In transect thirty-seven (344 E) shown in Figure 11, there is an intrusion of the middle layer into the upper layer which persists through transect thirty-nine (340 E). The elevation continues to fade until around transect forty-five (328 E) when the transects have mostly left the mound and once more appear as they did in the first five profiles with a level surface layer, and few intrusions between layers. The survey ends with transect forty-nine (320 E).

While it is tempting to examine all of the inhomogeneities visible between the first
Figure 9: ERT Mound B Transect 17: As the transects continue up the sides of the mound it becomes apparent that the mound is composed two layers.
Figure 10: ERT Mound B Transect 24: As transects cross the summit of the mound, the platform, erosional gully and internal features of the mound are all apparent.
Figure 11: ERT Mound B Transect 37: As the transects pass down the other side of the mound there appears to be an interruption in the surface layer, perhaps due to erosion.
and second layers within the mound with great excitement, some caution is advisable. Two dimensional modeling of the subsurface is fast and practical, but it should always be remembered that the medium measured is in fact three dimensional. The assumption of the model that the resistivity variation only occurs in two dimensions is certainly incorrect. In cases of simple structures, with little variation in the directions perpendicular to the survey transects, two dimensional modeling is quite effective. More complex cases, however, may be problematic for a two dimensional inversion algorithm and may result in falsely generated artifacts in the profile due to its three dimensionality (Papadopoulos et al. 2006). To account for the dimensionality of the subsurface and remove the potential of interpreting artificial anomalies, it is therefore useful to compare these data to the three dimensional model.

MOUND B IN THREE DIMENSIONS

The three dimensional model of Mound B can be displayed here as a series of two dimensional slices. It is important to remember, however, that while these slices are two dimensional, the model from which they were taken utilized a three dimensional approach and should be less prone to producing false anomalies as artifacts of the inversion scheme. However, care is still required when interpreting resistivity values around the edges of the model at any significant depth, as due to the triangular shape of the data collected, deep data was not collected on the edges. For the purposes of comparison to the two-dimensional data, it is useful to produce slices along the direction of the transect. These slices show a very similar stratigraphic profile and structure to the two-dimensional data previously discussed, however the upper layer appears to be considerably more homogeneous and relatively rarely shows significant intrusions into the middle layer. This would seem to indicate that many of the anomalies visible in the two dimensional data are indeed artifacts of the inversion algorithm, rather than archaeological or geologic features. Finally, the dataset was only quasi-three-dimensional because all transects were taken.
along the same direction.

The initial transects to the East of Mound B in the three-dimensional model, between eastings 416 and 402, are well represented by a slice at 406 E (Figure 12), which shows the same thin lens of high resistivity values at the surface, underlain by a thicker layer of low resistivity as was present in the two dimensional inversion. There are, however,

Figure 12: ERT Mound B 3D Inversion 406 E: An example of a typical off-mound profile

some significant differences between this profile and the two dimensional version, the most apparent being the very weak appearance of the high resistivity water table previously visible as a robust third layer. This may be the result of a slightly decreased maximum depth in the three dimensional model when compared to the two dimensional one. Furthermore, some of the localized inhomogeneities visible in the two-dimensional model appear to have been somewhat smoothed, creating a more homogeneous appearance to the surface layer. Finally, it should be noted that while an increase in the thickness of the surface layer was quite evident by 404 E in the two dimensional models, this does not
appear to occur for another two meters in the three dimensional model. Despite these differences, the three-layer model and general trends remain very much the same as the two dimensional models.

A slice of the three dimensional model at 394 E, shown in Figure 13, demonstrates the thickening of the highly resistant surface layer and an associated rise in surface elevation as the slices begin to cross the mound. The thickness of this surface layer varies between two and five meters across the mound, but is fairly consistently approximately three meters thick.

![Figure 13: ERT Mound B 3D Inversion 394 E: The surface begins to grow as the transects start to pass over the edge of the mound.](image)

At 390 E the profile reveals an interruption in the upper layer near the center of the profile. This interruption moves down the northern slope of the mound between profiles 390 and 385 E, briefly disappears around 384 E, reappears and grows to its largest extent around 378 E, before disappearing again around 375 E. Throughout these profiles, the middle layer expands, forming the inside of the mound, much as it does in the two dimensional profiles. On the southern slope of the mound a low resistivity region also
Figure 14: ERT Mound B 3D Inversion 386 E: Upper and middle layers grow as the transects continue up the side of the mound appears on the surface of the mound between profiles 388 E and 384 E. Despite the disruptions listed above, the upper layer still appears more cohesive than it did in the comparable profiles from the two dimensional inversion, showing relative homogeneity away from the disruptions. The northern and southern low resistance interruptions and the beginnings of the middle layer’s growth into the subsurface of the mound are all represented in profile 386 E shown in Figure 14.

Around 379 E, shown in Figure 15, the increase in elevation of the profiles slows at the summit of the mound is reached. Furthermore, the base layer of high resistivity is once more clearly visible, though it is still not nearly as robust as it was in the two dimensional profiles. This three-layer profile is maintained throughout the remainder of the profiles. As the profiles cross the surface of the mound between 379 and 350 E there is a marked increase in the frequency of local high resistivity anomalies in the surface layer. Furthermore, there appear to be two major intrusions from the upper high resistivity layer
Figure 15: ERT Mound B 3D Inversion 379 E: Upper and middle layers continue to grow as the transects continue up the side of the mound into the deeper low resistivity layer at the summit of the mound between 374 and 366 E. These intrusions, along with the erosional cut on the southern side of the mound and various inhomogeneities on the northern side, are visible in a slice at 372 E, shown in Figure 16.
Figure 16: ERT Mound B 3D Inversion 372 E: As the profiles cross the summit of the mound, two trenches running perpendicular to the transects are also crossed.
The profiles west of 350 E, show a decrease in elevation as they travel down the western side of the mound. The overall stratigraphy is very similar to that on the eastern slopes of the mound, with the addition of the now clearly visible lowest layer. Figure 17 shows the structure of the mound at 344 E. The low resistivity interruption on the north side of the mound has once again returned, appearing around 346 E and moving up the slope until around 338 E where it disappears for the final time. By 322 E, the profile once more is a simple three horizontal layer model, with a surface layer of high resistivity less than two meters thick, a five to ten meter thick very low resistivity middle layer, and a five to ten meter thick very high resistivity water table layer.

Figure 17: ERT Mound B 3D Inversion 344 E: As the profiles travel down the other side of the mound the surface interruption is once more visible

Due to the three dimensionality of the data, it can be quite difficult to develop a full understanding of the variation and patterns within the data through vertical slices alone. Therefore, it is useful to examine the resistivity of the mound as a surface or plan map as shown in Figure 18. The majority of the study area clearly has a relatively high resistivity
value at the surface, with exceptions on the slopes of the mound where zones of low resistivity are evident, particularly on the north eastern and north western slopes of the mound. These low resistivity zones correspond with the low resistivity interruptions in the surface layer shown in many of the profiles. With this view it is apparent that rather than being discrete interruptions, they in fact form zones of low resistivity that require interpretation. There are also linear anomalies of higher resistance visible on top of the mound platform which would have been very difficult to identify from individual slices. Other traits include a region of especially high resistance on the southernmost corner of the mound near the summit, and another region of very high resistivity values at the base of the northern side of the mound. Finally, it should be noted that the two low resistivity areas on the northern corners of the image are locations where measurements were not taken, and so do not truly represent low resistivity values.

Figure 18: View from above of the surface of the full three-dimensional model
MOUND A: ERT PROFILES

The survey of Mound A was not oriented along grid north, but rather in relation to the lake. Therefore the two sets of transects collected over Mound A will be referred to as transects A or transects AY, where A0 to A90 is oriented perpendicular to the lake shore with A0 on the south western edge of the mound, and AY14 to AY104 are oriented parallel to the lake shore with AY14 running directly along the edge of the lake. The beginning and ending locations, names and lengths of each of these transects is given in Table 2 for reference.

<table>
<thead>
<tr>
<th>Name</th>
<th>Start Point</th>
<th>End Point</th>
<th>Line Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>143.2 N, 231.9 E</td>
<td>222.1 N, 188.2 E</td>
<td>94</td>
</tr>
<tr>
<td>A15</td>
<td>147.3 N, 246.0 E</td>
<td>228.9 N, 201.7 E</td>
<td>94</td>
</tr>
<tr>
<td>A30</td>
<td>150.5 N, 262.1 E</td>
<td>235.6 N, 215.1 E</td>
<td>104</td>
</tr>
<tr>
<td>A45</td>
<td>156.9 N, 275.4 E</td>
<td>242.3 N, 228.5 E</td>
<td>104</td>
</tr>
<tr>
<td>A60</td>
<td>170.1 N, 284.7 E</td>
<td>249.0 N, 241.9 E</td>
<td>94</td>
</tr>
<tr>
<td>A75</td>
<td>184.8 N, 293.6 E</td>
<td>255.7 N, 255.3 E</td>
<td>82</td>
</tr>
<tr>
<td>A90</td>
<td>196.0 N, 304.4 E</td>
<td>262.4 N, 268.7 E</td>
<td>76</td>
</tr>
<tr>
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<td>AY24</td>
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<td>200.9 N, 305.8 E</td>
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</tr>
<tr>
<td>AY44</td>
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<td>212.8 N, 294.3 E</td>
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<tr>
<td>AY54</td>
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<td>217.9 N, 291.1 E</td>
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</tr>
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<td>244.7 N, 277.7 E</td>
<td>94</td>
</tr>
<tr>
<td>AY104</td>
<td>222.1 N, 188.2 E</td>
<td>264.3 N, 272.2 E</td>
<td>94</td>
</tr>
</tbody>
</table>

Table 2: Description of Mound A Transects
The starting point for each line in the A transects is therefore the lake shore, from which they extend south east, and the starting point for each of the AY transects is A0 from which they extend north east. The A transects begin where the mound meets the lake and extend across the mound to the south east, ending in the plaza region. This gives them a fairly distinctive shape with the mound located near the start of the line and the end of the line being primarily flat. A three-layer model of the subsurface very similar to that identified in the Mound B profiles is also present in the Mound A transects. In the regions away from the mound there is a very thin surface layer of high resistivity, underlain by the same low resistivity layer visible at Mound B. The deepest layer is once again composed of a high resistivity material and likely represents the water table. At some locations in the Mound A survey, this third layer is much closer to the surface than it was for any location in the Mound B survey. This is likely due to Mound A’s close proximity to the lake and therefore the water table. As shown in Figure 19 for transect A0, the third

![ERT Mound A Transect A0](image)

Figure 19: ERT Mound A Transect A0: The south western side of Mound A shows a rise in the water table to meet the lake at the edge of the mound.
layer joins the surface at the water front, but then quickly falls away to a depth of around six meters. A similar pattern is also found in profiles A5 through A45. The edge of the mound was also captured in A0 and is represented by a low rise in elevation from the water to a height of approximately 2.5 meters comprised of high resistivity material. This then fades away, and the last approximately twenty meters of the profile extends into the plaza. This off-mound portion of the profiles shows a stratigraphy that very closely matches that observed near Mound B.

Transect A15 continues to show a relatively thick (2.5 to 3 meter) high resistivity layer at the surface of the mound which fades to a very thin lens off the mound. It also appears that Mound A has both an upper layer with highly resistant soils, and a lower level which is composed of low resistivity soils. These layers are comparable to the laying identified in Mound B. This trend continues in profile A30, shown in Figure 20, though it appears that the surface layer is especially thick here, perhaps as great as four meters at some locations near the top of the mound. It is difficult to be certain of the precise dimensions of these layers. The surface layer appears to be highly variable, algorithmic artifacts similar to those encountered in Mound B are also present in the data from mound A. This makes interpretation of anomalies and stratigraphic depths tenuous at best, however general trends may still be examined and some anomalies are interpretable.

Transects A30 and A45 both cross the narrow platform at the summit of Mound A and have very similar stratigraphy, as does transect A60 which is located on the north eastern slope of Mound A. A75 returns to the edge of the mound and shows only a gentle rise in surface elevation, comprised of high resistivity material much like transect A0. The final transect on this orientation is A90, which only shows slight evidence of the mound in the form of a slight elevation increase near the lake, and otherwise appears as a standard off-mound profile.

The transects parallel to the lake shore not surprisingly show a very similar stratigraphic pattern to the other profiles collected across Mound A. Transect AY14,
collected directly next to the lake shore and shown in Figure 21 is the major exception to this, and appears to show exceedingly complex geological structures. As previously discussed, complex geology in two dimensional inversions can cause the algorithm to develop artificial anomalies and erroneous results. The close proximity of the lake likely resulted in this complexity, and was further exacerbated by the fact that it was not possible to keep the transect absolutely straight due to the curvature of the lake shore. Transect AY24, however, returns to the standard three-layer model with the mound composed primarily of high resistivity material. Transects AY34 through AY64 are well represented by AY44 shown in Figure 22, which shows a very thick surface layer, and the expansion of the middle layer to produce some of the mound’s subsurface.

Transect AY84 is mostly off of the mound, with only a small surface elevation change evident across the profile, and Transect AY104, shown in Figure 23, is entirely off of the mound and appears to have entered the plaza area. The surface layer appears to be
Figure 21: ERT Mound A Transect AY14: The close proximity of the lake is likely the cause for this very different looking profile.

extremely thin, and is underlain by the expected low resistivity layer. The base layer appears to be interrupted by a lower resistivity region, and may represent a geologic disturbance, however this is very unlikely to have an anthropogenic origin as it begins greater than eight meters below the ground surface and appears to continue past twenty meters below the surface.
Figure 22: ERT Mound A Transect AY44: The platform on top of this conical mound is apparent from this profile, as are the multiple layers of the mound.
Figure 23: ERT Mound A Transect AY104: This transect is entirely off the mound and out into the plaza area.
The secondary survey produced maps of the magnetometry and electrical resistance of the mound platform, as well as time slices and profiles from the ground penetrating radar data. For ease of discussion all descriptions of the survey use the orientation of the arbitrary grid established over the survey area for reference. Therefore, “grid north” is located at the upper left edge of the image and is roughly north-west when compared to magnetic north. Magnetic north is given by the north arrow in the maps provided.

Despite having recorded resistance measurements with six different electrode spacings, all the resistance maps generated with spacings greater than 50 cm show the same general trends as in the 50 cm map, but with a lower resolution. Therefore, only the map generated with 50 cm electrode spacing is analysed here.

The resistance map generated in the secondary survey shows a remarkably good correlation with the resistivity map created using the ERT method. For example, on the western edge of the map there is a region of higher resistance, with a circular region of very low resistance directly to grid north. This region looks very similar in the ERT data as is shown in Figure 24. The linear features identified in the ERT data are also present in the resistance data on the eastern side of the map, and indeed it appears that two more faint linear features complete a square.

The magnetometry map of the survey area, shown in Figure 25 reveals a clear linear feature between the western side and northeast corner of the arbitrary grid. This feature, composed of strong dipolar anomalies, is almost certainly the result of dispersed iron fragments. A similar, though perhaps slightly more diffuse linear feature also crosses the southeastern corner along the same orientation as the first line. Finally, anomalies in the northeast and southwest corners of the survey grid suggest that these two parallel lines may be connected by yet another set of linear features, perpendicular to the first two. These final features are more difficult to see as they are primarily outside of the survey area, but they appear to complete the rectangle. It is important to note that these features
Resistance at 50 cm

Surface ERT in $\Omega m$: Red Box indicates Location of Secondary Survey

Figure 24: Resistance and Resistivity Survey Comparison: Note the high degree of correlation
do not correlate with the features identified in the ERT and resistance data. A break in the magnetic anomalies also appears in the southwestern corner of the survey area.

The two ground penetrating radar surveys generated a total of eighty profiles over the study region. When surveying with the 200 MHz antenna, data was collected to a time-depth of 110 ns, much deeper than the 65 ns time-depth collected with the 400 MHz antenna. This was done with the expectation that the lower frequency would be capable of
penetrating significantly deeper into the mound before attenuating. Comparing Figure 26 and Figure 27, it becomes clear that in both cases, around 2 meters below the surface, the data begins to be overcome by noise as the signal attenuates. Surprisingly, it does not appear that the 200 MHz antenna was able to attain significantly deeper readings than the 400 MHz one. The rapid pace of degeneration at this depth seems to suggest it may be caused by a transition to a much more conductive material such as clay which prevented the collection and interpretation of any data below approximately 2 meters.

While the attenuation of the signal at the 2 meter mark is consistent across profiles, the precise nature of that phenomenon is not. In some profiles, such as Profile 8 shown in Figure 28, the transition appears so dramatic that the resulting reflection echoes throughout the rest of the image. In others the transition is much more subdued as has already been seen in Figure 26. Still others such as Profile 34 shown in Figure 29 have regions which simply attenuate, with intermittent strong reflections. It is not immediately

Figure 26: This profile shows the effects of a metallic fragment near the surface. Also note the severe attenuation below 2 meters.
Figure 27: Compare to the 200MHz data. Some attenuation is visible at the bottom of the profile.

Figure 28: There is a strong reflection in this profile beginning between 1.5 and 1.7 meters and echoing throughout.

clear what causes these variations.

Above the two meter mark the profiles are remarkably clear of anomalies and the 400 Mhz antenna did not reveal significantly more information than did the 200 Mhz, so
any analysis of the 200 Mhz data is representative of both datasets. The most prominent feature in all of the profiles is the strong response caused by metallic items which block the radar waves and generate reflections throughout the profile. In radargrams, the precise location of the ground surface is a matter of debate, but it may be interpreted as being somewhere around the center of a thick, dark line at the top of the radargrams which is removed by the destriping process and represents a very high amplitude reflection as the radar wave passes from air to ground. Therefore, it is clear that the metallic items identified in the magnetometry survey are located at or very slightly, at most 30 cm (though likely less) below the ground surface. In order to identify the pattern of these metallic fragments, and interpret any other localized features that occur across multiple profiles, it is useful to consider timeslices.

Three select timeslices from the 200 Mhz antenna are sufficient to explore the anomalies visible in the data. A time slice from near the surface of the mound is shown in
Figure 30 shows one clear linear anomaly stretching between the northernmost corner and the center of the south western edge of the survey area resulting from the metallic fragments identified in the profiles. Other linear anomalies are also present near the corners of the survey grid. Some of these may be the results of topographical effects from the edge of the mound platform, but others appear to be more features associated with metal fragments.

Figure 30: GPR Timeslice approximately 0.5 ± 0.17 meters below the surface
A second time slice taken from approximately two meters in depth, shown in Figure 31 clearly shows the increased noise as the signal begins to attenuate. Some of the linear features are still visible as the signal continues to reflect down through the profile. There also appears to be a small circular anomaly near the center of the survey grid, though it is difficult to distinguish through the noise.

Figure 31: GPR Timeslice approximately 2 ± .17 meters below the surface

Below two meters the noise rapidly takes over nearly all of the image. Even the
linear anomalies begin to fade away. The circular anomaly, approximately 3 meters in diameter, is the only feature that remains visible in Figure 32.

Figure 32: GPR Timeslice below 2 meters below the surface

INTERPRETATIONS

The primary purpose of this research was to use Electrical Resistivity Tomography to explore the stratigraphy and structure of Mound B by constructing a full three-dimensional
model of the resistivity of the mounds subsurface. One of the goals of this exploration was to the extent possible test the hypothesis that the mound had been fundamentally altered by later additions or ploughing. A secondary goal was to examine the structure of Mound A and determine if possible whether it had at any point been a platform mound and whether its form had been dramatically altered through erosion or other forms of destruction. It is important to remember and understand the capabilities and restrictions of these datasets. The electrodes were placed at two meter intervals along each transect and the transects of Mound B were separated by two meters, while the transect spacing on Mound A was much wider. While this survey took the majority of the time reserved for the project to complete and generate a large dataset, such a large resolution does place some restrictions on interpretation. Each element in the resulting model has a maximum vertical resolution of approximately half the electrode spacing, which is equal to one meter. Therefore it is very unlikely that relatively narrow building stages such as those identified in the excavation of the erosion cut in Mound B would be recognizable in the data collected. Furthermore, as with any geophysical method, a contrast in the physical property examined is required in order to be discovered. Therefore, if multiple stages were built out of physically similar materials, they may not be discovered through ERT. Similarly, while the identification of features such as burials is of great interest for interpretation of the site and for developing an understanding of how the Plum Bayou culture used the mounds at Toltec, doing so from this dataset is highly unlikely. Disturbances related to a burial are not likely to be significantly different from the surrounding soil, and would not likely occupy a space much greater than a meter. Therefore, it is not likely that this dataset would allow the researcher to identify such a feature. Nevertheless, in spite of the limitations, there are still many useful interpretations and insights into Toltec Mounds that result from an evaluation of the ERT data.
MOUND B: ERT

A slice through the mound as shown in Figure 33 makes it immediately clear that at least two different materials were used in the construction of the mound. The inner material has a very low resistivity and is capped with a much more resistant material that is between two and three meters thick. Edward Palmer states in his records of excavations on the mound that for the first two feet the soil was a “black sticky clay,” after which the soil became a “yellow greasy clay,” and at 10 ft (≈ 3 meters) the yellow clay became too hard to work (Palmer 1990:258). It is somewhat surprising that the clays which Palmer describes as extending to the base of the mound would be recorded as a high resistivity reading. Rolingson (2012:203) describes the soils in the 1979 erosion cut excavation as being primarily composed of “very fine sandy loam,” or a “silt loam” as well as midden.
deposits, although a "massive clay" layer was also identified. This indicates that perhaps Palmer’s description of clay throughout is perhaps not an accurate portrayal of the mound’s composition, as a very fine sandy loam or a silt loam would certainly better match the resistivity values. However, his description of clay at 10 ft and his decision to stop his excavation there may suggest that at this depth he encountered a hardened layer, corresponding to the lower resistivity middle layer, causing him to stop his work.

As previously mentioned, one of the primary questions of interest involves the rectangular shape and flat summit of Mound B. Such a mound is rare in the Woodland period, particularly when it is not the largest mound on the site (Rolingson 1982). This has led to speculation that the mound may have been fundamentally reshaped, either by a later Mississippian culture, or through ploughing and erosion. A profile of the three dimensional model is able to begin addressing this question. In spite of this, it appears that the lower mound surface is very similar in shape to the current mound with a flat surface on top. This would seem to indicate that the rectangular mound with a large platform at the summit was not a later addition, or the result of ploughing but rather was evident even in the earlier stages of construction.

When the three dimensional model is sliced parallel to the transects around Transect 372, an even more intriguing feature is evident. In Figure 34 the approximate interface between the inner and outer mound structures is drawn in red. While the inner mound maintains the general shape of a platform mound, it appears that it may also contain two ditch-like features in its surface. These anomalies are approximately two meters wide and two meters deep, and persist for approximately eight meters between 374 and 366 East, the equivalent of being present in four transects. The smoothing required to generate a stable inversion model causes the features to appear to extend quite deeply into the mound, but there remains a clear line between the lower and upper resistivity values that is easily distinguishable from this “shadow.” One may only speculate what the purposes of these ditches may have been. It is possible that they were used for ceremonial
or communal feasting prior to the construction of the higher resistivity cap on the mound. Rolingson (2012:159) has hypothesized that a large concentration of animal bones excavated from Mound S originated from communal feasting, which may have been associated with ceremonies or construction projects. Furthermore, Kelly et. al. (2008:310) report that immediately before Mound 34 at Cahokia was constructed, “a large trench was excavated, lined with black clay, and filled with elaborate serving vessels” suggesting communal feasting. It is possible that similar activity occurred before the high resistance surface layer was added to the mound.

Figure 34: Slice through Mound B parallel to the Transects at East 372 showing the ditch features

In addition to the two trenches, the repaired erosion gully is also visible on the southern corner of the transect shown in Figure 34 and is outlined in blue. This image clearly demonstrates the limited resolution of the survey, because while the gully is identifiable as a region with exceedingly high resistivity, there is no evidence of the features in the report and indeed little more than the general shape of the erosion cut is visible.
Despite the large size of the excavation. There are also periodic interruptions of the surface high resistivity material around the edges of the mound as is shown on the northern slope of the transect in Figure 34. The most dramatic of these intrusions occurs on the western side of the mound around transect 342 East and is shown in Figure 35, and similar areas of low resistivity occur between transects 390 and 360, primarily on the northern side of the mound. These intrusions may be the result of inconsistency in the sources for material used in the construction of the outer layer of the mound, water flow patterns, or even erosion patterns. In any case, the low resistance interruptions of the surface layer are generally visible on the north east and north west slopes of the mound as is shown in Figure 36.

![Image of Mound B transection](image.png)

**Figure 35:** Slice through Mound B parallel to the Transects at East 342 showing the interruption in the surface layer.

The shallowest depth imaged by the ERT survey is approximately one meter. As shown in Figure 36, there are several features of interest visible at this depth. To the north of the mound is a region of very high resistivity. This may most reasonably be interpreted in one of two ways. It is possible that the high resistivity mound surface material has
eroded off the mound and created a region of higher resistivity at the base of the mound. Alternatively, and perhaps more interestingly, the high resistance locations may indicate an off-mound midden. Middens, which may accumulate during feasting, are commonly found near mounds, and this high resistivity anomaly is located on the side of the mound opposite the plaza (Horton 2014; Rolingson 2012). It seems very reasonable to conclude, therefore, that this is indeed a midden. In support of the erosion hypothesis, the northern and western sides of the mound closest to the very high resistance show a markedly low resistivity, similar to that found inside the mound. It is possible that the sides of the mound have eroded away, leaving the low resistivity material exposed on the slopes, and increasing the resistivity of the base of the mound. Naturally, some combination of these hypotheses is also possible. Excavation or coring near the northern side of the mound would likely confirm either or both hypotheses.

The remaining features visible from the surface view in Figure 36 are more likely related to historic activities. The very high resistivity feature on the southern corner of the mound is evidence of the erosion gully and the repairs done in 1979. The small points of exceedingly high resistivity on the northern corner and eastern sides of the mound very likely correspond to locations that at one time had large trees growing on them. Henry J. Lewis drew “An Elm tree 18 inches in diameter” on what appears to be the northern corner of the mound and more recent photographs such as those of the excavation at the base of Mound B in 1980 show large trees covering the mound, including an exceptionally large one on the northern corner (Jeter 1990; Rolingson 2012:250,200). Finally, there are two high resistivity anomalies visible on the mound platform which may be associated with historic activities. One is a roughly linear feature traversing the northwestern side of the summit, while the other is a right angle with one side along the north eastern side of the summit. The identification of these anomalies and the presence of narcissus at the mound’s summit, indicative of historic activity, created a third goal for the project to further examine and interpret these features through the use of shallow geophysical methods.
MOUND B: SECONDARY SURVEY

The first shallow geophysical method used to further examine the platform of Mound B was ground penetrating radar. The 200Mhz antenna appears to have revealed a major soil transition around 2 meters below the surface. This transition may be the top of the lower portion of the mound identified in the ERT results. However, it appears to be about a meter above where this transition was expected to occur. It may also be a thinner construction phase that was not identified by the ERT survey such as the "massive clay" layers encountered by Rolingson 2012:202 in the erosion cut excavation. Soil cores or a re-excavation of Palmer’s trench would likely be able to resolve this question. By taking timeslices it is possible to formulate maps of the research area at multiple depths. The primary features of interest are a series of linear anomalies forming roughly the shape of a rectangle, shown in Figure 37. These anomalies originate very near the surface, but reflect most of the way through the profile shown in Figure 38, indicating that the anomalies are
likely the result of metallic items located near the surface. More mysterious is the small anomaly located near the center of the survey area. It may be evidence of a floor surface or some other feature from the time of the mound’s construction, or it may be related Palmer’s excavation at the summit of the mound. There is a depression on the mound’s surface very near to where the anomaly is located and the dimensions roughly match Palmer’s 1990 description of his trench.

Figure 37: Interpretations of Ground Penetrating Radar Data
The linear anomalies shown in the GPR are also present in the magnetometry data shown in Figure 39. They appear to clearly indicate the boundaries of some sort of enclosure. Such strong dipolar anomalies are almost certainly the result of metallic fragments. However, the lines also appear somewhat diffuse, particularly in the southeastern corner of the arbitrary grid. This would seem to indicate the remnants of some sort of fencing material, perhaps chain-link or barbed wire. There appears to be a gap in the anomalies in the south western portion of the grid, which may indicate the presence of a gate or opening to enter the enclosure. This gap is approximately located next to the erosion gully on the southern corner of Mound B and may provide a possible explanation for the increased erosion on this portion of the mound. Increased foot traffic as people worked to gain entrance to the enclosure could significantly contribute to the erosion of the slope. Edward Palmer reported as early as 1883 that the top had been cultivated as a garden and in 1940 the WPA reported that it was still being used as such.
Palmer 1990; Rolingson 2012). While Lewis’ drawings do not indicate any fencing on the top of Mound B, it is possible that this was intentionally excluded, or that sometime over the next sixty years of gardening, fencing was added. Therefore, it is very likely that the anomalies present in the GPR and magnetometry data are the result of an enclosure around or relating to this garden.

Figure 39: Interpretations of Magnetometry Data:

At first glance it is a concern that the ground penetrating radar and the
magnetometry data do not show a strong correspondence with the ERT data, especially in relation to the linear anomalies which were the impetus for the secondary survey. There is no physical reason why the other methods and resistivity should necessarily be related. However anomalies in one physical domain often have an effect in other domains as well, and it was hoped that the new methods would aid the interpretation of those anomalies. The resistance data, however, mapping the same property as the ERT survey, did show significant correspondence. As is clear in Figure 41, nearly all of the features visible in the ERT survey are also visible in the resistance survey, including a high resistance anomaly on the western side of the grid with a very low resistance anomaly to the north of it. The right angle anomaly in the ERT data is also visible in the resistance data, and has been completed with two more sides of faintly higher resistance than the background values, creating a roughly 7x7 meter square. It is still not clear what this anomaly represents as it is not aligned with the enclosure and is located to the eastern side of the mound, although its rectangular shape suggests that it likely results from a historic activity.

Finally, and perhaps most excitingly, when the resistance data is overlaid with the GPR data as in Figure 40, the two datasets reinforce each other, showing a correspondence between the primary line of metallic reflections running from the western side to the north eastern corner of the grid and high resistance data. This linear feature was not easily visible prior to this overlay and serves to tie together all four geophysical methods. While six separate depths were collected using the multiplexer, the 50 cm depth showed the most detail, with the remaining depths appearing virtually the same, with a lower resolution. Therefore only the 50 cm data is interpreted here.
Figure 40: Overlay of the GPR and Resistance Data, note the correlation between the linear anomaly in the GPR and a line of high resistance.
Figure 41: Interpretations of Resistance Data

Interpretations
- Green: Rectangular Feature
- Blue: High Resistance Anomaly
- Black: Very Low Resistance Anomaly
- Red: Linear Anomaly

Legend:
- 0 2 4 m
MOUND A

As discussed above, interpreting the two dimensional profiles of Mound A is a challenging task. Unfortunately, a full three dimensional inversion is not reasonable for the Mound A data due to the large spacing of the transects, and so the only available option is to try to understand the profiles as they are. In spite of these difficulties, it is still possible to understand the general trends present in the data and begin to answer some questions about the mound’s structure, history and condition.

All of the transects that cross the central portions of Mound A such as A30 in Figure 20, clearly show that the mound, like Mound B, is constructed out of at least two distinct materials. The lower portion being composed primarily of a low resistivity material and the upper of a much higher and more heterogeneous material or set of materials. This outer material is likely between two and three meters thick. This stratigraphic profile also matches remarkably well with Edward Palmer’s descriptions of his excavation in the mound wherein he describes “2 ft. of vegetable mould” which he describes as being mixed with bones and pottery fragments, perhaps suggesting some midden features which would likely have a very high resistivity (Palmer 1990:257-258). The next eight feet he describes as “sandy loam” which would also have a relatively high resistivity value. Then he reports that at 10 ft. (≈ 3 meters) he struck solid clay, which would almost certainly account for the very low resistivity values measured for the remainder of the depth of the mound (Palmer 1990). He continues to describe a similar stratigraphy from his trench in the side of the mound, further supporting the model. Therefore, despite Palmer’s questionable efforts at measuring the mounds under the direction Cyrus Thomas, his notes on his excavations provide the only known record capable of providing archaeological support for the geophysical results from Mound A.

The apparent correlation between the two to three meter addition of highly resistant material on both Mound B and Mound A may be important. In the absence of dating material, it is possible to hypothesize that the deposition of approximately the same
amount of similar materials on the surface of both mounds may indicate that the mounds were built up either during the same building episodes, or at least around the same time. It does not appear that this construction occurred only on the top of the mound surfaces already present, but rather in both cases covered the entirety of the mound surface, completely, and relatively evenly. This suggests once again that the intentions in these phases of mound construction were the same on both mounds and may have been concurrent.

It is also possible using these data to begin examining the hypothesis that Mound A may once have been a platform mound, perhaps rectangular in shape, which has been reduced through ploughing, erosion, and other destructive forces to its current conical shape. Given that the mound appears to have been covered fairly evenly in the higher resistivity material, it seems likely that if Mound A had indeed been subject to such dramatic erosion or destruction that its shape had been fundamentally changed, this material would have been removed. Therefore, only the thin superficial deposits of high resistivity material seen off-mound would remain above the low resistivity clay center. This does not appear to be the case from the models. The thickness of the outer layer on the northern side of the mound does appear to be slightly less than it does on the southern side, but it is difficult to determine whether this is reality or an artifact of the algorithm. Regardless, it does not appear to reduce so dramatically to fundamentally have changed the shape of the mound. This would therefore seem to indicate that the conical Mound A was not once a large platform mound, but rather has always been conical. A higher resolution survey, allowing for three dimensional modeling and further refinement would aid in confirming this assessment, as could soil coring.

CONCLUSIONS

The purpose of this research was to begin to explore the subsurface of Toltec’s tallest mounds, Mound B and Mound A. Despite decades of professional research, very little was
known about these massive structures including their internal form, stratigraphy, condition and purpose, due to a lack of resources and a preservation ethic which prevents excavation. In order to address these problems electrical resistivity tomography was used to create a three dimensional model of the resistivity of the subsurface of Mound B, and models of two dimensional transects of the subsurface of Mound B. Given a RMS error of less than five percent for each transect and a RMS of 5.5% for the three dimensional model, the models likely are strongly correlated to the resistivity distribution of the true subsurface, and therefore provide good models for archaeological interpretation.

The understanding of Mound A and Mound B is crucial for developing an understanding of Toltec, the Plum Bayou Culture, and the Terminal Woodland in the Arkansas River Valley. This great importance is largely due to the peculiarity of the ceremonial center in this larger context. The size and complexity of Toltec is unusual for any site during the Terminal Woodland, a period generally thought of as at best nothing more than the time between the Woodland and Mississippian cultural complexes, and at worst an outright cultural collapse, a low point in stylistic and cultural complexity. Perhaps more than its impressive dimensions, however, Toltec is important because of the arrangement and shapes of its mounds, suggesting the Terminal Woodland in the Arkansas River Valley to be a much more diverse and complex period than the above evaluations would suggest. The presence of large, open plazas and the square platform mound shape of Mound B, is strongly reminiscent of the later Mississippian Cultures which developed to the North. Equally as perplexing, the conical shape of Mound A defies the expectations of the largest mound at a site with plazas and platform mounds. These anomalies are perhaps among the most important features of the site in terms of understanding the rise of cultural and political complexity. It is little surprise therefore that Rolingson characterized the lack of knowledge about the largest mounds as one of the biggest gaps in our understanding of the site. Mounds A and B may play a key role in understanding the site’s role in the transition between Woodland and Mississippian cultures.
One of the first considerations that must be addressed to understand Mound A and Mound B is the current condition of the mounds. After more than a thousand years of erosion and more than a century of agriculture and historic activity, many of the prehistoric structures at Toltec have been eroded, destroyed, or otherwise dramatically modified from their previous forms. The extent of historic damage to Mound A and Mound B is not precisely known, and presents the possibility that the unusual nature of the two mounds is not the result of prehistoric cultural activity, but rather historic modification. In order to evaluate this hypothesis it was useful to compare the resistivity stratigraphy of the two mounds surveyed in this research. It appears from the models that both mounds were composed primarily of a low resistivity clay material, and were capped with a two to three meter thick layer of high resistivity material, likely a silty loam, over the entirety of the mound surface. Edward Palmer’s excavations appear to confirm these results, and also provide assurance that this addition was indeed a prehistoric one, as do the carbon dates from the Mound B erosion gully excavation. The consistent depth of this outer layer, and its presence on both mounds suggest that it is reasonable to hypothesise that these surfaces were applied at a similar time and with a similar purpose, if not as a part of the same episode of construction. Furthermore, it seems reasonable to conclude that if the basic form of Mound A or Mound B had been fundamentally altered through erosion or historic activity, these surface deposits would likely have been removed. However, there is no evidence in the data that this is the case. Therefore, it is likely that the current forms of A and B are not dramatically different than they were following the final stage of construction in prehistoric times.

Having concluded that the current shape of the mounds are not the result of historic modification, it is necessary to try to determine whether the Mississippian style form of Mound B may be the result of later Mississippian modification. This proposal, however, is problematic on several levels. During the Early Mississippian period the region surrounding Toltec was largely abandoned and there is no evidence of such organization as
would be necessary to carry out such a large scale modification (Nassaney 1994).

Furthermore, Edward Palmer reports that within the first two feet of his excavation, he discovered “2 fine crystals.” (Palmer 1990:258). Quartz crystals are typical of the Plum Bayou Culture. The 1979 excavation also precludes this possibility as radio carbon dates from charcoal retrieved during this work yielded a date of 800 to 900 C.E (Rolingson 2012).

Finally, the three dimensional model of the resistivity of Mound B appears to indicate that the square platform mound shape of the mound was present prior to the addition of the high resistivity surface deposits. It is almost certain therefore that the shape of Mound B has been much the same since the Terminal Woodland.

In addition to examining the condition and basic structure of the mounds, the survey also offers some tantalizing clues to other activities that may have occurred on the site. Although the interpretation of two trench features in the surface of the lower level of Mound B, beneath the high resistivity layer, requires what may at best be described as guesswork, their presence as a deposit from ceremonial feasting would not be uncharacteristic of Toltec. It is possible, and even likely, that such a feast would have occurred just prior to the construction of the outer layer of the mound.

The shallow geophysical methods used on the platform of Mound B did not yield much information about the prehistoric occupation or activities at the site. The resistance mapping showed much the same results as the ERT, with a slightly better resolution. The GPR data may have shown a single feature two meters below the surface, but this is as likely related to Palmer’s excavation as otherwise, and the Magnetometry data was rapidly overwhelmed by metallic debris from the enclosure and any subtle anomalies that may have represented more ephemeral prehistoric features were obscured. Nevertheless the survey was certainly not a waste of time. The primary goal of this phase of the research was to further examine what is likely anomalies from historic activities identified by the ERT survey. Unfortunately, these anomalies did not appear in any of the secondary surveys except for the resistance survey, which completed a square anomaly but otherwise did not
offer more information about the features. However, the magnetometry and ground penetrating radar surveys did reveal an important element of the historic occupation that was previously unknown. It was well documented that the top of Mound B was the location of a garden for many years (Rolingson 2012; Palmer 1990). This fact is still evidenced by the domestic flowers that grow to this day, when the mound is not mowed. The new addition of this research is that at some point there was a metallic enclosure on the mound platform, likely around the garden. This enclosure is oddly oriented, not aligned with the mound surface but rather approximately aligned with magnetic north. It is possible that this alignment is due to the presence of trees or some other obstruction on the mound’s surface at the time of its construction. Furthermore, the absence of metallic remnants near the southernmost corner of the mounds suggests that perhaps this was an opening or gate in the enclosure. This opening is directly adjacent to the repaired erosional gully, and consistent and prolonged foot traffic may be at least a partial explanation of the severe erosion that occurred. One feature that is surprisingly absent, from all datasets is any definitive evidence of the excavations completed by Edward Palmer. The reason for this absence is not apparent. There is a physical dip in the surface of the mound that is very likely a remnant of this excavation, however it mysteriously does not appear to be reflected in the geophysical data, and serves as a reminder that without a contrast in physical properties, there is no way of detecting a feature.

Having therefore examined all of the data collected, a central question still remains. If the fundamental structure of Toltec’s two largest mounds has not been dramatically modified since their creation, how does one explain the presence of a Mississippian style platform mound, and why is it not the tallest structure on the site? Further research is certainly required to begin to answer these questions, however the rest of the archaeology of the site may offer some clues. The Plum Bayou Culture is largely defined through its unique combination of ceramic styles and elements present in the cultures around it. The predominantly plain ceramics demonstrate the cultures roots in the Baytown culture, but
simplistic pottery does not necessarily translate into a simplicity of culture. While the Terminal Woodland is often viewed as a “nadir in ceramic decoration and mortuary ceremonialism,” (Nassaney 1994:45). Toltec strongly demonstrates that this does not suggest a nadir in cultural complexity. Rather the massive mound complex seems to have reached its peak during this time, serving as a repository for ideas which could be maintained, modified and developed.

In order to better understand the role Toltec played in the Terminal Woodland and the transition to Mississippian cultures, more research on the mounds is required. Soil cores would provide a more detailed stratigraphic profile and organic material collected could allow this stratigraphy to be dated, to better understand not only the structure but the development of the mounds. Further ERT surveying could allow the three dimensional modeling of Mound A as was done on Mound B. Future ERT work however should also include selected transects with very high resolution, with electrodes spaced at half meter intervals as was done in the recent survey of a Late Woodland mound in Mississippi (Kassabaum et al. 2014). This would allow for the greatest potential to identify very small anomalies such as burials which could improve the understanding of the purposes and uses of the mounds. Finally, a high resolution digital elevation model of the site such as one generated from LIDAR or photogrammetry could reveal features and trends not readily visible from the surface, and would be useful for monitoring erosion and damage that may continue to occur. These techniques are just the beginning to see and understand the deepest reaches and meanings of Arkansas tallest mounds.
CITED

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APPENDCIES

MOUND B ERT INVERSION RESULTS
MOUND A ERT RESULTS

Mound A Transect 0

Mound A Transect 15
GROUND PENETRATING RADAR 200MHZ PROFILES

200MHZ GPR Profile 1

200MHZ GPR Profile 2

200MHZ GPR Profile 3
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200MHZ GPR Profile 31

Approximate Depth (m)

Surface 0.34
0.68
1.02
1.36
1.7
2.04
2.38
2.72
3.06
3.4

Distance (m)

200MHZ GPR Profile 32

Approximate Depth (m)

Surface 0.34
0.68
1.02
1.36
1.7
2.04
2.38
2.72
3.06
3.4

Distance (m)

200MHZ GPR Profile 33

Approximate Depth (m)

Surface 0.34
0.68
1.02
1.36
1.7
2.04
2.38
2.72
3.06
3.4

Distance (m)
200MHZ GPR Profile 40

Approximate Depth (m)

Distance (m)

Surface
0.34
0.68
1.02
1.36
1.7
2.04
2.38
2.72
3.06
3.4
GROUND PENETRATING RADAR TIMESLICES

Time slice: approximately 0.5 m below the surface

GPR Timeslice approximately 0.5 meters below the surface
GPR Timeslice approximately 2 meters below the surface
GPR Timeslice below 2 meters below the surface

Time slice:
below 2 m
below the surface