ELECTRICAL IMAGING OF A TRIASSIC FAULT SYSTEM IN NORTHERN NEW JERSEY

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Abstract

Continuous vertical electrical sounding (CVES) imaged early Triassic normal faults on the southeastern side of Mount Arlington Ridge, part of the northeast-southwest trending ridges within the New Jersey Highlands physiographic province of north-central New Jersey. The site had been previously characterized with a regional normal (down to the east) fault, the Longwood Valley Fault that places undefined Proterozoic bedrock units against the sandstone/conglomerate Silurian Green Pond Formation. The sandstone/conglomerates of the older Cambrian Hardyston Formation conformably overlie the Green Pond Formation. The Hardyston with the overlying Leithsville Formation and veneer of Pleistocene-aged glacial deposits comprises most of Long Valley within the study area.

CVES profiles collected normal to the Longwood Valley Fault show displacement within the Mesozoic sediments that are beneath the Pleistocene-aged glacial sediments in the contiguous valley. This previously unnamed fault system is termed the Kenvil Works Fault. Further, four or more synthetic faults exist between the Kenvil Works Fault and the Longwood Valley Fault. These faults accommodate right-rotational torsion between the two fault systems. The synthetic faults and Kenvil Works Fault System can act as a migration pathway for the movement of groundwater from the upland impermeable bedrock to the more permeable valley-fill sequences.

Introduction

A former explosives manufacturing facility in Kenvil, New Jersey, has been decommissioned and most of the buildings have been razed (Figure 1). Groundwater in the southeastern portion of Mount Arlington ridge area has been impacted by the former activities and developing an understanding of the subsurface geology and hydrogeology in this area is necessary to converting this site to commercial use. An electrical imaging (EI) survey was selected as the most appropriate method for imaging the subsurface due to the site geology and likelihood of deep fractures and faults.

Electrical Imaging Investigation

Electrical resistance is based upon Ohm's Law:

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

Where, resistance, **R** (Ohms), is equal to the ratio of potential, **V** (volts) to current flow, **I** (amperes). Resistivity is the measure of the resistance along a linear distance of a material with a known cross-sectional area. Consequently, resistivity is measured in Ohm-meters.

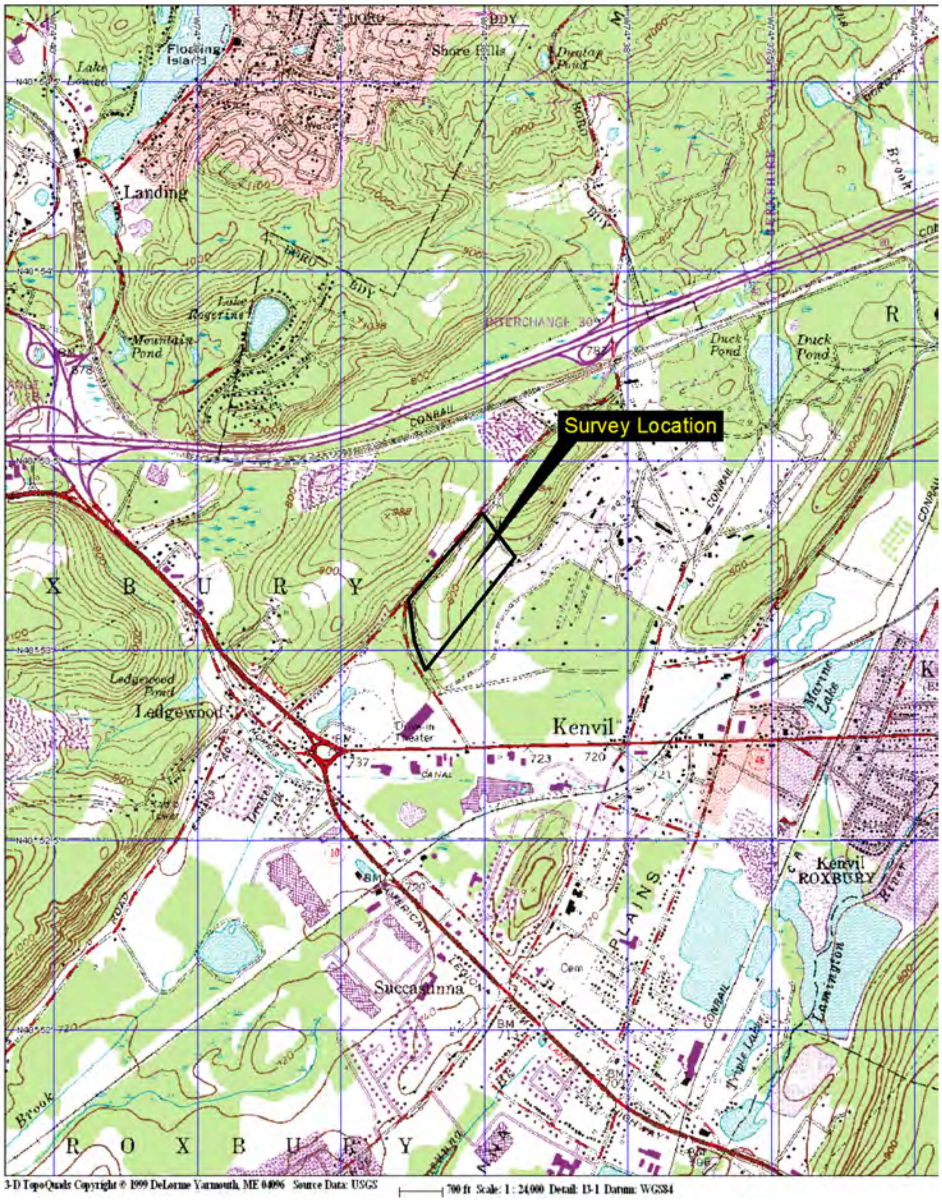

Figure 1: Location map of the site investigation.

Electrical currents propagate as a function of three material properties: (1) ohmic conductivity, (2) electrolytic conductivity, and (3) dielectric conductivity. Ohmic conductivity is a property exhibited by metals. Electrolytic conductivity is a function of the concentration of total dissolved solids and salts in the groundwater that exists in the pore spaces of a material. Dielectric conductivity is a function of the permittivity of the matrix of the material. Therefore, the matrix of most soil and bedrock is highly resistive. Of these three properties, electrolytic conductivity is the dominant material characteristic that influences the apparent resistivity values collected by this method. In general, resistivity values decrease in water-bearing rocks and soil with increasing:

a. Fractional volume of the rock occupied by groundwater;
b. Total dissolved solid and chloride content of the groundwater;
c. Permeability of the pore spaces; and,
d. Temperature.

Materials with minimal primary pore space (i.e., limestone, granite) or lack groundwater in the pore spaces will exhibit high resistivity values (Mooney, 1980). Highly porous, moist or saturated soil, such as fat clays, will exhibit very low resistivity values. Most soil and bedrock exhibit medium to low resistivity values.

In homogeneous ground, the apparent resistivity is the true ground resistivity. However, in heterogeneous ground, the apparent resistivity represents a weighted average of all formations through which the current passes. Many electrode placements (arrays) have been proposed (for examples see Reynolds, 1997); however, the Schlumberger array has proven to be an effective configuration for imaging bedrocks. The following Schlumberger array was used in the collection of data:

$$R_i = \frac{\pi a^2}{b}\left[1 - \frac{b^2}{4a^2}\right]R;\ a = 5b$$

Where, $\boldsymbol{R_i}$, resistivity, is related to the number of poles, ***n***, the separation distance between the current source and current sink ***b***, and the pole spacing, **a**.

Methods

The resistivity survey was performed using the ARES multi-electrode cable system (GF Instruments, s.r.o., Brno, Czech Republic). The survey was conducted using bronze electrodes and stainless-steel cylinder-bearing cables.

Three east-west EI survey lines (Line 1, Line 2, and Line 3) totaling 4,050 feet (1,550 ft, 1,350 ft, and 1,140 ft, respectively) were collected normal to the hill slope. One profile (Line 4; 3,250 ft) was oriented northeast-southwest, parallel to the long axis of Long Valley.

A forward modeling subroutine was used to calculate the apparent resistivity values using the EarthImager program (AGI, 2002). This program is based on the smoothness-constrained least-squares method (deGroot-Hedlin and Constable, 1990; Loke and Barker, 1996). The smoothness-constrained least-squares method is based upon the following equation:

$$J^T g = (J^T J + \mu F)d$$

Where, **F** is a function of the horizontal and vertical flatness filter, **J** is the matrix of partial derivatives, **μ** is the damping factor, **d** is the model perturbation vector and **g** is the discrepancy vector.

The EarthImager program divides the subsurface 2-D space into a number of rectangular blocks. Resistivities of each block are then calculated to produce an apparent resistivity pseudosection. The pseudosection is compared to the actual measurements for consistency. A measure of the difference is given by the root-mean-squared (rms) error.

GEOLOGY

The site is located within the New Jersey Highlands physiographic province of north-central New Jersey. The Highlands belt is approximately 20 miles wide, positioned between Kittatinny Valley to the west and the Piedmont to the east. It is about 40 miles long, bounded to the north by Dutchess County, New York, and to the south by Reading, Pennsylvania. The Province can be divided into three belts that are separated by discontinuous valleys. These belt groups include: the western Highlands, the central Highlands, and the Eastern Highlands. The Province is distinguishable by the Paleozoic sedimentary rocks to the northwest, and the Triassic rocks to the southeast.

The mountains of the Highlands are characterized by broad-topped ranges alternating with deep, narrow valleys trending northeast-southwest. The Highlands is a result of a Grenville-aged (pre-Cambrian) collision. The impact of these ancient crustal plates is recorded through folded strata, volcanic rocks, and granitic intrusions that are prevalent within the province . The Highlands province is made up of gneisses, metamorphosed sediments, and igneous intrusions. The original strata were interbedded limestone and dolomite, along with shale and sandstone. The rocks are difficult to interpret due to their degree of metamorphism. The Highlands province is classified as a first order anticlinorium containing a core of crystalline rocks. Folds vary in size from seven inches to as much as seven miles, and can span over a mile wide in areas . The fold orientations are varied due to local tectonic complexity. Only one folding event was recorded geologically during Precambrian time. Folding within the area is classified as flexural slip, and flexural flow within the more cohesive strata . The terms antiform and synform have been applied to the local structures due to the stratigraphic complexity. The faults of the province commonly intersect both Precambrian and lower Paleozoic strata, creating the boundaries of the Highlands province. Small scale structural features are prominent within the Precambrian rocks. Mineral lineations were found to plunge parallel to the fold axes. Joints within the Precambrian rock have been studied to show that they are products of tectonic folding .

The landscape of the Highlands province was carved out through three independent stages of Pleistocene glaciations. These periods of glaciations carpeted valley floors with thick deposits of sand and gravel and caused relief, with a maximum elevation of 1,496 feet .

The study area is located on the southeastern side of Mount Arlington Ridge, part of the northeast-southwest trending ridges in the Highlands area. The western side of the study area (i.e., Howard Blvd.) is characterized by a regional fault, the Longwood Valley Fault of Mesozoic and or Cenozoic age. This normal fault (down to the east) places undefined Proterozoic bedrock units against the sandstone/conglomerate Silurian Green Pond Formation. The sandstone/conglomerates of the older Cambrian Hardyston Formation conformably overlies the Green Pond Formation. The Hardyston with the overlying Leithsville Formation comprises most of Long Valley within which the Kenvil Works Facility was developed.

GEOPHYSICAL ANALYSES

Introduction

Four EI profiles for a total of 7,300 feet were collected at the site. Three profiles were collected normal to the east-facing slope to the Mount Arlington Ridge along the western portion of the property (Lines 1, 2, and 3). One profile (Line 4) was collected along the base of the Mount Arlington. The profiles imaged the subsurface geo-electric stratigraphy to a depth of approximately 120 feet below grade.

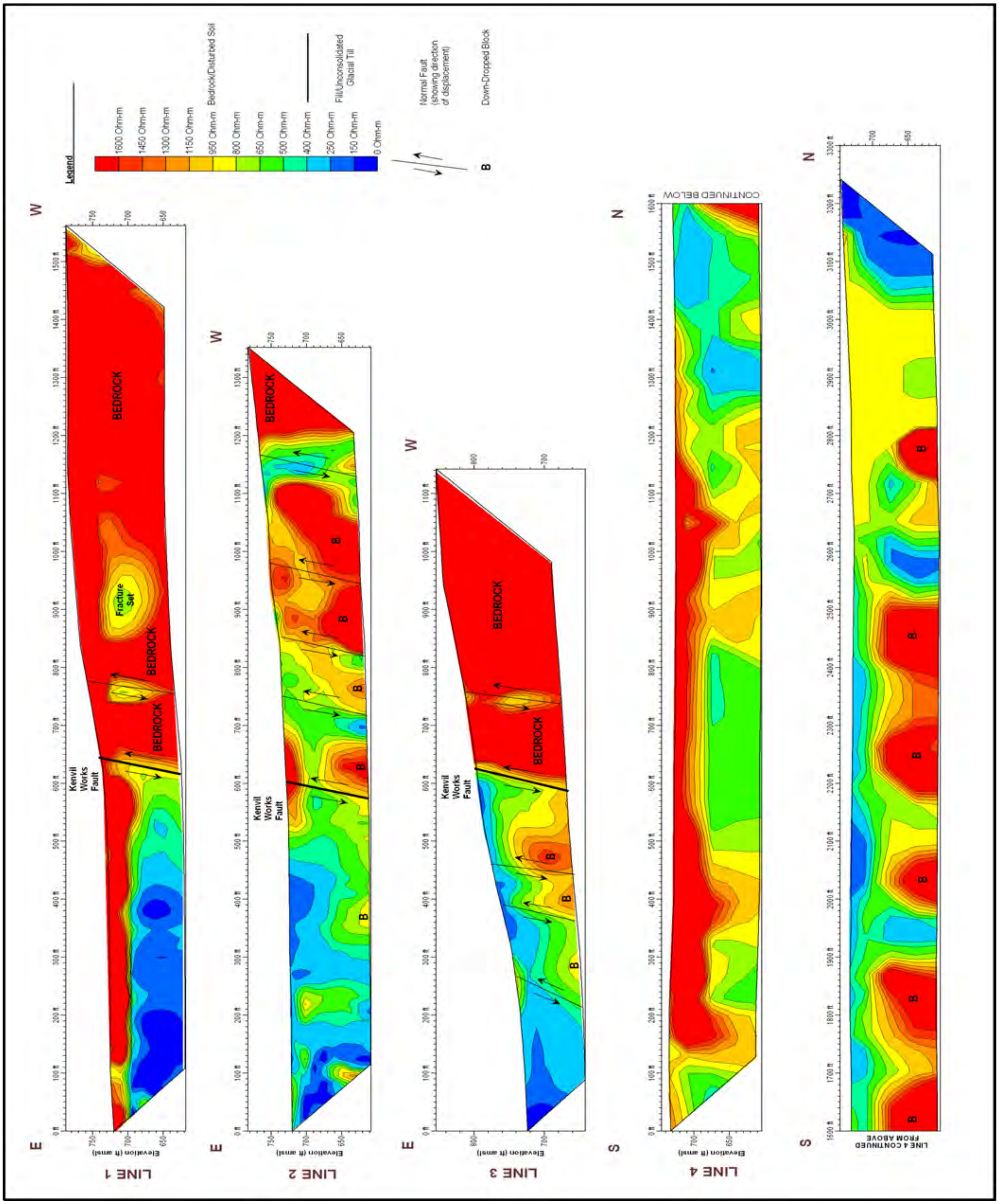

Figure 2: Electrical profiles of subsurface

Line 1

Profile Line 1 was collected east to west in the southern portion of the study area and is approximately 1,560 feet long (Figure 2). The western portion of the profile shows very high apparent resistivities indicating that bedrock is dense, hard and shallow. A major normal fault, the Kenvil Works Fault, is located in the middle of this profile. Throw for this fault is estimated at over 100 feet and down to the east. A minor synthetic fault (with unknown displacement) to the Longwood Fault, the western border of the study area, is present west of the Kenvil Works Fault (Figure 3).

East of the Kenvil Works Fault bedrock appears to occur at a depth of greater than 100 feet. West of the fault, bedrock is near the surface (i.e., within 5 feet of the surface). Fracture sets within massive bedrock tend to appear as lower apparent resistivity anomalies within the high apparent resistivities of the bedrock. This phenomenon is due to the relative increase in permeability within the fracture set.

Line 2

Profile Line 2 was collected east to west in the middle of the study area and is approximately 1,350 feet long (Figure 2). The western portion of the profile shows very high apparent resistivities indicating that bedrock is dense, hard and shallow (i.e., less than 5 feet). A major normal fault, the Kenvil Works Fault, is located in the middle of this profile (Figure 3). Throw for this fault is estimated at over 100 feet and down to the east. Two additional normal faults with the same attitude as the Kenvil Works but with smaller throws (estimated at 40 to 60 feet of dip-slip displacement) are located east of the Kenvil Works Fault. Four synthetic faults with minor dip-slip displacement (estimated at 10 to 25 feet) exist between the Kenvil Works Fault to the east and the Longwood Fault to the West (Figure 3). The presence of these synthetic faults indicates that there was some rotation between the Kenvil Works and the Longwood Valley Fault during displacement and the synthetic faults accommodated this twisting action.

The synthetic faults west of the Kenvil Works Fault have broken the bedrock and thereby increasing porosity and permeability. These faults can act as an avenue for the migration of groundwater.

The focus of this investigation was to image the sediment/fault interface; however, from this survey, it appears that the valley sediments are stratified and show the presence of a clay layer (i.e., lower apparent resistivities) at depth (approximately 75 feet below grade). Discrimination of these apparent resistivity inversions would require a more detailed EI survey.

Line 3

Profile Line 3 was collected east to west in the northern portion of the study area and is approximately 1,140 feet long (Figure 2). The western portion of the profile shows very high apparent resistivities indicating that bedrock is dense, hard and shallow (i.e., less than 5 feet from grade). The east-dipping Kenvil Works Fault is well displayed in this profile and shows at least 100 feet of throw (Figure 3). An unmapped but possible fault (or fracture) is shown within the bedrock west of the Kenvil Works Fault. Three additional normal faults with the same attitude as the Kenvil Works Fault but with smaller throws (estimated at 40 to 60 feet of dip-slip displacement) are located east of the Kenvil Works Fault (nb., the eastern-most fault is not mapped on Figure 2; however, it is probably sub-parallel to the Kenvil, but is buried deeper than this survey imaged to the south). Three synthetic faults with minor dip-slip displacement exist between the Kenvil Works Fault to the east and the Longwood Valley Fault to the West (Figure 3).

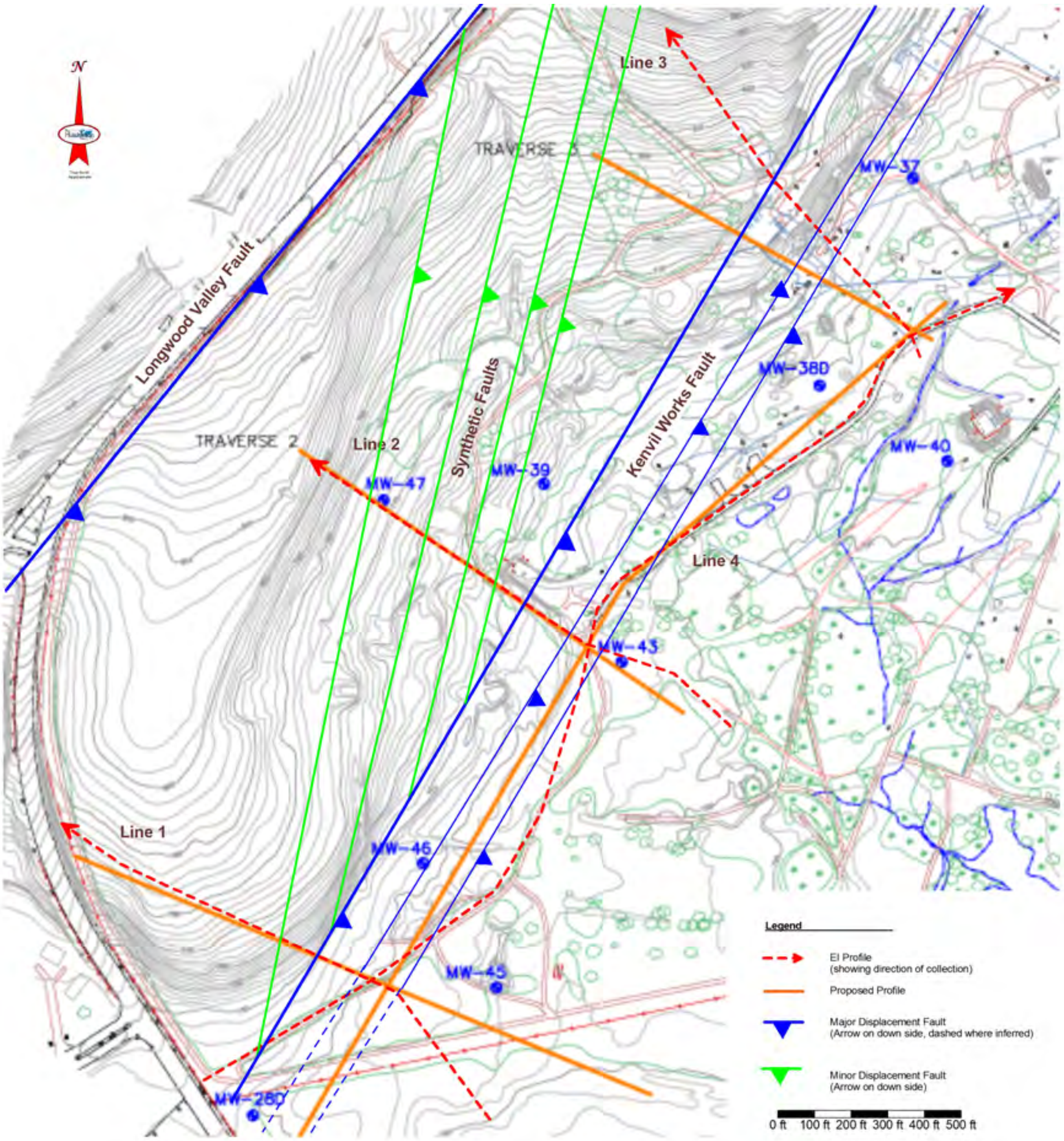

Figure 3: Topographic map (contour interval 2 feet) showing geophysically-derived interpreted faults.

Bedrock in the valley portion of this profile exists at varying depths from 25 feet to over 100 feet below grade. The sediments within the valley appear to be stratified, with a clay layer that may be draped over the easternmost buried bedrock block.

Line 4

Profile Line 4 was collected southwest to northeast, parallel to the structural grain in this portion of the facility and is approximately 3,250 feet long (Figure 3). The southwestern portion of the profile shows a deep soil section with limited bedrock, whereas the northeastern portion shows the presence of bedrock blocks. These bedrock blocks represent the Kenvil Works Fault and ancillary synthetic faults snaking in and out of the profile plane (Figure 3).

The apparent resistivity inversion along the northernmost portion of this profile probably represents clay as it drapes the down-dropped bedrock blocks.

Summary

A previously unnamed normal fault that trends N33ºE and dips 10ºE was imaged in the western portion of the site, named herein as the Kenvil Works Fault. The fault is characterized to the east by having several (up to 4) ancillary sub-parallel synthetic faults.

During the early Triassic, the extensional environment that opened the proto-Atlantic Ocean and deformed this area, produced right-rotational torsion between the Mount Arlington block and the Kenvil Works block. This rotation is manifest in the 4 synthetic faults located between the Kenvil Works Fault and the Longwood Valley Fault. The dip-slip offset of the Kenvil Works is estimated at over 100 feet and the offset across the synthetic faults between the Kenvil Works and Longwood Valley is estimated at between 50 to 100 feet. The net dip-slip displacement of the Kenvil Works Fault system (i.e., including the mapped sub-parallel synthetic faults) is estimated to be several hundred feet.

Apparent resistivity inversions within the valley sediments are interpreted to be clay and appear to drape over the buried bedrock blocks. These clay layers appear to be laterally extensive and may restrict the vertical migration of groundwater.

Conclusion

Approximately 1.4 miles of EI profiles were collected in 4 profiles at the Hercules Kenvil Works Facility, Kenvil, New Jersey. The EI data quality was good to excellent; however, the dense basement rock showed little geo-electrical resolution probably due to very low permeability.

Displacement from the apparently unnamed fault, herein named the Kenvil Works Fault, created the valley. This fault system may be an avenue for groundwater migration. Synthetic faults located west of the Kenvil Works Fault are probably good conductors of groundwater from the upland impermeable bedrock to the more permeable valley-fill sequences.

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