



July 28, 2020

Mr. Steve Palmer, PE
South Dakota Department of Transportation
2300 Eglin Street
Rapid City, SD 57703

**Re: Geophysical Exploration
Meade 07DK
I-90 Exit 52 Hideaway Mine Workings Exploration
Black Hawk, South Dakota**

Dear Mr. Palmer:

As requested, we have performed a geophysical exploration for the referenced project. The purpose of this evaluation was to investigate the possible presence of voids beneath I-90 near Exit 52 in Black Hawk, SD.

The field work, analyses and findings of this report were conducted in accordance with generally accepted professional engineering and geophysical practices. We make no other warranty, either express or implied.

We trust this information to be sufficient. If you have any questions or desire any additional information, please do not hesitate to contact us.

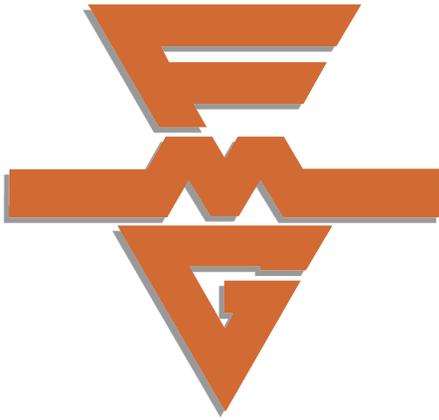
Respectfully submitted,

FMG Engineering

Alex Fisher, P.E., G.E.

Enclosures

c: Z:\200870 SDDOT I-90 ERT at Hideaway Hills\Geotech\FMG Report

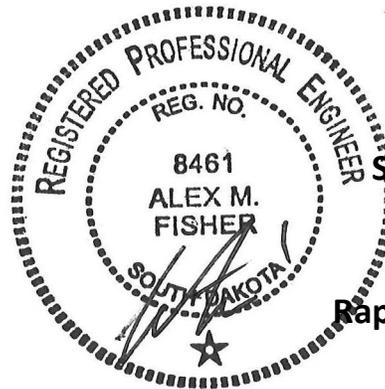


Geophysical Exploration

for

**Meade 07DK
I-90 Exit 52 Hideaway Mine Workings
Exploration
Black Hawk, South Dakota**

July 28, 2020



Prepared for
**South Dakota Department of
Transportation
2300 Eglin Street
Rapid City, South Dakota 57703**

FMG Project No. 200870

Civil Engineering
Geotechnical Engineering
Materials Testing Laboratory
Land Surveying
Environmental Services
Water Resources

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1. INTRODUCTION

In late April 2020, a collapse of historic underground gypsum mine workings occurred in the Hideaway Hills Subdivision in Black Hawk, South Dakota. The collapse resulted in a sinkhole opening near East Daisy Drive, approximately 1,380 feet south of I-90 Exit 52 at Peaceful Pines Road.

The sinkhole opening allowed observation, exploration and mapping of the void by the Paha Sapa Grotto group, a team of experienced cave mappers and a subchapter of the National Speleological Society. The Paha Sapa Grotto group found the void to be associated with relatively shallow historic underground gypsum mine workings. Laser-scan mapping found the accessible extents of the room and pillar workings to extend approximately 500 feet in the north-south direction and approximately 160 feet in the east-west direction. The workings appeared to follow an approximately 10-foot thick gypsum body which generally dipped to the east on the order of 10 to 11 degrees. Exploration efforts necessarily terminated where the workings were collapsed or extended below groundwater levels, generally at a point approximately 200 feet west of the east-bound lane of I-90.

Because the recently discovered and mapped mine workings were near the I-90 right-of-way (ROW), the South Dakota Department of Transportation (SDDOT) desired to investigate the shallow subsurface beneath the ROW for the presence of voids.

2. PROJECT SCOPE

The project scope included a geophysical exploration of an approximately 1,500-foot length of I-90 ROW adjacent to the mapped mine workings. The depth of exploration, or interest, was determined to be approximately 60 feet, below which any voids overlain by competent geomaterials would not be of immediate concern. The length of exploration was selected to span the north-south length of the mapped mine workings parallel to the interstate.

Due to the length of the desired exploration and the uncertain location of possible voids, geophysical exploration methods were chosen rather than more location-specific individual boreholes or test pits.



The geophysical exploration consisted of four profile lines; one west of the east-bound lane, one in the median and two east of the west-bound lane. The geophysical field exploration, data processing and data interpretation was conducted by *GeoVision*, a geophysical subconsultant to FMG Engineering (FMG). The specific physical location of the profile lines was surveyed by FMG. The project scope also included geotechnical boreholes performed by FMG at select anomaly locations identified in the geophysical data. The geophysical field exploration is illustrated on Figure 1 in Appendix A.

Engineering recommendations for structure rehabilitation or remediation of voids was beyond the scope of this project. The project scope was limited to the I-90 ROW limits and did not extend into private property. The project scope was cooperatively developed by FMG, *GeoVision* and the SDDOT.

3. METHODOLOGY

The geology in the vicinity of the project was expected to consist of clayey alluvial or residual soils overlying Sundance and Spearfish Formation bedrock, including the Gypsum Springs Formation. Several possible geophysical exploration methods were considered for the scope of work, depth of interest and geologic environment. Ground penetrating radar (GPR), microgravity, seismic reflection surveys, and electrical resistivity tomography were all initially considered as applicable for void investigations. In selecting the most appropriate exploration method, GPR was eliminated due to its inability to image effectively through clays or clayey soils. Microgravity, typically an excellent void exploration tool, was not cost effective for the small scale of the survey and would also have overriding negative impacts by the adjacent traffic noise. Similarly, seismic reflection was not considered cost effective for the project scale and would also have been significantly impacted by the adjacent traffic noise.

Ultimately, electrical resistivity tomography (ERT) was selected for the exploration for its proven effectiveness in void detection, its scalability, its indifference to traffic noise, and its range of observation depths.



A 300-ft tape was used to lay out the ERT lines and each electrode location was surveyed with GPS survey equipment to establish the surface elevation profile of the line.

After completion of the ERT data collection and initial processing, boreholes were drilled at the locations of four near-surface, highly resistive anomalies observed in the ERT data. The boreholes were drilled to explore the nature of these anomalies and to obtain physical samples of the geomaterials in the soil profile for reference and correlation of the geophysical data.

A detailed description of the project methodology and exploration locations can be found in the *GeoVision* final report presented as Appendix A. The borehole data and laboratory testing results are presented in Appendices A and B.

4. FINDINGS

The profile models, detailed discussion of each of the profile analyses and a detailed discussion of the project findings can be found in the *GeoVision* final report in Appendix A. Figure 1 of the *GeoVision* report in Appendix A includes the location of the sinkhole and mine workings mapped by the Paha Sapa Grotto group.

In summary, the ERT surveys and the boreholes indicated three general subsurface units. A surficial clayey soil profile which exhibited relatively low resistivities was encountered in each profile. This unit is interpreted to be the surficial alluvial, residual and embankment fill soils. The surficial soils are underlain by shale and siltstone bedrock and gypsum which exhibited relatively high resistivity values. At the bottom of the ERT models, a relatively conductive unit was noted. This unit was below the total depths of the boreholes and not physically sampled but may consist of saturated sediments or rock with a high porosity. Alternatively, this unit could represent a differing rock type, such as limestone.

The ERT data models indicated a small number of high-amplitude resistivity anomalies in the shallow subsurface, generally within 45 feet of the surface and within the siltstone bedrock and gypsum subsurface unit. These anomalies had resistivity signatures which could indicate air-filled voids and, as such, were explored with boreholes. In each case, the borehole encountered either very hard, dry and massive gypsum or hard, dry siltstone within the anomalous zone. No voids were encountered. Based on the findings of the boreholes,



the anomalies in the ERT data models are interpreted to be bodies of high-grade gypsum or zones of highly resistive, dry, low-porosity siltstone bedrock.

When correlated with the borehole findings and laboratory testing, the ERT data models do not appear to suggest the presence of voids within the depth of exploration beneath the profile lines conducted in the I-90 ROW.

This report concludes the contracted scope of work. The project scope was completed within understood limitations including physical site accessibility, budget, depth of exploration and schedule. Additional subsurface information may be gathered via additional boreholes, additional ERT profiles, and/or alternative geophysical methods.

Appendix A

Geo*Vision* Final Report



GEOPHYSICAL REPORT

ELECTRICAL RESISTIVITY SURVEY

I-90

Black Hawk, South Dakota

GEOVision Project No. 20164

Prepared for

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Report 20164-2

July 24, 2020

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APPENDICES

Electrical Resistivity Method

1 INTRODUCTION

A geophysical investigation was conducted from May 28-30, 2020. The objective of the investigation was to screen a portion of the I-90 right-of-way for voids associated with abandoned mine workings.

The geology in the vicinity of the geophysical survey was expected to consist of clayey soils overlying Spearfish Formation and Gypsum Spring Formation rocks, which includes shale, siltstones, sandstone and some limestone members.

Screening for voids with geophysical tools is difficult, in large part because the challenge is to prove a negative result, rather than a “positive” anomaly map that may be verified by drilling. We typically propose one or more of the following geophysical methods for void investigations: ground penetrating radar (GPR), microgravity, high-resolution shear-wave reflection, and electrical resistivity tomography (ERT). GPR does not image through clays or clayey soils and was discounted early during our scoping conversations. Microgravity, which responds directly to mass deficiencies and is a superb detector of voids, was considered quite expensive to be conducted on a tight survey scale, and it would have been strongly impacted by traffic noise. Similarly, high-resolution shear-wave reflection is a very good imaging method for shallow voids, air-filled or water-filled, but is also relatively expensive and would be negatively impacted by traffic noise.

ERT data were collected along four lines at the project site. The general locations of the lines were selected by FMG Engineering, Inc. (FMG) and the South Dakota Department of Transportation (SD DOT) and modified as needed by *GEOVision*. The position of each geophysical line was marked by *GEOVision* personnel using pin flags, and GPS data points were collected of each pin flag by FMG. These lines are shown in Figure 1. A summary of the GPS data including line lengths and line end coordinates is included as Table 1.

ASTM International has issued document D6431-18 “Standard Guide for Using the Direct Current Resistivity Method for Subsurface Investigation.” This document is a guide only and was used as a baseline for conducting the resistivity testing. The document does not address the use of electrical resistivity imaging, but rather focuses on the principles of 1D resistivity soundings and 2D resistivity profiling.

This report includes a discussion of equipment and field procedures, methodology, data processing, and results of the geophysical survey. Geophysical techniques used during the investigation are discussed in Section 2. Equipment and field procedures are described in Section 3. Data processing is discussed in Section 4. A discussion of the results of the geophysical survey is presented in Sections 5 & 6. Technical references are provided in Section 7 and our professional certification is presented in Section 8.

2 METHODOLOGY

Electrical resistivity tomography (ERT) involves the measurement of the apparent resistivity of subsurface soil and rock as a function of depth and/or position. The ERT method can identify variations in subsurface geologic features where contrasts in the resistivities are present. Changes in the electrical properties of the subsurface are non-unique indicators of geologic conditions (Dahlin, 1996). Variations in subsurface moisture content, porosity, permeability, and soil or rock type (i.e., lithology) affect electrical resistivity measurements. Cultural features (man-made features such as fences, power lines, pipelines, and buried debris) can influence resistivity measurements.

During a resistivity survey, electrical current is applied to a pair of electrodes (a dipole), and the potential difference (voltage) is measured between one or more pairs of potential electrodes. For a 2-D resistivity survey, the current and potential electrodes are generally arranged in a linear array. Common array types include pole-pole, dipole-dipole, Schlumberger, Wenner, and gradient arrays. The apparent resistivity is the resistivity of a homogenous and isotropic half-space that would yield the measured resistivity for a given input current and potential difference for a given arrangement of electrodes. It is calculated by dividing the measured potential difference by the input current and multiplying by a geometric factor calculated for the array.

Apparent resistivity is typically run through an inverse modeling algorithm to generate a geoelectric section of the subsurface directly beneath the profile (Loke and Barker, 1996). The inversion process involves creating a hypothetical earth model of cells with infinite length perpendicular to the line, calculating the theoretical resistivity of this model, and iteratively adjusting the resistivity of the cells to minimize error between the calculated and observed resistivity. The final result of the inversion process is a resistivity model of the subsurface that fits the observed data with input error and smoothness constraints.

Depth of investigation for the ERT method is a complex function involving receiver array length and the electrical properties of the subsurface materials (Oldenburg and Li, 1999). In general, for 2D electrical resistivity surveys, resolution and depth of investigation are inversely proportional. High resolution is typically obtained by using relatively small electrode spacing. However, using small electrode spacing reduces investigation depth. Conversely, large electrode separation will typically provide greater depth of investigation but sacrifices resolution.

3 EQUIPMENT AND FIELD PROCEDURES

ERT equipment used during this investigation consisted of an Advanced Geosciences, Inc. Supersting R8/IP transceiver, 18-inch stainless-steel electrode stakes, and multi-core electrode cables with Mueller-style takeouts. The 400-volt transmitter is capable of output current levels of 2-amperes at 200 watts. It was powered by 12-volt automobile batteries. The instrument can record up to eight channels simultaneously and switching between up to 112 electrode pairs to act as current or potential dipoles.

All four lines used a 10-foot electrode spacing. A 300-foot measuring tape was used to lay out the lines, and each electrode location was later surveyed using GPS. The electrodes were driven into the ground approximately 12 inches (or more). Each electrode was connected to the multicore electrode cable to create electrical coupling between the metal electrode stake and metal Mueller cable takeout.

A contact resistance test was performed to monitor the resistance values between each pair of electrodes. Dipoles with anomalously high contact resistances were checked (ensuring adequate coupling of the electrode to the soil and verifying clean metal-metal contact between the multicore cable and electrode) and the contact resistance test repeated. If anomalously high contact resistance readings persisted, the electrode location was adjusted and/or a salt-water solution was applied to the electrodes in question.

Operation of the AGI Supersting was partially automated. Prior to taking measurements, a sequence file was loaded to the instrument. This file specifies which pairs of electrodes to function as the current dipole, and which pairs of electrodes to act as potential difference dipoles for each measurement. The instrument read this sequence file and commenced with the automatic data collection. Two sequences were acquired along each line, one using a Dipole-Dipole array (typical for void investigations) and another using a Strong Gradient array (a very fast, reconnaissance-level electrode array). For each line of the sequence, multiple measurements were performed and the standard deviation between those measurements was calculated. If that standard deviation value exceeded a percentage programmed by the operator (for this project, 5%), that measurement was repeated up to two times. If the standard deviation after two repeats did not improve below the programmed threshold, the reading was stored and flagged for later evaluation during data processing. Typically, the standard deviation for the shallow readings (close dipoles) was within the 3% threshold, and the instrument stored the reading and advanced to the next line of the sequence file. Data at longer dipoles (deeper readings) were of poor quality and flagged for review during data processing.

During the measurement cycle, the instrument displayed the sequence number, current applied, voltage differential recorded at each dipole, and the standard deviation between repeat measurements. The operator monitored these values for anomalously low current values, negative recorded voltages, and high standard deviation values that may indicate potential problems for the geophysical survey. If a problem was identified during data collection, the operator paused the measurement cycle and inspected the electrode array for problems such as loose electrodes, disconnected electrodes, or nearby cultural features that may impact the recorded apparent resistivity values. If no obvious sources of error were noted, the operator made note in the data recording log for evaluation during data processing.

4 DATA PROCESSING

Raw resistivity data were first evaluated in *pseudosection* format (i.e. station versus “n” spacing). Note that pseudo-sections are not cross-sections or earth models as the dipole-dipole pseudosection plotting method is not a depth representation (Edwards, 1977), but it is a useful means of evaluating data graphically. The pseudosection was analyzed for individual data points with high reported error (RMS error between measurements). Data with extremely high (>10%) variance between measurements were automatically discarded. Points interpreted as outliers beyond the trends observed in the geophysical data as expected for the geologic environment were manually evaluated and removed. Due to physical and geometric constraints, a single spurious point would not represent an accurate apparent resistivity value for a measurement point. These spurious points can be identified on the raw pseudosections and removed. This does not include all outlier data. For example, if a broad zone of anomalously high apparent resistivity values is observed in the data, those points would not be removed prior to inversion. Other data points with lower error were discarded if they did not appear to match the geoelectric section – a spurious high resistivity value surrounded by conductive measurements, for example. When patterns of “noisy” data were determined to be associated with a single electrode location, all data associated with that electrode location was reviewed in greater detail. It is uncommon, but possible, for an electrode to become unplugged after preliminary testing but during data collection, and all subsequent data collected using that electrode to be in error.

After data processing, the averaged apparent resistivity data were input into EarthImager2D for two-dimensional modeling. An ASCII formatted station file summarizing the electrode geometry, project stationing, and elevation is imported prior to inversion. The final model cross-sections for the ERT survey are derived from smooth-model inversion results of the dipole-dipole data. Smooth-model inversion mathematically back-calculates (or “inverts”) the measured data to determine a subsurface resistivity structure. The results of the smooth-model inversion are intentionally gradational, rather than showing abrupt, blocky changes in the subsurface. The smooth-model algorithm includes accurate modeling of two-dimensional topography along with subsurface resistivity (MacInnes and Zonge, 1996).

These inversion results should not be considered a unique solution, and some ambiguity remains in any mathematical representation of the data. The inversion assumes a 2D earth with bodies having a significant lateral extent outside of the 2D cross-sectional plane. For 3D bodies this inversion will be in error. In addition, the ERT method will detect anomalies that are off-line or out of the plane from the transect but without the ability to determine where those out of plane anomalies originate. This is an important consideration when drilling targets for confirmation and ground truth.

Inversion output was saved as an ASCII format XYZ file containing position, elevation, and resistivity. The data were imported into Surfer mapping system where the resistivity models were converted to a log format, gridded, contoured, and annotated for presentation. Results are presented as color cross sections showing the resistivity distribution derived from the smooth-model inversion process. Profile distance is shown across the base of the cross section, and elevation is labeled along the side. Additional masking of data along the edges of the cross-section is performed, beyond the limits of the geometric locations of the data points.

5 RESULTS

The purpose of the electrical resistivity survey was to identify potential features which may be indicative of underground mine workings. Electrical resistivity tomography data is presented along profiles labeled Line 1 to Line 4. The lines are presented along the layout established in the field, with the left-hand side of the cross-section corresponding to the northwest end of the survey line.

The models for Line 1 to Line 4 are presented “fit-to-page” plots at the end of this report and digitally attached as scaled plots in pdf format. In tomographic models, sharp layer contacts are not clearly defined and thus ranges of resistivity values are used to interpret possible soil and rock conditions. A color bar is used to describe modeled resistivity values from the tomographic modeling process. The color scheme used on the electrical resistivity images is a semi-log scale to enhance the contrast between high and low resistivities. The color scheme consists of blue-green, yellow-orange, and red-magenta representing low, intermediate, and high resistivity, respectively.

5.1 *Line 1*

Line 1 is approximately 1500 feet in length and located in the western right-of-way of I-90E. The “start” of the line was offset from a creek and box culvert. This line was situated between noise sources including an electrical line (shown on Figure 1) and the reinforcing bars within the concrete of the roadway. The resistivity models for the gradient and dipole-dipole arrays are presented in Figure 2.

The data collected beneath this array includes points that could be modeled to depths of over 200 feet beneath the ground surface (BGS), but we have cropped this model to less than 200 feet BGS. Sensitivity analysis performed on the data suggests that the extremely conductive material encountered beneath this line should limit the effective depth of investigation (DOI).

In general, the ERT data suggests a subsurface described by three geoelectric units: a surface unit with moderately-low resistivity soils (<50 ohm-meters) underlain by a moderately-resistive (100+ ohm-meter) unit interpreted as bedrock. Beneath this layer is a very low-resistivity unit (<5 ohm-meters) interpreted as saturated rocks with a high porosity and potentially high TDS groundwater. Within the uppermost interpreted soil layer, there is a thin zone of very low resistivity (high conductivity) interpreted as a possible clay layer, or soil layer with higher concentration of fines. The intermediate layer has very high resistivity anomalies (over 1000 ohm-meter) inconsistent with fine-grained sediments or sedimentary rock such as claystone or shale. Several locations along this profile were suggested by GEOVision for ground truthing to help correlate our results to local geologic conditions.

Borehole BH-1 was located approximately 770 feet along ERT Line 1. At this location, a very high-amplitude, isolated, shallow anomaly was observed in the gradient model, with a minor anomaly in the dipole-dipole data. The top of the resistivity anomaly was at approximately 20 feet BGS and relatively accessible via drilling. This anomaly would be a typical size, shape, and magnitude for an air-filled void. At this point in the boring log, the core transitioned by very hard, dry gypsum to siltstone (Spearfish Formation). No indication of underground mine workings was observed in the boring. If we use the borehole information to guide an

interpretation of the ERT data, that implies that the siltstone unit has an apparent dip to the north / northwest, with pockets of very resistive (more resistive than typical) gypsum stringers or other mineralization possible. No groundwater was encountered during the drilling, to a total hole depth of 60 feet BGS. The low-resistivity unit was at least 75-80 feet BGS at this location (depending on the apparent dip) and was unable to be correlated to a geologic unit or subunit by the boring log.

On the Northern end of the resistivity models (stations 100-400) there is a very high amplitude (highly resistive) resistivity zone observed in both the gradient and dipole-dipole models. Given the smoothing of the modeling algorithm, it is difficult to determine the exact top of the source of the anomaly, but we estimate it at 80 feet BGS at its shallowest point (profile distance/station 140 feet). This may indicate a transition to another rock unit (such as limestone) or subunit with lower porosity. This anomaly, much like the more localized anomalies at profile stations 920 feet and 1080 feet, were considered deeper than expected for the known mine workings.

At a depth of 70-80 feet BGS beneath BH-1, the ERT model indicates a conductive anomaly (less than 1 ohm-m). A similar feature is observed at a depth of 50-60 feet beneath profile distance 1300. This may represent a poorly resolved water table, but the discontinuous nature of the anomaly could be representative of large, fluid-filled voids. Without deep ground truth information we should not speculate on the source of the anomaly.

5.2 **Line 2**

Line 2 is approximately 1680 feet in length and located in the center median between the eastbound and westbound lanes of I-90. The “start” of the line was located north of the box culvert, though it was not evident in the data due to the limited data modeled along the edges of the profile. No other utilities or noise sources were noted other than the reinforcing bars within the concrete of the roadway. The resistivity models for the gradient and dipole-dipole arrays are presented in Figure 3.

The gradient array and dipole-dipole array models both indicate a roughly three-layered system similar to Line 1: surface soils with low resistivity indicative of clayey soils, a moderately resistive unit interpreted as bedrock, containing pockets of very resistive mineralization or anomalies, underlain by a more conductive unit interpreted as saturated bedrock with higher fine content.

Borehole BH-2 was located on this line, at approximate station 1470 along the ERT profile. This corresponded to a shallow, high-amplitude, localized ERT anomaly within the interpreted bedrock unit. The top of this anomaly is ~ 15-20 feet BGS, corresponding to the Spearfish Formation identified in BH-2, where high blow count, moderately hard siltstone is once again described. Groundwater was not encountered to the boring extent of 60 feet. There is an apparent break in the conductive unit beneath this anomaly, which we had hoped to correlate to a geologic unit or subunit by the borehole at this location (qualify the shallow “blue” low-resistivity structure).

There are two other anomalies that we feel warrant discussion beneath or about Line 2. The first is a high-amplitude, resistive anomaly in both the gradient and dipole data, centered at profile station 377 feet and a modeled depth of 50 feet BGS. The size and shape of the anomaly is broader in the gradient model but that is expected, as the gradient array generates fewer data

points and the model will smooth across more cells during the inversion process. This anomaly appears at the top of the interpreted Spearfish Formation. A similar anomaly is at profile distance 865 feet and depth 65-70 feet BGS. This anomaly is larger. Please note that the source of anomalies may be out of plane from the 2D cross-section.

5.3 **Line 3**

Line 3 is approximately 830 feet in length and located between the eastern right-of-way for I-90W and the offramp. The “start” of the line was located south of the box culvert. No other utilities or noise sources were noted other than the reinforcing bars within the concrete of the roadway. The resistivity models for the gradient and dipole-dipole arrays are presented in Figure 4.

The gradient array and dipole-dipole array models both indicate a roughly three-layered system similar to Line 1 and Line 2: surface soils with low resistivity indicative of clayey soils, a moderately resistive unit interpreted as bedrock, containing pockets of very resistive mineralization or anomalies, underlain by a more conductive unit interpreted as saturated bedrock with higher fine content.

Borehole BH-3 was located at profile station 210 feet along this line. There was a localized high-amplitude resistivity anomaly at a depth of 20-25 feet at this location. The borehole describes this as being the transition between the gypsum and siltstone of the Spearfish Formation. Similar to the other boring logs, reported blow counts are quite high and groundwater is not encountered in the upper 60 feet beneath the surface.

5.4 **Line 4**

Line 4 is approximately 830 feet in length and located east of the offramp toward Peaceful Pines Road. The “start” of the line was located north roughly projected from a property boundary / fence corner and utility pole line. No other utilities or noise sources were noted other than the reinforcing bars within the concrete of the roadway. The resistivity models for the gradient and dipole-dipole arrays are presented in Figure 5.

The gradient array and dipole-dipole array models both indicate a roughly three-layered system similar to the other ERT lines: surface soils with low resistivity indicative of clayey soils, a moderately resistive unit interpreted as bedrock, containing pockets of very resistive mineralization or anomalies, underlain by a more conductive unit interpreted as saturated bedrock with higher fine content.

Borehole BH-4 was located on this line, at approximate station 720 along the ERT profile. This corresponded to a resistive unit interpreted as shallow bedrock. BH-4 indicates gypsum at a depth of approximately 7 feet, underlain by siltstone of the Spearfish Formation at a depth of approximately 28 feet BGS. Groundwater was not encountered during drilling to total depth of 60 feet. This is at the edge of the ERT model, but the model suggests a more conductive material would be encountered at depths 60-70 feet BGS near this location.

There are localized resistivity highs in the interpreted Spearfish Formation that could be over-interpreted as mine workings. Certainly, the resistivity anomalies at profile distance 280 and 375

feet (both approximately 75 feet BGS) are relatively higher than the surrounding materials, but overly so. BH-4 was selected in an attempt to classify these materials where shallower and easier to sample. This record indicated siltstone with high blow counts. We interpret these anomalies to reflect zones within the rock that are harder, with lower porosity and pore-fluid / mineralization content.

Beneath the resistive geo-electric layer interpreted as siltstone within the Spearfish Formation, there is a very conductive apparent layer 75-100 feet BGS. This may represent a different lithologic unit with higher porosity, fluid, mineral, or ionic content. Given the breadth of the zone we do not think it likely to represent water-filled voids associated with room and pillar mining, as the zone is at least 300 feet in width.

6 SUMMARY

Electrical resistivity tomography was conducted along four profiles adjacent to Interstate 90 in Black Hawk, South Dakota. The results of the geophysical survey are attached as Figures 2-5.

The geology understood at the beginning of this investigation, as provided in the RFP discussion was

The Blackhawk Mine is from the Dakota Plaster Co.. The two kettle mill at Blackhawk was built in 1910 and could produce about 200 tons/day of crushed and roasted gypsum, and made stucco and wall plaster, gypsum blocks, and plaster. Some product was used as a soil conditioner. Limited amounts of product were shipped outside of the local area. Much of the production went to the State Cement Plant in Rapid City where it was mixed with cement to slow the curing time. The mix was 10 pounds of gypsum per barrel of cement. The Dakota Plaster mill was built next to two gypsum bodies. Mining was mainly underground, but also with open cuts in gypsum beds near the lower part of the Spearfish Formation that were typically 6 feet thick, and at the top of the Spearfish in the Gypsum Spring Formation, which is about 8-25 feet thick in the Blackhawk area. The open cut in the lower gypsum bed exposed a 6 foot thick gypsum face. The mill burned in 1916, was rebuilt in 1917, and was active when examined by Connolly and O'Harra in 1929. In 1930, the mill was purchased by the United States Gypsum Company and may have closed shortly after. The area possibly had mining activity before 1900, but no records exist.

The area of subsidence and previous excavation on East Daisy Dr. is on the Gypsum Spring Formation. The Gypsum Spring thickens to the northwest into Wyoming, and thins to the south, pinching out just south of Rapid City. It is about 8-25 feet thick in the Blackhawk area. They probably dug the open cut to expose the gypsum bed, and then drifted laterally underground. The line of affected houses lies directly over an elongate pit that was dug into the Gypsum Spring Formation, and later filled in.

The interpretation of geophysical anomalies is inherently ambiguous as any given anomaly could be caused by several possible sources (Kearey and Brooks, 1991). An important task in interpretation is to decrease the ambiguity by using all external constraints on the nature and form of the anomalous body. Such constraints include geologic information derived from surface outcrops, boreholes, and from other complementary techniques.

Typical resistivity values for gypsum range from 10-1000 ohm-m, depending on grain size and grade, with traditional gypsum between 100-700 ohm-meters and “pure” gypsum 700 – 1000 ohm-meters (Guinea, 2010). Siltstones may be extremely resistive as well, with primary consideration to pore space and pore geometry. The resistivity of rocks may be anisotropic in layered media.

There appears to be three general geo-electric subsurface units identified in the ERT data. The shallowest, near-surface unit consists of relatively low-resistive (conductive) materials suggestive of clayey soils retaining meteoric water. This is underlain by a resistive unit correlated to gypsum and the siltstone subunit within the Spearfish Formation. The resistivity range for this shallow bedrock is very broad (100-1000+ ohm-meters) and higher than expected for siltstone. Some of these extremely high resistivity values may represent very high-grade gypsum. At the bottom of the ERT models is a relatively conductive geo-electric unit that is

likely the bottom of our confidence limit and represents the depth of investigation. A very conductive (weakly-resistive) unit with resistivity values ranging from <1 ohm-meter to 10 ohm-meters is dispersing the electrical current, yielding very weak returned signals at the surface. We limited the depth of our models based on sensitivity analysis of the weakly-returned signal. This unit was not characterized by the borehole program, which terminated at 60 feet BGS. Our interpretation is that this unit represents saturated sediments with high porosity. It could represent a different rock type, such as claystone, or limestone with a weathering profile to clay, for example.

In the upper 60 feet, using the provided borehole ground truth for control, we can assume sediments to be above the water table, and any fluid content a product of meteoric transfer. Air-filled voids in rock are typically imaged in ERT data as very high-amplitude resistive anomalies. The shape of the anomaly does not reflect the shape of the void, nor is the size of the anomaly a direct correlation to the size of the void, other than in a relative manner. It can be difficult or impossible to distinguish between voids and rock if the host medium is itself resistive (target is a resistor within a resistor). Very resistive “bullseye” anomalies are typically selected for follow up investigation such as drilling or additional geophysical testing. For this investigation, the anomaly at station 770 feet along Line 1 was selected for drilling. No mine workings, voids, or groundwater were encountered to a total hole depth of 60 feet BGS. This anomaly corresponded to the contact between gypsum rock and siltstone. A similar anomaly along Line 2 was selected for drilling, where it corresponded to the contact between residual soils and siltstone. The boring selected along Line 3 (BH-3) also displayed an anomaly at the contact between gypsum and siltstone. The boring BH-4 on Line 4 was selected to help characterize what appeared to be a continuous, resistive layer in the shallow subsurface. These four borings imply that the siltstone member of the Spearfish Formation is very resistive, with zones exhibiting very high bulk resistivity.

Our data indicates a more conductive geo-electric unit at depths of 70+ feet. This is interpreted as the groundwater table and saturated sediments / more porous rock, though we have no ground truth information. Pure water is very resistive, but the resistivity for what is commonly referred to as “freshwater” usually falls within the range of 10-150 ohm-meters. Higher amounts of total dissolved solids will lower the resistivity range. Water-filled voids in rock would be more conductive than air-filled voids, with conductivity increasing (resistivity decreasing) depending on the type and concentration of ions and dissolved solids in the water. Similar to air-filled voids, fluid-filled voids can be difficult or impossible to detect when within conductive host rocks (the target is a conductor within a conductor). The conductive anomalies observed beneath Line 1, Line 2, and Line 4 are all deeper than expected for the upper mined gypsum layer described above.

7 REFERENCES

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- Olhoeft, Gary. (1981). *Electrical properties of rocks*. Physical properties of rocks and minerals: Hemisphere Publ. Corp., New York, NY, United States (USA), II-2
- Oldenburg, D. W. and Li, Y., 1999, Estimating Depth of Investigation in DC resistivity and IP surveys, *Geophysics*, *Geophysics*, 64. 403-416.

8 CERTIFICATION

All geophysical data, analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by a **GEOVision** California Professional Geophysicist.

Prepared by

JB Shawver

JB Shawver
California Professional Geophysicist
GEOVision Geophysical Services



7/24/2020

Date

This geophysical investigation was conducted under the supervision of a California Professional Geophysicist using industry-standard methods and equipment. A high degree of professionalism was maintained during the project from the field investigation and data acquisition, through data processing interpretation and reporting. Original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review for a period of at least one year.

A professional geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations or ordinances.

9 TABLE & FIGURES

ERT Line	Length (feet)	Start X	Start Y	End X	End Y
		<i>South Dakota State Plane Zone North</i>			
		<i>NAD83, US Survey Feet</i>			
Line 1	1500	134094	1101773	132719.8	1102357
Line 2	1680	134314.6	1101909	132740.1	1102458
Line 3	830	134188.6	1102091	133392.8	1102325
Line 4	830	133500.3	1102404	132691.6	1102588

Table 1 ERT Line Geometry



Figure 1 Site Map

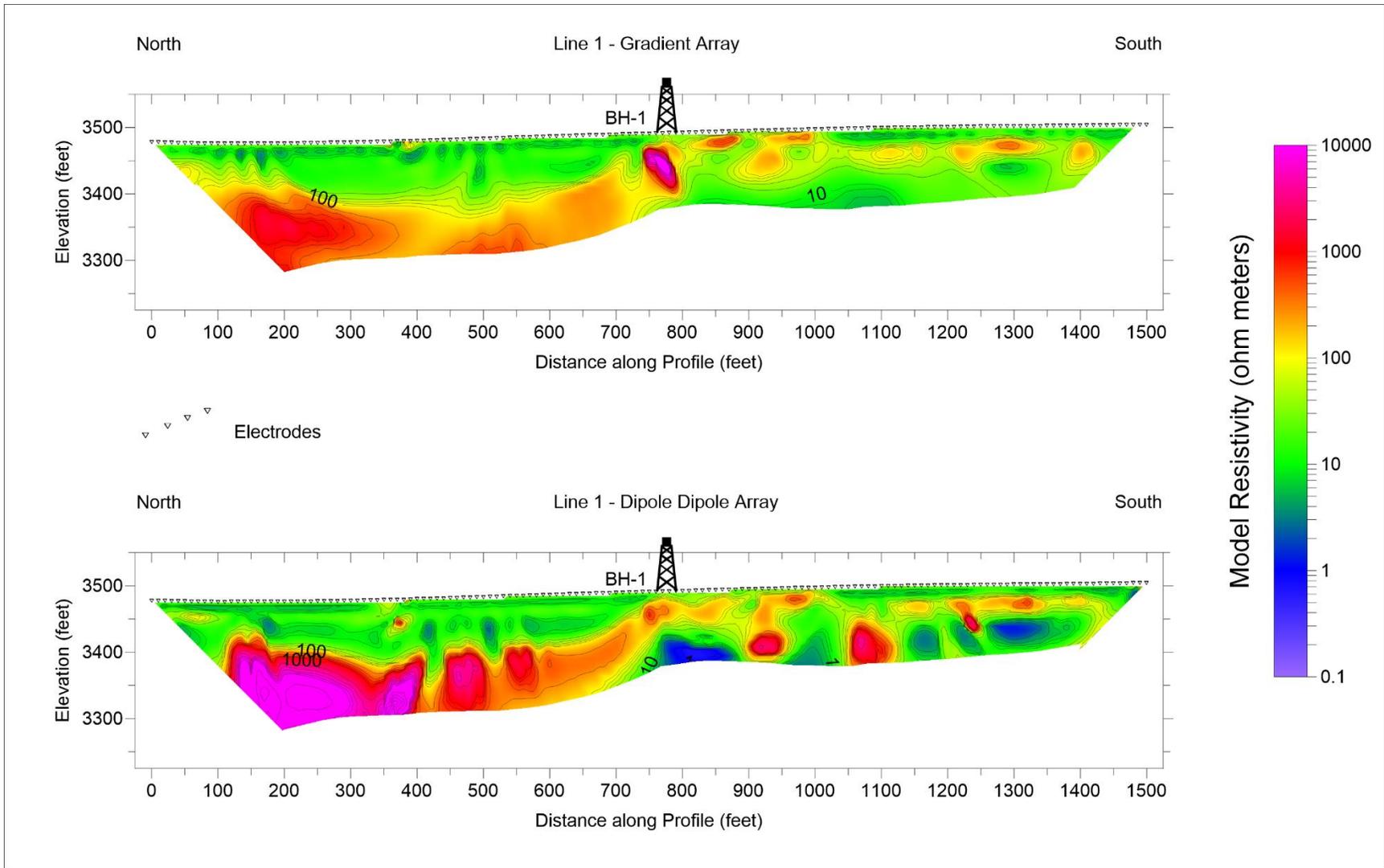


Figure 2 Line 1 Electrical Resistivity Tomography Models

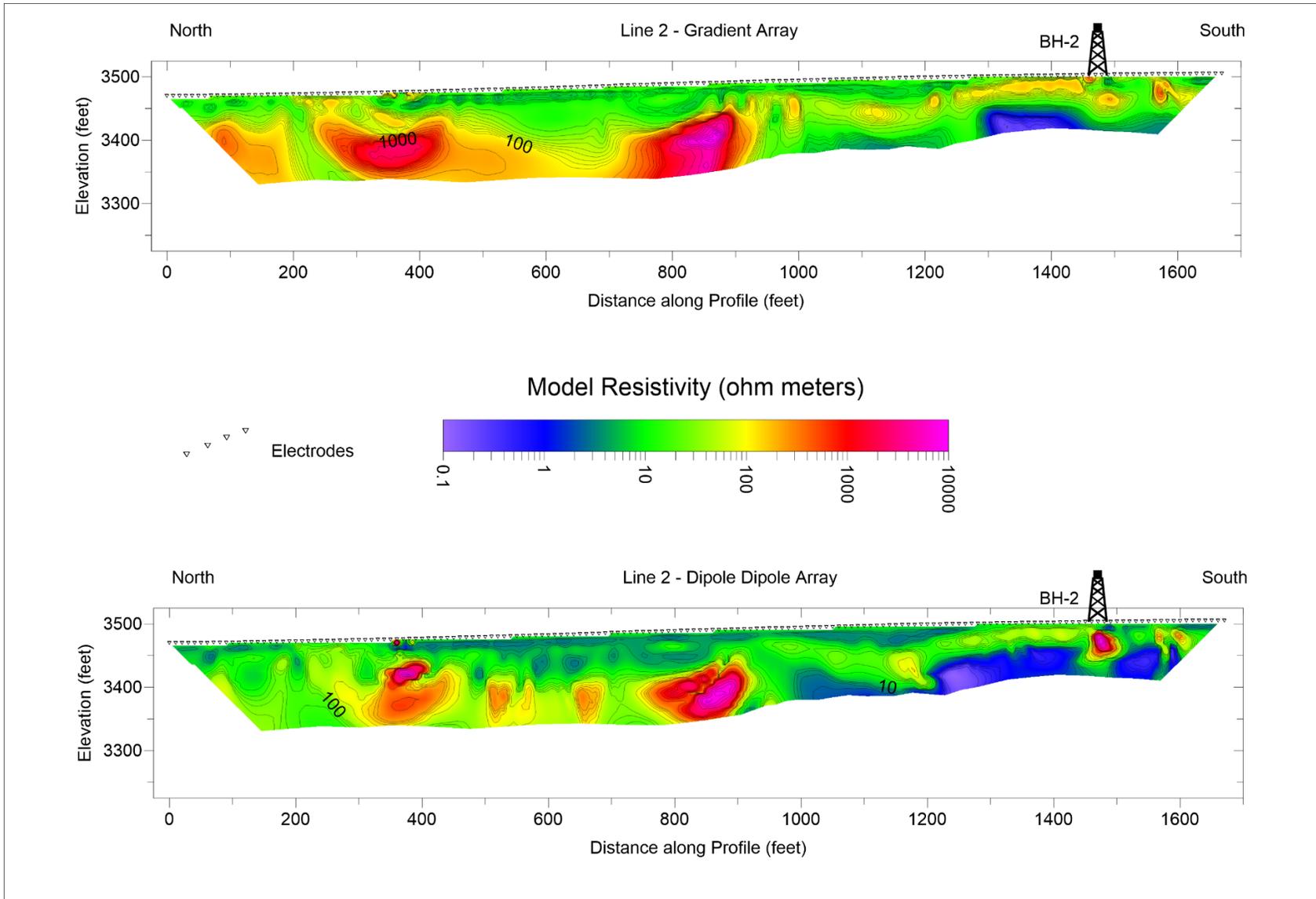


Figure 3 Line 2 Electrical Resistivity Tomography Models

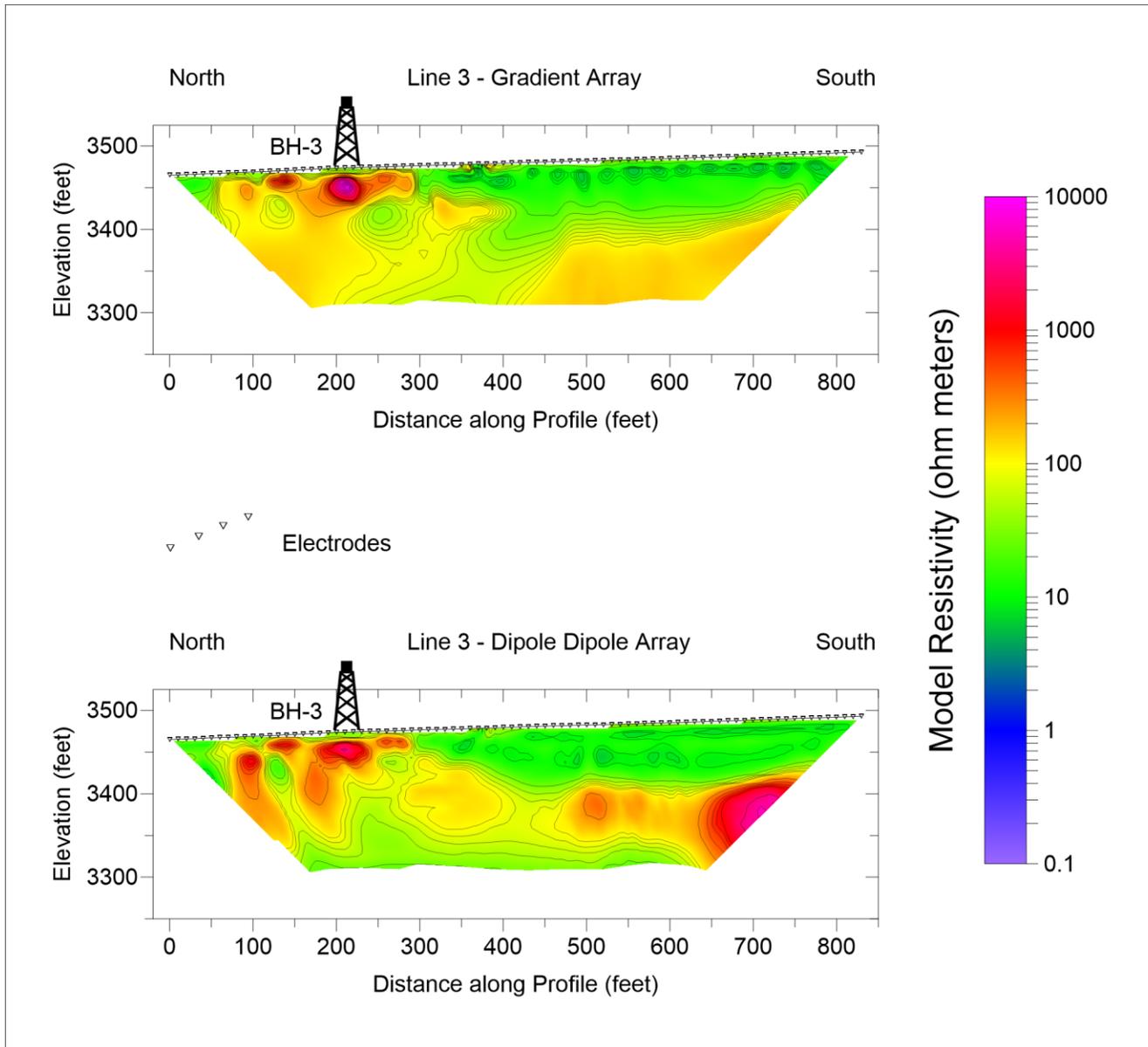


Figure 4 Line 3 Electrical Resistivity Tomography Models

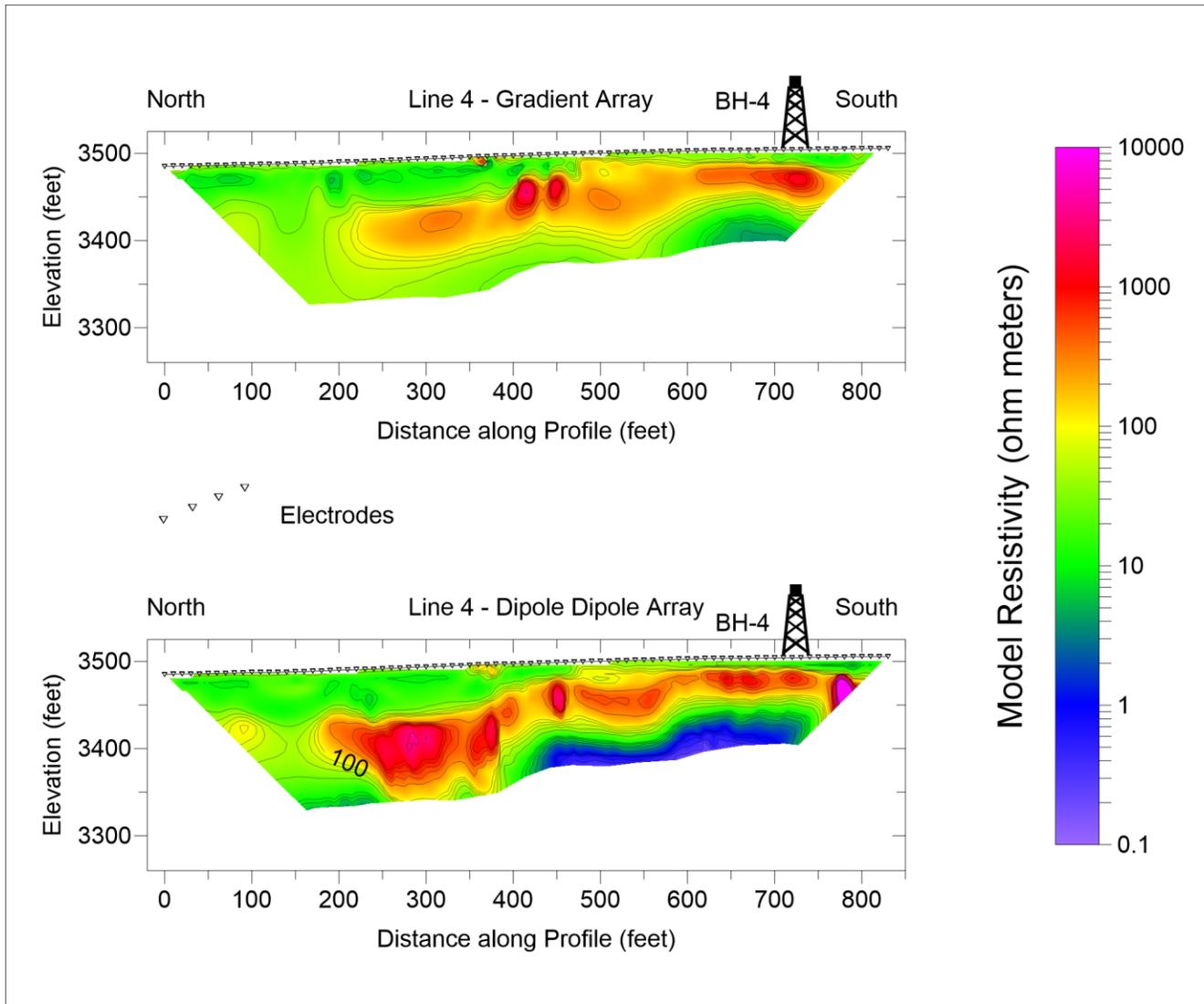


Figure 5 Line 4 Electrical Resistivity Tomography Models

Appendix B

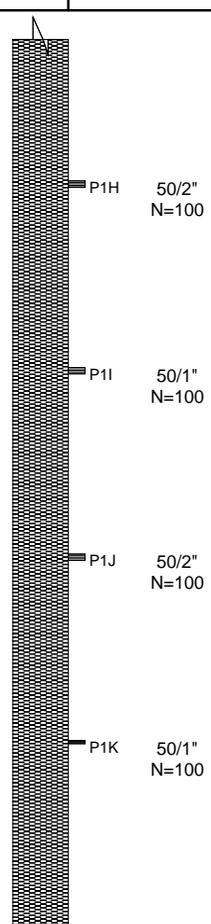
Borehole Logs

PROJECT: I-90 ERT at Hideaway Hills	GEOLOGIC LOG OF BOREHOLE 1  605-342-4105 3700 Sturgis Road Rapid City, SD 57702 fmgengineering.com	BORING LOCATION: Line 1 West ROW -- N1102102, E133401 GROUND ELEVATION: 3491.4 DATUM: FMG Survey BORING DIAMETER: 5" COLLAPSE DEPTH: No Collapse FILL DEPTH: No Fill Observed
LOCATION: Blackhawk, SD PROJECT #: 200870.00 DATE STARTED: 6/11/2020 COMP.: 6/11/2020 CONTRACTOR: FMG, Inc DRILL METHOD: Solid Stem Auger/Mobile B57		

ELEVATION / DEPTH	WATER	GEOLOGY GRAPHIC	Sample Info Type, #/Blows	USCS	DESCRIPTION	NM %	DD (pcf)	LL (%)	PI (%)	Qu (psf)	phi (deg)	Swell (%) (ksf)
0		Topsoil Residual Soil		TOPS	Topsoil, Approx. 4" in Thickness							
3490		Gypsum		CL	Lean Clay, Brown, Moist, Low to Medium Plasticity, Stiff.							
5			P1A 50/1" N=100		Gypsum, White, Dry, Very Hard.							
3485												
10			P1B 50/2" N=100	ML		7.0	17	1				
3480												
15			P1C 50/1" N=100									
3475												
20			P1D 50/3" N=100		-- Approximate top of anomaly in ERT model.							
3470		Spearfish FM		SILTS	Siltstone: Red to Pale Red, Fine Grained, Moderately Hard to Hard, Minor Gypsum Veins Throughout.							
25			P1E 50/1" N=100									
3465												
30			P1F 50/2" N=100									
3460												
35			P1G 50/4" N=100									

SEE ATTACHED KEY FOR ABBREVIATIONS, NOTES & DESCRIPTIONS

PROJECT: I-90 ERT at Hideaway Hills	GEOLOGIC LOG OF BOREHOLE 1  <small>605-342-4105 3700 Sturgis Road Rapid City, SD 57702 fmgengineering.com</small>	BORING LOCATION: Line 1 West ROW -- N1102102, E133401 GROUND ELEVATION: 3491.4 DATUM: FMG Survey BORING DIAMETER: 5" COLLAPSE DEPTH: No Collapse FILL DEPTH: No Fill Observed
LOCATION: Blackhawk, SD PROJECT #: 200870.00 DATE STARTED: 6/11/2020 COMP.: 6/11/2020 CONTRACTOR: FMG, Inc DRILL METHOD: Solid Stem Auger/Mobile B57		

ELEVATION / DEPTH	WATER	GEOLOGY GRAPHIC	Sample Info Type,#/Blows	USCS	DESCRIPTION	NM %	DD (pcf)	LL (%)	PI (%)	Qu (psf)	phi (deg)	Swell (%) (ksf)
3455												
40			P1H	50/2" N=100		- Minor Gypsum Veins.						
3450												
45			P1I	50/1" N=100								
3445												
50		P1J	50/2" N=100									
3440												
55		P1K	50/1" N=100									
3435												
60		P1L	50/1" N=100		- End of Borehole at 60Ft. No groundwater encountered during drilling.							
3430												
65												
3425												
70												
3420												

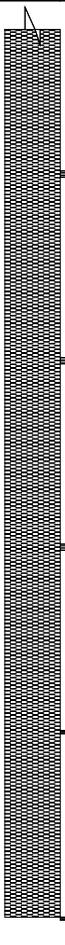
SEE ATTACHED KEY FOR ABBREVIATIONS, NOTES & DESCRIPTIONS

PROJECT: I-90 ERT at Hideaway Hills	GEOLOGIC LOG OF BOREHOLE 2  <small>605-342-4105 3700 Sturgis Road Rapid City, SD 57702 fmgenengineering.com</small>	BORING LOCATION: Line 2 Median -- N1102393, E132929 GROUND ELEVATION: 3503.2 DATUM: FMG Survey BORING DIAMETER: 5" COLLAPSE DEPTH: No Collapse FILL DEPTH: No Fill Observed
LOCATION: Blackhawk, SD PROJECT #: 200870.00 DATE STARTED: 6/11/2020 COMP.: 6/11/2020 CONTRACTOR: FMG, Inc DRILL METHOD: Solid Stem Auger/Mobile B57		

ELEVATION / DEPTH	WATER	GEOLOGY GRAPHIC	Sample Info Type,#/Blows	USCS	DESCRIPTION	NM %	DD (pcf)	LL (%)	PI (%)	Qu (psf)	phi (deg)	Swell (%) (ksf)
0		Topsoil Fill		TOPS	Topsoil, Approx. 3" in Thickness							
3500		Residual Soil		CL	Lean Clay with Gravel, Brown, Moist, Low to Medium Plasticity, Stiff.							
5			P2A 13/12/15 N=27	SM	Silty Sand, Pale Brown, Fine, Moist, Non Plastic.							
3495												
10			P2B 12/14/14 N=28	SM	Silty Sand, Pale Brown to Light Gray, Fine, Moist, Non Plastic.	11		NV	NP			
3490		Spearfish FM		SILTS	Siltstone: Gray, Fine Grained, Moderately Hard to Hard, Minor Gypsum Veins Throughout.							
15			P2C 50/1" N=100	SILTS	Siltstone: Red to Pale Red, Fine Grained, Moderately Hard to Hard, Minor Gypsum Veins Throughout.							
3485					-- Approximate top of anomaly in ERT model.							
20			P2D 50/2" N=100									
3480												
25			P2E 50/2" N=100									
3475												
30			P2F 50/3" N=100									
3470												
35			P2G 50/2" N=100									

SEE ATTACHED KEY FOR ABBREVIATIONS, NOTES & DESCRIPTIONS

PROJECT: I-90 ERT at Hideaway Hills	GEOLOGIC LOG OF BOREHOLE 2  <small>605-342-4105 3700 Sturgis Road Rapid City, SD 57702 fmgengineering.com</small>	BORING LOCATION: <u>Line 2</u> <u>Median -- N1102393, E132929</u> GROUND ELEVATION: <u>3503.2</u> DATUM: <u>FMG Survey</u> BORING DIAMETER: <u>5"</u> COLLAPSE DEPTH: <u>No Collapse</u> FILL DEPTH: <u>No Fill Observed</u>
LOCATION: <u>Blackhawk, SD</u> PROJECT #: <u>200870.00</u> DATE STARTED: <u>6/11/2020</u> COMP.: <u>6/11/2020</u> CONTRACTOR: <u>FMG, Inc</u> DRILL METHOD: <u>Solid Stem Auger/Mobile B57</u>		

ELEVATION / DEPTH	WATER	GEOLOGY GRAPHIC	Sample Info Type,#/Blows	USCS	DESCRIPTION	NM %	DD (pcf)	LL (%)	PI (%)	Qu (psf)	phi (deg)	Swell (%) (ksf)
3465			P2H 50/4" N=100		- Minor Gypsum Veins.							
40			P2I 50/1" N=100									
3460			P2J 50/1" N=100									
45			P2K 50/1" N=100									
3455			P2L 50/1" N=100									
50												
3450												
55												
3445												
60						- End of Borehole at 60Ft. No groundwater encountered during drilling.						
3440												
65												
3435												
70												

SEE ATTACHED KEY FOR ABBREVIATIONS, NOTES & DESCRIPTIONS

PROJECT: I-90 ERT at Hideaway Hills	GEOLOGIC LOG OF BOREHOLE 3  <small>605-342-4105 3700 Sturgis Road Rapid City, SD 57702 fmgengineering.com</small>	BORING LOCATION: Line 3 W. Bound Off Ramp -- N1102151, GROUND ELEVATION: 3473.9 DATUM: FMG Survey BORING DIAMETER: 5" COLLAPSE DEPTH: No Collapse FILL DEPTH: No Fill Observed
LOCATION: Blackhawk, SD PROJECT #: 200870.00 DATE STARTED: 6/12/2020 COMP.: 6/12/2020 CONTRACTOR: FMG, Inc DRILL METHOD: Solid Stem Auger/Mobile B57		

ELEVATION / DEPTH	WATER	GEOLOGY GRAPHIC	Sample Info Type,#/Blows	USCS	DESCRIPTION	NM %	DD (pcf)	LL (%)	PI (%)	Qu (psf)	phi (deg)	Swell (%) (ksf)
0		Topsoil Fill		TOPS	Topsoil, Approx. 4" in Thickness							
		Sundance FM		CL	Lean Clay with Gravel, Brown, Moist, Low to Medium Plasticity, Stiff.							
3470		Gypsum		SHALE	Shale: Pale Brown, Fine Grained, Moderately Hard.							
5		P3A	50/2" N=100									
3465		P3B	50/1" N=100		Gypsum, White, Dry, Very Hard.							
10		P3C	50/4" N=100									
3460		P3D	50/3" N=100									
15		Spearfish FM		SILTS	Siltstone: Red to Pale Red, Fine Grained, Moderately Hard to Hard, Minor Gypsum Veins Throughout.							
20		P3E	50/3" N=100									
3450		P3F	50/3" N=100	CL	Siltstone: Red to Pale Red, Fine Grained.	4.0		35	20			
25		P3G	50/1" N=100		- Minor Gypsum Veins.							
3445												
30												
3440												
35												

SEE ATTACHED KEY FOR ABBREVIATIONS, NOTES & DESCRIPTIONS

PROJECT: I-90 ERT at Hideaway Hills	GEOLOGIC LOG OF BOREHOLE 3  <small>605-342-4105 3700 Sturgis Road Rapid City, SD 57702 fmgengineering.com</small>	BORING LOCATION: <u>Line 3</u> <u>W. Bound Off Ramp -- N1102151,</u> GROUND ELEVATION: <u>3473.9</u> DATUM: <u>FMG Survey</u> BORING DIAMETER: <u>5"</u> COLLAPSE DEPTH: <u>No Collapse</u> FILL DEPTH: <u>No Fill Observed</u>
LOCATION: <u>Blackhawk, SD</u> PROJECT #: <u>200870.00</u> DATE STARTED: <u>6/12/2020</u> COMP.: <u>6/12/2020</u> CONTRACTOR: <u>FMG, Inc</u> DRILL METHOD: <u>Solid Stem Auger/Mobile B57</u>		

ELEVATION / DEPTH	WATER	GEOLOGY GRAPHIC	Sample Info Type,#/Blows	USCS	DESCRIPTION	NM %	DD (pcf)	LL (%)	PI (%)	Qu (psf)	phi (deg)	Swell (%) (ksf)
3435			P3H	50/3" N=100								
3430	40		P3I	50/1" N=100								
3425	45		P3J	50/1" N=100								
3420	50		P3K	50/1" N=100								
3415	55		P3L	50/1" N=100		- End of Borehole at 60Ft. No groundwater encountered during drilling.						
3410	60											
3405	65											
3405	70											

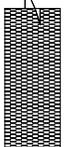
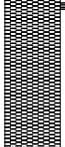
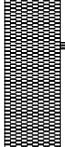
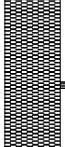
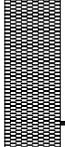
SEE ATTACHED KEY FOR ABBREVIATIONS, NOTES & DESCRIPTIONS

PROJECT: I-90 ERT at Hideaway Hills	GEOLOGIC LOG OF BOREHOLE 4  605-342-4105 3700 Sturgis Road Rapid City, SD 57702 fmgengineering.com	BORING LOCATION: Line 4 East ROW -- N1102563, E132795 GROUND ELEVATION: 3504.2 DATUM: FMG Survey BORING DIAMETER: 5" COLLAPSE DEPTH: No Collapse FILL DEPTH: No Fill Observed
LOCATION: Blackhawk, SD PROJECT #: 200870.00 DATE STARTED: 6/12/2020 COMP.: 6/12/2020 CONTRACTOR: FMG, Inc DRILL METHOD: Solid Stem Auger/Mobile B57		

ELEVATION / DEPTH	WATER	GEOLOGY GRAPHIC	Sample Info Type,#/Blows	USCS	DESCRIPTION	NM %	DD (pcf)	LL (%)	PI (%)	Qu (psf)	phi (deg)	Swell (%) (ksf)
0		Topsoil Residual Soil		TOPS CL	Topsoil, Approx. 4" in Thickness Silty Lean Clay, Brown, Moist to Dry, Low to Medium Plasticity, Stiff.							
3500		Sundance Fm	P4A 17/19/37 N=56	WS CL	Weathered Shale: Brown to Greenish Brown, Fine Grained, Moderately Hard to Hard. Weathered Shale/Siltstone: Lean Clay, Greenish Brown to Reddish Brown, Laminated.	8.0		32	14			
3495		Gypsum	P4B 50/1" N=100		Gypsum, White, Dry, Very Hard.							
3490			P4C 50/3" N=100									
3485			P4D 50/2" N=100		-- Approximate top of anomaly in ERT model.							
3480			P4E 50/3" N=100									
3475		Spearfish Fm	P4F 50/2" N=100	SILTS	Siltstone: Red to Pale Red, Fine Grained, Moderately Hard to Hard, Minor Gypsum Veins Throughout.							
3470			P4G 50/2" N=100									

SEE ATTACHED KEY FOR ABBREVIATIONS, NOTES & DESCRIPTIONS

PROJECT: I-90 ERT at Hideaway Hills	GEOLOGIC LOG OF BOREHOLE 4  <small>605-342-4105 3700 Sturgis Road Rapid City, SD 57702 fmgengineering.com</small>	BORING LOCATION: <u>Line 4</u> <u>East ROW -- N1102563, E132795</u> GROUND ELEVATION: <u>3504.2</u> DATUM: <u>FMG Survey</u> BORING DIAMETER: <u>5"</u> COLLAPSE DEPTH: <u>No Collapse</u> FILL DEPTH: <u>No Fill Observed</u>
LOCATION: <u>Blackhawk, SD</u> PROJECT #: <u>200870.00</u> DATE STARTED: <u>6/12/2020</u> COMP.: <u>6/12/2020</u> CONTRACTOR: <u>FMG, Inc</u> DRILL METHOD: <u>Solid Stem Auger/Mobile B57</u>		

ELEVATION / DEPTH	WATER	GEOLOGY GRAPHIC	Sample Info Type,#/Blows	USCS	DESCRIPTION	NM %	DD (pcf)	LL (%)	PI (%)	Qu (psf)	phi (deg)	Swell (%) (ksf)
3465 40			P4H 50/2" N=100		- Minor Gypsum Veins.							
3460 45			P4I 50/3" N=100									
3455 50			P4J 50/1" N=100									
3450 55			P4K 50/1" N=100									
3445 60			P4L 50/1" N=100		- End of Borehole at 60Ft. No groundwater encountered during drilling.							
3440 65												
3435 70												

SEE ATTACHED KEY FOR ABBREVIATIONS, NOTES & DESCRIPTIONS

KEY TO SYMBOLS

Symbol Description

Strata Symbols



Topsoil



Low plasticity clay



Gypsum



Siltstone

Symbol Description



Fill



Silty sand



Shale



Weathered Shale

Notes:

1. The exploratory borings were drilled on the dates presented on the geologic logs. Please refer to the attached Soils Classification System Chart (Figure 2) for more detailed explanations on the soils and their properties.
2. The geologic logs of the boreholes and related information depict only the conditions and materials encountered at the specific boring location and at the particular time designated on the logs. Soil conditions at other locations will vary from those indicated at each specific boring or sampling location. The given depths of material changes and the sample depths are approximate. Variations will occur.
3. These Logs are subject to the limitations, conclusions and recommendations provided in this report.
4. The numbers adjacent to the SPT sample locations are the blow/interval and represent the number of blows required to drive the 1" I.D. split spoon sampler the given distance into the soil with a 140# automatic hammer that drops 30". The SPT test is performed to a length of 18". The N Value for each given SPT is the number of blows required to drive the 1" I.D. sampler into the last 12".
5. Cobbles, boulders and other large objects generally cannot be recovered from borings, and they may be present in the subsurface even if not noted on the Logs.
6. The topsoil thicknesses indicated on the Logs are for general informational purposes only, and are based on general transistions and very limited sampling points, and should not be used to calculate topsoil stripping depths or volumes. Significant variations in topsoil thickness will occur throughout the project.
7. The ground elevations noted on the logs are approximate, and should only be used for general reference.

The results of some tests conducted on samples recovered are reported on the Logs. Abbreviations used are:

- NM = Natural Moisture Content of the Soil (%)
- DD = Dry Density of the Soil (pcf)
- LL = Atterburg Liquid Limit of the Soil (%)
- PI = Atterburg Plasticity Index of the Soil (%)
- phi = Internal Angle of Friction (degrees)
- Qu = Unconfined Compressive Strength (psf)
- Swell % = Percent Swell Against 100psf Surcharge Upon Saturation (%)
- Swell Press = Maximum Swell Pressure (ksf)

KEY TO SYMBOLS

Symbol Description

Misc. Symbols

 Boring continues

Soil Samplers

 Standard Penetration Test Sample

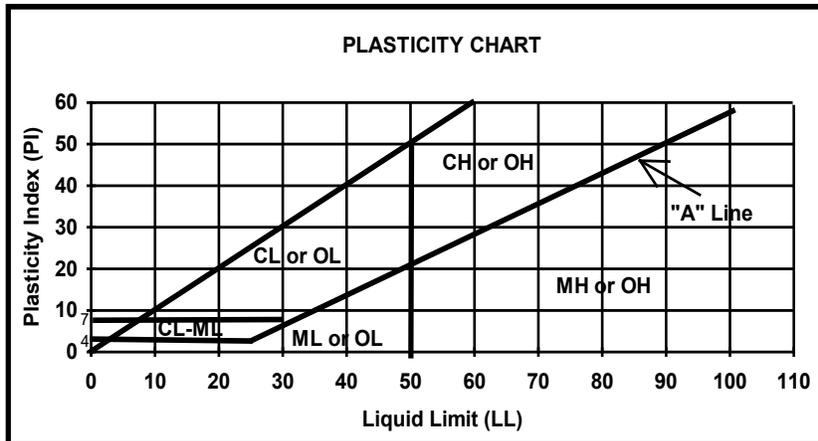
CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES

ASTM Designation: D 2487-90 and D 2488-90 (Unified Soil Classification System)

Soil Classification				Group Symbol Name	
Criteria for Assigning Group Symbols and Group Names ^A					
COARSE-GRAINED SOILS More than 50% retained on the No. 200 sieve	Gravels More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines ^C	$Cu \geq 4$ and $1 \leq Cc \leq 3^E$ $Cu < 4$ and/or $1 > Cc > 3^E$	GW	Well-Graded Gravel ^F
		Gravels with Fines More than 12% fines ^C	Fines classify as ML or MH Fines classify as CL or CH	GM	Silty Gravel ^{F,G,H}
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines ^D	$Cu \geq 6$ and $1 \leq Cc \leq 3^E$ $Cu < 6$ and/or $1 > Cc > 3^E$	SW	Well-Graded Sand ^I
		Sands with Fines More than 12% fines ^D	Fines classify as ML or MH Fines classify as CL or CH	SM	Silty Sand ^{G,H,J}
				SP	Poorly Graded Sand ^I
				SC	Clayey Sand ^{G,H,I}
FINE-GRAINED SOILS 50% or more passes the No. 200 sieve	Silts and Clays Liquid limit less than 50	inorganic soils	$PI > 7$ and on or above "A" line ^J $PI < 4$ or plots below "A" line ^J	CL	Lean Clay ^{K,L,M}
		organic soils	Liquid limit-oven dried -----<.75	OL	Organic Clay ^{K,L,M,N}
			Liquid limit-not dried		Organic Silt ^{K,L,M,O}
	Silts and Clays Liquid limit 50 or more	inorganic soils	PI plots on or above "A" line PI plots below "A" line	CH	Fat Clay ^{K,L,M}
		organic soils	Liquid limit-oven dried -----<.75	OH	Organic Clay ^{K,L,M,P}
			Liquid limit-not dried		Organic Silt ^{K,L,M,Q}
HIGHLY ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor			PT	Peat

- A. Based on the material passing the 3-in. (75-mm) sieve.
 B. If field sample contained cobbles or boulders, or both, add "with cobbles and boulders, or both" to group name.
 C. Gravels with 5% to 12% fines require dual symbols:
 GW-GM well-graded gravel with silt
 GW-GC well-graded gravel with clay
 GP-GM poorly graded gravel with silt
 GP-GC poorly graded gravel with clay
 D. Sands with 5% to 12% fines require dual symbols:
 SW-SM well-graded sand with silt
 SW-SC well-graded sand with clay
 SP-SM poorly graded sand with silt
 SP-SC poorly graded sand with clay
 E. $Cu = D_{60}/D_{10}$ $Cc = (D_{30})^2/D_{10} \times D_{60}$
 F. If soil contains $\geq 15\%$ sand, add "with sand" to group name.

- G. If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM
 H. If fines are organic, add "with organic fines" to group name.
 I. If soil contains $\geq 15\%$ gravel, add "with gravel" to group name.
 J. If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.
 K. If soil contains 15% to 29% plus No. 200, add "with sand" or "with gravel," whichever is predominant.
 L. If soil contains $\geq 30\%$ plus No. 200, predominantly sand, add "sandy" to group name.
 M. If soil contains $\geq 30\%$ plus No. 200, predominantly gravel, add "gravelly" to group name.
 N. $PI \geq 4$ and plots on or above "A" line.
 O. $PI < 4$ or plots below "A" line.
 P. PI plots on or above "A" line.
 Q. PI plots below "A" line.



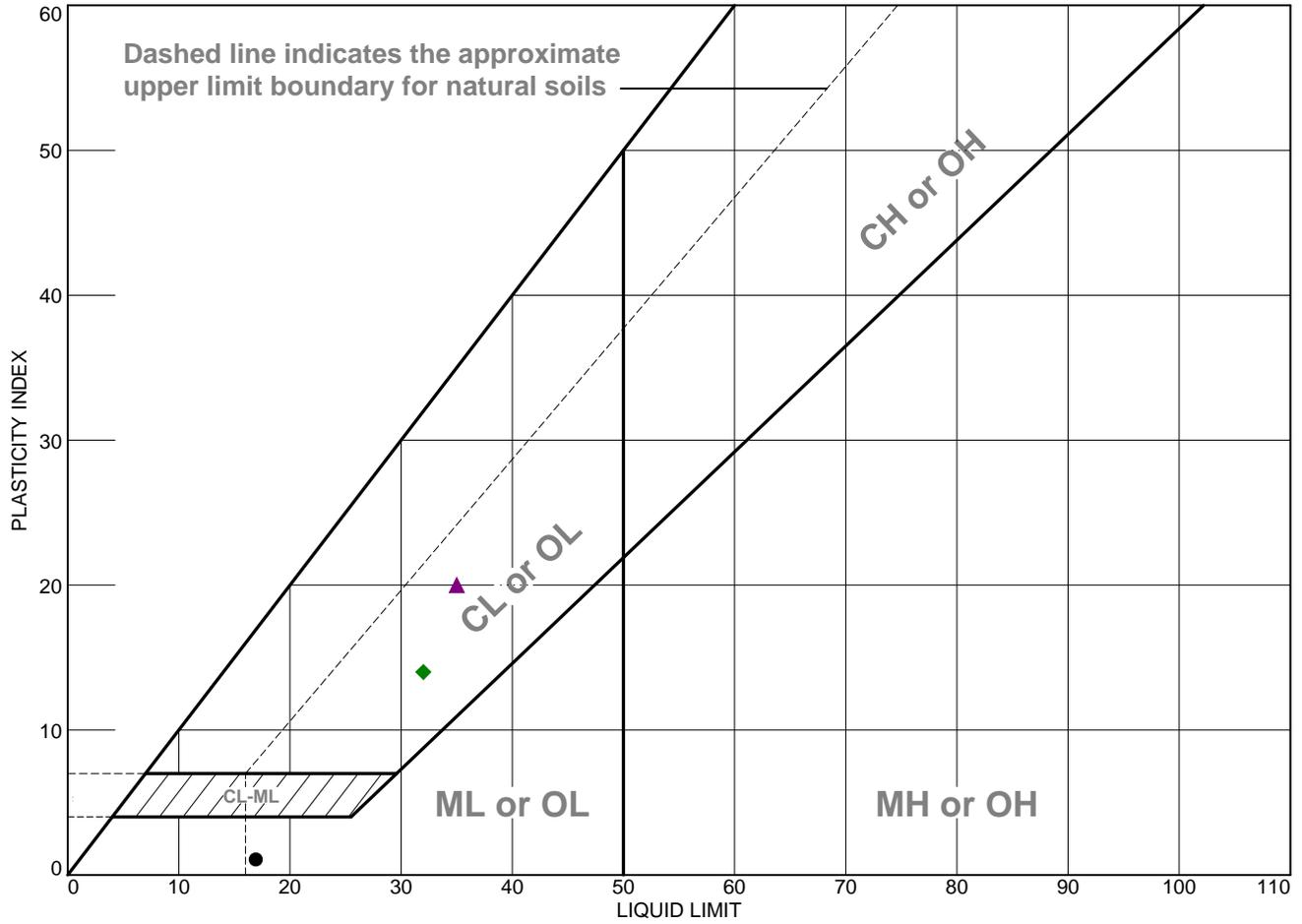
Equation of "A" - line: Horizontal at $PI = 4$ to $LL = 25.5$, then $PI = 0.73(LL - 25.5)$ (Chart is for general graphic presentation purposes only)

- Figure 2-

Appendix C

Laboratory Testing

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Gypsum, White, Dry, Very Hard.	17	16	1	94	85	ML
■	Silty Sand, Pale Brown to Light Gray, Fine, Moist, Non Plastic.	NV	NP	NP	100	45	SM
▲	Siltstone: Red to Pale Red, Fine Grained.	35	15	20	99	95	CL
◆	Weathered Shale/Siltstone: Lean Clay, Greenish Brown to Reddish Brown, Laminated.	32	18	14	100	96	CL

Project No. 200870.00 **Client:** SDDOT
Project: I-90 ERT at Hideaway Hills

● **Source of Sample:** 1 **Depth:** 10 **Sample Number:** P1B
■ **Source of Sample:** 2 **Depth:** 10 **Sample Number:** P2B
▲ **Source of Sample:** 3 **Depth:** 25 **Sample Number:** P3E
◆ **Source of Sample:** 4 **Depth:** 5 **Sample Number:** P4A

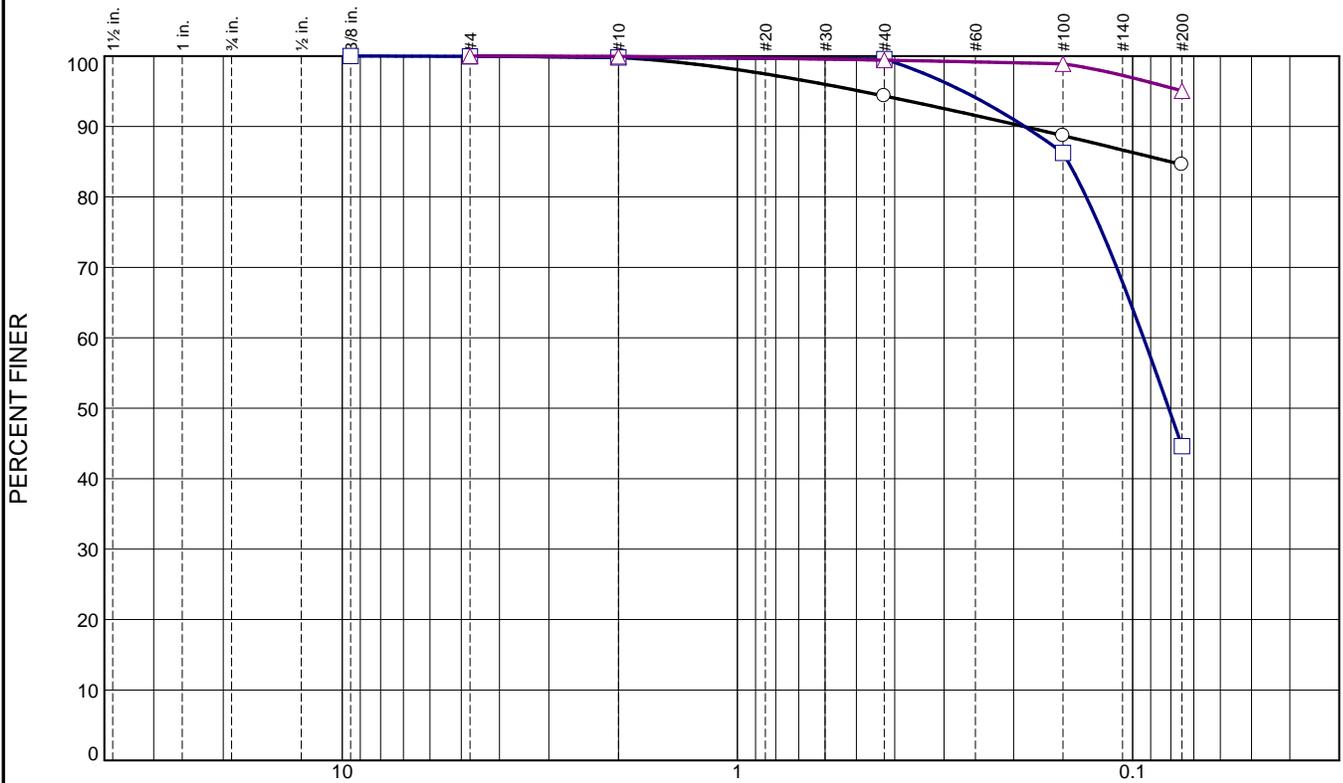
Remarks:

Figure

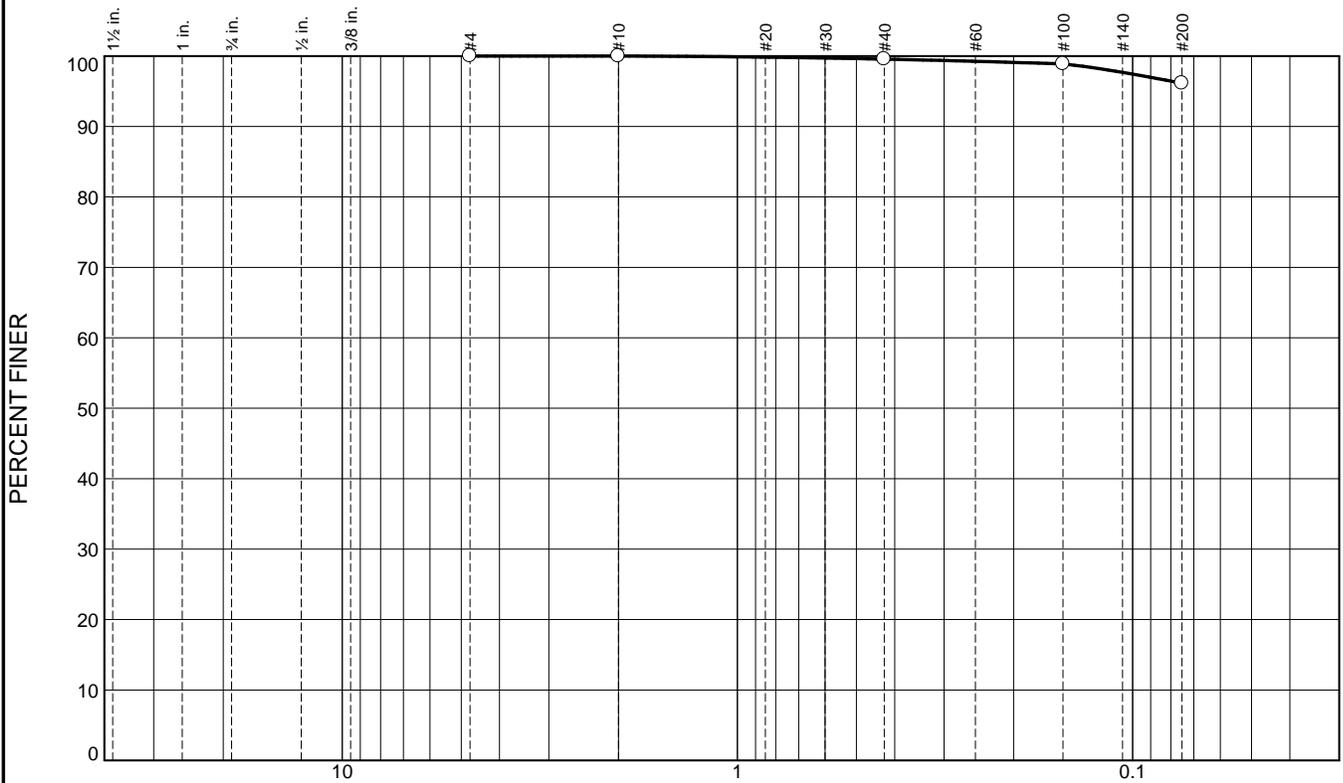


FMG, Inc.

Particle Size Distribution Report



Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	AASHTO	PL	LL
○	0	0	4	96		CL	A-6(13)	18	32

SIEVE inches size	PERCENT FINER		
○			
GRAIN SIZE			
D ₆₀			
D ₃₀			
D ₁₀			
COEFFICIENTS			
C _c			
C _u			

SIEVE number size	PERCENT FINER		
○			
#4	100		
#10	100		
#40	100		
#100	99		
#200	96		

Material Description
 ○ Weathered Shale/Siltstone: Lean Clay, Greenish Brown to Reddish Brown, Laminated.

REMARKS:
 ○

○ Source of Sample: 4 Depth: 5 Sample Number: P4A

Appendix D

References

Lisenbee, A.L., and Hargrave, R.G., 2005, Geologic map of the Blackhawk quadrangle, South Dakota: South Dakota Geological Survey, Geologic Quadrangle Map GQ24K-05, scale 1:24,000

Paha Sapa Grotto, 2020, Mine Workings Map, Hideaway Mine, Meade County, SD

Paha Sapa Grotto, 2020, Hideaway Mine Research Data, Mapping and Images