

**DRAFT REPORT**

**Geophysical Test Phase  
Dundalk Marine Terminal  
Baltimore, Maryland**

**for  
CH2M Hill, Inc.  
Tampa, Florida**

**October 11, 2006**

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## TERMINOLOGY

The following terms are used in this report.

<i>Anomaly:</i>	In geophysical investigations, anomaly is the term used to describe a change in the condition of soil or rock (from “background” conditions) based upon a deviation in data values observed in a given geophysical measurement (e.g. seismic anomaly).
<i>MASW:</i>	Multi-channel analysis of surface waves. A surface geophysical method that uses the dispersive characteristics of seismic surface waves to obtain a shear-wave velocity cross-section.
<i>OhmMapper:</i>	A geophysical instrument manufactured by Geometrics, Inc. that provides electrical resistivity data by capacitively-coupling AC current into the ground.
<i>Tomography:</i>	An inverse mathematical method to develop a model based upon observed data.

## **PURPOSE AND SCOPE**

The Dundalk Marine Terminal is located in Baltimore, Maryland at geographic coordinates 39.25°N, 76.53°W (Figure 1). An 85-acre portion of the property was filled with dredged materials and chromite ore processing residue (COPR) and covered with soil and a layer of asphalt or concrete pavement (GeoSyntec, 2005). Over time, the COPR has become indurated and has produced significant surface heaving, deforming the surface and damaging subsurface utilities.

Previous investigations have attempted to map the extent of the COPR using a combination of boring and CPT data (GeoSyntec, 2005). The borings describe the COPR as being dense to very dense brown or black sand and silty-sand, with zones of lithification. The COPR is generally identified in the upper 20 feet of fill material. CPT pushes show anomalously high tip stress values in the COPR layers when compared with natural sand and clay deposits (GeoSyntec, 2005).

Since the COPR fill is quite extensive, CH2M Hill is attempting to provide a more site-wide assessment of the lateral and vertical extents of the COPR. As part of this assessment, CH2M Hill retained Technos, Inc. (Technos) to carry out a test of surface geophysical methods that may be able to non-invasively map the extent of the COPR based on its physical properties. Two geophysical methods were tested, and include multi-channel analysis of surface waves (MASW) and OhmMapper resistivity imaging. The MASW method is a seismic technique in which variations in the hardness of subsurface materials can be mapped, and, in this case, related to the lithified COPR fill. The OhmMapper resistivity imaging is an electrical method in which variations in subsurface resistivity may be related to the COPR fill.

Geophysical survey lines were established within areas having existing or future boring and CPT data for comparison to the geophysical data. Data were acquired along six

survey lines totaling 3,200 linear feet (Figure 2). Technos carried out the field activities between October 2<sup>nd</sup> and 4<sup>th</sup>, 2006.

## TECHNICAL APPROACH

### SURVEY LINES

Survey lines were established within Areas 1800, 1600, and 1300/1400 based on the direction of CH2M Hill on-site personnel (Figure 2). Lines 1800-1 and 1800-2 are located along reinforced concrete where a significant amount of boring and CPT data exist. Lines 1800-3, 1300-1, 1300-2, and 1600-1 are located on non-reinforced asphalt.

The survey lines were marked with a distance wheel and spray paint. Stations along the lines were marked at 100-foot intervals for positioning control. Geographic coordinates for the survey lines were obtained with a Trimble Ag-132 differential GPS system, having a lateral accuracy within 3 feet. The survey line locations were translated to Maryland State Plane easting and northing coordinates using CORPSCON software (U.S. Army Corps of Engineers – Topographic Engineering Center) and overlaid onto the AutoCAD basemap (Figure 2). Table 1 contains a listing of the survey line control point coordinates.

**Table 1. Survey Line GPS Control Points**

Line	Station	S.P. Easting (ft)	S.P. Northing (ft)
1800-1	0	1448846.1	575815.8
1800-1	700	1449366.9	575351.5
1800-2	0	1448880.5	575855.6
1800-2	700	1449399.5	575387.4
1800-3	0	1448584.7	575684.3
1800-3	400	1448878.3	575412.2
1300-1	0	1446841.5	574450.6
1300-1	400	1447207.4	574604.9
1300-2	0	1446865.4	574383.1
1300-2	400	1447238.6	574535.0
1600-1	0	1447930.6	575684.6
1600-1	200	1448123.9	575655.6
1600-1	600	1448425.1	575399.4

**MULTI-CHANNEL ANALYSIS OF SURFACE WAVES (MASW)**

Multi-channel Analysis of Surface Waves (MASW) is a seismic method that uses the dispersive characteristics of surface waves to determine the variation of shear-wave (S-wave) velocity with depth. S-wave velocity values are calculated by analyzing seismic surface waves generated by an impulsive source and recorded with an array of geophones. The resulting shear wave profiles from multiple locations along a survey line are combined and contoured into a 2-D cross-section of shear-wave velocity. Shear-wave velocity is a function of the elastic properties of the soil and rock and is directly related to the hardness (N-values) and stiffness of the materials.

**Data Acquisition**

MASW data were acquired along each of the survey lines (Figure 2). The data were recorded using a Geometrics StrataVisor NZ seismograph and twenty-four 4½-Hz geophones. An elastic weight drop attached to the back of an ATV (Kawasaki MULE) was used as the source of seismic energy.

Acquisition parameters were based on established procedures and on-site testing. The source was located 32 feet from the first geophone in the spread. Each geophone spread consisted of 24 geophones spaced at 4-foot increments along the survey lines for a total spread length of 92 feet. Shots were spaced at 20-foot intervals along the survey lines. The 24 geophones were mounted in a landstreamer configuration to quickly move the array down the survey lines between each recorded shot. The landstreamer was pulled using the ATV, while maintaining a constant 32-foot offset between the shot point and the first geophone in the spread. For each recorded shot point, the seismic data were stacked (enhanced) three or four times to improve the signal to noise ratio. There were no filters applied during the recording of the data.

**Data Processing**

Data were processed using the SurfSeis v. 2.0 software package (Kansas Geological Survey). Dispersion curves for each shot record were created by analyzing the phase-



velocity power spectra of the surface waves (phase velocity vs. frequency). The dispersion curves were then input into the SurfSeis inversion algorithm to produce a 1D model of shear-wave velocity for each shot point. The models along the survey lines were contoured using Surfer v. 8.0 to produce 2D cross-sections of shear-wave velocity.

### **Quality Control**

The MASW data quality can be considered good over most of the site, with most of the shot records providing well-defined dispersion curves. Shot points that did not yield coherent dispersion curves were discarded and only well defined dispersion curves were input into the inversion.

### **Interpretation**

Shear-wave velocity values provide a measure of the hardness of the soil and rock. The correlation to SPT N-values is site-specific. In general, lower seismic velocity is attributed to looser, weaker materials. The Building Seismic Safety Council provides some general guidelines in Table 2.

**Table 2. Soil and Rock Shear Wave Velocity Classification (BSSC, 2000)**

<b>Velocity (ft/s)</b>	<b>Classification</b>
> 5,000	Hard rock
2,500 to 5,000	Rock
1,200 to 2,500	Very dense soil and soft rock
600 to 1,200	Stiff soil
<600	Soft soil

At this site, we are interested in defining the harder COPR material within the fill. We have highlighted anomalously high velocity zones (>1,000 ft/s) to provide an indication of the harder materials. Zones with velocities greater than 1,000 ft/s contain very dense material, generally harder than would be expected for natural sand and clay fill materials.

**Limitations**

The depth of investigation is limited by the seismic source, the frequency range of the geophones, and the geophone spread length. The amplitude of the surface wave decreases exponentially with depth, and the attenuation is largely dependant on the local site conditions. The maximum depth of investigation varies between 60 and 100 feet at this site, and is dependent upon the fill conditions encountered at each location. Vertical resolution is approximately 20% of the depth (e.g. features at a depth of 20 feet, will be averaged over a thickness of approximately 4 feet). Lateral resolution is approximately 25% of the geophone spread length (typically averaged over a lateral distance of 20-25 feet). Comparisons of MASW measurements and borehole measurements indicate that MASW velocity models are accurate to within 15% of actual values in unconsolidated materials (Xia, et al., 2002).

## **OHMMAPPER**

Capacitively-coupled resistivity measurements use the capacitance of an antenna to non-invasively couple an AC signal into the ground. OhmMapper, manufactured by Geometrics, Inc., is a capacitively-coupled resistivity system that is configured with coaxial cable in a dipole-dipole array. The conductors in the cable act as one plate of the capacitor and the earth acts as the other plate, with the insulating sheath as the capacitor's insulator. Since an AC signal can pass between the plates of a capacitor, the transmitter on the OhmMapper system sends an AC signal (16.5 kHz) into the ground using the coaxial cable. The receiver measures the AC voltage at the transmitter frequency. This provides an AC equivalent to traditional DC resistivity measurements (Geometrics, 1999).

## **Data Acquisition**

OhmMapper data were acquired along each of the survey lines using an OhmMapper TR-2 system (Figure 2). A dipole length of 5 m was used for all data acquisition. Multiple passes along the same line were run with a separation between dipoles ranging from 2.5 m to 10 m. The relatively high conductivity of the ground prohibited larger dipole separations.

## **Data Processing**

Magmap 2000 software (Geometrics, 1999) was used to perform the initial processing of the data. The data were spatially adjusted and filtered to remove spurious noise spikes in the data. The data were spatially averaged at a 4-foot interval along each of the survey lines.

RES2DINV software was used to provide a 2D tomographic image of the resistivity data. The data were inverted using an iterative least-squares algorithm. The resulting model was gridded and contoured with Surfer v. 8.0 software.

## **Quality Control**

Prior to obtaining data along the survey lines, the OhmMapper was setup at a stationary point to ensure that the system was operating correctly and providing repeatable data. Two passes for each dipole separation were carried out along Line 1800-3 to assess the repeatability of the measurements. These repeatability tests guided the maximum dipole separation that could be obtained at this site (10 m). Dipole-separations that were too large to produce repeatable measurements were not used in the modeling.

## **Limitations**

The depth of investigation at this site is severely limited by the relatively high conductivity of subsurface materials, contaminants, and saltwater infiltration. The maximum depth of investigation ranged between approximately 10 and 15 feet.

Data along Lines 1800-1 and 1800-2 are not valid due to interference from the steel-reinforced concrete, and were not used to produce a resistivity model. In other areas, numerous subsurface utilities and surface metal produced interference in the measurements that result in unreliable subsurface models of resistivity.

## **RESULTS**

### **MASW DATA**

The MASW data consist of good-quality surface waves, which produce well-defined dispersion curves and resulting shear-wave velocity models to maximum depths ranging between 60 and 100 feet. The models for each survey line are shown in Figures 3 to 10. In order to emphasize the shallow portions of interest in this survey, the upper 30-feet of the models have been enlarged and shown above the full model for each survey line.

The shear-wave velocity models contain velocities ranging between 300 and 2,000 ft/s, with the highest velocities corresponding to the deep, denser/more compact materials. Areas of anomalously high velocities ( $>1,000$  ft/s) are also evident in the shallow portions of each survey line. These shallow, high-velocity zones are likely related to the lithified COPR or very dense fill materials.

### **Area 1800**

The MASW models along Lines 1800-1 and 1800-2 are shown in Figures 3 and 4, respectively. These models are separated by approximately 50 feet and show consistent trends from line-to-line. In general, there is a gradational trend towards higher velocity values with depth. A zone of shallow, high-velocities is evident along both lines between Stations 300 and 650, which extends from the surface to a depth of approximately 25 feet.

Simplified boring logs from nearby borings have been annotated onto the MASW model along Line 1800-2 (Figure 4). The correlation between the models and the boring logs is not conclusive. COPR is evident in both low-velocity and high-velocity areas of the model, which indicates that the COPR itself may have a broad range of hardness.

Figure 5 shows the shallow sections of both models along Lines 1800-1 and 1800-2 along with CPT logs of the cone tip resistance. There is a good correlation between the MASW models and CPT data, supporting the fact that higher shear-wave velocities correspond with harder materials. For example, CPTs 27 and 49, show relatively low tip resistance values in modeled low-velocity zones, while the other CPTs indicate much higher tip resistance values in modeled high-velocity zones. The correlation is not 1:1 however, since the MASW method samples a much larger volume of material and averages over a much wider area than the CPT pushes.

Figure 6 shows the MASW models along Line 1800-3, which is located within an asphalt area adjacent to the reinforced concrete. A 5 to 10-foot thick zone of high-velocity material is evident at depths ranging from 5 to 25 feet along this line. This high-velocity layer (>1,000 ft/s) is laterally continuous with pockets of higher velocities of up to 1,500 ft/s. These velocities are generally higher than those typical of shallow sand and clay fill, and are likely related to lithified COPR.

### **Area 1300/1400**

Figures 7 and 8 show the MASW models along Lines 1300-1 and 1300-2, respectively. Both models show a relatively thick zone of shallow, high-velocity material in the upper 25 feet. The highest velocities are centered at Station 200 along Line 1300-1, and at Station 300 along Line 1300-2. These velocities are generally higher than those typical of shallow sand and clay fill, and are likely related to lithified COPR.

### **Area 1600**

Figure 9 shows the MASW model along Line 1600-1. The shallow portions of the model contain variable velocities and less-continuous anomalies than measured along the other survey lines. Limited areas of shallow, high-velocity material are centered at Stations 80, 210, and 330. However, velocity values greater than 1,000 ft/s are generally constrained to depths greater than 12 feet.

**OHMMAPPER DATA**

Example profiles of the OhmMapper data along Line 1600-1 are shown in Figure 10. Data for the 5 m and 10 m dipole separations are shown for two different passes along the same line as a measure of repeatability. The profiles show very variable, but repeatable, measurements. This indicates that the OhmMapper is providing repeatable data, but the data are being influenced by extremely variable subsurface resistivity values and/or metal interference.

Figure 11 shows the OhmMapper resistivity models along each of the survey lines (excluding Lines 1800-1 and 1800-2, which contain steel reinforced concrete). The models contain extremely variable values of resistivity ranging from less than 10 to over 4,000 ohm-m. This variability is much greater than would be expected for the depth range of the models and is likely due to subsurface and surface metal interference. Therefore, we do not have confidence that the OhmMapper models can be related to COPR or other subsurface materials.

## **CONCLUSIONS AND RECOMMENDATIONS**

Based on the results of this geophysical test phase, we can infer the following conclusions:

- The MASW data provide repeatable and consistent models of shear wave velocity to depths of 60 to 100 feet.
- The MASW models contain anomalously high velocity values (>1,000 ft/s) in the upper 20 feet that are higher than typical shallow sand and clay, and are likely related to lithified COPR.
- High-velocity zones in the MASW models correlate with anomalously high tip resistance values in existing CPT data.
- The MASW models cannot discriminate between “brown” and “black” COPR and may not identify areas of softer or unlithified COPR.
- Surface and subsurface metal along with high conductivity values limit the effectiveness of the OhmMapper method and produce unreliable models of subsurface resistivity.

The test phase shows that MASW is an effective tool for mapping hard zones related to lithified COPR in the fill materials. MASW data can provide a site-wide assessment of the fill hardness, which can then be used to identify anomalous zones associated with lithified COPR. The results of the MASW data can guide CPT pushes and borings into the most significant features in order to better quantify its thickness and composition. Since the COPR appears to be highly variable in thickness and distribution, the combination of MASW data, CPT pushes, and borings will provide a much more complete assessment of the COPR than from any one of these methods alone.

We recommend that MASW data be acquired along survey lines through accessible areas of the site. The survey lines should be at least 400 feet long and un-interrupted by surface obstructions. Multiple parallel survey lines in each area should be used to assess the lateral continuity of the identified anomalies.



*Note that the interpretations made in this report are from surface geophysical data and the results of previous geologic investigations (see References). No borings, excavations, or other tests were made by Technos to confirm the causes of the anomalies.*

## REFERENCES

- Building Seismic Safety Council (BSSC), 2000, NEHRP recommended provisions for seismic regulations for new buildings, <HTTP://www.bssconline.org/provisions>
- Geometrics, Inc., 1999, OhmMapper TR1 Operation Manual, San Jose, CA, 116p.
- GeoSyntec Consultants, 2005, Subsurface investigation data summary report, Area 1800, Dundalk Marine Terminal, GeoSyntec Project No. ME0418-06, October 4, 2005.
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- Xia, J., Miller, R.D., Park, C.B., Hunter, J.A., Harris, J.B., and Ivanov, J., 2002, Comparing shear-wave velocity profiles inverted from multichannel surface wave with borehole measurements, Soil Dynamics and Earthquake Engineering, Vol. 22, P. 181-190.

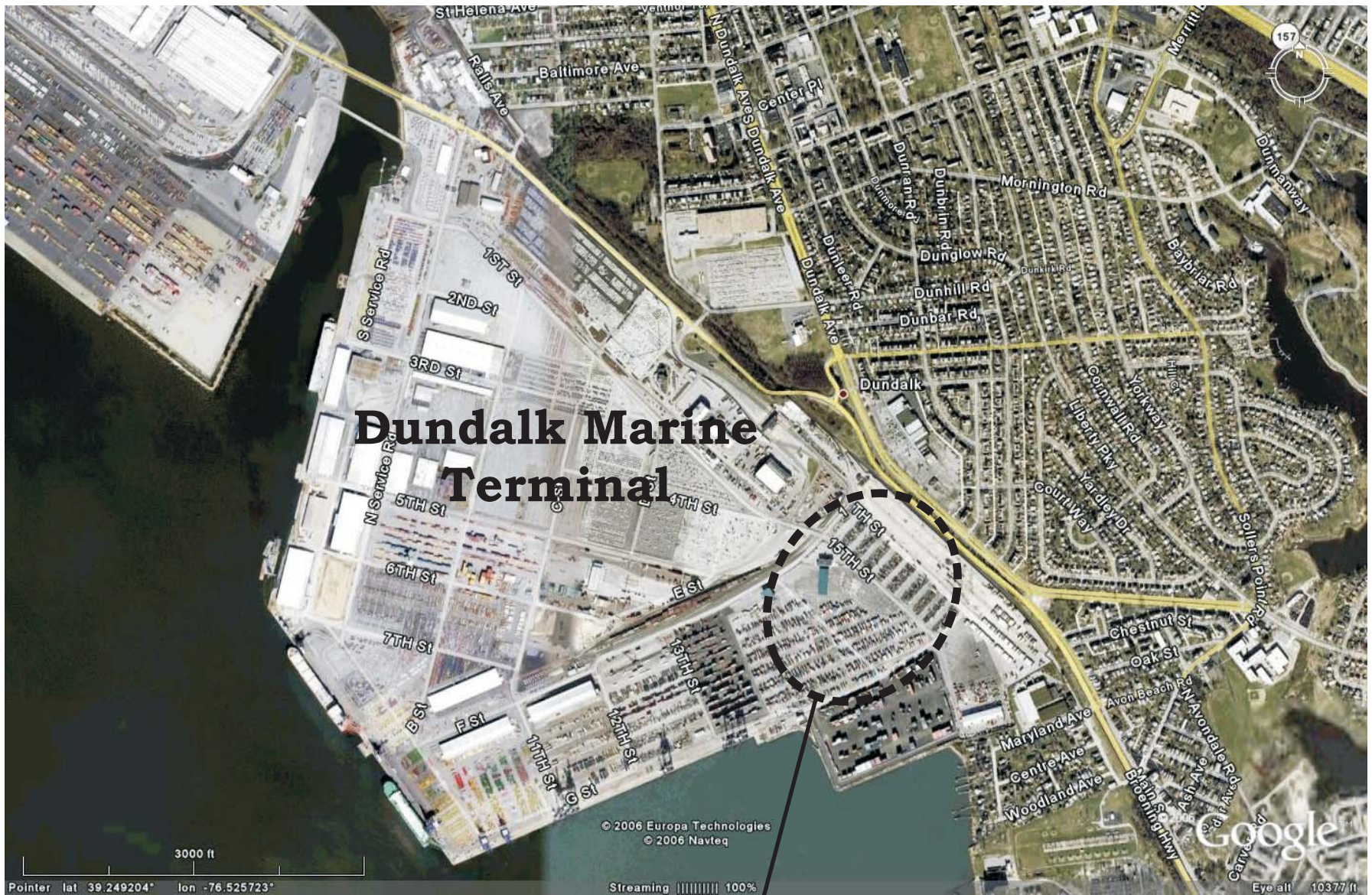


Figure 1. Site location map



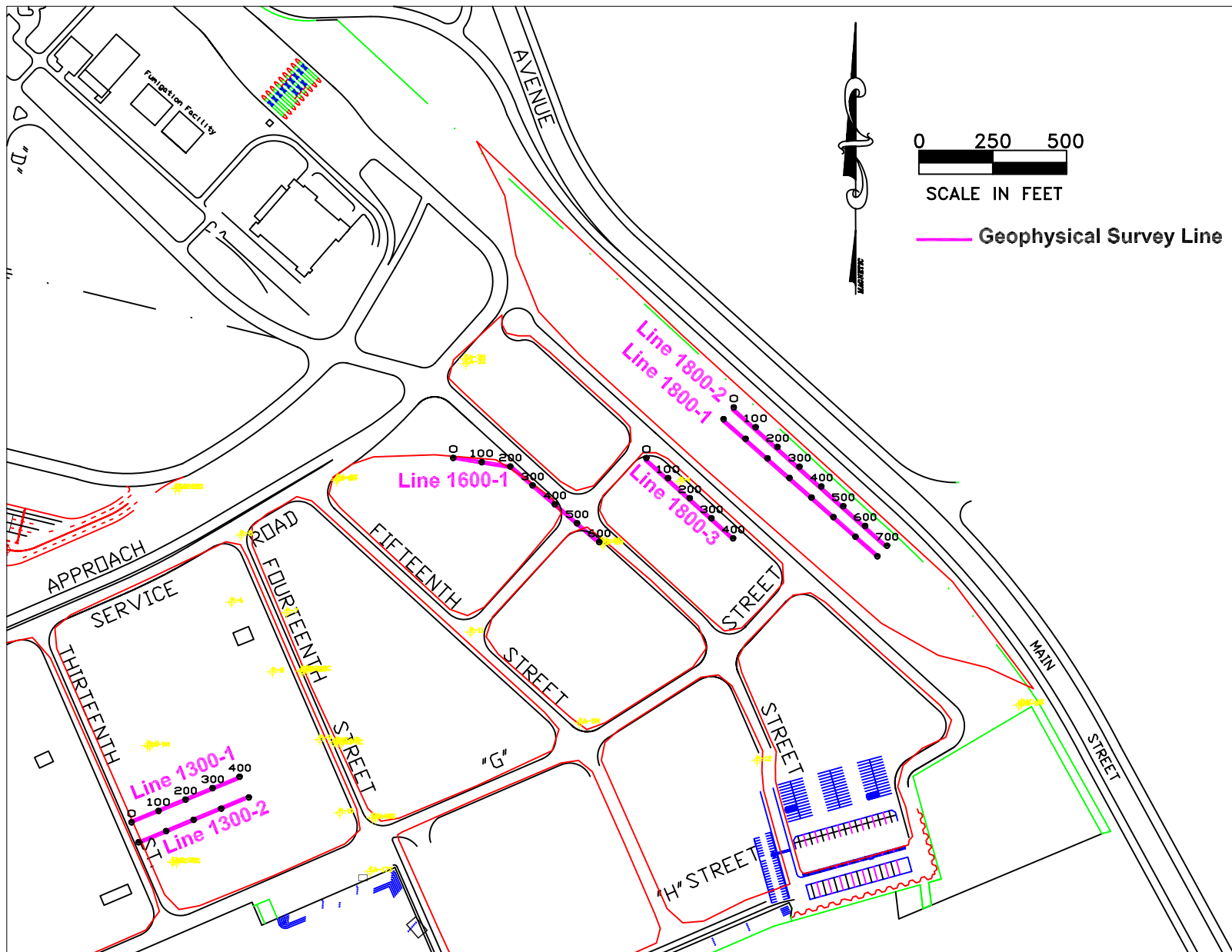


Figure 2. Survey line locations

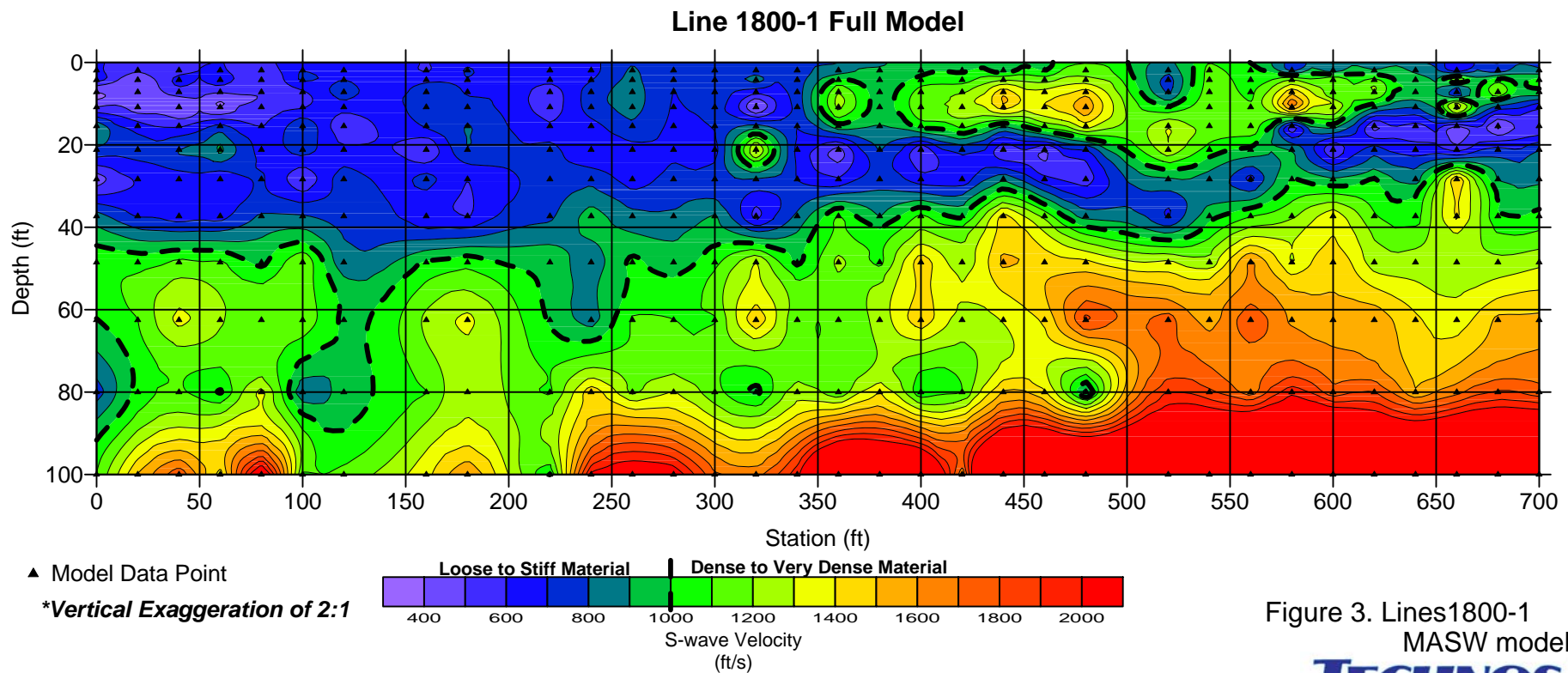
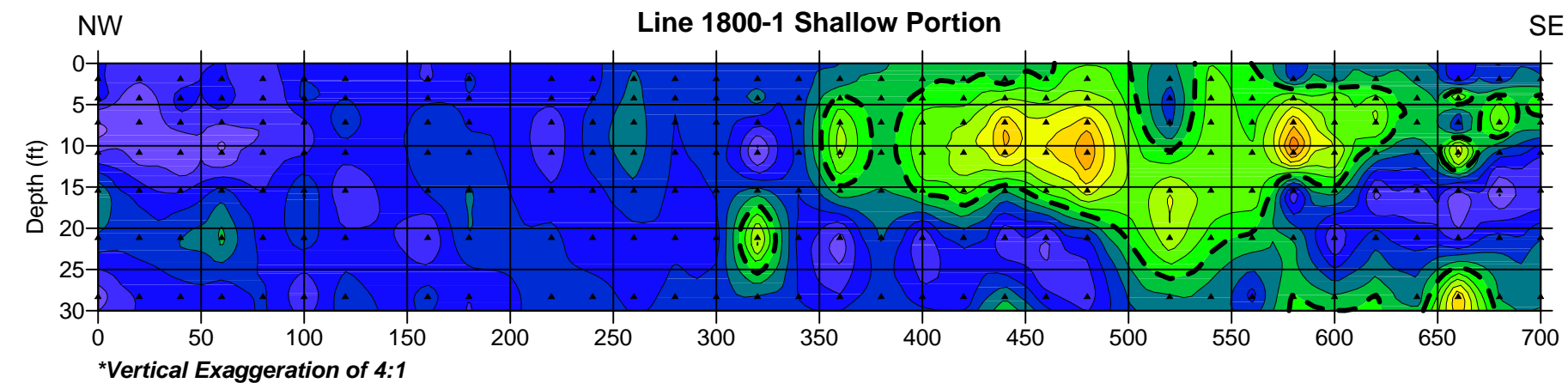
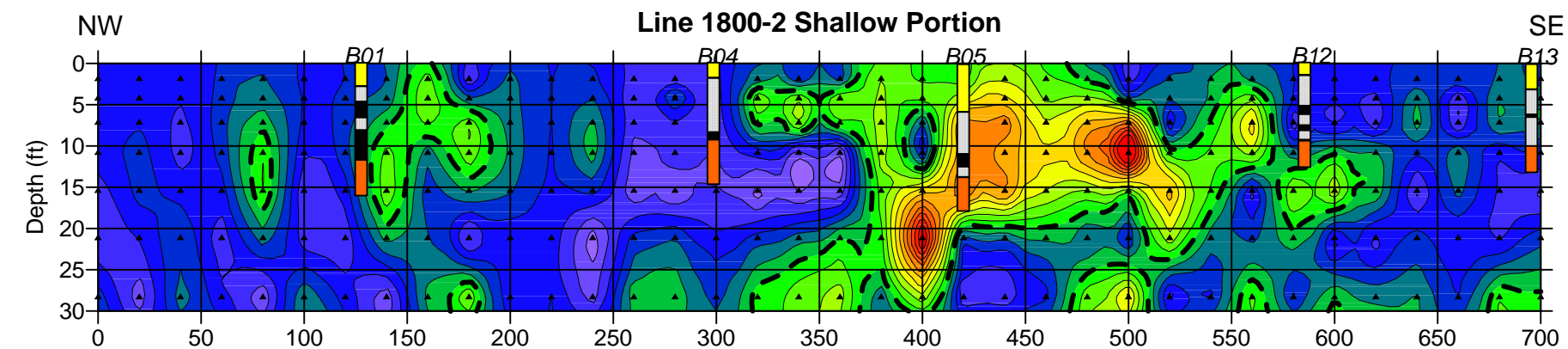


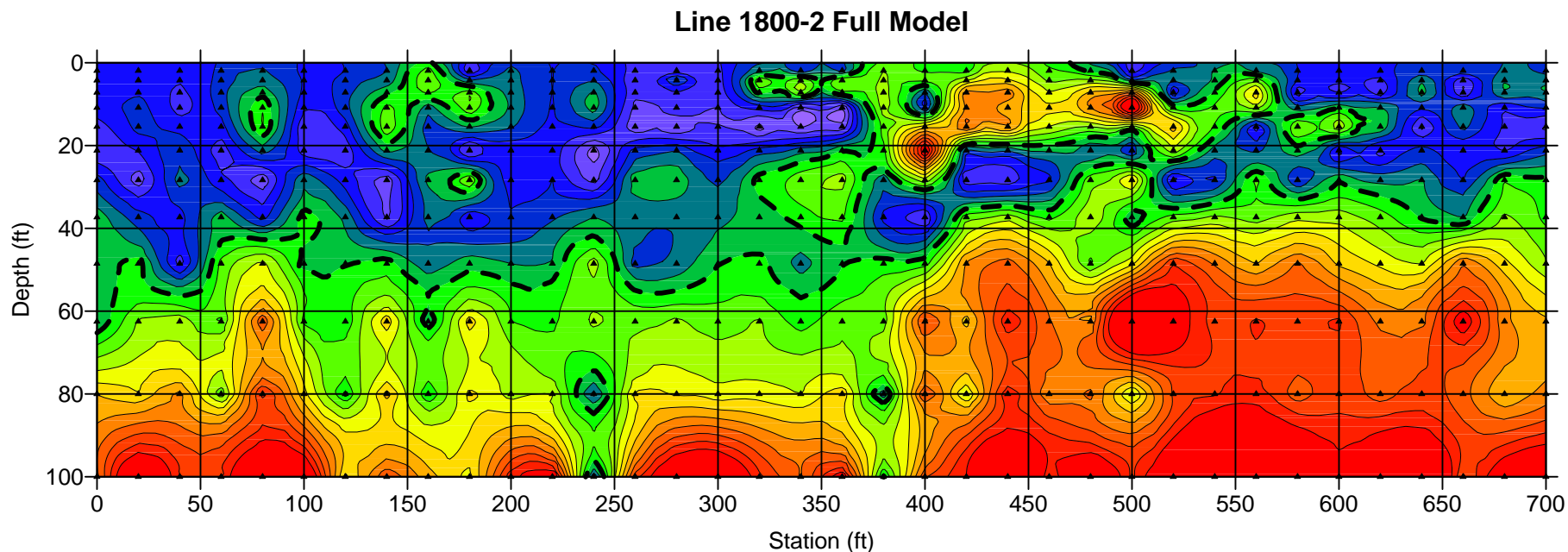
Figure 3. Lines1800-1  
MASW model  
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*\*Vertical Exaggeration of 4:1*

*Simplified Boring Logs from GeoSyntec Consultants, 2005*

Fill & Pavement   
  Black COPR   
  Brown COPR   
  Natural Deposits (sand and clay)



▲ Model Data Point

*\*Vertical Exaggeration of 2:1*

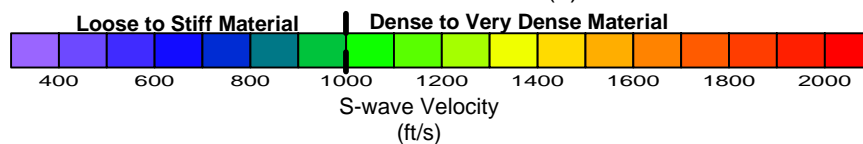
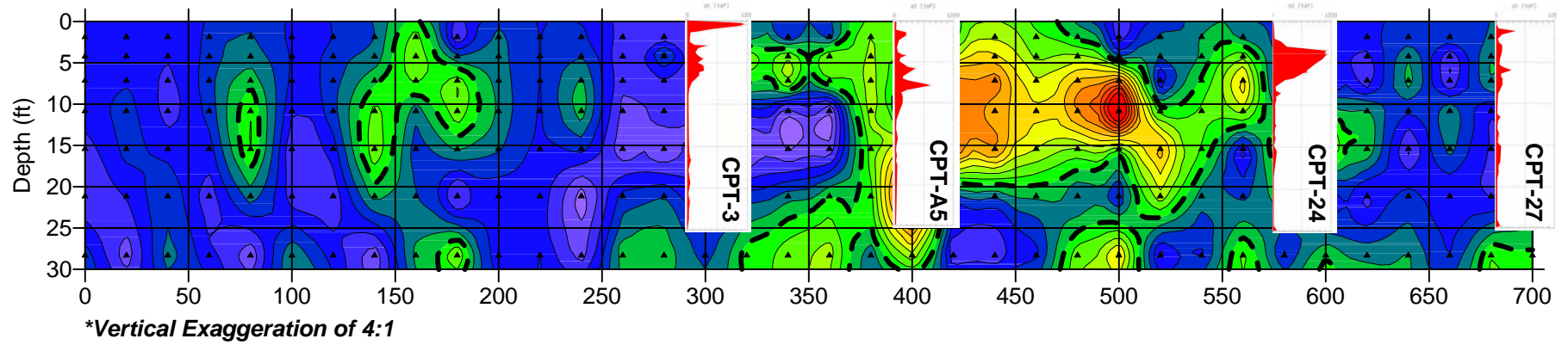


Figure 4. Line 1800-2  
MASW model

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### Line 1800-2 Shallow Portion



### Line 1800-1 Shallow Portion

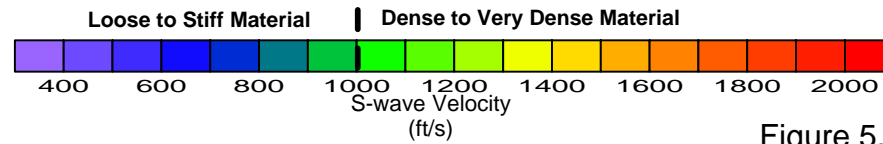
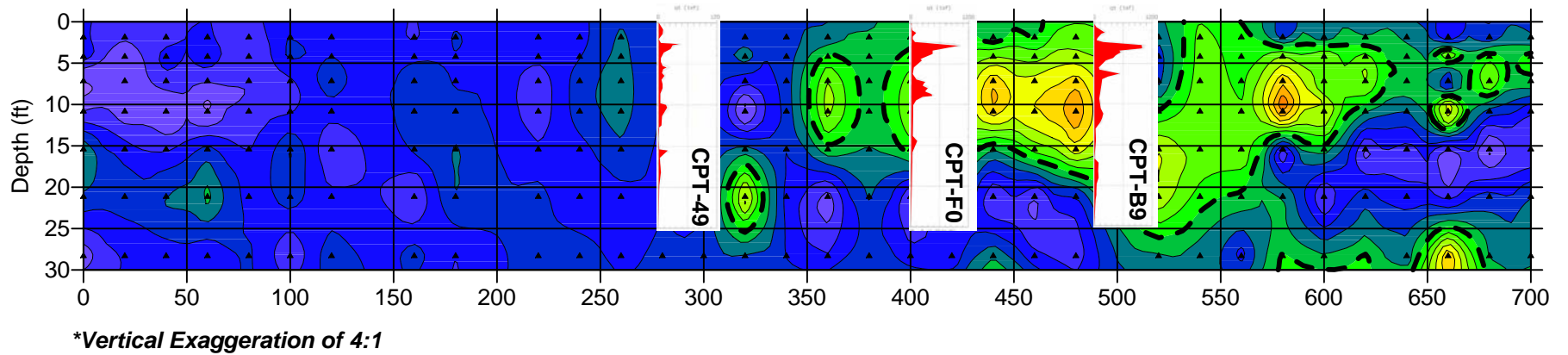


Figure 5. Comparison of MASW models with CPT data

CPT data from GeoSyntec Consultants, 2005

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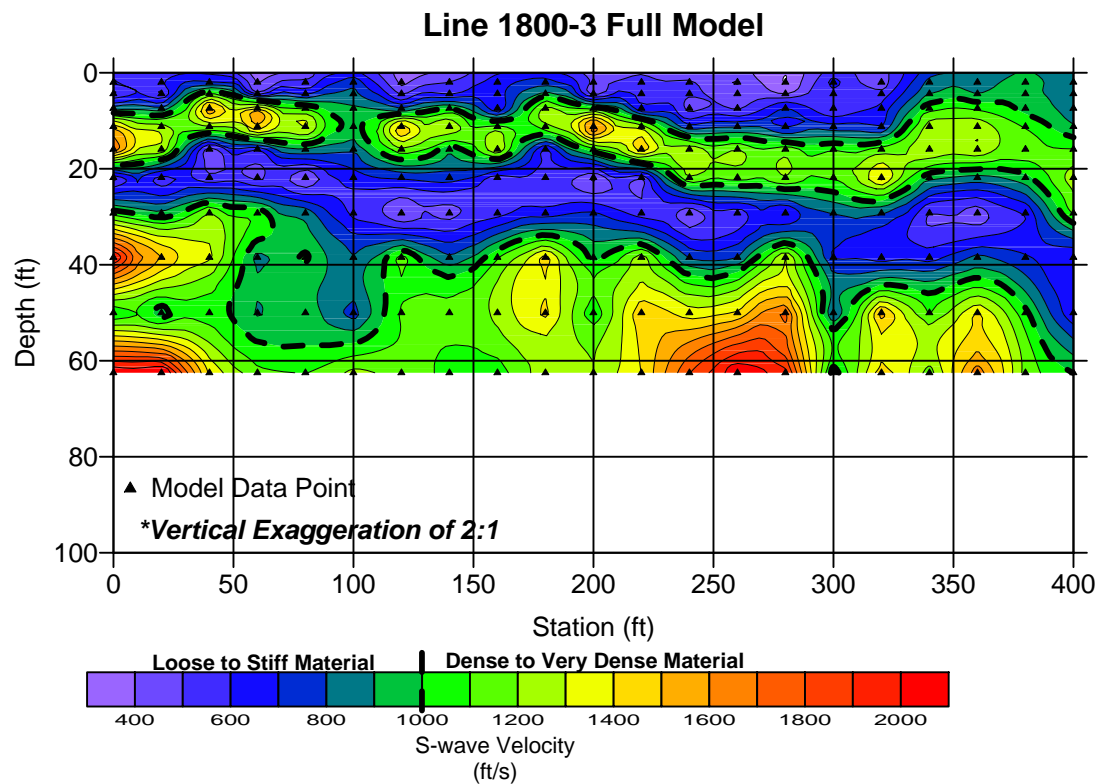
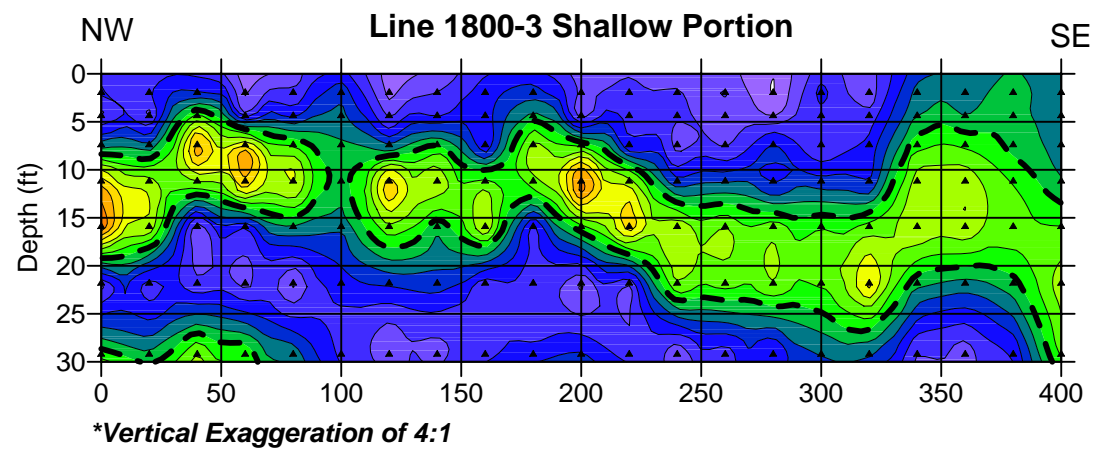


Figure 6. Line 1800-3  
MASW model



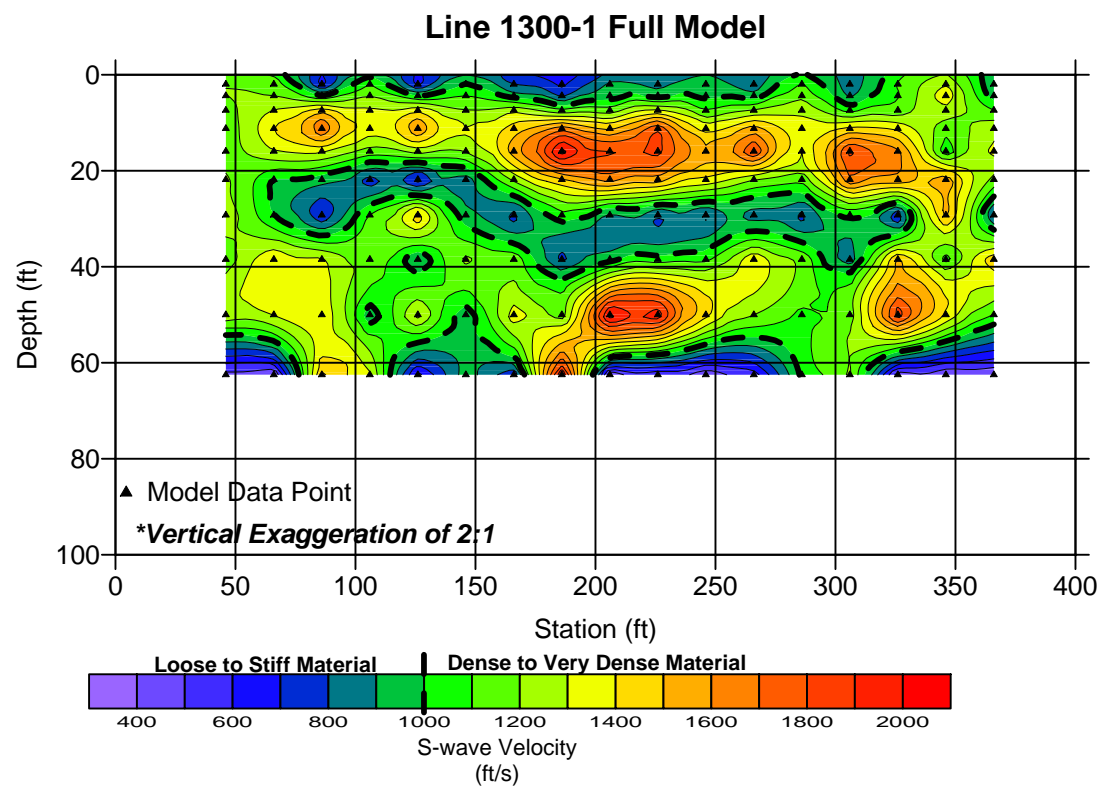
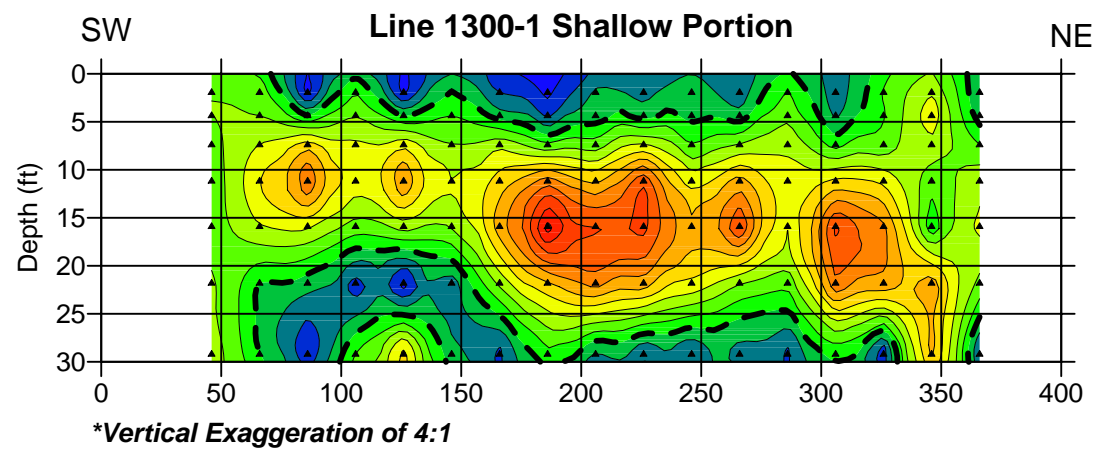


Figure 7. Line 1300-1  
MASW model

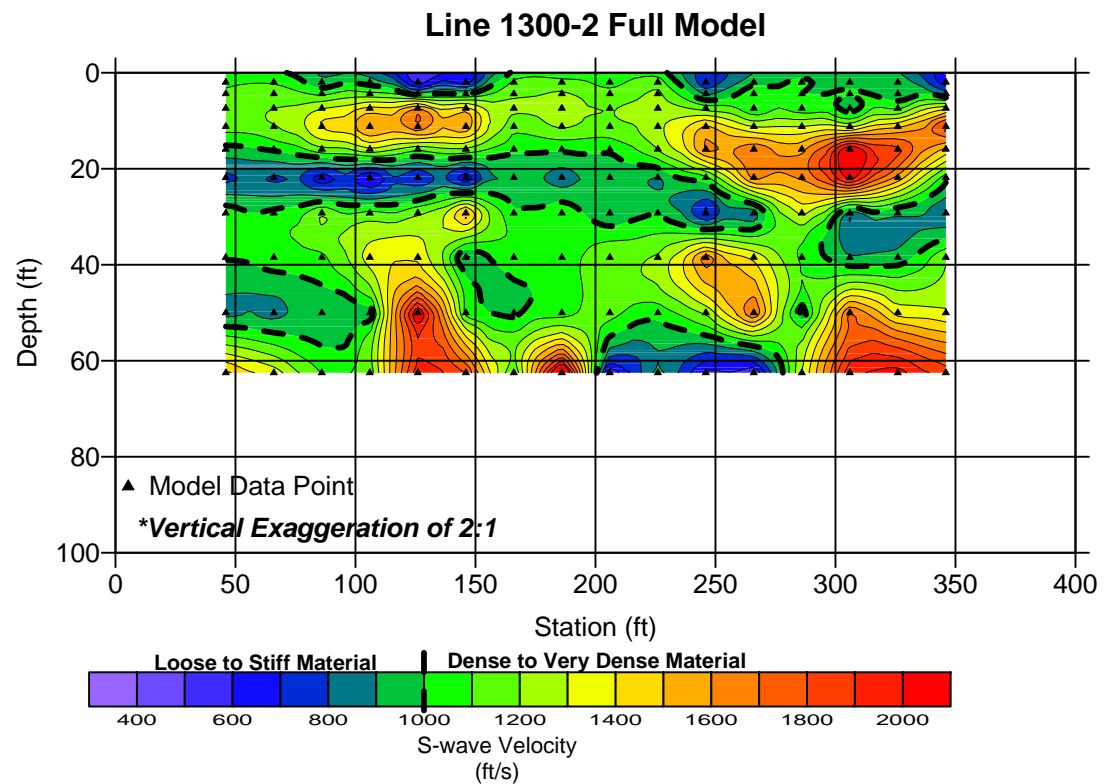
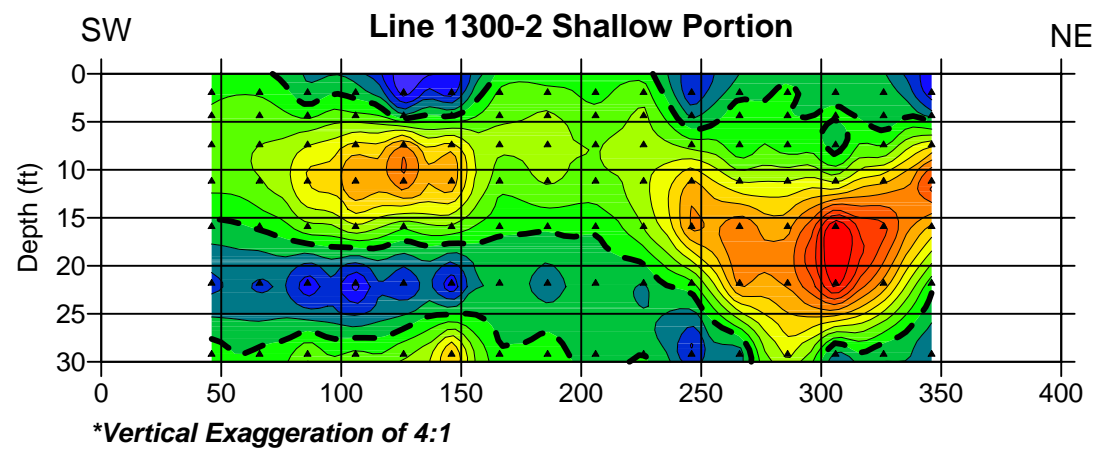


Figure 8. Line 1300-2  
MASW model

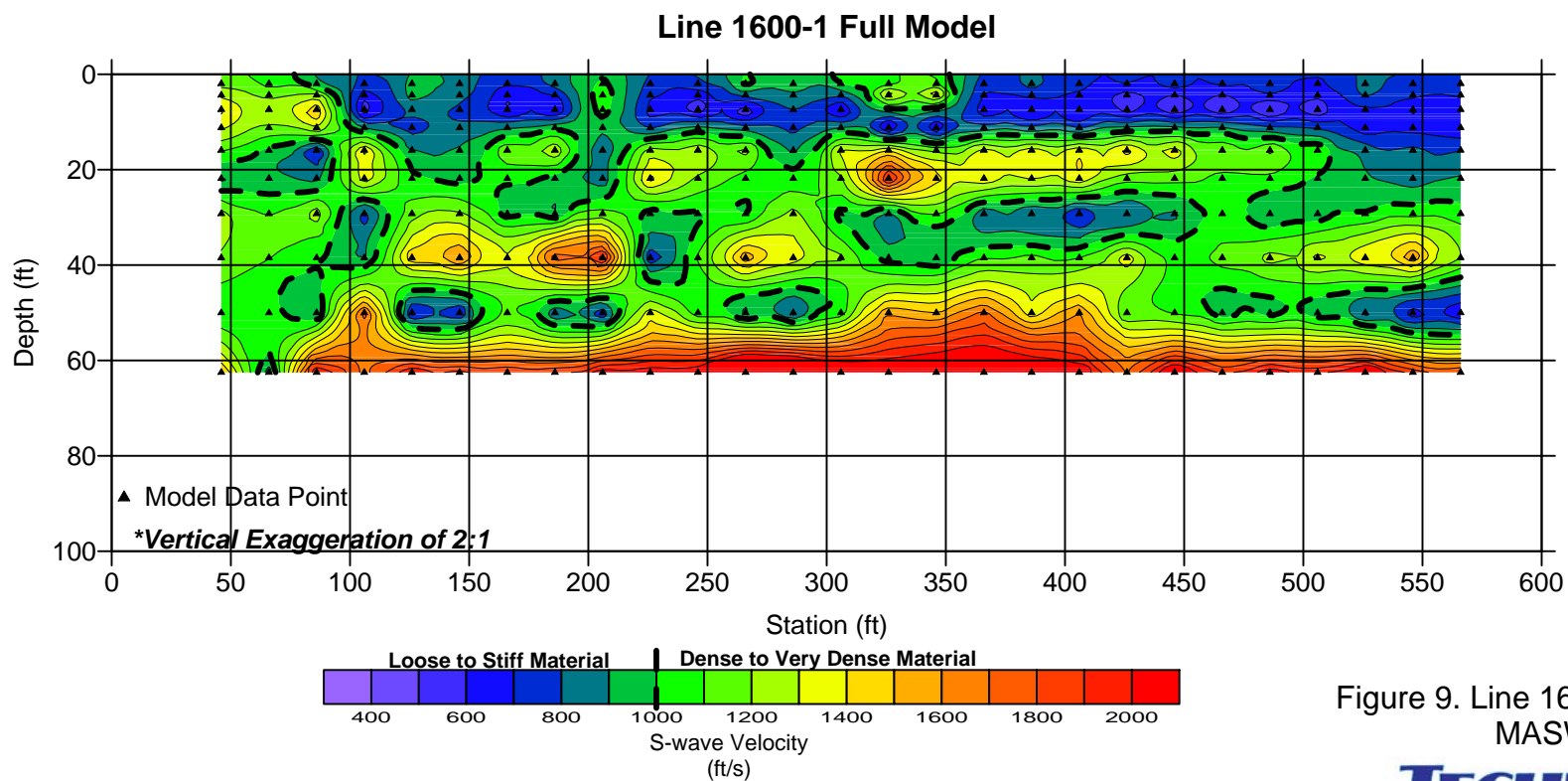
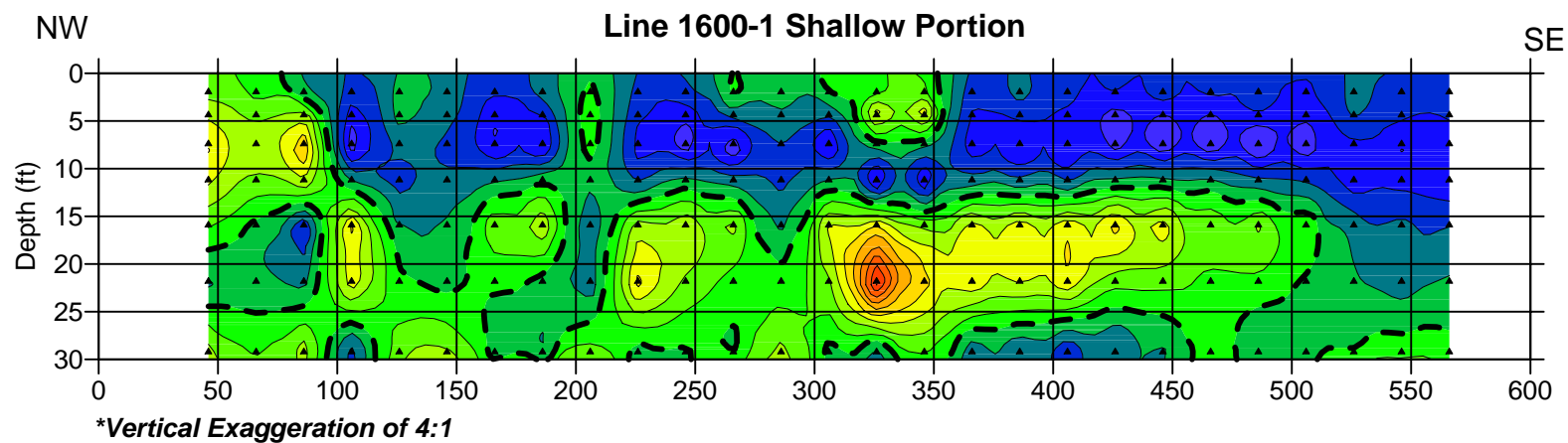
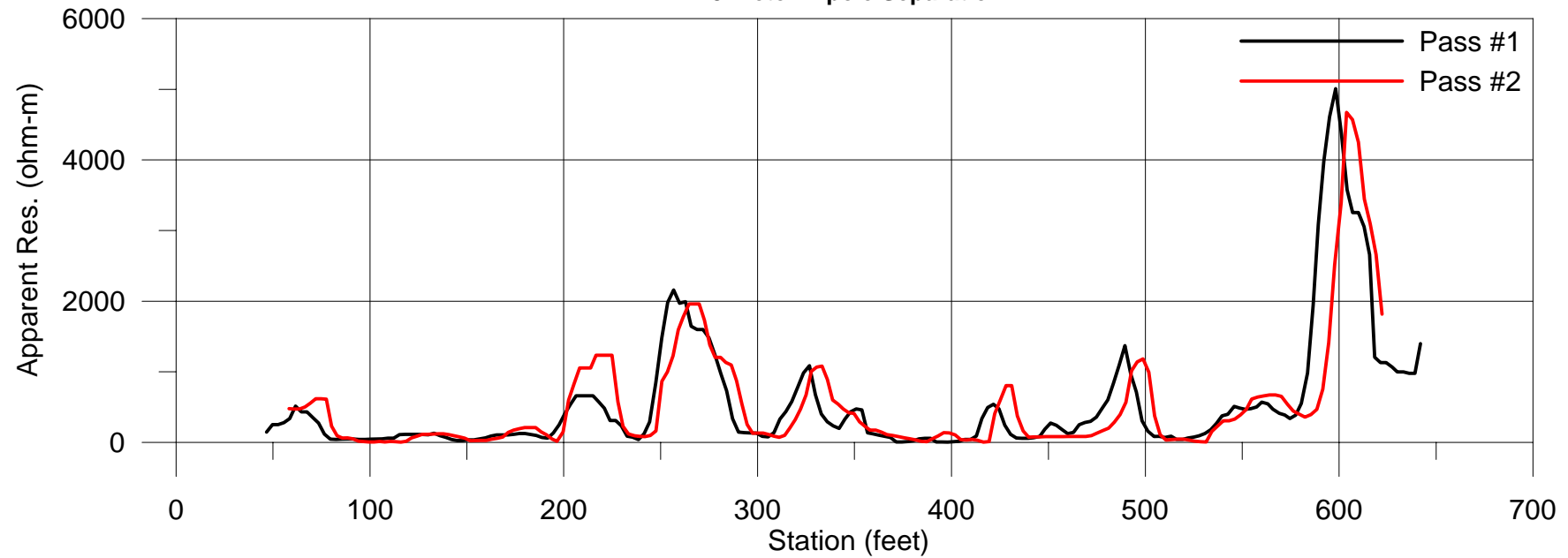


Figure 9. Line 1600-1  
MASW model

### 5-meter Dipole Separation



### 10-meter Dipole Separation

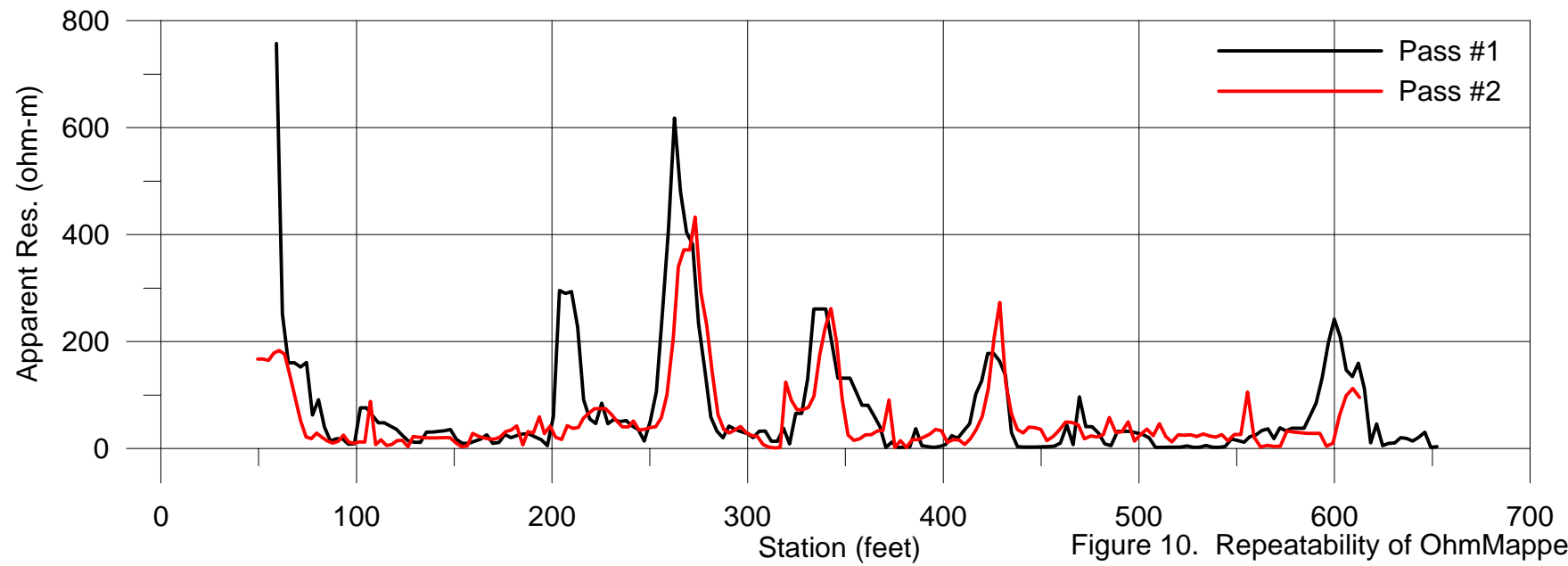


Figure 10. Repeatability of OhmMapper data along Line 1600-1

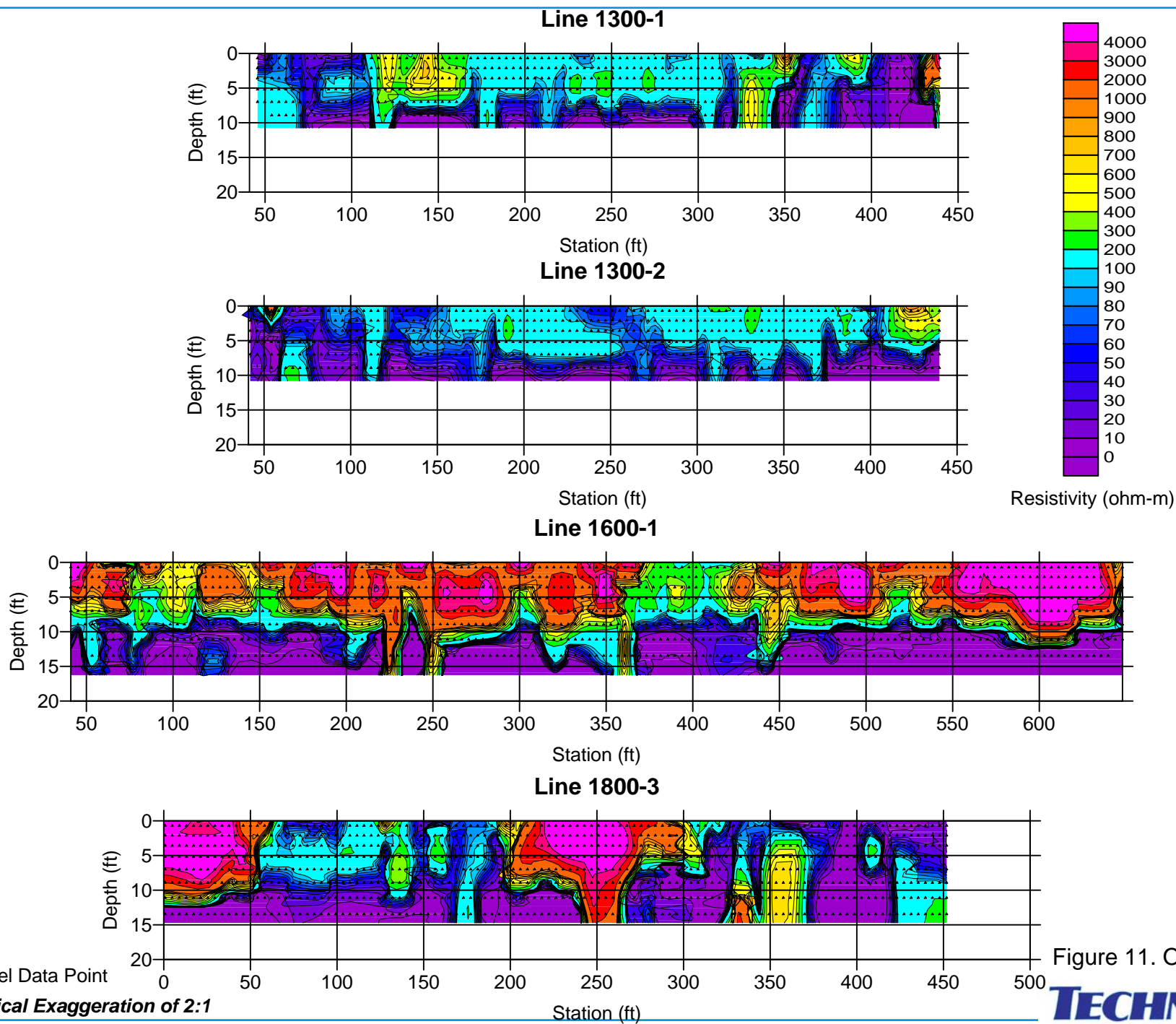


Figure 11. OhmMapper  
models  
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