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GEOPHYSICAL INVESTIGATION – RANCHO VISTOSO VALLEY VISTA, ORO VALLEY ARIZONA

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LIST OF TERMS

Conductivity: The ability of a material to conduct an electrical impulse (in Siemen per meter, S/m); reciprocal of resistivity.

Inversion: Inversion, or inverse modeling, attempts to reconstruct subsurface features from a given set of geophysical potential measurements, and to do so in a manner that the model response fits the observations according to some measure of error.

Resistance: A measure of a material's ability to resist electrical current flow, in ohms.

Resistivity: A material property that is measured as its resistance to current per unit length for a uniform cross-section in ohm-meters.

1.0 INTRODUCTION

hydroGEOPHYSICS, Inc. (HGI) conducted a multi-channel analysis of surface waves (MASW) seismic and electrical resistivity tomography (ERT) survey of the Rancho Vistoso Valley Vista (RVVV) neighborhood in Oro Valley, Arizona.

The RVVV neighborhood was built along the Canada del Oro (CDO) wash, about 10 feet above the elevation of the wash and 100 feet below the elevation of surrounding neighborhoods near Rancho Vistoso Boulevard. From these surrounding neighborhoods, there are a number of incised channels in the highwalls around the RVVV neighborhood to allow precipitation run-off to drain to the CDO wash. Recently, some houses near the wash have been experiencing cracking in walls, foundations, and pavements. These homes are near remnants of the incised channels that were buried to accommodate standard building grade. The cracking could possibly be due to differential ground subsidence where ground stresses may affect clayey or saturated materials differently than sandy or drier materials.

The geophysical survey included three lines each of MASW and ERT. The lines were located near three properties of the RVVV neighborhood: lots 19, 20, and 31. Figure 1 shows the locations of the geophysical survey lines relative to the properties under investigation and previous soil borings conducted by ProTeX. The ERT lines were 650 feet in length and the MASW lines were 890 feet in length. The MASW lines were 120 feet longer on each end of the ERT lines to allow for off-end shots and ensure a complete profile of 650 feet.

1.1 OBJECTIVE

The objective of the geophysical investigation was to identify subsurface properties that could be used to provide broader context to the subsidence issues at each residential property in the RVVV neighborhood. The resistivity values obtained from ERT imaging can be used to distinguish sandy or gravelly media from clayey media, where clay is much lower in resistivity than sands and gravels. Additionally, wet or saturated soils will also exhibit lower resistivity values relative to drier soils. The MASW data provide relative stiffness of the different materials, whether wet or dry / clay or sand. Stiffness is defined as the resistance of the material to stress-induced deformation. The stiffness is determined by the velocity of propagating sound waves, where faster waves travel through stiffer materials. The MASW information may also show very competent materials at depth that could be used to stabilize the foundations of the properties as suggested in the ProTeX forensic reports.

1.2 SCOPE OF WORK

The scope of the geophysical investigation included data acquisition over three coincident electrical resistivity and MASW survey lines. These methods essentially provide two-dimensional (2D) cross-sectional information, which allows for a continuous and high-resolution evaluation of potential voids and sinkhole features. For the electrical resistivity method, the response we expect to observe in the model results will depend on the material type and degree of saturation. The response in the MASW model results would typically be a reduction in shear-wave velocity associated with loose sands and an increase in velocity for cemented soils.

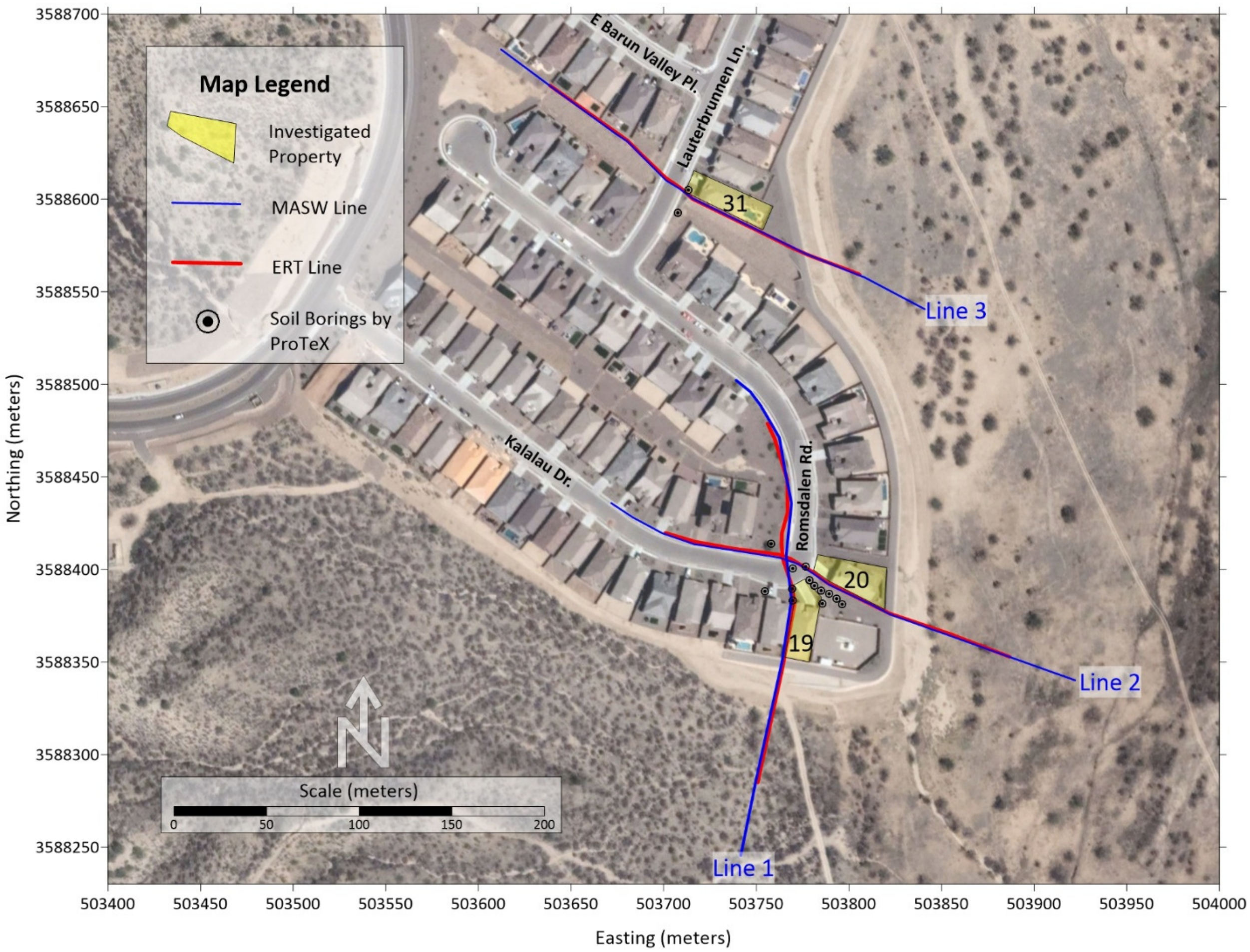
1.3 SURVEY LOCATION

The geophysical investigation was conducted along three occupied properties in Oro Valley, Arizona, which is immediately adjacent to, and north of Tucson, AZ. Figure 1 displays an overview of the survey area along E Kalalau Dr. Three coincident electrical resistivity and MASW survey line were acquired:

1. Survey Line 1 is on the west side of the property at 780 E Kalalau Dr. (Lot 19),
2. Line 2 is on the south side of the property at 803 E Romsdalen Rd. (Lot 20), and
3. Line 3 is on south side of the property at 12616 N Lauterbrunnen Ln (Lot 31).

All lines extend beyond the formal property boundaries so that a reasonable depth of investigation could be obtained from data collected on the surface.

Figure 1. Survey area overview.

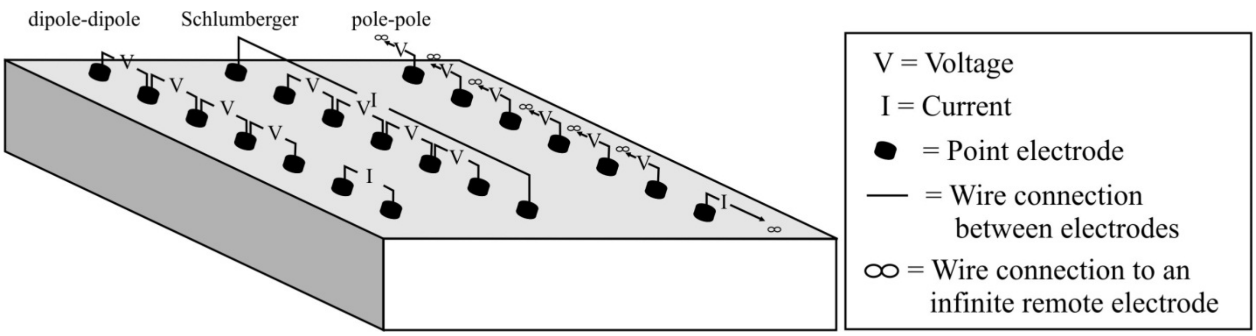


2.0 DESCRIPTION OF GEOPHYSICAL METHODS

2.1 ELECTRICAL RESISTIVITY

Electrical resistivity is a volumetric property that describes the resistance of electrical current flow within a medium (Rucker *et al.*, 2011; Telford *et al.*, 1990). Direct electrical current is propagated in rocks and minerals by electronic or electrolytic means. Electronic conduction occurs in minerals where free electrons are available, such as the electrical current flow through metal. Electrolytic conduction, on the other hand, relies on the dissociation of ionic species within a pore space. With electrolytic conduction, the movement of electrons varies with the mobility, concentration, and the degree of dissociation of the ions. Mechanistically, the resistivity method uses electric current (I) that is transmitted into the earth through one pair of electrodes (transmitting dipole) that are in contact with the soil. The resultant voltage potential (V) is then measured across another pair of electrodes (receiving dipole). Numerous electrodes can be deployed along a transect (which may be anywhere from feet to miles in length), or within a grid. Figure 2 displays examples of electrode layouts for surveying. The figure displays transects with a variety of array types (dipole-dipole, Schlumberger, pole-pole). A complete set of measurements occurs when each electrode (or adjacent electrode pair) passes current, while all other adjacent electrode pairs are utilized for voltage measurements. Modern equipment automatically switches the transmitting and receiving electrode pairs through a single multi-core cable connection. Rucker *et al.*, (2009) describe in more detail the methodology for efficiently conducting an electrical resistivity survey.

Figure 2. Possible arrays for use in electrical resistivity surveying.



The modern application of the resistivity method uses numerical modeling and inversion theory to estimate the electrical resistivity distribution of the subsurface given the known quantities of electrical current, measured voltage, and electrode positions. A common resistivity inverse method incorporated in commercially available codes is the regularized least squares optimization method (Loke *et al.*, 2003). The objective function within the optimization aims to minimize the difference between measured and modeled potentials (subject to certain constraints, such as the type and degree of spatial smoothing or regularization) and the optimization is conducted iteratively due to the nonlinear nature of the model that describes the potential distribution. The relationship between the subsurface resistivity (ρ) and the measured voltage is given by the following equation (from Dey and Morrison, 1979):

$$-\nabla \cdot \left[\frac{1}{\rho(x,y,z)}\nabla V(x,y,z)\right] = \left(\frac{I}{U}\right)\delta(x-x_s)\,\delta(y-y_s)\,\delta(z-z_s) \qquad (1)$$

where I is the current applied over an elemental volume U specified at a point (x_s, y_s, z_s) by the Dirac delta function.

Equation 1 is solved many times over the volume of the earth by iteratively updating the resistivity model values using either the L_2-norm smoothness-constrained least squares method, which aims to minimize the square of the misfit between the measured and modeled data (Ellis & Oldenburg, 1994):

$$\left(J_i^T J_i + \lambda_i W^T W\right)\Delta r_i = J_i^T g_i - \lambda_i W^T W r_{i-1} \qquad (2)$$

or the L_1-norm that minimizes the sum of the absolute value of the misfit:

$$\left(J_i^T R_d J_i + \lambda_i W^T R_m W\right)\Delta r_i = J_i^T R_d g_i - \lambda_i W^T R_m W r_{i-1} \quad (3)$$

where g is the data misfit vector containing the difference between the measured and modeled data, J is the Jacobian matrix of partial derivatives, W is a roughness filter, R_d and R_m are the weighting matrices to equate model misfit and model roughness, Δr_i is the change in model parameters for the i^{th} iteration, r_i is the model parameters for the previous iteration, and λ_i = the damping factor.

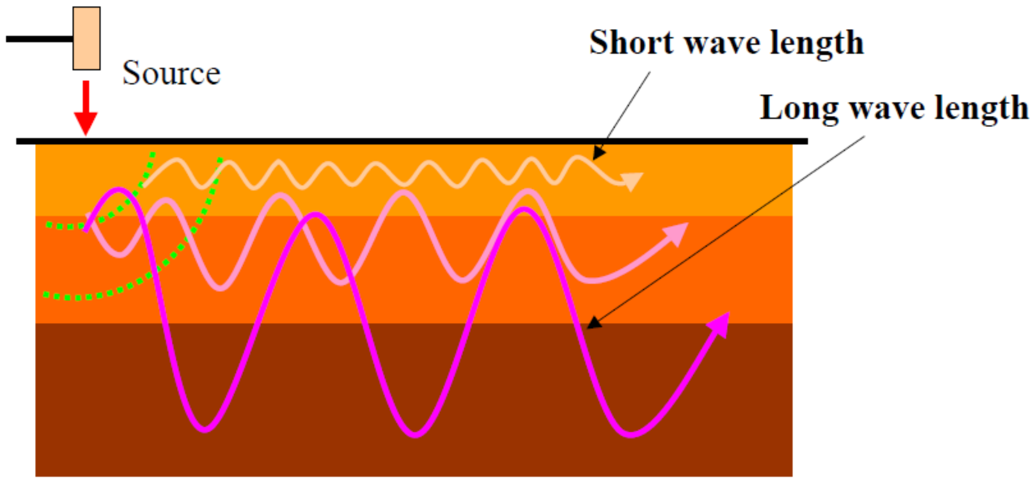
2.2 MASW

Dispersion, or change in phase velocity with frequency, is the fundamental property utilized in surface-wave seismic methods. Phase velocity of surface-waves is sensitive to the shear wave velocity (Vs); phase velocity of surface-waves is typically 90-95% that of the shear wave velocity. Surface wave dispersion can be significant in the presence of velocity layering, which is common in the near-surface environment. There are other types of surface waves, or waves that travel along a surface, but in this application we are concerned with the Rayleigh wave, which is also called “ground roll” since the Rayleigh wave is the dominant component of ground roll.

“Active source” surface-wave surveying means that seismic energy is intentionally generated at a specific location relative to the geophone spread and recording begins when the source energy is imparted into the ground. This is in contrast to “passive source” surveying, also called “microtremor” surveying or “refraction microtremor” (or the commercial term “ReMi”) surveying, where there is no time break and motion from ambient energy (generated by cultural noise, wind, wave motion, etc. at various, and usually unknown, locations relative to the geophone spread) is recorded. Only the active source technique was used for this survey effort.

Surface-wave energy decays exponentially with depth beneath the surface. Longer wavelength (that is, longer-period and lower-frequency) surface waves travel deeper and thus contain more information about deeper velocity structure (Figure 3). Shorter wavelength (that is, shorter-period and higher-frequency) surface waves travel shallower and thus contain more information about shallower velocity structure. In this context, by their nature and proximity to the geophone spread, it can be said that higher-frequency active source surface waves resolve the shallower velocity structure and lower-frequency passive source surface waves resolve the deeper velocity structure.

Figure 3. Example of surface wave dispersion produced during a MASW survey.



MASW surveys are conducted using the same source and seismograph equipment as the more common P-wave seismic refraction surveys, requiring only a change to lower frequency geophones (typically 4.5Hz). They are much easier to conduct than shear wave surveys, and benefit from increasing source power efficiency (for each sledgehammer blow 67% of the energy produced is in the form of surface-waves, 26% shear waves, and 7% P-waves) and consequently improved signal-to-noise ratio. The technique works best in soft rock geology conditions with minimal or constant topography change across the spread.

Shear wave velocity is one of the elastic constants and is closely related to Young's modulus. Under most circumstances, shear wave velocity is a direct indicator of the ground strength (stiffness) and therefore can be used to derive load-bearing capacity.

3.0 METHODOLOGY

3.1 SURVEY AREA AND LOGISTICS

Data acquisition consisted of three coincident ERT and MASW survey lines. Data acquisition occurred from November 30th to December 2nd, 2022, and included set-up, data acquisition, and cleanup. The field crew consisted of three people, with a fourth added to hasten acquisition on the last day.

3.1.1 Detailed Coverage

Total geophysical survey coverage over the RVVV property equaled approximately 1,950 linear feet of electrical resistivity and 2,670 linear feet of MASW. For the electrical resistivity acquisition, electrodes were installed at a constant spacing of approximately 9.8 feet (3 meters) along the survey lines. The overall length of each electrical resistivity survey line and additional coverage information is detailed in Table 1. For the MASW acquisition, geophones were installed at a constant spacing of approximately 10 feet (3.05 meters) along the survey lines. The overall length of each MASW survey line and additional coverage information is detailed in Table 2. A detailed coverage map of the electrical resistivity and MASW survey line locations are displayed in Figures 4 and 5. Electrode and geophone locations were surveyed using a handheld Garmin handheld global positioning system (GPS) unit by HGI.

Table 1. Electrical resistivity survey details.
Coordinates surveyed using a handheld Garmin GPS unit with typical accuracy level of ±3 meters

Line #	Start Position (UTM Zone 12, meters)		End Position (UTM Zone 12, meters)		Electrode Spacing (feet)	Total # of Electrodes	Length (feet)	Acquisition Date (2022)
	Easting	Northing	Easting	Northing				
1	503750	3588284	503756	3588477	9.8	67	650	11/30
2	503700	3588419	503885	3588353	9.8	67	650	12/1
3	503638	3588661	503805	3588559	9.8	67	650	12/2

Table 2. MASW survey details.

Line #	Start Position (UTM Zone 12, meters)		End Position (UTM Zone 12, meters)		Geophone Spacing (feet)	Total # of Geophones	Length (feet)	Acquisition Date (2021)
	Easting	Northing	Easting	Northing				
1	503742	3588246	503737	3588504	10	90	890	11/30
2	503671	3588435	503922	3588340	10	90	890	12/1
3	503611	3588681	503841	3588540	10	90	890	12/2

3.2 DATA ACQUISITION

3.2.1 Electrical Resistivity

Data were collected using a SuperSting™ R8 multichannel electrical resistivity system (Advanced Geosciences, Inc. [AGI], Texas) and associated cables, electrodes, and battery power supply. The SuperSting™ R8 meter is commonly used in surface geophysical projects and has proven itself to be reliable for long-term, continuous acquisition. The stainless steel electrodes were laid out along lines with a constant electrode spacing (~6.5 feet/2 meters). Multi-electrode systems allow for automatic switching through preprogrammed combinations of four electrode measurements.

3.2.2 MASW

Two Geode Ultra-Light Exploration 24–Channel Seismographs (Geometrics, Inc., San Jose, California) were used for MASW surveying, providing a total of 48-channels. 4.5-Hz geophone placement was every 5 feet, and using a shot point offset of 40 feet from the end geophone (a number of off-end shot point distances, or offsets, were tested at each line location to determine the optimum offset to use). The seismic source consisted of a 16-pound sledgehammer striking a metal plate. The seismographs were controlled from a laptop in order to view each shot to ensure acceptable data quality, and record and process the data. Additional shots with the source forming a new "stack" of data were added until the desired data quality was achieved. The shot record (seismogram) was also saved to the computer and stored for subsequent processing. A real-time noise monitor showing all active geophones was carefully scrutinized during shots to ensure that noise levels were at a minimum for each shot. This included watching for breaks in wind noise, construction and other traffic, and other sources of noise.

Figure 4. ERT Line layout with Electrode Number

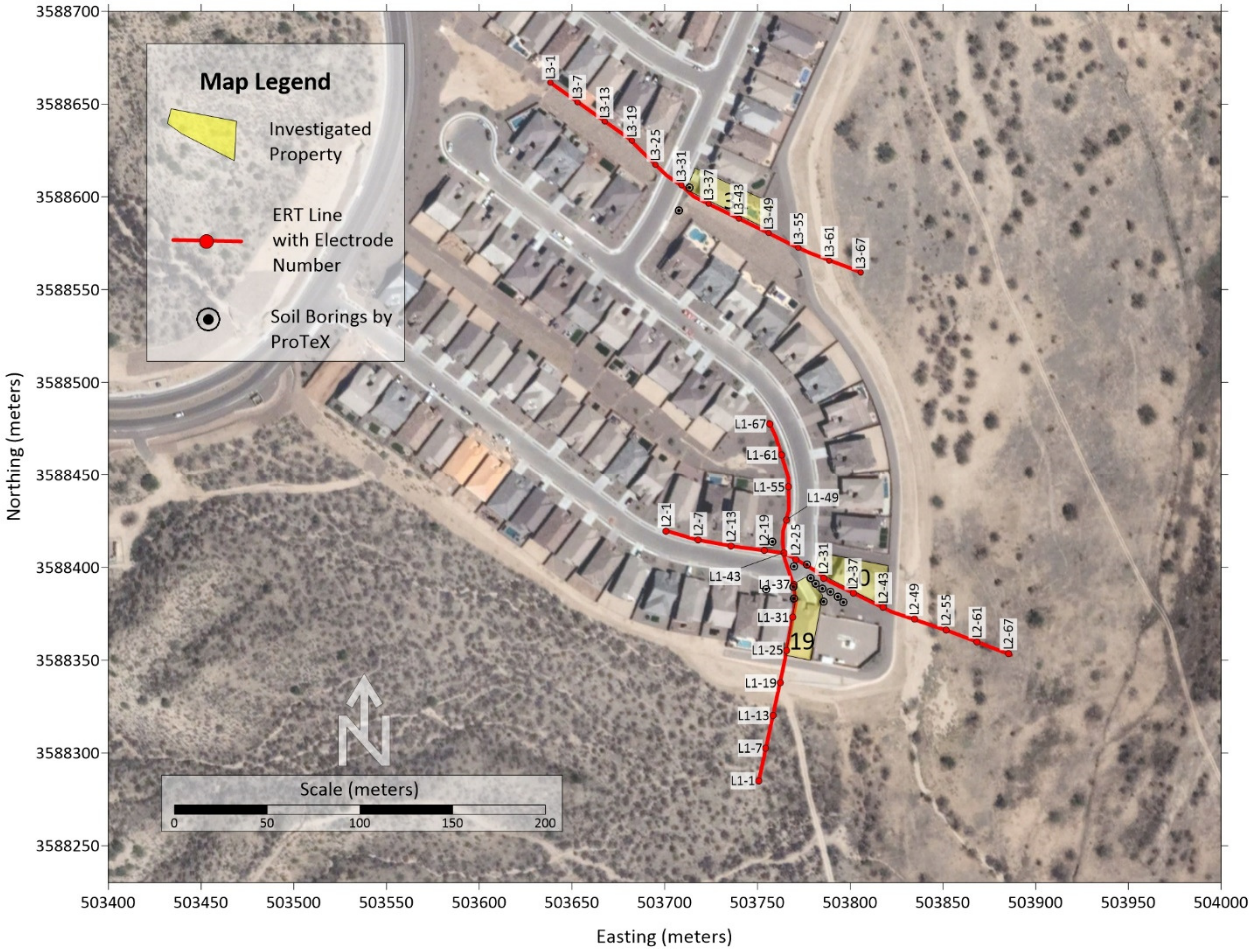
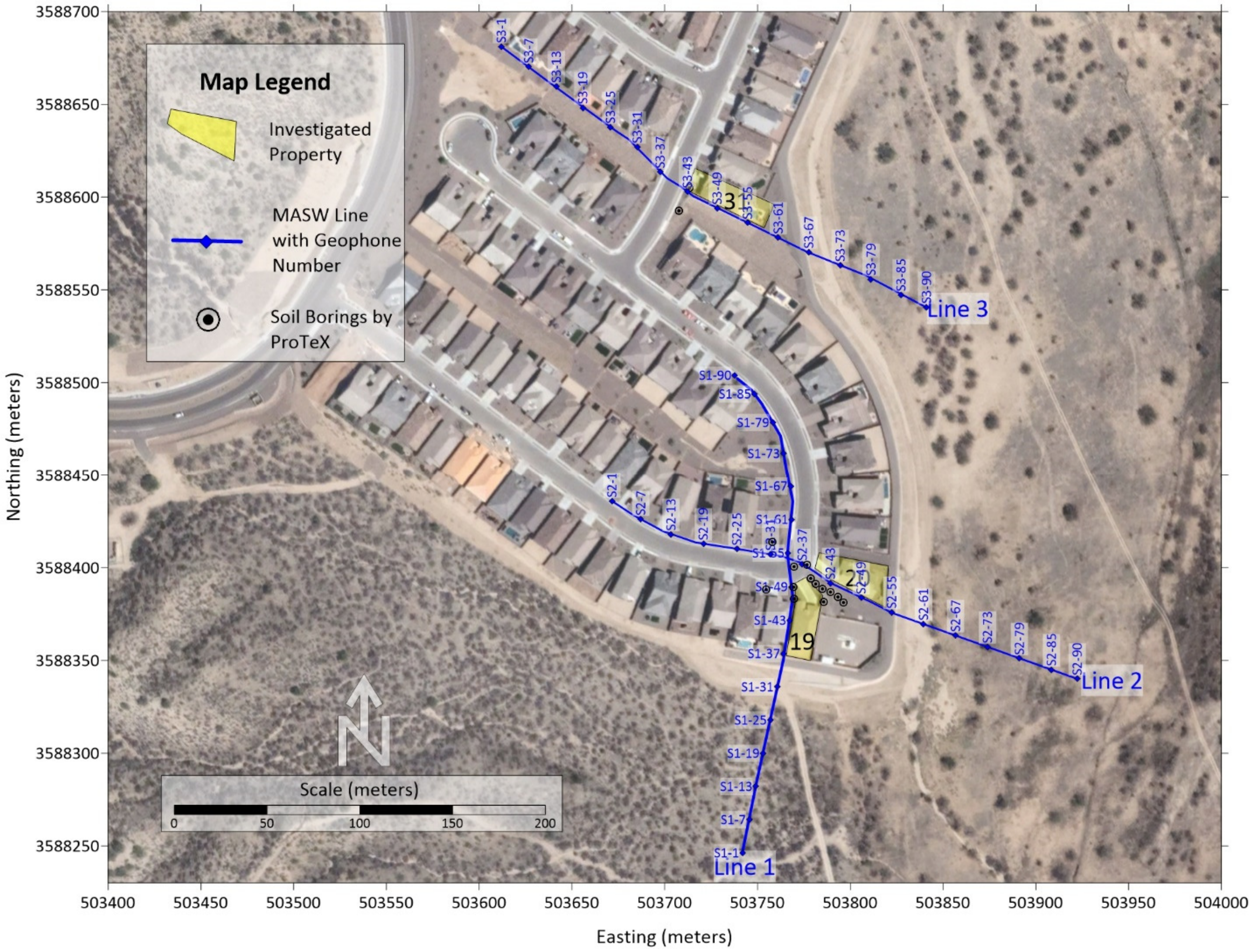


Figure 5. MASW Line Layout with Geophone Number



3.3 DATA PROCESSING

3.3.1 Electrical Resistivity

3.3.1.1 Quality Control

The geophysical data for the resistivity survey, including measured voltage, current, measurement (repeat) error, and electrode position, were recorded digitally with the AGI SuperSting™ R8 resistivity meter. Quality control, both in-field and in-office, was performed throughout the survey to ensure data quality passed accepted standards and to assure quality of data before progressing the survey. Following onsite QC, the data were transferred to the HGI server for storage and detailed data processing and analysis.

3.3.1.2 Resistivity Processing

Data removal was performed based on degree of noise/other erroneous data. During data removal, those data that appeared to be extremely noisy and fell outside the normal range of accepted conditions were manually removed within an initial Excel spreadsheet analysis. Examples of conditions that would cause data to be removed include, negative or very low voltages, high-calculated apparent resistivity, extremely low current, and high repeat measurement error. No resistivity data values were manipulated or changed, such as with smoothing routines or box filters; noisy data were only removed from the general population. The final edited datasets were formatted for input into the 2D inverse modeling software.

3.3.1.3 2D Resistivity Inversion

RES2DINVx64 software (Geotomo, Inc.) was used for inverting individual lines in two dimensions. RES2DINV is a commercial resistivity inversion software package available to the public from www.geotomosoft.com. The inversion process followed a set of stages that utilized consistent inversion parameters to maintain consistency between each model. Inversion parameters were chosen to maximize the likelihood of convergence. Inversion parameter choices included the starting model, the inversion routine (robust or smooth), the constraint defining the value of smoothing and various routine halting criteria that automatically determined when an inversion was complete. Convergence of the inversion was judged whether the model achieved an absolute error of less than 5% within three to five iterations. If convergence was not achieved during the first inversion run, a filter run was initiated using a filtered dataset based on high error for measured versus modeled data, not to exceed 10% data removal per filter run. The data quality for the three survey lines did not require filtering.

The data were inverted with appropriate topography. The inverted data were output from RES2DINV into an XYZ data file and were then gridded and color contoured in Surfer (Golden Software, Inc.).

3.3.2 MASW

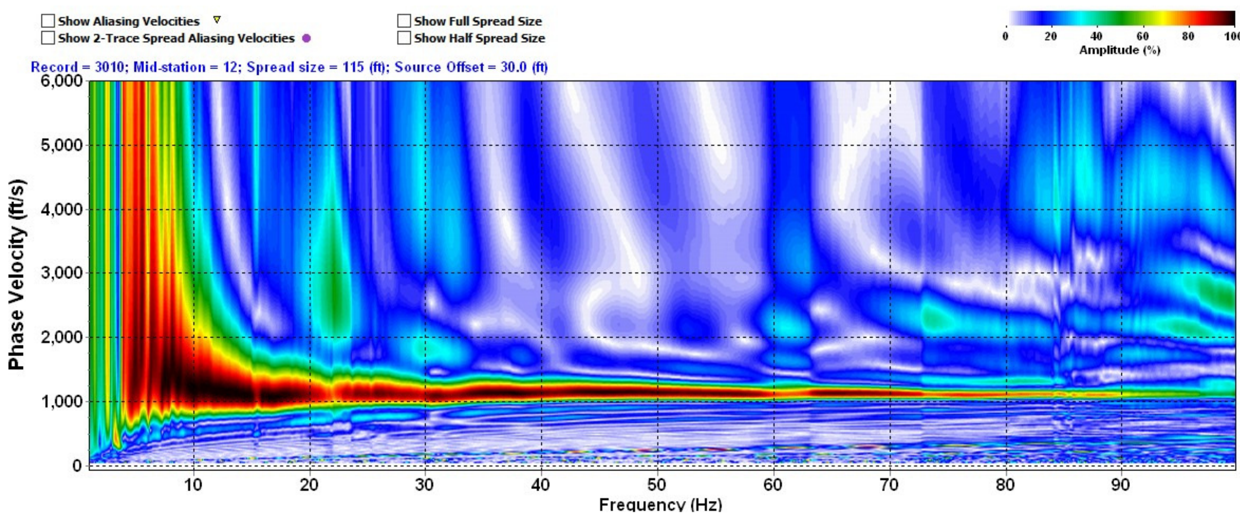
3.3.2.1 Quality Control

Data were given a preliminary assessment for quality control (QC) in the field to assure quality of data before progressing the surveys. Following onsite QC, all data were transferred to the HGI server for storage and detailed data processing and analysis. Data quality was inspected and checked for consistency, and data files were saved to designated folders on the server. Records of survey configuration, location, equipment used, environmental conditions, proximal infrastructure or other obstacles, and any other useful information were recorded during data acquisition and were saved to the HGI server.

3.3.2.2 MASW Processing

The data processing flow for the MASW analysis used the SurfSeis (Kansas Geological Survey, Lawrence, Kansas) MASW processing software. The processing sequence included: encoding the field geometry, generating dispersion images (example shown in Figure 6), extracting dispersion curves, and inversion of the dispersion curves using a gradient-based iterative approach, with the goal of minimizing the RMS error between the observed and calculated velocity curves. The inversion produces a cross section of shear wave velocity as a function of depth, generally ranging between 400 to 2,500 feet/second (ft/s). The quality of the inversion is judged by its convergence achieving an RMS of less than 10% within five to seven iterations.

Figure 6. Example Dispersion Curve



General soil classifications from the National Earthquake Hazards Reduction Program (NEHRP) are shown in Table 3. The table assumes an average of the shear-wave velocity (Vs) over the top 100 feet.

Table 3. NEHRP soil classification for 100-foot average shear-wave velocity.

Site Class	Soil Profile	Shear Wave Velocity (feet/sec)
A	Hard Rock	Vs > 5,000
B	Rock	2,500 < Vs < 5,000
C	Very Stiff Soil / Soft Rock	1,200 < Vs < 2,500
D	Stiff Soil	600 < Vs < 1,200
E	Soft Soil	Vs < 600

4.0 RESULTS

The modeled results for the electrical resistivity and MASW survey lines are presented as two-dimensional (2D) profiles in Figures 7 through 9. A common color contouring scale is used for each method across all of the survey lines to highlight any features that may be indicative of lithologies and to provide the ability to compare intensity of targets from survey line to survey line. For the electrical resistivity profiles, electrically conductive (low resistivity) subsurface regions are represented by cool hues (pink through blue shades) and electrically resistive regions are represented by warm hues (orange through brown shades). For the MASW profiles, low shear-wave velocity is represented by cool hues (purple through blue shades) and high shear-wave velocity is represented by warmer hues (orange through red shades). Other notes of interest about the site, either observed by or relayed to HGI, are also annotated on the profiles. Targets that will be discussed in detail are labeled A-F on each figure.

Complete and independent profiles are presented in the appendix and are best viewed when printed as 11x17.

4.1 LINE 1 RESULTS

Figure 7 displays the electrical resistivity and MASW model results for Line 1, which was collected adjacent to lot 19, starting in the south in the wash. The most obvious feature of the profile is labeled A-A'. This target is an extremely conductive, vertically oriented anomaly that is approximately 20 feet wide starting at a depth of around 15 to 20 feet. It is located beneath electrode 31, placing it beneath the northern wall of the west side of the property. Located near this electrode is the external portion of the air conditioning (AC) unit. There are a few explanations that could explain the anomaly:

- It could be large clayey body, as soils with high clay percentages have much lower resistivity than low or no clay content. It could also be possible that A and A' are two separate and unrelated targets that appear to join together based on lowered resolution as a function of depth. Therefore, they artificially blend together as a results of the model.

- It could be an underground leak that has been leaking for some time based on the size of the anomaly. Highly saturated soils have lower resistivity than drier soils. However, a long-term underground leak is unlikely the case, as a puddle would have likely expressed itself at the surface and there would have been some soil collapse or sinkhole develop. However, there is a water spigot next to the AC unit which could be the source and investigated

- It could be metallic infrastructure of some type. Metal is extremely conductive, much more so than soil. However, this feature does not have a typically recognized pattern of buried metallic objects in the resistivity data. Metal objects typically show an extremely conductive body that is flanked on both sides by bodies with very high resistivity values.
- The AC unit may be causing the interference through electrical grounding. This is an unlikely scenario as the AC unit was not operational for the few hours of collection.

When the A-A' target location is viewed in the MASW data, there is nothing particular that stands out to suggest it is unusual. The very near surface (i.e., top 20 feet) of the entire RVVV neighborhood exhibits soft soils with velocities less than 600 ft/s, with values as low as 395 ft/s. This is different from that of the wash, where all soils have shear wave velocities above 650 ft/s, representing stiff soils. Based on this, we would hypothesize that the body at A is a clayey body unrelated to the very conductive and unknown feature at depth (at A'). At a depth of 30 feet and more, the soils become stiff with higher velocities around 1,000 ft/s, before reducing again to around 800 ft/s at a depth of 45 feet. An isolated conductive clayey body at A fits the pattern of the rest of the ERT data through the neighborhood, as shown at locations B and C. The difference is that below B and C, the soil is resistive, representing higher sand and gravel content (at location D). The borings by ProTeX, FB8, FB11, and FB12, confirm that the near surface is higher in clay content and more damp/moist than the deeper material.

In the wash itself (e.g., at location E), the character of the data is much different, where resistivity and shear wave velocities are both higher. Very stiff soils with values above 1,200 ft/s are observed closer to the surface and there is not a pervasive near surface moist clayey layer. It could be that over the past +10,000 years the position of the drainage channel starting west of the RVVV neighborhood meandered northward or was a braided system depositing alluvial flood materials with high clay.

4.2 LINE 2 RESULTS

Figure 8 shows the ERT and MASW results for Line 2, which was placed south of and adjacent to lot 20. The line started in the west near 725 E Kalalau Dr. and finishes in the wash on the east side, and ran proximal to many of the ProTeX borings. Similar to Line 1, the resistivity data shows several small scale isolated conductive bodies in the upper 30 feet of the profile, e.g., at locations A, D, and G. Boring FB11 penetrates the conductive body at A and shows silty clayey sand from 5 to 35 feet depth, coincident with low resistivity. Below this depth, the soil returns to a silty sand represented by higher resistivity values. For many of the borings, there is a strong correlation between the resistivity and lithology allowing us to extend the boring data outward to better define the entire soil make up beneath the profile.

Within the top 30 feet of soil from distance 200 to 600 feet along the line, we observe two very resistive bodies within the boundaries of lot 20 (marked as B and C), with the western body directly beneath the large cracks of the block wall used for privacy. The cracks exceed one inch in places and suggest large soil displacements. Below the eastern resistive body, marked as C, a larger conductive body is observed likely representing clay.

The MASW data shows low velocity material (less than 600 ft/s, representing soft soil) in the upper 25 feet across the same area and is similar to observations of Line 1. Below this depth, the velocity is highly variable, showing very stiff soil below locations B and C (with values at 1,200 ft/s or higher) and slightly slower velocities between them. As confirmation, boring FB13 near location B shows blow count for the boring penetration as exceeding 30 in the very stiff soils. This is compared to values much less than 30 in FB12 further west with no very stiff soils identified. It would seem reasonable to hypothesize, then, that the soil lithology and variable stiffness may be causing uneven settling of the soils beneath lot 20. The high variability in soil stiffness is below a depth of 30 feet, making them naturally deposited and buried below the existing topography at the time construction began.

On the west side of the line, west of the road marked on the geophysical profiles and west of FB12, we see a slightly lower resistivity layer in the near surface with much higher resistivity below it (at location F). The character of the resistivity along E Kalalau Dr is different than that nearer the wash. The MASW data also shows less variability in shear wave velocities than that beneath lot 20. The lower variability in shear wave velocity with consistent sandy-like soil seen in the resistivity may be the reason the houses in the western portion of E Kalalau Dr. have not experienced significant settling.

Within the wash towards the east (location G), we observe the low resistivity layer continuing for the entire distance of the line. The lower resistivity correlates to higher clay content or wetter soils. This fits with the hypothesis of the historic buried channel described in Line 1 depositing fine-grained soils during flooding. The historic channel appears to have a finite boundary as identified by the higher resistivity values along the southern extent of Line 1.

4.3 LINE 3 RESULTS

Figure 9 displays Line 3 with geophysical profiles along lot 20, perpendicular to Lauterbrunnen Ln. The line started to the west behind houses along E Barun Valley Place and continued eastward into the CDO wash. The line was placed immediately south of the block privacy wall along the upper portion of a large drainage channel armored with rip-rap on the sides and bottom. The most obvious feature within the line is the large very resistive feature within the confines of the concrete retaining wall; this feature is marked as A. Below A is an extremely conductive feature marked as A’. The resistivity values at A greatly exceeded those of Lines 1 and 2, therefore the resistivity color scale was extended to values above 10,000 ohm-m (log transformed to 4) to accommodate the data. There are a few possible explanations for the large resistivity feature:

- Electrodes were placed between the privacy wall and the concrete retention structure. The space was approximately 6 to 8 inches wide filled with loose sand. Some electrodes could not penetrate the soil beyond a few inches because it hit concrete. Therefore, the high resistivity could simply be due to the confined space, and the data represent the cured concrete. We have imaged around concrete structures before, but not in such close proximity. The values of concrete in other datasets have been shown to vary between 100 and 1000 ohm-m depending on the surrounding soil moisture conditions.

- The high resistivity could represent rip-rap, which have large, open, and dry spaces. We have imaged rip-rap in other situations and they have been shown to be highly resistive.

- The high resistivity could be extremely dry (desiccated) and compacted soils. The MASW data, however, discounts this hypothesis because the shear wave velocity through this material is quite low. It is not until a depth of 45 feet below surface that we observe some very stiff soils.

- The top 5 to 7 feet above the resistive feature is shown to be extremely conductive, likely representing moist soil conditions.

- The feature at A' in the electrical resistivity profile is an overfitting of the model and is calculated to be artificially highly conductive against the large resistive target at A. We have observed this model overfitting before. The area below A is likely wet and have low resistivity value, but more on the order seen at depth in the beginning of the line.

The prevailing hypothesis is that the electrical current was confined by the concrete retention structure. At locations B, C, and D, we observe the same isolated clayey bodies that were in Lines 1 and 2, therefore we can likely interpret through the feature at A and assume that the same pattern exists here. Additionally, the MASW data between B and D exhibit the same level of variability of soil stiffness as Lines 1 and 2, which may be contributing to the differential settlement across lot 31.

Near location B is boring FB15 by ProTeX. The top 25 feet of the driller's log of FB15 indicates silty sand and gravel with clay increasing to the bottom of the hole. The notes also indicate that the soil is damp, likely from surficial runoff from the property and from the adjacent drainage channel. These observations match closely with the resistivity data.

Moving westward to location E, we see another large resistive body. It is not as resistive as A, and there were no obvious concrete retention structures. We believe that the material at E is a large sandy gravel lens with fairly uniform soil stiffness. The small conductive bodies above correlated with small drainage ditches that allow water to drain from residential backyards.

Figure 7. Coincident electrical resistivity and MASW model results for Line 1.

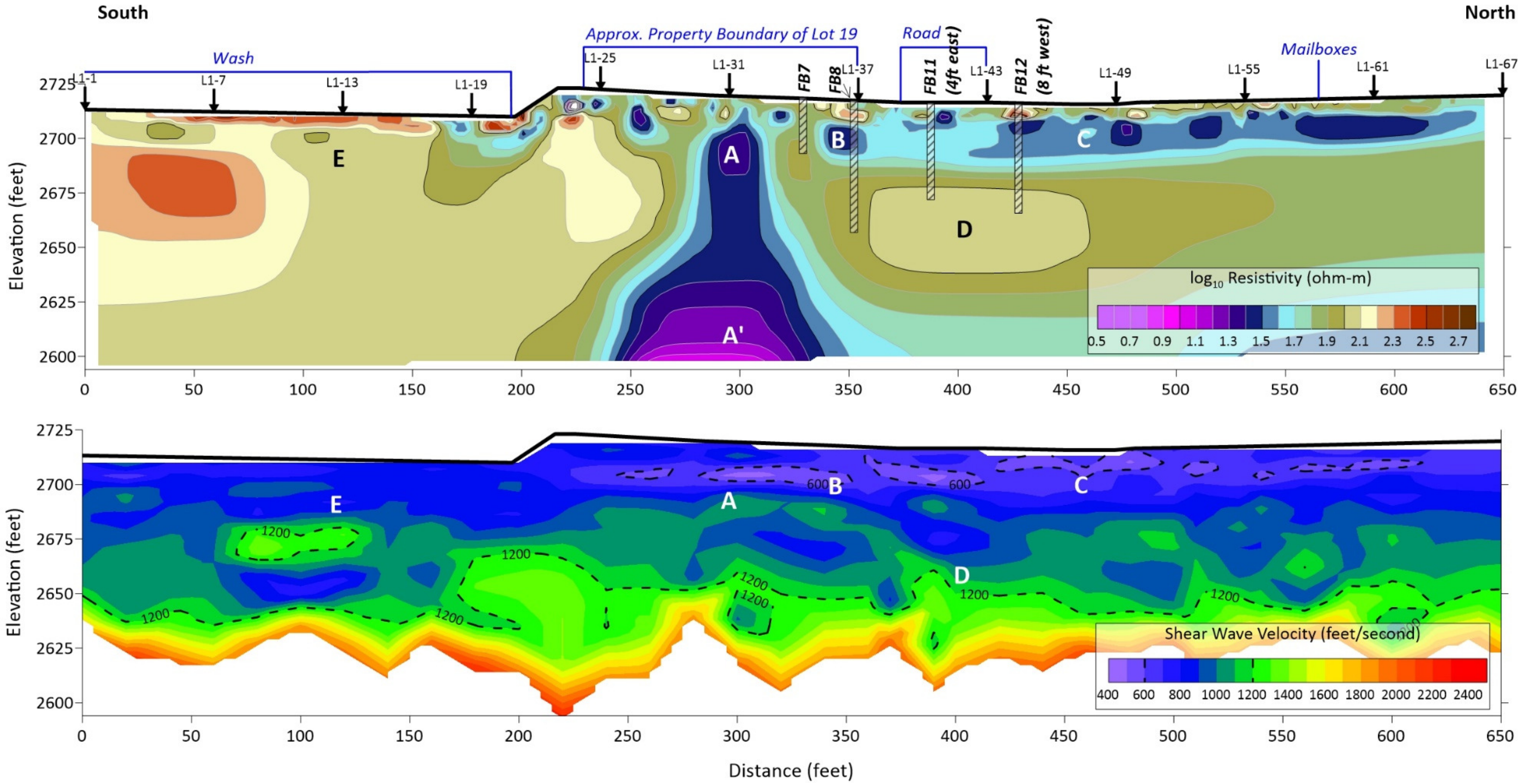


Figure 8. Coincident electrical resistivity and MASW model results for Line 2.

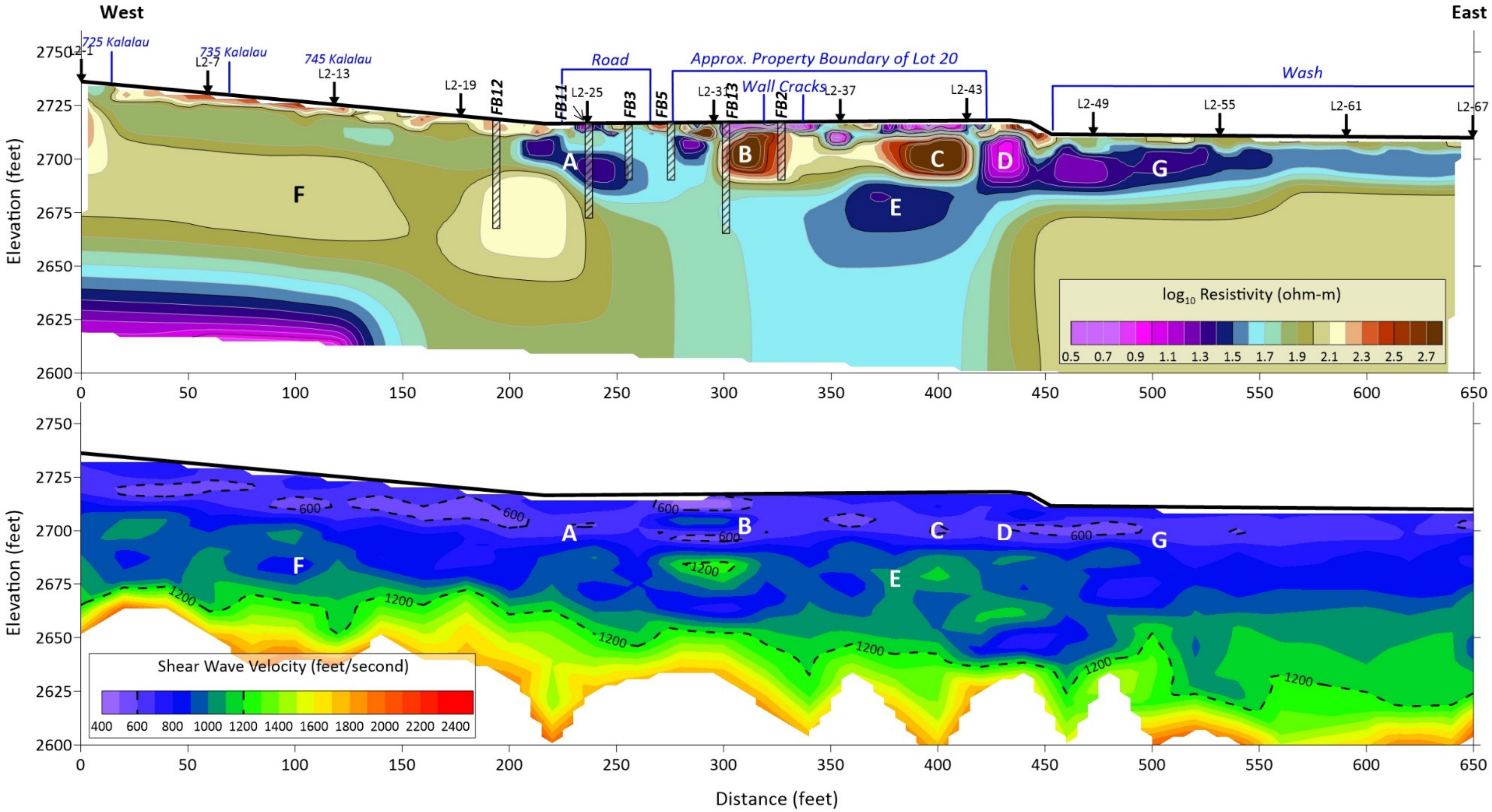
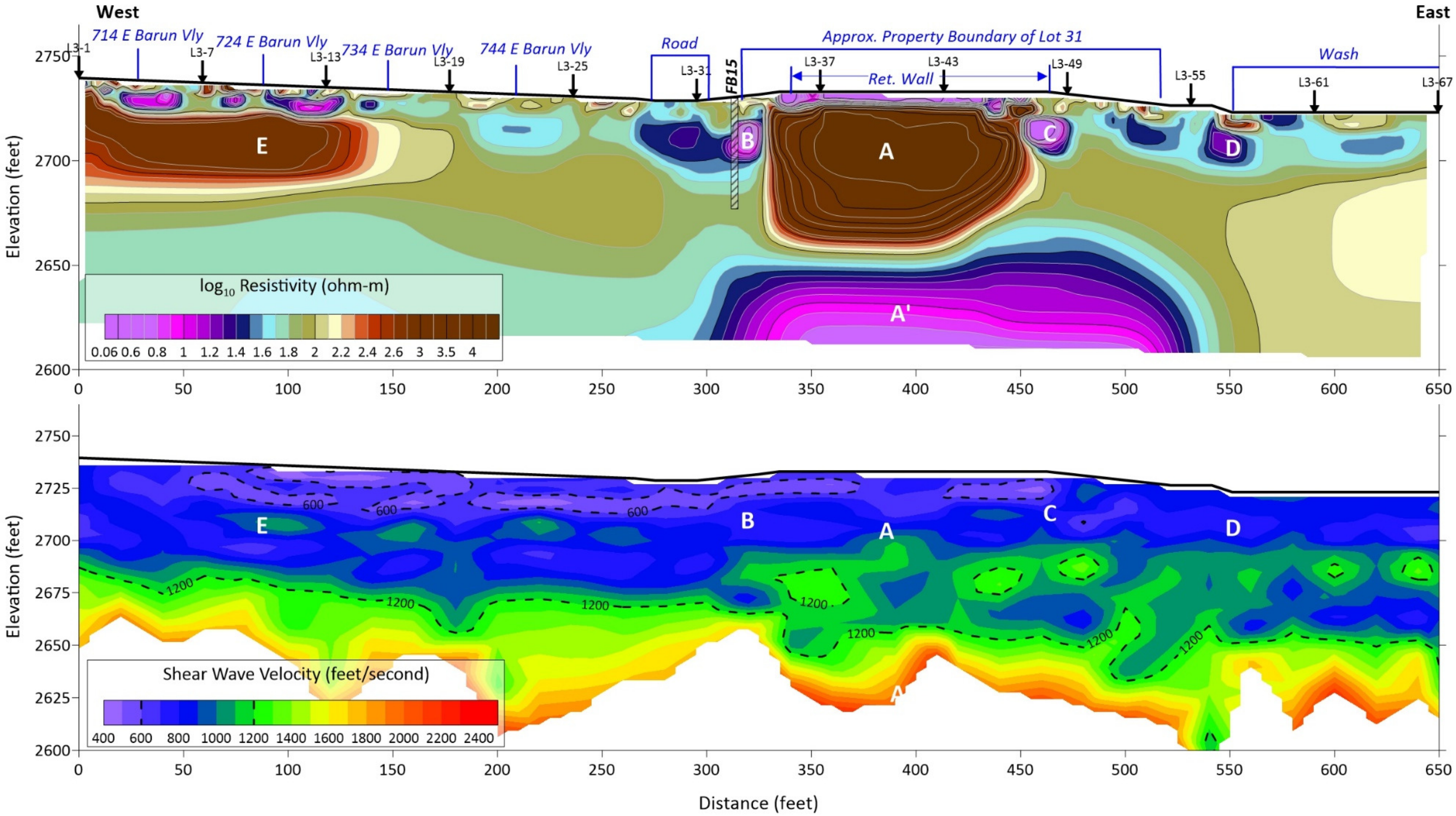


Figure 9. Coincident electrical resistivity and MASW model results for Line 3.



5.0 CONCLUSIONS

A geophysical investigation, that included coincident ERT and MASW data collection, was conducted adjacent to three lots in the RVVV neighborhood to provide context to subsurface conditions that may be leading to differential settling and cracking in foundations, pavements, and walls. The ERT data provided information on the generalized lithology, where clayey soils manifest as low resistivity values and sandy/gravel soils will be high resistivity. Moisture also plays a role to make the soil more conductive (lower resistivity). The MASW survey measured the shear wave velocity of sound waves moving through different soils. Higher velocities relate to stiffer soils that are more resistant to stress-induced deformation. Slow velocities, typically below 600 ft/s, are defined as soft soils.

Within all three lines, we observed in the ERT data a generalized layer of possible clayey materials in the near surface (top 20 feet) that was typically soft as defined by shear wave velocity. The soft soils were limited to the boundaries of the neighborhood and did not continue in the adjacent wash. The soft soils also extend below that of the fill, which was likely less than 10 feet deep across the survey area. The possible clays were likely deposited from a meandering or braided channel during flooding and appears to be confined to the southern boundary of the RVVV neighborhood. The area to the south of lot 19, for example, did not show any clayey materials in the resistivity data.

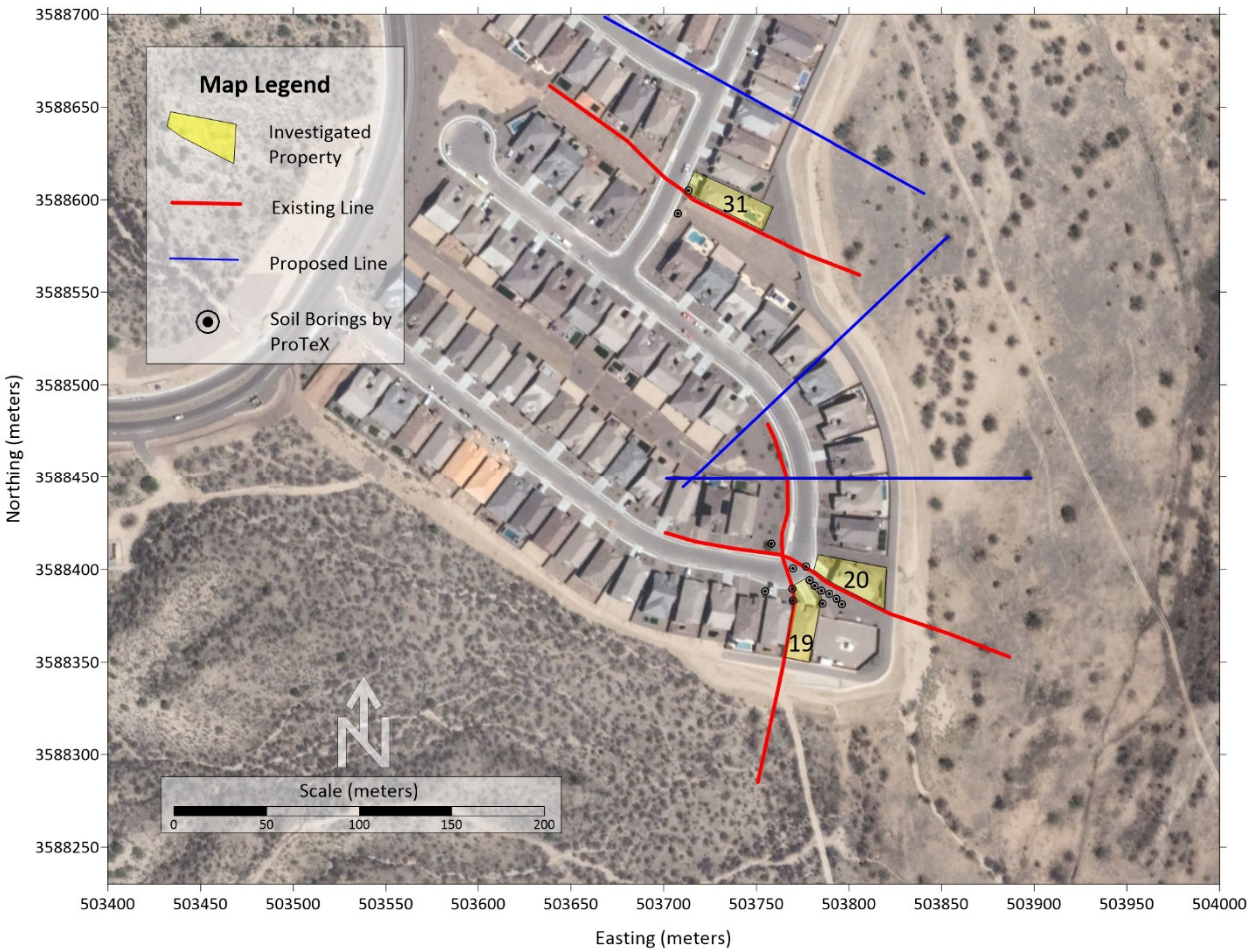
The next layer down, extending up to 45 feet depth showed, possibly higher sand content and higher resistivity. This material appears to be more competent with isolated areas showing shear wave velocities above 1,200 ft/s. The issue, however, is the variability in the velocity, where large changes were observed over short distances, particularly beneath each lot. The variability in stiffness at depth may be contributing to the differential settling at the surface.

We recommend more borings to follow up on targets to validate and calibrate our findings. The boring should extend deeply (75 feet or more) to characterize the stiffer soils. The locations include:

- Position A on Line 1
- Positions B, C, D, and E on Line 2, closer to lot 20 than existing borings
- Position F on Line 2 as a validation of stiffer soils and minimal clay
- Between positions A and B on Line 3 and position C. For access, these may need to be angled borings

We also recommend three additional survey lines within this neighborhood to determine if similar adverse soil conditions may exist. A key tenant in risk mitigation is to have as much information as possible to develop plans for remedial action. The additional geophysical lines will help guide drilling if those adverse conditions are shown to exist.

Figure 10. Recommendations for Additional Geophysical Data in RVVV.



6.0 REFERENCES

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APPENDIX A

Figure A1. ERT Line 1

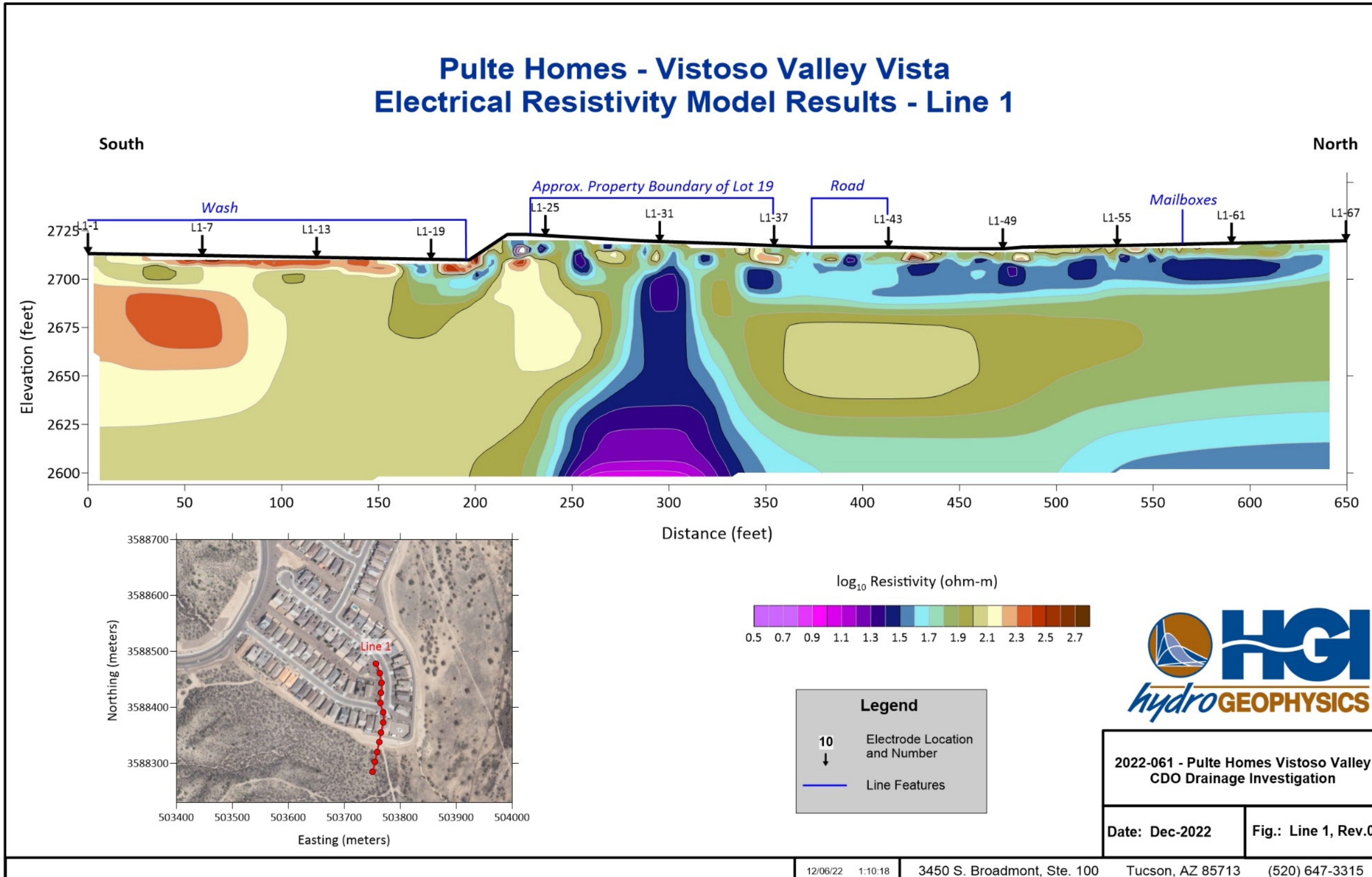

Figure A2. ERT Line 2

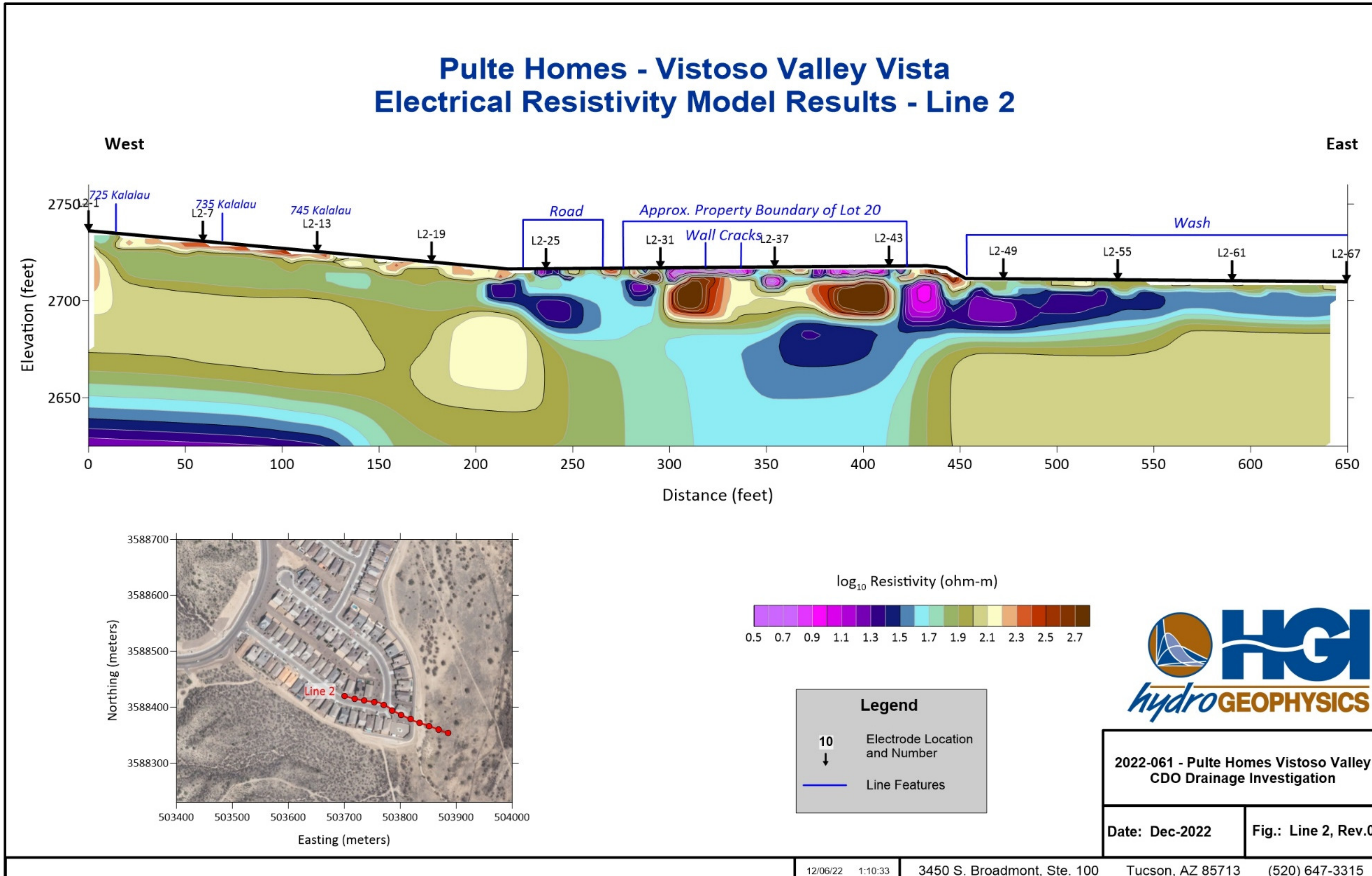

Figure A3. ERT Line 3

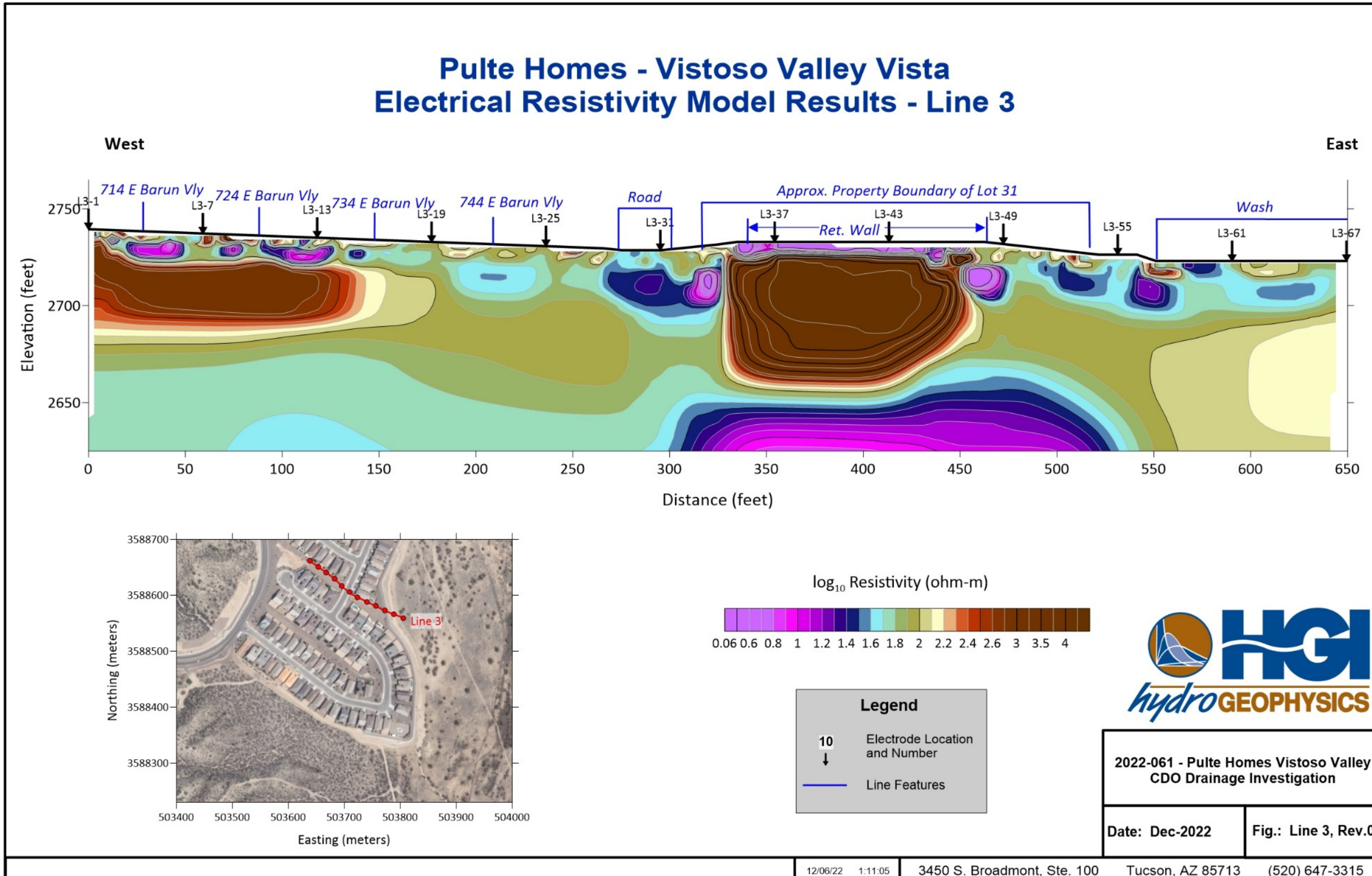

Figure A4. MASW Line 1

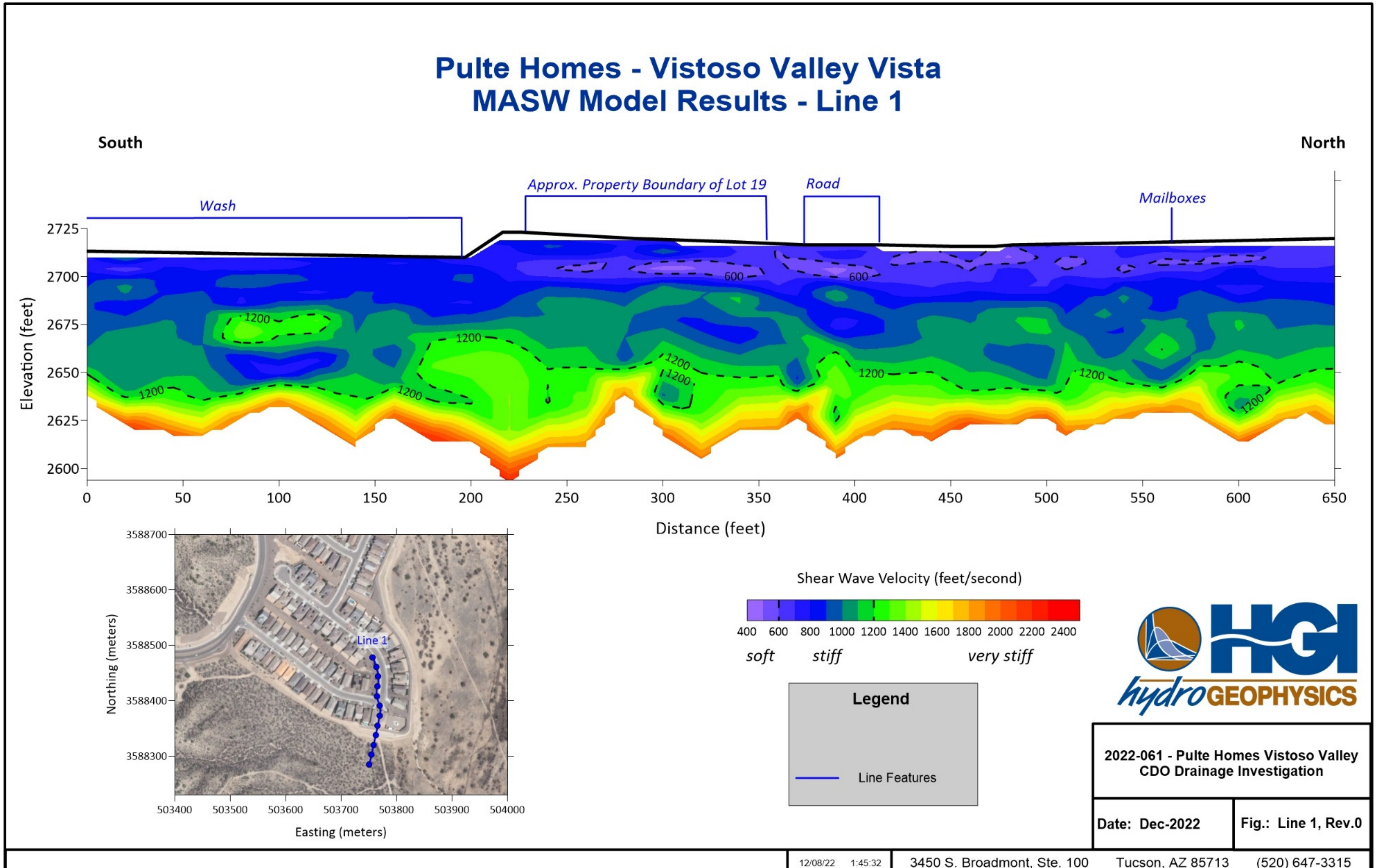

Figure A5. MASW Line 2

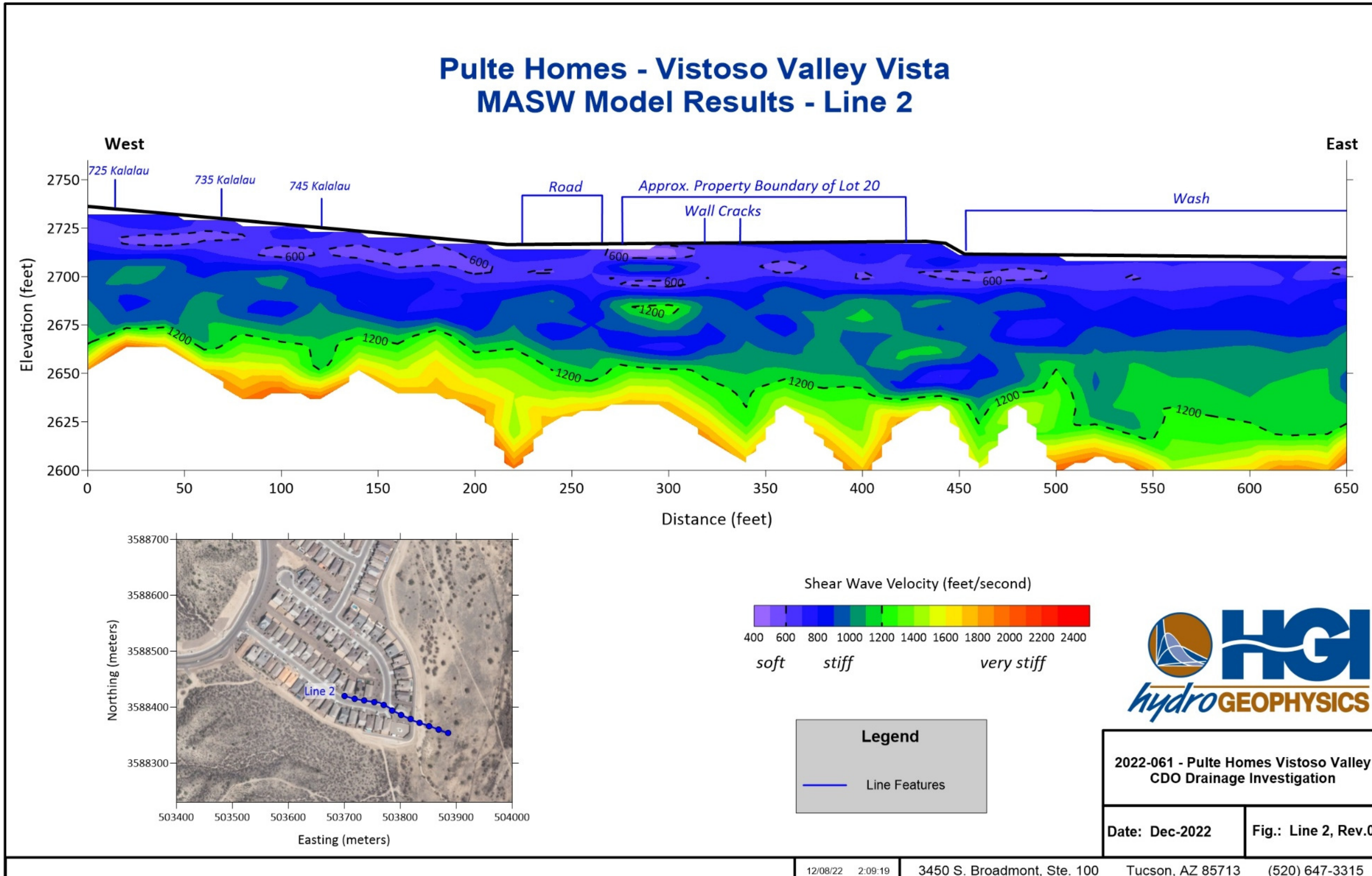

Figure A6. MASW Line 3