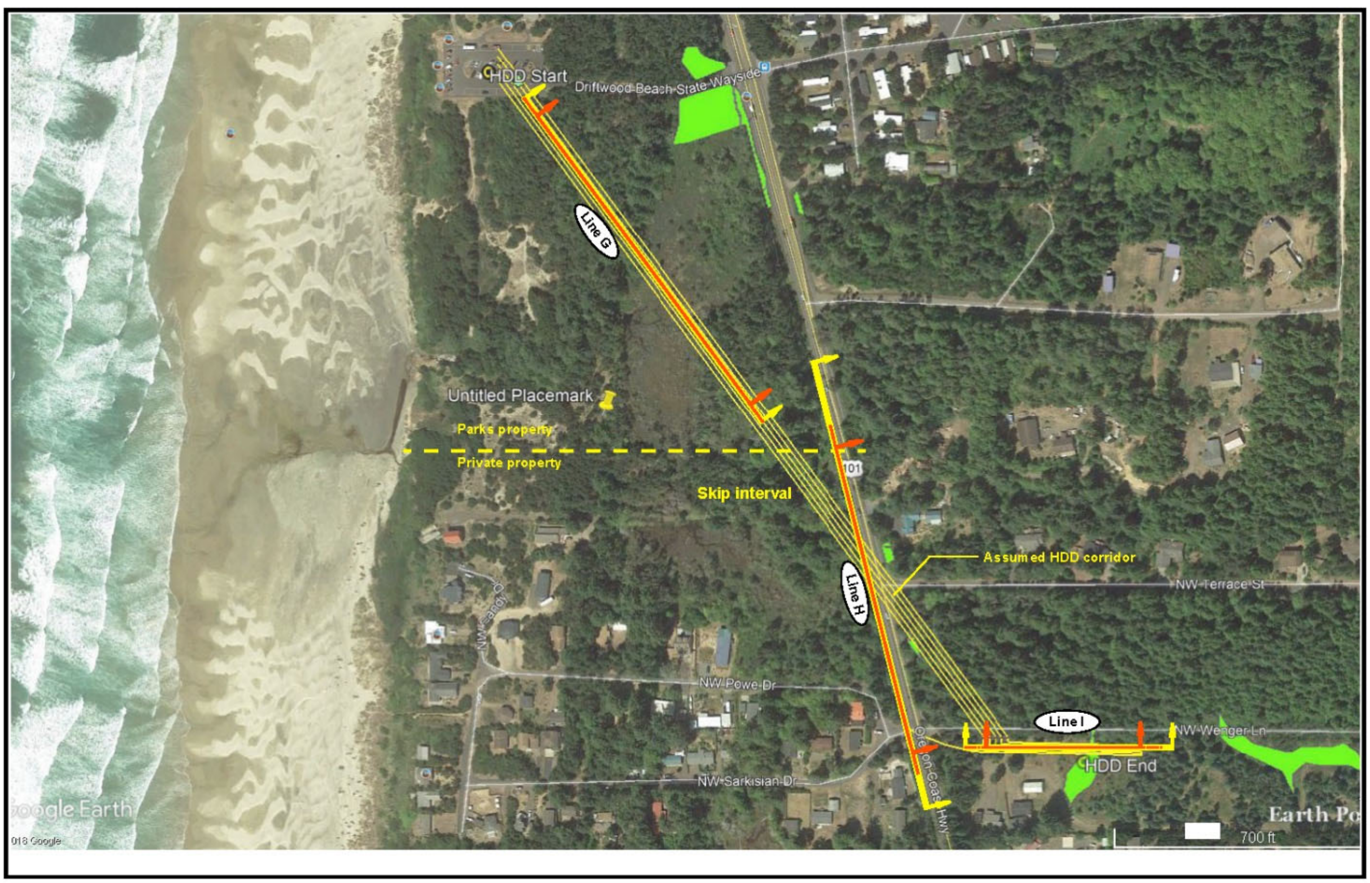
PacWave
TESTING WAVE ENERGY FOR THE FUTURE

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

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RE: Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave
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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

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16,377
OREGON
JAN. 19, 1993
J. ANDREW SIEMENS

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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.

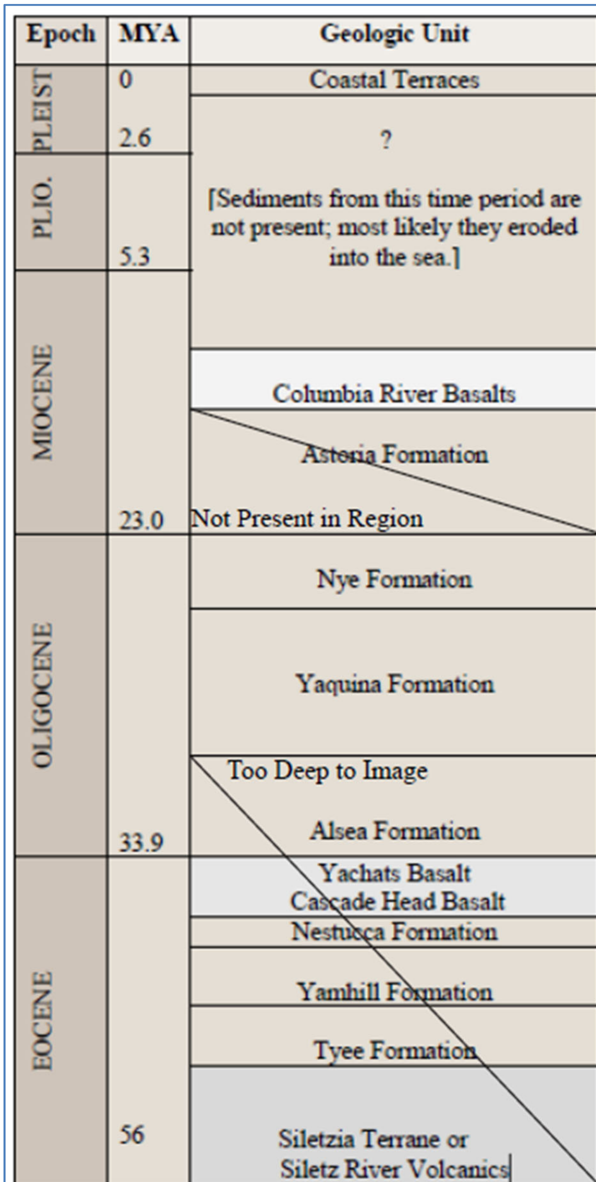
2. Conditions Encountered

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.

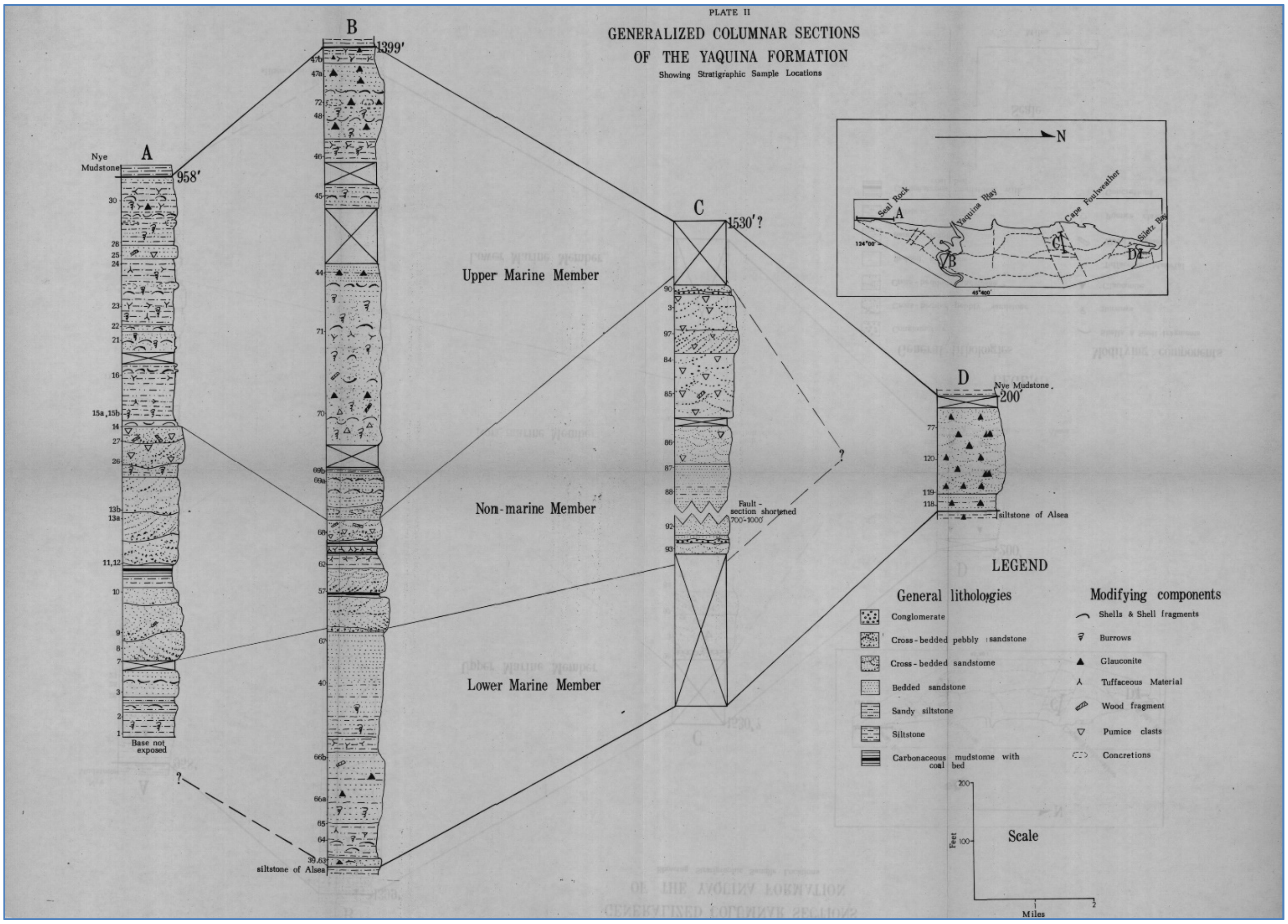
- Layer 3: Sedimentary Rocks including the Nye, Yaquina, and Alsea Formations

  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

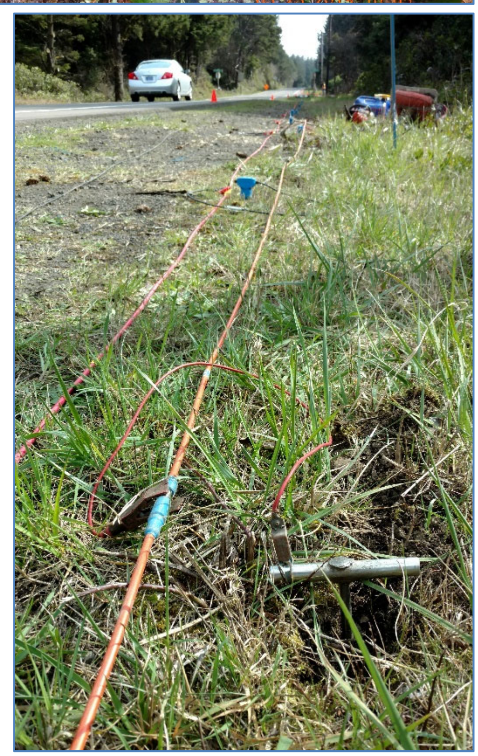
Geologic Condition	Location	HDD Implication	Mitigation Considerations
Granular dune and terrace deposits	• Dune deposits at the northern end • Terrace deposits along the southern half of the alignment	• Granular soils can be highly erodible, particularly with multiple HDD drives as successive passes 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



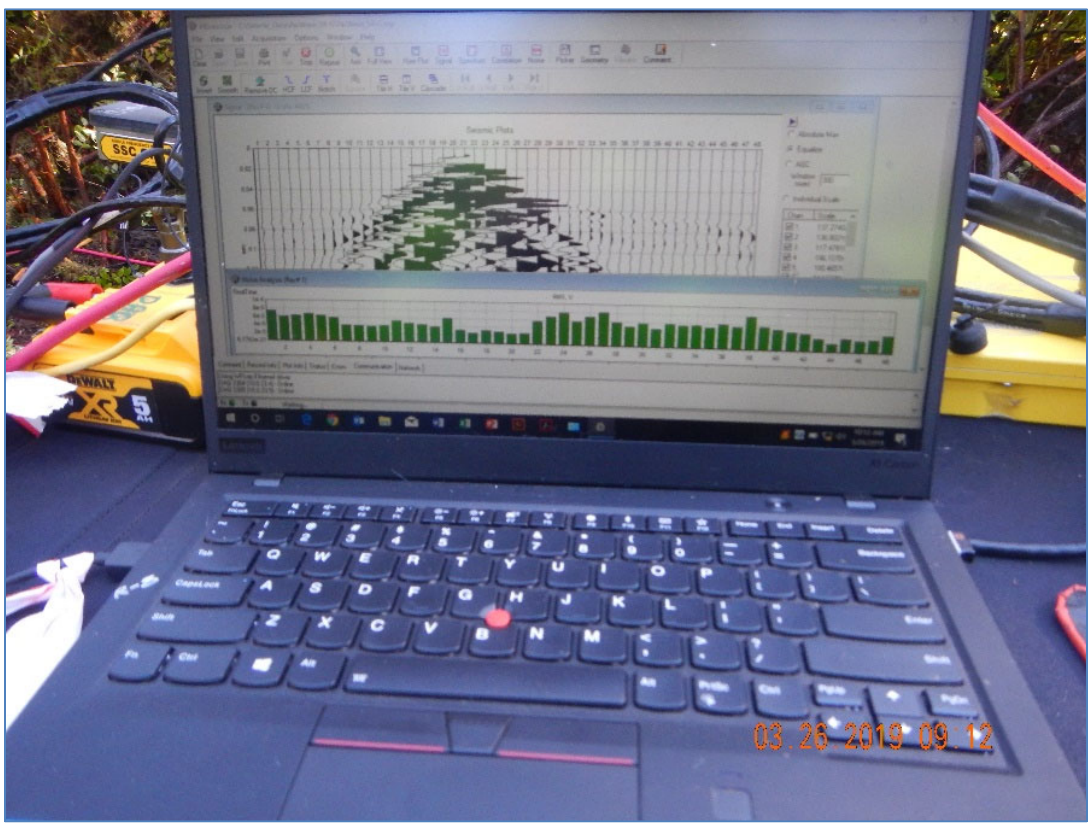
3.1.1. Electrical Resistivity (ER)

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.

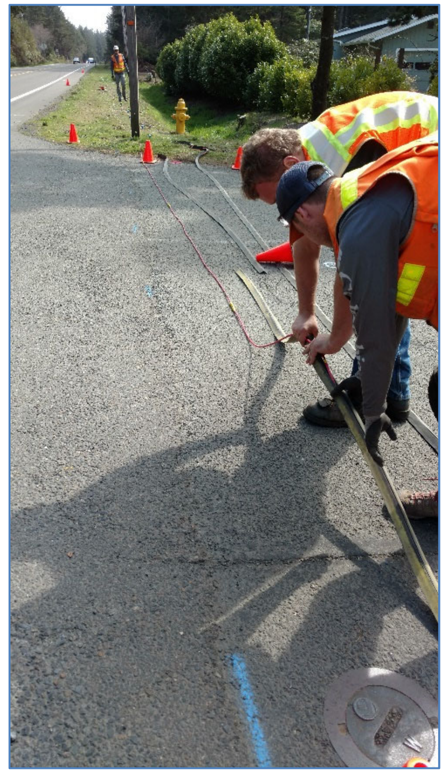
Following the collection of the geophysical data, surveyor John Thompson, PLS, of John Thompson & Associates, Inc., visited the site to determine precise location and elevation of the temporary benchmarks set by SA using RTK methods. The elevation profiles were then converted to match Oregon State Plane 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

Lines G through I

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.

Unconsolidated Sediments

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.

Terrace Deposits

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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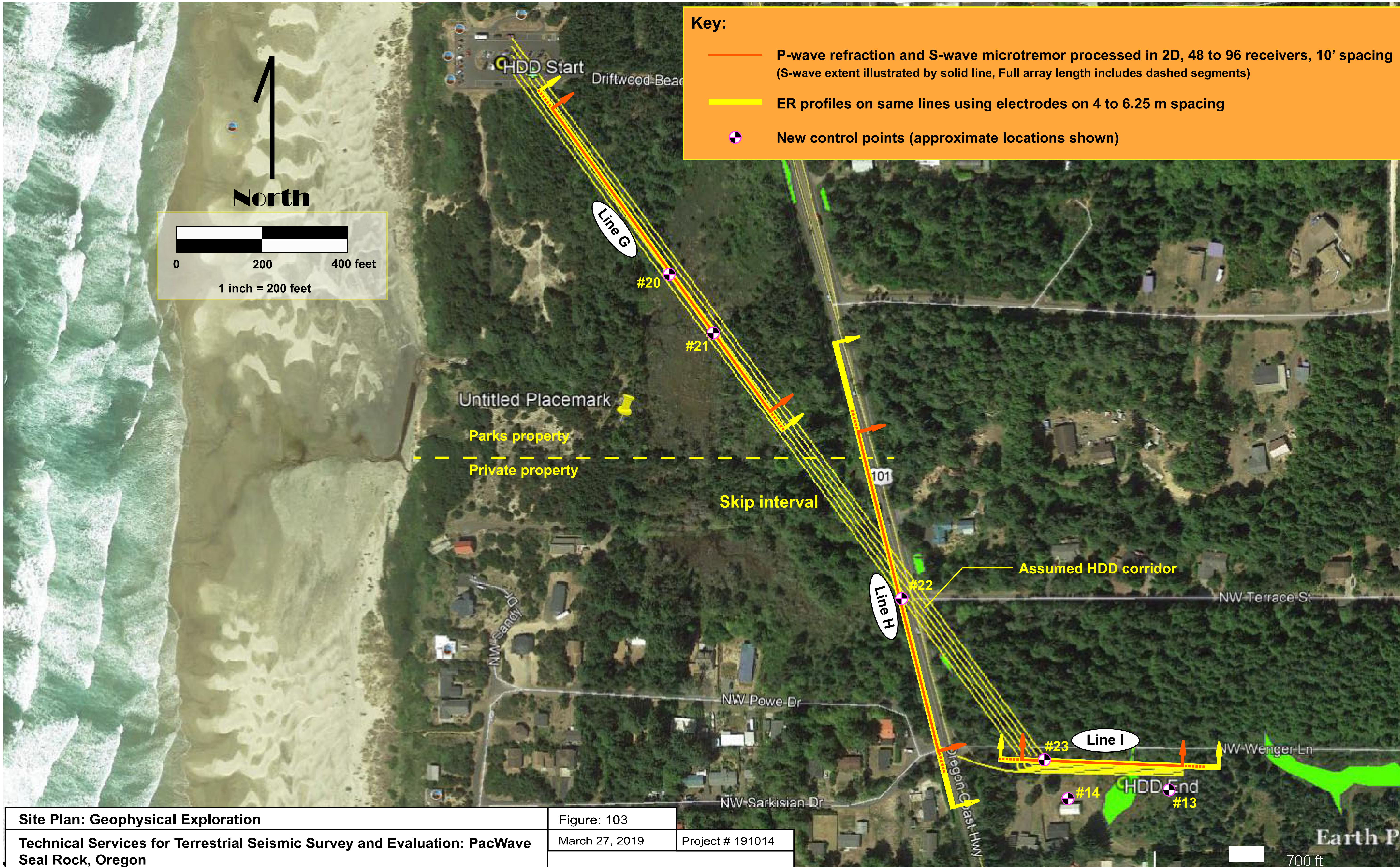
7. Graphical Presentation of Results

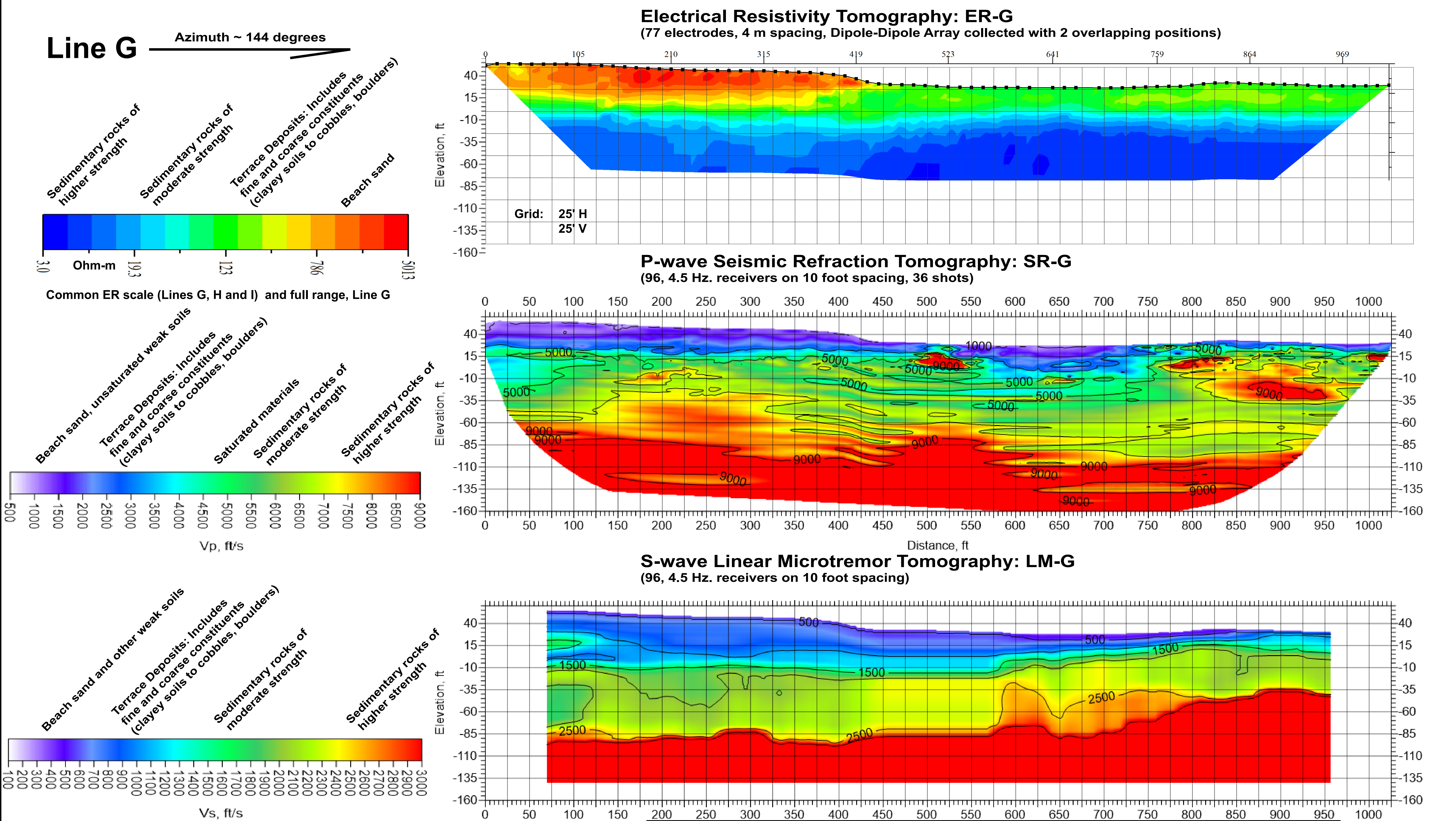
The interpretations are presented in 2D with the locations of the various lines illustrated on Figure 103.

7.1. Figure 103: Site Plan: Terrestrial Geophysical Surveys



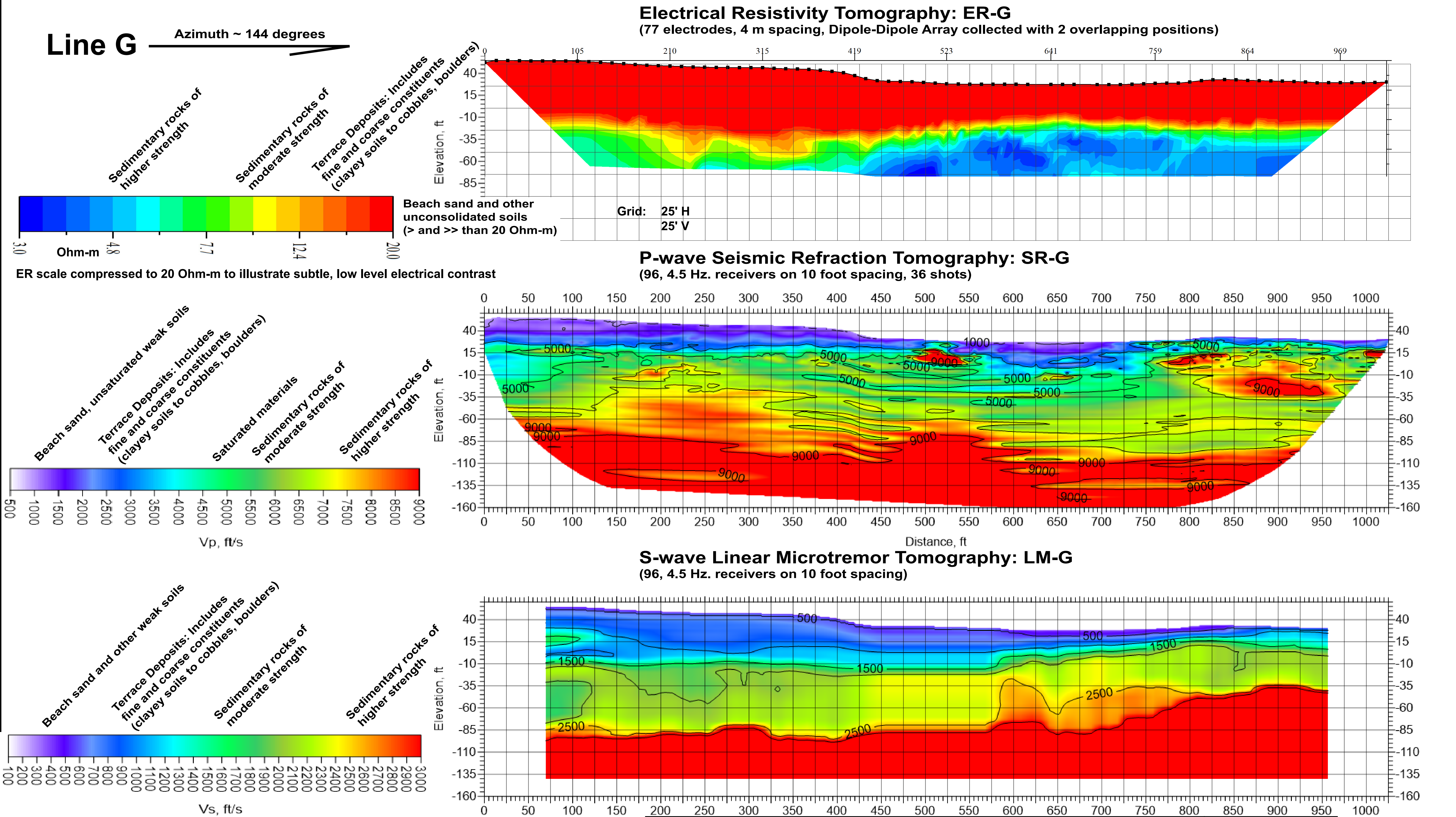
Site Plan: Geophysical Exploration	Figure: 103	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	Siemens & Associates	

7.2. Results: Line G



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

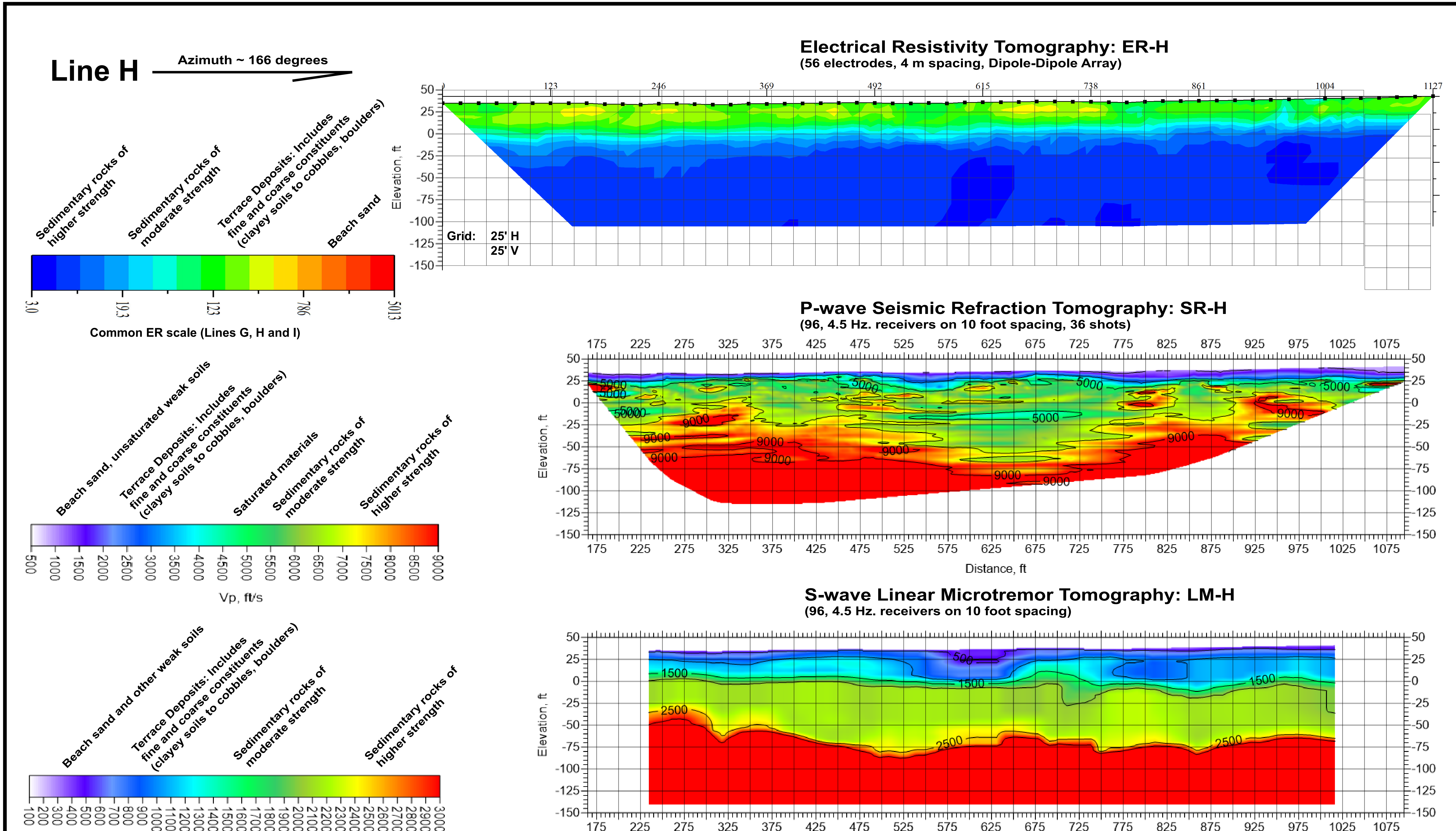
Geophysical Results: Line G	Figure: G-1	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	Siemens & Associates	



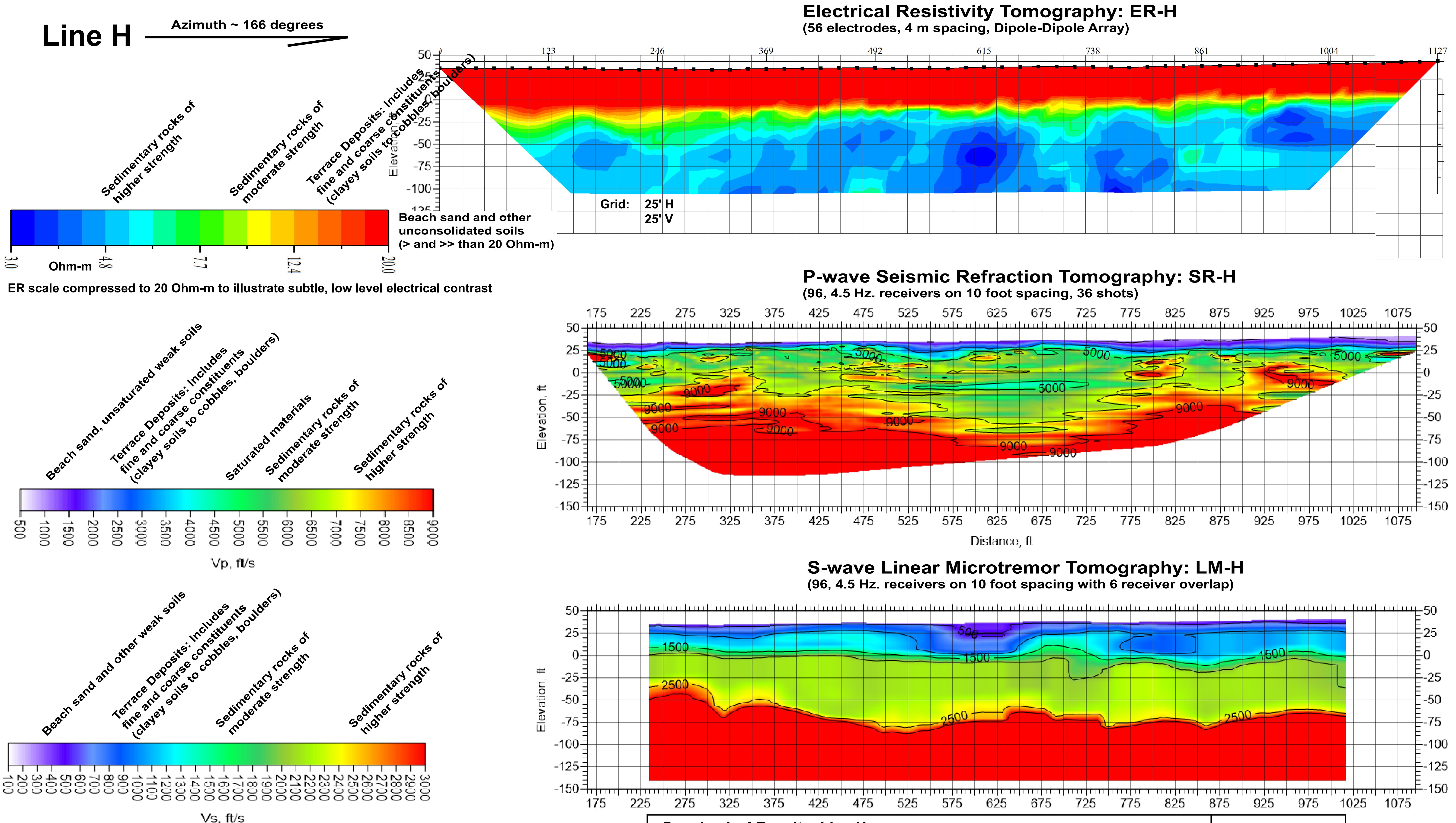
Scale:
H: 1 inch = 100 feet
V: 1 inch = 100 feet

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	

7.3. Results: Line H

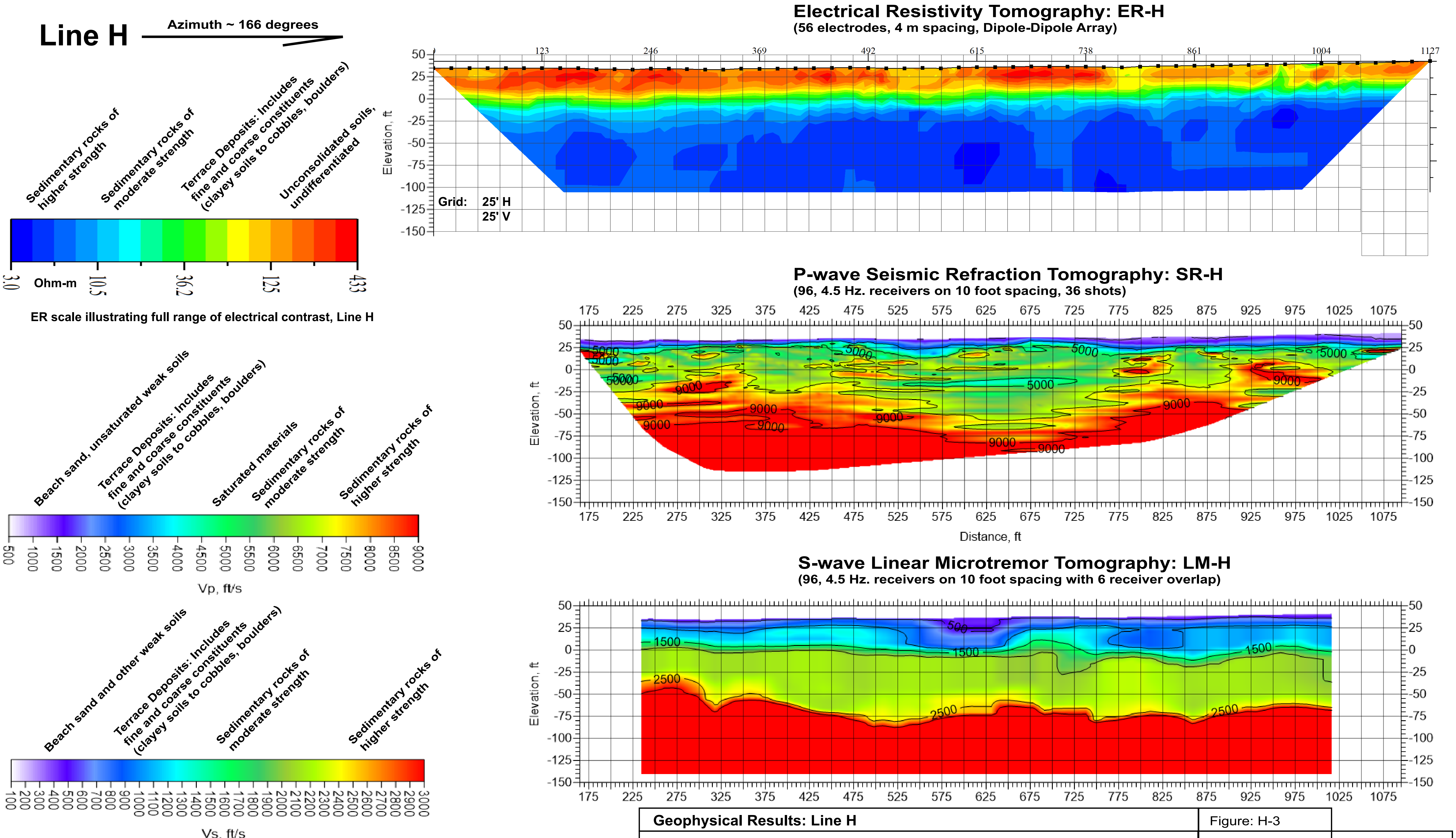


Geophysical Results: Line H	Figure: H-1	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	**Siemens & Associates**	



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

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	



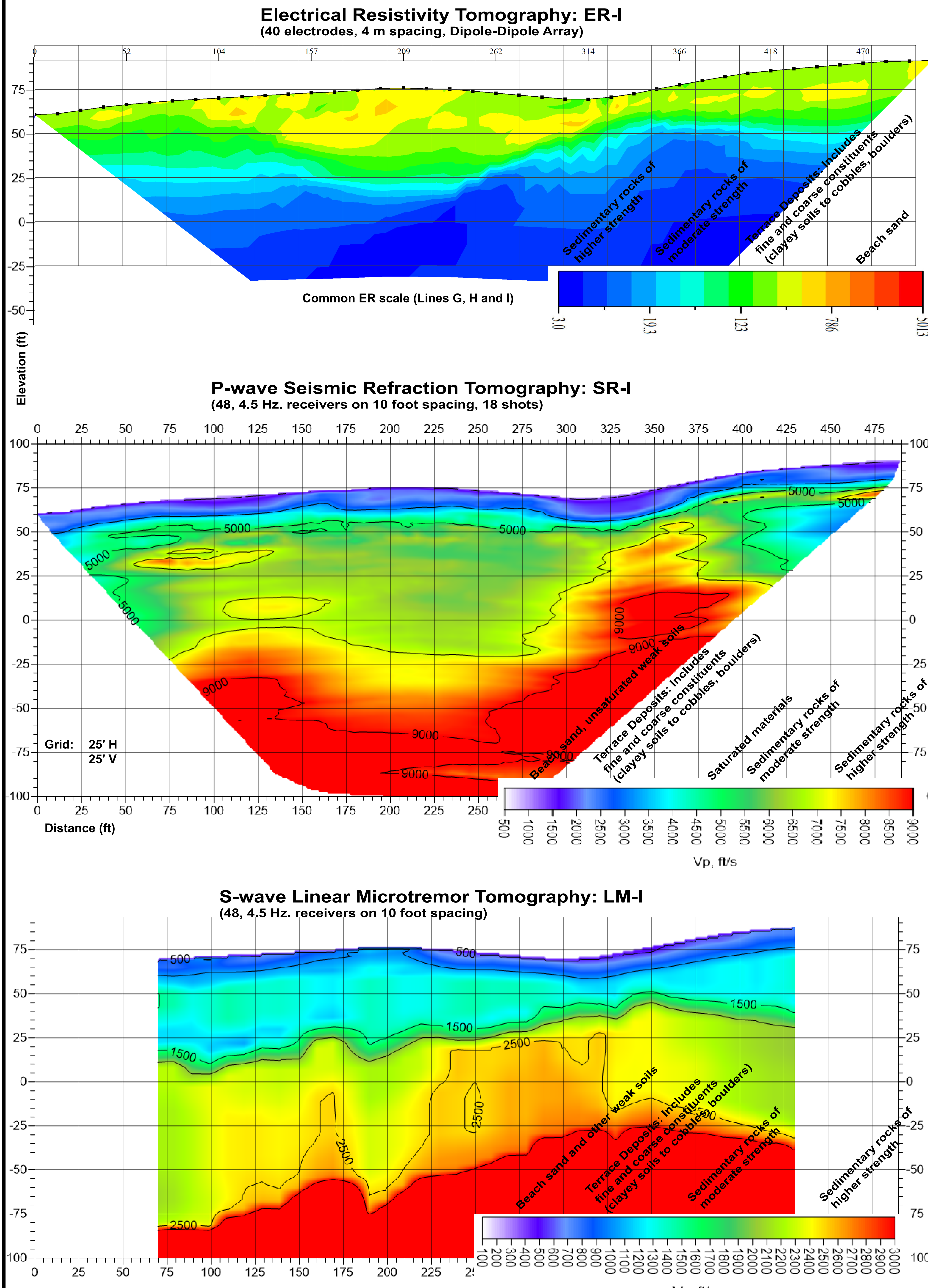
Scale:
H: 1 inch = 100 feet
V: 1 inch = 100 feet

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

Azimuth ~ 90 degrees



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

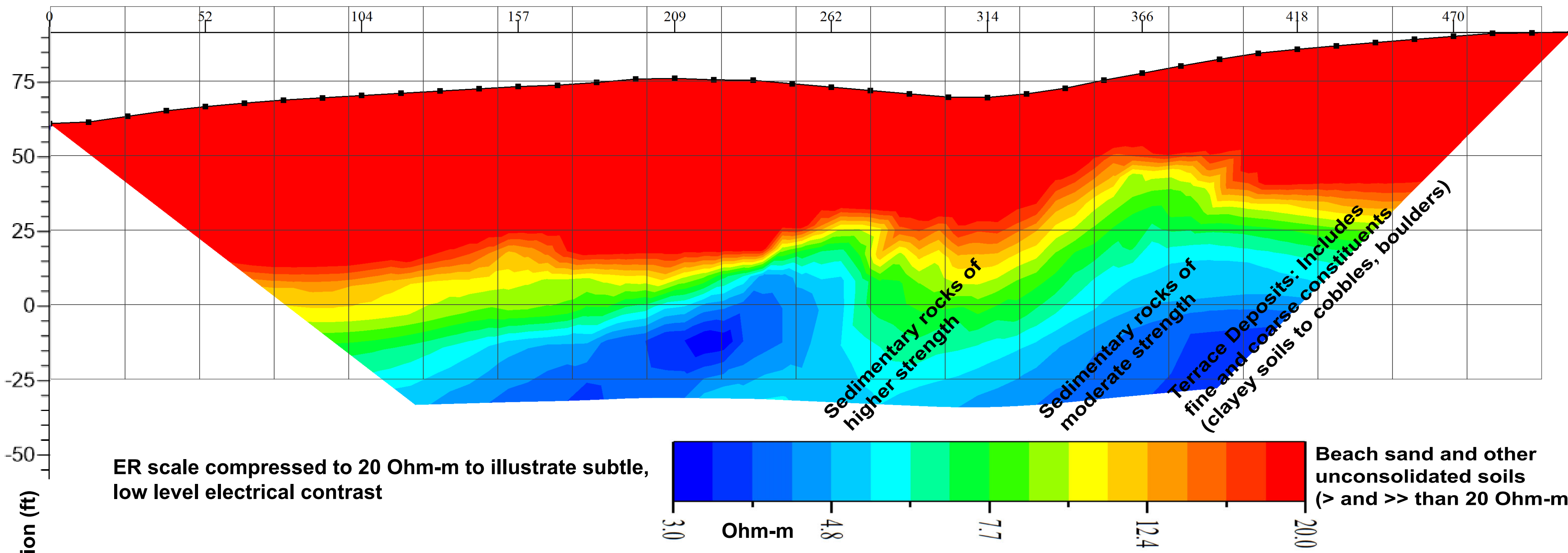
Geophysical Results: Line I	Figure: I-1	
Technical Services for Terrestrial Seismic Survey and Evaluation: PacWave Seal Rock, Oregon	March 27, 2019	Project # 191014
Prepared for: Oregon State University	**Siemens & Associates**	

Line I

Azimuth ~ 90 degrees

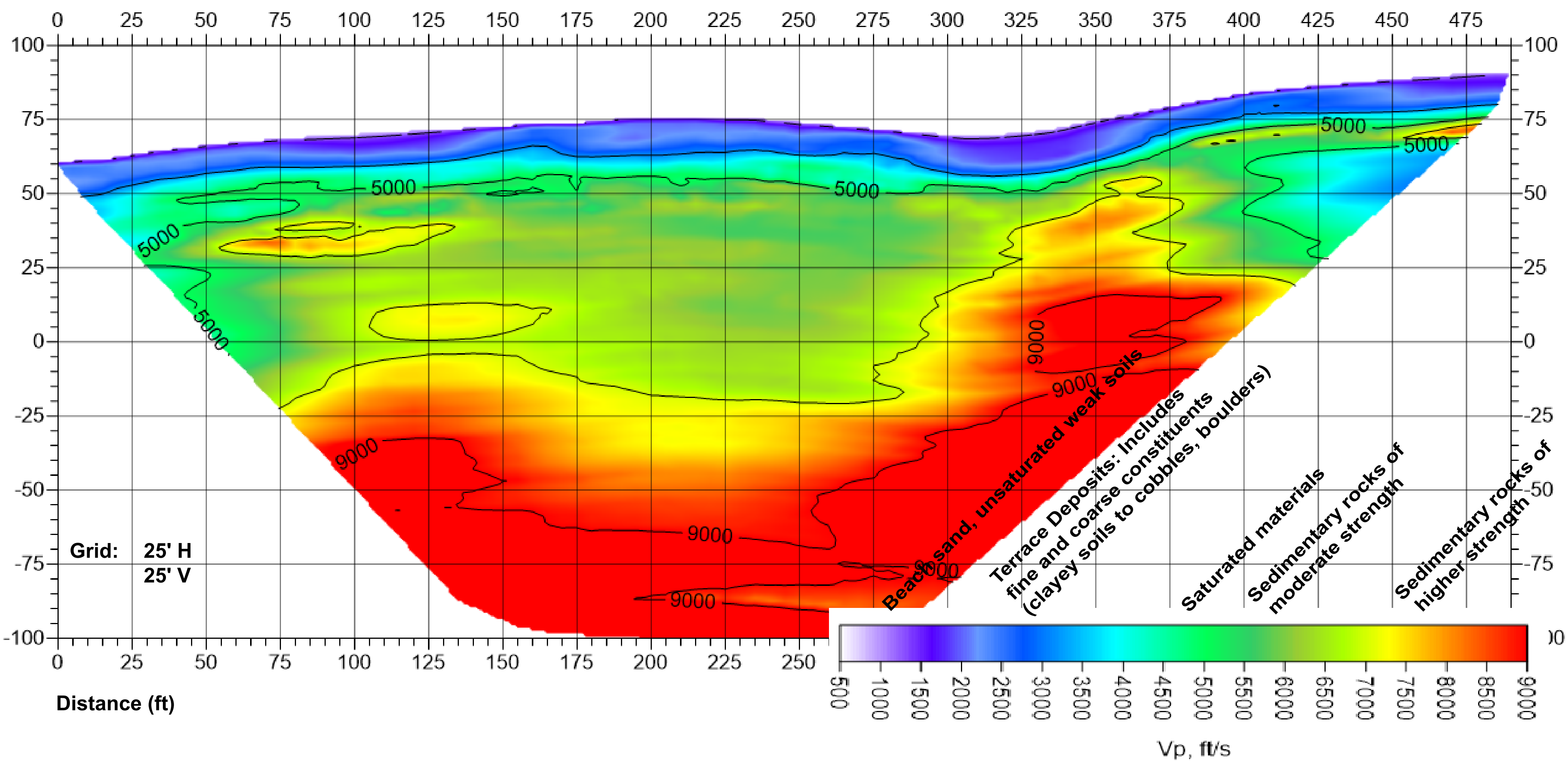
Electrical Resistivity Tomography: ER-I

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



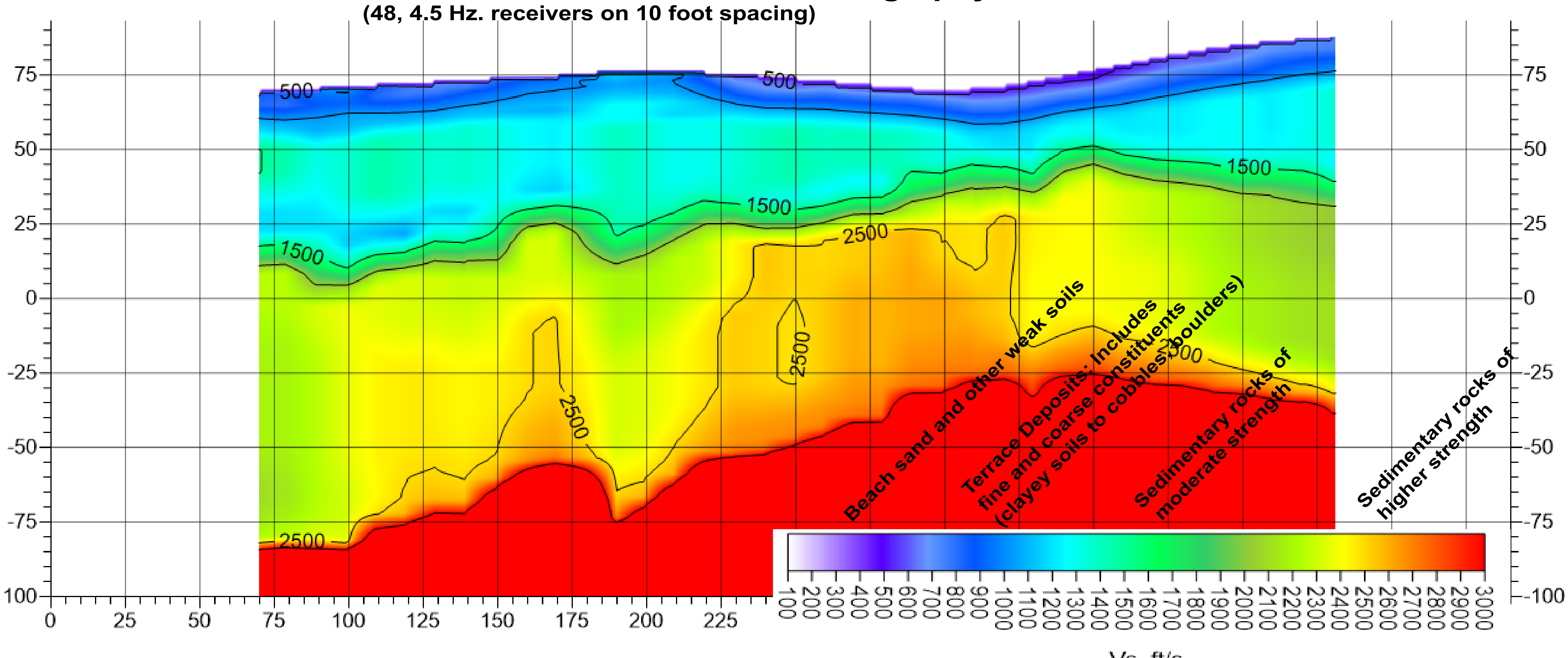
P-wave Seismic Refraction Tomography: SR-I

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



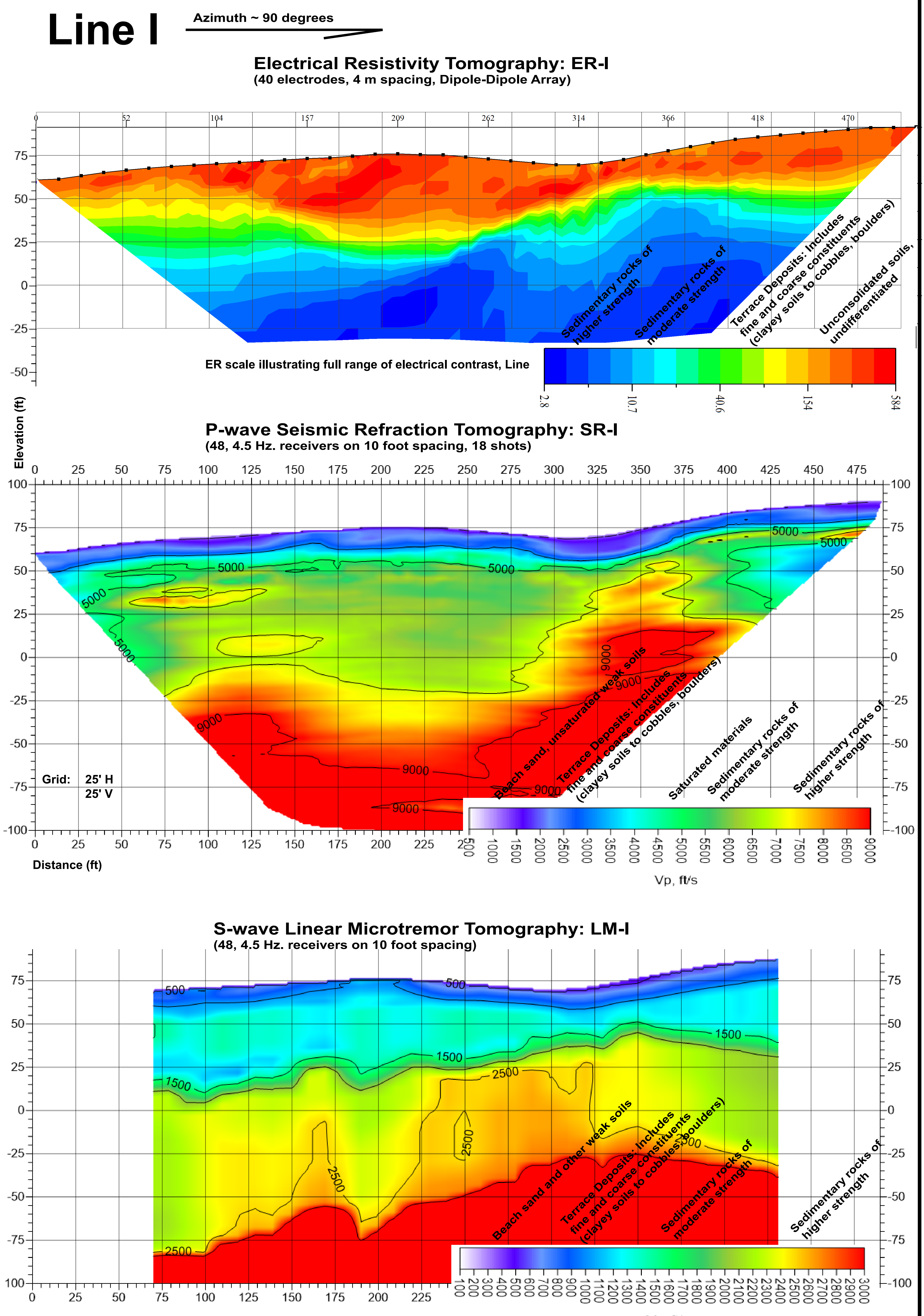
S-wave Linear Microtremor Tomography: LM-I

(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**	



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**	