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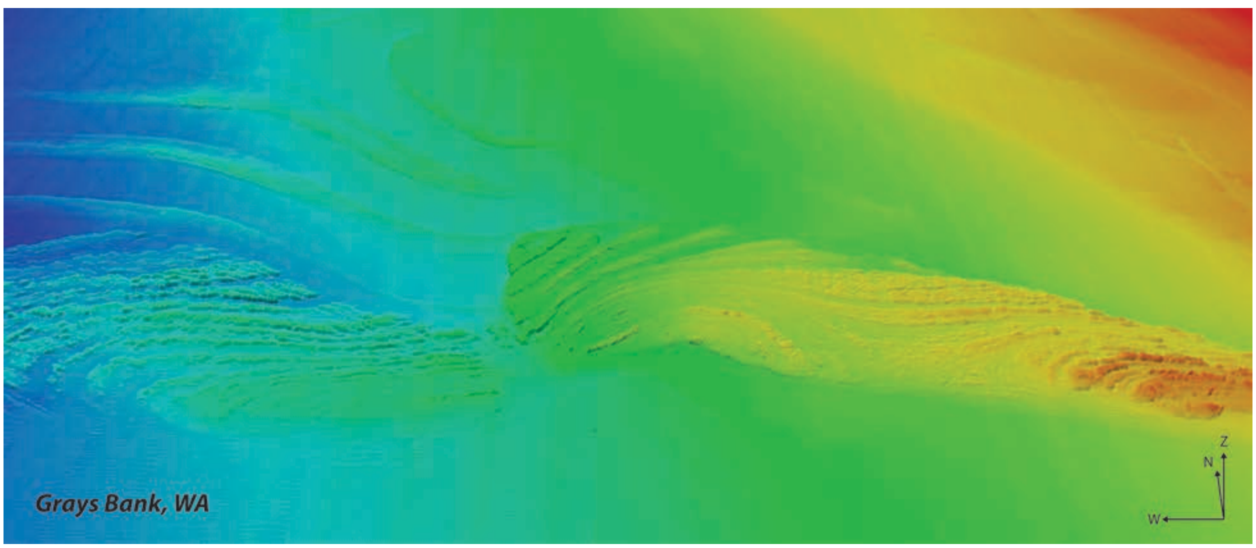
BOEM 2014-662

Benthic Habitat Characterization Offshore the Pacific Northwest Volume 1: Evaluation of Continental Shelf Geology



US Department of the Interior

Bureau of Ocean Energy Management

Pacific OCS Region

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Survey of Benthic Communities near Potential Renewable Energy Sites Offshore the Pacific Northwest

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Abbreviations and Acronyms

AT&SML	Active Tectonics and Seafloor Mapping Lab
BOEM	Bureau of Ocean Energy Management
CEOAS	College of Earth Ocean and Atmospheric Sciences
CMECS	Coastal and Marine Ecological Classification Standard
COR	Contracting Officer's Representative
CSE	Council of Science Editors
CTD	Conductivity, Temperature, Depth
DOI	US Department of the Interior
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EPA	US Environmental Protection Agency
ESP	Environmental Studies Program
ESPIS	Environmental Studies Program Information System
FRAM	Fisheries Resource Analysis and Monitoring
GIS	Geographic Information System
GPS	Global Positioning System
IMU	Inertial Motion Unit
MMI	Marine Mammal Institute
MLC	Maximum Likelihood Classification
NAMSS	National Archive of Marine Seismic Surveys
NGDC	National Geophysical Data Center
NMFS	National Marine Fisheries Service
NNMREC	Northwest National Marine Renewable Energy Center
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
OCNMS	Olympic Coast National Marine Sanctuary
OCS	Outer Continental Shelf
ODFW	Oregon Department of Fish and Wildlife
ONR	Office of Naval Research
OSU	Oregon State University
PO	Project Officer
PMEC	Pacific Marine Energy Center
RMS	Root Mean Square
ROV	Remotely Operated Vehicle
SETS	South Energy Test Site
SGH	Surficial Geologic Habitat
SWMP	State Waters Mapping Program
TPI	Topographic Position Index
USGS	United States Geological Survey
VRM	Vector Ruggedness Measure

1. Executive Summary

The wave and wind climates along the west coast of North America provide some of the best prospects for offshore renewable energy development, yet initial assessments of the seafloor have been patchy. The Bureau of Ocean Energy Management (BOEM) requires knowledge of the seafloor environment and of seafloor-associated (benthic) organisms that may be affected by renewable energy activities. This program of research on benthic habitats and organisms of the Outer Continental Shelf off Washington, Oregon and northern California was designed to provide baseline knowledge of seafloor geology and marine invertebrate distributions at a regional scale by undertaking new mapping, synthesizing existing mapping data, conducting biological assessments and developing new predictive models. By focusing on the physical properties of the seafloor and species-habitat associations throughout the region, this study has delivered tools and information directly useful for assessing renewable energy development in the Pacific Northwest and for determining the nature and extent of future seafloor explorations.

The Active Tectonics and Seafloor Mapping Lab at Oregon State University (OSU) mapped the seafloor at five sites during the summers of 2010 (four sites) and 2011 (one site) located 4.8 to 19 km (three to 12 miles) offshore. Bathymetry was mapped using high-resolution multibeam sonar, accurate to within a few centimeters resolution, and seabed hardness and texture were interpreted from multibeam backscatter data. Seabed grab samples were acquired from soft-bottom areas and analyzed using a laser diffraction particle size analyzer to identify relationships between grain size, the bathymetry and backscatter data. With this wealth of new seabed imagery and sampling data, the project team mapped 848 km^2 of seafloor. This significantly narrows the information gap for seafloor imagery in the region. Opportunities to partner with Oregon and California's extensive state waters mapping efforts, the National Science Foundation-funded Ocean Observing Initiative, National Oceanic and Atmospheric Administration's (NOAA) Ocean Explorer Program and the US Geological Survey accounts for a combined total of seven percent of the continental shelf now mapped in the study area. At 13 of these mapped sites, habitat maps were developed at a local-scale. Regionally, the Surficial Geologic Habitat (SGH Version 4) map of the continental shelf of Oregon and Washington has been extended to include northern California and updated with both the local-scale habitat maps over shelf areas and new mapping of canyons and channels in deep-water slope areas. An underlying map series representing data density and quality was updated and extended to accompany the SGH Version 4 map. A predictive rock outcrop model for the continental shelf extends was created from seismic reflection profiles, interpreted isocore and slope stability contours. This is a large update from previous rock outcrop maps and together with the SGH Version 4 map can aid in marine spatial planning.

Additionally we sampled benthic invertebrates, and the habitats in which they were found, to identify species-habitat associations and classify benthic habitats based on biological species groupings or assemblage distributions, rather than geological features alone. Rocky reefs and soft-bottom sediments such as sand and mud were classified and sampled separately. We visited three sites with rocky reef habitat using a remotely operated vehicle: Grays Bank, Washington, and Siltcoos and Bandon-Arago, Oregon during the summers of 2011 and 2012. Substrate type (on and off the reefs) was quantified and observed invertebrates living on or attached to the sediments (mega-invertebrates) were identified from the resulting footage. We found four main substrate associations of these mega-invertebrate assemblages: (1) pure sand/mud dominated by sea whips and burrowing brittle stars; (2) mixed mud-rock (which may be further divided based on size of mixed-in rocks) characterized by various species in low density; (3) consolidated rocks characterized by high diversity and density of sessile and motile mega-invertebrates; and (4) rubble rocks showing less diversity and density than the consolidated rocks. Mega-invertebrate assemblages found in both consolidated and rubble rock habitats were not distinct among sites; however, there were considerably more organisms observed on the rocks at Bandon-Arago than Grays Bank and Siltcoos. All four main habitat types were associated with mega-invertebrates that provided structure and complexity to the seafloor environment. Some taxa groups such as gorgonians and sponges, which are long-lived and slow growing, were found not just on rocky reefs but also were characteristic of the areas with smaller rocks around the reef. The four habitat classifications described above based on associated observed invertebrates are different than geological classifications and should be considered in future surveys as distinct seafloor habitats. Analysis of surveys done with distinct methodology from 1992-1995 supported many of these habitat classifications but also indicated that depth is a critical component to distinguishing among mega-invertebrates assemblages.

Prior to this study, invertebrate assemblages living on or in seafloor sediments (macrofauna) had not been comprehensively sampled since 2003. To sample macrofauna living in soft-bottoms, we visited the six originally proposed sites during summer 2010 and collected 118 macrofaunal and sediment samples across the region using a 0.1 m^2 box-corer. These samples were used for community characterization, analyzing organics in the sediment and ground-truthing the backscatter mapping results. We sampled two additional sites during the summer of 2012 to fill in latitudinal and habitat gaps. Sediment samples were sieved using 1 mm mesh and all macrofaunal organisms were identified and counted after a sub-sample of sediment was removed for particle size analysis. As expected, significant differences in species assemblages were observed when comparing sandy and silty habitats. Areas comprised of very high percentages of sand (> 87%) contained multiple significantly different assemblages, differentiated based on particle size. Additionally, depth-related changes were observed within sediment types, occurring at approximately 10 m depth intervals. Similar to the habitat associations of mega-invertebrates, these biological-based sediment classifications of habitat differ somewhat from the geologic classifications mapped. While the lithological classification of “sand habitat” is defined as having > 90 % sand, these analyses indicate that from the organisms’ perspective, this seemingly homogenous seafloor is actually multiple distinct habitats. Knowing how macrofaunal communities respond to changes in grain size and depth can inform future site surveys and led us to develop tools for mapping macrofauna based primarily on these physical factors.

Bayesian Networks were developed to statistically infer suitable habitat for seven species of soft-sediment associated benthic macrofauna along on the continental shelf of the Pacific Northwest. The final products are static Habitat Suitability Probability maps communicating areas along the shelf that are likely good habitat for species of interest. We also developed maps communicating error or uncertainty associated with the each Habitat Suitability Probability map. Models were learned from benthic macrofauna sampling data collected from the eight sites along the Pacific Northwest continental shelf. Netica software was implemented for the design and analysis of statistical models. A benthic macrofauna model structure was developed for reusability and update capacity. Modeling metrics were applied to ascertain the effectiveness of each model in its accuracy and robustness, aiding in the final model selection. This effort represents the first attempt to map any benthic invertebrate in the Pacific Northwest using a Bayesian Network model. Low uncertainty values, strong error measurements in the initial cross validation and field validation efforts all support this novel approach for mapping benthic species across large regions of the seafloor and have several applications that can inform future spatial and science-based planning.

This study provides BOEM with information on seafloor habitats and invertebrate communities to be used in consideration of Outer Continental Shelf renewable energy development. Because benthic resources are an important factor contributing to the production of benthic fish species and some commercial fisheries, this project provides important baseline data that can be used by other Federal agencies and states in their efforts to understand and manage marine resources. Data gathered from this project may be used in documents and analyses that are necessary for the National Environmental Policy Act. The regional scale of these data can aid in marine spatial planning efforts and provide a context for siting seafloor construction activities and future surveys. Overall, the information derived from this study has greatly contributed to the greater body of knowledge regarding seafloor habitats and biological communities in the Pacific Northwest.

2. Introduction to the Study

While the oceans of western North America hold great potential for the development of both marine hydrokinetic and floating wind renewable energy technologies, concerns have been raised about effects on seafloor-associated (benthic) organisms by the installation of devices and complex mooring systems. To predict potential effects of development on benthic resources, it is necessary to gather a baseline understanding of the distributions of benthic organisms and how they use the physical environment (habitat). However, little is known about natural species-habitat relationships and community processes in depths and substrate types targeted by renewable energy developers. While sedimentary habitats from the inner continental shelf to the slope in the Pacific Northwest are those most likely to be developed for offshore renewable energy, this portion of the seafloor is the least characterized. Further, the area of impact to benthic organisms could be larger than the direct footprint of development. Since sediment grain size often determines which animals can live in the sediment, changes to sediment movement due to ocean energy extraction or alterations of flow around large device arrays may affect the distribution invertebrate species that are dependent on grain size, near-bottom sedimentation and particle loads (Etnoyer & Morgan 2003). Studying benthic invertebrates is critical because although little knowledge of their assemblages exists, many serve important functional roles in maintaining biodiversity. Macrofaunal invertebrates modify the sediment and structure the habitat, making them key species despite their individual small sizes as well as serving as prey for upper trophic levels. Mega-invertebrates also provide food and additional structure to the seafloor that is utilized by other invertebrate and fish communities many of these species also used as indicators of stress or variability in long-term environmental conditions that might cause changes in community structures (Tissot et al. 2006).

The first step in evaluating benthic species-habitat associations is to understand the benthic habitat, which for this project is defined as the depth and surficial substrate (or lithology). Historically, there have been few surveys in the Pacific Northwest. In 1995-1998, the STRATAFORM project, initiated by the Office of Naval Research, resulted in thorough maps and sediment analysis of the continental slope and shelf between Trinidad Head and Cape Mendocino, California. In 1992-1996, geologists from Oregon State University (OSU) funded by National Oceanic and Atmospheric Administration's (NOAA's) National Undersea Research Program employed the manned submersible *Delta* to explore the continental margin of Oregon and Washington for tectonic and faulting activities, and other efforts by OSU scientists have mapped a number of the rocky banks offshore Oregon and Washington. More recently, Oregon and California have undertaken a large effort to map considerable proportions of their state waters. However, relatively small and isolated areas of mapping data are of limited use to resource managers until they are integrated into broader regional products. To conserve and enhance groundfish essential fish habitat on the west coast, in 2005 NOAA Fisheries worked with OSU, Moss Landing Marine Labs, and others to create the first comprehensive habitat map of California, Oregon and Washington (NOAA 2006, Romsos et al. 2007, Copps et al. 2008). The BOEM study described in this report (in collaboration with additional agencies and entities) surveyed many new areas of the continental shelf between state waters and offshore rocky reefs and significantly improved habitat maps for this region.

Establishing a baseline of benthic species-habitat associations over broad spatial and temporal scales is useful to marine spatial planning and as well as specifically to siting and evaluating offshore renewable energy development. Just as isolated mapping data was not sufficient for the groundfish EFH process, knowing that 100 worms were found in sand at one specific site does not alone provide the tools for resource managers to assess benthic resources or describe potential impacts from development. However, knowing the distributions of benthic invertebrates at a regional scale provides data applicable to cumulative impact assessments and context for project-specific surveys.

In this study we survey two major seafloor habitats known to support different species and sampled with different methods; rocky reef or consolidated rock areas and unconsolidated sediments such as sand or mud. Rocky reefs are associated with greater densities of sessile and structure-forming mega-invertebrates including long-lived sponges and gorgonians whose presences often are considered indicators of relatively stable habitat conditions. Rocky reefs also are associated with several commercial fish species. Although sandy or muddy habitats may comparatively seem barren, they are highly dynamic and host a high diversity of macrofaunal invertebrates, which also serve as prey for commercially important groundfish and crustaceans. The organisms living in and on the sediment have to contend with significant changes to their habitat as a result of wave action and ocean currents, making them generally resilient to disturbance. When species-habitat relationships are known (by evaluating both individual observations and regional analyses) data of the physical environment may be used to predict the habitat suitability for rock or sediment-associated species of interest.

The purpose of this project is to provide a regional understanding of the distribution and location of physical properties and invertebrates on the seafloor for Federal waters in the Pacific Northwest. By collecting this information for the first time in this region, this project provides predictive capabilities of where benthic invertebrate species of interest and unique communities may occur to inform decision-making regarding siting of facilities in areas where comprehensive surveys have not been conducted.

The following chapters step through the project components. Volume 1: Chapter 3 discusses the new seafloor mapping data collected at five sites as part of this project and how those new data were integrated, with both existing habitat maps and a backlog of un-interpreted datasets to develop new local-scale seabed habitat maps for 13 sites in Washington, Oregon, and Northern California. Additionally, Volume 1: Chapter 3 covers how the regional Surficial Geologic Habitat map for Oregon & Washington has been extended to include northern California and describes the development of other products such as a predictive model for rocky outcrops, slope stability, isocore, and data quality maps. Volume 2: Chapter 4 describes the ROV surveys of rocky habitats that were carried out at three newly mapped sites and also from the processing of video surveys conducted near those three sites in the early 1990s. We describe megafaunal invertebrate species assemblages and their substrate associations as well as consistencies and differences across sites and between the recent and historical surveys. Volume 2: Chapter 5 describes box core surveys and subsequent analyses to describe macrofaunal invertebrate species assemblages and associated habitat characteristics. Finally, Volume 2: Chapter 6 integrates the regional mapping products with the site-specific macrofaunal invertebrate data to develop habitat suitability maps for seven macrofaunal species across the entire region. Appendices 1 – 3 provide supplementary material for the mapping report (Chapter 3). Appendix 4 provides supplementary material for the ROV report (Chapter 4). Appendix 5 provides maps of significant macrofaunal assemblages at each of the 8 sites as described in Chapter 5. Appendix 6 provides supplementary material for the benthic macrofauna habitat suitability models (Chapter 6). Appendix 7 describes the online resources where data and products from this report can be accessed as well as the process by which voucher specimens of macrofaunal invertebrates have been submitted to the Smithsonian.

Because benthic invertebrates serve as a link between the physical seafloor environment and a more mobile fish and mammal community, they often are used as indicators to assess long-term environmental conditions that might cause changes in community structures (Tissot et al. 2006), such as sedimentation or pollution (Ranasinghe et al. 2009). Decadal scale shifts in the California Current affect the benthic macrofaunal communities in this ecosystem with warm regimes and associated declines in planktonic production resulting degradation of the community (Oliver et al. 2008). On shorter timescales El Niño events, which increase wave activity and storms (leading to sedimentation), can cause major, though short-term, disturbances to benthic communities. Thus, evaluation of this ecosystem must be made in the context of seasonal and climatic trends. Fieldwork for this project began in August 2010 with the previous El Niño event ending in spring 2010. Thus most biological data for this project were collected during La Niña conditions with 2012 surveys conducted during neutral conditions. Comparative historical data for rocky reef invertebrate observations were made in 1993 – 1995 and macrofauna data were from 2003, both considered mostly neutral time periods on the Oceanic Niño Index (based on ERSSTv3b data; Smith et al. 2008).

2.2 Literature Cited

Copps S, Parkes G, Wakefield W, Yoklavich M, Bailey A, Goldfinger C, Greene G (2008) Integration of geology and fish ecology to assess west coast essential fish habitat for groundfishes at the scale of the exclusive economic zone. In: Todd BJ, Greene G (eds) Mapping the seafloor for habitat characterization. Geological Association of Canada, p 439-450.

Etnoyer P and Morgan L (2003) Occurrences of habitat-forming deep sea corals in the northeast Pacific Ocean: A Report to NOAA's Office of Habitat Conservation. Marine Conservation Biology Institute, Bellevue, WA.

National Oceanographic and Atmospheric Assocation (NOAA) National Marine Fisheries Survey (NMFS) (2006) Final Groundfish Essential Fish Habitat (EFH) Environmental Impact Statement. Volume 2006, National Oceanic and Atmospheric Administration.

Oliver JS, Kim SL, Slattery PN, Oakden JA, Hammerstrom KK, and Barnes EM (2008) Sandy bottom communities at the end of a cold (1971-1975) and warm (1997-1998) regime in the California Current: impacts of high and low plankton production. Available from Nature Proceedings.

Ranasinghe J, Weisberg S, Smith RW, Montagne DE, Thompson B, Oakden JM, Huff DD, Cadien DB, Velarde RG, Ritter KJ (2009) Calibration and evaluation of five indicators of benthic community condition in two California bay and estuary habitats. Marine Pollution Bulletin 59 (1-3): 5-13.

Romsos C, Goldfinger C, Robison R, Milstein R, Chaytor J (2007) Development of a regional seafloor surficial geologic habitat map for the continental margins of Oregon and Washington, USA. In: Todd BJ, Greene G (eds) Mapping the seafloor for habitat characterization, Vol Special Paper 47. Geological Association of Canada p 209-234.

Smith TM, Reynolds RW, Peterson TC, Lawrimore J. (2008) Improvements NOAAs Historical Merged Land–Ocean Temp Analysis (1880–2006). Journal of Climate 21: 2283–2296.

Tissot BN, Yoklavich MM, Love MS, York K, Amend M (2006) Benthic invertebrates that form habitat on deep banks off southern California, with special reference to deep sea coral. Fisheries Bulletin 104: 167–181.

3. Seafloor Mapping & Regional GIS Report

3.1 Purpose

New technologies are being rapidly developed to produce renewable energy (wave, wind, etc.) to reduce our dependence on fossil fuels. The energetic continental shelf environment of the Pacific Northwest is particularly appealing for Marine Renewable Energy development (Figure 1), and large areas of the seafloor have the potential to be leased to developers for this purpose. An assessment of the impacts as a result on marine environments is legally required, but the lack of baseline data on the characteristics, distribution, abundance and condition of seabed habitats limits their accuracy. This knowledge gap also affects other aspects of Marine Renewable Energy development from the evaluation of technical device suitability to the impacts on biological resources such as fisheries. Here we present the results of our study to characterize and map benthic habits, specifically with respect to substrate type. Habitat in this chapter refers to the surficial geology of the seafloor. The objective is to better understand the relationships between marine species and benthic habitats they require, and attempt to use the data we acquire to determine if we can predict benthic habitat using related data. The results of this effort can then be used to more accurately assess the impacts of Marine Renewable Energy development.

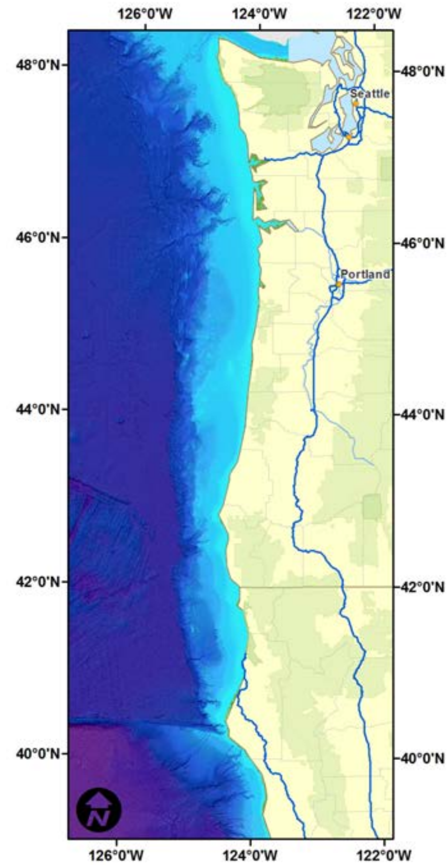


Figure 1. Project study area
The study area included the continental margin of southern Washington, Oregon, and northern California.

Historically, there have been few geologic surveys in the study region. In 1995-1998, the STRATAFORM project, initiated by the Office of Naval Research (ONR), focused on the region of the continental slope and shelf between Trinidad Head and Cape Mendocino, California. In 1992-1996, geologists from Oregon State University (OSU) funded by National Oceanic and Atmospheric Administration (NOAA's) National Undersea Research Program employed the manned submersible Delta to explore the continental margin of Oregon and Washington for tectonic and faulting activities (e.g., Goldfinger et al. 1997). Other efforts by OSU scientists have mapped rocky banks offshore Oregon and Washington, including the majority Oregon's state waters. From 2009 through 2011, a joint project of NOAA, OSU and two commercial partners was completed mapping approximately 47 % of waters from 10 m depth to three miles offshore (http://activetectonics.coas.oregonstate.edu/state_waters.htm). Limited mapping information is available on Washington's shelf and slope in part due to US Navy restrictions on mapping that were in effect until 2008. However, there are data in and around the Juan de Fuca Canyon, the Olympic Coast National Marine Sanctuary, and Puget Sound. Recently, California has completed high-resolution seafloor mapping survey of their territorial sea through a collaboration of the California Ocean Protection Council (OPC), the California Coastal Conservancy, the California Department of Fish and Game, USGS, California Geological Survey, California State University Monterey Bay, and NOAA.

Periodic large efforts have been undertaken to integrate geological, oceanographic, and fisheries datasets within the California Current Large Marine Ecosystem. Many of these datasets were compiled into a regional habitat map (WA & OR SGH Version 1.1) that was created for inclusion in the NOAA

Groundfish Essential Fish Habitat Environmental Impact Statement (Copps et al. 2008, NOAA 2006, Romsos et al. 2007). The Pacific Coast Ocean Observing System (PaCOOS) Marine Habitat Server (http://pacoos.coas.oregonstate.edu) and the EFH-Catalog (http://efh-catalog.coas.oregonstate.edu/overview) provide online access to integrated data for the nearshore Pacific Northwest, and includes the result of efforts by the Northwest Fisheries Science Center (NWFSC) – Fishery Resource Analysis and Monitoring (FRAM) Division and the Active Tectonics and Seafloor Mapping Laboratory (AT&SML) in the College of Earth, Ocean, and Atmospheric Sciences (CEOAS) at OSU with support scientists and staff from the University of Washington, Pacific States marine Fisheries Commission, and the Pacific Fisheries Management Council. Despite these efforts to integrate and map seabed habitats, key information needed for Marine Renewable Energy development is either not available, or available data in many areas is of inadequate resolution. Additionally, new mapping efforts in the region made it necessary to update existing regional information and extend analysis of Washington and Oregon into northern California.

To remedy this, we built upon existing datasets by collecting new data from key locations and integrating these results into a suite of data products designed to improve our understanding of seabed habitats at both local and regional scales. We acquired two general types of new seabed data: acoustic remote sensing data (multibeam sonar bathymetry and backscatter) and in-situ observational or reference data (seabed sediment samples and direct observations via ROV). From these inputs, and previously collected data, three principal data product types were developed: (1) local and regional scale seabed habitat type maps, (2) regionally predictive maps of sediment grain size, sediment thickness, and rock outcrop potential, and (3) a contextual map representation of data density and data quality. All products will be available in both digital hardcopy and web-service formats to support the varied activities of the BOEM with respect to Marine Renewable Energy planning and development (See Appendix 7).

3.1.1 Local- and Regional-Scale Seabed Habitat Maps

The desire to manage seafloor resources regionally has guided the development of the regional Surficial Geologic Habitat (SGH) maps since the first version was produced in 2002 (Goldfinger et al. 2002). The SGH map describes continental shelf and slope habitat types from northern California to the US/ Canadian border. Development of a regional map, like the SGH map, incorporates local scale site-specific products, often referred to as “postage-stamp” surveys, with datasets of broader or more generalized coverage as a compilation product.

Locating hard consolidated sediments and rocky outcrops, remains a primary motivation for developing SGH maps and a primary application of the SGH maps in management activities. We also employ predictive products and techniques to infer the presence of an outcrop where there is sufficient indirect evidence to support the outcrop prediction. Sources of indirect evidence include structure evident in seismic reflection or sub-bottom profile data over shelf environments as well as steep (>10 degrees) seabed slopes in regions below the Pleistocene low-stand shoreline. This study develops new local-scale habitat maps and advances our regional habitat map product to SGH Map Version 4.0 by incorporating both newly acquired survey data and existing survey data that was not widely accessible.

3.1.2 Regionally Predictive Seabed Maps

In our original efforts to develop a regional habitat map for the 2001-2005 review of west coast groundfish EFH we introduced two methods of rock outcrop prediction for data poor environments, (1) mapping of unstable surface slopes for deep-water regions and (2) mapping the likelihood of seabed outcrop from seismic refection profiles on the continental shelf where slope stability based methods do not apply. The continental shelf is a wave cut platform formed by numerous Pleistocene transgressive-regressive cycles. Because of this external sea level forcing, processes that generate and relieve steeper slopes through tectonism and mass wasting have only just begun to generate new topography on the shelf, and it is therefore unlikely to find features prone to slope failure. In this study we attempt to improve our regional understanding of where rock outcrop exists or is likely to exist by: (a) incorporating available local-scale habitat maps into a new regional map, (b) updating the data quality maps to reflect new survey and habitat work at local scales, (c) extending the slope stability predictive layer to include previously unmapped areas in Washington and Northern California, (d) extending our interpretation into Northern California of structural features having the potential to expose rock outcrops, (e) apply a new approach to predicting outcrop by mapping sedimentary units (where lithified rock should not crop out) from seismic reflection profiles, and (f) develop a predictive model of outcrop that draws from all of the products above. This approach resulted in four updated data products (a, b, c, & d above) and two new products (e & f above). A predictive map of sediment grainsize was also developed to support modeling benthic infauna (see section 6 of this report) but is restricted geographically to cover only the modeling footprint area (between 20 and 130 m water depth).

3.1.2.1 Incorporating local-scale habitat maps to update the regional map

The first versions of the SGH map, for Washington and Oregon, contained very few local-scale habitat mappings. In California the Center for Habitat Studies at Moss Landing Marine Labs had already completed a few local studies and had incorporated their work into the a similar regional map of California that together with the Washington and Oregon SGH map would provide the habitat map foundation for the 2006 EFH Environmental Impact Statement. In SGH Map Version 2 the Active Tectonics and Seafloor Mapping Lab began to incorporate local-scale map products; Nehalem Bank, Oregon was an early effort in SGH Map Version 2 and the Oregon State Waters Mapping Program products were incorporated at SGH Map Version 3.6. This effort provides a significant amount of new local-scale mapping over mid- and outer-continental shelf habitats, some of the more poorly known environments, and continues our goal of updating the regional map to include the latest in available high-resolution seabed mapping.

3.1.2.2 Data density and quality maps

Regional scale surficial geologic habitat (SGH) maps cover the entire seabed from the coastline out to the base of the continental slope (deeper than 3000 m). The SGH maps provide a habitat type classification (under various schemes) for any submerged point in the area just defined despite the knowledge that the underlying data is certainly patchy and of variable quality. This variable distribution and quality of input data translates to a regional habitat map of variable thematic quality. To describe this variable quality spatially a set of “data quality maps” has been maintained and distributed as companion to the SGH maps since Version 1.0. Due to the manual interpretive mapping methods used to develop the SGH map we take a first principals approach to estimating habitat map thematic accuracy and assume that the quality of the habitat map’s classifications are a function of density and type of underlying data.

3.1.2.3 Predicting rock outcrop from slope stability

Our deep water-rock outcrop prediction (Romsos 2004, EFH/EIS 2005) was based on a local surface slope criterion of 10 degrees, constrained by information from seismic reflection profiles, submersible observations, and core samples. The angle of repose of submarine sediments on exposed slopes varies with geomechanical properties such as cohesion, angle of internal friction, porosity gran size and shape, clay content and other factors (e.g. Morgenstern 1967, Janbu 1973). Lacking specific data to perform engineering analysis of regional surficial sediments, we estimated the effective maximum angle of repose from empirical observations using bathymetric data, submersible observations and high-resolution seismic reflection profiles. In particular, observational data from *DSV Alvin* submersible suggested that high slope areas, greater than 10 degrees, were likely to be areas of exposed rock.

This technique was first implemented in 1995 as part of a survey for a trans-Pacific cable route (Unpublished report to Pacific Telecom, Kulm, Goldfinger and McNeil 1995) when the Pacific Telecom cable parted at the spot predicted to have the roughest and steepest surface slope, causing a cable suspension above the seabed. This inadvertent test of the method showed the prediction to be similar to field observations, though undershooting the actual slope angle. Through this project we extend the deep-water slope stability predictive layer into area north of 46 degrees North latitude where previous naval restrictions on data access limited the data available for analysis. We also extend the slope stability layer south of 42 degrees North Latitude into the northern California study area.

3.1.2.4 Predicting rock outcrop from subsurface structure

High-resolution seismic reflection profiles may be used as aids is mapping rock outcrops as well as areas underlain by soft sediment deposits, and can be particularly useful in areas where no other data are available. Seismic interpretation techniques provide clues as they are capable of imaging eroded, faulted, or slump scarp surfaces. Additionally, the technique confirms the presence of depositional environments where hard rock outcrops are less likely to exist and vice versa.

Seismic reflection profiling uses a variety of sound sources to produce a two dimensional, subsurface image of stratigraphy. These images do not directly distinguish stratigraphic lithology; instead they provide a means to distinguish areas of rock outcrop from areas of sedimentary lithology by revealing exposed or "rough" stratigraphy. Other structural features such as tectonic deformations (anticlines, synclines) and faults may also be imaged using this technology and can aid in interpreting exposures of rock. Romsos (2004), Romsos et al. (2007) and EFH/EIS (2005) used this method to map rock probability along the seismic profiles, in conjunction with other data where available.

Most seismic profiling methods have limits to their ability to image the near surface due to masking of the uppermost materials by the first reflection of the seismic sound source from the seafloor. This masked region may extend from a few to tens of meters into the subsurface, making surficial interpretation problematic in some areas. In our initial work (Romsos et al. 2007), we mapped three classes of rock probability based on inspection of all available records: (1) high probability/certainty of rock; (2) probable rock; and (3) possible rock outcrop according to the criteria established for the continental shelf adjacent to Washington and Oregon. Rock was mapped as high or near certain probability if the surface reflectors were clearly part of a deformed area, clearly broke the seafloor and created significant topography, and clearly exposed older strata at and above the local seafloor. Areas of probable outcrop were areas where deformed older units approached the seafloor and appeared likely to break the surface, or had equivocal evidence for breaking the surface. Possible rock areas were similar to the above but surface evidence was completely masked by the seafloor reflector, rendering it impossible to differentiate between exposure of rocks and rock that was shallowly buried.

3.1.2.5 Predicting sediment thickness (minimum Isocore sediment thickness) from subsurface structure

In this project, we build upon on earlier work that supported the SGH maps Versions 1-3.X, specifically, by re-examining industry and academic seismic reflection data for the region we constructed a complimentary predictive layer for the study area (continental shelf only). In the original SGH mapping we focused solely on the positive identification of rock outcrop from structure evident in seismic reflection profiles. We did not consider (or record) sediment thickness near or between the mapped outcrops, yet this information is another component (negative evidence) that drives the likelihood of finding rocky seabed in an area. Furthermore, in the EFH/EIS study, the "possible" and "probable" predictive categories were dropped from the mapping scheme to simplify the maps and so the possible and probable rock classes were never implemented in any version of the SGH maps.

Here we construct a map of sediment cover using the original predictive outcrop mapping of Romsos et al. (2004), and including multichannel reflection profiles collected by USGS and Western GECO, available in the National Archive of Marine Seismic Surveys (NAMSS, http://walrus.wr.usgs.gov/NAMSS/), and proprietary seismic data acquired from Shell (high-resolution sparker), Chevron, Exxon (multichannel airgun) OSU academic sparker profiles and other sources. Four sediment thicknesses are mapped; 40, 60, 80 and 100 milliseconds two-way travel time (TWT). Thus the map represents a minimum Isocore sediment thickness, or true vertical thickness, rather than an Isopach map. Isopachs present sediment thickness within a geologic unit perpendicular to the unit boundary, or true stratigraphic thickness. Ultimately the new approach re-implements the missing probability categories of "possible" and "probable" and extends the probability range from "rock", "probable rock", "possible rock" to include "sediment basin". Further details are given in "Methods"

3.1.2.6 Predicting the likelihood of rock outcrop regionally

One of the goals of this Benthic Habitat Characterization survey is to use the available and newly developed mapping data to predict where hard seabed may occur within the study area. That is, a comprehensive continental shelf mapping program to locate and verify hard seabed substrates is unlikely in the foreseeable future. Yet, planning for and managing for ocean activities such as marine renewable energy could greatly benefit from knowing where hard seabed is likely or unlikely to occur. Therefore, we develop an expert model for integrating the data products just described. While a predictive model of seabed outcrop can't be certain or replace a site specific study, it can reveal were multiple sources of information indicate that outcrop is likely or not. It also provides a summary integration of the data products and example of how to interpret the information.

3.1.2.7 Modeling sediment grain size and composition

To support the benthic community study, models were developed to predict the mean grain size and percent sand composition of the study area. These predictive sediment grain size and % composition models improve upon the varied categorical classifications of sediment and habitat type available in the local and regional scale habitat maps and are more easily used as inputs to the benthic infauna modeling components.

3.2 Setting: Regional Geology

Interpretation of new and existing data shown in this report requires a regional geologic context. Fluctuating sea level, river sedimentation, sediment transport under gravity and wave loading, and the complex and active fault systems in the project area are the major drivers for surficial sediments. The Cascadia subduction zone consists of two small plates, the Gorda, and Juan de Fuca (JDF), subducting to the northeast beneath the North American plate (NOAM) (Figure 2). The subduction system is bounded to the north and south by triple junctions and includes the smaller Explorer plate to the north, which may not be presently subducting (Rohr and Furlong 1995). JDF-NOAM convergence is estimated as 40 mm/yr., directed 062° at 45° N. along the deformation front (rotation poles of DeMets et al. 1990). No active arc-parallel faults equivalent to the Japanese Median Tectonic Line (MTL) or Great Sumatran fault have been identified onshore in Cascadia. Snavely (1987) inferred that the Fulmar fault, a north-striking dextral strike-slip fault, offsets the continental slope and outer shelf in Oregon by about 200 km, and attributed an abrupt truncation of the basaltic Siletzia terrane to this fault. The Fulmar fault exhibits small offsets of Quaternary strata in southern Oregon, but was mainly active in the Eocene (Snavely 1987). Paleomagnetically determined clockwise rotations of coastal basalts in Oregon and Washington suggest that a process of dextral shear of the forearc has operated throughout the

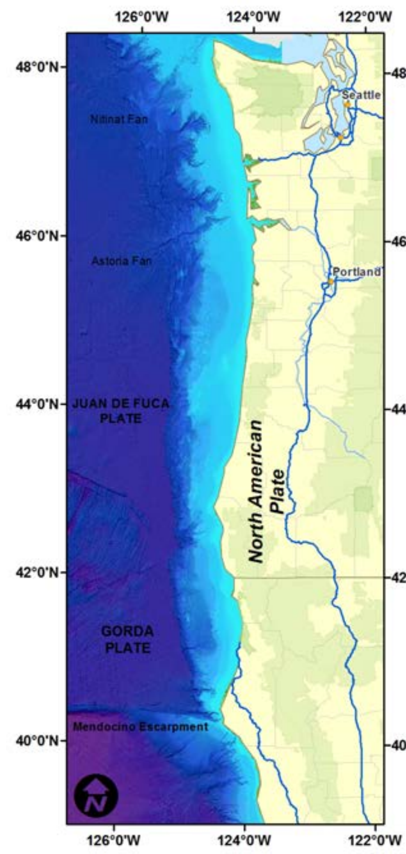


Figure 2. The tectonic setting of the Cascadia Subduction Zone

Tertiary. Miocene (12-15 Ma) Columbia River Basalts in western Oregon are rotated 10-30° clockwise, and Eocene Siletz River Volcanics rotated up to 90° clockwise (Wells and Heller 1988; England and Wells 1991). Mechanisms proposed to explain these rotations include microplate rotation during terrane accretion, basin and range extension, distributed small block rotation, or a combination (see Wells and Heller 1988 for summary).

The Quaternary portion of the accretionary wedge is widest off the Washington and northern Oregon margins, coincident with the accretion of the thick Pleistocene Astoria and Nitinat Fans (Carlson and Nelson 1987), and narrows to the south. The active accretionary thrust faults and folds of the lower slope are characterized by mostly landward vergent (LV) thrusts on the Washington and northern Oregon margins and seaward vergent (SV) thrusts on the central and southern Oregon margin (Mackay et al. 1992, Seely 1977, Goldfinger et al. 1992). Virtually all of the incoming section in the LV province is accreted to the margin above a deep décollement, whereas a shallower décollement in the seaward vergent portion of the margin results in accretion of the upper two-thirds of the incoming stratigraphic section and subduction and/or underplating of the lower one-third (Mackay et al. 1992). In addition to the SV and LV thrust faults and folds that comprise the Cascadia accretionary wedge, nine WNW-striking left- lateral strike slip faults (Goldfinger et al. 1997) also cut across the lower slope of the wedge. These faults form in the lower plate as a result of dextral shear of the forearc, due to the oblique subduction, and propagate upward into the accretionary wedge through time. The outermost accretionary wedge abuts a steep slope break that separates it from the Eocene oceanic basalt Siletz terrane that underlies the continental shelf off the central Oregon to southern Washington margins (Snavely 1987, Trehu et al. 1994). Above this oceanic basement terrane is a modestly deformed Eocene through Holocene forearc basin sequence (Snavely 1987, McNeill et al. 2000).

Structural geology of the Cascadia continental shelf (generally < 200 m depth) and stratigraphy has been interpreted by Snavely (1987), Niem et al. (1990), Goldfinger (1994, 1997), McNeill et al. (1999) and McCrory et al. (2002). The Oregon continental shelf was subjected to multiple Pleistocene transgressive/regressive cycles during the sea-level fluctuations caused by glacial advance and retreat. The last transgressive/regressive cycle left a widespread unconformity over which a thin Holocene sequence of transgressive sand and gravel was deposited on the middle to inner shelf, and a hemipelagic mud deposited on the middle to outer shelf (Kulm et al. 1975, Peterson et al. 1984). The age of the underlying strata ranges from Pleistocene (conformable in some locations on the middle to outer shelf) to Eocene and older on the southern Oregon inner shelf (Kulm and Fowler 1974). This unconformity represents a relatively low-relief and generally seaward-dipping surface, and thus serves as an effective strain marker for latest Pleistocene and Holocene deformation. This erosional event is time-transgressive over the shelf. The last sea-level minimum of 110-130 m below modern sea-level occurred approximately 20,000 -22,000 years ago (Stanford et al. 2011), with sea-level rising to within a few meters of present level by about 7000 years ago (Curray 1965, Blackwelder et al. 1979, Chappel and Shackleton 1986, Fairbanks 1989, Matthews 1990, Stanford et al. 2011). Thus tectonic activity that deforms this surface has a maximum age of about 22,000 years. Deformation of the Holocene shelf sand or mud on the inner shelf (< 40 m) has a maximum age of about 9000 years. Deformation of these sediments on the inner shelf is less common, and more difficult to detect, as water depths less than about 150 m are subject to active erosion and sediment transport by bottom currents and storm waves (Komar et al. 1972). In some areas of the inner shelf where sediment supply is low, recent sediments are thin and patchy or altogether absent. Deformation mapped in these older rocks is difficult to evaluate without younger sediments to reveal young offsets, however faults can be evaluated in terms of late Quaternary deformation by satisfying one of several possible criteria: 1) The fault deforms surficial materials; 2) The fault can be traced seaward into deep enough water that a Holocene scarp in unconsolidated sand or mud is preserved along the same structure, 3) the fault can be correlated to a known onshore fault that offsets late Quaternary deposits.

3.2.1 Structure of the Central Oregon Continental Shelf

On the middle to inner shelf (< 80 m) deformation rates are generally slower than on the accretionary wedge, and the interplay between tectonics and sediment transport and erosion is more important. Deformation on the continental slope steepens the bathymetry creating a topography where slope failures may expose rocky stratigraphy. On the continental shelf, a relatively flat erosional feature, process that expose or cover rocky features may be driven by tectonic, sedimentary, erosional, or some combination of each process.

The nearshore structure is dominated by folds and faults related to Miocene and younger compression along the Cascadia subduction plate boundary. Goldfinger (1994) mapped two sets of Neogene through Holocene structures. The older structures have NNW-NNE trends and are exposed in nearshore reefs such as the Seal Rock reef, Stonewall Bank reef (Yeats et al., 1998), Siletz Reef, Nehalem Bank, and Heceta Bank. The seafloor expression of these reefs is commonly exposed and eroded strike ridges sub-parallel to the fold axes. These strike ridges are generally composed of probable Miocene-Pliocene Astoria formation units of siltstones and sandstones and are resistant enough to erosion to exhibit emergent strike ridges. Further offshore, structures evident at the surface and near subsurface are NW trending folds and associated faults intersect the older folds ant high angles. The relationship between the younger and older folds is not completely clear. It may be that the older folds have been rotated through time (see Wells 1990) and are beginning to be overprinted by younger structures oriented normal to modern convergence as shown in Goldfinger et al. (1994, 1997). Both older and younger structures are deforming the modern sea floor as folding continues to deform the modern and relict Pleistocene wave cut platforms. The deformation commonly is of the form of numerous flexural slip faults (Yeats 1986). These shallowly rooted faults invert the topography of the local seafloor as the synclinal axes are uplifted through bedding plane faulting (Figure 3). The recent subbottom and boomer surveys show that many of these faults are active, deforming the modern seafloor and transgressive gravel layer. Typical offsets are ~ 1-2 meters. If the deformed surface is assumed to be completely eroded and ~ 15,000-18,000 years old, corresponding to the Last Glacial Maximum (LGM) and rapid transgressive phase, the slip rates of these faults are on the order of 0.05-0.13 mm/yr. Slip rates would be lower in the event of some offset surviving the post LGM transgression. Numerous faults of this type are in the study area.

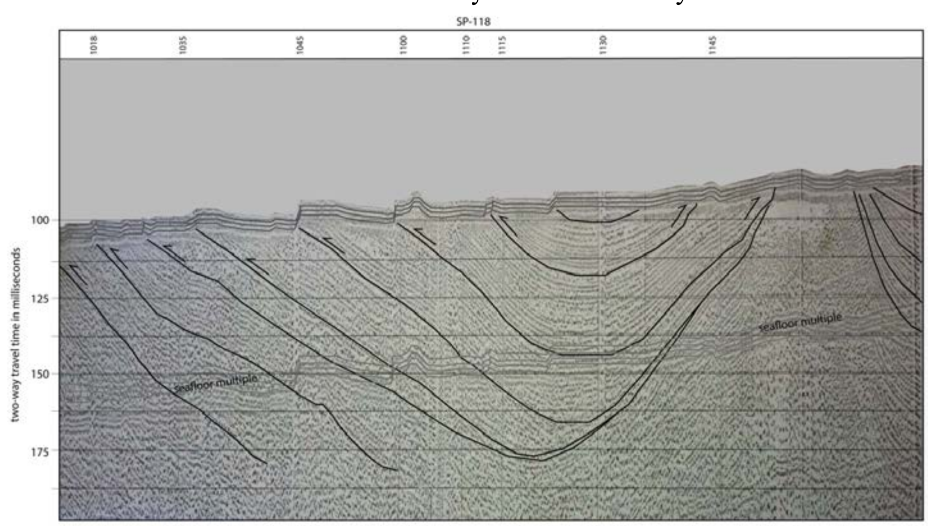


Figure 3. An example of typical flexural slip faulting style ubiquitous on the mid to inner shelf in the study area
Continued folding after the last glacial maximum (LGM) regression/transgression deforms the modern seafloor and creates a topographic inversion (syncline axis is up rather than down). This topographic inversion is important because bathymetric and structural maps cannot always be used directly to infer the locations of sedimentary basins. Image is a seismic reflection sparker profile from the 1960's (SP-118, unpublished at OSU).

The erosion surface is relatively rough topography in the shallow subsurface that comprises buried channels and other subaerial erosion features such as sea stacks, sea cliffs, exposed strike ridges and other features (Figure 4). A common feature of the erosion surface is lag gravel, typical of transgressive surfaces. This gravel is imaged in shallow seismic data, and is exposed in a number of "windows" through the overlying sand or gravel sheet that are clearly evident in the backscatter data. These windows are observed coast wide and have been termed "ripple scour depressions" (Cacchione et al. 1984, Thieler et al. 1998; Hallenbeck et al. 2012). Samples collected in 2009-2011 show mostly gravel and coarse sand in these windows on the central Oregon shelf. Other faults and intrusions are observed locally.

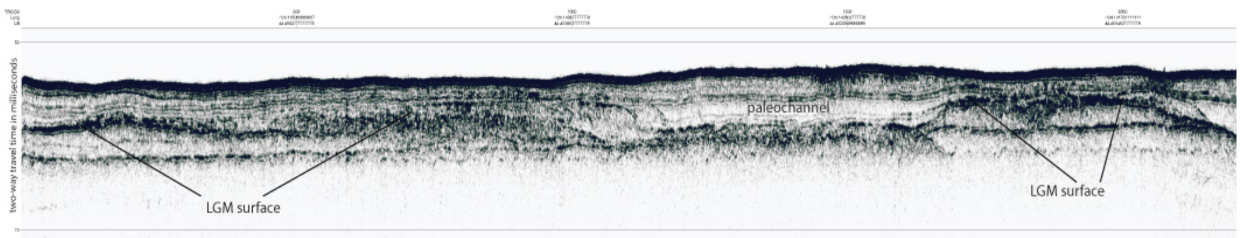


Figure 4. Chirp subbottom profile in the vicinity of Newport, Oregon
Near surface sediments cover a strong reflector interpreted to be the last glacial maximum (LGM) erosion surface. This rough surface was the subaerial land surface during the last lowstand, and comprises subaerial erosion features, stream channels, and transgressive features such as sea stacks and paleo seacliffs. A paleochannel is shown in this CHIRP sub-bottom profile image (OSU, Pacific Marine Energy Center, unpublished data).

3.2.2 Structural or Wave Control of Ripple Scour Depressions?

Seafloor features called "rippled scour depressions" were first described on the inner continental shelf off northern California in the early 1980's (Cacchione 1984). In the northern California examples, the fine-to-medium sand shelf surface of the inner shelf is interrupted by elongate depressions with low relief (< 1 m) extending shore-normal to slightly oblique in water depths from 20-70 m (Cacchione 2005). Similar features have been mapped elsewhere (i.e. Trembanis et al. 2011). The northern California depressions vary widely from 50-500 m in width, have sharp sidewalls and have one wall marking a sharp contact between the fine to medium sand and the other less distinct and irregular. The coarse sand and gravel exposed in the depressions is arranged in ripples with crests aligned normal or slightly oblique to the sidewalls (Cacchione 2005). The large ripples are thought to be generated by wave-induced bottom stresses during storms, and are commonly erased or reset during high wave episodes. Recent work has shown that ~ 3.6% of the shelf within California State waters (Davis et al. 2012, Hallenbeck et al. 2012), and that there is an increased frequency of RSD's near rocky reefs. The RSD's thus comprise an important component of hard substrate in the California shelf.

Along the Oregon shelf, recent surveys including data from the Oregon State Waters Mapping Program (ORSWMP; e.g. Kane et al. 2011, Erhardt et al. 2011) show numerous depressions similar to those reported off Northern California. These depressions have been mapped as hard substrate, but were not explicitly distinguished from other hard substrates in the Oregon State Waters habitat maps. To date, we have not observed ripples in these depressions, which appear to be mostly coarse sand and gravel, supported by targeted grab sampling. Not enough data exist to show whether the sidewall sands interfinger with the gravels or are in sharp contact, but morphologically they appear sharp and otherwise similar to the Northern California examples. Many of the Oregon examples also lack a preferred trend relative to the coast or prevailing wind and wave environment as noted for the northern California examples. Given these differences, it remains unclear whether the Oregon depressions are the same as their Northern California counterparts.

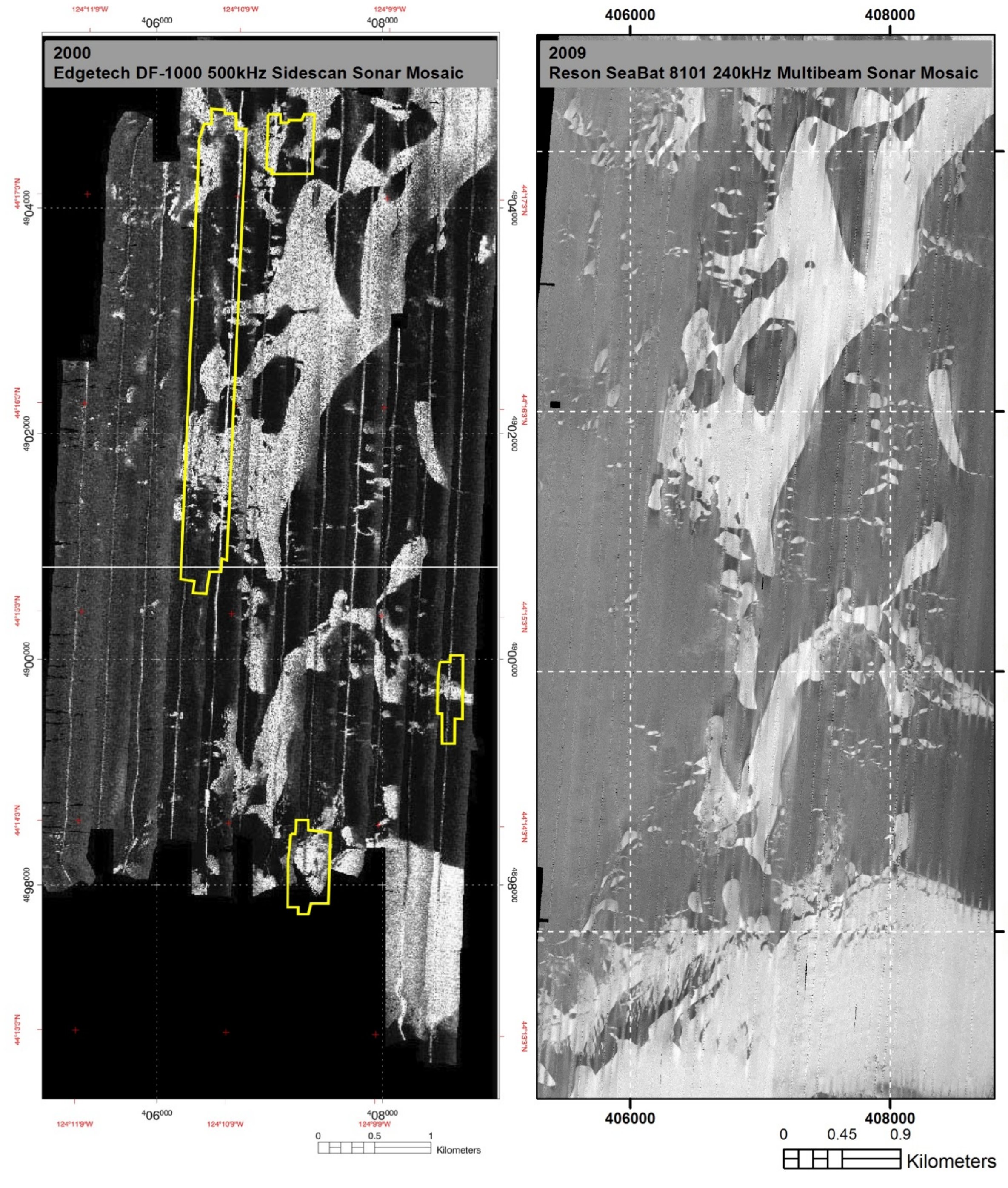


Figure 5. Repeat backscatter surveys (2000 left & 2009 right) at Cape Perpetua, Oregon
Repeat surveys spanning nine years show little if any change in scour depression location. Bright backscatter intensity areas in the northern and central portions of the imagery are known to be scour depressions from bathymetry and ROV observation. Backscatter image on left from Fox et al. 2004.

We note that in repeat surveys in the Cape Perpetua area (Figure 5), the depressions mapped in water depths of 45 m to 50 m in two surveys in 2000 and 2009, nine years apart show that the depressions are in the same positions at these two times, with very little change in morphology (Figure 5). We found this surprising given the interpretation of the northern California depressions as generated by storm waves.

Thus the Oregon versions should probably not be termed "ripple scour depressions" as they are neither rippled, nor do they show clear evidence of scouring by waves as they may have remained fixed in position over time. We note that the Oregon depressions appear to have an association with shallow subsurface structure or topography, suggesting that they may be linked to these features. Although this study (and the Oregon State Waters Program) did not explicitly study these features, they are discussed in some detail in the Newport area in a subsequent section.

3.2.3 Temporal Change in Surface Sediments

Seabeds at water depths of less than about 150 m are subject to active erosion and sediment transport by bottom currents and storm waves (Komar et al. 1972). At depths greater than 150 m, only rare tsunami waves (down to ~ 450 m; Goldfinger et al. 2012) and potentially internal waves can externally disturb bottom sediments. Otherwise, processes are generally dominated by hemipelagic sedimentation, disturbance and slope failures related to tectonicsm and earthquakes (Goldfinger et al. 2012). On the inner shelf (< 40 m) anecdotal information from local crab fishermen (Bob Eder, Ronald Briggs pers. comm.) suggests sand mobility is high in this region. Some crab fishermen, primarily in a depth range of ~7-30 m, use a "pot pump" to hydraulically pump out crab pots that have been buried during their deployment. Such burials can be up to a meter, and possibly more in rare cases. Our repeat bathymetric surveys at Redfish Rocks (southern Oregon coast, 30 m and shallower) in the summer of 2008 and late spring of 2009 (Amolo 2010) support this level of sand mobilization between summer and winter months, where variability of 0-1.5 m is apparent (Figure 6). Greater mobility may exist in some areas, but no documentation that we are aware of exists for this. The lack of movement of the scour depressions in the Cape Perpetua area (Figure 5) suggest otherwise, however the repeated surveys were not exactly equivalent, the first being sidescan only with no bathymetric information.

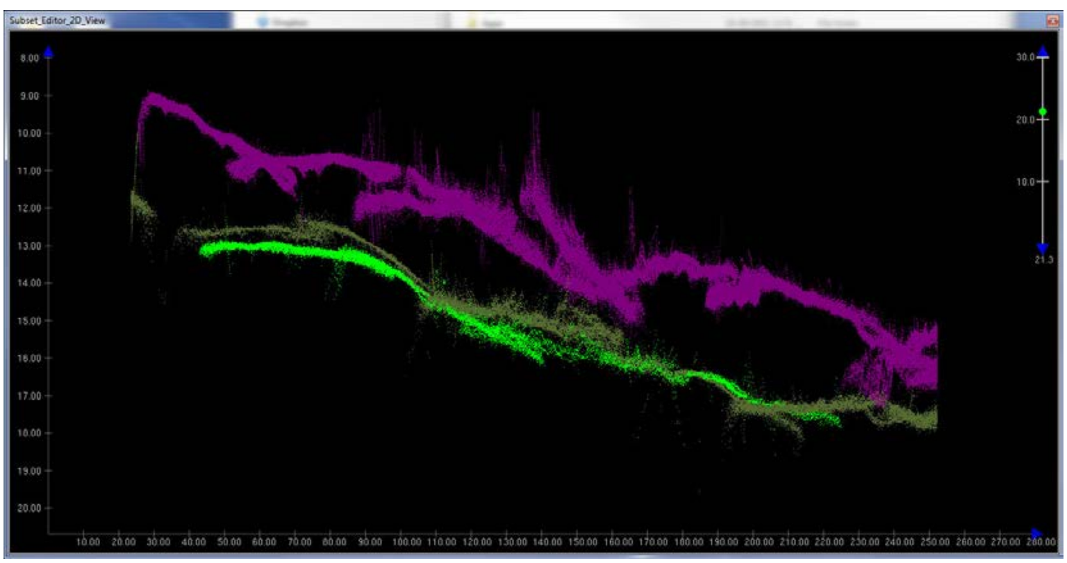


Figure 6. Vertical offset in repeat surveys at Redfish Rocks, Oregon
An approximate two meter offset is observed between the 2008 survey (green) and 2009 survey (purple) soundings at Redfish Rocks, Oregon. The offset is presumed to be caused by seasonal migration of nearshore sands. Data provided by the Port Orford Ocean resources Team, Golden Marine Consulting, and Seavisual Inc.

3.2.4 Possible Methane Venting and Carbonate Deposition

Methane vents are common on active continental margins, and Cascadia is well known to have numerous such vents (Trehu et al. 1995, Suess et al. 2001, Johnson et al. 2003). The continental shelf of Oregon, at depths shallower than 160-200 m, is entirely above the gas hydrate stability zone (~ 550 m and deeper). Venting on the shelf therefore is not indicative of shallowly buried gas hydrates, but rather of direct venting of biogenic gas. Such venting occurs along fault zones, scarps from submarine landslides and other geologic features. On the shelf, such vents can appear at the surface venting through pits in the surface sands. Examples of methane vents are discussed in Johnson et al. (2003), Goldfinger et al. (1996) and many other resources. A byproduct of methane venting can be deposition of carbonates (Kulm and Suess 1990). These carbonates are extremely hard rocks that are found widely scattered on the Oregon margin (Schroeder et al. 1987). Carbonate deposition related to venting is commonly imaged in backscatter and sidescan data given its high acoustic reflectivity, thus backscatter mosaics are effective tools for evaluating the potential occurrence of surficial carbonates. In the backscatter images of the shelf study sites, we observe few "pockmarks" which are the backscatter signature of gas venting and sometimes associated with carbonate rocks in deeper water. More details of the site specific geology are given in the site results sections below.

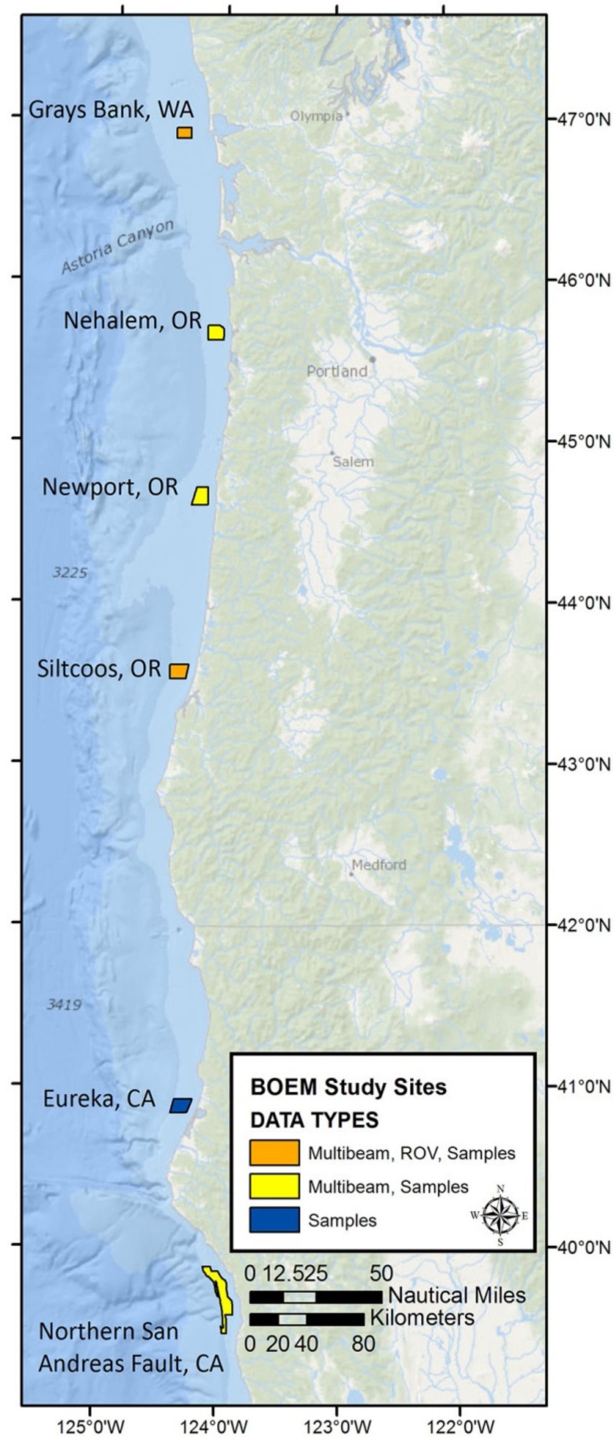


Figure 7. Distribution of BOEM study sites
Colors indicate the type of data collected at each for the Survey of Benthic Communities near Potential Renewable Energy Sites Offshore the Pacific Northwest.

3.3 Methods

3.3.1 Local-Scale Mapping

High-resolution multibeam sonar and seabed sediment sampling surveys were implemented at key study sites (Figure 7) to acquire seabed imagery and reference data. Survey operations were conducted during the summer months of 2010 and 2011. Digital and hardcopy bathymetry and backscatter data products (maps) were developed directly from this survey work. Site maps were later classified into local-scale maps of seabed habitat type by supervised and expert image classification guided by the seabed reference samples and video imagery collected as ground-truth.

3.3.1.1 Vessel

The 85-foot *R/V Pacific Storm*, owned and operated by OSU's Marine Mammal Institute (MMI), was contracted as a mapping vessel for the survey. Installation parameters and equipment offsets were known for this vessel from previous work on the Oregon Territorial Sea Mapping Program and translated into a significant mobilization time savings overall. The *R/V Pacific Storm* accommodates up to seven scientists and is capable of 24-hour operations with a four-person ship's crew. Custom mapping modifications (Figure 8) on this vessel include an articulated (aft-pivoting) sonar pole with break-a-way waterline crutch, clear sky view overhead antenna mounting bar for high-precision GPS antennas, computer racks with 30-Amp, 110V service, ComNav autopilot and coupled Furuno GPS compass, and a mount for the Applanix Inertial Motion Unit (not shown). As stated all equipment installation locations and fixed mounting offsets had been previously determined through a professional vessel survey by David Evans and associates in July of 2009.

Figure 8. The *R/V Pacific Storm*, owned and operated by the Marine Mammal Institute at Oregon State University, was utilized as the multibeam mapping platform for this study
Note the 20' 6" diameter stainless steel articulated sonar pole (in the up position) just aft of the house on the starboard side.

3.3.1.2 Equipment

OSU's Active Tectonics and Seafloor Mapping Lab (AT&SML) provided a NavCom SF-3050 StarFire™ GPS with an ALL-AREAS (Global) correction service subscription providing decimeter precision horizontal positioning. An Applanix POS MV 320 Inertially-Aided Real-Time-Kinematic motion reference unit, Seabird SBE-19Plus CTD, Reson SVP 70 sensor, and Reson Sea-Bat 8101 multibeam sonar (280 kHz) with snippets backscatter were leased from Harvey-Lynch Inc. of Stafford Texas. AT&SML provided the CARIS HIPS and QPS FMGeocoder Toolbox© (FMGT) for bathymetric and backscatter processing.

3.3.1.3 Multibeam Operation

OSU AT&SML staffed the mapping vessel for the 2010-2011 seasons. The science team was overseen by Chris Goldfinger who managed the program, supervised students, technicians and the completion of the project, including participation in seagoing legs as needed. At sea, two 12-hour watches were maintained for round the clock operations. Watches consisted of two student multibeam operators and chief scientist (either Sr. Faculty Research Assistant Chris Romsos or Principal Investigator Chris Goldfinger). The chief scientist directed daily mapping operations, supervised students, and directed mobilization and demobilization operations. Sr. Faculty Research Assistant Chris Romsos also managed data handling, backups, and the processing scheme at OSU.

Vessel motion was measured by an Applanix POS/MV 320 inertial measurement unit during all surveys. The POS/MV system utilizes and an inertial motion unit (IMU) and L1 and L2 carrier phase measurements from multiple GPS antenna arrayed on the vessel to produce an Inertially-Aided Real-Time Kinematic (IARTK) attitude and position for the vessel. The system is used for ships position, heading, and to determine roll, pitch, yaw attitude as well as heave. The Reson 8101 utilizes real-time roll data supplied by the POS/MV, to beam steer outgoing pings such that they are formed normal to the seabed. A NavCom StarFire SF 3050 GPS system was used as the primary position system (primary GPS) input for the POS/MV. The NavCom Starfire system is a commercial satellite based differential system known as GSBAS (Global Satellite Based Augmentation System). Access to the system is though a subscription service providing positional accuracy of ~ 10 cm horizontal, and 15 cm vertical worldwide. Use of the GSBAS system eliminates the need for land based base stations, or location dependent differential signals such as the Coast Guard differential beacon system. Continuous 'real-time" sound speed measurements were made with a sound-speed probe at the Reson 8101 transducer head, a particularly important place to measure sound speed due to the physics of forming multiple sonar beams. Water column profiles of sound-speed were collected at roughly three hour intervals and within the survey area using a Seabird SBE 19 CTD.

Bathymetric data were acquired using Hypack/Hysweep 2010 in .81X, .HSX, and .RAW formats. Hypack integrates the incoming bathymetric data, time stamped by the sonar sensor, and the incoming navigation data from the Starfire DGPS and PosMV motion sensors to generate a ping-by-ping data record with integrated navigation and vessel motion data. Bathymetric data from all surveys were processed using CARIS (http://www.caris.com) HIPS/SIPS v7.0 data processing software in order to produce tide, motion- and sound-speed-corrected, geo-referenced bathymetry and backscatter imagery. Backscatter mosaics were generated with Interactive Visualization Systems (IVS) Geocoder version 7 software to additionally produce backscatter mosaics that incorporate geometric and beam pattern corrections, as well as removing artifacts of gain and pulse length changes and topography during the survey (Fonseca and Calder 2005; Fonseca and Mayer 2007). The data were collected using standard hydrographic protocols (NOAA Field Procedures Manual 2010, NOAA 2013 Specification and Deliverables 2013).

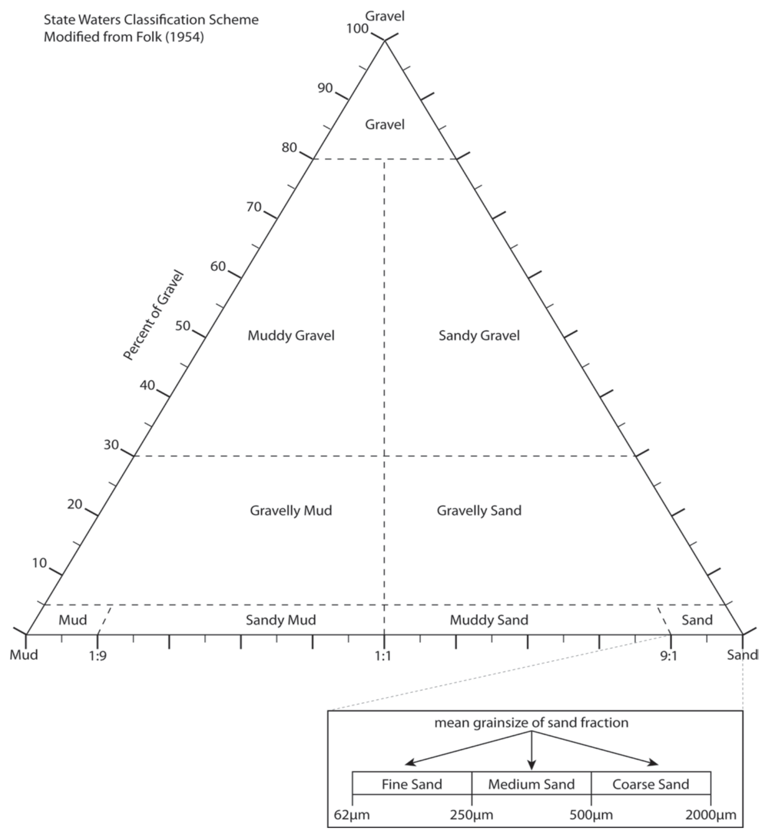


Figure 9. Ternary diagram showing basis for the textural classification of sediments collected under this project
The textural classification illustrated here was also the basis for the sedimentary habitat types of local-scale mapping products.

The surveys were conducted at speeds of 6-8 knots, depending on weather conditions and other factors such as proximity to the coast, water depth, sea state, visibility, and density of crab pots. During pervious sea-trials conducted for the Oregon State Waters Mapping Program in 2009 it was determined that vessel speeds within the capabilities of the *Pacific Storm* had little or no effect on data quality, validating the construction and use of a massive and deeply placed sonar pole for this project. Standard squat tables were constructed for the changes in vessel pitch at various speeds, and are applied during processing. Changes in draft during each cruise leg were applied after re-measuring the vertical draft marks established on the hull for that purpose. Weather data was provided in real time either through satellite or cell based web access, using a subscription weather service available from Buoyweather.com, or through a Garmin 496 Aviation/Marine GPS system with XM satellite weather overlays when out of range of cell service.

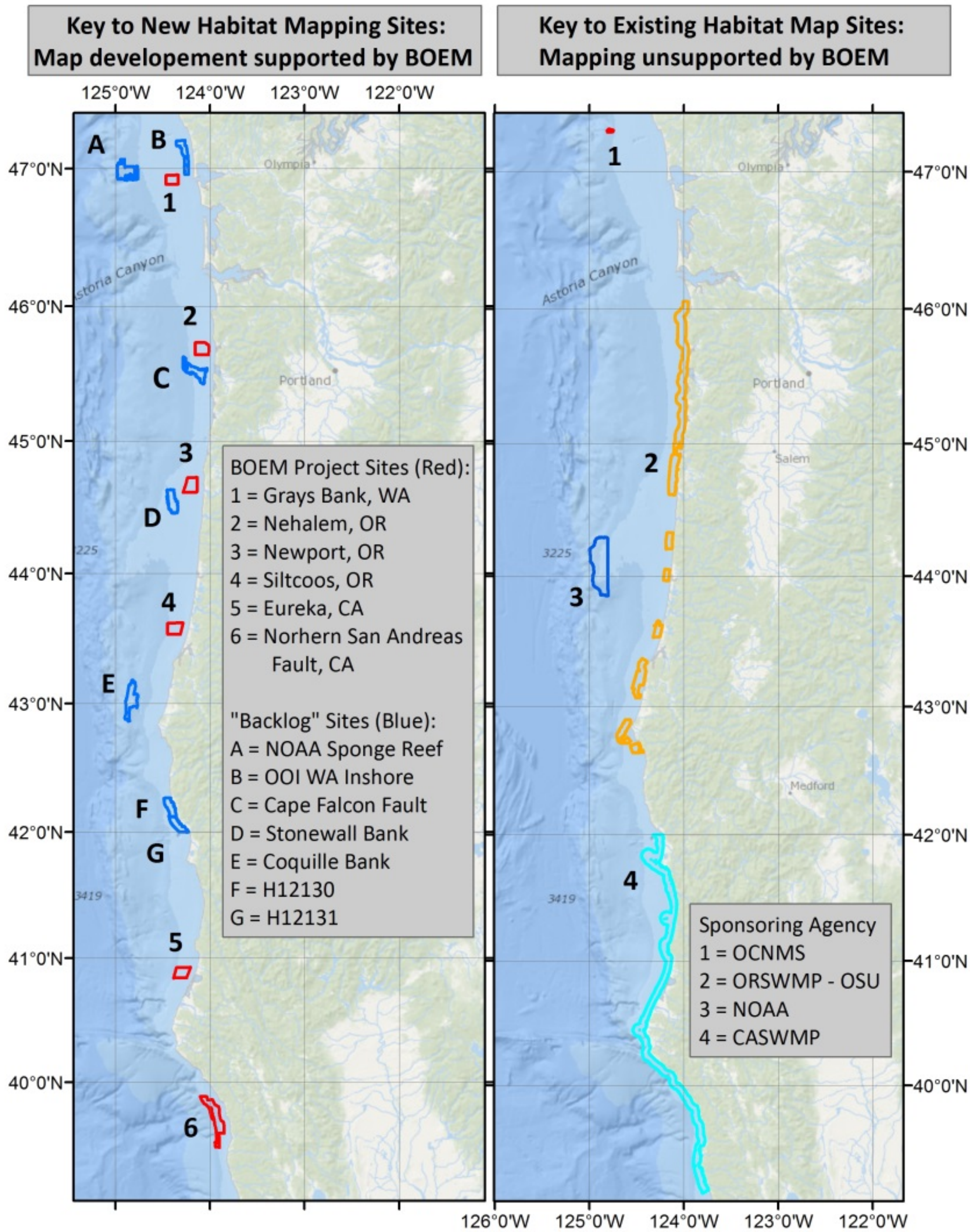


Figure 10. New and existing data for habitat maps
Overview of local sites both newly mapped (new data acquisition) and existing, used to update the SGH Map Version 4.0. The left panel shows locations where BOEM supported the development of habitat maps; either interpretation of "backlog" data (blue color) or both the data acquisition and interpretation (red color) of habitat maps. The right panel shows existing maps developed external to the BOEM project.

3.3.1.4 Seabed Sampling

A Shipek Grab Sampler and Grey O'Hare Box Corer were used to collect surface sediment samples (104 Grab Samples & 152 Box Cores) within the study sites. Sediment samples from both sampling devices were qualitatively described and recorded at sea and retained for laboratory analysis of grain size. Sample stations were primarily selected on the basis of contrasts in backscatter imagery in sediment covered areas and also targeted unique backscatter signatures not sampled by the Box Core device. Given the stratified sampling design for Box Cores stations, we selected this targeted sample collection method as a way to collect additional sediment data for areas that appeared to be unique or novel from the imagery. The sampling approach provides well constrained information on seabed sediments, leaves a permanent archive of samples for future investigations, and is fast and low cost in comparison to video ground truth methods. While ideally suited for homogeneous habitats of soft unconsolidated sediments, sampling is not sufficient to provide context for patchy or rocky areas where a Remotely Operated Vehicle (ROV) was utilized instead.

Grain size analyses on the Grab Samples and Box Cores were performed with the Fraunhofer and Mie methods of laser diffraction using a Beckman-Coulter LS 13-320 particle size analyzer (Blott and Pye 2006). The Beckman-Coulter unit analyzes samples up to 2 mm in grain size, and has an auto-sampler unit to speed up the processing of large numbers of samples. Samples that contained grain size fractions larger than sand were first sieved using a 2 mm mesh. The ratio of coarse to fine sediment was determined by weight. The grain size characteristics of the fine fraction were determined with the LS 13-320. A sedimentary textural class was assigned to each sample based upon PSA analysis results modified from Folk (1954). The textural classification scheme (Figure 9) is a component of the National Geophysical Data Center's (NGDC) Index to Marine and Lacustrine Geological Sample Database and was also used locally for the Oregon State Waters Mapping Program seabed habitat maps.

3.3.1.5 Local-Scale Habitat Product Development

Local-scale habitat maps were developed from the multibeam seabed imagery at six BOEM study sites as well as for seven sites where existing multibeam "backlog" data were available from external sources (Table 1). The footprints of these data are mapped in Figure 10 on the left panel. The results (maps) of the local-scale mapping efforts were integrated along with external sources of newly developed habitat maps from NOAA OCNMS, the OR SWMP, and the CA SWMP (Figure 10, right panel) into the regional Surficial Geologic Habitat map for WA, OR, and Northern CA.

Seabed type mapping at local sites, both BOEM project sites and backlog sites (where existing data from other sources were available), followed a supervised image classification approach for unconsolidated soft sediments followed by a rules based seabed roughness classification for rock outcrop. The sediment mapping method used for this study is identical to that used for the Oregon State Waters Mapping Program (ORSWMP) and is outlined below. The outcrop mapping method however differs from the ORSWMP outcrop mapping method in that an interpreter delineated the outcrops for ORSWMP manually. Outcrop at these study sites, with the exception of Coquille Bank and the Sponge Reef was determined using the Vector Ruggedness Measure (VRM) terrain algorithm (Sappington et al. 2007). Both techniques are useful and can be quite accurate for identifying outcrop; however the vector ruggedness approach mates well with extensive mapping of California's State Waters Tier 2 data products, (Kvitek et al. 2007) and allowed us to apply a fairly consistent technique across a broad geographic extent. The general mapping method is presented below, details related to sediment sample classification and rock mapping are also provided.

Due to the low-relief nature of the rocky outcrop or hard seabed at Coquille Bank and the Sponge Reef outcrop mapping at these sites was done by geologic interpretation only. Reference still imagery (Seabed AUV) from the 2005 NOAA Northwest Fisheries Science Center's Advanced Technology Cruise (unpublished data, NWFSC 2005) was used to guide expert image interpretation at Coquille Bank, OR.

Similarly, still imagery from the Seabed AUV (unpublished data, NWFSC 2009) was used to guide expert interpretation of seabed habitat type at the Sponge Reef, WA.

Table 1. Data sources, resolutions, and ground truthing methods used at local mapping sites Funding (Source) for data collection were by BOEM, OSU, NOAA, OOI, OR, ODFW. Resolution of bathymetry (Bathy) and backscatter (BSKTR) ranged from 50 cm to 15 m, depending on the equipment used and depth. Sediment samples (Samples) and visual imaging (Video/Still) used to ground truth the multibeam data and create habitat maps. X = No data of this type is available.

Site	State	Source	Bathy Res.	BSKTR Res.	Samples	Video/Still
Sponge Reef, WA	WA	NOAA/OSU	8 m	2 m	X	AUV Still
Grays Bank, WA	WA	BOEM/OSU	8 m	1 m	Yes	ROV Video
OOI WA Inshore	WA	OOI/OSU	2 m	1 m	Yes	X
Nehalem, OR	OR	BOEM/OSU	4 m	50 cm	Yes	X
Cape Falcon Fault, OR	OR	OR SWMP/OSU	4 m	1 m	X	X
Newport, OR	OR	BOEM/OSU	4 m	1 m	Yes	Sled Video
Stonewall Bank, OR	OR	ODFW/OSU	2 m	2 m	X	Drop Video
Siltcoos Bank, OR	OR	BOEM/OSU	4 m	1 m	Yes	ROV Video
Coquille Bank, OR	OR	NOAA/OSU	15 m	10 m	X	AUV Video
H12130, OR	OR	NOAA	4 m	X	X	X
H12131, OR	OR	NOAA	4 m	X	X	X
Eureka, CA	CA	ONR	18 m	18 m	Yes	X
NSAF, CA	CA	BOEM/OSU	8 m	4 m	Yes	X

<u>Differentiating Hard vs. Soft Seabed:</u>

Using the ArcGIS for Desktop 10.1 Benthic Terrain Modeler Toolkits terrain algorithm Vector Ruggedness Measure (VRM) (http://www.csc.noaa.gov/digitalcoast/tools/btm), we initially partition the survey area into 2 classes, hard or soft seabed. The VRM method captures terrain variability in slope and aspect into a single measure between 0 (no terrain variation) and 1 (complete terrain variation). Similar to rugosity, VRM is an alternate method for measuring the roughness of the seabed. A Vector Ruggedness breakpoint or threshold for differentiating between hard seabed and soft unconsolidated sediment areas is determined expertly by evaluating Vector Ruggedness Measures (VRM's) over known seabed types. We selected and used a common VRM of (0.002, Table 2) by matching *in-situ* observations at Grays Bank & Siltcoos (BOEM ROV) and Stonewall Bank (ODFW Video Lander). The VRM breakpoint was applied uniformly to all local sites (except Coquille Bank and the Sponge Reef, see above) to segment the survey into hard and soft classes. Where the VRM threshold does not match the geology we intervene to make visual interpretive corrections. Splitting the survey area into hard and soft classes leads to two separate tracks for interpretation of these disparate classes.

<u>Hard Seabed:</u>

Within the Hard (rocky) seabed class, we further partitioned the terrain into three relief classes based upon an analysis of Topographic Position: Ridge, Mid-Relief, and Valley. Sometimes referred to as Benthic Position (Wright et al. 2005), Topographic Position measures the position of a location relative to its neighbors (Weiss 2001). Note that raw Topographic Position Index (TPI) score (meters) was used in favor of standard deviation breaks, as recommended by the Benthic Terrain Modeler toolkit, because absolute units will represent the same measure of relief across all sites. Three TPI) classes are implemented (Table 2) to subdivide areas of hard substrate; Ridge (TPI >1 m), Mid Relief (1 m > TPI > -1 m), and Valley (TPI < -1 m).

Table 2. Survey site summary statistics and metrics for delineation of hard and soft habitat type and relief classes
Grid Pixel Size ranged from 2 m to 15 m, Vector Ruggedness Measure Scale (VRM Scale) is presented as the analysis neighborhood ratio in cell units. Vector Rugedness Measure Breakpoint (VRM Breakpoint) was set at 0.002 to distinguish rock from sediment. Topographic Position Index Scale (TPI Scale) ranged from 40 m/80 m for innershelf sites to 100 m/200 m for large mid-shelf Stonewall Bank. Three sites had no rock outcrop and Coquille bank was not analyzed because the outcrop was very low relief.

Site	Grid Pixel Size	VRM Scale (Neighborhood)	VRM Breakpoint	TPI Scale (radius/diameter)	TPI Breakpoints
Sponge Reef	8 m	5x5	0.002	NA	No High Relief
Grays Bank	8 m	5x5	0.002	44 m/88 m	+1 m & -1 m
OOI WA Inshore	2 m	9x9	0.002	40 m/80 m	+1 m & -1 m
Nehalem	No Rocks	No Rocks	No Rocks	No Rocks	No Rocks
Cape Falcon Fault	4 m	5x5	0.002	40 m/80 m	+1 m & -1 m
Newport	No Rocks	No Rocks	No Rocks	No Rocks	No Rocks
Stonewall Bank	2 m	19x19	0.002	100 m/200 m	+1 m & -1 m
Siltcoos	4 m	5x5	0.002	40 m/80 m	+1 m & -1 m
Coquille Bank*	15 m	Not Analyzed	Not Analyzed	Not Analyzed	Not Analyzed
H12130	4 m	3x3	0.002	40 m/80 m	+1 m & -1 m
H12131	4 m	3x3	0.002	40 m/80 m	+1 m & -1 m
Eureka	No Rocks	No Rocks	No Rocks	No Rocks	+1 m & -1 m
NSAF	8 m	5x5	0.002	40 m/80 m	+1 m & -1 m

*Rock outcrop mapping was performed through manual interpretation of bathymetry and backscatter at Coquille Bank where the seabed is predominantly low relief outcrop, bedded cobble and boulder substrate with little if any high relief ridge types present.

Soft Seabed:

Seabed sediment distributions were mapped at each site using a maximum likelihood classification (MLC) of multibeam bathymetry and backscatter. Sample data (Shipek Grab Samples, Box Core Samples, and/or usSEABED sample data) from each site were classified using a textural classification (Figure 9) outlined in McCoy (1977), modified from Folk (1954) and used to develop site-specific classification signatures relating sediment class to bathymetry and backscatter value. Classification signatures were extracted from multibeam backscatter (0-255, 8 bit greyscale data representing scaled backscatter intensity) and multibeam bathymetry (depth) within a 10 m radius buffer or neighborhood around each classified sample point. Signatures were applied to the classification using the ArcGIS for Desktop 10.1 Spatial Analyst Tools, Maximum Likelihood Classification tool. The resultant output raster was smoothed (artifact minimization cleaning) using a focal majority filter at 9x9 or 11x11. For mixed classes of coarse sediments, where gravel is the dominant component, we bin the mixture before classification as mixed gravel. This method produces a robust fully ground-truthed classification. If the user requires fewer classes, these can be simply merged or recoded. For page size figures of all sites please see the Appendix 1.

Merging Hard and Soft Seabed Classes:

The classified images from the two parallel classification tracks are combined in a final step and converted to polygon format with quality control by a geologist/interpreter to resolve conflicts and clean additional artifacts or gross misclassifications if any. We use the ArcGIS Desktop 10.1 Conversion Toolbox, Raster to Feature tool to make the raster to polygon conversion. A 100 m^2 minimum mapping unit is created using the Arc GIS 10.1 Desktop Dissolve Tool. Habitat patches less than 100 m^2 in area are dissolved (merged) into larger neighboring patches.

3.3.2 Regional-Scale Mapping

3.3.2.1 Surficial Geologic Habitat (SGH) Mapping Methods

Owing to the new local site mapping at BOEM and other external sites, the regional Surficial Geologic Habitat maps for Washington, Oregon, and California were updated to include this new local mapping information. Regionally, canyon and channel systems in WA and CA were updated significantly from their previous versions. In addition to adding new and more detailed habitat classifications to the SGH Map Version 4.0 we also added new attribute fields for the Coastal and Marine Ecological Classification Standard (CMECS) Substrate Component classification codes (FGDC-STD-018-2012). The map product distributed through the Year 3 Report was considered PROVISIONAL (July 2nd 2013). The addition of new BOEM sites, externally derived map products, new CMECS codes cross walked to SGH codes, and updated lithologic codes throughout represent significant improvements over previous versions but also represent significant modifications from previous versions.

SGH Map Version 4.0, Attribute Table Changes:

Listed below are SGH Map Version 4.0, we detail several important updates to attribute field definitions of SGH Map Version 4.0 that were implemented, including adding additional fields for new classification schemes.

1. In previous versions of the SGH maps we presented Primary and Secondary Lithology types as SGH_Lith1 and SGH_Lith2 (add references). This resulted in some confusion between homogeneous sediment mixtures and heterogeneous patchy substrate. Here, a homogeneous sediment mix is defined as a homogeneous and map-able unit of sediment (i.e. sandy mud). A heterogeneous patchy substrate is defined as a heterogeneous unit where it's not possible to map distinct patches by specific lithology type (i.e. a sandy substrate with boulder patches, or a rocky outcrop with gravel patches). Under the previous coding methods the sandy mud habitat would have been coded as SGH_Lith1 = mud, SGH_Lith2 = sand leaving it unclear if the habitat patch is a sandy mud sediment mixture or instead includes distinct patches of homogeneous sand and mud at scales below the minimum mapping unit. We now define primary lithology as the dominant component and secondary lithology as the secondary component. Homogeneous sediment mixtures can occur under either level, their position determined by their relative composition in the patch. Therefore a sandy mud sediment mixture is now coded as V4_Lith1 = sandy mud and V4_Lith2 = <EMPTY>. A patchy habitat such as the boulder patches in sand is distinguished as V4_Lith1 = sand, V4Lith2 = boulder.

2. The second SGH_Prefix character is meant to describe Seafloor Induration (Greene et. al. 1999). Three induration modifiers are available; h = hard substrate, rock outcrop, relic beach rock or sediment pavement, m = mixed hard & soft substrate, s = soft substrate, sediment covered. SGH versions 3 to 3.6 used the mixed induration modifier in a manner inconsistent with the above

definition. Specifically, the version 3 habitat maps coded any polygon with a secondary lithologic component as a mixed "m" induration type. This resulted in mixed (hard and soft substrate) induration codes for many habitat patches that should have been correctly coded soft "s" (i.e. Ss/sand/mud, Ss/sand/gravel). In version 4 we have split the single SGH_Prefix field into SGH_Pref1 and SGH_Pref2. SGH_pref1 is the physiographic feature type, or Greene et al. (1999) "Macrohabitat". SGH_pref2 now matches the Greene et al. (1999) "Seafloor Induration" definition. Soft seabed types like Sandy Mud are homogeneous sediment mixtures and are now coded correctly as Ss/Sandy Mud instead of Sm/Mud/Sand. Patchy habitats that include the hard types boulder or rock and any soft type (smaller than boulder) are now coded as mixed.

3. SGH Map Version 4.0 now includes attribute fields for CMECS Origin, Class, Subclass, Group, and Subgroup as well as fields for Mega habitat, Mesohabitat/Macrohabitat, Induration and Modifiers from Greene et al. (1999).

<u>SGH Map Version 4.0 Incorporating Local Polygon Maps:</u>

Incorporating local polygon maps into the regional habitat map entailed standardizing the minimum mapping unit and performing a GIS union of datasets. To standardize minimum mapping unit the raster format, California State Water Seafloor Mapping Program Tier 2 products (automated classifications of hard and soft bottom) were first converted to polygon shapefiles. Patches less than 100 m^2 were eliminated (merged into the adjacent feature with the largest shared border, default setting). The polygon format BOEM, BOEM backlog, and OCNMS datasets were also generalized by eliminating habitat patches less than 100 m^2 prior to incorporating into the SGH Map Version 4.0.

We incorporated individual survey datasets using the ArcGIS for Desktop Analysis Tools, Union Tool. The Union Tool computes the geometric union of input features and preserves all attributes in the output. This method preserves the shape of features in all input layers allowing physiographic habitat type to persist from version to version. Where a new updated lithologic type modified or overprinted a previous feature we used conditional statements to select and eliminate the outdated features such that the new feature would persist. After all new features were incorporated into the map layer we used the CMECS crosswalk table (Table 3) to populate the five CMECS attribute fields.

<u>SGH Map Version 4.0 External Review</u>

In the Year 3 report we recommended that an expert review to take place prior to the Year 4 Report delivery. Invited reviewers included the existing SRG members and a few select professionals with expertise specific to CMECS or the external data sources integrated into Version 4.0. The scientific review of the Version 4.0 Surficial Geologic Habitat Map for Washington, Oregon and Northern California was conducted via advance briefing materials (Appendix 2), webinar presentation and discussion, and post webinar written feedback (Appendix 3).

3.3.2.2 Data Density & Quality Mapping Methods

As described above, our previous regional SGH maps, Versions 1 through 3.6, are largely manual interpretations of macro- and meso-scale habitat types. The mapping for each habitat patch was developed from geologic interpretation of underlying datasets. Because both data coverage (data density) and data utility (for mapping seabed habitat) are variable, the resultant regional SGH map is non-uniform in minimum mapping unit (some areas are mapped in greater detail than others) and non-uniform in thematic accuracy (some areas have higher confidence than others). The Version 1 SGH Data Quality Map (Romsos 2004, 2007; Romsos and Lanier 2007) and the subsequent Version 3 update were developed to illustrate this thematic uncertainty.

We understand that thematic map accuracy for an interpreted product to be a function of:

- input data type (some data types provide more useful information than others)
- input data distribution (more information is better)
- mapping technique (interpretive techniques dominated until Version 4)

Owing to the fact that we now incorporate stand-alone map products, generated both internally and externally, and utilizing techniques that vary from the previous manual interpretation methods, a new approach to Data Quality or Thematic Confidence mapping was needed. The objective being to update the Version 3 quality map so that it (1) maintains earlier quality/confidence estimates for unchanged map regions and (2) modifies only areas updated by new local mapping efforts in a manner compatible with earlier work. This objective required mapping the footprint of the previously described local & regional mapping updates and ranking those updates on a 1 -10 scale (10 = highest confidence).

Table 4 presents the framework that was developed to support scoring newly mapped local sites and updated areas of SGH Map Version 4.0. First, each footprint was scored for data type (coverage):

- Regional Data = 1
- One type of high resolution data present (bathymetry or backscatter) = 2
- Both types of high resolution data present = 3

Next, each footprint was scored for the mapping type:

- regional = 1
- local = 2

Finally footprints were scored for the use of ground-truth data to guide the mapping:

- no ground-truth = 0
- ground-truth used = 2.

Scores were summed to a composite score ranging from 1 to 7. Composite scores of 4 or greater were re-scaled by adding 3 to each score to yield a 7-9 final score indicating new local mapping. Composite scores of less than 4 indicate areas where no local-scale mapping occurred and are either unchanged from SGH Map Version 3.6 or updated for Version 4.0 using regional-scale data only.

Table 3. SGH Map Version 4.0 and CMECS Crosswalk Key

Crosswalk is between SGH Map Version 4.0, V4_Lith Codes and CMECS (FGDC-STD-018-2012) Origin, Class, Subclass, Group, and Subgroup codes. Cells in red are imperfect crosswalks between SGH codes and CMECS codes.

V4_Lith1	V4_Lith2	V4_LithMod	CMECS_org	CMECS_cls	CMECS_scls	CMECS_grp	CMECS_sgrp	CMECS_co_oc
shell			Biogenic Substrate	Shell Substrate	Shell Hash			
shell	gravel		Biogenic Substrate	Shell Substrate	Shell Hash			Granule & Pebble
mud			Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Mud		
mud	rock		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Mud		Bedrock
mud	gravel		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Mud		Gravel
mud	shell		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Mud		Shell Hash
mud	sand		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Mud		Sand
gravelly mud			Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Slightly Gravelley	Slightly Gravelley Mud	
sandy mud			Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sandy Mud		
sand mud			Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Muddy Sand		
sand			Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand		
sand		fine sand	Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand	Fine Sand	
sand		medium sand	Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand	Medium Sand	
sand		coarse sand	Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand	Very Coarse & Coarse Sand	
sand	rock		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand		Bedrock
sand	boulder		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand		Boulder
sand	gravel		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand		Granule & Pebble
sand	shell		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand		Shell Hash
sand	mud		Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Sand		Mud
muddy sand			Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Muddy Sand		
gravelly sand			Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	Slightly Gravelley	Slightly Gravelley Sand	
gravel			Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel	Granule & Pebble	
gravel	rock		Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel		Bedrock
gravel	shell		Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel		Shell Hash
muddy gravel	sandy mud		Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel Mix	Muddy Gravel	Sandy Mud
sandy gravel			Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel Mix	Sandy Gravel	
muddy gravel			Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel Mix	Muddy Gravel	
gravel mix			Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel Mix	UNKNOWN	
cobble			Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel	Cobble	
cobble	gravel		Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel	Cobble	Granule & Pebble
cobble	boulder		Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel	Cobble	Boulder
cobble mix			Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel Mix	UNKNOWN	
boulder			Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel	Boulder	
boulder	sand		Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel	Boulder	Sand
boulder	mud		Geologic Substrate	Uncns. Mineral Substrate	Coarse Uncn. Substrate	Gravel	Boulder	Mud
rock			Geologic Substrate	Rock Substrate	Bedrock			
rock	mud		Geologic Substrate	Rock Substrate	Bedrock			Mud
rock	boulder		Geologic Substrate	Rock Substrate	Bedrock			Boulder
rock	gravel		Geologic Substrate	Rock Substrate	Bedrock			Granule & Pebble
rock	sand		Geologic Substrate	Rock Substrate	Bedrock			Sand
rock	shell		Geologic Substrate	Rock Substrate	Bedrock			Shell Hash
rock	gravel mix		Geologic Substrate	Rock Substrate	Bedrock			Gravel*
rock	cobbley boulder		Geologic Substrate	Rock Substrate	Bedrock			Gravel,Boulder/Cobble
rock mix			Geologic Substrate	Rock Substrate	Bedrock	UNKNOWN		
soft			Geologic Substrate	Uncns. Mineral Substrate	Fine Uncn. Substrate	UNKNOWN		
mixed			Geologic Substrate	UNKNOWN				
hard			Geologic Substrate	Rock Substrate	Bedrock			

* To avoid redundant attribution we do not include the upper levels of the CMECS SC hierarchy when indicating a co-occurr
because co-occuring elements typically represent an endpoint in the hierarchy. The lone exception is the Gravel co-occurring element which can't be crosswalked any lower.

Table 4. Theoretical framework used for assessing thematic map confidence ("Data Quality") for the SGH Map Version 4.0 for Washington, Oregon, and northern California

Data Coverage Score	Mapping Coverage Score	Groundtruth Coverage Score	Composite Score	Final Score	Explanation
1	1	NA	2	(1-6)	No Change or Regionally Updated
2	0	NA	2	(1-6)	No Change or Regionally Updated
2	1	NA	3	(1-6)	No Change or Regionally Updated
2	2	0	4	7	Locally Updated
2	2	2	6	9	Locally Updated
3	0	NA	3	(1-6)	No Change or Regionally Updated
3	1	NA	4	(1-6)	No Change or Regionally Updated
3	2	0	5	8	Locally Updated
3	2	2	7	10	Locally Updated

3.3.2.3 Slope Stability Mapping Methods

The local surface slope was calculated from the regional bathymetric grid of 100 m resolution in a 3x3 pixel neighborhood Digital Elevation Model and is defined as the maximum rate of change in elevation over the central cell and its eight neighbors. Bathymetry was derived from an NSF Cascadia Initiative grant and a cruise to the Washington slope in 2008-2009 and 2011-2012 cruises measuring depths of 500 to 3000 m (data available at http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html). After classification, the slope grid was converted to a vector feature class representing regions of greater than or equal to 10 degrees slope as predicted rock outcrops. This method did not account for regional differences in lithology, sedimentation rates, sediment supply due to limited availability of sediment samples as ground truth, and the limited geographic scope of the survey. The primary assumption was that the 10 degree slope cutoff angle determined for the area of the cable survey applied to the entire regional continental slope. The resulting outcrop prediction is incorporated in the 2005 EFH/EIS for Oregon and Washington (Romsos et al. 2007).

3.3.2.4 Structural Mapping Methods

In areas where mapping data do not exist, numerous seismic reflection profiles can provide an indication of where rock outcrops break the seafloor. Seismic reflection profiling produces a two dimensional, subsurface image of stratigraphy (Figure 11). These images do not directly distinguish lithology; instead they provide a means to distinguish areas of rock outcrop from areas of sedimentary lithology by revealing exposed or "rough" seabed. Other structural features such as tectonic deformations (anticlines, synclines) and faults may also be imaged using this technology and are the main sources of rough seafloor topography.

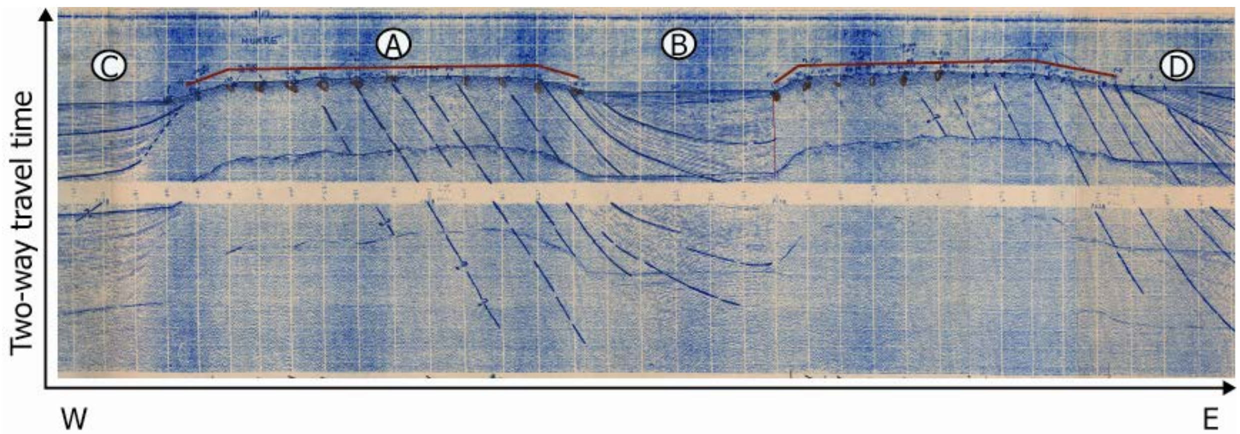


Figure 11. An industry two-dimensional seismic reflection profile over Nehalem Bank
Areas in red (A) correspond to areas of predicted rock outcrop. Sedimentary stratigraphy is evident in the region between outcrops (B) and in the extreme eastern (D) and western (C) margins of the bank.

Seismic reflection profiles are interpreted to locate rock outcrops along survey tracks. The resolving power of the varied datasets to show seafloor offset varies. Low frequency multichannel profiles may not show seafloor relief less than 10 m, while high resolution sparker records will likely show relief of ~1 m or greater. We have not attempted to differentiate the data source in this analysis, but these differences are included in the data quality assessment discussed in section 3.3.2.2. Areas of potential outcrop are noted and recorded from the images and later digitized along a vector representation of the survey navigation. Supporting information from other data sources (bathymetric, structural, sidescan, or sample) were used to both verify the existence of the outcrop and help delineate its extent where overlap existed. Digitized outcrop predictions are stored in ArcGIS® polyline feature classes and displayed with other data types to while mapping physiographic habitat. Three classes were mapped, rock outcrop, probable rock outcrop, and possible rock outcrop. Navigational accuracy for each of the seismic surveys is widely variable from ± 5 to 3000 m (Appendix 1) but may be generally estimated at about ± 500 m for the majority of the datasets used (the data are discussed in more detail in Goldfinger (1994) and Romsos (2002). This estimate is based on the known accuracy of Loran C navigation (Goldfinger 1994, Melton 1986, Nasby-Lucas et al. 2002). While most of the data are now available in digital form, a large portion of the seismic reflection data for this survey area is analog data stored as paper plots. Analog data formats likely introduce additional positional errors through interpretation and transcription processes. Positional errors of these magnitudes render exacting dynamic segmentation procedures (typical method to segment polyline features) overkill for our interpretative purposes.

3.3.2.5 Isocore Mapping Methods

Relevant seismic reflection data were imported into the IHS/Kingdom 8.6 seismic reflection interpretation package. We primarily used digital multichannel data collected by Western GECO in the 1980's and available at http://walrus.wr.usgs.gov/NAMSS/. These data were augmented by analog data collected by OSU and Shell Oil. The analog profiles collected by OSU and Shell were high-resolution Sparker profiles. While the OSU lines had modest navigational accuracy (~ 0.5-1 km), they cover many areas where no other gophysical data exist. The Shell profiles, while widely spaced at ~ 9-25 km, were accurately navigated with shore stations, and included numerous dart core samples along each line from which lithologic and biostratigraphic information was extracted. The digital data formed the backbone of the exercise, and were augmented where required using the shallower penetration sparker data where higher resolution was required. Four arbitrary horizons at 40, 60, 80 and 100 millisecond two-way travel time were digitized representing basin sediment thickness of approximately 33, 50, 66, and 83m. The goal was not to isopach a specific unit or horizon, but to generate isocore contours of *minimum* vertical sediment thicknesses outlining structural highs. Areas interior to the 100 ms contour have greater thickness not represented in this layer. The ages and formation designations of the units bounding the four contours are not known, though enough information may exist to determine this in some cases. Isocore polygons were then generated from these data. Although we do have age control in the central Oregon part of the study area and scattered other locations (summarized in McNeill et al. 1998), the available age control is not particularly useful in a map of this type where our area of greatest interest is the regions with relatively thin sediment cover. This is because unconsolidated sediment cover greater than ~ 20 m is the likely maximum depth currently needed for renewable energy device anchors. Greater depths therefore were not considered relevant for this study, thus our target is essentially the opposite of a traditional isocore map and focused on the thin edges of basins rather than on the thickest basin sections or complete unit.

3.3.2.6 Rock Outcrop Modeling Methods

The five regional map products in sections 3.3.2.1 – 3.3.2.5 above (SGH Map Version 4.0, Data Quality, Slope Stability, Structural Outcrop, and minimum Isocore sediment thickness) were integrated using an expertly defined Bayesian Network (BN) Model to estimate the overall probability of rock outcrop throughout the region. Four of the five regional datasets (excluding the Data Quality Map) provide an estimate of seabed outcrop presence or absence from a slightly different yet interconnected perspective. For example, the Isocore Map estimates the absence of outcrop through the identification of contiguous sedimentary units in seismic reflection data. The Structural Outcrop Map is related to the Isocore map and estimates outcrop likelihood where seismic reflection data indicate near surface structure. Neither product is a perfect estimator nor uniformly covers the region. The SGH Map attempts to integrate any and all geologic and geophysical data but is also imperfect and non-uniform due to variable and patchy input data. The Data Quality Map, a companion to the SGH Map, doesn’t estimate seabed type, but instead provides a means to describe spatial confidence in SGH type.

This interconnectedness among estimators of seabed type provides an opportunity to evaluate or describe a locale given the agreement or disagreement of predictors. An expert BBN model structure has been developed to approximate how a geologist might evaluate and integrate these individual predictors. A quick look at the model structure (top panel, Figure 12) reveals three basic levels that we can term: Predictor Nodes, Modifier Nodes, and Output Nodes. Modifier nodes are used to apply expertly defined relationships between predictors to develop summary probabilities by map type. Here we estimate the modifier node probability of outcrop (ProbOfOutcropSGH) from the SGHHabType and DataQuality Predictor Nodes by adjusting SGHHabType Outcrop or Sediment according to data quality level. A similar modifier node adjustment is made for the probability of outcrop (ProbOfStructuralIsocore) using the Structural Outcrop and Isocore map layers in a second modifier node. The rational for each of these summaries is presented in Figure 13 and Figure 14.

The expertly defined relationship presented in Figure 13 is applied through the model at the *ProbOfOutcropSGH* node. The relationship simply states that likelihood of the observed (or real) habitat class matching the expected (from the SGH map) class increases with increasing data quality. Poor quality data drives the likelihood of the observed class toward a probability of 0.5.

The expertly defined relationship presented in Figure 14 is applied through the model at the *ProbOfOutcropStructureIsocore* node. This relationship simply states that likelihood of the observed (or real) habitat class matching the expected (from the Structural Outcrop and Isocore maps) is a function of agreement between the Structural Outcrop and Isopach maps. Examples of agreement, (a) structural class rock and low Isocore thickness, or (b) structural class not rock and high Isocore thickness should yield a high probability of the expected class outcrop actually occurring in the environment. Conversely, where disagreement is observed such as, structural class not rock and low Isocore thickness, the likelihood of the expected class outcrop should tend toward a probability of 0.5.

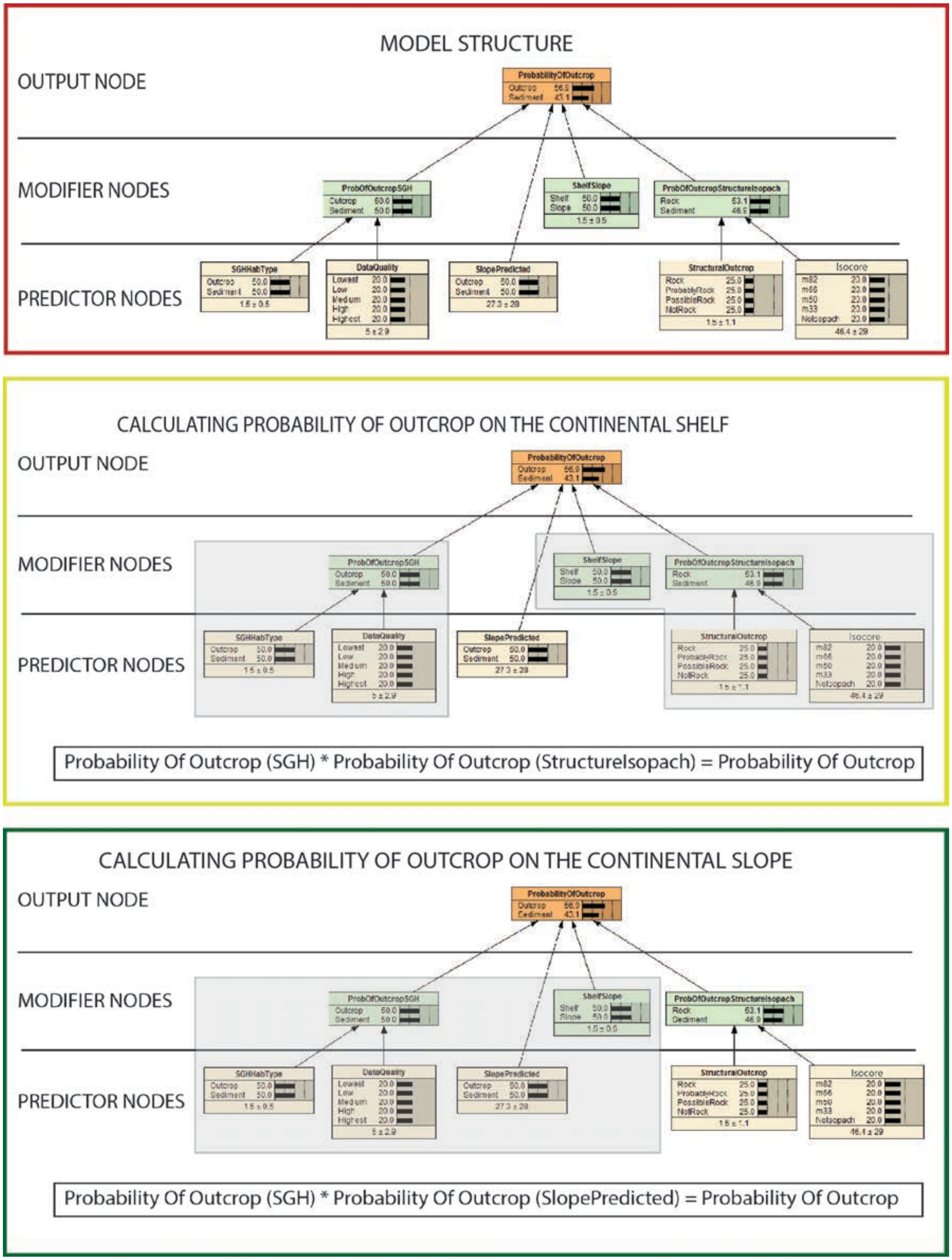


Figure 12. The Rock Outcrop Model Bayes net structure and differences between predicting outcrop on the continental shelf and slope

The top panel shows the relationships between predictor nodes (yellow), modifier nodes (green) and the output node (orange). The bottom two panels show which nodes are active (highlight box) when predicting outcrop over continental shelf or slope areas.

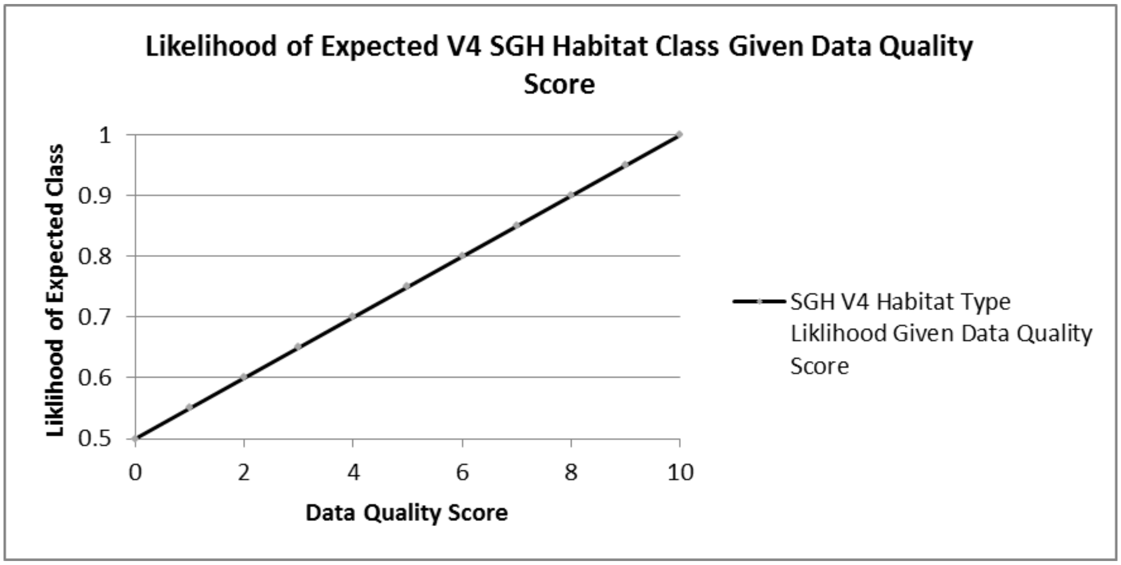


Figure 13. The relationship between Data Quality Score and the likelihood of observing the expected SGH habitat class.
A linear relationship between data quality score and likelihood of habitat type is expertly defined and applied to the model at the ProbOfOutcropSGH node.

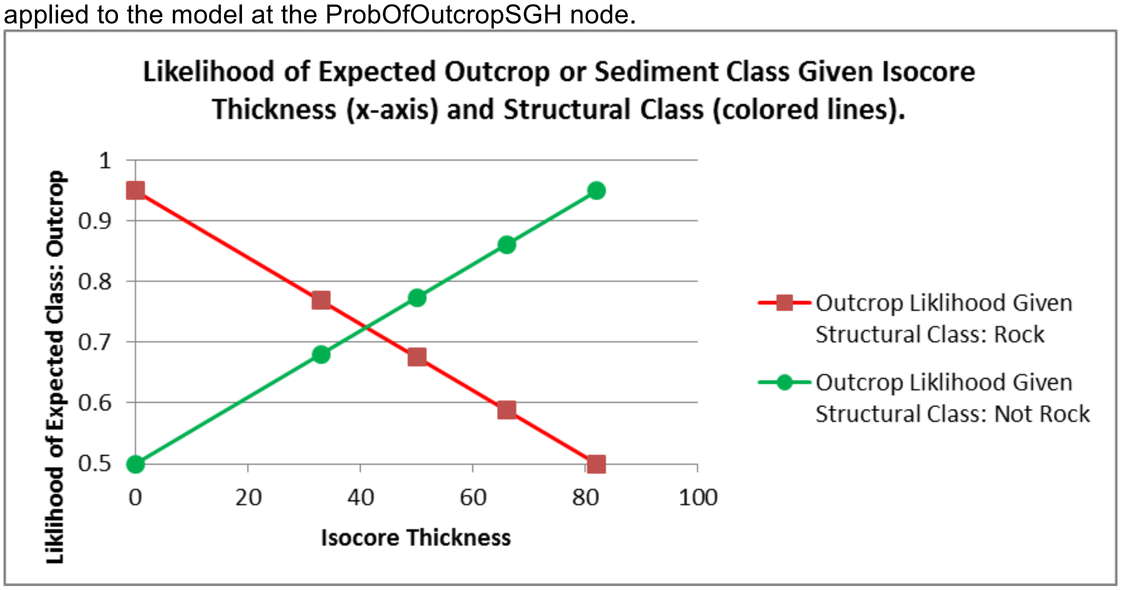


Figure 14. The relationship between Isocore Thickness, Structural Outcrop Class, and the likelihood of observing an outcrop or sediment class
A linear relationship between data quality score and likelihood of habitat type is expertly defined and applied to the model at the ProbOfOutcropSGH node.

Final probability of outcrop is determined by in a similar fashion to the relationship of Figure 14. However, for continental slope environments we combine *ProbOfOutcropSGH* with *SlopePredicted* probability and don't include *ProbOfOutcropStructureIsocore* in the calculation. It's known that the Structural Outcrop and Isocore maps are of greatest utility on the continental shelf. Instead, for continental slope habitats we apply the *SlopePredicted* node. In summary, the overarching rules for determining probability of outcrop through this model are based upon two principles: (1) high input data quality corresponds to high confidence in a map product; and (2) corroborating evidence increases confidence while contradictory information decreases confidence.

3.3.2.7 Grain Size & Composition Modeling Methods

Results of the benthic sampling components of this study show that benthic infauna community structure and species distribution may be controlled or explained in part by the character of the unconsolidated sediments in which they live. During the model development phase of the predictive habitat suitability project component we determined that a regionally continuous GIS model of sediment mean grain size and percent sand would be needed for use as an input (a predictor) to the benthic infauna habitat suitability models such that they could be applied in areas outside of the immediate project study sites.

We integrated sediment samples from the usSEABED Pacific Coast Version 1.0 (Reid et al. 2006), the OSU Sample Archive (http://pacoos.coas.oregonstate.edu/archive/), and samples from this study to model mean grain size (phi) and percent sand for an environmental space described latitudinally by our north/south study extents and by our minimum and maximum study depths. We buffered this prediction envelope by 10 km in all directions and included any samples within that 10 km buffer in our sample set to help avoid edge effect in the area of interest. The sample set was filtered to include only quantitative grain size information for samples taken within the top 10 cm of sediment. Duplicate samples (repeated samples at the same station) were maintained and averaged.

We evaluated several modeling techniques including Ordinary Kriging, Radial Basis Functions and Inverse Distance Weighted (IDW) techniques. As a deterministic and exact technique the Inverse Distance Weighted model (ESRI ArcGIS 10.1Geostatistical Analyst) performed well and was selected as the simplest method that yielded the lowest visual "noise", lowest RMS error and smoothest gradients while honoring the data point at each observation.

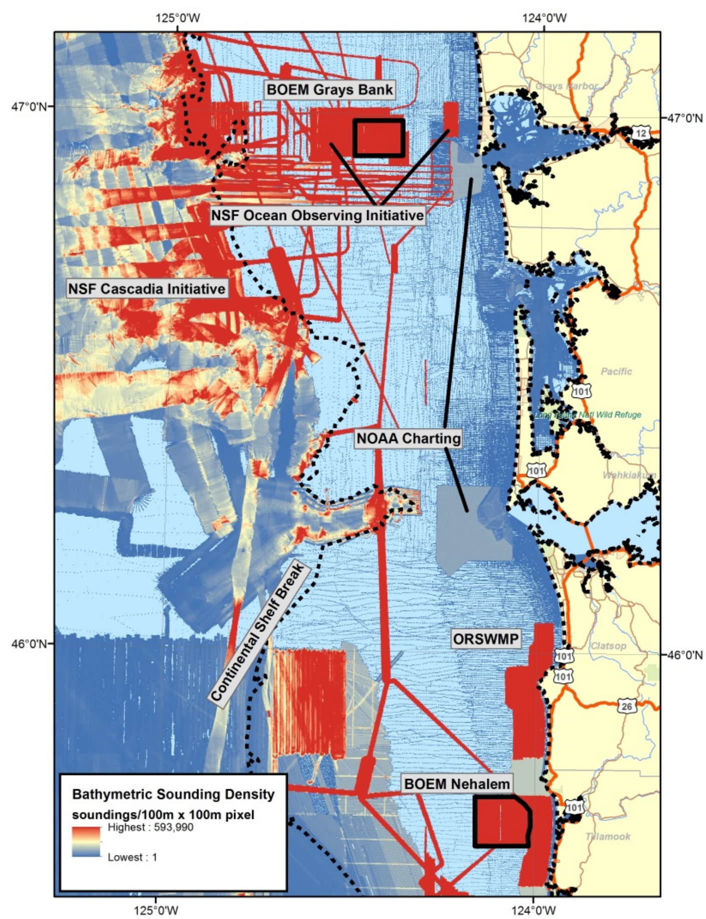


Figure 15. Bathymetric data density
Map showing the density of bathymetric soundings on the continental shelf and slope of the Oregon-Washington border. Note that over shelf environments new data contributions have come from varied sources.

3.4 Results

The individual mapping components (report deliverables) each provide an important update for the regional knowledge base independent of any integrated package. For example, multibeam bathymetry and backscatter data collection funded under this project at local-scale study sites corresponds to an approximately 5% increase in mapping coverage over the continental shelf study region (8 – 130 m depth from Southern WA to Northern CA). When including and accounting for the coverage that was made possible by leveraging external projects such as the OOI sites survey and the NOAA Ocean Explorer NSAF study the new data coverage estimate is closer to 7%. Though much of the continental shelf remains unmapped by modern techniques (Figure 15), programs such as the BOEM Survey of Benthic Communities near Potential Renewable Energy Sites Offshore the Pacific Northwest (labeled BOEM in Figure 15), NSF's Ocean Observing and Cascadia Initiatives, and state funded programs in California and Oregon are contributing significant quantities of new coverage by incorporating seabed mapping components as part of the study design.

In addition to the increase in raw seabed mapping coverage, results of this study integrates local-scale mapping with other existing data to provide regional information on key seafloor characteristics for the development and management of Marine Renewable Energy. To ensure that the information transfers to management, a GIS database has been developed, delivered, and implemented online through web mapping and web catalog services. Included within the database are 13 new maps of local scale seabed habitat, an update to the regional seabed habitat map (SGH Map Version 4.0); three new map themes targeted for predicting rock outcrop; and an updated set of data distribution and data quality maps.

3.4.1 Local-Scale Mapping Results

New multibeam bathymetry and backscatter imagery data (left panel, Figure 10, section 3.3.1.5) were collected at five of the six project study sites totaling 848 km^2 mapped directly under project funding. By developing in-kind support partnerships with the NSF Ocean Observing Initiative, NOAA Ocean Explorer, and the Oregon State Waters Mapping Program an additional 454 km^2 was mapped to extend coverage at the 5 sites by 52% overall to 1302.05 km^2 in total new coverage. By comparison, the Oregon State Waters Mapping Program acquired 1639.90 km^2 of coverage. Figure 16 and Figure 17 show an example of the multibeam bathymetry and backscatter imagery collected locally and also shows how partnering with the OOI provided the resources to increase the mapping footprint (planned footprint represented by the dotted line) to better cover the rocky feature in the southern portion of the survey.

Seabed imagery was classified for seabed habitat type for each of the six project study sites and seven additional backlog sites. Figure 18 provides an example of a local-scale seabed habitat type map. Habitat mapping at the local sites resulted in a corresponding improvement in seabed habitat type knowledge regionally. Sedimentary lithologies and rocky outcrops mapped at the local sites were incorporated into a revision of the regional SGH map.

3.4.1.1 BOEM Sites

Grays Bank, WA:

The Grays Bank area off Grays Harbor WA is so named for a large rocky reef trending E-W across the middle to inner shelf. This reef is the exposed core of an active anticline originally mapped using seismic reflection data by Goldfinger et al. (1997) and again by McCrory (2005) using boomer records and sidescan sonar. The anticline appears to have an association with a previously mapped strike-slip fault known as the North Nitinat Fault (Goldfinger et al. 1997). Recent mapping for this project revealed left lateral slip on this structure on the inner shelf, something inferred by the earlier work. McCrory (2005) also mapped a number of nearly E-W structures on the inner WA shelf, some of which we also imaged in work for the OOI (Ocean observing Initiative) project. McCrory (2005) interpreted these structures as being related to the southern fold belt associated with uplift of the Olympic Mountains, and we agree with this interpretation. Deformation along the coast has shown that young terrace materials are deformed by these likely active structures. A transition from margin normal to margin parallel structures that control the surficial geology occurs on the outer shelf in this area.

Surficial Geology of Grays Bank, WA:

The Grays Banks complex and surrounding seabed habitat was mapped during July 2009 and July 2010 from the *R/V Pacific Storm* using a Reson 8101 (240 kHz) multibeam sonar (Figure 16 and Figure 17). Coverage at the BOEM Grays Bank study site was extended from the original 7 km by 10 km BOEM site to 11 km by 20 km with additional mapping support provided by the Ocean Observing Initiative (OOI) and NOAA Deep Sea Coral Research Program. Box Core sampling (n = 14), Shipek Grab sediment sampling (n=29) and ROV dives (n = 42) were conducted within the BOEM study site area for benthic infauna analysis and for mapping reference data collection. Additional sediment sample data in this area was identified from the usSEABED database (Reid et al. 2006). Classified grain size information from the BOEM Box Cores, BOEM Shipek Grab Samples, and usSEABED database was used to map sedimentary habitats at Grays Bank (Figure 18). Classified ROV "segments" from the BOEM ROV dives in 2011 were used to guide the rocky habitat mapping at Grays Bank, WA.

Surficial geology of the Grays Bank area is primarily controlled by the discharge of sediment from the Columbia River. The sediment laden Columbia River plume during the winter is directed northwestward along the shelf by the Davidson countercurrent, leaving a thick blanket of silt, sand and mud on the WA shelf in an area known as the Mid Shelf Silt Deposit (MSSD) (Wolf et al. 1999). The Holocene to Late Pleistocene MSSD in this area are ~ 5-40 m in thickness except where absent over the crest of the Grays Reef anticline (Wolf et al. 1999). Scour depressions (without obvious rippling) are evident in the Northern part of the survey box. Like the Oregon survey areas, these depressions do not have an obvious trend at high angle to the coastline, but rather appear to be controlled by subsurface features, or possibly are randomly distributed (Figure 18). Lack of a subbottom survey grid precludes a genetic linkage to structure or subsurface topography in this area.

Grays Bank geophysical and sample data (Figure 16 and Figure 17) show that the inner shelf area is composed largely of coarse sand, and gravel mix, bounded to the west by a broad band of gravel mix, and grading westward to muddy sand. The backscatter imagery shows this particularly well, with bright specular reflections associated with the gravel, as compared to the les reflective sand. Interestingly, the rocky reef itself is lower backscatter than the gravel due the fact that this and many PNW rocky reefs are composed of exposed siltstones and generate reduced sonar returns when compared to the high specular reflectivity of the sands and gravels. This effect has been observed at Nehalem Bank (Lanier 2006) and elsewhere. The sediment and topographic classification results are shown in Figure 18.

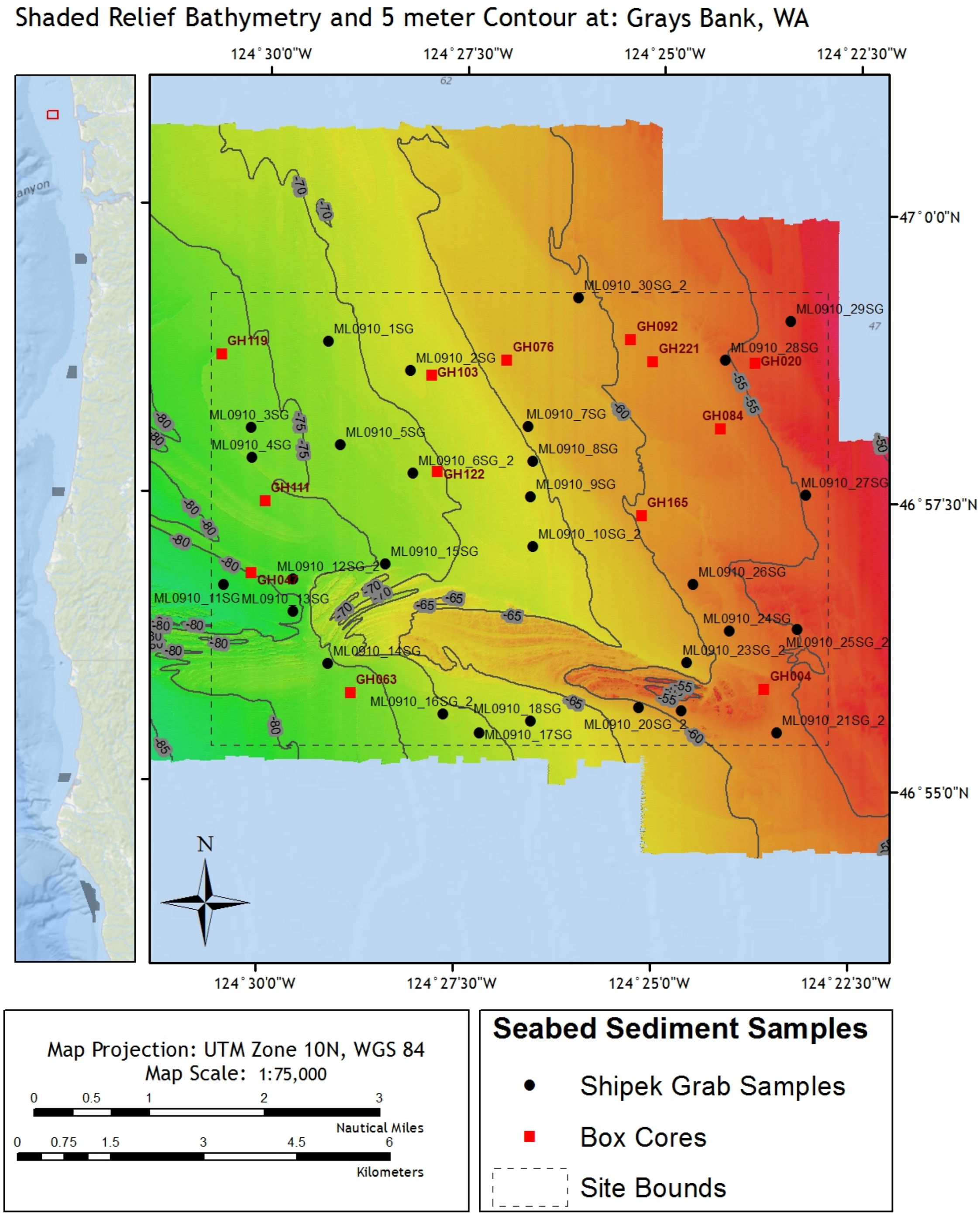


Figure 16. Color shaded-relief multibeam bathymetry data collected at Grays Bank, WA
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam.

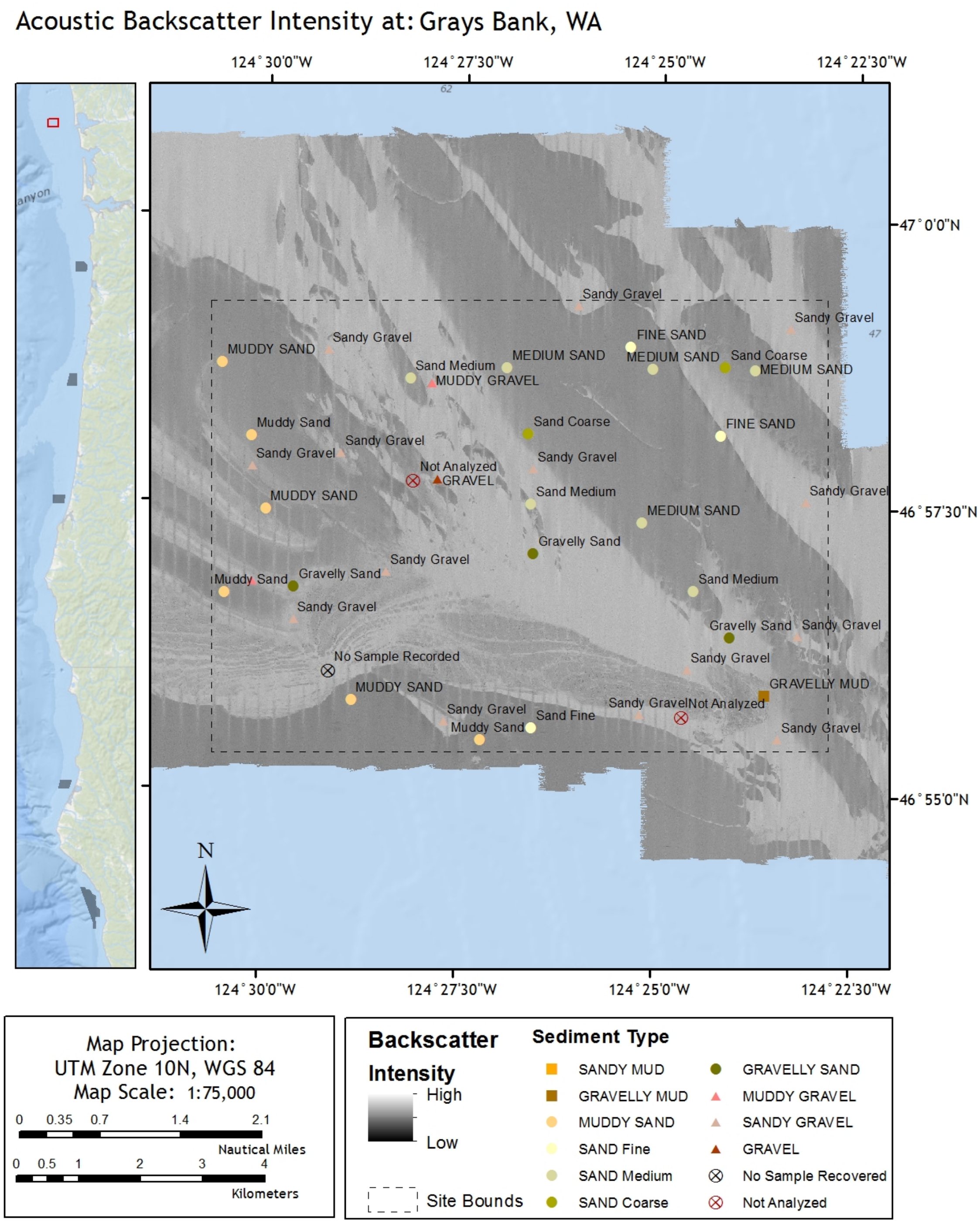


Figure 17. Multibeam backscatter data collected at Grays Bank, WA
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) backscatter data.

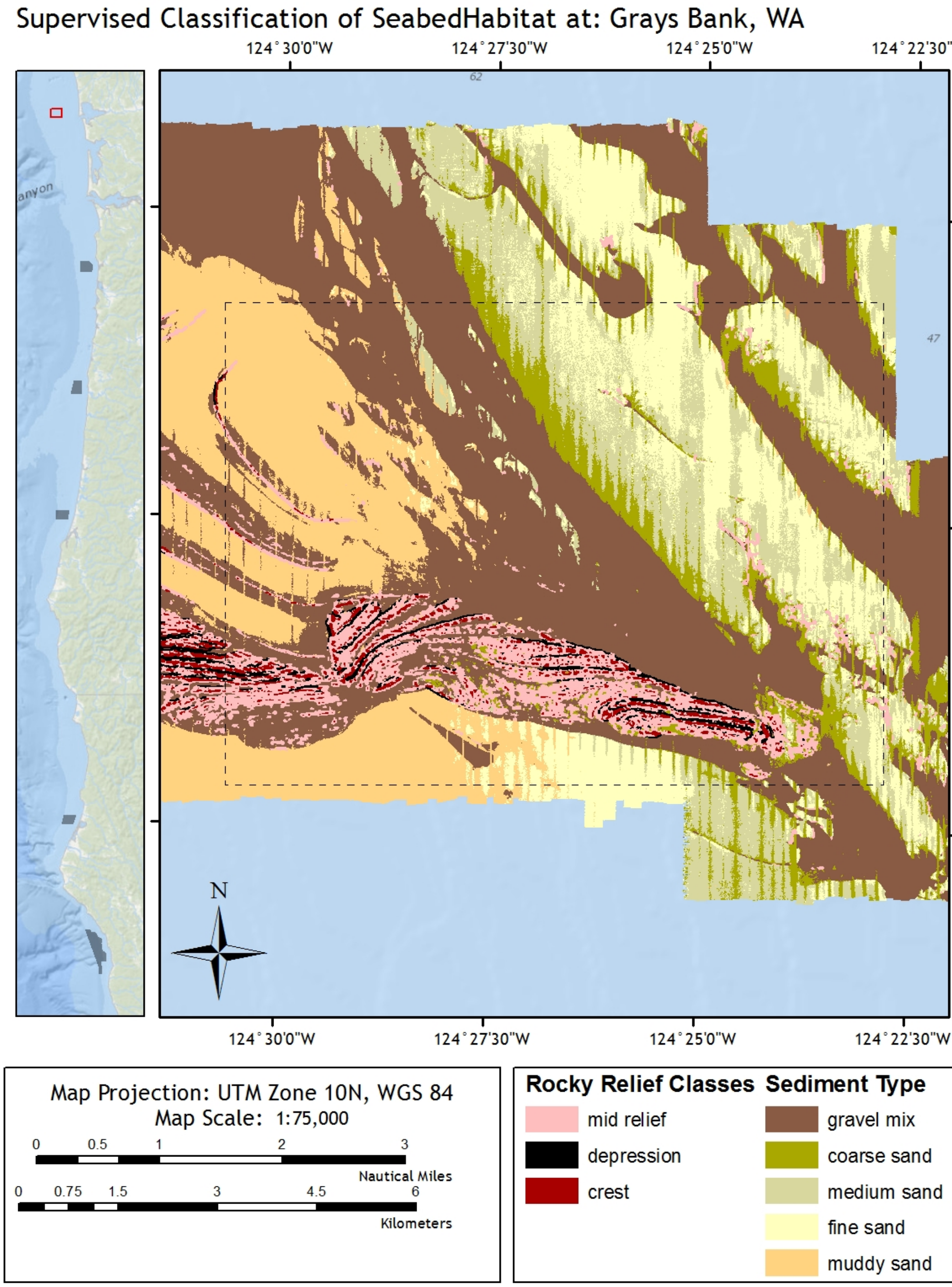


Figure 18. Seabed substrates at Grays Bank, WA
Rocky relief classes are predicted by an analysis of topographic (here, bathymetric) vector ruggedness and topographic position.

Nehalem, OR:

The Nehalem Oregon shelf area (Figure 19) has much in common with areas of the Oregon shelf further to the south. The low relief reefs are structurally controlled, and predominately N-S trending. Where exposed, the rocks are likely Miocene Astoria Formation or equivalent rocks similar to coastal exposures. A significant structure in the area is the Cape Falcon Fault, located 25 km west of the northern Oregon coast, on the landward side of Nehalem Bank. The fault trends north, gently curving southeastward toward the coast at its southern end south of the BOEM study area (Fig. 9). This fault is shown on a cross-section published by Niem et al. (1990; Fault F) which we correlate with Fault C of Niem et al. (1992). Using a magnetic profile and co-located industry reflection profile, Niem et al. (1992) have interpreted the Nehalem Bank fault as the boundary between the Siletzia terrane, (to the east) with a basement of early to middle Eocene oceanic basalt, and Miocene and younger marine sedimentary rocks (to the west). We infer right-lateral slip on the Cape Falcon Fault, which is vertical north of Tillamook Head, flattening to moderate northeast dips as it bends southeastward toward Netarts Bay where we infer the right-lateral fault becomes a thrust. The southeastern projection of the Cape Falcon Fault coincides with the northern margin of Netarts Bay, where a late Quaternary WNW striking thrust fault, named the Happy Camp fault, has been mapped by Wells et al. (1992). The Happy Camp fault involves southward thrusting of Miocene Columbia River Basalt over Pleistocene terrace or fluvial deposits on a northeasterly dipping thrust. Late Quaternary faulting on this structure is clear, but Holocene motion has not been demonstrated. OSU single channel reflection profiles and 150 kHz sidescan records collected over the Cape Falcon fault in 1995 show the fault zone to be a complex structural zone developed in P ranging in age from Pleistocene to Pliocene with Holocene offset at the seafloor (Niem et al. 1990, Goldfinger et al. 1994). In addition to the seismic profile shown in Niem et al. (1990), Quaternary motion on this fault is suspected because the fault zone has a seafloor expression of approximately 10-20 meters in water depth of 130-150 m, estimated from the sidescan and seismic records. We infer the present surface deformation in these relatively soft siltstones would have been mostly eroded during the last Pleistocene lowstand and during the LGM transgression, though incomplete erosion is equally possible.

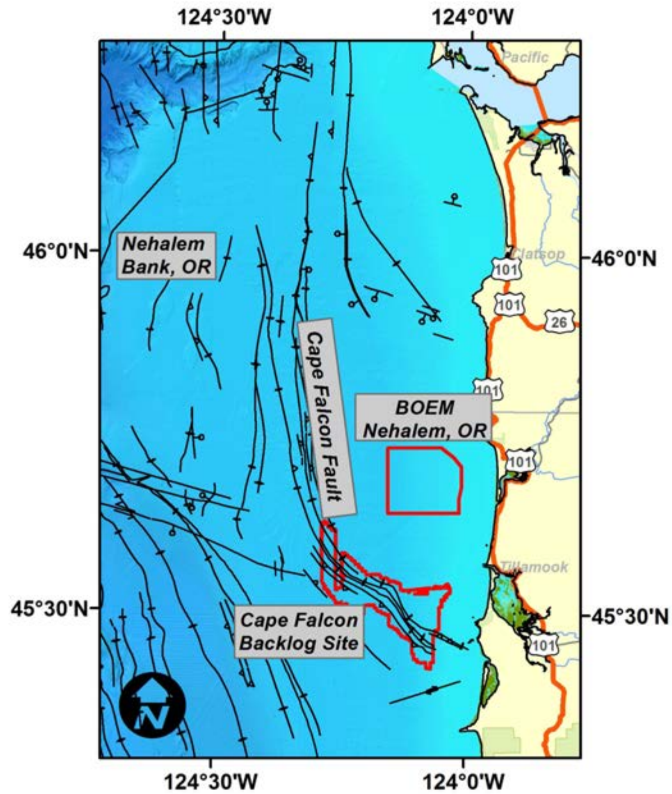


Figure 19. Oregon continental shelf in the vicinity of the Nehalem, OR BOEM study site

Surficial Geology of Nehalem, OR:

This mid-shelf soft sediment region was mapped in July of 2010 from the *R/V Pacific Storm* using a Reson 8101 (240 kHz) multibeam sonar. The BOEM Nehalem study site covers an 11 km by 10 km area and abuts Oregon State Waters Mapping Program multibeam data creating continuous data coverage from approximately 7-10 m water depth nearshore to 80 m water depth offshore. Box Core (n=19) and Shipek Grab (n=22) sampling was conducted in the Nehalem study site (Figure 20 and Figure 21). Classified grain size information from the BOEM Box Cores and usSEABED database was used to map sedimentary habitats at Nehalem, OR (Figure 22). Surface sediments within the BOEM study area are the most uniform of any of the study sites. The major structures discussed above lie outside the box to the south. There is no rock outcrop at this site. The limited exposures of medium-find sand that are the only expressions of backscatter contrast at this site show a pervasive NNW trend. We interpret these as ripple scour depressions at as other sites, but without obvious rippling and unrelated to the trend of the slope or coastline. There are most likely controlled by the underlying structural trends and are sub-parallel to the regional structural fabric of the accretionary prism. We suspect this fabric apparent in the northeast part of this map area is related to underlying flexural slip or other faulting, though there is no modern subbottom data in the Nehalem area for confirmation. There is only modest (0-2 m) bathymetric expression of these features. As in other areas, the NNW trending probable faults (dipping to the NE) appear to localize the ripple scour depressions in the eastern part of the survey area.

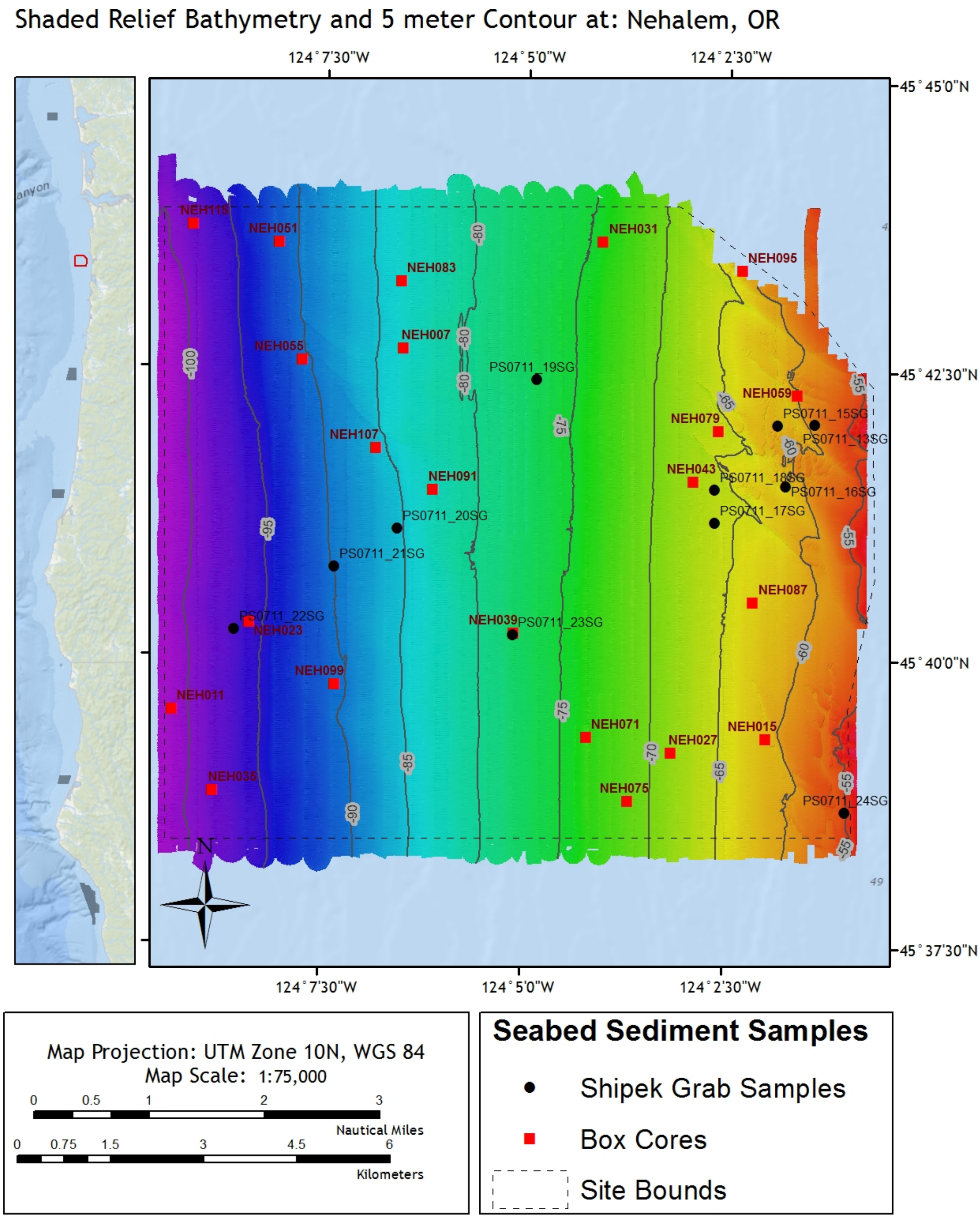


Figure 20. Color shaded-relief multibeam bathymetry data collected at Nehalem, OR
Sediment sample are plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

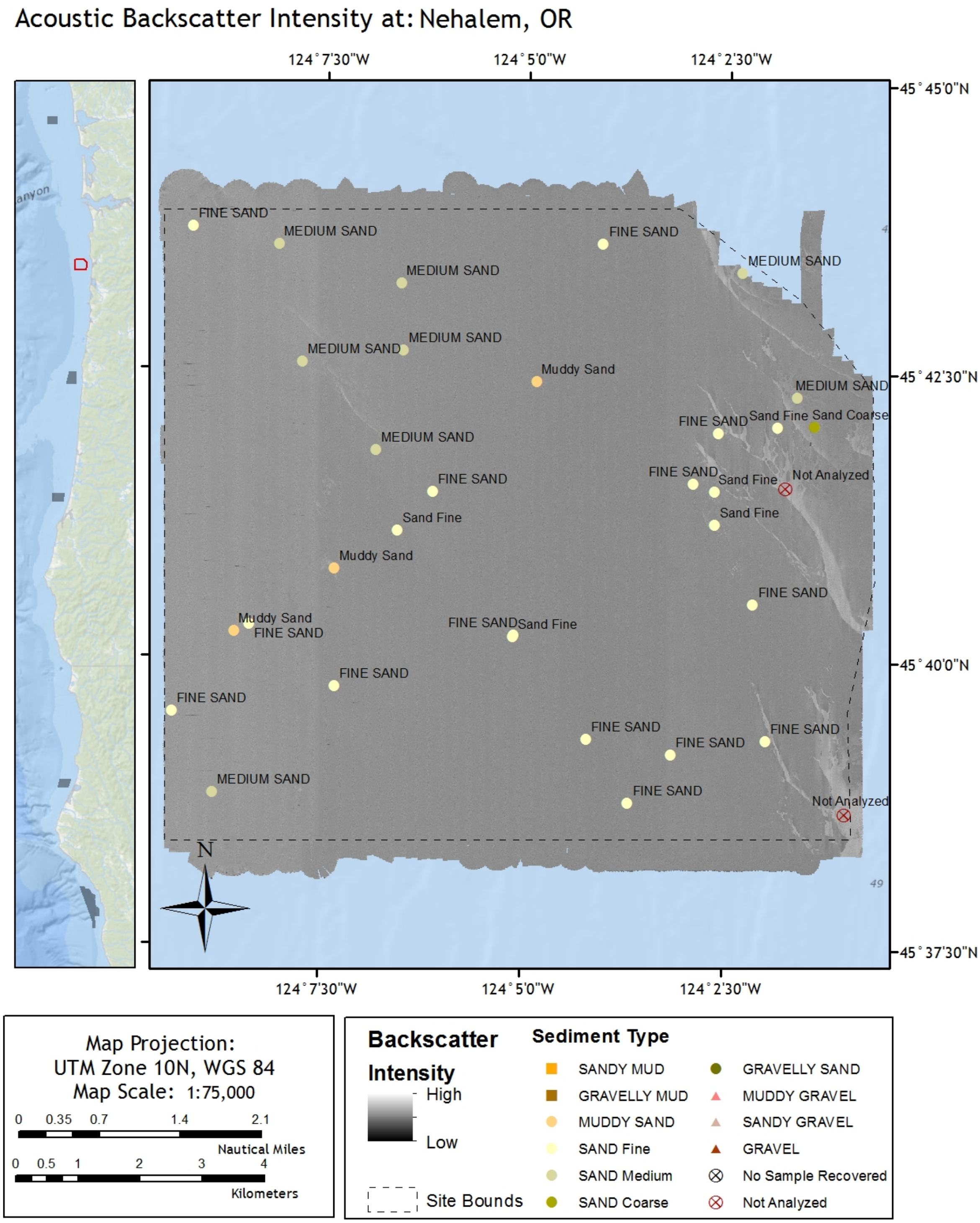


Figure 21. Multibeam backscatter data collected at Nehalem, OR
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam backscatter data.

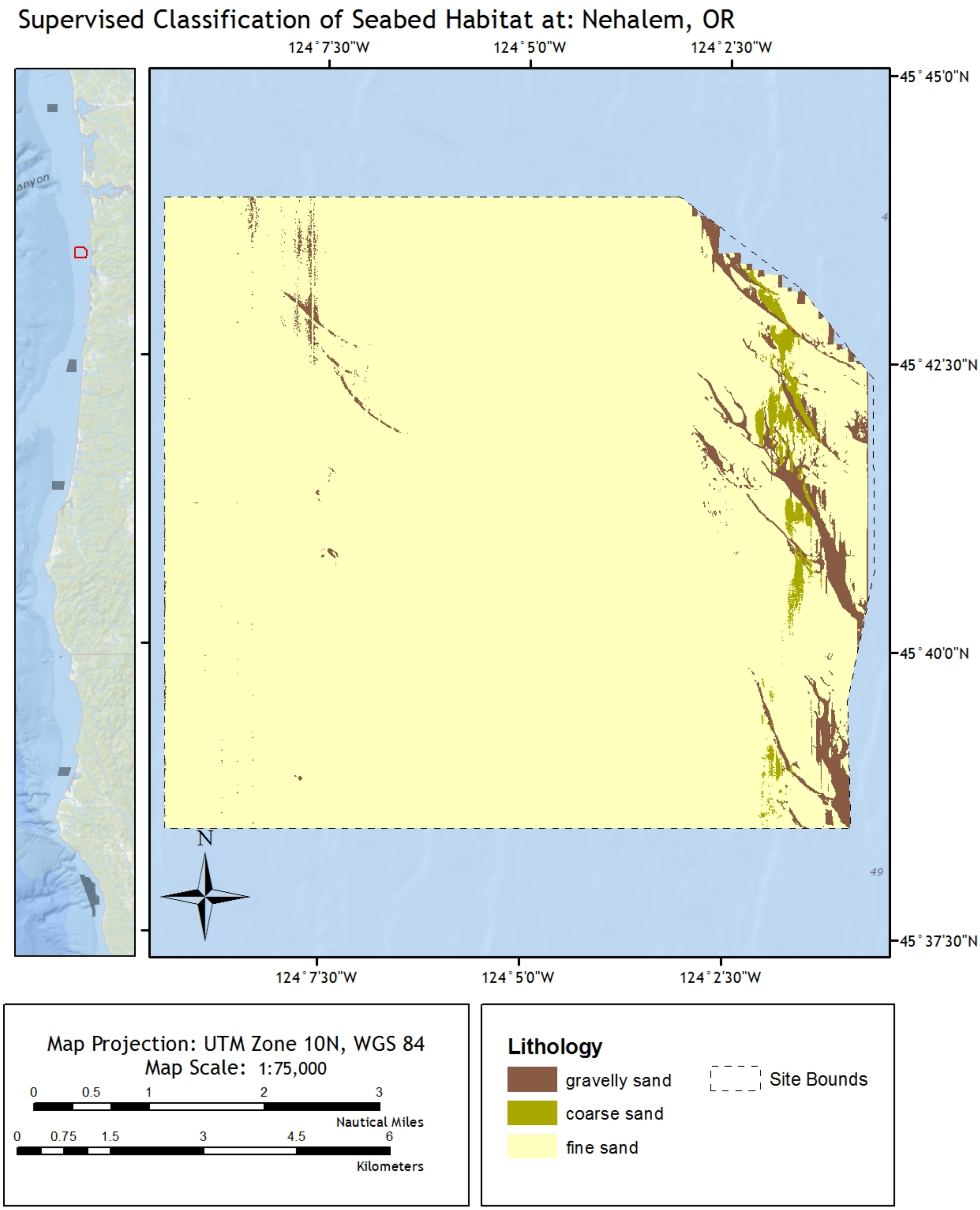


Figure 22. Seabed substrates at Nehalem, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

Newport, OR:

The Newport survey area lies within a structural zone known as the Newport syncline or Newport embayment. This major downwarp is part of the discontinuous en-echelon outer Cascadia forearc basin (Goldfinger et al. 1994, 1997; McNeill et al. 2000). Within the basin other secondary folds and faults are found in the survey area that exert control on the surficial geology. The effect of this type of faulting on the seafloor topography depends on the style of the underlying fold. If the folding is gentle, growth of a set of flexural slip faults produces a topography that mimics the underlying fold, that is, the seafloor is topographically lowest at the synclinal axes, highest at the anticlinal axes. With tighter folding, topographic inversion occurs as previously described. This type of topographic inversion is a temporary function of the interaction of the growing folds with the flat Pleistocene erosion surface, and would not persist through continued long term fold growth. Sidescan sonar images of these growing folds reveal that, in plan view, the flexural slip faults converge or diverge from the synclinal axes depending on the plunge direction of the fold. In the study area, a pervasive NW trending set of flexural slip faults is evident, with offsets of a few 10's of cm to up to ~ 2 m. Submersible observations of the seafloor scarps from several localities nearby indicate that these submarine features are better preserved than their land counterparts. Goldfinger (1994) observed overhanging scarps in several locations, and mole tracks in several others, both geomorphic features that would have very short life spans on land. Both mole tracks and high-angle scarps were observed to deform both the late Pleistocene gray clay, and the overlying olive-gray Holocene unconsolidated silt, indicating movement younger than 6,000 yrs. In several cases, colonization of the fault scarps by burrowing and attaching marine organisms decreased toward the bottom of the scarp, suggesting that uplift had occurred in multiple stages of fault movement.

A pervasive NW trending fabric of bathymetric features is also present at the Newport site (Figure 23 and Figure 24) that has been difficult to interpret due to lack of sub bottom data. In a subsequent section, similar features in the SETS wave energy test berth site are interpreted with sub bottom data and lined to the Newport BOEM site.

Surficial Geology of Newport, OR:

This mid-shelf soft sediment region was mapped in June of 2010 from the *R/V* Pacific Storm using a Reson 8101 (240 kHz) multibeam sonar (Figure 23 and Figure 24). The BOEM Newport study site covers a 12 km by 10 km area and abuts Oregon State Waters Mapping Program multibeam data to the east and Ocean Observing Initiative data to the west creating continuous data coverage from approximately 10 m water depth nearshore to 80 m water depth offshore. Box Core (n=25) and Shipek Grab (n=31) sampling was conducted in the Newport study site. Classified grain size information from the BOEM Box Cores and Shipek grab samples were used to map sedimentary habitats at Newport, OR. The surface lithology is primarily medium sand, with thin NW stringers of coarse sand (Figure 25). There is no rock outcrop at this site. As with Nehalem, and the NNMREC SETS test berth a few km to the south, this pervasive NW trending fabric of sand and high backscatter depressions has modest bathymetric expression.

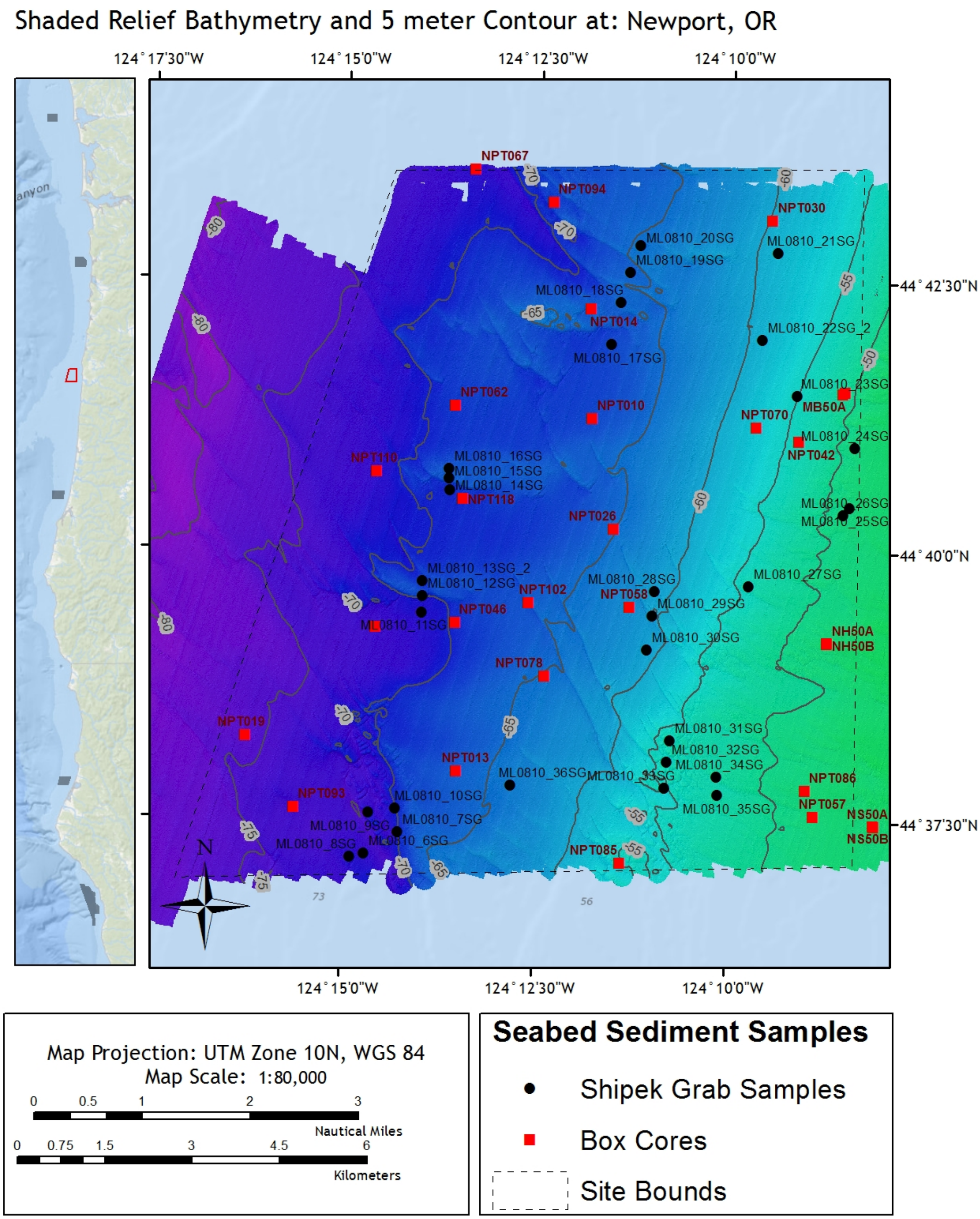


Figure 23. Color shaded-relief multibeam bathymetry data collected at Newport, OR
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

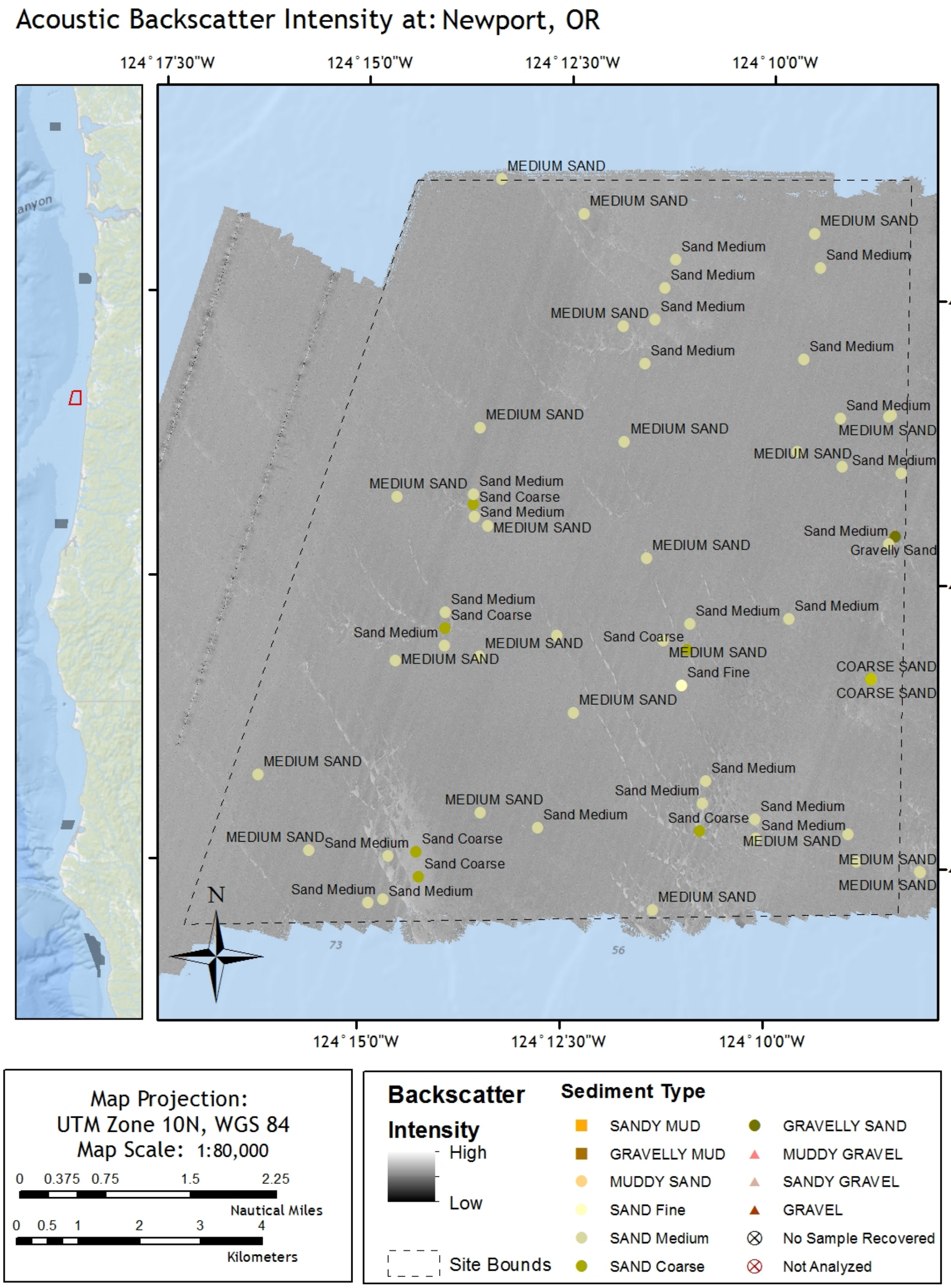


Figure 24. Multibeam backscatter data collected at Newport, OR.
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam backscatter) data.

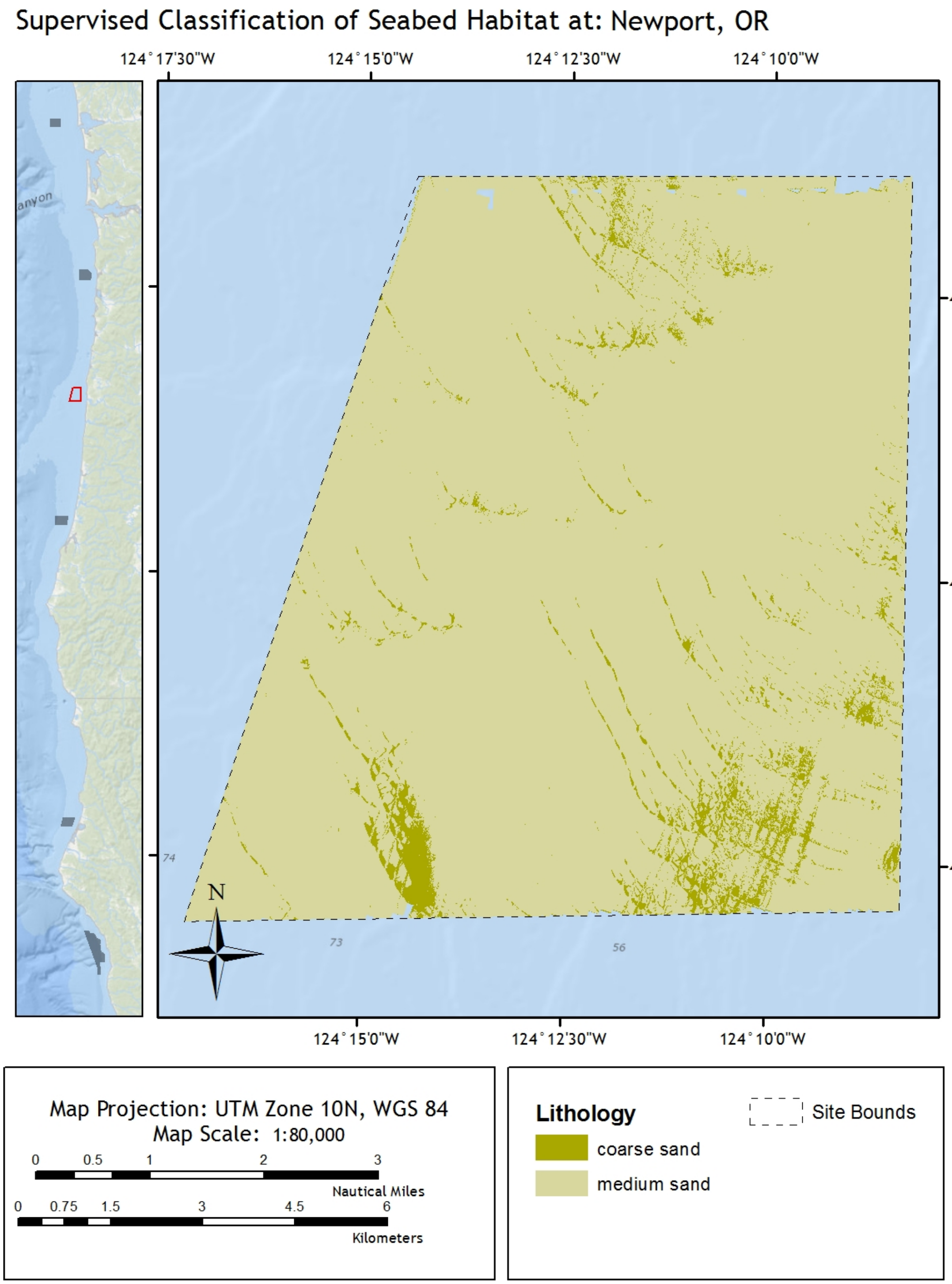


Figure 25. Seabed substrates at Newport, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

South Energy Test Site (SETS), OR:

Although a full structural and morphologic analysis of the BOEM Newport area is beyond the scope of this study, we have been working on the interpretation of this site and the nearby NNMREC SETS site off Seal Rock, to the south of the BOEM study site. Here we include a summary of the subsurface geology of the SETS site because it is the most detailed geophysical survey of an area of the PNW inner shelf, and reveals a great deal about the subsurface and surficial geology that is applicable to the adjacent BOEM Newport site as well as much of the Oregon and southern Washington inner shelf. The NNMREC project staff has graciously allowed us to include these data and preliminary interpretations in this report.

At the SETS site, an intensive geophysical survey was conducted in June 2014 in which more multibeam and backscatter data were collected, along with a closely spaced grid of CHIRP and boomer sub bottom profiles. The goal of these surveys was to locate a viable route for cables leading to wave energy test devices located offshore. At part of the route was to be buried, the shallow subsurface geology is a critical factor. The SETS site geology is somewhat challenging, and therefore the detailed survey was required. Figure 26 shows the SETS survey overview with bathymetric data overlain with tracklines from the boomer and CHIRP profiles. Figure 27 shows the SETS study area, overlain with regional structural geologic interpretation of the major structures in the area based on industry and academic single channel sparker profiles, as well as industry multichannel profiles. The sets site (and the BOEM site just to the north, lie in an active syncline between the Seal Rock anticline onshore to the east, and the Stonewall anticline just to the west (Yeats et al. 1998). These anticlines expose rocks of Miocene age (Relizian and Saucezian Stage faunal calls based on proprietary industry dart core data) equivalent to Astoria Formation units mapped onshore (Snavely et al. 1969). The crest to crest distance between the two anticlines is at least 25 km. This broad syncline has several active flexural slip faults on its western margin, and several down the west faults of unknown type on its eastern margin. Seafloor offsets on these faults indicate that they, and the underlying syncline, have been active in the Holocene. A prominent unconformity is apparent in the seismic profiles, which is also observed in the 2014 boomer profiles. This unconformity separates two primary units with greater (lower) and lesser (upper) degrees of deformation.

Northwest Trending Bathymetric Features

We investigated the pervasive NW trending topographic features seen in Figure 28 to determine their origin and relationships to hard substrate as seen in the bathymetry and backscatter data (Figure 28 and Figure 29). We initially thought that the features were likely structural, as they are pervasive through the area, extend well to the north through the BOEM study box and much further north along the Oregon inner shelf (limits are presently unknown). These features also lie at nearly right angles to the plate convergence direction, suggesting a potential link. However, they also lie at 50-70 degree angle to the major active structures shown in Figure 27, making a structural origin less than straightforward.

In Figure 30, we show one of the CHIRP profiles across the NW trending features, along with backscatter data for the same area. The low amplitude topographic highs correspond to the backscatter highs, which generally are strongest on the SW flanks of these features. The topographic highs are asymmetric, with steeper slopes to the southwest, and shallower slopes the NE. The backscatter data also follow this pattern, with high backscatter tracing the SW (steeper) flanks and fading in intensity to the NE. The sub bottom image shows that the topographic highs generally do not correspond to faults as we had initially assumed. There are small diffractions in the data most likely related to steps in acoustic impedance (hard to soft) that extend downward, but are artifacts and not structures. We have not found any examples where these low amplitude asymmetric highs are linked to faulting. We also observe that the underlying unconformity is not deformed below these features, as one would expect if they were generated by faulting. There is however a slight mimicking of the upper topography that we interpret as velocity "pullup" and artifact of having more high velocity material overlying the topographic highs.

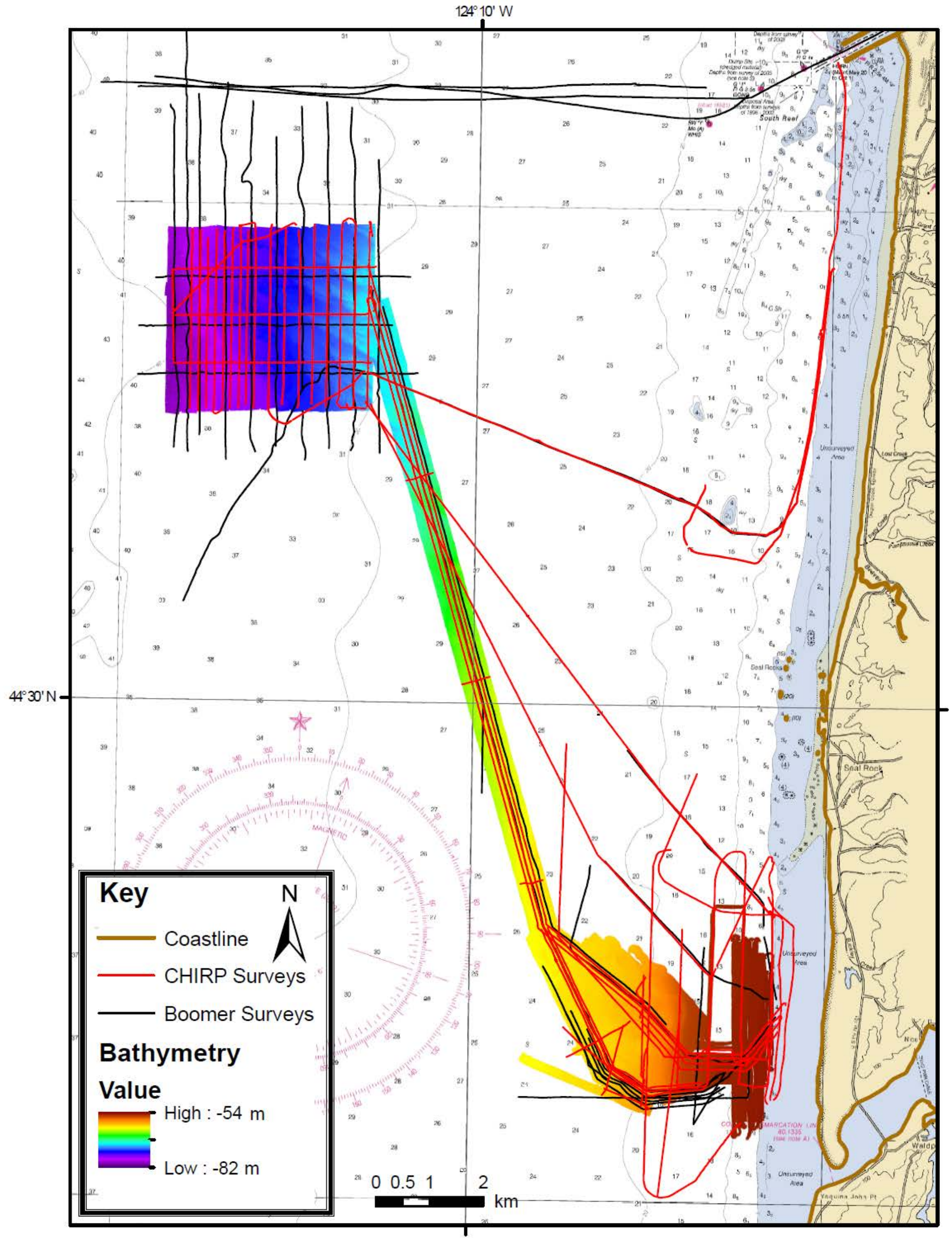


Figure 26. SETS survey area bathymetric data and geophysical tracklines near Seal Rock, OR

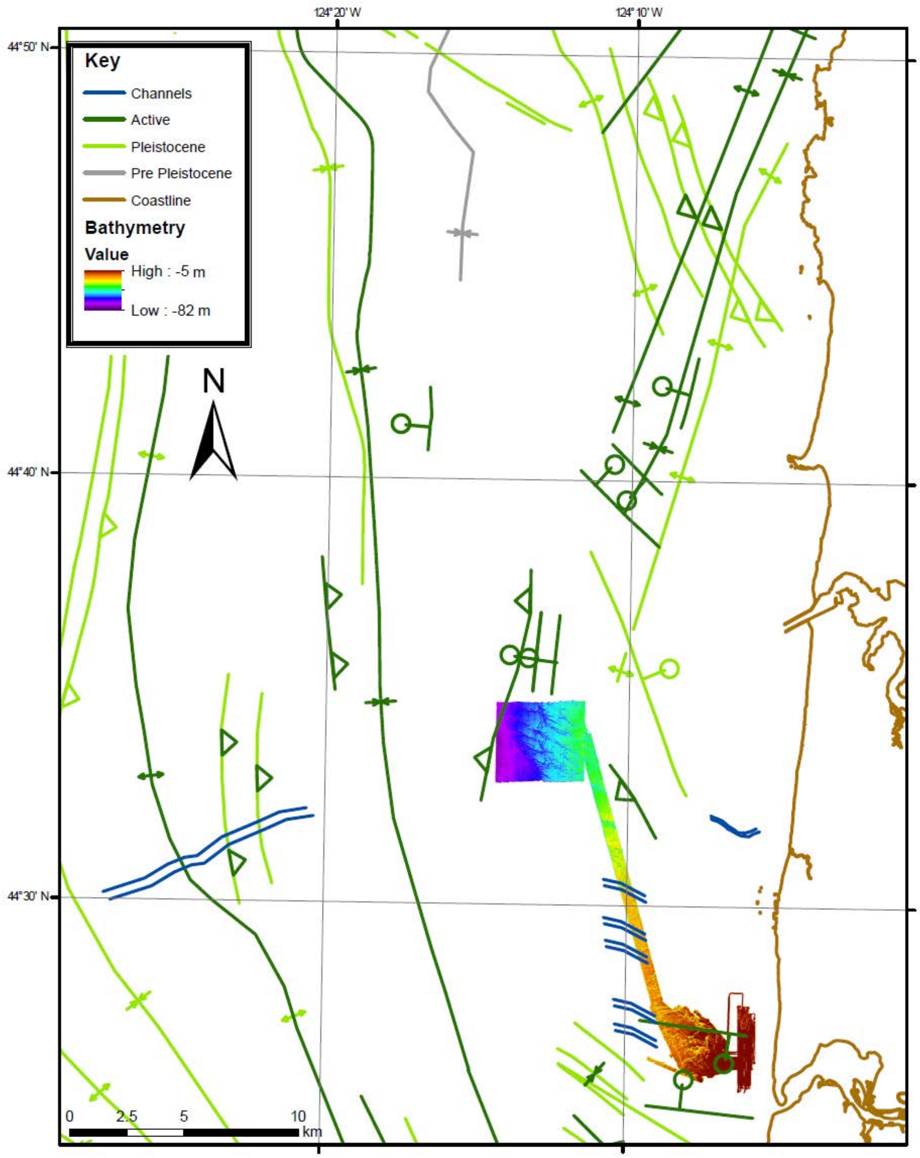


Figure 27. **Major structures of the inner shelf off Newport, OR**
SETS bathymetric data shown. SETS sites lies on the east flank of major syncline at center. NW trending bathymetric features in the SETS bathymetry (and BOEM Newport as well) cross the structural grain at an obtuse angle.

Examination of the CHIRP and boomer datasets reveals that the relationship between the topographic highs and the backscatter is very strong, and the lack of underlying structure is pervasive. The low amplitude topographic highs have wavelengths of 200-600 m, and are overlain by sub-parallel but smaller features that are generally similar, which we interpret as sand waves.

Looking closely at the backscatter and bathymetric data we see that the high backscatter areas are depressions as previously described, but also that they are closely related to the underlying low amplitude highs. Many of the high backscatter depressions form along the steeper SW flank of the highs, and many also form dendritic drainages off these highs into the swales between them (Figure 28 and Figure 29).

The presence of drainage patterns like this suggest that the underlying features are long-lived enough that

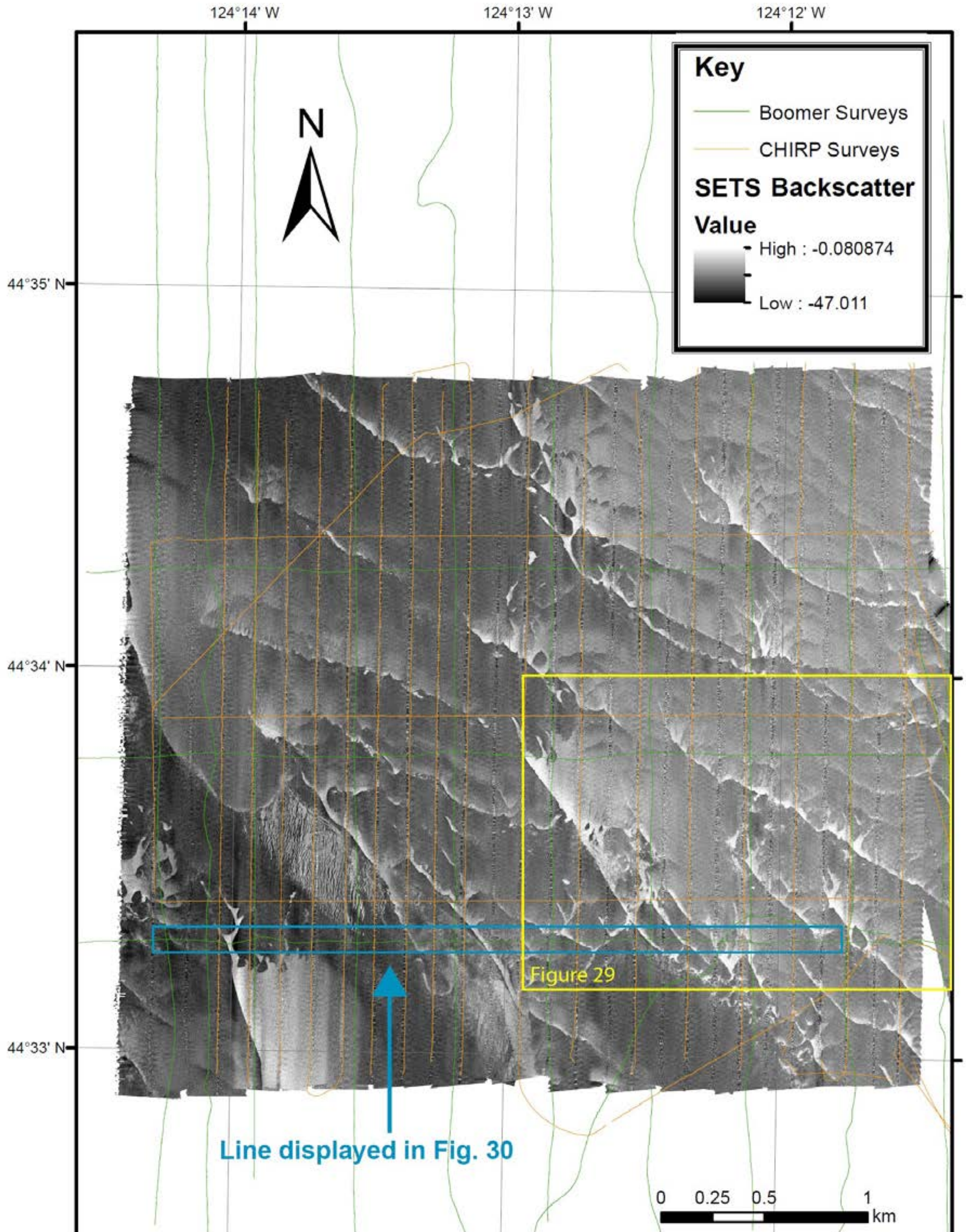


Figure 28. Backscatter data in the SETS test berth site overlain with boomer and CHIRP sub bottom profile tracklines

Pervasive NW trending features are shown, with high backscatter concentrated on the SW faces of the asymmetric features. Areas of Figure 29 and Figure 30 are shown.

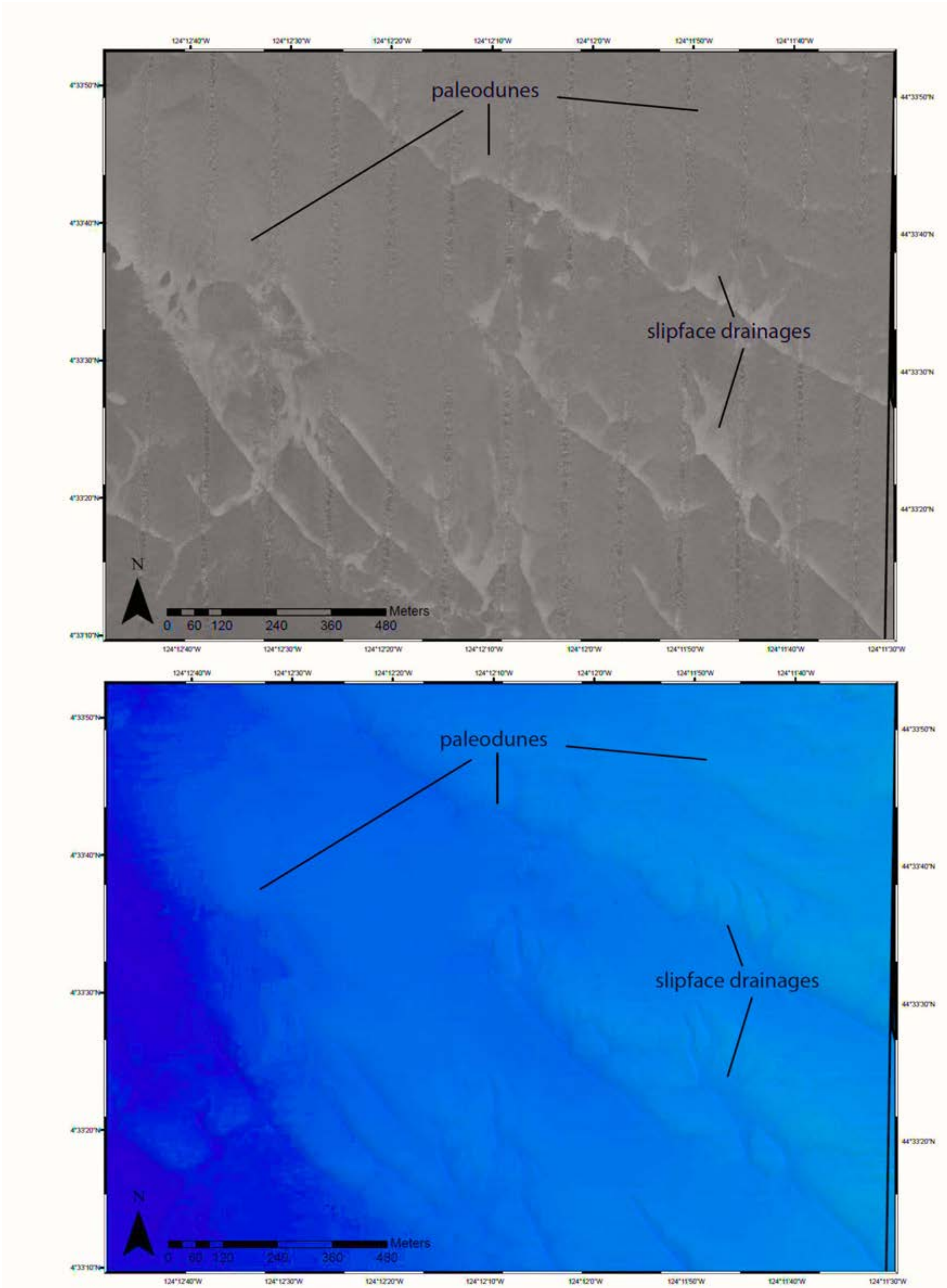


Figure 29. Backscatter (top) and shaded relief imagery of a part of the SETS test berth site
NW trending asymmetric bathymetric features are shown in the seabed imagery. Steeper faces toward the SW. Scour depressions (high backscatter) form drainages, mostly on the steeper faces. Features are tentatively interpreted as subaerially formed paleo dunes.

secondary erosion processes are modifying them significantly. This also provides an explanation for the lack of temporal movement of these high backscatter features. At least within the SETS study area, and perhaps elsewhere, the high backscatter depressions are linked directly to the underlying substrate. Therefore at least in this case, these features cannot be equated with the "ripple scour depressions" as discussed by Cachionne et al. (1984) but have a different association with underlying topography. It is possible however that erosion of these features may be enhanced in this area by scouring around the topographic highs, and or sediment transport controlled or modified by these features in such a way to exaggerate the bathymetric expression of the underlying features. In this case, the scour is due to increase wave energy stress related to the topography. In this way there may be a looser genetic association with the ripple scour depressions described elsewhere. In any case, this apparent linkage between surface and subsurface features suggests somewhat less temporal and therefore volumetric mobility of the surficial sand sheet that would be expected if the scours were randomly generated during individual storm events, at least in the water depths in the study area, 45-75 m.

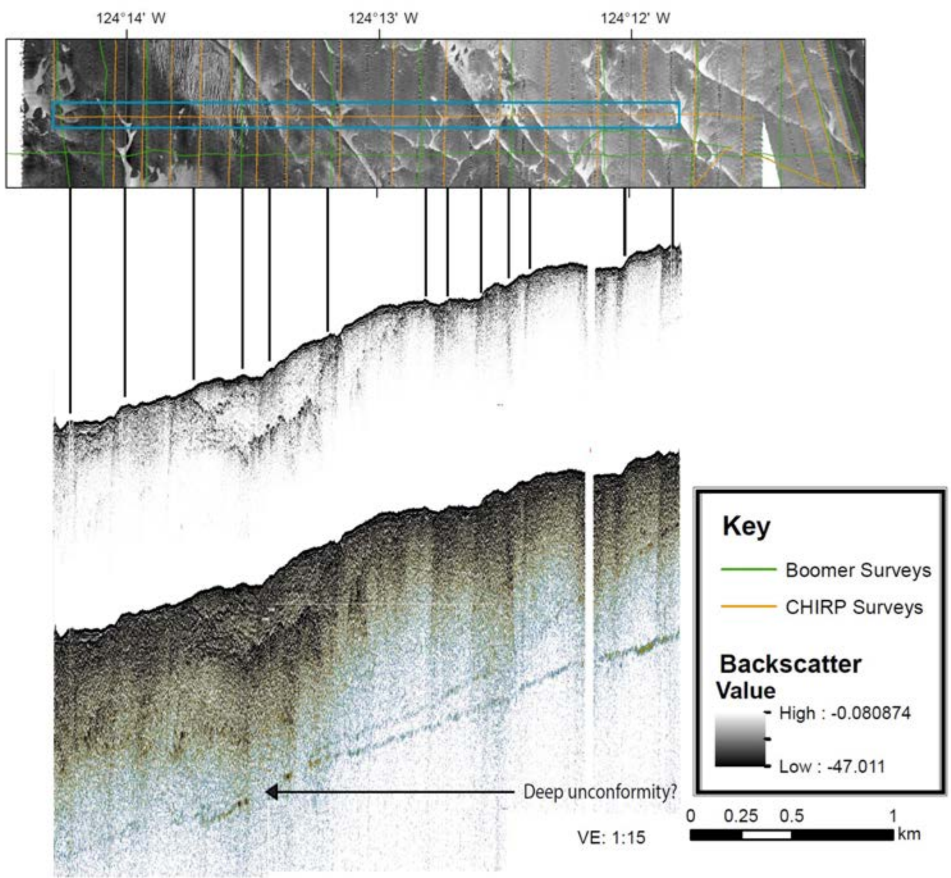


Figure 30. CHIRP profile and corresponding backscatter across possible paleodunes, SETS test berth
Tie line between backscatter and profile are shown. Lower panel shows profile optimized to show deeper possible unconformity surface (this potentially also could be an artifact).

The larger asymmetric highs are generally similar in form to sand waves, and similar in orientation to the overlying smaller sand waves, yet their wavelengths (200-600 m) are very large for this type of environment. We know of no modern analog on the PNW shelf where such features are forming today. As these features appear inactive, and without a modern submarine analog, we suspect that they may in fact be Pleistocene subaerial features that are now partly exposed and being overlain and modified by recent marine processes. Candidate features that could fit this description are very large subaerial dunes such as those observed between Florence and Coos Bay today along the modern coast. The dunes of the southern Oregon coast are similar in scale, and at least some areas have a NW orientation (Figure 31 and Figure 32), though E-W and SW trends are also seen in the same region. Dunes of that orientation have a much smaller wavelength and have a NW gentle face, consistent with summer N-NW winds. Dunes generally form with the gentle face on the upwind side (Figure 31). The asymmetry of the dunes observed on the southern Oregon coast (near Winchester OR) with a NW strike is with the gentle face facing SW, the predominant storm wind direction. The possible relict dunes in the SETS study area have the opposite orientation, with the gentle face on the NE side, suggesting prevailing NE winds, very different from seasonal prevailing winds today.

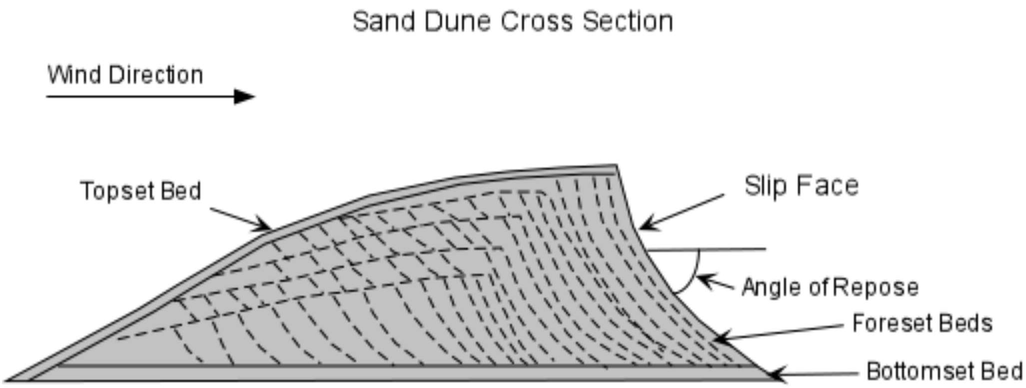


Figure 31. Typical subaerial dune cross section.
http://www.tulane.edu/~sanelson/images/dune.gif

Figure 32. Dune field south of Winchester, OR.
These dunes are roughly the same scale as the interpreted paleo dunes on the SETS and BOEM study areas, having wavelengths of ~ 300-400 m (other nearby dune filed have much shorter wavelengths). The wind direction indicated by these dunes is northerly, while the offshore possible paleo dunes suggest a northeasterly prevailing wind.

Subsurface Topography

The CHIRP and boomer seismic profiles reveal a complex shallow subsurface topography that is for the most part not apparent in the surface topography and pical example geology (Figure 33). In addition to the pervasive NW trending “paleo dunes” and probably modern sand waves observed at the surface, the shallow subsurface (< ~ 20 m) is characterized by a generally irregular and commonly rough surface defined by several prominent reflectors in the sub-bottom profiles. We used the IHS Kingdom seismic interpretation package to integrate the SEGY seismic data from the boomer and CHIRP surveys with bathymetric and backscatter data for interpretation. We interpret 2-5 (typically 3) significant subsurface reflectors traced throughout the study area that we have used to track the variability of what are most likely old erosion surfaced. A planned vibra-coring survey was not successful in ground-truthing the sub bottom data, thus the following discussion lacks definitive ground truth regarding the lithology, hardness or age of the stratigraphic sequence. Figure 33 shows the high degree of subsurface topography apparent in much of the study area.

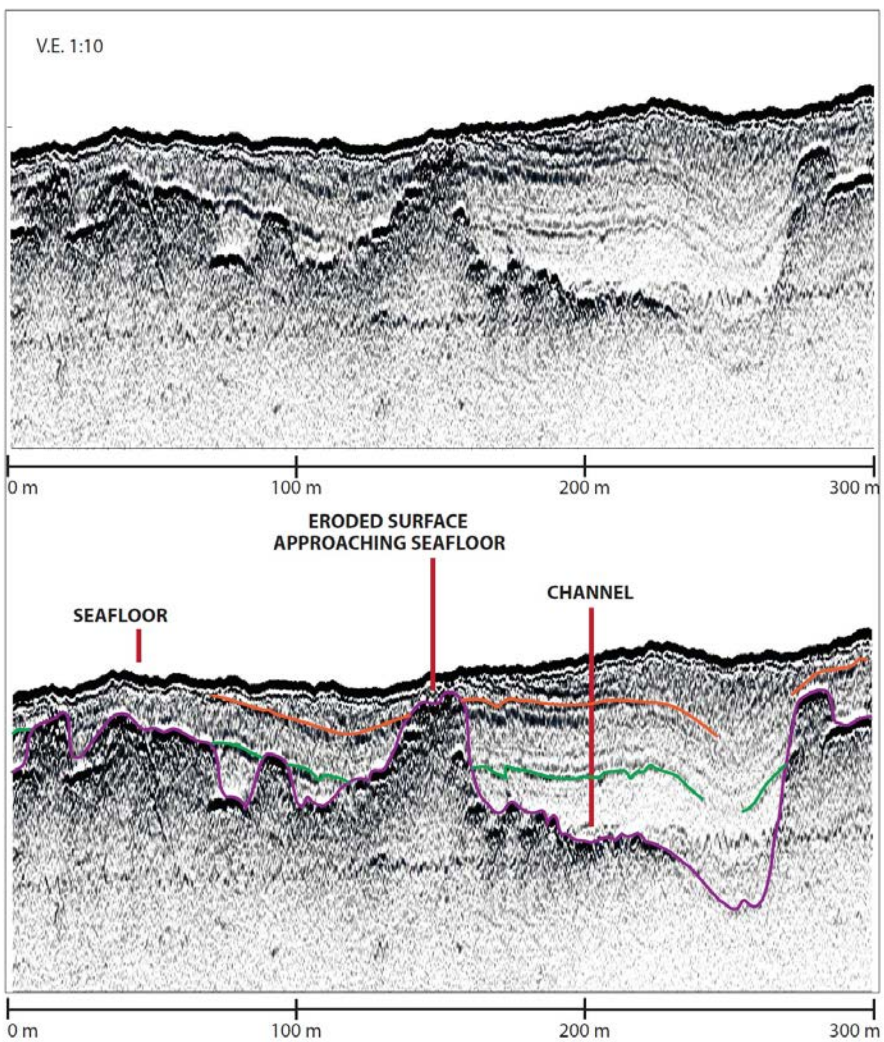


Figure 33. Chirp profile, SETS test berth site
This profile shows the subsurface paleo-topographic surface, a buried channel, and overlying transgressive sand cover in the SETS test berth site.

While it was known or surmised that a transgressive gravel sheet existed in the subsurface, and presumed that a subaerial topography drowned after the LGM transgression existed, these data are among the first to show this surface in detail. In the SETS area we observe what are most likely former stream channels associated with the modern Beaver Creek, Alsea River and Yaquina River Channels. While not enough data exist to definitively connect the mapped channels with these modern systems, they positions and trends are highly suggestive of such a connection. The former channels are now filled with probable transgression and post transgression sediments. In addition to the channels, the uppermost hard reflector, here interpreted as the transgressive surface in most cases, has significant topography that may have been the pre-transgression land surface, perhaps modified as it passed through the surf zone during rapid inundation of the latest Pleistocene meltwater pulses. Not enough data exist to map the surface in great detail, but the depth to the youngest surface (in two-way travel time) is shown in Figure 34.

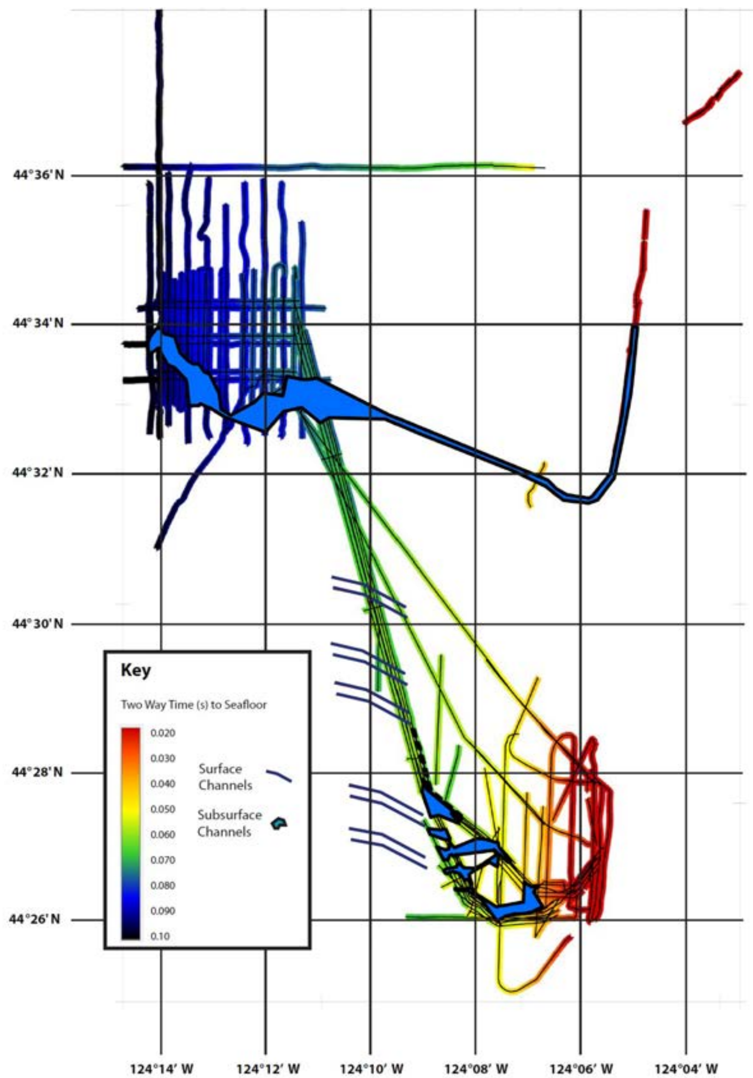


Figure 34. Two-way travel time to shallowest unconformity surface, SETS test site
This colored surface represents the depth (in two way travel-time) to the first and most prominent unconformity surface thought to represent the now buried Pleistocene land surface. Buried channels also shown, in blue.

This surface merges with the seafloor reflector in many places. In such cases we are unable to determine whether the surface reaches the seafloor or is thinly covered in some places, though in others this surface merges with the seafloor in the area of possible relict dunes. The shallow subsurface imaged in the SETS study resembles that described onshore where under high-stand conditions, Pleistocene sands filled channels and low spots cut into the Astoria Formation and Nye mudstones and are now exposed in the Newport area (Snavely et al. 1969). Without additional geophysical data we cannon know with certainty that the rough paleo surfaces observed at the SETS site are typical of the Oregon inner shelf, or in somewhat anomalous. We know of no particular reason, however, to suspect that this particular site is anomalous and think in more likely that it is relatively typical of the mid to inner continental shelf of at least the central Oregon margin.

Siltcoos, OR:

The Siltcoos Oregon shelf area is generally similar to other areas of the Oregon shelf between approximately Coos Bay and the Nehalem area. The low relief reef exposures are structurally controlled, and predominately NNW-N-S trending. Where exposed the rocks are likely Miocene Astoria Formation or equivalent rocks similar to coastal exposures. The low relief hard substrate lies along the crests of several anticlines that lie within the Coos Basin, another element of the en-echelon larger basin system that comprise the outer forearc basin of Cascadia. Flexural slip faulting is present though not as evident at the surface as it is in the Newport area. The fold related faults appear to be largely either slower moving or perhaps smothered by greater sediment thickness associated with significant deposition from the Umpqua River (Wheatcroft et al. 2013). Just to the south of the Siltcoos area, a major structural terrane boundary is found separating Eocene and younger rocks from much older crystalline Klamath terrane. We describe this briefly here as it has a profound effect on the surficial geology and relates to both the Siltcoos and Bandon-Arago areas. Snavely (1987) has inferred that a major arc-parallel dextral strike-slip fault, the Fulmar fault, underlies much of the Oregon shelf, and truncates the seaward edge of the Eocene Siletz River volcanics, the oceanic basalt unit that forms the basement of western Oregon (Snavely 1987). This fault comes ashore at Five Mile Point, ~ 21 km south of the Siltcoos site, where Pleistocene terrace deposits are deformed by it. Based upon industry test well biostratigraphy, he infers 200 km of dextral slip on this fault, mostly during the Eocene. Overlying this location is a minor fault in the axis of a young anticline at the seafloor in Plio-Pleistocene strata. We have not found any evidence for a throughgoing arc-parallel fault in Neogene strata on the Oregon shelf, and we conclude that the Fulmar fault is probably not currently active in this part of the central Oregon margin, though the uplifted reef forming strata in the Siltcoos survey box could conceivably be related to it.

Surficial Geology of Siltcoos, OR:

Lacking the pervasive flexural slip faulting, major structures, or CRB intrusives, the Siltcoos area surficial geology simpler and more uniform. This mid-shelf region of soft sediment and rocky outcrop was mapped in July of 2010 from the *R/V Pacific Storm* using the Reson 8101 (240 kHz) multibeam sonar (Figure 35 and Figure 36). The BOEM Siltcoos study site covers a 10 km by 11 km area and abuts Oregon State Waters Mapping Program multibeam data creating continuous data coverage from approximately 10 m water depth nearshore to 95 m water depth offshore. Box Core sampling (n=19), Shipek Grab sampling (n=6), and ROV dives (n=30) were conducted in the Siltcoos study site. Classified grain size information from the BOEM Box Cores and Shipek grab samples were used to map sedimentary habitats at Siltcoos. Classified ROV “segments” from the BOEM ROV dives in 2011 were used to guide the rocky habitat mapping at Siltcoos, OR (Figure 37).

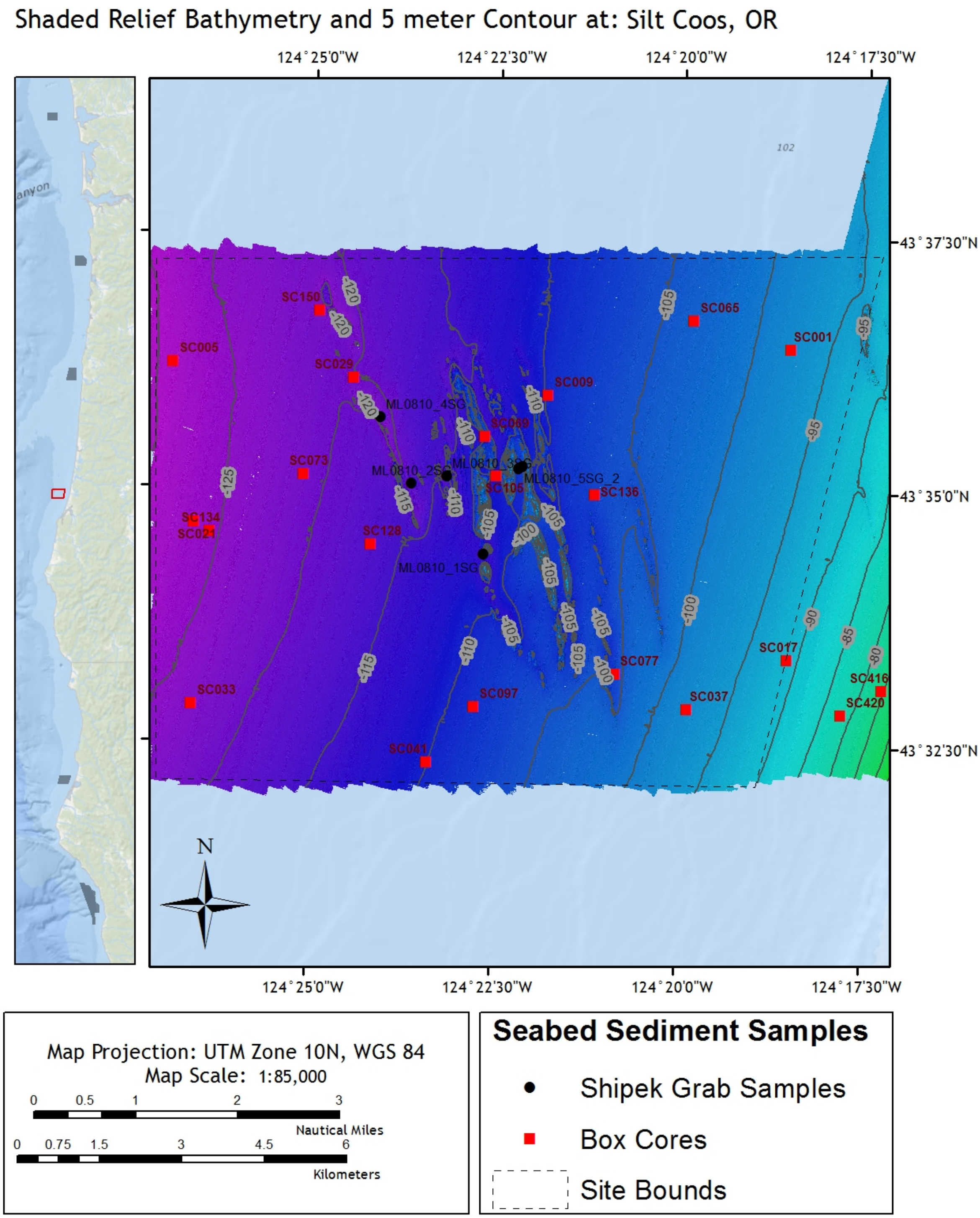


Figure 35. Color shaded-relief multibeam bathymetry data collected at Siltcoos, OR
Sediment sample are plotted over the Reson 8101 (240 kHz) multibeam data.

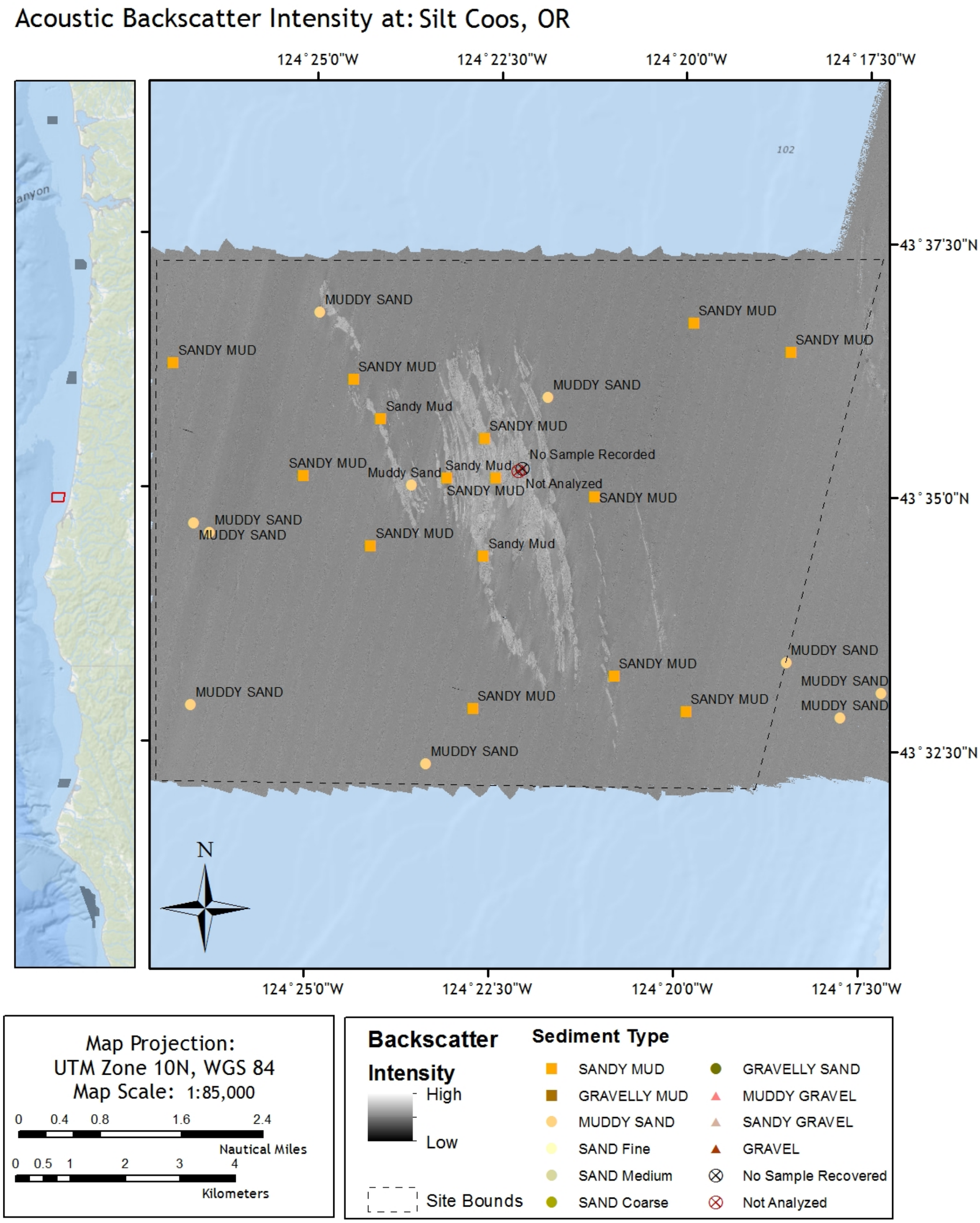


Figure 36. Multibeam backscatter data collected at Siltcoos, OR
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam backscatter data.

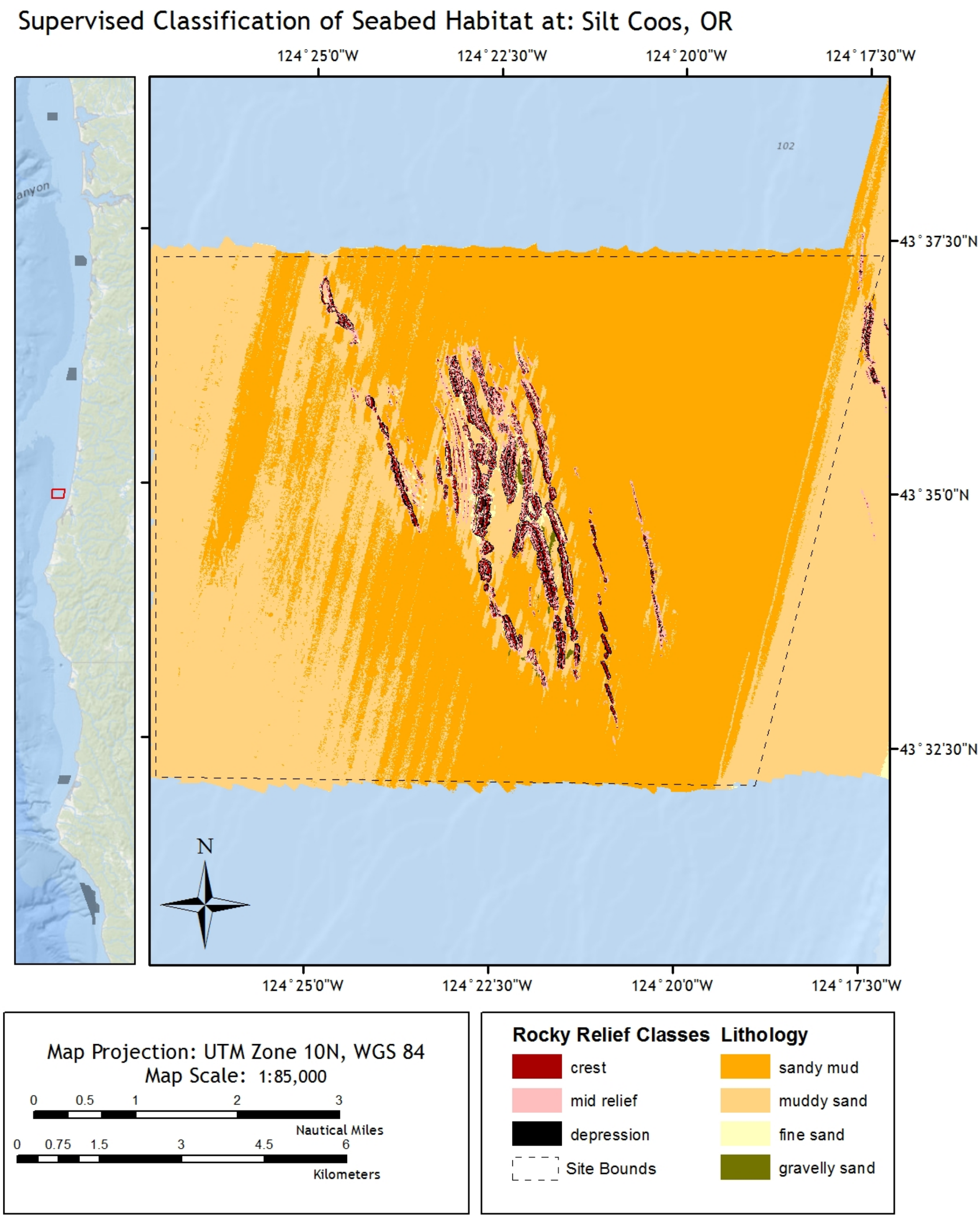


Figure 37. Seabed substrates at Siltcoos, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

Bandon-Arago Area, OR:

Although not a site specifically surveyed for this study, some analysis was done in this area, and dives were made on the basis of bathymetric data collected as part of the Oregon State Waters Mapping Program, thus we briefly describe the geology here. As previously mentioned, a major structural terrane boundary is found separating Eocene and younger rocks from much older crystalline Klamath terrane. This boundary may be defined in part by the Coquille Fault, located on the inner southern Oregon shelf, which was first mapped by Clarke et al. (1985). We investigated this structure first in 1992 using an analog Klein 50 kHz sidescan sonar, then again in September, 1993 using the AMS 150 kHz digital system (Goldfinger 1994). The rocks exposed at the surface in this area are principally a siliceous diatomaceous unit of late Miocene age, overlain unconformably by unconsolidated Pleistocene and Holocene sand (Fowler et al. 1971). This unusual unit may be in fault contact with Jurassic-Cretaceous Klamath terrane rocks in this area (Fowler et al. 1971), possibly across the Coquille fault, which our records and a nearby Chevron multichannel reflection record show to be a significant structure. Goldfinger et al. (1992) infer approximately 3 kilometers of dextral slip on this structure based on offsets of NE trending fold axes mapped from seismic reflection records. Sidescan records of the Coquille fault show a structurally complex zone of primary and secondary faults and associated folding. Bathymetric data show broad NNW trending folds exposed and eroded forming complex and convoluted strike ridges throughout the area. Tight parasitic folding was also observed from the DELTA submersible. The strata in the anticlinal hinges are separating from underlying beds by what appears to be a form of exfoliation along the bedding planes. The upper bedding surfaces break off in tabular blocks that we observed in the bottoms of the synclines and between strike ridges. We infer that one of two processes may be occurring: 1) a form of exfoliation of sedimentary/metamorphic rocks, or 2) continued active folding, causing separation of the uppermost beds which have no confining boundary. These processes are not mutually exclusive and may occur contemporaneously. Despite the somewhat indirect nature of evidence for late Quaternary deformation associated with the Coquille fault, deformation of the marine terraces where the Coquille fault comes ashore demonstrates clearly that this is an active structure. There is very little unconsolidated sediment in this area, and what exists is mainly limited to rubble in the small swales between strike ridges, and some possibly mobile sand patches.

Eureka, CA:

The continental shelf in the Eureka area is dominated by active deformation associated with the Cascadia accretionary prism. The Cascadia margin narrows in this area, and the active accretionary wedge comes across the shelf and onshore into Humboldt County (Clarke and Carver 1995). Active strike slip or oblique slip faults such as the Little Salmon and several other faults cross the coastline and extend out onto the shelf, crosscutting the accretionary prism faults (Carver 2000). As in other areas of the Cascadia shelf, active faulting is the primary driver for uplift of consolidated rocks and controls the distribution of unconsolidated sediments. The Eel River is a large sediment source in the area, exceeding in modern times the sediment discharge of the Columbia River. As with other Northwest river systems, highest discharge is in the winter, and transport is generally to the north and northwest via the Davidson countercurrent. Puig et al. (2003) document the transport of the high Eel sediment load during storm conditions across the shelf toward the head of Eel Canyon.

Surficial Geology of Eureka CA:

This mid-shelf soft sediment region was mapped as part of the Office of Naval Research funded STRATAFORM project in 1995 from the *R/V Pacific Hunter* Cruise 9507016 (Goff et al., 1996) using a Kongsberg EM 1000 multibeam sonar (95 kHz). The BOEM Eureka study site covers a 9 km by 12 km area with continuous data coverage from approximately 40 m water depth inshore to 200 m water depth offshore. Box Core (n=20) sampling was conducted in the Eureka study site; however, no Shipek Grab samples were collected. Classified grain size information from the BOEM Box Core samples were used to map sedimentary habitats at Eureka, CA. There is no rock outcrop at this site.

The high sediment load results in fairly deep burial of active folds and faults that cannot keep up with the deposition rate, leaving no outcrops at the surface. On the inner shelf, only one rock outcrop is seen in the bathymetry and backscatter data related to a known fold/faults system (several km's south of the study site). In deeper water, several NW trending folds breach the surface and form rocky high backscatter outcrops. At mid water depths in the study area sediment wave fields are apparent, as is a rilled topography related to downslope sediment transport from the shelf to the upper continental slope. The wave fields on the upper slope are high backscatter sand (not sampled), while the mid and inner shelf is mostly muddy sand and sandy mud (Figure 38 and Figure 39). Figure 40 shows the area of the larger sonar survey that was mapped for seabed habitat type. The full survey dataset was not mapped due to lack of Box Core or Shipek Grab sample data. The classified habitat map for this region is shown in Figure 40.

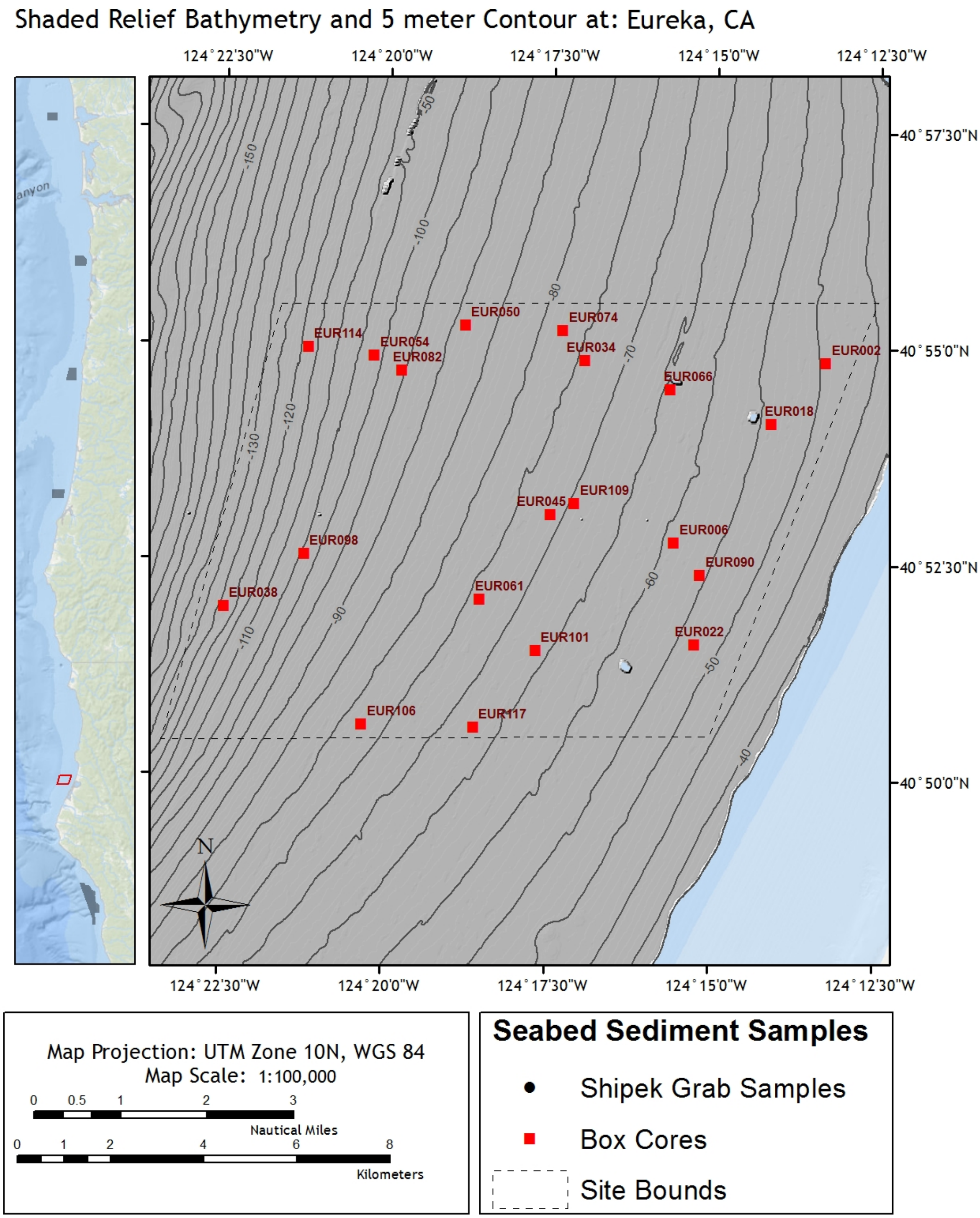


Figure 38. Multibeam bathymetry data collected at Eureka, CA
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

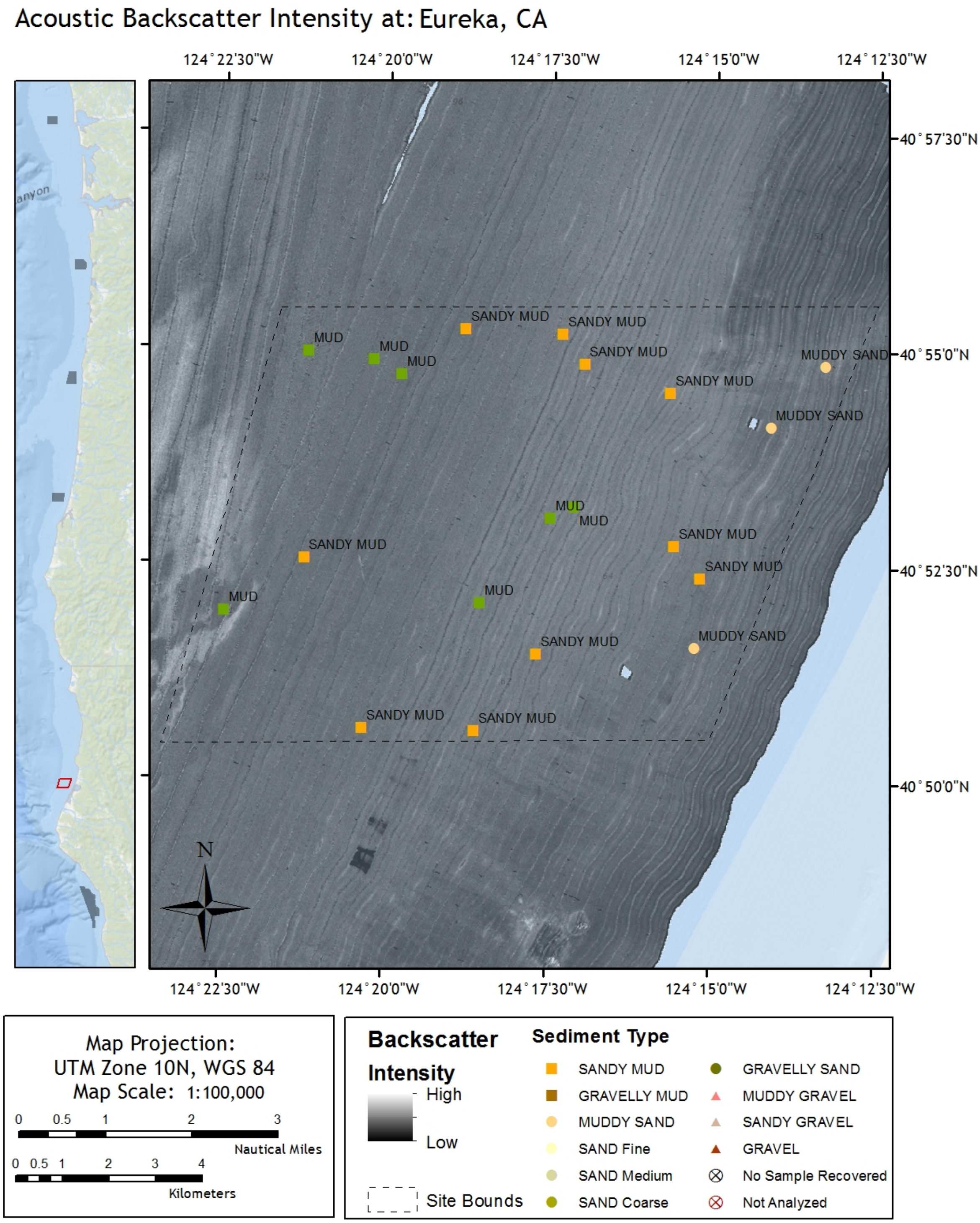


Figure 39. Multibeam backscatter data collected at Eureka, CA
Sediment textural classifications plotted over the Kongsberg EM3000 (300 kHz) multibeam backscatter data.

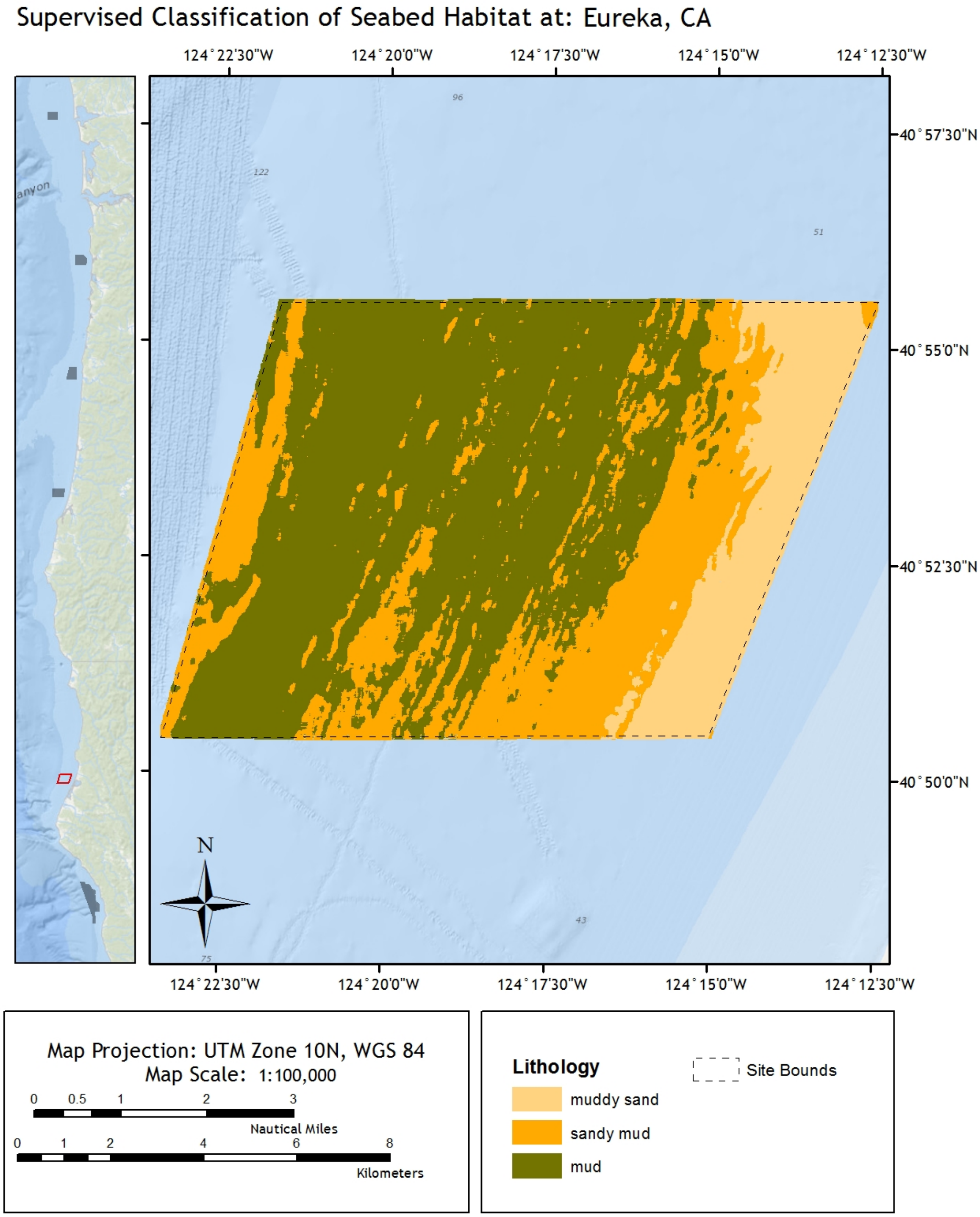


Figure 40. Seabed substrates at Eureka, CA
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

Northern San Andreas Fault (NSAF), CA:

The surficial geology west and northwest of Fort Bragg, CA in the southernmost BOEM study area is dominated by the northern San Andreas Fault (NSAF). The NSAF is offshore between Point Arena and its northern termination at the Mendocino Triple Junction. The NSAF is a right-lateral, strike slip fault and is the main structural boundary in the widely distributed plate boundary between the Pacific plate and the Serra Nevada Great Valley (SNGV) micro-plate (Williams et al. 2006). The NSAF is the primary structure along this plate boundary with an estimated slip-rate in northern California between 18 - 25 mm/yr (Kelson et al. 2006, McLauglin 1994, Niemi and Hall 1992, Williams et al. 2006). The offshore section of the NSAF's location and geometry is poorly known because of its challenging environment to collect geologic and geophysical data. Curray and Nason (1967) showed through a series of widely spaced analog, seismic reflection profiles that the NSAF offshore of Point Arena, CA, and likely coming back onshore at Shelter Cove, CA.

The joint multibeam dataset was collected under support from this project and a concurrent NOAA Ocean Explorer supported project to investigate the NSAF and associated groundfish habitats along the San Andreas Fault (Beeson et al. 2011, 2012). Collaborators to the NOAA Ocean Explorer project included the USGS Pacific Coastal & Marine Science Center, NOAA Northwest Fisheries Science Center, and Oregon State University. Preliminary interpretations reported here include both the BOEM supported multibeam mapping and sampling, and the preliminary interpretations of stratigraphy and structure related to the joint OSU USGS NOAA supported seismic reflection dataset, final interpretation of which is in preparation as of this writing.

Neogene sedimentary units in this area consist of sandstone/mudstones of Miocene to Pliocene age. On seismic reflection profiles these units are characterized by low amplitude, high frequency reflections that typically occur below a prominent erosional surface (Hoskins and Griffiths 1971, Beeson et al. 2012). These units likely are part of marine and non-marine basin fill deposits of varied lithology and thickness associated with the offshore Point Arena basin (Blake et al. 1978, Beeson et al. 2012).

Quaternary sediments are well imaged in the high resolution sparker seismic profiles, and where the likely base of the Quaternary is visible, the sediments overlie a transgressive erosional surface separating the Quaternary sediments above from Pliocene marine sandstones of Point Arena basin below (Hoskins and Griffiths 1971, McLauglin 1994). This unit is characterized by low to moderate amplitude, low to high frequency sets of parallel reflectors that truncate at the seafloor in deeper water or against other Quaternary unconformities in in shallower sections. The Quaternary unit likely was deposited largely during Marine Isotope Stage 5 (ca. 130 – 170 ka), the last long lived sea-level high stand, similar to today's shelf environment. This unit includes multiple erosional unconformities and packages of clinoform reflectors, possibly related to Pleistocene sea-level fluctuations.

Latest Pleistocene to Holocene marine sediments ("H") are the uppermost and youngest units imaged in the seismic data, and correspond to rising sea-level since the Last Glacial Maximum (LGM) (ca, < 20 ka) (Clark et al. 2009, Mix et al. 2001). This unit is imaged overlying a transgressive erosional surface characterized by low to moderate amplitude, low to high frequency, sets of parallel to sub-parallel sets of continuous clinoforms. Similar post-LGM sediment facies overlying a transgressive erosional surface are imaged throughout the California margin (Johnson and Watt 2012, Draut et al. 2009, Slater et al. 2002, Anima et al. 2002).

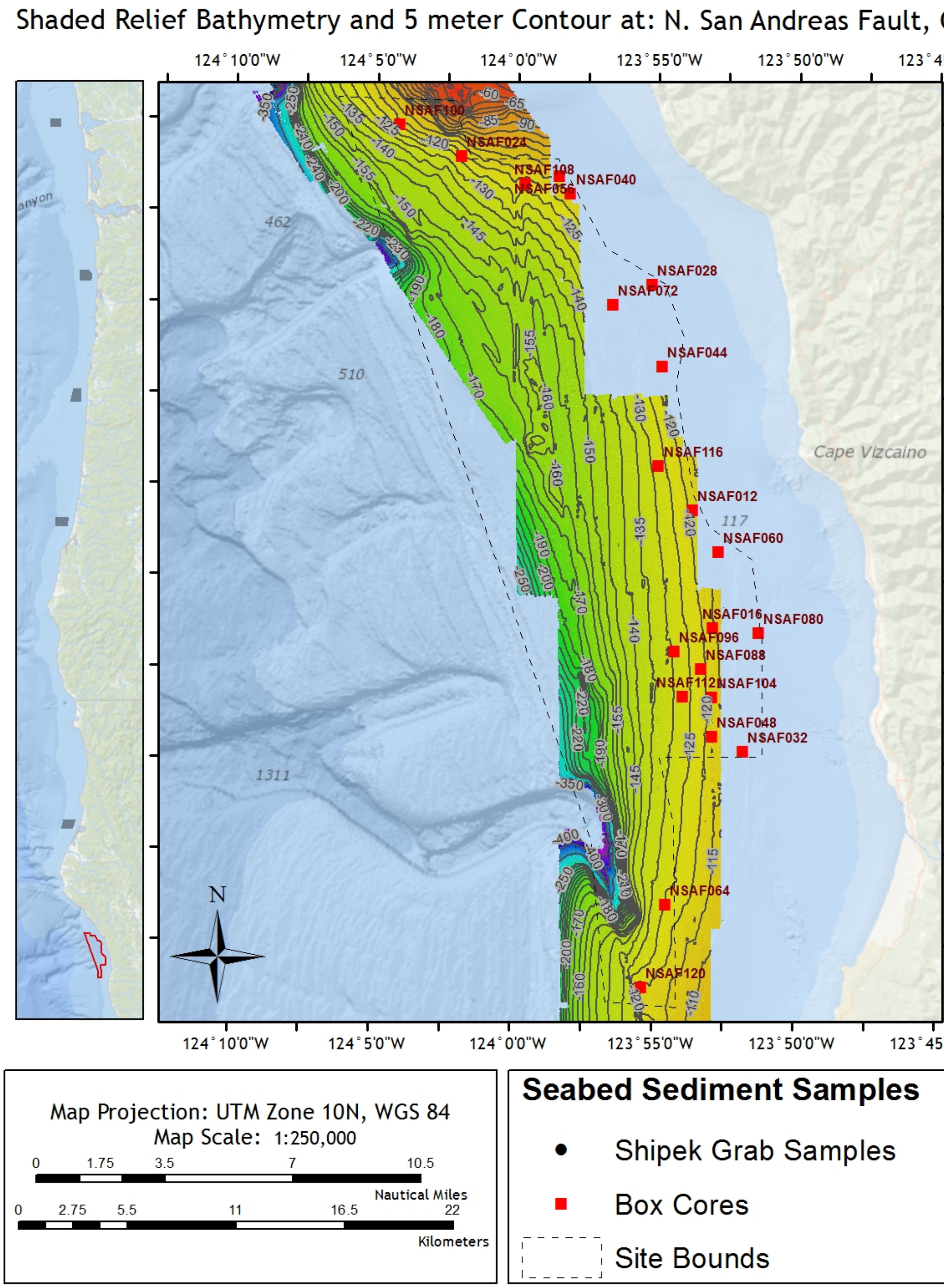


Figure 41. Color shaded-relief multibeam bathymetry data collected at Northern San Andreas Fault (NSAF), CA

Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam data.

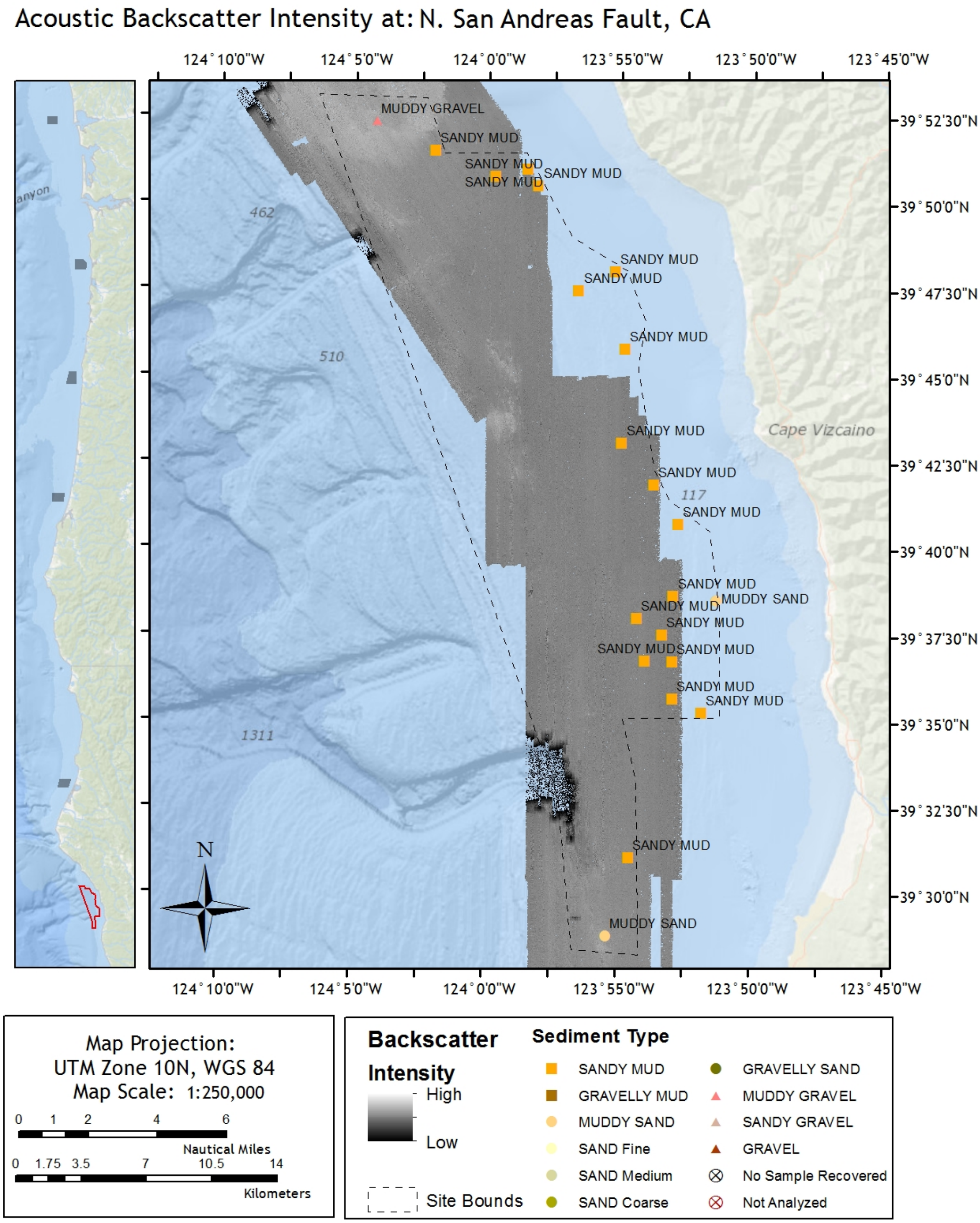


Figure 42. Multibeam backscatter data collected at Northern San Andreas Fault (NSAF), CA
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam data.

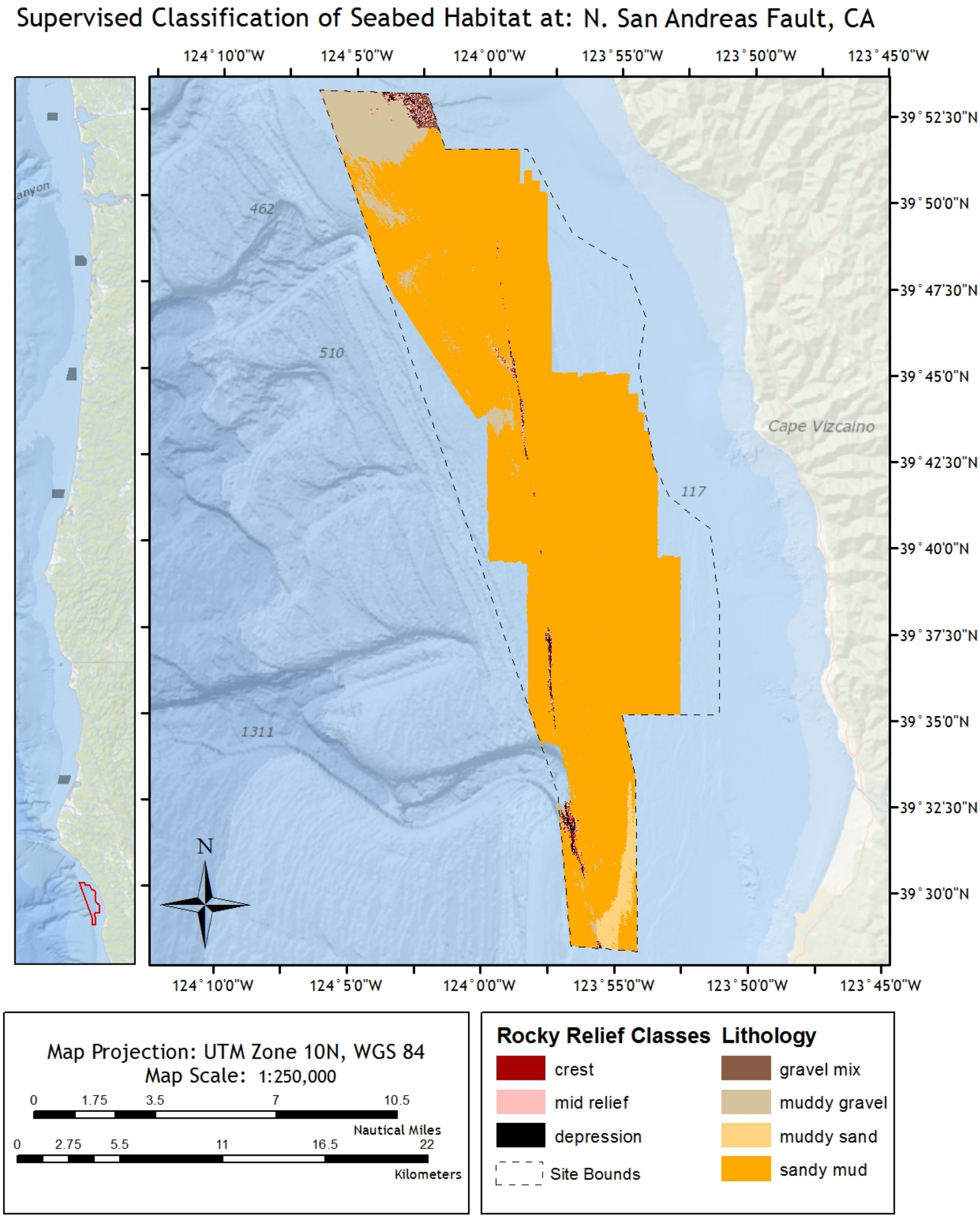


Figure 43. Seabed substrates at Northern San Andreas Fault (NSAF), CA
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

Surficial Geology of the NSAF area, CA:

This mid-shelf region of soft sediment and rocky outcrop was mapped in September of 2010 from the *SR/V Derek M. Baylis* using the Reson 8101 (240 kHz) multibeam sonar (Figure 41 and Figure 42). The BOEM NSAF study site covers a 45 km by 15 km area and abuts California State Waters Mapping Program multibeam data creating continuous data coverage from the nearshore to 300 m deep canyon heads. Box Core (n= 19) sampling was conducted in the NSAF site; however, no Shipek Grab samples were collected. Classified grain size information from the BOEM Box Core samples were used to map sedimentary habitats. Rock outcrop at this site was mapped using Vector Ruggedness classification of bathymetry (Figure 43).

3.4.1.2 Backlog Local Mapping Sites: Distribution & Details

These sites are termed "backlog" because they have existing data, but no analysis was either supported or undertaken as part of the original project. See Appendix 1, Figures 81-87.

NOAA Sponge Reef, WA:

This outer continental shelf site (~10 km by 16 km) of low relief rock outcrop and coarse sediments was mapped in 2010 from the *R/V Pacific Storm* using a Reson 8101 (240 kHz) multibeam sonar. Mapping of the Sponge Reef seabed was funded by the NOAA Deep Sea Coral Research Program. Seabed AUV dives were conducted by NOAA Northwest Fisheries Science Center (NWFSC) and were used to guide the outcrop mapping at the Sponge Reef Site completed here. No sediment sampling was conducted, though samples are available through usSEABED.

OOI WA Inshore, WA:

This nearshore rocky reef complex and adjacent sedimentary shelf was mapped over three years, 2009, 2010, and 2011, under funding from the Ocean Observing Initiative. In 2001, 13 Shipek Grabs samples were collected and in the northern one third of the survey area.

Cape Falcon Fault, OR:

The mid-shelf site was mapped in 2011 from the *R/V Pacific Storm* using a Reson 8101 (240 kHz) multibeam sonar. The data coverage follows a thin zone of rock outcrop (Cape Falcon Fault) and connects 2009 OSWMP nearshore multibeam data coverage to 2002 Ocean Explorer offshore multibeam data coverage. No samples or ROV video is available within the survey coverage.

Stonewall Bank, OR:

This mid-self rocky bank was surveyed in 2012 from the *R/V Pacific Storm* using a Kongsberg EM2040 (300 kHz) multibeam sonar. Oregon Department of Fish and Wildlife funded the survey and provided drop camera points and habitat types for seabed classification purposes. No sediment samples were collected.

Coquille Bank, OR:

This outer-shelf bank was surveyed from the *R/V Thomas Thompson* in 2005 using a Kongsberg EM300 (30 kHz) multibeam sonar. NOAA NWFSC funded data collection including seabed AUV dives for seabed classification. No samples were collected.

H12130 & H12131, OR:

This nearshore area of Oregon's State Waters was surveyed by Fugro Inc. under funding from NOAA Office if Coast Survey. Available data include multibeam bathymetry. Fugro collected but did not process backscatter for this survey. OSU has partially processed the backscatter but technical issues with the data have prevented OSU from deriving a backscatter map for classification use. No samples or video were collected at this survey site.

3.4.2 Regional-Scale Mapping Results

3.4.2.1 Surficial Geologic Habitat (SGH) Mapping Results

Regionally, the SGH Version 3.6 map for Oregon and Washington was developed in 2010. Version 4.0 created with this project adds to the map extent and covers the northern continental margin of California south to Fort Bragg by incorporating polygon habitat types of California developed by the Center for Habitat Studies at Moss Landing Marine Labs (Greene et al. 2003). Other updates to V4.0 were possible due to significant synergy with several other concurrent projects. The NOAA Essential Fish Habitat 5 Year Review was underway from 2011 to 2014 and supported compilation of all new habitat and bathymetric information on the US west coast. The compilation in the EFH review did not extend to actually rectifying all these new data into a single habitat or bathymetric compilation, but rather was a "mash up", with no reconciliation or creation of new mapping products (see EFH synthesis report: http://www.pcouncil.org/wp-content/uploads/D6b_NMFS_SYNTH_ELECTRIC_ONLY_APR2013BB.pdf).

This BOEM project was able to extend beyond the EFH "mash up" compilation and produce a new regional bathymetric and habitat map for the study area from Fort Bragg to Grays Harbor. Significant new deep-water multibeam data (unpublished at the time of and not included in the EFH review) was also collected over the Washington continental slope during 2011 and 2012 under two major NSF supported research programs. The Cascadia Initiative (CI) program supported mapping of much of the Washington continental slope as well as selected areas of the northern California slope in support of a major deployment of ocean bottom seismographs (OBS's; http://cascadia.uoregon.edu/CIET/). These new bathymetry data were used to replace the older bathymetry grid and update it to a 100 m x 100 m pixel resolution bathymetry dataset for Cascadia (Vancouver Island, Canada south to Cape Mendocino, California), under NSF funding and in support of the Cascadia Initiative. The updated bathymetry of the region was used to re-map deep-water canyon and channel systems for Washington and northern California.

The completion of 13 site-specific habitat maps (Section 3.4.1) as well as the consolidation of 37 new externally developed sources of mapping data, largely collected through the OR and CA State Waters Mapping Programs and identified in the EFH review, laid the groundwork for making significant updates to continental shelf habitats of the regional Surficial Geologic Habitat (SGH) Map Version for Oregon and Washington resulting in the new SGH Map Version 4.0 (Figure 44).

In addition to newly mapped areas of continental shelf and slope described above, the SGH Map Version 4.0 also includes significant modifications/updates to its underlying attributes. The "mixed" seabed induration modifier (second character of SGH Prefix) usage was corrected to be consistent with (Greene et al., 1999). The SGH primary and secondary lithology codes were redefined to clear up ambiguities making the distinction between homogeneous sediment mixtures and heterogeneous habitat patches more clearly defined. We now include CMECS habitat codes developed by cross-walking SGH primary and secondary lithology codes to the CMECS substrate component (Table 3). Finally, an expert review of the SGH Map Version 4.0 was conducted. The review identified and helped to additionally clarify usage of the two lithologic habitat components as well as provided useful guidance regarding the crosswalk of SGH codes to CMECS codes. We adopt the recommended definition of SGH_Pref1 and SGH_Pref2 presented in the review and have incorporated some of the recommendations for CMECS crosswalk in the SGH Map Version 4.0 (see Appendix 3 for the written review and our comments and notes on points raised by the review).

3.4.2.2 Data Density & Quality Mapping Results

The SGH Data Quality Maps Version 3 were updated resulting in a complete new set of SGH Data Quality Maps Version 4 products (Figure 45). The update extended the bathymetry density and sediment sample layers south into California waters in order to reflect the usage of new regional bathymetry and sample data for regional SGH mapping in this region where physiographic canyon and channel systems were modified and sediment type was added. Seismic data lines for California were not added to the data quality maps because they were not directly used to update the SGH Map Version 4.0 but instead provided the foundation to develop the predictive Structural Rock Outcrop and Isocore maps (sections 3.4.2.4 & 3.4.2.5). Generally speaking data quality maps of four different data types were derived first for the preceding SGH map versions 1 & 3 (Lanier et al. 2007; Romsos 2004, 2007) and then combined to produce a final map of Data Quality for the SGH Maps Versions 1 & 3. The SGH Data Quality Map Version 3 was updated according to the methods provided in section 3.3.2.2 to update the layer so that it presents a view of data quality consistent with the updates to the SGH Map Version 4.0.

Overall, bathymetric density and quality has been improved along the entire slope and a good percentage of nearshore waters with the recent NSF Cascadia Initiative and Oregon and California state waters mapping programs. The continental shelf area has the lowest bathymetric data density of the entire Pacific continental margin due to the high cost of surveying these relatively shallow and expansive waters. Bathymetric data that does exist on the shelf is either historic soundings data or high quality multibeam in state waters. Side scan data distribution and quality is bimodal with either data existing and high quality, or does not exist. Seismic density is more ubiquitous across the shelf and latitude range. Scores decay away from the trackline as the applicability of this profile data is limited to near the track. Sediment samples show a higher density of collections near to the coast predominantly in the nearshore depth range of less than about 60 m. The lowest density of sediment samples is on the California continental shelf and slope.

As mentioned in Section 3.3, that although 2011-2014 has seen many new data collection efforts on the seafloor and including mapping shown in this report, the mid to outer continental shelf remains the area of lowest data density of the entire Pacific continental margin. Where mid or outer continental shelf data exists is generally over large rocky banks such as Coquille Bank, Heceta Bank, Stonewall Bank, Nehalem Bank and now Grays Bank. Note that two local-scale sites, NSAF and Sponge Reef (Figure 43 and Figure 82), had their quality scores reduced due to lower than normal input data quality. Both sites have reduced bathymetry and backscatter quality due to either system installation or operation difficulties. Mapping confidence is thus affected and amended here to account for these unique survey issues.

3.4.2.3 Slope Predicted Rock Mapping Results

In an effort to develop a predictive tool to evaluate the probability of rock outcrop throughout the study area despite the lack of comprehensive sonar mapping, we developed a methodology to evaluate this probability. The problem is that large areas of the margin remain unmapped, and will likely remain so for the foreseeable future. In areas of high resolution multibeam or sidescan mapping, mapping rock outcrop is simple. Other areas have a variety of less diagnostic data of variable quality and spatial density that require more comprehensive interpretation to be useful in an a regional evaluation of rock probability. These include multichannel seismic reflection, high resolution chirp and boomer subbottom data, and thousands of bottom sample data points. In areas of the continental slope, these datasets are too sparse to use directly, and a proxy method based on slope stability and maximum angle of repose is adopted. We adopt a Bayesian approach to this problem that takes advantage of the strengths of these datasets for answering part of the problem in areas for which they are most appropriate.

Slope Stability and Angle of Repose

To evaluate the probability of rock outcrop in areas where sample and seismic data were too sparse, but regional multibeam bathymetry of moderate resolution is available (~ 100 m resolution), a predictive map of rock outcrop was generated for deep-water continental slope and canyon environments using the slope stability method (Figure 46). The new product extends from the original Oregon study area into previously unmapped slopes of Washington northern California. The basis for this regional analysis is an assessment of the stability of the slopes regionally to assess a threshold angle above which there would be no static stability for unconsolidated sediments, and therefore rock exposure would be likely. This was done based on two criteria, 1) empirical observations and 2) slope stability analysis.

Bathymetry Data for Slope Stability Analysis

The primary dataset for the regional slope calculations were the EEZ survey data collected with SeaBeam "Classic" 16 beam system in the mid 1980's for Oregon and Northern California (Mills and Perry,1992; EEZ-SCAN-84). The narrow beam system made surveys in water depths less than ~ 600 m prohibitive, and thus typically defines the upper depth limit of the EEZ data. EEZ data for Washington were "classified" by the Navy until 2008. By that time, the data were lost and have never been found (C. Fox, NGDC, pers. comm.). For Washington, the dataset is a compilation of mostly EM 300and EM -122 data collected in 2011 and 2012 by

OSU and others as previously described (Section 3.4.2). All NOAA 1980's surveys were conducted to International Hydrographic Organization (IHO) standards, which required (at the time) that 95 percent of all soundings have a horizontal positioning error of less than 75 meters at the 1:50,000 scale and sounding accuracies in deep water to within 1 percent of true water depth. NOAA currently advertises that the horizontal positioning error of individual soundings is better than a 5 meter circular error. Several equipment calibration or validation tests are conducted aboard NOAA survey vessels to ensure that these accuracy standards are met. Each multibeam system is checked for alignment periodically, using a "patch test," where data are collected on inverse courses steered over a flat or gently sloping bottom. In the survey area, there are conductivity/temperature/depth (CTD) measurements (which are entered into the multibeam system's sound velocity tables) with daily checks using expendable bathythermographs (XBT's) to see that conditions have not changed. Daily velocity profiles are inadequate by today's standards, but are likely not to affect the regional results of this stability exercise. The prefiltering technique used for the 1985 and 1986 multibeam surveys is described in Herlihy et al. (1992), and general methods described in Hillard and Lynch (1989).

Empirical method

In a previous proprietary study for a transpacific telecommunications cable, slope stability was evaluated empirically for a region of the central Oregon margin. Submersible video data from *DSV Alvin, Delta* and other vehicles was evaluated to derive a maxim slope value that could remain sediment covered. Slope data (inclination of the seafloor) were derived from the 100 meter bathymetric grid for the study area. Each slope value is given to the nearest 1° of inclination, and represents an average adjacent 100 m pixels. The steepest slopes in the bathymetric data are ~35°. Ground truthing from a submersible (near the Wecoma fault; Goldfinger et al. 1997) indicates that the steepest slopes (35°) is actually composed of several flat benches 5-10 m across and vertical slopes 5-10 m high. Therefore, slopes derived from multibeam data may be significantly lower than actual slopes, especially for slopes reported to be >15°. This is a common artifact of multibeam data of any resolution, where the resolving power of the system cannon accurately model slopes or features smaller than that size. The impact of this is that our slope derived map should be considered a *minimum* prediction of rock outcrop because additional slopes steep enough for rock exposure are almost certainly present but undetected. Over prediction of slopes due to other artifacts of processing is likely in limited areas of poor data quality, swath overlaps and nadir areas, but these are considered to be of lesser prevalence and importance. From this earlier study, we derived a value of 9-10 degrees as measured on the multibeam grid as a slope value above which sedimentary cover was unlikely. This value is specific to the deeper part of the Oregon margin, and although we have extended this analysis further to the north and south, it has not been empirically tested at other localities.

Slope stability

We have evaluated slope stability numerically for slopes and materials common the northern Cascadia margin to assess the efficacy of the empirical method described above. There are numerous methods for assessing slope stability, and an in depth analysis is beyond the scope of this paper. To apply a simple screening approach to the problem, we apply a simple vertical slice limit equilibrium approach (also known as pseudostatic), using search methods to locate the critical slip surface for a given slope. We used probabilistic (probability of failure) analyses with reasonable ranges of material properties to assess slope stability spread across normal distributions.

A typical variant of the limit equilibrium equation from Morgenstern (1967) modified to include seismic accelerations (i.e. Azizian and Popescu 2001, Hadj-Hamou and Kavazanjian 1985) expressed as a "factor of safety', where a value of 1 is a neutrally stable slope. We calculated stability using four variants of this basic method, using reasonable ranges of physical property data to establish likely stability ranges. The methods used were Morgenstern-Price (Morgenstern and Price 1965), a simplified (Bishop 1955), Janbu corrected (Janbu 1973) and Spencer (Spencer 1967), which are averaged in the subsequent sections. These methods are implemented in the stability code *Slide* ("SLIDE 6.0 – 2D Limit Equilibrium Slope Stability Analysis", http://www.rocscience.com; Toronto, Canada: retrieved Aug. 10, 2012).

Engineering data from Cascadia sediments is available as input from existing cores and ODP drilling data. Wet bulk densities in the upper part of our cores average ~1.3, with a submerged bulk density then being ~ 0.3. The unit weight is 18 kN/m3, with a saturated unit weight of 26 kN/m3. The angle of internal friction is estimated from upper few meters of IODP hole 1244 at Hydrate Ridge as 32-36° (Tan et al. 2006). Cohesion is averaged from the upper few meters of sediment in cores from the abyssal plain, ridge tops and ponded basins on the central Oregon margin containing both hemipelagic and turbidite sediments, as reported in Hempel (1995). This value is 4-15 kPa. However, these values may not represent uppermost values for typical surficial sediments, as they were obtained after piston coring and some water loss and thus likely represent an upper bound. Johnson et al. (2012) have developed a method for capturing cohesion of the uppermost sediments *in situ*. Although their study was conducted in Nova Scotia, the methods are likely more accurate for surficial sediments and we consider this an improvement over the local values that are likely biased by sampling effects. Johnson et al. (2012) find *in situ* values with a mean of ~9 kPa for surficial materials, and we adopt this value, with a maximum upper bound from local core data at 15 kPa based on Hempel (1995). We allow all variables to lie on normal distributions with the reasonable limits described above to fall at the 2 points.

For open slopes in southern Cascadia, the slope of the frontal thrusts ranges from ~ 7-9° in the Rogue Canyon area, to a maximum of ~ 16° in the Trinidad Canyon area. Average slopes for the Rogue and Trinidad lower continental slope are ~ 3.5° and 4.5° respectively. Surface slopes in the mid to upper reaches of Rogue Canyon range from 5-22° and can be as high as 35°. Probabilistic calculations using these material ranges suggest that the maximum angle of repose is in the range of 15-20 degrees. We believe that the difference between the calculated and observed values is the fact that the study area is an active tectonic margin, and the limiting factor is accelerations from earthquakes as well at static slope stability. Earthquake accelerations reduce the slope angle that can be sedimented and remain so over time to a lower value. For example, a statically stable 15 degree slope could sustain an acceleration of ~ 0.25g before failure. Nevertheless, considerable uncertainties exists in this type of analysis, and while the time history for earthquakes is well known (Goldfinger et al. 2012), the associated seismic accelerations are not.

3.4.2.4 Structural Predicted Rock Mapping Results

The second element in rock prediction is the estimation of rock outcrop areas from seismic reflection data. We examined seismic reflection profiles for the Northern California region to extend coverage of the structural outcrop map that previously covered only Washington and Oregon (unpublished data, OSU) using similar methods. Three classes of rock probability were noted and recorded from the seismic reflection images and later digitized along a vector representation of the survey navigation. Supporting information from bathymetric, structural, sidescan, or samples were used to both verify the existence of the outcrop and help delineate its extent. Digitized outcrop predictions were stored in ArcGIS® polyline feature. Navigational accuracy for each of the seismic surveys (Appendix 1, Table 6) is widely variable from ± 5 to 3000 m, but may be generally estimated at about ± 500 m. This estimate is based on the known accuracy of Loran C navigation (Goldfinger 1994, Melton 1986, Nasby-Lucas et al. 2002). A large portion of the seismic reflection data for this survey area is in the form of analog data stored as paper plots (Oregon State University, historical archives at the Active Tectonics and Seafloor Mapping Lab). Analog data formats likely introduce additional positional errors through interpretation and transcription processes.

The track line map showing datasets used in this and the next section is shown in Figure 47. The map results of this analysis are shown in Figure 48. The three probability classes, Possible Rock, Probable Rock, and Rock are qualitative and meant to reflect the likelihood that a structure observed in the profile actually occurs as outcrop on the seabed. Areas where the imagery shows rough (vertical relief) seabed and exposed stratigraphy or other structure were coded Rock. Areas in the imagery where structure is at or near the seabed but no corresponding vertical offset or surface roughness is evident are coded either Probable or Possible Rock. The distinction between Possible Rock and Probable Rock is determined on a suite of factors such as the source reflector, local structures, and geologic setting.

Three areas for exploration are presented in Figure 48 (A, B, &C). Inset A shows the local-scale mapping at the WA Inshore OOI site as it's been incorporated into the SGH Map Version 4.0. There is good agreement between the structural outcrop classes and the mapped outcrop at this site. The structural class Rock corresponds well with the core of the outcrop. The Probable Rock and Possible Rock classes occur at the margins of the outcrop and suggest that the outcrop may extend westward further than currently mapped. Inset B shows another nearshore shelf area between Cape Arago, OR and Bandon, OR. This area was recently mapped through the Oregon State Waters Mapping Program (2010). Again the structural outcrop map shows good agreement with the high resolution local scale product. Offshore of the local-scale Bandon-Arago dataset the Regional SGH Map Version 4.0 predicts a mixed habitat of hard and soft seabed. This feature has been refined several times since the SGH Map Version 1 and is known to be complex feature of varying hardness and relief. The underlying or background bathymetry for the feature is poor and as a result we can't easily map a contiguous hard feature. Therefore the unit is classified as a mixed, both hard and soft classes present, feature. Finally, inset C reveals that on the continental slope, structural outcrop "picks" often correlate to accretionary ridges (outlined features in inset C). We currently use a 10 degree slope class to predict hard rock seabed on the continental slope. However, the structural outcrop map picks include ridge tops. While the formation of authigenic carbonate on ridge tops is one known mechanism that could account for rock in these areas it's not likely that this type of rock would be imaged in the seismic reflection data. More work is needed to determine if our model for outcrop on ridge features should include a ridge top component.

3.4.2.5 Regional Minimum Isocore Sediment Thickness Mapping Results

The third element of rock prediction is to use the same seismic reflection data to map the inverse of rock outcrop; that is the areas that have little or no possibility of outcrop at the seafloor. A predictive map (Figure 49) of minimum Isocore sedimentary thickness was generated for shallow-water continental shelf environments by examination of seismic reflection profiles. Isocores (vertical sediment thickness) were generated at intervals of 40 ms, 60 ms, 80 ms, and 100 ms. All seismic profiles are recorded in two way travel time, the units of the Isocore map. For the most part, no explicit velocity data are available to convert these data comprehensively to depth. However, the range of velocities for unconsolidated sediments is relatively narrow so that using a reasonable value of 1650 m/sec yields values of 33 m, 49.5 m, 66 m, and 82.5 m or the four Isocore contours, with an estimated uncertainty of 2 to 5 m for these values (based upon a +/- 25 ms error in velocity). We did not develop a comprehensive Isocore map for the Cascadia margin as this was beyond the scope of the project, but instead focused on the shallow (less than 100 m of sediment) sedimentary cover as an indicator of the probability of rock outcrop. The new

Isocore product extends and compliments the previous seismic rock prediction work in Washington and Oregon and slope stability work for the study region (Figure 49).

The minimum Isocore interval, 40 ms, means that in these regions the sediment thickness extends vertically from the seabed surface down to a depth of 33 m. Areas not shown as having a sediment depth are either unknown or have a potential to be rock exposed at the seabed. Conversely, small-scale outcrop may still occur within an Isocore as not all possible sources of rock at the seabed are observable in seismic reflection data. Isocore extents are greater and more contiguous over the northern portion of the study area due in part to the wider continental shelf. In the south a larger number of submarine canyon systems intersect or bisect the shelf contributing to Isocore patchiness. The spacing between seismic lines used for Isocore mapping was closer in the California portion of the analysis. This may also contribute to the greater degree of patchiness in the south.

3.4.2.6 Rock Probability Modeling Results

To evaluate the overall probability of rock outcrop in the study area, we incorporate the components described in sections 3.4.1 – 3.4.5 into an expert model for calculating the probability of rock outcrop (Section 3.3.2.6). The Bayesian model was constructed using Netica®, the same modeling software system used for habitat suitability probability (HSP) modeling in section 6 of this report. The basic model elements or inputs to the model are:

1) Surficial Geology Habitat Map Version 4.0 (model node: ***SGHHabType)***
2) Data Quality Map (model node: ***DataQuality***)
3) Slope Stability Map (model node: ***SlopePredicted)***
4) Continental Shelf/Slope Map (model node: ***ShelfSlope)***
5) Structural Outcrop Map (model node: ***Structural Outcrop***)
6) Isocore Map (model node: ***Isocore)***

Intermediate outcrop probabilities were determined at intermediate "modifier" nodes using conditional probabilities provided by the conceptual framework for utilizing data quality information and supporting or conflicting information outlined in report section 3.3.2.6. The environmental data was sampled at a 200 m x 200 m spaced grid interval and predictions were made for over 2.5 million prediction points. A final Probability of Rock Outcrop map was assembled from the model output (Figure 50).

Overall the model predicts a higher probability of rock outcrop on the continental shelf than the continental slope throughout the study area. This is evident in the transition from light green ($p < 0.3$) to light yellow ($p > 0.3$) at the continental shelf break. On the continental slope, exceptions to this low background outcrop probability are areas of steep seabed or areas that have either rock mapped from high resolution bathymetry or identified through structural mapping. On the continental shelf the Isocore and structural outcrop map interact to create greater variability in outcrop probability. Generally, where not modified by high resolution data, areas outside the Isocores yield probabilities of outcrop of .5 or greater. A meso-scale (sub-regional) trend is also apparent where higher probabilities of outcrop occur in nearshore regions and again along the outer continental shelf. This trend is reasonable and in agreement with what's seen on Oregon's continental shelf where there are numerous nearshore rocky reefs and complexes and several large outer continental shelf rocky banks.

The influence of incomplete data coverage and quality can be seen in the model output as intended. Though the effect is generally small it is important to understand that decreasing data quality has a neutralizing effect driving the probability of outcrop toward 0.5. In the most extreme case of moving from lowest to highest (or highest to lowest) data quality in a sedimentary habitat on the continental shelf the final probability of outcrop only changes by 0.3 and does not push the resultant probability of outcrop over 0.5. Typically the effect of data quality is much lower than this extreme case.

3.4.2.7 Regional Grain Size Modeling Results

Figure 51 shows the results of the Inverse Distance Weighted modeling for mean grain size and percent sand composition on the continental shelf from 20 m to 130 m water depth. Parameters used to develop both sediment models are reported in Table 5. The Root-Mean-Square (RMS) error for the mean grain size model is 8.33% or less than one phi unit (class break). RMS error for the percent sand model is 14.03%. The response variables of Phi units ($-\log_2 D$ where D = particle diameter in mm) and % sand are modeled as floating point numbers and binned to classes for display purposes only. Figure 51 organizes the modeled mean grainsize according to the Wentworth Class (Wentworth, 1922) so that the reader might better relate modeled particle size to well-known and widely used size class common names. Percent sand composition, from 0 to 100% is binned in 10% wide bins. We do not model sediment class according to the textural classification of Folk 1954 (section 3.3.1.5) used for the sampling and local-scale mapping here. The textural classification method requires knowledge of percent gravel, percent sand, percent mud, and mean grainsize. The data available for modeling do not adequately provide these metrics over the study area precluding modeling sediment texture regionally. Furthermore, the objective of modeling mean grainsize is to support the infauna modeling effort which utilizes mean grainsize and percent sand as predictor variables.

Overall the results of modeling mean grainsize and percent sand from the compiled dataset reveals a few significant trends in sediment characteristics of the continental shelf regionally (Figure 51 and Figure 52). In addition to an expected offshore gradient of decreasing grainsize and decreasing percent sand we observe a latitudinal gradient with finer mean grainsize and lower percent sand in the southern extent of the study region. Locally we observe fine sediments (silts) and low percent sand (<50%) in areas influenced by large river system discharge (Columbia River, Umpqua River, Rogue River, and Eel River). In Washington at the Grays Bank site, the model shows a grainsize gradient from coarse sand to very fine sand and variable sand percentage. In contrast the Newport site is almost uniformly medium grained and well sorted (100% sand). The model predicts very fine sand to coarse silt with low sand percentage at the Siltcoos site. All of these predictions are consistent with the local scale mapping of seabed habitat type (Figure 18, Figure 25, and Figure 37) particularly for the relatively simple lithologies presented at Newport and Siltcoos. The Grays Bank outcrop and locally eroded gravels around the outcrop are composed of clasts sizes greater than the model attempts to predict (gravels and larger). Furthermore, the highly variable seabed character presents a fine-scale heterogeneity that isn't well predicted with a 250 m x 250 m pixel model. Note that the benthic infauna models are not designed to predict habitat suitability into gravel or coarser grainsizes.

Table 5. ArcGIS 10.0 Geo-Statistical Wizard Inverse Distance Weighted (IDW) Parameters used for both sediment models

Power	1
Neighborhood Type	Standard
Maximum Neighbors	5
Minimum Neighbors	2
Sector Type	4 Sectors with 45° offset
Angle	4
Major Semiaxis	15,000
Minor Semiaxis	8,000
Anisotropy Factor	1.875

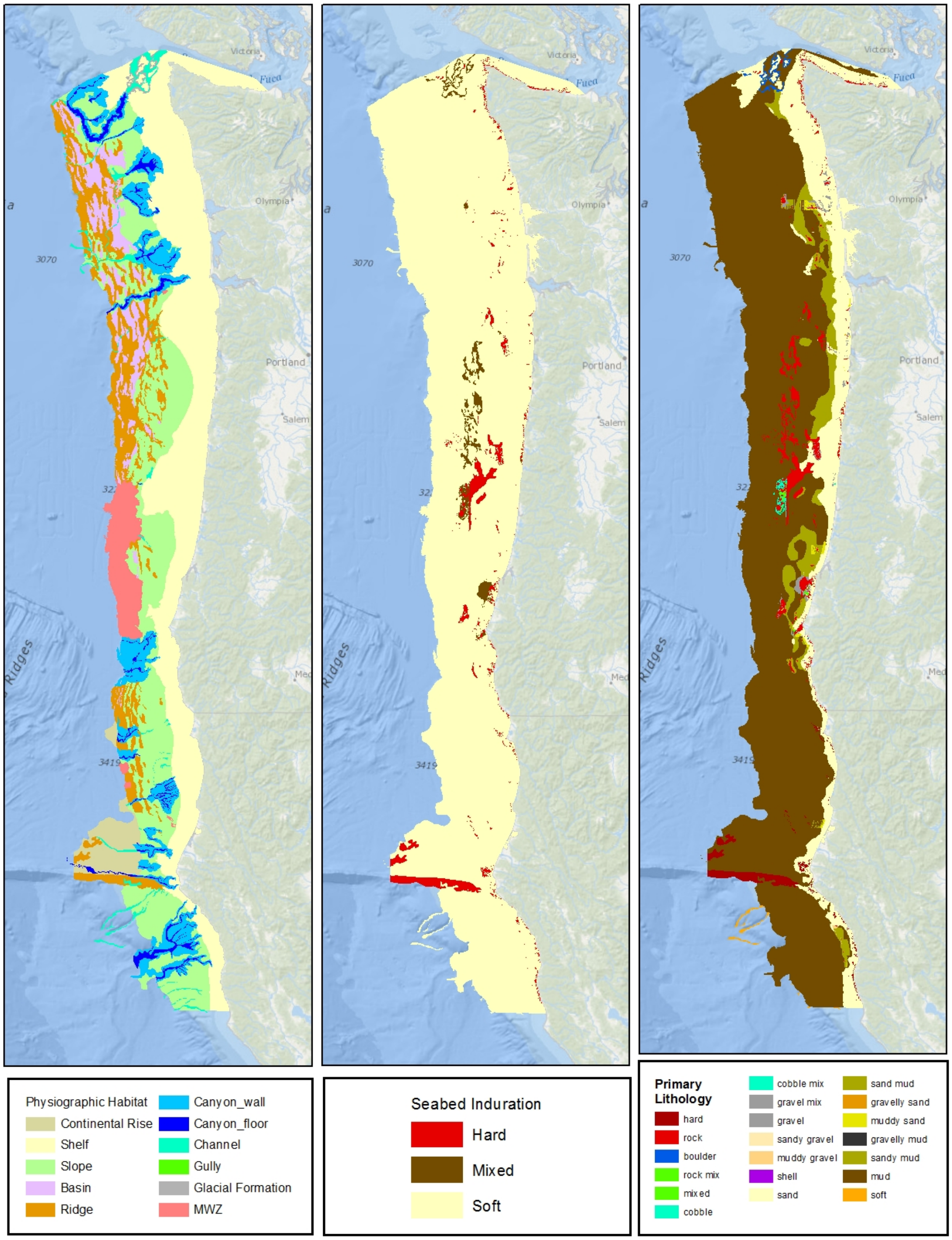


Figure 44. Version 4.0 Surficial Geologic Habitat maps for WA, OR, and northern California
Each map panel is derived from the same underlying polygon feature class, but is symbolized according to a different map attribute with Physiographic Habitat (left), Seabed Induration (center), and Primary Lithology (right). MWZ = Mass wasting zone.

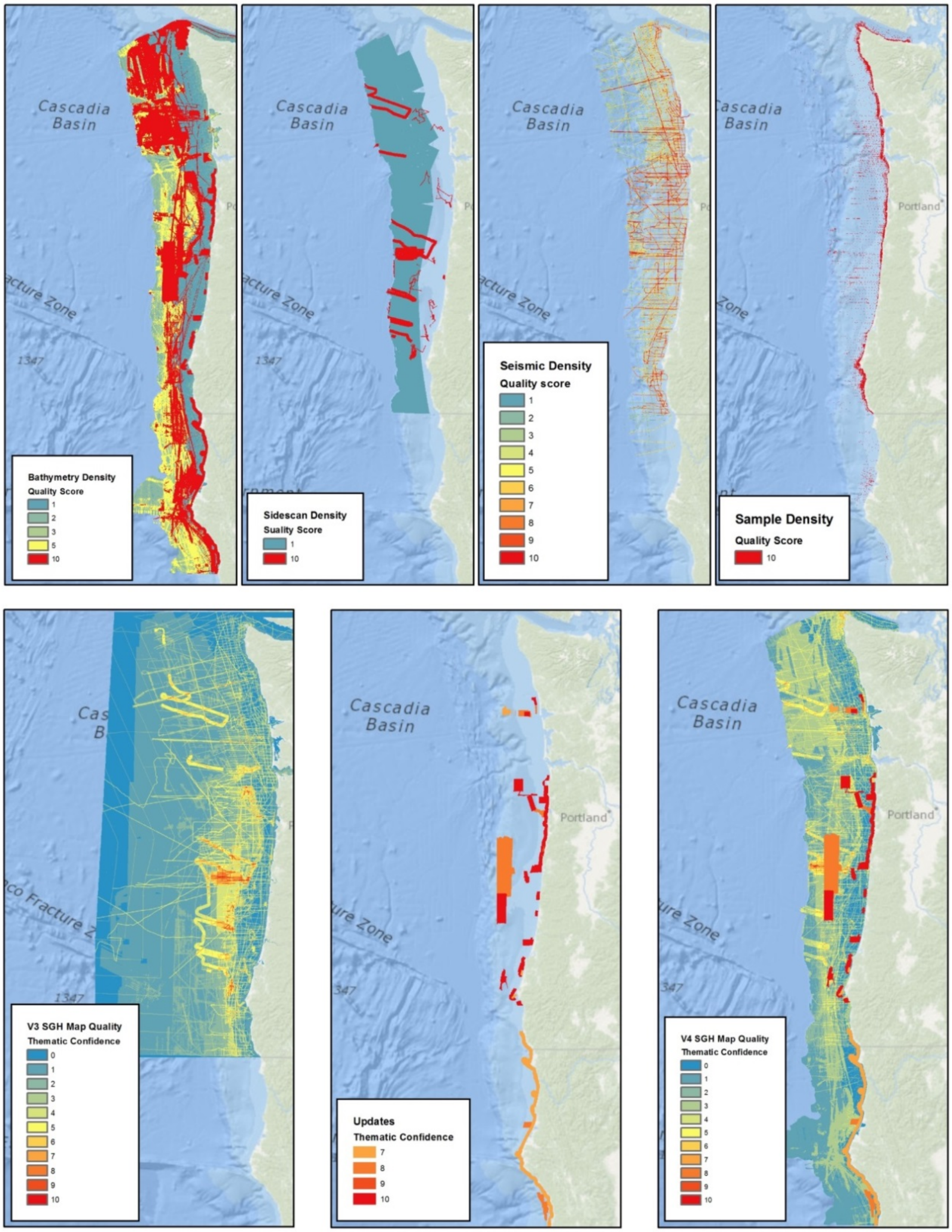


Figure 45. Version 4.0 Data Quality map series
Each of the four principal data types for habitat mapping (Bathymetry Density, Sidescan Density, Seismic Density, and Sample Density) are represented as ranked data density maps in the top panels. The panel on the bottom left (V3 SGH Map Quality) represents the aggregate SGH Data Quality Map Version 3.0. The bottom middle panel (Updates) shows areas that have been updated with local-scale mapping. The bottom right panel (V4 SGH Map Quality) shows the aggregate SGH Data Quality Map Version 4.

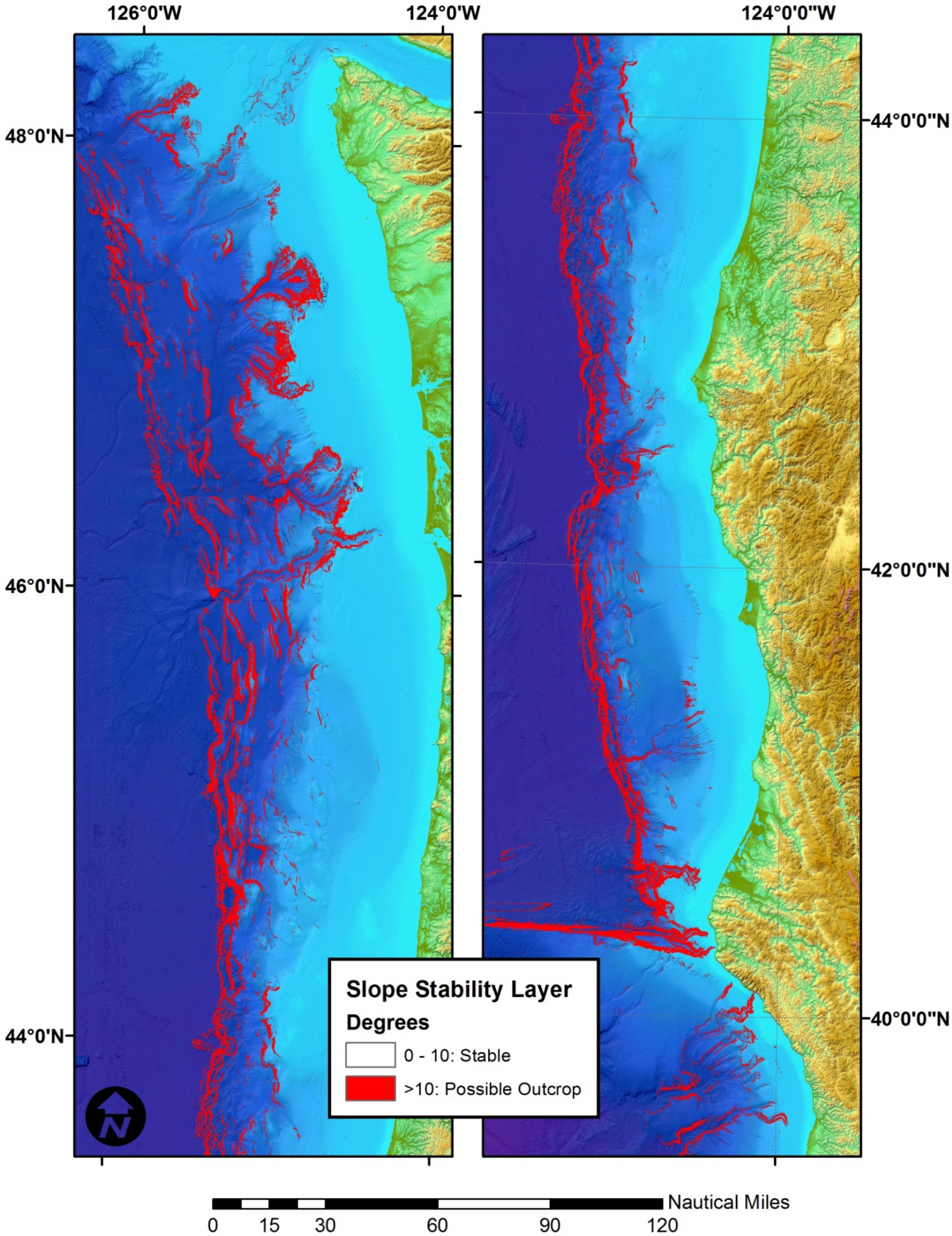


Figure 46. Slope stability derived predictive rock outcrop map for deep-water (continental slope and canyons)

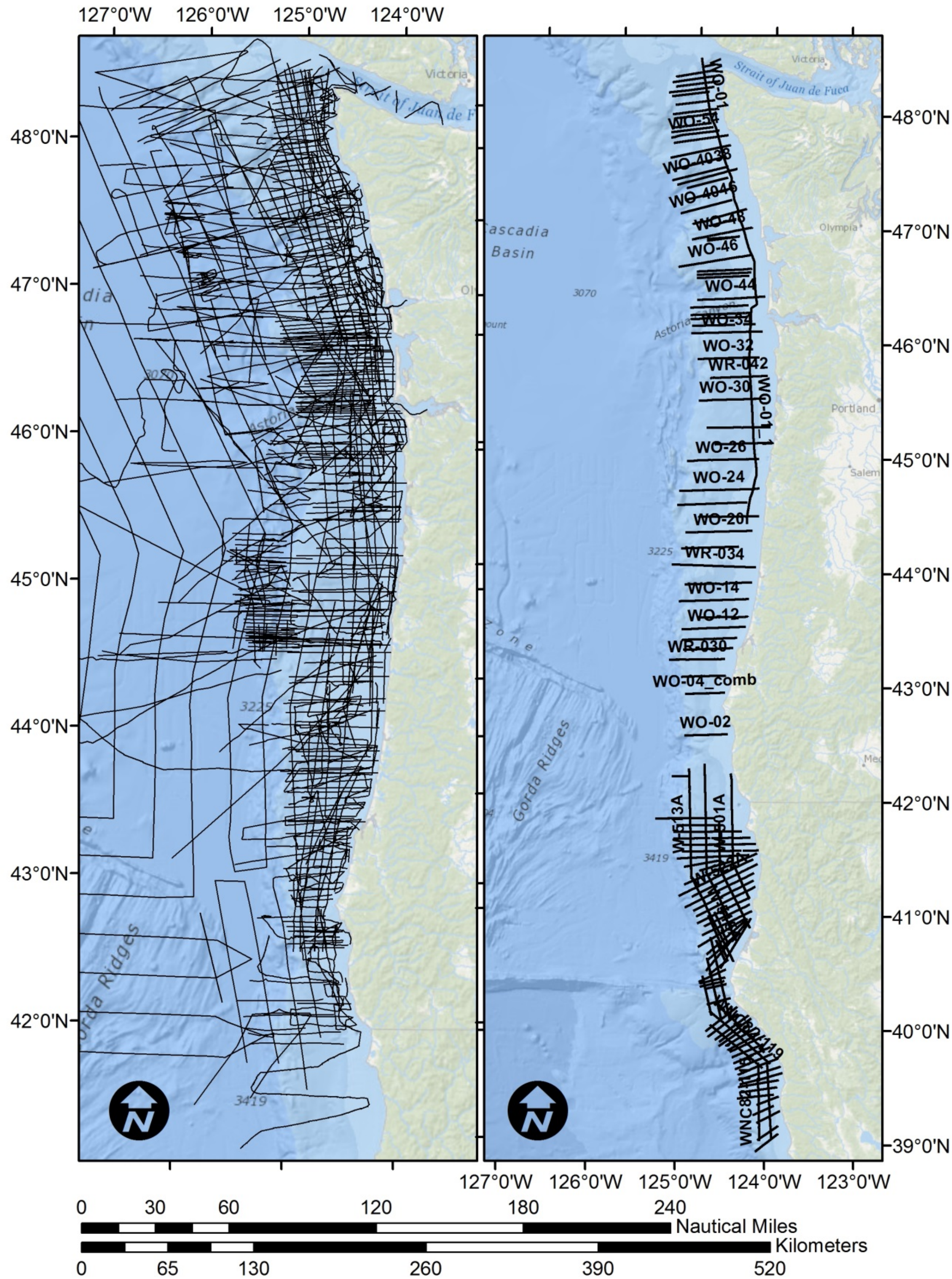


Figure 47. Seismic reflection trackline maps
The left panel shows the navigation for the seismic reflection profiles that were used to develop the structural outcrop map. The right panel shows the tracklines that were used to create the Isocore map.

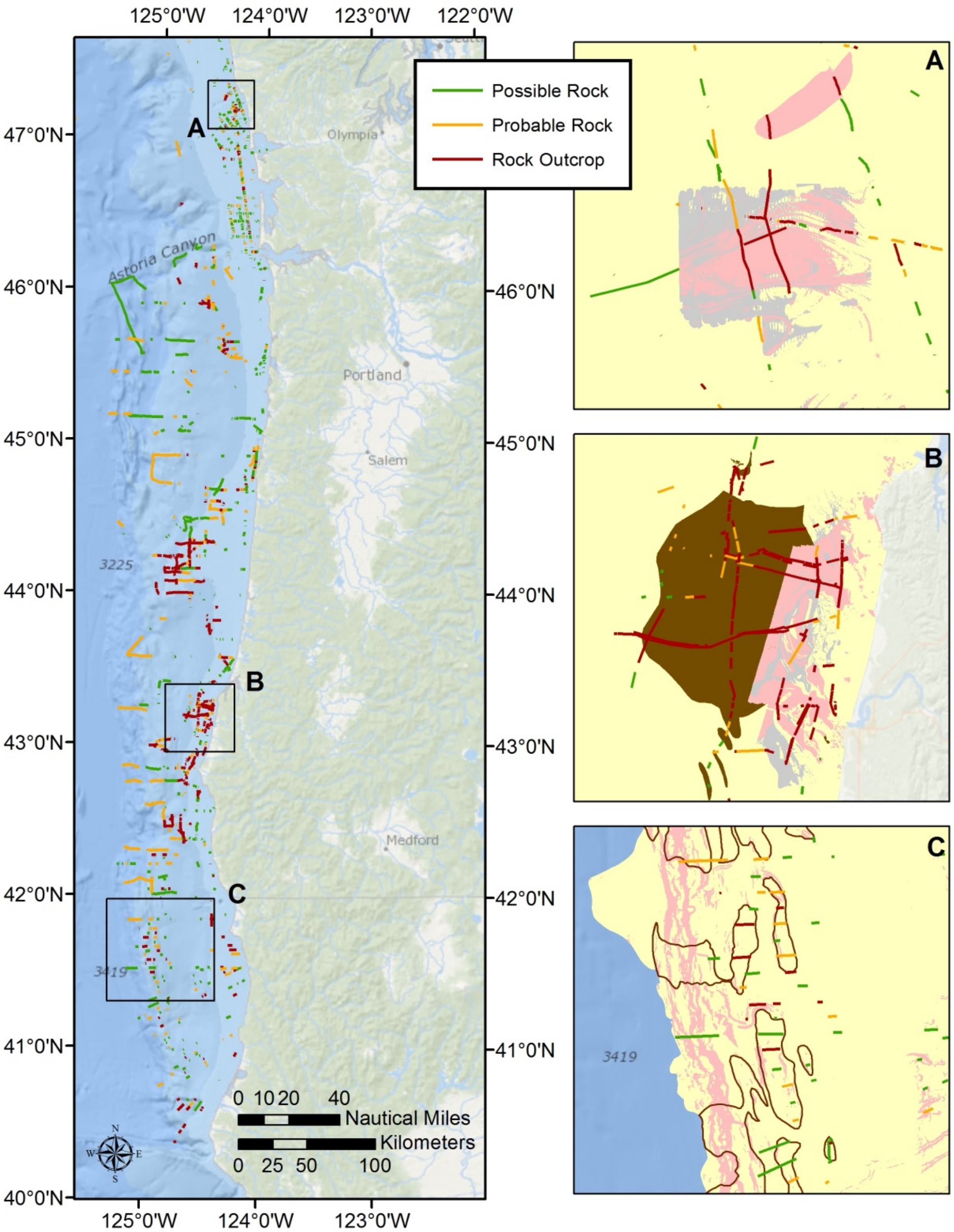


Figure 48. Predictive map of rock outcrop map derived from interpretation of seismic reflection profiles over shelf and slope environments

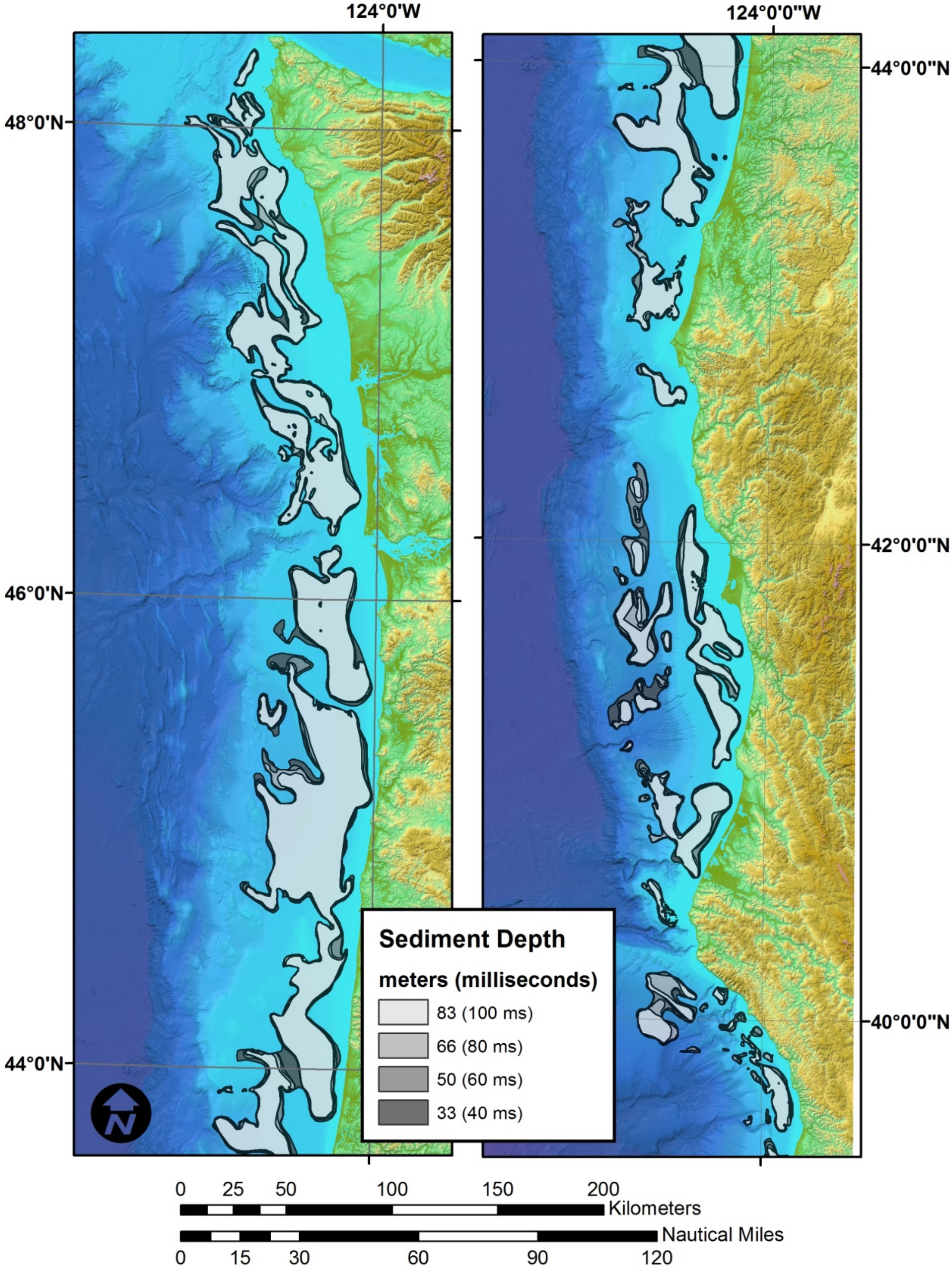


Figure 49. Isocore map showing vertical units of minimum sediment thickness in meters (and two-way travel time in milliseconds)

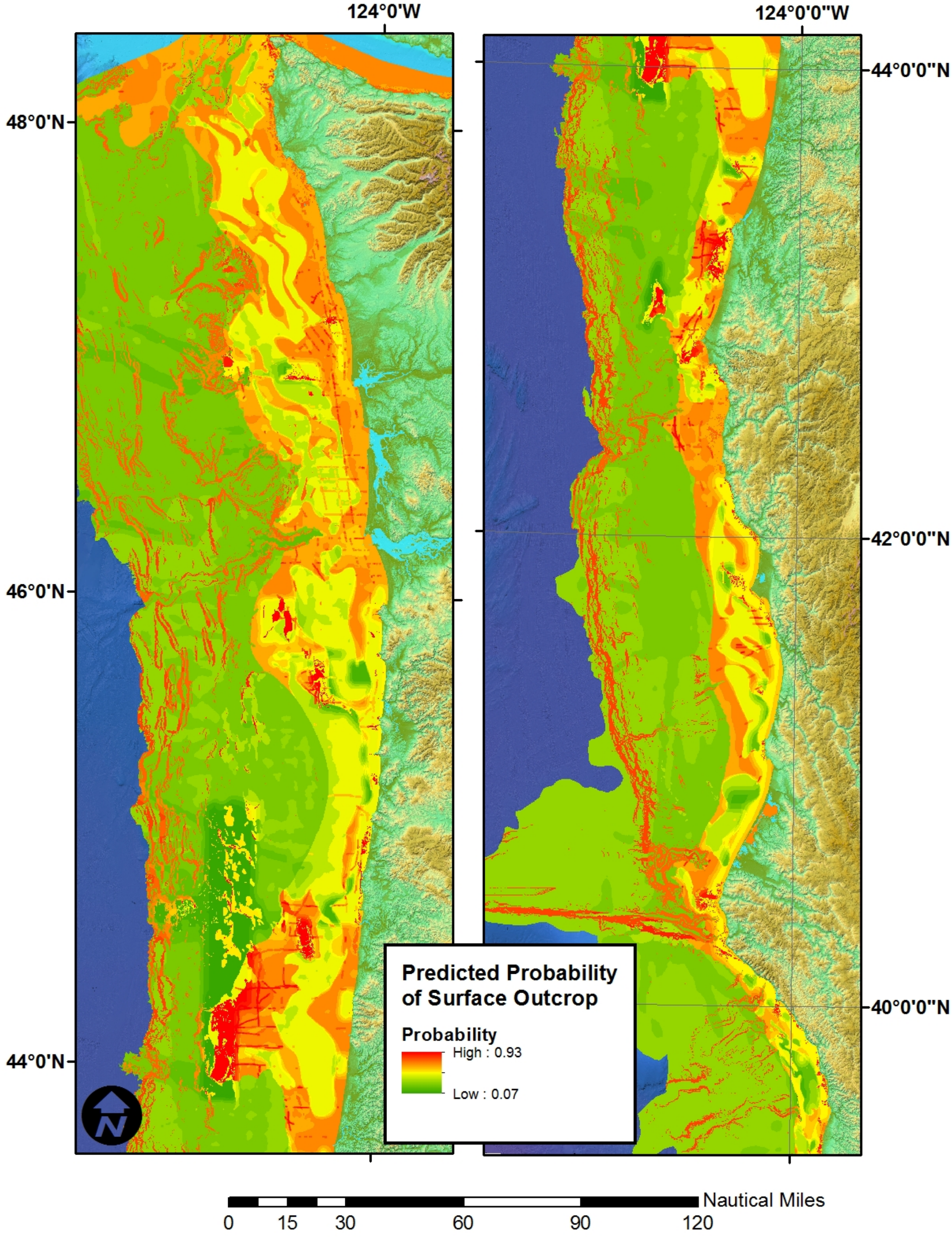


Figure 50. Maps showing modeled probability of rock outcrop of the continental shelf and slope from the Canadian border into central Oregon (left panel) and central Oregon to northern California (right panel)

This Bayesian model was created from six inputs derived from this study and combined to produce a continuous map depicting areas were rocky outcrops are more likely (red and orange colors 60-92%) and unlikely (green colors, 7-40%) to be found. Yellow colors are unknown, most often due to insufficient underlying data.

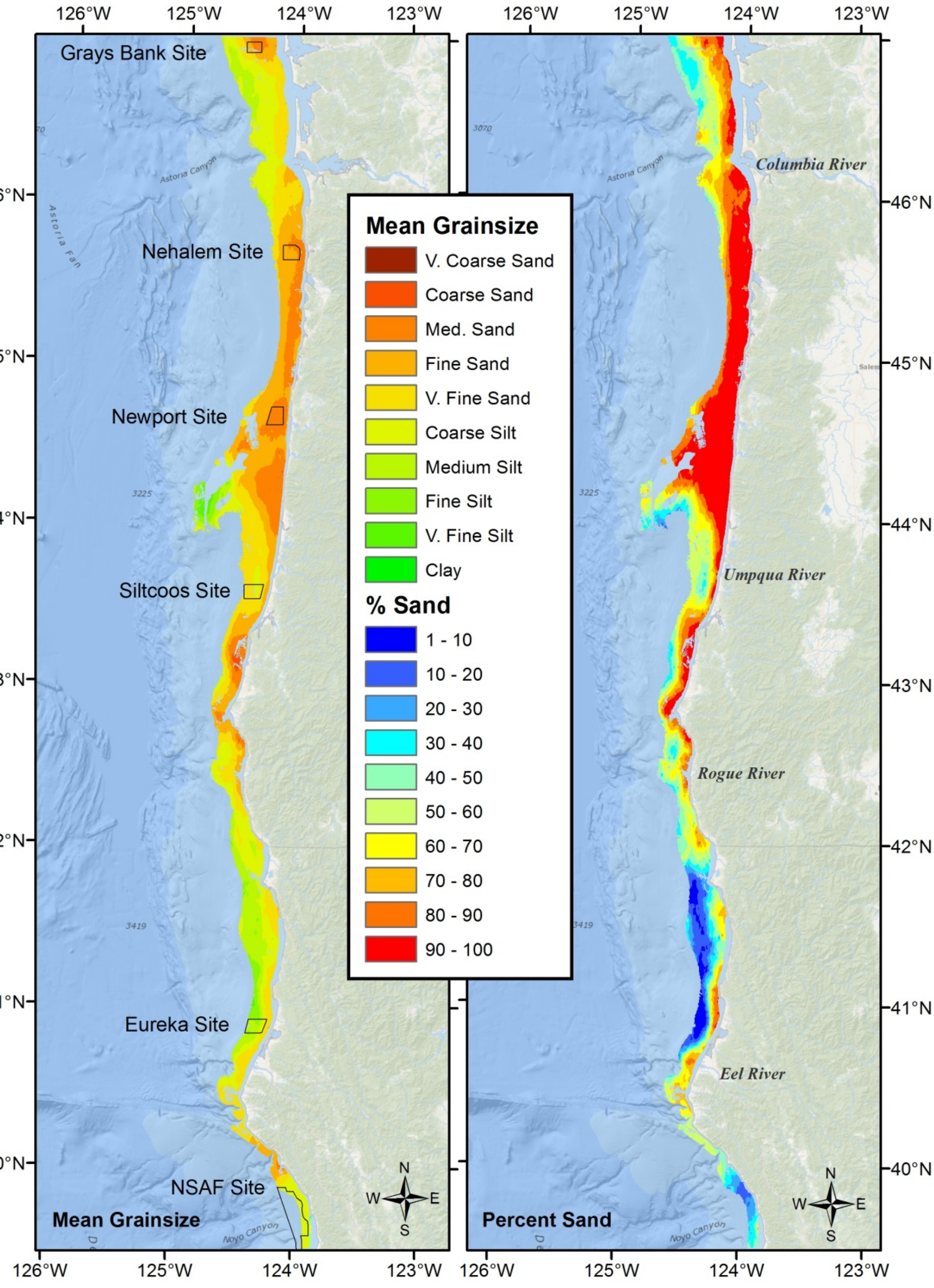


Figure 51. Mean grain size (left panel) and percent sand composition (right panel) models of the continental shelf margin out to 130 m depth and inshore to 20 m water depth

Maps were developed to support modeling of benthic infauna project component (see report Section 6). The Inverse Distance Weighted models use seabed sample data gleaned from usSEABED, the Oregon State Waters Mapping Program, and this study.

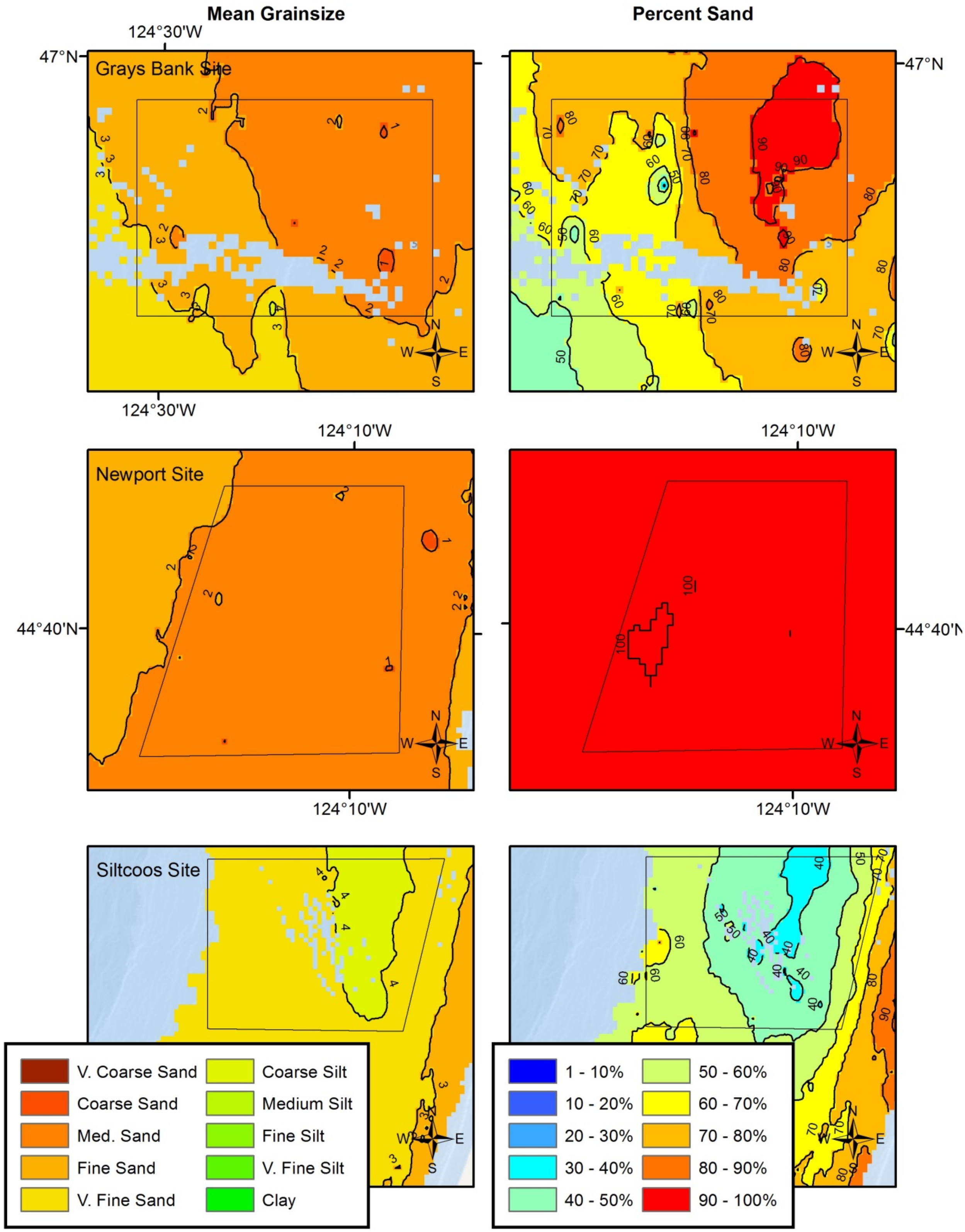


Figure 52. Grainsize and percent sand at local mapping sites Grays Bank, WA, and Newport & Siltcoos, OR.

3.5 Discussion

Each of the local-scale seabed habitat maps developed through this study provides a first look at seabed bathymetric structure and surficial sedimentary texture at the site. For the sites where some knowledge or expectation of outcrop was present (Grays Bank, Siltcoos and Northern San Andreas Fault) we found greatly varying rocky reef complexes. Grays Bank exhibited the greatest diversity of habitat types consisting of a large outcrop approximately nine miles long and ¾ of a mile wide with significant (9 m, measured in a 3x3 cell neighborhood) vertical relief. The sedimentary environment that surrounds the reef is also quite diverse with large expanses of gravel and four classes of homogeneous sand mixtures. In contrast, the Siltcoos reef is surrounded by much finer class of sediments (sandy mud and muddy sand). While both sites are adjacent to large sources of terrigenous sediments (the Columbia River and Umpqua River) the Siltcoos site appears to be a sink for these fine silts (Wheatcroft et al. 2013). The Grays Bank site occupies a transition zone from coarse well sorted inner shelf sediments to silty Columbia River mud deposit on the mid to outer shelf. The rock outcrop at the Northern San Andreas Fault site is locally restricted to a narrow zone along the fault scarp.

While seasonal riverine discharge of sediment likely controls the patterns in unconsolidated sediment grain size and sorting found at Siltcoos and Eureka sites, we did not sample the sediment seasonally in this study. We do, however find evidence for seasonal or perhaps annual change at the Nehalem site where the Box Coring was completed in the year prior to the multibeam mapping and Shipek Grab sampling. The Shipek Grab samples show a slightly finer distribution of sediment grain size in the latter year perhaps indicating that the surficial sedimentary characteristics of the site vary from year to year.

The SGH Map Version 4.0 for WA, OR and CA represents a significant update to the regional knowledge base for seabed habitats. By incorporating existing products from the OR and CA State Waters Mapping Program as well as the sites developed here we have updated the baseline mapping coverage, which underpins the regional SGH map, by approximately 7% for continental shelf habitats. This constitutes the largest incremental improvement in new mapping coverage for any of the previous SGH map versions and also provides improvement where it is needed most, in the relatively data poor continental shelf environment. The SGH map attribute table updates render the map more consistent across the OR-CA border through the clarification of induration code usage in WA and OR and also by extending the usage of Gary Greene's Deepwater Classification Code (Greene et al. 1999) north into WA and OR where it wasn't previously implemented fully. Finally, the SGH Map Version 4.0 takes steps toward implementing the CMECS substrate component. However, we did not find it possible to make a perfect crosswalk between SGH or Greene classification codes to CEMCS classes. For this reason it may be necessary to develop new CMECS delineations of habitat that differ from SGH map habitats in subsequent efforts. Users of the SGH Map Version 4.0 should be aware that the CMECS classification was applied to pre-existing habitat patch delineations and should be considered a test implementation.

Despite extensive recent mapping programs and this effort (California State Waters Mapping Program, Oregon State Waters Mapping Program, NSF Cascadia Initiative and others such as this project): data coverage over areas subject to marine renewable energy development is incomplete and patchy. This patchiness is decreasing in key areas like the inner continental shelf (especially in near shore state waters) making management decisions that hinge on seabed or habitat type factors like rocky outcrops less uncertain. To address the need of reducing uncertainty in areas without full coverage swath imagery this study has developed a suite of predictive data products that can be used to qualitatively estimate the likelihood that a rocky feature might occur at a location where the SGH Map Version 4.0 would otherwise indicate an unconsolidated class. The thematic quality of the SGH Map Version 4.0 is clearly non-uniform and there are certainly areas of rock outcrop that remain undiscovered and thus misclassified through omission in the regional map. The data quality layers, the deep-water slope stability layer, and the outcrop and Isocore layers for the continental shelf provide an indirect method for evaluating the chance that an area of interest could be rocky. Figure 53 presents a look data quality and predictive map types at three rocky outcrops on the continental shelf. The structural and isocore predictor maps (maps B and C) support the outcrop mapped at sites 1, 2, and 3 in the SGH Map Version 4.0 (map D). These sites are all areas of reasonably high data density and quality (map A) where a local survey data exists and outcrop has been mapped (1 = Heceta Bank, 2 = Siltcoos, 3 = Bandon-Arago Reef).

An objective of this study was to also estimate the probability of rock outcrop where local data is sparse. The data products developed here and presented in Figure 54 are instructive for this purpose. The seabed area between sites 1&2 (labeled 4 in Figure 54 panel D) and sites 2&3 (labeled 5 in Figure 54**Error! Reference source not found.** panel D) show much different outcrop potential given the structural outcrop and Isocore mapping. Area 4 shows structural outcrop and shallow sediment thickness. Area 5 shows lower likelihood for structural outcrop and sediment cover as indicated by the Isocore map. Therefore areas 4 and 5 should have much different, or opposing, probabilities of rock outcrop, even with low data quality in these areas (Figure 54 panel A). The model for probability of rock outcrop is designed to integrate the habitat map, its data quality companion, and the predictive maps in an organized and consistent method and ultimately translate the example above regionally. Outcrop probabilities shown in area 4 are greater than 0.6 probability of outcrop (warm colors). In area 5, to the south southwest of site 2 the predictor maps suggest low chance of outcrop and considerable sediment cover (green colors). This example illustrates that the suite of study products effectively translates locally derived data to regional interpretations.

Caveats and cautions regarding the use of the Predicted Outcrop Map

Overall, this Predicted Outcrop model as a preliminary example of integrating predictive data products developed under this project. The inputs vary in their uncertainties. The relationships between the predictors are expertly defined, not empirically derived. The slope prediction for example was derived from direct observations from submersibles (Kulm and Goldfinger 1995), and is consistent with slope stability calculations using locally appropriate materials. The seismic reflection data is of variable quality and efficacy for the purpose of mapping unconsolidated materials. Thus the relationships between the predictors are in some cases expertly defined, in others empirically derived. The model is particularly useful in areas of low data density or quality where there is a need to estimate the likelihood or possibility of finding rock, however, one should always consider the SGH Map Version 4.0 habitat type and the Version 4 Data Quality Map layers before using the Predicted Outcrop model which is under development and considered “beta” as of this writing.

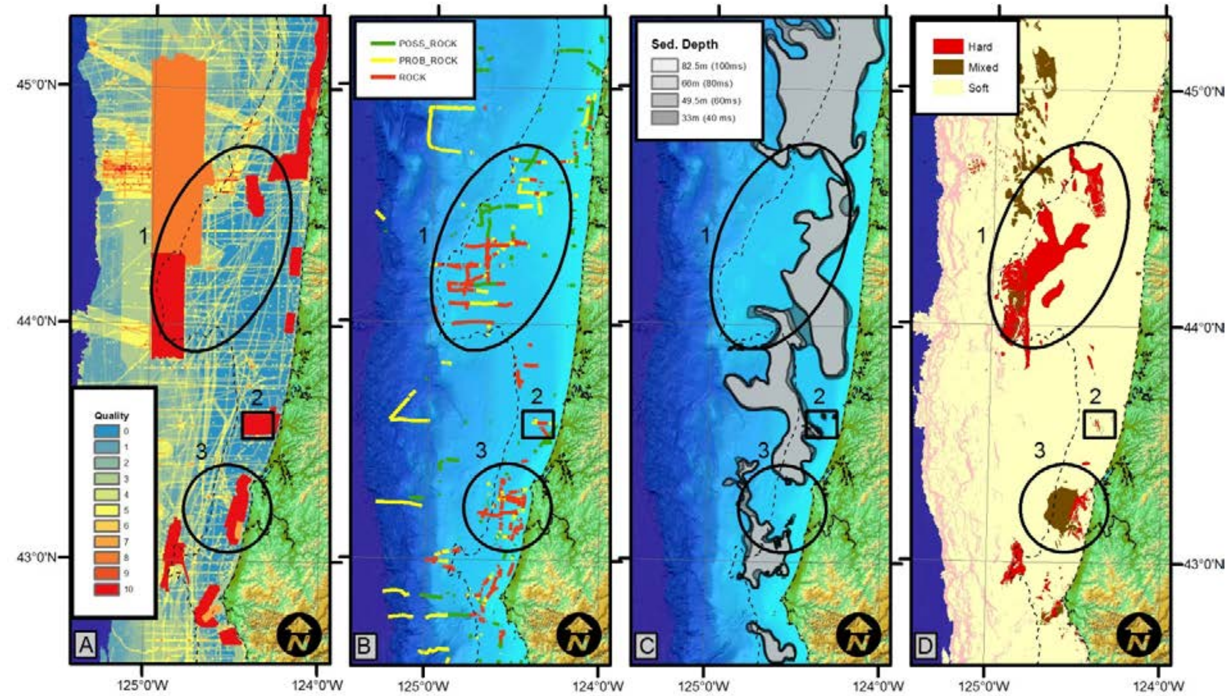


Figure 53. Map products reveal seabed character (hard or soft seabed)
Map A shows weighted data density or “data quality”. Maps B&C show outcrop and Isocore sed. thickness derived from interpretation of seismic reflection data. Map D represents the Version 4.0 SGH Map for Oregon, Washington and Northern California.

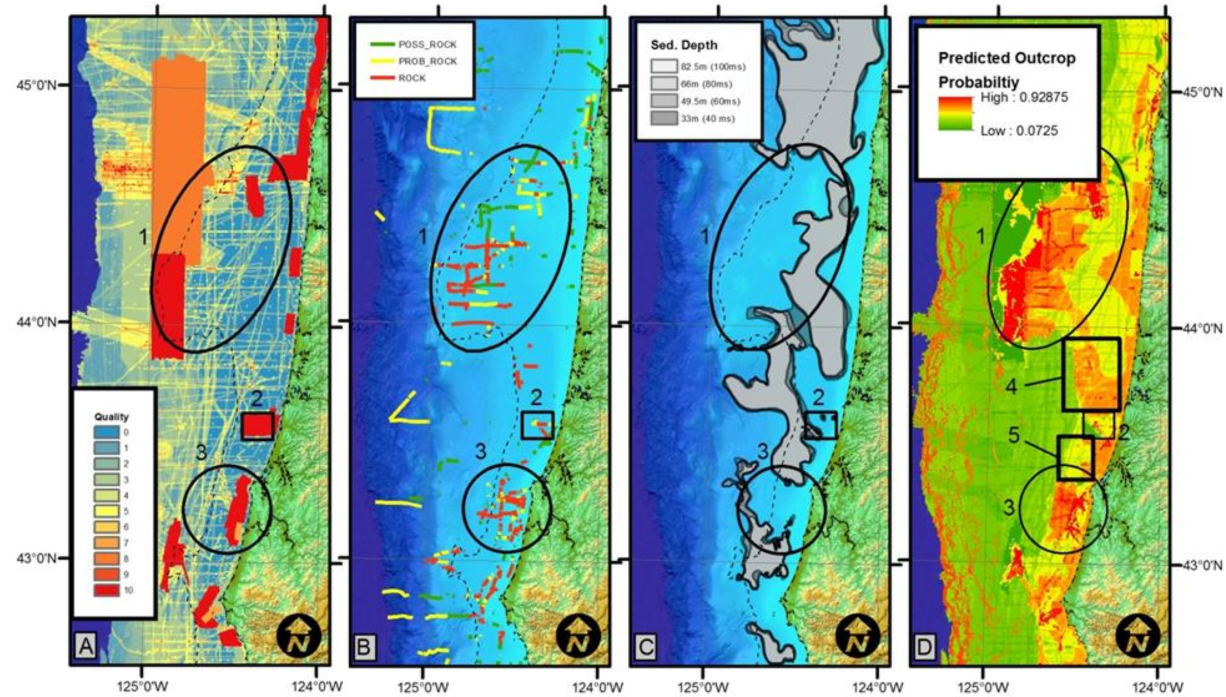


Figure 54. Map products predict seabed character
Map D now includes the predicted outcrop results from our model. The modeled output in areas 4 and 5 correspond to our interpretation of the local geologic structure and sediment cover.

3.5.1 Comparison of Two Sites Not Related to This Study

The independent investigation of two sites (SETS and Wind Float) unrelated to this project in the late stages of production of this final report offers an opportunity to compare regional results from this study to more detailed investigations as a test of the applicability of regional results.

3.5.1.1 South Energy Test Site, OR:

The SETS site is described in some detail in the Newport area local mapping section. We found it surprising that the shallow subsurface topography was as varied and complex as it was, revealed by the SETS survey. In retrospect, it should not have been surprising, as onshore analogs are abundant and were described in considerable detail by Parke Snavely and other investigators in the 1960's and 1970's. But extrapolation of the complex Pleistocene subaerial topography into the offshore could not be done, and still cannot be done without geophysical surveys that include the subsurface. The discovery of Pleistocene paleo dunes was another aspect that could not have been expected from regional mapping, or even local mapping as was done in the BOEM Newport area because that mapping lacked coring or sub bottom profiling that would have revealed the nature of these features. This was a new discovery that required a full suite of surface and subsurface information to make, though now these features perhaps can be inferred elsewhere with less data by comparison to the SETS site. At a superficial level, the hard substrates associated with these unusual features was reliably mapped during the BOEM surveys, and so the habitats could be relatively well understood locally. What was missing was the ability to understand the genesis of the NW trending features, and therefore it was not possible to extrapolate what was known with much confidence. The complex subsurface topography is completely unpredictable from surface data and therefore cannot be inferred or extrapolated from surface mapping anywhere in the study area. While the presence of a complex paleo land topography is expected, and in general can be inferred to exist in most areas of the inner to mid shelf, specifics of such surfaces cannot be inferred even generally. One thing that was helpful was the evolution of a new version of the structural map of the Cascadia region, a separate project running in parallel to this one. The structural evolution and configuration of the Cascadia shelf has been improved over the original version (Goldfinger et al., 1992, 1994, 1997) through the full release of industry multichannel data in digital form (http://walrus.wr.usgs.gov/NAMSS/). Previous version of the structure map used paper copies of these data that were donated to our lab in the 1990's, but the digital data greatly improved our ability to interpret structural details. The complete release of the next version (7.0) will be in mid-2015, but the in progress version was used in some regions for this project. In particular, it became evident that the NW features in the Newport area were unlikely to be fault related through re-examination of the multichannel data as well as the SETS data.

3.5.1.2 Wind Float, OR:

SETS represented an area directly adjacent to one of the BOEM study sites, and therefore should have a close relationship and a short path of extrapolation. Wind Float on the other hand, is in in area of poor data quality and density, and distant from any well studied site, and therefore a worst-case scenario for predictive capabilities of the regional maps. The Wind Float site is outside the areas of modern multibeam data, therefore the primary tools available are the SGH Map Version 4.0 habitat map, the isocore maps, the Cascadia structure map, along with individual seismic profiles and simple analysis of slope stability. The SGH Map Version 4.0 habitat map in this area is mostly based on the 2 km grid of samples collected by OSU in the 1960's, and incorporated into the surficial map interpretation. Generally, Wind Float lies along the "mud line", the regional transition from surface sands inshore to muds offshore (Figure 55).

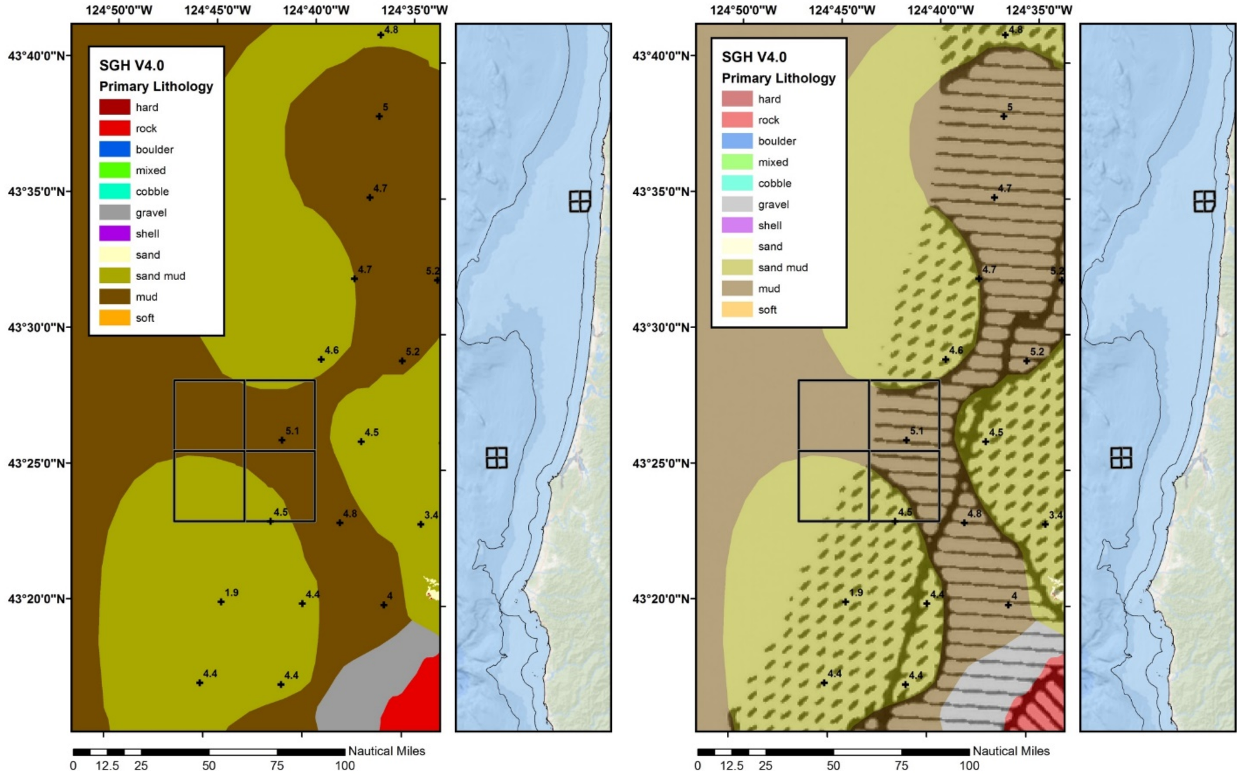


Figure 55. SGH Map Version 4.0 in the vicinity of the Wind Float site, southern Oregon
Wind float site shown by subdivided square. Original interpretation of the “mud line” (Kulm et al., 1975) overlaid (hatch pattern) in right panel.

The figure shows that the mud line is somewhat convoluted in this area, with irregular patches of sand and mud. These data are more than 4 decades old however, and surface materials may not be the same today. Seismic profiles and the structure map show that Wind Float lies mostly in an asymmetrical syncline between NNW trending anticlines to the east and west. The isocore map suggests little chance of rocky outcrop except in the SW corner of the Wind Float site, where a NE striking anticline passes through the site, and the basin sediments pinch out on its eastern flank. We briefly investigated the Wind Float site using available data used in this project with a higher level of scrutiny than possible regionally. Western GECO profile WO-12 and OSU sparker line SP-141 crosses through the Wind Float site, and OSU profile SP-64, and Shell profile 7083 pass just to the south. These lines were used to construct the isocore map. These lines show a gently west sloping seabed, and west dipping subsurface reflectors. An unconformity at a depth of ~ 0.2-0.5 sec. TWT slopes gently to the west, and separates more highly deformed strata from more gently deformed strata that show evidence of recent folding on the same axes as the deeper strata (Figure 56; see also McNeill et al. 2000). Dart core data along the Shell profile show that the underlying anticline is covered with Quaternary friable sand and clay, consistent with the habitat map and OSU sample data, with no older materials exposed at those sample sites. The anticline to the west also had dart core samples that show Quaternary to Pleistocene silt and clay exposed on the western flank. No samples were collected between the two anticlines.

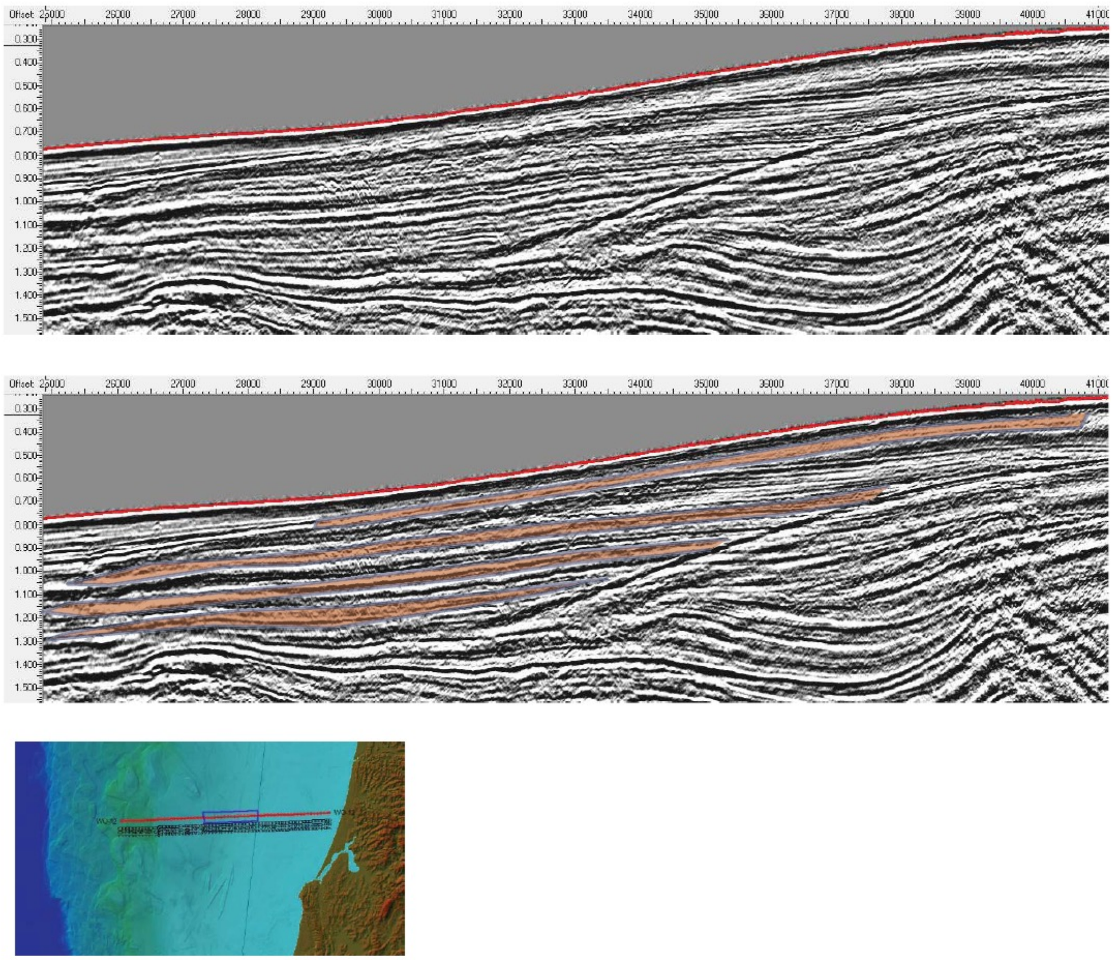


Figure 56. Multichannel profile WO-12, Coos Basin, OR
Four interpreted slide packages are shown in the lower panel, above a regional unconformity.

Multichannel profile WO-12 shows that above the unconformity, four episodes of landsliding can be identified in the seismic section at this site (Figure 56). In approximately 425 m of section, at least four landside aprons are imaged, evidenced by jumbled chaotic reflectors that grade to conformable reflectors to the west. At a typical sedimentation rate of 15-25 cm/1000 yrs., this represents approximately 1.7-2.8 Ma of section, implying landslide repeat times of ~ 340,000-560,000 years. Local sedimentation rates are unknown, thus rates higher than this estimate could result in a higher landslide frequency. The high-resolution Shell profile suggests an episode of surface or near-surface landsliding is also present that cannot be interpreted from the lower resolution multichannel data. We conducted a preliminary assessment of slope stability at the wind float site using engineering values from nearby cores as input. We ran a model using method of slices infinite slope stability calculations in Slide 6.0. Slopes of 2 degrees with material properties similar to this site require ~ 0.5 g (vertical and horizontal) accelerations for failure on shallow slip planes (Figure 57) assuming no excess pore fluid pressure is either ambient or generated during the event. The local slope is ~ 1.5 degrees to the west, and though a slope model of 1.5 degrees were not run, this would clearly require much higher accelerations.

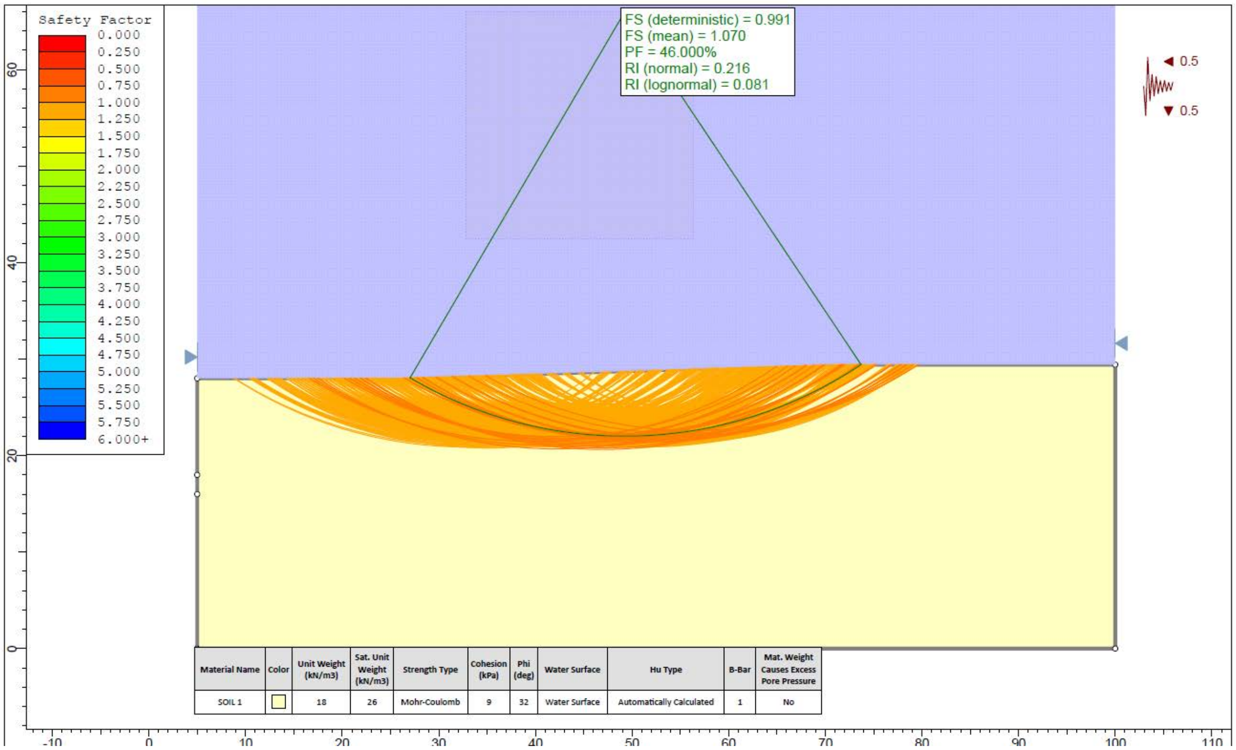


Figure 57. Slope stability model for a 2 degree slope
Physical property values from nearby cores are shown in the data block.

The low frequency of events does not match the known frequency of great earthquakes in this part of the Cascadia margin of 240-500 years (Goldfinger et al. 2012, 2013), being lower by ~ an order of magnitude. Accelerations in great earthquakes likely saturate at ~ 1g, thus the lower slide frequency at this site suggests that material properties of this site can sustain most (but perhaps not all) of even the great earthquakes experienced in the last 1-2 million years.

3.6 Conclusions and Limitations

In summary, the multi-faceted approach to narrowing the information gap taken by this project has yielded measureable gains in baseline data coverage in the study area. Additionally, we have added value to these new data by developing seabed classifications at project survey sites as well as incorporating underutilized data from external sources into the classification. A key accomplishment of the project has been carrying the new mapping through to the regional synthesis data sets, the Version 4.0 Surficial Geologic Habitat Map for WA, OR, and northern CA and the probability of outcrop model ensuring that the most up to date seabed habitat information is available for marine renewable energy planning. While these integrations were not intended as comprehensive region-wide data collection and mapping efforts, they have provided key datasets that can be used to assess data distribution, thematic habitat map quality, likelihood of rock outcrop, and surficial sedimentary character.

As with any large scale or regional mapping effort some cautions and appropriate uses of the data should be discussed and understood. Regional information can provide decision makers with important information for planning and a context for a specific site, however, regional maps like the SGH map and the probability of outcrop model are not intended to replace local site mapping nor are they meant to suggest that all areas are equally well known. There has been considerable effort taken to develop a data quality map that is specifically designed to act as a guide to data rich, high quality areas and data poor low quality areas. This data quality map and the regional predictive outcrop map should be used in concert, and can help direct where additional acoustic or visual surveys are needed. They may also be used to suggest sites that have the potential to meet some suite of design or habitat protection criteria.

Some types of questions and analyses might require a level of uniformity or detail that the regional products cannot provide due to their mixed resolution, and heterogeneous quality and efficacy for a given purpose. Depending upon the question at hand, additional surveys and mapping will likely be needed to either verify habitat type in data poor areas or provide greater detail about habitat patchiness at local scales.

The limitations of regional maps and methods are not only limited to the obvious limitations of scale and resolution. For example, in areas where we have mapped sedimentary sequences of significant thickness in the Isocore map, the presumption was that this sedimentary sequences would be very unlikely sites for exposure of hard substrates. While generally true, there are enough exceptions to this to warrant some caution. For example, low-relief and hard seabed features can still occur within sedimentary basins at the surface and in the shallow subsurface under some conditions, even though they may not be tied to significant tectonic structures that form most of the larger hard substrate features in the region. These exceptions include: 1) Ripple scour depressions of the ephemeral type described by Cachionne et al. (1984) are likely common in the nearshore area in ~ < 50 m water depth; 2) hard substrate depressions of the type first described here, which are spatially fixed and linked to paleo topographic features are common and typically contain hard sand and gravel; 3) paleo dunes described in this report that may have a lag gravel carapace and may contain semi-lithified materials; 4) paleo erosion surfaces with or without lag gravels may come to the surface or be thinly covered; 5) Carbonates related to methane bearing fluid venting are known to occur on continental slope accretionary ridge features in many areas. Our predictive outcrop model does not currently account for the possibility that these hard substrates may be widespread on ridge crests and less commonly in sedimentary basins throughout the study area. These classes of features are likely underrepresented as hard seabed in the SGH map, a result of low data density and poor understanding of structural or other controls on their occurrence. They are also not imageable with multichannel or even single channel sparker seismic reflection profiles available for the regional study. As many of these features require sub bottom data of high-resolution to image, and they may occur in sedimentary basins, their prediction is mostly not currently possible with any known technology and they must be assesses with site surveys at high resolution.

Given the limitations outlined above and throughout this report, it should be clear that while regional mapping efforts are a good reconnaissance step that can help agencies evaluate the potential for favorable renewable energy sites, and the potential for conflicts with uses of critical habitats, that a regional map also cannot substitute for detailed local studies. We found it surprising that the shallow subsurface topography was as varied and complex as it was, revealed by the SETS survey. In retrospect, it should not have been surprising, as onshore analogs are abundant, but this illustrates the tendency to assume that areas that are not well known are probably simple. This assumption is commonly incorrect, and points out the need for caution when interpreting local conditions from a regional scale mapping product. In a complex tectonic environment, prevalent along the entire western US coast, finding proxies and predictive tools is not at all a straightforward process, and in many cases is simply not possible. The need for appropriately scaled studies of sufficient resolution and data density cannot be emphasized enough for the purposes of local scale assessment and decision making.

3.7 Next Steps

3.7.1 Regional High-Resolution Mapping

In order to move forward to a next version of the regional SGH maps, we suggest that regional mapping of the seabed of the upper slope and continental shelf is the next logical step. We and others have been mining the existing data for many years, collecting and assimilating new data as it becomes available. At this stage, there is not a great deal of existing data left to mine. Of course the cost of high resolution mapping of the shelf is high since mapping costs increase exponentially with decreasing water depth, but to advance our knowledge to the next stage, this is what is required.

3.7.2 Sub Bottom Surveys

In the short term, directed surveys may be able to fill knowledge gaps in specific areas or environments that can aid specifically in areas of renewable energy development, conceived or proposed. For example, the state of knowledge of the inner-mid shelf in Oregon was improved dramatically with the SETS subsurface geophysical surveys. Although some high-resolution bathymetric and backscatter data were available, the interpretation required sub bottom data. This suggests that sub bottom profiling, targeting poorly known areas could have a similar effect in revealing the geologic makeup of poorly known provinces in advance of eventual full coverage mapping. We recommend high resolution sparker and concurrent CHIRP profiling concentrated in poorly known areas and guided by local knowledge as one next logical step that could be undertaken with significantly lower cost that full coverage multibeam mapping. Such geophysical surveys would not then be replaced by eventual mapping, but rather would be required in any case to augment such mapping, as demonstrating by the surprising outcome of the SETS surveys.

3.7.3 Coral and Sponge Modeling and Mapping

Another next step that we feel is important would be to continue development of the coral/sponge modeling (see Section 6), augmented by targeted surveys to help fill in the blanks concerning structure-forming biological habitats. As of this writing, knowledge of the habitats of these species is improving with each field cruise. A cruise just completed has added significant new information on coral and sponge occurrence and habitats in unexplored areas in the Klamath basin off Northern California. However, as noted, there is a significant gap in our understanding of coral/sponge habitats in areas thought to be free of hard substrates as illustrated by the NOAA Trawl survey data. These areas are unexplored, and currently unexplained. While some of them have low biomass in trawl surveys, and might not be considered significant, other areas, such as the Newport embayment, have significant biomass that currently is not explained. As these anomalous basin areas are trawlable, as opposed to most rocky reefs and ridges that are not, it is these anomalous areas that would seem to require significant attention with respect to habitat degradation through human activities.

3.7.4 Improving Rock Prediction

Predicting rocky habitats in the absence of complete multibeam coverage is a long term problem that is difficult to manage. We have made several evolving attempts to use existing data to predict rocky outcrops from seismic reflection data, from angle of repose and slope considerations, and from predicting areas where rocky outcrops are unlikely through isocore mapping. Our final rock prediction layer is the merging of these three methods. It can be improved in several ways. First, the prediction of rocky outcrops on the continental slope is predicated on several ground truth points from *Alvin* dives in northern Oregon. To improve this layer, other ground truth can be incorporated to make this layer more regionally defensible. In addition, core sample data combined with slope stability calculations can extend and improve this layer regionally with less dependence on spot observations that are available from the limited number of *Alvin*, SeaCLIFF, ATV, and other submersible dives. On the shelf, where slope predictions do not predict outcrop due to the formation of the Pleistocene wave cut platform, prediction depends on the isocore maps, the seismic profiles, and the areas of existing multibeam data and ROV and submersible dives. Our first cut isocore could not make use of all the existing data, so there is room for improvement by incorporating additional data and refining this isocore layer. Beyond that, regional sub bottom profiling recommended above would lead directly to an improved rock prediction model for the PNW shelf.

3.7.5 Temporal Change

The SGH Map Version 4.0 and all previous versions have one major Achilles heel in addition to the more obvious ones related to heterogeneous data. This is the smearing that time represented by many decades of data into a single map. While geology may change slowly most of the time, this is less true on a tectonic coast, and much less true in the nearshore regions most likely to be used for renewable energy applications. We currently do not know very much about the flux of sediments seasonally and over decadal time scales and how such changes influence the surficial habitats, let alone how renewable energy installations will be influenced by this or how they will exert their own influence upon the system. Based on current knowledge, we now know that at least one class of "windows" into the shallowly buried transgressive lag deposits is relatively fixed with respect to shallow subsurface features, while others known as ripple scour depressions, may move. Repeat surveys and anecdotal evidence suggest that in shallow water, flux of at least several meters is expected from one storm cycle to the next. We also know that significant areas of shallowly buried hard substrates exist, such as in the Cape Perpetua area and in the SETS test berth. Shallowly buried hard substrates can be covered and uncovered in single storm events, thus the surface area in such habitats is subject to significant change on short or longer timescales. We recommend that efforts be taken to investigate temporal sediment flux with repeat surveys and coring to establish a framework of first order understanding of this process. This will aid in understanding the uncertainties surrounding snapshot multibeam surveys, as well as providing information important to the suitability of various renewable energy devices.

3.7.6 Other Factors

Several other logistical factors will help lead to the next version of the regional SGH maps. As of this writing, habitat mapping of the extensive datasets from the California State Waters mapping program is not complete. The current SGH Map Version 4.0 therefore does not incorporate the most advanced versions of these new data, and use only the Tier II automated rocky classifications available at present. Inclusion of the final Tier III habitat maps when available will be an important improvement. Another important improvement needed is to incorporate full attribution and methods metadata for habitat polygons included in the SGH map. Currently, the methods used, and the datasets used cannot be explicitly linked to specific map areas easily, and thus direct attribution will help future researchers determine how specific areas of the map were generated and with what data.

3.8 References

Amolo RC (2010) Habitat Mapping and Identifying Suitable Habitat of Redfish Rocks Pilot Marine Reserve, Port Orford, Oregon [Ms thesis]: Corvallis, Oregon State University

Barnard WD and McManus DA (1973) Planktonic Foraminiferan-Radiolarian stratigraphy and the Pleistocene-Holocene boundary in the northeast Pacific. Geological Society of America Bulletin 84: 2097-2100.

Beeson JW, Goldfinger C, Johnson, SY, Wakefield, WW (2011), A Geophysical Investigation of the Offshore Portion of the Northern Segment of the San Andreas Fault on e "Green" Research Vessel, American Geophysical Union Fall Meeting, San Francisco, Calif., Abstract OS43C-1840

Beeson JW, Goldfinger C, Johnson, SY (2012), Investigation of the Offshore Section of the Northern San Andreas Fault: Slip Partitioning, Shallow Deformation, and Fault Trend Influence, American Geophysical Union Fall Meeting, San Francisco, Calif., Abstract OS43C-1840

Blackwelder BW, Pilkey OR, Howard JD (1979) Late Wisconsinan sealevels on the southeast U S Atlantic shelf based on in-place shoreline indicators. Science 204: 618-620

Blott SJ and Pye K (2006) Particle size distribution analysis of sand-sized particles by laser diffraction: an experimental investigation of instrument sensitivity and the effects of particle shape. Sedimentology 53: 671–685 doi: 101111/j1365-3091200600786x

Cacchione DA, Drake DE, Grant WD, Tate GB (1984) Rippled scour depressions on the inner continental shelf off central California. Journal of Sedimentary Research 54(4) 1280-1291

Cacchione DA (2005) Rippled Scour Depressions off Northern California – Process and Patterns. AGU Spring Meeting 2005, abstract #OS31A-01

Carlson PR, Nelson CH (1987) Marine geology and resource potential of Cascadia Basin *in* Scholl DW, Grantz A, Vedder JG Eds. Geology and Resource Potential of the Continental Margin of Western North America and Adjacent Ocean Basins. Houston Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Sciences Series: 523-535

Chappel J and Shackleton NJ (1986) Oxygen isotopes and sea-level. Nature 324: 137-140

Clarke Jr. SH, Field ME, Hirozawa CA (1985) Reconnaissance geology and geologic hazards of the offshore Coos Bay Basin, Oregon. U.S. Geological Survey Bulletin 1645, 41 p.

Copps S, Parkes G, Wakefield W, Yoklavich M, Bailey A, Goldfinger C, Greene G (2008) Integration of Geology and Fish Ecology to Assess West Coast Essential Fish Habitat for Groundfishes at the Scale of the Exclusive Economic Zone, *in* Todd BJ and Greene G, eds, Mapping the Seafloor for Habitat Characterization. Geological Association of Canada Special Paper 47: 439-450

Curray JR (1965) Late Quaternary history, continental shelfs of the U S, *in* Wright HE and Frey DG, eds. The Quaternary of the United States, Princeton, NJ, Princeton Univ Press: 723-735

DeMets C, Gordon RG, Argus DF, Stein S (1990) Current plate motions. Geophys J. Int. 101: 425-478

Dixon K (2006) StarFire™: A Global SBAS for Sub-Decimeter Precise Point Positioning, *in* Proceedings of 19th International Technical Meeting of the Satellite Division, ION GNSS September 2006, Fort Worth, TX, 26-29 Sept: 2286-2296

England P, Wells RE (1991) Neogene rotations and quasicontinuous deformation of the Pacific Northwest continental margin. Geology 19: 978-981.

Erhardt, M., Romsos, C., Goldfinger, C., Hairston-Porter, R., Kane, T., Lockett, D., 2011, Habitat Classification, Shipek Grab Sample, Bathymetry, and Backscatter Maps, Newport, Oregon, Oregon State University Active Tectonics and Seafloor Mapping Laboratory Publication 2011-01, 4 maps sheets, scale 1 : 24,000, Oregon State University and Oregon Department of State Lands.

Etnoyer P and Morgan L (2003) Occurrences of habitat-forming deep sea corals in the northeast Pacific Ocean: A Report to NOAA's Office of Habitat Conservation. Marine Conservation Biology Institute, Bellevue, WA.

Fairbanks RG (1989) A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature 342: 637-642

Folk RL (1954) The distinction between grain size and mineral composition in sedimentary rocks. Journal of Geology 62: 344-359

Fonseca L and Calder BR (2005) Geocoder: An Efficient Backscatter Map Constructor. US Hydrographic Conference (US HYDRO), San Diego, CA, USA, Mar 29 - Mar 31 Conference Proceeding

Fonseca L and Mayer LA (2007) Remote estimation of surficial seafloor properties though the application of Angular Range Analysis to multibeam sonar data. Marine Geophysical Researches 28, n. 2, pp. 119-126, DOI 10.1007/s11001-007-9019-4

Fowler, GA, Orr WN, Kulm LD (1971) An Upper Micene Diatomaceous Rock Unit on the Oregon Continental Shelf. J of Geology 79: 603-608

Fox D, Merems A, Amend M, Weeks H, Romsos C, Appy M (2004) Comparative Characterization of Two Nearshore Rocky Reef Areas: A high-use recreational fishing reef vs. and unfished reef, Oregon Department of Fish and Wildlife. 67 p.

Goff JA, Mayer LA, Hughes-Clark J and Pratson LF (1996) Swath mapping on the continental shelf and slope: The Eel River Basin, Northern California. *Oceanography* 9(3):178–182, http://dxdoiorg/105670/oceanog199607

Goldfinger C (1994) Active deformation of the Cascadia forearc: Implications for great earthquake potential in Oregon and Washington [PhD thesis]: Corvallis, Oregon State University

Goldfinger C, Kulm LD, Yeats RS (1992) Neotectonic map of the Oregon continental margin and adjacent abyssal plain. Portland, Oregon Department of Geology and Mineral Industries Open-File Report O-92-4, scale 1:500,000

Goldfinger C, Kulm LD, Yeats RS, Appelgate B, MacKay ME, Moore GF (1992) Transverse structural trends along the Oregon convergent margin: Implications for Cascadia earthquake potential and crustal rotations. Geology 20: 41-144

Goldfinger C, Kulm LD, Yeats RS, Hummon C, Huftile, G J, Niem, A R, Fox, C G, and McNeill, L C, (1996) Oblique strike-slip faulting of the Cascadia submarine forearc: The Daisy Bank fault zone off central Oregon, *in* Bebout GE, Scholl D, Kirby S and Platt JP, eds. Subduction top to bottom. Geophysical Monograph 96: Washington, DC, American Geophysical Union: 65-74

Goldfinger C, Kulm LD, Yeats RS, McNeill LC and Hummon C (1997) Oblique strike-slip faulting of the central Cascadia submarine forearc. Journal of Geophysical Research 102: 8217-8243

Goldfinger C, Romsos C, Robison R, Milstein R, and Myers SA (2002) Interim Seafloor Lithology Maps for Oregon and Washington. Oregon State University Active Tectonics and Seafloor Mapping Laboratory Publication 02-01, 1 digital multilayer map on CD, and text, 11 pp.

Greene HG, Yoklavich M, Starr R, O'Connell V, Wakefield W, Sullivan D, McRea J, Caillet G (1999) A classification scheme for deep seafloor habitats. Oceanologica Acta 22: 663-678.

Hallenbeck, T.R., Kvitek, R., Lindholm, J. (2012) Rippled scour depressions add ecologically significant heterogeneity to soft sediment habitats on the continental shelf. Marine Ecology Progress Series, (468): 119–133.

Henkart P (2006) Chirp Sub-Bottom Profiler Processing - A review. Sea Technology: 35-38

Janbu N (1973) Slope Stability Computations Embankment Dam Engineering - Casagrande Volume *in* Hirschfeld RC and Poulos SJ eds., John Wiley and Sons, New York: 47-86

Johnson JE, Goldfinger C, and Suess E (2003) Geophysical constraints on the surface distribution of authigenic carbonates across the Hydrate Ridge region, Cascadia margin. Marine Geology 202: 79-110.

Kane, T., Romsos, C., Goldfinger, C., Erhardt, M., Hairston-Porter, R., Lockett, D., 2011, Habitat Classification, Shipek Grab Sample, Bathymetry, and Backscatter Maps, Nehalem, Oregon, Oregon State University Active Tectonics and Seafloor Mapping Laboratory Publication 2011-01, 4 maps sheets, scale 1 : 24,000, Oregon State University and Oregon Department of State Lands.

Komar PD, Neudeck RH, and Kulm LD (1972) Observations and significance of deep-water oscillatory ripple marks on the Oregon continental shelf, *in* Swift DJP, Duane DB, and Pilkey OH eds. Shelf sediment transport. Stroudsburg, Pennsylvania, Dowden, Hutchinson and Ross, Inc.: 601-619

Kulm, LD and Goldfinger, C. (1995) An Analysis and Display of Seafloor Features on the Northern Oregon Continental Slope: Information for the North Pacific Cable Routes: Oregon State University, 117 p, 7 plates and maps

Kulm LD, and Fowler GA (1974) Oregon continental margin structure and stratigraphy: a test of the imbricate thrust model, *in* Burke CA and Drake CL, eds. The geology of continental margins. New York, Springer-Verlag: 261-284

Kulm LD and Suess E (1990) Relation of carbonate deposits and fluid venting: Oregon accretionary prism. Journal of Geophysical Research 95: 8899-8915

Kulm LD, Roush RC, Harlett JC, Neudeck RH, Chambers DM and Runge EJ (1975) Oregon continental shelf sedimentation: Interrelationships of facies distribution and sedimentary processes. Journal of Geology 83: 145-175

Lanier A, Romsos C and Goldfinger C (2007) Seafloor habitat mapping on the Oregon continental margin: A spatially nested GIS approach to mapping scale, mapping methods, and accuracy quantification. Marine Geodesy 30: 51-76

Lockett DE (2012) A Bayesian Approach to Habitat Suitability Prediction [MS thesis]: Corvallis, Or, Oregon State University, 85 p

MacKay ME, Moore GF, Cochrane GR, Moore J Casey, Kulm LD (1992) Landward vergence and oblique structural trends in the Oregon margin accretionary prism: Implications and effect on fluid flow. Earth and Planetary Science Letters 109: 477-491

Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee (FGDC) (2012) The Coastal and Marine Ecological Classification Standard (CMECS), FGDC-STD-018-2012 http://www.csc.noaa.gov/digitalcoast/publications/cmecs

Matthews RK (1990) Quaternary sea-level change, *in* Panel on Sea-Level Change. Washington, DC, National Academy Press: 88-103

Melton L (1986) The complete Loran-C handbook. Camden, ME, International Marine PublishingCompany, 221 p

McCoy FM (1977) Marine Curators Gather. GEOTIMES, December 1977: 26

McCrory, P. A., Foster, D. S., Danforth, W. S., and Hamer, M. R. (2002), Crustal Deformation at the Leading Edge of the Oregon Coast Range Block, Offshore Washington (Columbia River to Hoh River): U.S. Geological Survey Professional Paper 1661-A, 53p.

McNeill LC, Goldfinger C, Kulm LD, and Yeats RS (2000) Tectonics of the Neogene Cascadia forearc basin: Investigations of a deformed late Miocene unconformity: Geological Society of America Bulletin 112: 1209-1224

McNeill LC, Goldfinger C, Yeats RS, and Kulm LD (1999) The Effects of Upper Plate Deformation on Records of Prehistoric Cascadia Subduction Zone Earthquakes, *in* Vita-Finzi C, and Stewart I, eds. Coastal Tectonics, Volume Geological Society Special Publication 146: Bath, The Geological Society: 319-343

Morgenstern NR (1967) Submarine Slumping and the Initiation of Turbidity Currents, *in* Richards AF, ed. Marine Geotechnique: 189-220 University of Illinois Press, Urbana, Illinois

Nasby-Lucas NM, Embley BW, Hixon MA, Merle SG, Tissot BN, and Wright DJ (2002) Integration of submersible transect data and high-resolution multibeam sonar imagery for a habitat-based groundfish assessment of Heceta Bank, Oregon. Fishery Bulletin 100(4): 739-751

National Oceanographic and Atmospheric Assocation (NOAA) National Marine Fisheries Survey (NMFS) (2006) Final Groundfish Essential Fish Habitat (EFH) Environmental Impact Statement. Volume 2006, National Oceanic and Atmospheric Administration

National Oceanographic and Atmospheric Assocation (NOAA) Hydrographic Manual (1976) NOAA/NOS Hydrographic Manual, 4th edn. US Department of Commerce, Washington, DC

National Oceanographic and Atmospheric Assocation (NOAA) Field Procedures Manual (2010) National Oceanic and Atmospheric Administration, Office of Coast Survey, 325 p

National Oceanographic and Atmospheric Assocation (NOAA) (2013) NOS Hydrographic Specifications and Deliverables, 177 p

Niem AR, Snavely PD Jr, and Niem WA (1990) Onshore-offshore geologic cross section from the Mist gas field, northern Oregon coast range, to the northwest Oregon continental shelf. Oregon Department of Geology and Mineral Industries, Oil and Gas Investigation 17: 46 p

Oliver JS, Kim SL, Slattery PN, Oakden JA, Hammerstrom KK, and Barnes EM (2008) Sandy bottom communities at the end of a cold (1971-1975) and warm (1997-1998) regime in the California Current: impacts of high and low plankton production. Available from Nature Proceedings.

Pearl, J (1988) Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference. Elsevier, Netherlands, 552 p

Peterson CP, Loubere PW, and Kulm LD (1984) Stratigraphy of the continental shelf and coastal region, *in* Kulm LD, and others, eds. Atlas of the Ocean Margin Drilling Program, Western North American Continental Margin and Adjacent Ocean Floor off Oregon and Washington, Region V. Joint Oceanographic Institutions, Inc, Marine Science International, Woods Hole, MA, sheet 30 with text

Ranasinghe J, Weisberg S, Smith RW, Montagne DE, Thompson B, Oakden JM, Huff DD, Cadien DB, Velarde RG, Ritter KJ (2009) Calibration and evaluation of five indicators of benthic community condition in two California bay and estuary habitats. Marine Pollution Bulletin 59 (1-3): 5-13.

Reid JA, Reid JM, Jenkins CJ, Zimmermann M, Williams SJ, and Field ME (2006) usSEABED: Pacific Coast (California, Oregon, Washington) offshore surficial-sediment data release. US Geological Survey Data Series 182, ver. 10 available at http://pubs.usgs.gov/ds/2006/182/.

Rohr KMM, Furlong KP (1995) Ephemeral plate tectonics at the Queen Charlotte Triple Junction. Geology 23: 1035-1038

Romsos C, Goldfinger C, Robison R, Milstein R, Chaytor J (2007) Development of a Regional Seafloor Surficial Geologic Habitat Map for the Continental Margins of Oregon and Washington, USA, *in* Todd BJ, and Greene G, eds. Mapping the Seafloor for Habitat Characterization. Geological Association of Canada Special Paper 47: 209-234

Sappington JM, Longshore KM, Thompson DB (2007) Quantifying Landscape Ruggedness for AnimalHabitat Analysis: A Case Study Using Bighorn Sheep in the Mojave Desert. J Wildl Manage 71(5): 1419–1426 doi:102193/2005-723

Schroeder NAM, Kulm LD, and Muehlberg GE (1987) Carbonate chimneys on the outer continental shelf: Evidence for fluid venting on the Oregon margin. Oregon Geology 49: 91-98

Seely DR (1977) The significance of landward vergence and oblique structural trends on trench inner slopes *in* Talwani M, Pitman WCI eds., Island Arcs, Deep Sea Trenches, and Back-Arc Basins, Maurice Ewing Series, Washington, D.C., American Geophysical Union 1: 187-198

Smith TM, Reynolds RW, Peterson TC, Lawrimore J. (2008) Improvements NOAAs Historical Merged Land–Ocean Temp Analysis (1880–2006). Journal of Climate 21: 2283–2296.

Snavely PD Jr (1987) Tertiary geologic framework, neotectonics, and petroleum potential of the Oregon-Washington continental margin, *in* Scholl DW, Grantz A, and Vedder JG, eds. Geology and resource potential of the continental margin of western North America and adjacent ocean basins-Beaufort sea to Baja California. Houston, Circum-Pacific Council for Energy and Mineral Resources: 305-335

Stanford, J. D., Hemingway, R., Rohling, E. J., Challenor, P. G., Medina-Elizalde, M., and Lester, A. J., (2011), Sea-level probability for the last deglaciation: A statistical analysis of far-field records: Global and Planetary Change, (79): 193-203.

Suess, E., Torres M., Bohrmann G, Collier RW, Rickert D, Goldfinger C, Linke P, Heuser A, Sahling H, Heeschen K, Jung C, Nakamura K, Greinert J, Pfannkuche O, Trehu A, Klinkhammer G, Whiticar MJ, Eisenhauer A, Teichert B, and Elvert M (2001) Sea Floor methane hydrates at Hydrate Ridge, Cascadia Margin. American Geophysical Union Monograph 124: 87-98.

Thieler ER, Schwab WC, Allison MA, Denny JF, and Danforth WW (1998) Sidescan-Sonar Imagery of the Shoreface and Inner Continental Shelf, Wrightsville Beach, North Carolina. US Geological Survey Open-file Report OF: 98-616

Tissot BN, Yoklavich MM, Love MS, York K, Amend M (2006) Benthic invertebrates that form habitat on deep banks off southern California, with special reference to deep sea coral. Fisheries Bulletin 104: 167–181.

Tréhu AM, Asudah I, Brocher TM, Luetgert JH, Mooney WD, Nabelek JL, Nakamura Y (1994) Crustal architecture of the Cascadia forearc. Science 266: 237-243

Tréhu A, Lin G, Maxwell E, and Goldfinger C (1995) A seismic reflection profile across the Cascadia subduction zone offshore central Oregon: New constraints on methane distribution and crustal structure. Journal of Geophysical Research 100(B8): 15,101-115, 116

Uusitalo L (2007) Advantages and challenges of Bayesian networks in environmental modelling. Ecological Modelling 203(3-4): 312-318 doi:101016/jecolmodel200611033

Weiss AD (2001) Topographic Positions and Landforms Analysis (Conference Poster) Proceedings of the 21st Annual ESRI User Conference, San Diego, CA, July 9-13

Wells RE (1990) Paleomagnetic rotations and regional tectonics of the Cascade arc, Washington, Oregon, and California. Journal of Geophysical Research 95: 19,409-19,418

Wells, RE, Heller PL (1988) The relative contribution of accretion, shear, and extension to Cenozoic tectonic rotation in the Pacific Northwest. Geol. Soc. Am. Bull. 100: 325-338

Wentworth, C.K. (1922) A scale of grade and class terms for clastic sediments J. Geology 30: 377-392

Wheatcroft, RA, MA Goñi, KN Richardson & JC Borgeld (2013) Natural and human impacts on centennial sediment accumulation patterns on the Umpqua River margin, Oregon. *Marine Geology* 339: 44-56.

Wolf SC, Nelson CH, Hamer MR, Dunhill G, Phillips, RL (1999) The Washington and Oregon Mid-Shelf Silt Deposit and Its Relation to the Late Holocene Columbia River Sediment Budget. USGS Open File Report 99-173

Wright DJ, Lundblad ER, Larkin EM, Rinehart RW, Murphy J, Cary-Kothera L, and Draganov K (2005) ArcGIS Benthic Terrain Modeler Corvallis, Oregon, Oregon State University, Davey Jones Locker Seafloor Mapping/Marine GIS Laboratory and NOAA Coastal Services Center Accessible online at: http://mapscscnoaagov/digitalcoast/tools/btm

Yeats RS (1986) Active faults related to folding, *in* Wallace RE, ed. Active Tectonics. Washington, DC, National Academy Press: 63-79

Yeats RS, Kulm LD, Goldfinger C, and McNeill LC (1998) Stonewall anticline: An active fold on the Oregon continental shelf. Bulletin of the Geological Society of America 110: 572-587

Appendix 1. Local-Scale Seabed Habitat Data and Maps

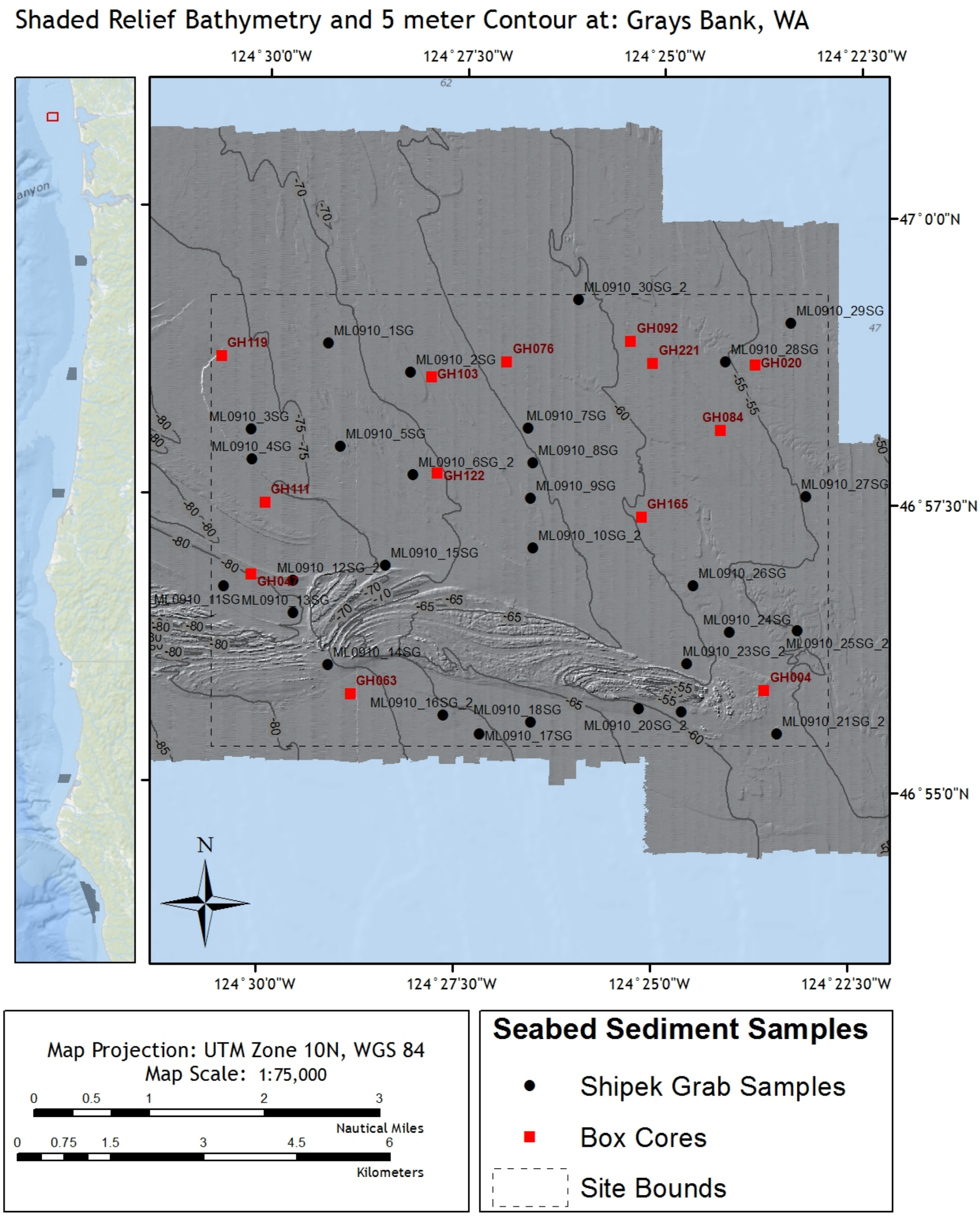


Figure 58. Shaded-relief multibeam bathymetry data collected at Grays Bank, WA
Sediment sample are plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

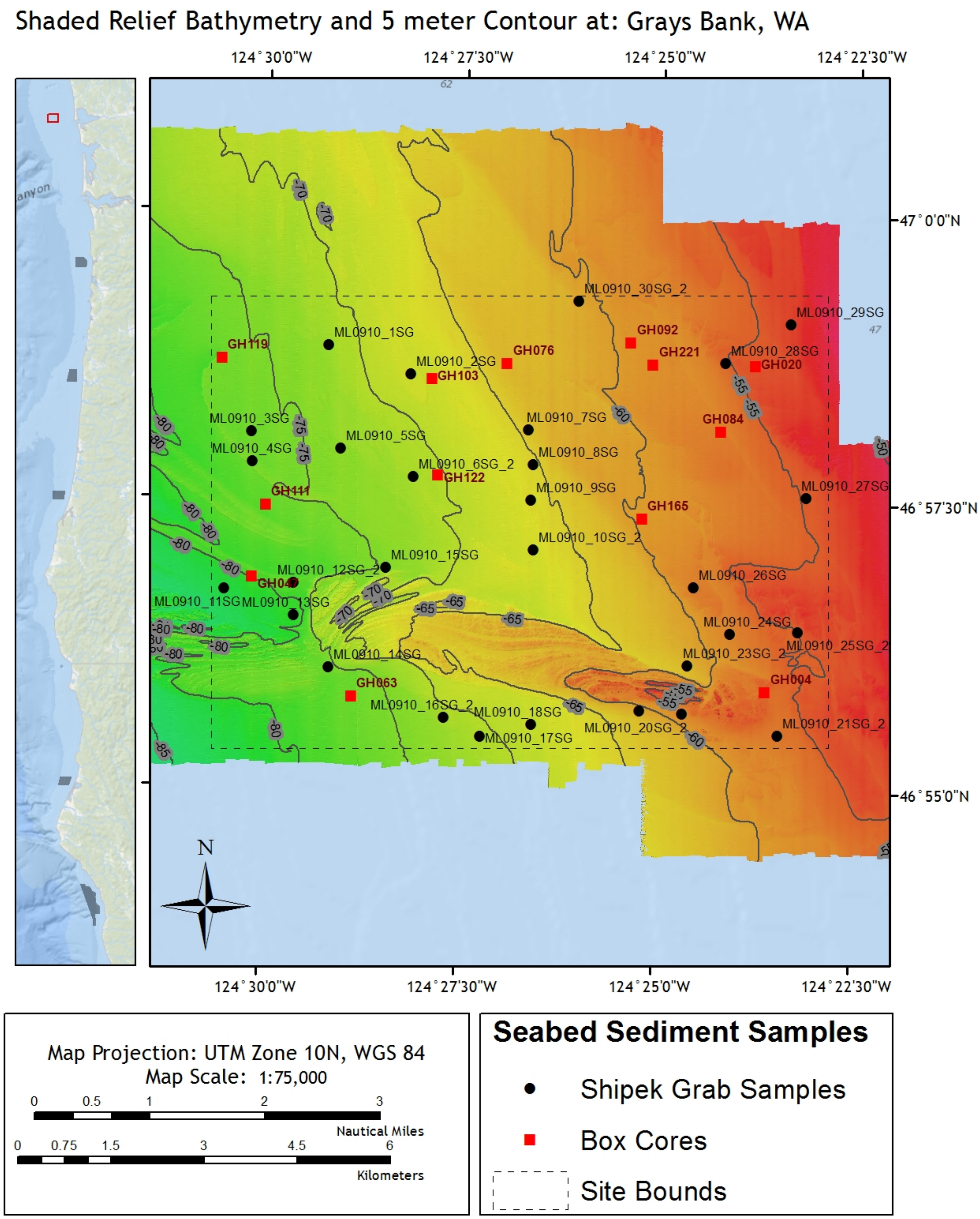


Figure 59. Color shaded-relief multibeam bathymetry data collected at Grays Bank, WA
Sediment sample are plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

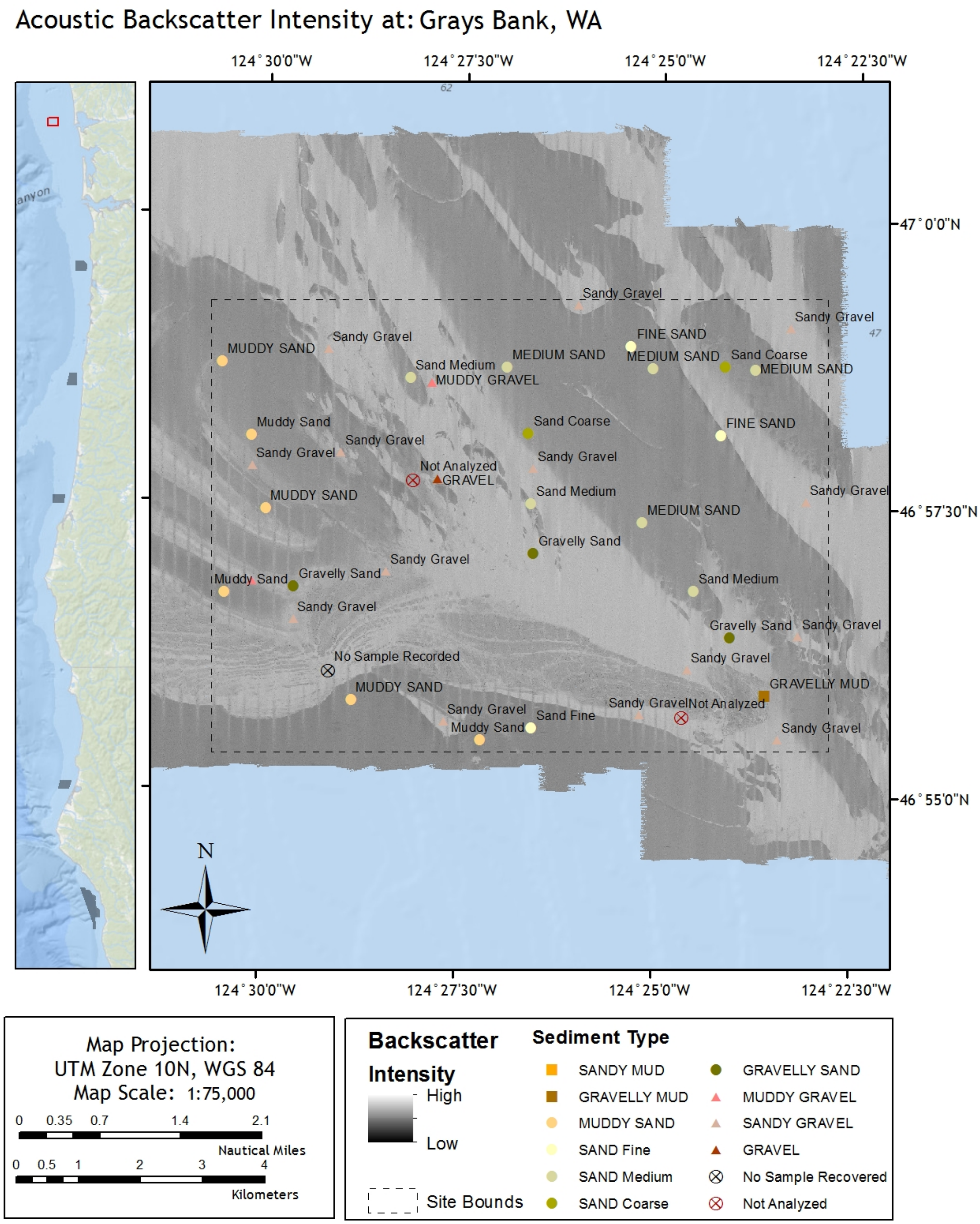


Figure 60. Multibeam backscatter data collected at Grays Bank, WA
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) backscatter data.

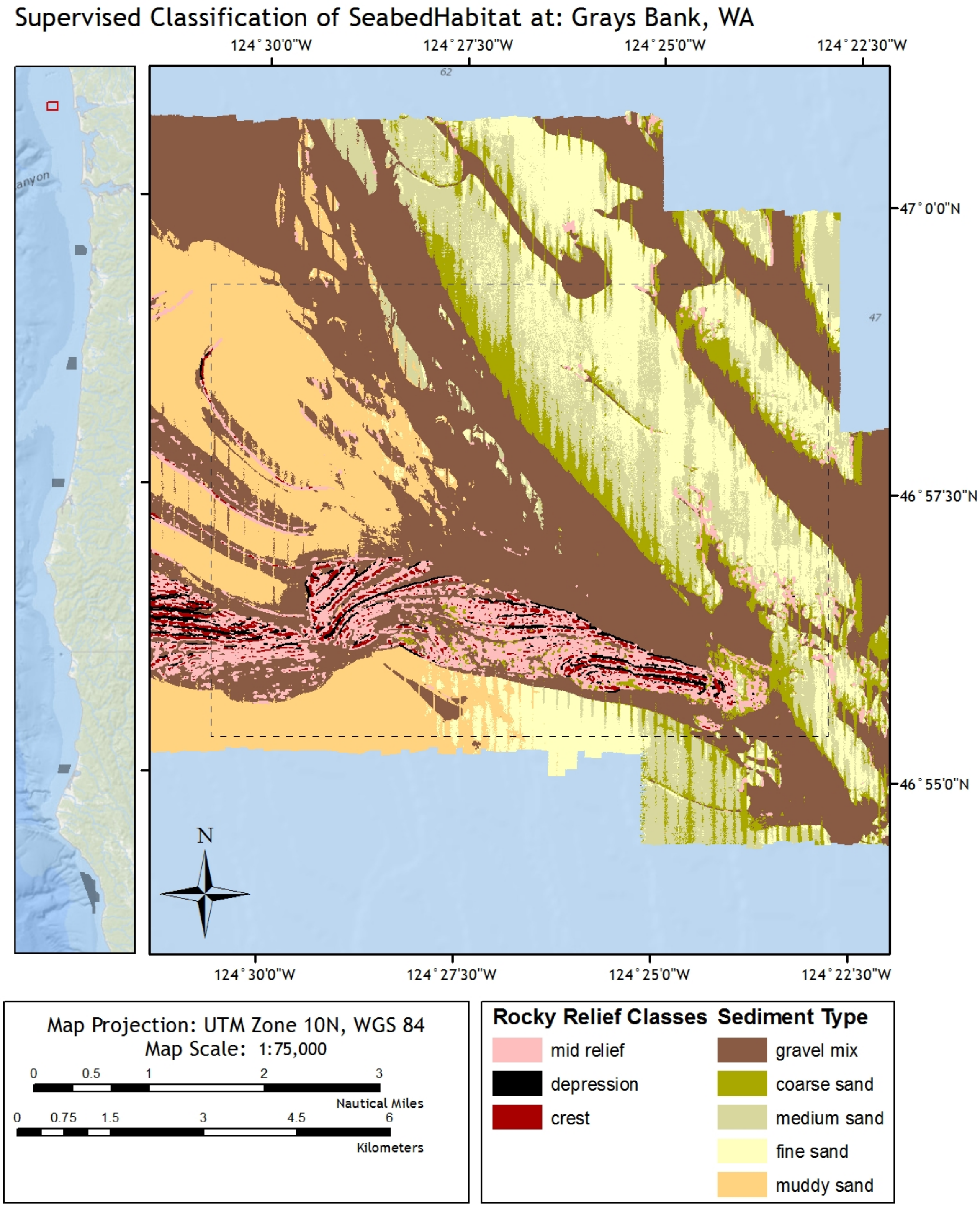


Figure 61. Seabed substrates at Grays Bank, WA
Rocky relief classes are predicted by an analysis of topographic (here, bathymetric) vector ruggedness and topographic position.

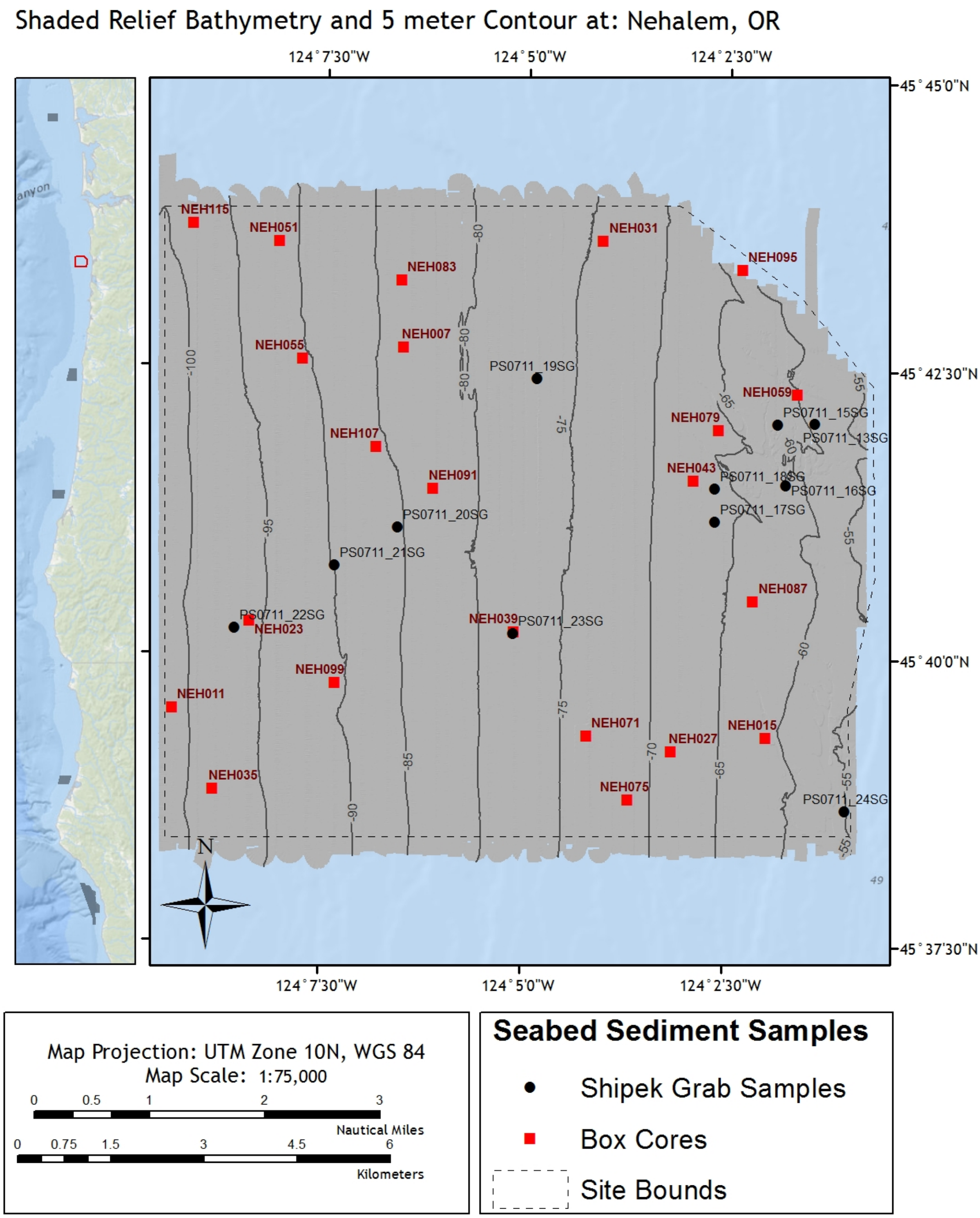


Figure 62. Shaded-relief multibeam bathymetry data collected at Nehalem, OR
Sediment sample are plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

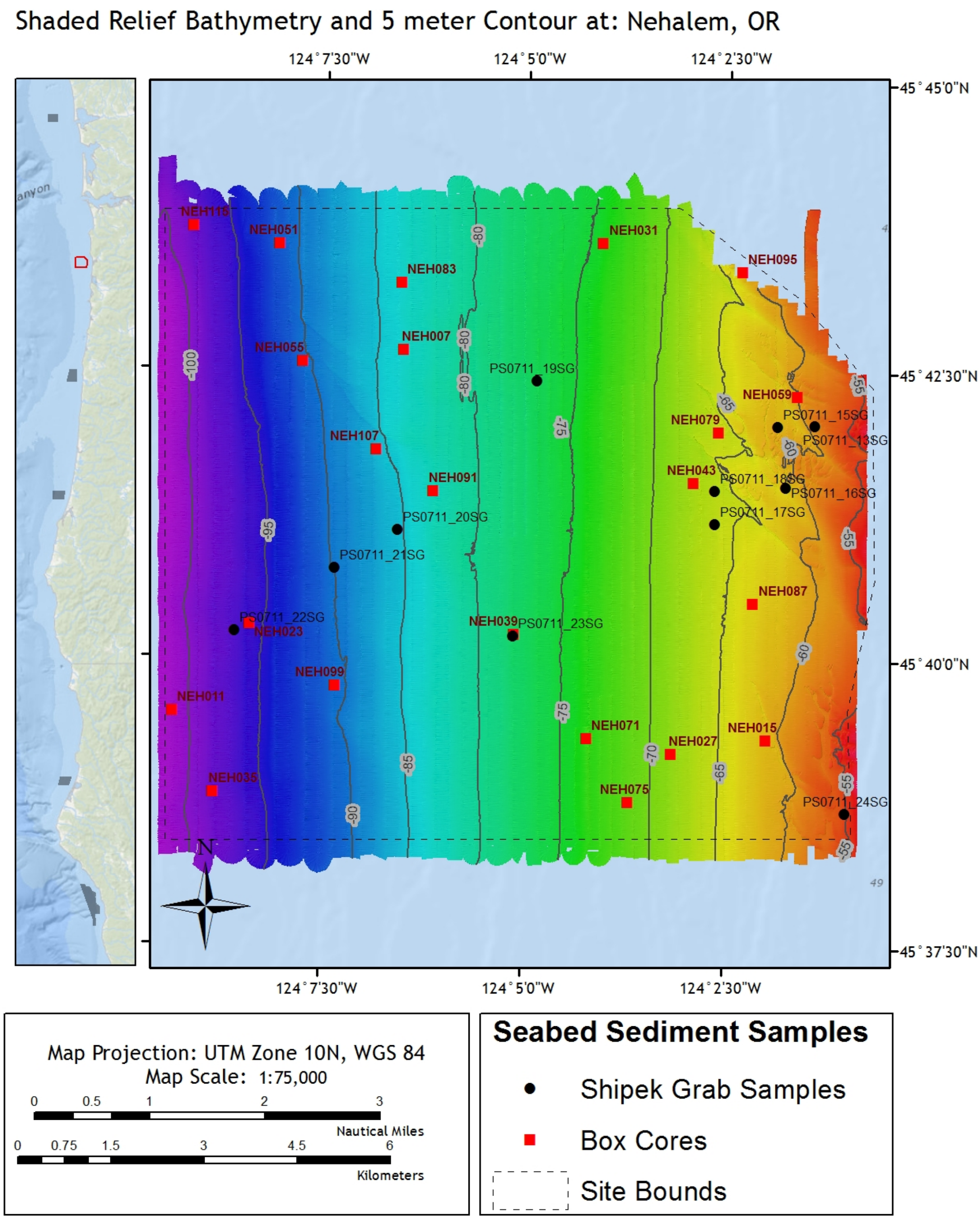


Figure 63. Color shaded-relief multibeam bathymetry data collected at Nehalem, OR
Sediment sample are plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

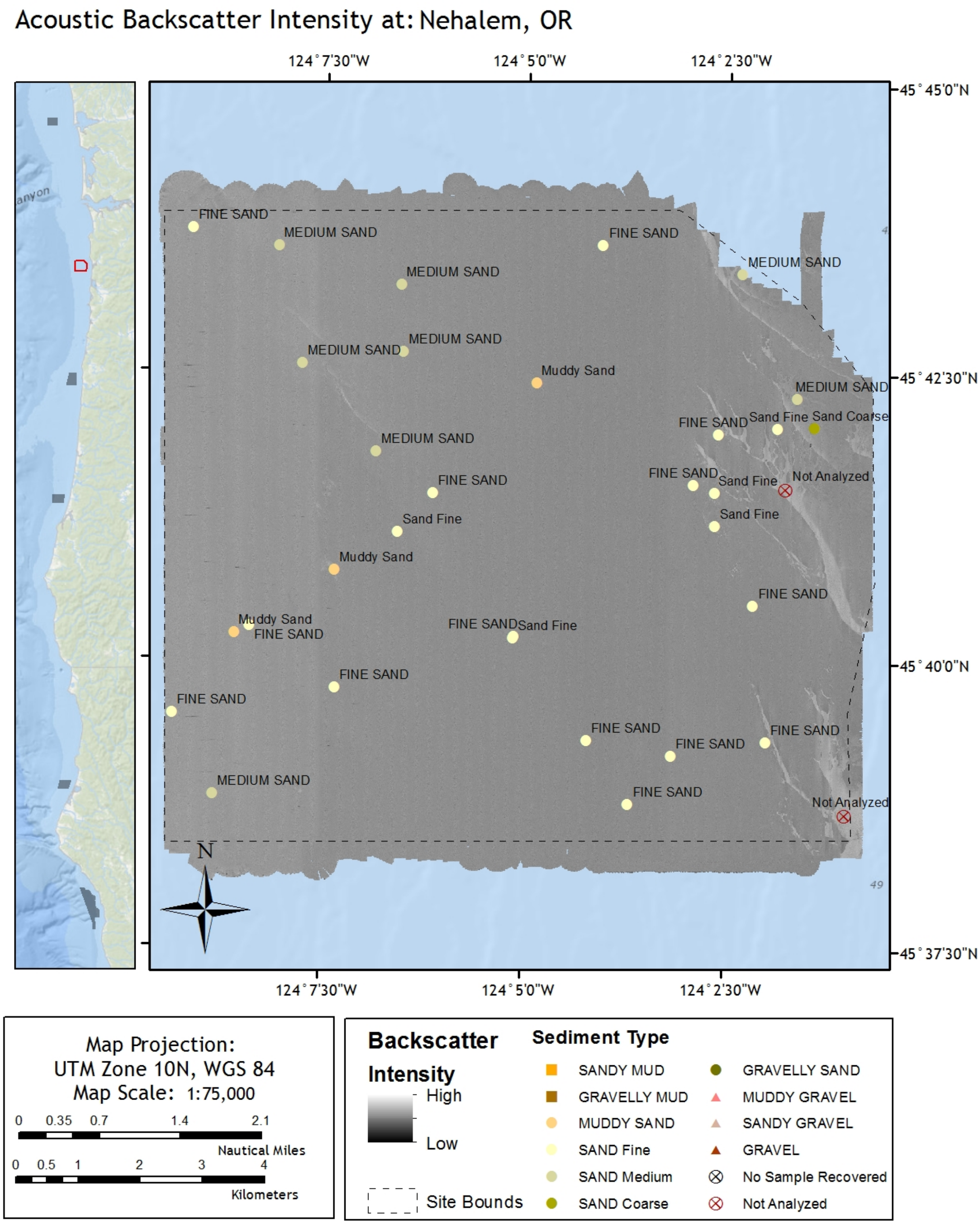


Figure 64. Multibeam backscatter data collected at Nehalem, OR
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam backscatter data.

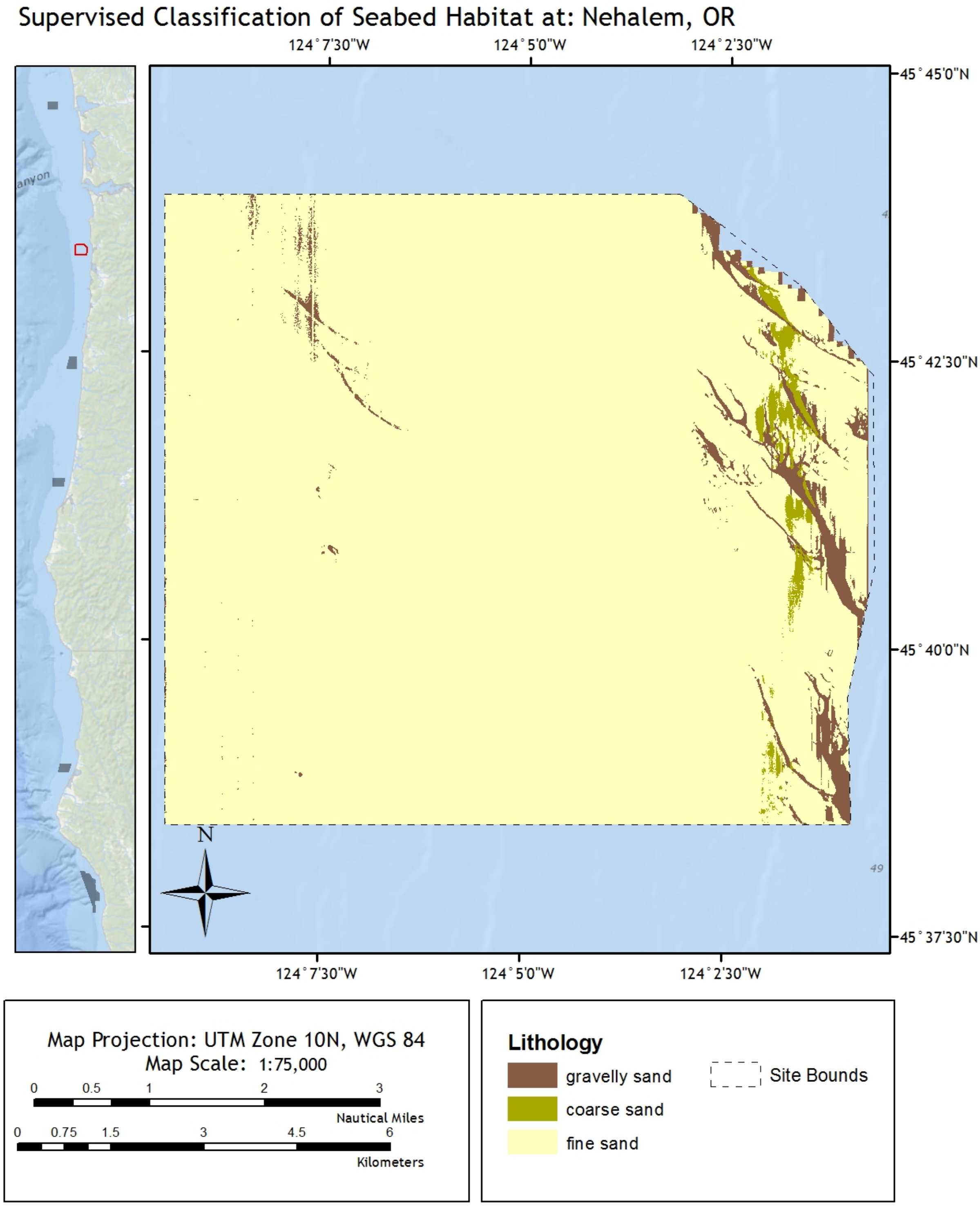


Figure 65. Seabed substrates at Nehalem, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

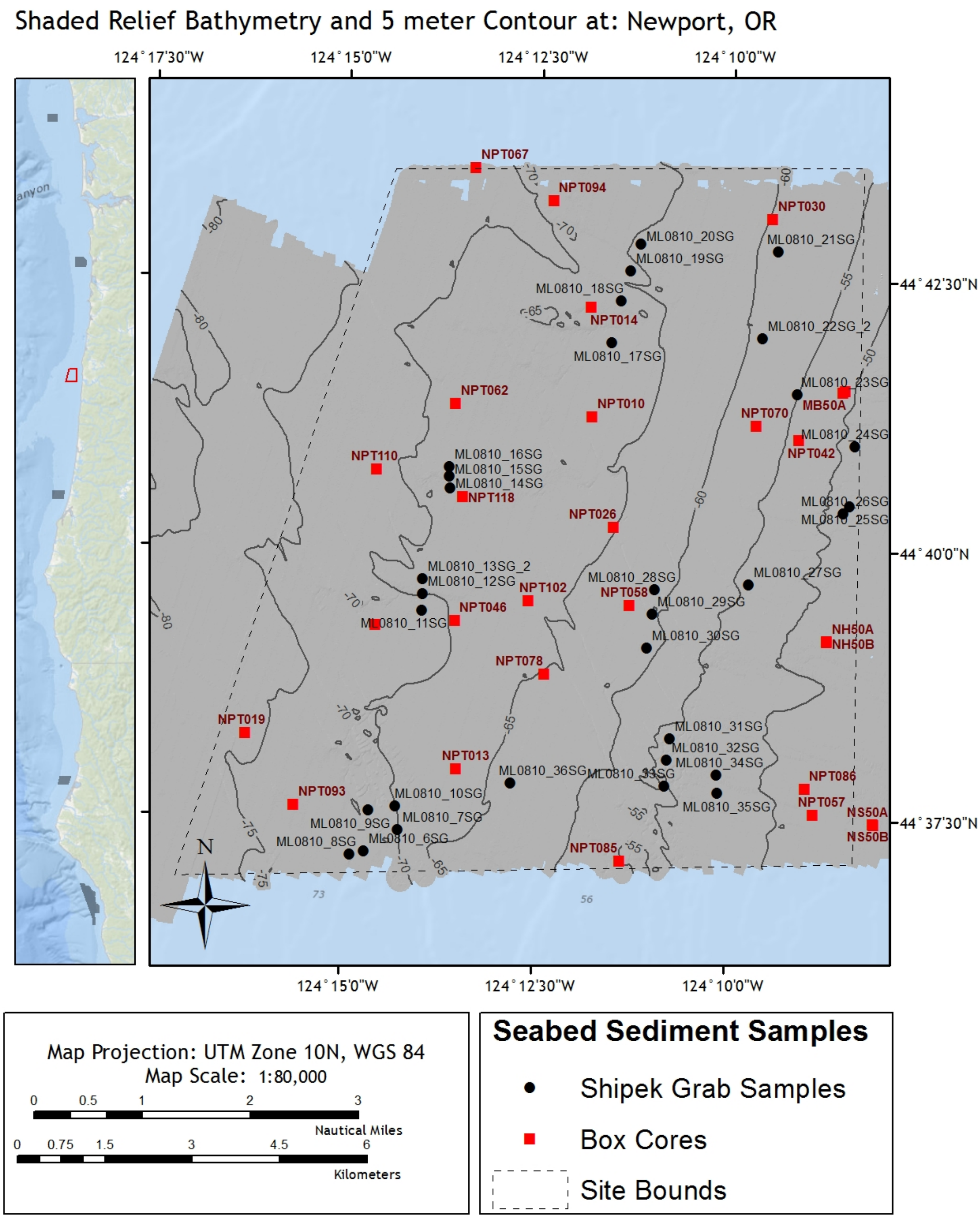


Figure 66. Shaded-relief multibeam bathymetry data collected at Newport, OR
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

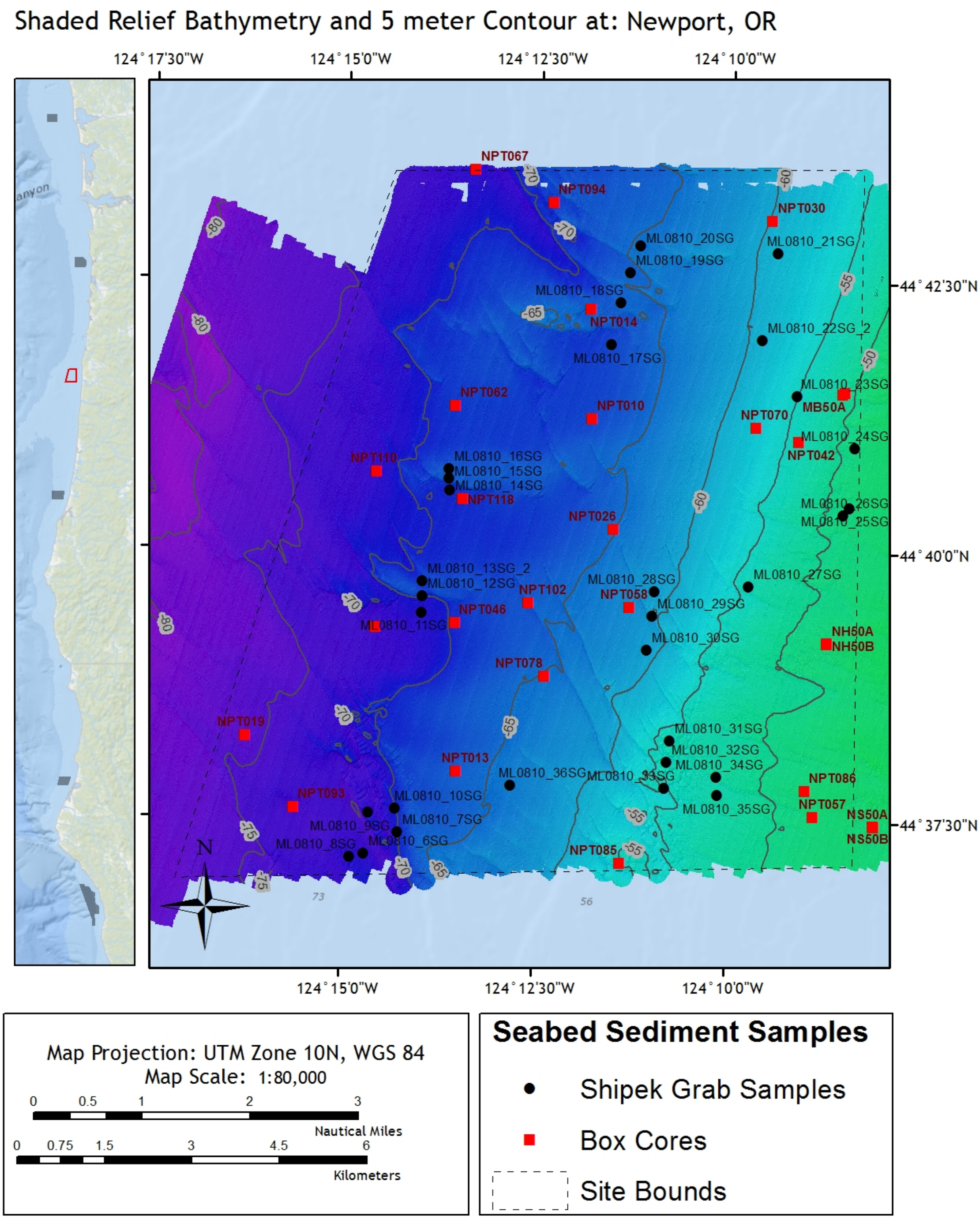


Figure 67. Color shaded-relief multibeam bathymetry data collected at Newport, OR
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

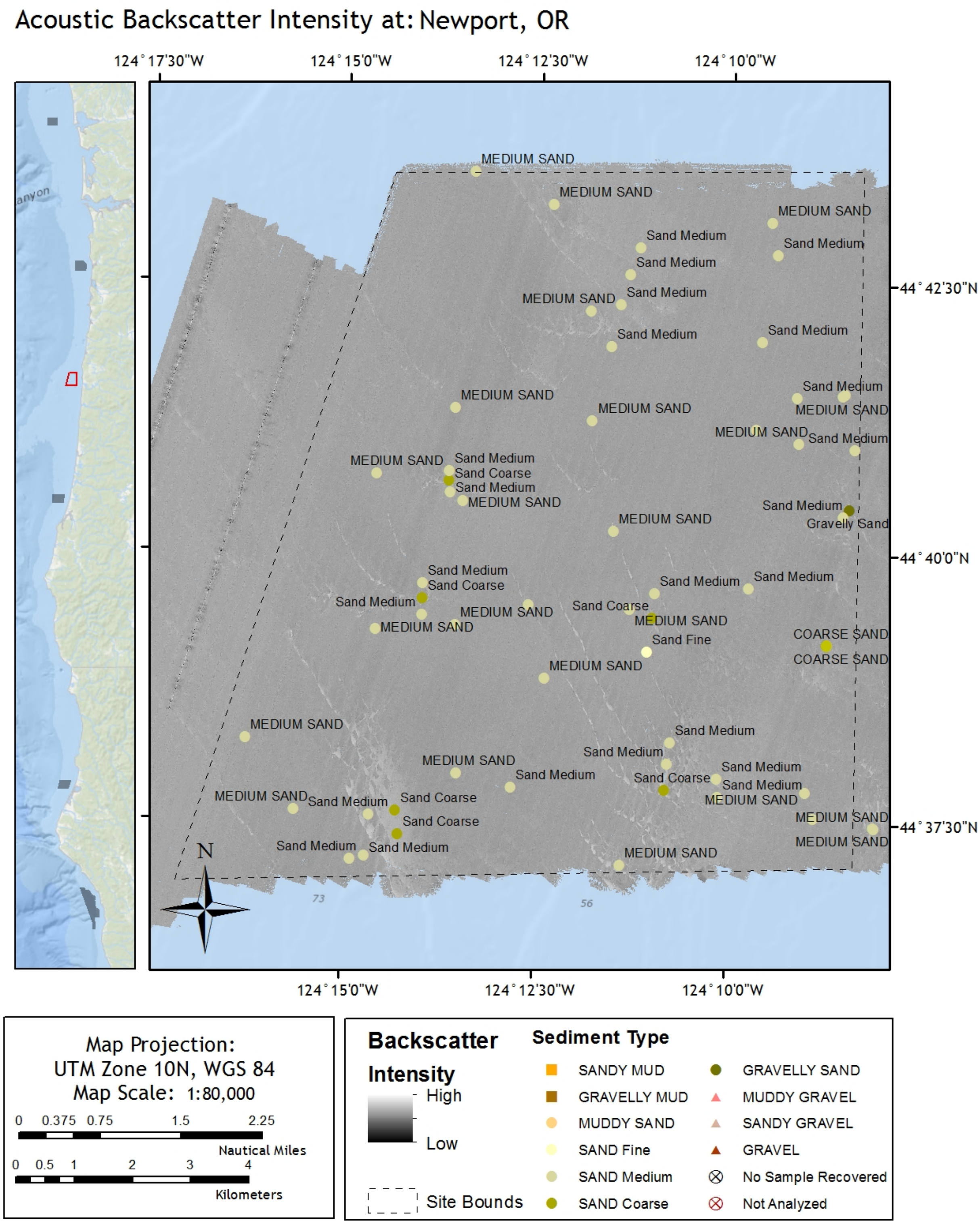


Figure 68. Multibeam backscatter data collected at Newport, OR
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam backscatter) data.

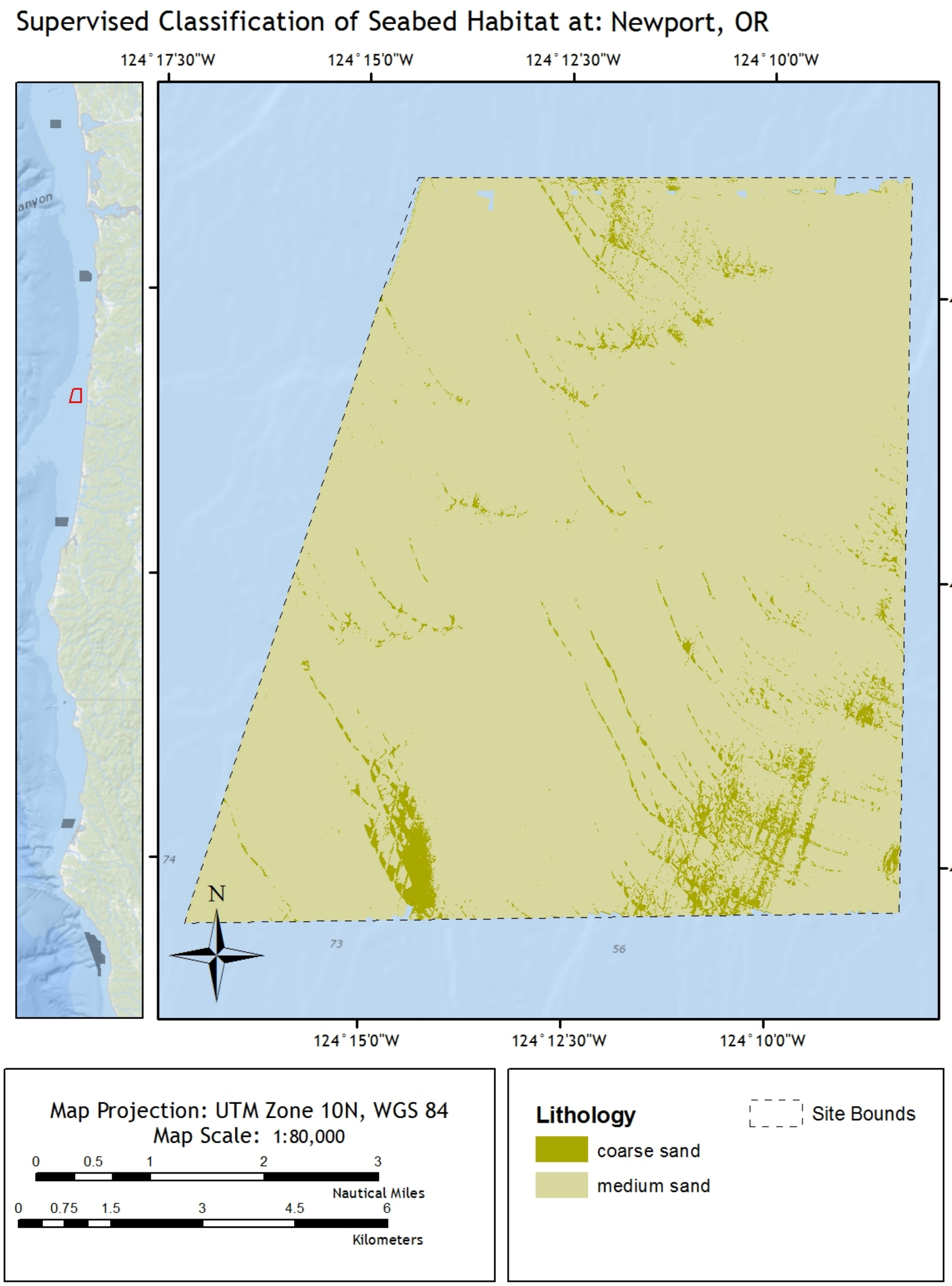


Figure 69. Seabed substrates at Newport, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

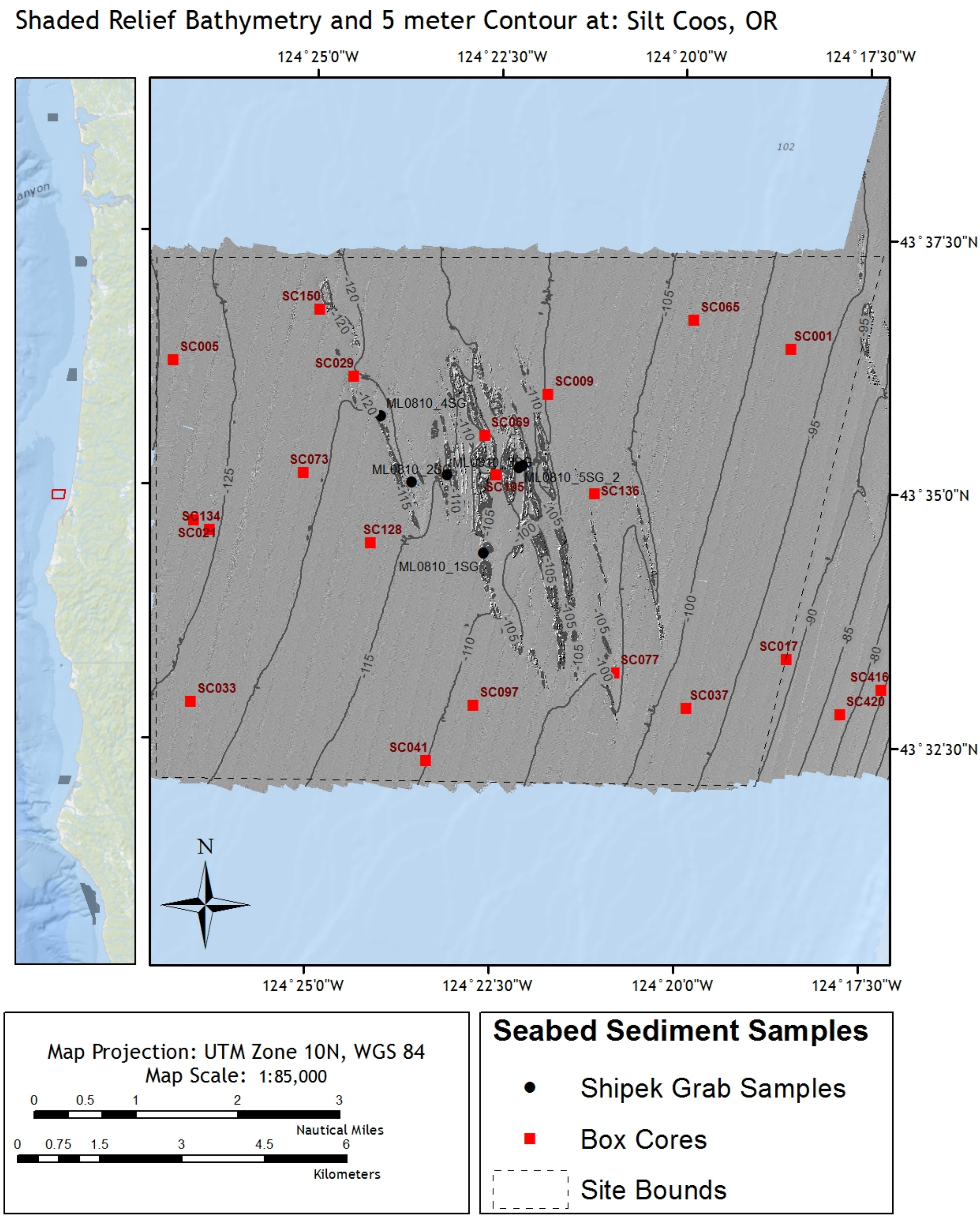


Figure 70. Shaded-relief multibeam bathymetry data collected at Siltcoos, OR
Sediment sample are plotted over the Reson 8101 (240 kHz) multibeam data.

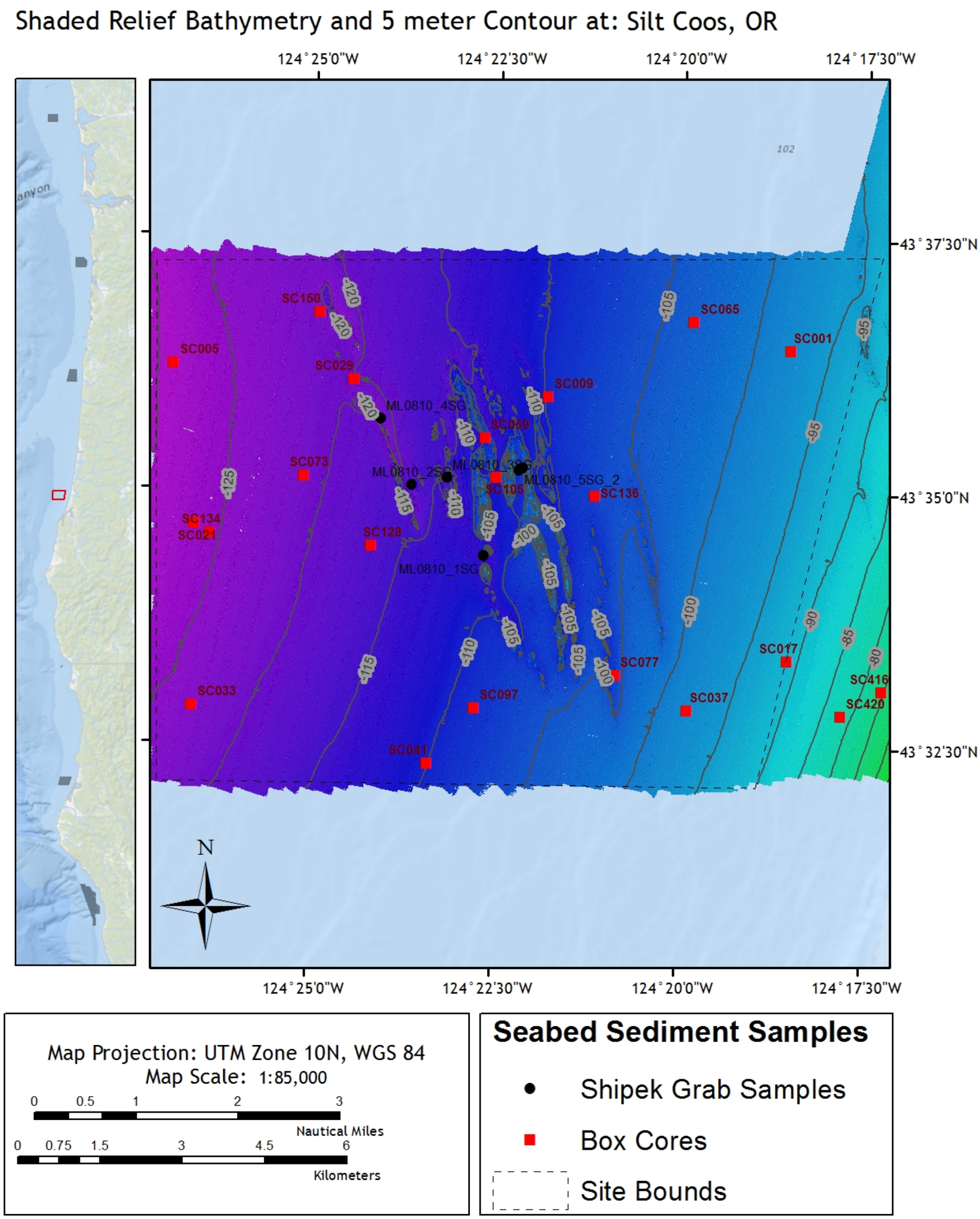


Figure 71. Color shaded-relief multibeam bathymetry data collected at Siltcoos, OR
Sediment sample are plotted over the Reson 8101 (240 kHz) multibeam data.

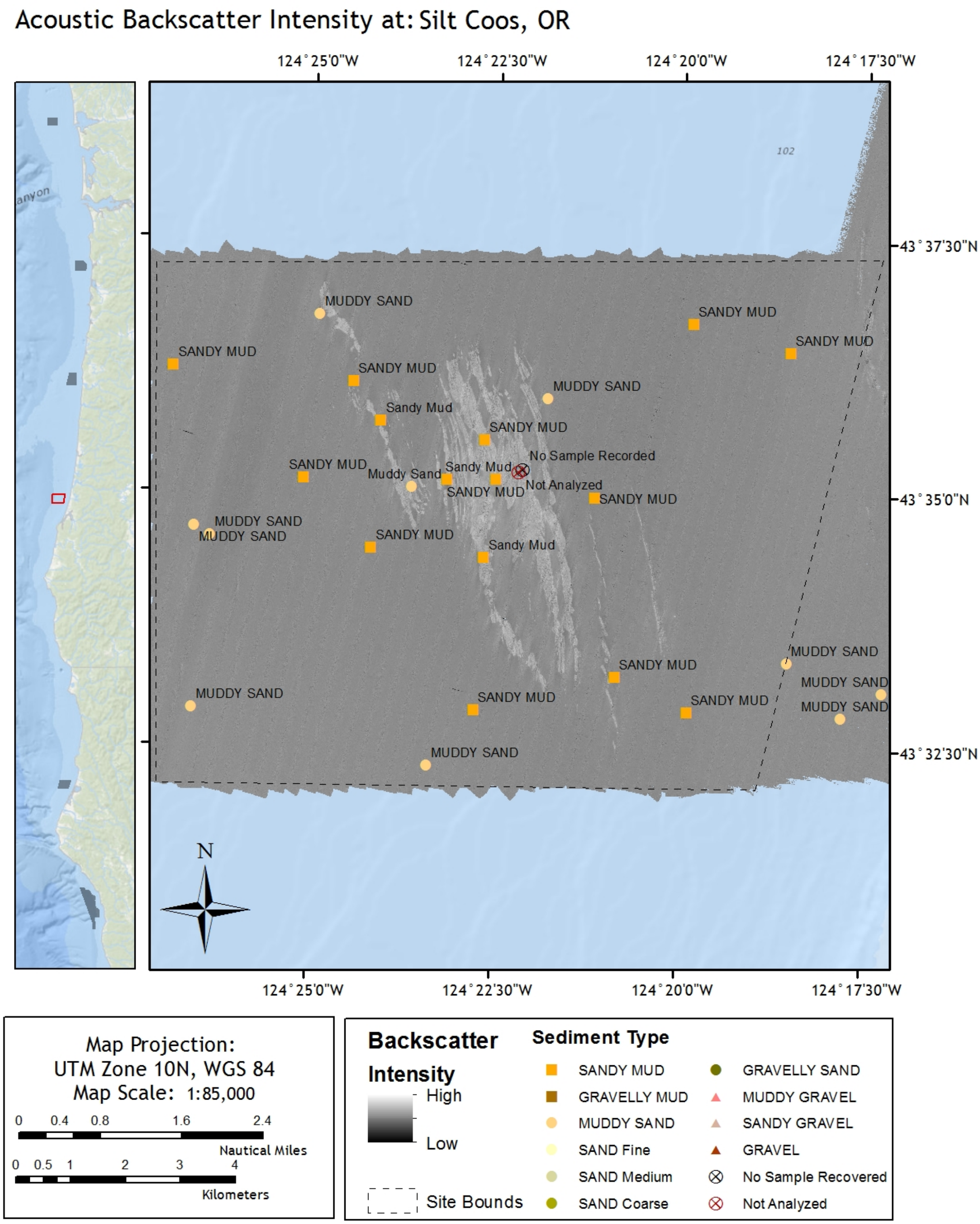


Figure 72. Multibeam backscatter data collected at Siltcoos, OR
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam backscatter data.

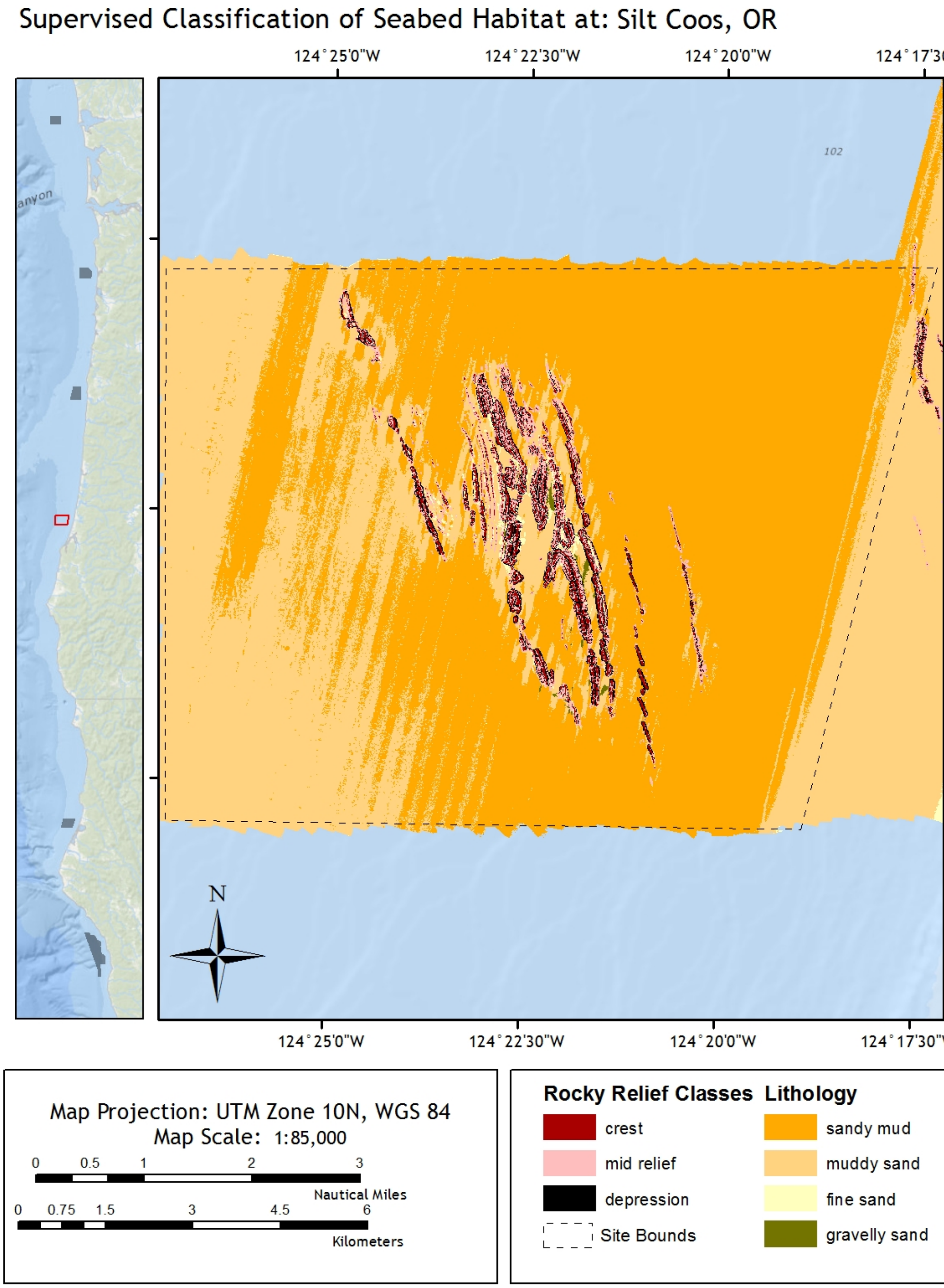


Figure 73. Seabed substrates at Siltcoos, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

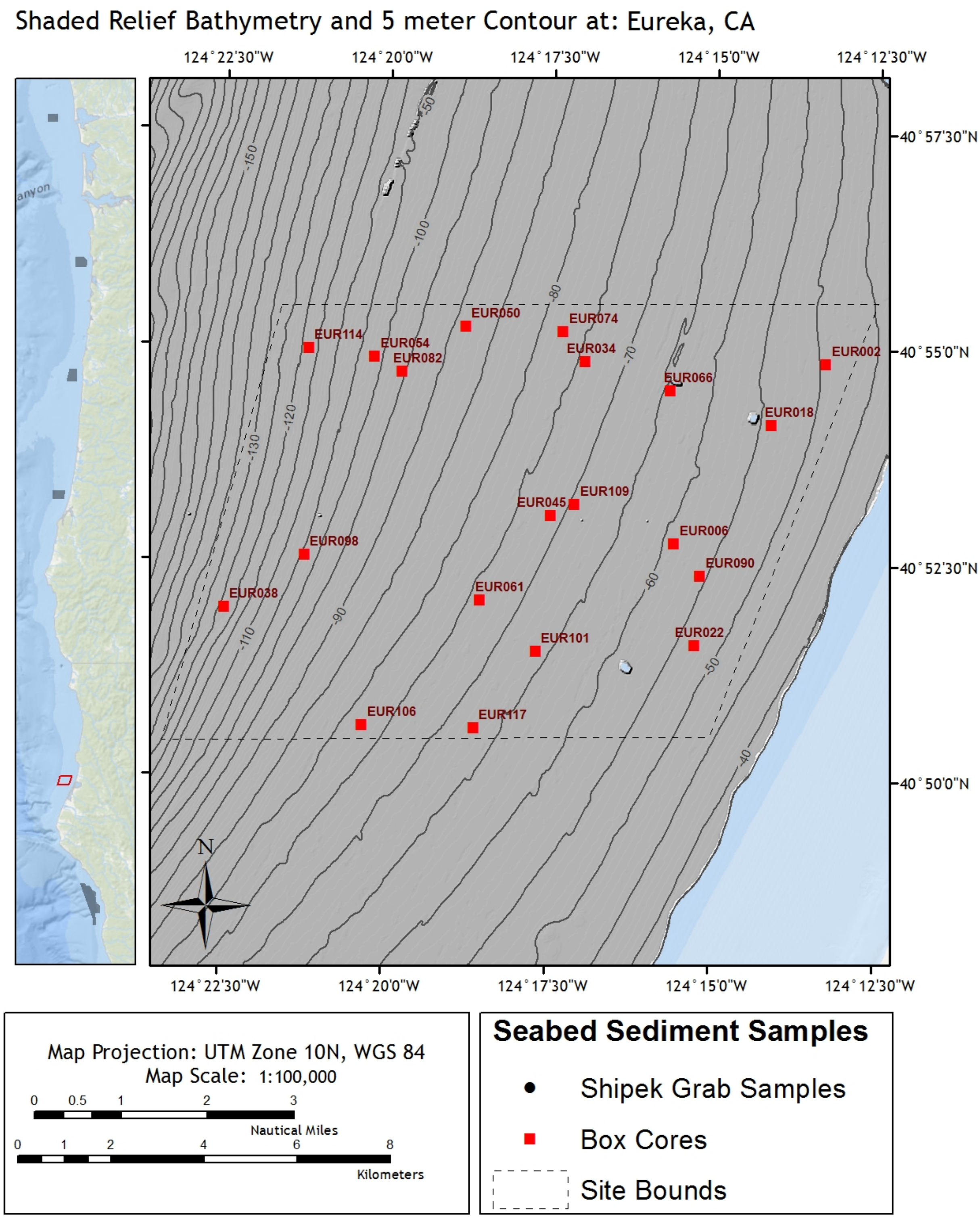


Figure 74. Multibeam bathymetry data at Eureka, CA
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

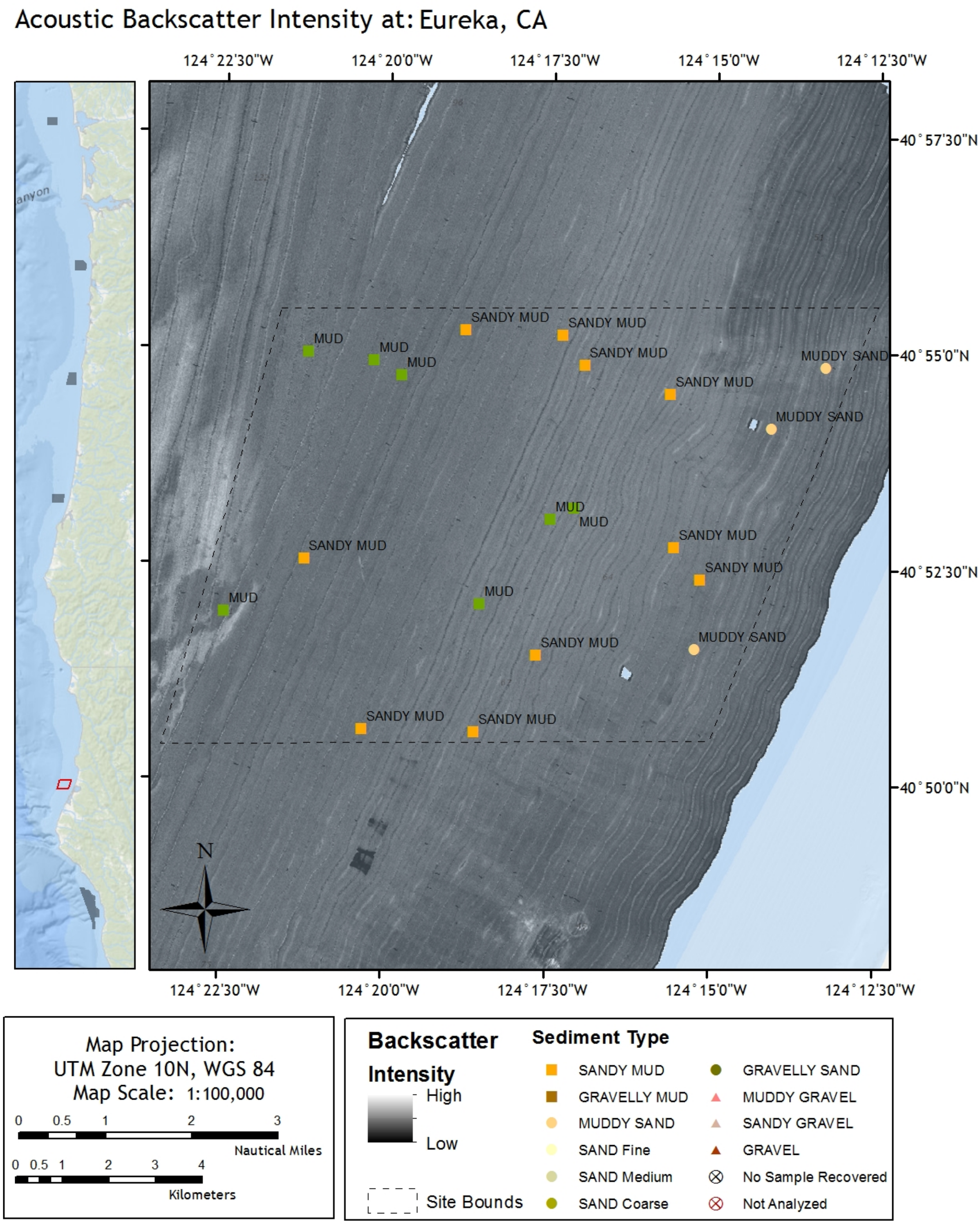


Figure 75. Multibeam backscatter data at Eureka, CA
Sediment textural classifications plotted over the Kongsberg EM3000 (300 kHz) multibeam backscatter data.

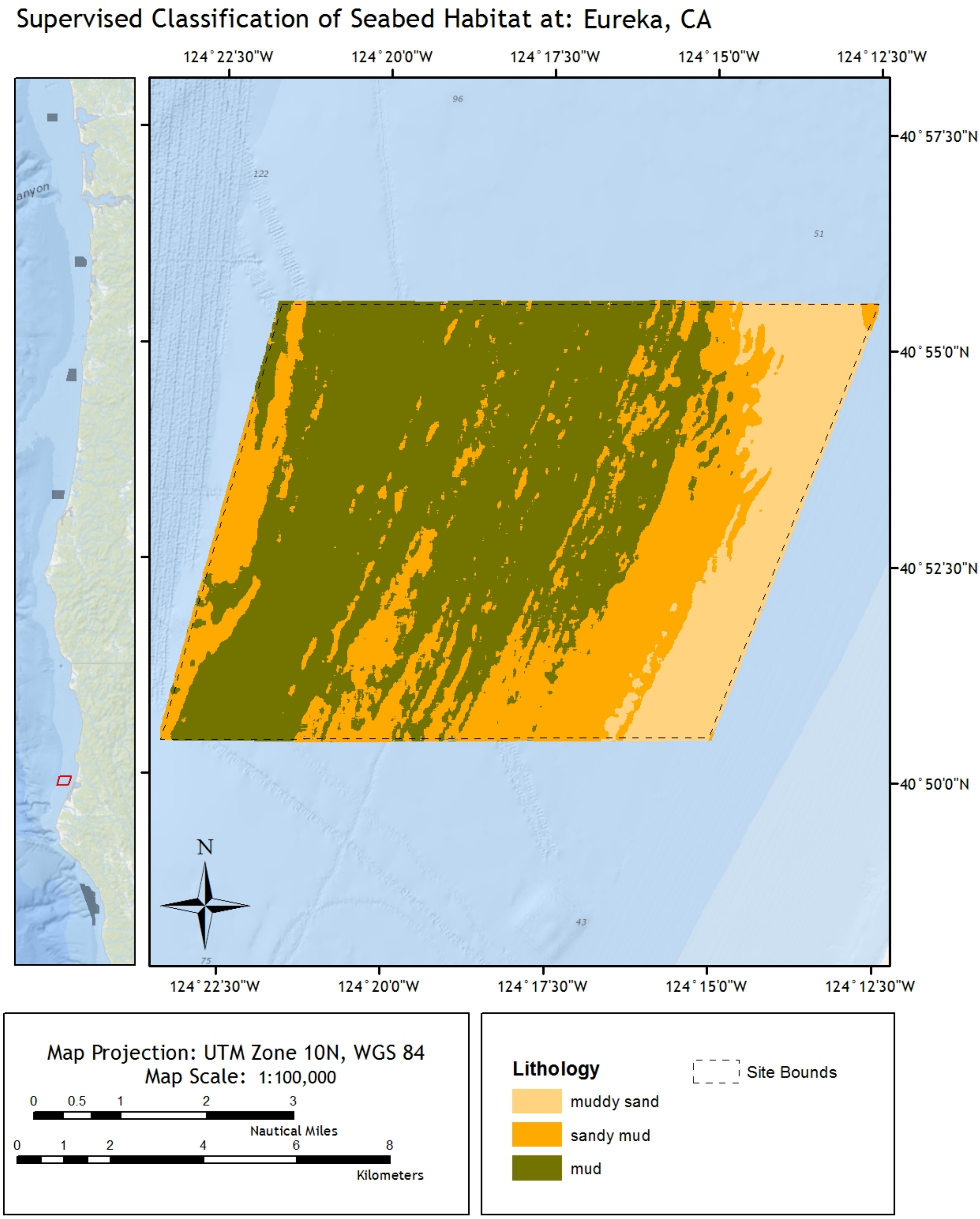


Figure 76. Seabed substrates at Eureka, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

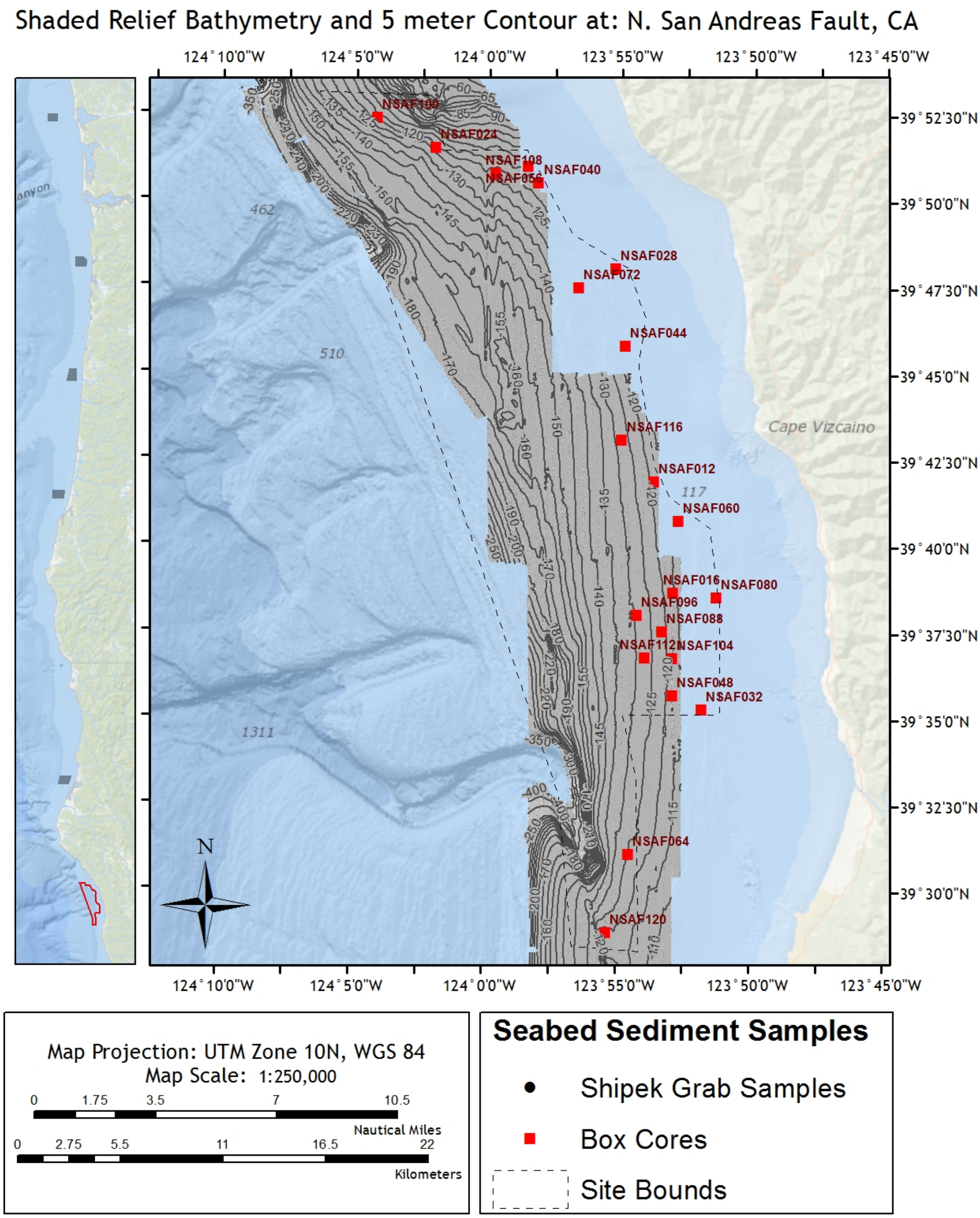


Figure 77. Multibeam bathymetry data collected at Northern San Andreas Fault (NSAF), CA
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam data.

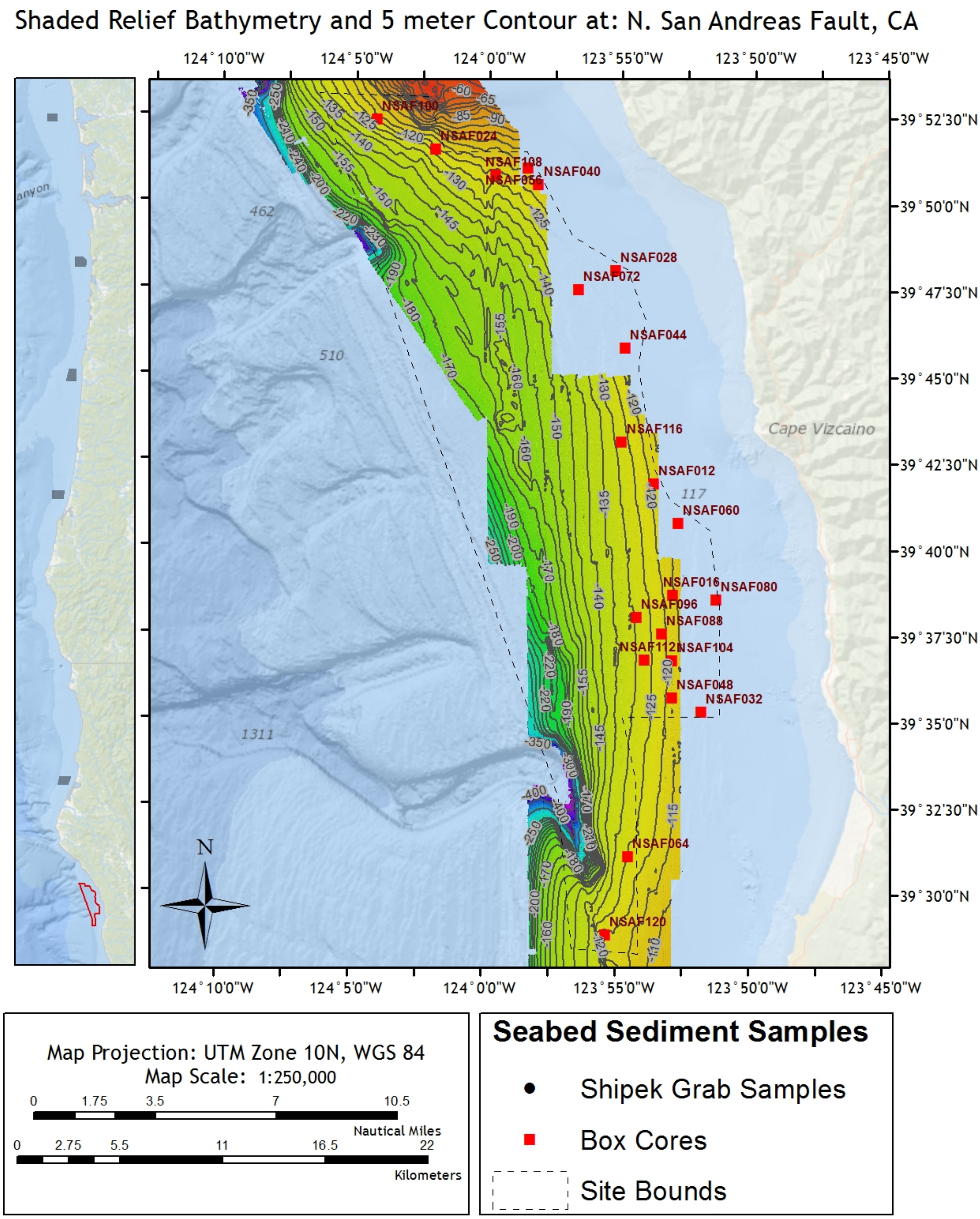


Figure 78. Color shaded-relief multibeam bathymetry data collected at Northern San Andreas Fault (NSAF), CA
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam data.

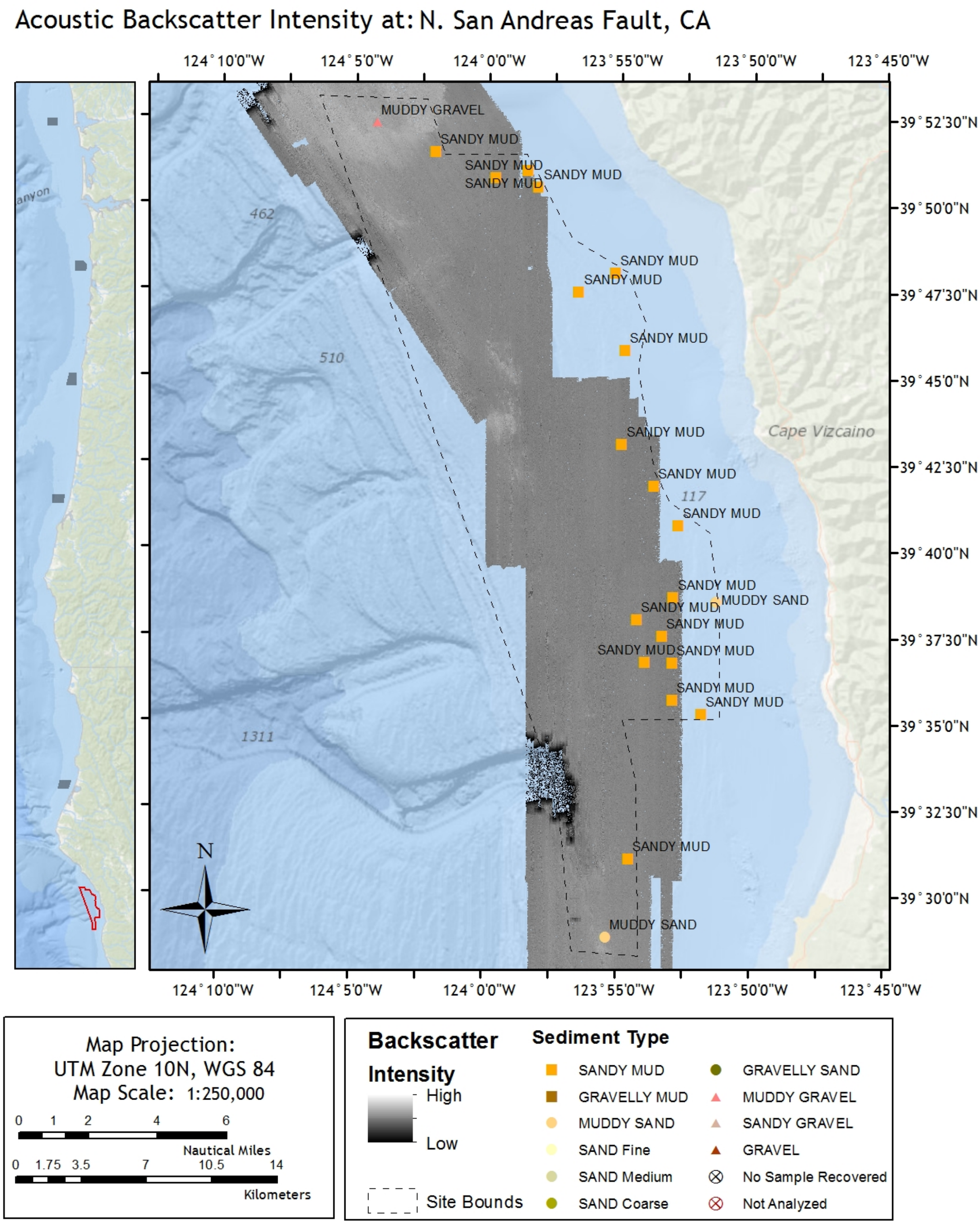


Figure 79. Multibeam backscatter data collected at Northern San Andreas Fault (NSAF), CA
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam data.

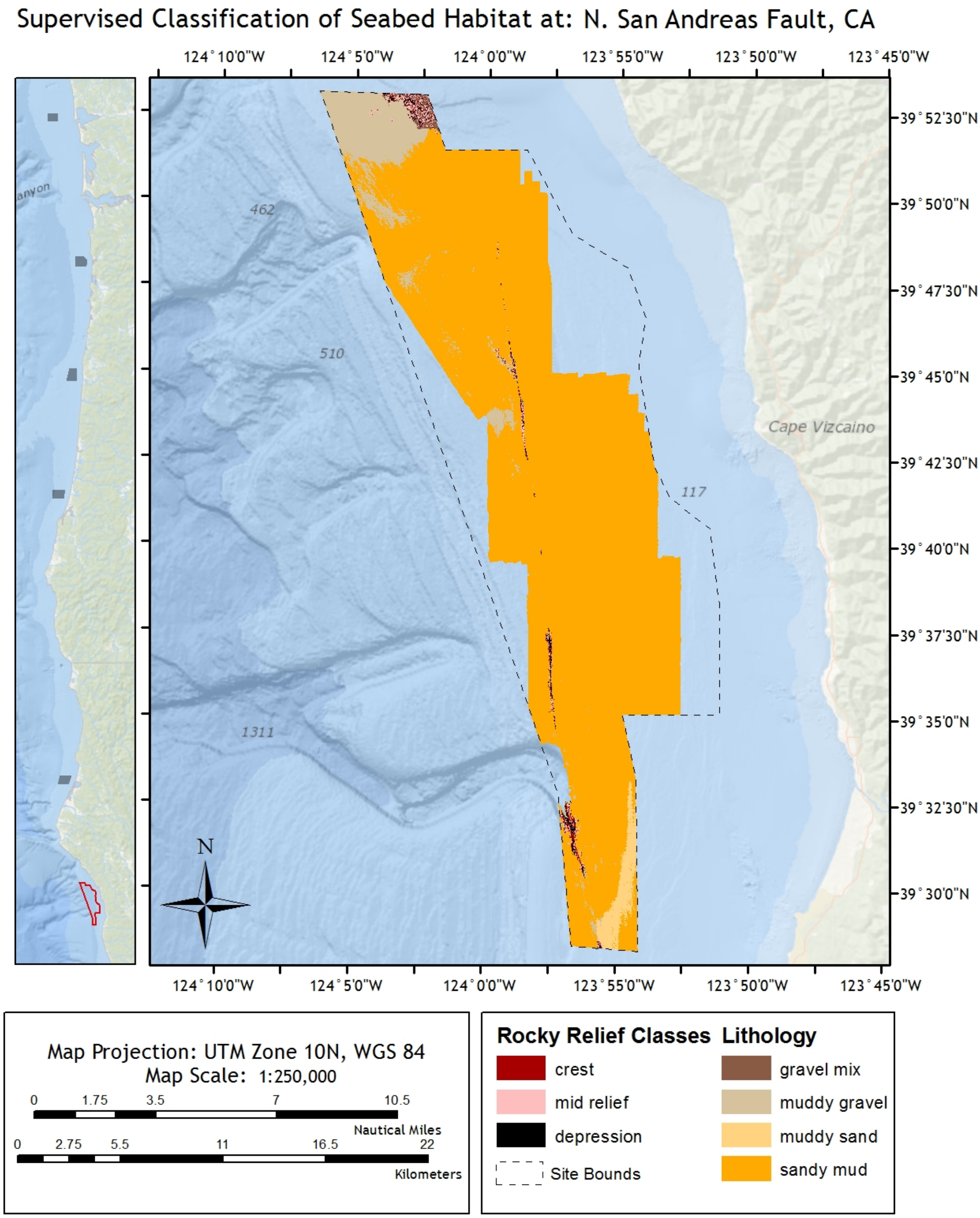


Figure 80. Seabedsubstrates at Northern San Andreas Fault (NSAF), CA
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

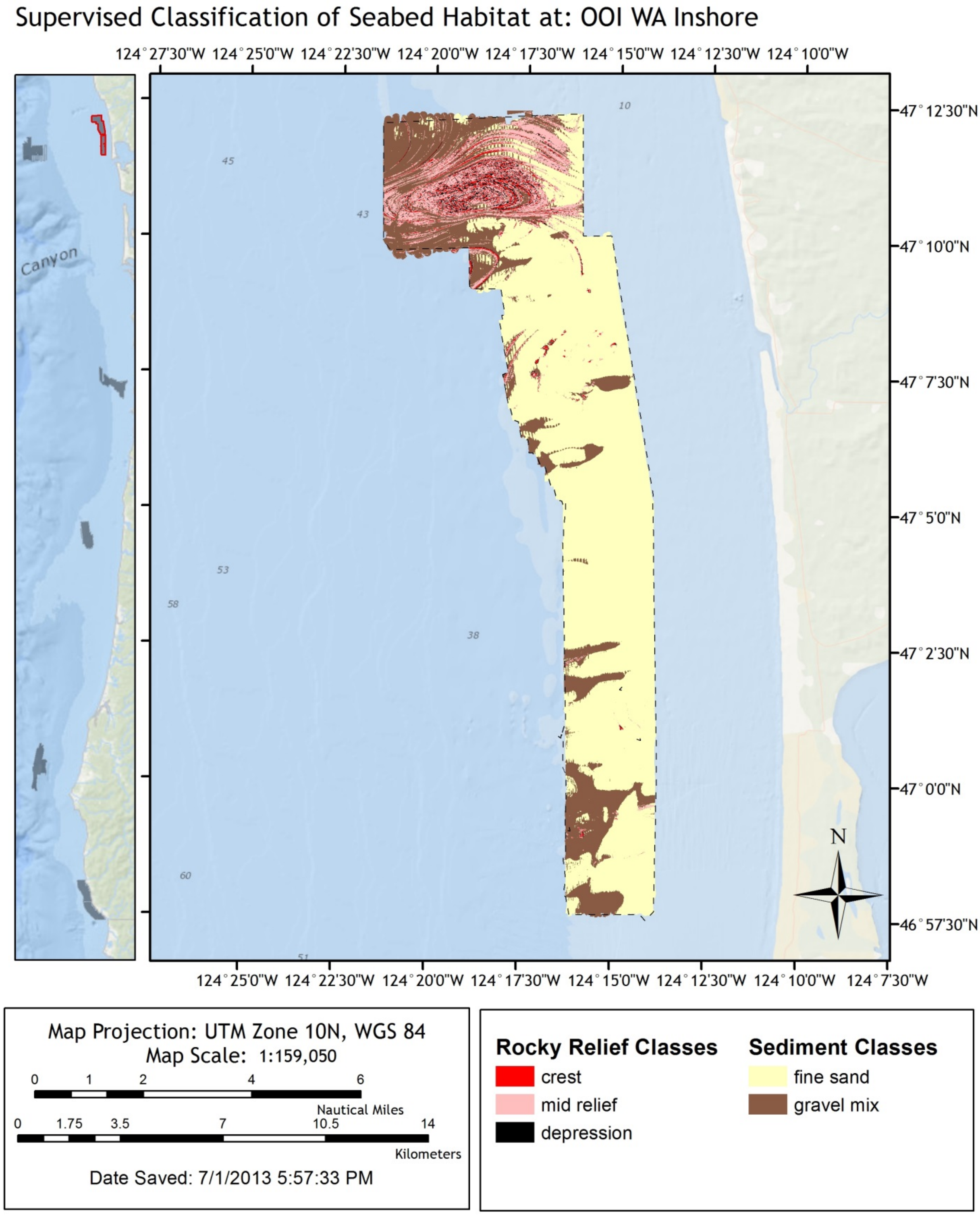


Figure 81. Seabed substrates at OOI Inshore Site, WA
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

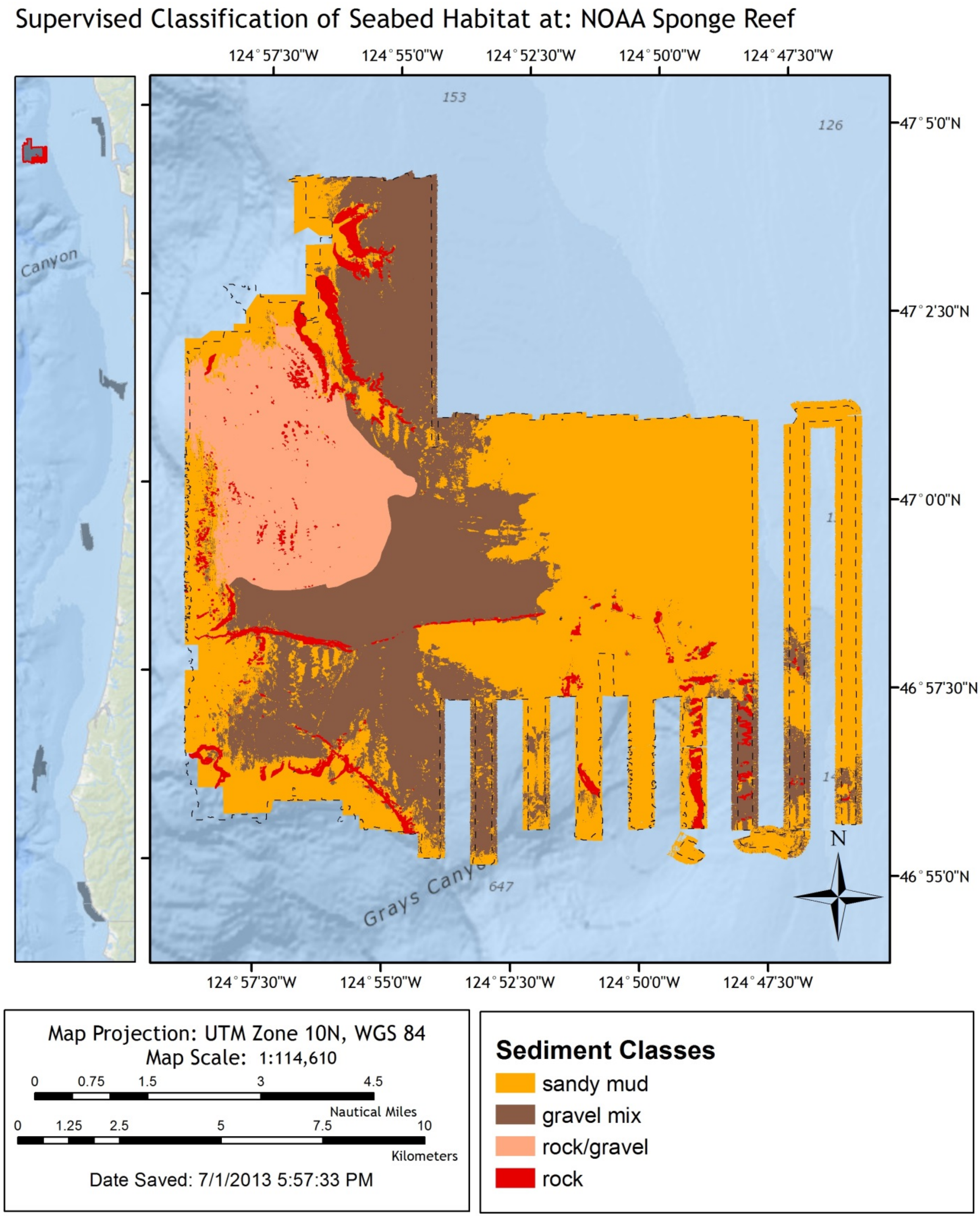


Figure 82. Seabed substrates at Sponge Reef Site, WA
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

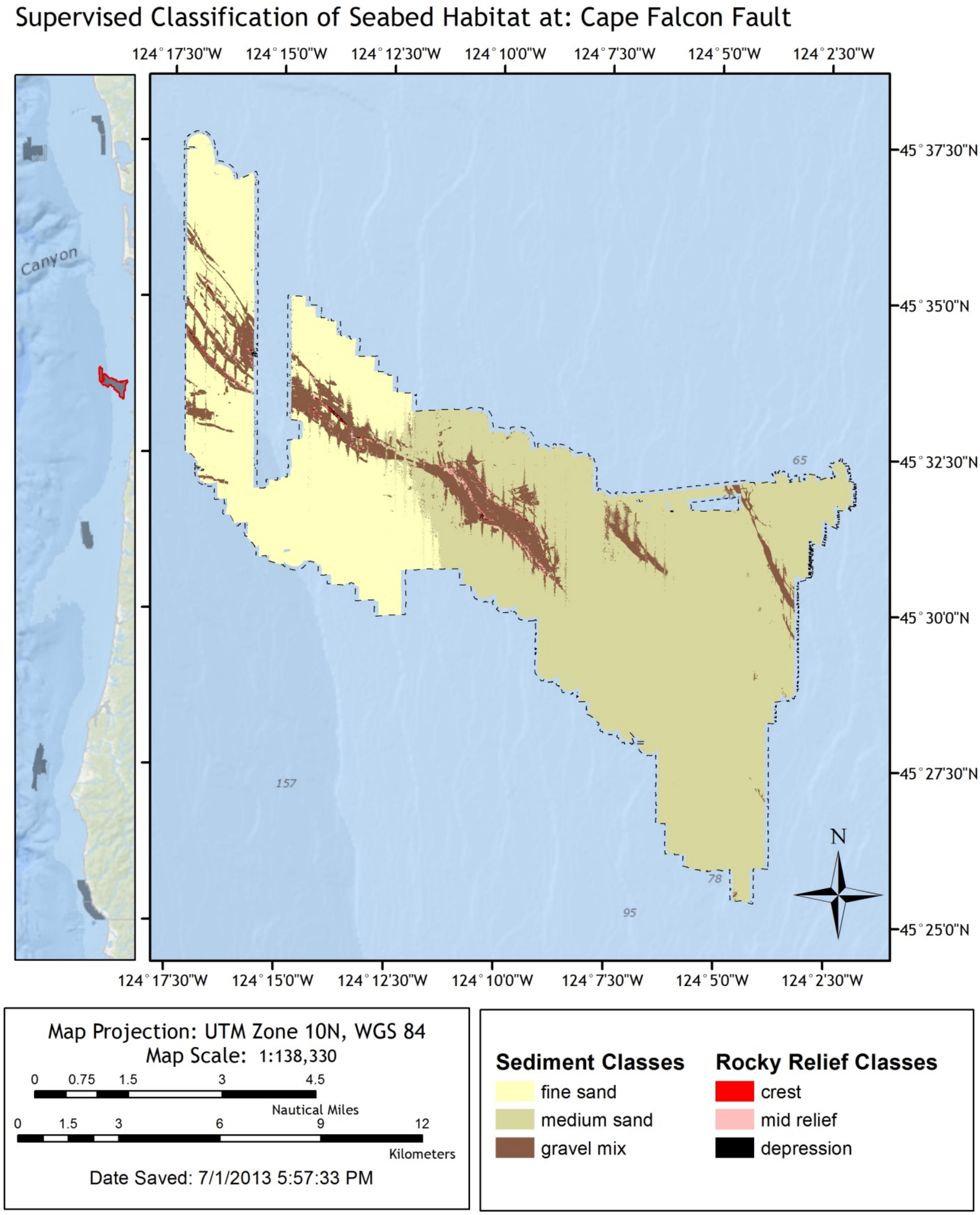


Figure 83. Seabed Substrates at Cape Falcon Fault, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

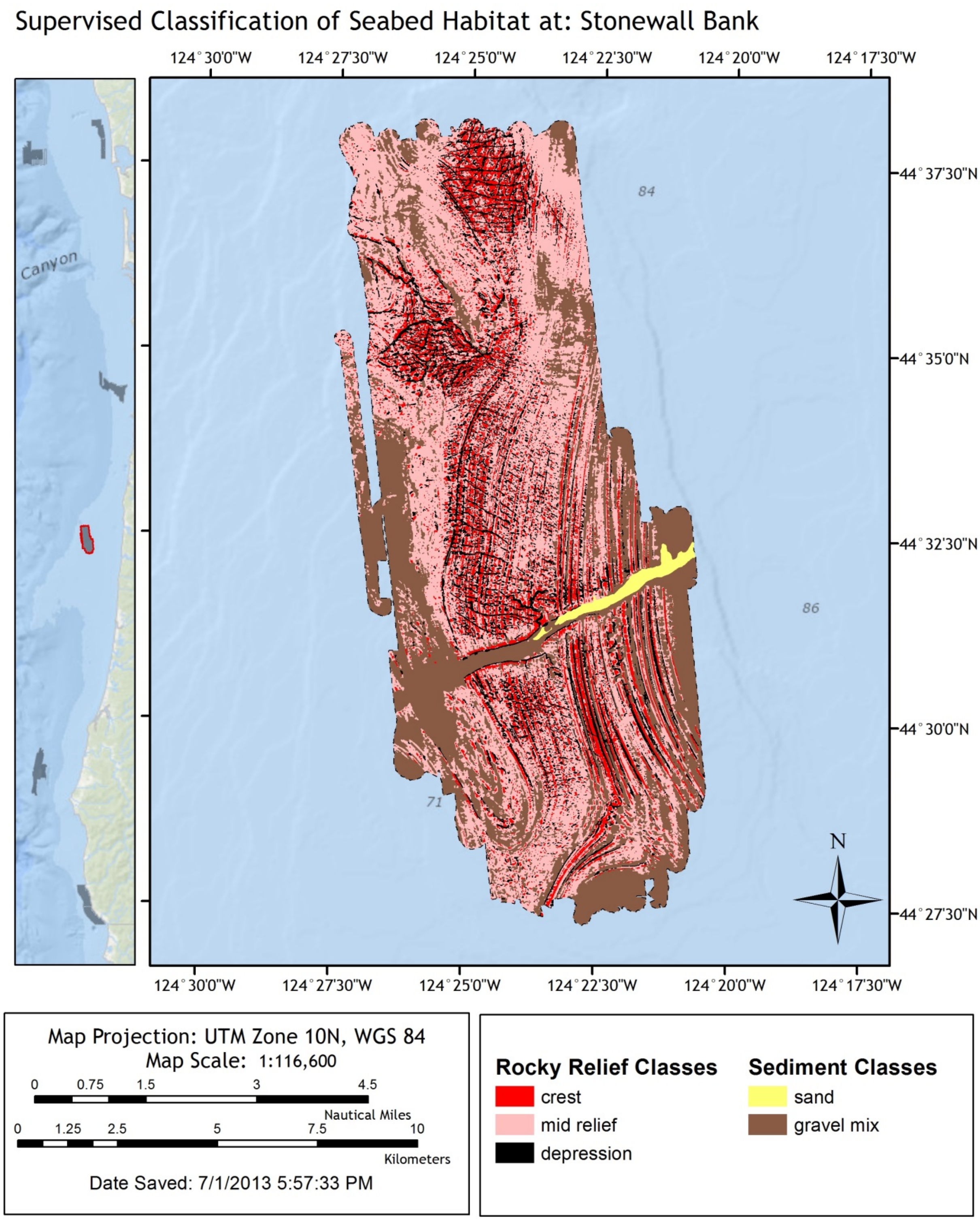


Figure 84. Seabed substrates at Stonewall Bank, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

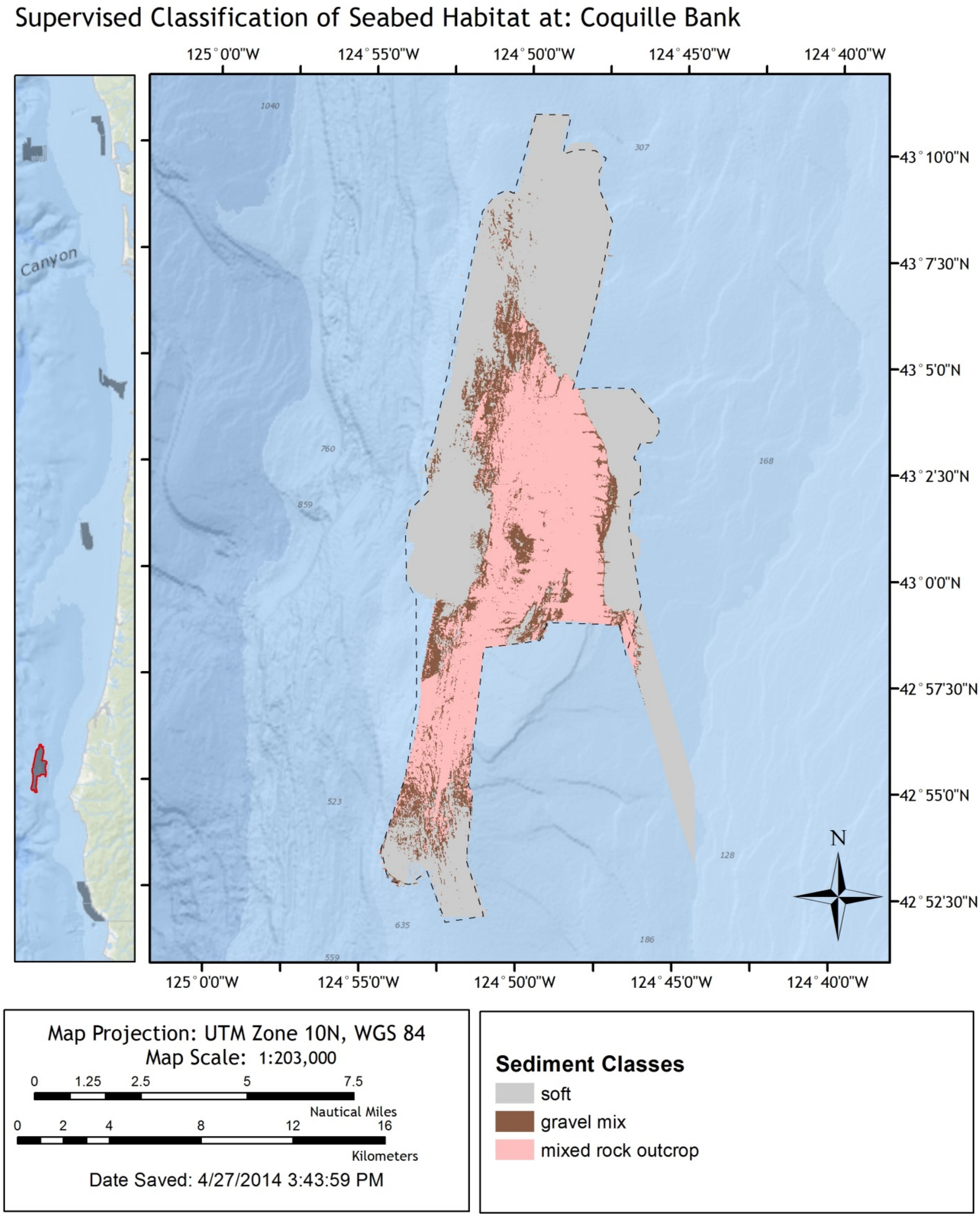


Figure 85. Seabed substrates at Coquille Bank, OR
Sediment classes are unclassified due to lack of seabed samples. Rocky relief classes are manually interpreted by analysis of bathymetric imagery and AUV video.

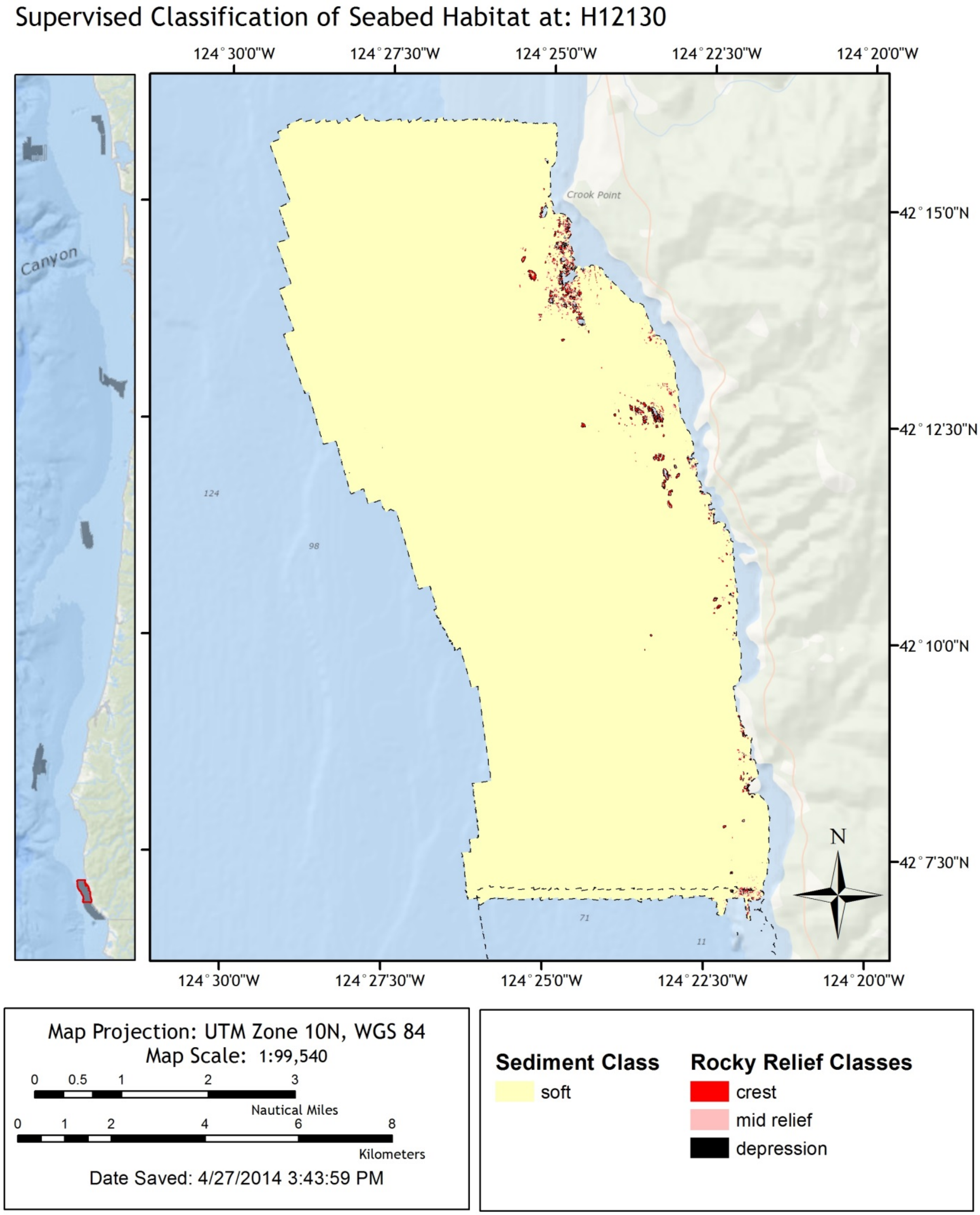


Figure 86. Seabed substrates at H12130 Survey Sheet, OR
Sediment classes are not predicted due to lack of seabed samples. Rocky relief classes are predicted by analysis of bathymetric data.

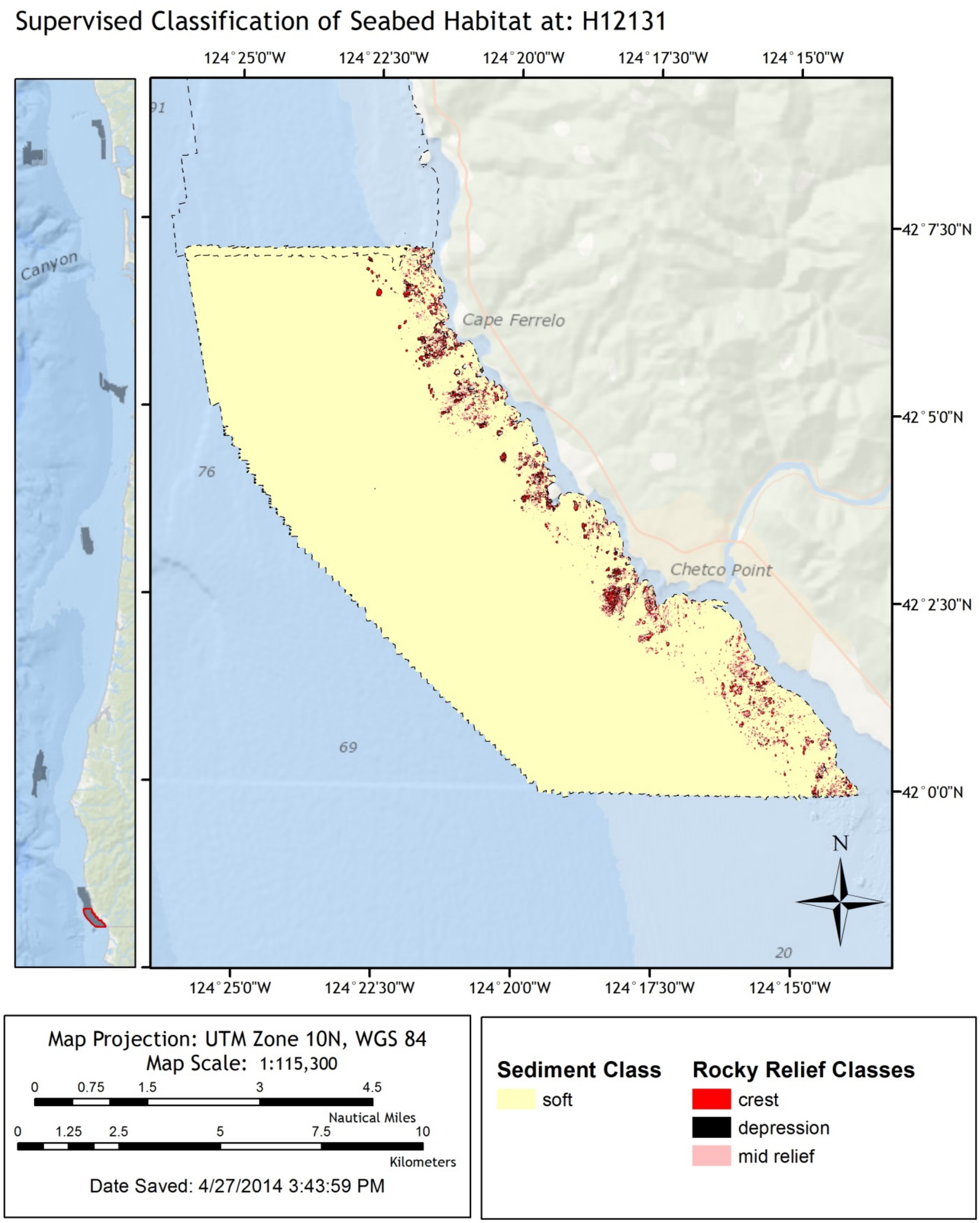


Figure 87. Seabed substrates at H12131 Survey Sheet, OR
Sediment classes are not predicted due to lack of seabed samples. Rocky relief classes are predicted by analysis of bathymetric data.

Table 6. Seismic data sources

Name	System	Source	Navigation System	Approximate Navigation Error
UW	Sparker and Airgun SCS	(McNeill et al., 1997; Palmer and Lingley, 1989)	Loran A	**1000-3000 m**
USGS MCAR	Airgun SCS & MCS	(Foster et al., 2000)	Transit/Loran C	**Less than 500 m**
Sonne	Airgun MCS	(Flueh et al., 1996)	GPS, Transit	**Less than 5 m**
Silver	Airgun MCS	(Goldfinger, 1994; Silver, 1972)	Satellite Navigation	**Unknown accuracy**
OSU	Sparker and Airgun SCS	(Goldfinger, 1994)	Loran A	**1000-3000 m**
MMS		(McNeill et al., 1997)		
Digicon	MCS	(MacKay et al., 1992)	GPS	**Less than 100 m**
Corliss	Boomer MCS	(Cross et al., 1998)	GPS	**Less than 50 m**
Industry Datatset 1	Sparker SCS	Proprietary	SHORAN	**Less than 50 m**
Industry Dataset 2	**MCS**	**Proprietary**	**Transit/Loran C**	**Less than 500 m**

Appendix 2. SGH Map V4.0 Review Briefing Book

Briefing Materials: February 9th, 2014

Version 4.0 Surficial Geologic Habitat Map for Washington, Oregon, and Northern California

Abstract:

Seabed habitat mapping efforts undertaken by OSU's 4-year study: Survey of Benthic Communities near Potential Renewable Energy Sites offshore the Pacific Northwest have resulted in several new map products. First, site-specific seabed habitat maps were developed from high-resolution acoustic remote sensing data, sediment sample data and visual observation. Site-specific maps were completed for all of the new BOEM study sites (6) and additionally for external sources of data considered "backlog" (7) but of high importance. After completing the local scale, site-specific maps the regional Surficial Geologic Habitat (SGH) map version 3.6 was updated to incorporate these (13) new map products as well as other externally developed habitat maps (CA & OR State Waters Mapping Program, OCNMS, and NOAA n = 35) resulting in publication of a "Provisional" SGH Map Version 4.0 for the region of this study. In addition to newly mapped areas, the version 4.0 SGH map also underwent significant modifications/updates to its attribute fields. We now include CMECS habitat codes developed by cross-walking SGH to CMECS and have made some changes to our primary and secondary habitat codes to clear up ambiguities and make the fields internally consistent.

The objective of this review is to gather external comments primarily focused on:

1. The clarified definition of ***SGH_Prefix**** attribute field
    a. More consistent use of induration code across the region?
2. The clarified definition of ***V4_Lith1*** and ***V4_ Lith2*** attribute fields
    a. Easier to distinguish mixed habitat patches from sediment mixtures?
3. The crosswalk between SGH habitat map codes and the CMECS Substrate Component
    a. Evaluate goodness of fit – where are the misfits?
    b. Should higher or additional levels of CMECS be implemented?
4. Implementation of the 100 m^2 minimum mapping unit
    a. The new Version 4.0 map renders extremely slowly as a result of adding the high-resolution areas. What mapping unit scale or size is appropriate for regional products?
5. Options for adding sedimentary lithology for the CA habitat polygons
    a. Add sedimentary classification to CA polygons using predictive maps of grainsize (also developed through this study)?
6. ODFW NEDA Case Study
    a. Does your agency have a map application or management plan integrated with the SGH maps Versions 1.1 – 3.6.1 ->?

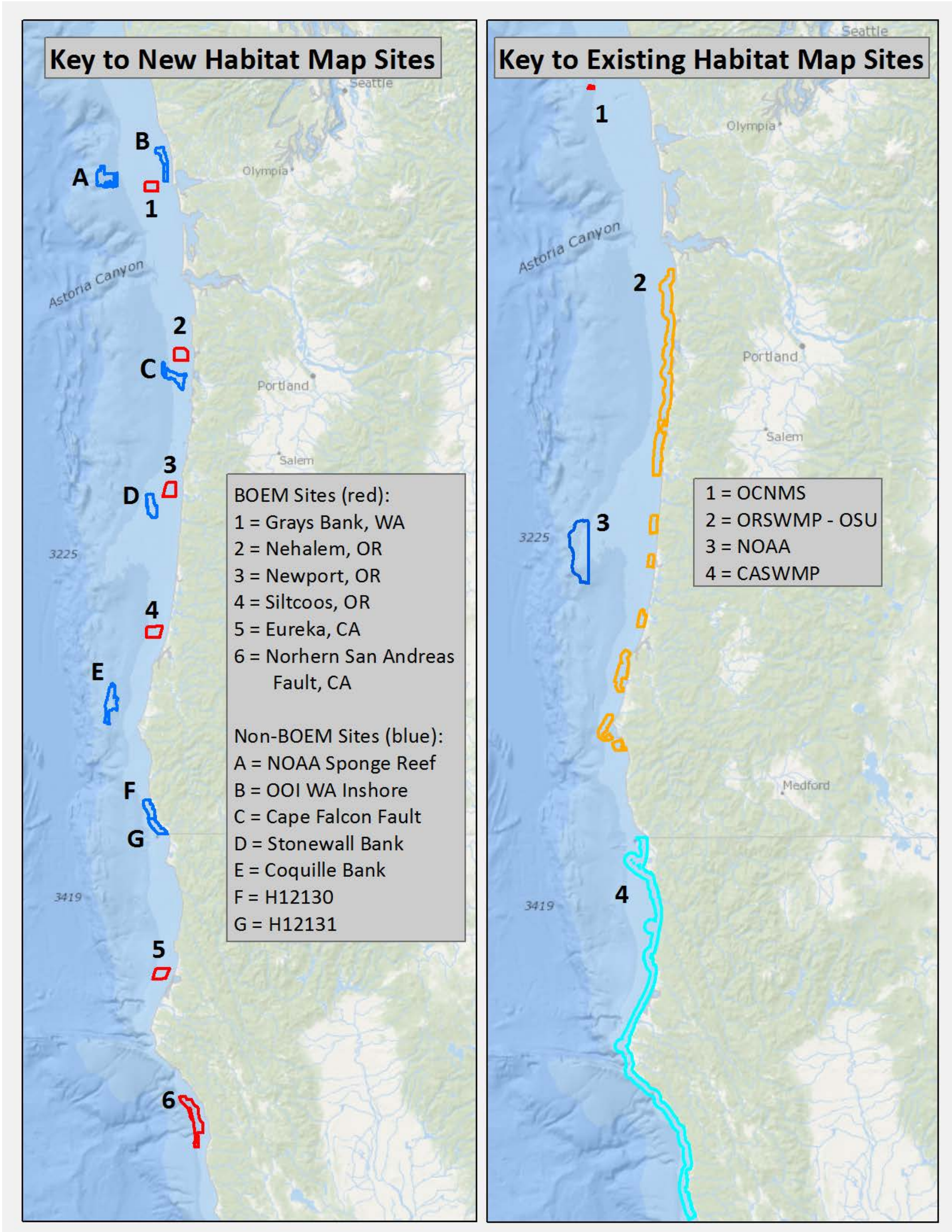
A quick overview of what's new in the Version 4.0 Habitat Map!

- The SGH Map for Washington and Oregon was extended to cover northern California (Oregon border south to 39.4 N). Within a sub-region extending from Grays Harbor, WA to 39.4N the following new map interpretations were added:
    - The BOEM funded study, *Survey of Benthic Communities near Potential Renewable Energy Sites offshore the Pacific Northwest,* included seabed mapping data collection at 6 new mid-continental shelf sites over southern WA, OR, and northern CA (Figure 1 red polygons). Resultant seabed habitat interpretations have been incorporated into Version 4.0.
    - Under the same BOEM project backlog datasets at an additional 7 sites were interpreted for seabed habitat type and incorporated into Version 4.0 (Figure 1 blue polygons).
    - 19 California State Waters Mapping Program, Tier 2, seabed habitat maps were incorporated into Version 4.0
- For the entire map area the following modifications were made:
    - An SGH code to CMECS Substrate Component code crosswalk was developed (Table 3) and implemented for all areas.
    - ***SGH_Lith1*** and ***SGH_Lith2*** attribute field definitions have been clarified (and codes adjusted from previous) to more easily discriminate habitat patches of homogeneous sediment mixtures from habitat patches of heterogeneous or patchy sediments. Previous definitions made it difficult or impossible to determine if the primary/secondary ***SGH_Lith1/SGH_Lith2*** components indicated a homogeneous mixture or a heterogeneous patchy environment.

Useful external sources of information:

- CMECS
    - See http://www.cmecscatalog.org/ for an online catalog of CEMCS units.
    - See below for a copy of CEMC Version 4 http://csc.noaa.gov/digitalcoast/sites/default/files/files/publications/14052013/CMECS_Version%20_4_Final_for_FGDC.pdf
- Live Maps of figures presented in this document
    - http://bhc.coas.oregonstate.edu/arcgis/rest/services/V4_Review/V4_Review_MapService/MapServer
        - Navigate to the above website. Choosing View In "ArcMap" will initiate a download of a .lyr file. (Check your downloads folder if you can't find it). Add the .lyr file to ArcMap and the maps will be added as live content (you must have an internet connection). The map service supports queries (try it with the "I" button). Remember that the layers are indexed according to Appendix Figure and panel. Generally the Version 4.0 layer is in the RIGHT panel on any appendix figures.

Section 1: New Local Mapping Sties Incorporated into SGH Map Version 4.0



Overview of local sites both newly mapped (new data acquisition) and existing, used to update the Version 4.0 regional habitat map
The left panel shows new habitat maps developed or interpreted under BOEM support. The right panel shows existing maps developed external to the BOEM project.

Local Site Mapping- Developing and consolidating areas to update in Version 4.0!

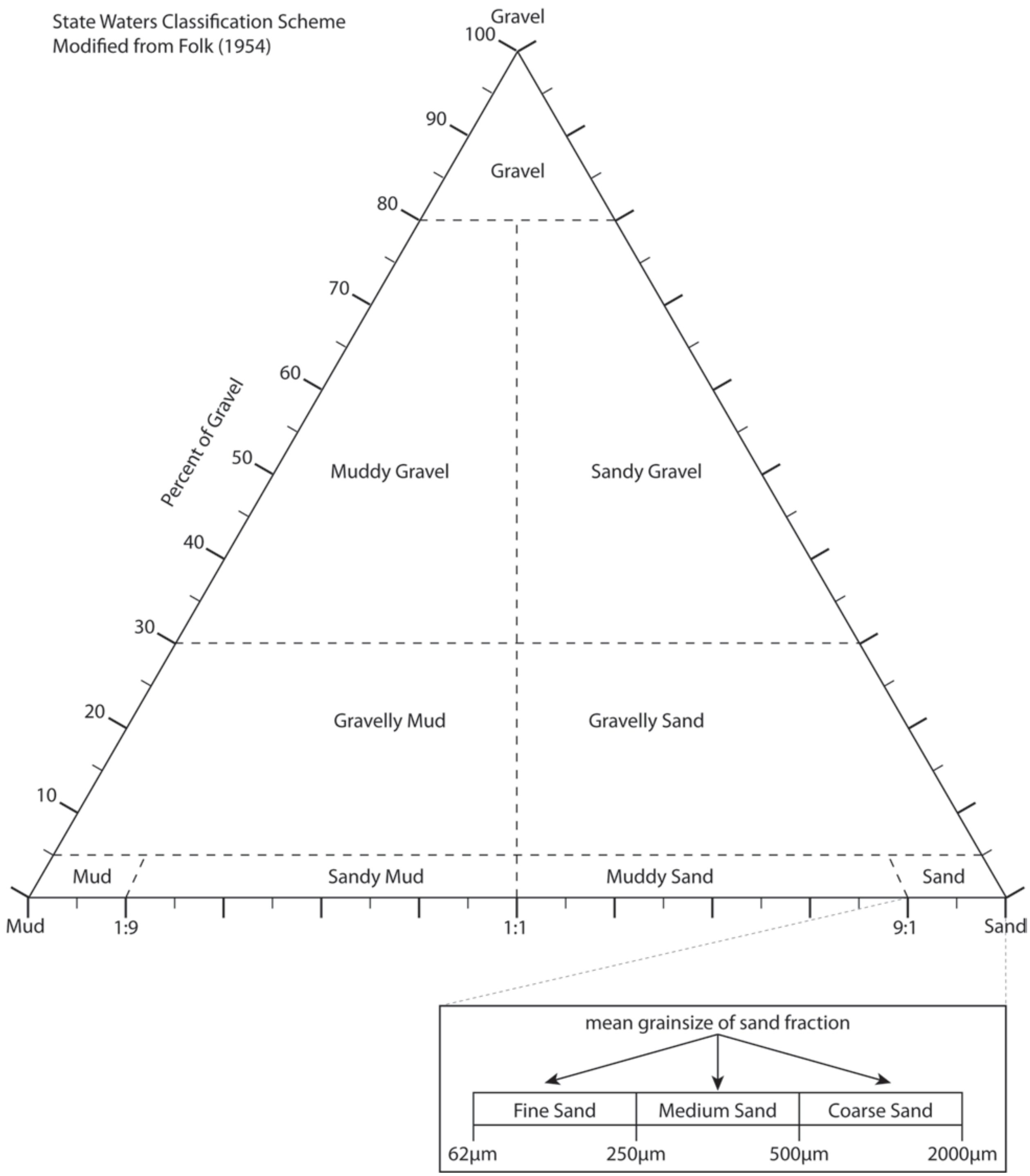
Seabed type mapping at local sites, both BOEM project sites and backlog sites (Figure 1, left panel), followed a supervised image classification approach for unconsolidated soft sediments followed by a rules-based seabed roughness classification for rock outcrop. The sediment mapping method used here is identical to that used for the Oregon State Waters Mapping Program (ORSWMP). The outcrop mapping method differs from the ORSWMP rock mapping method in that the outcrops for ORSWMP were interpreted manually while outcrop for these sites was determined using the Vector Ruggedness Measure (VRM) terrain algorithm. Both techniques are useful and can be quite accurate for identifying outcrop; however the VRM approach mates well with extensive mapping of California's State Waters (Tier 2 data products) and allowed us to apply a fairly consistent technique across a broad geographic extent. The general mapping method is presented below, details related to sediment sample classification and rock mapping are also provided.

1) We separate hard seabed from soft unconsolidated sediment using the VRM terrain algorithm (http://www.csc.noaa.gov/digitalcoast/tools/btm), augmented by visual interpretation where needed. This leads to two separate tracks for interpretation of these two basic classes. A breakpoint or threshold is used to differentiate between hard (rock outcrop) seabed and soft unconsolidated sediment areas. We used a common (0.002) VRM breakpoint derived by matching in-situ observations at Grays Bank & Siltcoos (BOEM ROV) and Stonewall Bank (ODFW Video Lander). The breakpoint was applied uniformly to all local sites with the exception of Coquille Bank. See Table 2 for neighborhood analysis and breakpoint details.

2) For the soft substrate class, we use the reference samples (Shipek Grab Samples, Box Core Samples, and/or usSEABED sample data) and a 10 m buffer around them as training areas for the supervised Maximum Likelihood Classification (MLC) of bathymetry and backscatter imagery data. Hard substrate areas, identified in step one, are masked from the results of the MLC sediment type classification. Where possible, we make distinctions to the maximum number of clearly resolved sediment classes observed in the analysis of grain size data following the textural classification of sediment samples outlined in McCoy, 1977, modified from Folk, 1967 (see Figure 54, Figure 55). For mixed classes of coarse sediments, where gravel is the dominant component, we bin the mixture before classification as mixed gravel. This method produces a robust fully ground-truthed classification. If the user requires fewer classes, these can be simply merged or recoded.

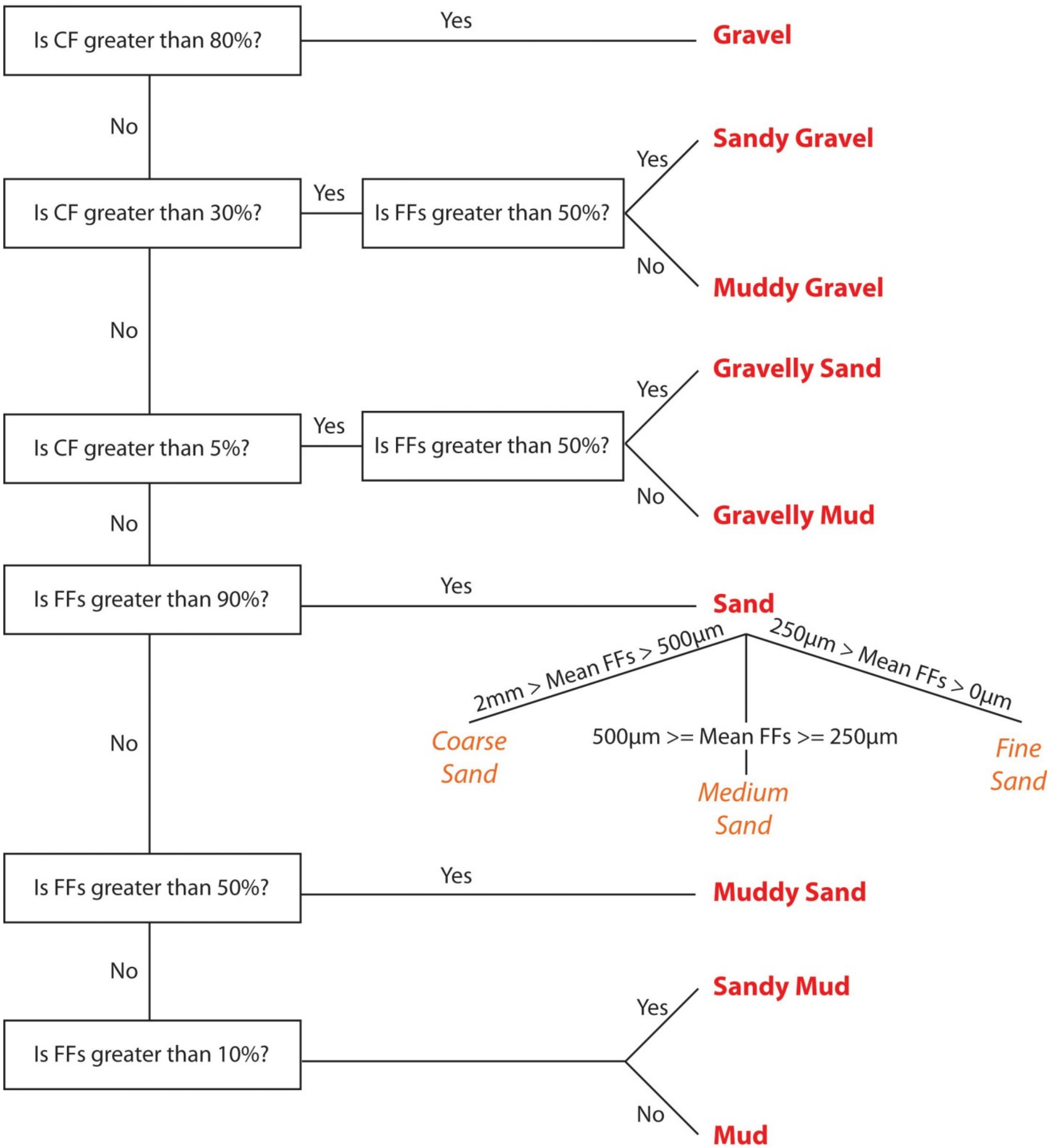
3) Three Topographic Position Index Classes: Ridge (TPI >1m), Mid Relief (1m > TPI >-1m), and Valley (TPI < -1m), are derived for areas of hard substrate. See Table 2 for neighborhood analysis and breakpoint details.

4) The classified soft and hard substrate units, along with the 3 TPI relief classes are remerged in a final feature class, with quality control by a geologist/interpreter to resolve conflicts and artifacts if any. Additionally, the resultant output raster was smoothed (artifact minimization cleaning) using a focal majority filter at 9x9 or 11x11. After smoothing, the classified raster is converted to polygon format with 100 m^2 minimum patch size.



Ternary diagram showing basis for the textural classification of sediments used for the BOEM, "Backlog", and ORSWMP local sites. Modified after Folk (1954)

Coarse Fraction (>2mm) (CF) and Fine Fraction (< 2mm) (FF) Determined by Weight
Fine Fraction Sand (2mm > Sample >= 62µm) Percentage (FFs) Determined by Volume
Fine Fraction Mud (62µm > Sample >= 0.0µm) Percentage (FFm) Determined by Volume



A key to the classification of seabed sediment sample data. The rules presented here implement the ternary diagram classes from Figure 54 through spreadsheet functions to assign a class determination for each sample in our database

Relief Mapping Analysis Scale by Site

Site	Grid Pixel Size	VR Scale (radius/diameter)	VRM Breakpoint	TPI Scale (radius/diameter)	TPI Breakpoints
Sponge Reef	8m	5x5 = 20 m/40 m	0.002	NA	No High Relief
Grays Bank	8m	5x5 =20 m/40 m	0.002	44 m/88 m	+1 m & -1 m
OOI WA Inshore	2m	9x9 = 9 m/18 m	0.002	40 m/80 m	+1 m & -1 m
Nehalem	No Rocks	No Rocks	No Rocks	No Rocks	No Rocks
Cape Falcon Fault	4m	5x5 = 10 m/20 m	0.002	40 m/80 m	+1 m & -1 m
Newport	No Rocks	No Rocks	No Rocks	No Rocks	No Rocks
Stonewall Bank	2m	19x19 =19 m/38 m	0.002	100 m/200 m	+1 m & -1 m
Siltcoos	4m	5x5 = 10 m/20 m	0.002	40 m/80 m	+1 m & -1 m
Coquille Bank	NA*	NA	NA	NA	NA
H12130	4m	3x3 = 6 m/12 m	0.002	40 m/80 m	+1 m & -1 m
H12131	4m	3x3 = 6 m/12 m	0.002	40 m/80 m	+1 m & -1 m
Eureka	No Rocks	No Rocks	No Rocks	No Rocks	+1 m & -1 m
NSAF	8m	5x5 = 20 m/40 m	0.002	40 m/80 m	+1 m & -1 m

***Rock outcrop mapping was performed through manual interpretation of bathymetry and backscatter at Coquille Bank where the seabed is predominantly bedded cobble and boulder substrate with little if any high-relief "rocky ridge" type present.

Updating Version 4.0 - Incorporating local polygon maps

Incorporating local polygon maps (from sources: BOEM, "Backlog", ORSWMP, OCNMS, and CASWMP) into the regional habitat map entailed standardizing the minimum mapping unit and performing a GIS union of datasets. Prior to standardizing the minimum mapping unit all raster format habitat maps (maps originating from the CA State Waters Mapping Program) were first converted to polygon shapefiles. Patches (polygons) less than 100 m^2 were eliminated (merged into the adjacent feature with the largest shared border). The polygon format BOEM, BOEM backlog, and OCNMS datasets were also generalized by eliminating habitat patches less than 100 m^2 prior to incorporating into the Version 4.0 SGH map. ORSWMP datasets had been previously standardized.

We incorporated individual survey datasets using the ArcGIS for Desktop Analysis Tools, Union Tool. The Union Tool computes the geometric union of input features and preserves all attributes in the output. This method preserves the shape of features in all input layers allowing physiographic habitat type to persist from version to version. Where lithologic type modifies or overprints a previous feature we used conditional statements to select and eliminate the outdated features such that the new feature would persist. After all new features were incorporated into the map layer we used the CMECS crosswalk table (Table 4) to populate the five CMECS attribute fields.

Section 2: Attribute table changes

*Clarifying the **SGH_Prefix** Attribute*

Previous habitat map versions included a field entitled ***SGH_Prefix***. This field included a 2 letter code developed by shortening the Geo_Hab filed. The Geo_Hab field was developed under the 2002-2005 EFH-EIS for West Coast Groundfish and is simply a subset of the Greene et al. 1999 code. The first character of the ***SGH_Prefix*** code is the Greene et al. Macrohabitat. The second ***SGH_Prefix*** character is meant to describe Seafloor Induration. Three induration modifiers are available:

1. h = hard substrate, rock outcrop, relic beach rock or sediment pavement,
2. m = mixed hard & soft substrate
3. s = soft substrate, sediment covered

SGH Versions 3.0 to 3.6 used the mixed induration modifier in a manner inconsistent with the above definition. Specifically, the Version 3.0 habitat maps coded any polygon with a secondary lithologic component indicated as ***SGH_Lith2***= m (mixed induration type). This resulted in mixed (hard and soft substrate) codes for many polygons that should have been coded soft "s" (i.e. Sm/sand/mud should be Ss/sand/mud). The inconsistency was that our previous use of the "m" modifier simply described where sediment mixes or patchy habitat types occurred and did not describe seabed hardness as intended. In Version 4.0 we have split the single ***SGH_Prefix*** field into ***SGH_Pref1*** and ***SGH_Pref2*** and recoded the ***SGH_Pref2*** code to match the Greene et al. "Seafloor Induration" definition. Soft seabed types like Sand/Mud are sediment mixes or mixtures and now coded consistently as soft. Patchy habitats that include the hard ***V4_Lith1*** types, boulder or rock and modified by any soft ***V4_Lith2*** type (smaller than boulder), are now coded as mixed.

Note: When developing the map graphics that are included in the 5-Year review of EFH, we were careful to use the "m" induration class consistent with its Greene et al. definition which ensured that the "m" induration code was used consistently across state lines and across data produced by various groups.

*Updated Definitions of **SGH_Lith1** and **SGH_Lith2**, now **V4_Lith1** and **V4_Lith2***

In previous versions of the SGH maps we presented Primary and Secondary Lithology types (***SGH_Lith1*** and ***SGH_Lith2***) to distinguish between the relative abundance of seabed types present in a habitat polygon. This created some unintended confusion between homogeneous sediment mixtures and heterogeneous or patchy habitat type mixes.

To clarify:

- A sediment mixture is a homogeneous map-able unit of sediment (i.e. sandy mud).
- A patchy habitat type mix is a heterogeneous unit where it's not possible or not intended to map distinct patches of each specific type known to occur (i.e. boulder/sand, gravel/rock, and etcetera).

Under the previous ***SGH_Lith1/SGH_Lith2*** coding scheme the sediment mixture "sandy mud" would have been coded as ***SGH_Lith1*** = mud, ***SGH_Lith2*** = sand leaving it unclear if the habitat patch is a sandy mud mixture or if the habitat patch includes distinct patches of homogeneous sand and mud at scales below some minimum mapping unit.

We now define the primary lithology, ***V4_Lith1*** to be the dominant component (whether it's a mix, mixture or there is no secondary component).

We define secondary lithology ***V4_Lith2***, as either the full mixture description or the secondarily abundant component. Therefore, the "sandy mud" mixture example above would now be coded as:

- ***V4_Lith1*** = mud
- ***V4_Lith2*** = sandy mud

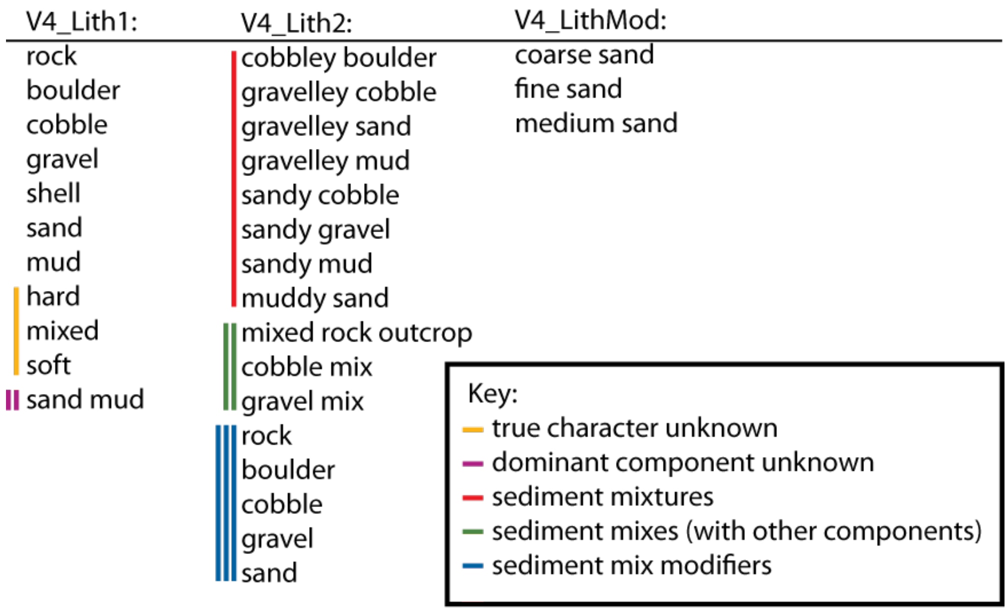
A patchy habitat such as "boulders with sand" is distinguished as:

- ***V4_Lith1*** = boulder
- ***V4_Lith2*** = sand.

Under the new rules it's clear that the first example is a mixture while the second is a mix. We also implement a new field entitled ***V4_LithMod***. The ***V4_LithMod*** filed is meant to further modify or define the dominant component. Currently we only use the ***V4_LithMod*** field to distinguish coarse, medium, and fine sand. The ***V4_Lith3*** field simply concatenates ***V4_Lith1***, ***V4_lith2***, and ***V4_LithMod***. See Table 2 for valid lithologic attribute fields.

Valid codes for the *V4_Lith1*, *V4_Lith2*, and *V4_LithMod* attribute fields.

Hard, Soft, and Mixed induration codes (yellow highlighted codes in column 1) occur as valid options of *V4_Lith1* because the California regional maps never included a true primary lithology descriptor. However, we will soon replace the Hard, Soft, and Mixed *V4_Lith1* codes with estimates of primary lithologic character derived from predictive maps of mean grainsize and % sand. Note that sediment mixtures are easily identified as two word pairs describing mixture composition (i.e. sandy gravel). Mixes are either explicitly stated (i.e. cobble mix) or indicated by the presence of a singular *V4_Lith2* code (gravel).



CMECS Version 4.0 to SGH Habitat Code Crosswalk

We implement the Substrate Component (SC) of CMECS Version 4.0. The Substrate Component is a 5-level hierarchy (Origin, Class, Subclass, Group, and Subgroup). We only implement the Geologic Substrate Origin as the SGH map does not attempt to describe biogenic or anthropogenic substrates. Table 2 presents all unique combinations of ***V4_Lith1***, ***V4_Lith2***, and ***V4_LithMod*** (45 unique options). Note that presently we include the Hard and Soft generic induration types from the CA regional map but these will be replaced over continental shelf habitats with the appropriate sediment class derived from interpolated sediment sample data. ***V4_Lith1*** codes map easily to CMECS Origin, Class, Subclass, and even Group. However ***V4_Lith2***, particularly sediment mixes (heterogeneous patches such as mud/rock, sand/rock, gravel/rock, and any secondary component in a rocky habitat) begin to present problems. These problem areas are highlighted in red. Red cells don't exist as CMECS options but have been included anyway so that the secondary component information is not lost in the CMECS attribute fields. A relevant question would be whether to include these even though they are not true CMECS codes, or to follow the CMECS code/convention and to leave them blank.

A key to crosswalk SGH Map Version 4.0, V4_Lith Codes to CMECS (FGDC-STD-018-2012) Origin, Class, Subclass, Group, and Subgroup codes

V4_Lith1	V4_Lith2	V4_LithMod	CMECS Origin	CMECS Class	CMECS Subclass	CMECS Group	CMECS Subgroup
shell			Geologic Substrate	Shell Substrate	Shell Hash		
shell	gravel		Geologic Substrate	Shell Substrate	Shell Hash		
mud			Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Mud	
mud	rock		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Mud	Rock
mud	shell		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Mud	Shell
mud	sand		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Mud	Sand
mud	gravelly mud		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Slightly Gravelley	Slightly Gravelley Mud
mud	sandy mud		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Sandy Mud	
sand			Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Sand	
sand		coarse sand	Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Sand	Coarse Sand
sand		medium sand	Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Sand	Medium Sand
sand		fine sand	Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Sand	Fine Sand
sand	rock		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Sand	Rock
sand	shell		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Sand	Shell
sand	mud		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Sand	
sand	bouldery sand		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Slightly Bouldery	Slightly Bouldery Sand
sand	gravelly sand		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Slightly Gravelley	Slightly Gravelley Sand
sand	muddy sand		Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Muddy Sand	
gravel			Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Granule
gravel	rock		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Rock
gravel	shell		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel Mix	Shell
gravel	gravel mix		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel Mix	
gravel	sandy gravel		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel Mix	Sandy Gravel
cobble			Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Cobble
cobble	boulder		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Cobble
cobble	cobble mix		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel Mix	Gravelley Cobble
cobble	gravelly cobble		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel Mix	Gravelley Cobble
cobble	sandy cobble		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel Mix	Sandy Cobble
boulder			Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Boulder
boulder	sand		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Boulder
boulder	mud		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Boulder
boulder	cobbley boulder		Geologic Substrate	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Boulder
rock			Geologic Substrate	Rock Substrate	Bedrock		
rock	boulder		Geologic Substrate	Rock Substrate	Bedrock	Boulder	
rock	gravel		Geologic Substrate	Rock Substrate	Bedrock	Gravel	
rock	shell		Geologic Substrate	Rock Substrate	Bedrock	Shell	
rock	sand		Geologic Substrate	Rock Substrate	Bedrock	Sand	
rock	mud		Geologic Substrate	Rock Substrate	Bedrock	Mud	
rock	mixed		Geologic Substrate	Rock Substrate	Bedrock	Mixed	
rock	gravel mix		Geologic Substrate	Rock Substrate	Bedrock	Gravel	
rock	muddy sand		Geologic Substrate	Rock Substrate	Bedrock	Sand	
soft			Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate		
hard			Geologic Substrate	Rock Substrate	Bedrock		
sand mud			Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate		

Case Study: The Oregon Nearshore Ecological Data Atlas reclassification code

During Oregon's recent Territorial Sea Planning exercise, ODFW and DSL staff used the Version 3.6.1 Surficial Geologic Habitat map for Oregon in various capacities (basemaps, modeling, marxann, etc.) as part of their Nearshore Ecological Data Atlas. The managers, biologists, planners, and modelers understood well that "***to date there has been no systematic survey (data collection) of continental margin seabed environments for the entire west coast***" and that "***the original survey methods, input data resolution, scale of habitat map interpretation, and degree of groundtruthing differ substantially among the various data sources used to assemble the regional habitat map dataset***".

Since the analyses of the NEDA data required that treatment across the Territorial Sea be as consistent and ecologically relevant as possible, ODFW chose to collapse the various seafloor types into the four categories below based on physical composition, particle size, and degree of consolidation. The classes and rationale developed by the NEDA team are:

- **Rock -** The NEDA rock category includes all SGH seafloor types with either rock or boulder as the primary or secondary habitat type.

- Rock bottom is readily recognizable in multibeam/backscatter data and can be consistently mapped
- While modern remote sensing surveys (i.e. multibeam bathymetry/backscatter, sidescan sonar) have covered about 50% of the Territorial Sea, the focus of surveys has been on rocky habitat, such that approximately 80% of the rock habitat in state waters is mapped with high-resolution survey methods.
- Boulder seafloor is difficult to distinguish from bedrock without extensive groundtruthing. Because only a few areas have received the necessary groundtruthing to make this distinction, we choose to combine boulder and rock (bedrock) into one category.
- The fish, invertebrate and algal communities on rock (bedrock or boulder) seafloor areas are very distinct from unconsolidated seafloor areas, justifying the distinct class.
- Twelve years of visual surveys in the nearshore ocean have demonstrated that even areas of relatively isolated rock or boulder outcrops exhibit "rocky reef" species, providing rationale for including areas with rock as a secondary habitat in the NEDA Rock category, even if the primary habitat is sand or gravel, for example.
- Rocky habitat is a relatively rare (~7% of the Territorial Sea) and typically has relatively high fish, invertebrate, and algae abundance and diversity compared to unconsolidated substrate habitats.

<u>Notes and guidance to the NEDA Team:</u> The updated or clarified usage of the “hard” induration code in the EFH map products and now in Version 4.0 address the issue driving the NEDA Rock Class. Habitat patches (polygons) coded as ***SGH_Pref2*** = “h” in Version 4.0 include all seabed types with either rock or boulder as the primary or secondary habitat type. Also note that for some remaining areas of California, ***V4_Lith1*** = “hard” is also a valid ***SGH_Pref2*** = “h” code.

- **Sand -** The NEDA sand category includes all SGH seafloor types with sand as the primary habitat and either omits secondary habitat, or mud as the secondary habitat.
- **Mud -** The NEDA mud category includes all SGH seafloor types with mud as the primary habitat and either omits secondary habitat, or sand as the secondary habitat.
    - Grain size is an important factor influencing the benthic community in unconsolidated sediments types.
    - Sand and mud have been mapped consistently as separate categories in the Territorial Sea, using existing survey techniques and available groundtruth data.
    - Until recently, groundtuthing data have not been adequate to consistently break these sediment types into finer categories than mud and sand. The OSU Active Tectonics Lab is currently developing maps that present a finer classification of sedimentary seafloor categories (mud, sandy mud, muddy sand, fine sand, medium sand, coarse sand) based on new groundtruth data collected during the recent Territorial Sea survey efforts. These maps are not yet available.

<u>Notes and guidance to the NEDA Team:</u> Clarifying the codes for sediment mixes and mixtures in ***V4_Lith2*** should not have an effect on the Sand or Mud NEDA classes. The induration codes “m” or “s” are not restrictive enough to satisfy the NEDA Sand and NEDA Mud classes however. We suggest that the definition of NEDA Sand and NEDA Mud be amended to include the following:

V4_Lith1: Sand, Mud, Sand Mud

V4_Lith2 codes: sand or mud (denoting heterogeneous patches of sand or mud as secondary components) and muddy sand or sandy mud (denoting homogeneous mixtures with appropriate dominant component listed second).

- **Gravel, Cobble, Shell, Mixed** - This NEDA category includes the remaining SGH seafloor types that consist of unconsolidated sediment and other materials, but with larger particle sizes than sand and smaller than boulders (2 - 256 mm). It includes various combinations of gravel, cobble, shell, and may have sand or mud as a secondary habitat type. This category is dominated by gravel seafloor type.
  - Unconsolidated seafloor types with larger particle sizes often have invertebrate and fish communities distinct from rock, sand, or mud.
  - Gravel is well mapped in the areas surveyed with multibeam bathymetry/backscatter methods, but inconsistently mapped in other areas.
  - While a finer division of the gravel, cobble, shell, mixed category (e.g., large gravel vs. gravel/sand, or gravel vs. cobble) is biologically justified, the degree of groundtruthing has not been adequate to accomplish this consistently, hence the need to combine them into one category.
  - This category represents approximately 2.5% of the Territorial Sea, of which approximately 80% has gravel as the primary seafloor type.

Notes and guidance to the NEDA Team: Again, the induration codes "m" and "s" are inappropriate for this class unfortunately. Mixed induration must include rock and boulder. Soft induration includes NEDA Sand and NEDA Mud. Updates from new mapping at BOEM and backlog sites (outside of State Waters) have revealed much new gravel habitat particularly in the vicinity of Cape Falcon Fault, Stonewall Bank, and Coquille Bank. Of all the possible habitat types, gravels and cobbles remain a likely suspect for higher than average misclassification due to the fact that they are patchily distributed (may occur on a reef, adjacent to a reef, or at great distance to structure), difficult to sample with non-visual techniques (non-visual groundtruth techniques are rarely applied away from structure. In summary, if these standardization needs are still relevant, then despite the significant improvement in high-resolution coverage this study provides, the class should persist.

Appendix 3. SGH Map V4.0 Review Participant Written Comments

MEMORANDUM

Oregon Department of Fish and Wildlife

Date: **March 13, 2014**

To: **Chris Romsos**

From: **Dave Fox, Scott Marion, Arlene Merems**

Subject: **Comments on SGH version 4.0**

NOTE: The authors have provided comments and details about review points and actions taken in-line throughout this appendix. Author comments are identified by italicized text in grey highlight.

Please consider the following comments on SGH version 4.0:

1) Use of Lith1 and Lith2 to characterize primary and secondary habitat

As I understand it, Lith1 and Lith2 are used to describe primary and secondary habitat. This has its derivations from earlier submersible video work where a system was developed to describe bottom habitat type using a binary code, where primary bottom type was generally 50% or more of the substrate in a view and secondary bottom type was generally 20-50% of the substrate in a view. It was developed because, in many cases, the bottom habitat consists of a patchy array of different substrate types. In general, it was meant to be a way to describe these secondary heterogeneous patches that occur along with the primary substrate type.

Two revisions you have proposed for SGH v.4.0 affect how Lith1 and Lith2 are expressed:

1) Your first revision seems to bring the use of Lith1 and Lith2 back into consistency with the original intent of expressing a heterogeneous mix of primary and secondary habitat type. Specifically the revision calls for the use Lith2 to express heterogeneous patches of secondary substrate type that exist with the primary (Lith1) type. Further, the revision dictates that the practice of using Lith 1 and 2 to express homogenous mixes of substrate would be stopped. As an example, sandy substrate that has boulder patches would be Lith1:Sand, Lith2:Boulder, but a homogeneous mix of sand and mud (with sand dominant) would not be Lith1:sand, Lith2:mud, but would be classified as muddy-sand.
2) Under the second revision, homogeneous sediment mixes have a different use of Lith1 and Lith2. Under this revision, Lith1 is used to describe the dominant sediment type in the mix, and Lith2 is used to describe the homogeneous mix. The muddy-sand example above would be expressed as Lith1:Sand, Lith2:muddy-sand.

Proposed revision 1, above, is consistent with the intention of the habitat system and seems like the best way to proceed. Proposed revision 2, above, is inconsistent with the habitat system and could cause confusion. For example, how would you express a situation where there are large enough patches of boulders to qualify as a secondary habitat in an otherwise muddy-sand area? As proposed, "muddy-sand" would occupy the Lith2 field and there would be nowhere to list boulders as a secondary habitat. It seems like the consistent method to treat this situation would be: Lith1:muddy-sand, Lith2:Boulder. If an area has only muddy-sand and no secondary habitat patches, it would be Lith1:muddy-sand, Lith2: blank. I summary the homogenous mix classes (muddy-sand, etc.) should be used in a consistent manner as the other types of classes, that is they occupy either the Lith1 or Lith2 field depending on their dominance in the habitat polygon, but don't use both Lith1 and Lith2 fields to describe them.

This is an excellent recommendation and we have implemented it in SGH Map Version 4.0 as suggested. We have also added an additional field entitled "V4_LithMod" to record subdivisions of the V4_Lith1 habitat type. Currently we subdivide V4_Lith1 to "Coarse Sand", "Medium Sand", and "Fine Sand".

2) Induration codes

There is some confusion about induration codes. It needs to be clearly defined which substrate types are classified as H, M and S. For example, it is unclear to me if gravel is classed in S or H.

From Green et al. (1999) seafloor induration is defined as:

Hard: hard substrate, rock outcrop, relict beach rock or sediment pavement

Mixed = hard and soft substrate

Soft = soft substrate, sediment covered

While the definition of HARD Seafloor Induration explicitly allows for sediment pavements we do not currently have any habitat polygons coded as HARD induration with sand, mud, or other sediment type for primary lithology. This is not meant to suggest that they don't exist. We simply do not yet have a good knowledge of where they exist because it's difficult to observe and quantify this type of hard induration. Therefore we currently encode HARD, MIXED, and SOFT Seafloor Induration as follows below.

HARD:

V4_Lith1 = Hard, Rock, or Boulder

V4_Lith2 = <EMPTY>

MIXED: Must have a HARD component in either the V4_Lith1 or V4_Lith2 position.

V4_Lith3 = sand/rock, sand/boulder,rock/sand, rock/mud,rock/mixed, rock/gravel mix,

rock/gravel,mud/rock,gravel/rock,cobble/boulder, boulder/sand, boulder/mud

SOFT: Can't have a HARD component in the V4_Lith1 or V4_Lith2 position.

3) CMECS crosswalk

There is a fundamental mismatch between the CMECS and SGH systems that can't easily be resolved with a conventional crosswalk. The CMECS system of class, subclass, group, subgroup, etc. is set up to express a single classification per habitat polygon (inherently assuming homogeneity within a polygon), whereas the SGH lith1/lith2 system expresses a binary classification per habitat polygon (allowing for secondary heterogeneous patches within a habitat polygon). There are two ways to resolve this within the context of CMECS:

1) CMECS has a "co-occurring element" modifier that is intended to be used to describe secondary habitat patches that occur within the primary habitat type in a habitat polygon. It seems reasonable in the context of CMECS that Lith1 can be crosswalked to the class/subclass/group/subgroup and lith2 can be expressed as a co-occurring element.
2) Crosswalk lith1 and lith2 separately and independently to CMECS and allow each habitat polygon to have two CMECS descriptors.

We prefer the second option because it is less ambiguous, and emphasizes the importance of the secondary habitat type (especially from a biological perspective). Under the first option the secondary habitat gets subsumed to the modifier level, along with many other potential modifiers, leaving less likelihood that it would be included in data analyses. CMECS folks may not like the idea of option 2, so it would be advisable to talk with them about it.

4) Two uses of the term "gravel"

CMECS uses the term "gravel" to include any rock fragment from 2mm to 4m in diameter (includes cobble and boulder), whereas SGH (and everyone else I know) uses "gravel" to include only the 2mm to 64mm size range (referred to as granule and pebble in CMECS). This is a constant source of confusion, and care must be taken in how the terms are used in a crosswalk between CMECS and SGH. For example, your Table 3 crosswalks SGH gravel to CMECS subgroup granule. It actually is an imperfect crosswalk that includes both granule and pebble in CMECS. Also, when CMECS using the term Gravelly, it can include large boulders.

5) Use of "mixture" and "mix"

Using "mixture" and "mix" to designate completely different situations seems like inviting confusion, even though they are defined. This pertains to the documentation, as only "mix" appears in a code. A possible solution would be to reword the descriptions using something like "homogeneous sediment mixture" and "heterogeneous patchy substrate", eliminating use of "mix".

We've made the recommended documentation changes for clarity.

6) Minimum mapping unit

The references to minimum mapping unit I see in the document refer to eliminating features smaller than 100 m^2, but it's not clear to me whether this standard means that the minimum resolution is also 100 m^2. I.e. should we expect that any feature that is at least 100 m^2 should be represented in the map? Some of the large polygon edges appear straighter than that, implying less resolution.

7) Finer resolution maps

We discussed and support the idea of a finer-resolution map, such as 50 m^2. At this resolution, it would be best to split the coastwide map into the 3 states.

8) Reef Specific Comments

Siletz Reef (north)

- A large area was classified as boulder in the ODFW/Romsos 2004 interpretation, but in v4 (Lith 3), this area is now classified as rock. Was this area re-interpreted?

- Areas formerly delineated as rock (low relief bedrock) in 2004 are now classified as sand in v4 (Lith 3). Was this intentional?

Seal Rock Reef

- We think the ODFW bathy data was used to classify habitats at Seal Rock reef. And there is more detail in this Lith 3 classification (two rock types) than for Siletz (one rock type). Is there a difference in interpretation methods or interpretation scales between the two reefs?

Yes the ODFW data was used to map the Seal Rock reef area. This area has not been modified from Version 3, (no change in mapping for SGH Map Version 4.0). The 2 rock types noted by reviewers are not 2 hard types but instead a hard and mixed type. No, the methods of mapping do not differ between sites. Both were classified manually for the SGH maps. An automated classification of Siletz Reef was prepared in 2004 but was not incorporated into the regional habitat map. We feel that the 2004 interpretation should be re-evaluated for possible inclusion in a regional map.

- There is additional LIth 3 rock to the north and also shoreward on the south end where the ODFW ends. What data were used to classify these new areas in v4?

Additional rock is interpreted from data collected during the ATSML program (but not groundtruthed with sediment samples

Perpetua Reef

- V4, Lith 3 rock is more coarse than ODFW's "rough" rock interpretation using sidescan,

Yes the coarse scale is a result of the ORSWMP mapping method and minimum mapping unit.

- ODFW interpretation has "islands" of "non-rock" within rocky reefs. V4 classifies as solid rock.

Again, the ODFW interpretation supports a smaller minimum mapping unit due to the higher resolution of input data.

- Some smaller polygons identified as rock by ODFW, were not delineated in v4.
- Is this a result of the scale of interpretation or something else? Was the ODFW classification referenced?

We re-visited the ODFW classification after receiving these comments and found 156 ODFW rock polygons (mapping date = 2000) to evaluate. Of these 156 polygons 10 were found to be duplicate polygons. Of the remaining 146, 89 are smaller than our 100 m2 minimum mapping unit. Of the remaining 57 polygons, 7 were assessed as not currently in existence. Given the low relief habitat found in the area these may have been covered up at some point in the 9 years between surveys. Of the remaining 50 rock polygons 36 were assessed as "OK" and 14 were determined to be currently in existence but incorrectly registered geographically (as is common with sidescan sonar data). Our recommendation is to work cooperatively with ODFW staff to explore the options for incorporating missing rocky habitat (from the 50 "OK" polygons) which will include correcting registration problems in the ODFW habitat data, deciding how to reconcile overlapping rock interpretations, etc.

Orford Reef

- No boulder habitat interpreted in v4, but we have it in the older, ODFW interpretation.

The main portion of Orford Reef has not been modified in versions 3 or 4. However, there is a large portion of the middle reef that includes Boulder habitat type classified as She/Rock/Boulder. If this habitat type differs from the older ODFW interpretation then this area should be placed on the list of items to address in the next version.

General

- Some edges of polygons in v4 are unnaturally angular, compared to polygons from ODFW data.
- Is there opportunity to review, and possibly rectify, these differences?
- It would be helpful to update the individual, high resolution reef SGH layer with the CMECS classification attribute
- It is unfortunate to not have all the high resolution data interpreted at the same scale. ODFW surveyed areas not included in the SWM interpretation appear less complex as a result, and can misinform users. Is there any possibility that these data could be reinterpreted at finer scale, or use the previous interpretations?
- Create a Survey Index layer to capture resolution of original data (if haven't already).
- Concern for scale of interpretation, as with Redfish Rocks where some areas interpreted at finer scales than other, within the same reef. And this could occur across reefs too. How will this be documented?