RESISTIVITY STUDY FOR THE PROPOSED DEVELOPMENT ON CLAY STREET

Blacksburg, Virginia

PREPARED FOR:

Matt Chamberlain
Blacksburg, LLC
510 Floyd St
Blacksburg, VA 24060

September 20, 2018

Draper Aden Associates
Engineering • Surveying • Environmental Services

DAA Project Number: **18010224-010203**

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September 20, 2018

Matt Chamberlain
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510 Floyd St
Blacksburg, VA 24060

RE: Resistivity Study for the Proposed Development on Clay Street, Blacksburg, Virginia

Dear Mr. Chamberlain,

Draper Aden Associates has completed the geophysical study for your proposed development on Clay Street in Blacksburg, Virginia. The objective of this study was to provide subsurface geologic information regarding depth to bedrock and potential karst formation beneath the site. The following report documents our methodologies and findings.

We value our professional relationship with Blacksburg, LLC., and hope that you will contact us with any similar needs in the future. If you have any questions regarding this report, or if we can be of any further service to you please do not hesitate to contact us.

Sincerely,

Johanna Vaughan, G.I.T.
Geologist

<u>3RD PARTY REVIEW</u>

This report has been subjected to technical and quality reviews by:

Warren T. "Ted" Dean, PG Geophysical Services Team Leader	9/20/2018 Date
Christopher Printz, PG Senior Project Geologist	9/20/2017 Date

FIGURES

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

Draper Aden Associates (DAA) was retained by Blacksburg, LLC to conduct an electrical resistivity imaging study for a proposed development project on Clay Street in Blacksburg, Virginia. The objective of this study was to provide subsurface geologic information with regard to karst formation and depth to bedrock beneath the site.

The site is underlain by carbonate bedrock of the Knox Group, which is comprised of massive, thick bedded dolomite with 1 to 6 foot thick chert interbeds. The bedrock strata beneath the site are likely to dip gently to the east. No discernible karst features were observed at the site. However, “karst terrane” is indicated on the geologic map approximately 1,700 feet northwest of the site, where numerous dolines are present at the ground surface.

The resistivity data suggest an irregular bedrock surface as is common in karstified carbonate bedrock, with the interpreted depth to bedrock ranging from the near surface to approximately 28 feet. The interpreted bedrock surface ranges in elevation from approximately 2,212 to 2,266 feet. The contour models at the end of this report illustrate the lateral variations in the interpreted bedrock surface elevation and depth to bedrock.

The resistivity data also suggest a low to moderate degree of karstification of the bedrock beneath the site. A pair of isolated high-resistivity zones are observed beneath electrodes 2-17 and 4-42 that may represent air-filled voids within the bedrock zone. However, no discernible pathways are observed which would allow surface soils to ravel downward into the deeper possible air-filled voids.

A possible soil-filled void is observed beneath electrodes 1-26 and 1-27. On either side of this feature (beneath electrodes 1-23 and 1-29), possible solutionally-enlarged pathways are observed which may allow soils to ravel downward toward the possible soil-filled void. Similarly, possible solutionally-enlarged pathways into the bedrock are observed beneath electrodes 3-6 and 3-17, although no anomalies indicative of possible soil- or air-filled voids are observed beneath them.

To further characterize these anomalous areas and to verify the depth to bedrock at select locations, we recommend a series of eight soil borings. These borings should be drilled to a depth of 25 feet or until auger refusal is encountered, whichever occurs first. For evaluation of the possible karst anomalies, we recommend drilling at electrode locations 1-23, 1-29, 3-6, and 3-17. For the purpose of verifying the depth to bedrock, we recommend drilling at electrode locations 1-14, 1-27.5, 8-7, and 8-20. The estimated depth to rock based on the resistivity interpretations at each of these locations can be seen in the final figure at the end of this report.

2.0 INTRODUCTION

Draper Aden Associates (DAA) was retained by Blacksburg, LLC to conduct an electrical resistivity imaging study for a proposed development project on Clay Street in Blacksburg, Virginia. The site is located just west of the intersection of Clay Street and Cherry Lane (Figure 1). The objective of this study was to provide subsurface geologic information with regard to karst formation and depth to bedrock beneath the site. The topography of the site and layout of the proposed building are illustrated in Figure 2.

The tasks involved in this study included:

1. Researching published geologic maps or other available literature;
2. Collection, processing, and interpretation of electrical resistivity imaging data;
3. Preparation of this document to detail theory, methods and findings.

3.0 SITE GEOLOGY

The site lies within the Valley and Ridge Province, which is characterized by highly folded and faulted sedimentary rocks. The site is mapped as being underlain by the Knox Group, which is described as light to medium gray, massive, thick bedded, fine to medium-grained dolomite with 1 to 6 foot thick chert interbeds (Bartholomew, M.J., & Lowry, W.D., 1979). Nearby strike-and-dip symbols on the geologic map suggest that the bedrock strata beneath the site strike northwest-southeast, and likely dip gently to the east (Figure 3).

Limestone and dolomite rocks are susceptible to karst formation. Carbonate rocks are more susceptible to dissolution than other rock types because of the chemical reaction of the carbonates to slightly acidic rainwater. The dissolution takes place primarily along bedding planes and joints as water percolates through those features. As the carbonates dissolve, the percolating water carries away the soluble components and leaves behind the insoluble clay minerals and silicates, and in the process enlarging the spaces through which the water flowed. The remaining soils are often plastic clayey soils and may be soft and compressible.

The continued dissolution of carbonate rocks can sometimes result in open cavities in the rock. Numerous commercial caverns throughout the eastern United States are good examples of large-scale dissolution of carbonates. As these cavities grow, the overlying soils are susceptible to raveling into the underlying cavities, carried downward by the percolating water and the influence of gravity. As the surface soils ravel, the ground surface can subside and result in the gradual formation of closed depressions referred to as dolines or sinkholes. This type of sinkhole is known as a cover-subsidence sinkhole and is usually characterized by imperceptible growth and therefore these types of sinkholes are often covered by vegetation in undeveloped areas.

Where the soils are very stiff with high tensile strength, raveling at depth can occur beneath surface soils that bridge over the growing soil cavity. Continued raveling enlarges the cavity until it eventually grows to the point where the soils become too thin to maintain the bridge, resulting in a sudden collapse of the surface soils. This type of sinkhole is known as a cover collapse sinkhole. These sinkholes tend to be less common than the cover subsidence type. No obvious cover collapse features, closed topographic depressions, springs, or disappearing streams were observed during field activities that would be indicators of strong karstification at the site. However, “karst terrane” is indicated on the geologic map approximately 1,700 feet northwest of the site, where numerous dolines are present at the ground surface.

4.0 ELECTRICAL RESISTIVITY IMAGING

To provide cross-sectional imaging of the subsurface beneath the site, two-dimensional surface resistivity imaging methods were employed. Resistivity imaging provides cross-sectional images of the resistance of subsurface materials to electric current, from which geologic conditions can be inferred. Electrical resistivity is a fundamental parameter describing how easily a material can transmit electrical current. High values of resistivity imply that the material is very resistant to the flow of electricity; low values of resistivity imply that the material transmits electrical current very easily.

4.1 Principles of Resistivity

Experiments by George Ohm in the early 19th century revealed the empirical relationship between the current flowing through a material and the potential required to drive that current. This relationship is described by

$$V = IR$$

where V is voltage in volts, I is the current in amperes, and R is the proportionality constant. Rearranging the equation to

$$\frac{V}{I} = R$$

gives resistance with the units of volts divided by amperes, or ohms.

The resistance of a material is dependent not only on the property of the material but also the geometry of the material. Specifically, a longer travel path for the current or smaller cross-sectional area would cause the resistance to increase. The geometry-independent property used to quantify the flow of electric current through a material is resistivity, given by

$$\rho = \frac{RA}{L}$$

where ρ is the resistivity, R is the resistance, A is the cross-sectional area through which the current flows, and L is the length of the current flow path. With all length units expressed as meters, the units associated with resistivity are ohm-meters.

Resistivity surveys are conducted by inducing an electric current into the ground between two electrodes, and measuring the potential at other electrodes. Numerous configurations of electrode placement are commonly employed, each with unique data characteristics. The configuration utilized for this study was the dipole-dipole array. For the dipole-dipole array, a current is applied to two adjacent electrodes positioned a predetermined distance apart (distance a). The voltage across two other electrodes is measured simultaneously with the applied current. The two sets of electrodes are always spaced distance “a” apart and the distance between the current and voltage electrodes is always a multiple of a (n• a). To obtain apparent resistivity values, the voltage and current measurements are input into the following formula for dipole-dipole surveys

$$\rho = 2\pi(n+1)\cdot(n+2)\cdot a\cdot\frac{V}{I}$$

4.2 Field Methods

Data for eight resistivity lines were collected at the site on September 13 and 14, 2018. Field data were collected using a SuperSting R8 IP® multi-electrode resistivity system manufactured by Advanced Geosciences Inc. Data were collected using the dipole-dipole array with a current of up to 2000 milliamps. For each electrode configuration in the array, measurements were repeated a minimum of two times, and percent error between the repeated measurements were stored for subsequent evaluation of data quality. Large errors between repeated measurements can be an indication of poor data quality.

The layout and locations of electrodes for the eight lines are illustrated in Figure 4. The resistivity lines utilized spacings between electrodes ranging from three to six meters (9.84 to 19.68 feet), and ranged in total length from 288 to 623 feet. The electrodes were assigned a unique identifier consisting of the line number followed by a dash and the electrode number. For example, the first electrode on Line 1 is 1-1, the fifth electrode is 1-5, etc. The locations of the resistivity electrodes were recorded with a Trimble Pro 6H GPS unit capable of sub-foot accuracy and plotted onto LiDAR topographic data acquired online from the Virginia Geographic Information Network (VGIN, 2014). The elevations of each electrode were extracted from the LiDAR terrain model and integrated into the resistivity data so that the resistivity sections would reflect the local topographic relief.

4.3 Inversion Modeling

The resistivity measurements on a section are called apparent resistivities. They may differ from the actual resistivities because of passage through inhomogeneous materials and the distance of travel through the media. Therefore, linear inversion techniques were applied to the data. Linear inversion modeling fits the measured data in the resistivity section to an earth model that may represent the actual resistivities in the section. The inversion modeling is completed by calculating apparent resistivity from the earth model for comparison to the measured data. If the comparison is within reasonable limits, the earth model can be accepted as an approximation of subsurface conditions. Details of the inversion process may be found in Lines and Treitel (1984), Loke and Barker (1995), and Loke and Barker (1996).

5.0 RESISTIVITY RESULTS

The primary factors affecting the resistivity of earth materials are porosity, water saturation, clay content, and ionic strength of the pore water. In general, the minerals making up soils and rock do not readily conduct electric current and thus most of the current flow takes place through the material's pore water. The relatively high levels of pore water in soils and other unconsolidated materials tend to give low resistivity values for the shallow subsurface. Rock contains significantly less pore water than soils resulting in generally higher resistivity values. The soil-bedrock boundary is usually exhibited in resistivity data as a relatively sharp vertical transition from low resistivity soils to higher resistivity rock.

Karst voids in the subsurface can be filled with air, water, sediment, or any combination of these. Because water and moist sediment conduct electrical current more readily than the surrounding bedrock, voids filled with these materials tend to be expressed as low-resistivity anomalies. Conversely, air is an insulator, so air-filled voids are expressed in theory as high-resistivity anomalies in contrast to the surrounding bedrock. It should be noted that in some instances, open-air voids which contain a large amount of moist clay or sediment (highly conductive materials) may be expressed as low-resistivity anomalies. The resistivity data were evaluated for the top of bedrock and anomalies indicative of karst formation. The resistivity results and interpretations are illustrated in Figure 5.

5.1 Top of Rock

No drilling were yet available with which to correlate the resistivity interpretations of the soil-rock interface. Additionally, no rock outcrops observed onsite were immediately coincident with the resistivity lines. However, the soil-bedrock interface is usually characterized by a relatively abrupt change from low-resistivity soils to high-resistivity rock. This is observed on the resistivity at approximately 250 to 300 ohm-meters, illustrated in each of the resistivity sections in Figure 5 by a dashed black line. The resistivity sections display an irregular soil-rock interface as is typical of karst environments, characterized by instances of alternating deep soil cutters and shallower rock pinnacles.

The elevation of the estimated bedrock surface was digitized in each of the resistivity sections, to produce a three-dimensional data set of the interpreted bedrock surface elevations. These bedrock elevation data were contoured using a kriging algorithm in Surfer V.15.5.382 contouring software to create a rock surface elevation contour model (Figure 6). The same data were also used to generate a depth-to-rock model, illustrated in Figure 7. Figures 8 and 9 illustrate these same contour models, but with the resistivity electrode locations overlain for reference.

The interpreted bedrock surface ranges in elevation from 2,212 to 2,266 feet, and the interpreted depth to rock from the ground surface ranges from the near-surface to approximately 28 feet.

5.2 Karst Formation

The resistivity results indicate a low to moderate degree of karstification of the bedrock beneath the site, with a few possible karst features observed. A pair of isolated high-resistivity zones with modeled resistivity values between 50,000 and 100,000 ohm-meters are observed at depth beneath electrodes 2-17 and 4-42, which may represent air-filled voids. However, no discernible pathways are observed which would allow surface soils to ravel downward into the deeper possible air-filled voids.

An isolated low-resistivity zone within the interpreted bedrock zone is observed beneath electrodes 1-26 and 1-27 that may represent a soil-filled void. On either side of this feature (beneath electrodes 1-23 and 1-29), mid-range resistivities are observed that may represent solutionally-weathered pathways for soils to ravel downward. These features are significantly less pronounced than other known sinkhole throats we have imaged in the past. However, the possibility that these zones may represent soil raveling pathways cannot be ruled out. Similarly, beneath electrodes 3-6 and 3-17, low-resistivity "gaps" in the bedrock surface may represent solutionally-enlarged pathways into the subsurface where soils may have the potential to ravel downward, although no anomalies indicative of possible soil- or air-filled voids are observed beneath them.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The resistivity data suggest an irregular bedrock surface as is common in karstified carbonate bedrock, with the interpreted depth to bedrock ranging from the near surface to approximately 28 feet. The interpreted bedrock surface ranges in elevation from approximately 2,212 to 2,266 feet. The contour models at the end of this report illustrate the lateral variations in the interpreted bedrock surface elevation and depth to bedrock.

The resistivity data also suggest a low to moderate degree of karstification of the bedrock beneath the site. A pair of isolated high-resistivity zones are observed beneath electrodes which may represent air-filled voids within the bedrock zone. However, no discernible pathways are observed which would allow surface soils to ravel downward into the deeper possible air-filled voids.

A possible soil-filled void is observed beneath electrodes 1-26 and 1-27. On either side of this feature (beneath electrodes 1-23 and 1-29), possible solutionally-enlarged pathways are observed which may allow soils to ravel downward toward the possible soil-filled void. Similarly, possible solutionally-enlarged pathways into the bedrock are observed beneath electrodes 3-6 and 3-17, although no anomalies indicative of possible soil- or air-filled voids are observed beneath them.

To further characterize these anomalous areas and to verify the depth to bedrock at select locations, we recommend a series of approximately eight soil borings to a depth of 25 feet or until auger refusal is encountered. For evaluation of the possible karst anomalies, we recommend drilling at electrode locations 1-23, 1-29, 3-6, and 3-17. For the purpose of verifying the depth to bedrock, we recommend drilling at electrode locations 1-14, 1-27.5, 8-7, and 8-20. The estimated depth to rock based on the resistivity interpretations at each of these locations can be seen in Figure 9.

7.0 LIMITATIONS

This study was conducted by qualified geologists - including registered professional geologists - with over 44 years of collective experience in the collection, processing, and interpretation of geophysical data. It should be noted, however, that all geophysical methods are interpretive. It should also be noted that the distribution of the resistivity lines results in some substantial data gaps in some areas of the site. Therefore, it is possible that geologic features of interest exist in areas between the resistivity lines which were not revealed by this study. To verify the interpretations within this report and to further characterize anomalous areas, additional exploration would be required.

8.0 REFERENCES

Bartholomew, M.J., and Lowry, W.D., 1979. Geology of the Blacksburg Quadrangle, Charlottesville: Commonwealth of Virginia, Dept. of Conservation and Economic Development, Division of Mineral Resources Publication 14, scale 1:24,000.

Lines, L.R., and S. Treitel, 1984. A review of least-squares inversion and its application to geophysical problems, Geophysical Prospecting, Vol. 32, Pages 159-186.

Loke, M.H., and R.D. Barker, 1995. Least-squares deconvolution of apparent resistivity pseudosections, Geophysics, Vol. 60, No. 6, Pages 1682-1690.

Loke, M.H., and R.D. Barker, 1996. Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method, Geophysical Prospecting, Vol. 44, No. 1, Pages 131-152.

9.0 FIGURES

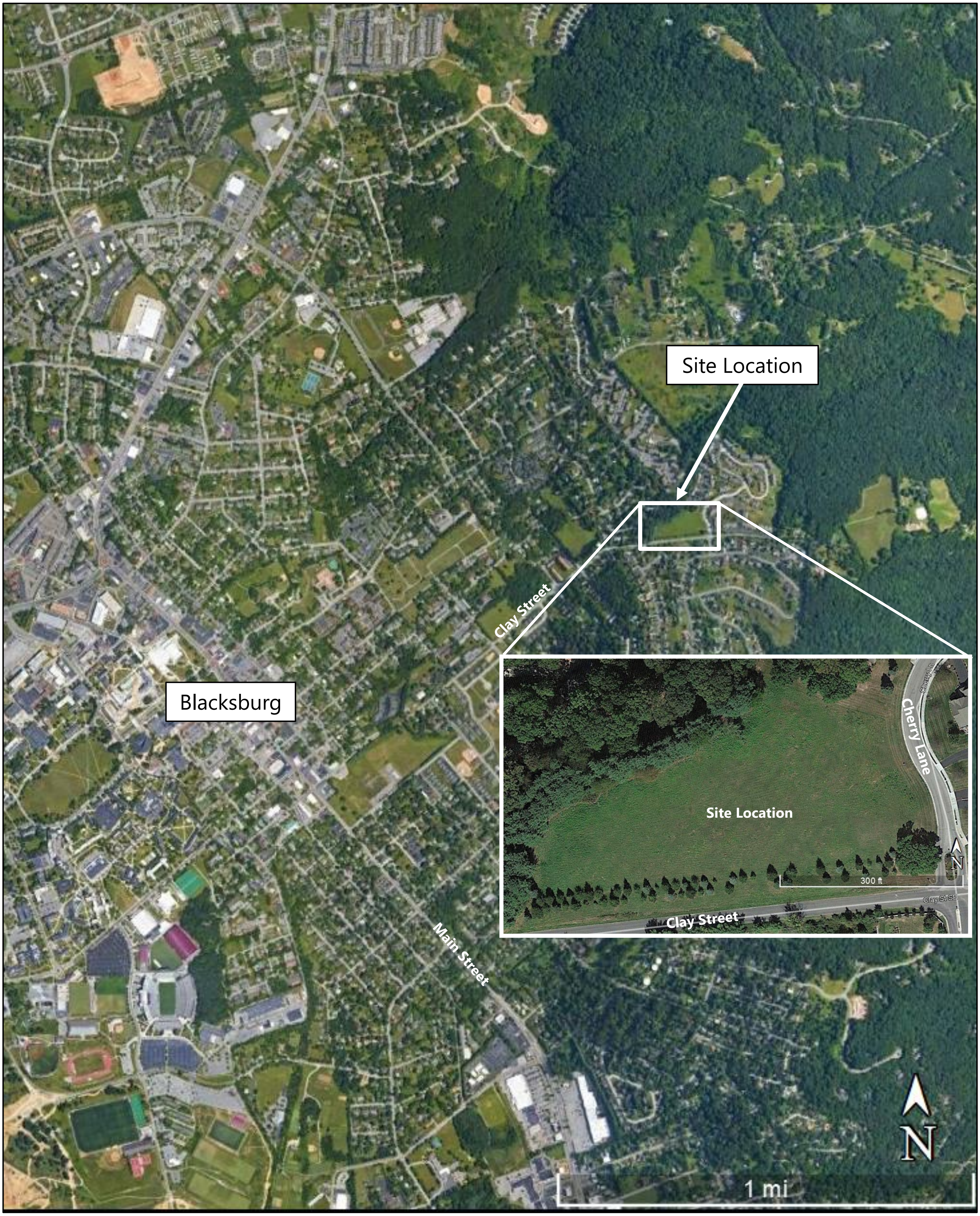

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Figure 1. Site location map.

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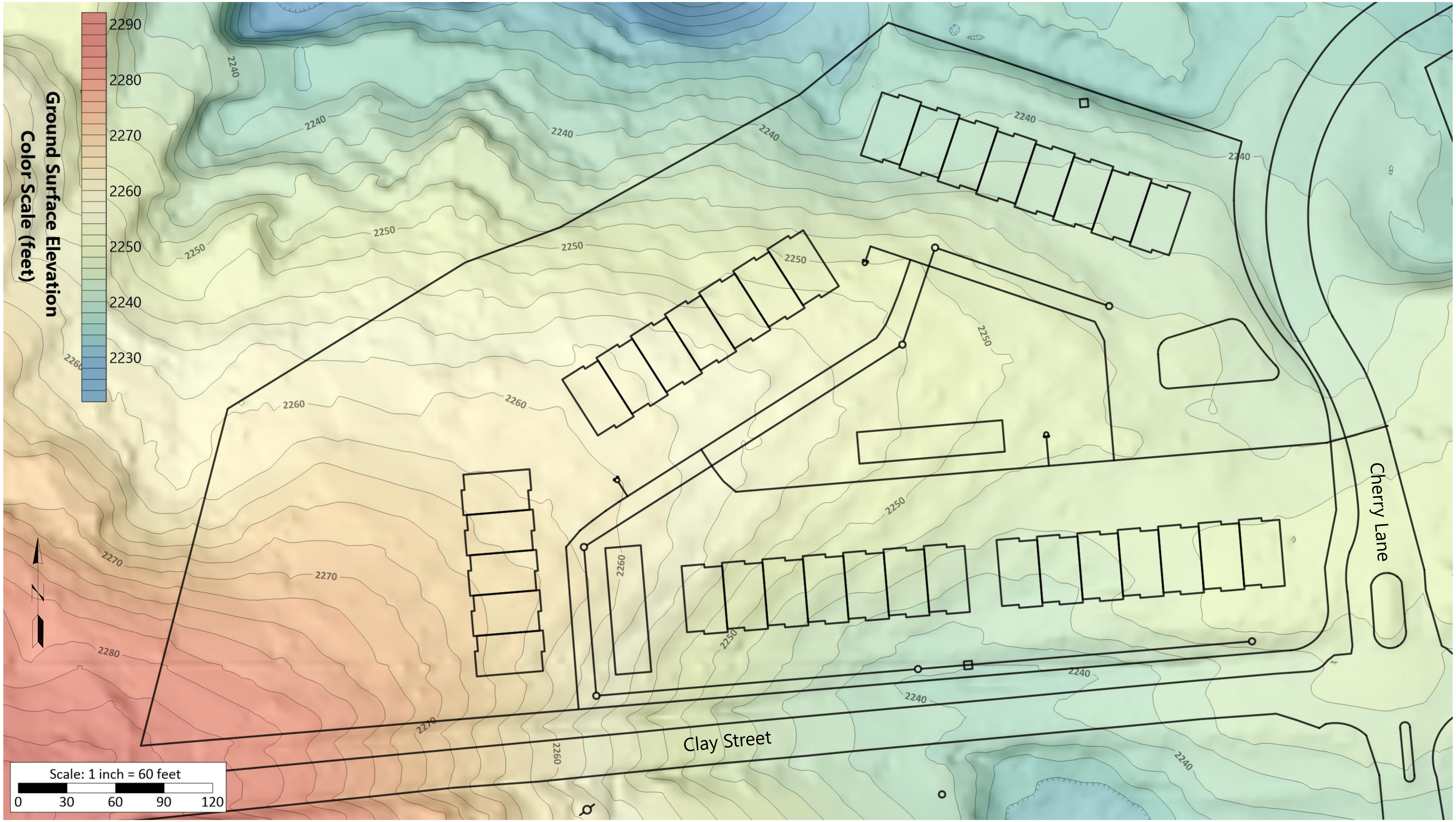

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Figure 2. Topography of the site and layout of the proposed development.

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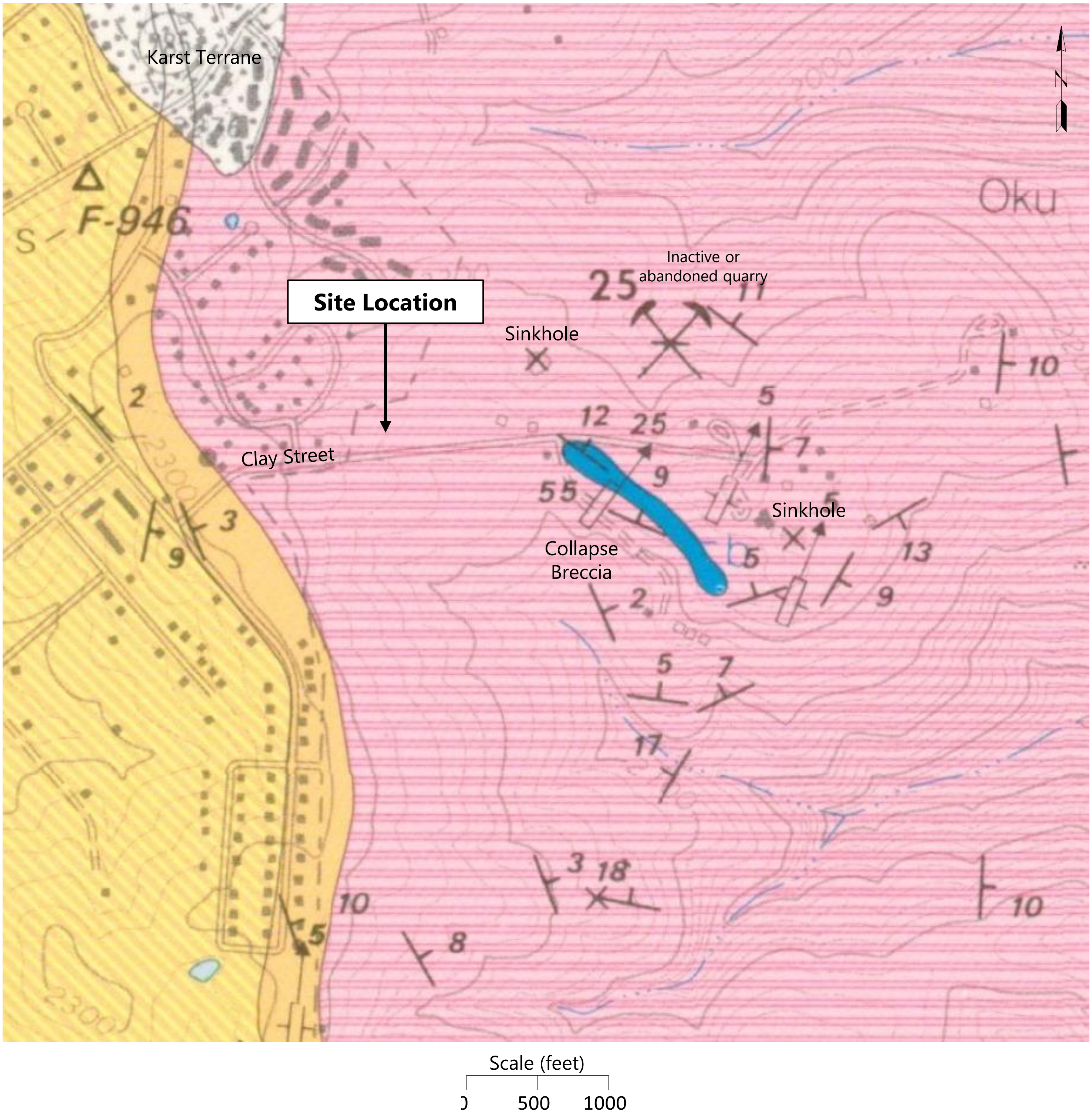

Oku -Knox Group (upper part): *Light to medium gray, massive, thick-bedded, fine to medium grained dolomite with 1-6 foot-thick chert interbeds.*

b –Collapse Breccia: *Angular blocks of dolomite cemented together with coarse-grained spar.*

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Figure 3. A portion of the published geologic map for the site. From Bartholomew and Lowry, 1979.

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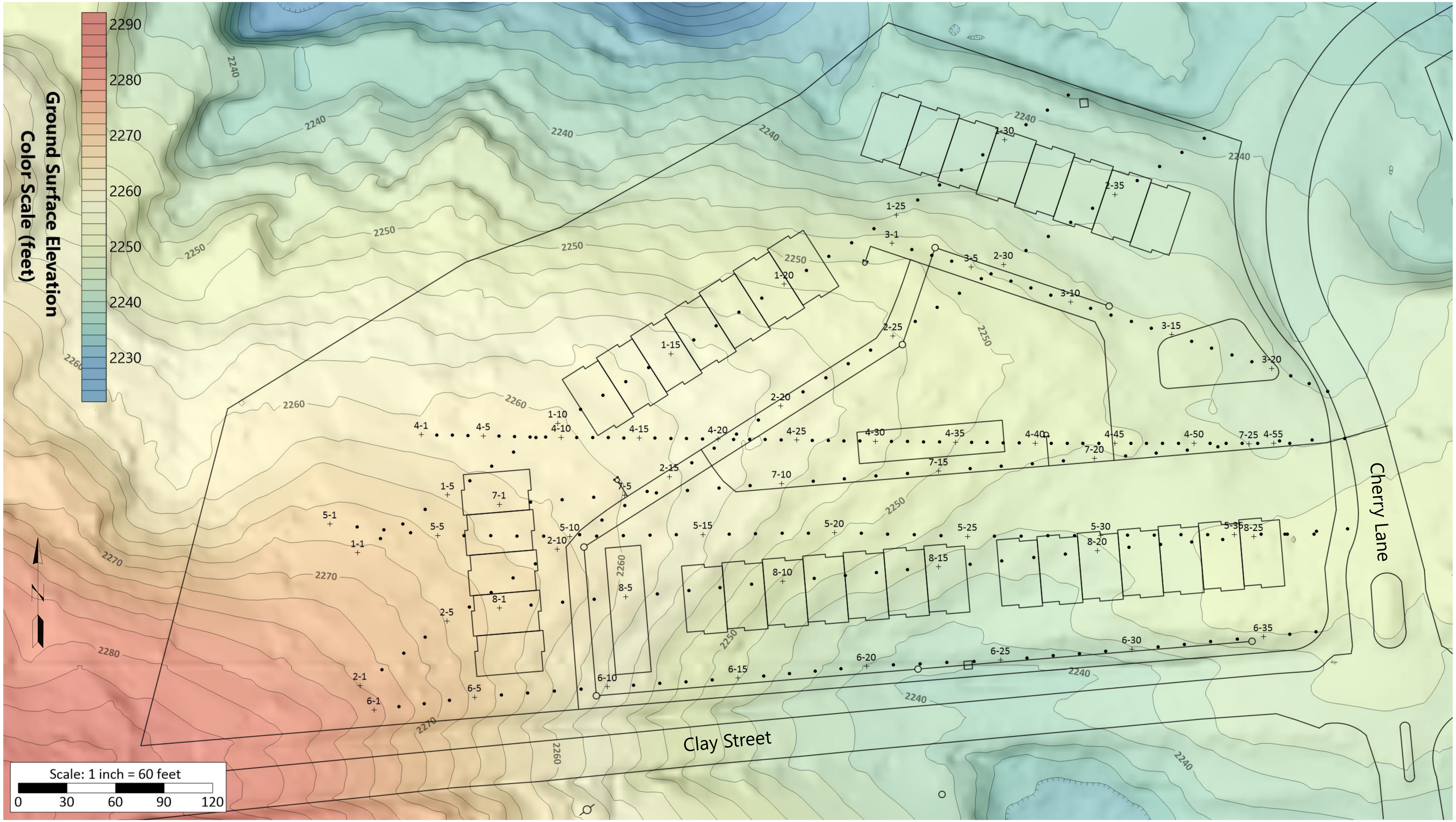

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Figure 4. Locations of electrodes for the eight resistivity lines.

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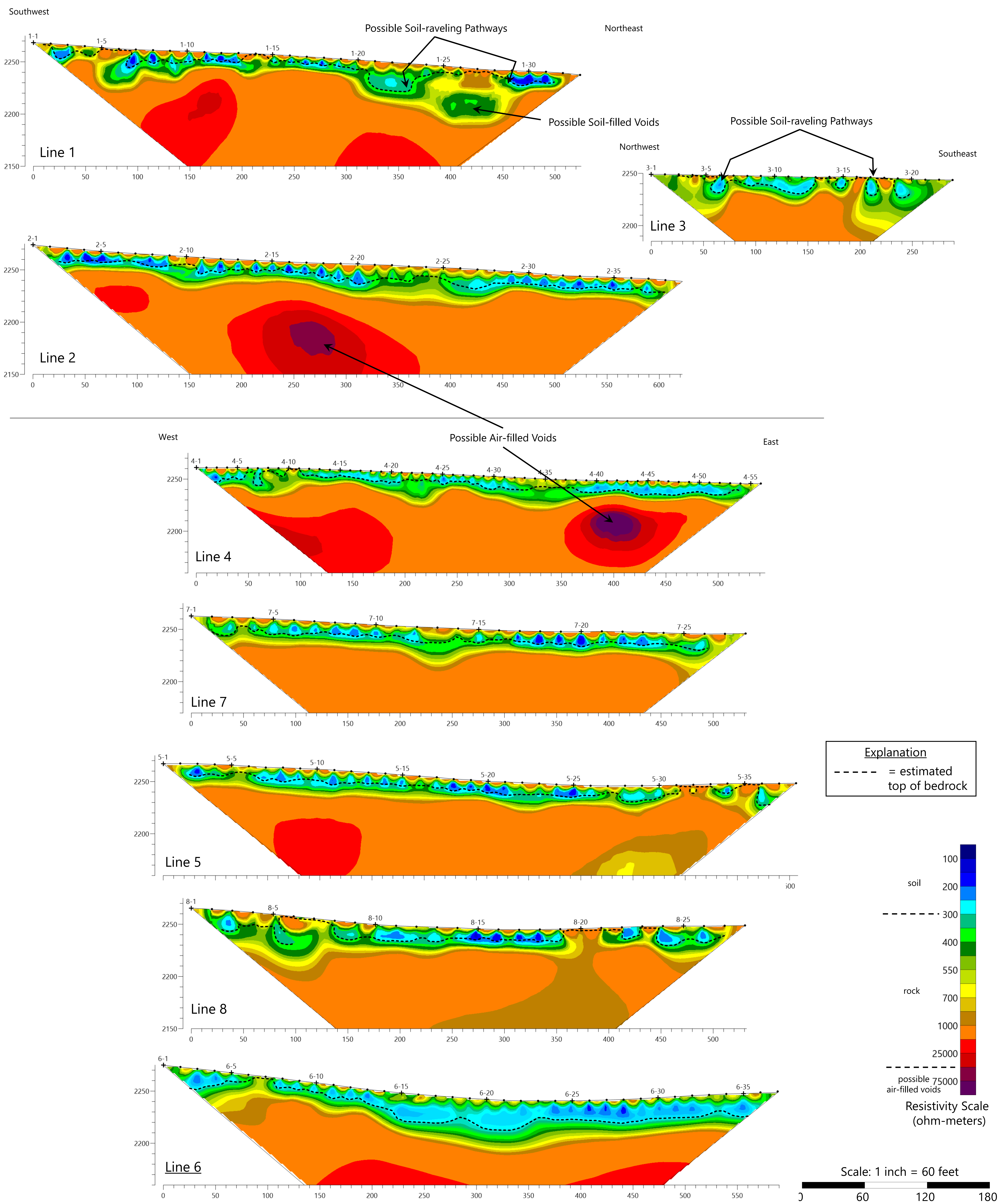

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Figure 5. Resistivity results and interpretations.

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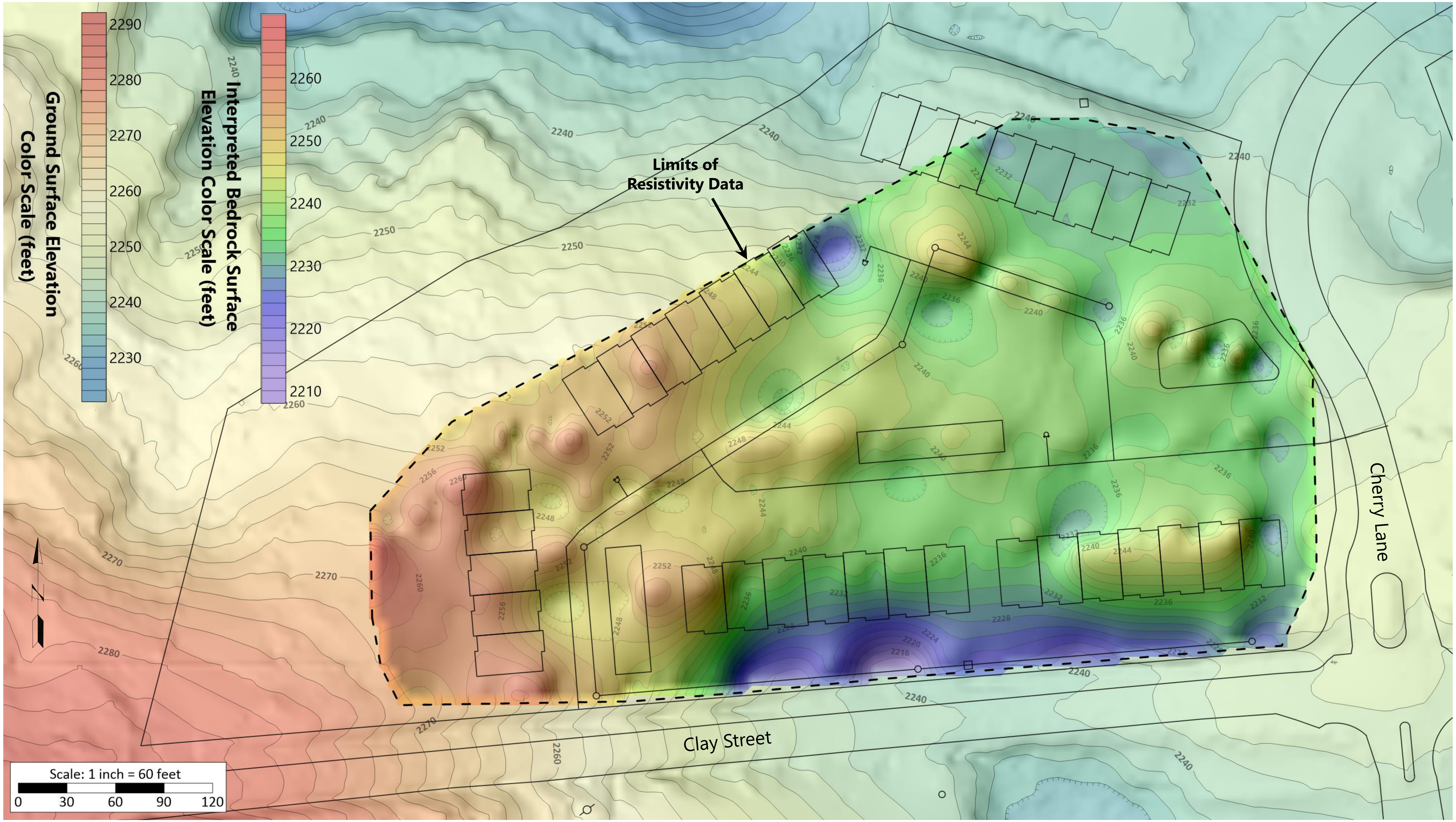

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Figure 6. Contour model of the estimated bedrock surface elevations as digitized from the resistivity interpretations in Figure 5.

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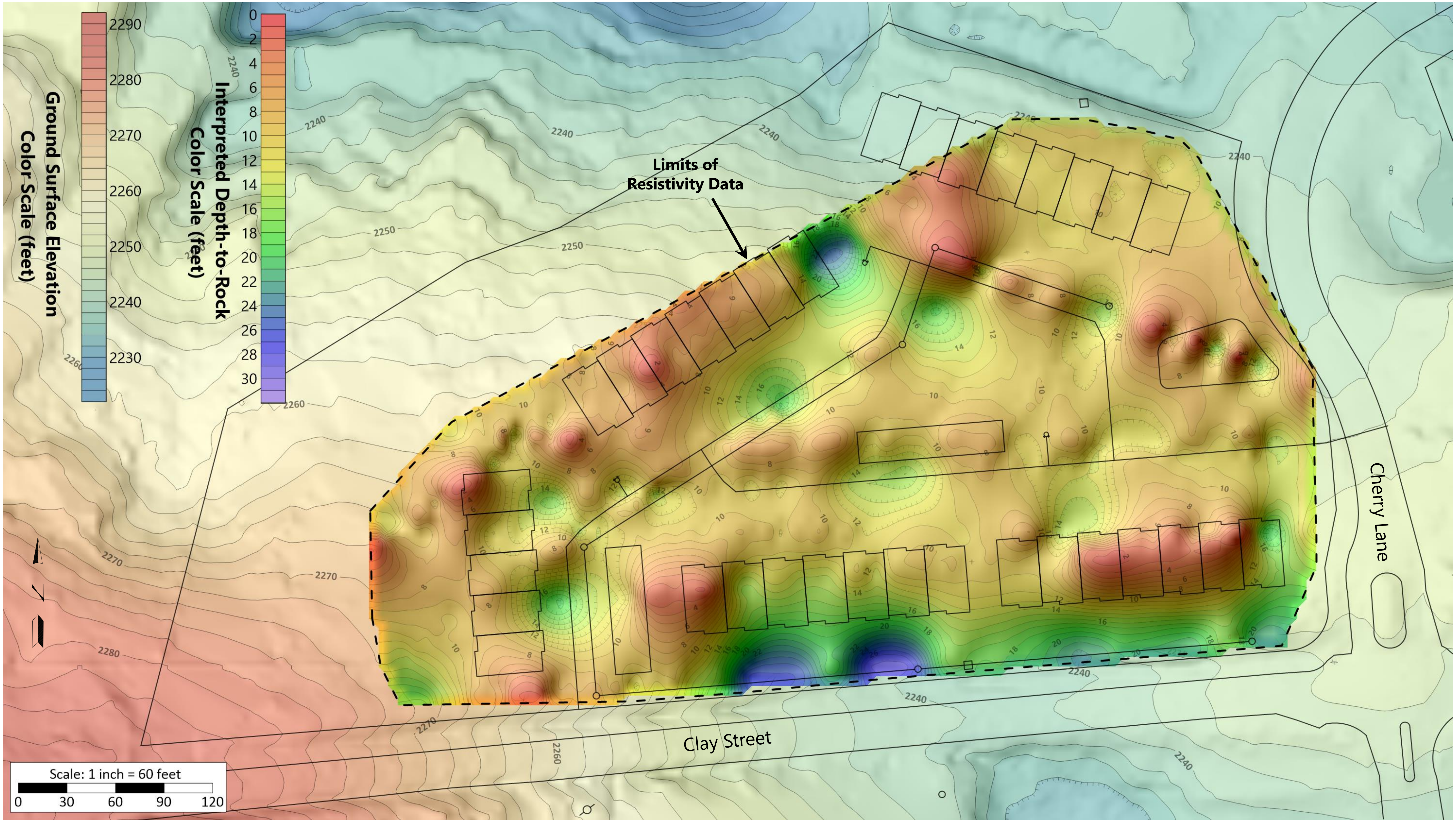

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Figure 7. Contour model of the estimated depth to rock as digitized from the resistivity interpretations in Figure 5.

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DAA Project No. 18010224-010203

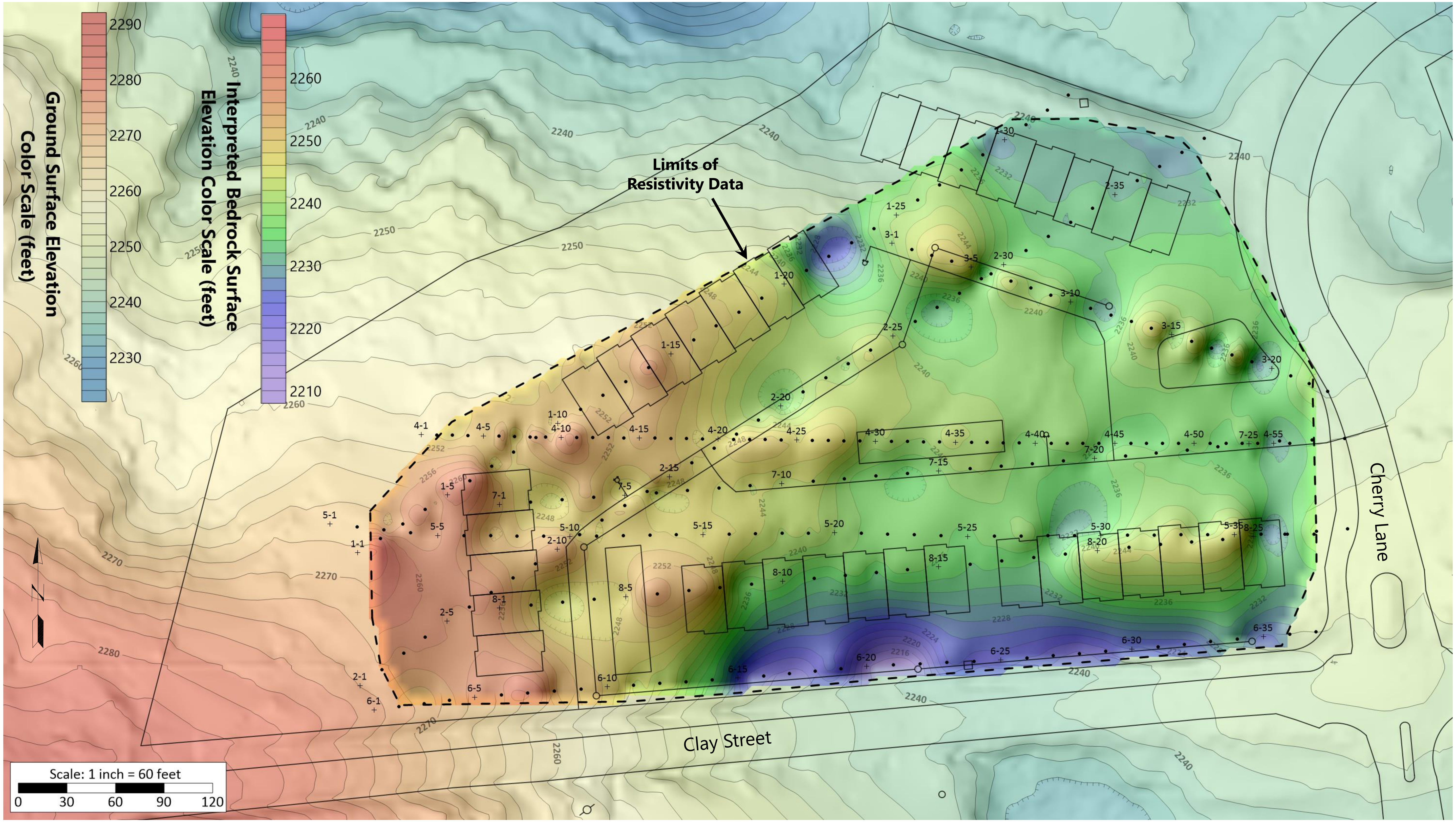

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Figure 8. Bedrock surface elevation contour model with resistivity electrode locations overlain for reference.

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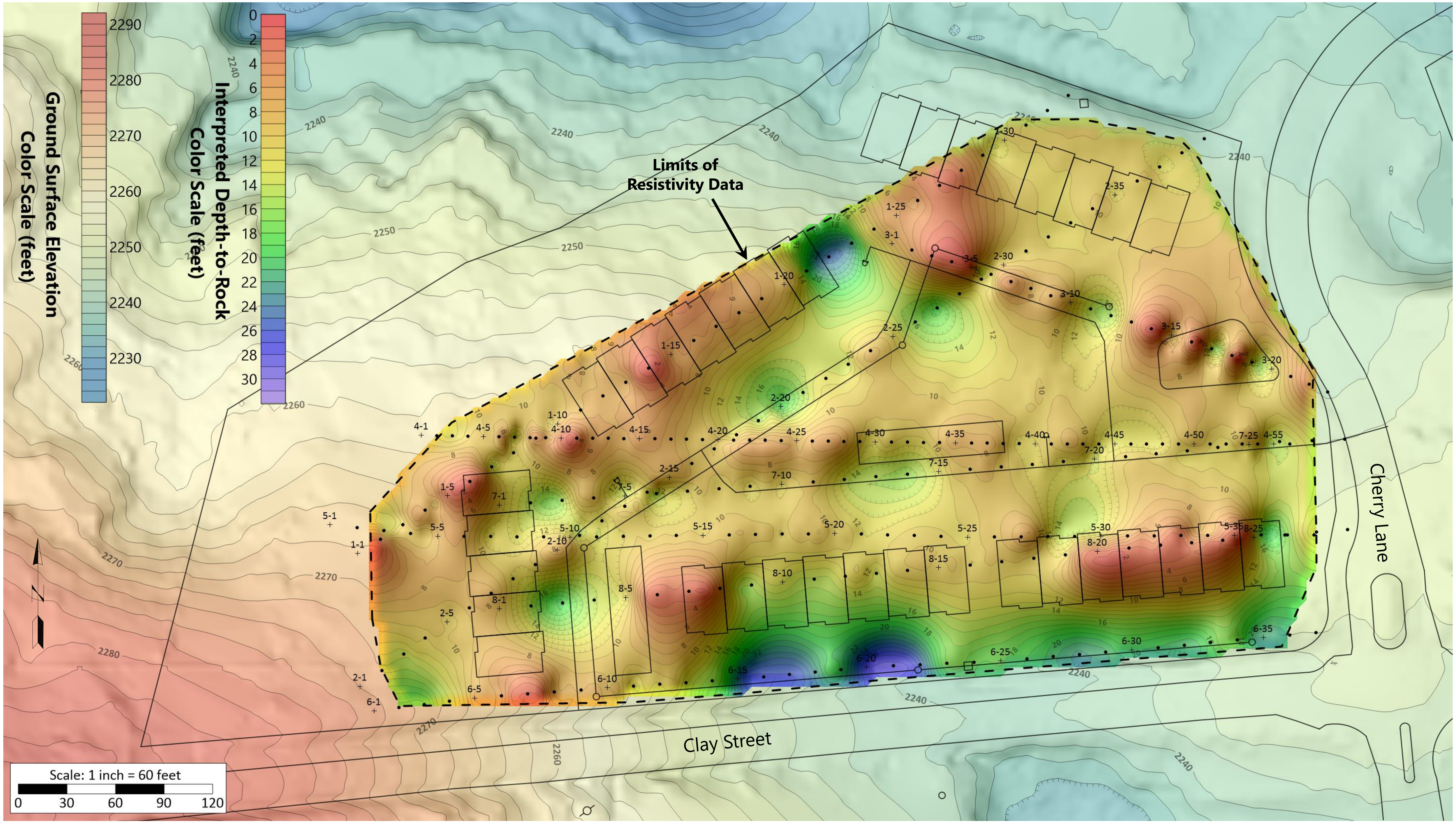

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Figure 9. Depth-to-rock contour model with resistivity electrode locations overlain for reference.

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