Searching For Graves From the 1921 Tulsa Race Massacre: Geophysical Survey of Oaklawn Cemetery, The Canes, and Newblock Park

By

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Abstract

From October 7-11 and 14-17, 2019, at the request of the City of Tulsa, the Oklahoma Archeological Survey conducted a geophysical survey of portions of Oaklawn Cemetery, The Canes, and Newblock Park to locate potential burial locations associated with the Tulsa Race Massacre of 1921. No anomalies consistent with graves were found at Newblock Park. However, possible common graves were identified at The Canes and the Sexton Area in Oaklawn Cemetery.

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Acknowledgements

This project could not have been completed without the help of a number of people. Scott Ellsworth and Betsy Warner identified the areas to be surveyed. Betsy also served as our buffer from visitors so that we could get work done. Angela Berg assisted us in the field every day of the project and provided some of the photographs used in this report. Brandi Bethke, Bobi Deere, Jen Dewey, Alicia Odewale, and Kary Stackelbeck also helped with fieldwork. Finally, Michelle Brooks and Amy Brown from the City of Tulsa provided valuable logistical support. Finally, Sheila Bobalik Savage provided helpful comments on an earlier draft of the report. We thank you all.

Introduction

From October 7-11 and 14-17, 2019, at the request of the City of Tulsa, the Oklahoma Archeological Survey conducted a geophysical survey of portions of Oaklawn Cemetery, The Canes, and Newblock Park to locate potential burial locations associated with the Tulsa Race Massacre of 1921 (Figure 1). The areas surveyed were identified by historians Dr. Scott Ellsworth (University of Michigan) and Betsy Warner (Tulsa, Oklahoma) based upon their scrutiny of evidence from written sources, photographs, and oral interviews. Parts of these areas were previously surveyed (Maki and Jones 1998; Witten, et al. 2001), but most locations were surveyed for the first time.

Figure 1. Survey areas: 1. Newblock Park; 2. The Canes; 3. Oaklawn Cemetery. Base image downloaded from Google Earth, 12/9/2019.

Methods and Technologies

Surveying and Mapping. The instruments used for the surveys were a Bartington Grad 601 gradiometer, a Geoscan Research RM15 electrical resistance meter with multiplexer, and a Geophysical Survey Systems, Inc. (GSSI) UtilityScan ground-penetrating radar (GPR) system. Data were collected in 20x20 m (65.61x65.61 ft) grid squares. Grid corner stakes were positioned using a laser total station for accurate measuring. Standardized ropes 20 meters (65.61 ft) in length and marked at 50 cm (1.64 ft) intervals were then used to guide the operators.

Geophysics**.** Geophysics has become a common tool in archaeology and consists of a number of non-invasive methods to find and analyze subsurface features (Clark 1996; Conyers 2012; Kvamme 2001; Weymouth 1986). Cultural features are usually recognized by contrasts or other differences between a feature and undisturbed surrounding soils. Human activities alter soil texture in many ways, including compaction, stratigraphy, moisture retention, and burning, among others. Geophysical technologies allow us to measure and locate variations of the physical characteristics of the soil. These instruments operate near or at ground surface. The use of the ropes described above allow for spatial control and the subsequent accurate location of soil anomalies detected with geophysical technologies.

Ground-penetrating radar (GPR). GPR is commonly used in cemeteries (Conyers 2006). It is an active technology, meaning it introduces an artificial field to measure response. GPR works by sending pulses of radar into the ground, which are reflected, absorbed, or otherwise deflected by these buried features. The return time of these pulses indicates the depth to the anomaly. Data are collected in sequential profiles, which can then be combined in proprietary software (in this case, RADAN 7) to create three-dimensional views. Data can then be viewed vertically and horizontally to search for anomalies.

Soil properties and the frequency of the GPR antenna determine both the depth that the radar pulse will penetrate and its resolution. Higher frequencies will not go particularly deep, but can detect smaller objects. Lower frequencies will go deeper and can detect larger objects (Conyers 2004). The speed of the pulse depends on the composition of the soil through which the signal travels. Likewise, GPR generally works better in wetter, siltier soils than dry, sandy soils (Conyers 2004); dry sands are some of the worst soils for GPR.

Graves appear in the data as multiple types of anomalies. These are generally caused by the deflection/reflection of the radar pulse created by the contrast between a grave and the surrounding soil (Bevan 1991; Conyers 2004, 2012). Hyperbola-shaped anomalies often appear directly over archaeological features. These can mark burial vaults, air pockets created by coffins, coffin furniture, or buried foundations such as headstones and stone outlines (Bevan 1991; Conyers 2004, 2006, 2012; Gaffney and Gater 2003). However, tree roots, rocks, and rodent burrows can cause similar hyperbolas, thus requiring careful mapping of the survey area and care in interpretation of the data. Generally, if an anomaly appears in the same place in multiple sequential profiles, it is more likely to be a grave than a naturally occurring feature.

A GSSI Utility Scan with a 350 MHz antenna was used for this project (Figure 2). It was moved in a sequential zigzag pattern across the survey area and the antenna constantly remained on the ground surface during data collection. Data was collected at 100 readings per meter with 0.5-meter (1.64 ft) spacing between transects. Signal strength was good to a depth of roughly 2 meters (6.56 ft), well within the depth of historic graves, although the lower meter at Oaklawn and Newblock suffered from signal attenuation due to highly conductive soils. Data were downloaded into RADAN 7 for processing. Results are presented in this report as both vertical profiles and horizontal depth slices.

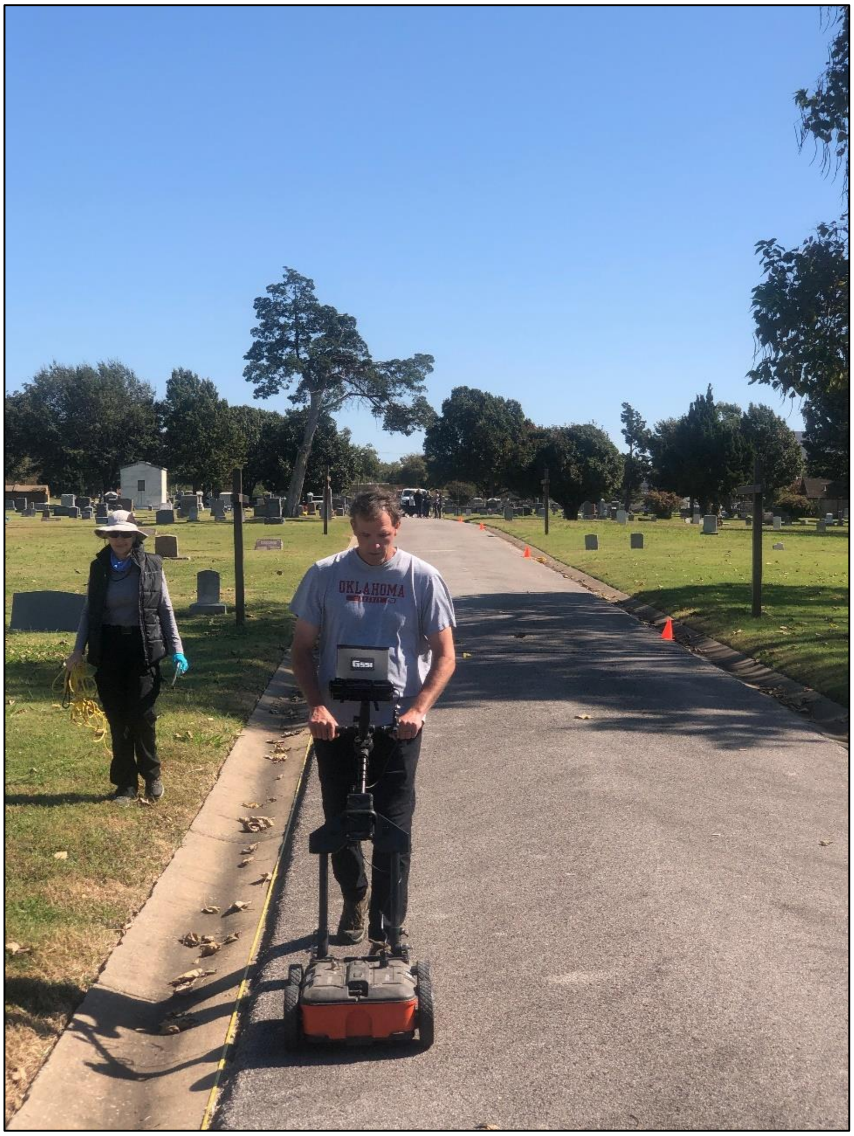

Figure 2. GSSI UtilityScan GPR in use on a paved road in Oaklawn Cemetery.

Electrical Resistance. Electrical resistance measures the resistance of soils and other materials to the conduction of an electrical current. Subsurface features have different physical properties and therefore have varied levels of resistance to the flow of electricity. Compaction, porosity, moisture retention (among others) affect the electrical current in different ways. The electrical resistance meter is placed on a specialized rack with a set of steel probes. These probes are inserted into the ground for each measurement and an electrical current is sent between these probes in an arc. The instrument measures the amount of resistance to the flow of this current as it completes its circuit (Gaffney and Gater 2003; Schmidt 2013).

Resistance surveys are useful in identifying buried walls, rubble, surfaces, roads, geological features, ditches, pits, gullies, drains, metal pipes, and graves (Gaffney and Gater 2003; Schmidt 2013; Somers 2006). Graves are detectable because of the presence of coffins and/or the movement of earth by the digging of the grave (Bevan 1991). The amount of moisture in the soil can have a significant effect on survey results. Since water is highly conductive, electricity flows through it with decreased resistance. Therefore, heavy rain or the presence of localized areas where water collects can cause low resistance readings. In cemeteries, graves often have depressions above them. Water can collect in them and indicate the presence of the grave as a low-resistance anomaly compared to the undisturbed soil adjacent to it. Depressions may also be created by natural events such as erosion or tree throws. Trees can cause both high and low resistance anomalies. High resistance anomalies can be produced by the depletion of water near the tree's roots, while low resistance anomalies are created by loose soil around the base of the tree or localized high moisture under the canopy.

A Geoscan Research RM15 with an MPX15 multiplexer in a PA20 multi-probe array was used for this project (Figure 3). Data were collected in a zigzag pattern along the same transects used for GPR. Two simultaneous readings covering one meter were taken along each traverse. This resulted in a .5 x .5 m cell size along the x-axis and y-axis. This array can detect anomalies to a depth of around 1 m (3.28 ft). Data were downloaded into GeoPlot 4 and standard processing measures were applied.

Figure 3. Geoscan Research RM15 electrical resistance meter in use at Oaklawn Cemetery. Photo by Angela Berg.

Gradiometry. A gradiometer is a passive sensor that measures changes in magnetic fields in a unit known as nanoteslas (nT) (Aspinall, et al. 2008; Clark 1996). Burning and disturbance both alter the magnetic reading of soil, meaning features such as fire pits, mounds, old excavation units, burials, and house floors are typically detectable using this technology. Soils with high organic contact also have slightly higher magnetic readings (Lockhart 2010). Metal objects have very high readings and are visible as dipoles (a strong alternate high and low nT reading). The presence of large quantities of metal on a site can sometimes make data collection with a gradiometer problematic but can also be helpful, particularly at historic sites.

A Bartington Grad 601 gradiometer was used for this project (Figure 4). Data were collected in a zigzag pattern every 12.5 cm (0.41 ft) along transects spaced 50 cm (1.64 ft) apart. The data were downloaded into TerraSurveyor 3 and standard processing methods were applied in order to identify any possible subsurface anomalies.

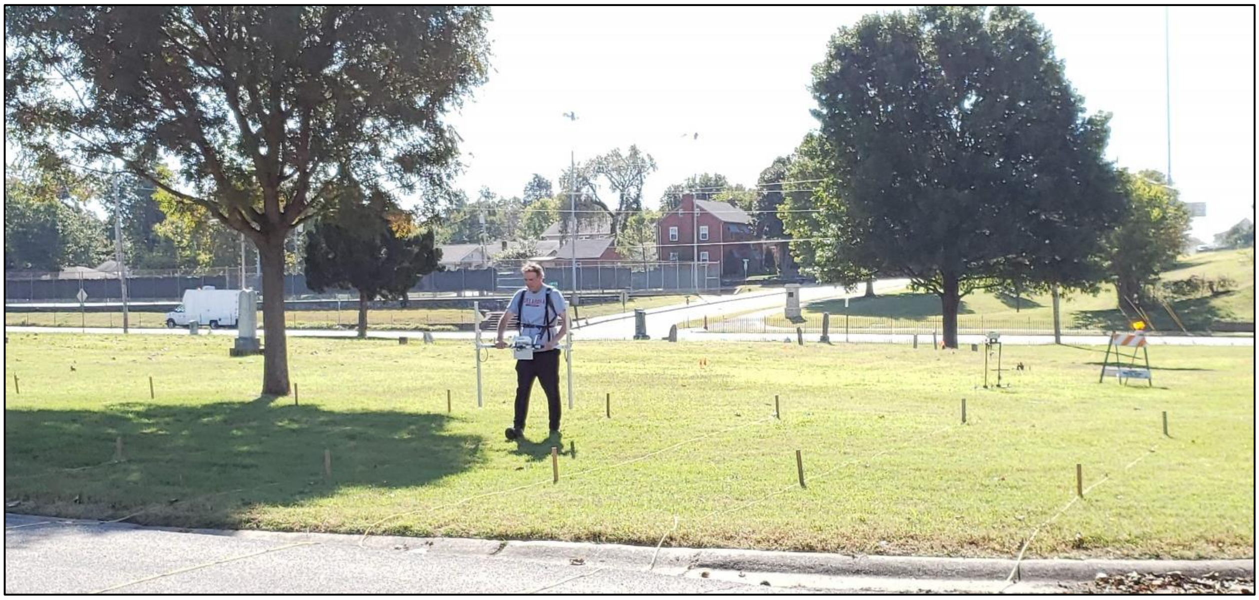

Figure 4. Bartington Grad 601 gradiometer in use at Oaklawn Cemetery. Photo by Angela Berg.

Results

Newblock Park. Investigations at Newblock Park focused on an area to the east of the sewage transfer station and was bordered by the railroad tracks to the south and the drainage ditch to the east (Figure 5). The survey area was also defined by the artificial topographic relief caused by levee and ditch construction to the north and south. GPR was used in all grids shaded in Figure 5, but the gradiometer and resistance meter were only used in a subset of the grids due to interference from the large power line that parallels the railroad tracks (Figures 6 and 7).

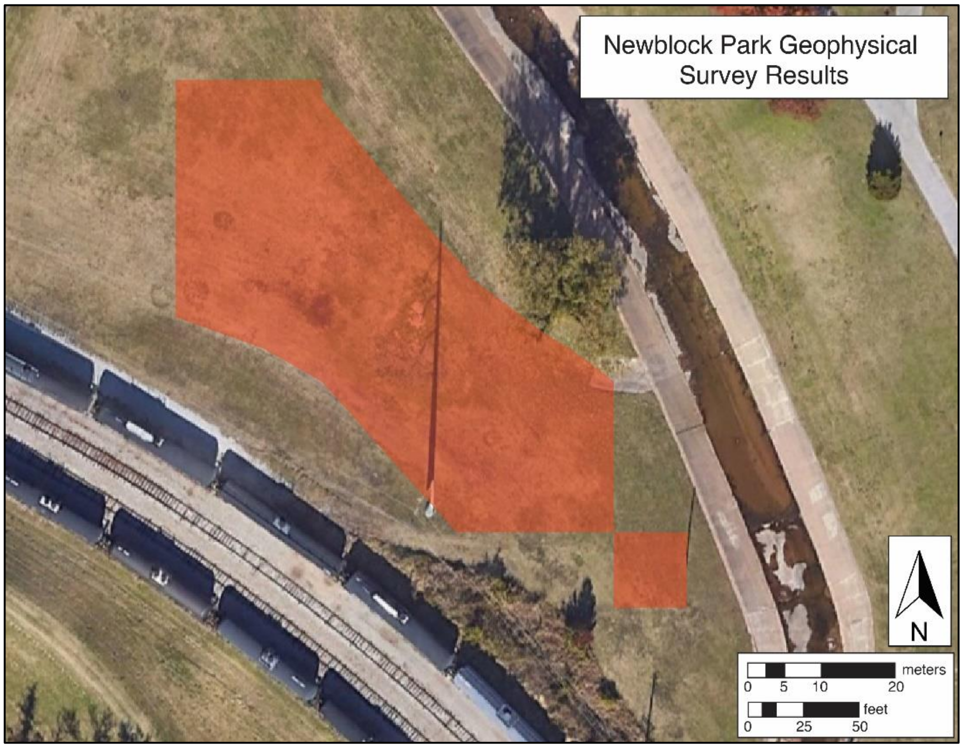

Figure 5. Newblock Park survey area. Base image downloaded from Google Earth, 12/2019.

Figure 6. Large power line at Newblock Park, facing roughly west from the southeastern corner of our survey area.

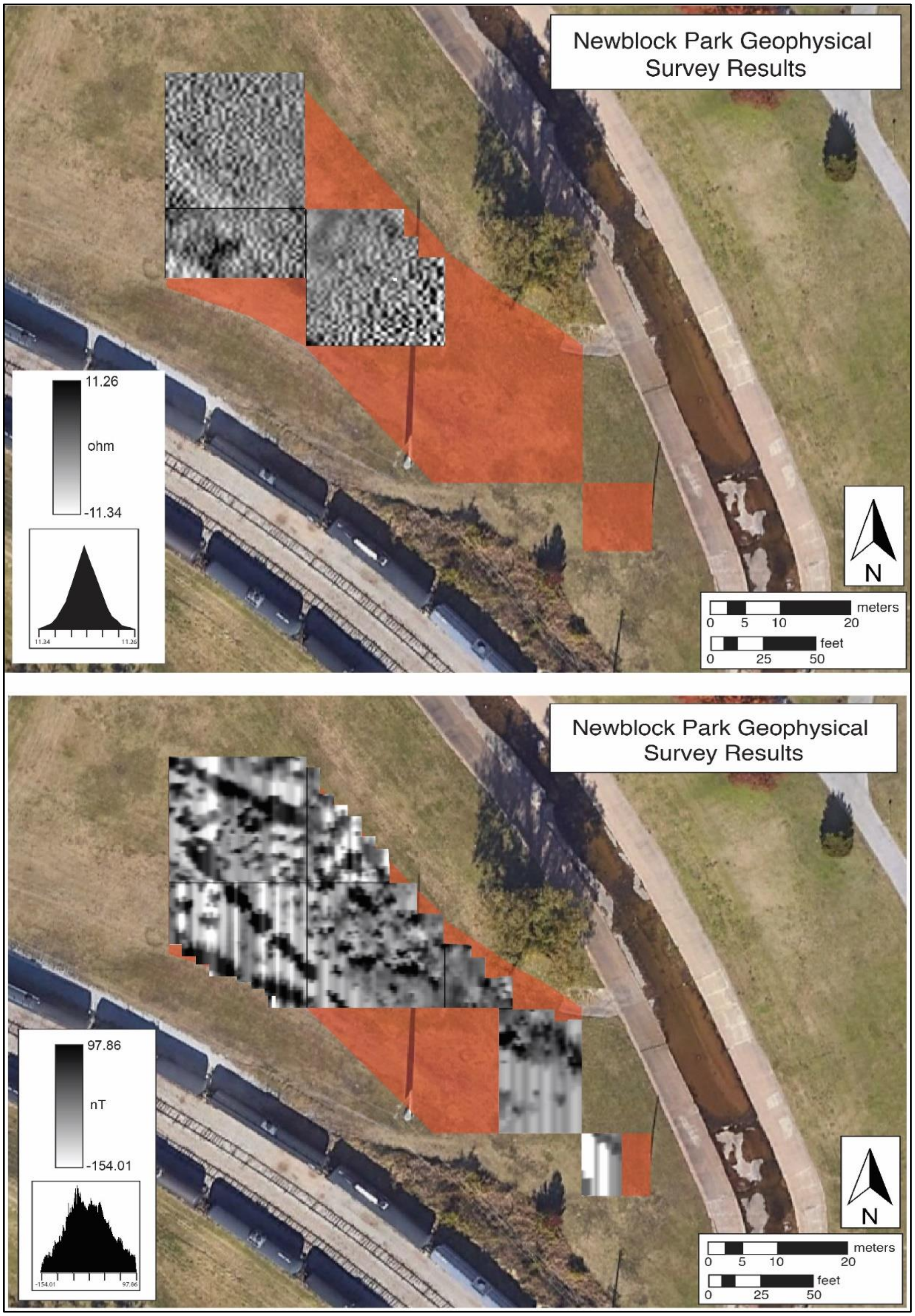

Figure 7. Location of electrical resistance (top) and gradiometer (bottom) survey areas at Newblock Park. Base image downloaded from Google Earth, 12/2019.

The power line significantly affected gradiometer and resistance results at Newblock Park. It rendered the resistance data essentially useless (Figure 8) and caused interference (seen by "striping") in the gradiometer data (Figure 9). Despite this interference, human-made features, likely pipes or filled-in ditches, are evident. No anomalies consistent with graves were evident.

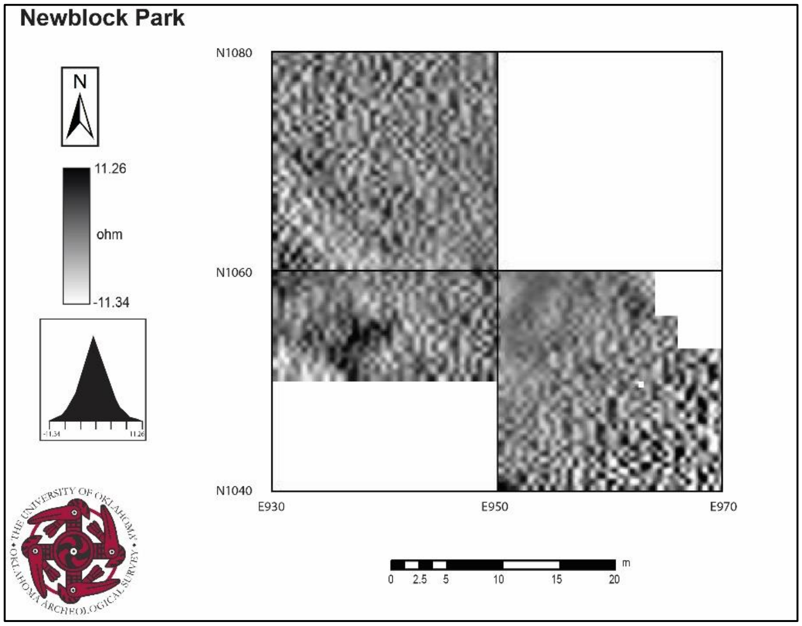

Figure 8. Newblock Park electrical resistance results. Data affected by power line interference.

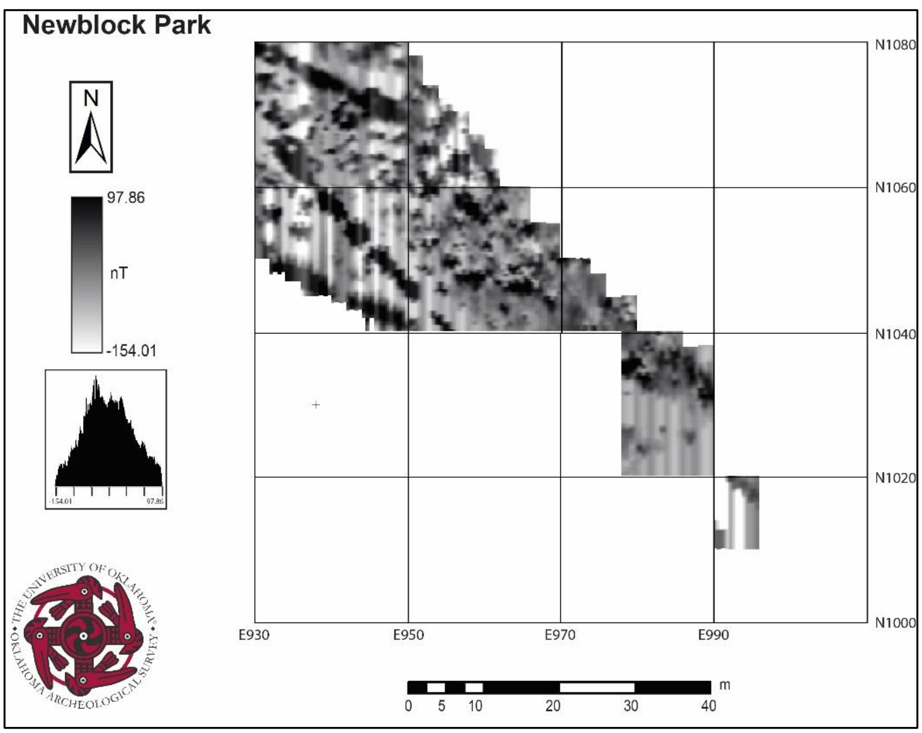

Figure 9. Newblock Park gradiometer results. Note striping caused by power line interference and long linear anomalies that are likely pipes or filled-in ditches.

The GPR was not affected by the power line. However, no features consistent with graves were noted; only the same pipes that were detected by the gradiometer (Figure 10).

Based on the lack of grave-like features in the data from all three instruments and the extensive land modification that has taken place since 1921, we do not believe that any intact burials are located at Newblock Park.

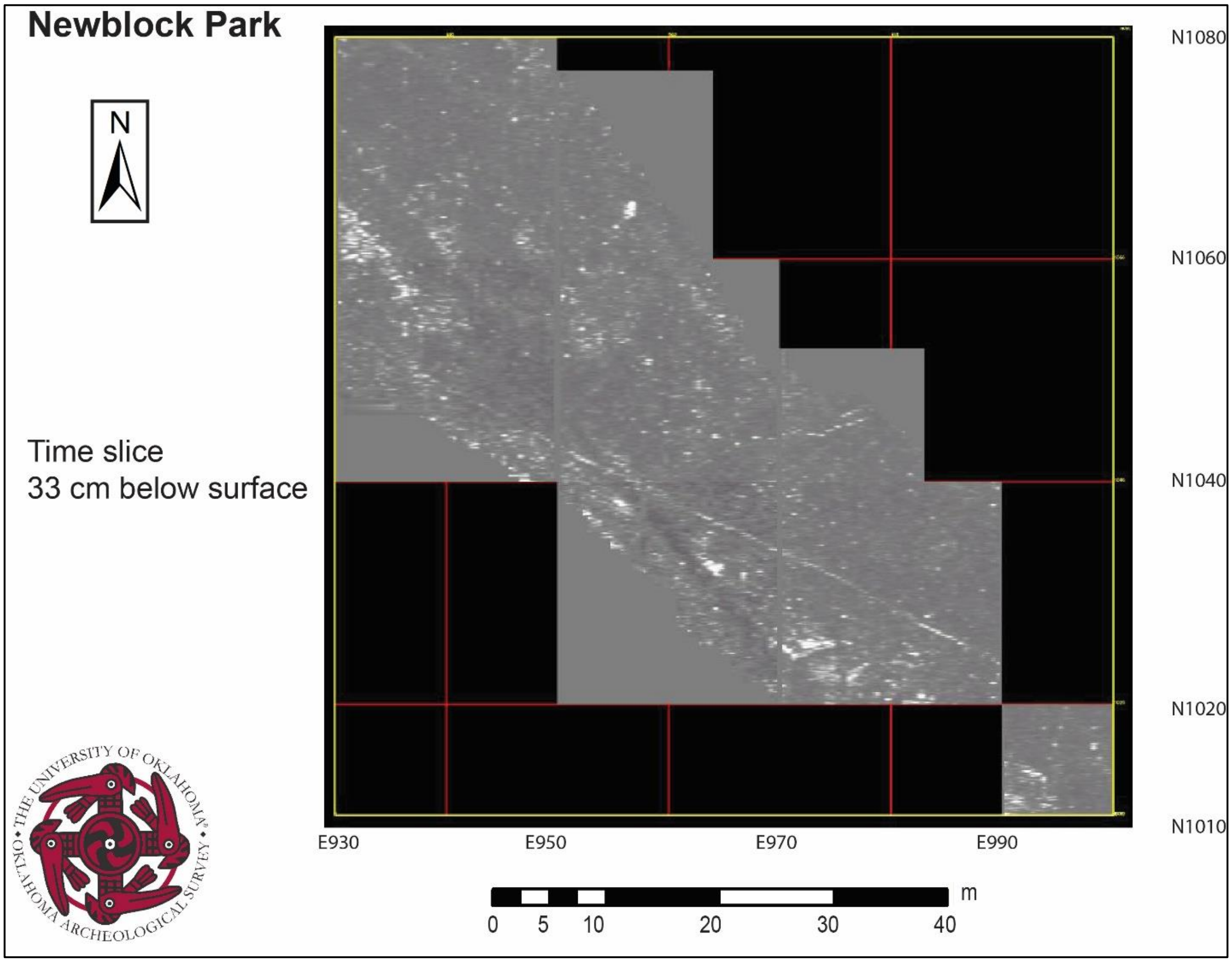

Figure 10. Newblock Park horizontal GPR slice at a depth of 33 cm (1.08 ft) below surface. Linear features represent pipes or ditches.

The Canes. The Canes is east of Newblock Park and located on a bluff along the Arkansas River adjacent to Highway 75 and the railroad tracks that parallel it (see Figure 1). It is heavily wooded (Figure 11) and is currently the site of a homeless encampment. The amount of metal debris associated with these campsites made it impossible to use the gradiometer. The dry sandy soil in this area limited the effectiveness of the electrical resistance meter and it was likewise not used. GPR was not affected by the soil or the metal.

Despite the tree cover, two small areas were surveyed using GPR. Area 1 (Figure 12) measured 8x17 m (26.25 x 55.77 ft) and Area 2 was 4x7 m (13.12 x 22.97 ft). No grave-like anomalies were found in Area 2.

Figure 11. The Canes. Base image downloaded from Google Earth, 12/2019.

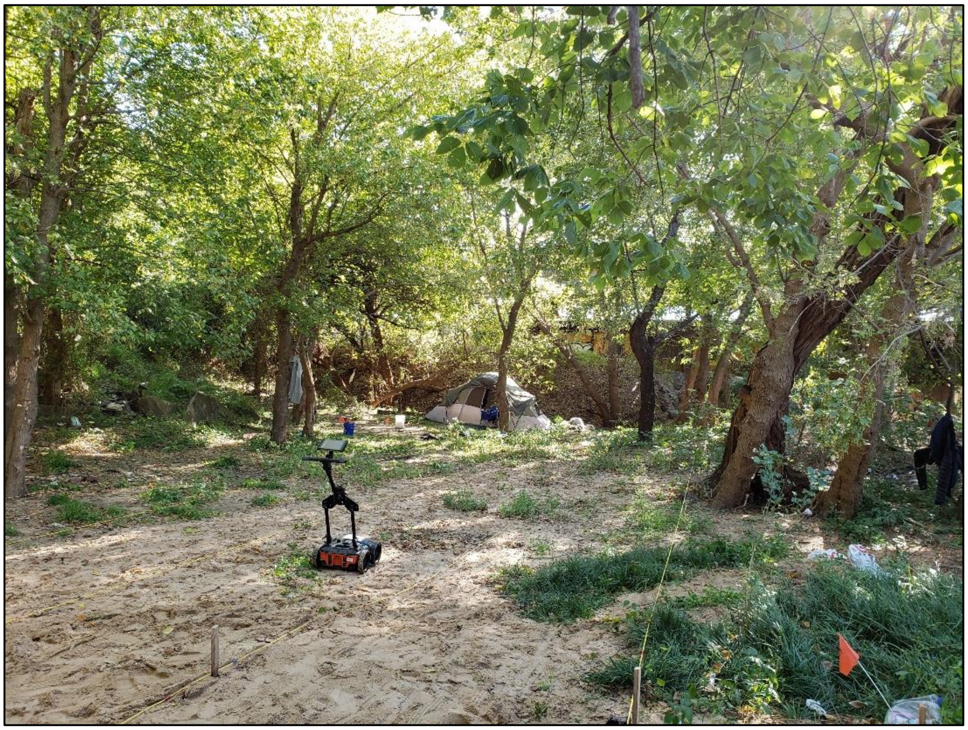

Figure 12. Area 1 at the Canes, facing roughly east. This area is in the southeastern corner of Figure 11. Photo by Angela Berg.

In Area 1, there are two anomalies that are consistent with potential large graves in the northwestern corner of the survey area (Figure 13). They measure roughly 2x3 m (6.56 x 9.84 ft) and extend to a depth of at least 1.5 m (4.92 ft) below the ground surface. Figure 13 shows a horizontal view at a depth of 74 cm (2.43 ft) below ground surface and features two potential large graves. The images to the left and right show the profile of each anomaly. Each is evident at ground surface but becomes most pronounced around 74 cm (2.43) below the surface.

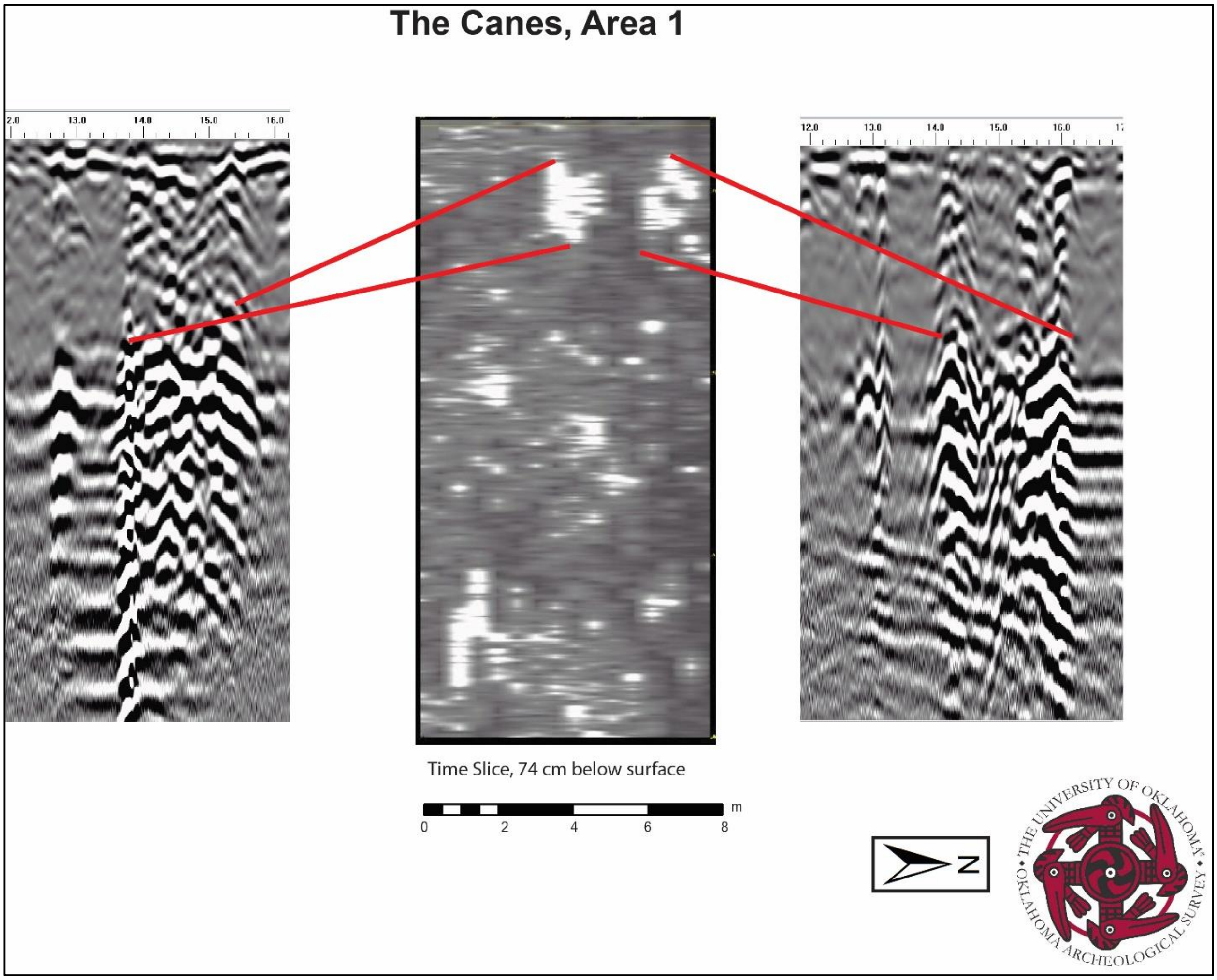

Figure 13. GPR data from Area 1 at The Canes. The center image shows a horizontal view at a depth of 74 cm (2.43 ft) below ground surface and features two anomalies that have the potential to be large graves. The images to the left and right show the profile of each anomaly.

Oaklawn Cemetery. Six separate areas were surveyed at Oaklawn Cemetery (Figure 14). These are the Clyde Eddy area (plus extensions to the east and west), the Original 18, the southwest corner of the cemetery, the Sexton area, the bike path between the cemetery and the Inner

Dispersal Loop[1] (IDL; Highway 75), and the western 100 m of the paved road running through the cemetery. GPR was conducted in all six areas. Features were identified despite signal attenuation at approximately 1 m (3.28 ft) depth, likely due to highly conductive soils. The Eddy area was not surveyed with the gradiometer because the large metal fence that surrounds the cemetery created too much magnetic interference. Only a portion of the southwest corner of the cemetery and the Original 18 were surveyed with the gradiometer for the same reason. The gradiometer and resistance meter were not used on the bike path or paved road because of a combination of metal fencing and their general lack of suitability for penetrating asphalt.

Figure 14. Oaklawn Cemetery survey areas: 1. Clyde Eddy area with extensions; 2. The Original 18; 3. Southwest corner; 4. Sexton area; 5. Bike path; 6. Western end of paved road. Base image downloaded from Google Earth, 12/2019.

Bike Path and Asphalt Road (Figure 14). No burial-like features were noted beneath the bike path or the paved road. The asphalt showed up as a distinct layer near the surface in both areas and cracks in the pavement were readily apparent (e.g., Figure 15). In one grid on the bike path, a pipe associated with a nearby culvert was visible in a horizontal slice (Figure 16).

[1] Surveying under the IDL is not feasible because of its height and the fact that the materials used in its construction (such as steel girders) will scatter the GPR signal and render it meaningless. The bike path was surveyed to get as close to the IDL as possible.

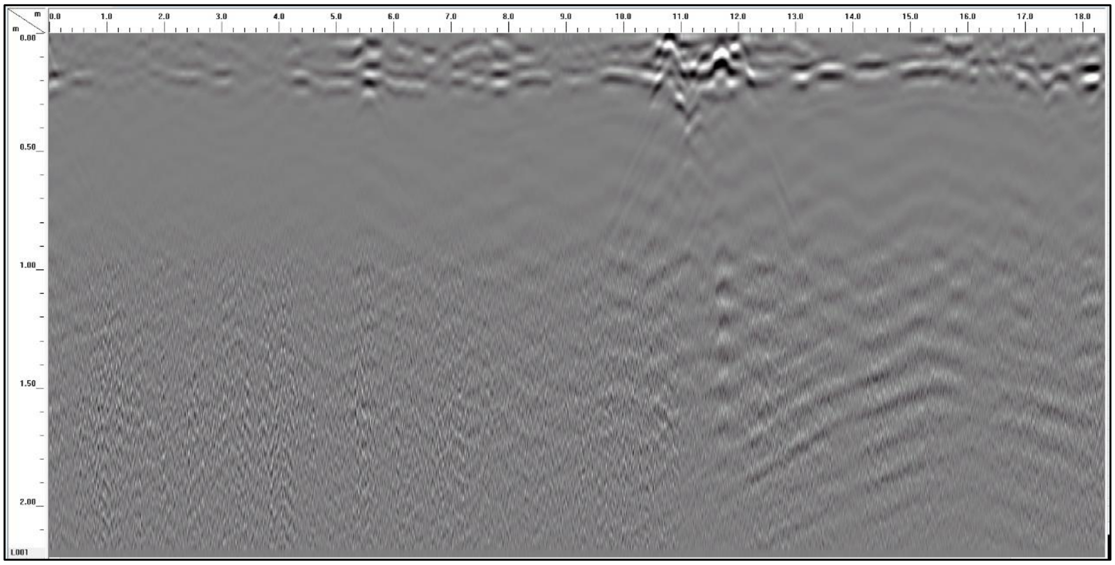

Figure 15. GPR profile from Grid 1 (the easternmost grid surveyed) of the paved road showing asphalt at top. The large anomaly at the top right-center is a crack in the pavement. Note signal attenuation starting at roughly 1 m below surface. This attenuation is typical of profiles at Oaklawn.

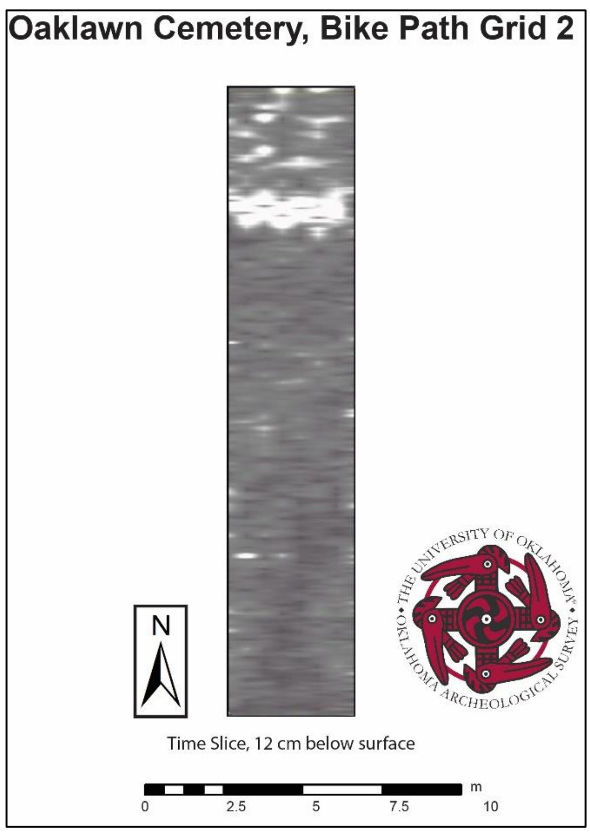

Figure 16. GPR horizontal slice of a section of the bike path showing pipe (white line near top of image) at 12 cm below surface.

Southwest Corner of the Cemetery (Figure 14). This area was previously surveyed using GPR and no graves were identified (Maki and Jones 1998). A 20x20 m (65.61x65.61 ft) grid was re-surveyed since we were using multiple instruments that can sometimes pick up on subtle variations that GPR might miss. Only the northeast corner was surveyed with the gradiometer because of the cemetery fence. There are known graves on the eastern edge of the grid that were readily apparent in the data but no new graves were found (Figure 17). There are several areas of high magnetism present, but these do not have a magnetic signature that matches what we would expect for a grave.

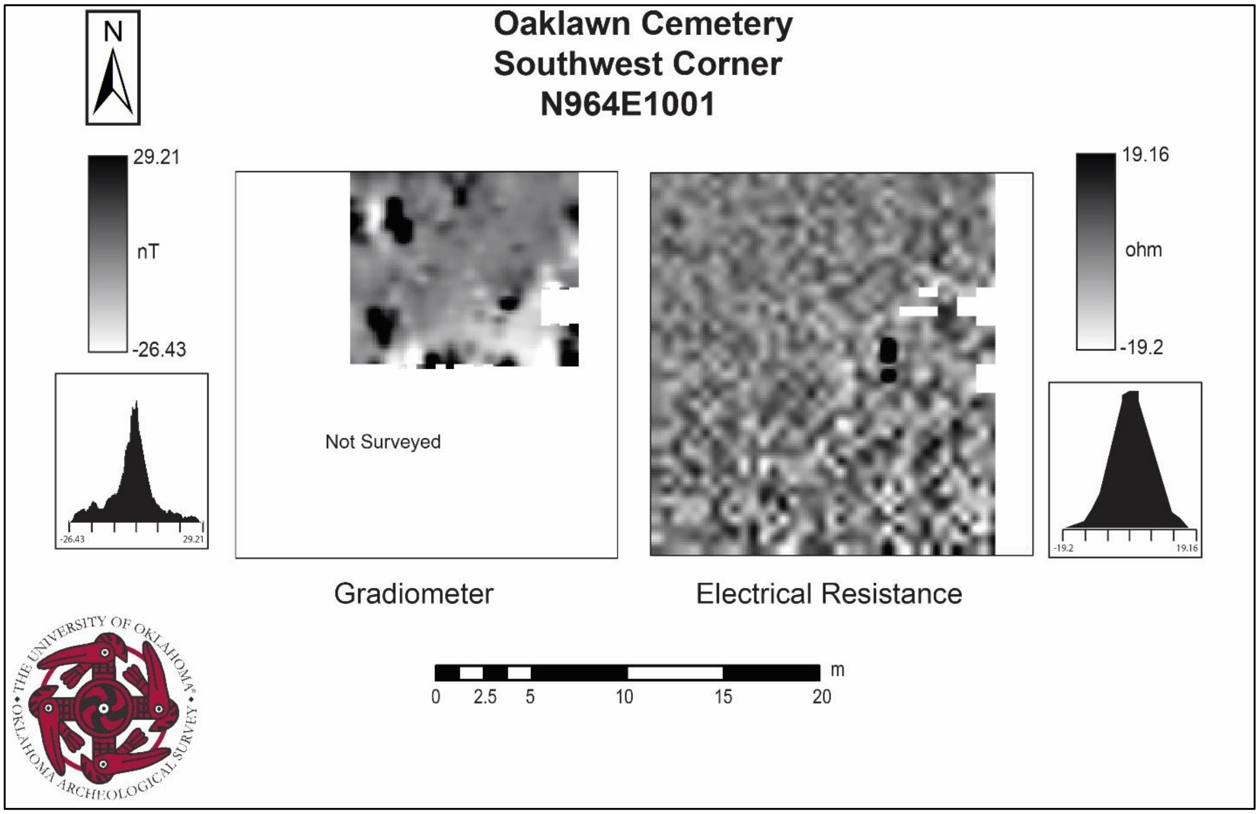

Figure 17. Gradiometer and electrical resistance data from the southwest corner of Oaklawn. White gaps mark the location of a tree and headstones.

The Clyde Eddy Area and Extensions (Figure 14). Portions of this area were also previously surveyed and a large magnetic anomaly, possibly a large burial area, was recorded (Witten, et al. 2001). However, the field notes from this project are no longer available and the exact location of this anomaly is not known, therefore the area was resurveyed. We extended the survey to the east and west to ensure that we covered as much ground as possible (Figure 18). It measured 136x11 m (446.19x36.09 ft) east-to-west, with a small 10x5 m (32.81x16.4 ft) extension to the north. The area was only surveyed using GPR and electrical resistance because the metal cemetery fence prevented the use of the gradiometer.

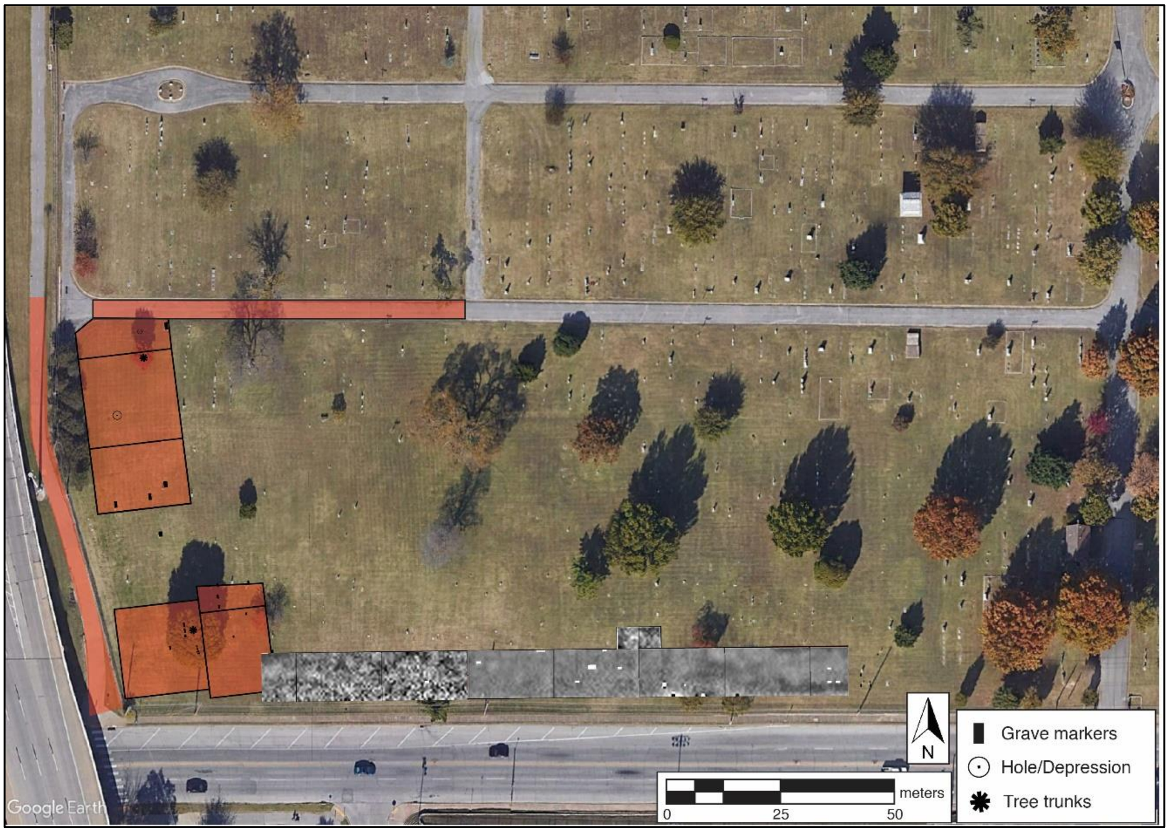

Figure 18. The Clyde Eddy extended survey area with resistance results overlain on an aerial photo. Base image downloaded from Google Earth, 12/2019.

The electrical resistance survey did not locate any unmarked graves (Figure 19). Previously identified graves were apparent in the data but no new unmarked graves were identified. GPR easily identified known graves (Figure 20) and three anomalies consistent with unmarked single graves (Figure 21). These were located in grid squares N997.58E971.64, 997.58E1051.64, and N997.58E1071.64

Neither resistance nor GPR relocated the magnetic anomaly identified by Witten, et al. (2001). There are two possibilities for this. One is that the anomaly is not suitable for identification using GPR or electrical resistance. The other is that it is located in an area that we did not survey. We believe that the latter possibility is more likely.

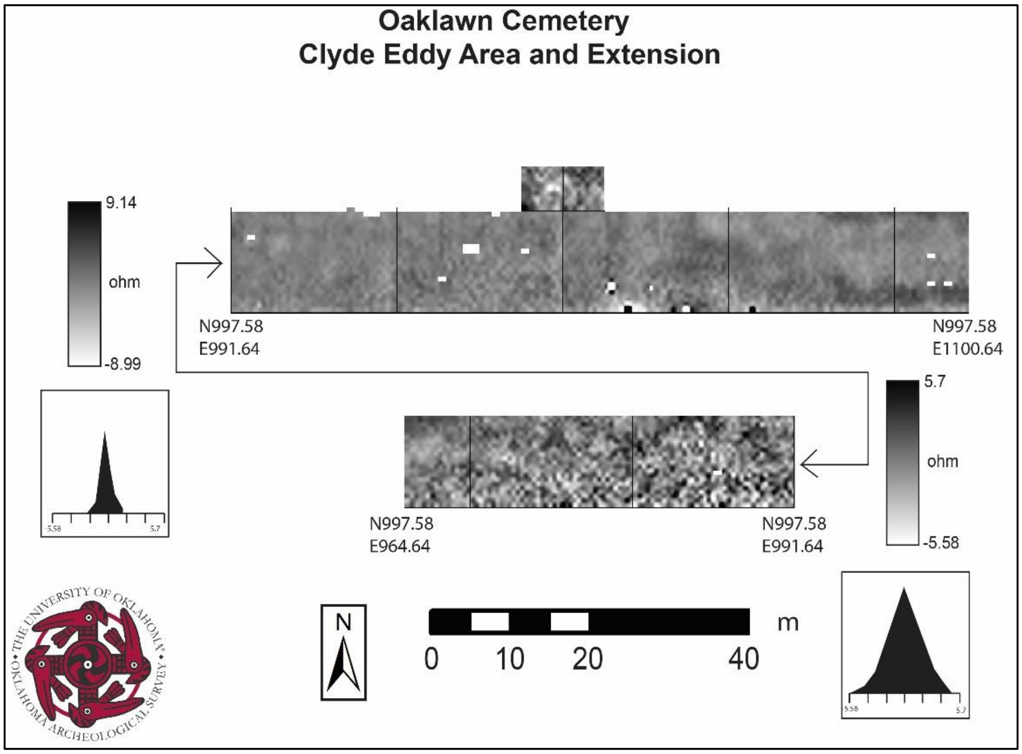

Figure 19. Resistance data from the Clyde Eddy area and extensions. White boxes indicate locations of above-ground headstones.

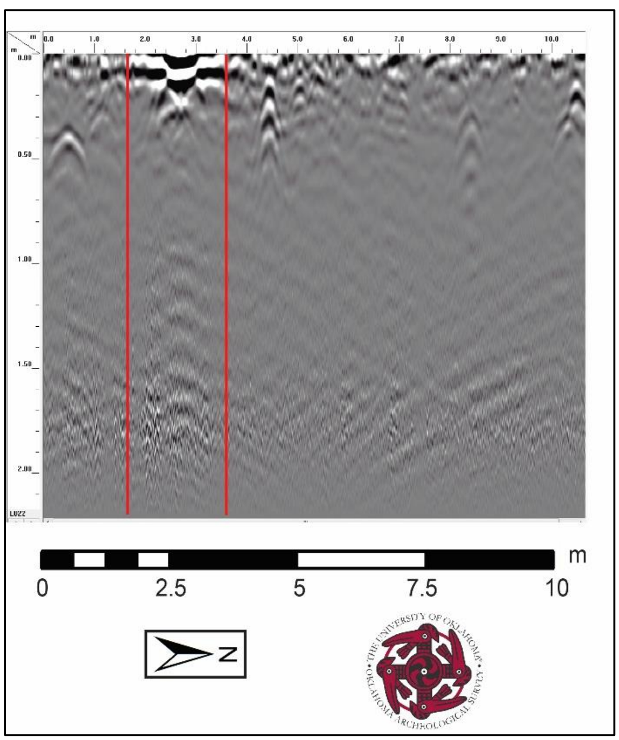

Figure 20. Flat metal headstone (bracketed in red) from a previously known grave in a GPR profile. Grid square N997.58E1051.64

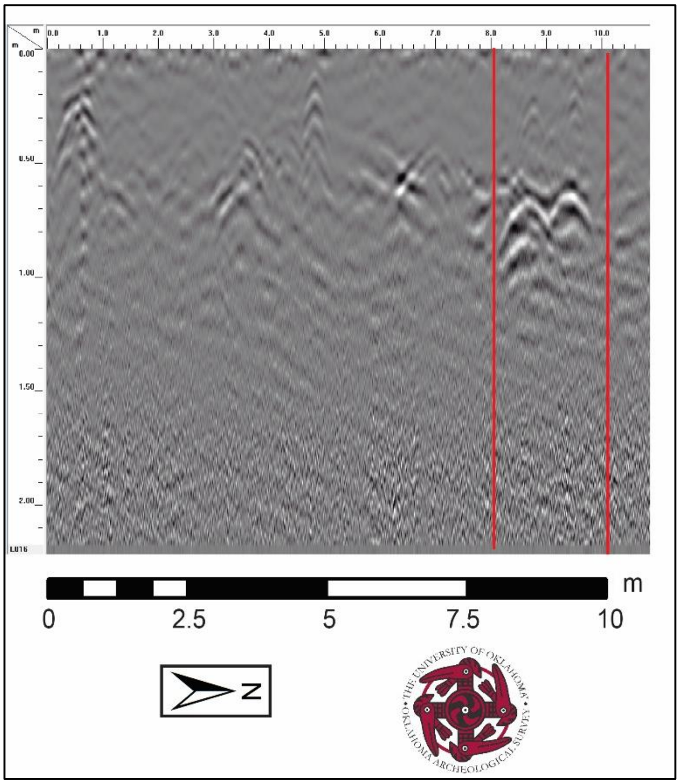

Figure 21. Possible unmarked grave (bracketed in red) in a GPR profile. Grid square N997.58E971.51.

The Original 18 (Figure 14). This area contains the headstones of the only two individuals at Oaklawn who have been confirmed as massacre victims. One of which is Eddie Lockard, whose grave was identified in our gradiometer survey (Figure 22). The other headstone apparently marks an empty grave and the individual named on the stone is buried elsewhere (Scott Ellsworth, personal communication 2019); this is borne out by the geophysical data.

Several headstones are located in the northern portion of Figure 22. However, magnetic anomalies suggest that other graves may be located in the southern portion of this area (which is devoid of headstones). The resistance results are not as clear as the magnetic results, but an area of higher resistance suggests confirmation of the magnetic data (Figure 23).

GPR results in some cases confirm the possible presence of individual graves in this area (Figure 24). However, the top 30 cm below surface is impacted by roots from a nearby tree which obscures the near-surface data (Figure 25).

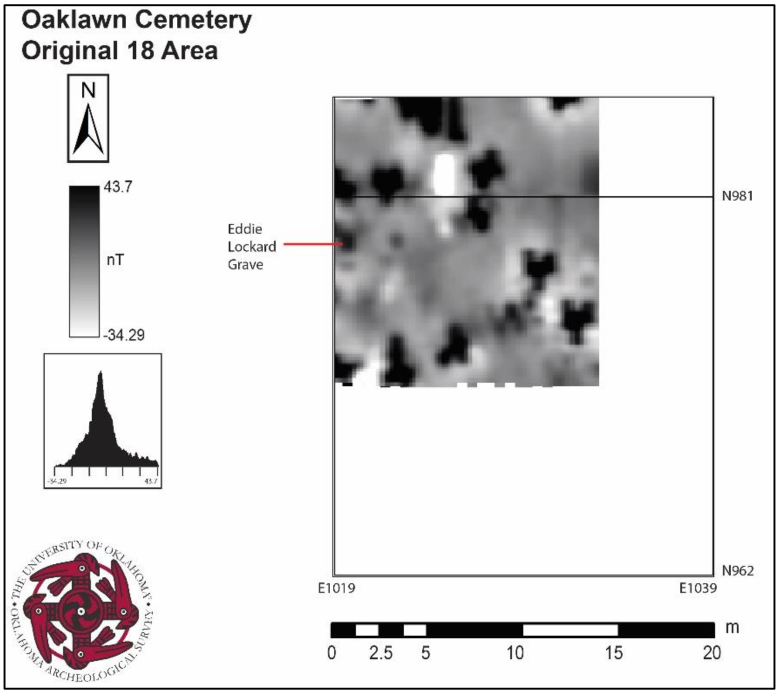

Figure 22. Original 18 gradiometer results. Dark areas of high magnetism mark the locations of probable graves.

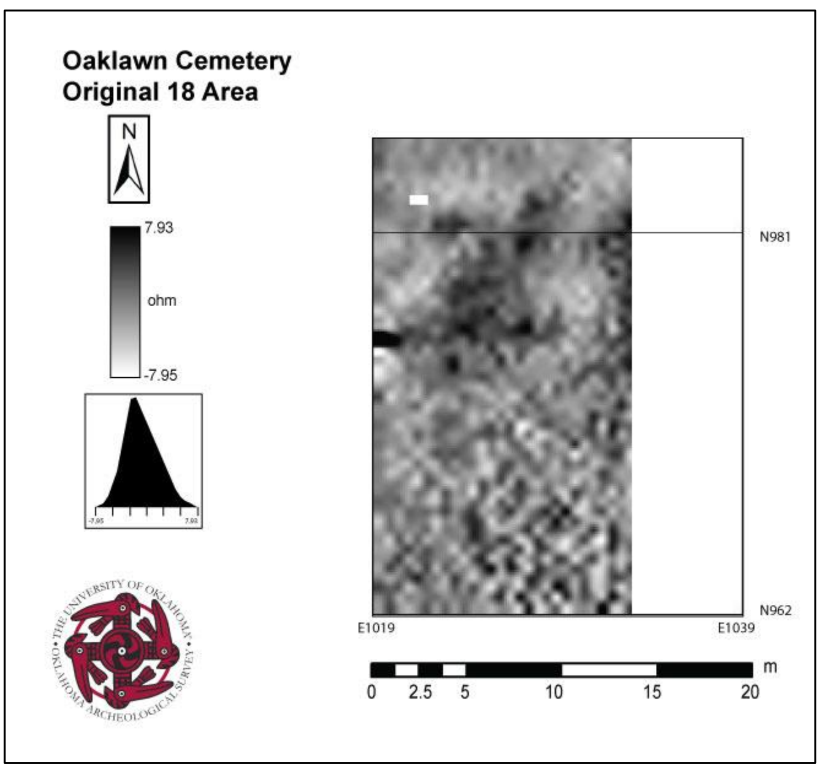

Figure 23. Original 18 electrical resistance results. Dark area of higher resistance overlaps with a number of possible graves in gradiometer results.

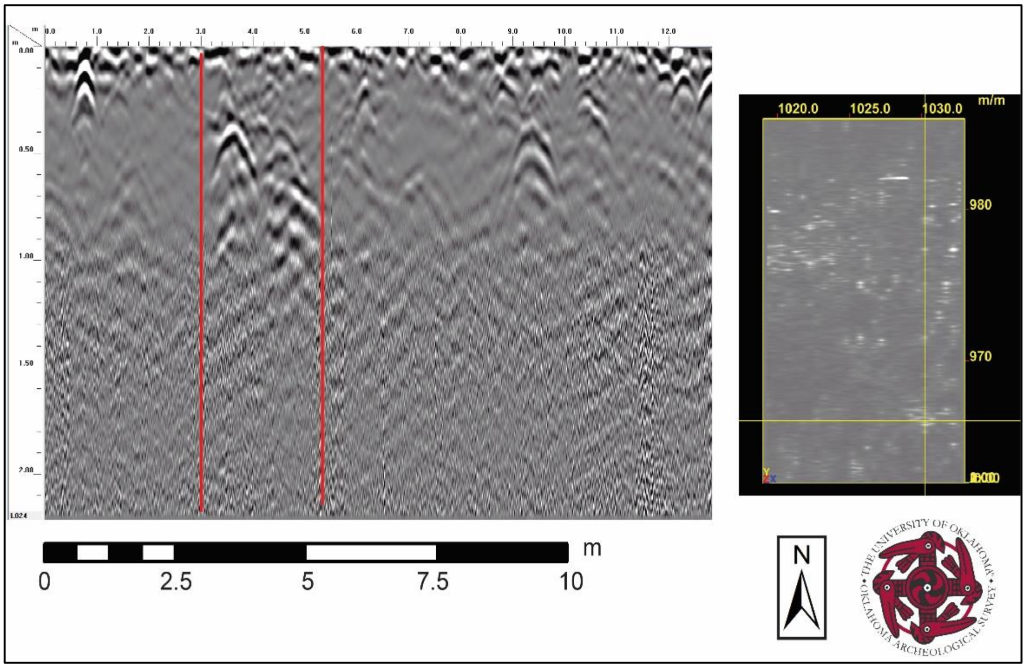

Figure 24. GPR profile (left; bracketed in red) and horizontal slice (right; yellow crosshairs) showing a possible unmarked grave in the Original 18 area. Note "clutter" from tree roots at surface.

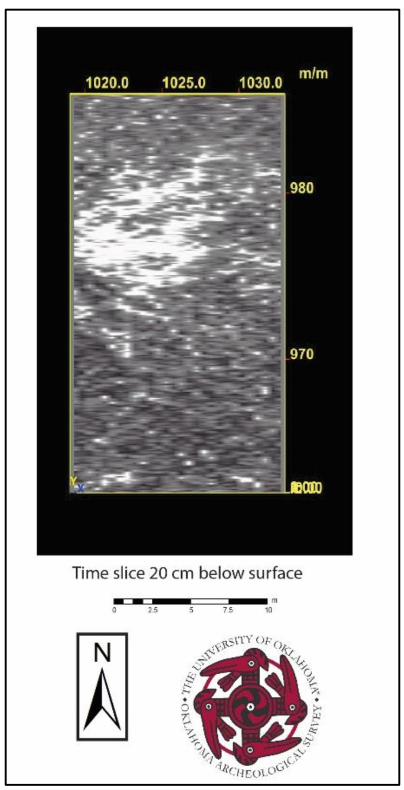

Figure 25. Tree roots (white linear lines) in a GPR horizontal slice 20 cm below surface.

The Sexton Area (Figure 14). All three instruments were used at the Sexton Area, although the amount of ground covered varied due to interference from headstones and the metal fence to the west of the cemetery. Electrical resistance was not particularly effective (Figure 26), although a comparison of the northern portion of the survey area with the GPR and the gradiometer data from the same location suggests that it did register an anomaly.

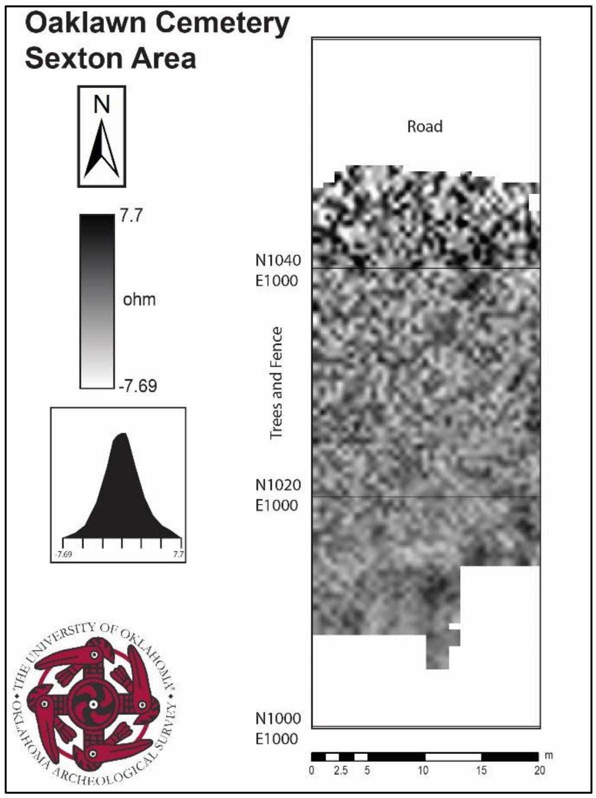

Figure 26. Sexton Area electrical resistance results.

Both the GPR and gradiometer data present a compelling case for a possible common grave. The gradiometer data indicates a large, but diffuse, metallic anomaly in the northwest corner. As will be shown below, this anomaly is also obvious in the GPR results. An open sinkhole is also evident in the magnetic data, as are a number of larger areas of high magnetism in a rough arc in the southern area. The largest of these, in the southwest corner, does not appear in GPR data therefore it may not be a cultural feature. The others may be associated with individual graves, but this is not clear.

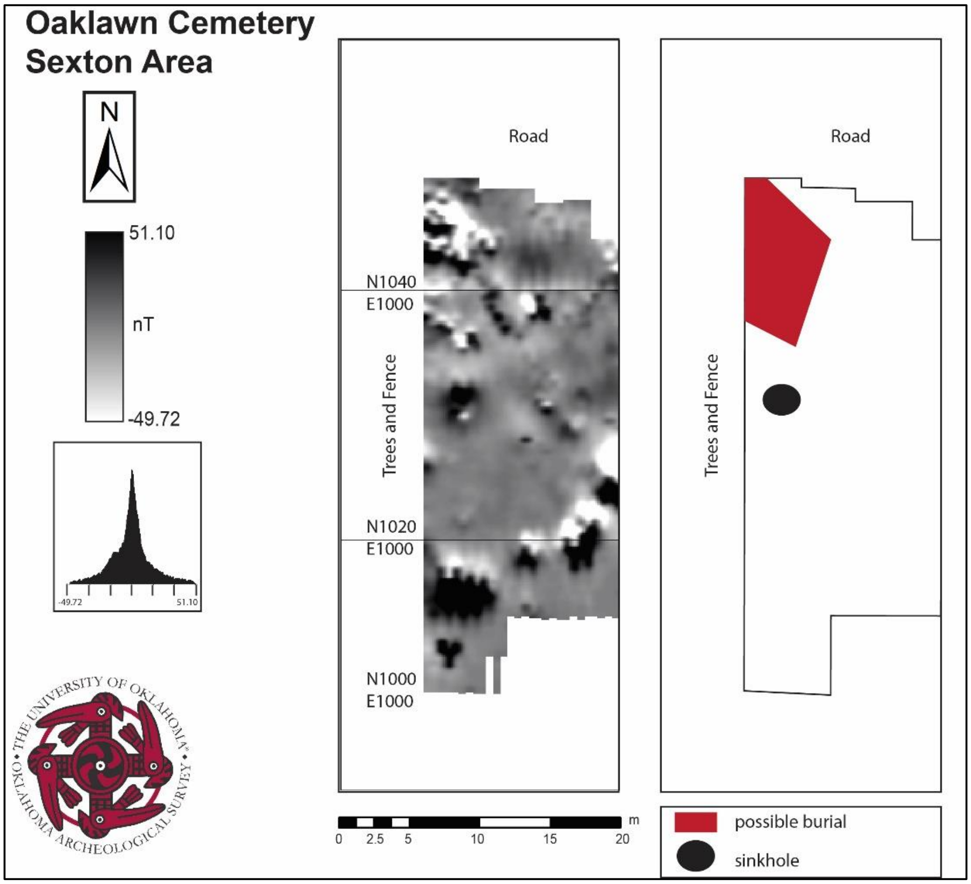

Figure 27. Sexton Area gradiometer results. Data on the left, interpretations on the right.

There are a number of anomalies of interest in the GPR data. First is a long, linear anomaly oriented roughly east-west at a slight angle. It is approximately 8 m (26.25 ft) long and 2-2.5 m (6.56-8.2 ft) wide, and is shown in profile and in a horizontal slice at 26 cm (0.85 ft) below surface in Figure 28. It does not appear to be a naturally occurring feature, although it is not evident in either gradiometer or electrical resistance data.

There are many low-amplitude parabolas scattered throughout the area that could indicate unmarked graves. However, these usually only appear in one or two profiles and then disappear. In most cases, we expect graves to appear in at least 3-4 consecutive profiles (e.g., roughly the length of a human body). If these were graves, they were either not in caskets or were in simple ones that have disintegrated.

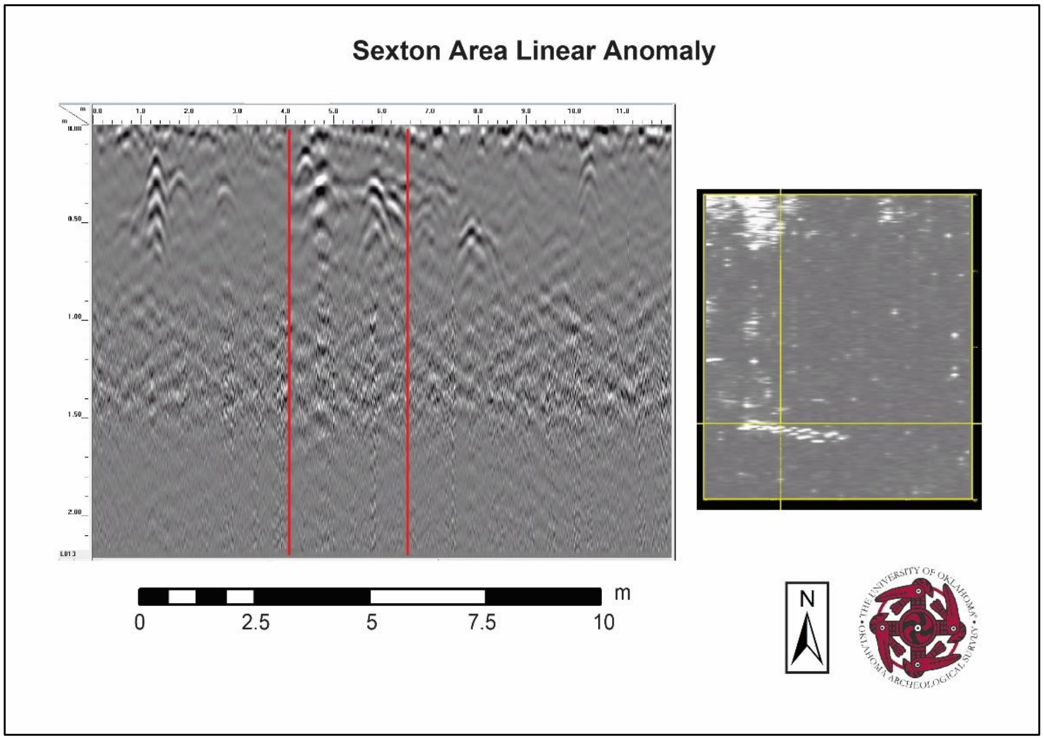

Figure 28. Linear anomaly in profile and horizontal slice at 26 cm (0.85 ft) below surface, Grid N1020E1000, Sexton Area.

GPR corroborates the presence of the large anomaly discovered by the gradiometer in the northwest corner of the Sexton Area (Figures 29 and 30). It measures approximately 8x10 m (26.25 x 32.81 ft) in horizontal distance. The profiles indicate a rather abrupt straight-walled boundary on the north and south edges. The overall size of this anomaly, the amplitude strength, the contrast with the surrounding soils, and the straightness of the sides combine to suggest that this anomaly may be a common grave.

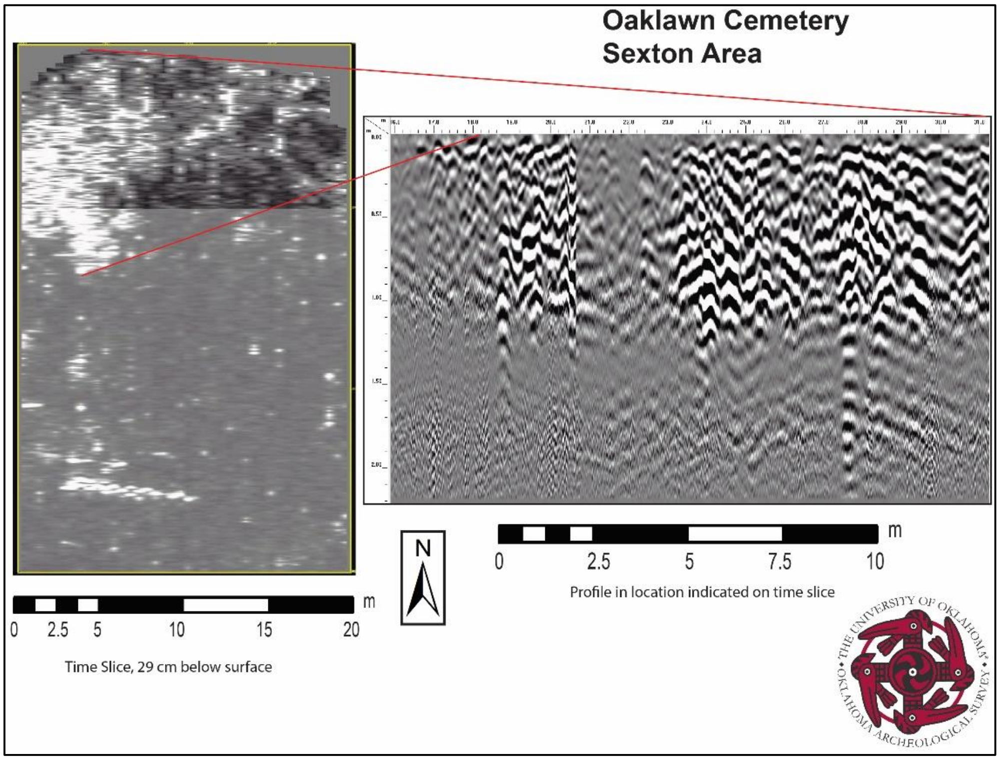

Figure 29. Horizontal slice at 29 cm (0.95 ft) below surface (left) and profile (right) of a large anomaly that is consistent with a common grave.

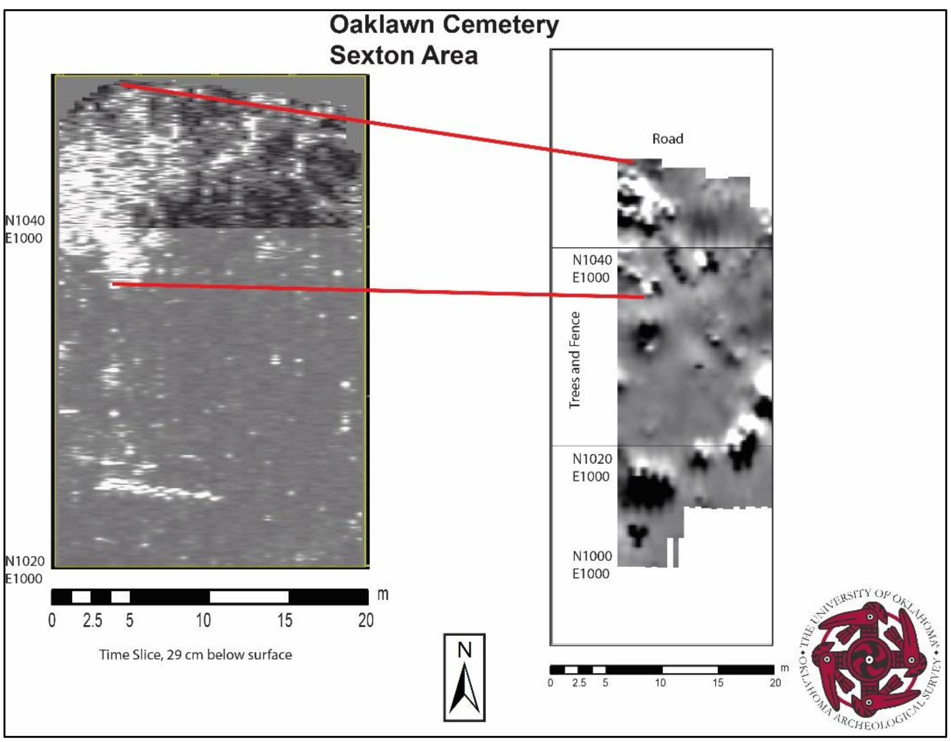

Figure 30. Comparison of GPR (left) and gradiometer (right) data from an anomaly consistent with a common grave.

Summary and Conclusion

Portions of Newblock Park, the Canes, and Oaklawn Cemetery were surveyed with a gradiometer, an electrical resistance meter, and GPR to search for potential burial locations associated with the 1921 Tulsa Race Massacre. Newblock Park can be ruled out for further study based upon the results presented in this report, especially when combined with earlier work (Maki and Jones 1998).

However, the data from two locations, Area 1 at the Canes and the largest anomaly in the Sexton Area at Oaklawn Cemetery, suggest the possible presence of common graves based upon their size, high-amplitude GPR reflections, and abrupt contrasts with the surrounding (presumably sterile) soils. We consider these areas to be the most likely candidates to be common graves associated with the massacre.

It is clear that Oaklawn Cemetery also has a number of unmarked burials, including the concentration of probable graves in the Original 18 area, the hints of ephemeral burials in the Sexton Area, and the handful of potential burials in the Clyde Eddy area and its extensions. Since the geophysical survey results in these areas were not necessarily conclusive, stripping the topsoil with a smooth-bladed backhoe may reveal grave shafts that can then be marked.

While we are confident about the results presented in this report, we wish to emphasize that geophysical survey alone cannot determine the precise nature of these anomalies. Archaeological testing and excavation is the best way to confirm or refute both that they are: a) common burials; and b) associated with the race massacre.

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Appendix A: Technologies Used by Location

Location	Grid	Gradiometer	Electrical Resistance	GPR
Newblock Park	N1010E990	X	X	X
Newblock Park	N1020E950	-	-	X
Newblock Park	N1020E970	X	-	X
Newblock Park	N1040E930	X	X	X
Newblock Park	N1040E950	X	X	X
Newblock Park	N1040E970	X	-	X
Newblock Park	N1060E930	X	X	X
Newblock Park	N1060E950	X	-	X
Oaklawn-Sexton	N1000E1000	X	X	X
Oaklawn-Sexton	N1020E1000	X	X	X
Oaklawn-Sexton	N1040E1000	X	X	X
Oaklawn-Original 18	N962E1019	X	X	X
Oaklawn-Original 18	N981E1019	X	X	X
Oaklawn-SW corner	N964E1001	X	X	X
Oaklawn-Eddy + extension	N997.58E951.64	-	X	X
Oaklawn-Eddy + extension	N997.58E971.64	-	X	X
Oaklawn-Eddy + extension	N997.58E991.64	-	X	X
Oaklawn-Eddy + extension	N997.58E1011.64	-	X	X
Oaklawn-Eddy + extension	N997.58E1031.64	-	X	X
Oaklawn-Eddy + extension	N997.58E1051.64	-	X	X
Oaklawn-Eddy + extension	N997.58E1071.64	-	X	X
Oaklawn-Eddy + extension	N997.58E1091.64	-	X	X
Oaklawn-Eddy + extension	N1008.58E1031.64	-	X	X
Oaklawn-Eddy + extension	N1008.58E1051.64	-	X	X
Oaklawn-Bike Path	1	-	-	X
Oaklawn-Bike Path	2	-	-	X
Oaklawn-Bike Path	3	-	-	X
Oaklawn-Bike Path	4	-	-	X
Oaklawn-Bike Path	5	-	-	X
Oaklawn-Central Paved Road West End	1	-	-	X
Oaklawn-Central Paved Road West End	2	-	-	X
Oaklawn-Central Paved Road West End	3	-	-	X
Oaklawn-Central Paved Road West End	4	-	-	X
Oaklawn-Central Paved Road West End	5	-	-	X
The Canes	Area 1	-	-	X
The Canes	Area 2	-	-	X

Appendix B: Oaklawn Cemetery Survey Areas with Gradiometer and Electrical Resistance Data Overlays

Figure B.1. Southwest corner of the cemetery (N964E1001) gradiometer data.

Figure B.2. Southwest corner of the cemetery (N964E1001) electrical resistance data.

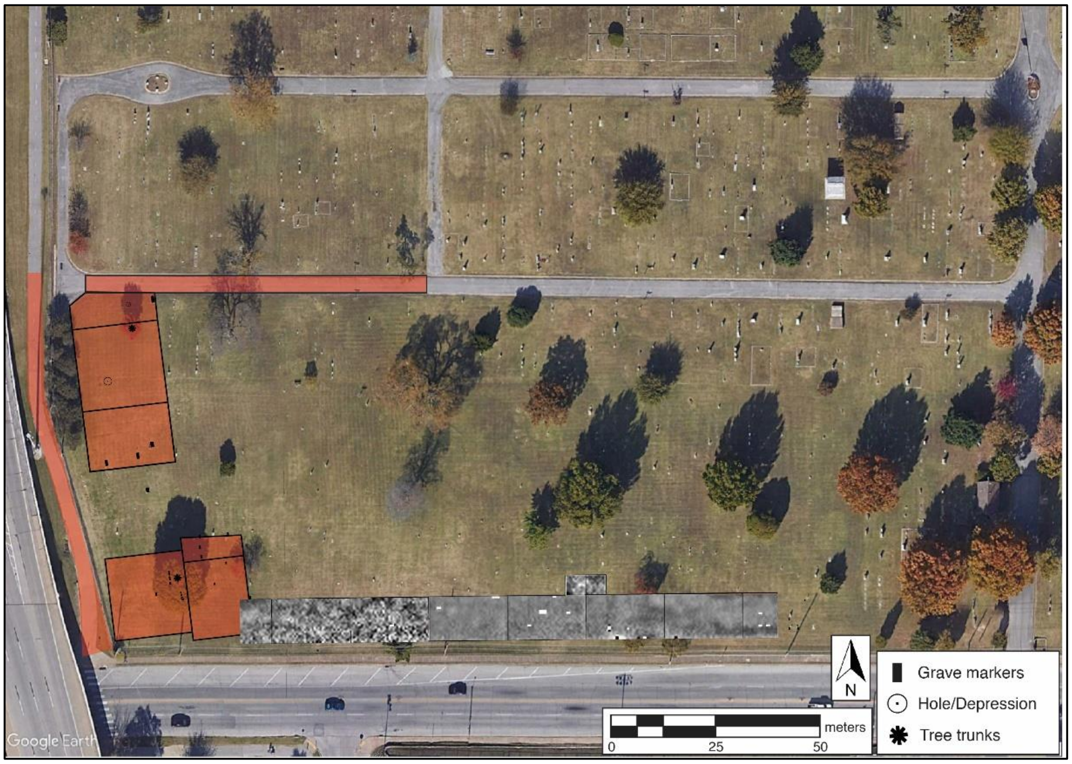

Figure B.3. Clyde Eddy area and extensions, electrical resistance data.

Figure B.4. Original 18 gradiometer data.

Figure B.5. Original 18 electrical resistance data.

Figure B.6. Sexton Area gradiometer data.

Figure B.7. Sexton Area electrical resistance data.