PacWave: HDD Path

On the Pacific Ocean, near Waldport, Oregon

<u>DATA REPORT:</u>

Results of Geophysical Exploration

By: Siemens & Associates
Bend, Oregon

Prepared for: Oregon State University
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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

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Andy Siemens, PE, GE
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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

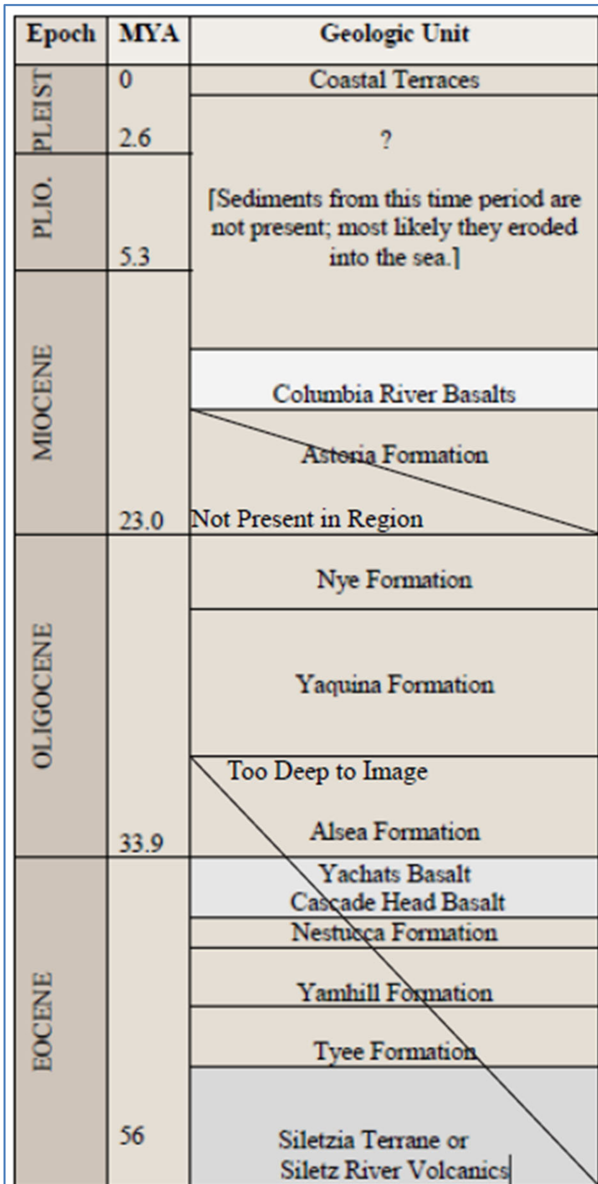
SA have completed marine based geophysical services to support geotechnical evaluations associated with the HDD path extending from the shore out into the Pacific Ocean.

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:

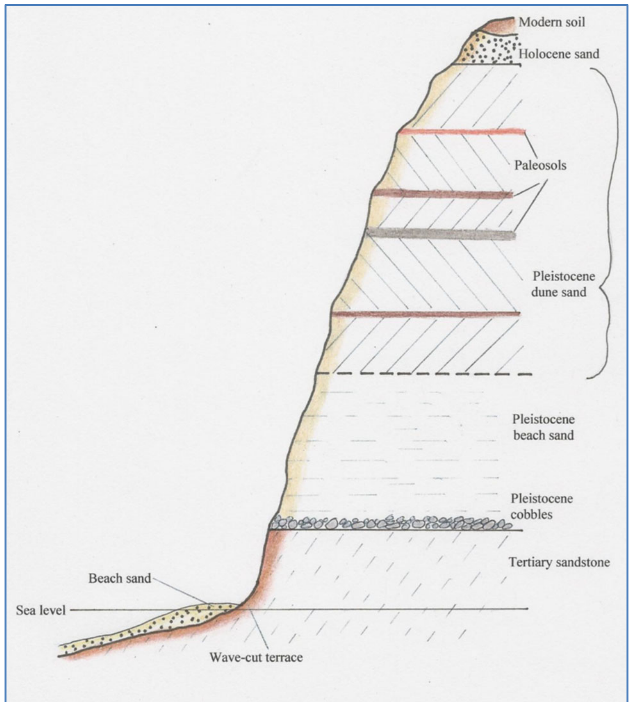
- Layer 1: Unconsolidated Sediments:

  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').



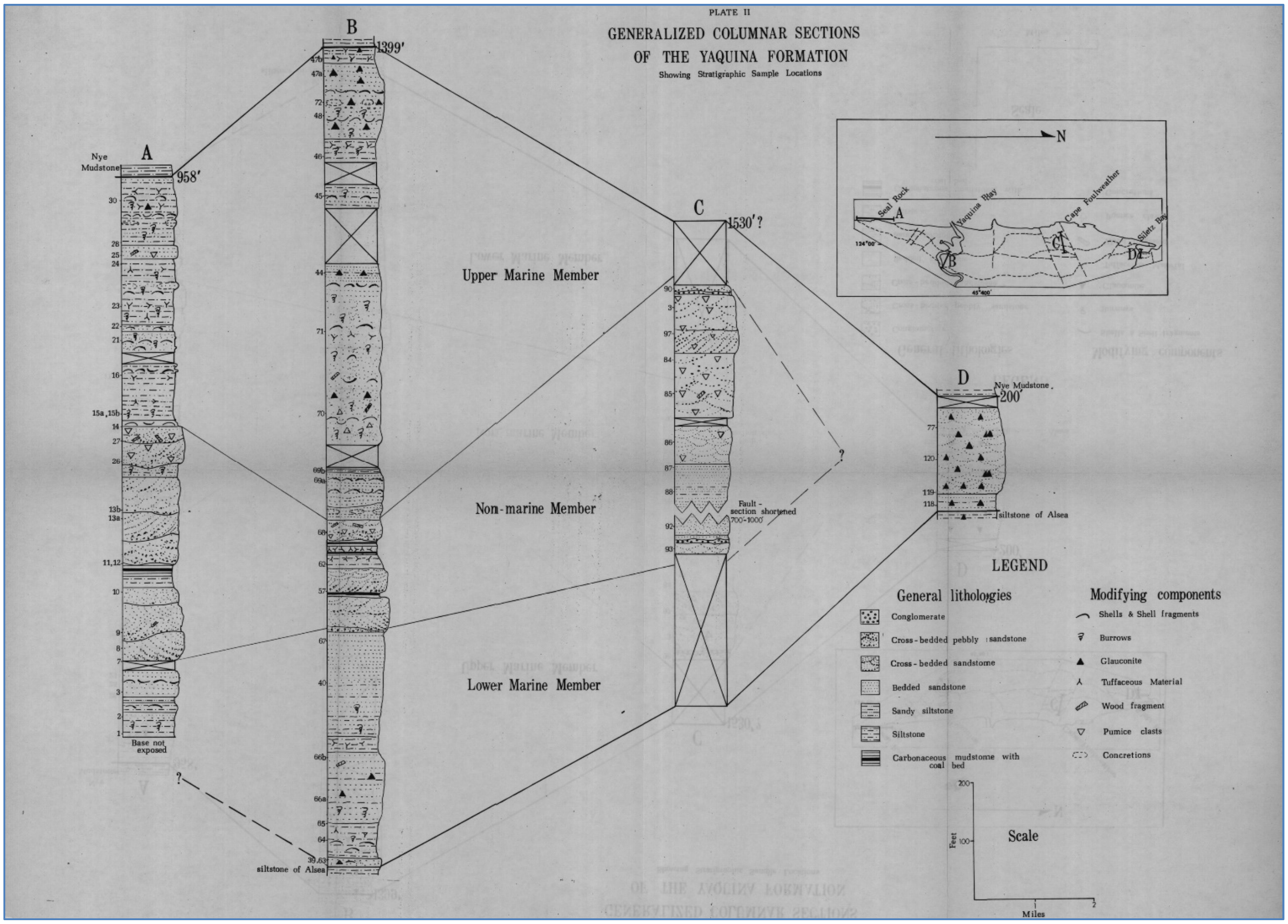
Based on Lund, 1972, and Clough, 2005.

- 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

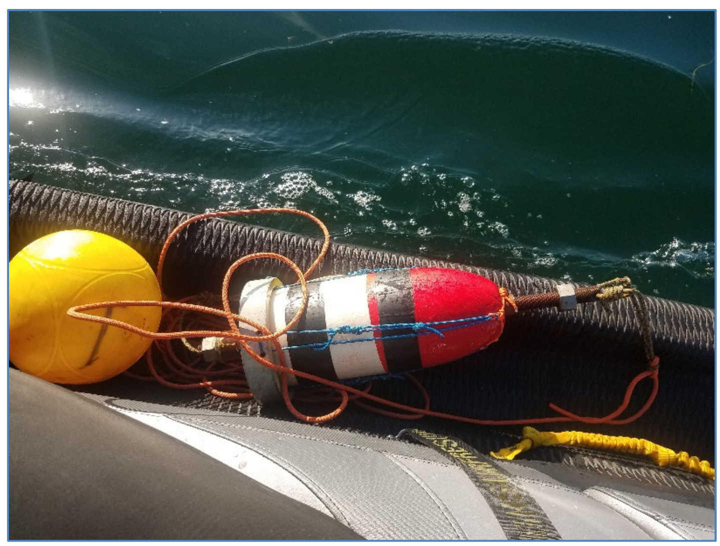
3.1.1. Electrical Resistivity (ER)

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.

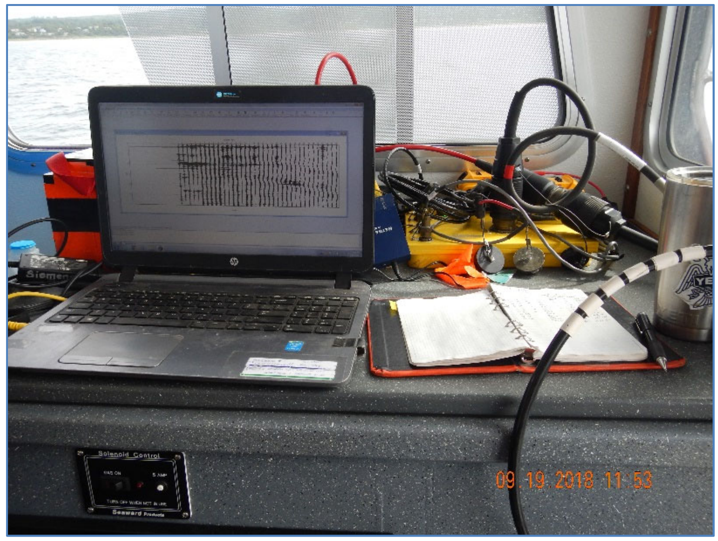
The investigation depth of any measurement is related to the spacing between the electrodes that inject current. Therefore, sampling at different depths can be done by changing the spacing between the electrodes. Measurements are repeated along a survey line with various combinations of electrodes and 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.



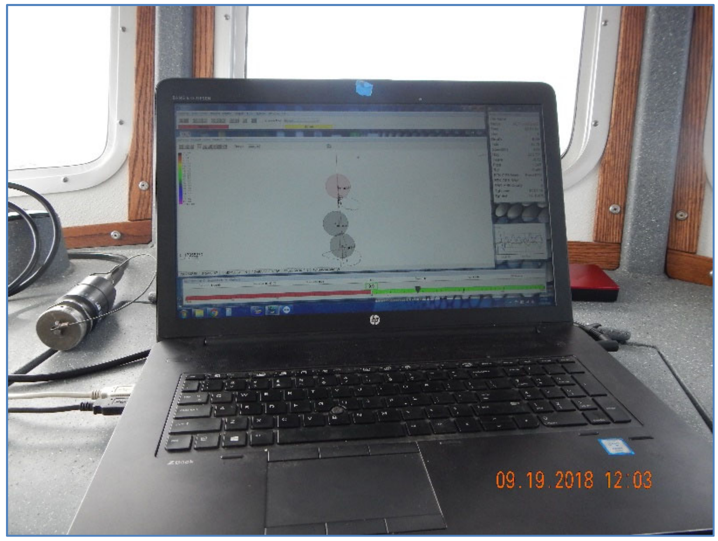
How it works: The ReMi analysis develops the shear-wave velocity/depth profile using an engineering seismograph, low frequency receivers (geophones or hydrophones) and straight-line array aperture (Louie, 2001). Ambient surface wave energy is recorded using relatively long sample window (30 seconds) 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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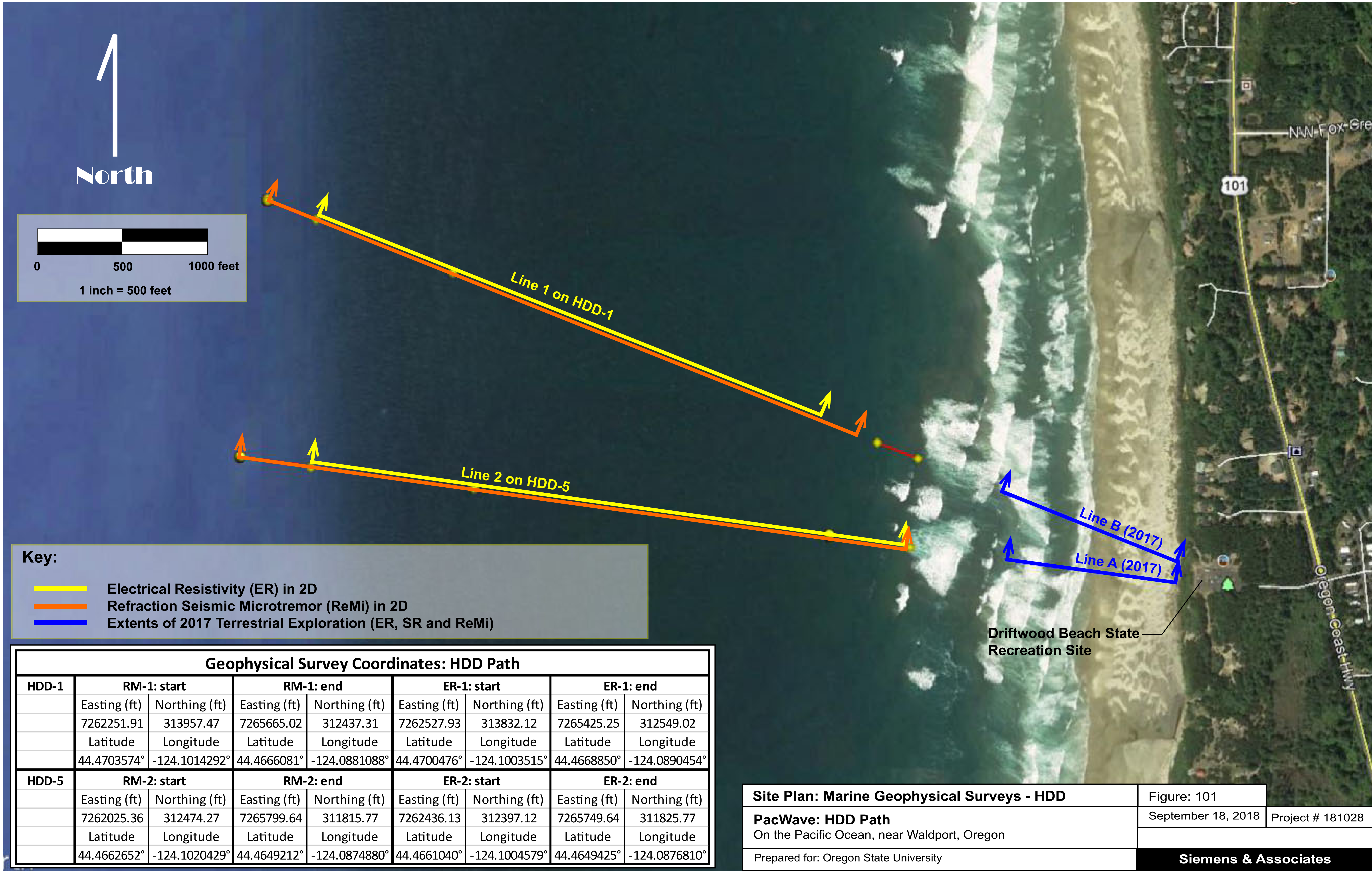
6. Graphical Presentation of Results

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

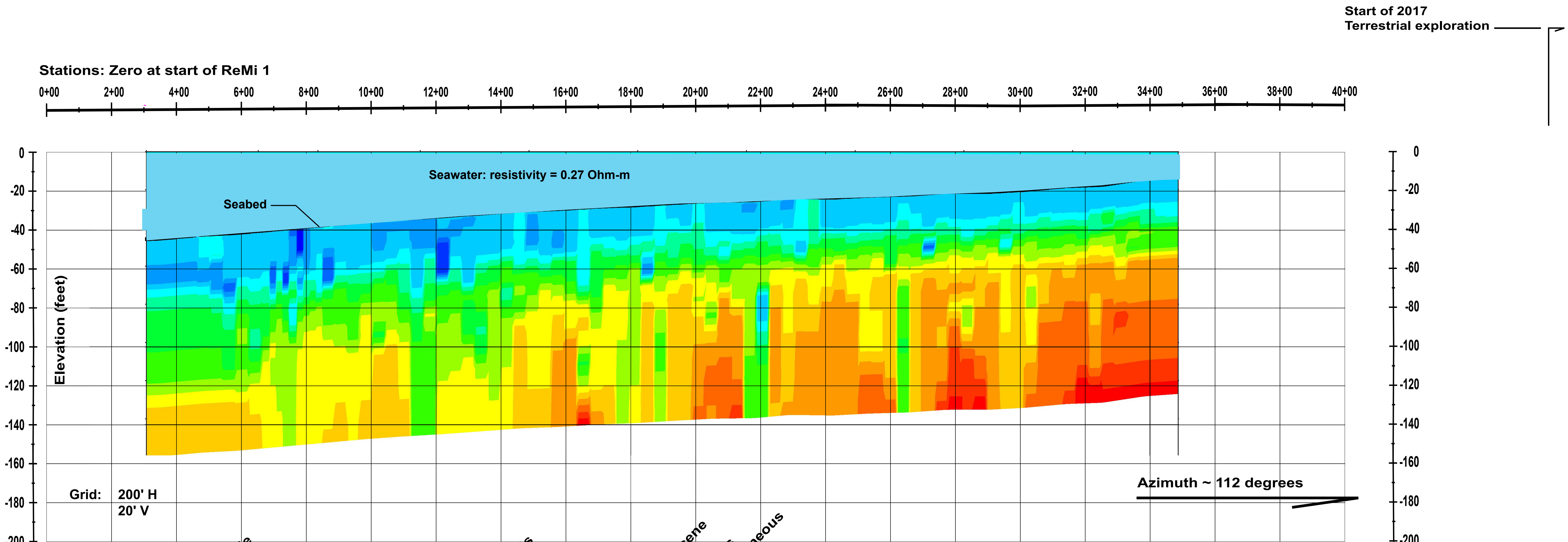
HDD-1	RM-1: start		RM-1: end		ER-1: start		ER-1: end	
	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)	Easting (ft)	Northing (ft)
	7262251.91	313957.47	7265665.02	312437.31	7262527.93	313832.12	7265425.25	312549.02
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	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**

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)



KEY:

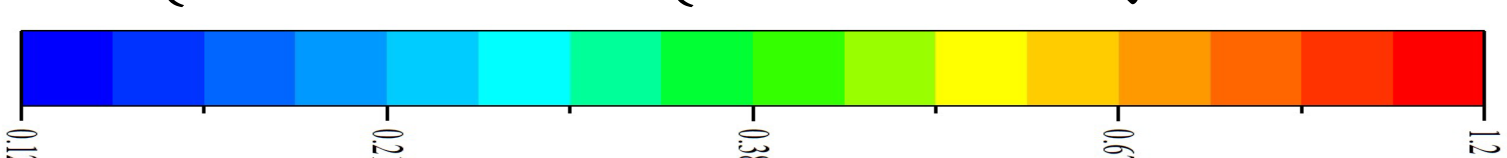
Unconsolidated sediment: possible limited inclusions of Miocene basalt (similar to Seal Rock)

Terrace Deposits: heterogeneous Includes fine and coarse constituents (clayey soils to cobbles, boulders)

Sedimentary rocks: early Miocene to Oligocene. Includes Astoria, Nye, Yaquina and Alsea formations (stratification is likely more homogeneous than indicated by ER

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

(print full scale on 11 x 17 inch sheet)

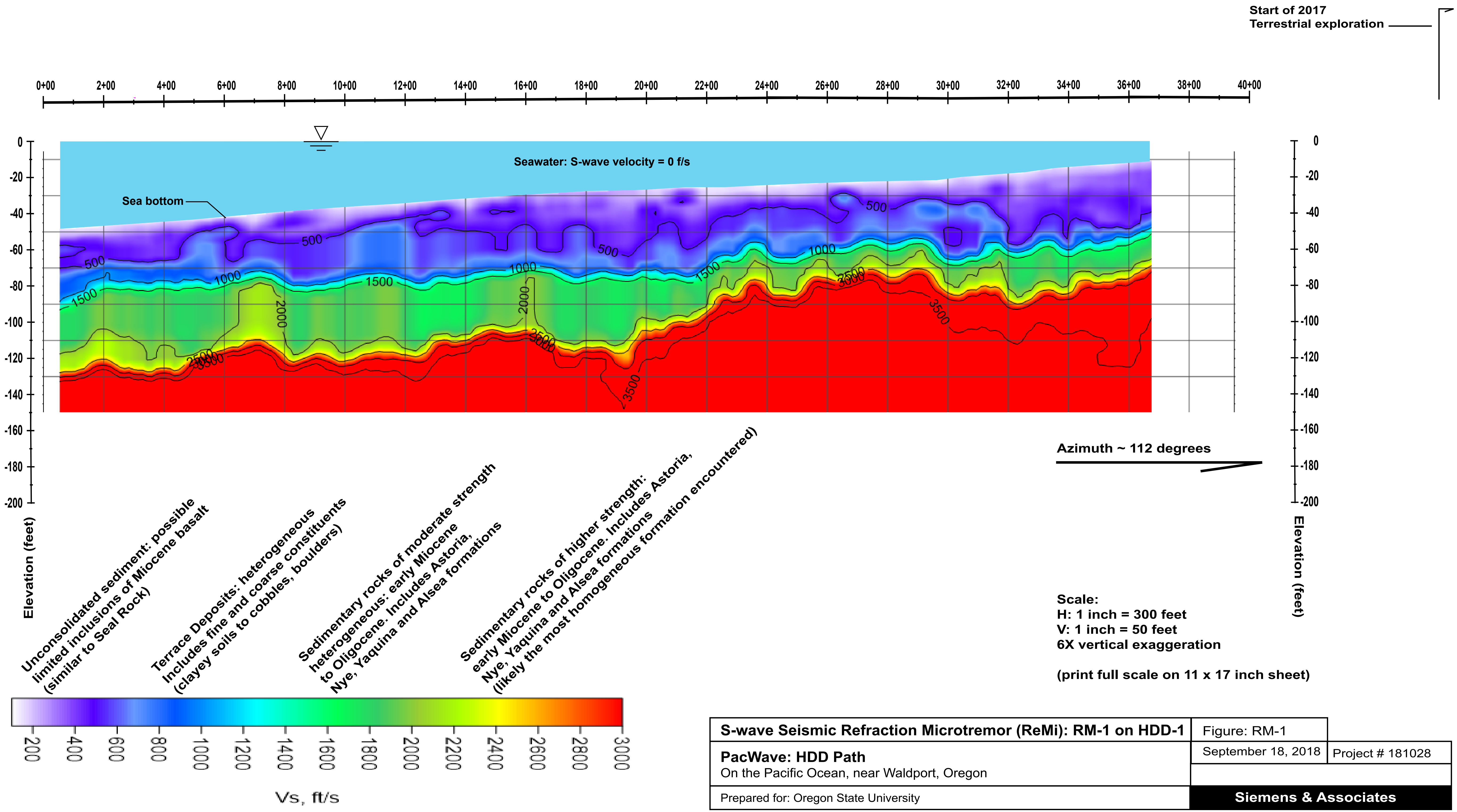


Resistivity in ohm.m

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**	

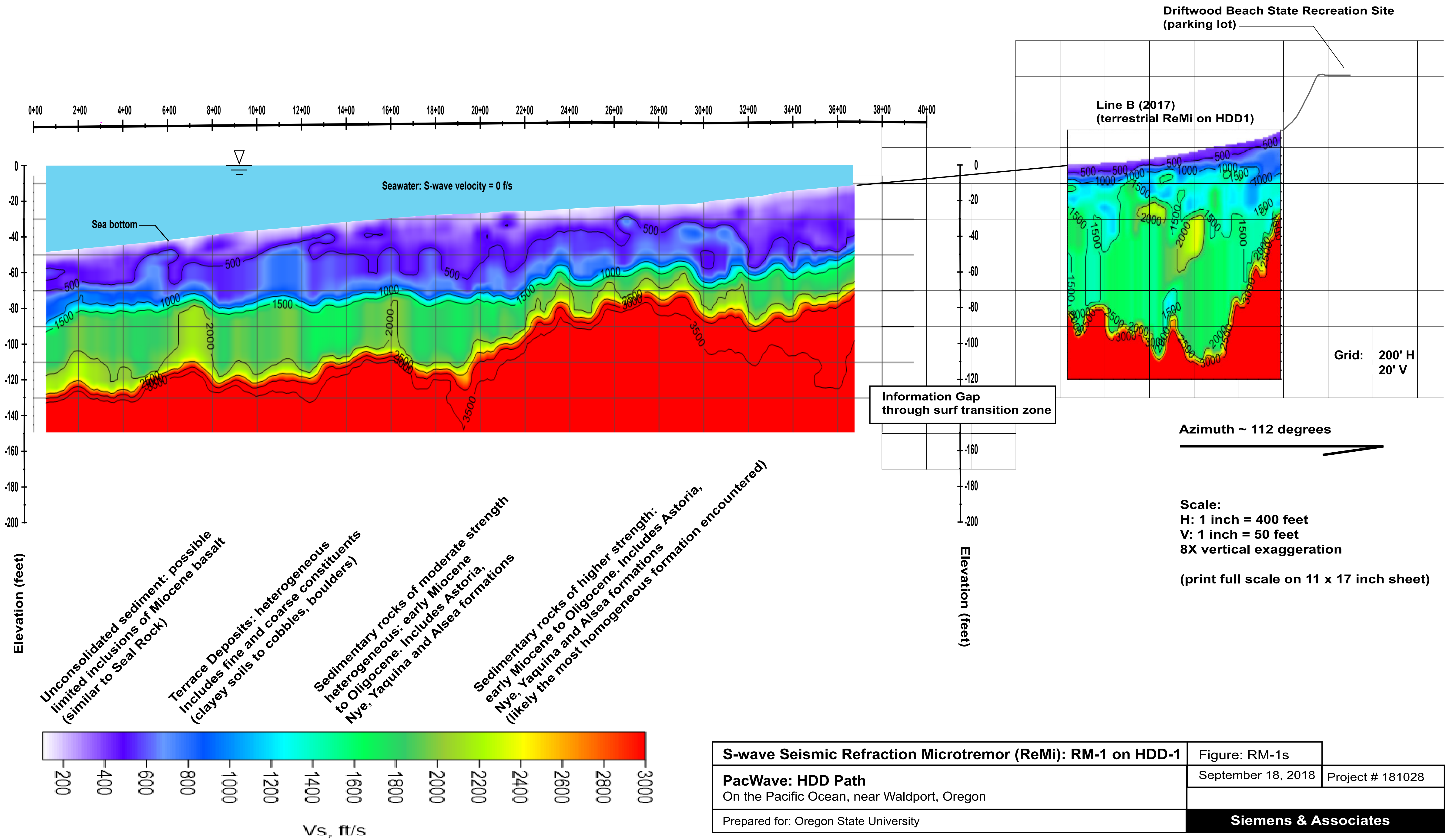
S-wave velocity: Seismic Refraction Microtremor: RM-1 on HDD1

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



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

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

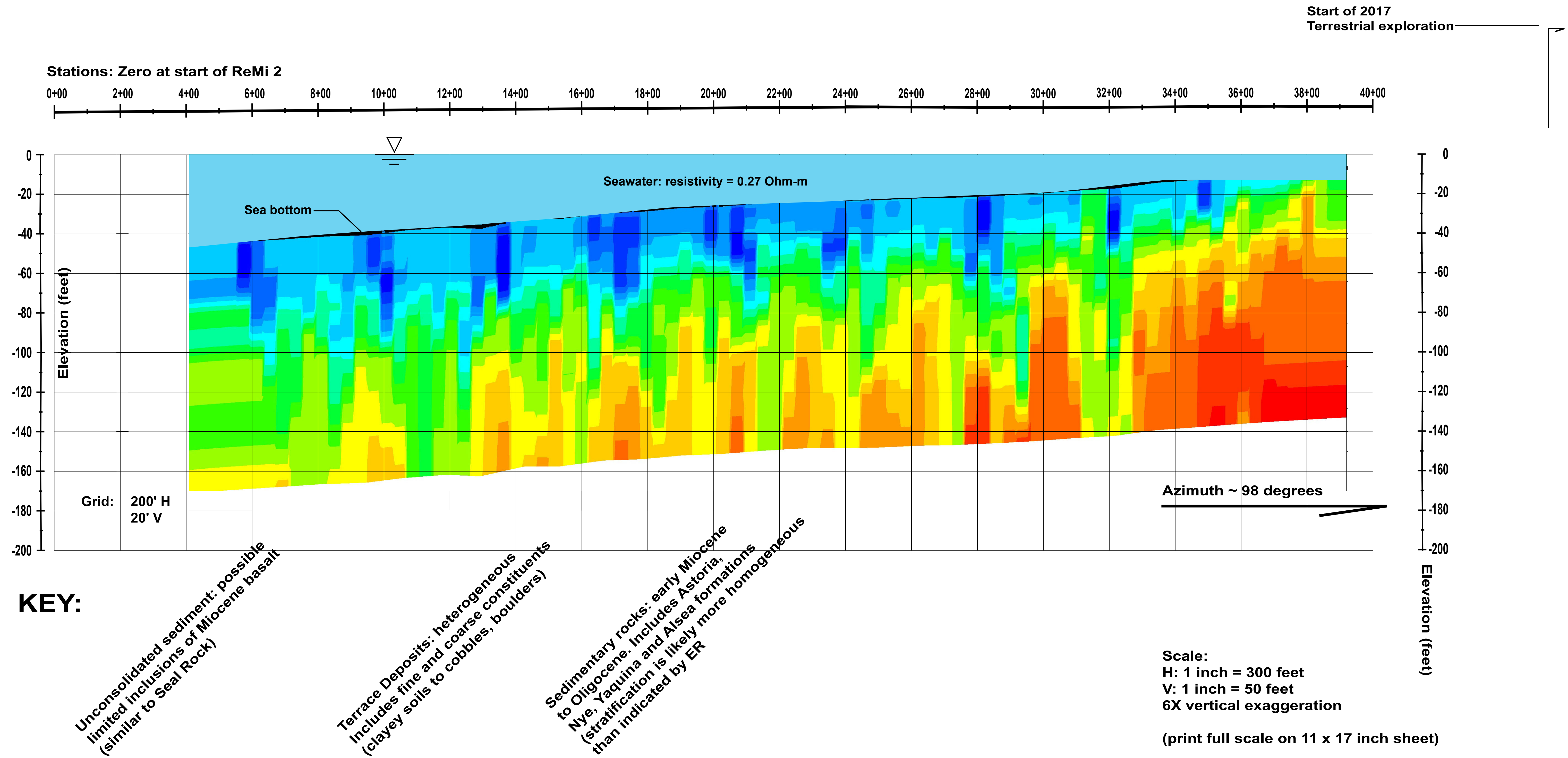


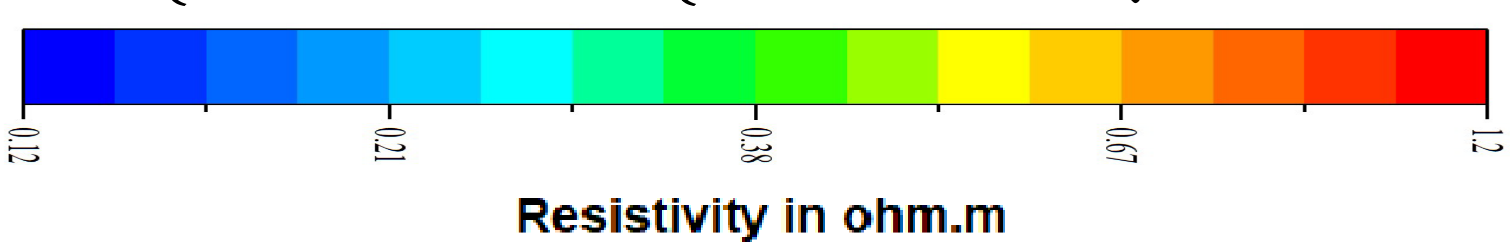
S-wave Seismic Refraction Microtremor (ReMi): RM-1 on HDD-1	Figure: RM-1s	
PacWave: HDD Path On the Pacific Ocean, near Waldport, Oregon	September 18, 2018	Project # 181028
Prepared for: Oregon State University	**Siemens & Associates**	

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)

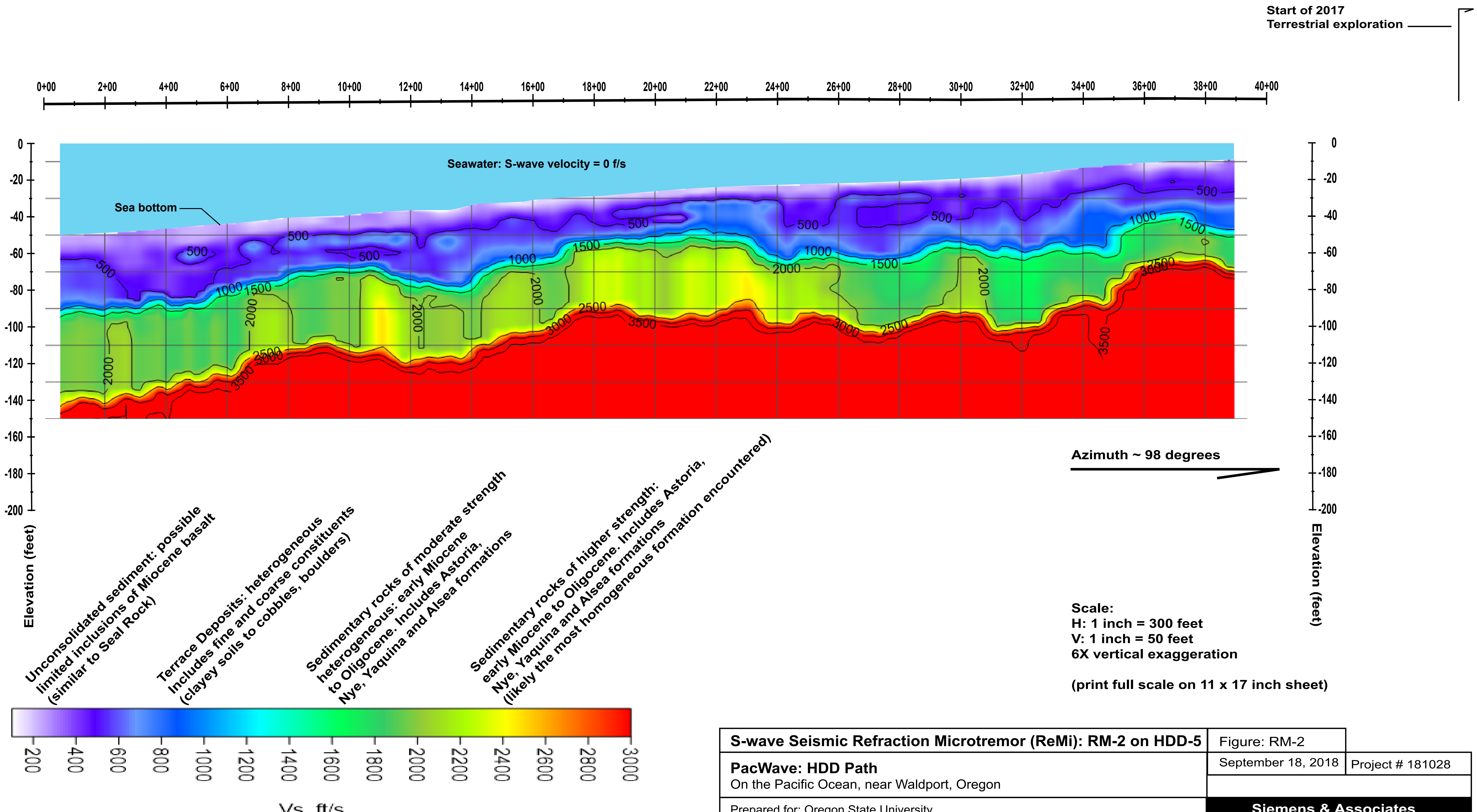




Electrical Resistivity Tomography: ER-2 on HDD-5	Figure: ER-2	
PacWave: HDD Path On the Pacific Ocean, near Waldport, Oregon	September 16, 2018	Project # 181028
Prepared for: Oregon State University	**Siemens & Associates**	

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)



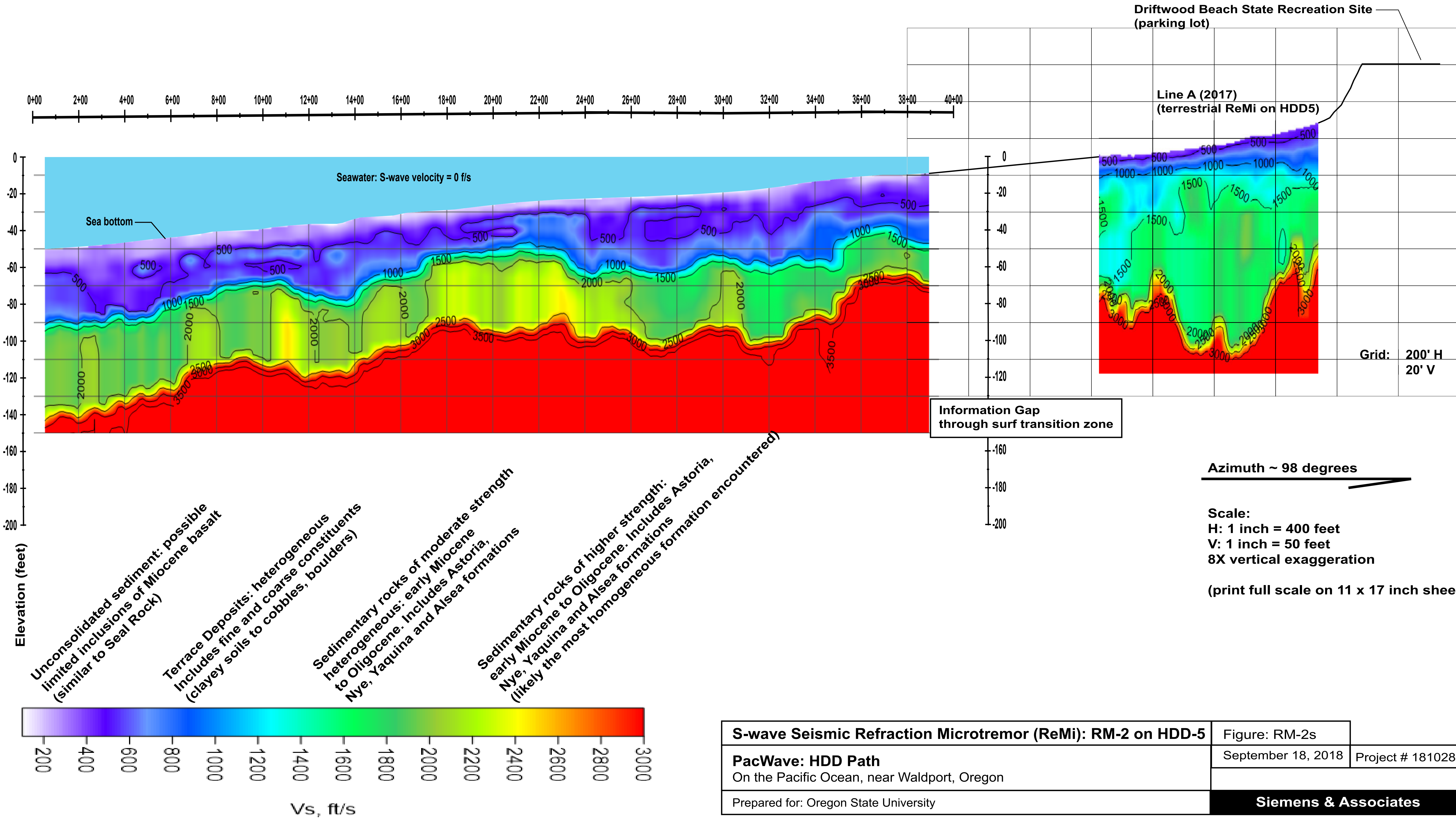
Scale:
H: 1 inch = 300 feet
V: 1 inch = 50 feet
6X vertical exaggeration

(print full scale on 11 x 17 inch sheet)

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**	