Appendix A - Driftwood Beach State Recreation Site Geophysical Exploration Report (Siemens and Associates)

Pacific Marine Energy Center South Energy Test Site

Near Waldport, Oregon

<u>DATA REPORT:</u>

Results of Geophysical Exploration

By: Siemens & Associates
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Prepared for: Oregon State University

July 24, 2017

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RE: Pacific Marine Energy Center South Energy Test Site: Geophysical Exploration
Near Waldport, Oregon

Hello Dan,

Siemens & Associates is pleased to present the results of the geophysical exploration.
The geophysical interpretations incorporate the results of an area geologic reconnaissance which strongly influences our interpretation. A draft of this document has been reviewed by OSU and 3U Technologies and comments have been incorporated.

Data were gathered and processed for three geophysical methods: Electrical Resistivity (ER), Seismic Refraction (SR) and Seismic Refraction Microtremor (ReMi). The results are presented to describe continuous, 2D profiles. The interpretations suggest a complicated system of sediments and sedimentary rock through the proposed HDD alignment currently at ~ 50 foot depth. Through this zone, heterogeneous materials of variable strength are expected to dominate. The more homogeneous Alsea Formation is interpreted at lower elevations.

The independent geophysical methods describe similar geologic features in terms of thickness and character of stratification. As described in the report, several factors are judged to be responsible for apparent discrepancies and the results must be interpreted with care.

Siemens & Associates expresses sincere appreciation for the opportunity to conduct this exploration and as new challenges, discoveries and questions arise, we are standing by to offer our assistance.

Prepared by,
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1. Introduction

1.1. Purpose

Siemens & Associates (SA), in conjunction with Optim and John Thompson Associates (JTA), have completed terrestrial geophysical services to support geotechnical evaluations associated with improvements proposed at Driftwood Beach State Recreation Site. The information is intended to provide a first look at geotechnical conditions that can be related to the distribution and strength of shallow, unconsolidated soil and sediment as well as depth to hard rock.

1.2. Methods

Three geophysical methods were used:

- Electrical Resistivity (ER) in 2D
- Seismic Refraction (SR) in 2D
- Seismic Refraction Microtremor (ReMi) in 2D

Details concerning the procedures, the equipment used and results are presented later in this report.

1.3. Project Description

It is understood that Driftwood Beach State Recreation Site is proposed as the entry point for a series of horizontal direction drillings (HDDs) that will extend west below the surf zone providing conduits for communication, control and power distribution to the grid from the test site to be located at sea. The HDDs will extend roughly 3500 feet beyond the west end of the parking lot and will extend to depths approaching 50 feet. Currently, five HDDs are scheduled with diameters on the order of 5 inches.

1.4. Scope

Working under contract with OSU, the SA team completed geophysical measurement throughout the terrestrial portion of the HDD corridor using three independent geophysical methods. Guidelines for the work were outlined in the agreement executed on March 20, 2017, prepared by OSU Capital Planning and Facilities Services. The original work scope as described in the agreement was modified to facilitate permitting and resulted in a an extra mobilization, 18% additional ER survey, 50% additional SR survey and 20% additional ReMi survey in order to limit the need to clear vegetation through the originally proposed geophysical routes. The completed scope is summarized as follows:

- ER, SR and ReMi surveys on four different lines
- SR only, on two additional lines
- Geologic reconnaissance

- Onsite mapping and establishment of permanent survey monuments
- Survey data including locations of geophysical traverses uploaded to GIS database

1.5. Location

The project is located on the Pacific Ocean within the property lines of Driftwood Beach State Recreation Site managed by Oregon Parks and Recreation Department. Twenty four hour access to the site is provided off Highway 101 about two miles north of Waldport, Oregon. Specifically, the project is at Latitude 44.464313°N and Longitude -124.080387°W.

1.6. Limitations

This report has been prepared for the exclusive use of OSU for specific application to the project known as Pacific Marine Energy Center South Energy Test Site. This report has been prepared in accordance with generally accepted geophysical practice consistent with similar work done near Waldport, Oregon, by geophysical practitioners at this time. No other warranty, express or implied, is made.

The information contained in this report is based on data obtained from the field explorations described in Section 4 of this report. The explorations indicate geophysical conditions only at specific locations and times, and only to the depths penetrated. They do not necessarily reflect variations that may exist between exploration locations. The subsurface at other locations may differ from conditions interpreted at these explored locations. Also, the passage of time may result in a change in conditions. If any changes in the nature, design or location of the project are implemented, the information contained in this report should not be considered valid unless the changes are reviewed by SA to address the implications and benefit of enhancing the work as necessary. SA is not responsible for any claims, damages or liability associated with outside interpretation of these results, or for the reuse of the information presented in this report for other projects.

2. Geologic Setting

The project site lies along the Pacific shoreline of Oregon, approximately two miles north of the mouth of the Alsea River and the town of Waldport. The site lies west of the relatively steep, north-south-trending Coast Range, on the coastal margin at Driftwood Beach State Recreation Site. The shoreline area at the project site consists of a relatively flat parking area on a terrace surface approximately 30 feet above the active shoreline. In the vicinity of the site, the shoreline is characterized by a relatively steep, 20- to 40-foot high, steep bluff formed by wave-cut erosion at the toe of the slope. At the project area, the slope from the parking area to the beach is relatively subdued and modified with paths and minor fill.

Based on our literature review and site reconnaissance, the units encountered at the site, from youngest to oldest, consist of Holocene (recent) surficial deposits of unconsolidated fine- to medium-grained dune and beach sand, recent alluvium; Pleistocene marine terrace deposits; and Tertiary siltstone, claystone, and fine sandstone. The recent dune deposits are principally located in the periphery of the parking lot and to areas north, south, and east. The base of the dune sand may exhibit some consolidation. In addition to the recent dune sand deposits along the uplands, active shoreline processes are reworking the older, fine to medium grained terrace sand. Other recent deposits observed near the site include stream alluvium at the mouths of small drainages located north and south of the site. The alluvium consists of sand, gravel and cobbles composed predominantly of erosionally-resistant basalt. The thickness of the recent (Holocene) deposits varies between 0 and tens of feet-thick.

Flat-lying marine terrace deposits underlie the unconsolidated recent deposits in the project vicinity. These semi-consolidated terrace soils are remnants of older beach deposits. The marine terrace deposits are exposed in the shoreline bluffs along most of the Lincoln County shoreline, including the project area. The semi-consolidated, Pleistocene marine terrace deposits form steep bluffs along the shoreline and extend inland as much as a mile. The terrace deposits directly overlie the wave-cut benches formed on westward-tilted, Tertiary marine siltstone and fine sandstone of the Alsea Formation. The base of the marine terrace deposit may contain a lag deposit of coarse sand, gravel and cobbles that formed as a lag deposit at the shoreline transgressed to the east, prior to the deposition of the Pleistocene beach deposit. The Pleistocene marine terrace deposits range in thickness between 0 and 50 feet or more (Schlicker, et. al., 1973).

Tertiary (middle to late Oligocene), dark gray, marine siltstone and fine sandstone (Alsea Formation) underlie the marine terrace deposit. The contact between the Alsea Fm. and the Plio-Pleistocene terrace deposit is unconformable, with the underlying Alsea interbedded claystone, siltstone and fine sandstone inclined westward at dips ranging between 5 and 30 degrees, based on exposures along the Alsea River embayment and east of the project site. Thicknesses of individual interbeds of siltstone versus fine sandstone are unknown at the project site as this unit is not exposed at the surface in the project vicinity. The erosional contact between the Plio-Pleistocene terrace deposits and the underlying Oligocene siltstone and sandstone is regionally flat, however locally may be irregular due to variable erosional resistance between the siltstone, claystone and sandstone. Additionally, due to the unfavorable dip towards the west and active shoreline erosion, bedding plane failures (landslides) within the Alsea Formation exists and displaces the overlying Plio-Pleistocene through Holocene-aged deposits. The thickness of the Tertiary marine Alsea Formation ranges in thickness between 150 and 3,500 feet (Snavely, et. al., 1975).

3. Executive Summary: Conditions Encountered

The data from the various geophysical methods are processed to present the results as “tomograms”; a word derived from the Greek “tomo” meaning to cut or slice. Data were collected to illustrate subsurface conditions a distance of roughly 1200 feet along the westerly route of the proposed HDD corridor as illustrated by Figure 100 (Geophysical Exploration Plan). The tomograms are annotated to communicate our interpretation of the various types of soil and rock believed to be identified by each geophysical method.

As described in the previous section (Geologic Setting), the SA team has identified three distinct strata that dominate the materials to be encountered through this section of the HDD corridor. Stratification is simplified as follows:

- Beach Sand: The recent beach sand consists of unconsolidated, cohesionless, fine- to medium-grained sand derived from the reworking of the older, underlying marine terrace deposits. The sand ranges in density between loose and medium dense, and ranges in moisture between moist and saturated. The thickness of the beach sand varies between approximately 10 and 30 feet in the study area. Geophysical properties are summarized as follows:
  - ER: Wide variations in electrical properties were encountered mostly due to variable moisture content and moisture characteristics. When saturated by salt water, the sand offers a very low electrical resistivity, on the order of 1 Ohm-m. At higher elevations, the sand is moist and the connate water is fresh; the apparent electrical resistivity is on the order of 1,000 Ohm-m. This variation within the same strata promotes difficulty distinguishing the beach sand based on electrical resistivity alone.
  - SR: Unsaturated P-wave velocity was only measured through the higher elevations of the parking lot. Here the beach sand is characterized by P-wave velocity ranging from about 500 to 2000 f/s. In the saturated environment, the P-wave velocity will be similar to the compression wave propagation speed through water: about 4700 f/s.
  - ReMi: S-wave velocity is considered to be an excellent means of distinguishing the extents of the beach sand and the contact with stronger, underlying units. S-wave velocity is valid in both the saturated and unsaturated environment and SA interprets the S-wave velocity of the beach sand to vary from about 300 f/s to around 1000 f/s with these velocities identifying loose to dense characteristics, respectively.
- Marine Terrace Deposits: The Pleistocene terrace deposits consist of orange-brown, fine to medium-grained sand, with abundant organic fragments. Scattered, thin (1- to 2-inch) seams of sandy silt exist within the unit. Previous borings performed in this unit exhibit densities ranging between medium dense and dense. Subsurface information for the proximal area is sparse, however based on observations from the field, the terrace deposit ranges in thickness between 25 and 35 feet in the vicinity of the parking lot and to between 20 and 50 feet in the near shore area investigated in this study. Geophysical properties are summarized as follows:

- ER: Again, the ER interpretation is challenged by a wide range of electrical resistivity mostly driven by the character of the connate water. However, within each ER tomogram, electrical contrast exists to help define the upper and lower boundary of the marine terrace deposits.
- SR: P-wave refraction is an ineffective method to define the character and thickness of this stratum. SA suggests that this is due to numerous, thin layers offering variable P-wave velocity. When a high velocity layer is situated at a higher elevation than a lower velocity layer, the first arrival P-waves are carried by the higher elevation layer and the lower layers are not sampled properly. Thus, limited sampling of the marine terrace has been accomplished by SR. This blind zone leads to problems associated with defining the marine terrace thickness and position of lower strata.
- ReMi: The ReMi method provides clear definition of the marine terrace layers and identifies numerous velocity reversals, heterogeneity and a reasonable estimate regarding thickness, and strength. SA interprets S-wave velocity ranging from about 800 f/s to roughly 2200 f/s represent the marine terrace. This suggests a wide range of strength and texture.

- <u>Tertiary Alsea Formation</u>: The fine grained marine Alsea Formation is an indurated, interbedded, gray, siltstone, claystone, and fine sandstone. Based on previous explorations within this formation elsewhere in the region, the Alsea is hard/very dense and exhibits refusal standard penetration tests (SPTs). As described above, the top of the Alsea is a former shoreline and may exhibit an undulating erosional surface due to the variability in erosional resistance between the siltstone and sandstone interbeds. The thickness of the individual interbeds of siltstone and sandstone are unknown at the site, but outcrop evidence suggests a range between inches and tens of feet. Geophysical properties are summarized as follows:
    - ER: The ER results suggest that the Alsea Formation offers a low resistivity layer and the formation is well defined in both the saltwater and freshwater environment. The Resistivity varies widely based on the character of the connate water. In the higher elevations a strong electrical contrast exists that defines the depth to the Alsea that closely correlates with the depth defined by both SR and ReMi.
    - SR: Where thick deposits of the marine terrace deposits exist, the SR method is not considered to be an effective geophysical method to reliably define the depth and P-wave velocity of the Alsea.
    - ReMi: In each tomogram, the Alsea is clearly defined by an increase in S-wave velocity. SA interprets an S-wave velocity on the order of 2200 f/s and higher to represent the Alsea Formation. The contact with the overlying marine terrace is typically abrupt and S-wave velocity as high as about 3800 f/s are interpreted.

4. Geophysical Data Acquisition: Terrestrial

The three geophysical methods were designed to explore the geotechnical conditions to depths of 100 feet and beyond. Data were procured in a manner to extend the exploration as far west as possible by scheduling operations to coincide with low tide. In order to facilitate permitting with Oregon Parks and Recreation Department, the lines on the beach were terminated below the parking lot to prevent the need to clear vegetation. Exploration was continued at the higher elevation of the parking lot with the survey locations selected to avoid vegetation removal and limit damage to the parking lot pavement. Line locations are illustrated by Figure 100 (Geophysical Exploration Plan).

In this section, the geophysical methods, equipment, challenges, and quality are described.

4.1. Geophysical Methods and Equipment

4.1.1. Electrical Resistivity (ER)

How it works: Two-dimensional (2D) electrical resistivity tomography is a geophysical method to illustrate the electrical characteristics of the subsurface by taking measurements on land or in a marine setting. These measurements are then interpreted to provide a 2D electrical resistivity profile which is, in turn, related to the likely distribution of geologic or cultural features known to offer similar electrical properties. Measurement in an electrical survey involves injecting DC current though two current-carrying electrodes and measuring the resulting voltage difference at two or more potential electrodes. The apparent resistivity is calculated using the value of the injected current, the voltage measured and a geometric factor related to

the arrangement of the four electrodes.

The investigation depth of any particular measurement is related to the spacing between the electrodes that inject current. Therefore, sampling at different depths can be done by changing the spacing between the electrodes. Measurements are repeated along a survey line with various combinations of electrodes and spacing to produce an apparent resistivity cross-section (tomogram). In this case, SA used both Wenner and Dipole-Dipole arrays with electrode spacing ranging from 3 to 4 m along overlapping lines composed of 56 electrode take-outs built into the cable.

ER lines were set to coincide with low tide and continue from the surf zone to the toe of the brushy slope west of the parking lot. Additional lines were extended north to south both near the toe and crest of slope near the west end of the parking lot. Line length varies from 540 feet to 1141 feet with depth of exploration as great as 160 feet. Figure 100 (Geophysical Exploration Plan) illustrates the location of each line.

Electrical resistivity data were recorded using an R-8 SuperSting manufactured by Advanced Geosciences, Inc., Austin, Texas, USA. The instrument is an eight channel, automated system capable of completing over 1600 measurements in about one hour. For this project, the measurement sequence was configured for a high density data set and data were subsequently filtered during the processing stage.

4.1.2. Seismic Refraction (SR)

Seismic refraction (SR) is an active seismic method utilizing geophone receivers set along a straight line gathering data from signals induced by a small explosive charge (8 gauge, 400 grain black powder shell detonated using a Betsy Seisgun). Data were processed using forward modeling software developed by Optim known as SeisOpt@2D; the models developed are considered questionable due to velocity reversal “blind zones” as described in Section 5. SR provides a 2D profile illustrating P-wave velocity with depth. Lower P-wave velocity is related to unconsolidated materials while heavily consolidated materials and rock are illustrated by higher P-wave velocity.

How it works: When the explosive charge detonates, the receivers are triggered and the wavelet energy is recorded. The P-wave is the fastest of the various seismic waves that are generated and only the time of the first arrival wave form at the receiver is considered in the SR method. These "first arrivals" are picked for each record. As the energy travels through the ground, the waves are refracted and the arrival time, combined with distance from the source is related to both the velocity and distance to the layers promoting refraction. This distance is not necessarily vertical depth; rather the nearest refractor and the image can be skewed when oriented along a dipping refractor.

In this case, the soils on the beach are saturated promoting P-wave travel through and velocity measurement of the fluid rather than the soil. This means that P-wave velocity lower than about 4700 f/s (speed through water) will not be measured by seismic refraction.

Data were recorded using a networked pair of DAQ III seismographs manufactured by Seismic Source in Ponca City, Oklahoma, USA, connected to a HP laptop computer.

4.1.3. Seismic Refraction Microtremor (ReMi)

The refraction microtremor, known as ReMi is a passive, surface-wave analysis method for obtaining near surface shear-wave velocity models to constrain strength and position of shallow geologic boundaries. These analyses provide information about land and marine soil and rock properties that are very difficult to obtain through alternative methods. SA recorded passive ambient vibrations (background noise) augmented by an active seismic source (un-timed plate and hammer) operated near the array.

On land, surface wave analysis is performed using Rayleigh waves because they can be detected on an air-ground interface (earth surface) using geophones. However, the Scholte wave, which is a similar type of seismic surface wave propagating along the interface between a fluid layer and an underlying solid (the seabed), dominate in marine work. Hence, the Scholte wave is capitalized in marine work and measured with hydrophones set at the water-seabed interface to record ambient vibrations. Both hydrophones and geophones measure the vertical component of the surface wave (Scholte or Rayleigh) and the results are considered a reasonable estimate of the vertical distance (depth) to layers below the receivers.

How it works: The ReMi analysis develops the shear-wave velocity/depth profile using an engineering seismograph, low frequency receivers (geophones or hydrophones) and straight line array aperture (Louie, 2001). Ambient surface wave energy is recorded using relatively long sample window (30 seconds) recording the ambient wavefield. At this site, quality low frequency signals were consistently recorded from waves crashing on the beach, nearby highway traffic (trucks) and SA enhanced the mid-range frequency (about 15 Hz. to 50 Hz.) using a plate and hammer.

The microtremor records are transformed as a simple, two-dimensional slowness-frequency (p-f) plot where the ray parameter “p” is the horizontal component of slowness (inverse velocity) along the array and “f” is the corresponding frequency (inverse of period). The p-f analysis produces a record of the total spectral power in all records from the site, which plots within the chosen p-f axes. The trend within these axes, where a coherent phase has significant power is “picked”. Then the slowness-frequency picks are transformed to a typical period-velocity diagram for dispersion. Picking the points to be entered into the dispersion curve is done manually along the low velocity envelope appearing in the p-f image.

Terrestrial measurements were completed using 8 Hz. vertical receivers (geophones) using the same arrays configured for SR. Receiver overlap of 12 channels were used to provide continuous records through the long arrays of Lines A and B.

Data were recorded using a pair of networked DAQ III seismographs manufactured by Seismic Source in Ponca City, Oklahoma, USA, connected to an HP laptop computer.

4.2. Horizontal and Vertical Control

The horizontal and vertical locations were recorded by JTA as the geophysical operations were in progress. JTA worked alongside the geophysical crew each day of operations and provided staking to locate the lines in accordance with data illustrating the anticipated orientation of the HDD corridor. The North American Vertical Datum of 1988 is the basis for the elevations presented by the geophysical tomograms and details regarding the onsite survey including tabulations of the measured coordinates and a scaled site plan are presented in Section 8 of this report. Coordinates have also been uploaded to ArcGIS, a GIS database for future reference. Details regarding the GIS database and upload data formats are described in Section 9 of this report. Figure 100 (Geophysical Exploration Plan) is a rough, visual illustration of the line locations and not intended to reflect the accuracy of the JTA survey.

4.3. Ancillary Operations

4.3.1. Traffic Control

At the start of each workday, SA established a safe corridor to maintain public awareness. When operations moved to the parking lot, the west end of the lot was closed to traffic. The plan consisted of signage and cones and a few cars that where within the closed area were allowed to exit across the survey cables that were protected by a rubber road mat that allowed traffic to travel directly over the survey cables as operations were underway.

4.4. Summary of Challenges

4.4.1. Operations

Several difficulties were experienced with the most severe related to the rapid flood tide experienced on the first day of operations and associated strong wave breaks that displaced the initial setting of the ER cable along Line A. The crew needed to adjust operations including changing the planned sequence for the SR survey on Line B and re-doing the ER on Line A at a later time. Also, at the higher elevations of the parking lot, the sand was quite resistive and significant difficulty was experienced in achieving proper contact resistance at the electrode pins. The pins were watered with a saline solution and driven deep to mitigate this condition. Along Line D, both Dipole-Dipole and Wenner electrode configurations were used and the Wenner data proved to be more robust due to a stronger signal and was used in the final data processing.

4.4.2. Data Quality and Interpretation Challenges

In general, the recorded data are judged to be of moderate to high quality. The lines were laid out to optimize definition of the subsurface throughout the upper 100 feet, roughly twice the anticipated depth of the HDDs through this zone. The results provide an outstanding first look at subsurface conditions including a solid understanding of the relative strength, character and position of the various layers encountered. A summary of the engineer's judgment regarding quality and confidence in the results presented by each geophysical line is as follows:

ER-1, ER-2, SR-5, SR-6 and RM-1 through RM-4: High quality/confidence

SR-4: Good quality, challenged by some velocity reversal, not severe

ER-3, ER-4, SR-1 and SR-2, SR-3: Moderate quality, challenged by high contact resistance at the electrode pins (ER) and velocity reversal (SR)

5. Processing

5.1. General

During the data gather, partial interpretation was completed in the field for quality control purposes and to assist in setting and confirming proper data acquisition parameters.

The interpretation for each line is presented as appendix to this report with the general locations shown graphically on Figure 100 (Geophysical Exploration Plan).

It is worthy to emphasize that the geophysical results are presented in 2D yet the data collection is influenced by a 3D environment. Unless the geology is simple, like a flat stack of pancakes, the various geophysical methods cannot be expected to match perfectly. In addition, geophysical interpretations are often compared to direct observation of conditions discovered in geotechnical drill holes. Note that the drill hole is a 1D representation of the subsurface and represents a very small sampling, unlike the geophysical approach. Correlation and conflict are expected and both must be considered in context with the complication of the subsurface and the various factors influencing the measurements.

A description of the data processing, interpretation methods and results are presented as follows:

5.2. Electrical Resistivity (ER)

Important factors which affect the resistivity of different geological material are:

- Porosity
- Moisture content
- Dissolved electrolytes
- Temperature (resistivity decreases with increasing temperature)

- Water conductivity (in marine environments)

5.2.1. Processing

The AGI, R-8 SuperSting stores field measurements to proprietary data files with a .stg extension. Each dataset was filtered to remove spikes and noisy data through a systematic progression to produce inversion models with acceptable RMS error data fit without excessive iteration, which tends to produce artificial anomaly. Geometry (elevation data) was included in the processing. The data sets from overlapping measurements were combined for processing using AGI Earth Imager and Res2DINV by Geotomo Software. In the end, SA selected the inversion produced by Earth Imager; however, the two software packages produced similar findings.

5.2.2. Presentation and Interpretation

At this site, electrical contrast ranges from less than 10 Ohm meters near the ocean and is roughly 4 orders of magnitude near the parking lot. This presents a challenge in presenting the results since using a common resistivity scale for each of the tomograms effectively masks important characteristics. The difficulty was resolved by changing the resistivity presentation scale to match the range illustrated by the data measured along each line.

Since different resistivity scales are used, it is difficult to correlate similarities from line to line. Nevertheless, the ER results tend to illustrate stratification boundaries that generally are supported by the results of the other geophysical methods.

A common horizontal and vertical scale of 1 inch = 50 feet was selected for presentation of each line and the long lines A and B are presented with a horizontal scale of 1 inch = 100 feet while the shorter lines C and D offer a horizontal scale of 1 inch = 50 feet to better illustrate the findings.

5.2.3. Seismic Refraction (SR)

Refraction data were recorded along each line and the data were excellent. Lines A, B and C were challenged by several factors. First, the soils were either saturated from the surface or the water table was very shallow. This promotes P-wave velocity related to the saturated condition (essentially the speed of a compression wave traveling through water) and can be many times faster than the velocity of the same wave through the same soil if it were not saturated. Hence, the P-wave is a poor measure of soil strength when saturated. Second, the sediments appear to be layered such that stronger, faster layers are bedded at depths above weaker, slower layers. This causes problems with the refraction method since the fastest raypaths return to the receivers from shallow depth and deep geology is not sampled as thoroughly.

5.2.4. Processing

SA processed the refraction data using software known as SeisOpt@2D, version 6.0, developed by Optim. The process uses a forward modeling and nonlinear optimization procedure capable of resolving features to about one-half of the receiver spacing generating results using only geometry, source and receiver locations, and first arrival times. Many models were generated for each line to determine the best fit for various possibilities of raypaths refracting to each receiver from each shot. The primary variable (and unknown) is the depth to the refractor and in this is case, SA judges that the refractors are a complicated system of layers offering velocity reversals challenging the normal precision of the refraction method. This is particularly true for Lines A, B and C, and less of an issue with the remaining lines that are at higher elevations.

The raypath hitplots are presented to illustrate the path of the refracting waves for the models that were selected. These plots clearly show that the P-wave velocity through the interior regions of Lines A, B and C is not well constrained. This is a classic example of when the refraction seismic method is not the most effective geophysical technique for the given geology.

5.2.5. Presentation and Interpretation

The geology described by the 2D refraction surveys defines a strong layer with an elevation that ranges as deep as about -80 feet to as shallow as about -20 feet. This interpretation is judged to be suspect due to the velocity reversal “blind zone” as discussed. In the opinion of SA, the 2D ReMi interpretations are probably a better estimate for depth to hard, strong layers and a much better description of the strength of the shallow, saturated soils and the lateral variability.

A common vertical scale of 1 inch = 50 feet was selected for presentation of the Lines A, B, C and D, and a horizontal scale of 1 inch = 30 feet was used for the short lines E and F to better illustrate the findings. A common velocity range was used for each velocity tomogram.

5.3. Refraction Micro-tremor (ReMi)

A two-dimensional shear-wave model was produced along each of the geophysical traverses for Lines A through D. The models are of particular value as the shear wave velocity is directly related to the strength of a geologic material and is not influenced by saturation since water has no shear strength. The models were produced by Dr. Satish Pullammanappallil, Ph.D. of Optim, Reno, Nevada, USA using SeisOpt ReMi software. The 2D models illustrate the trend in the subsurface in terms of shear-wave velocity that correspond closely with trends in the ER and, in some cases, SR adding confidence in the interpretation.

Shear-wave velocity, V_s is used to determine the shear modulus, G, of soil or rock:

$G = \rho (V_s^2)$: a valuable measure of soil stiffness and rock strength.

Where ρ = mass density (i.e. total unit weight / gravitational acceleration constant, 32.2 ft/s^2).

The ReMi derived V_s from small strain measurements produced by non-destructive surface waves (Rayleigh waves) with strain on the order of 10^{-4} %. Shear modulus (G) derived from shear-wave velocity measured insitu using surface wave methods is commonly referred to as the small-strain shear modulus G_{max}.

The shear-wave velocities observed in the 2D ReMi profile illustrates numerous velocity reversals in the shallow layers and a clear, typically abrupt transition to hard, strong material at elevations ranging from about -100 feet to as shallow as -20 feet or so. The data for ReMi analysis are robust and SA judges the 2D ReMi profile to be a valid estimate of the prevailing geology. Overall, the ReMi appears to define complicated, disconnected layers of variable strength underlain by competent, hard strata.

5.3.1. Processing

Dr. Pullammanappallil, Ph.D. took the lead on processing the ReMi datasets. He created a series of 1D shear-wave depth profiles along each line using 12 to 24 channels per analysis progressing through the data one channel at a time (channels 1 to 12, 2 to 13, 3 to 14 and so on). As many as 24 channels were used to constrain the deepest parts of the models; however, even the 12 channel analysis offered data constraining depth of exploration approaching 70 feet.

5.3.2. Presentation and Interpretation

The 2D ReMi data is presented using a template similar to the ER and SR with common horizontal and vertical scales.

5.3.3. Seismic Site Classification (ASCE 7)

Seismic Site Classification in accordance with ASCE 7 was also calculated from data along each of the 2D ReMi lines. Site Class C dominates with the average V100 well above 1200 f/s.

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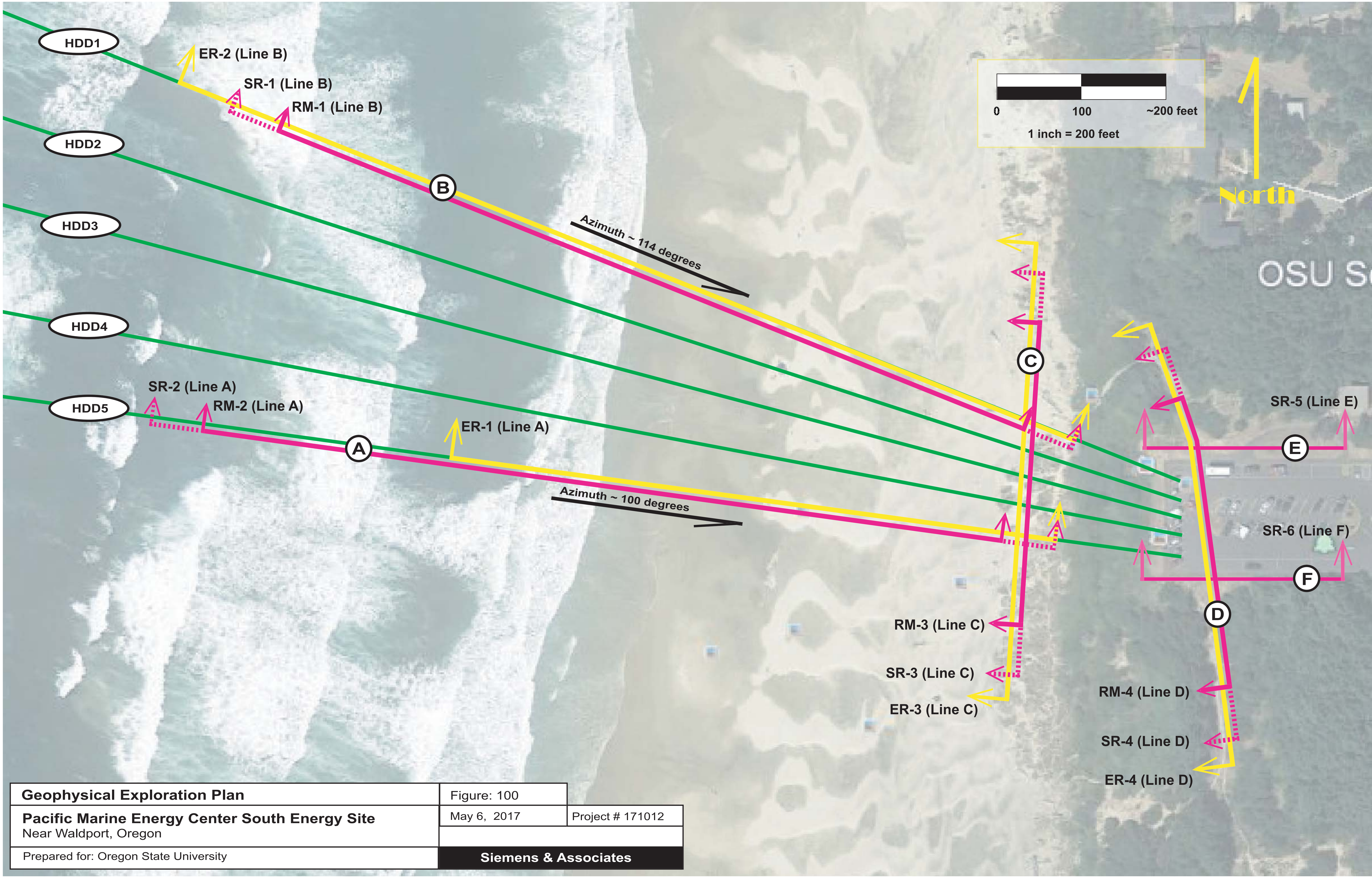
7. Graphical Presentation of Results

The interpretations are presented in 2D with the location of each line illustrated on Figure 100 (Geophysical Exploration Plan).

7.1. Figure 100: Geophysical Exploration Plan



Geophysical Exploration Plan

Pacific Marine Energy Center South Energy Site
Near Waldport, Oregon

Prepared for: Oregon State University

Figure: 100

May 6, 2017

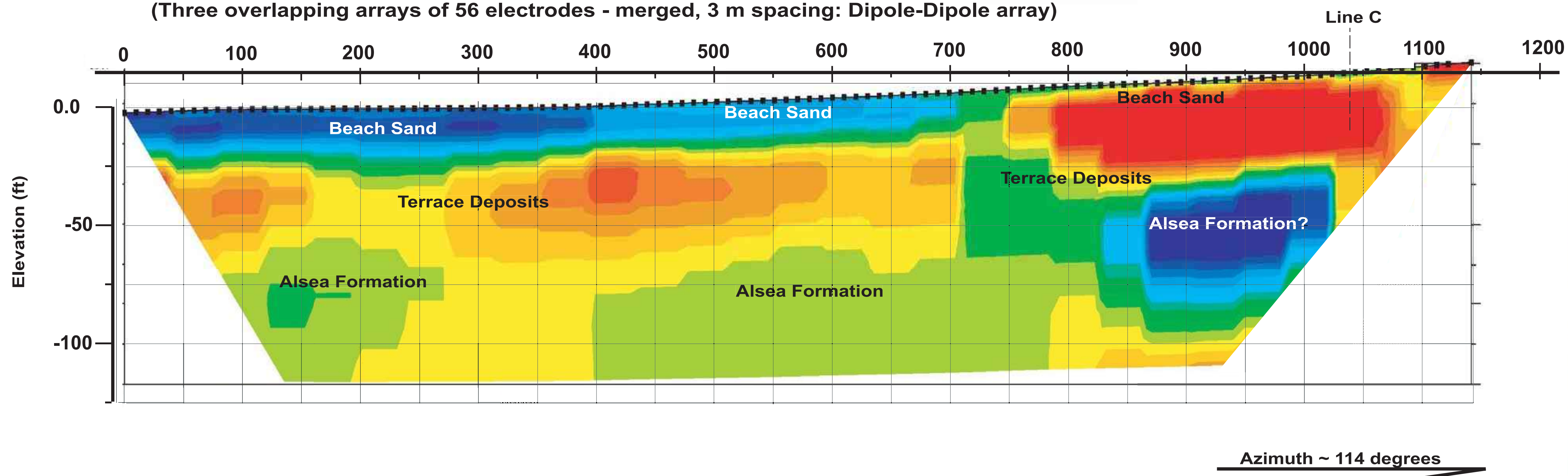
Project # 171012

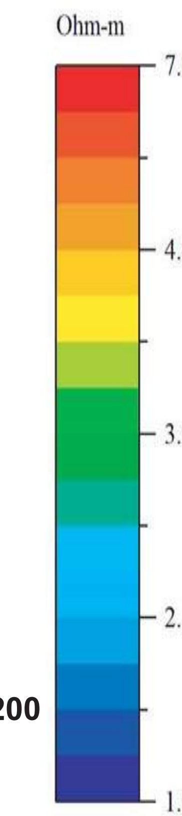
Siemens & Associates

7.2. Results on Line A: ER, SR and ReMi

Line B: Electrical Resistivity Tomography: ER-2

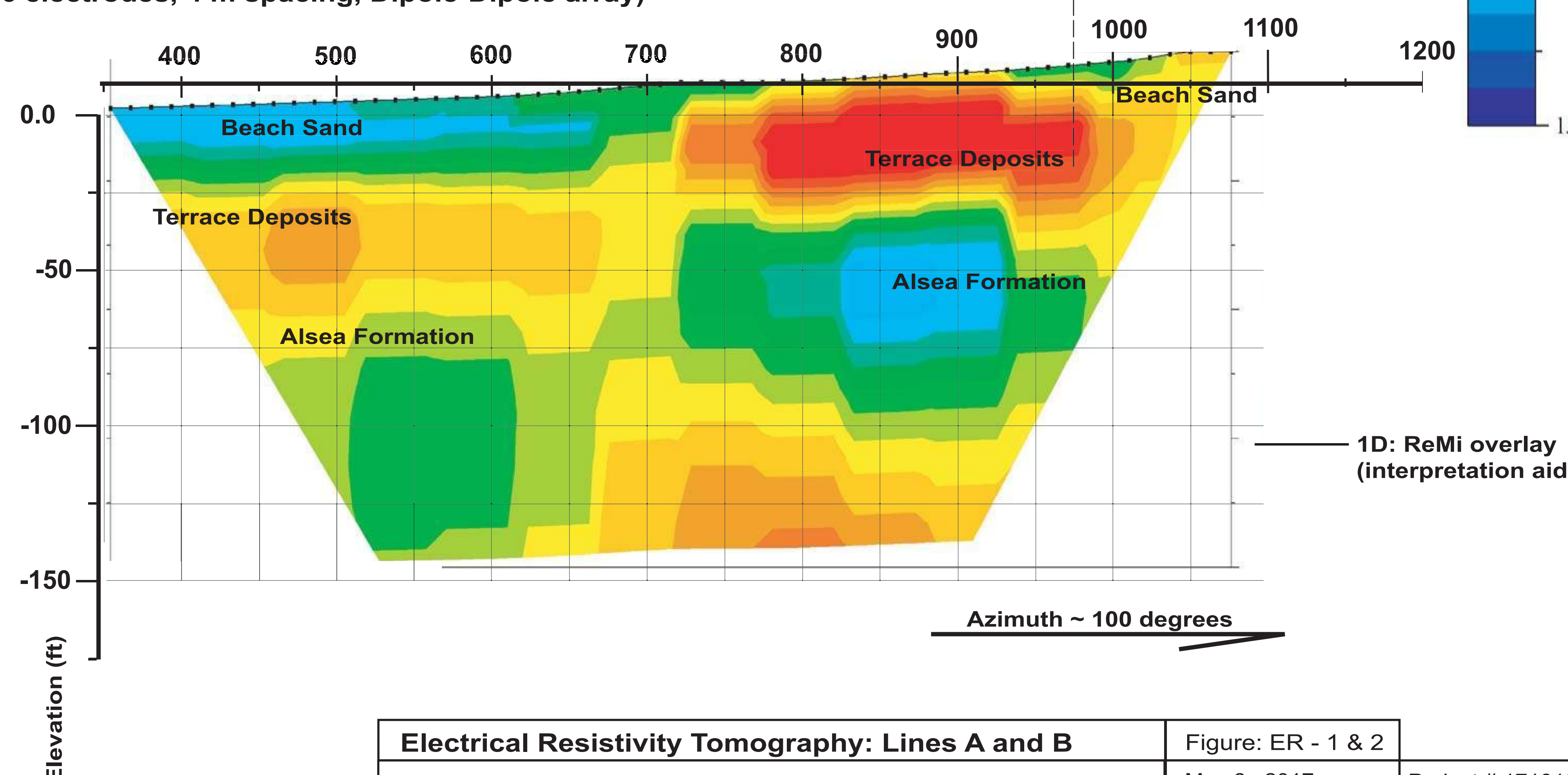
(Three overlapping arrays of 56 electrodes - merged, 3 m spacing: Dipole-Dipole array)





Line A: Electrical Resistivity Tomography: ER-1

(56 electrodes, 4 m spacing, Dipole-Dipole array)

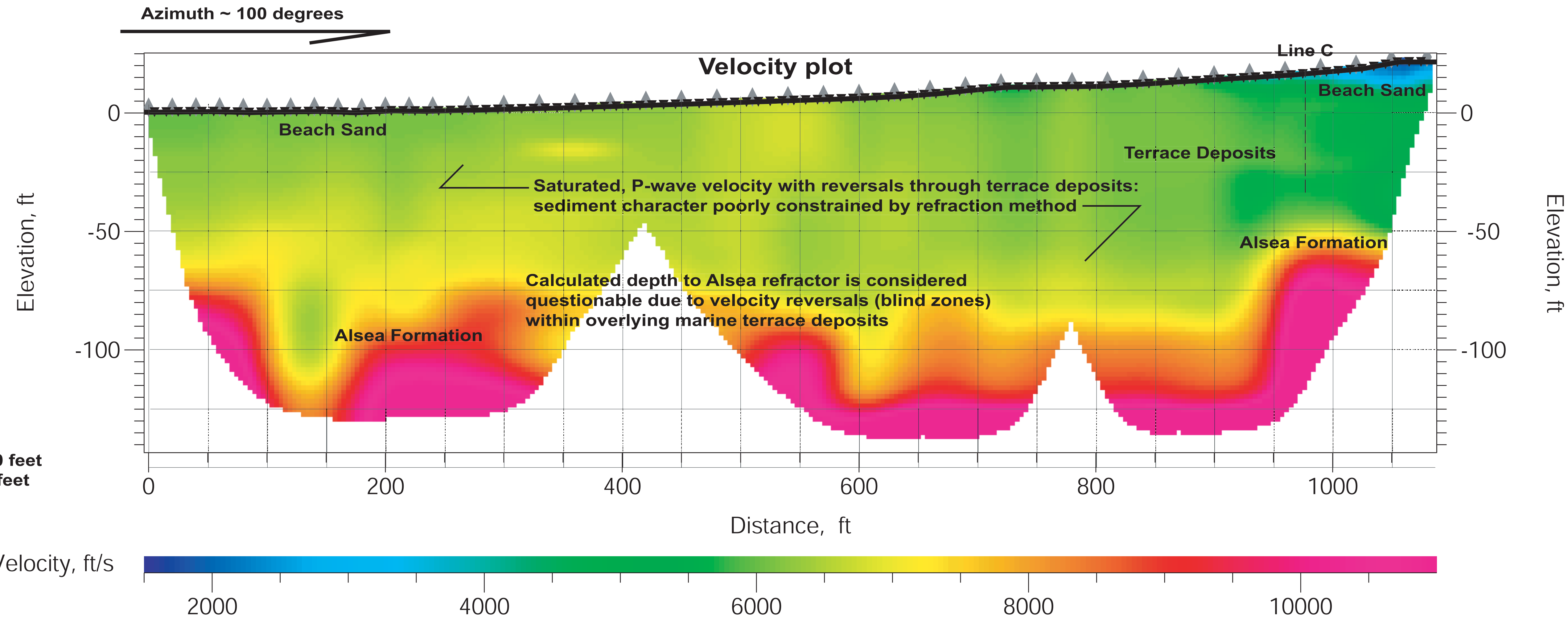


Scale:
H: 1 inch = 100 feet
V: 1 inch = 50 feet

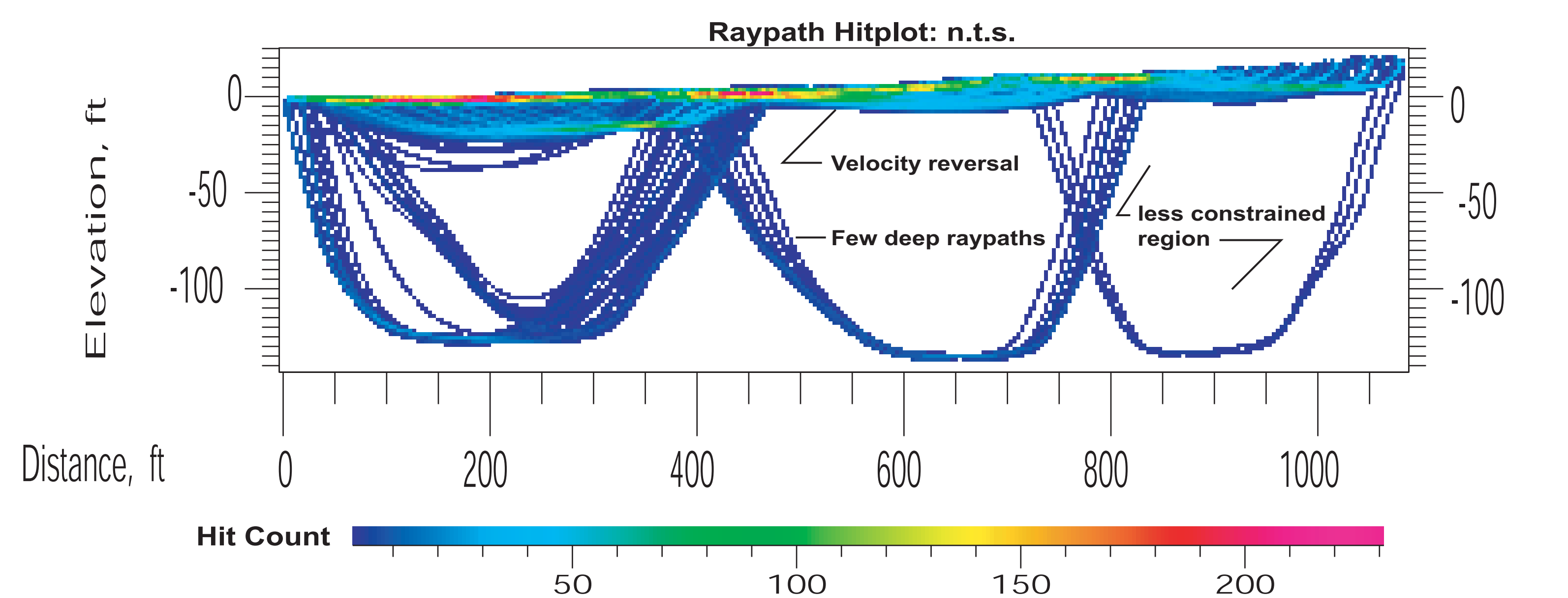
Electrical Resistivity Tomography: Lines A and B	Figure: ER - 1 & 2	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	May 6, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

Line A: P-wave Seismic Refraction Tomography: SR-2

(two 48 receiver spreads and one 36 receiver spread on 10 foot spacing, 12 receiver overlap, 8 Hz. receivers: shots on 20 to 30 foot spacing)



Scale:
H: 1 inch = 100 feet
V: 1 inch = 50 feet

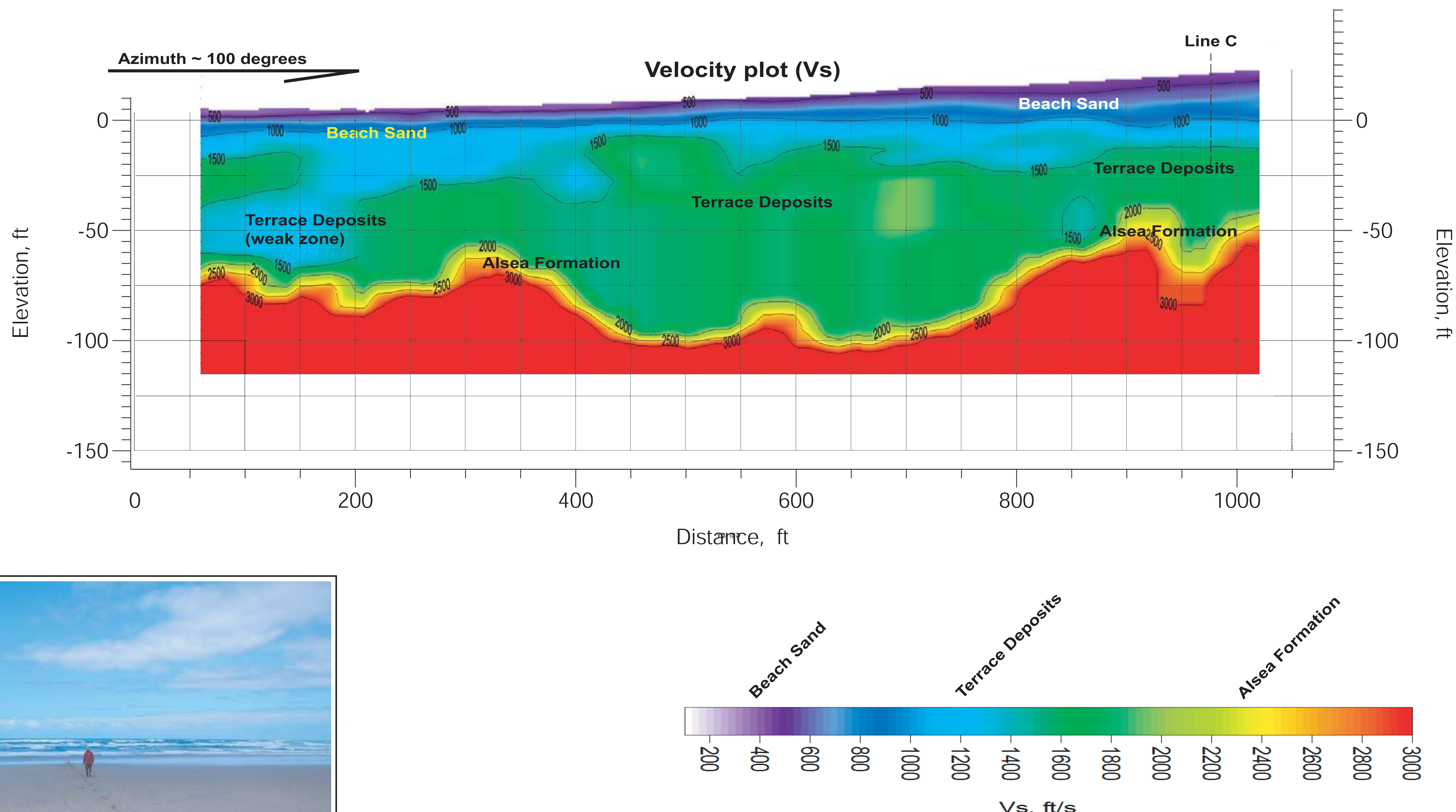


P-wave Seismic Refraction Tomography: SR-2	Figure: SR-2	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	April 29, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

Line A: S-wave Seismic Refraction Microtremor (ReMi): RM-2

(two 48 receiver spreads and one 36 receiver spread on 10 foot spacing, 12 receiver overlap, 8 Hz. receivers)

SeisOpt ®ReMi ™



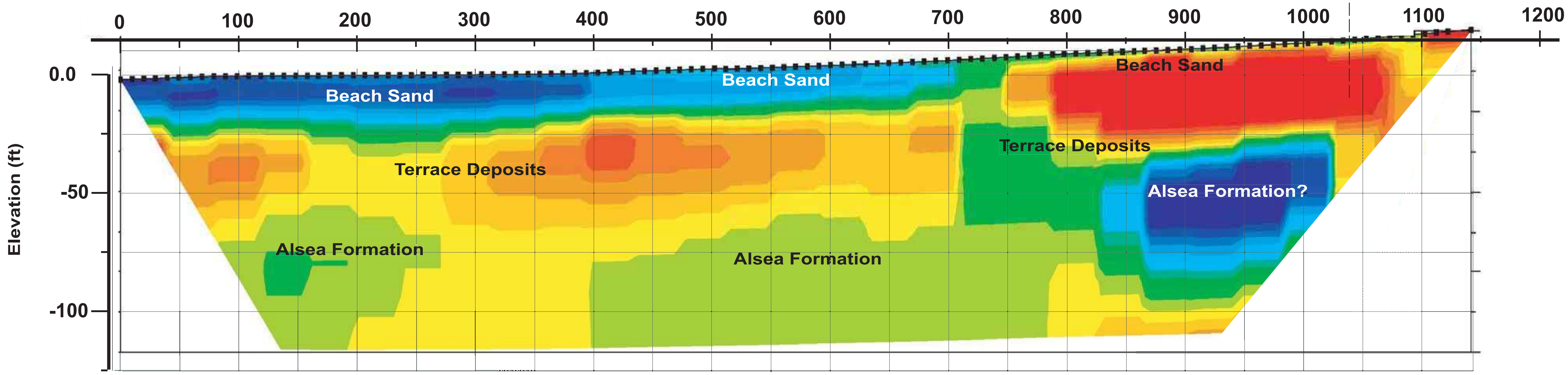
Scale:
H: 1 inch = 100 feet
V: 1 inch = 50 feet

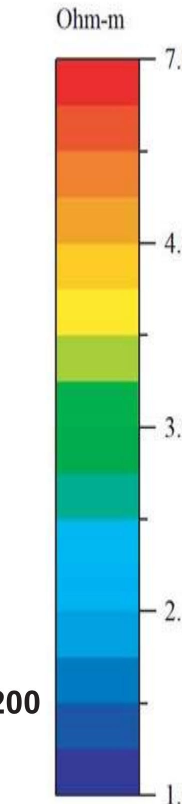
Seismic Refraction Microtremor (ReMi): RM-2	Figure: RM-2	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	April 29, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

7.3. Results on Line B: ER, SR and ReMi

Line B: Electrical Resistivity Tomography: ER-2

(Three overlapping arrays of 56 electrodes - merged, 3 m spacing: Dipole-Dipole array)

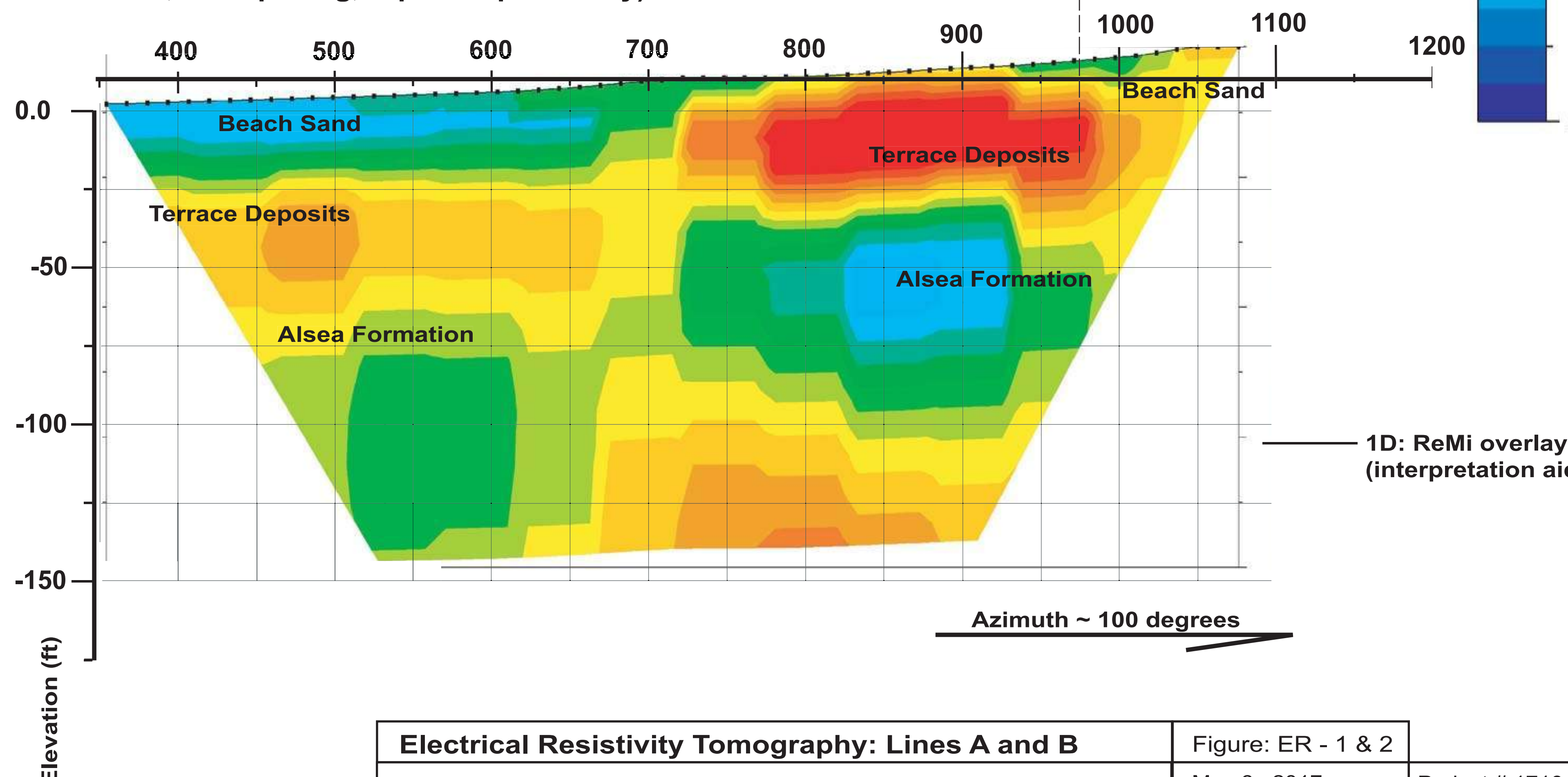




Line A: Electrical Resistivity Tomography: ER-1

(56 electrodes, 4 m spacing, Dipole-Dipole array)

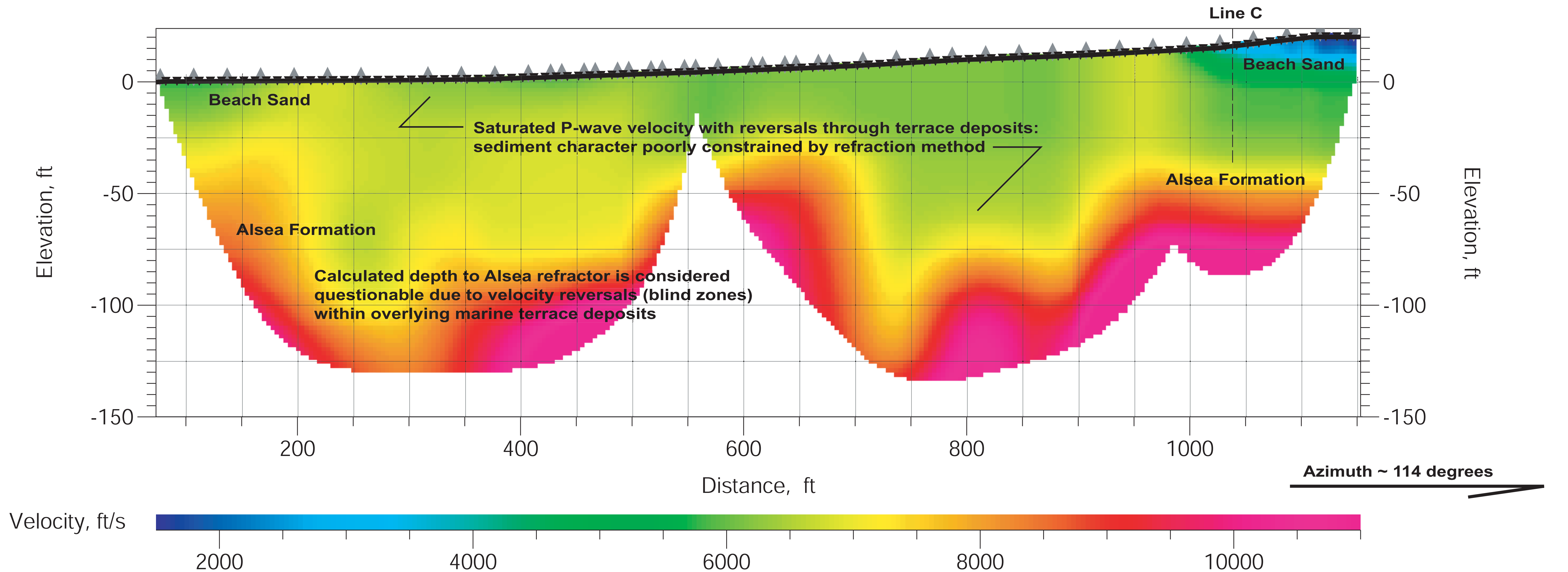
Scale:
H: 1 inch = 100 feet
V: 1 inch = 50 feet

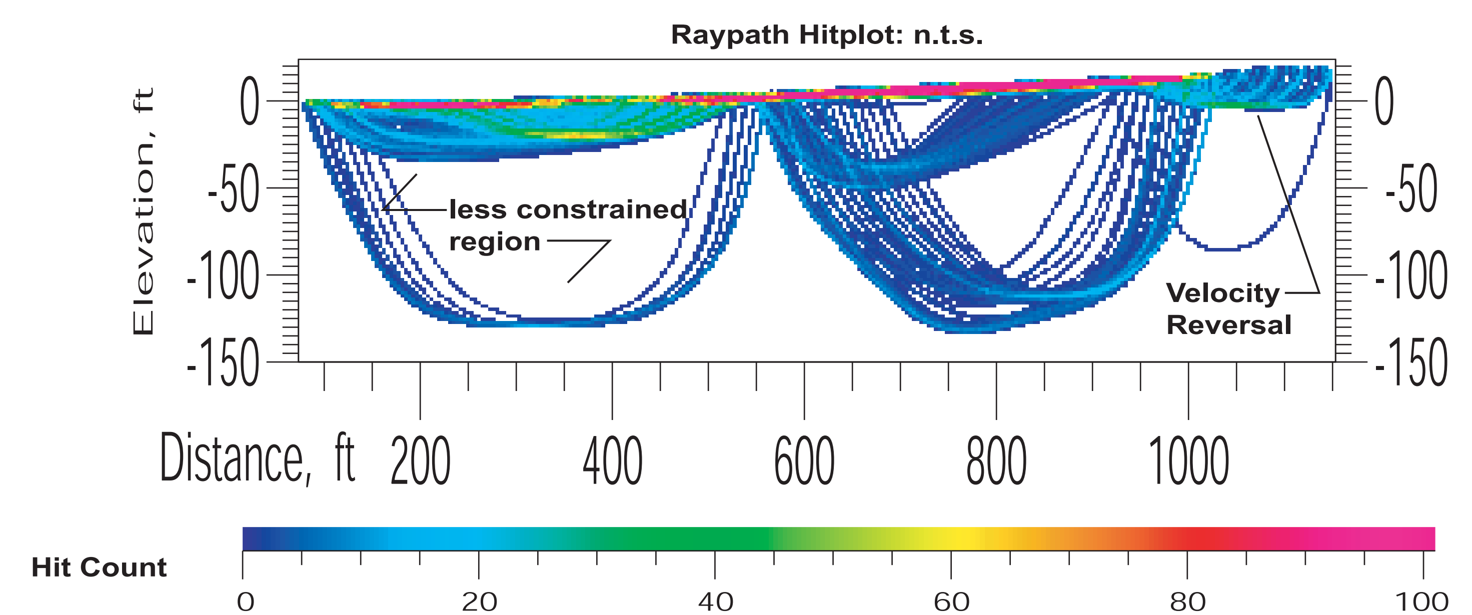


Electrical Resistivity Tomography: Lines A and B	Figure: ER - 1 & 2	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	May 6, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

Line B: P-wave Seismic Refraction Tomography: SR-1

(two 48 receiver spreads and two 24 receiver spreads on 10 foot spacing, 12 receiver overlap, 8 Hz. receivers: shots on 30 foot spacing)





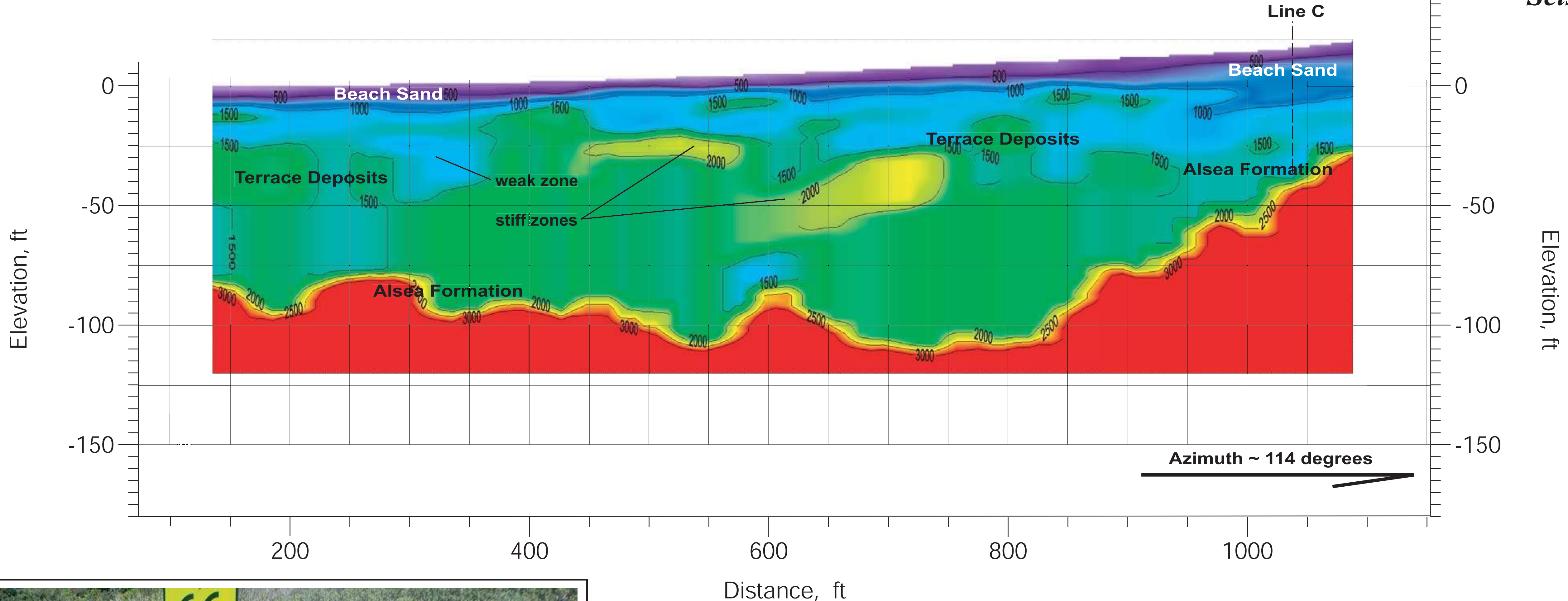
Scale:
H: 1 inch = 100 feet
V: 1 inch = 50 feet

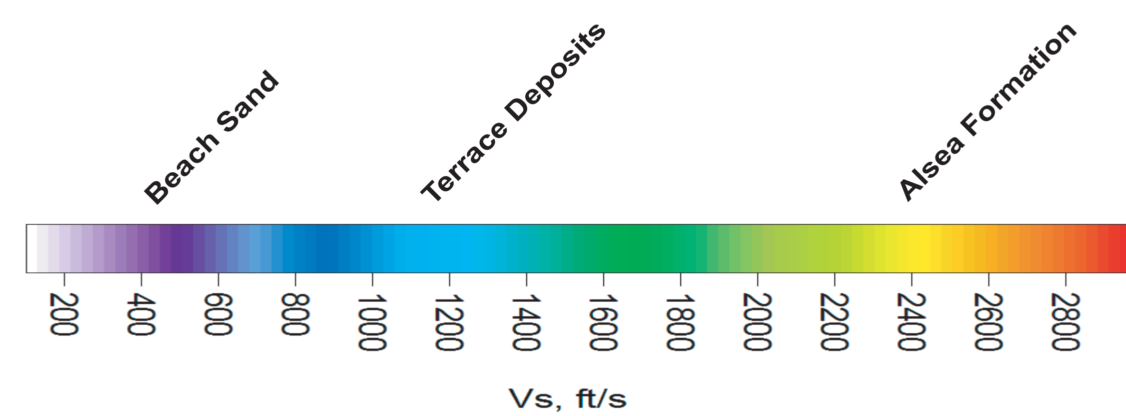
P-wave Seismic Refraction Tomography: SR-1 on Line B	Figure: SR-1	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	April 27, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

Line B: S-wave Seismic Refraction Microtremor (ReMi): RM-1

(two 48 receiver spreads and two 24 receiver spreads on 10 foot spacing, 12 receiver overlap)

SeisOpt® ReMi™





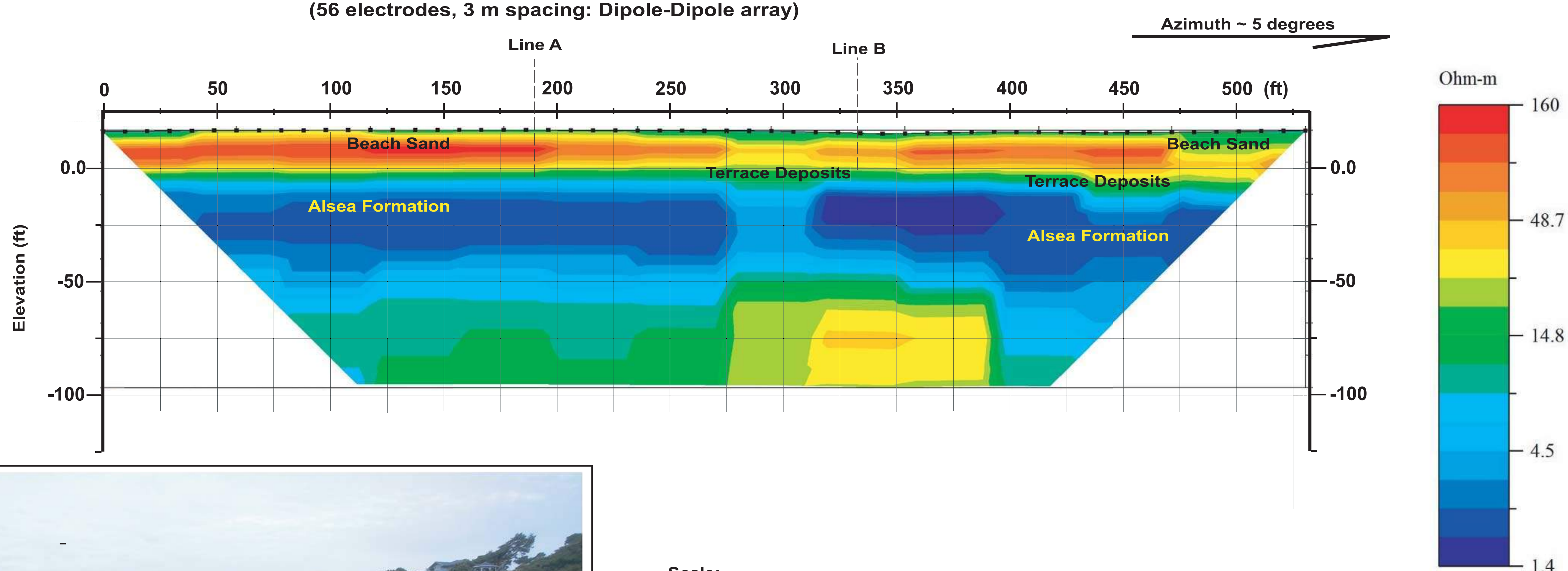
Scale:
H: 1 inch = 100 feet
V: 1 inch = 50 feet

Seismic Refraction Micrtotremor (ReMi): RM-1	Figure: RM-1	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	April 27, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

7.4. Results on Line C: ER, SR and ReMi

Line C: Electrical Resistivity Tomography: ER-3

(56 electrodes, 3 m spacing: Dipole-Dipole array)

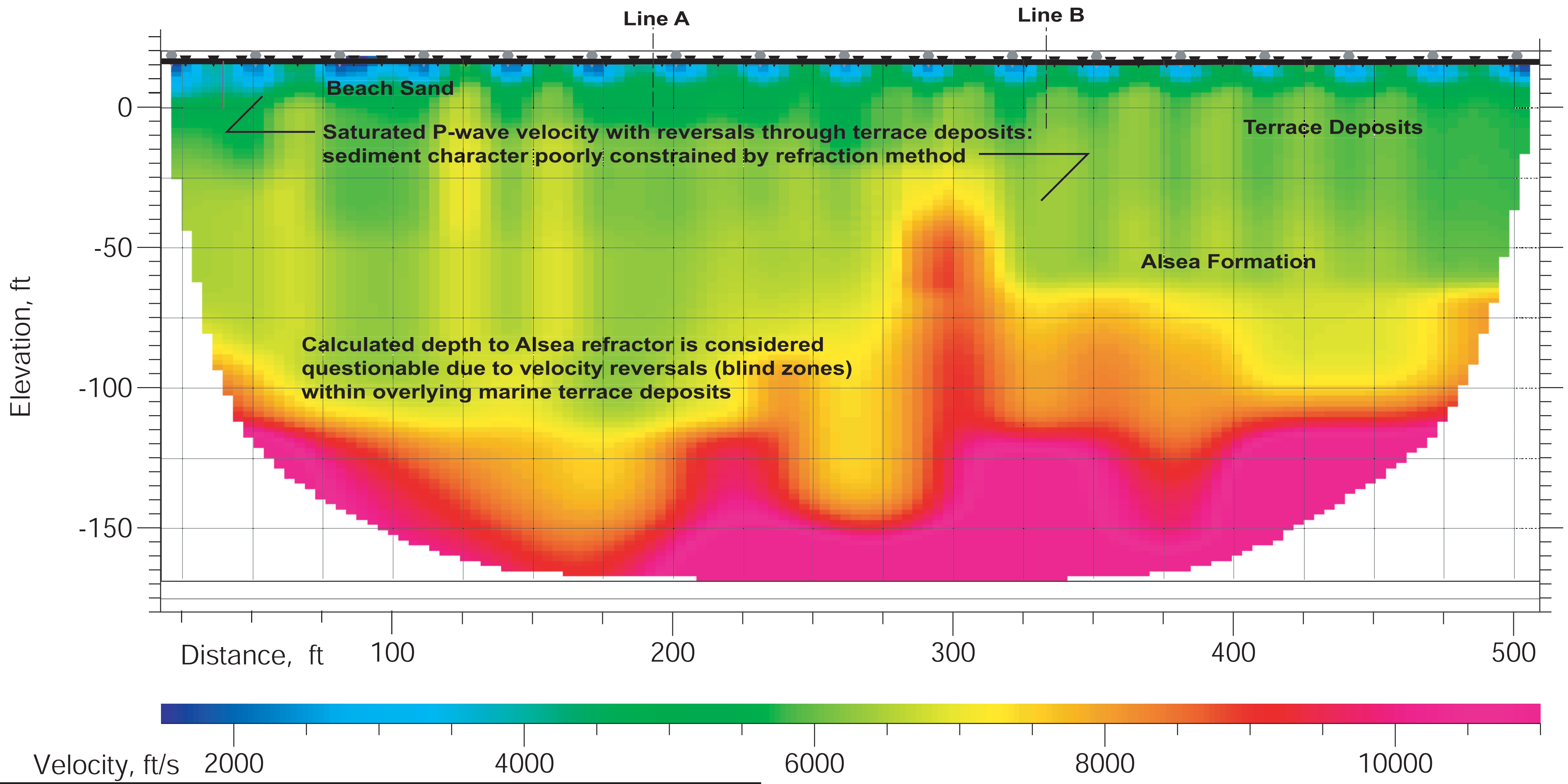


Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet

Electrical Resistivity Tomography: Line C	Figure: ER-3	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	April 29, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

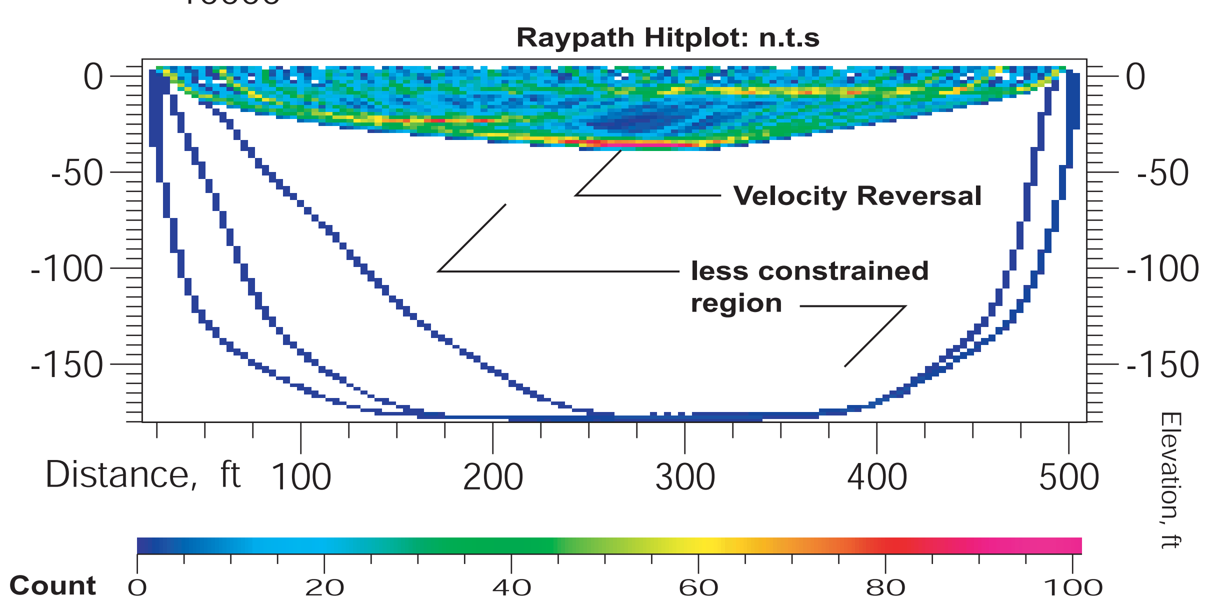
Line C: P-wave Seismic Refraction Tomography: SR-3

(48, 8 Hz. receivers on 10 foot spacing, shots on 30 foot spacing)



Azimuth ~ 5 degrees

Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet

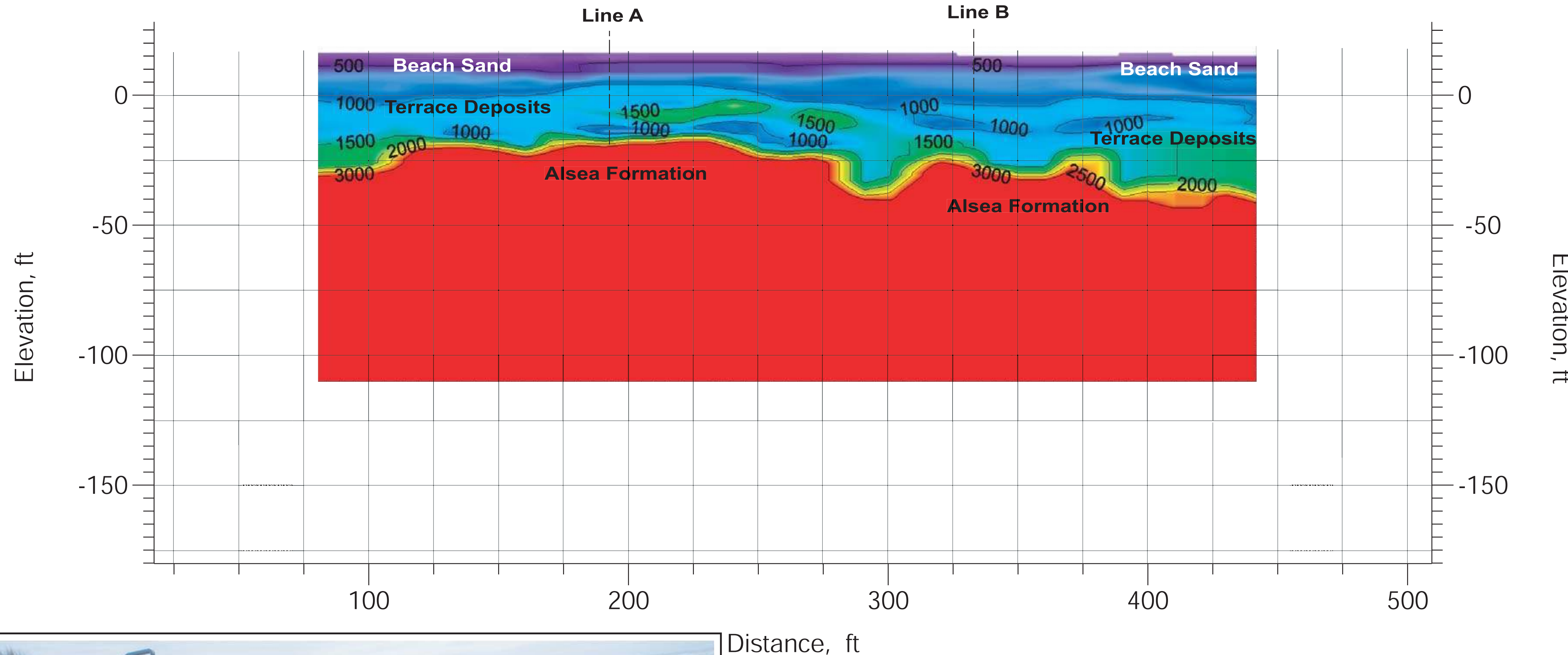


P-wave Seismic Refraction Tomography: SR-3 on Line C	Figure: SR-3	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	April 28, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

Line C: S-wave Seismic Refraction Microtremor (ReMi): RM-3

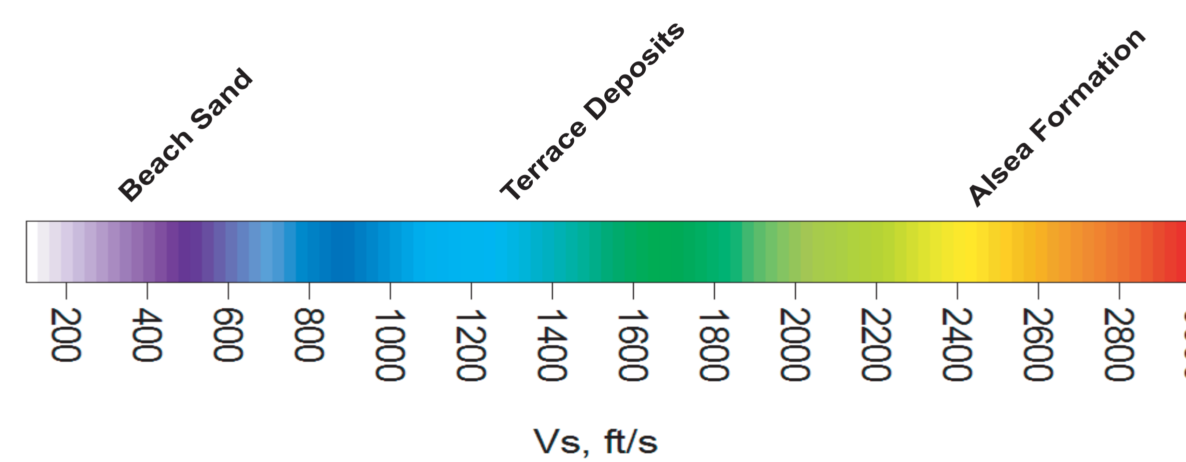
(48, 8 Hz. receivers on 10 foot spacing)

SeisOpt® ReMi™



Azimuth ~ 5 degrees

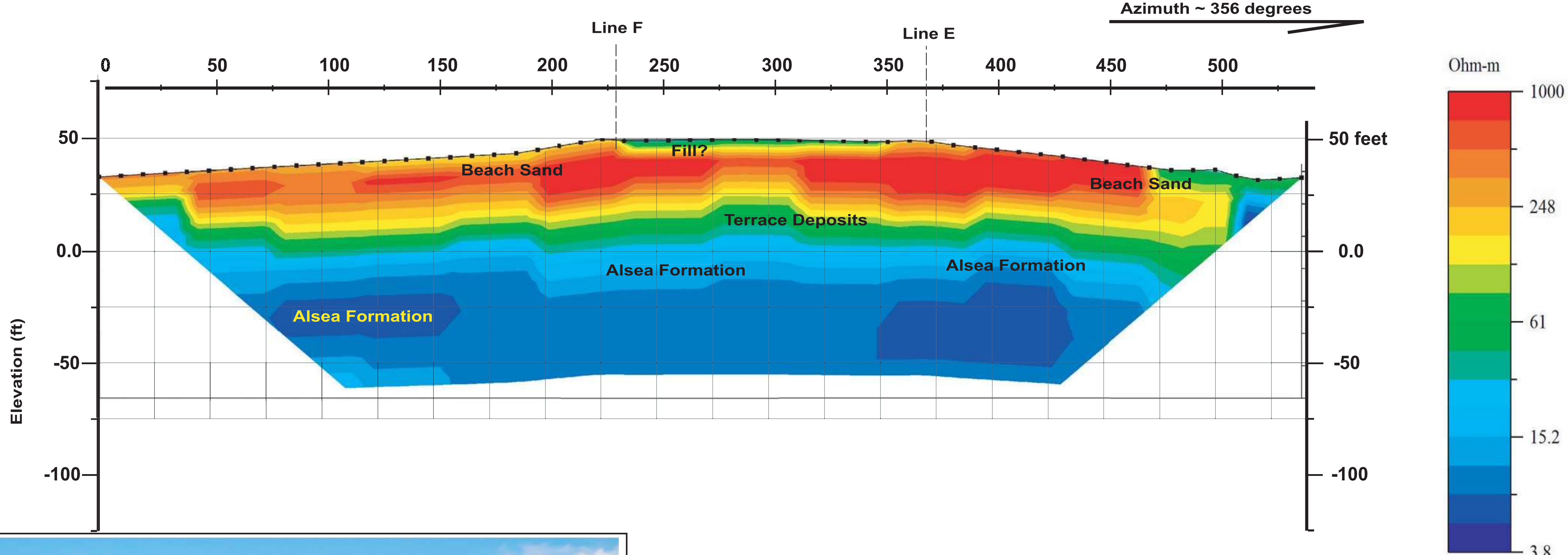
Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet



S-wave Seismic Refraction Microtremor (ReMi): RM-3	Figure: RM-3	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	April 29, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

7.5. Results on Line D: ER, SR and ReMi

Line D: Electrical Resistivity Tomography: ER-4
(56 electrodes, 3 m spacing: Wenner array)

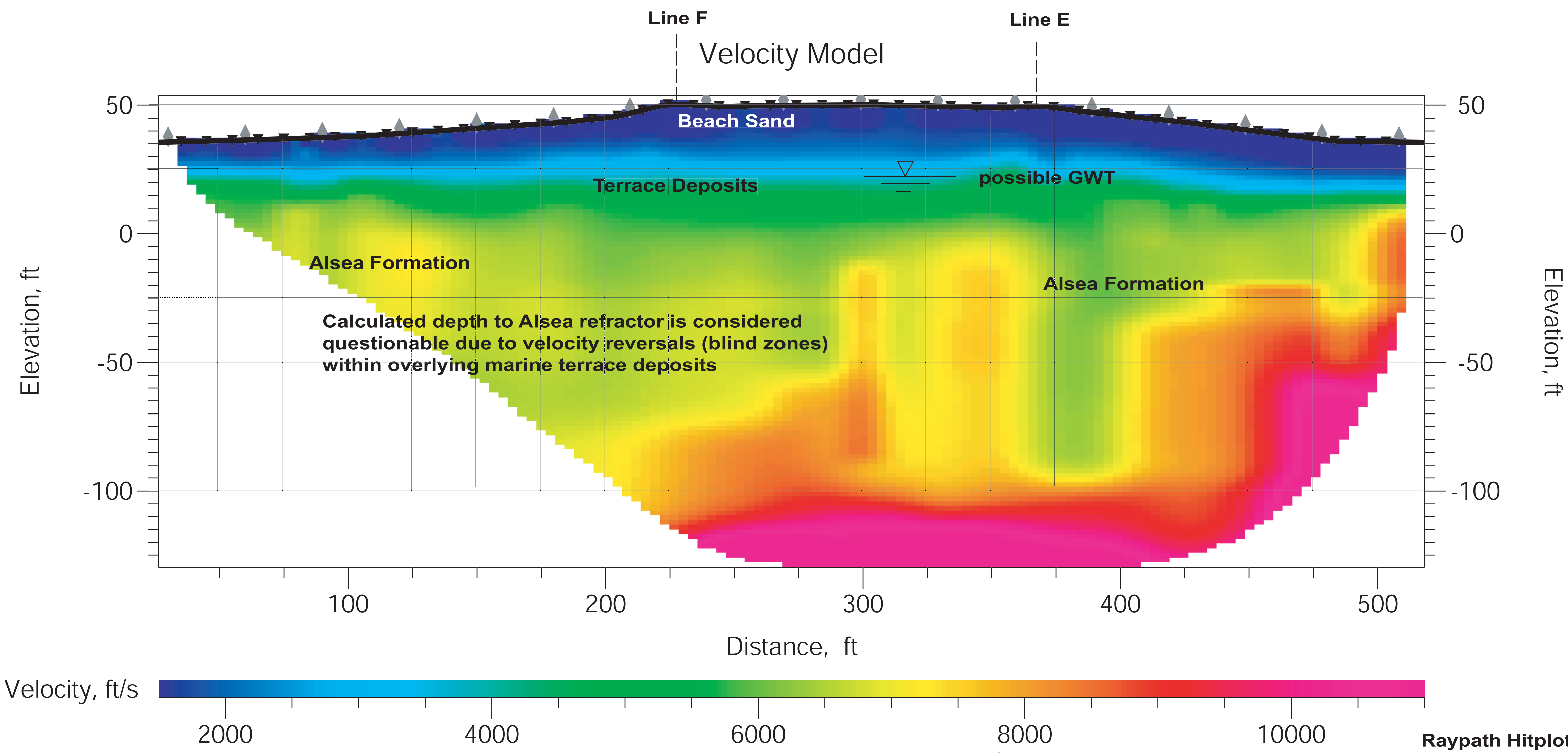


Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet

Electrical Resistivity Tomography: Line D	Figure: ER-4	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	May 6, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

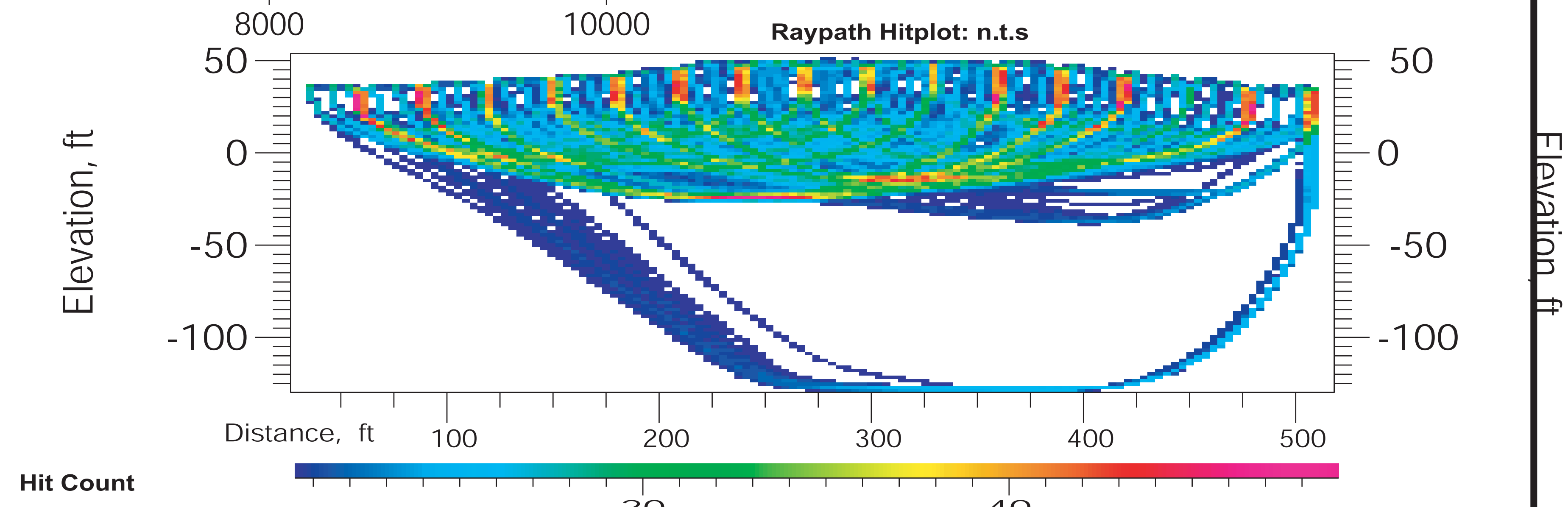
Line D: P-wave Seismic Refraction Tomography: SR-4

(48, 8 Hz. receivers on 10 foot spacing, shots on 30 foot spacing)



Azimuth ~ 356 degrees

Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet

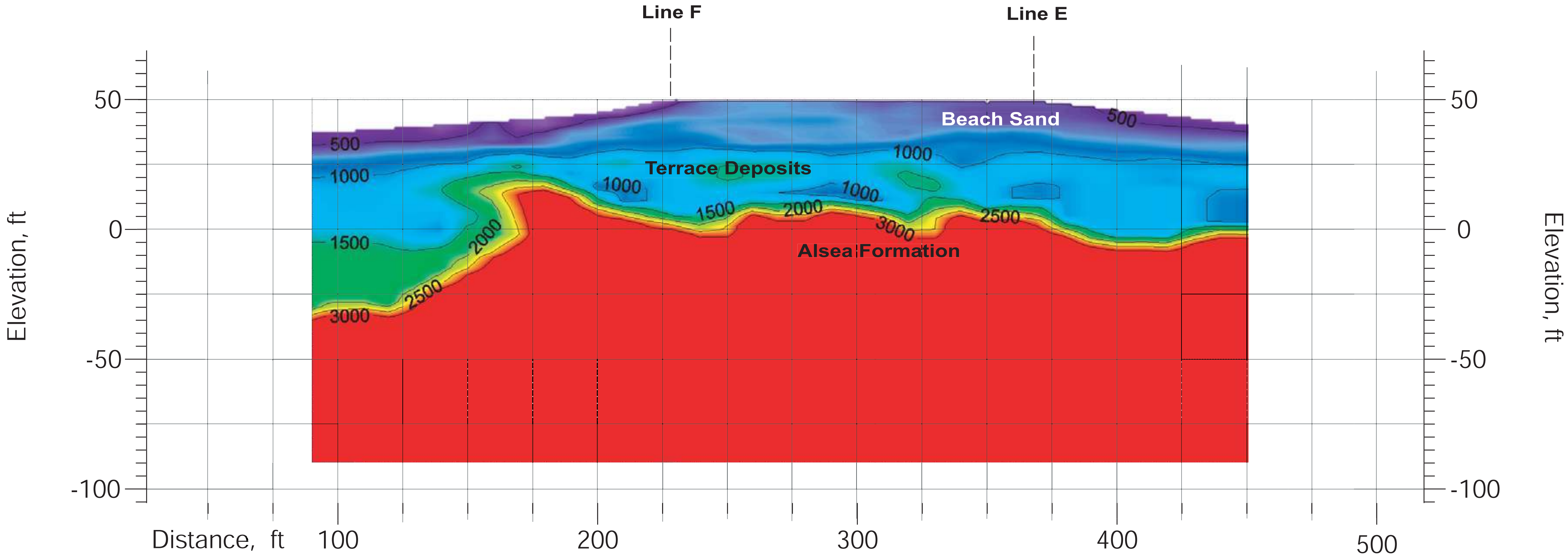


P-wave Seismic Refraction Tomography: SR-4 on Line D	Figure: SR-4	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	May 6, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

SeisOpt® ReMi™

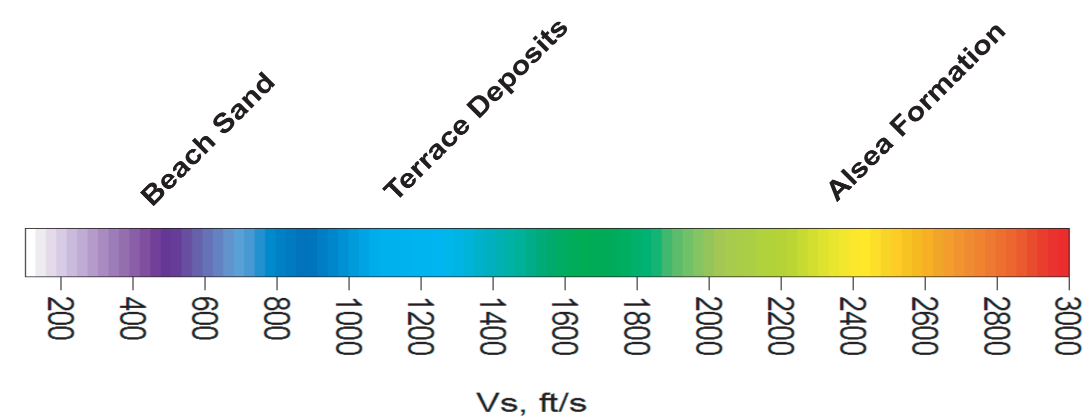
Line D: S-wave Seismic Refraction Microtremor: RM-4

(48, 8 Hz. receivers on 10 foot spacing)



Azimuth ~ 356 degrees

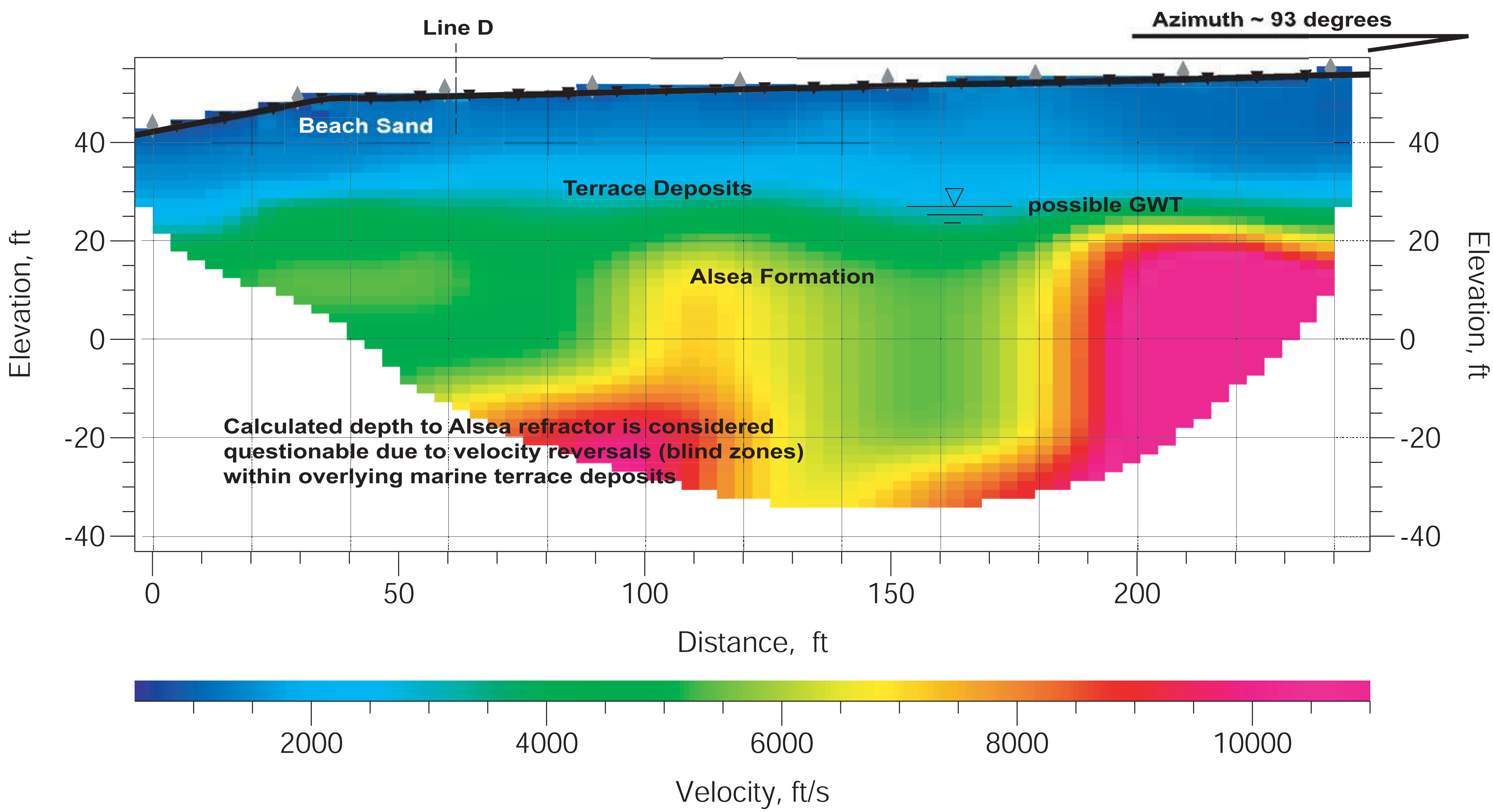
Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet



S-wave Seismic Refraction Microtremor (ReMi): RM-4	Figure: RM-4	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	May 6, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

7.6. Results on Line E: SR only

Line E: P-wave Seismic Refraction Tomography: SR-5
(24, 8 Hz. receivers on 10 foot spacing, shots on 30 foot spacing)



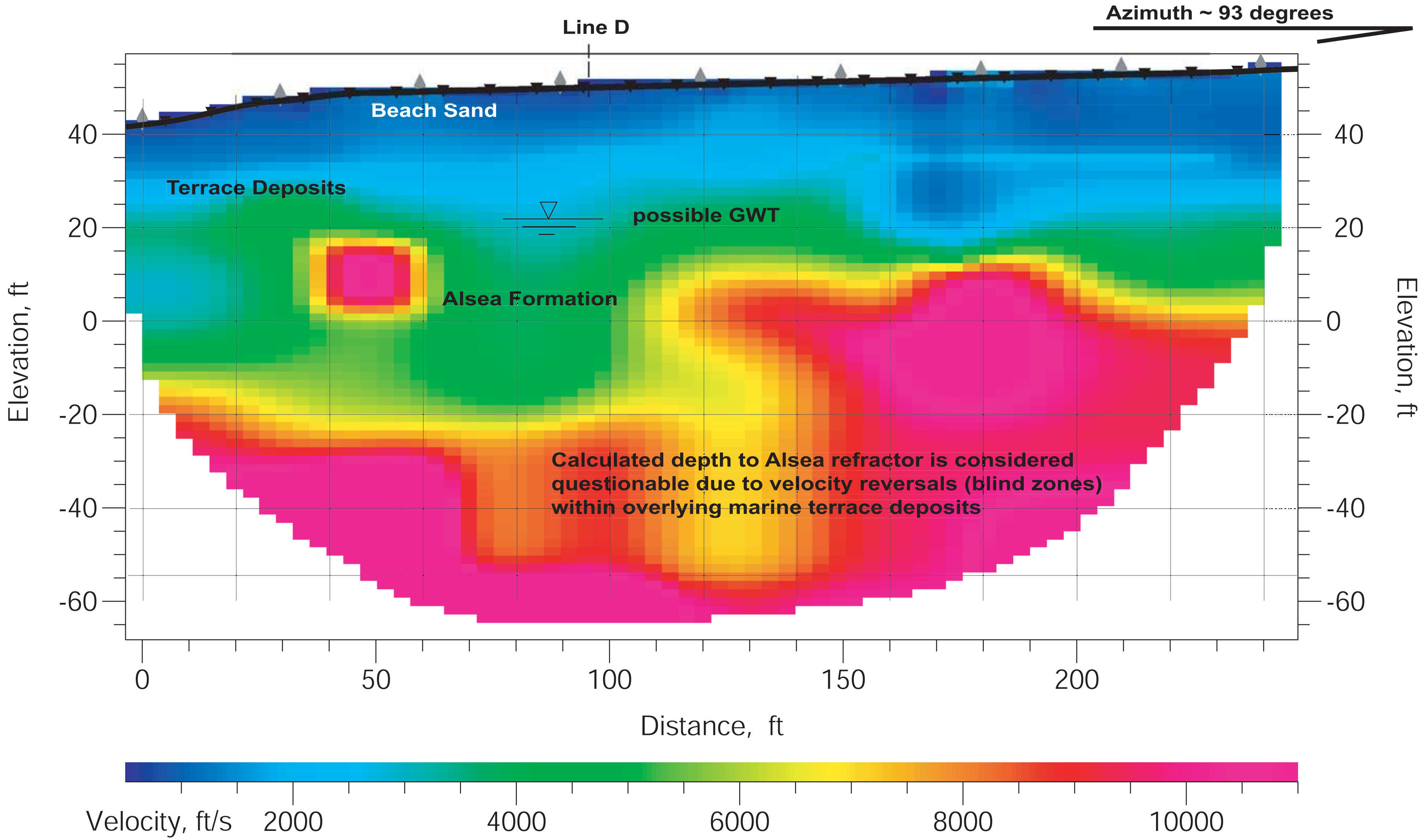
Scale:
H: 1 inch = 30 feet
V: 1 inch = 30 feet

P-wave Seismic Refraction Tomography: SR-5 on Line E	Figure: SR-5	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	May 6, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

7.7. Results on Line F: SR only

Line F: P-wave Seismic Refraction Tomography: SR-6

(24, 8 Hz. receivers on 10 foot spacing, shots on 30 foot spacing)



Scale:
H: 1 inch = 30 feet
V: 1 inch = 30 feet

P-wave Seismic Refraction Tomography: SR-6 on Line F	Figure: SR-6	
Pacific Marine Energy Center South Energy Site Near Waldport, Oregon	May 6, 2017	Project # 171012
Prepared for: Oregon State University	**Siemens & Associates**	

8. Land Survey Records: John Thompson and Associates, Inc. (JTA)

8.1. Control

Three survey control points were set in the Driftwood Beach State Recreation Site parking area. JTA selected 5/8 inch iron rods and 1-1/2 inch aluminum caps for monument construction because of their durability. These control points can be used throughout the lifecycle of the project.

8.2. Reference

This project is referenced to NAD 83(2011) Epoch 2010.00 and NAVD 88. This is the current reference frame supported by the National Geodetic Survey (NGS). Using the current NGS datum simplifies the establishment of on-site survey control. NGS also computes Oregon State Plane North Zone (3601) coordinates on their Data Sheets. The CAD deliverables use this reference frame and the project units are international feet.

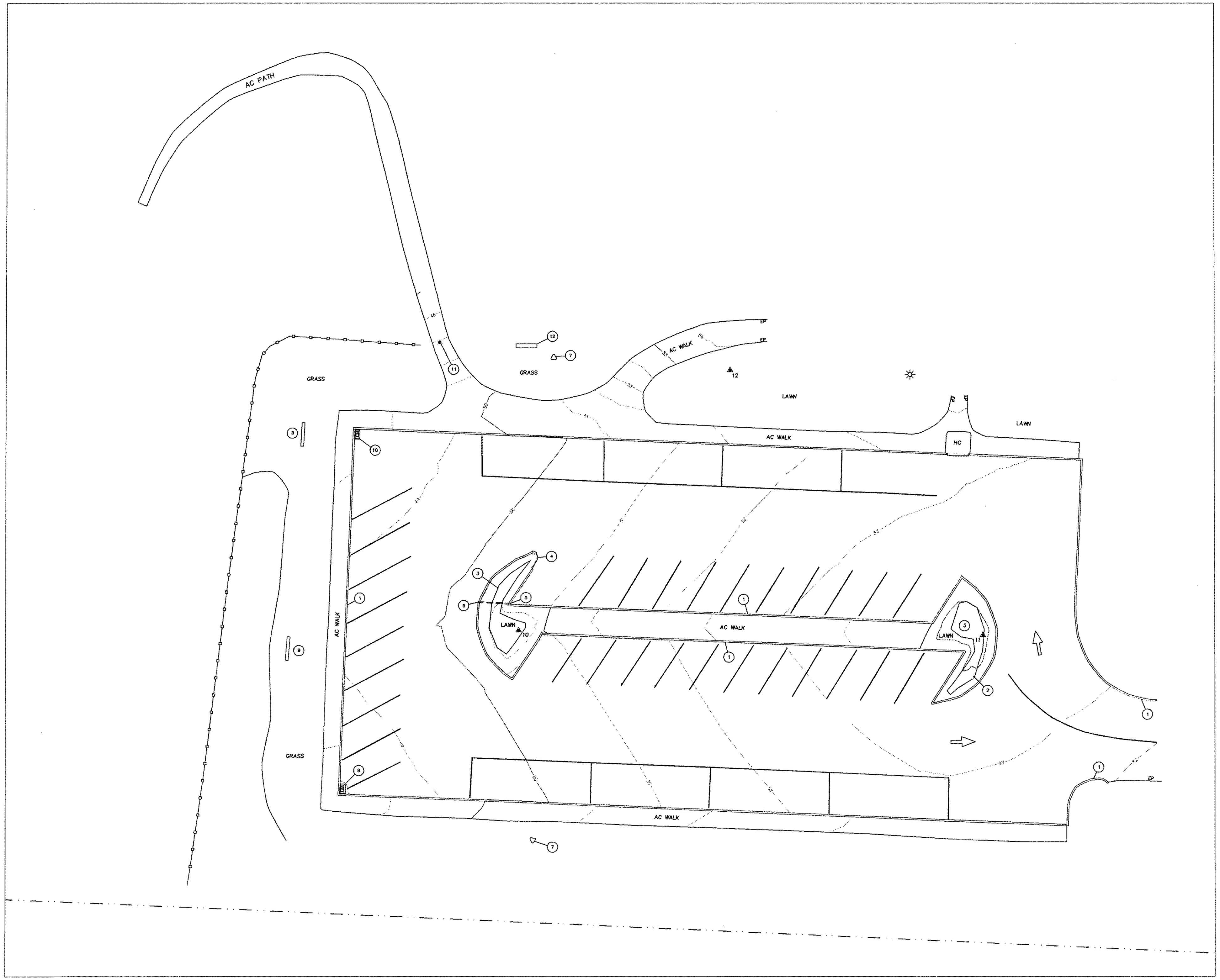
8.3. Mapping Products

JTA created two mapping products for this project. The first is the topographic map of the parking area of Driftwood Beach State Recreation Site. This map and digital terrain model will aid the design engineers in the development of the boring equipment staging plan and can be used to document the existing condition of the parking area which will be useful if repairs to the parking area are needed after construction. The second mapping product illustrates the geophysical survey line geometry in plan dimension. This map is used for both for the on-shore and off-shore phases of this site exploration. The line geometry is the basis of sampling for the on-shore study. The survey coordinates along Lines A and Line B are useful to integrate similar explorations and associated overlap when similar data are gathered during the marine survey of the HDD route.

The mapping products are delivered in several formats. The CAD drawings were created using Autodesk Civil 3D. The drawing files will include the survey point data, 3D breakline data and a digital terrain model (DTM) of the existing ground surface conditions. JTA compiled an ASCII file of the survey data points and LandXML files for the survey point data and the existing ground DTM. These files can be imported into various engineering or GIS programs used by project stakeholders. Also provided were PDF files generated from the CAD drawing files.

XREF INDEX:

T.13S. R.12W. W.M.
SEC. 01



NORTH
SCALE: 1"=20'
0 10 20 40

LEGEND

- BOLLARD
- LIGHT POLE (TAPER METAL BASE.)
- SIGN AS NOTED
- STORM CATCH BASIN
- SURVEY BENCH MARK / CONTROL POINT

LEGEND

- EP EDGE OF PAVEMENT
- HC HANDICAP RAMP AC SURFACE POOR CONDITION

LEGEND

- FENCE WOOD HT=3.0 FT. (TYP.) CONDITION VARIES
- PARCEL BOUNDARY LINES APPROXIMATE, SEE NOTE 3

NOTES

1. THE COORDINATES SHOWN ARE BASED ON THE OREGON STATE PLANE NORTH ZONE (3601). THE PROJECT IS REFERENCED VERTICALLY TO NATIONAL GEODETIC SURVEY MARK V 79 (PID QE1300) BY STATIC GPS OBSERVATIONS.

   LINEAR UNITS: INTERNATIONAL FEET
   HORIZONTAL DATUM: NAD 83(2011)(EPOCH: 2010.0000)
   PROJECT COMBINED FACTOR (GROUND TO GRID): 0.99997084

   VERTICAL DATUM: NAVD88 (GEOID 12B)

2. CONTOUR INTERVAL IS 1 FOOT.

3. THE PRORERTY LINES SHOWN ARE BASED ON DATA PROVIDED BY CLIENT AND ARE APPROXIMATE ONLY. BOUNDARY DETERMINATION AND RESOLUTION ARE OUTSIDE THE SCOPE OF THIS PROJECT.

UTILITY STATEMENT

THE UNDERGROUND UTILITIES SHOWN ARE BASED ON SURVEYED UTILITY LOCATE MARKINGS AND EXISTING DRAWINGS. THE SURVEYOR MAKES NO GUARANTEE THAT THE UNDERGROUND UTILITIES SHOWN COMPRISE ALL SUCH UTILITIES IN THE AREA, EITHER IN SERVICE OR ABANDONED. THE SURVEYOR FURTHER DOES NOT WARRANT THAT THE UNDERGROUND UTILITIES SHOWN ARE IN THE EXACT LOCATION INDICATED ALTHOUGH HE DOES CERTIFY THAT THEY ARE LOCATED AS ACCURATELY AS POSSIBLE FROM INFORMATION AVAILABLE. THE SURVEYOR HAS NOT PHYSICALLY LOCATED THE UNDERGROUND UTILITIES.

EXISTING FEATURES

(1) CURB (TYP.)
(2) LANDSCAPE FEATURE, DRIFTWOOD WITH SIGN "ONE WAY"
(3) LANDSCAPE FEATURE, DRIFTWOOD
(4) DAMAGED CURBING
(5) STORM DRAINAGE PIPE STEEL, 4-IN. DIA. I.E.=50.59' (IN)
(6) STORM DRAINAGE PIPE STEEL, 4-IN. DIA. I.E.=50.32' (OUT)
(7) POSSIBLE LIGHT POLE BASE, NO POLE BASE, PLATED. NOT IN USE
(8) STORM CATCHBASIN, WATER FILLED NO INVERTS VISIBLE. GRATE EL.=47.96'
(9) BENCH WOOD
(10) STORM CATCHBASIN, WATER FILLED NO INVERTS VISIBLE. GRATE EL.=48.03'
(11) BOLLARD, CONCRETE DIA.=8-IN. HT.=3.4 FT. W/SIGN: "MOTOR VEHICLES PROHIBITED"
(12) SIGN 6"x6" WOOD POST W/SIGNS "DRIFTWOOD" & MULTIPLE PLACARDS

SURVEY CONTROL DATA TABLE

POINT	NORTHING	EASTING	ELEVATION	DESCRIPTION
10	311507.8949	7267656.6567	52.87	5/8" IRON ROD W/2-1/2" ALUM. CAP MARKED "JTA INC. CONTROL POINT 10 2017"
11	311506.3886	7267812.3870	55.41	5/8" IRON ROD W/2-1/2" ALUM. CAP MARKED "JTA INC. CONTROL POINT 11 2017"
12	311595.0785	7267727.6627	57.34	5/8" IRON ROD W/2-1/2" ALUM. CAP MARKED "JTA INC. CONTROL POINT 12 2017"

UNITS: INTERNATIONAL FEET

[DATE: 7/22/2017 8:02 PM] [AUTHOR: admin] [PLOTTER: HP LJ 5000DN Universal Printing PCL 6.pc3] [STYLE: DEA-STD-STB.stb]
[PATH: L:\PDrive_Recover\Projects\SIEM0001-Waldport\Dwg_Deliverables\SIEM1DWPARKING.dwg] [LAYOUT: SHEET1]

JOHN THOMPSON & ASSOCIATES, INC.
P.O. BOX 683 BEND, OREGON 97709
PHONE: (541)312-9421
JPT@JTASURVEY.COM

07-22-2017
REGISTERED PROFESSIONAL LAND SURVEYOR
OREGON
JANUARY 12, 1999
JOHN P. THOMPSON
49220
RENEWS 06-30-2018

REVISIONS

NO.	BY	DATE	REMARKS

SHEET INFO

DRAWN	JPT
CHECKED	JPT
APPROVED	JAS
LAST EDIT	06/26/2017
PLOT DATE	07/22/2017
SUBMITTAL	

PACIFIC MARINE ENERGY CENTER SOUTH ENERGY TEST SITE:
GEOPHYSICAL EXPLORATION
DRIFTWOOD BEACH STATE RECREATION SITE

SCALE 1"=20'

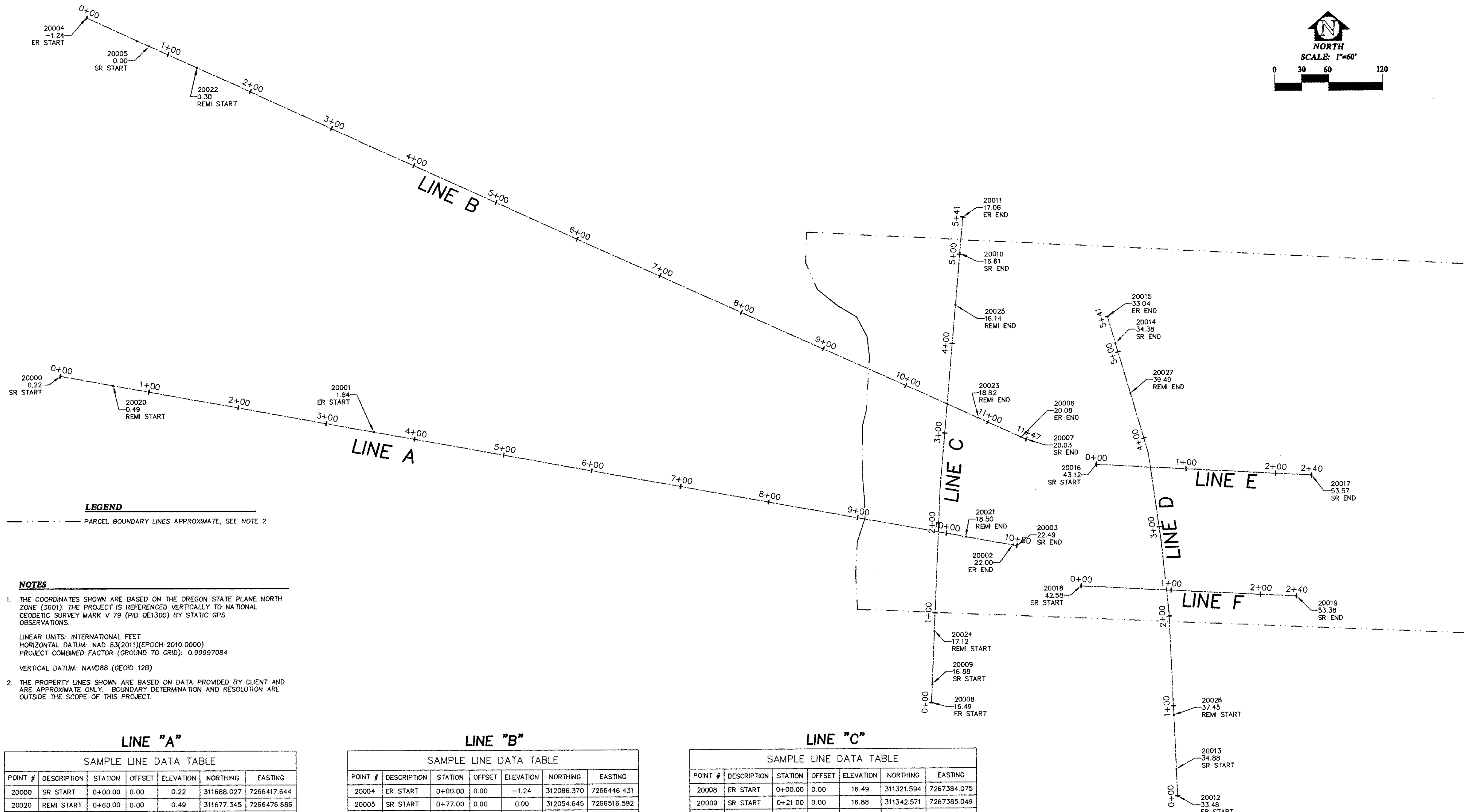
PROJECT NUMBER SIEM0001

DRAWING FILE NAME SIEM1DWPARKING

SHEET NUMBER
1
OF 2 SHEETS

XREF INDEX:

T.13S. R.12W. W.M.
SEC. 01



LEGEND

— · — · — PARCEL BOUNDARY LINES APPROXIMATE, SEE NOTE 2

NOTES

1. THE COORDINATES SHOWN ARE BASED ON THE OREGON STATE PLANE NORTH ZONE (3601). THE PROJECT IS REFERENCED VERTICALLY TO NATIONAL GEODETIC SURVEY MARK V 79 (PID QE1300) BY STATIC GPS OBSERVATIONS.

   LINEAR UNITS: INTERNATIONAL FEET
   HORIZONTAL DATUM: NAD 83(2011)(EPOCH: 2010.0000)
   PROJECT COMBINED FACTOR (GROUND TO GRID): 0.99997084

   VERTICAL DATUM: NAVD88 (GEOID 12B)

2. THE PROPERTY LINES SHOWN ARE BASED ON DATA PROVIDED BY CLIENT AND ARE APPROXIMATE ONLY. BOUNDARY DETERMINATION AND RESOLUTION ARE OUTSIDE THE SCOPE OF THIS PROJECT.

LINE "A"

SAMPLE LINE DATA TABLE

POINT #	DESCRIPTION	STATION	OFFSET	ELEVATION	NORTHING	EASTING
20000	SR START	0+00.00	0.00	0.22	311688.027	7266417.644
20020	REMI START	0+60.00	0.00	0.49	311677.345	7266476.686
20001	ER START	3+54.00	0.00	1.84	311625.004	7266765.989
20021	REMI END	10+22.00	0.00	18.50	311506.080	7267423.318
20002	ER END	10+75.00	0.00	22.00	311496.644	7267475.471
20003	SR END	10+80.00	0.00	22.49	311495.754	7267480.391

LINE "B"

SAMPLE LINE DATA TABLE

POINT #	DESCRIPTION	STATION	OFFSET	ELEVATION	NORTHING	EASTING
20004	ER START	0+00.00	0.00	−1.24	312086.370	7266446.431
20005	SR START	0+77.00	0.00	0.00	312054.645	7266516.592
20022	REMI START	1+35.00	0.00	0.30	312030.749	7266569.440
20023	REMI END	10+89.00	0.00	18.82	311637.691	7267438.705
20006	ER END	11+41.00	0.00	20.08	311616.266	7267486.086
20007	SR END	11+47.00	0.00	20.03	311613.794	7267491.553

LINE "C"

SAMPLE LINE DATA TABLE

POINT #	DESCRIPTION	STATION	OFFSET	ELEVATION	NORTHING	EASTING
20008	ER START	0+00.00	0.00	16.49	311321.594	7267384.075
20009	SR START	0+21.00	0.00	16.88	311342.571	7267385.049
20024	REMI START	0+80.00	0.00	17.12	311401.508	7267387.787
20025	REMI END	4+43.00	0.00	16.14	311763.508	7267413.566
20010	SR END	5+01.12	0.00	16.61	311821.391	7267418.773
20011	ER END	5+41.47	0.00	17.06	311861.579	7267422.389

LINE "D"

SAMPLE LINE DATA TABLE

POINT #	DESCRIPTION	STATION	OFFSET	ELEVATION	NORTHING	EASTING
20012	ER START	0+00.00	0.00	33.48	311216.431	7267656.667
20013	SR START	0+30.00	0.00	34.88	311246.407	7267655.467
20026	REMI START	0+90.00	0.00	37.45	311306.359	7267653.068
20027	REMI END	4+52.00	0.00	39.49	311664.180	7267607.614
20014	SR END	5+10.19	0.00	34.38	311720.063	7267591.376
20015	ER END	5+41.19	0.00	33.04	311749.832	7267582.726

LINE "E"

SAMPLE LINE DATA TABLE

POINT #	DESCRIPTION	STATION	OFFSET	ELEVATION	NORTHING	EASTING
20016	SR START	0+00.00	0.00	43.12	311585.277	7267568.981
20017	SR END	2+40.00	0.00	53.57	311572.158	7267808.622

LINE "F"

SAMPLE LINE DATA TABLE

POINT #	DESCRIPTION	STATION	OFFSET	ELEVATION	NORTHING	EASTING
20018	SR START	0+00.00	0.00	42.58	311450.548	7267551.208
20019	SR END	2+40.00	0.00	53.38	311437.988	7267790.879

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JPT@JTASURVEY.COM

07-22-2017
REGISTERED PROFESSIONAL LAND SURVEYOR
OREGON JANUARY 12, 1999 JOHN P. THOMPSON 49220
RENEWS 06-30-2018

REVISIONS			
NO.	BY	DATE	REMARKS

SHEET INFO	
DRAWN	JPT
CHECKED	JPT
APPROVED	JAS
LAST EDIT	06/26/2017
PLOT DATE	07/22/2017
SUBMITTAL	

PACIFIC MARINE ENERGY CENTER SOUTH ENERGY SITE:
GEOPHYSICAL EXPLORATION
GEOPHYSICAL SAMPLE LINE GEOMETRY

SCALE 1"=60'

PROJECT NUMBER SIEM0001

DRAWING FILE NAME SIEM1GEOLAYOUT3

SHEET NUMBER 2 OF 2 SHEETS

9. GIS Database Records: Rhine-Cross Group

9.1. Summary

The mapping and geophysical sample line geometry represented in the Autodesk Civil 3D drawings was converted to .dxf files that can be accessed by non-CAD users utilizing the Global Mapper Software. The data can aid stakeholders in the future planning and decision making process.

In addition, the processes results used for the generation of the geophysical tomograms were provided to the client in text delimited format. The deliverable included georeferenced beginning and endpoints for each line and tabulated points describing the x-distance and elevation along the traverse associated with a value relative to the physical property measured, including, P-wave velocity (f/s), S-wave velocity (f/s) and apparent electrical resistivity (Ohm-m).

Appendix B – PacWave South Nearshore HDD Path Geophysical Exploration Report (Siemens and Associates)

PacWave: HDD Path

On the Pacific Ocean, near Waldport, Oregon

DATA REPORT:

Results of Geophysical Exploration

By: Siemens & Associates
Bend, Oregon

Prepared for: Oregon State University
Corvallis, Oregon

December 28, 2018

Dan Hellin
Operations & Logistics Manager
PacWave
College of Earth, Ocean and Atmospheric Sciences
370 Strand Hall
Corvallis, Oregon, 97331

RE: PacWave Marine Geophysical & Geotechnical Services: HDD Path
On the Pacific Ocean, near Waldport, Oregon

Hello Dan,

Siemens & Associates is pleased to present the results of the geophysical exploration. The geophysical interpretation of the results considers local geology and incorporates the benefit of using multiple methods.

Data were gathered and processed for two geophysical methods in the marine environment: Electrical Resistivity (ER) and Seismic Refraction Microtremor (ReMi). The results are presented to describe continuous, 2D profiles. The interpretation is simplified in context with a general understanding of the area's geologic history and suggest the possibility of encountering a variety of material types with the most consistent conditions occurring at depths greater than 80 feet below the seabed. The interpretation of the geophysical results can be enhanced by correlation with direct exploration to confirm the findings.

Siemens & Associates expresses sincere appreciation for the opportunity to conduct this exploration and as new challenges, discoveries and questions arise, we are standing by to offer our assistance.

Prepared by,
Siemens & Associates

J. Andrew "Andy" Siemens, P.E., G.E.
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CONTENTS

1. Introduction

1.1. Purpose

Siemens & Associates (SA) have completed marine based geophysical services to support geotechnical evaluations associated with the HDD path extending from the shore out into the Pacific Ocean. The exploration provides insight regarding seabed conditions and extends similar exploration previously completed on the beach.

1.2. Methods

Two marine geophysical methods were used:

- Electrical Resistivity (ER) in 2D
- Seismic Refraction Microtremor (ReMi) in 2D

Details concerning the procedures, the equipment used, and results are presented later in this report.

1.3. Project Description

SA understands that details regarding the HDD plan are not finalized although the general path is set and includes up to five routes extending from Driftwood Beach State Recreation Site. These paths are currently designed to extend roughly 4000 feet out to sea on a northwest heading. Bore diameter, method, curvature, and depth information has not been provided. SA assumes that decisions regarding such details of design are likely to be partially driven by the results of this exploration.

1.4. Scope

Working under an agreement with Oregon State University (OSU), the SA team completed geophysical measurement bounding the zone of interest. Guidelines for the work were outlined in the proposal prepared by SA dated July 13, 2017. The original scope was agreed upon and documented under an agreement executed on October 25, 2017 (OSU Project # 1991-17), and includes amendments #1, #2, and #3 dated June 15, September, 18 and October 8, 2018, respectively. The field work was performed on September 15 through 18. The completed scope is summarized as follows:

- Consultation with the design and management team
- Planning, preparation for, and scheduling services
- Basic surface reconnaissance and review of readily available geologic resources
- Geophysical data acquisition along HDD1 and HDD5
- Bathymetry data acquisition and delivery throughout HDD corridor and beyond

- Geophysical data processing and QC
- Special processing of previous geophysical data for correlation
- Consultation with outside geology resources
- Preparation of this data report

1.5. Location

The project is located west of Driftwood Beach State Recreation Site roughly two miles north of Waldport, Oregon. The HDD corridor includes the western portion of the recreation site and extends out into the Pacific Ocean to roughly the 10-meter depth mark and possibly farther.

1.6. Limitations

This report has been prepared for the exclusive use of OSU (and consultants of their choosing) for specific application to the project known as PacWave Marine Geophysical and Geotechnical Services. This report has been prepared in accordance with generally accepted geophysical practice consistent with similar work done near Waldport, Oregon, by geophysical practitioners operating in the surf transition zone at this time. No other warranty, express or implied is made.

The information presented is based on data obtained from the marine explorations described in Section 3 of this report. The explorations indicate geophysical conditions only at specific locations and times, and only to the depths penetrated. They do not necessarily reflect variations that may exist between exploration locations and the subsurface at other locations may differ from conditions interpreted at these explored locations. Also, the passage of time may result in a change in conditions. If any changes in the nature, design, or location of the project are implemented, the information contained in this report should not be considered valid unless the changes are reviewed by SA to address the implications and benefit of enhancing the work as necessary. SA is not responsible for any claims, damages, or liability associated with outside interpretation of these results, or for the reuse of the information presented in this report for other projects.

2. Executive Summary

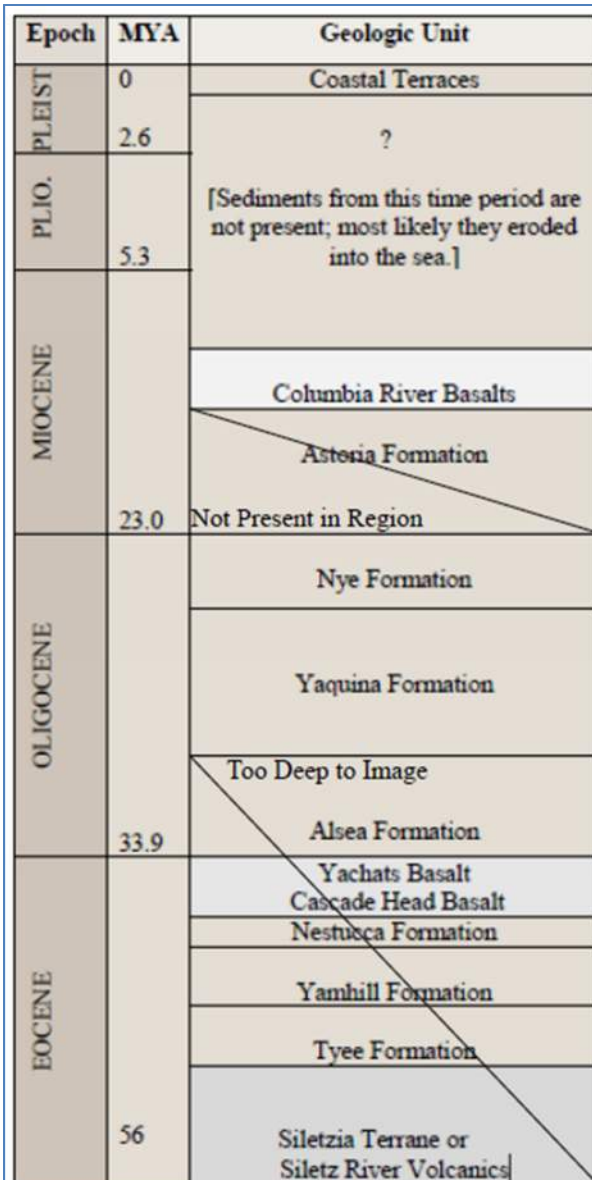
SA have completed marine based geophysical services to support geotechnical evaluations associated with the HDD path extending from the shore out into the Pacific Ocean.

The results developed from the geophysical methods are presented as “tomograms”; a word derived from the Greek “tomo” meaning to cut or slice. Data were collected to illustrate subsurface conditions through the agreed upon routes and the lines were positioned as near to the previously completed terrestrial explorations as physically possible given constraints offered by sea conditions and associated safety concerns when operating near the surf transition zone. Figure 101 (Site Plan: Marine

Geophysical Surveys - HDD) illustrates the location of each line. The tomograms are annotated to communicate our interpretation of the various types of geomaterials discovered by each geophysical method. SA is not aware of any geotechnical information (such as borings) that is available to confirm the interpretation.

2.1. Geologic Setting

The project site lies along the Pacific shoreline of Oregon, approximately two miles north of the mouth of the Alsea River and the town of Waldport. The site lies west of the relatively steep, north-south-trending Coast Range, on the coastal margin near Driftwood Beach State Recreation Site (Driftwood). The shoreline at Driftwood consists of a relatively flat parking area on a terrace surface approximately 40 feet above the active shoreline. The shoreline is characterized by relatively steep bluffs formed by wave-cut erosion at the toe of the slope. Based on our literature review and site reconnaissance, the units encountered at the site, from youngest to oldest, consist of Holocene (recent) surficial deposits of unconsolidated fine to medium-grained dune and beach sand, recent alluvium; Pleistocene marine terrace deposits; and Tertiary siltstone, claystone, and sandstone. The recent dune deposits are principally located in the periphery of the parking lot and to areas north, south, and east. The base of the dune sand may exhibit some consolidation. In addition to the recent dune sand deposits along the uplands, active shoreline processes are reworking the older, fine to medium grained terrace sand. Other recent deposits observed near the site include stream alluvium at the mouths of small drainages located north and south of the site. The alluvium consists of sand, gravel, and



Modified from Schlicker and others, 1973, and Orr and Orr, 2012.
Numeric ages from Walker and others, 2012.
MYA = Million years ago

cobbles composed predominantly of erosionally-resistant basalt. The thickness of the recent (Holocene) deposits varies between zero and tens of feet-thick.

Flat-lying marine terrace deposits underlie the unconsolidated recent deposits in the project vicinity. These semi-consolidated terrace soils are remnants of older beach deposits. The marine terrace deposits are exposed in the shoreline bluffs along most of the Lincoln County shoreline, including the project area. The semi-consolidated Pleistocene marine terrace deposits form steep bluffs along the shoreline and extend inland as much as a mile. The terrace deposits directly overlie the wave-cut benches formed on westward-tilted, Tertiary marine siltstone, sandstone, and marine clasts of the two formations exposed in the region; the Yaquina and Nye formations. The base of the marine terrace deposit may contain a lag deposit of coarse sand, gravel, and cobbles that formed as the shoreline transgressed to the east, prior to the deposition of the Pleistocene beach deposit. The Pleistocene marine terrace deposits range in thickness between 0 and 50 feet or more (Schlicker, et. al., 1973).

Tertiary (middle to late Oligocene), marine siltstone, and sandstone (Nye, Yaquina, and Alsea Formations) underlie the marine terrace deposit. The contact between the Yaquina/Nye Fm. and the Plio-Pleistocene terrace deposit has an approximate 40 MA year unconformity with the underlying Yaquina/Nye bedded sandstones, siltstones, and biogenic clasts inclined westward at dips ranging between 5 and 30 degrees, based on exposures along the Alsea River embayment and east of the project site. Thicknesses of individual beds of siltstone versus sandstone are unknown at the project site as this unit is not exposed at the surface in the project vicinity. The thickness and extent of these units is extremely variable laterally within the formations. The erosional contact between the Plio-Pleistocene terrace deposits and the underlying Oligocene siltstone and sandstone is regionally flat, however locally may be irregular due to variable erosional resistance variability between the materials composing the formations, as well as by downcutting of small streams in the young weakly consolidated material. Additionally, due to the unfavorable dip towards the west and active shoreline erosion, bedding plane failures (landslides) within the local sedimentary rocks exists and displaces the overlying Plio-Pleistocene through Holocene-aged deposits. The thickness of the Tertiary marine Alsea Formation ranges in thickness between 150 and 3,500 feet (Snavely, et. al., 1975).

In addition to the sedimentary units, regionally there are significant volcanic flows associated with the Columbia River Flood Basalts (CRBs). These flows occurred between the marine terraces and the Yaquina/Nye formations. The flows originate in Central Oregon and follow topographic lows in the region, and cause an inversion of topography. This is exposed north of Driftwood at Seal Rock where there is a contact between the CRBs and the Yaquina formation below it. The CRBs would only be present in a region that had a stream discharging into the ocean, such as the Alsea into the Yachats bay south of the job site, or any other major depressions in the topography. These flows often produce prominent outcrops in the form of headlands and sea stacks, as observed at Seal Rock.

There is some indication from the local geology of the headlands composed of CRBs that the surface flows may have "dove" subsurface. This would occur only in regions of very weak sediments with a low density, such as dunes and beach sand. This is caused by the much higher density lava flowing over less dense sediment and the flow essentially "sinks" into the material until it reaches a more resistant material, such as underlying rock, and follow that material's topography.

The units outlined in the above section are representative at the inferred units in the region. This inference is based on the stratigraphy of Seal Rock and other cliff-terrace outcrops north and south of Driftwood. This inference is made with high confidence as the sedimentary units that are outlined are on either lateral boundary in outcrop to both the north and south.

2.2. Conditions Encountered

Based on geophysical interpretations, the stratification is simplified as follows:

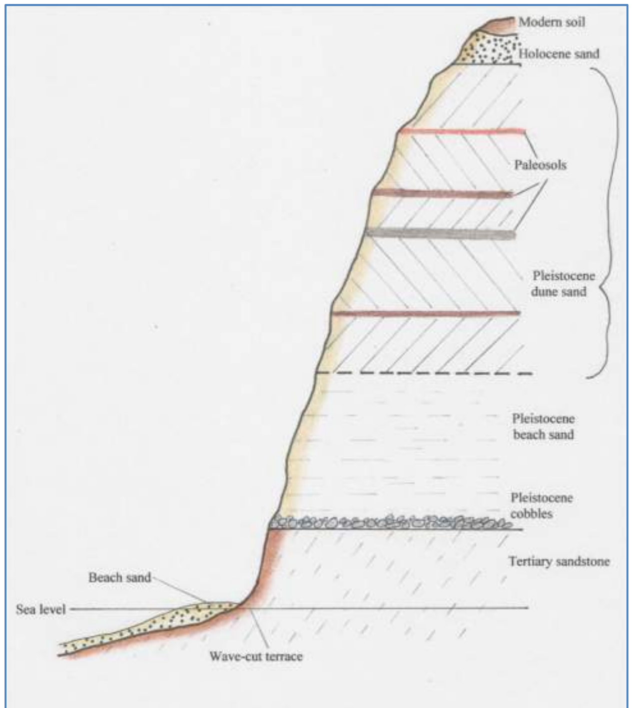
- Layer 1: Unconsolidated Sediments:

  Primarily beach sands are comprised of well sorted medium grained, moderate to well-rounded quartz, and other sediments collecting on the seabed. The sediment fines upward in layers eroded and deposited by wave action on the beach and shallow marine environments. There is a moderate amount of biogenic clasts; predominantly shells that vary in size and are generally fractured by wave action on the sediment surface.

- Layer 2: Terrace Deposits:

  Weak to moderately lithified and consolidated beach sand, compositionally similar to Layer 1, but much older. This layer is also deposited in several subsets of layers all compositionally variable dependent on water depth of deposition. This unit is likely deposited on top of a wave cut platform of more erosion resistant rock. These terraces are exposed by wave-cut cliffs regionally.

  The figure to the right shows a simplified stratigraphic column of what a marine terrace may look like in outcrop in the Seal Rock area (taken from "Geology of the Seal Rock Area" by Maxine Centala').



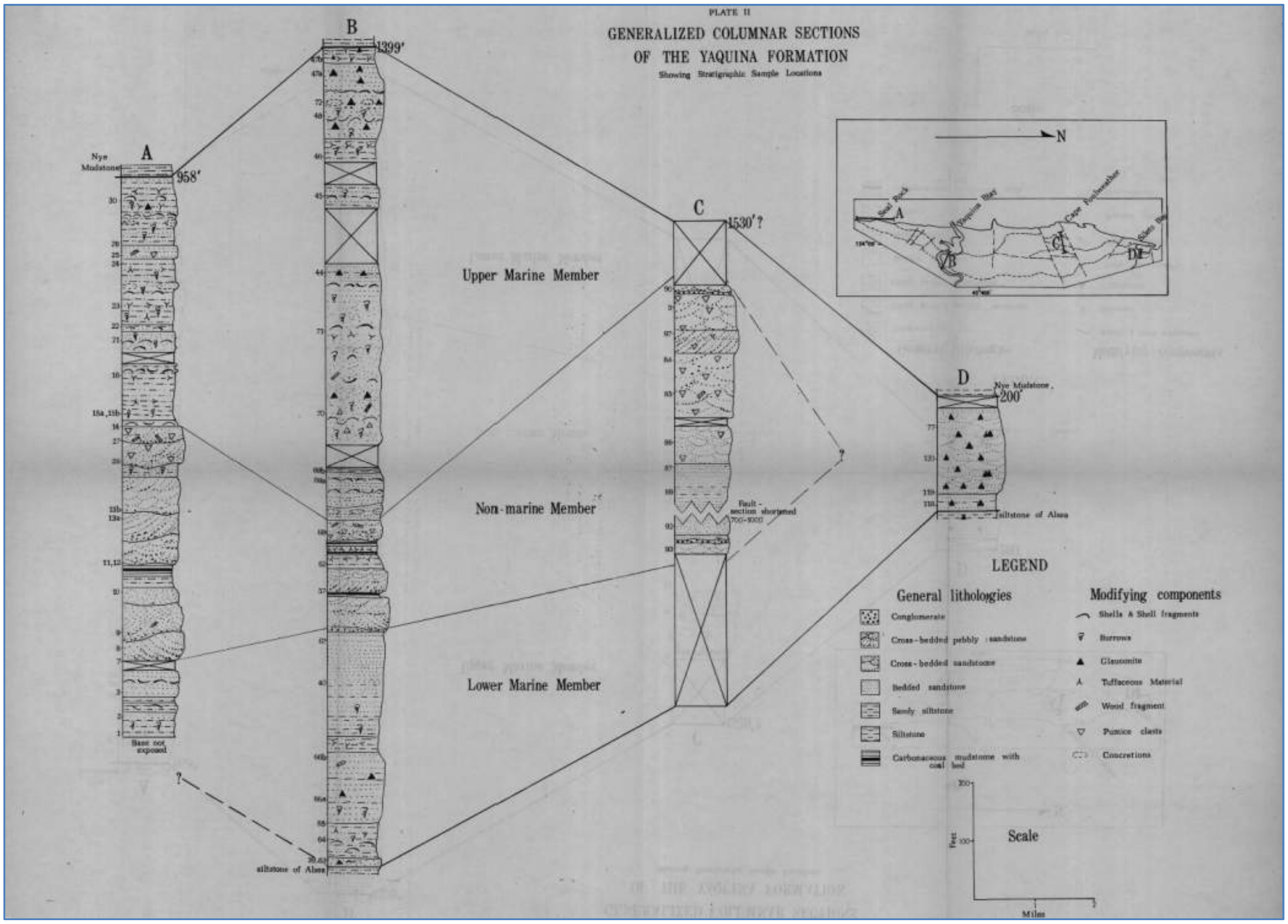
Based on Lund, 1972, and Clough, 2005.

- Layer 3: Sedimentary Rocks including the Nye, Yaquina, and Alsea Formations:

  Yaquina and Nye formations are likely present in the work site. The Nye formation overlays the Yaquina formation and is dominated by well sorted, well rounded sandstone that is moderately consolidated. If present, it would be only a few feet thick or less, and relatively homogenous.

  The Yaquina formation is the lower most unit in the scope of the data. A detailed stratigraphic column of the unit is displayed in the figure below. Note that the stratigraphic column is only a generalization and is not derived from observations on the site; the actual materials found will vary locally. The stratigraphic column (From Goodwin 1972) is only intended to serve as a description of what materials and the order of stacking that is likely to be found.

  The Yaquina is broken into three general pieces. The oldest is shallow marine sediments, varying from beach sand to silt sized particles, and forming a moderate to well-consolidated sandstone. The middle age materials were deposited by rivers and can contain cobbles to silt sized particles, as well as organics such as wood. This layer is the most variable regionally as shown between the three columns below. The youngest and most substantial deposit in the unit, and the portion that is most likely on site, is shell rich sandstone, moderately to heavily consolidated. Column A is best representative of the geology that is expected to appear in Layer 3 through the HDD corridor.



Note:

The assemblage of local geologic knowledge "Geology of the Seal Rock Area" prepared by Maxine Centala (2013) is available on-line at www.sealrockor.com/Geology.html and is recommended for review to gain an improved understanding of the history that drives the possible conditions to be encountered through the HDD corridor.

3. Geophysical Data Acquisition: Marine

The geophysical methods were designed to explore the geotechnical conditions to depths of 100 feet and beyond. The use of multiple methods improves the confidence of the interpretation as each method offers particular strength (and weakness) and the combined results provide complimentary information that is more valuable than any of the methods individually.

In this section, the geophysical methods, equipment, challenges, and data quality are described.

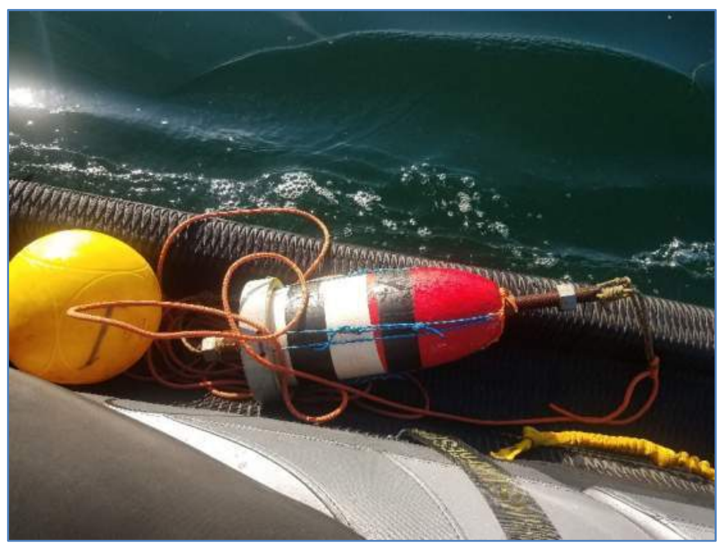
3.1. Geophysical Methods and Equipment

3.1.1. Electrical Resistivity (ER)

How it works: Two-dimensional (2D) electrical resistivity tomography is a geophysical method to illustrate the electrical characteristics of the subsurface by taking measurements on land or in a marine setting. These measurements are then interpreted to provide a 2D electrical resistivity tomogram which is, in turn, related to the likely distribution of geologic or cultural features known to offer similar electrical properties. Measurement in an electrical survey involves injecting DC current though two current-carrying electrodes and measuring the resulting voltage difference at two or more potential electrodes. The apparent resistivity is calculated using the value of the injected current, the voltage measured, and a geometric factor related to the arrangement of the four electrodes.

The investigation depth of any measurement is related to the spacing between the electrodes that inject current. Therefore, sampling at different depths can be done by changing the spacing between the electrodes. Measurements are repeated along a survey line with various combinations of electrodes and spacing to produce an apparent resistivity cross-section (tomogram). In this case, SA used the Dipole-Dipole array with electrode spacing of 3 m along a specially manufactured marine resistivity cable built with 56 stainless steel electrodes. The cable was deployed to rest on the seabed and stabilized with steel weights positioned near the first and last electrodes. Each measurement sequence was designed for a data collection that required about 30 minutes and at the end of the sequence, the cable was slid forward approximately 2/3 of its length for the position of the next measure sequence providing for a data overlap equal to 1/3 of the cable length.

3.1.2. Seismic Refraction Microtremor (ReMi)



The refraction microtremor, known as ReMi is a passive, surface-wave analysis method for obtaining near surface shear-wave velocity models to constrain strength and position of shallow geologic boundaries. These analyses provide information about land and marine soil, and rock properties that are very difficult to obtain through alternative methods. SA recorded passive ambient vibrations (background noise) augmented by an active seismic source (Thumper) operated from a jet-ski near the array.

On land, surface wave analysis is performed using Rayleigh waves because they can be detected on an air-ground interface (earth surface) using geophones. However, the Scholte wave, which is a similar type of seismic surface wave propagating along the interface between a fluid layer and an underlying solid, dominate in marine work. Hence, the Scholte wave is capitalized in marine work and measured with hydrophones set at the water-seabed interface to record ambient vibrations. Both the hydrophones and geophones measure the vertical component of the surface wave (Scholte or Rayleigh) and the results are considered a reasonable estimate of the vertical distance (depth) to layers distinguished by velocity contrast below the receivers.

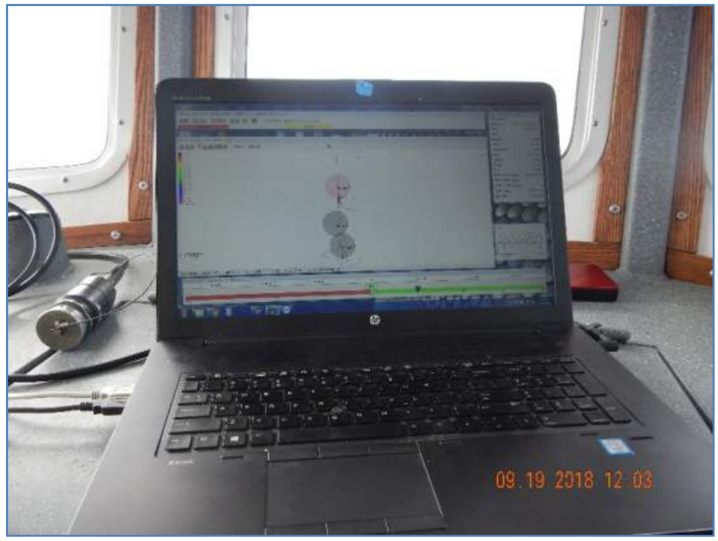
How it works: The ReMi analysis develops the shear-wave velocity/depth profile using an engineering seismograph, low frequency receivers (geophones or hydrophones) and straight-line array aperture (Louie, 2001). Ambient surface wave energy is recorded using relatively long sample window (30 seconds) recording the ambient wavefield. At this site, quality low frequency signals were consistently recorded although the records contain significant frequencies related to ocean swell, vessel engine vibrations, and more. Higher frequency input was provided using "Thumper," a proprietary marine source that was operated from a jet-ski along the hydrophone array.

The microtremor records are transformed as a simple, two-dimensional slowness-frequency (p-f) plot where the ray parameter "p" is the horizontal component of slowness (inverse velocity) along the array and "f" is the corresponding frequency (inverse of period). The p-f analysis produces a record of the total spectral power in all records from the site, which plots within the chosen p-f axes. The trend within these axes, where a coherent phase has significant power is "picked." Then the slowness-frequency picks are transformed to a typical period-velocity diagram for dispersion. Picking the points to be entered into the dispersion curve is done manually along the low velocity envelope appearing in the p-f image.

Marine measurements were completed using a string of 36, 8 Hz. hydrophones built into a marine cable. Receiver spacing was set at 10 feet. Extended line length was accomplished by sliding the hydrophone array along the seabed leaving a 12 receiver overlap at each position.

Data were recorded using a networked pair of DAQ 4 seismographs manufactured by Seismic Source in Ponca City, Oklahoma, USA, connected to an HP laptop computer.

3.2. Horizontal and Vertical Control



Survey route coordinates were provided by 3U Technologies and these data were interpreted and utilized by Solmar Hydro for navigation and route survey control. Solmar mobilized a Trimble R8-3 RTK-GNSS (real-time kinematic global navigation satellite system) receiver, an SBG Systems Eclipse 2-A attitude and heading reference system (AHRS), and a Teledyne Odom CV100 singe-beam echo sounder (SBES) to complete the hydrographic survey.

Xylem Hypack hydrographic surveying software was used for data acquisition. Data were correlated with the NOAA Tides and Currents tide gauge at the NOAA terminal. This correlation provides a basis for converting the recorded NAVD88 datum to other datum formats if required.

The equipment provided real-time positioning along the survey routes with sub-meter accuracy. Bathymetry is judged to offer an accuracy on the order of $1/10^{th}$ of a foot.

3.3. Ancillary Operations

3.3.1. Vessel

Vessel support was provided by Solmar Hydro, Inc. who mobilized a 29-foot, aluminum hull vessel with twin 200 HP outboards. The vessel was equipped for hydrographic survey and provided an excellent platform for data acquisition and navigation.

Support to extend the survey into the surf zone was provided by Ossies Surf Shop, Newport, Oregon, who mobilized to the site on a jet ski. The jet ski was launched from Waldport and met the SA survey team on site.

3.4. Summary of Challenges

3.4.1. Operations

Several weeks prior to the scheduled survey, the client requested a plan to modify the scope that included extended survey line length and bathymetry measurement throughout the HDD corridor. SA accommodated the request and adapted the data collection operation accordingly. Specifically, the original plan to draw the geophysical cables toward the shoreline using a long retrieval winch stationed at Driftwood was abandoned. Cable positions were determined using the vessel navigation system rather than distance measured with the retrieval winch. As it turned out, this change was favorable given the prevailing tide, weather, and sometimes rough seas at the time of the survey.

Although the weather was reasonably favorable in the mornings, wind, wave, and swell gained intensity in the early afternoon. As a result, the available survey time that included avoiding difficult weather was shortened. To complete the survey given the shortened schedule, SA altered the data collection methods to speed the collection sequences to fit the available time.

The transition surf zone was more difficult to safely approach than anticipated. This led to a larger than anticipated information gap between the terrestrial geophysical results completed in 2017 and the marine exploration even though marine data collection started near the surf at high tide. The jet ski was used to limit the information gap by handing the weighted end of the geophysical cable to the jet ski that was able to safely extend the cable directly into the surf as far as the cable length allowed. The survey vessel maintained a safe position just outside of breaking waves as the jet ski maneuvered into the surf.

3.4.2. Data Quality and Interpretation Challenges

In general, the recorded data are judged to be of moderate quality compared to the results from the terrestrial survey and of very good quality given the challenging survey environment. Data quality were compromised by several factors including shortened survey time as described and the dynamics of the surf transition zone. The shortened schedule required a reduction in the quantity of data collected (particularly in redundant collection) which condenses the data available for scrutinization during processing. The dynamics of the ocean promotes movement of the bottom cables even though they are heavily weighted and drawn tight during each slide to the new position. Cable movement causes noisy data and this promoted challenges for processing both ER and ReMi data.

Even so, it is the opinion of SA that the results provide an effective overall look at subsurface conditions through the north and south boundaries of the HDD offshore corridor and the reasonable correlation between the stratigraphy illustrated by independent geophysical methods leads to greater confidence in the findings than would be had by only one method.

4. Processing and Interpretation

4.1. General

During the data gather, partial interpretation was completed in the field for quality control purposes and to assist in setting and confirming proper data acquisition parameters. The instruments were continuously monitored through the data acquisition phase.

The interpretation for each line is presented in this section and the locations of the lines are shown graphically on Figure 101. Results for each method along each line are presented in appendices to this report. ER and ReMi tomograms are presented using the same horizontal and vertical scales and horizontal zero coordinate to assist in correlation. ReMi results are also presented on a scale of 1 inch = 400 feet horizontal and 1 inch = 50 feet vertical to incorporate the terrestrial results measured along the same HDD lines in 2017. The apparent resistivity scaling factors do not correlate well between the marine and terrestrial surveys and although attempted by SA, no benefit was found by providing a similar correlation between marine and terrestrial ER results.

In the opinion of SA, the 2D S-wave (ReMi) tomograms are the most robust and plausible description of the conditions encountered. While the ER results are similar, visual review of the ER tomograms are more challenging to interpret.

It is worthy to emphasize that the geophysical results are presented in 2D yet the data collection is influenced by a 3D environment. Unless the geology is simple, like a flat stack of pancakes, the various geophysical methods cannot be expected to match perfectly. In addition, geophysical interpretations are often compared to direct observation of conditions discovered in geotechnical drill holes. Note that the drill hole is a 1D description of the subsurface and represents a very small sampling, unlike the geophysical approach. Correlation and conflict are expected, and both must be considered in context with the factors that influence data quality, complication of the subsurface and the geophysical parameters measured.

A description of the data processing, interpretation methods and results are presented in the following sections.

4.2. Electrical Resistivity (ER)

Important factors which affect the resistivity of different geological material are:

- Porosity
- Moisture content
- Dissolved electrolytes
- Temperature (resistivity decreases with increasing temperature)

Each dataset was filtered to remove spikes, noisy, and mis-fit data through a systematic progression to produce plausible inversion models without excessive iteration. As discussed, data were noisy due to various reasons and this led to filtering (removal) of nearly 50% of the data collected. This level of filtering is high although not uncommon in a difficult saltwater marine environment. The remaining data still provides a sampling through depth well beyond 100 feet. The best resolution is within the upper 50 feet or so and fewer data are available to resolve deeper strata. For this reason and the effect of merging overlapping data sets, the ER tomograms are blocky and illustrate stratification that is more complicated than reality.

4.2.1. ER Processing and Presentation

The data sets were processed using AGI Earth Imager Software and Res2D INV by Geotomo Software, Malaysia. After many iterations and trials with various algorithms and review of the results, SA selected the images developed with the AGI software as the most plausible description of the conditions encountered. The tomograms are graphically scaled 1 inch = 300 feet horizontal and 1 inch = 50 feet vertical. The temperature and conductivity of the water layer was measured onsite and utilized in the data processing: water conductivity = 0.27 Ohm-m, Temperature = 14.9^0 C.

4.2.2. Considerations in ER Interpretation

Lines 1 and 2 on HDD-1 and HDD5, respectively: The results present similar findings along each line that roughly correlate with stratification developed using the ReMi method. The tomograms are blocky and effective interpretation requires a broad simplification to knit layers together and close the gaps where data were filtered in the processing stage and not recorded due to the length of the overlapping measurement. Considering this simplification, the ER results clearly show at least three layers to differentiate geologic boundaries below the seabed.

Unconsolidated Sediments

In general, the apparent resistivity increases with depth and the lowest resistivity is interpreted to be associated with conductive, unconsolidated sediments of the seabed. The layer resistivity ranges from about 0.1 to 0.3 Ohm-m. Layer thickness ranges from 10 to about 40 feet. This layer is likely composed of fine-grained materials that include silts and sands like beach deposits although probably finer.

Terrace Deposits

Below the unconsolidated layer, the apparent resistivity increases and through the range of about 0.3 to 0.45 Ohm-m, SA interprets the results to be indicative of terrace deposits. The texture and consolidation of this layer is expected to vary as the layer is composed of materials cut, reworked, and then deposited with its origins being a variety of soil and rock types including beach sand, cobbles, and boulders of the CRBt and remnants of local sedimentary rocks.

Sedimentary Rocks (undifferentiated)

The highest apparent resistivity, occurring at depths below the seabed ranging from about 40 to 60 feet (possibly greater) are interpreted to represent undifferentiated sedimentary rock. Apparent resistivity is not an indicator of the strength of geologic materials and in this case, it appears that the electrical contrast at this boundary is not distinct. Since there are a variety of local formations that could have similar electrical properties because they have similar origin and texture, it is the opinion of SA that distinct sedimentary units are not defined by the electrical method. Further, the transition from the overlying terrace deposits to the sedimentary units is also not distinguished in these tomograms.

Based on geologic research, the CRB (like that present ~1500 feet north of HDD-1) could occur within this and other layers. To evaluate this potential, SA collected submerged sample of this basalt from the surf zone at Seal Rock State Park and tested the apparent resistivity in the laboratory with the specimens submerged in seawater. The results indicate an apparent resistivity that ranged from 1.1 to 1.4 Ohm-m. Apparent resistivity in this range was not measured within the upper layer and although unconformable, it is remotely possible that apparent resistivity on the order of 1 Ohm-m could be indicative of isolated basalt features.

4.3. Refraction Micro-tremor (ReMi)

ReMi data were procured along the same routes as ER. The models are of particular value as the shear wave velocity is directly related to the strength of a geologic material. The models were produced by Dr. Satish Pullammanappallil, Ph.D. of SubTerraSeis, LLC, using Geogiga SubsurfacePlus 8.3 software. The 2D models illustrate the trend in the subsurface in terms of shear-wave velocity that correspond closely with trends in the ER although the fit is not perfect.

Shear-wave velocity, V_s is used to determine the shear modulus, G, of soil or rock:

$G = \rho (V_s^2)$: a valuable measure of soil stiffness and rock strength

Where ρ = mass density (i.e. total unit weight / gravitational acceleration constant, 32.2 ft/s^2)

The ReMi derived V_s is interpreted from small strain measurements produced by non-destructive surface waves (Scholte waves) with strain on the order of 10^{-4} %. Shear modulus (G) derived from shear-wave velocity measured insitu using surface wave methods is commonly referred to as the small-strain shear modulus G_{max}.

4.3.1. ReMi Processing and Presentation

Dr. Pullammanappallil, Ph.D. created the 2D profiles using a series of 1D shear-wave depth profiles along each line typically using 12 to 24 channels per analysis progressing through the data with two channel increments (channels 1 to 12, 3 to 14, 5 to 16 and so on). As many as 36 channels were used to constrain the deepest parts of the models. The data were noisy due to surf, vessel motor frequencies, swell, and possibly other factors. Dr. Pullammanappallil applied various filtering techniques during the data processing effort.

The ReMi tomograms are presented on the same scale as ER for correlation and SA developed a second presentation with a horizontal scale of 1 inch = 400 feet and added the results of the terrestrial ReMi surveys along the same HDD lines. This presentation is useful and illustrates consistency in the depth to the fastest velocity and diminishing thickness of the upper, unconsolidated sediment to the east. The thickness of the intermediate layer interpreted as terrace deposits is greater through the terrestrial interval due to the nature of the environment of the unit's deposition. The terrace is dominated by beach sand and sand dunes, and was predominately shallow ocean and subaerial when deposited. When deposition was occurring in the unit, it was much thicker inland and tapered down in thickness moving east into deeper water.

4.3.2. Considerations in ReMi Interpretation

<u>Lines 1 and 2 on HDD-1 and HDD5, respectively:</u> The results present similar findings along each line that roughly correlate with stratification developed using the ER method. The tomograms illustrate progressively increasing velocity with depth with a few velocity reversals and irregular transitions to the various layers.

Unconsolidated Sediments

Through the upper layers, shear-wave velocities as low as ~200 f/s are interpreted and represent very weak sediment through many shallow intervals. The lowest velocity up to about 500 f/s are representative of the unconsolidated layer and based on this range, thickness varies from 10 to nearly 35 feet.

Terrace Deposits

This intermediate layer is interpreted to be represented by S-wave velocity in the range of about 500 to 1200 f/s, possibly a bit higher in areas. As discussed, the terrace deposit is anticipated to include a variety of material types including variable degree of consolidation. As a result, S-wave velocity cannot be directly related to any specific material type although geologic materials with S-wave velocity in this range offer moderate to moderately high strength. Due to the heterogeneity inherent to a terrace deposit, these characteristics are likely to change significantly over short distances and the irregularity of the ReMi tomograms support that conclusion. Terrace deposit thickness through the marine ReMi survey varies from about 10 to 30 feet.

Sedimentary Rocks (undifferentiated)

S-wave velocity on the order of 1200 f/s and higher are interpreted to represent strong, more homogeneous geology typical of the various sedimentary units described in the geologic literature available to SA. The highest velocity region (>2200 f/s) is interpreted to represent the most homogeneous of the sedimentary layers. The tomograms illustrate much greater variability within the velocity zone 1200 to 2200 f/s, probably due to surficial erosion, weathering, and other disturbance. Depth to the top of the sedimentary layer varies from about 45 to 65 feet with the top of the highest velocity rock ranging from 45 to 90 feet.

Although unlikely, there is a possibility of basalt inclusions within these higher velocity regions. As described earlier, the CRB deposition associated with the nearby Seal Rock area could extend into the HDD corridor and fill ancient depressions or displaced weak materials present at the time of deposition. Fresh, non-weathered, and lightly fractured/jointed basalt typically offers S-wave velocity greater than 2500 f/s and these velocities (and higher) are interpreted at depth. This occurrence would be unconformable and is considered a possibility, although remote.

ReMi is a volume averaging method and hence, it is challenging to resolve small variations within high velocity layers. Also, the resolving power decreases with depth and thus variations (particularly velocity reversal) are less likely to be imaged within the deep, higher velocity layers.

4.3.3. Seismic Site Classification (ASCE 7)

Seismic Site Classification in accordance with ASCE 7 was calculated from data along each of the 2D ReMi lines. The average shear wave velocities through the upper 100 feet (Vs100) which defines the seismic site classification ranges from Site Class E to C and is dominated by Site Class D. A summary of the calculated values of Vs100 are as follows:

- RM-1 on HDD-1: Vs100 range: 584 to 1071 f/s, average: 821 f/s (Site Class E to D)
- RM-2 on HDD-5: Vs100 range: 578 to 1289, average: 945 f/s (Site Class E to C)

5. References

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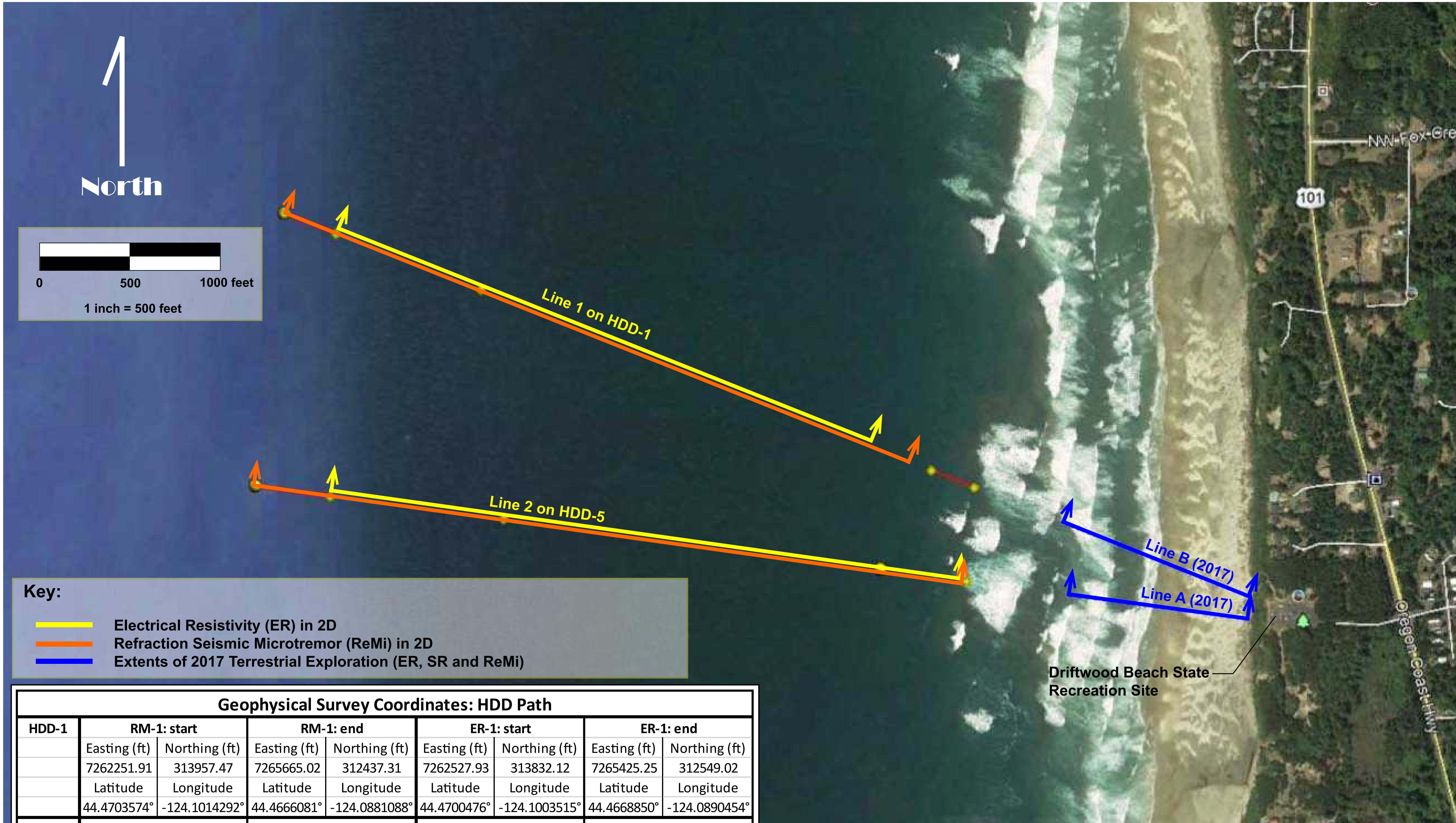
6. Graphical Presentation of Results

The interpretations are presented in 2D with the locations of the various lines illustrated on Figure 101.

6.1. Figure 101: Site Plan: Marine Geophysical Surveys - HDD



Geophysical Survey Coordinates: HDD Path

HDD-1	RM-1: start		RM-1: end		ER-1: start		ER-1: end	
	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)
	7262251.91	313957.47	7265665.02	312437.31	7262527.93	313832.12	7265425.25	312549.02
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
	44.4703574°	-124.1014292°	44.4666081°	-124.0881088°	44.4700476°	-124.1003515°	44.4668850°	-124.0890454°
HDD-5	**RM-2: start**		**RM-2: end**		**ER-2: start**		**ER-2: end**	
	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)
	7262025.36	312474.27	7265799.64	311815.77	7262436.13	312397.12	7265749.64	311825.77
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
	44.4662652°	-124.1020429°	44.4649212°	-124.0874880°	44.4661040°	-124.1004579°	44.4649425°	-124.0876810°

Site Plan: Marine Geophysical Surveys - HDD

Figure: 101

PacWave: HDD Path
On the Pacific Ocean, near Waldport, Oregon

September 18, 2018

Project # 181028

Prepared for: Oregon State University

Siemens & Associates

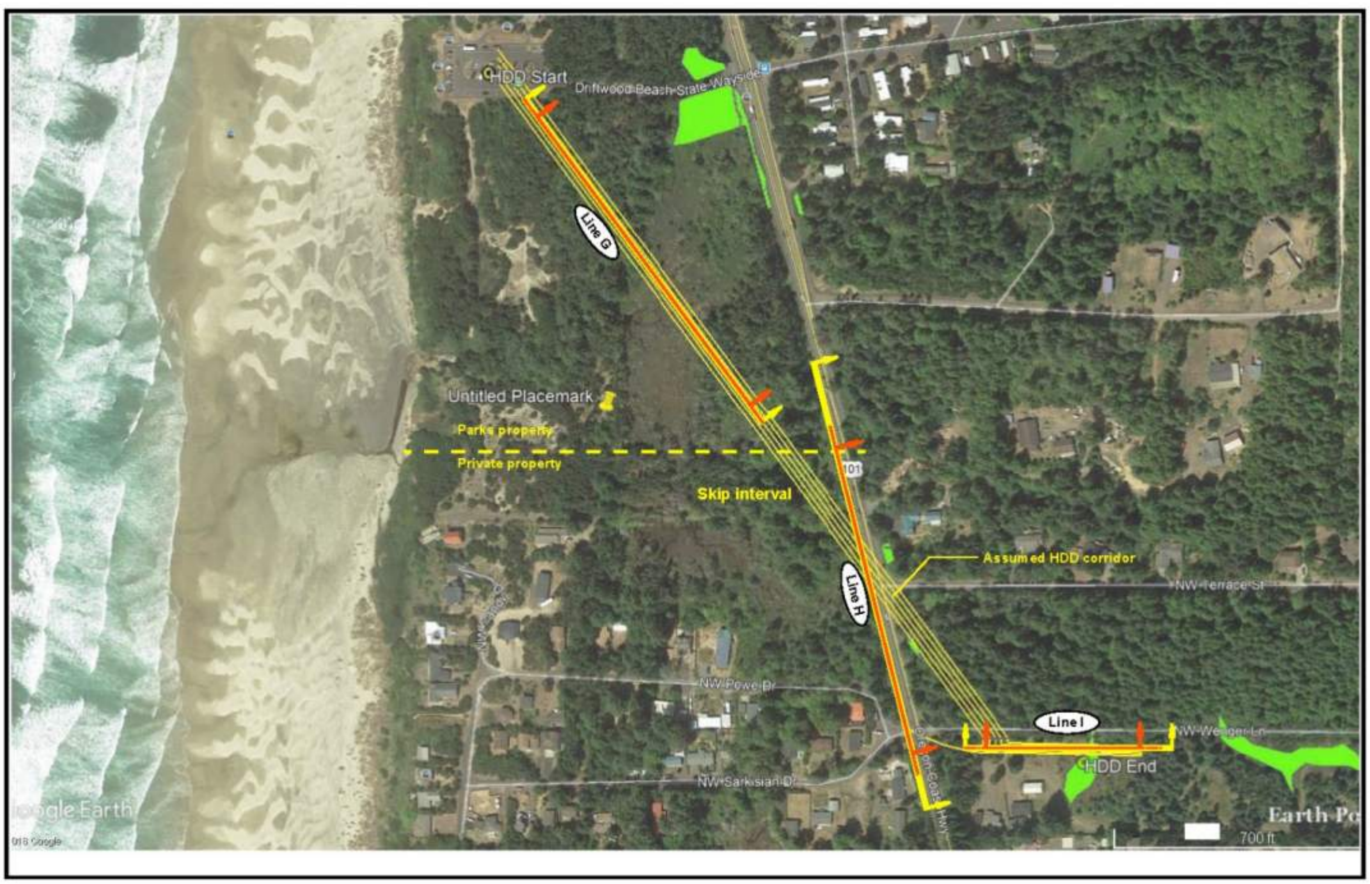
Appendix C – Terrestrial HDD Path Geophysical Exploration Report (Siemens and Associates)

Technical Services for Terrestrial Seismic Survey and Evaluation

DATA REPORT:

Results of Geophysical Exploration

Prepared by: Siemens & Associates, Bend, Oregon
Prepared for: Oregon State University, Corvallis, Oregon



May 28, 2019

Dan Hellin
Operations & Logistics Manager
PacWave
College of Earth, Ocean and Atmospheric Sciences
370 Strand Hall
Corvallis, Oregon, 97331

RE: Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave
Seal Rock, Oregon

Hello Dan,

Siemens & Associates (SA) is pleased to present the results of this geophysical exploration. The geophysical interpretation considers local geology and incorporates the benefit of using multiple methods. This report presents the third geophysical exploration prepared by SA for PacWave and the most comprehensive evaluation of the prevailing geology and associations with HDD. These correlations and considerations are judged to be applicable to both the terrestrial and marine HDDs planned for PacWave.

Data were gathered and processed for three geophysical methods in the terrestrial environment: Electrical Resistivity (ER), Seismic Refraction (SR), and Linear Microtremor (LM). The results are presented to describe continuous, 2D profiles through most of the alignment. The interpretation is simplified in context with a general understanding of the area's geologic history and suggest the possibility of encountering a variety of material types with the most consistent conditions occurring through the sedimentary bedrock. SA recommends enhancing and confirming the geophysical findings using traditional geotechnical exploration.

Siemens & Associates expresses sincere appreciation for the opportunity to conduct this exploration and as new challenges, discoveries and questions arise, we are standing by to offer our assistance.

Prepared by,
Siemens & Associates

REGISTERED PROFESSIONAL ENGINEER 16,377 OREGON JAN. 19, 1993 J. ANDREW SIEMENS

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CONTENTS

1. Introduction

1.1. Purpose

Siemens & Associates (SA) have completed geophysical services to support geotechnical evaluations associated with terrestrial HDD (horizontal directional drilling). Geophysical exploration methods were selected as a first approach since the surface terrain is complicated by heavy brush and wetlands limiting drill rig access to much of the route. The results provide a basis for addressing feasibility and planning as well as targets for continued exploration using conventional geotechnical methods.

1.2. Methods

Three geophysical methods were used:

- Electrical Resistivity (ER) in 2D
- Seismic Refraction (SR) in 2D
- Linear Microtremor Shear-wave (LM) in 2D

Details concerning the procedures, the equipment used, and results are presented later in this report.

1.3. Project Description

It is understood that the transmission and communication lines from the off-shore test facility are to be routed through an approximately 2000 foot HDD extending from the landing at Driftwood Beach State Recreation Site (Driftwood) to the property recently acquired for the Utility Connection and Monitoring Facility (UCMF) located south and east of Driftwood. Only the general route has been defined as details like the number of HDDs, diameter, and depth are not available at this time.

1.4. Scope

Working under contract with Oregon State University (OSU), the SA team completed geophysical measurement along the HDD path generating results along most of the path excluding sections occupied by private landowners. Guidelines for the work were outlined in the agreement executed on March 9, 2019, prepared by OSU. The completed scope is summarized as follows:

- Consultation with the design team
- Preparation of a detailed workplan
- Brush clearing to provide access
- ER, SR, and LM surveys along the proposed HDD path

- Basic surface reconnaissance including elevation surveys of each line
- Establishment of permanent control points along the HDD path and at UCMF
- Geophysical data processing and quality control
- Area geologic reconnaissance and research
- Interpretation of the findings
- Preparation of this report

The line location and number sequence were developed through mutual agreement between SA and the design team. The lines are designated by letter that continues the sequence established on previous similar explorations for this project.

1.5. Location

The project is located along a corridor extending southeast from Driftwood to the property known as UCFM located immediately east of Highway 101 on NW Wenger Lane. Specific exploration points and the HDD path are identified in this report by Figure 103 (Site Plan: Geophysical Exploration).

1.6. Limitations

This report has been prepared for the exclusive use of OSU for specific application to the project known as Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave. This report has been prepared in accordance with generally accepted geophysical practice consistent with similar work done near Seal Rock, Oregon, by geophysical practitioners at this time. No other warranty, express, or implied is made.

The information presented is based on data obtained from the field explorations described in Section 3 of this report. The explorations indicate geophysical conditions only at specific locations and times, and only to the depths penetrated. They do not necessarily reflect variations that may exist between exploration locations. The subsurface at other locations may differ from conditions interpreted at these explored locations. Also, the passage of time may result in a change in conditions. If any changes in the nature, design, or location of the project are implemented, the information contained in this report should not be considered valid unless the changes are reviewed by SA to address the implications and benefit of enhancing the work as necessary. SA is not responsible for any claims, damages, or liability associated with outside interpretation of these results, or for the reuse of the information presented in this report for other projects.

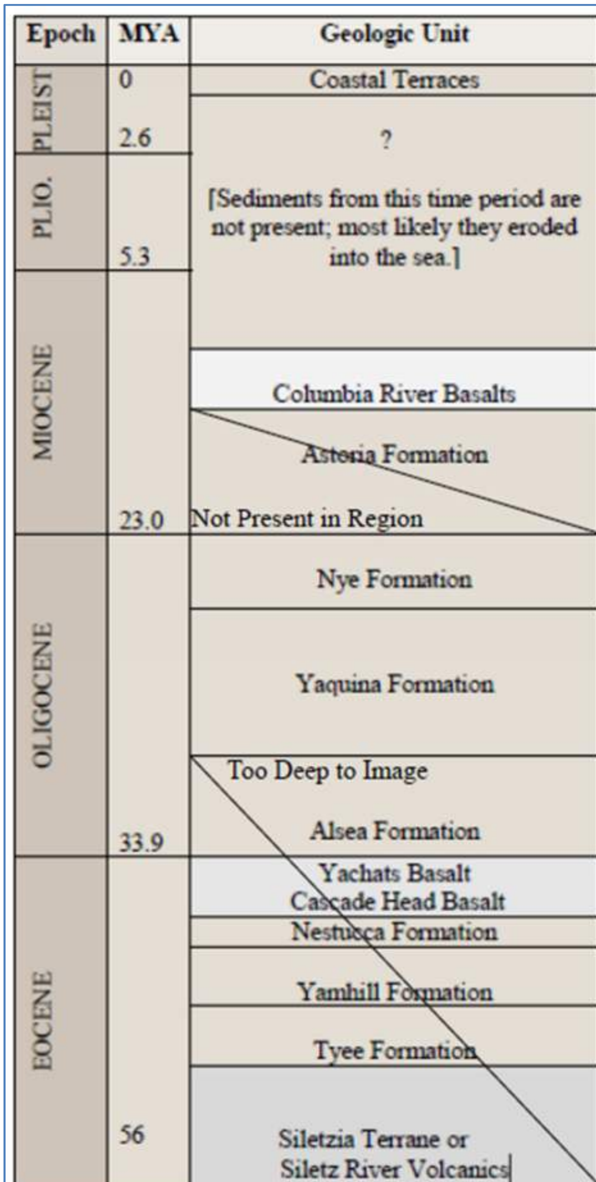
2. Conditions Encountered

The results developed from the geophysical methods are presented as tomograms; a word derived from the Greek "tomo" meaning to cut or slice. The tomograms are annotated to communicate our interpretation of the various types of geomaterials discovered by each geophysical method. SA is not aware of any geotechnical information (such as borings) that is available to confirm the interpretation.

2.1. Geologic Setting

The project site lies along the Pacific shoreline of Oregon, approximately two miles north of the mouth of the Alsea River and the town of Waldport. The site lies west of the relatively steep, north-south-trending Coast Range, on the coastal margin near Driftwood Beach State Recreation Site (Driftwood). The shoreline at Driftwood consists of a relatively flat parking area on a terrace surface approximately 40 feet above the active shoreline. The shoreline is characterized by steep bluffs formed by wave-cut erosion at the toe of the slope.

Based on our literature review and site reconnaissance, the units encountered at the site, from youngest to oldest, consist of Holocene (recent) surficial deposits of unconsolidated fine to medium-grained dune and beach sand, recent alluvium and peat / fine-grained lake deposits; Pleistocene marine terrace deposits; and Tertiary (middle to late Oligocene aged) mudstone, siltstone, claystone, and sandstone.



Modified from Schlicker and others, 1973, and Orr and Orr, 2012.
Numeric ages from Walker and others, 2012.
MYA = Million years ago

The recent dune deposits are principally located in the periphery of the parking lot and to areas north, south, and east. The base of the dune sand may exhibit some consolidation. In addition to the recent dune sand deposits along the uplands, active shoreline processes are reworking the older, fine to medium grained terrace sand. Other recent deposits observed near the site include stream alluvium at the mouths of small drainages located north and south of the site. The alluvium consists of sand, gravel, cobbles and boulders composed predominantly of erosionally-resistant basalt. The thickness of the recent (Holocene) deposits varies between zero and tens of feet. East of the dune deposits is a marsh that is interpreted as a drained back-dune pond. Deposits in this area likely include soft, organic-rich silts and fine sands.

Flat-lying marine terrace deposits underlie the unconsolidated recent deposits in the project vicinity. These semi-consolidated terrace soils are remnants of older beach deposits. The marine terrace deposits are exposed in the shoreline bluffs along most of the Lincoln County shoreline, including the project area. The semi-consolidated Pleistocene marine terrace deposits form steep bluffs along the shoreline and extend inland as much as a mile. The Pleistocene marine terrace deposits range in thickness between 0 and 50 feet or more (Schlicker, et. al., 1973; Oregon Water Resources water well records). The terrace deposits directly overlie the wave-cut benches formed on westward-tilted, Tertiary marine siltstone, sandstone, and marine clasts of the two formations exposed in the region; the Yaquina and Nye formations.

The base of the marine terrace deposit may contain a lag deposit of coarse sand, gravel, and cobbles that formed as the shoreline transgressed to the east, prior to the deposition of the Pleistocene beach deposit. These deposits were not observed in the project area but are exposed along the beach to the north at Seal Rock. Deposits in this area were measured at up to 2 feet thick (Photograph 1). These gravels were also reported in water well records from the Seal Rock area but were not recorded south of the project area. Gravel fan deposits at the mouth of the drainages north and south of Driftwood indicate the presence of some gravel deposits above the sedimentary bedrock contact within the project area. These Pleistocene deposits also contain rare large woody debris that was likely driftwood rafted in on ocean currents. This driftwood can be in excess of two feet in diameter and may be present throughout these deposits (Photograph 1).

Photograph 1. The outcrop exposes the contact between the underlying Yaquina Formation and recent deposits. Note the approximately 2 foot thick gravel lens immediately above the bedrock and the large (up to 2 foot diameter) woody debris in the overlying sandy terrace deposits.

Tertiary (middle to late Oligocene), marine siltstone, and sandstone (Nye, Yaquina, and Alsea Formations) underlie the marine terrace deposit. The contact between the Yaquina/Nye Formation and the Plio-Pleistocene terrace deposit has an approximate 40 MA year unconformity with the underlying Yaquina/Nye bedded sandstones and siltstones. These formations are regionally inclined westward at dips ranging between 5 and 30 degrees, based on exposures along the Alsea River embayment and east of the project site. Measured bedding dips ranged from 14 to 17 degrees. Thicknesses of individual beds of siltstone versus sandstone are unknown at the project site as this unit is not exposed at the surface in the project vicinity with the exception of an incised channel at the outlet to the marsh south of Driftwood. Siltstone is exposed in the creek channel at this location immediately beneath terrace and dune deposits (Photograph 2).

Photograph 2. This is a view west along the outlet stream for the marsh on Driftwood. The red arrow points to exposed siltstone in the lower portion of the channel. The yellow arrow points to the overlying beach dune deposits.

The erosional contact between the Plio-Pleistocene terrace deposits and the underlying Oligocene siltstone and sandstone is overall relatively flat, however locally may be irregular due to erosional resistance variability between the materials composing the formations, as well as by downcutting of small streams in the young, weakly consolidated material. A potential bedrock low is present along seismic profile I. Additionally, due to the unfavorable dip towards the west and active shoreline erosion, bedding plane failures (landslides) within the local sedimentary rocks exists and displaces the overlying Plio-Pleistocene through Holocene-aged deposits.

In addition to the sedimentary units, regionally there are significant volcanic flows associated with the Columbia River Flood Basalts (CRBs). These flows occurred between the marine terraces and the Yaquina/Nye Formations. The flows originate in eastern Oregon and follow topographic lows in the region, and cause an inversion of topography. This is exposed north of Driftwood at Seal Rock where there is a contact between the CRBs and the Yaquina Formation below it. The CRBs would only be present in a region that had a stream discharging into the ocean, such as the Alsea into the Yachats bay south of the job site, or any other major depressions in the topography. These flows often produce prominent outcrops in the form of headlands and sea stacks, as observed at Seal Rock. They are also the source of basaltic gravels present at the base of the terrace deposits.

2.2. Stratification

Based on geophysical interpretations, the stratification is simplified as follows:

- Layer 1: Unconsolidated Sediments

  Primarily beach sands are comprised of well sorted medium grained, moderate to well-rounded quartz, and other sediments collecting on the seabed. The sediment fines upward in layers eroded and deposited by wave action on the beach and shallow marine environments. There is a moderate amount of biogenic clasts; predominantly shells that vary in size and are generally fractured by wave action on the sediment surface. As noted above, these deposits may contain large woody debris rafted in during storm events. Based on the geophysical results, these deposits may be in excess of 50 feet thick.

  East of the beach sand deposits within Driftwood and along the HDD alignment are organic-rich silts and fine sands associated with a drained back dune lake. This area is currently a marsh with groundwater present at approximately ground surface. The thickness of these deposits is likely less than 25 feet thick.

- Layer 2: Terrace Deposits

  Weak to moderately lithified and consolidated beach sand, compositionally similar to Layer 1, but much older. This layer is also deposited in several subsets of layers all compositionally variable dependent on water depth of deposition. This unit is likely deposited on top of a wave cut platform of more erosion resistant rock. These terraces are exposed by wave-cut cliffs regionally. As noted above, basal gravel lenses are present within these terrace deposits immediately above the bedrock. While not directly observed or defined by geophysics, gravel fan deposits are present at the mouth of the marsh outlet, indicating some gravels are present in the vicinity of the project area (Photograph 1).

  Exposures of these deposits are present in numerous road cuts along US 101 both north and south of the site. These deposits are cut nearly vertical and up to 20 feet high (Photograph 3). These vertical cuts reflect a degree of cementation / lithification of these older deposits. Water well logs in the area indicate that these deposits can be in excess of 50 feet thick and are anticipated to be moderately dense to dense. Based on the seismic profiles, the terrace deposits are anticipated to be less than 50 feet thick along most of the HDD alignment. These terrace deposits may also underlie the marsh / lake bottom deposits within Driftwood.

Information regarding groundwater conditions within the terrace deposits was not readily available. Seeps or springs were not observed in roadcuts but were present along the beach fronts at the contact with the underlying bedrock. Groundwater is anticipated to be present in the lower portions of this unit.

Photograph 3. These terrace deposits are exposed along US101 south of the HDD alignment. This cut is nearly 20 feet high and subvertical.

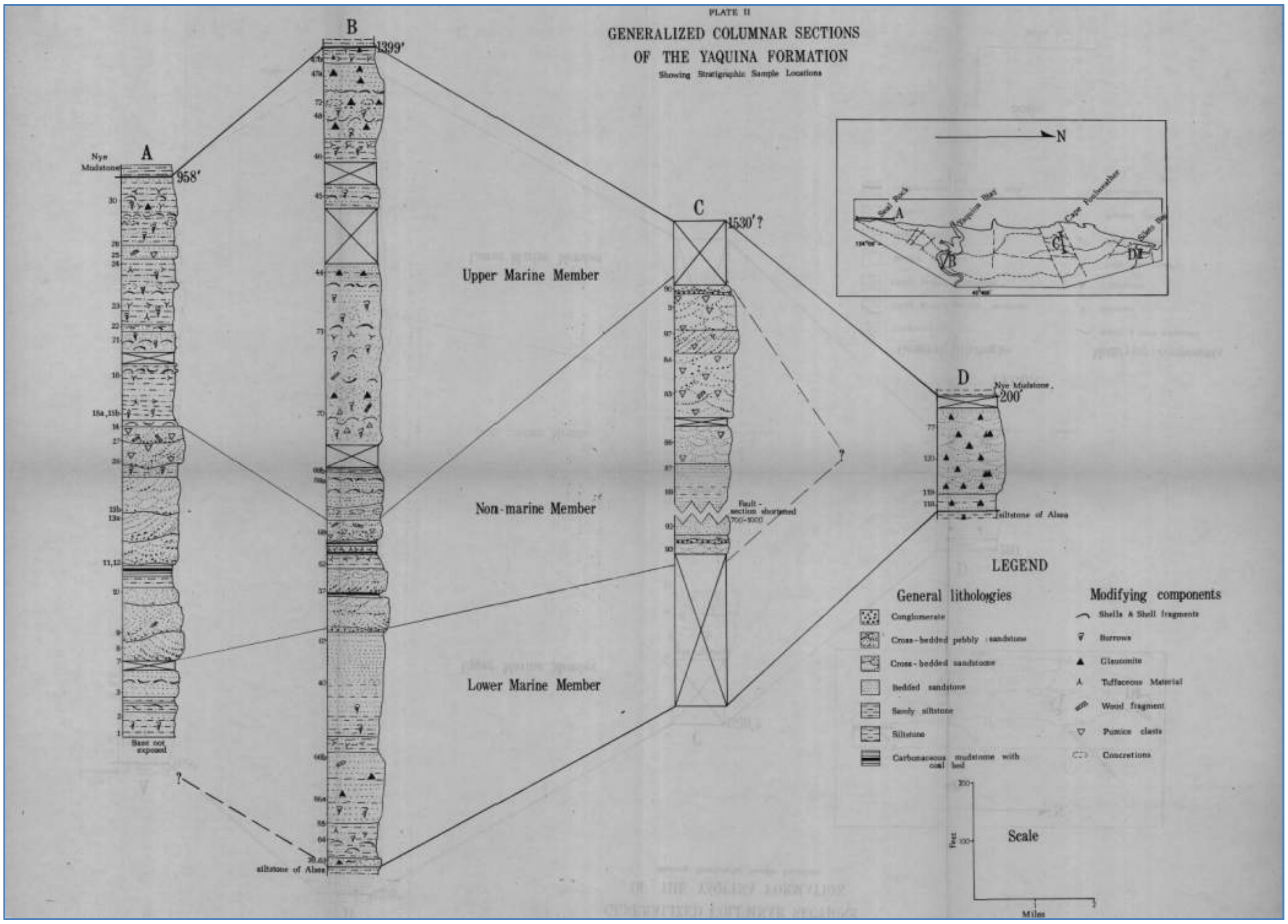
- Layer 3: Sedimentary Rocks including the Nye, Yaquina, and Alsea Formations

  Yaquina and Nye Formations are likely present beneath the work site. The Nye Formation overlays the Yaquina Formation and is primarily a very weak mudstone associated with deeper marine sediments. The contact between the Nye Formation and upper Yaquina Formation is transitional and difficult to identify in outcrop and geophysical contrast. The siltstone observed along the base of the incised stream outlet channel for the marsh south of the Driftwood parking lot may be the Nye Formation or upper Yaquina Formation.

The Yaquina Formation is the oldest unit beneath the project area. A detailed stratigraphic column of the unit is displayed in the figure below. Note that the stratigraphic column is only a generalization and is not derived from observations on the site; the actual materials found will vary locally. The stratigraphic column (from Goodwin 1972) is only intended to serve as a description of what bedrock formations are present at depth.

The Yaquina Formation is broken into three general pieces. The oldest is shallow marine sediments, varying from beach sand to silt sized particles, and forming a moderate to well-consolidated sandstone. The middle age materials were deposited by rivers and can contain cobbles to silt sized particles, as well as organics such as wood. This layer is the most variable regionally as shown between the three columns below. The youngest and most substantial deposit in the unit, and the portion that is most likely on site, is a weak siltstone with interbeds of shell rich sandstone. In outcrops north and south of Driftwood, this unit has widely spaced fractures.

Bedrock along the HDD alignment is most likely mudstone / siltstone representing the lower portion of the Nye Formation or upper Yaquina Formation. The siltstone of the upper Yaquina Formation is anticipated to be over 400 feet thick beneath the site. Water well records indicate this siltstone has low permeability. Column A below is best representative of the geology that is expected to appear in Layer 3 through the HDD corridor.



Note:

The assemblage of local geologic knowledge "Geology of the Seal Rock Area" prepared by Maxine Centala (2013) is available on-line at www.sealrockor.com/Geology.html and is recommended for review to gain an improved understanding of the history that drives the possible conditions to be encountered through the HDD corridor.

2.3. Geologic Impacts along the HDD Alignment

As discussed above, there are several anticipated subsurface conditions that could impact construction of pipelines installed using HDD methods. These hazards and their associated project risks are summarized in Table 1.

Table 1

Geologic Condition	Location	HDD Implication	Mitigation Considerations
Granular dune and terrace deposits	• Dune deposits at the northern end • Terrace deposits along the southern half of the alignment	• Granular soils can be highly erodible, particularly with multiple HDD drives as successive passes can loosen soils.	• Install casing from the surface to bedrock contact at end of HDD profiles. • Reduce the number of HDD drives by installing a larger carrier pipe.
Large woody debris in dune, terrace deposits	• Present along the entire alignment	• Woody debris can be difficult to penetrate with drill rig.	• Install casing from the surface to bedrock contact at end of HDD profiles. • Include this hazard in the specifications.
Basalt gravels in the terrace deposits	• Potential for gravel deposits along the entire alignment above the bedrock contact. • Higher potential for basalt gravels in bedrock low along seismic line I.	• Gravels can be difficult to penetrate and cause delays.	• Install casing from the surface to bedrock contact at end of HDD profiles. • Include this hazard in the specifications.
Variable bedrock weathering and strength	• Along the entire alignment.	• Weathering and strength variations can impact drilling rates and production.	• Conduct additional subsurface explorations to characterize strength and weathering to be included in contract documents.

3. Geophysical Data Acquisition: Terrestrial

The geophysical methods were designed to explore the geotechnical conditions to depths of 100 feet and beyond. The use of multiple methods improves the confidence of the interpretation as each method offers strength (and weakness) and the combined results provide complimentary information that is more valuable than any of the methods individually.

In this section, the geophysical methods, equipment, challenges, and data quality are described.

Geophysical Methods and Equipment

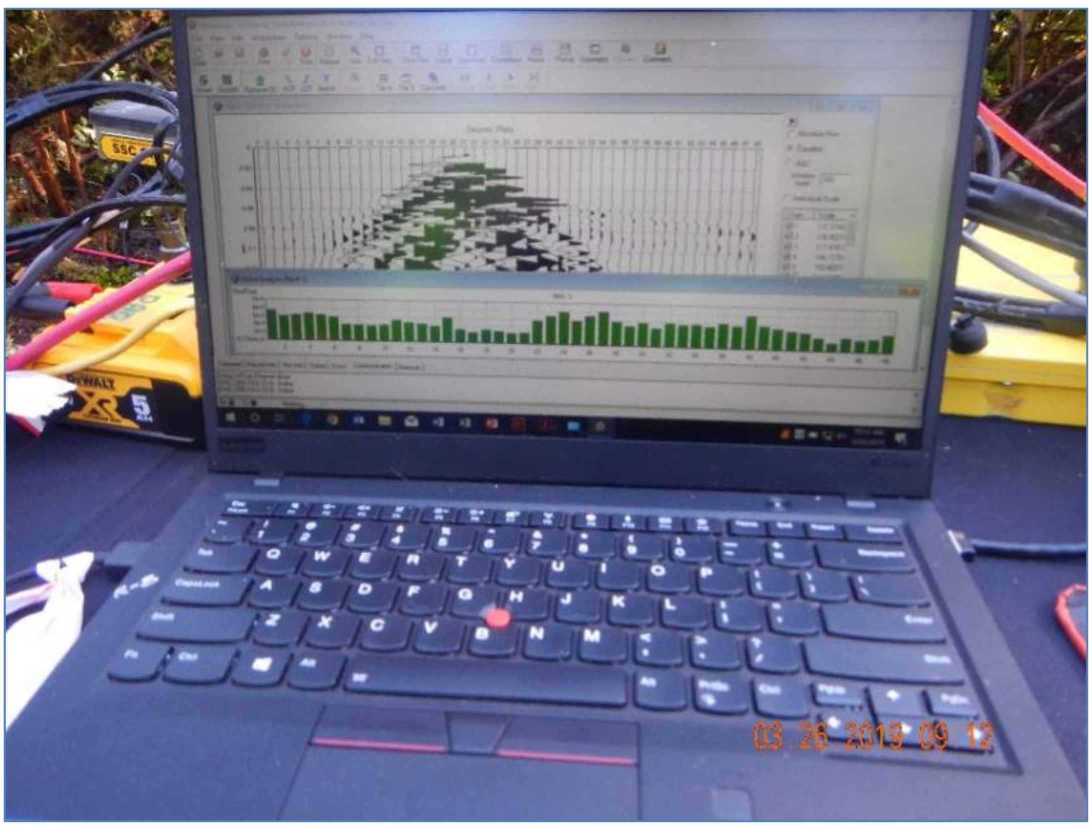
3.1.1. Electrical Resistivity (ER)

How it works: Two-dimensional (2D) electrical resistivity tomography is a geophysical method to illustrate the electrical characteristics of the subsurface by taking measurements on land or in a marine setting. These measurements are then interpreted to provide a 2D electrical resistivity tomogram which is, in turn, related to the likely distribution of geologic or cultural features known to offer similar electrical properties. Measurement in an electrical survey involves injecting DC current though two current-carrying electrodes and measuring the resulting voltage difference at two or more potential electrodes. The apparent resistivity is calculated using the value of the injected current, the voltage measured, and a geometric factor related to the arrangement of the four electrodes.

The investigation depth of any measurement is related to the spacing between the electrodes that inject current. Therefore, sampling at different depths can be done by changing the spacing between the electrodes. Measurements are repeated along a survey line with various combinations of electrodes and spacing to produce an apparent resistivity cross-section (tomogram). In this case, SA used the Dipole-Dipole array with electrode spacing of either 4 or 6.25 m. Electrode pins were 20 inch long, 3/8 inch diameter stainless rods fully embedded into mineral earth and wetted with a saline solution to reduce contact resistance.

3.1.2. Seismic Refraction (SR)

Seismic refraction (SR) is an active seismic method utilizing geophone receivers set along a straight-line gathering data from signals induced by a small explosive charge (8-gauge, 400 grain black powder shell detonated using a Betsy Seisgun). Data were processed using forward modeling software developed by Geogiga known as DW Tomo 8.3. The models developed are plausible and illustrate a reasonably uniform although sometimes complicated top of rock profile. Lower P-wave velocity through the upper layers is related to unconsolidated materials while heavily consolidated materials and rock are illustrated by higher P-wave velocity. P-wave velocity reversals with depth are present in the shallow



geology. These reversals combined with a shallow water table complicate processing and interpretation.

How it works: When the explosive charge is triggered, the receivers are activated, and the wavelet energy is recorded. The P-wave is the fastest of the various seismic waves that are generated and only the time of the first arrival wave at the receiver is considered in the SR method. These first arrivals are picked for each shot at each receiver. As the energy travels through the ground, the waves are refracted and the arrival time, combined with distance from the source is related to both the velocity and distance to the layers promoting refraction. This distance is not necessarily vertical depth; rather the nearest refractor and the image can be skewed when oriented along a dipping refractor.

Data were recorded using a networked pair of DAQ 4 seismographs manufactured by Seismic Source in Ponca City, Oklahoma, USA, connected to an IBM laptop computer. Lines were composed of 48 to 96 receivers on 10 foot spacing with shot intervals of 30 feet.

3.1.3. Linear Microtremor S-wave (LM)

The linear microtremor method, referred to as LM is a passive, surface-wave analysis technique for obtaining near surface shear-wave velocity models to constrain strength and position of shallow geologic boundaries. These analyses provide information about land

and marine soil, and rock properties that are very difficult to obtain through alternative methods. SA recorded passive ambient vibrations (background noise) augmented by an active, un-timed seismic source (plate and hammer) operated along the array to induce higher frequency, rapidly attenuating energy.

On land, surface wave analysis is performed using Rayleigh waves because they can be detected on an air-ground interface (earth surface) using geophones. The low frequency geophones measure the vertical component of the surface wave (Rayleigh) and the results are considered a reasonable estimate of the vertical distance (depth) to layers distinguished by velocity contrast below the receivers.

How it works: The LM analysis develops the shear-wave velocity/depth profile using an engineering seismograph, low frequency receivers (geophones or hydrophones) and straight-line array aperture (Louie, 2001). Ambient surface wave energy is recorded using relatively long sample window (30 seconds) recording the ambient wavefield. At this site, quality low frequency signals were consistently recorded.

The microtremor records are transformed as a simple, two-dimensional slowness-frequency (p-f) plot where the ray parameter "p" is the horizontal component of slowness (inverse velocity) along the array and "f" is the corresponding frequency (inverse of period). The p-f analysis produces a record of the total spectral power in all records from the site, which plots within the chosen p-f axes. The trend within these axes, where a coherent phase has significant power is "picked." Then the slowness-frequency picks are transformed to a typical period-velocity diagram for dispersion. Picking the points to be entered into the dispersion curve is done manually along the low velocity envelope appearing in the p-f image.

The terrestrial records were completed using arrays composed of 48 and 96, 4.5 Hz. geophones. Receiver spacing was set at 10 feet. Extended line length was accomplished by overlapping the receivers on Line H and data are interpolated between the receiver gap on Line G.

3.2. Horizontal and Vertical Control

Coordinates describing the general HDD route were provided by OSU and these data were interpreted and utilized by SA to establish the exploration extents. The beginning and end-points of the geophysical lines were initially established using hand-held GPS (Garmin 755t). As geophysical operations progressed, SA set temporary lath and hubs marking select positions along each geophysical line. The SA crew measured the elevations along the lines with reference to these temporary benchmarks using a theodolite (Nikon NT-1) and grade rod.

Following the collection of the geophysical data, surveyor John Thompson, PLS, of John Thompson & Associates, Inc., visited the site to determine precise location and elevation of the temporary benchmarks set by SA using RTK methods. The elevation profiles were then converted to match Oregon State Plane Datum (International Foot) and this is the basis for elevations presented on the geophysical results.

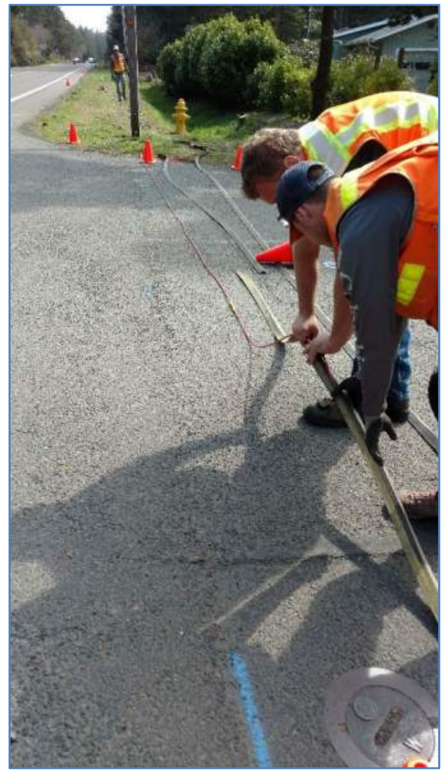
3.3. Ancillary Operations

3.3.1. Brush clearing for access:

Lines G and I included clearing of light to heavy undergrowth along the survey routes. These operations were conducted several days prior to geophysical data acquisition. The effort was completed by the SA crew equipped with both hand and power tools including a Sthil 560 brush cutter designed specifically for the task.

3.3.2. Traffic Control:

Operations for Line H along Highway 101 were complicated by traffic both along the highway and intersecting roads. Safe operating conditions were maintained by positioning the survey line as far west as practical, setting a row of traffic cones along the working area and posting signs to alert drivers approaching the survey. A rubber road mat was used at intersections to allow traffic to cross the geophysical cables without interrupting operations. An SA crew member was posted at each of these intersections to slow and direct vehicles as they approached the crossing. The precautions were successful and no adverse traffic incidents were experienced.



3.4. Summary of Challenges

3.4.1. Operations

Few difficulties were experienced. The heavy brush presented a challenging clearing task and negotiations through the wetland were difficult due to soft ground and surprisingly deep streams. Soft ground conditions also presented challenges for effective geophone plants which the SA crew enhanced by digging to solid earth and at many locations, extensions were added to the geophone spikes to improve coupling.

Traffic noise slowed the P-wave acquisition along Highway 101 as it was necessary to wait for gaps in the traffic to detonate the source. Shot stacking was done to compensate for noisy conditions when necessary.

The HDD path is below private property as it approaches Highway 101 from the north and again as the path approaches the UCMF on the east side of Highway 101. Surface geophysical survey through these areas would have required trespass, substantial brush clearing, and associated landowner permission. The SA team and client agreed that attempting to acquire this permission was not in the project's best interest. Rather, exploration was conducted along the Highway 101 right of way which crosses and is near the HDD path through these zones.

Further, operations were not conducted on the east side of Highway 101 as originally planned. SA made a field decision to limit operations to the wider right of way along the west side of Highway 101 as a safety precaution since only a narrow strip was available on the east and traffic control with flaggers was beyond the scope.

3.4.2. Data Quality and Interpretation Challenges

The recorded data are judged to be of excellent quality. Few cultural features appear to be available to influence the ER signal. P-wave first arrivals were almost always very clear and easy to pick and a strong wide range in frequency of ambient vibrations were available to enhance the linear microtremor (LM) records.

Due to these favorable factors, it is the opinion of SA that the results provide an effective look at subsurface conditions through the HDD path. Although the different geophysical methods respond in their own way to the conditions encountered, similarity exists and this leads to greater confidence in the findings than would be had by only one method.

4. Processing and Interpretation

4.1. General

During the data gather, partial interpretation was completed in the field for quality control purposes and to assist in setting and confirming proper data acquisition parameters. The instruments were continuously monitored through the data acquisition phase.

The interpretation for each line is presented in this section and the locations of the lines are shown graphically on Figure 103. Results for each method along each line are presented in appendices to this report. ER, SR, and LM tomograms are presented on the same page using the same horizontal and vertical scales and horizontal zero coordinate to assist in correlation.

In the opinion of SA, the 2D S-wave (LM) tomograms and ER results are the most robust and plausible description of the conditions encountered. As discussed later, ER results are presented with several resistivity scales to illustrate subtle variations through the low resistivity bedrock layer.

It is worthy to emphasize that the geophysical results are presented in 2D yet the data collection is influenced by a 3D environment. Unless the geology is simple, like a flat stack of pancakes, the various geophysical methods cannot be expected to match perfectly. In addition, geophysical interpretations are often compared to direct observation of conditions discovered in geotechnical drill holes. Note that the drill hole is a 1D description of the subsurface and represents a very small sampling, unlike the geophysical approach. Correlation and conflict are expected, and both must be considered in context with the factors that influence data quality, complication of the subsurface, and the geophysical parameters measured.

A description of the data processing, interpretation methods and results are presented in the following sections.

4.2. Electrical Resistivity (ER)

Important factors which affect the resistivity of different geological material are:

- Porosity
- Moisture content
- Dissolved electrolytes (including saltwater intrusion)
- Temperature (resistivity decreases with increasing temperature)

Each dataset was filtered to remove spikes, noisy, and misfit data through a systematic progression to produce plausible inversion models without excessive iteration. The level of filtering was modest, and most data points were used in the final inversion.

4.2.1. ER Processing and Presentation

The data sets were processed using AGI Earth Imager Software and Res2D INV by Geotomo Software, Malaysia. After many iterations and trials with various algorithms and review of the results, SA selected the images developed with the AGI software as the most plausible description of the conditions encountered.

4.2.2. Considerations in ER Interpretation

<u>Lines G through I</u>

The results present similar findings along each line that correlate reasonably well with stratification developed using the other methods. Line G intersects a layer of beach sand with relatively high resistivity not encountered on the other lines. To maintain easy comparison of findings, SA presents each ER line on a scale that includes the high resistivity associated with the beach sand as a common scale. Alternate scales are also presented to better illustrate the electrical contrasts encountered on Lines H and I. Of interest, is the scale compressed to 20 Ohm-m that highlights the subtle, low resistivity contrasts associated with the sedimentary bedrock anticipated to dominate the HDD path. These subtle contrasts are interpreted to be indicative of either heterogeneity within the bedrock that are not well defined by the other methods or variations in pore-water characteristics which could be altered by saltwater intrusion.

<u>Unconsolidated Sediments</u>

As discussed, the highest apparent resistivity (up to about 5000 Ohm-m) is associated with unsaturated, poorly-graded beach and dune sand. This high resistivity layer is defined only through the beginning of Line G leading south from Driftwood toward the wetland. The unconsolidated layer is present along the remainder of the alignment within a range of about 100 to 500 Ohm-m.

<u>Terrace Deposits</u>

Below the unconsolidated layer, the apparent resistivity illustrates a slight decrease to define the boundaries of the terrace deposit. Rough interpretation suggests the terrace to be defined within apparent resistivity ranging from about 100 down to about 30 Ohm-m. The distinction between the terrace deposit and underlying rock, in terms of apparent resistivity, varies and this is likely due to the variability in texture and lithification of the terrace deposit at this transition (see geologic description of Section 2.2).

Sedimentary Rocks (undifferentiated)

The sedimentary bedrock is defined by ER as a low resistivity layer with subtle electrical contrast within the unit. Geologic research indicates the rock type to be mudstone, siltstone, and possibly sandstone. The sedimentary bedrock apparent resistivity is relatively low owing to its fine-grained texture combined with the likely saturated condition. The apparent resistivity tomograms are presented in several ways to visualize the electrical contrast within each. This subtle electrical contrast could be indicative of several features including heterogeneity and possible saltwater intrusion that could be quite variable. These are uncertainties inherent to the ER method and confirmation must be provided by other geophysical methods and/or direct exploration.

4.3. P-wave Seismic Refraction (SR)

Lines G through I

Refraction data were recorded along each line and the data were excellent. Challenging factors associated with data processing include a layered soil overburden that includes saturated soil.

The shallow water table below the wetland on Line G promotes P-wave velocity related to the saturated condition (essentially the speed of a compression wave traveling through water) and can be many times faster than the velocity of the same wave through the same soil if it were not saturated. Hence, the P-wave is a poor measure of soil strength when soils are saturated. SA suspects that organics within the shallow soil horizon throughout the wetlands and possibly beyond promote some gas within the soil column such that the soil layer is not 100% saturated in all areas. In the opinion of SA, this is the reason that low velocity (less than about 5000 f/s) occurs within the wetland even though the water table is at or near the surface.

In some areas, the unconsolidated zone appears to be layered or otherwise complicated such that stronger, faster layers are bedded at depths above weaker, slower layers. This causes problems with the refraction method since the fastest raypaths return to the receivers from shallow depth and deeper geology is not sampled by the first arrival waves. The P-wave raypath tends to propagate along the shallow boundary of the higher velocity layer. SA suggests that in some cases apparent irregularities in the velocity distribution are caused by these effects and layer interface boundaries are probably complicated. In general, the transition from unconsolidated materials to sound rock is represented by a P-wave velocity on the order of 6000 to 7000 f/s. Weaker rock layers could be similar to saturated soil velocity (about 5000 f/s) and are not distinguished by the refraction method.

4.3.1. SR Processing and Presentation

Data processing was completed using Geogiga DW Tomo 8.3 software developed by Geogiga Technology Corp. Calgary, Alberta, Canada. The software utilizes a robust grid ray tracing and regularized inversion with constraints in topography and elevation along the seismic array as input for calculations. The software is suitable for strong elevation and lateral velocity variation. Data sets included a moderately dense shot pattern (shots centered at 3X the receiver spacing) and this lead to the generation of robust P-wave velocity models based on many first arrivals. Dr. Satish Pullammanappallil, Ph.D. of SubTerraSeis, LLC lead the data processing effort. To develop input geometry, SA measured the vertical locations along the line using a theodolite. Horizontal location was measured along the ground with reference to receivers and shot points using the seismic take-out cable.

4.3.2. Considerations in SR Interpretation

Unconsolidated Sediments

As discussed, the shallow water table and variations within plays an important role in the behavior of velocities related to P-wave refraction. The character of the unconsolidated layer is difficult to constrain due the effect of saturation as saturated weak soils could offer P-waver velocity similar unsaturated strong soils.

Terrace Deposits

Similar to the unconsolidated layer, the velocity of saturated, weaker zones within the terrace deposit could be similar to unconsolidated sediments. Also, variations within this unit include partially lithified regions that could offer P-wave velocity similar to the underlying bedrock. These factors combine to add uncertainty in delineating the boundaries of the terrace deposit.

Sedimentary Rocks (undifferentiated)

The depth to the higher velocity, lower elevation sedimentary layer is reasonably well defined and correlates well with other geophysical methods. The upper rock layer is less defined and includes velocity reversals on Lines G and H. Shallow, high P-wave velocity anomaly are also calculated in unexpected areas and these anomalies are not defined by the other geophysical methods which raises some suspicion regarding validity. SA has no plausible explanation regarding the shallow, high P-wave anomalies although the data clearly support the results of the calculation.

The P-wave tomograms define flat lying, linear features through the sedimentary bedrock (best defined on Lines G and H) and this characteristic is likely due to alternating strength of thinly bedded layers; a structure common to sedimentary rocks.

4.4. S-wave Linear Microtremor (LM)

LM data were procured along the same routes as ER and SR and the models are of value as the shear wave velocity is directly related to the strength of a geologic material and is not influenced by saturation as water has no shear strength. The models were produced by Dr. Satish Pullammanappallil, Ph.D. of SubTerraSeis, LLC, using Geogiga SubsurfacePlus 8.3 software. The 2D models illustrate the trend in the subsurface in terms of shear-wave velocity that correspond closely with trends in both ER and SR and since each method responds to the geology differently, the fit is not perfect.

Shear-wave velocity, V_s is used to determine the shear modulus, G, of soil or rock:

$G = \rho\,(V_s^2)$: a valuable measure of soil stiffness and rock strength

Where ρ = mass density (i.e. total unit weight / gravitational acceleration constant, 32.2 ft/s^2)

The LM derived V_s is interpreted from small strain measurements produced by non-destructive surface waves (Rayleigh waves) with strain on the order of 10^{-4} %. Shear modulus (G) derived from shear-wave velocity measured insitu using surface wave methods is commonly referred to as the small-strain shear modulus G_{max}.

4.4.1. LM Processing and Presentation

Dr. Pullammanappallil, Ph.D. created the 2D profiles using a series of 1D shear-wave depth profiles along each line typically using 12 to 24 channels per analysis progressing through the data with single channel increments (channels 1 to 12, 2 to 13, 3 to 14, and so on). As many as 36 channels were used to constrain the deepest parts of the models. The data were strong due to vibrations related to nearby traffic, ocean waves, and other unidentified sources.

The LM tomograms are presented on the same scale and same page as ER and SR for correlation.

4.4.2. Considerations in LM Interpretation

<u>Lines G though I</u>

The results present similar findings along each line that roughly correlate with stratification developed from the ER and SR methods. The tomograms illustrate progressively increasing velocity with depth, no significant velocity reversals, and suggest both abrupt and gradual/irregular transitions to the various layers. The LM method is judged to be the most effective at defining top of rock and clearly illustrates distinct layers defined by S-wave velocity contrast.

Unconsolidated Sediments

Through the upper layers, only a few zones offer S-wave velocity less than 600 f/s representing weak soils and these include a thin layer through the wetland along Line G. The lower reaches of the unconsolidated zone are judged to be associated with S-wave on the order of 800 to 1000 f/s and given this definition, the thickness of the unconsolidated soils range from about 5 to 45 feet.

Terrace Deposits

This intermediate layer is interpreted to be represented by S-wave velocity in the range of about 600 to 1200 f/s, possibly a bit higher in areas. As discussed, the terrace deposit is anticipated to include a variety of material types including variable degree of consolidation and lithification. As a result, S-wave velocity is not necessarily directly related to any specific material type although geologic materials with S-wave velocity in this range offer moderate to moderately high strength. Due to the heterogeneity inherent to a terrace deposit, these characteristics are likely to change significantly over short distances although the LM interpretation does not illustrate this characteristic as well as the other methods. Terrace deposit thickness through the terrestrial LM survey varies from about 5 to 50 feet.

Sedimentary Rocks (undifferentiated)

S-wave velocity on the order of 1200 f/s and higher is interpreted to represent strong, and sometimes heterogeneous geology typical of the shallow sedimentary units described in the geologic literature available to SA. The highest velocity region (>2500 f/s) is interpreted to represent the most homogeneous of the sedimentary layers. The tomograms illustrate slight variability within the velocity zone 1200 to 2500 f/s (supported by both ER and SR), probably due to surficial erosion, weathering, and other disturbance within the upper sedimentary unit. Depth to the top of the sedimentary layer varies from about 15 to 50 feet with the top of the highest velocity rock ranging from 60 to 150 feet.

Although unlikely, there is a possibility of basalt inclusions within these higher velocity regions. As described earlier, the CRB deposition associated with the nearby Seal Rock area could extend into the HDD corridor and fill ancient depressions or displaced weak materials present at the time of deposition. Fresh, non-weathered, and lightly fractured/jointed basalt typically offers S-wave velocity greater than 2500 f/s and these velocities (and higher) are interpreted at depth. This occurrence would be unconformable and is considered a possibility although remote.

LM is a volume averaging method and hence, it is challenging to resolve small variations within high velocity layers. Also, the resolving power decreases with depth and thus variations (particularly velocity reversal) are less likely to be imaged within the deep, higher velocity layers.

4.4.3. Seismic Site Classification (ASCE 7)

4.4.4. Seismic Site Classification in accordance with ASCE 7 was calculated from data along each of the 2D LM lines. The average shear wave velocities through the upper 100 feet (Vs100) which defines the seismic site classification ranges from 966 f/s (Line H) to 2093 f/s (Line G) defining Site Class D. At UCMF Site Class C dominates with an average of 1588 f/s.

5. Conclusions and Recommendations

5.1. Conclusions

Based on the results of the geophysical exploration, SA concludes that the proposed HDD is feasible and favorable conditions for maintaining a stable boring are available within the sedimentary layers encountered. Table 1 (page 15) identifies various geologic conditions related to HDD planning in context with the prevailing geology. These (and probably others) must be considered in planning and preparing specifications.

Stratification appears reasonably consistent along the HDD path and the 2D results indicate no reason to suspect that the alignment crosses unknown geologic faults or other geologic hazard.

5.2. Recommendations

SA recommends that the geophysical findings be verified by direct exploration using conventional methods (drilling and sampling) at select locations. During our geologic reconnaissance, appropriate locations were identified that consider both the geophysical results and practicality of mobilizing drilling equipment. These locations are identified as follows:

- Driftwood parking lot
- Highway 101 at the approximate 600-foot mark on Line H (adjacent NW Terrace Street)
- Along Line I at the approximate the 100-foot mark at UCMF

Few geotechnical borings are required due to the existence of the long geophysical traverses that effectively cover most of the alignment which is fortunate as most of the alignment offers difficult drill rig access considering both terrain and permitting. The objective of a geotechnical exploration is to confirm stratigraphy and material characteristics and procure sample for testing. Material properties that will be of interest in HDD design and planning include dynamic testing of the unconsolidated layer (N-value), unit weight, rock strength and groundwater table.

6. References

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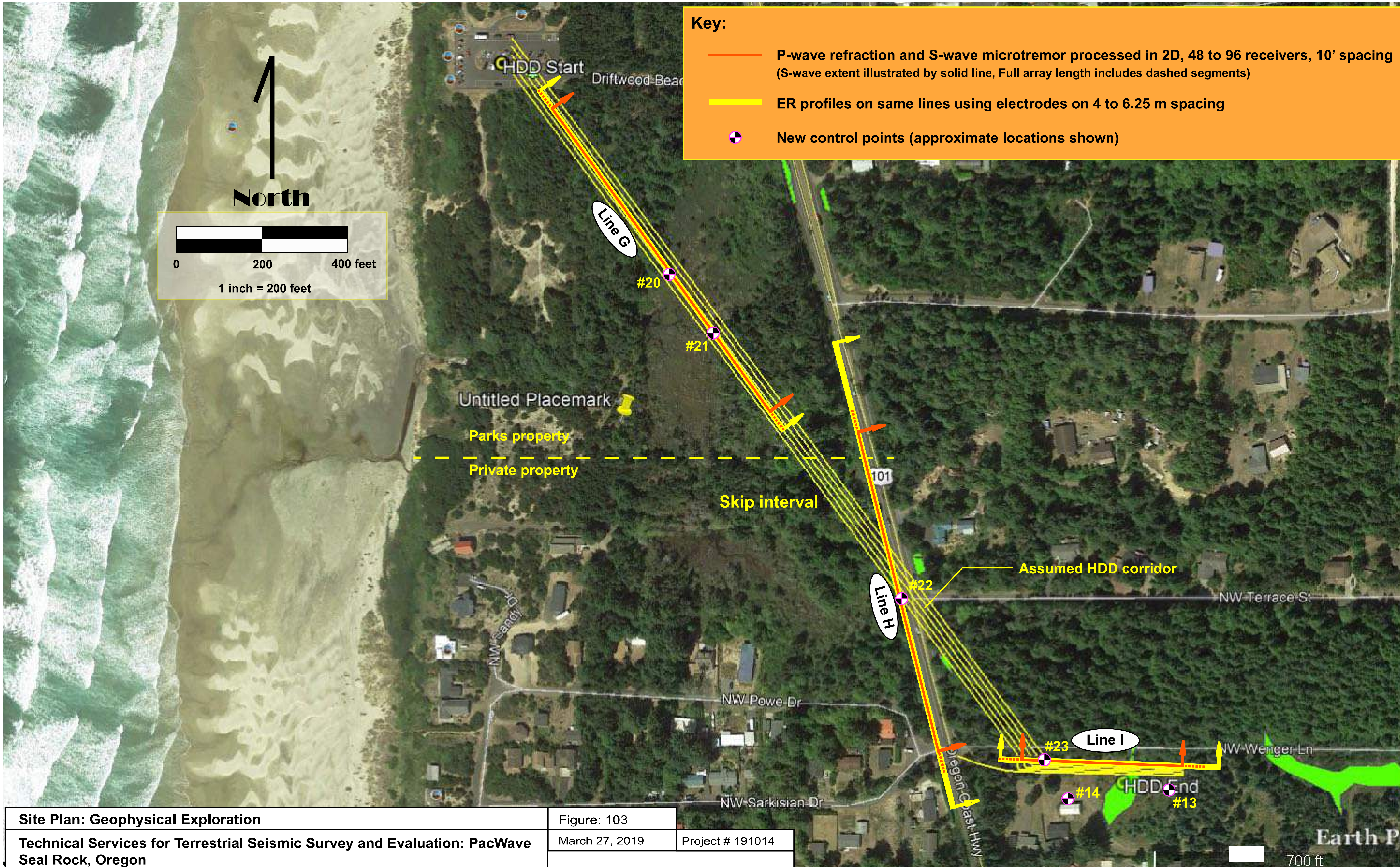
7. Graphical Presentation of Results

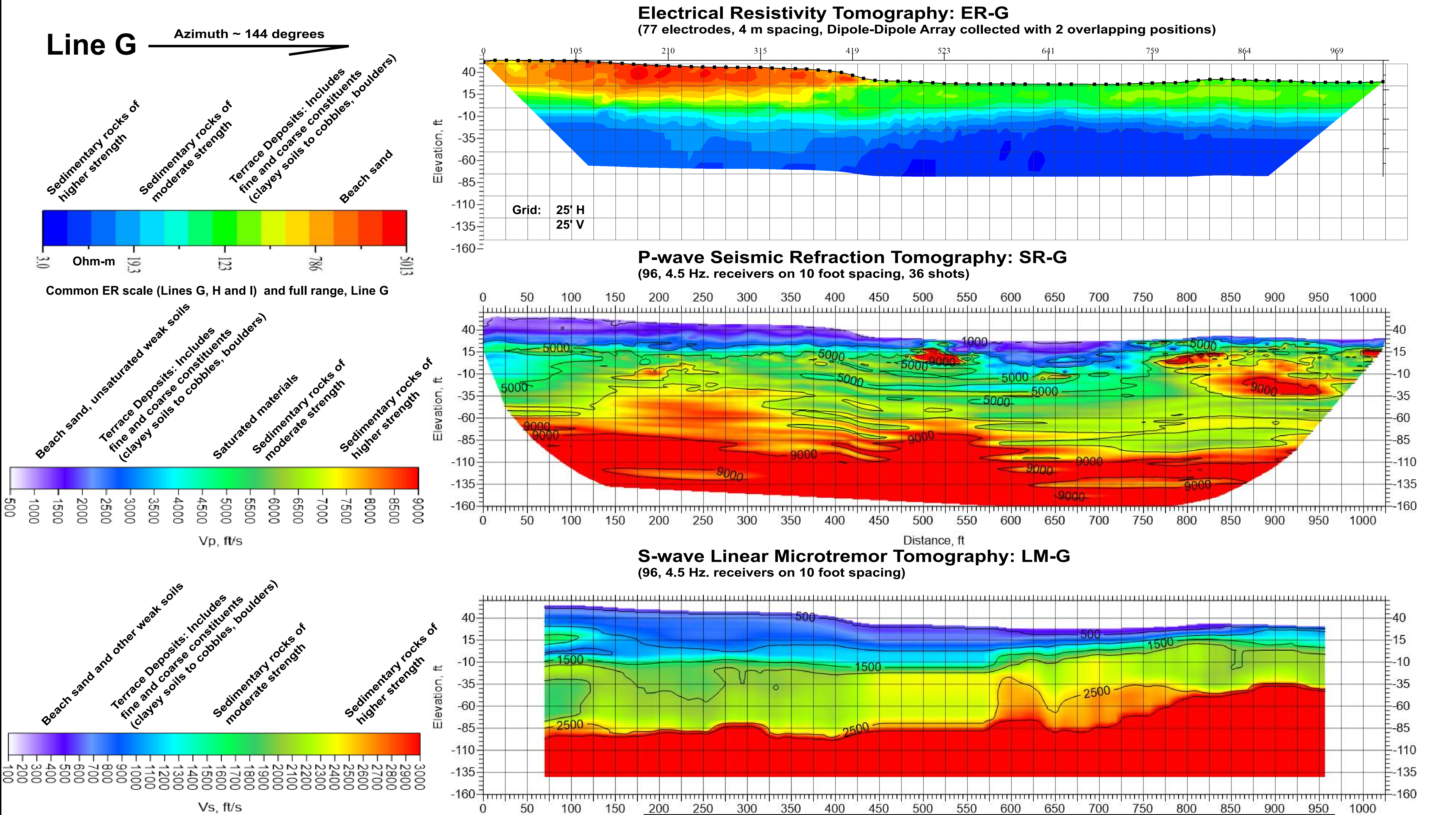
The interpretations are presented in 2D with the locations of the various lines illustrated on Figure 103.

7.1. Figure 103: Site Plan: Terrestrial Geophysical Surveys



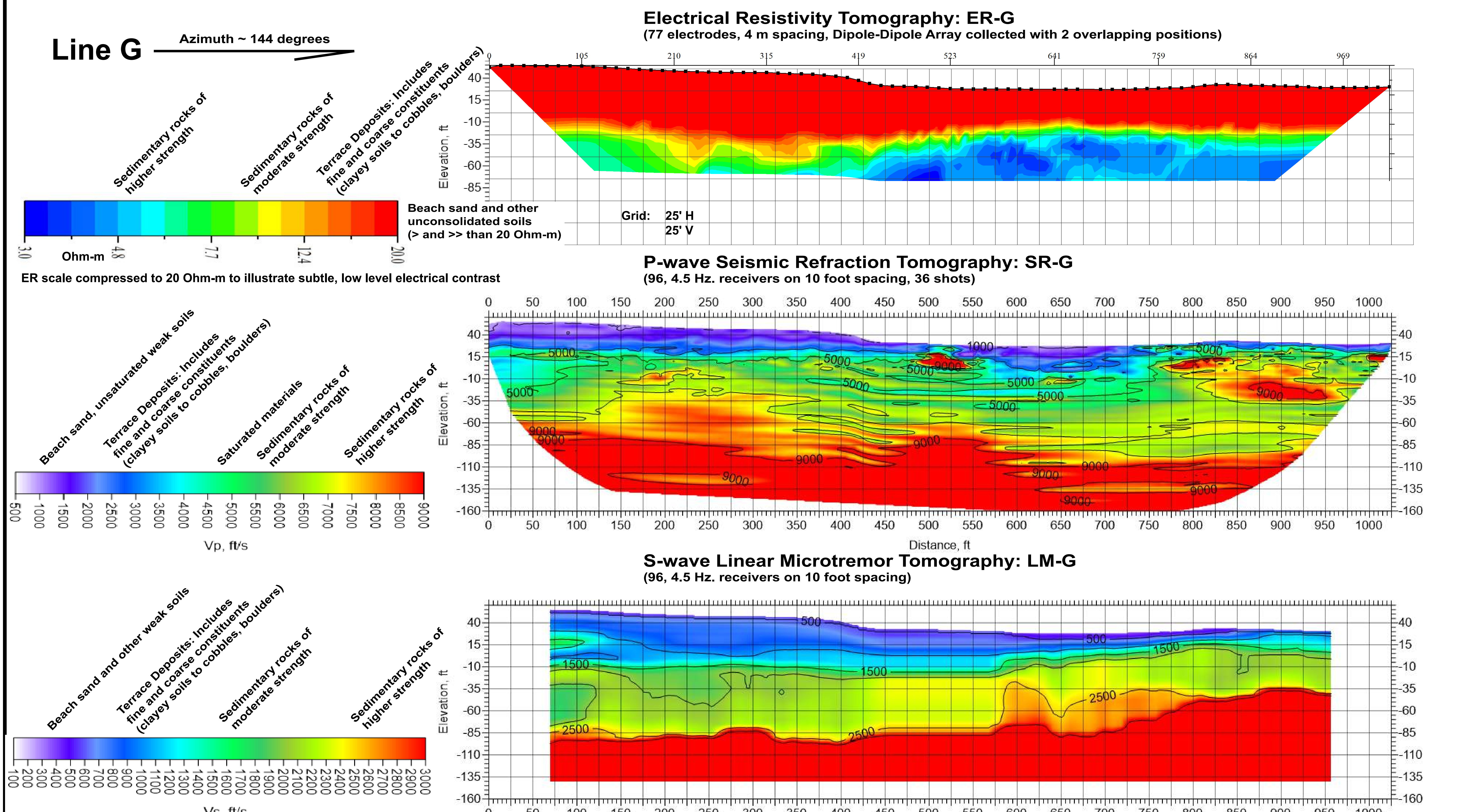
Site Plan: Geophysical Exploration	Figure: 103	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	**Siemens & Associates**	

7.2. Results: Line G



Scale:
H: 1 inch = 100 feet
V: 1 inch = 100 feet

Geophysical Results: Line G	Figure: G-1	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	Siemens & Associates	



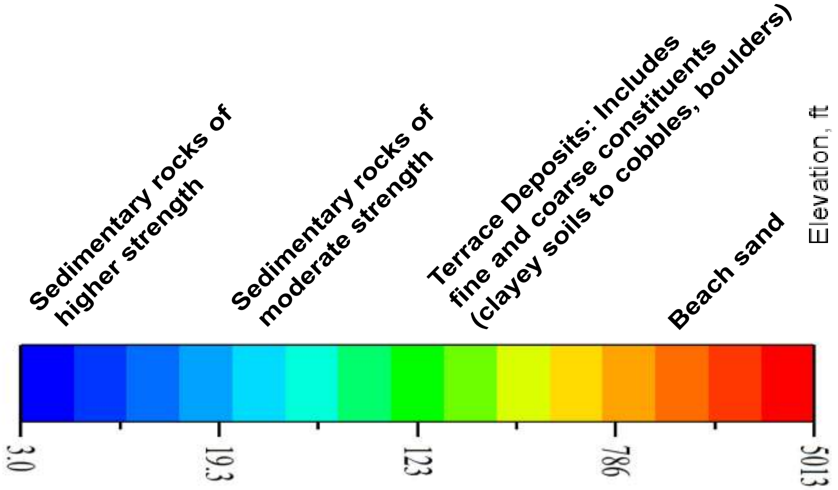
Geophysical Results: Line G	Figure: G-2	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	Siemens & Associates	

Scale:
H: 1 inch = 100 feet
V: 1 inch = 100 feet

7.3. Results: Line H

Line H

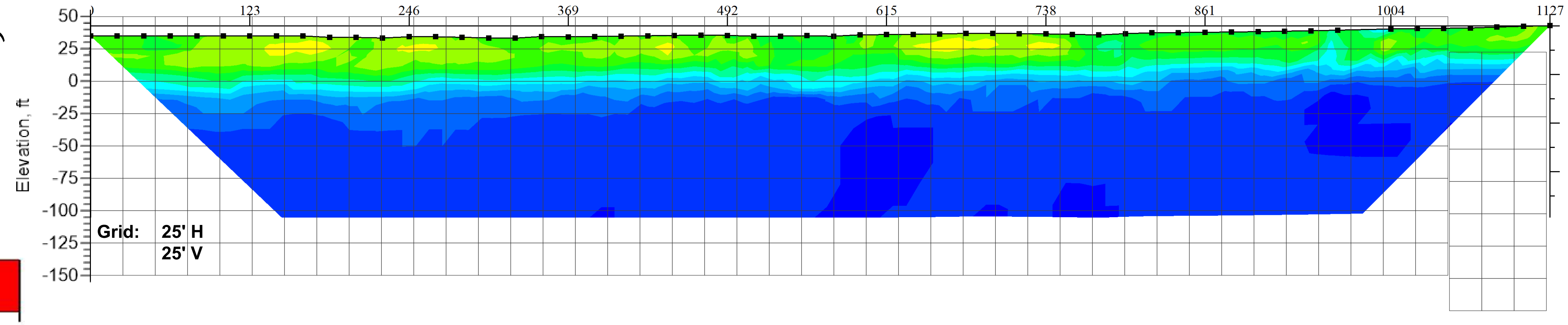
Azimuth ~ 166 degrees

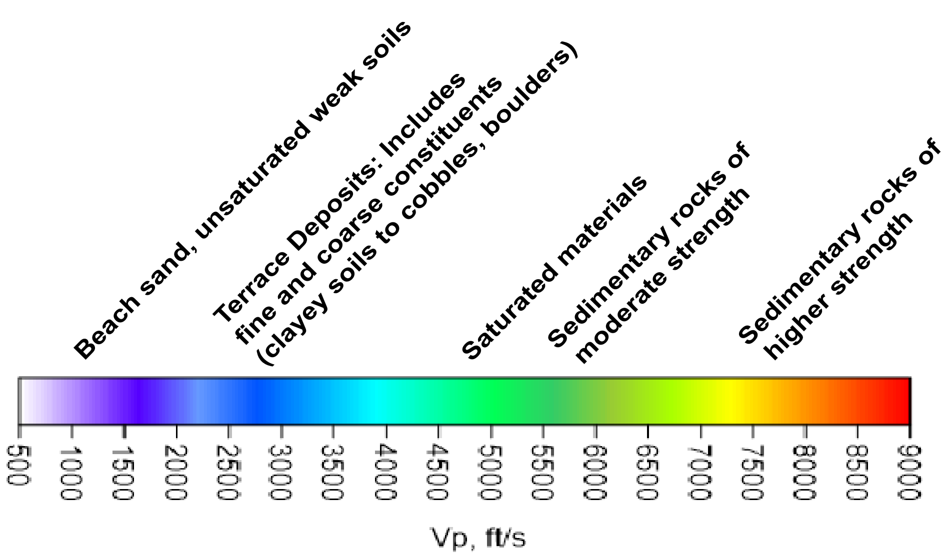


Common ER scale (Lines G, H and I)

Electrical Resistivity Tomography: ER-H

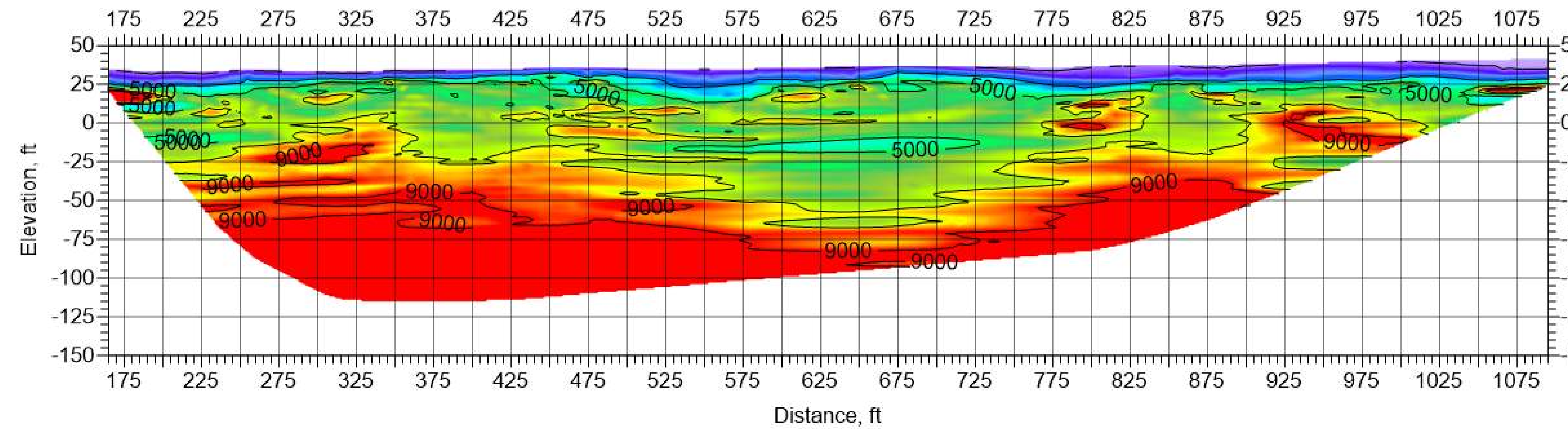
(56 electrodes, 4 m spacing, Dipole-Dipole Array)

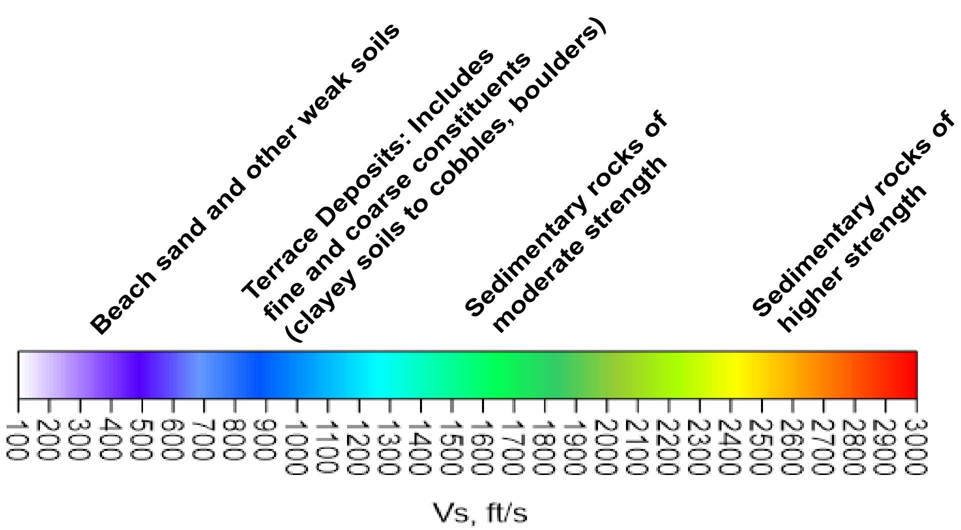




P-wave Seismic Refraction Tomography: SR-H

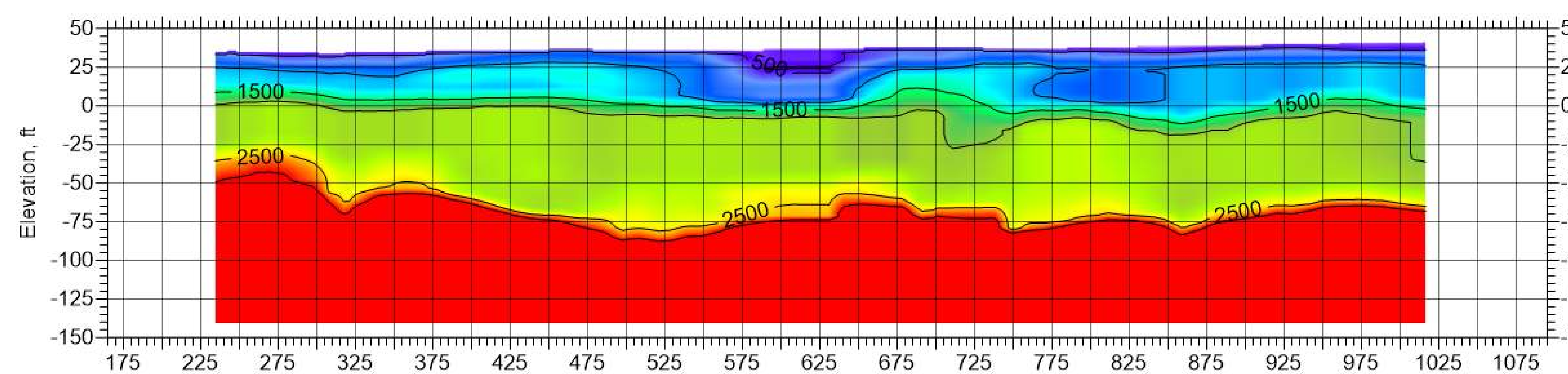
(96, 4.5 Hz. receivers on 10 foot spacing, 36 shots)





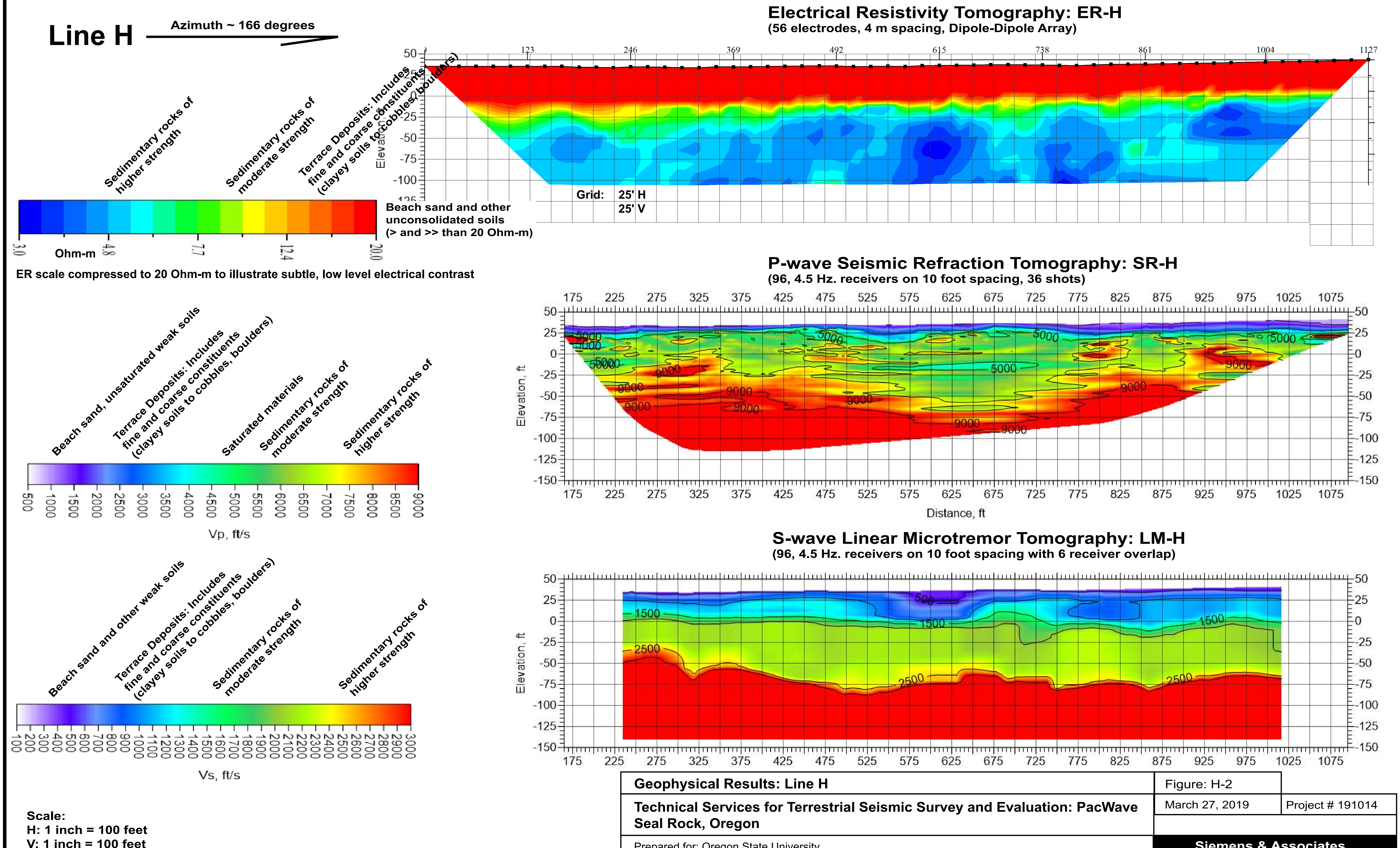
S-wave Linear Microtremor Tomography: LM-H

(96, 4.5 Hz. receivers on 10 foot spacing)

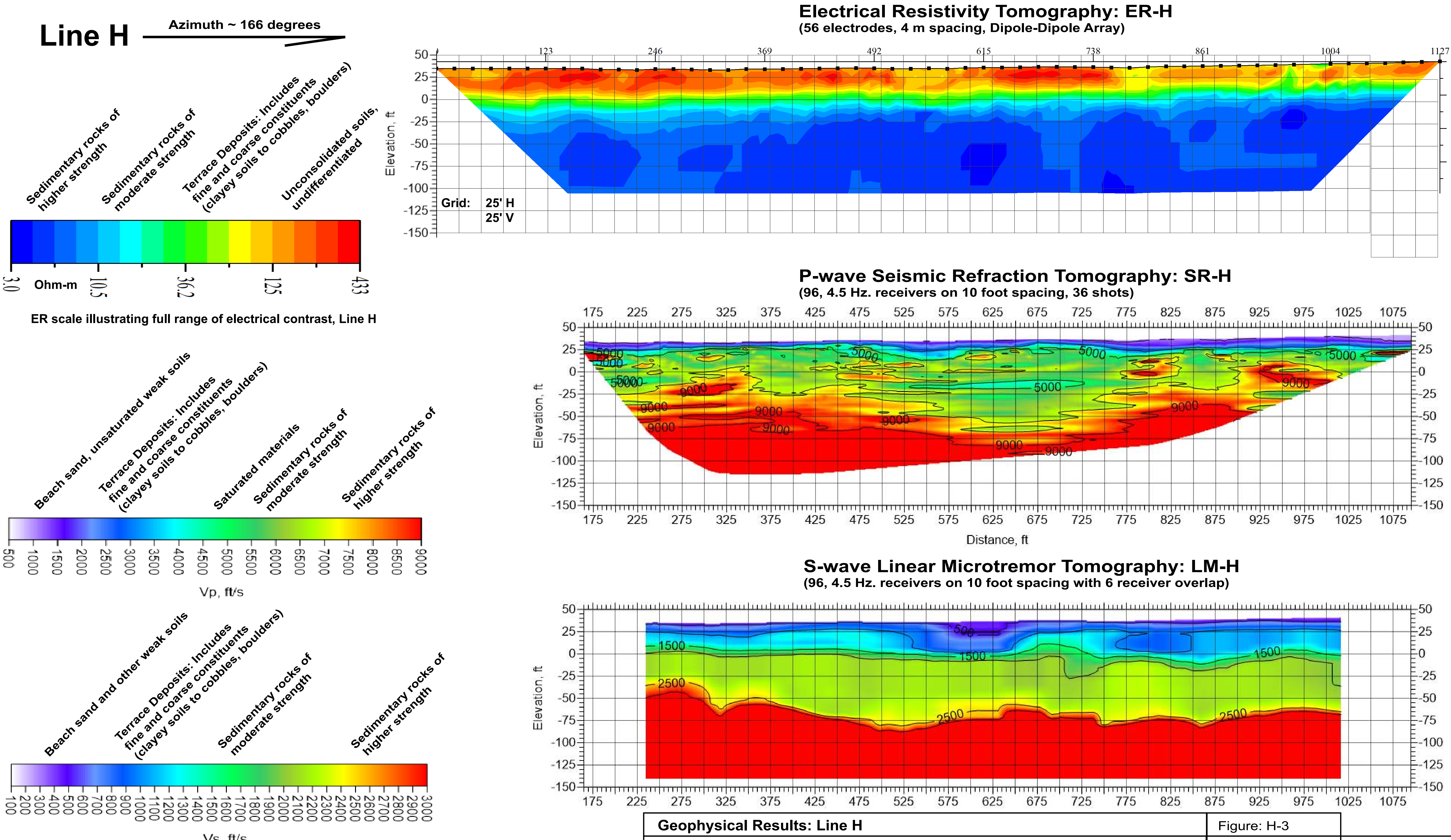


Scale:
H: 1 inch = 100 feet
V: 1 inch = 100 feet

Geophysical Results: Line H	Figure: H-1	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	**Siemens & Associates**	



Geophysical Results: Line H	Figure: H-2	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	**Siemens & Associates**	

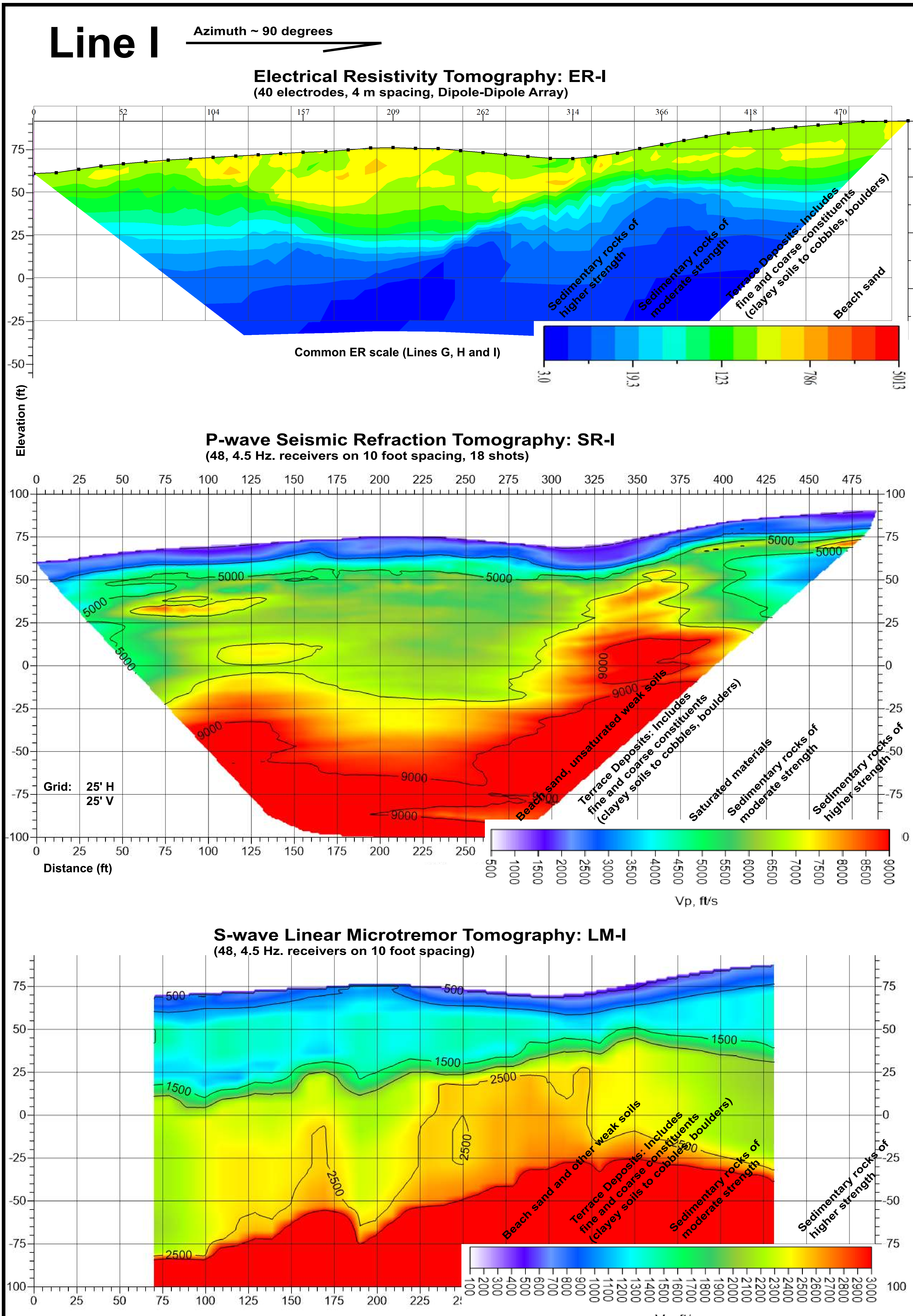


Scale:
H: 1 inch = 100 feet
V: 1 inch = 100 feet

Geophysical Results: Line H	Figure: H-3	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	**Siemens & Associates**	

7.4. Results: Line I

Line I



Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet

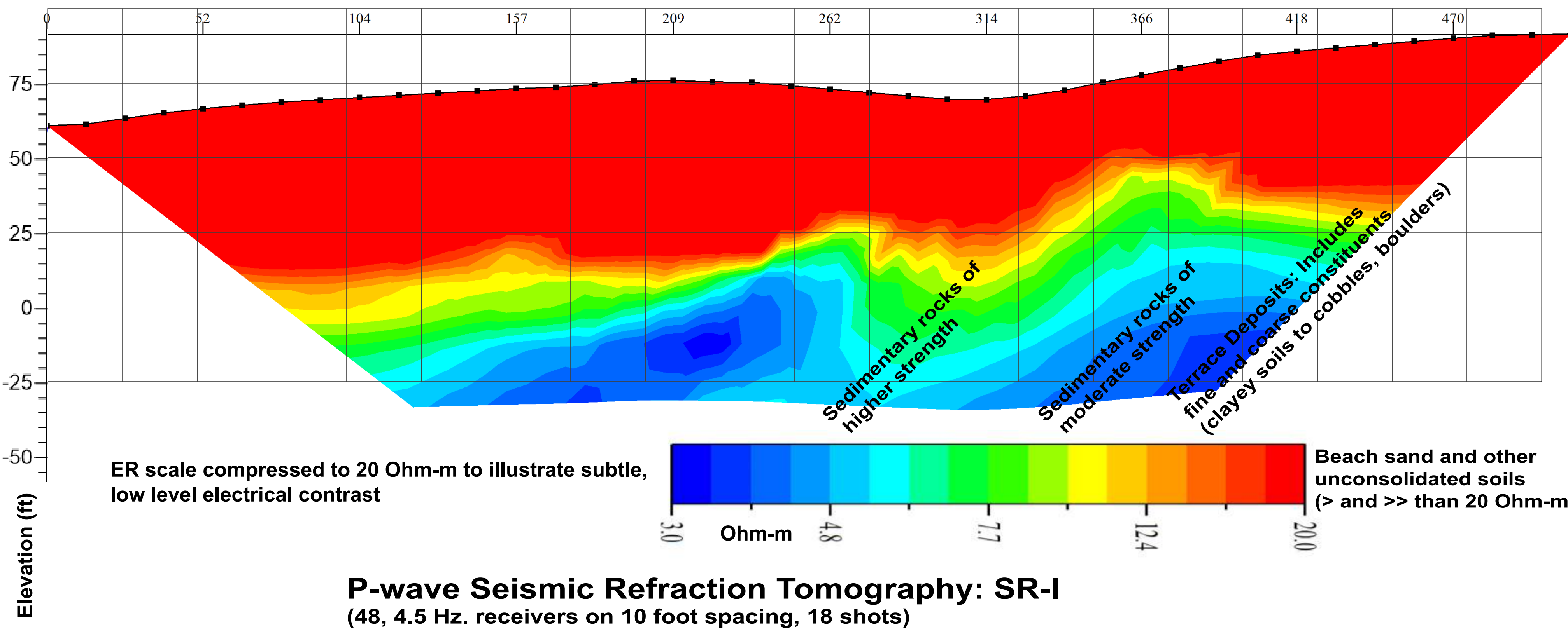
Geophysical Results: Line I	Figure: I-1	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	Siemens & Associates	

Line I

Azimuth ~ 90 degrees

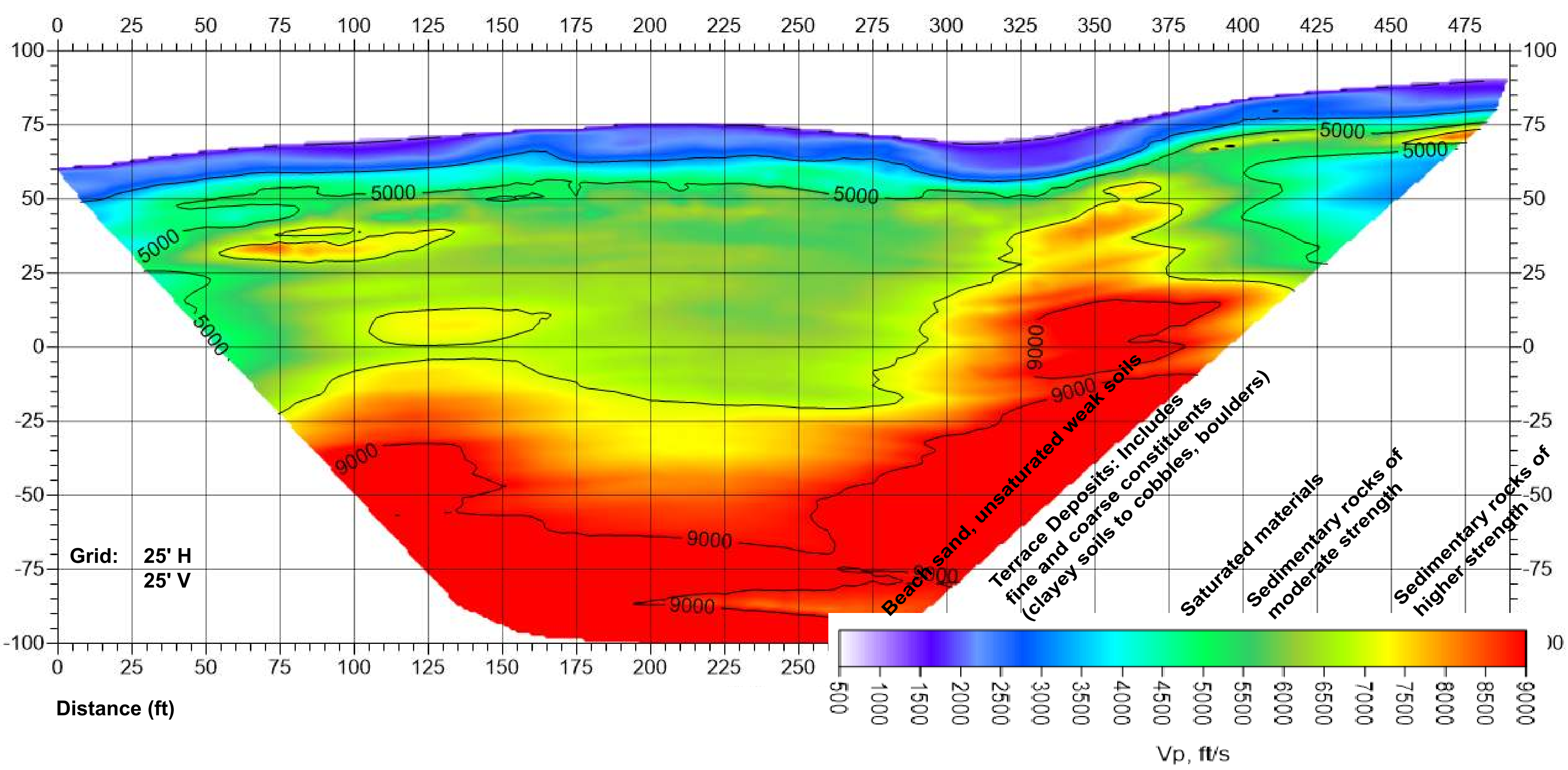
Electrical Resistivity Tomography: ER-I

(40 electrodes, 4 m spacing, Dipole-Dipole Array)



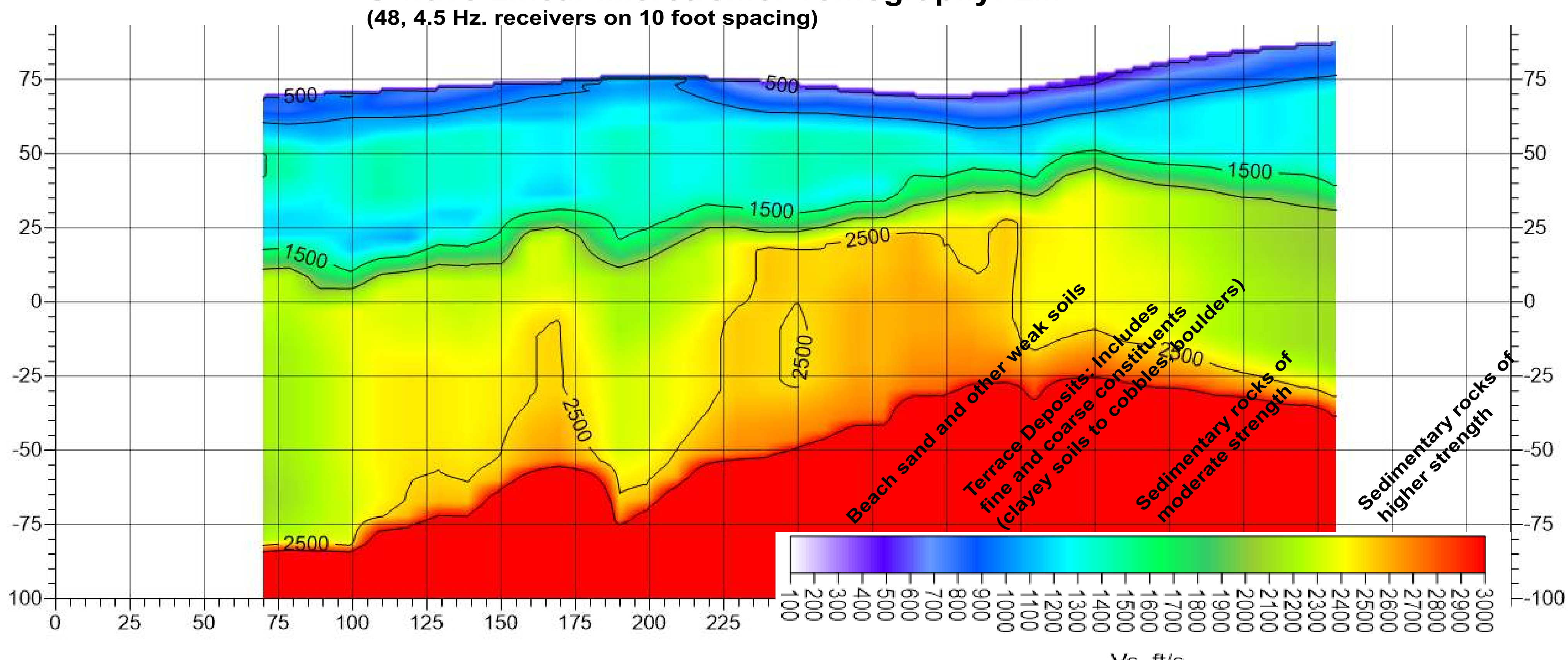
P-wave Seismic Refraction Tomography: SR-I

(48, 4.5 Hz. receivers on 10 foot spacing, 18 shots)



S-wave Linear Microtremor Tomography: LM-I

(48, 4.5 Hz. receivers on 10 foot spacing)



Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet

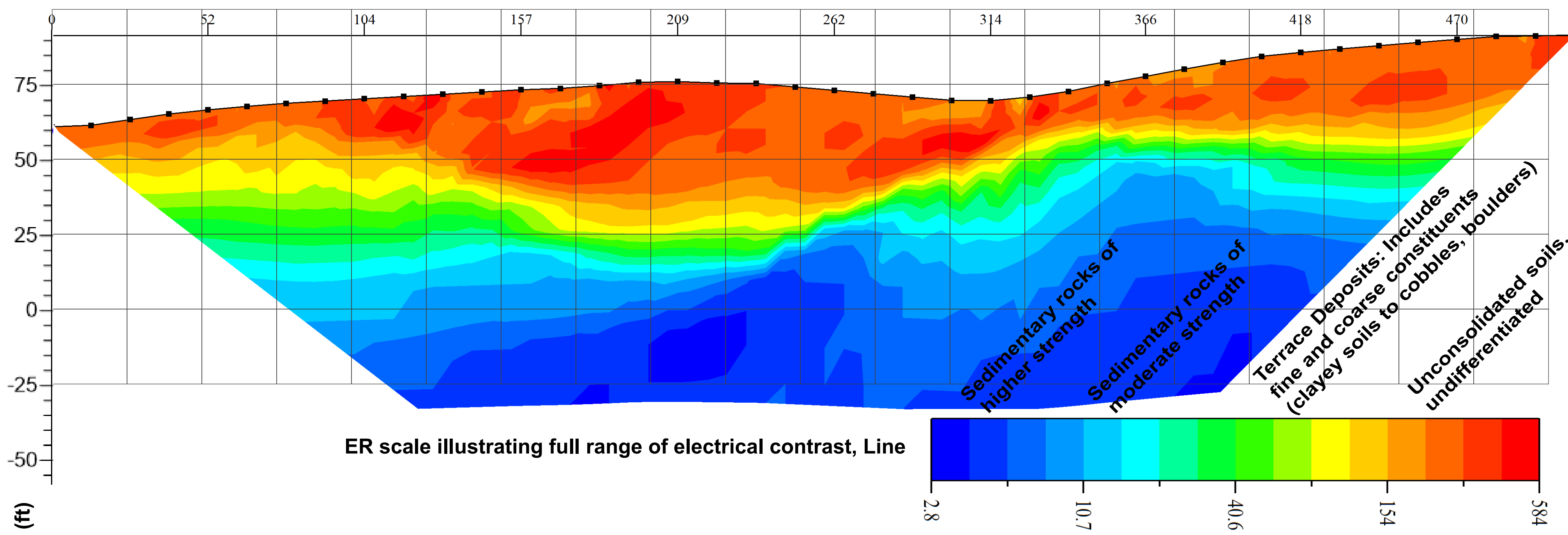
Geophysical Results: Line I	Figure: I-2	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	Siemens & Associates	

Line I

Azimuth ~ 90 degrees

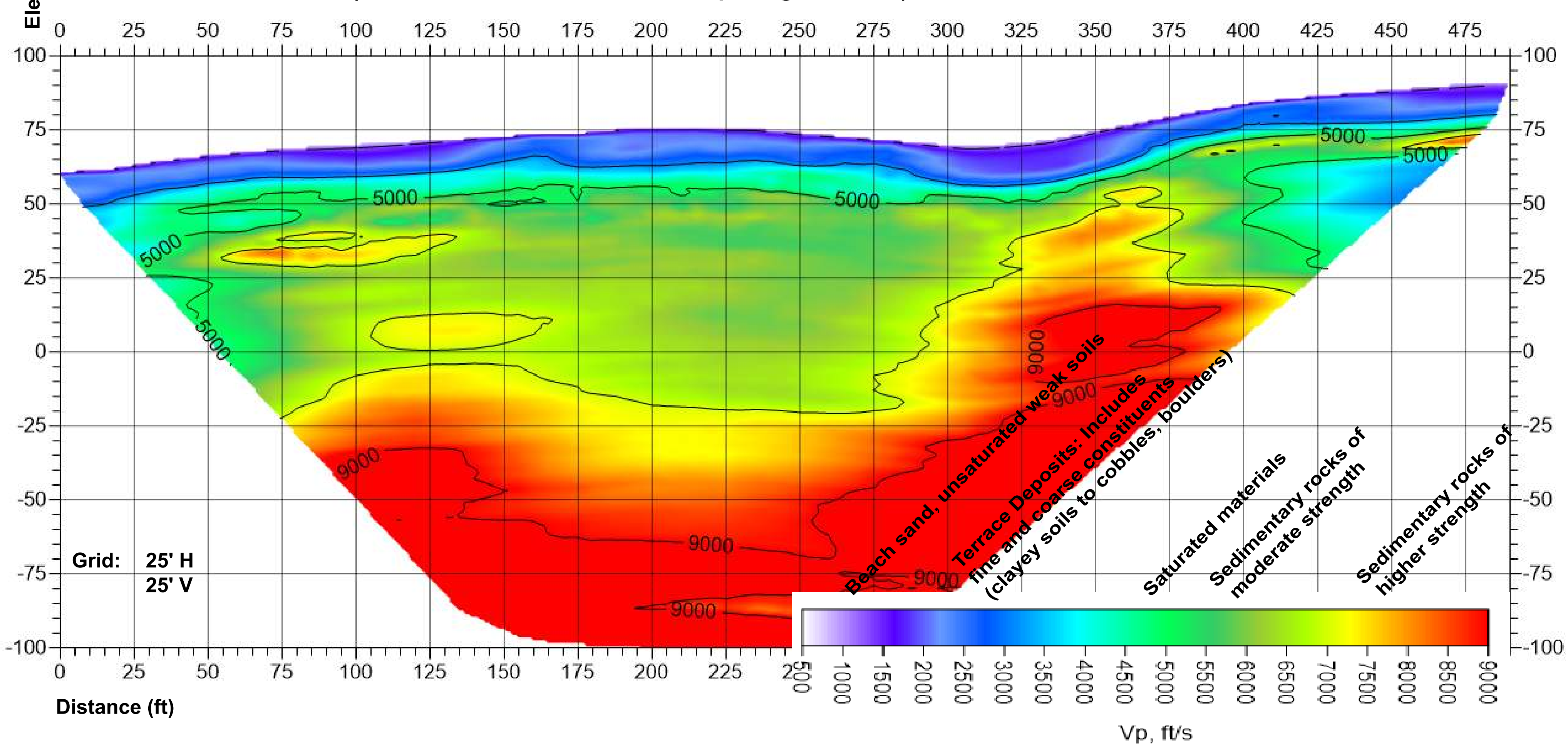
Electrical Resistivity Tomography: ER-I

(40 electrodes, 4 m spacing, Dipole-Dipole Array)



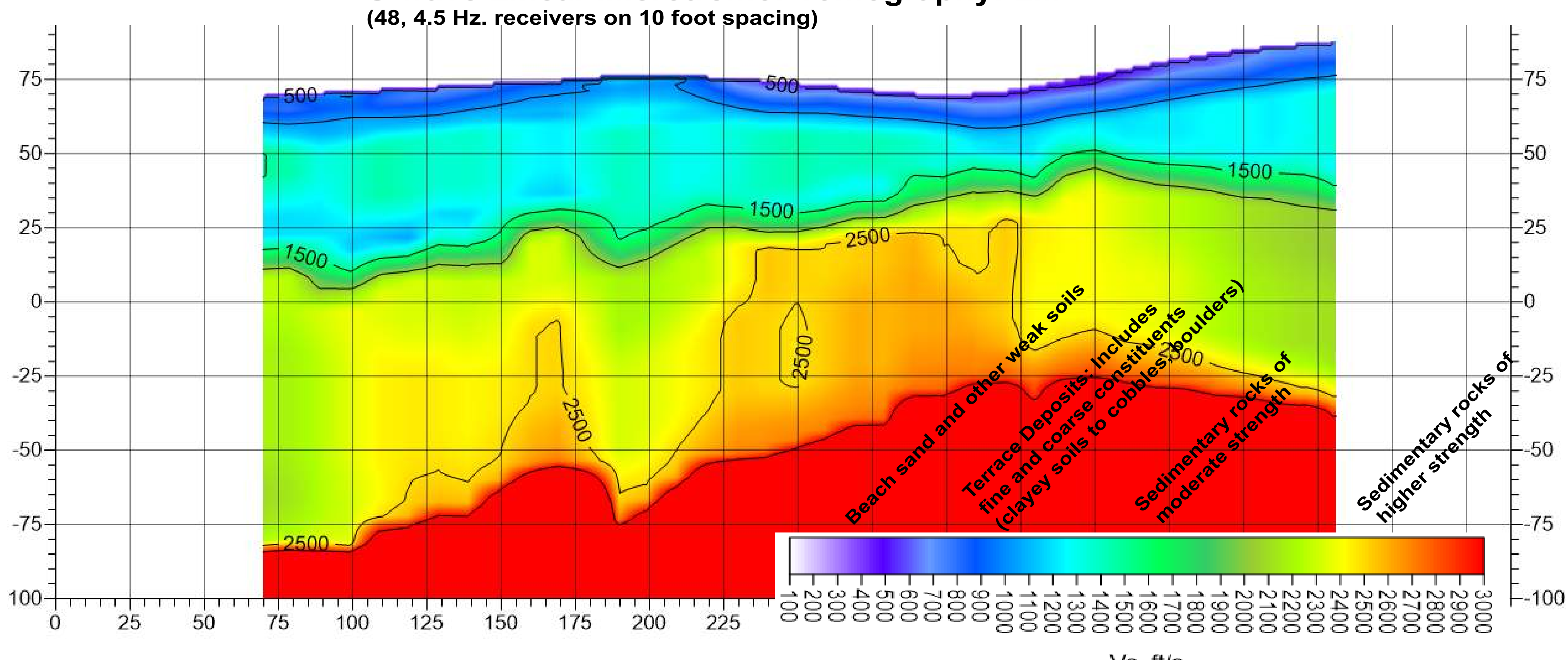
P-wave Seismic Refraction Tomography: SR-I

(48, 4.5 Hz. receivers on 10 foot spacing, 18 shots)



S-wave Linear Microtremor Tomography: LM-I

(48, 4.5 Hz. receivers on 10 foot spacing)



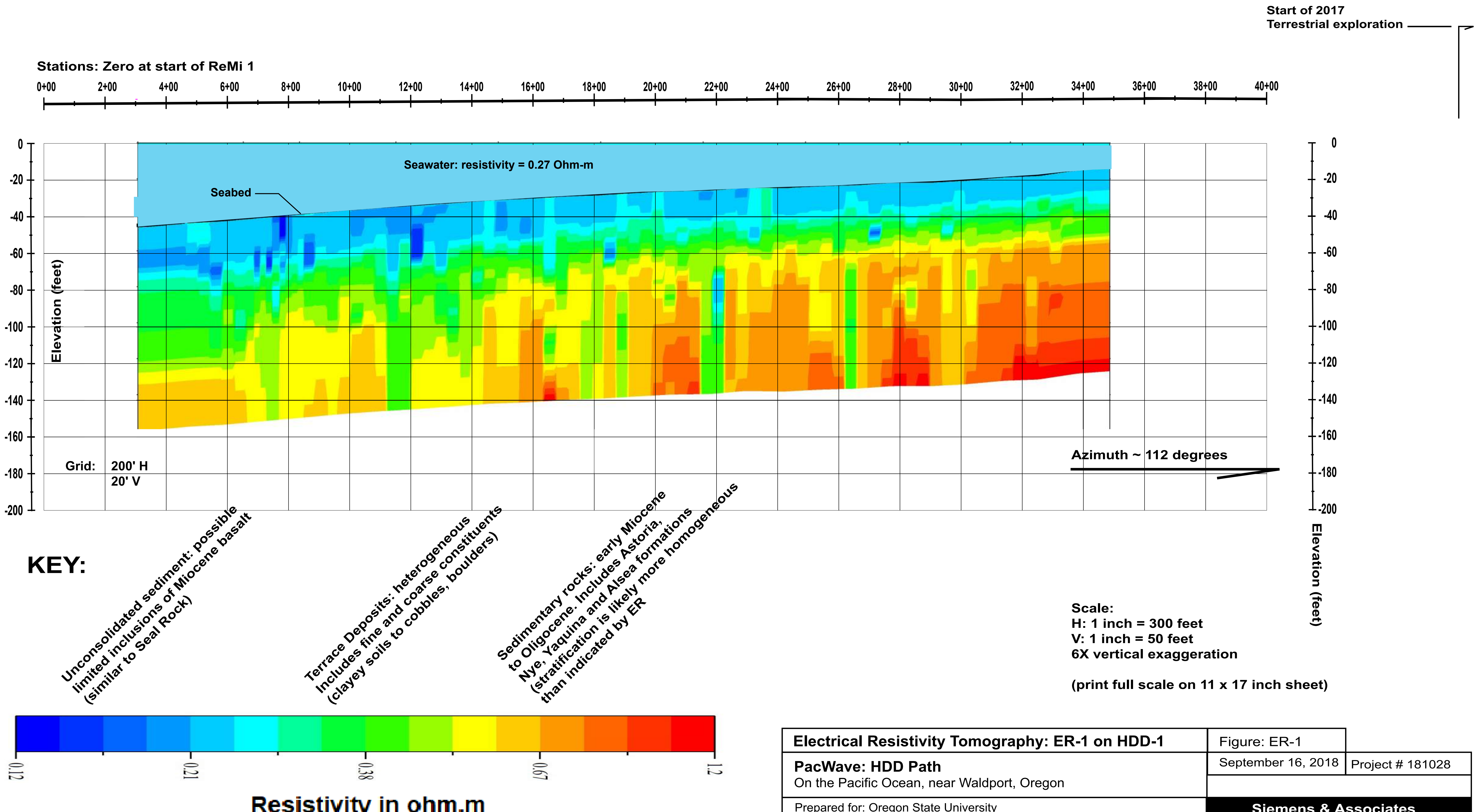
Scale:
H: 1 inch = 50 feet
V: 1 inch = 50 feet

Geophysical Results: Line I	Figure: I-3	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	**Siemens & Associates**	

6.2. Results: ER and ReMi, Line 1 on HDD-1

Electrical Resistivity Tomography: ER-1 on HDD1

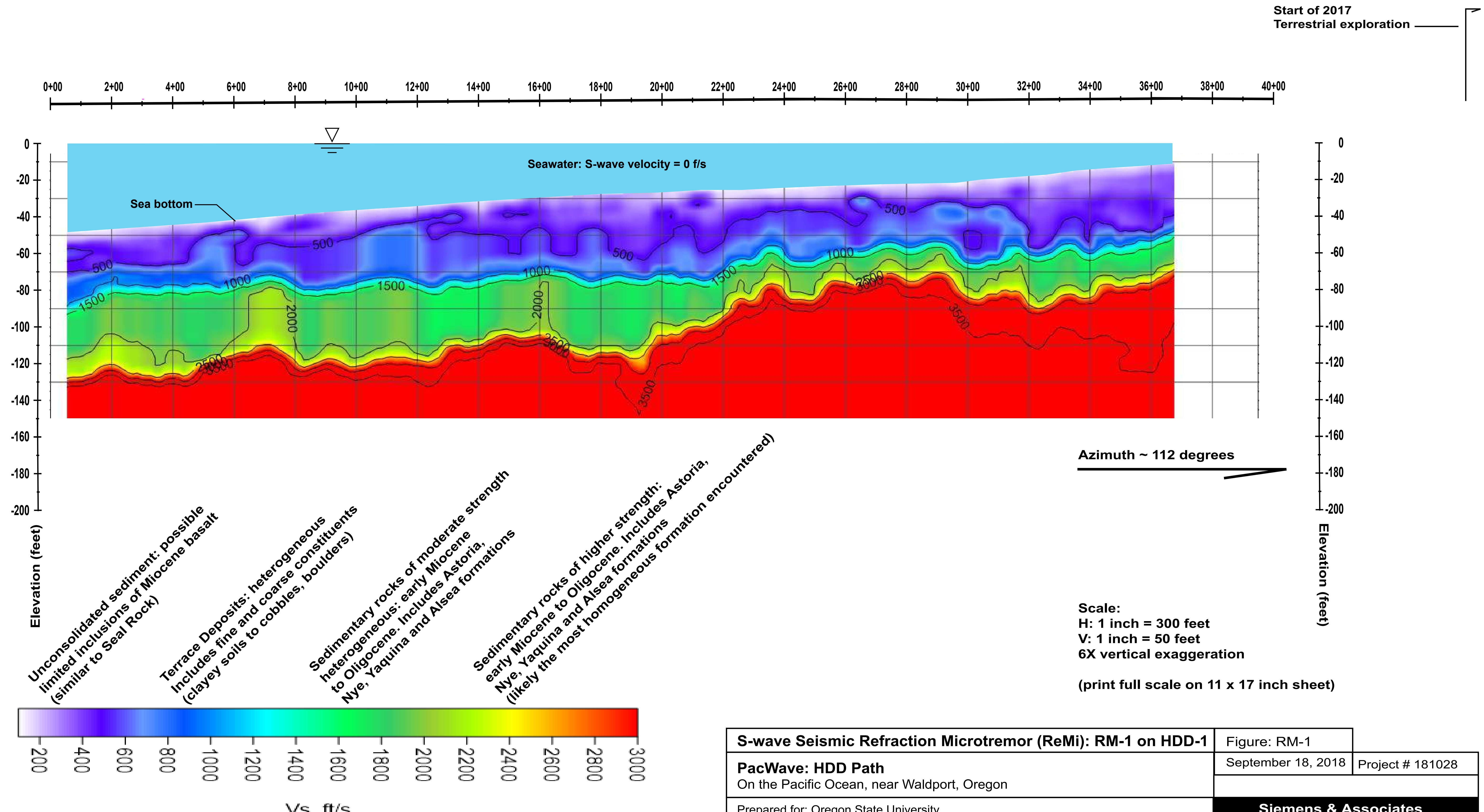
(320 electrodes, 3 m spacing, Dipole-Dipole Array collected with 8 overlapping positions)



Electrical Resistivity Tomography: ER-1 on HDD-1	Figure: ER-1	
PacWave: HDD Path On the Pacific Ocean, near Waldport, Oregon	September 16, 2018	Project # 181028
Prepared for: Oregon State University	**Siemens & Associates**	

S-wave velocity: Seismic Refraction Microtremor: RM-1 on HDD1

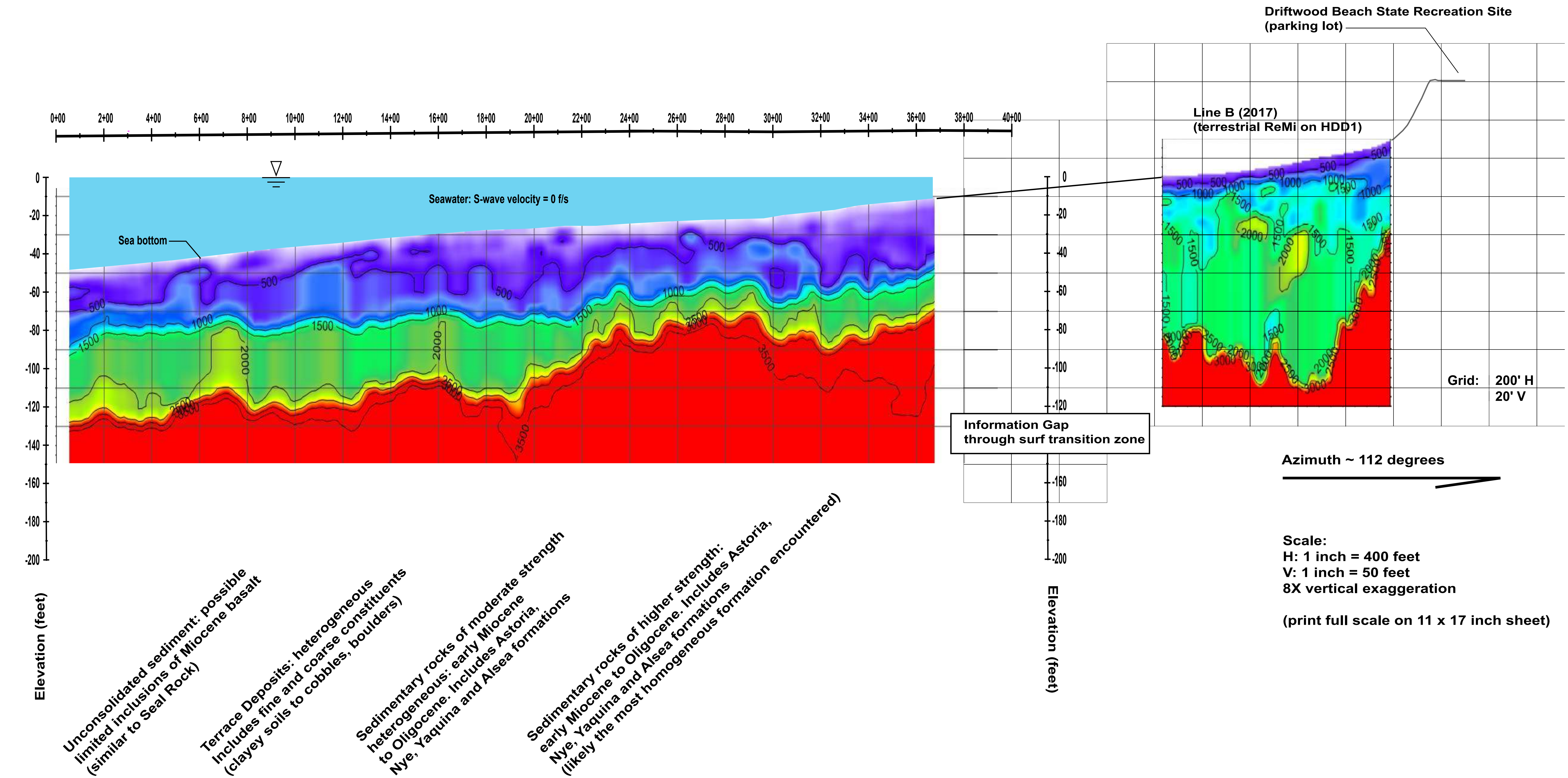
(374, 10 Hz. hydrophones on 10 foot spacing, recording bottom conditions at 14 overlapping positions)

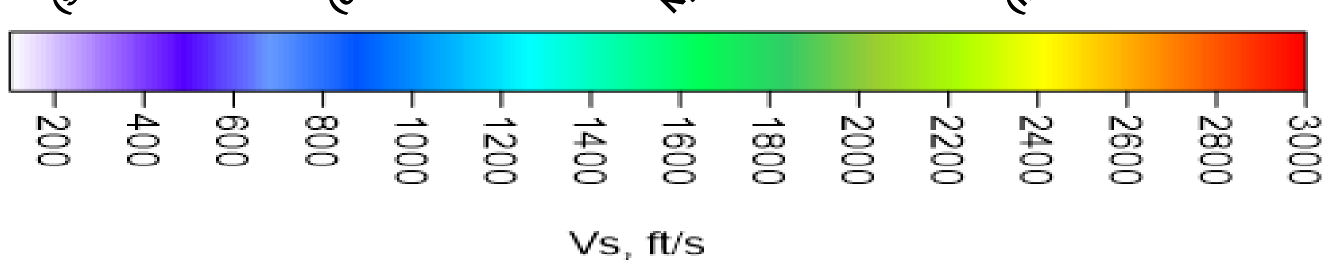


S-wave Seismic Refraction Microtremor (ReMi): RM-1 on HDD-1	Figure: RM-1	
PacWave: HDD Path On the Pacific Ocean, near Waldport, Oregon	September 18, 2018	Project # 181028
Prepared for: Oregon State University	**Siemens & Associates**	

S-wave velocity: Seismic Refraction Microtremor: RM-1 on HDD1

(374, 10 Hz. hydrophones on 10 foot spacing, recording bottom conditions at 14 overlapping positions)



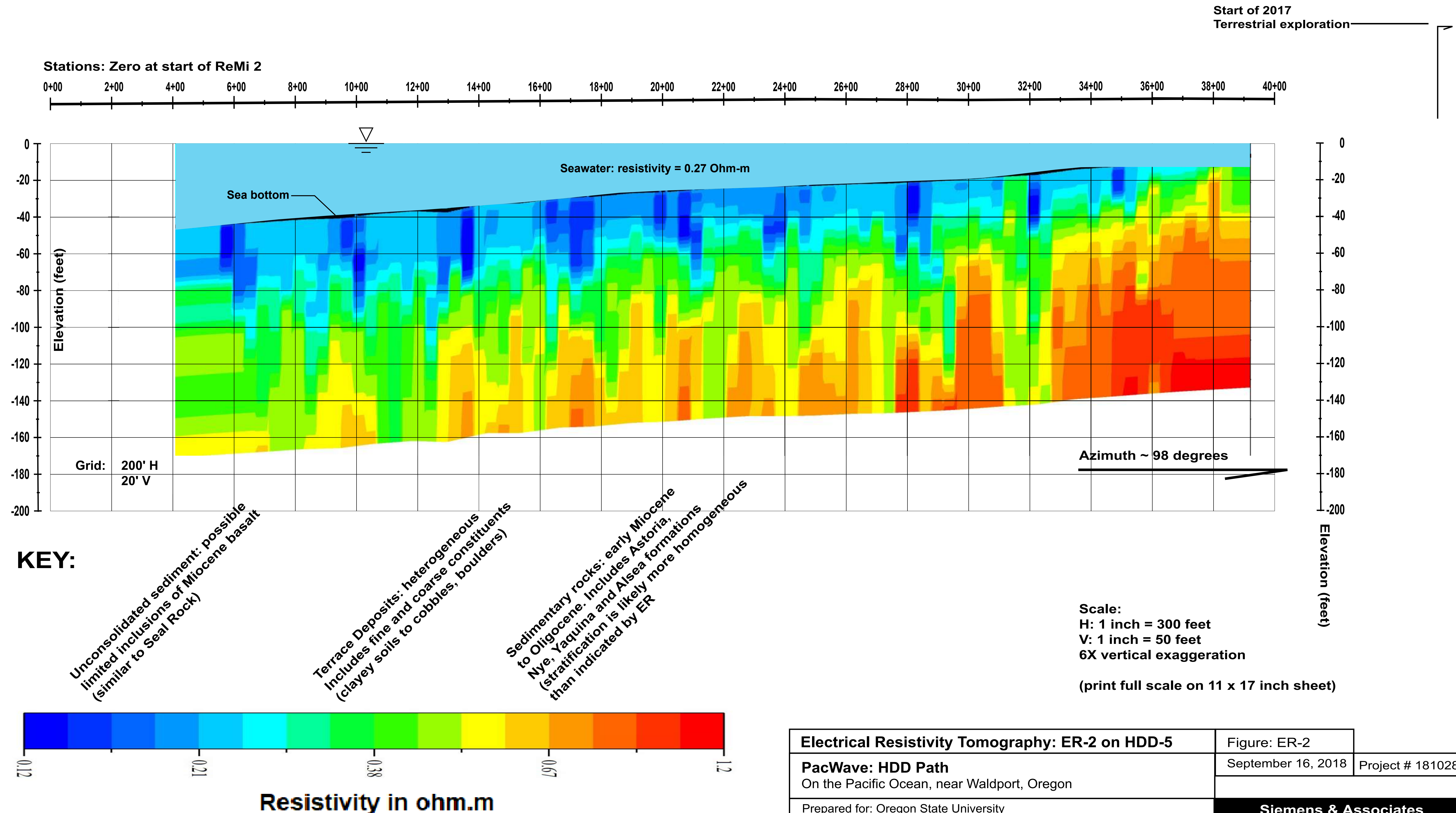


S-wave Seismic Refraction Microtremor (ReMi): RM-1 on HDD-1	Figure: RM-1s	
PacWave: HDD Path On the Pacific Ocean, near Waldport, Oregon	September 18, 2018	Project # 181028
Prepared for: Oregon State University	Siemens & Associates	

6.3. Results: ER and ReMi, Line 2 on HDD-5

Electrical Resistivity Tomography: ER-2 on HDD5

(356 electrodes, 3 m spacing, Dipole-Dipole Array collected with 9 overlapping positions)



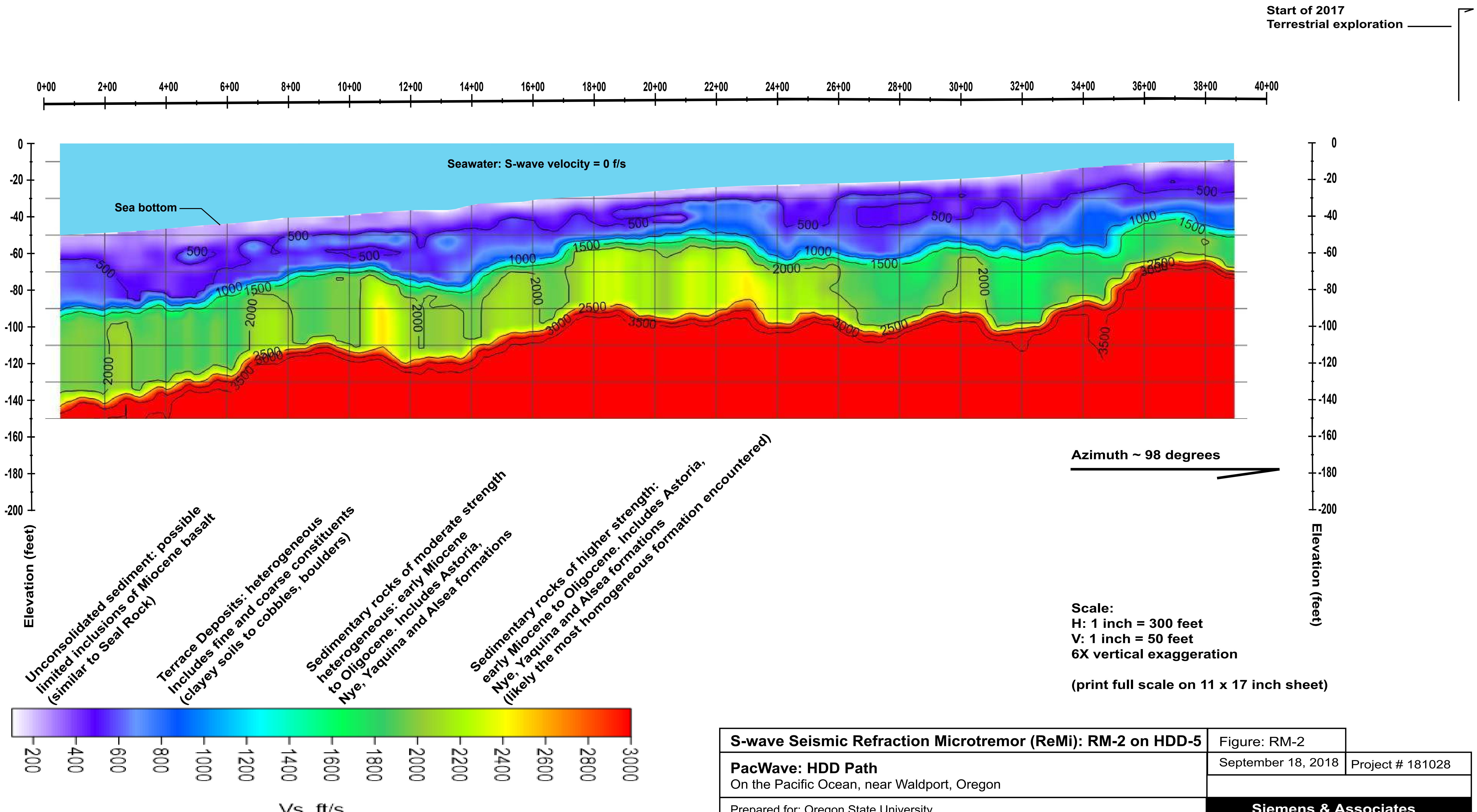
Scale:
H: 1 inch = 300 feet
V: 1 inch = 50 feet
6X vertical exaggeration

(print full scale on 11 x 17 inch sheet)

Electrical Resistivity Tomography: ER-2 on HDD-5	Figure: ER-2	
PacWave: HDD Path On the Pacific Ocean, near Waldport, Oregon	September 16, 2018	Project # 181028
Prepared for: Oregon State University	**Siemens & Associates**	

S-wave velocity: Seismic Refraction Microtremor: RM-2 on HDD5

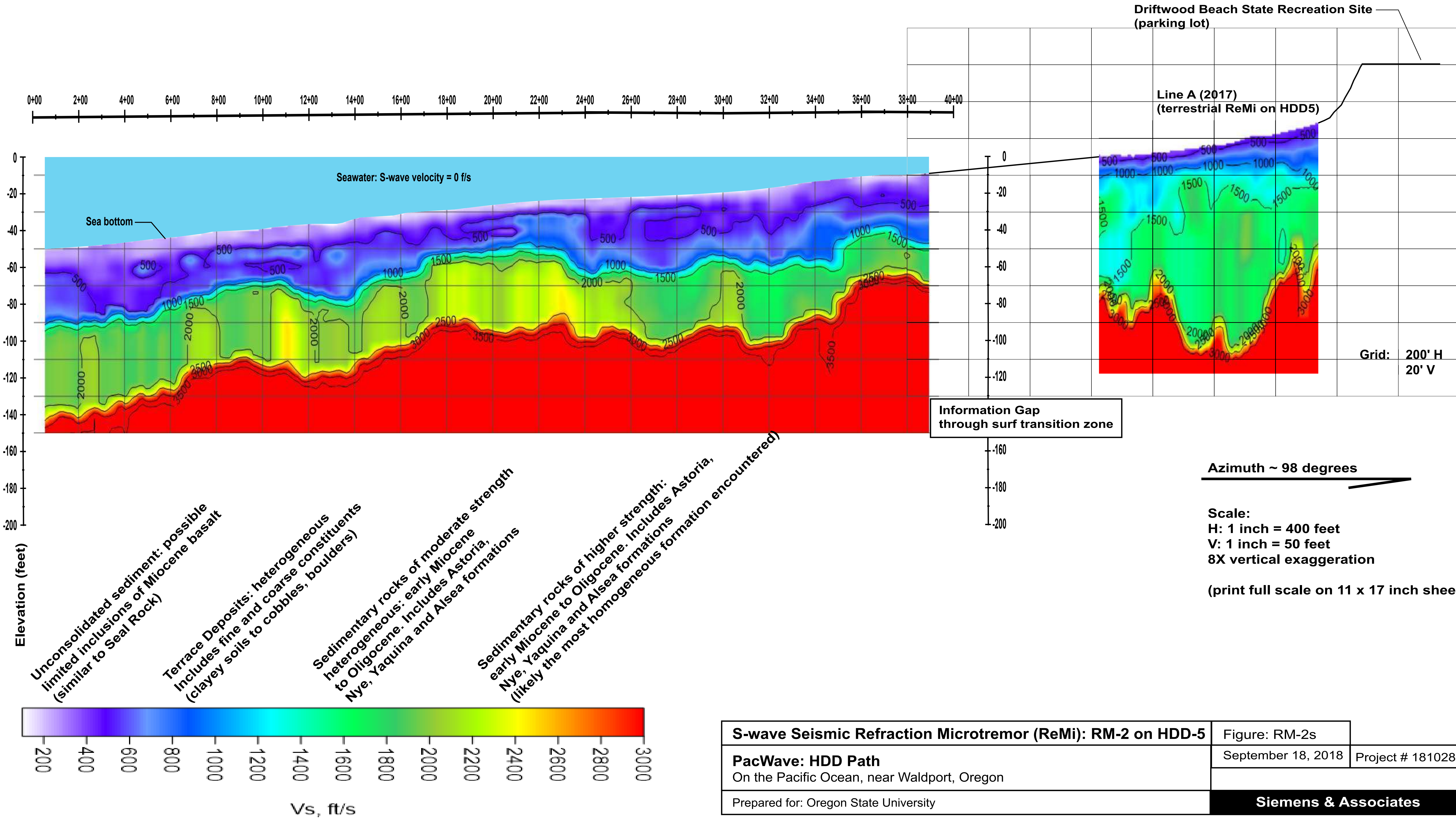
(396, 10 Hz. hydrophones on 10 foot spacing, recording bottom conditions at 15 overlapping positions)



S-wave Seismic Refraction Microtremor (ReMi): RM-2 on HDD-5	Figure: RM-2	
PacWave: HDD Path On the Pacific Ocean, near Waldport, Oregon	September 18, 2018	Project # 181028
Prepared for: Oregon State University	**Siemens & Associates**	

S-wave velocity: Seismic Refraction Microtremor: RM-2 on HDD5

(396, 10 Hz. hydrophones on 10 foot spacing, recording bottom conditions at 15 overlapping positions)



S-wave Seismic Refraction Microtremor (ReMi): RM-2 on HDD-5	Figure: RM-2s	
PacWave: HDD Path On the Pacific Ocean, near Waldport, Oregon	September 18, 2018	Project # 181028
Prepared for: Oregon State University	**Siemens & Associates**	