APPENDIX 1

Active Tectonics and Seafloor Mapping Laboratory Publication 02-01

Interim Seafloor Lithology Maps for Oregon And Washington
Version 1.0

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Project Description

As harvest levels for northeast Pacific groundfish fisheries continue to shrink, increasing attention is turning to conservation strategies and to the complex questions of the contribution of habitat to the productivity and long-term sustainability of fish stocks. The Sustainable Fisheries Act of 1996 (amending the Magnuson-Stevens Fishery Conservation and Management Act) requires regional fishery management councils to define and describe essential fish habitat. The Pacific Fishery Management Council amended its groundfish fishery management plan in October 1998 (Amendment 11) to meet this mandate. It further requires Councils to minimize adverse impacts on EFH due to fishing activities.

Those seeking solutions for the current groundfish crisis are considering controversial changes in fisheries management including gear modifications, time-area closures and areas that are closed to fishing along with more traditional approaches. However, little is known about the physiography, state, and role of marine habitats, the effects of annual and inter-decadal ocean variability, or how fishing and other human activity affect marine habitats or fisheries resource productivity on broad scales. Future management decisions to conserve and restore marine fisheries resources will depend on the availability of well-curated data sets of habitat and species distributions. These future decisions will also need to consider the impacts of fishing (and other human) activities in the context of natural changes in the environments through climatic and geologic processes.

The goal of this project is the creation and use of a comprehensive, helpful and easily accessible, multi-layer GIS database of the geologic and geophysical data for the Oregon and Washington continental margin. The project expands on one recently completed for the Oregon Department of Fish and Wildlife (ODFW) that was more limited in geographic scope (Goldfinger et al., 1998). Using similar methods and datasets, we are expanding this earlier database to include the Oregon and Washington continental shelves and margins, incorporating many important new datasets collected since the ODFW project was completed in 1998.

The Interim Seafloor Lithology Maps for Oregon and Washington are being supported by the National Marine Fisheries Service, The Cooperative Institute for Marine Resources Studies (CIMRS), Pacific States

Marine Fisheries Commission, Oregon Sea Grant, U. S. Geological Survey, the National Science Foundation, and Marine Conservation Biology Institute (MCBI).

Due to time constraints for release of the Interim Maps, complete references for data sources and investigations used in this report are not yet available. We apologize to all the original investigators who collected and interpreted geological and geophysical data used in these maps for this temporary omission, which will be rectified in the next release of the Interim Seafloor Lithology Maps for Oregon and Washington.

Oregon and Washington Groundfish Geological and Geophysical Database

Many types of geological and geophysical data (e.g., seafloor bathymetry, sidescan sonar images, sediment and rock types, active fault zones, observations and measurements from submersibles) have been collected on the U.S. West Coast continental margin. The goal of this project is to integrate these extensive datasets in a Geographical Information System (GIS) so that they can be utilized to characterize, classify and predict the distribution of geological features and associated biological entities. The Oregon-Washington GIS integrates the datasets described below into this database, designed for ease of use and interpretation. The interpretations are designed for use by both a lay audience and a scientific audience with no geologic background. The underlying data are maintained at full resolution (not included on this CD) so they may be used for quantitative studies of fisheries habitats of interest.

Sediment and Rock types

Coastal rivers supply sediments that are deposited on the continental shelf and slope off Oregon and Washington. These sediments record complex processes of dispersal, deposition, and subsequent seasonal re-suspension by surface waves on the shelf with eventual re-deposition on the slope (Harlett and Kulm, 1972; Kulm et al., 1975; Nittrouer et al., 1978; Carson et al., 1986). Superimposed upon this regime is the seasonal production of biological material (organic matter, diatoms, foraminifera, radiolarians) from the upwelling centers and their subsequent transport and deposition with the terrigenous materials at localities seaward of the upwelling centers. A large historical database of bottom sediment samples has been converted to an Arc/Info coverage to map their distribution on the Oregon and Washington shelf and margin. Individual samples have been attributed with lithologic data, biological components, organic carbon, texture, and mineralogy data. These data are from a combination of surface sampling, including surface grabs and box cores, dredge hauls, piston and gravity cores, and dart cores from a database of oil industry data donated to OSU, and submersible samples. Approximately 3500 sediment samples are included in the Oregon and Washington Interim maps.

Bathymetry/Topography

Bathymetry of the continental margin and abyssal plain off, Oregon and Washington is available in a variety of forms. Bathymetric data of the continental slope, between water depths of 600 and 3000 m, were collected during the Deep Water SeaBeam surveys of the EEZ Bathymetric Mapping Program (1984 - 1992) conducted by NOAA (National Oceanic and Atmospheric Administration) and NOS (National Ocean Service), (Lockwood and Hill, 1989). Hydrosweep and SeaBeam swath bathymetry of areas of the Washington margin was collected in 1993-1999 during NSF funded geologic investigations at OSU. Some areas of the outer continental shelf and upper slope (150-600m water depths) were surveyed with a shallow water 36 kHz multibeam system (BSSS; S. Mutula, NOAA, pers. comm. 1993). The BSSS data have been made available to the OSU group and have been incorporated in offshore geologic studies. The Monterey Bay Aquarium Research Institute (MBARI) has collected additional high-resolution bathymetry data at Heceta Bank, and Hydrate Ridge on the central Oregon shelf and slope. These data, collected using the Simrad EM-300 system and gridded at 10m resolution, present a remarkable view of the seafloor environment never before available to scientists and managers. Continental shelf bathymetry elsewhere consists of point soundings available in digital form from NGDC. New swath bathymetric data were also collected on the Oregon shelf in 1993-1995 using a deep-towed sidescan system as part of an OSU geologic investigation, funded by NOAA National Undersea Research Program. The data represent partial coverage of all of the submarine banks: Coquille, Siltcoos, Heceta, Stonewall, Daisy, and Nehalem banks.

These data have been combined and resampled to a smooth 100 m grid using a natural-neighbor gridding scheme, which produces excellent results with clumped or otherwise non-uniformly distributed data. The Washington data present several difficulties in that the data are patchier, with significant gaps. The holes are being filled by a hybrid technique of hand contouring available soundings constrained by GLORIA regional sidescan data. The contours honor the data points, and use the sonar data to extract the shapes of the features. Washington bathymetry presents a number of problems stemming from the lack of public domain uniform surveys. The NOAA EEZ surveys that were conducted are now restricted by the Navy, and the remaining data are assembled from academic surveys using a variety of multibeam systems (EEZ-SCAN 84 Scientific Staff, 1988).

Bathymetry data are used to distinguish physiographic provinces that are found in the maps (e.g. shelf, slope, canyon). The data are also used to interpret surficial lithology, mostly to distinguish rock outcrop from other types, where the data are of sufficient resolution to provide such information. Bathymetry data have also been used to predict the occurrence of rock outcrop in a regional sense based on bottom slope. Direct observations from submersibles suggests that there is a minimum slope value at which unconsolidated sediment will give way to outcrops of what lies beneath. The critical slope is determined using definitive areas of sidescan coverage and or submersible observations to determine the minimum value of slope at which underlying strata, be it rock or semi-consolidated material will be exposed (Goldfinger and McNeill, 1997; Goldfinger, 1999). This scheme is used on the continental slope, and does not work on the relatively flat abrasion platforms of the shelf, where slope and outcrop are not correlated in a regional sense due to the interference of the severe subaerial erosion that created the shelf.

Geologic Structure

Geologic maps and structure of both the coastal and nearshore region have been integrated as digital data. Structural geologic maps off shore Oregon and Washington have been completed at OSU as a part of other tectonic studies, and were used to guide interpretations of surficial geology (Goldfinger et al., 1997; McNeill et al, 1997).

Sidescan Sonar Imagery

Existing sidescan sonar imagery have been integrated in the GIS, including high-resolution AMS 150 kHz sidescan sonar imagery (Oregon shelf; Goldfinger et al., 1997); Klein 50 kHz sidescan sonar imagery (Oregon Shelf); GLORIA long-range sidescan collected as part of the EEZ project throughout the Cascadia continental slope (Oregon and Washington; EEZ-SCAN 84 Scientific Staff, 1988); deep-towed SeaMARC-1A 30 kHz sidescan (Oregon and Washington continental slope; Goldfinger et al., 1997); Simrad EM-300 backscatter data (Oregon shelf; MBARI 2001); and several other small studies conducted for either cable routes or habitat. In particular, a 1999 survey at 1m pixel resolution off central Oregon provides an anchoring high-resolution transect across the entire margin that can be used for future habitat analysis (Johnson and Goldfinger, in review). This extensive survey was funded by the National Science Foundation.

Seismic Reflection Data

Seismic reflection profiling produces sub-surface images of rock and sediment layers at and below the seafloor. While these images cannot distinguish between sediment types, they can offer a basic distinction between rock outcrops and sediments, and are used particularly where little other data exist. We have used all existing seismic reflection profiles on the Oregon and Washington margins to enhance our ability to map rock outcrops in this way. We cross check these interpretations with sidescan, core and observational data where available. Approximately 30,000 line km of reflection data have been used in this study. The sources of these data include USGS, Oregon State University, University of Washington, Western Geophysical GECO, Shell Oil Company, Arco Oil Company, Chevron Oil Company, Exxon Corporation, GEOMAR, and Scripps Institution of Oceanography

Miscellaneous

Submersible tracklines are separated and stored according to the year of fieldwork, allowing differentiation between individual study areas and the ability to cross-correlate with data stored outside the GIS database. Each submersible dive has an associated videotape and textual record of measurements and observations made by the observer as well as photographic data, and sediment and rock samples. The trackline vector layers are presently time coded to key sample sites to these external databases. Submersible observations have been integrated in a limited sense to provide ground truth for data layers used in this project.

Methodology

The datasets that have been used to produce the Interim Seafloor Lithology Maps for Oregon And Washington are by their nature patchy, and form an irregular quilt of variable data density and quality. Uniform sampling and imaging of continental margins does not yet exist, thus these maps are an attempt to glean as much information as possible from the framework of existing data. In any given area of the maps, the quantity and quality of data available varied considerably, and required a hybrid method of interpretation based on this availability. For a given area, the precedence of data types was assessed first to determine which dataset gave the most detailed information. An initial interpretation of that area was done based on this primary dataset. Other datasets were interpreted in conjunction with the primary data to modify the initial interpretation. This process was completed iteratively around the loop of available data until misfits between datasets were minimized. Each dataset adds information, and also helps calibrate the other data.

Explanation of Assigned Lithologies and Sediment Types

Lithologic Units in Core Database (primary dataset)

- mud
- clay
- silt
- sand
- gravel
- tuff
- mud/sand (mostly fine grained)
- rock

Lithologic Units in the Seafloor Lithology Maps

Oregon	**Washington**
-Mud*	-Mud
-Sand*	-Sand
-Sand/Mud*	-Clay
-Gravel	-Gravel
-Mixed Sand & Gravel	-Mixed Sand & Gravel
-Rock	-Rock/Sand
-Predicted Rock	-Rock
	-Tuff

*Indicates sediment facies (Kulm et. al., 1975)

The facies shown differ slightly for several reasons. In the case of the "tuff" lithology, this has been reported only in Washington. The predicted rock unit is not shown in Washington, pending permission to release this product at the request of the US Navy. The other differences are due to differences in reporting schemes used by different investigators. Subsequent versions of the Seafloor Lithology Maps for Oregon And Washington will resolve this issue.

Mud
This unit indicates that the seafloor is covered with fine-grained sediment, silts and clays (by definition, < 0.0625 mm diameter). Common on much of the continental slope, although rock may be present less than 1 m below the seafloor (thin sediment drape).

Sand
Indicates the seafloor is covered with coarser-grained sediments (by definition, > 0.0625 mm, and <2mm diameter), largely sand (rare gravel). Most commonly found on the inner continental shelf close to the modern coastline, but also on uplifted submarine banks on the continental shelf where bedrock is exposed.

Mud/Sand
This unit contains mixed mud and sand with predominantly fine-grained sand. Fairly common on the outer shelf and uppermost slope in transition with mud on the mid to lower slope. Also contains glauconite mixed with sand on the outer shelf ("greensand").

Gravel
This unit indicates areas covered with unconsolidated sediments of mean grain size larger than sand (by definition, >2mm diameter). Relatively uncommon in the maps due to sampling and identification techniques.

Mixed Sand & Gravel
Areas of the seafloor that have sample data and some additional supporting data verification (usually sidescan) indicating a mixed seafloor environment (e.g. sand waves. transition zones around weathering rock outcrops).

Tuff
Sediment samples and seafloor areas with high concentrations of volcanic ash.

Rock
This unit indicates rock outcrops, and includes areas of authigenic carbonate deposits. Bedrock outcrop and associated boulder fields would be present in these areas. In some cases, sidescan sonar data may penetrate through a thin sediment drape to image underlying bedrock. This may introduce error to some interpretations of rock outcrop.

Predicted Rock
This unit is predicted from multibeam bathymetric data to show consolidated or semi-consolidated harder substrate. The criteria used here is slopes greater than 10°, which have been found from submersible dives, camera tows, and sidescan sonar data to nearly always contain a high percentage of harder substrates.

Physiographic Units
A simplified list of descriptors of major physiographic and lithologic units is used in the Interim Maps to depict major provinces, and show the relationship of these provinces to the lithologic units described above. These units are called GeoHab units in the attribute tables of the map, and are described in detail the separate file "Lithologic Unit Descriptions" in the directory with this report. These descriptors are modified from Greene at al., 1999. Map polygons are drawn according to their GeoHab and Lithology. Any unique combinations of these two attributes define a polygon (Lithologic and GeoHab unit descriptions follow). Map compositions in this first release version are symbolized by GeoHab only. It is possible to edit map compositions contained on the CD to symbolize polygons according to both attributes.

Uncertainties and Error Bars

Dataset Distribution
Due to the uneven distribution and incomplete coverage of datasets, there are certain errors or uncertainties incorporated into the maps. Greater detail is provided in areas of sidescan sonar data (other than GLORIA) where swaths of 1 - 5 km provide a resolution of ~ 0.5 - 5 m. Some generalization is incorporated here, providing resolution of ~ 20 - 30 m. Where no sidescan sonar data is available, sediment type is derived from bathymetry, bottom samples, and seismic reflection data only. Resolution is reduced in these areas (50 - 100's m) and sediment type is more generalized.

Navigational Precision
The navigation systems used for collection of the geophysical data and samples varied widely, resulting in different levels of position error associates with each dataset. Bottom samples were mostly collected in the 1960's and 70's with LORAN A or LORAN C navigation, introducing errors typically on the order of hundreds of meters (most of this is in the east-west direction). Therefore interpretations from these datasets alone may have reduced resolution. However, when these data are used as ground truth for other

more precisely navigated data, the error only matters if the older data lies close to an interpreted boundary within the newer data. Sidescan sonar data, multibeam bathymetric data, and submersible dives were navigated using either civilian code, differential or P-code (military grade) GPS, with errors of ~50m, and ~10-15 m respectively.

Resolution

Resolution is the ability of a given instrument to distinguish two objects from each other (Johnson and Helferty, 1990). Multiple objects below that resolution appear as one object. The resolution of raster datasets such as multibeam bathymetry that are collected with ship mounted systems is dependant on water depth, as the individual sonar beans are defined by fixed angles in the sonar array, and these beams get larger with increasing water depth. Such datasets are usually gridded at a compromise cell size, chosen to cover the range of depths in a given survey. Thus the resolution at most given locations will be less than the instrument is capable of, and cell size differs from resolution, though the terms are often confused. Sidescan sonar imagery is usually collected by deep-towed platforms towed at a fixed height above the bottom, so their resolution does not vary as much. These data are more often gridded at a cell size that closely reflects the instrument resolution.

Extrapolation and Geological Interpretation

Sidescan sonar data interpretation has been ground-truthed during sample collection and submersible dives, and this information is then extrapolated to non-ground-truthed regions. There is uncertainty in these extrapolations, but geological knowledge of the continental margin and likely distribution of sediment and lithology types was used to reduce this uncertainty as much as possible.

Misinterpretation of sidescan sonar data (reflectance, topography, penetration)

The reflectance in the sidescan sonar image reflects both sediment grain size and rock type as well as topographic relief. On the continental shelf, minimal relief allows much of the reflectance changes to be interpreted changes in sediment type. This correlation between reflectance and sediment type or grain size has been ground-truthed in several locations. However, changes in reflectance are also introduced by changes in gain, and by location relative to the center sonar beam. In addition, differentiation between sand, mud/sand, and mud can be difficult in areas without samples or direct observations.

On the continental slope, topographic relief introduces another source of variation in reflectance. For example, both a facing slope and a region of calcium carbonate may produce high reflectivity in a sidescan image. The topographic factor must be removed by eye using bathymetric data or digitally in order to determine sediment type. The former was used throughout because model driven methods fail to account for gain changes and height changes inherent in sidescan data, and are generally inferior to a geologist's interpretation.

Sidescan sonar may also penetrate the uppermost cm's to several meters of draped seafloor sediment to image the sub-surface depending on the frequency, radiated power, and pulse length of the sonar. This may lead to misinterpretation of seafloor character if the sediment drape is thin.

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Laboratories with whom we worked in parallel to complete this map series for the U.S. West Coast, and who developed a classification scheme, which is modified and used here. Many others contributed to the Interim Maps, including but not limited to Lisa McNeill (formerly at OSU) Suzanne Lovelady, Beth Myers, Jason Chaytor, Joel Johnson, and Britta Hinrichsen of Oregon State University, Marta Mas and Miquel Marin of the University of Barcelona, Mayte Pedrosa of the University of Granada, and Susane Schmid of the University of Liverpool. We thank the crews and officers of the Research Vessels R/V Revelle, R/V Thompson, R/V Melville, R/V Ronald Brown, F/V Auriga, and R/V New Horizon. We also thank Chevron Oil, Shell Oil, Exxon Corporation, the Washington Department of Natural Resources, the US Army Corps of Engineers, Ken Piper of the Mineral Management Service, and Western Geophysical for providing seismic reflection and or sidescan sonar data.

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Appendix A

Brief descriptions of datasets used in the Interim Seafloor Lithology Maps for Oregon And Washington

Sidescan Sonar
SeaMARC 1A deep-towed sidescan sonar system. 30 kHz. Images a 0.5-5 km swath width with spatial resolution of 0.5-2.5 m. May image 0-3 meters subsurface in soft sediment. Surveys conducted by Oregon State University.

AMS 150 kHz deep-towed sidescan sonar system. 150 kHz. Images swath widths of 0.5 - 1 km with spatial resolution of 0.2 - 0.5 m. May image 0-1 m subsurface in soft sediment. Surveys conducted by Oregon State University.

Klein 50 kHz deep-towed sidescan sonar system. Images swath widths of 0.5 - 1 km with spatial resolution of 0.2 - 0.5 m. May image 0-1 m subsurface in soft sediment. Surveys conducted by Oregon State University.

GLORIA shallow-towed sidescan sonar system. 6 kHz Images a swath width of 45 km, a positional error of < 200 m, and resolution of 50 - 100 m. May image 0-20 m subsurface in soft sediment. Surveys conducted by the US Geological Survey.

Edgetech DF-1000 deep-towed sonar system. 100/500 kHz. Surveys Conducted by the Oregon Department of Fish and Wildlife.

Edgetech DTSMS-3000 deep-towed sonar system. 75 & 410 KHz. Surveys conducted by Oregon State University and the Olympic Coast National Marine Sanctuary.

Multibeam Bathymetry
SeaBeam (now called "classic") 16 and 19 beam sonars. 16 or 19 beams, swath width ~ .75 x water depth. NOAA Exclusive Economic Zone (EEZ) surveys of the 1980's. Navigational error less than 50 m. The data cover all of the Oregon continental slope. Washington EEZ data are classified. Cell size 100 m.

SeaBeam 2000 and 2112. 151 beams. Backscatter data also available. These data were collected on academic cruises by Oregon State University. Navigational error less than 20 m. Cell size 100 m. Swath width ~ 3.4 x water depth.

Simrad EM-120. 191 beams. Backscatter data also available. These data were collected on academic cruises by Oregon State University. Navigational error less than 20 m. Cell size 100 m. Swath width ~ 3.4 x water depth.

Simrad EM-300. 135 beams. Backscatter data also available. These data were collected on joint cruises by Monterey Bay Aquarium Research Institute (MBARI) and NOAA . Navigational error less than 20 m. Cell size 10 m. Swath width ~ 3.4 x water depth.

AMS-150 Isophase bathymetry collected with AMS-150 deep-towed sidescan vehicle. Number of "beams" variable. Navigational error less than 50 m.

SeaBeam 10/50 (AKA Elac Bottomchart II). 50 kHz. 126 beams. Swath width ~ 3.4 x water depth. Data collected by Oregon State University and NOAA. Swath width ~ 3.4 x water depth.

Seismic Reflection Profiles
Oregon State University sparker profiles. Collected 1965-1970. 2 kJ "sparker" analog system.
Oregon State University/Digicon Multichannel survey. 1989. 144 channel multichannel survey.
Oregon State University 3.5 kHz profiles. 1985-2002
Oregon State University 4.5 kHz deep-towed sub-bottom profiles. 1992-1999.
USGS multichannel profiles. Various years and systems.
USGS single channel profiles. Various years and systems.
USGS/Geomar multichannel profiles.
Scripps/Silver single channel profiles. 1971.
Shell Oil Company. Analog single channel profiles. 1961-1963
Chevron Oil Company digital multichannel profiles. Mid 1980's.
Chevron Oil Company analog dynamite profiles. 1960's.
Exxon digital multichannel profiles. 1980's.
Western Geophysical digital multichannel profiles. 1980's
University of Washington. Analog single channel profiles. 1970's.

Bottom Samples
Oregon State University Core Repository samples and logs. Mostly Oregon State University and University of Washington samples. 1960 present.
Oregon State University Theses, 1960-present.
University of Washington Theses, 1960-present.
Shell Oil Company dart core samples, 1960-1962.
U.S. Geological Survey databases, 1960-present.
Geological Survey of Canada.