INTEGRATION OF SURFACE AND BOREHOLE GEOPHYSICAL METHODS TO DEVELOP A BEDROCK MODEL

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Abstract

A multi-method geophysical survey was performed at a contaminated facility in New Jersey to update the subsurface geological model for the project area, in order to advance the understanding of hydrogeologic conditions and constrain the placement of additional borings. Anomalous saprolite thicknesses, permeable stratigraphic contacts, and overturned stratigraphy introduced geologic complexities inhibiting the progress of the project.

More than 16,000 linear feet of geophysical data were collected over a survey area approximately 9 acres in size. GPR was selected as the primary method for modeling the saprolite and bedrock elevations, as well as profiling fill and other soil horizons above the saprolite. Seismic reflection and DC resistivity methods were used to obtain data to confirm saprolite of variable thickness, competent bedrock surfaces, geologic fault structures, and other geophysical anomalies. Seismic and resistivity data were integrated within common depth intervals to emphasize bedrock structures detected by both methods as well as those unique to each method. Resistivity profiles also assisted in mapping the spatial distribution of different geologic units. Borehole geophysical log data, obtained a year earlier, were integrated with the surface seismic data and provided key information for deciphering complex reverse fault structures.

The data collected by these three complementary geophysical methods were used to create bedrock and saprolite topographic models. The bedrock models were used to provide a better understanding of the spatial extent of older and younger units and possible structural contacts between them due to reverse faulting.

Introduction

Hager GeoScience, Inc. (HGI) was asked to design a geophysical exploration program to provide answers to complex geologic problems plaguing remediation efforts at a former industrial site in the Western Highland of northwest New Jersey. The then-current geologic model did not address stratigraphic and structural anomalies that precluded finalization of a remediation plan and the commitment of funding to install additional monitoring wells.

HGI’s objective was to provide a revised subsurface geologic model including elevation contour maps for the saprolite and competent bedrock surfaces, identify geologic structures, locate other geophysical anomalies, and integrate existing borehole geophysical log data with results of the current study. The specific purpose of a revised geological model was to advance the understanding of hydrogeologic conditions and constrain the placement of additional borings.

Background Geology

The project site is located in the New Jersey Highlands physiographic province in Morris County in northern New Jersey. The dominant drainage in the project area, the Lamington River, is an integral part of the structural framework of the area (Figure 1). Within the Lamington River floodplain, surface topography of the project area is relatively flat (Figure 2).

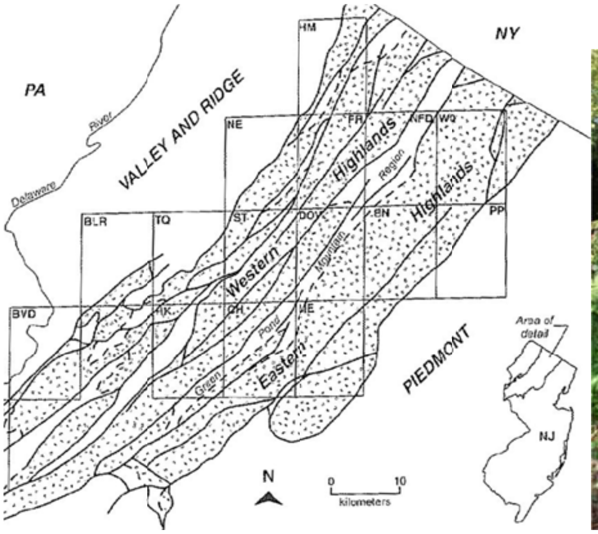

Figure 1: Physiographic province.

Figure 2: Typical topography of the survey area.

The bedrock overburden deposits consist of clay, silt, and sand and gravel. A saprolite veneer of variable thickness is present throughout the area. The average saprolite thickness is between 15 and 20 feet. In one location, the saprolite thickness ranges from approximately 20 feet to more than 200 feet within a distance of only 50 feet.

Bedrock stratigraphy in the project area is predominantly of Mesoproterozoic age. This includes a heterogeneous assemblage of granites, gneisses of sedimentary and volcanic origin, and rare marble (Volkert, 2010). Mesoproterozoic rocks were metamorphosed to granulite facies at about 1050 Ma during the Grenville orogeny (Volkert, 2004). Lower Paleozoic rocks of Cambrian through Ordovician age of the Kittatinny Valley Sequence underlie the Lamington River Valley. In the project area, the Cambrian Hardyston Quartzite formation is in fault contact and overlain by older Mesoproterozoic gneisses.

The predominant regional fault and fold structures in the project area developed from the Precambrian to the Mesozoic. The strike for regional faults, folds and foliation is northeast. The planar components of these structures dip southeast and northwest. Less pronounced, but equally important, are high-angle fractures aligned north to northwest. Commonly overlooked in regional studies, these structures play an important role in controlling soil development and groundwater movement.

Of particular importance to the project is an understanding of the following geologic features:

- The spatial extent of the Hardyston Formation (Paleozoic) within the project area
- The juxtaposition of Precambrian gneiss over Cambrian meta-sediments in well AB-1
- The anomalously thick saprolite (i.e., deep competent bedrock) observed in well AB-2

Understanding these geologic anomalies will result in a more complete geologic model and enhance the confidence level of future activities.

Data Acquisition

A network of seismic reflection and resistivity traverses were designed to intersect possible bedrock fracture zones and delineate the anomalous saprolite deposit. Low frequency GPR traverses were added to improve spatial resolution of the bedrock surface. Figure 3 illustrates the location of all geophysical traverses.

Figure 3: Geophysical survey and borehole survey locations.

The survey area was approximately 9 acres in size. A total of approximately 16,440 linear feet of geophysical data were collected. The individual totals include:

- Seven 100-MHz GPR transects totaling approximately 4,880 feet
- Six MLF GPR transects totaling approximately 2,160 feet
- Six DC resistivity profiles totaling approximately 4,700 feet
- Six seismic reflection lines totaling approximately 4,700 feet

Seismic Reflection

Reflection data were collected along six lines (Figure 3) using two different survey geometries. A variable shot offset technique with 48 active geophones at 10-foot spacing and shot increments every 10 feet between geophones was used on four lines. A 24-channel constant shot offset roll-along technique was used on two lines. A total of 422 48-channel shot gathers was collected: 63 for L100, 93 for L200, 90 for L300, 50 for L400, 73 for Line 500, and 53 for Line 600. The predominant fold coverage was 24 for Lines 300 and 500 and 48 for Lines 100, 200, and 400.

Resistivity

Resistivity data were collected along six lines (Figure 3) using a Multi-Phase Technologies, LLC (MPT) DAS-1 unit and 64 electrodes. Data along all six resistivity lines were collected using the dipole-

dipole array. Ten- and fifteen-foot electrode spacing was used to achieve horizontal resolutions of 5 and 7.5 feet and imaging to depths greater than 100 feet. Where necessary, holes for the electrodes were drilled through asphalt or concrete to avoid the detrimental effects of these materials on the injected currents. A saltwater solution was soaked into the soil at each electrode location to increase electrode coupling by minimizing electrode tip resistance.

GPR

Thirteen (13) low frequency GPR traverses were completed throughout the project area and perimeter where accessible (Figure 3). The low frequency GPR survey was conducted using GSSI SIR-2 and -2000 digital acquisition systems with very high powered 100-MHz and multiple low frequency (MLF) antenna systems. The MLF antenna was configured as a 40-MHz bi-static system. The 40-MHz data were collected in discrete point mode and the 100-MHz data in survey wheel mode. In point mode, the GPR pulses were manually triggered at 5-foot intervals along the line. Each scan was stacked 128 times at the measurement point to increase the signal-to-noise (S-N) ratio. A tape measure recorded distance along the line, with GPS locations taken for the line start and end points.

Borehole Geophysical Logging

The objective of the logging was to characterize fractured bedrock in nine recently drilled wells (Figure 3). Twelve types of log traces were obtained in each well from the following suite of probes (run in the order listed):

- Caliper
- Poly-electric
- Acoustic televiewer (ATV)

Borehole logs were compiled onto a one-sheet composite format to allow for more efficient graphical log analysis. Bedrock fracture data were presented as stereonets and rose diagrams. The HGI logging system consisted of a Mount Sopris Instruments 5MXA-1000 Matrix logger and MSI 4WNA-1000 winch; MSI 2CAA-1000 three-arm caliper probe; Advanced Logic Technologies FAC40 acoustic televiewer (ATV); and MSI 2PEA-1000 poly-electric probe with MSI 2PGA-100 gamma and MSI 2SFA-1000 fluid temperature and resistivity probes.

Results

GPR was selected as the primary method for modeling the saprolite and bedrock elevations, as well as profiling fill and soil horizons above the saprolite. Figure 4 is an example of a GPR radargram showing these interpreted stratigraphic horizons.

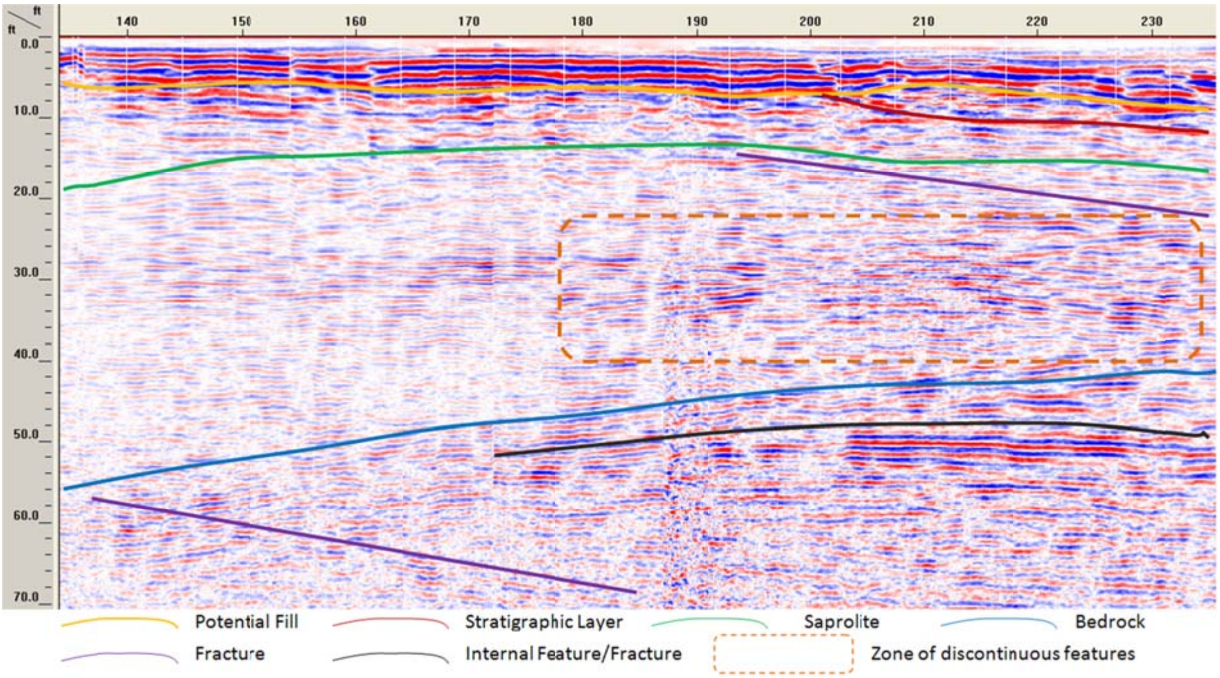

Figure 4: GPR profile (radargram) showing stratigraphy.

The seismic reflection and resistivity methods were used to identify bedrock structures and as a means of constraining GPR bedrock delineations. Seismic and resistivity data were integrated within common depth intervals (Figure 5). The integration technique emphasizes bedrock structures detected by both methods as well as those unique to each method. Resistivity profiles also provide evidence of changes in lithology, in particular the distribution of the Hardyston Formation.

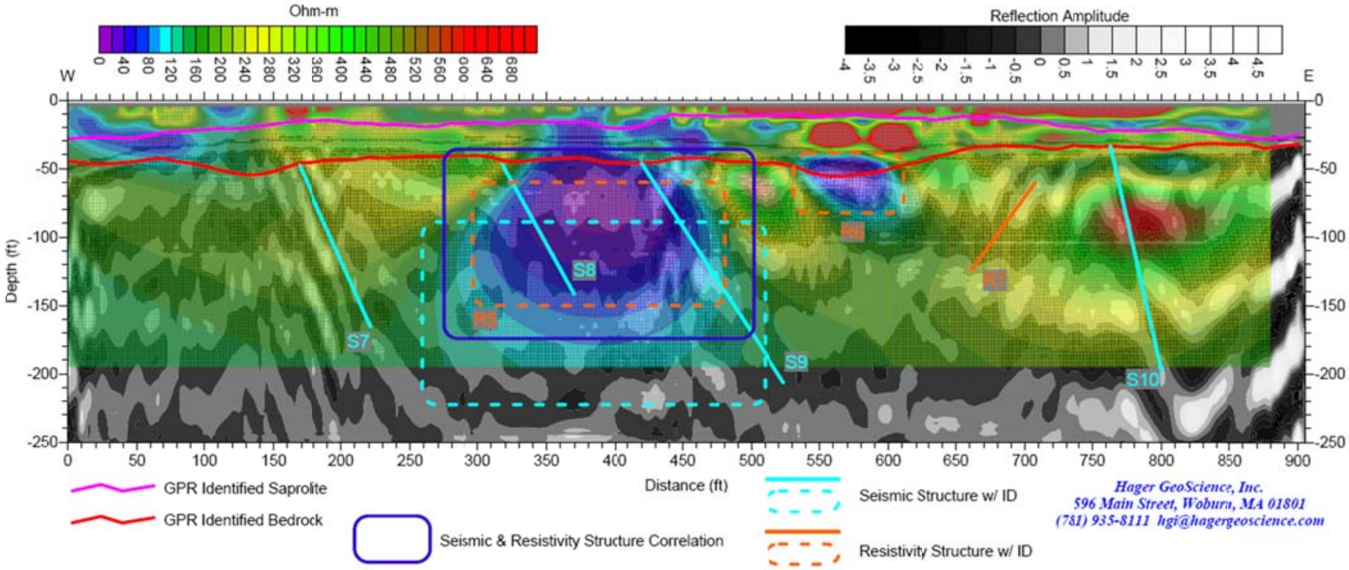

Figure 5: Integrated profile showing depth-matched resistivity and seismic profile structures.

Based primarily on GPR survey data constrained by seismic reflection data, structure maps of the saprolite and competent bedrock surfaces were constructed (Figures 6 and 7), as was an isopach map of the saprolite layer (Figure 8).

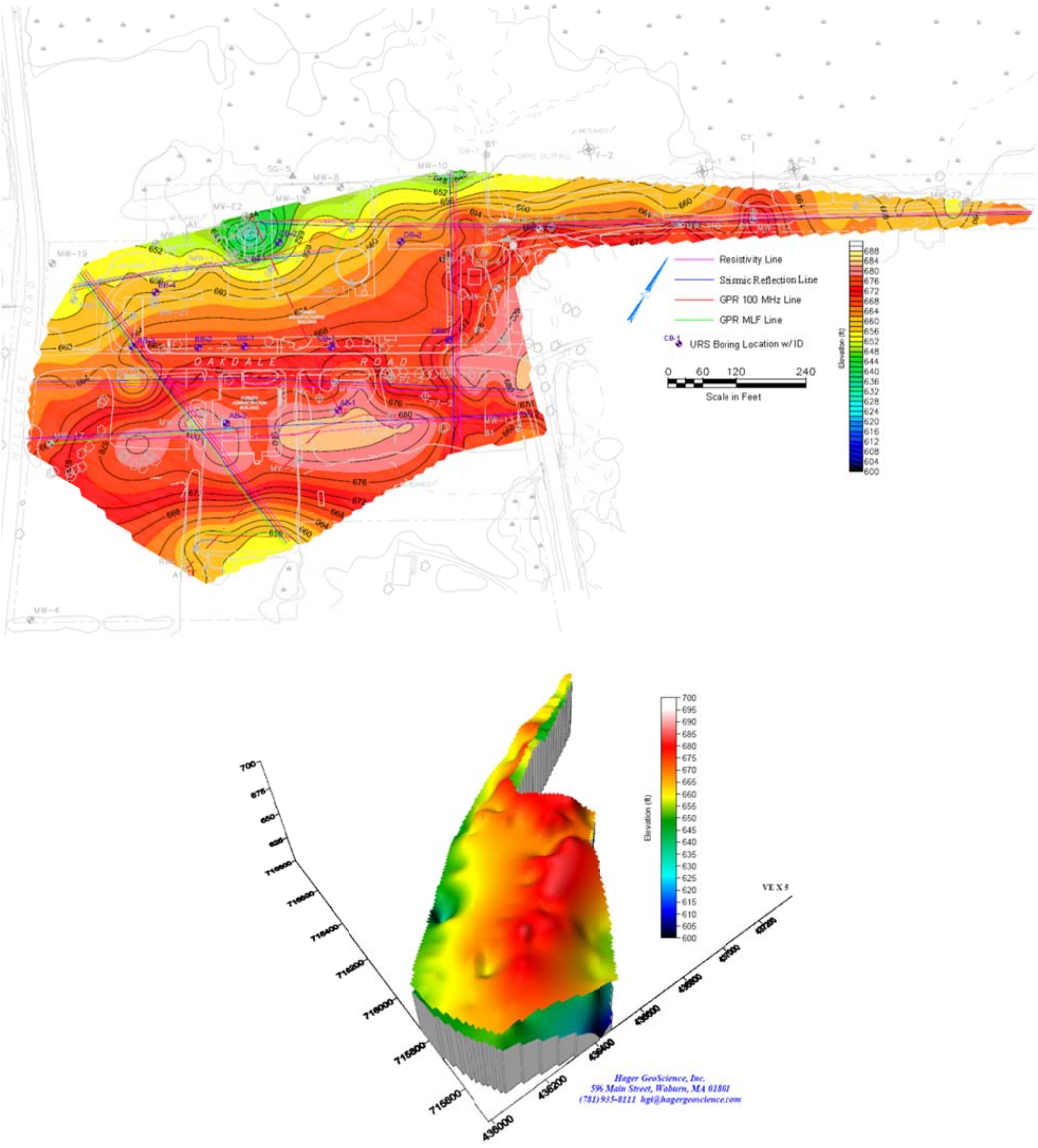

Figure 6: 2D and 3D saprolite elevation maps.

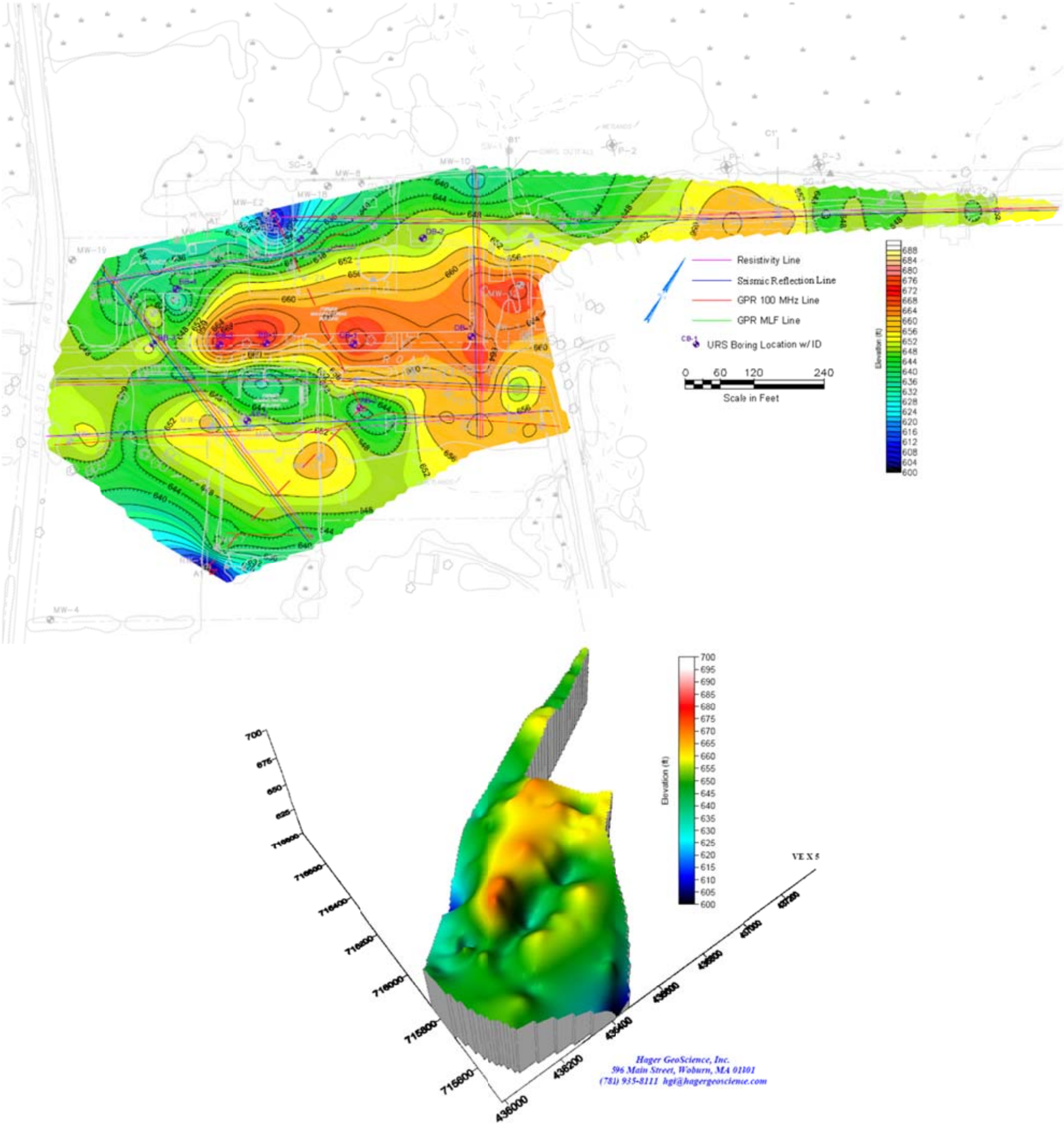

Figure 7: 2D and 3D bedrock elevation map.

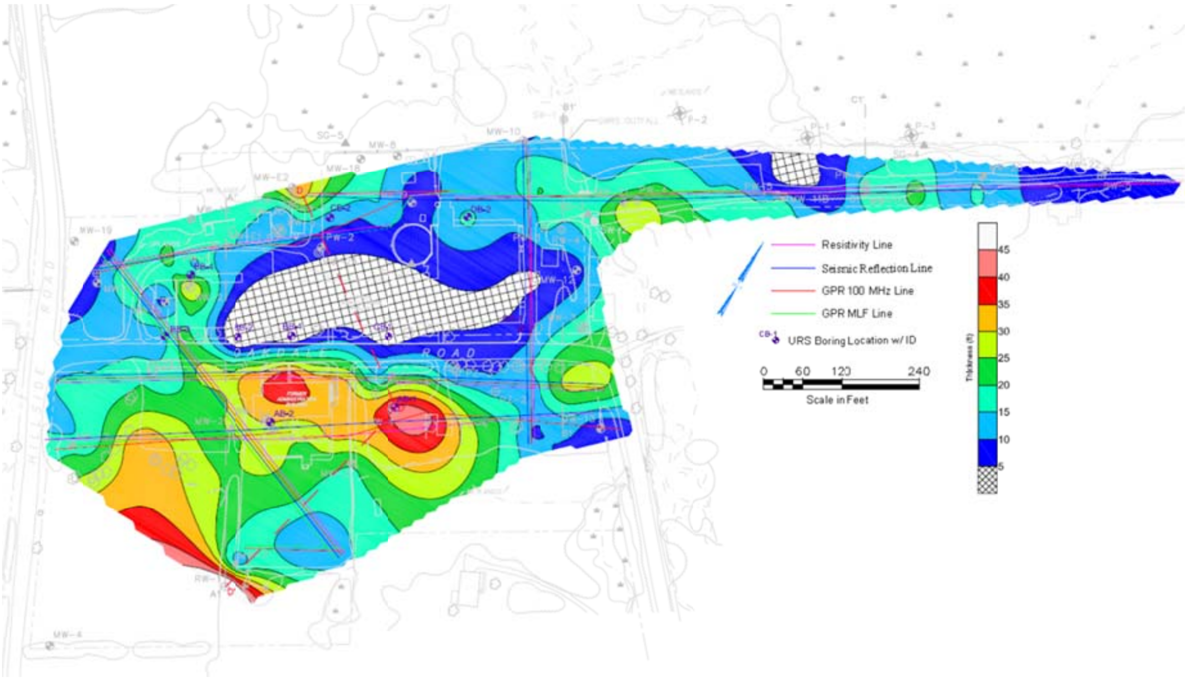

Figure 8: Saprolite thickness map.

Bedrock fractures in the project area were mapped based primarily on seismic reflection data. The approximate extent of the anomalous saprolite thickness was determined using primarily resistivity data and interpreted to be the result of advanced alteration in zones of highly fractured bedrock at the intersection of bedrock fracture zones (Figure 9).

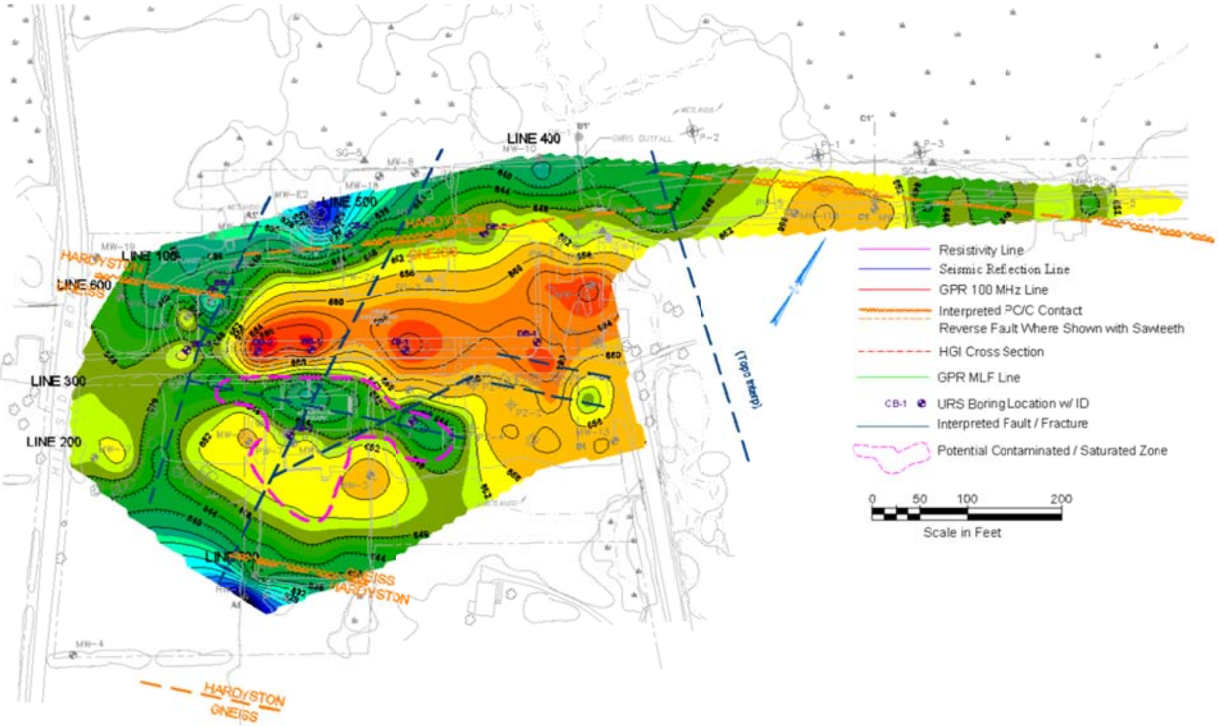

Figure 9: Bedrock structure map.

Borehole acoustic televiewer (ATV) data from nine wells previously collected by HGI were used to constrain the fracture orientations mapped by surface geophysical methods (Figure 10). The ATV data were also used to establish the extent and orientation of reverse fault contacts between the Precambrian gneiss and Cambrian Hardyston Formation. Figure 11 shows a model for the fault contact .

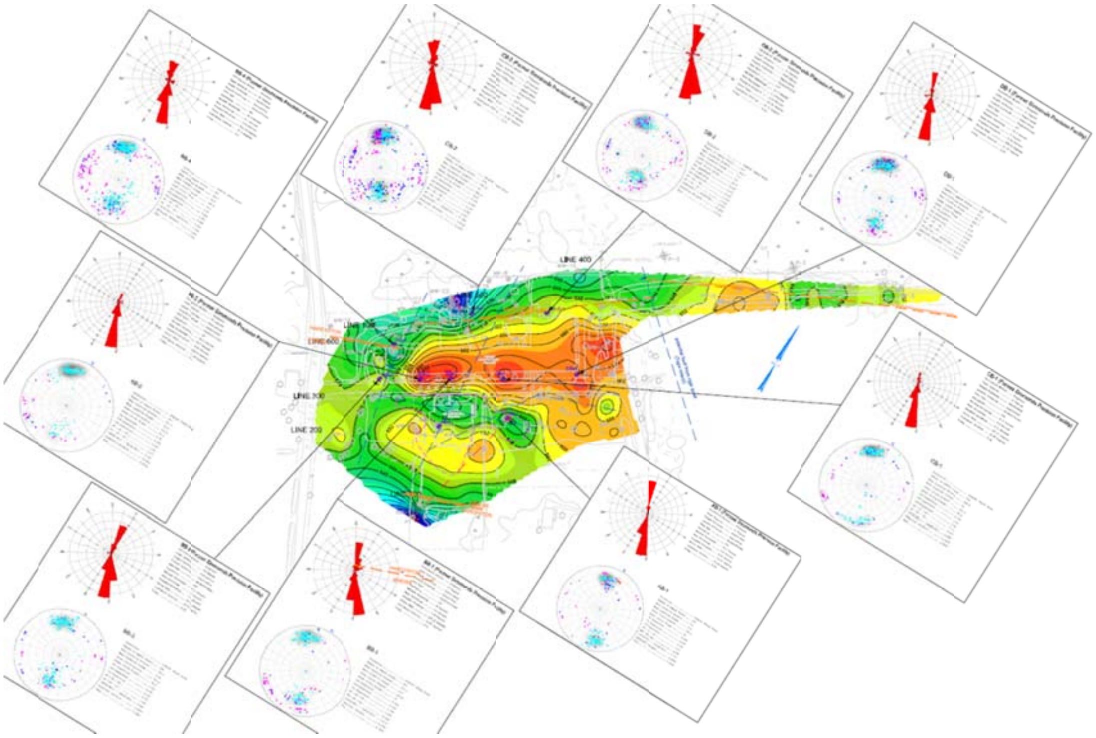

Figure 10: Bedrock structure model with borehole ATV orientation data.

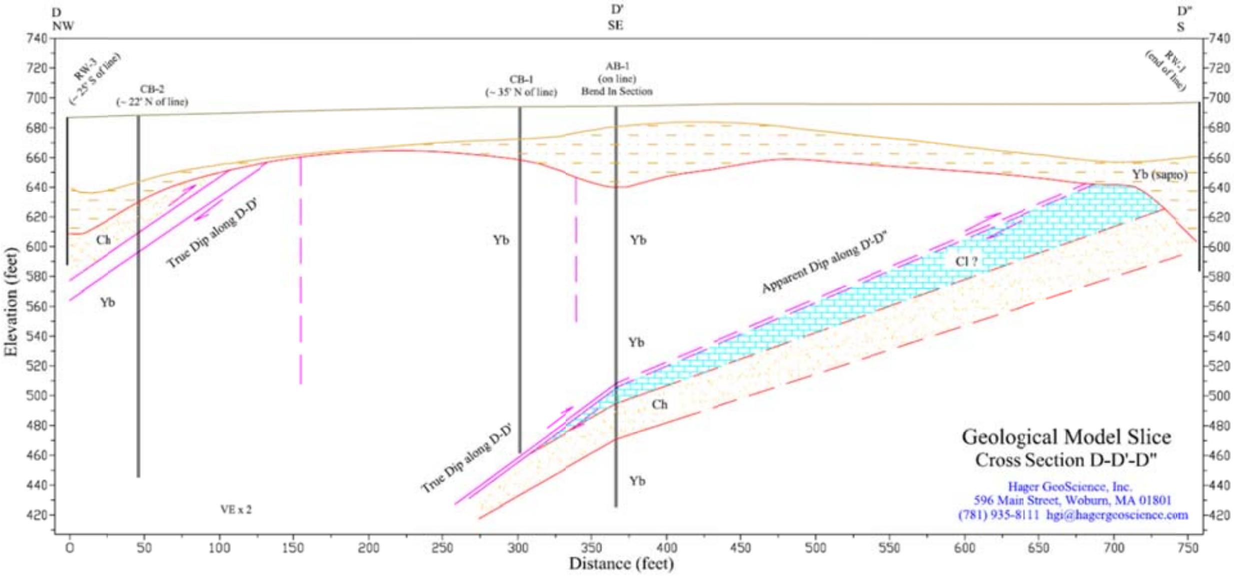

Figure 11: Geologic cross section.

Conclusion

The previous project geologic model was based on the Bedrock Geologic Map of the Chester Quadrangle (Volkert, Markewicz, and Drake, 1990), unpublished revisions of the Chester Quadrangle (Volkert, 2009, personal communication), and previous site investigations. The geophysical investigations provided a new project-specific geologic model with detailed mapping of saprolite, competent rock, and bedrock fractures. The new model was significantly enhanced when the Precambrian and Cambrian structural relationship and fracture orientations where determined using data from borehole geophysical logs.

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