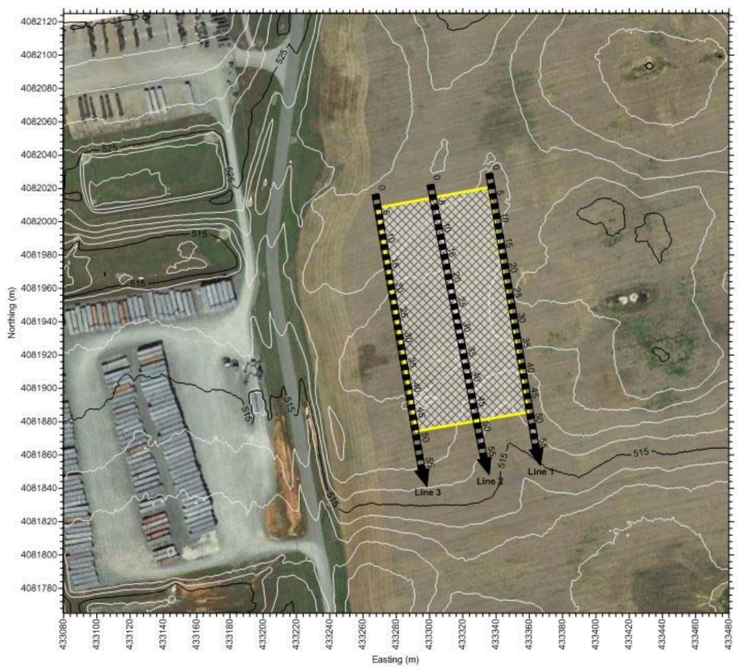
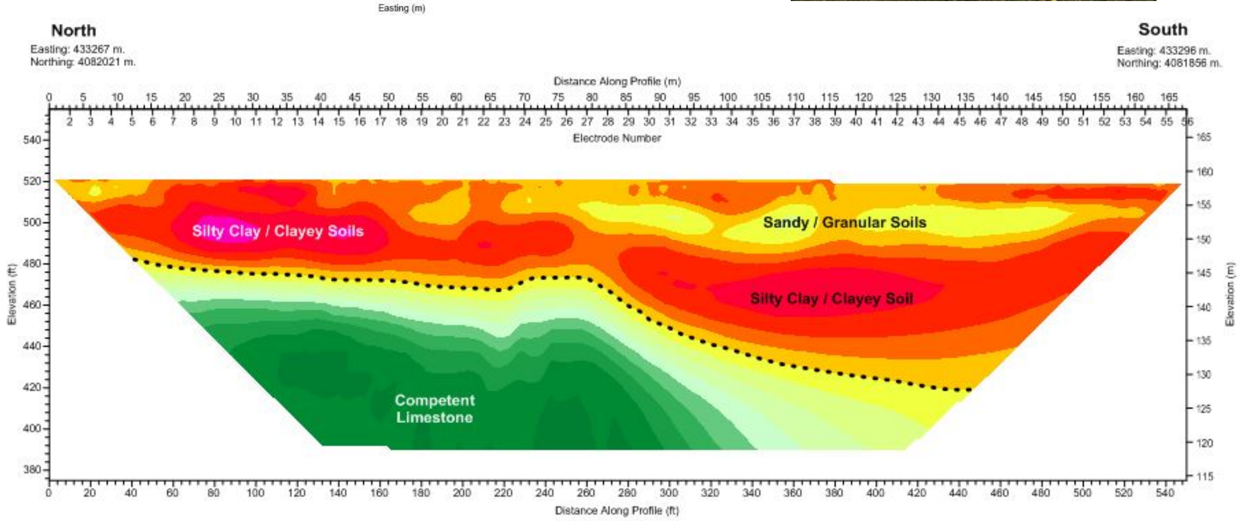
REPORT OF GEOPHYSICAL SURVEY

KARST IMAGING STUDY

CADIZ INDUSTRIAL PARK
CADIZ, TRIGG COUNTY, KY 42211
MUNDELL PROJECT NO. M16036
NOVEMBER 5, 2016





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November 5, 2016

Mr. Frank Williams, PLS
Ronald Johnson & Associates, PSC
24 West Center St.
Madisonville, KY 42431

Re: Results of Geophysical Survey
Karst Imaging Study
Cadiz Industrial Park
Cadiz, Trigg County, KY 42211
MUNDELL Project No. M16036

Dear Mr. Williams:

In accordance with Mundell Proposal No. P16054, MUNDELL & ASSOCIATES, INC. (MUNDELL) is pleased to present Ronald Johnson & Associates, PSC with this letter report providing written documentation of the geophysical exploration activities conducted at the above-referenced project site (the Site). The fieldwork was performed on October 13th, 2016. Documentation of this project is included in the following sections.

Introduction

The Site consists of a proposed 2.3-acre rectangular footprint within the Cadiz Industrial park (CADIZ) located immediately southwest of IH 24, south of the current facilities at CADIZ, and east of the town of Cadiz, in Trigg County, Kentucky (see **Figure 1**). The geophysical survey area encompasses approximately 2.3 acres of an agricultural field where soy bean crops had been recently harvested before the time of the survey. Truck access was granted to allow for an efficient work flow.

Site Geology

The Site has been mapped by the Kentucky Geologic Survey (KGS) as being underlain by the Mississippian-aged Ste. Genevieve Limestone (having a very high karst potential). The St. Genevieve is a light-gray to white, fine-to medium-grained, fossiliferous and oolitic limestone, with predominately thick to very thick bedding (Fox, 1965). The St. Genevieve conformably overlies the St. Louis Formation, which is a lightolive-gray to dark gray, very fine to medium grained, limestone, with medium to very thick beds. The St. Louis contains very few coarse detrital beds, relatively few oolitic beds, and is dolomitic in places.

While sinkhole development is extensively present throughout the immediate areas to the north, northeast, west, southwest and south of the Site as indicated by mapped sinkhole outlines located within 100 ft of the study area (see **Figure 2**), no mapped sinkhole features are shown within the proposed footprint according to Kentucky Geological Survey's (KGS's) geologic map server.

Technical Background – Karst Development

Karstification occurs when surface water and precipitation enlarge fractures in soluble bedrock. Karst, or karst geomorphology, is typically evidenced by numerous closed depressions, sink holes, karst windows or unroofed caves, springs and cave openings. The sinkholes occur when carbonic acid (H_2CO_3) from atmospheric carbon dioxide and rainwater percolates downward into subsurface waters and dissolves carbonate bedrock.

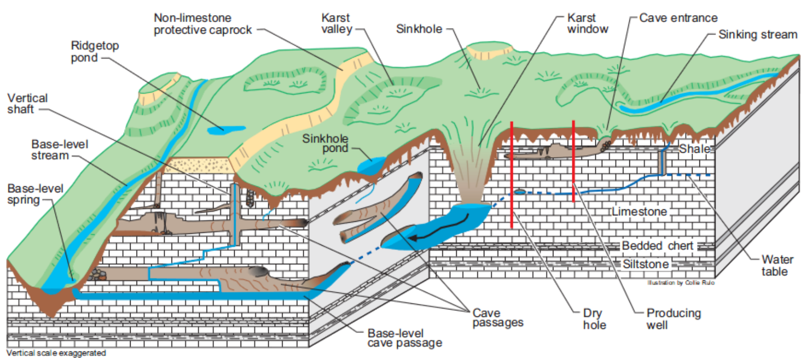


Diagram 1. Generalized Block Diagram of the Western Pennyroyal Karst Area (from Currens, 2001)

The Site is located within the Western Pennyroyal karst region of Kentucky (see inset **Diagram 1**), where the conditions for long cave systems occur. These include a thick block of limestone, a high rainfall rate, higher elevation areas draining toward a major stream, rocks dipping toward the stream, and large areas of the limestone protected from erosion at the surface by overlying insoluble rocks (Currens, 2001). As erosion progresses over geologic time, the major streams draining the karst terrain cut deeper channels.

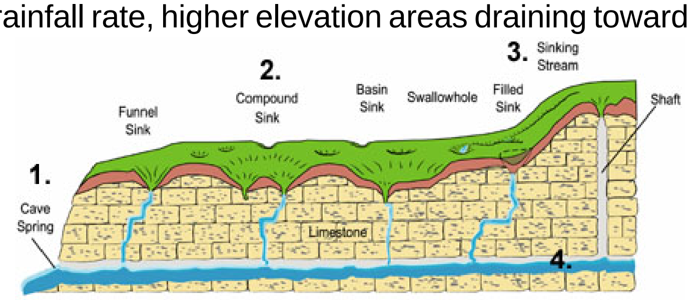


Diagram 2. Sinkhole Types and Features

Within mature karst systems (see inset **Diagram 2**), surficial depressions are caused by the dissolving (or solutioning) of underlying carbonate rocks along existing joints and fracture systems that result in enlarged void spaces. Subsequently, the loss of shallow soils (especially finer grained soils) occurs as surface water infiltration is directed to these void spaces and the soil is swept into them through the resulting fracture systems via rapid groundwater movement.

Karst features can be mapped by measuring contrasts in physical properties of the subsurface soil and bedrock. Geophysical mapping of karst features can range from a relatively rudimentary task of defining variations in apparent resistivity to the technically complex task of mapping the three-dimensional characteristics of the soil and bedrock. In cases such as this Site, where karst features are known to exist, geophysical mapping can provide insight into the locations of concealed features such as sinkholes, solution-enhanced fracture zones, and voids.

Technical Background – Geophysical Methodologies

In general, a large variety of geophysical techniques can be applied to the mapping of subsurface karst features; however, certain methods, sensitive to a range of contrasting physical properties, can have attributes that make them more suitable than others depending on the site-specific conditions. Contrasting physical properties that typically are found to be useful for mapping soil and bedrock include electrical conductivity or resistivity, acoustic velocity, density, seismic wave velocity and magnetic susceptibility. Of these, electrical conductivity (or resistivity) has the greatest range of contrast, and is often applicable to karst sites where the bedrock surface is relatively shallow.

Given the desired depth of penetration (greater than 100 feet below ground surface) and the desire to image both the lateral and vertical extent of possible weathered and/or solutioned features within the predominately carbonate bedrock, two-dimensional Electrical Resistivity Imaging (2-D ERI) was selected as the method of choice to characterize the soil and bedrock beneath the site. It is important to note that it is also effective in characterizing the type and thickness of unconsolidated materials above the bedrock surface.

Two-Dimensional Electrical Resistivity Imaging (2-D ERI)

Certain minerals, such as native metals and graphite, conduct electricity via the passage of electrons; however, electronic conduction is generally very rare in the subsurface. Most minerals and rocks are insulators, and electrical current preferentially travels through the water-filled pores in soils and rocks by the passage of the free ions in pore waters (*i.e.*, ionic conduction). It thus follows that the degree of saturation, interconnected porosity, and water chemistry (*i.e.*, total dissolved solids) are the major controlling variables of the conductivity of soils and rocks. In general, electrical conductivity directly varies with changes in these parameters.

Fine-grained sediments, particularly clay-rich sediments such as glacial till, are excellent conductors of electricity, while coarser-grained sands and gravels are much less conductive. Carbonate rocks (*i.e.*, limestone and dolomite) are very good insulators when they are unfractured, but can have significantly higher conductivity values when fractured and/or weathered and/or solutioned. In contrast, shale bedrock is relatively conductive.

As one would suspect, buried metallic objects and chemically altered soils (such as those with elevated chloride levels) have the highest conductivity values. Wet, clayey soils tend to have the second highest conductivity values, generally about an order of magnitude below metals. Water-filled voids are intermediate between wet clayey soils and competent limestone, with the exact value depending on the water chemistry (*i.e.*, the electrical conductivity of the water). Sand and gravel, which are often alluvial in nature or commonly used as fill materials, range widely depending on porosity and soil moisture. Limestone bedrock will be the least conductive, with increased competency leading to lower conductivity values. Finally, the least conductive materials tend to be air-filled voids.

Inset **Diagram 3** illustrates the relative distribution of electrical conductivity values (logarithmic in nature, resistivity = 1 / conductivity). Thus, by understanding the distribution of electrical conductivity values for known geologic materials, two-dimensional electrical resistivity imaging (2-D ERI) can be used to image variations in the geologic layers beneath the Site.

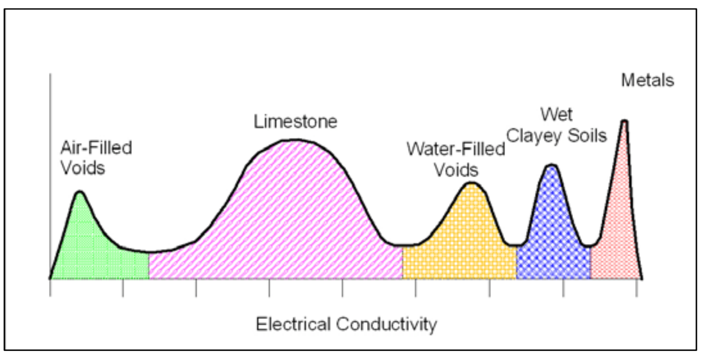


Diagram 3. Conductivity Variation with Materials

Resistivity data were collected with an *AGI SuperSting R8* earth resistivity meter using a dipole-dipole array of 56 electrodes along three (3) individual profile lines of equal spacing. All *Profile Lines* utilized a 10 foot electrode spacing, which resulted in the maximum depth of data collection and penetration of approximately 130 ft. below ground surface (bgs).

Once the data were collected, they were downloaded to a computer and subsequently inverse-modeled using the software Advanced Geosciences *EarthImager2D* to obtain a resistivity cross-section of the subsurface. This is obtained through the process of generating a model resistivity cross-section, calculating the apparent resistivity pseudo-section that would result from such a model, and comparing the calculated pseudo-section to the one collected in the field. The model is then altered through a number of iterations until the two pseudo-sections closely match each other. At this point the model is considered to be a reasonable estimation of the true resistivity of the actual subsurface materials.

It should be noted that the resistivity cross sections presented in this report are 2-dimensional representations of the general distribution of electrical resistivity in the 3-dimensional subsurface. There is no unique direct conversion from resistivity values to lithology. However, based on site knowledge, geometric shapes and relationships of various anomalies, and the observed ranges of resistivity values, reasonable geologic interpretations can often be made by experienced geophysical consulting professionals.

Scope and Results of Geophysical Survey Performed

2-D ERI Profile Line Results

A total of three (3) parallel resistivity profiles were collected at the Site with a constant electrode spacing of 10 feet and utilized a 56 electrode array. The locations of resistivity profile *Lines 1* through *3* are shown on **Figure 1** and presented individually as **Figures 3** through **5.** All three (3) *Lines* were oriented north to south.

The modeled resistivity values range from about 30 (pink in color) to greater than 2,048 ohm-meters (dark green). The lowest range of values, *i.e.*, less than 90 ohm-meters, (purple to dark red in color) is interpreted to be materials consisting of fine-grained soils with a high clay content (purple to red in color) in the upper subsurface, and weathered shale or severely-weathered limestone bedrock zones in the deeper subsurface with the potential for soil-filled voids. Mid-range resistivity values (90 to 724 ohm-meters, light red to light green in color) are interpreted to be more granular soils or bedrock residuum in the upper subsurface, and slightly weathered to competent shale bedrock or slightly- to moderately-weathered limestone bedrock (with fractures and/or solutioned features) in the deeper subsurface. The higher range of resistivity values, *i.e.,* greater than 724 ohm-meters (light green to dark green in color) is interpreted as dense, competent limestone bedrock.

In general, all three (3) resistivity profiles indicate an upper, unconsolidated soil layer of predominantly sandy granular soils mixed with fine-grained silty clays clays, overlying a gently undulating and sloping downward to the south, slightly-weathered limestone bedrock surface; no indications of severe bedrock weathering and/or karst development were observed along the profiles. The slightly- to moderately-weathered limestone bedrock surface has been estimated along each profile. In general, the bedrock surface appears to range from about 37 to 100 ft bgs. There appears to be more competent, shallower bedrock within the northern portion of the site, with areas of slight weathering, and a lower bedrock surface elevation within the southern half. Details regarding each profile line are described as follows:

Profile Line 1 – As indicated on **Figure 3**, the profile shows a slightly to moderately-weathered bedrock surface at approximately 90 ft bgs at the southern end of the profile that starts to increase in competency (indicated by darker green colors) and decrease in depth (to approximately 50 ft bgs) moving north along the profile. Along this profile, the near surface, overlying unconsolidated materials appear to consist of mixtures of granular sandy soils and fine-grained silty clay/clayey soils (possibly severely-weathered bedrock residuum) along the entire length of this profile, with the fine-grained soils present near the surface within the central part of the profile line between Electrode Nos. 20 to 31.

Profile Line 2 – As indicated on **Figure 4**, the profile also shows a slightly to moderately-weathered, undulating bedrock surface sloping downward overall to the south. The bedrock surface is encountered at approximately 37 ft bgs near the northern end of the profile, and drops to about 79 ft bgs near the southern portion of the Site. Overall, the limestone bedrock quality is more competent (shown as darker green in color) within the northern portion of the side, with an increase in weathering toward the south. Along this profile, the near surface materials consist primarily of sandy/granular soils (possibly severely-weathered bedrock residuum) mixed with some fine-grained silty clay/clay soils observed at greater depths (especially between Electrode Nos. 27 to 45).

Profile Line 3 – As indicated on **Figure 5**, the profile indicates a more uniform and competent bedrock surface at about 36 to 52 ft bgs from the northern end of the profile to about Electrode No. 27. North of Electrode No. 27, the bedrock surface slopes downward, dropping to almost 100 ft bgs and exhibiting an increase in the degree of weathering. There is a significant near surface granular sandy soil zone between Electrode Nos. 26 to 50 of about 16 to 28 ft in thickness underlain by fine-grained silty clay/clayey soils along the southern half of the profile. Fine-grained soils appear to be overlying the bedrock surface between about Electrode Nos. 7 to 14.

Conclusions

Based on the 2-D resistivity profile results, MUNDELL concludes the following:

1) The subsurface geophysical profiles indicate a slightly undulating and generally sloping downward to the south, slightly- to moderately-weathered limestone bedrock surface beneath upper unconsolidated soils consisting of a mixture of granular sandy soils and fine-grained silty clay/clay soils (possibly severely-

weathered bedrock residuum). No severe bedrock weathering and/or karst development was noted along the profile lines.

2) The top of the bedrock surface is shallower within the northern portion of the study area, and appears to range from about 37 ft to approximately 100 ft below ground surface within the southern portion of the site. There appears to be more competent (shown as darker green in color on the profile lines), limestone bedrock underlying the northern portion of the site, with areas of slight- to moderate-weathering and a deeper top of bedrock surface elevation present in the southern half of the site.
3) Any final subsurface investigation planning decisions should be made incorporating the enhanced understanding of the degree of bedrock weathering that has been determined and the expected condition of the subsurface materials present along the resistivity profile alignments.

Limitations

This study included a limited set of geophysical readings across limited portions of the Site. The results and interpretations of the geophysical survey performed are considered generally reliable and were conducted in a manner generally consistent with practitioners in the field of geophysical engineering. The methods used in this investigation are considered reliable; however, there may exist localized variations in the subsurface conditions that have not been completely defined at this time. The resistivity results are not unique to karst features and more than one geologic feature or model may give similar results. Therefore, **properly conducted soil/bedrock test borings and other exploratory techniques are necessary to 'ground-truth' the results provided and to more completely determine the subsurface conditions at the site**.

The Site features presented on the Site base map are for informational purposes only and no representation is made as to the accuracy or completeness of this information. It is recommended that a practicing geosciences or geotechnical engineering professional be contacted prior to conducting verification drilling or excavating activities.

Closing

We appreciate the opportunity to provide geophysical services to you on this project. If you should have any questions regarding the enclosed information, please do not hesitate to contact us at (317) 630-9060, or jmundell@MundellAssociates.com).

Sincerely,

MUNDELL & ASSOCIATES, INC.

Eric T. Chojnowski
Field Service Specialist

Forrest Kunkel
Staff Geologist/Geophysicist

John A. Mundell, P.E., L.P.G., P.G.
President/Director of Geophysical Services
Kentucky Professional Geologist No. 162945

/etc

Attachments:

Figure 1.	Site Map
Figure 2.	Sinkhole Outline Map
Figure 3.	Resistivity Profile Line 1
Figure 4.	Resistivity Profile Line 2
Figure 5.	Resistivity Profile Line 3

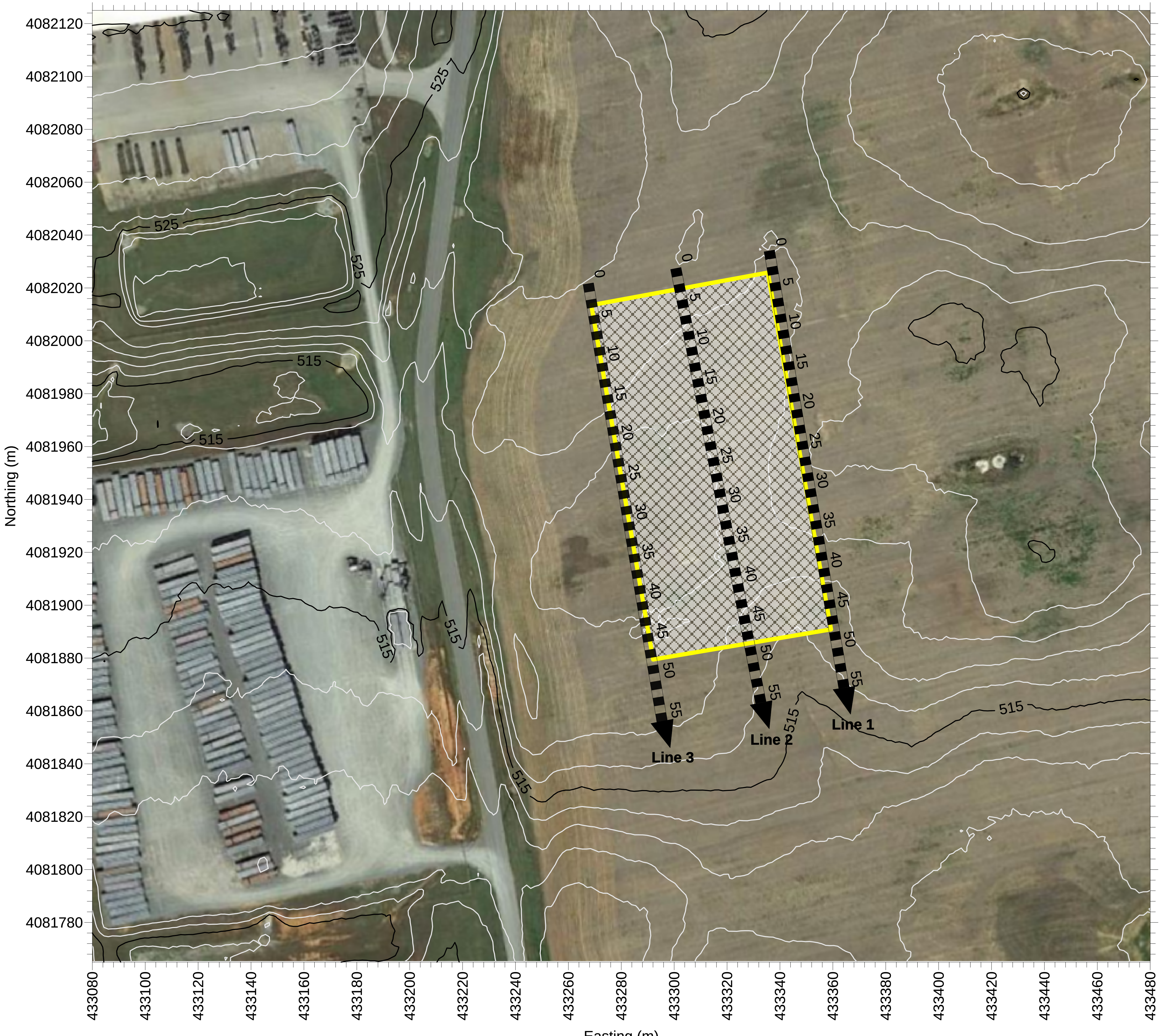
REFERENCES

Currens, J.C., 2001, Generalized Block Diagram of the Western Pennyroyal Karst: Kentucky Geological Survey, Map and Chart 16, Series XII, 1 sheet.

"Kentucky Geologic Map Information Service." *Kentucky Geological Survey*. University of Kentucky. Web. 29 September 2016.

http://kgs.uky.edu/kgsmap/kgsgeoserver/viewer.asp.

Fox, K. F., *Geology of the Cadiz Quadrangle*. Map GQ-412. Vol. Geologic Quadrangle Maps of the United States. Washington D.C., United States Geological Survey, Kentucky Geological Survey, 1965. Print.

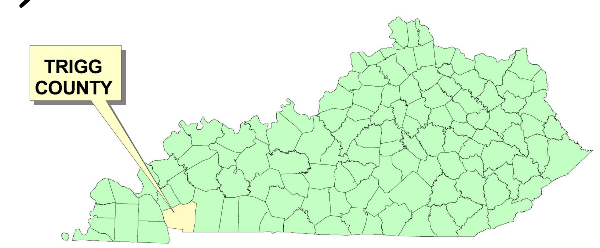


LEGEND

Resistivity Line Location (with Electrode Nos.)

Anticipated Building Footprint

Topographic Contours (ft)



Scale in meters

0 25 50 75 100

1" = 40 m

Scale in feet

0 100 200 300

N

NOTES:

1. Aerial photo is provided for site reference only. No claim is made as to the accuracy or completeness of this information.
2. Coordinates are referenced according to UTM, Zone 16N (meters), WGS84 datum.
3. Topographic contours were gridded using LiDAR data from Kentucky's Aerial Photography & Elevation Data Program.
4. Trigg County Reference Map provided by *"Generalized Geologic Map for Land-Use Planning: Trigg County, Kentucky - 2005"* (KGS).

Site Map

Karst Imaging Study
Cadiz Industrial Park
Cadiz, Trigg County, KY 42211
MUNDELL PROJECT NO. M16036

FIGURE

1

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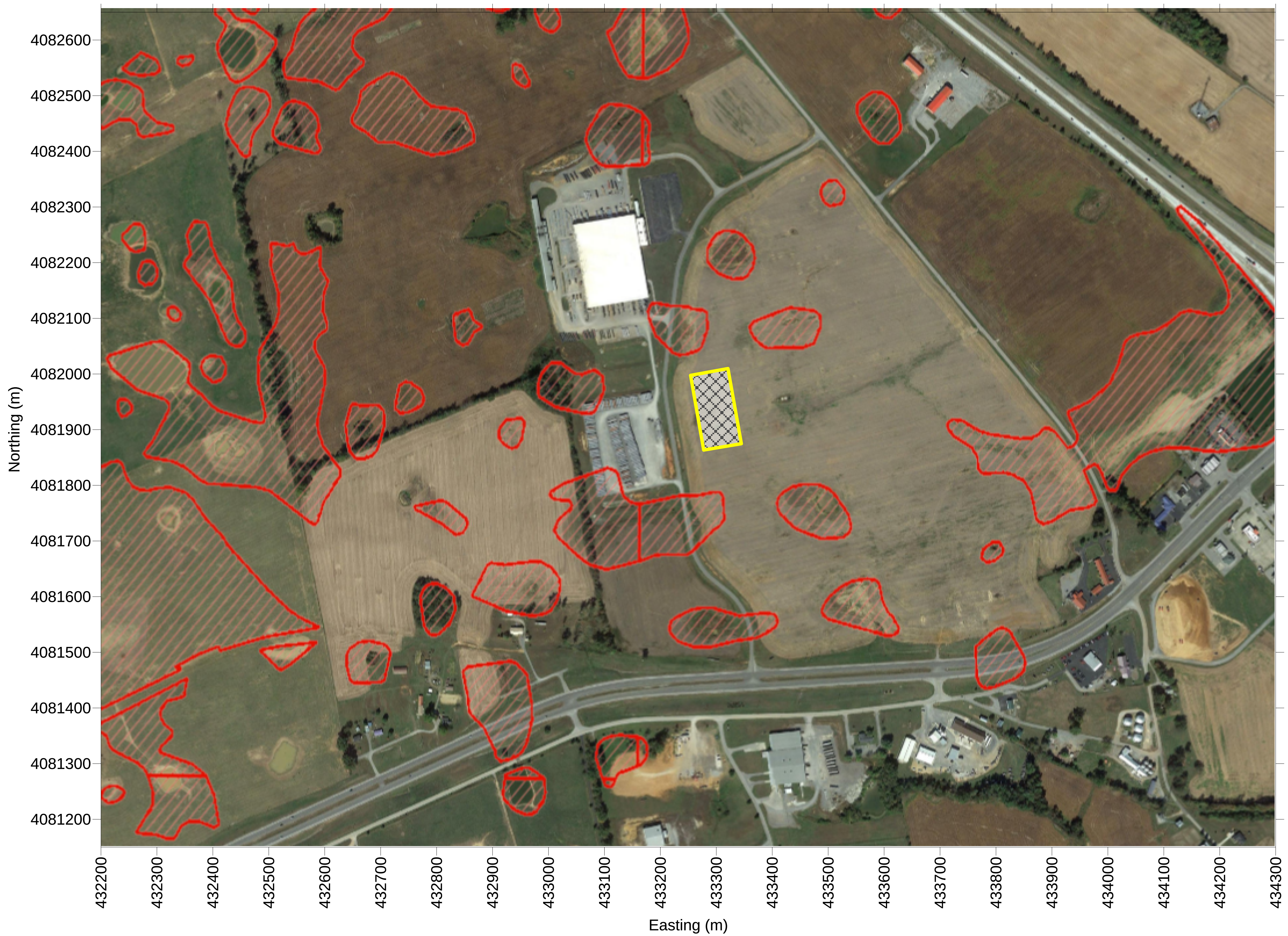

LEGEND

Anticipated Building Footprint

Sinkhole Outlines

N

Scale in meters

0 100 200 300 400

1" = 200 m

Scale in feet

0 500 1000 1500

NOTES:

1. Aerial photo is provided for site reference only. No claim is made as to the accuracy or completeness of this information.
2. Coordinates are referenced according to UTM, Zone 16N (meters), WGS84 datum.
3. Sinkhole Outlines provided by Kentucky Geological Survey's web geologic server (kgs.uky.edu).

Sinkhole Outline Map

Karst Imaging Study
Cadiz Industrial Park
Cadiz, Trigg County, KY 42211
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FIGURE

2

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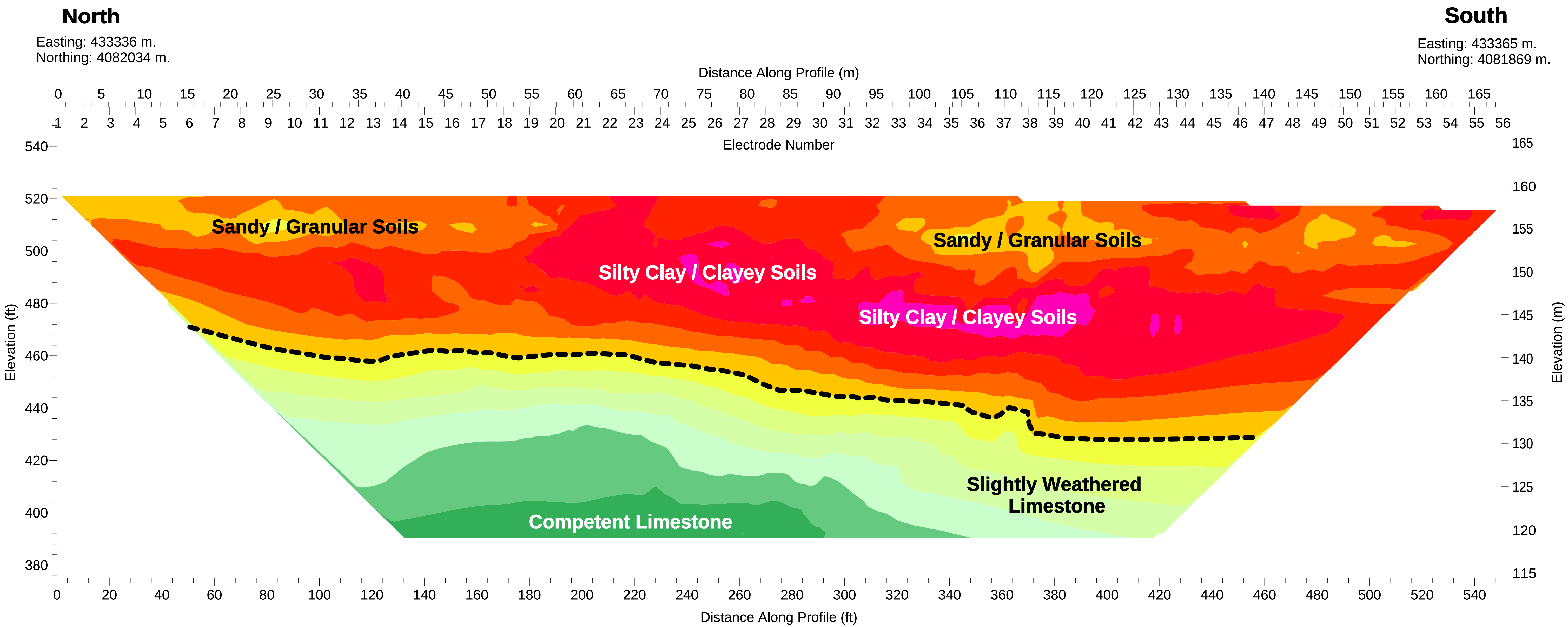
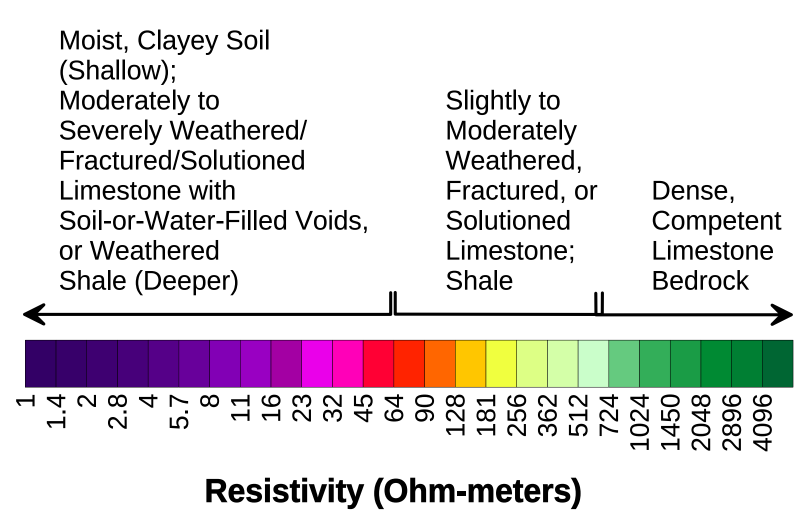


Interpreted Top of Bedrock
from the Resistivity Data

PROCESSING STATISTICS
Dipole-Dipole Array
Number of Iterations: 2
RMS Error: 2.67 %
Total Data Points in Model: 1114
Maximum Misfit: 11.1 %
Electrode Spacing: 10 ft. (3.05 m.)



Resistivity Profile Line 1
Karst Imaging Study
Cadiz Industrial Park
Cadiz, Trigg County, KY 42211
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FIGURE
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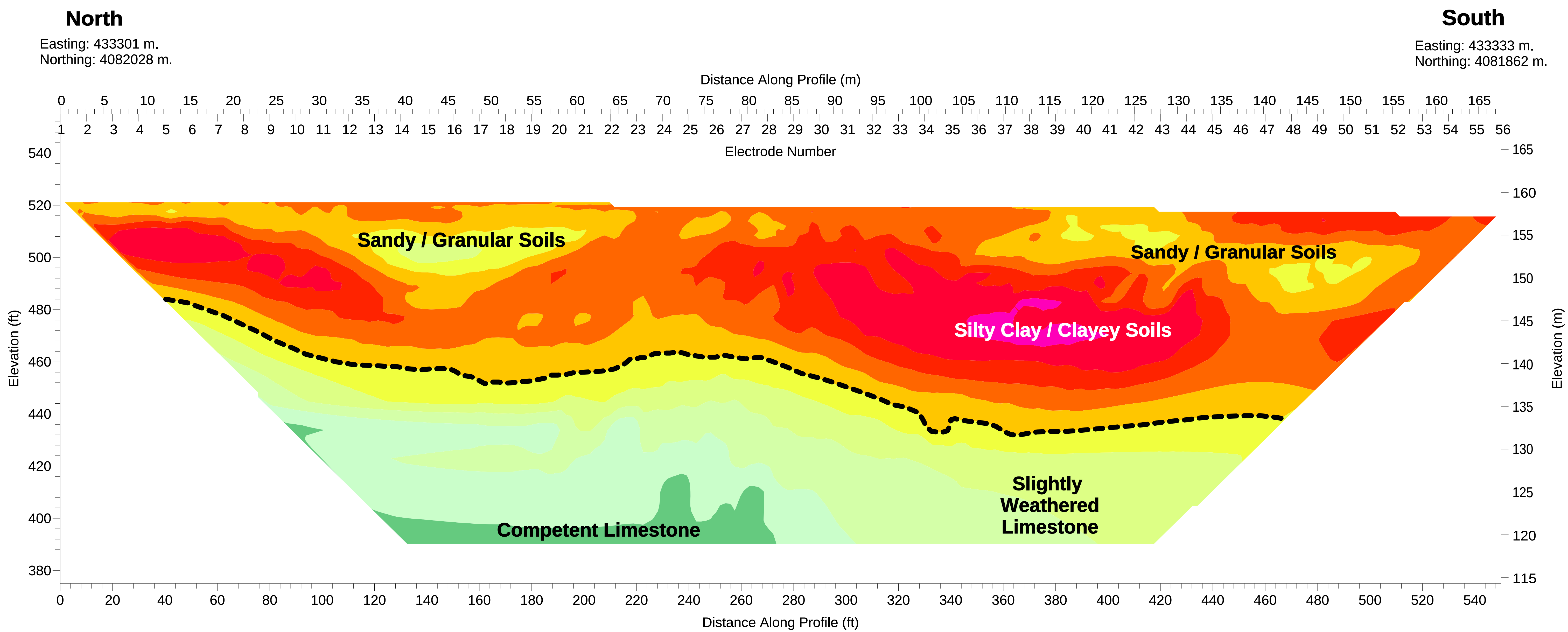
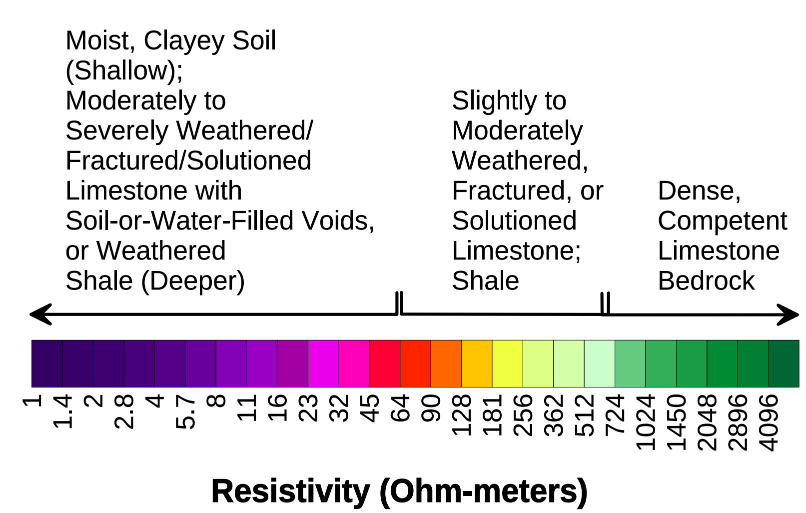


Interpreted Top of Bedrock from the Resistivity Data

PROCESSING STATISTICS
Dipole-Dipole Array
Number of Iterations: 2
RMS Error: 2.15 %
Total Data Points in Model: 1114
Maximum Misfit: 9.8 %
Electrode Spacing: 10 ft. (3.05 m.)



Resistivity Profile Line 2
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Cadiz Industrial Park
Cadiz, Trigg County, KY 42211
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FIGURE 4

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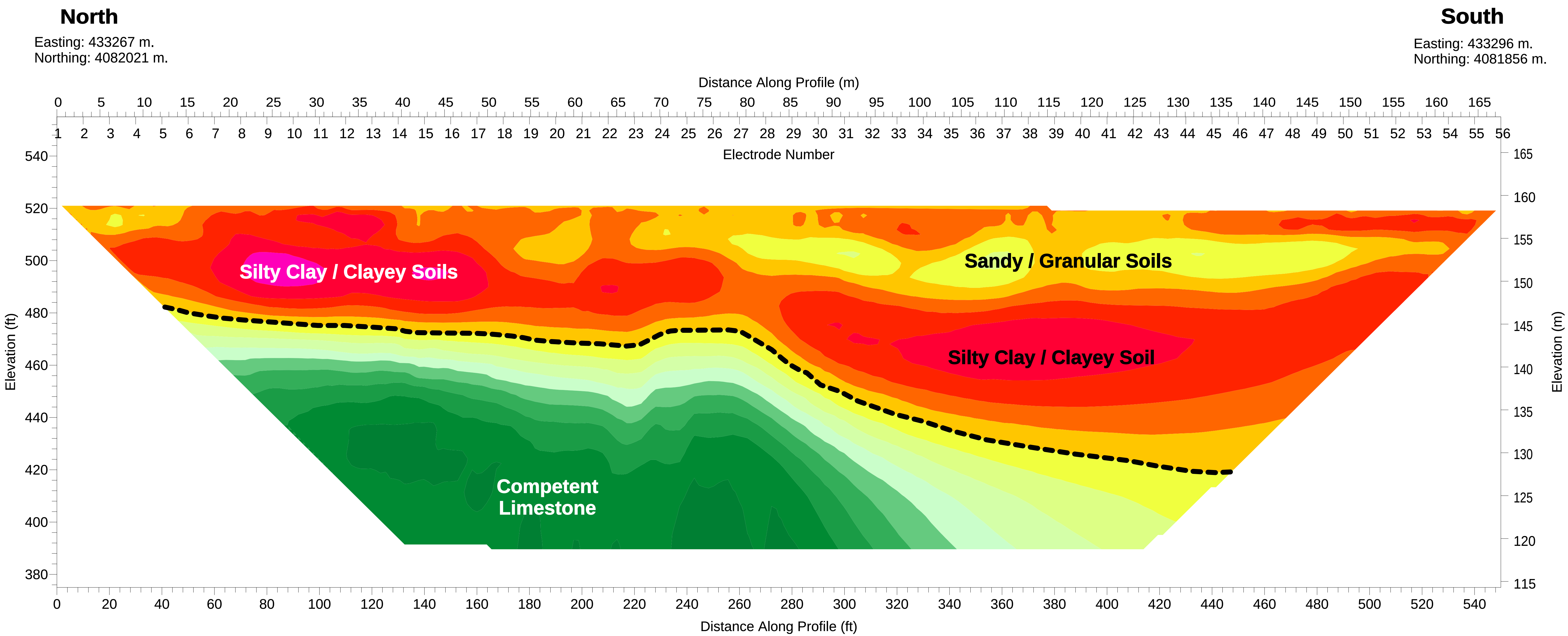


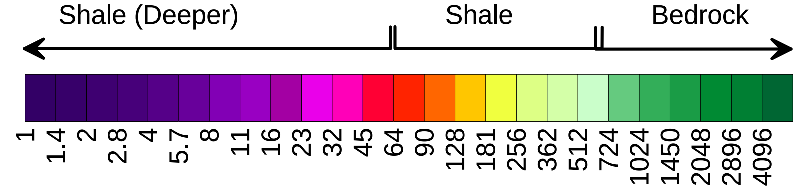
Interpreted Top of Bedrock from the Resistivity Data

PROCESSING STATISTICS
Dipole-Dipole Array
Number of Iterations: 5
RMS Error: 3.23 %
Total Data Points in Model: 1115
Maximum Misfit: 94 %
Electrode Spacing: 10 ft. (3.05 m.)

Moist, Clayey Soil (Shallow); Moderately to Severely Weathered/ Fractured/Solutioned Limestone with Soil-or-Water-Filled Voids, or Weathered Shale (Deeper)

Slightly to Moderately Weathered, Fractured, or Solutioned Limestone; Shale

Dense, Competent Limestone Bedrock



Resistivity (Ohm-meters)

Resistivity Profile Line 3
Karst Imaging Study
Cadiz Industrial Park
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FIGURE
5

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