Mapping Depth to Bedrock at Utility-Scale Solar Projects with Terrain Conductivity Meter Data

ABSTRACT

With the recent increase in utility-scale solar projects, engineers are faced with the challenge of determining the appropriate foundation design in geographic areas that are dominated by varying shallow subsurface conditions. Traditionally, information to aid in foundation design is obtained through geotechnical drilling programs. However, the relatively high cost of drilling programs often leads to highly detailed drill logs with a low spatial resolution, resulting in a model that may omit local depth to bedrock variations. This is especially true when constructing solar projects over highly weathered carbonate bedrock, where dissolution and other karst-related processes result in bedrock topography that varies greatly over short lateral distances. To supplement an existing drilling program, geophysical methods such as terrain conductivity mapping can help to rapidly "fill in the blanks" and map depth to bedrock with higher resolution at relatively low costs. THG has assisted in mapping shallow bedrock on several solar projects, some exceeding 1,000 acres, by deploying a UTV-mounted terrain conductivity meter.

THE INSTRUMENT

THG deployed a GF Instruments CMD Explorer terrain conductivity meter (TCM) to image the subsurface. The TCM is a 15-foot-long cylinder containing three sets of transmitting and receiving coils at dipole separations of 4.9, 9.3, and 14.7 feet, allowing for a penetration depth of up to 30 feet.

The TCM is used for the measurement of the electrical conductivity of subsurface soil, rock, and groundwater. The electrical conductivity (or its inverse, resistivity) is a function of the porosity, permeability, and the fluids in the pore spaces. TCM is an excellent tool for quickly mapping variations in subsurface materials.

Transmitter coils generate a primary electromagnetic field that induces eddy currents in the subsurface. These eddy currents generate a secondary electromagnetic field proportional to the magnitude of current flowing within the transmitter coil. The quadrature and in-phase components of this secondary field is captured by the receiver in the form of an output voltage that is linearly related to subsurface conductivity. These measurements can be obtained rapidly, often at a rate of 5-10 readings per second.

When paired with digital global positioning system and mounted on an all terrain vehicle, data can be acquired at speeds of up to 12 miles per hour, allowing for rapid, high-resolution data collection.

***Figure 1**. The GF Instruments CMD Explorer mounted on a UTV.*

DATA COLLECTION

A 35-acre portion of a larger solar project was imaged using TCM methods. The survey area consisted of rolling agricultural fields accessed during the off-season to avoid crop damage and avoid potentially difficult conditions for survey collection.

At this site, the subsurface consists of clay and sandy soils underlain by fine- to coarse-grained, horizontal, thin- to medium-bedded limestones. Some thin-bedded shales occur throughout the formation.

With the GF CMD Explorer, approximately 15,200 measurements were recorded with a line spacing of 40-60 feet and 1.5 feet between data points along the lines. Data collection was completed in about 2 hours and the following processing, inversion, and interpretation took about 8 hours.

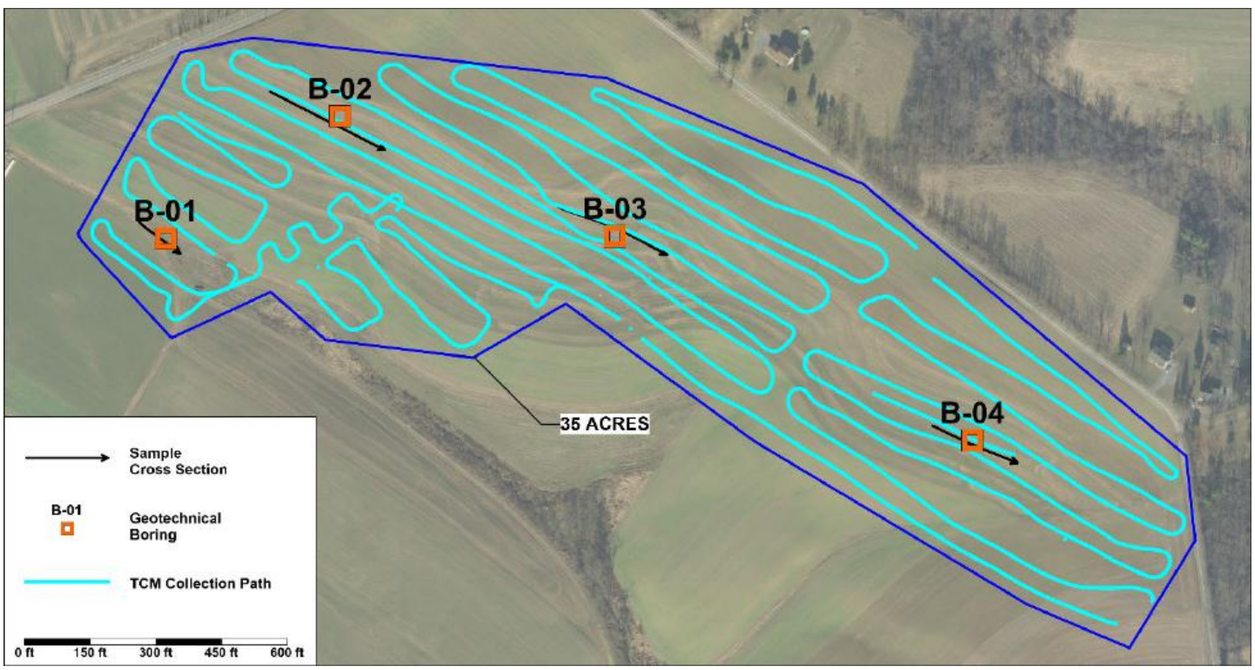

Figure 2*. Map of UTV-mounted TCM collection paths. Cyan lines represent collection paths with the GF Instruments CMD Explorer instrument. Orange squares are geotechnical borings. Once processed and inverted, cross sections (black lines) were generated over borings to compare resistivity data against known boring data.*

DATA PROCESSING AND INTERPRETATION

TCM data were post-processed and inverted using Aarhus Workbench software. The quadrature phase measurements were converted to resistivity for processing.

Processing resistivity data consists of several steps designed to improve the signal-to-noise ratio, allowing for a more successful inversion. Negative data and noisy data due to couplings to fencing and buried utilities were removed. The data was averaged using a median filter with a length of 3 meters. Client-provided LiDAR elevation data were applied to each measurement for accurate vertical positioning.

Processed data were inverted with a smooth model 15-layer, spatially constrained inversion (SCI) algorithm. An SCI is a 1D inversion with 3D constraints. There are constraints on resistivity along survey lines, between survey lines, and between vertical model layers. The strength of spatial constraints is scaled linearly with distance, effectively disabling constraints between measurements that are far from one another.

RESULTS

Post-processing and inversion resulted in approximately 15,000 locations containing resistivity values that vary with depth. To extract useful information such as depth to bedrock from this data, associations must be made between known boring data and resistivity.

To accomplish this, cross sections are drawn over existing borings and relevant boring data are overlaid on the profiles. The resistivity values at the transition from soil to bedrock are recorded. For this site, this transition occurs at 50-80 ohm-m.

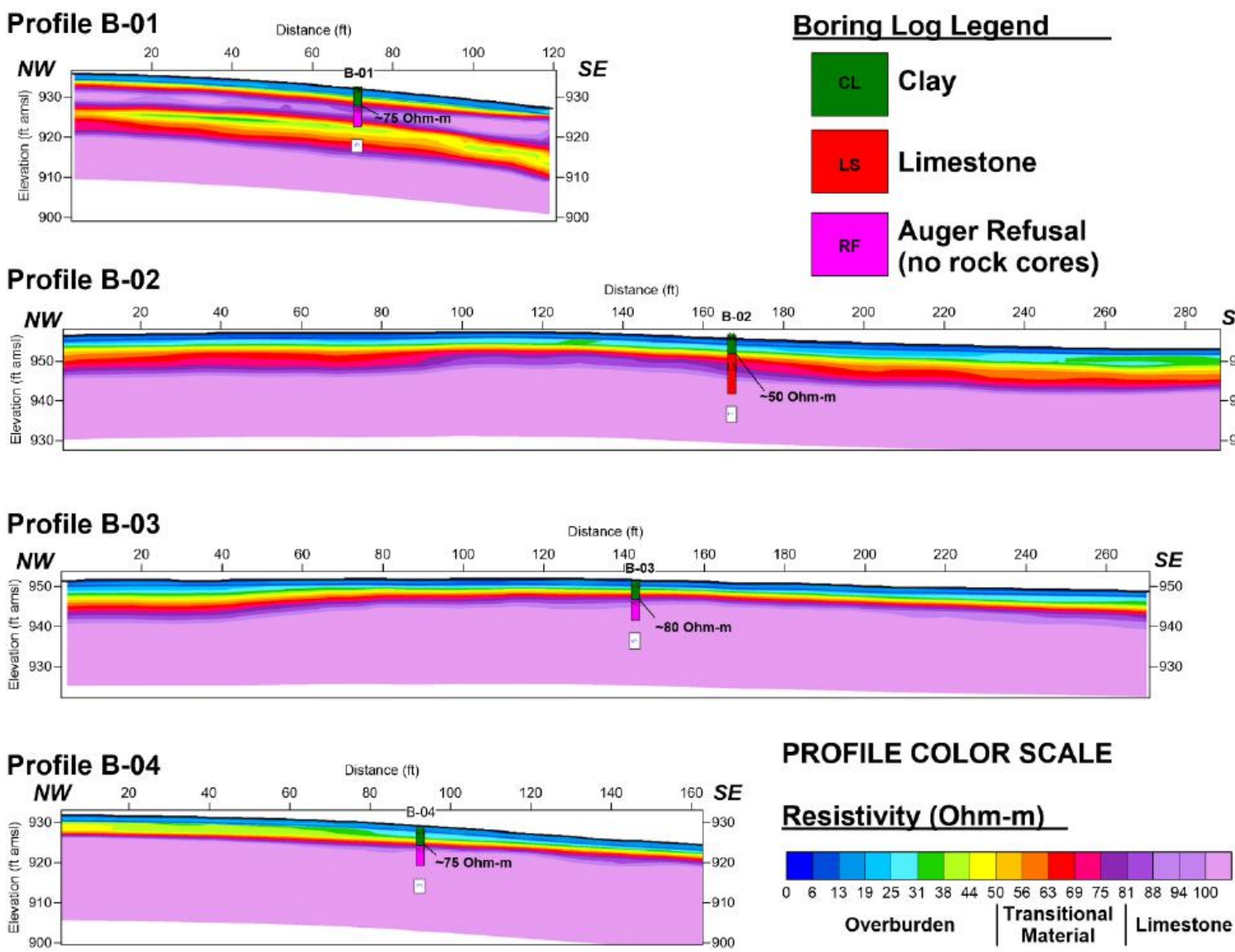

***Figure 3**. Cross section of inverted resistivity data derived from TCM measurements. Existing boring data are overlaid onto the profiles.*

Once the resistivity values at the transition from soil to bedrock are known, a weighted cutoff filter can be applied to the entire dataset using this range as the search criteria. This cutoff filter queries each individual vertical resistivity model and extracts the depth and elevation where the criteria are met. These data are then interpolated to generate modeled depth to bedrock maps. For this site, depth to bedrock maps exhibit a highly variable subsurface caused by uneven weathering of carbonate bedrock.

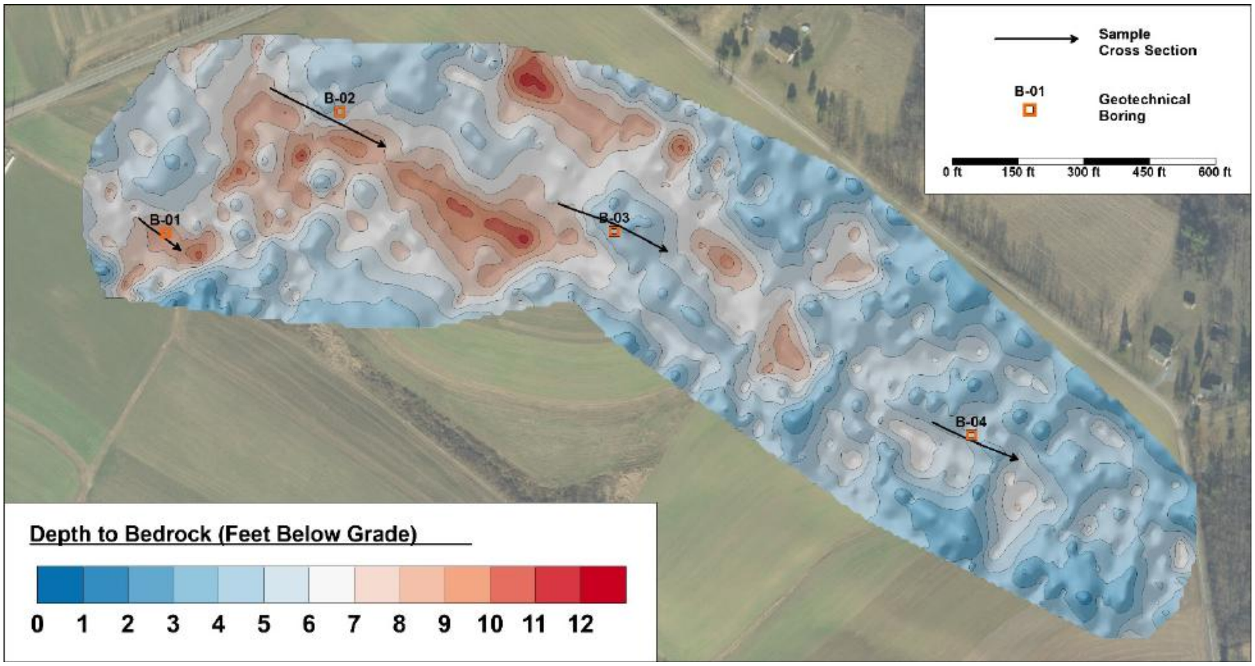

***Figure 4**. Depth to bedrock map derived from TCM data. GIS integration allows for depth to be displayed in units of feet below grade or elevation above mean sea level.*

To evaluate the relative success of the model, known bedrock depths from boring data are compared against modeled bedrock depths. The resulting residual difference is interpolated to generate a contour map highlighting the relative success of the model. For this site, approximately 85% of the area surveyed was mapped to within ±1 foot of known bedrock depths.

Location	BORINGS Depth to Refusal (ft bg)	MODEL Depth to Bedrock (ft bg)	Model vs Borings Residual (ft)
B-01	5.0	8.6	-3.6
B-02	4.8	5.5	-0.7
B-03	4.5	4.1	0.4
B-04	4.3	4.7	-0.4

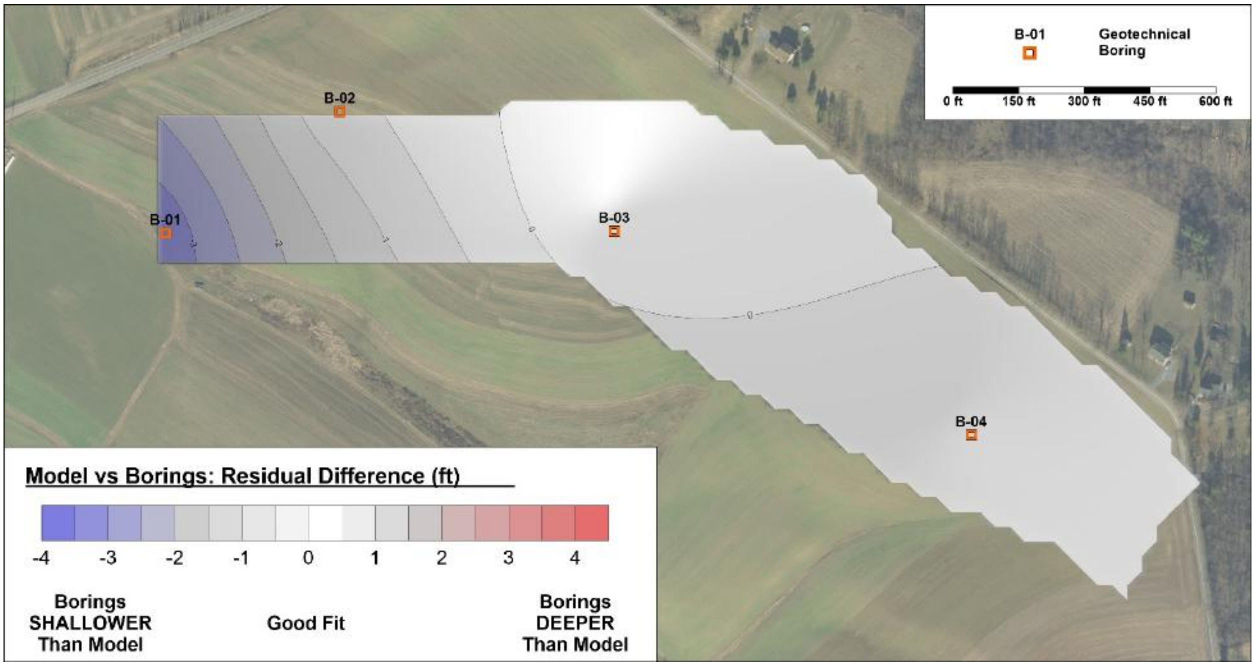

Figure 5. *Residual difference between modeled depth to bedrock and known depth to bedrock from geotechnical boring data.*

CONCLUSION

Using multi-dipole terrain conductivity meters to map variations in the shallow subsurface is fast, efficient, and results in highly detailed maps and profiles. When combined with existing geotechnical boring data, the depth to bedrock may be accurately estimated. This high-resolution information can be used by engineers when designing solar panel foundations and calculating cut-and-fill requirements. Providing residual difference maps that compare model depths to known depths from boring data indicate the degree to which models can be trusted. Supplementing existing geotechnical design programs with these geophysical techniques provides a fast and cost-effective means of increasing the amount of information available to engineers when designing a project.

Although this article is focused on mapping depth to bedrock at utility-scale solar projects, processing and inversion of multi-dipole terrain conductivity meter data can be used for many other applications such as mapping contaminant plumes, archaeological investigations, evaluating potential karst hazards, and other geotechnical engineering projects where understanding shallow subsurface conditions is paramount.