Geophysical Investigation of the Depth to Bedrock at a Chemical Recycling Center

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I. Introduction

Waste Recycling and Research (WRR) is chemical reclamation and recycling center in Eau Claire, WI. Underlying the WRR site are two unconsolidated aquifers: an overlying unconfined aquifer and a deeper partially confined aquifer. Contaminants have been detected in both aquifers, but the highest concentrations are found in the deepest wells in the lower aquifer, indicating that dense contaminants may be pooling at the bottom of this aquifer. The lower boundary of the partially confined aquifer is a sandstone unit, but the bedrock surface is highly irregular. To better remediate this aquifer, the depth to bedrock at different locations must be determined. In this project, we used geophysical techniques to help determine the depth to bedrock. We collected data using seismic refraction, resistivity, electromagnetic, and gravity methods (Figure 1) and integrated these data with boring logs (Figure 2) to better characterize the depth to bedrock across the site.

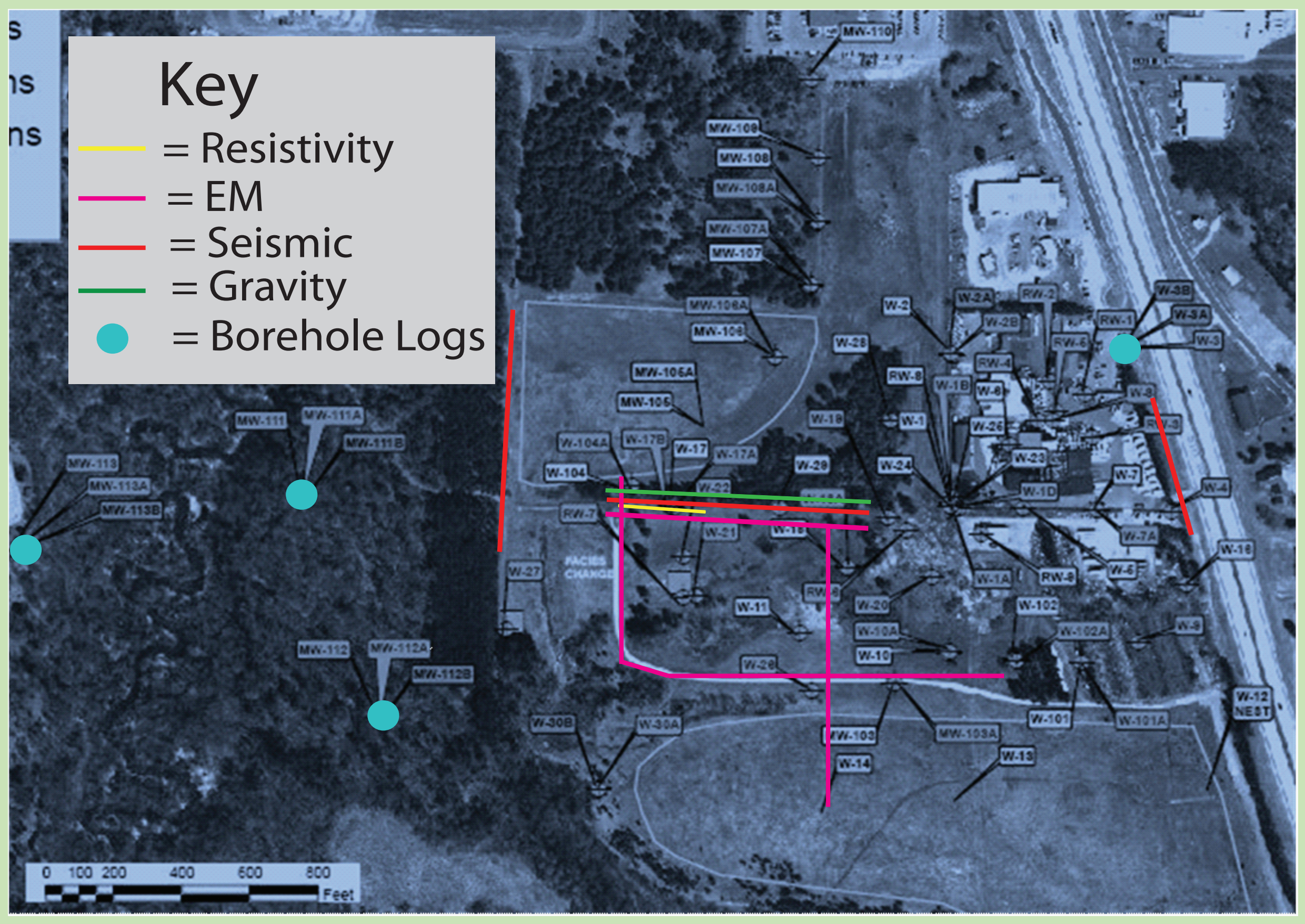

Figure 1: Site map of WRR showing the locations of geophysical data acquisition and boreholes. The four boreholes marked with a blue circle intersected the soil-bedrock interface.

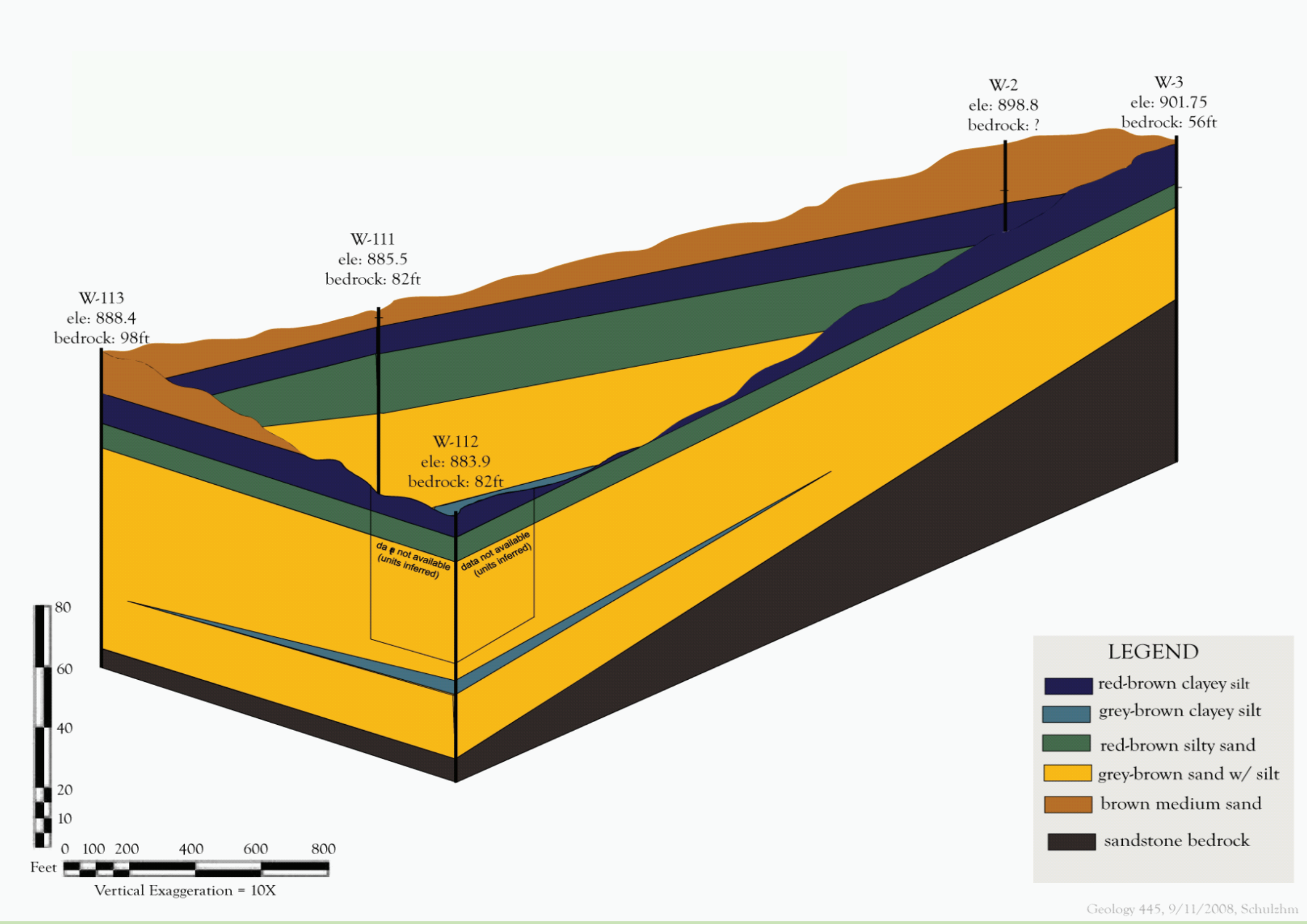

Figure 2: Fence diagram of WRR site based on borehole logs. The bedrock elevation decreases to the west.

II. Resistivity

Resistivity data were acquired using an offset Wenner array with a Bison electrode switchbox that allowed measurements to be acquired at many different electrode spacings without relocating the electrodes (Figure 3). After data had been acquired with all possible electrode spacings at one location, the entire array was moved along the traverse by 20 m. The electrodes were moved four times, resulting in an 80 m traverse (Figure 1).

Resistivity data were processed using Res2DInv software. The apparent resistivity (Figure 4) was calculated from voltage measurements, then a resistivity pseudosection was created (Figure 5). The resistivity pseudosection indicates a bedrock low near the center of the traverse, as the resistivity in this area is much lower than near the edges of the traverse. However, the resistivity pseudosection is probably invalid at depths greater than ~35 m, as the maximum electrode spacing of this survey (128 m) does not allow accurate resistivity estimation at depths greater than ~35 m. Thus, the resistivity pseudosection is useful for indicating the location of a possible bedrock low, but not the actual depth to bedrock at this location.

Figure 3: An Offset Wenner array was used to acquire resistivity measurements.

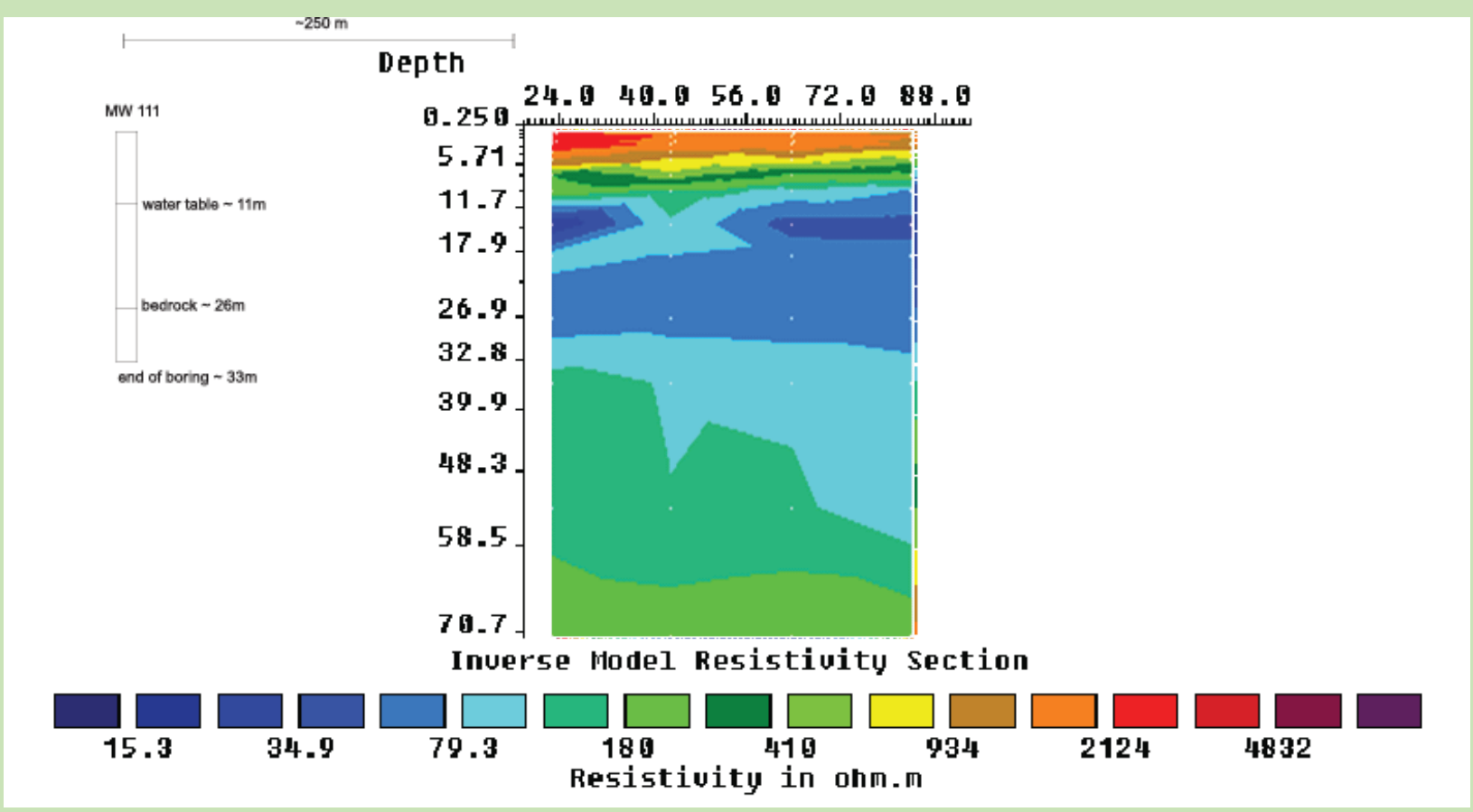

Figure 4: Apparent resistivity from the Wenner array.

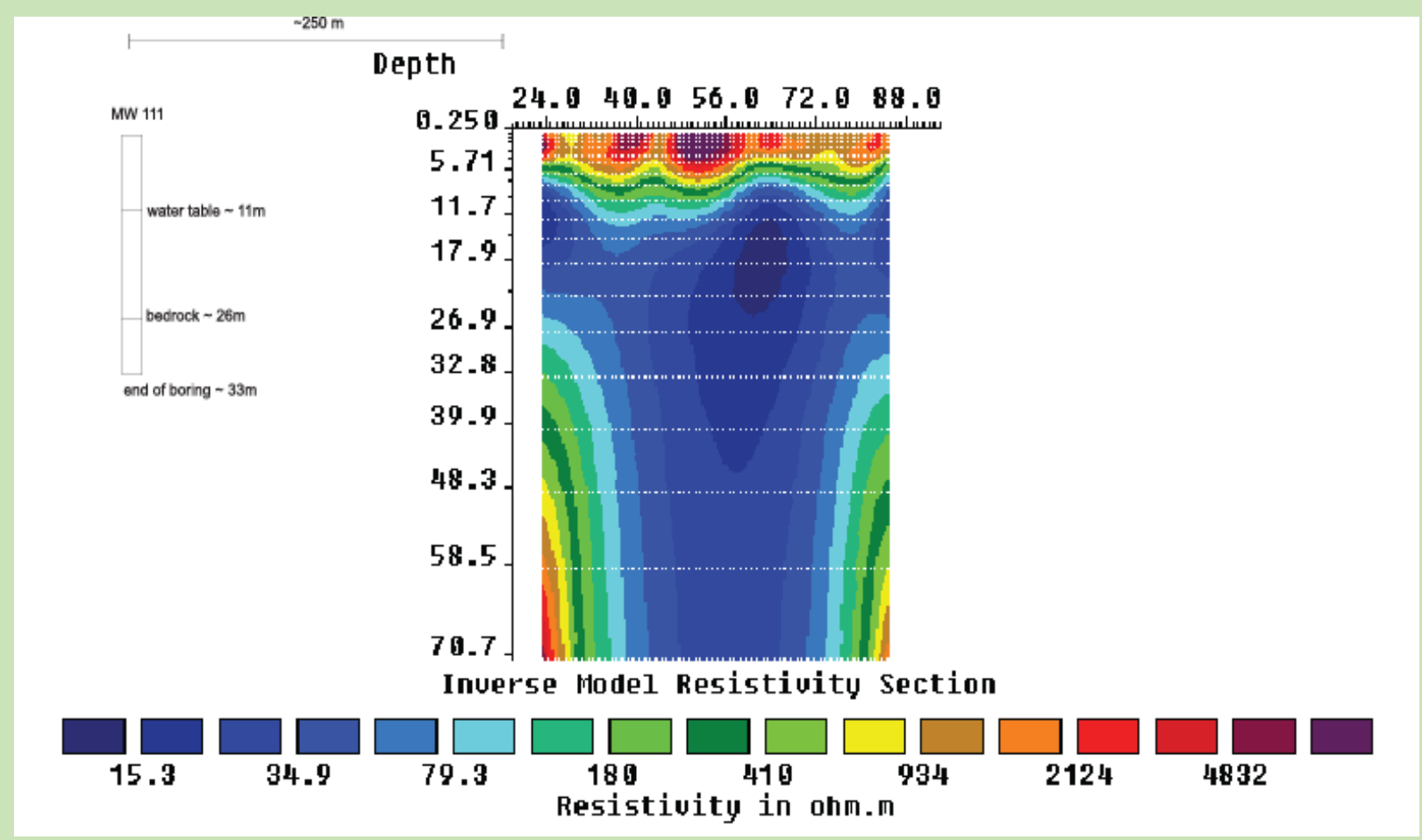

Figure 5: Resistivity pseudosection created using the apparent resistivity measurements in Figure 4.

III. EM34

An EM 34 (Figure 6) was used in a horizontal dipole mode to measure the electrical conductivity. Measurements were acquired with a 40 m separation between the transmitter and receiver; this separation distance is expected to result in an EM field that penetrates 30 m into the subsurface. EM34 measurements were aquired at 20 m increments along four traverses (Figure 1).

Figure 6: A Geonics EM 34 was used to acquire electrical conductivity data.

Using the four EM traverses, a contour map of electrical conductivity was created (Figure 7). This map shows that electrical conductivity is high in the northeastern portion of the survey area, but decreases to the west/southwest. Since the conductivity of the sandstone bedrock is expected to be lower than that of the overlying silty sand, we interpret the high conductivities in the northeast as an area of greater depth to bedrock. The very low conductivities observed on the southern portion of the map (and in the northwest corner) correspond to areas where the uppermost ~8 m of soil have been removed (these are borrow pits), so teh EM 34 field penetrates more fully into the low conductivity bedrock.

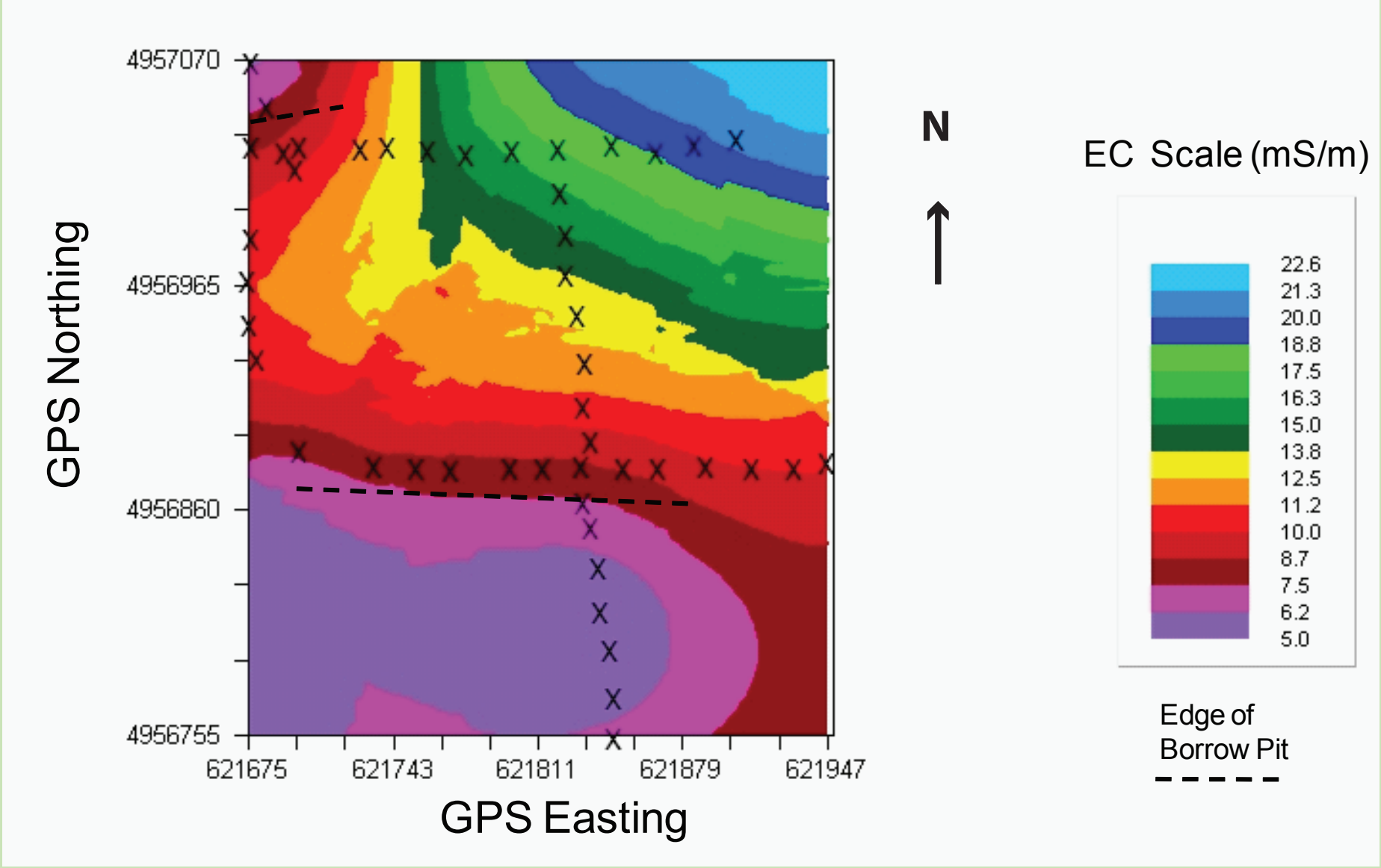

Figure 7: Contour map of electrical conductivity, where lower conductivity represents decreased depth to bedrock. The location of each measurement is shown by an "X".

IV. Seismic

Figure 8: A metal plate was struck with a sledgehammer to create a seismic wave.

Seismic refraction surveys were performed along three traverses, but only very limited information could be obtained from these surveys. Where the bedrock was thought to be shallow (the eastern-most traverse), a sledgehammer was used as the seismic source (Figure 8). In areas where the bedrock depth was greater, a backhoe source was used, where a seismic wave was generated by quickly dropping the backhoe bucket to the ground. Although data were stacked 10-15 times at each location, noise caused by highway traffic, vibrations from nearby machinery, and periodic light rain made it very difficult to accurately determine the arrival time of the refracted wave. Also, the penetration depth of the sledgehammer source was limited, and the backhoe source did not create a sharp seismic signal, further complicating data interpretation. For most surveys, only the direct wave could be chosen from the travel-time data. The only survey that showed a strong refraction event (Figure 9) was collected at the middle seismic traverse and indicated that the soil-bedrock interface was at ~30 m. Although this estimate is reasonable for the location, the measured bedrock velocity is higher than expected, casting doubt on the accuracy of the survey.

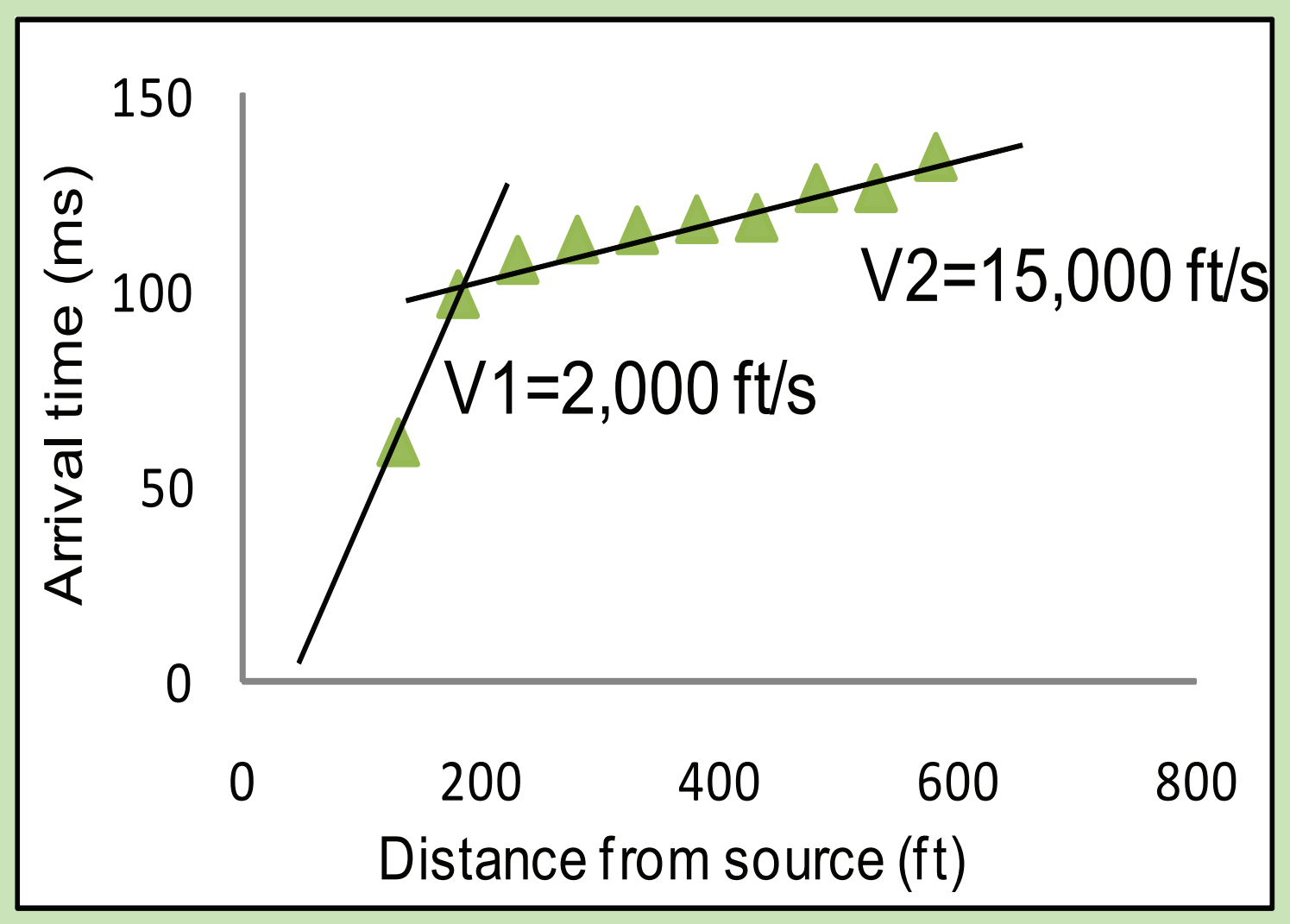

Figure 9: Seismic data acquired at the middle seismic traverse shown in Figure 1.

V. Gravity

Micro-gravity data were acquired using a Lacoste and Romberg gravity meter (Figure 10). Data were acquired at 10 m increments along the main E-W traverse shown in Figure 1 and were corrected for instrumental drift and earth tides. Corrections for elevation were not required due to the lack of topographic variation along the traverse, and latitude corrections were not required because these data were acquired along the same latitude and covered only a small area.

Figure 10: Aquisition of gravity data.

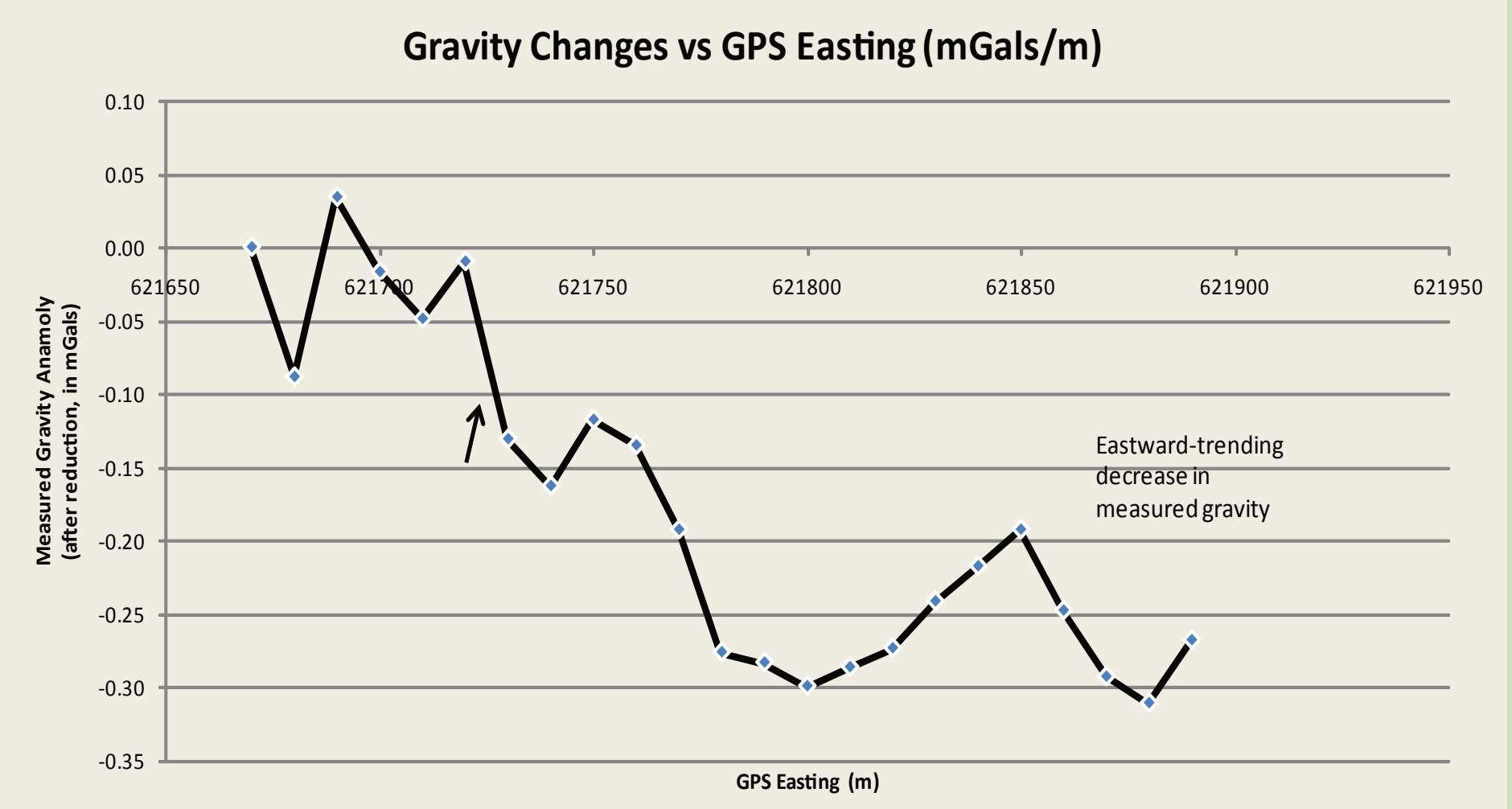

Figure 11: Gravity anomaly along the traverse shown in Figure 1.

The sandstone bedrock is expected to have a higher density than the overlying soil, so higher gravity measurements are interpreted as indicating zones where the bedrock is closer to the ground surface. Figure 11 shows that the gravity measurements vary along the traverse, indicating that the bedrock surface is uneven. Despite local variations, the general trend of the gravity measurements shows decreasing gravity to the east, suggesting that the depth to bedrock increases in this direction.

VI. Conclusions

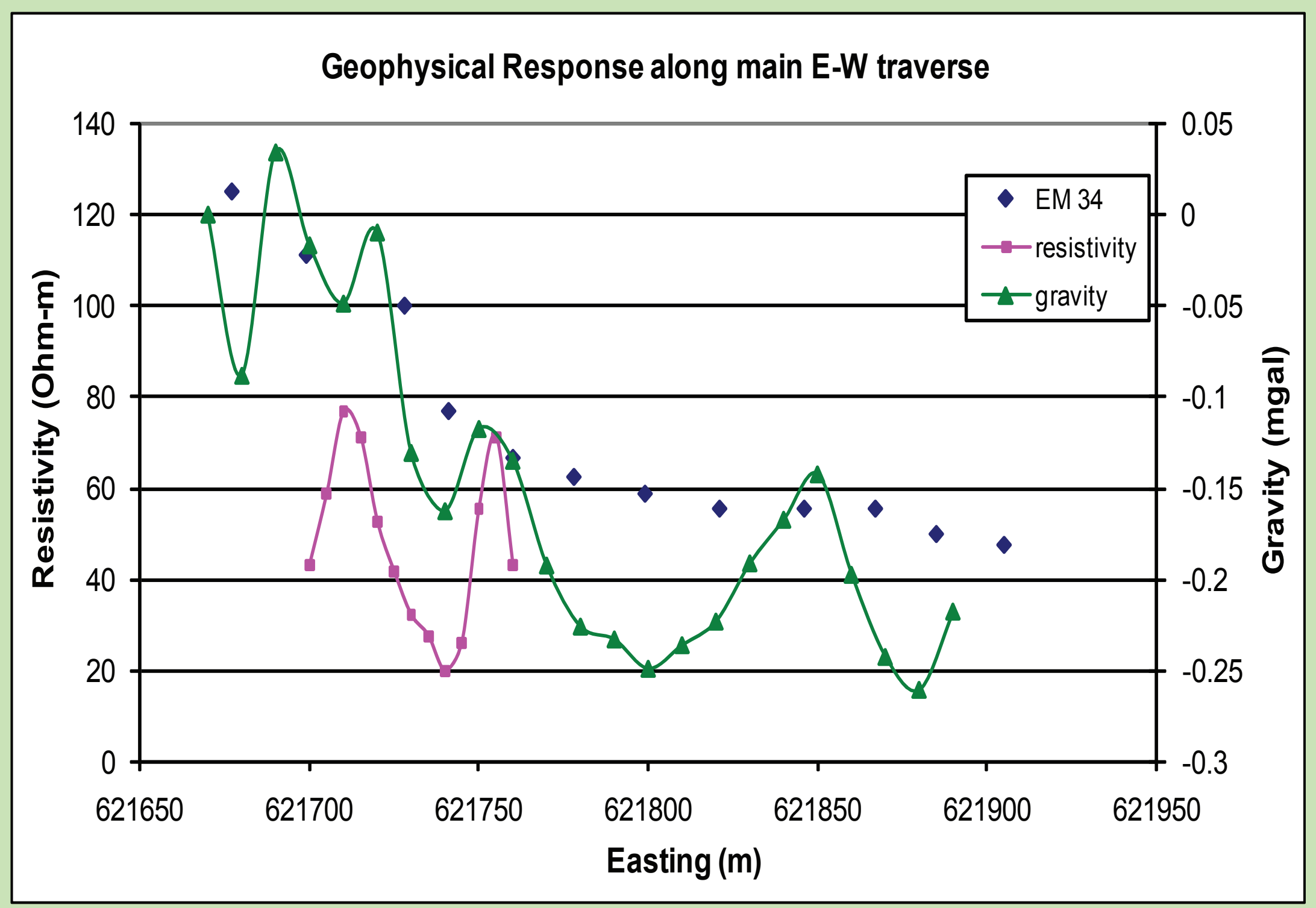

Figure 12: The different geophysical techniques show similar trends across the main E-W traverse shown in Figure 1.

Data from three of the geophysical methods were compared to better understand how bedrock depth varies across the site. Since the geophysical techniques have different sampling volumes, some manipulation was needed before meaningful comparisons could be made. To compare resistivity with the other techniques, "point" measurements of resistivity were created from the resistivity pseudosection by taking the vertical average of resistivity from 0-30 m depth at 5 m increments. These vertically averaged resistivity measurements could then be more easily compared with electrical conductivity and gravity. The electrical conductivity measurements from the EM34 were also converted to resistivity to make visualization of the data more straightforward.

The different geophysical methods generally agree quite well. The general trends of the gravity and EM34 data are similar (Figure 12); both methods indicate an increase in bedrock depth to the east. The electrical conductivity and resistivity data do not entirely agree, as the resistivity data show an area of low bedrock bounded by higher bedrock on each side, while the conductivity data show bedrock continuously decreasing in elevation to the east. Much of this apparent disagreement can be explained by considering the difference in sampling volumes and resolution of the two techniques. The EM34 samples a much larger volume with relatively poor resolution, while the resistivity samples a small volume in the shallow subsurface (large volume for deeper measurements) with high resolution. It is likely that the apparent disagreement in EM and resistivity data are caused by these differences; the EM34 covers a larger area but misses some of the more detailed information provided by resistivity methods. This conclusion is further supported by the comparison of the high-resolution gravity data with the resistivity measurements; these techniques show similar local undulations in the bedrock surface.

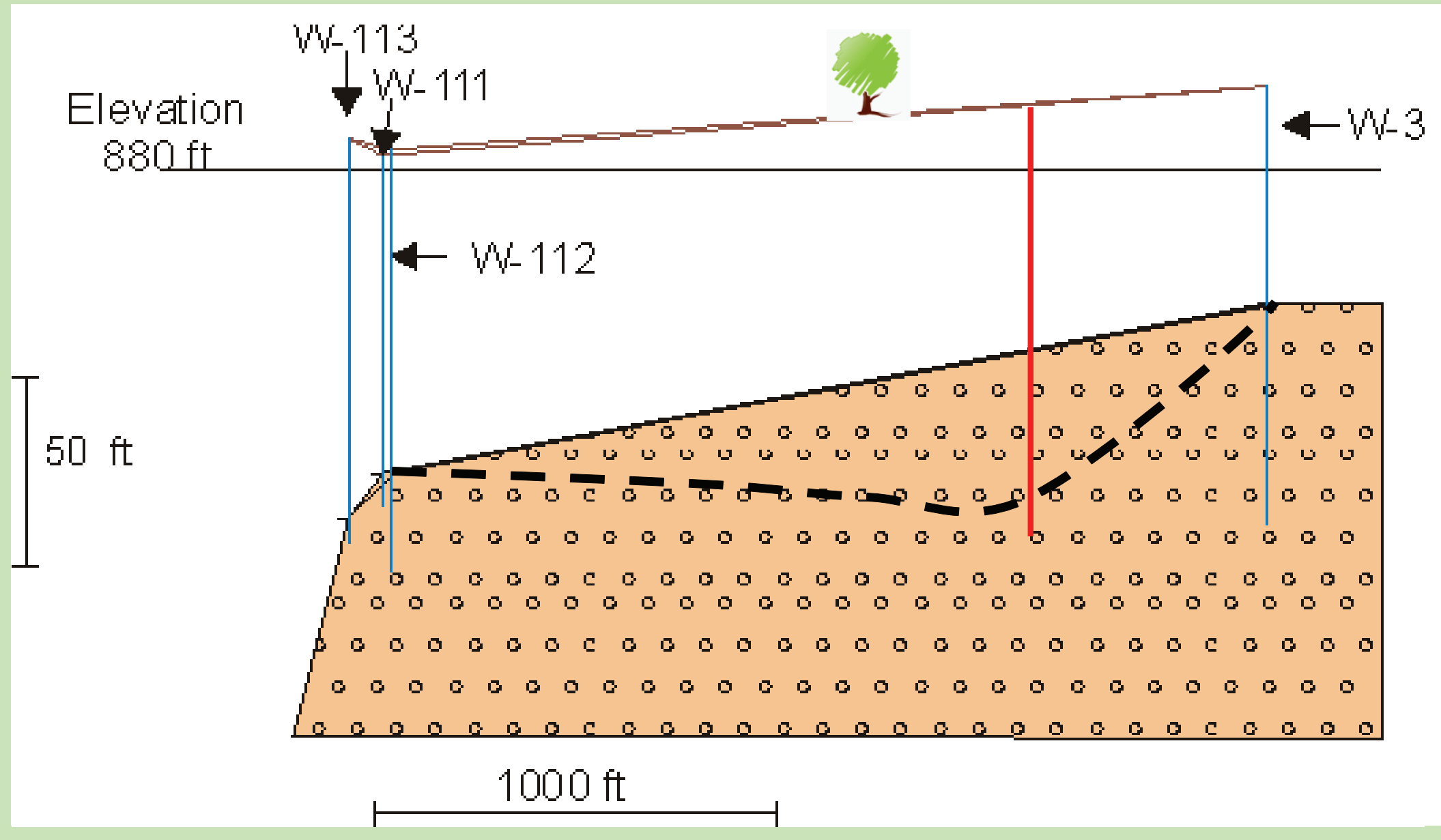

Figure 13: Cross-section of the bedrock surface (shown in tan) using borehole logs (interpolated constant slope) and after integrating geophysical data (dashed black line).

Although the geophysical data provided useful information about the depth to bedrock at this site, it is important to verify the geophysical information through borehole logging. Figure 13 shows the location of a proposed borehole. The cross-section shown in this figure is the bedrock surface interpolated from borehole information. Since borehole information is limited, the bedrock slope is shown as a straight line. The vertical red line in this figure shows the easternmost extent of the geophysical data and indicates the location of the proposed borehole. The black dashed line shows the suspected bedrock topography after integrating the geophysical and borehole information.