GEOServices, LLC, Geotechnical and Materials Engineers

November 3, 2021

City of Oak Ridge
200 South Tulane Avenue
Oak Ridge, Tennessee 37830

Attention: Mr. Bryan Mills
BMills@oakridgeTN.gov

Subject: **REPORT OF LIMITED GEOPHYSICAL SERVICES**
City of Oak Ridge
Outdoor Pool Distress
172 Providence Road
Oak Ridge, Tennessee
GEOServices Project No. 21-211149

Dear Mr. Mills,

We are submitting the results of the limited geophysical exploration performed in an effort to locate possible karst features or other anomalies that may indicate on-going karst migration (i.e. sinkhole) at the Oak Ridge Outdoor Pool. The geotechnical exploration was performed in accordance with our Proposal No. 11-21567, dated August 18, 2021, and as authorized by you. The following limited report presents our geophysical findings at the location in question. Should you have any questions regarding this report, or if we can be of any further assistance, please contact us at your convenience.

Project Information

Project information was provided in email correspondence and during a site visit dating from July 29, 2021. The project site is the Oak Ridge Outdoor Pool, located at 172 Providence Road in Oak Ridge, Tennessee.

We understand that the pool has consistently lost a large volume of water daily for the past several years, in excess of the expected evaporation loss, such that you are concerned with possible extensive leaking from the pool. Furthermore, we understand the City of Oak Ridge will be demoing or re-designing the pool at a later unknown date. There is a concern that the material underlying the pool may be karst (i.e. sinkhole prone) in nature and that future construction may encounter difficult issues related to any such karst features.

It is our understanding that the original pool was built in the 1940s with major renovations in the 90s. Based on our research we note this area originally contained a spring fed pond that was used for swimming that was later converted to the pool.

The pool is currently still spring fed, and we note the spring house is in close proximity to the pool. Ground cover at the site generally consists of concrete with isolated grassed areas. We note that during our initial exploration using Ground Penetrating Radar (GPR), rebar mesh was found within the pool and wire mesh was located within the concrete pool deck.

The purpose of this limited geophysical exploration was to explore the underlying materials in the bottom of the pool and along the edges of the pool deck in order to determine the existence of karst areas of concern within the existing pool footprint.

Field Exploration

Electrical Resistivity Imaging (ER) Survey

The ERI survey was conducted using the Advanced Geosciences, Inc. (AGI) Sting R8 automatic electrode resistivity system. Six (6) ERI transects were performed across the proposed building locations in accessible areas located away from metal or debris, with electrode spacing of 7 to 10 feet, for total array lengths ranging from approximately 200 to 320 feet. A dipole-dipole combined with a strong gradient electrode configuration was used with a maximum “n value” of ten. The ERI data was analyzed using EarthImager 2D, a computer inversion program, which provides a two-dimensional vertical cross-sectional resistivity model (pseudo-section) of the subsurface. The positions and topographic information of the geophysical array lines were recorded using site measurements and a TopCon handheld GPS unit.

Electrical Resistivity Imaging

Electrical resistivity surveying is a geophysical method in which an electrical current is injected into the earth; the subsequent response (potential) is measured at the ground surface to determine the resistance of the underlying earth materials. The resistivity survey is conducted by applying electrical current into the earth from two implanted electrodes (current electrodes C1 and C2) and measuring the associated potential between a second set of implanted electrodes (potential electrodes P1 and P2). Field readings are in volts. Field readings are then converted to resistivity values using Ohm's Law and a geometric correction factor for the spacing and configuration of the electrodes. The calculated resistivity values are known as "apparent" resistivity values. The values are referred to as "apparent" because the calculations for the values assume that the volume of earth material being measured is electrically homogeneous. Such field conditions are rarely present.

The resistivity of earth materials is controlled by several properties including composition, water content, pore fluid resistivity and effective permeability. For this exploration, the properties that had the primary control on measured resistivity values are composition and effective permeability. The general geological setting of this property area is clay overlying limestone. However, existing site conditions such as existing fill material and previous grading, may cause trapped water zones and present as low resistivity zones that may produce artifact affects. .

For this study, a dipole-dipole combined with a strong gradient resistivity array configuration was used for each test. The dipole-dipole array is different than most other resistivity arrays in that the electrode and current electrodes are kept together using a constant spacing value referred to as an "a spacing". The current and potential electrode sets are moved away from each other using multiples of the "a spacing" value. The number of multiples is referred to as the "n value". For example, an array with an electrode spacing of 5 ft and an "n value" of 6 would have the current and potential electrode sets spaced 30 ft apart with a separation between the two electrodes in the set of 5 ft. By sampling at varying "n values", greater depth measurements can be achieved. Strong Gradient data is collected with the current set of electrodes being kept with a fixed separation (L spacing) and the potential electrodes a minimum distance from the inner current electrodes. Dipole-dipole resistivity data is usually presented in a two- dimensional pseudo-section format. Strong Gradient data is usually presented as a vertical profile of resistivity distribution below the center point between the two current electrodes. The dipole-dipole and strong gradient data is combined and presented as either a contour of the individual data points (using the calculated apparent resistivity values) or as a geological model using least squares analysis. Such least squares analysis was used for this study using the computer software program (EarthImager 2D) developed for the equipment manufacturer.

Apparent resistivity values are calculated using the following formula for a dipole-dipole configuration:
$\gamma_a=\pi(b^3/a^2-b)\nabla V/I$:

Where:

γ_a =	apparent resistivity
π=	3.14
a=	"a spacing"
b=	"a spacing" x "n value"
∇V =	voltage between the two potential electrodes
I=	current (in amps)

For a strong gradient configuration, the apparent resistivity is calculated using: $\gamma_a=\pi([s^2-a^2]/4)\nabla V/aI$:

Where:

γ_a =	apparent resistivity
π=	3.14
a=	spacing between the inner set of electrodes
s=	distance between the outer electrode and nearest inner electrode
∇V =	voltage between the two potential electrodes
I=	current (in amps)

<u>Inversion Modeling of Electrical Resistivity Imaging Data</u>

The objective for inversion modeling of resistivity data is to create a description of the actual distribution of earth material resistivity based on the subsurface geology that closely matches the resistivity values that are measured by the instrumentation. This modeling is completed with the use of EarthImager 2D, a proprietary computer program developed by the equipment manufacturer (AGI). When evaluating the validity of the inversion model several factors need to be considered. The RMS, or root mean square error, expresses the quality of fit between the actual and modeled resistivity values for the given set of points in the model. The lower the RMS error the higher the quality of fit between the actual and modeled data sets. In general, inversion models with an RMS error of less than 5 to 10 percent are acceptable. The size of the RMS error is dependent upon the number of bad data points within a data set and the magnitude of how bad the data points are. As part of the modeling process bad data points are typically removed, which decreases the RMS error and improves (with limitations) the quality of the model. The quality of fit between the actual and modeled resistivity values is also expressed as the L-2 norm. When the modeled and actual data sets have converged, the L-2 norm reduces to unity.

However, as the number of data points is reduced, the validity of the inversion model is diminished. Accordingly, when interpreting a particular area of an inversion model the number of data points used to create that portion of the model must be taken into consideration. If very few points are within a particular area of the model, then the modeled solution in that area should be considered suspect and possibly rejected.

The entire ERI transect should be considered suspect if a model has a high RMS error and a large number of removed data points. It is likely that sources of interference have affected the field readings and rendered the modeled solution invalid. Such sources of interference can include buried metallic underground utilities, reinforced concrete slabs, septic leach fields or electrical grounding systems. Accordingly, all efforts need to be made in the field to locate, to the degree possible, the ERI transect lines away from such features. The locations of such features also need to be noted in the field so their potential effects can be considered when interpreting the modeled results. At this site we note an abundance of buried utilities and the pre-mentioned abundant rebar resulted in a relatively high RMS error and multiple zones of missing data points.

Geologic Conditions

The project site, and most of east Tennessee, lies in the Appalachian Valley and Ridge Physiographic Province. The province is characterized by elongated, northeasterly-trending ridges formed on highly resistant sandstones and shales. Between ridges, broad valleys and rolling hills are formed primarily on less resistant limestones, dolomites and shales.

Published geologic information indicates that the proposed construction area is underlain by limestones of the Chickamauga Group. The Chickamauga Group is comprised mostly of limestone with minor amounts of shale. Weathering of the Chickamauga Group generally produces a medium to high plasticity clay soil with minor amounts of chert gravel. More specifically, this site is located near the intersection of the Stones River Group (Osr) and Newala Formations (On), both part of the Chickamauga Group in the area. The pool area appears located within the Stones River Group, just south of its intersection with the Newala Formation. We note the spring house appears to correlate with this implied stratigraphy intersection. In this area we note the Stones River Group “sits” on top of the Newala Formation, both with a bedding dip towards the south approximately 20-40 degrees from vertical.

Since these formations consists of carbonate rock, the site is susceptible to the typical carbonate hazards of irregular weathering, cave and cavern conditions, and overburden sinkholes. Carbonate rock, while appearing very hard and resistant, is soluble in slightly acidic water. This characteristic, plus differential weathering of the bedrock mass, is responsible for the hazards. Of these hazards, the occurrence of sinkholes is potentially the most damaging to overlying soil supported structures. In East Tennessee, sinkholes occur primarily due to differential weathering of the bedrock and "flushing" or "raveling" of overburden soils into the cavities in the bedrock. The loss of solids creates a cavity or "dome" in the overburden. Growth of the dome over time or excavation over the dome can create a condition in which rapid, local subsidence or collapse of the roof of the dome occurs.

A certain degree of risk with respect to sinkhole formation and subsidence should be considered with any site located within geologic areas underlain by potentially soluble rock units. The results of the limited geophysical testing indicated some possible karst features. In addition, we did not observe any surface signs of sinkhole activity at the site. However, at least one closed contour depression, which denote past sinkhole activity, is shown on the United States Geological Survey (USGS - Windrock Quadrangle) topographic map in close proximity to the site. Based on these findings and our experience with this formation at other sites, we consider that this site has a high potential for sinkhole activity.

Subsurface Conditions

Overall, the ERI data indicated a transition from clay, saturated clays, and weathered bedrock. Analysis of the attached ERI array images can be simplified by considering that the colors correspond to how easily electricity can travel through the ground. The more easily the electricity can travel (i.e., low resistivity) we may imply that saturated/more moist conditions exist. The harder electricity has to travel (i.e., high resistivity or high resistance), we can imply less water or moisture is located there. Therefore, the purples to greens/yellows are likely clays or fine-grained materials while the oranges to reds are likely bedrock. It should be noted that ERI array lines #1 to #5 were conducted within the pool deck or concrete walkways, in which abundant rebar was encountered. While additional effort was made to avoid interaction thru the rebar, we note some low-quality data in these areas.

Typically, a trapped water zone can be relied upon for more accurate bedrock determination. However, at this site we note a relatively shallow ground water table, as well as what appears to be a perched water table(s), obscured bedrock determinations in this manner. We also note what appears to be a consistent groundwater level near about 830 feet mean sea-level (MSL).

Upon review of the inverted resistivity imagery, we note what appears to be “breaks” or “gaps” in the higher resistivity green zones in multiple locations across the site, also noted as a pink line on the provided imagery and figures below. It should be noted that we are not stating each of these locations are karst (i.e. sinkhole prone) in nature and some zones may overlap the same features. These gaps include relatively lower resistivity material that has extended below the higher resistance materials, which may imply a migration zone for water and possible fine-grained material to move into a karst feature. We note multiple relatively shallow zones exhibit the low resistance values, which likely reflect saturated stone below the slab. However, only zones in which the saturated near surface material extended to depths exceeding about 20 feet are noted as possible karst features.

Furthermore, we note three (3) outlier anomaly features, which in generality were areas that exhibited significantly higher resistance values than typically observed on site (i.e. resistance values generally exceeding 500 Ohm-m). These zones likely represent mass bedrock, very dense/dry clay, fractured bedrock zones, or possible more dry karst features. We note that Array #5 encountered such a high resistance feature generally near the deep diving well and in an area that appeared to contain shallow voids directly below the slab (i.e. found via coring and audibly thru hammer hits).

Recommendations

As previously mentioned, the result of the exploration indicates the site has a high chance of sinkhole formation, and we noted multiple possible zones that may exhibit ongoing characteristics of sinkhole formation. We also note a general prevalence of karst geology and low resistance zones indicate high likelihood that trapped or perched groundwater has found an easy path into the stone subgrade, which is not a large surprise given the nearby spring source. However, we observe numerous zones in which the previously mentioned likely trapped or perched water appears to migrate further down into the underlying (karst) geology. These zones of possible migration were observed throughout the test area;

however we do note more pronounced zones or features in a few specific areas near ERI Array #s 1, 2, and 5 (see figure below).

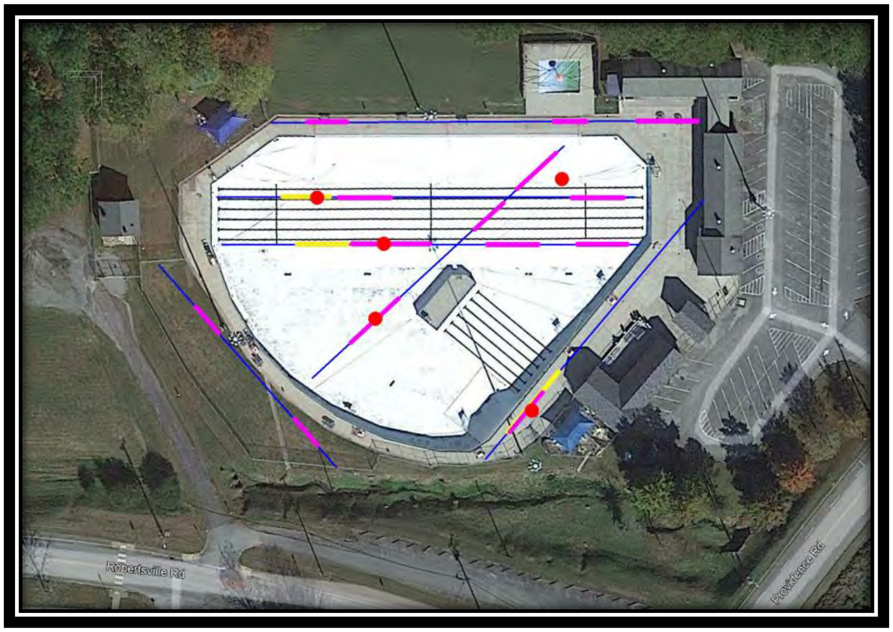

Figure 1 - Generalized Features

(Yellow - High Resistance, Pink - Low Resistance, Red Circles - Proposed Supplemental borings)

We note a feature/zone associated with ERI Array #1 and #2, generally near spacing 40 to about 140 feet from the beginning (left side) of each array. These arrays indicated a similar geometric relationship of a higher resistance possible karst feature (generally from spacing 50 to 90 feet) followed by a low resistance possible migration zone feature (generally from spacing 90 to 140 feet). We do note a drain line in this area, however given the depth of the high resistance feature (i.e. 25+ feet below the ground surface), it appears possible this is a major karst migration area.

We also note a very pronounced low resistance zones and the previous mentioned high resistance near surface zones along ERI Array #5, generally in close proximity to the diving well (i.e. deepest portion of the pool). In this zone we noted extensive settling of the concrete sidewalk and small voids directly below the slab (as found with GPR, coring, stake placement, and hollow sound from hammer impact). This is indicative of migrating backfill material. Given the results of the geophysical testing in this area, it appears likely this is another major karst concern and migration area.

Given the results of the exploration (i.e. generalized high karst risk across the pool with isolated more pronounced zones), it will be prudent follow this limited investigation with a more extensive "ground truthing" program consisting of multiple soil test borings extended to auger refusal, to better confirm the results herein, or to better refine the geophysical analysis. We have included a limited proposed additional boring location plan (please reference Figure 1 above) which details five (5) additional suggested boring locations. The suggested boring locations would be generally located in possible karst features or anomalies. If requested, we are prepared to provide a supplemental limited geotechnical report to explore these areas noted above and on the attached figures. This data will be incorporated into the geophysical data to either confirm, refine, or refute our assumptions.

Remediation

Remediation of the karst features observed will be challenging given the abundance of karst zones and easy conduit access to underlying features (i.e. water flowing thru the open graded stone will find easiest exit path). Remediation should consist of either in-place methods, such as compaction grouting or expansion foam injections, or via more destructive methods, such as removing the existing pool structure and constructing a cement treated base system prior to building a new pool. We understand the historical context of the pool may control the future remediation (i.e. may not be feasible to completely remove the pool for direct subgrade improvements). Therefore, the use of a foam injection system, in an attempt to limit migration within the near surface open graded stone, may be the most cost-beneficial approach for extended use of the existing pool as is. This approach would be geared to address the migration from the pool into the stone and not from the stone into any karst features. Additional or supplemental geotechnical drilling will be beneficial in determining the best fix.

GEOServices looks forward to continuing to work with you on this project. If you have any questions or require additional information, please feel free to call us.

Sincerely,

GEOServices, LLC

Matthew B. Haston, P.E.
Senior Geotechnical Engineer

Matthew T. Bible, E.I.T.
Geophysical Project Manager

SITE VICINITY MAP - TOPOGRAPHIC BACKGROUND

SITE VICINITY MAP TOPOGRAPHIC

OAK RIDGE POOL DISTRESS
172 PROVIDENCE ROAD
OAK RIDGE, TENNESSEE

DRAWN BY:	PGA
APPROVED BY:	MTB
SCALE:	N.T.S.
JOB NO.:	21-211149
DATE:	10-20-2021

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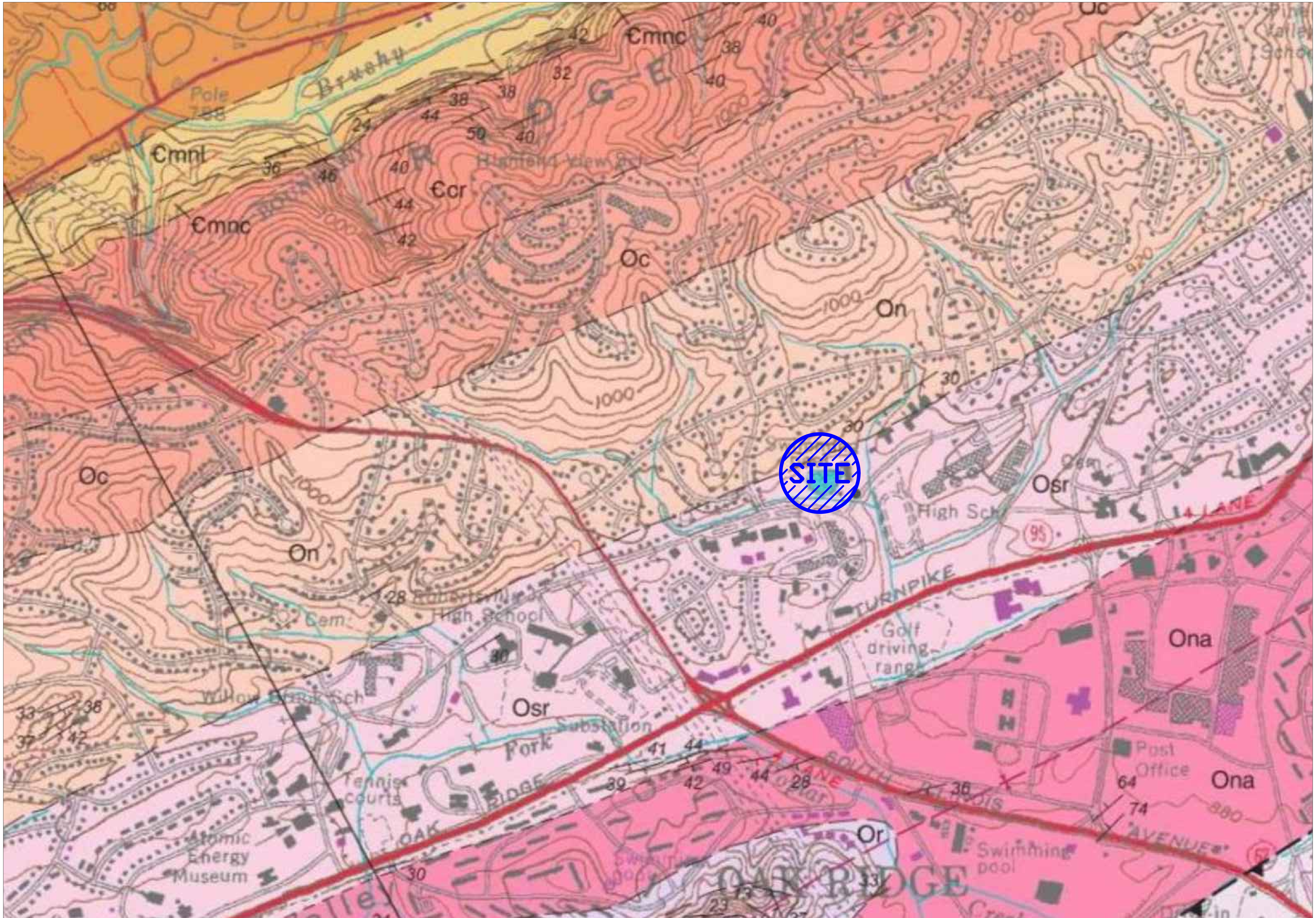
Figure 1



SITE VICINITY MAP - GEOLOGIC BACKGROUND - USGS WINDROCK TN, QUADRANGLE

SITE VICINITY MAP TOPOGRAPHIC

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Figure 2

SITE VICINITY MAP - GOOGLE EARTH AERIAL - ARRAY LOCATION PLAN

SITE VICINITY MAP
ARRAY LOCATION PLAN

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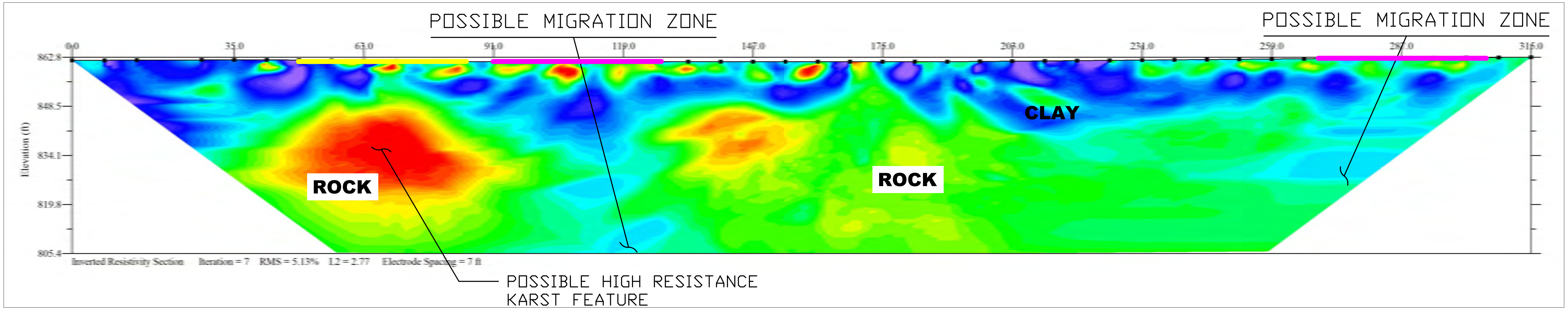
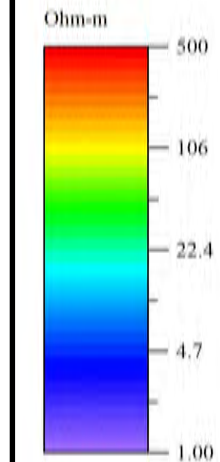
Figure 3.0





ERI ARRAY LOCATION

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Figure 3.1

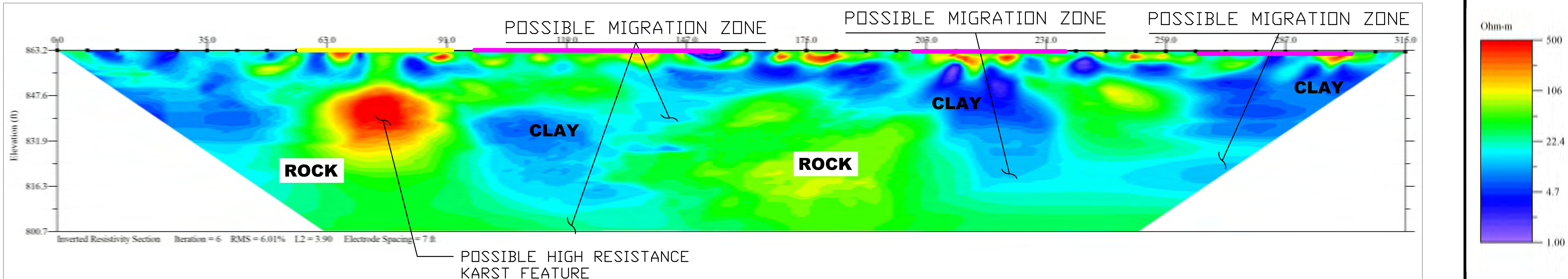

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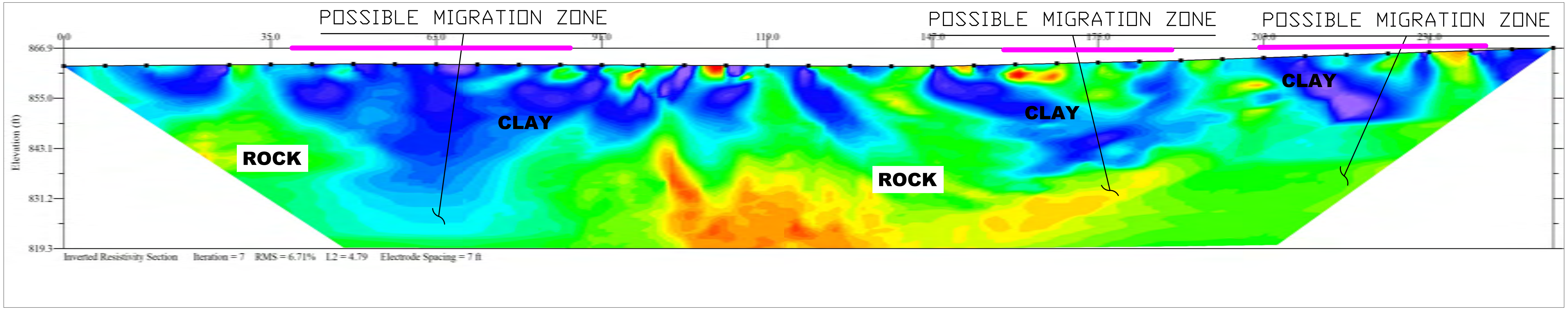
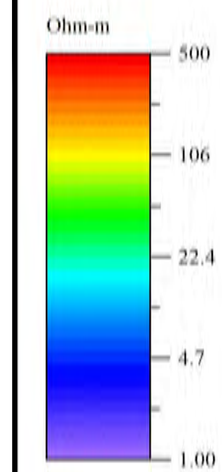
Figure 3.2





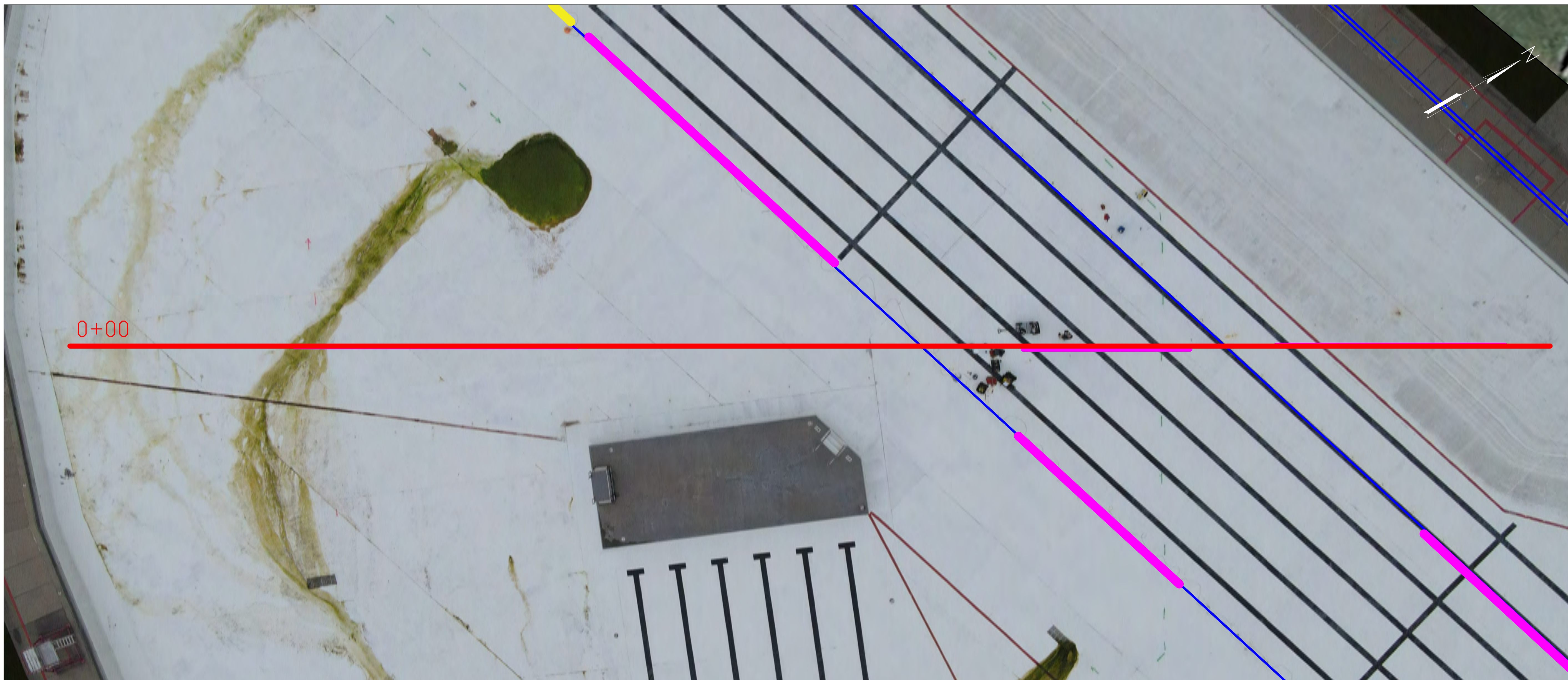


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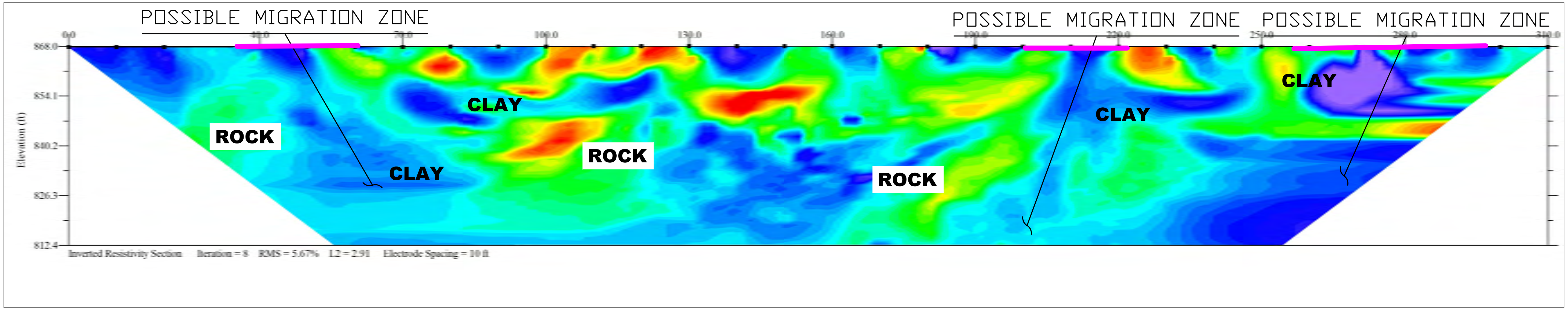
Figure 3.3



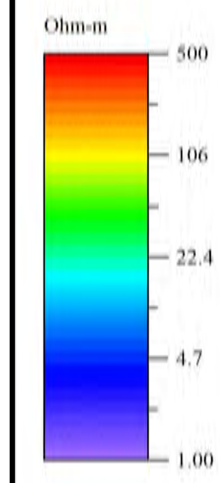


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Figure 3.4

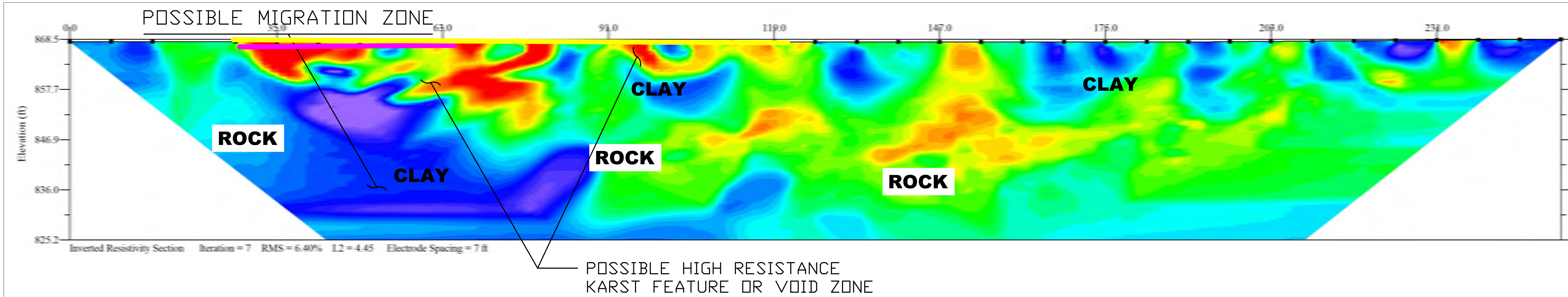

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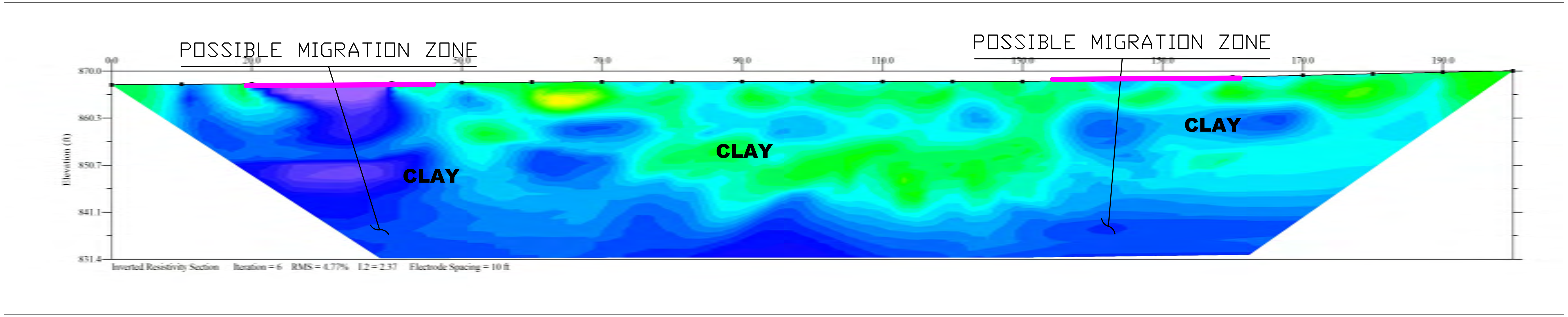
Figure 3.5



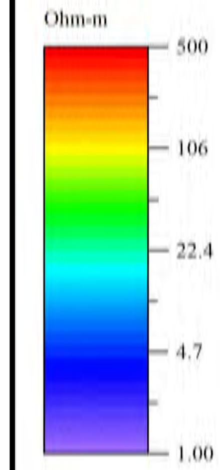


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Figure 3.6

NAME OF SUBMITTING FIRM

Criteria	Score (1-5)	Relative Weight	Weighted Score
Past experience specific to large-scale aquatic facility design & engineering		0.40	
Qualifications and availability of staff		0.20	
Past experience working with Municipal or other government clients		0.10	
Past experience working with historical sites		0.10	
Past experience with energy efficiency optimization		0.10	
Past experience working with natural water sources (spring fed)		0.05	
Client references		0.05	

Average Weighted Score