Multibeam Sonar Surveys and Geological Habitat Mapping of the Seafloor within the Cowcod Conservation Areas (CCA), Southern California Continental Borderland

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Project Summary:

As part of a collaborative project between Oregon State University and the Southwest Fisheries Science Center, we mapped six shallow submarine banks (ranging in depth from -40m to -430m) within the Cowcod Conservation Areas, Southern California Borderland. The at-sea data collection phases of this project occurred during October and November of 2003, and November of 2005. Leg one, October 17 – 24 2003, included surveys of the Pilgrim/Kidney Bank area using a Simrad SM 2000 multibeam echosounder and the human-occupied submersible *Delta*. Leg Two, October 26, 2003 – November 6, 2003, was a multibeam only survey of 43 Fathom Bank, Cherry Bank, Osborn Bank, and Potato Bank using the SM 2000 multibeam sonar. During Leg Three, November 3 – 7, 2005, Tanner Bank was surveyed using a Reson 8111ER multibeam sonar. Bathymetric maps and interpretive maps of surficial geology were produced for each survey area to support the fisheries research activities of NOAA Fisheries Southwest Fisheries Science Center. Data products from this project include surficial geologic habitat maps, bathymetric grids, bathymetric derivative grids (Shaded relief, Slope, Standard Deviation of Elevation, and Rugosity). These new data were combined with existing submersible video and limited exiting geologic information to develop Surficial Geologic Habitat (SGH) interpretive maps for these study areas.

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1. INTRODUCTION

The Oregon State University Active Tectonics and Seafloor Mapping Lab in cooperation with NOAA Fisheries Southwest and Northwest Fisheries Science Centers (SWFSC and NWFSC) conducted extensive multibeam sonar surveys of six shallow (-40m to -430m) submarine banks within the Cowcod Conservation Areas (CCA) of the Southern California Bight (Figure 1). The at-sea portion of this project was completed during the months of October and November 2003, and November of 2005. The survey produced high-resolution (10 meter grid cell size) multibeam sonar bathymetric maps for fisheries research and management as well as for on-going geologic investigations. Biologists from NOAA Fisheries SWFSC Santa Cruz Laboratory and University of California, Santa Barbara (UCSB) have completed extensive, *in situ* surveys of the groundfish and sessile macro-invertebrate populations and their associated habitats (i.e., depth, relief, and sediment type) within this region, using video transect methodologies from the occupied submersible *Delta*. Habitat data from video imagery collected in the fall of 2002 was used to interpret and map habitats in our study. Additional groundtruth data were compiled from sediment grab and core samples available through United States Geological Survey (USGS) and National Geophysical Data Center (NGDC) reports and data distribution systems online; these data were used to interpret the seafloor habitats.

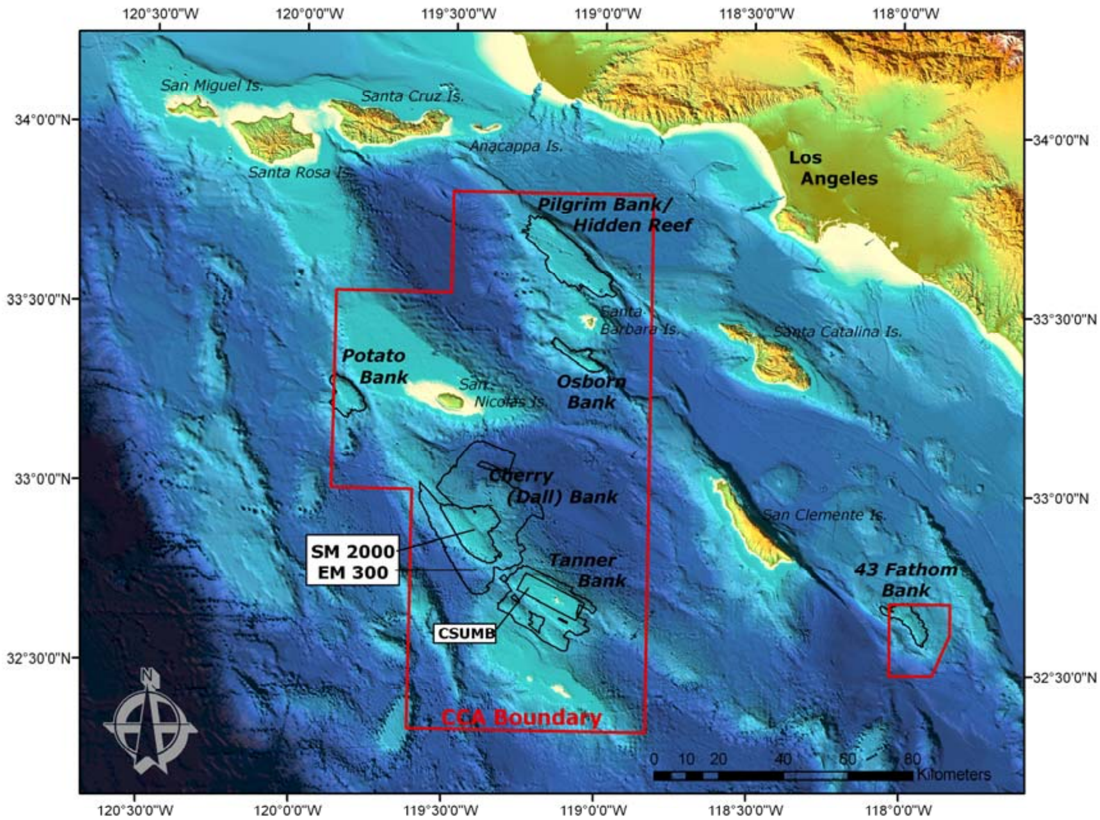


Figure 1. Overview map shows a Color-shaded, bathymetric/topographic representation of the Southern California Continental Borderland. The five shallow submarine bank survey areas are shown outlined in black.

2. METHODS

2.1 Multibeam Sonar

For this study we used a Kongsberg-Simrad Mesotech SM 2000 profiling multibeam sonar system (owned by NWFSC) and a Reson SeaBat 8111ER multibeam sonar (leased directly from Reson). These systems are composed of submarine transmit-and-receive transducer arrays and deck mounted acquisition and data storage units. The SM 2000 sonar is a dual-purpose system with the ability to co-acquire bathymetric profiles and water-column backscatter but does not acquire multibeam backscatter or pseudo-sidescan data from the seafloor. The SM 2000 has a 90° swath angle that can be formed into 128 individual profiling beams and a swath geometry of 0.71° in the across-track direction. The Reson SeaBat 8111 ER can have up to a 150° swath width formed by 101 individual beams with a nominal across-track beam width of 1.5°. These systems operate at 90 and 100 kHz respectively making them well-suited for mapping the seafloor within our targeted depth range (-40m to -430m). Simrad and Reson firmware was used to control the sensor operation; profiling data was logged using Triton-Elics® ISIS and Hypack® Hysweep software respectively.

The F/V *Velero IV* was contracted as a survey and dive platform for this project. *Velero IV* is a 110' LOA vessel with an 11' draft making it a very stable research platform with extended endurance compared to smaller vessels. The deep mounting of the single engine gave the vessel a slow and stable motion. The transmit-and-receive sonar arrays were mounted on a fabricated aluminum mounting bracket attached to a custom fabricated 6" diameter by 15' long pivoting pole (Figure 2), placing them about 2' below the ship's keel. The pole was deployed on the port side of the aft deck, immediately behind the main cabin. This pole mounted installation approach was done to minimize the effects of hydraulic disturbance created by ship motion and surface conditions, and to avoid surface bubbles created at the bow. In this respect the installation was highly successful, and good data could be acquired in seas of up to 8' at vessel speeds up to 8 knots. A Konsberg-Simard MRU-4 motion reference unit, which provided pitch, roll, and heave information, was mounted with the transducers at the end of the pole.

Figure 2. A view (looking aft) of the 15' pivoting pole mount in an upright position and showing the SM 2000 transducers, MRU, and fairing.

2.2 Acquisition/Processing

2.2.1 SM-2000

Triton Elics International (TEI) ISIS software was used to acquire and process, in near real-time, the raw profiling data into georeferenced heading- and motion-corrected beamformed swaths, which were subsequently saved in the Extended Triton Format (.XTF). A Furuno WGP-1850 WAAS-Capable DGPS acquired high-resolution (less than 3 meters) positioning information, while a SIMRAD HS-50 heading sensor (provided by Kongsberg-Simrad Mesotech) provided high-quality vessel heading information. To determine the water-column sound velocity for later use in correcting the bathymetry for acoustic refraction effects, CTD casts were deployed daily (except for Potato Bank where weather prevented over-the-side operations) using a custom programmed SeaBird 19plus CTD. Data from the *Delta* submersible's CTD were used over Pilgrim Banks.

Following completion of the survey, TEI Bathy Pro was used to post-process the XTF files prior to de-spiking and artifact removal. Corrections based on sound velocity profiles derived from the CTD casts and on NOAA tidal predictions for stations close to each survey location were applied during post-processing. Navigation and motion smoothing, mounting geometry corrections, and some automatic beam filtering also were applied. Processed XTF files were exported from BathyPro to ASCII XYZ format. Data editing was performed using the IVS Fledermaus 3-D area editor, part of the Fledermaus v6.0 suite of sonar data processing and visualization software (http://www.ivs3d.com). Following export from BathyPro, the XYZ files were pre-formatted and converted into the Pure File Magic (PFM) hydrographic sounding format and imported into the 3-D area editor. Once spikes and other artifacts were removed, each PFM file was unloaded into ASCII XYZ format. After all data from a survey site were edited a multibeam processing and gridding software package, *MB-System*, was used to create grids of the individual soundings. For these data, we used a Gaussian weighted mean algorithm with a 10 x 10 meter cell-resolution during the gridding operation. Resultant grids were produced in the netCDF format with geographic spatial parameters (WGS84 datum). Due to the widespread use of ESRI ArcGIS products, the netCDF grids were also converted to the ESRI Grid format. The MB-System program, mbm_grd2arc was used to convert netCDF to ESRI ASCII grid format.

2.2.2 SeaBat 8111

Hypack® Hysweep® was used log the survey data in .hsx (ASCII) format. Again, the Furuno WGP-1850 WAAS-Capable DGPS was used to acquire high-resolution (less than 3 meters) positioning information. A Meridian gyro-compass was used to obtain vessel heading information. Water velocity was measured with a Seabird SBE 19plus CTD.

Raw .hsx files were corrected for tide and sound velocity, and edited for spikes and artifacts as a post-processing routine using Hysweep's multibeam editing program. XYZ format data was exported from the edited .hsx files and gridded using a Gaussian weighted mean algorithm with MB System at 20 x 20 meter cell resolution. Resultant grids were produced in the netCDF format with geographic spatial parameters (WGS84 datum) and again converted to an ESRI Grid format.

2.2.3 Additional Multibeam Mapping at Cherry Bank

We used two multibeam sonar systems to map Cherry Bank, a Simrad/Mesotech SM2000 and a Simrad/Kongsberg EM300. SM2000 data is restricted to the shallow central bank-top while the EM300 data covers the deeper margins of the bank. Multibeam backscatter was acquired with the EM300 in addition to bathymetric profile data and greatly aided the subsequent mapping process. The bathymetric and backscatter data from the EM300 system is not provided with this report, but will be available at a later date.

2.3 Surficial Geologic Habitat Mapping

The surficial geologic character of each submarine bank was mapped using an interpretive geologic method similar to that described by Romsos (2004), and Romsos et al (in press). This interpretive method produces polygon-format habitat maps based on information gleaned from various data sources, including, bathymetric grids, bathymetric grid derivatives, sediment grab and core data, and observations from submersibles. Surficial Geologic Habitat (SGH) is the resulting interpretive GIS layer describing the surface geologic characteristics of each submarine bank. SGH's are composites of three unique attribute fields: 1) Structure, 2) Primary Lithology, and 3) Secondary Lithology. Structural habitats are macro-scale and range from 10's of meters to several kilometers ("Macro-Habitats" of Greene et al. 1999). Macro-Habitat types include: continental shelf (shelf), continental slope (slope), channels, and mass-wasting zones.

Primary Lithology describes the dominant sedimentary or lithologic character of each polygon, while Secondary Lithology identifies significant additional lithology that may be present. Determinations of primary and secondary lithology were based upon the available video and sample data. We were unable to strictly adhere to a percent coverage threshold due to the interpretative nature of the habitat mapping and to limitations of the groundtruth datasets. Generally, we restrict the Primary Lithology attribute field to a unique lithologic class, that class which dominates the reference data, but allow multiple classes to be listed within the Secondary Lithology field when necessary. In most cases the secondary lithology attribute of any habitat polygon is the dominant secondary habitat from the video groundtruth. Primary and Secondary Lithologic habitat classes (Table 1) include: high relief rock outcrop, low relief rock outcrop, boulder, cobble, pebble, sand and mud. Additional attribute fields are included with the SGH maps for Osborn and Tanner banks. Sedimentary Lithology, included with the SGH map for Osborn Bank, corresponds to characterizations made in a previous US Navy textural characteristics study (Heiner, 1970). At Tanner Bank we include an attribute field for the geologic units mapped by Green, et al., 1975.

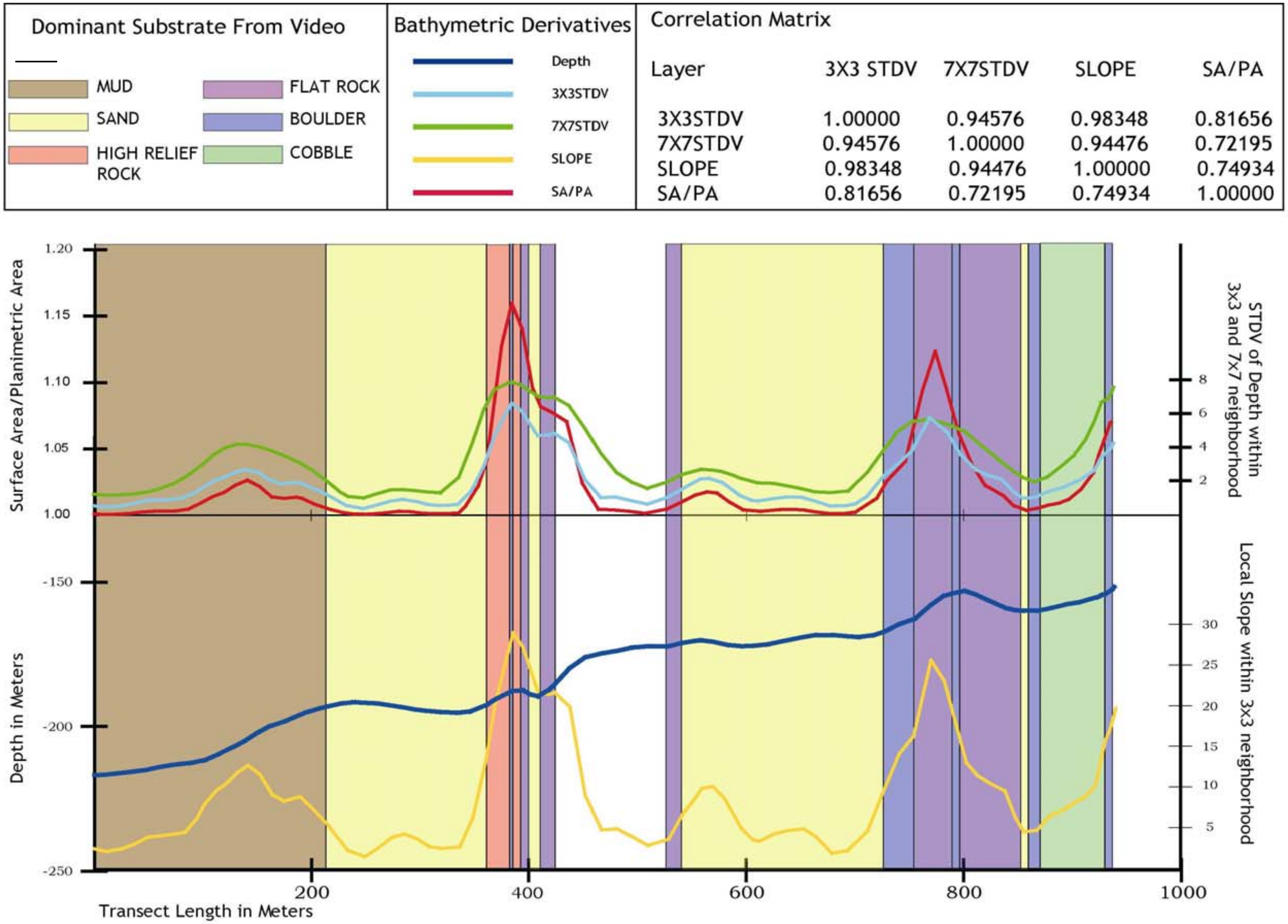
2.4 Discussion of Mapping Methods

An interpretive classification technique was used to map surficial geologic habitats of the banks within this study. While there are a number of other bathymetric classification methods (e.g. topographic DEM analyses, multivariate statistical classifications), all techniques depend on the nature, completeness and quality of the data available. The interpretive classification technique was chosen because of the heterogeneous and patchy nature of the available datasets. The lack of densely sampled groundtruth (e.g., sediment cores and grabs), a mismatch among bathymetric grid resolving power and real habitat patchiness, and bathymetric grid artifacts preclude the use of an automated or algorithmic technique. In other studies, techniques that correlate signals from bathymetric derivatives to real changes in seabed lithology or seabed character have been used to map rough or complex habitat patches (e.g. Dartnell, 2000; Kvitek et al., 2004; Whitmire, 2003). Such techniques are most appropriate when algorithmic or decision rule schemes are used and additional textural data (imagery) are available as input to the classification. We explored using the bathymetric derivatives of Slope, Rugosity (Surface Area over Planimetric Area), and Standard Deviation of Depth (STDV) at three unique neighborhood sizes to identify and classify rocky substratum. Preliminary correlation of these bathymetric derivatives with submersible observations highlighted significant problems with this classification approach (Figure 3):

1) Habitat classes are lithologic and do not necessarily have appreciable differences in topographic expressions among classes.

2) Observed habitats are patchy at a scale smaller than the resolving power of the available bathymetry and bathymetry derivatives.

3) Data artifacts virtually always cause classification errors (both commission and omission) resulting in the misassignment of habitat class.



Correlation Matrix

Layer	3X3 STDV	7X7STDV	SLOPE	SA/PA
3X3STDV	1.00000	0.94576	0.98348	0.81656
7X7STDV	0.94576	1.00000	0.94476	0.72195
SLOPE	0.98348	0.94476	1.00000	0.74934
SA/PA	0.81656	0.72195	0.74934	1.00000

Figure 3. A visual comparison of substratum patchiness during a dive transect (dive 5845, Pilgrim Bank) and the bathymetric derivatives of STDV, local slope, and Rugosity measured along the same transect. Bathymetric derivative grids were highly correlated (see the correlation matrix).

In this exploratory analysis, expansive sedimentary substrata (yellow and brown colors) seem to correlate relatively well with flat, low-rugosity, and low STDV of depth regions. However, it was not possible to distinguish among sand and mud substrata using bathymetric derivatives. We do however observe that these large unconsolidated sand and mud habitats (or patches) occur below and away from topographic highs or structural features. It's this type of geologic information that we strive to incorporate and preserve with our choice to use interpretive methods.

Large structural outcrops occur in the vicinity of the 400 m and 800 m transect distances on dive 5845. The selected bathymetric derivatives (our predictors) have similar responses and approach maximums over these regions, though we note from the video groundtruth data that the topographic features have unique and differing lithologic character. A deep feature (transect distance = 400m) has small patches of High Relief Rocky habitat interspersed with Low Relief Rock and Sand patches. A shallow feature (transect distance = 800m) has larger habitat patches of Boulder and Low Relief Rock. From this exploratory analysis in a well known region of large topographic features it remains difficult to differentiate among rocky substratum classes when using bathymetric derivatives alone. At best, we may presume that a changing bathymetric derivative "score" indicates or predicts a change in substratum, taking note of knick-points and using them to help us delineate habitat type boundaries. For this reason, we included the bathymetric derivative grids as guides to our interpretive mapping process, rather than as static layers with which to discriminate among substrata. Because of these inherent issues, a technique avoiding automated classification was used.

Table 1 shows our mix of strict and relaxed lithologic class descriptions used to classify habitats for this project. While we use typical and widely accepted class breaks in the classification, the combination of multibeam bathymetry and video/historic sample groundtruth data do not necessarily guarantee that our determinations are completely accurate at any given location. As noted, changes in lithology are not necessarily fixed to changes in topography or to changes in a topographic derivative. It is important to understand that observations made from submersibles and textural data retrieved from previous sampling efforts were used to guide our lithologic interpretations. We attempt to classify regions (areas) of homogeneous lithology based upon these samples and observations (points or transect lines of known lithology). For example when boulders are observed as the dominant habitat type over a segment of a submersible dive transect, we classify the adjacent seafloor as boulder habitat. This classification is extended until; (1) an alternate habitat type is encountered in the reference data, or (2) the topographic character of the seafloor changes.

Table 1. Description of the lithologic classification scheme.

Seafloor Substrate	Specifications	Attribute Code
High Relief Rock	High slope, rugosity, and bathy roughness	High_Rock
Low Relief Rock	Low slope, rugosity, and bathy roughness	Low_Rock
Boulder	0.25 – 3m	Boulder
Cobble	64 – 250mm	Cobble
Pebble	4-64mm	Pebble
Gravel	2-4mm	Gravel
Sand	0.6-2mm	Sand
Mud	<0.06mm	Mud

3 RESULTS

We present the results of interpretive surficial geologic habitat mapping at five shallow submarine banks within the Cowcod Conservation Areas, Southern California. All Surficial Geologic Habitat Maps are included as figures in the Appendix section due to their large size. Table two presents the total area mapped during the three legs of this project as well as the area mapped at each individual bank. We've included the multibeam sonar coverage we collected aboard the R/V Thomas Thompson in 2004 at Cherry Bank in these calculations, but have excluded the multibeam data collected by Cal State University and Monterey Bay at Tanner Bank. The total area and relative abundance of each primary and secondary habitat type over the complete survey area is presented by bank in Figures 4 and 5 as well as Table 3. We present an analysis of habitat abundance limited to shallow shelf regions in section 3.7.

Table 2. 2-D Surface (Planimetric) Area for each surveyed bank.

Bank	2D (Planimetric) Area (km2)
Pilgrim/Kidney	289.81
Potato	90.65
Osborn	54.21
Cherry*	972.53
43 Fathom	75.97
Tanner Bank**	340.39
Total	**1483.17**

* includes EM300 multibeam coverage from the 2004 TN174 cruise.
** does not include CSUMB multibeam data covering the top of the bank.

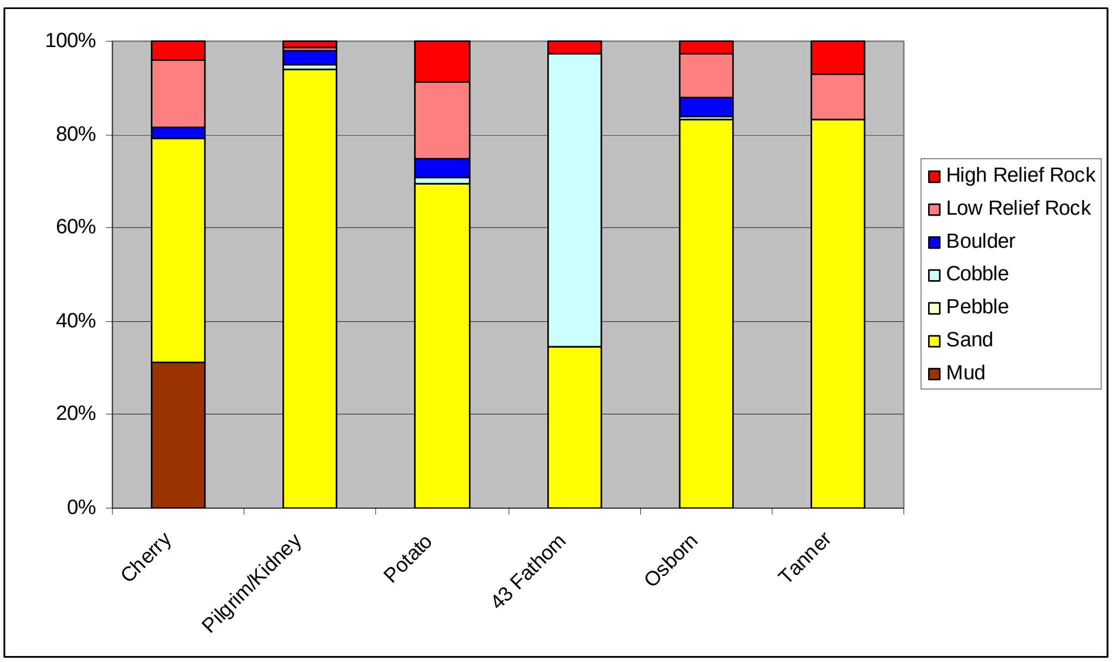


Figure 4. Relative abundance of Primary Habitat types at each survey area (percent of total habitat area).

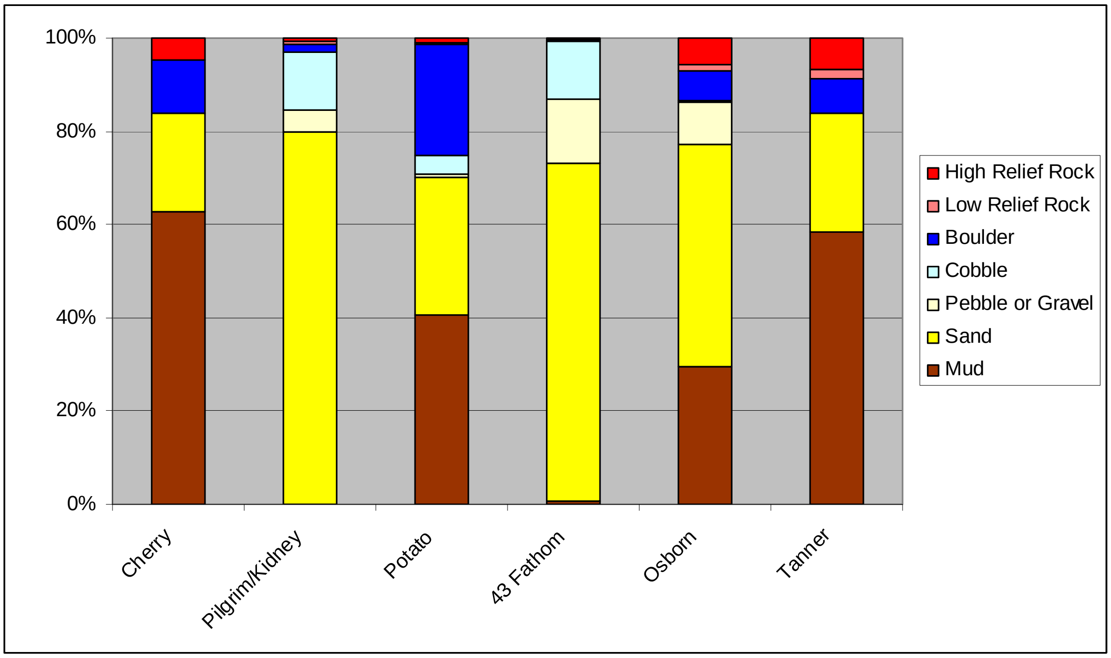


Figure 5. Relative abundance of Secondary Habitat types at each survey area (percent of total habitat area).

Table 3. Total area and relative abundance of Primary Lithology types for each submarine bank.

	Cherry	Pilgrim / Kidney	Potato	43 Fathom	Osborn	Tanner
Mud	302.73 km² 31.13 %	--	--	--	--	--
Sand	467.37 km² 48.06 %	272.75 km² 94.11 %	63.10 km² 69.61 %	26.32 km² 34.64 %	45.15 km² 83.28 %	360.10 km² 83.24 %
Pebble	--	0.04 km² 0.01 %	--	--	--	--
Cobble	--	2.62 km² 0.91 %	1.16 km² 1.28 %	47.54 km² 62.58 %	0.41 km² 0.76 %	--
Boulder	22.71 km² 2.33 %	8.76 km² 3.02 %	3.64 km² 4.02 %	0.06 km² 0.08 %	2.13 km² 3.93 %	--
Low Relief Rock	139.97 km² 14.39 %	2.23 km² 0.77 %	14.83 km² 16.36 %	--	5.10 km² 9.40 %	42.62 km² 9.85 %
High Relief Rock	39.75 km² 4.09 %	3.41 km² 1.18 %	7.92 km² 8.73 %	2.05 km² 2.70 %	1.42 km² 2.63 %	29.88 km² 6.91 %

3.1 Cherry Bank

Cherry Bank, a large feature of the southern Santa Rosa-Cortes Ridge (also called Dall Bank by Vedder, 1987), constitutes the largest contiguous survey area, covering 972.53 square kilometers (Table 2). Groundtruth information available for the Cherry Bank survey area includes 7,929 meters of previously interpreted submersible transect video (NOAA Fisheries, unpublished data) and 24 sediment samples collected from the USGS and NGDC data archives (Appendix C).

The bank is characterized by two perpendicularly opposed ridges each with significant amounts of exposed rock at the seafloor. The shallower ridge is a northwest trending elongate feature surficially composed of topographically-complex, high-relief rock outcrop and boulder. The deeper northeast trending ridge is composed of several smaller ridges of low-relief rock outcrop. High relief outcrop exists on the steep sides of these ridges while muddy sediments overlap the shallowly dipping low-relief rock on the opposite sides. Evaluation of the multibeam backscatter collected with the EM300 (NOAA NWFSC, unpublished data) reveals complex sedimentary lithologies along the margins of these rocky ridges. Areas and relative abundances of each primary habitat type are shown in Table 33 and Figure 4.

3.2 Pilgrim and Kidney Banks

Pilgrim and Kidney Banks (treated here as one large bank complex) represents the second largest contiguous survey area, covering 289.8 square kilometers (Table 2). Groundtruth information available for the Pilgrim and Kidney Bank survey area includes 32,526 m of previously interpreted submersible transects video (NOAA Fisheries, unpublished data) and 23 sediment samples collected from the USGS and NGDC data archives (Appendix D).

The Pilgrim-Kidney Bank complex is characterized by a broad and flat sandy plateau that was likely wave-cut or wave-formed during Pleistocene sea-level lowstands (Chaytor, 2006). A topographic high with complex rock outcrops exists in the Northwest corner of the survey area forming Pilgrim Bank. We map a series of high relief rock outcrops at Pilgrim Bank. Observations made from the Delta submersible during our 2003 survey cruise confirm the presence of high relief outcrops and reveal a complex mixed-lithologic habitat composed of eroded materials (boulder to pebble) at the base of the rocky outcrops. The rocky outcrops are distributed narrowly along a northwest trending ridge and the transition to a sandy primary lithology away from the outcrop is abrupt. Kidney Bank in contrast is characterized by low relief outcrops of boulder and cobble within a larger flat plain of sand. Areas and relative abundances of each primary habitat type at Pilgrim and Kidney Banks are shown in Table 33 and Figure 4.

3.3 Potato Bank

The Potato Bank multibeam and habitat survey area covers 90.7 square kilometers (Table 2). Groundtruth information available for the Potato Bank survey area includes 4,035 meters of previously interpreted submersible transects video (NOAA Fisheries, unpublished data) and 12 sediment samples collected from the USGS and NGDC data archives (Appendix E).

Potato Bank is another elongate NW trending feature on the Santa Rosa-Cortes Ridge. We map the bank-top as a large area of mixed low- and high-relief outcrops. A significant amount of boulder habitat is mapped at the southern bank-top. Bank flanks exhibit much less topographic roughness and sample data indicates that they are composed of sandy sediments. Areas and relative abundance of each primary habitat type is shown in Table 3 and Figure 4.

3.4 43 Fathom Bank

43 Fathom Bank multibeam and habitat survey area covers 75.97 square kilometers (Table 2). Groundtruth information available for the 43 Fathom Bank survey area includes 5,775 meters of previously interpreted submersible transects video (NOAA Fisheries, unpublished data) and 11 sediment samples collected from the USGS and NGDC data archives (Appendix F).

We mapped a very small area of high-relief rocky outcrop located in the center of the flat and round bank-top. SWFSC video transects noted several pinnacles and patches of boulder within this region. The elongate flanks of the bank are primarily sand with secondary components of mud to the north, gravel to the east and cobble to the south. A small channel is visible in the bathymetry just east of the bank-top as is a steep and rough slope is mapped as high-relief outcrop immediately to the west. The areas and relative abundances of each primary habitat type are shown in Table 3 and Figure 4.

3.5 Osborn Bank

Osborn Bank, the smallest survey area, covers 54.2 square kilometers (Table 2). Groundtruth information on habitats for Osborn Bank includes 5,824 meters of transect video from *Delta* submersible (NOAA Fisheries, unpublished data) and 15 sediment samples collected from the USGS and NGDC data archives (Appendix G). Area covered by each primary habitat type is shown in Table 8.

About 15% of Osborn Bank was rocky habitat (including Boulder, Table 3). The shelf habitat distribution is similar to that of Potato Bank, predominately rocky with flat sandy margins. Previous work by Heiner 1970 greatly enhanced our knowledge of the sedimentary lithology of Osborn Bank. Heiner mapped the sedimentary characteristics of Osborn Bank based on the textural analysis of ten core samples and thirty six grab samples collected in 1967. Surficial lithologic information from Heiner's maps was transferred to our habitat map polygons and may be viewed within their attribute tables.

3.6 Tanner Bank

The Tanner Bank SGH map covers 432.6 square kilometers (Table 2). Groundtruth information on habitats for Osborn Bank included 8,043 meters of transects video from *Delta* submersible (NOAA Fisheries, unpublished data) and 15 sediment samples collected from the USGS and NGDC data archives (Table 16, appendix). Area covered by each primary habitat type is shown in Table 3.

The distribution and abundance of primary habitats over Tanner Bank is similar to the other shallow submarine banks mapped here. Unconsolidated sands cover the greatest portion of the bank (83.24 %, Table 3 and Figure 6). High and Low relief rock is mapped over three large outcrops, the largest occurring atop of the main portion of Tanner Bank. Two smaller outcrops occur over the shoaling extended survey area to the south west between Tanner and Cortez Bank. We note an absence of boulder primary habitat at Tanner, possibly a commission error due to the interpretive nature of the classification.

3.7 Shelf Habitats (depths -40 to -300m)

In an effort to most accurately describe and contrast the habitat types of each surveyed bank we present an additional analysis of shelf (structural habitat type) habitats (Tables 9 and 10). Shelf habitats are found over the shoaling banktops generally shallower than 300m and were completely surveyed during the multibeam sonar survey phase of this project. Slope and channel habitats occurring over the margins of the banks cannot be considered to have complete coverage as they typically extend below the multibeam sonar depth limit. Therefore we do not attempt to make comparisons or draw conclusions about habitat types and habitat distributions over these incomplete survey areas.

From Figure 6 and Table 4 we note that Cherry Bank has the greatest abundance of High Relief Rock and Boulder Habitat. Potato Bank and Osborn Bank have similar proportions of High Relief Rock, Low Relief Rock, Boulder, and Sand Habitat. All three of these banks have greater than 58% of their shallow shelf habitats occurring as hard substrate. In comparison our habitat mapping reveals that the Pilgrim-Kidney Bank complex and 43 Fathom Bank exhibit much different Shelf lithology. Both banks are dominated by large expanses of Sand totaling 95.65 and 93.80 % respectively. We note a conspicuous absence of Boulder Primary Habitat at Tanner Bank, again a possible commission error given our interpretive classification methods.

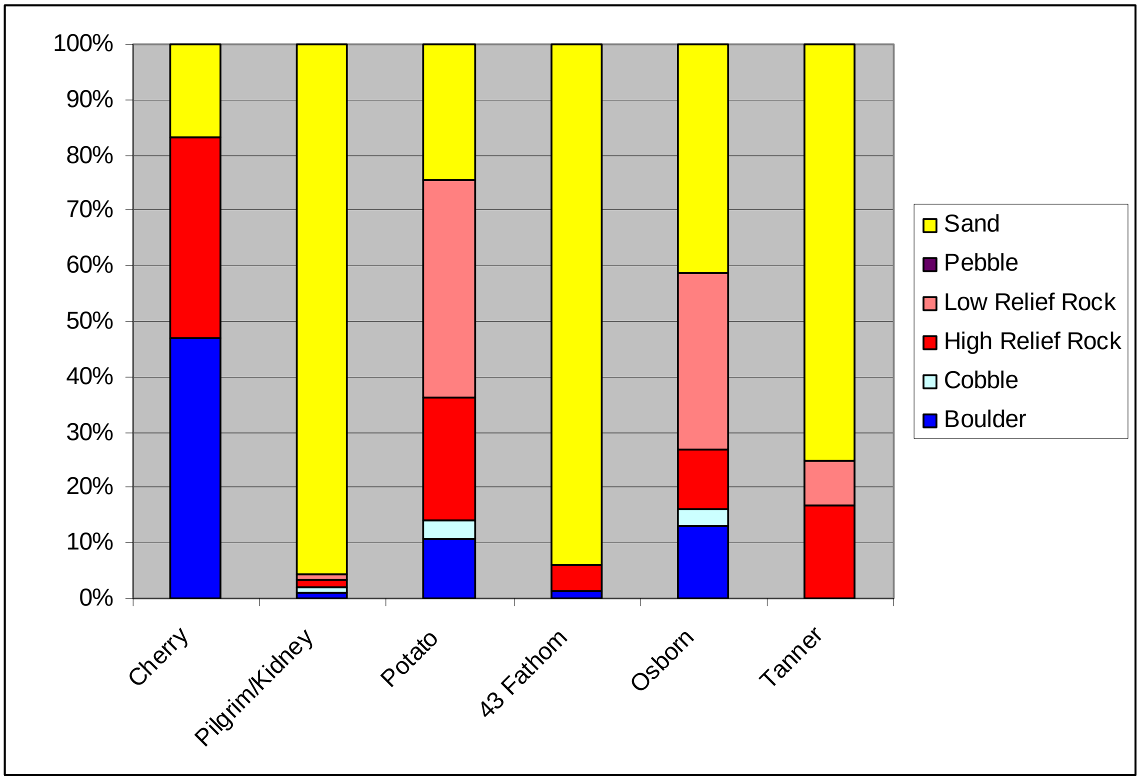


Figure 6. Relative abundance of Primary Habitat types for Shelf (Structure) habitats at each survey area (percent of total habitat area).

Table 4. Total area (Km2) and relative abundance of Primary Lithology types for Shelf (Structure) habitats at each submarine bank.

Primary Lithology	Cherry	Pilgrim / Kidney	Potato	43 Fathom	Osborn	Tanner
Boulder	22.04 km² 46.85 %	2.43 km² 1.01 %	3.64 km² 10.74 %	0.06 km² 1.48 %	1.75 km² 13.12 %	--
Cobble	--	2.62 km² 1.09 %	1.16 km² 3.41 %	--	0.41 km² 3.10 %	--
High Relief Rock	17.03 km² 36.21 %	3.41 km² 1.42 %	7.46 km² 22.01 %	0.19 km² 4.72 %	1.42 km² 10.68 %	27.55 km² 16.66 %
Low Relief Rock	--	1.93 km² 0.81 %	13.33 km² 39.29 %	--	4.23 km² 31.67 %	13.54 km² 8.18 %
Pebble	--	0.04 km² 0.02 %	--	--	--	--
Sand	7.97 km² 16.94 %	229.25 km² 95.65 %	8.33 km² 24.55 %	3.70 km² 93.80 %	5.53 km² 41.43 %	124.30 km² 75.16 %
Total	**47.04** km²	**239.68** km²	**33.93** km²	**3.95** km²	**13.34** km²	**165.38** km²

3.8 Data Products

Sediment data were collected from the National Geophysical Data Center (NGDC) and USGS online databanks. We also collected sediment sample data from reports and papers to compile our own sample database consisting of 867 records. All available data were retained and each record includes sample number, cruise number, position information, lithologic description, and gear type. Records of some sample data, particularly from the 1970's Velero IV cruises, were retained in the database even though the sample may not have been recovered or data for that sample may be missing. Additionally, several samples are included twice due to unresolved mismatches in the reported sample location among various data archives. A complete Microsoft Excel spreadsheet is included with the digital materials of this report. Samples that occur within the survey areas, a subset of samples from the spreadsheet, are included in the appendix.

All 10 meter resolution gridded multibeam datasets in UTM projections are included with the digital materials of this report. All polygon shapefile and coverage format surficial geologic habitat maps with complete metadata reference material are also included with the digital material.

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Appendices and Plates

Appendix A. List of Data Products

Data Layer	Data Format 1/ Projection(s)	Data Format 2/ Projection(s)	Resolution/ Neighborhood Size
Bathymetric Grids	**Arc Grid/ utm/geographic**	**netCDF/ geographic**	**10m**
Shaded Relief Grids	**Arc Grid/ utm**	**NA**	**10m**
STDV Grids	**Arc Grid/ utm**	**NA**	**10m/ 3x3/7x7**
Slope Grids	**Arc Grid/ utm**	**NA**	**10m/ 3/3**
SA/PA Grids	**Arc Grid/ utm**	**NA**	**10m**
Sample Data	**Arc Coverage**	**Arc Geodatabase Feature Class**	**NA**
Sediment/Core Sample Database	**Microsoft Excel/ASCII**		

Appendix B. List of cruises and cruise information for the sample database.

Year	Cruise ID	Organization	Ship	Area
1975	V-1-75-SC	USGSMP	Velero IV	ALL
1974	L-2-74-SC	USGSMP	Velero IV	ALL
1976	L-2-76-SC	USGSMP	Velero IV	ALL
1979	S-3-79-SC	USGSMP	Velero IV	ALL
1976	S-1-76-SC	USGSMP	Velero IV	ALL
1978	L-2A-78-SC	USGSMP	Velero IV	ALL
1967	T-AGOR 5	USN	Charles H. Davis	ALL
1970	H09112	NMNH	McArthur	43 Fathom
1980	1505	USC	Velero IV	43 Fathom
1956	274	USC	Velero IV	43 Fathom
1968	942	USC	Velero IV	43 Fathom
1968	947	USC	Velero IV	43 Fathom
1969	H09067	NMNH	Pathfinder	Cherry
1998	CRNR02 NH	SIO	New Horizon	Cherry
1970	1099	USC	Velero IV	Cherry
1972	1187	USC	Velero IV	Cherry
1975	1348	USC	Velero IV	Cherry
1976	1357	USC	Velero IV	Cherry
1976	1358	USC	Velero IV	Cherry
1977	1394	USC	Velero IV	Cherry
1977	1396	USC	Velero IV	Cherry
1978	1432	USC	Velero IV	Cherry
1957	307	USC	Velero IV	Cherry
1959	385	USC	Velero IV	Cherry
1965	670	USC	Velero IV	Cherry
1976	L276SC	USGSMP	Samuel P. Lee	Osborn, Potato
1976	1349	USC	Velero IV	Osborn
1965	768	USC	Velero IV	Osborn
1970	VA-70	SIO	Velero IV	Pilgrim-Kidney
1970	1099	USC	Velero IV	Pilgrim-Kidney
1976	1349	USC	Velero IV	Pilgrim-Kidney
1976	1353	USC	Velero IV	Pilgrim-Kidney
1977	1379	USC	Velero IV	Pilgrim-Kidney
1956	249	USC	Velero IV	Pilgrim-Kidney
1957	307	USC	Velero IV	Pilgrim-Kidney
1959	371	USC	Velero IV	Pilgrim-Kidney
1978	L278SC	USGSMP	Samuel P. Lee	Pilgrim-Kidney
1979	S379SC	USGSMP	Sea Sounder	Pilgrim-Kidney, Osborn
1976	1358	USC	Velero IV	Potato
1957	307	USC	Velero IV	Potato
1976	AGAZ	USC	Agassiz	Potato, Pilgrim-Kidney

Appendix C. Sediment and core data within the Cherry Bank survey area.

Latitude	Longitude	Depth	Description	Site	Cruise	Device
33.102	-119.45	1060	sandy mud or ooze	26027-C	1396	core, box
33.02	-119.52	475	Sand, silty, galuconitic (pelletal) foraminiferal; 5Y7/2 to 5Y5/2; sparse angular to subrounded mineral grains; massive with indistinct color streaks	L2-78-223	L-2A-78-SC	Dart Core
32.992	-119.51	413	Claystone, silty, calcareous; 5Y6/1; massive, hard,carbonate cement, low density	SCS-7	L-2-74-SC	Dart Core
32.993	-119.38	551	SAND	SD00000741.01	H09067	core
32.918	-119.5	354	Claystone, calcareous; massive; 5Y6/1; massive, low density	SCS-67	L-2-74-SC	Dart Core
32.917	-119.4	216	gravel	14414	1099	dredge (old fmt)
32.918	-119.4	170	no description	24910	1358	core, box
32.808	-119.26	536	Claystone, silty, diatomaceous, calcareous; 5Y4/1 to 5Y8/1;laminated, very low density	SCS-112	L-2-74-SC	Dart Core
32.932	-119.29	677	Claystone(?), silty; 5Y6/1 and 5Y4/1; laminated, glauconitic, crystalline carbonate	SCS-32	L-2-74-SC	Dart Core
32.885	-119.42	125	Claystone, silty, tuffaceous; 5Y6/1; massive, deformed, low-density	LCB-126-10	L-1-74-SC	Dart Core
32.872	-119.41	120	Claystone, silty, highly organic; 5Y6/1; moderately indurated, low-density	LCB-126-8	L-1-74-SC	Dart Core
32.878	-119.41	117	Siltstone, sandy, micaceous; 5GY6/1; poorly indurated	LCB-126-9	L-1-74-SC	Dart Core
32.83	-119.37	158	Claystone, silty, highly organic; 5Y6/1; sheared moderately indurated	LCB-126-2	L-1-74-SC	Dart Core
32.837	-119.37	141	Claystone, silty, micaceous, highly organic; 5Y5/2; fractured, laminated	LCB-126-3	L-1-74-SC	Dart Core
32.838	-119.44	370	Siltstone, clayey, micaceous; fragmented; 5GY6/1	SCA-472	V-1-75-SC	Dart Core
32.848	-119.44	350	Claystone, silty, micaceous, calcareous; N4, 5Y4/1; mottled; massive, low density	SCA-474	V-1-75-SC	Dart Core
32.82	-119.47	1110	muddy sand	25992-C	1394	core, box
32.862	-119.5	1425	sandy mud or ooze	25995-C	1394	core, box
32.9	-119.44	130	Claystone, silty, highly organic; 5Y6/1 and 5Y4/1, faintly laminated, 15 +/- degrees dip	LCB-126-12	L-1-74-SC	Dart Core
32.767	-119.42	1300	gravelly mud	25990-C	1394	core, box
32.71	-119.38	704	CLAY HARD,CHALK	SD00000732.01	H09067	core
32.917	-119.4	216	gravel	14414	1099	dredge (old fmt)
32.858	-119.38	117	gravel	14415	1099	dredge (old fmt)

Appendix D. Sediment and core data within the Pilgrim and Kidney Banks survey area.

Latitude	Longitude	Depth	Description	Site	Cruise	Device
33.765	-119.222	242	camera	25593	1379	core, box
33.76	-119.227	230	sand	25594	1379	core, box
33.747	-119.228	215	sand	25592	1379	core, box
33.753	-119.21	200	sand	25591	1379	core, box
33.758	-119.208	223	sandy gravel	5128	307	grab
33.705	-119.125	169	gravel	5136	307	grab
33.642	-119.1	198	sandy gravel	5137	307	grab
33.61	-119.042	219	sandy gravel	5138	307	grab
33.587	-118.987	199	gravel	5139	307	grab
33.715	-119.238	300	terrigenous clastic sedimentary rock	351	L278SC	core, dart
33.7	-119.242	260	terrigenous clastic sedimentary rock	352	L278SC	core, dart
33.703	-119.18	133	plutonic igneous rock	028D	VA-70	dredge (old fmt)
33.6	-119.018	165	terrigenous clastic sedimentary rock, sandstone	241A	S379SC	core, dart
33.575	-119.018	125	volcanic igneous rock, basalt oxidized	244	S379SC	core, dart
33.565	-119.018	140	terrigenous clastic sedimentary rock, MUDSTONE FROM SCRAPINGS OFF CORE BARRELS	245A	S379SC	core, dart
33.56	-119.01	150		246A	S379SC	core, dart
33.588	-118.977	43	muddy sand	4116	249	grab
33.62	-119.007	378	gravel	14391	1099	dredge (old fmt)
33.605	-119.017	225	muddy sand	14392	1099	grab
33.587	-119.038	153	sandy gravel	14393	1099	grab
33.65	-119.117	177	no description	24171	1349	core, box
33.65	-119.15	29	sand	6103	371	grab
33.61833	-119.09	157	Andesite, porphyritic; N3; enstatite, pyroxene	LCB-108-2B	L-1-74-SC	Dart Core

Appendix E. Sediment and core data within the Potato Bank survey area.

Latitude	Longitude	Depth	Description	Site	Cruise	Device
33.308	-119.87	345	Claystone, silty, micaceous, calcareous; 5Y6/1 to 5Y4/1;laminated; minute clay-filled fractures; low density	L2-76-70	L-2-76-SC	Dart Core
33.293	-119.88	152	Claystone, silty, micaceous, pumiceous (?); 5Y6/1; massive, low density	L2-76-71	L-2-76-SC	Dart Core
33.285	-119.89	310	Claystone, silty, micaceous, calcareous; 5Y4/1; massive; low density	L2-76-72	L-2-76-SC	Dart Core
33.258	-119.88	340	Diabase (?), amygdaloidal; 5Y4/1; subophitic texture; fresh, hard, possibly a rafted erratic	L2-76-76	L-2-76-SC	Dart Core
33.245	-119.88	300	Siltstone, clayey, micaceous; N6; fractured; moderately hard	L2-76-77	L-2-76-SC	Dart Core
33.222	-119.87	265	Siltstone, clayey, micaceous; N4 to N7; massive (?); fractured fragments; hard, relatively dense	L2-76-79	L-2-76-SC	Dart Core
33.213	-119.86	332	Siltstone, clayey, micaceous; N4 to N6; fractured and sheared; hard, relatively dense	L2-76-80	L-2-76-SC	Dart Core
33.292	-119.86	115	Claystone, silty, micaceous; 5Y5/2; massive, fractured	LCB-112-3	L-1-74-SC	Dart Core
33.285	-119.87	100	Siltstone, clayey, micaceous; 5Y6/1; minutely bioturbated, fractured, indurated	LCB-112-4	L-1-74-SC	Dart Core
33.277	-119.87	155	Siltstone, clayey, tuffaceous; 5Y6/1, composed primarily of glass shards	LCB-112-5	L-1-74-SC	Dart Core
33.238	-119.8	105	Siltstone, micaceous, clayey; 5Y6/1; fractured, indurated	LCB-113-3	L-1-74-SC	Dart Core
33.25	-119.83	86	gravel	5123	307	grab

Appendix F. Sediment and core data within the 43 Fathom Bank survey area.

Latitude	Longitude	Depth	Description	Site	Cruise	Device
32.687	-118.04	370	Sandstone	113	S379SC	core, dart
32.673	-118.04	260	Claystone	115	S379SC	core, dart
32.672	-118.04	260	Claystone	115A	S379SC	core, dart
32.667	-117.96	250	sandy gravel	28874-C	1505	core, box
32.658	-117.97	99	muddy sand	4668	274	core, gravity
32.658	-117.94	267	SAND COARSE, HARD	SD00000322.01	H09112	unknown device
32.635	-117.96	234	muddy sand	12027	942	grab
32.598	-117.93	245	Claystone, silty, micaceous, highly organic, 5Y5/2, massive, poorly indurated, very low density	LCB-141-5	L-1-74-SC	Dart Core
32.607	-117.93	190	Claystone, highly organic, 5Y5/2, deformed	LCB-141-6	L-1-74-SC	Dart Core
32.613	-117.94	175	Siltstone, 5Y5/2	LCB-141-7	L-1-74-SC	Dart Core
32.603	-117.92	345	gravel	12103	947	grab

Appendix G. Sediment and core data within the Osborn Bank survey area.

Latitude	Longitude	Depth	Description	Site	Cruise	Device
33.34	-119.018	310	terrigenous clastic sedimentary rock	208	S379SC	core, dart
33.345	-119.01	210	terrigenous clastic sedimentary rock	209	S379SC	core, dart
33.417	-119.132	380	terrigenous clastic sedimentary rock	248	S379SC	core, dart
33.417	-119.138	230	terrigenous clastic sedimentary rock	249A	S379SC	core, dart
33.413	-119.15	260	muddy sand	250	S379SC	core, dart
33.3566667	-119.04		silty sand	353-1	T-AGOR 5	Hydroplastic Gravity
33.3616667	-119.00833		sand	353-17	T-AGOR 5	Hydroplastic Gravity
33.3566667	-119.02333		sand	353-18	T-AGOR 5	Hydroplastic Gravity
33.3816667	-119.10333		clayey sand	353-23	T-AGOR 5	Hydroplastic Gravity
33.39	-119.06333		silty sand	353-38	T-AGOR 5	Hydroplastic Gravity
33.3866667	-119.04		gravely sand	353-40	T-AGOR 5	Hydroplastic Gravity
33.38538	-119.09151	155	mud or ooze	135	L276SC	core, dart
33.37702	-119.09624	235	sand	136	L276SC	core, dart
33.385	-119.09167	155	Siltstone, clayey, micaceous, pumiceous (?) in part; 5Y5/1;massive; low density	L2-76-135	L-2-76-SC	Dart Core
33.37667	-119.09667	235	Siltstone, clayey, claystone, silty; diatomaceous; 5Y8/1; indistinctly laminated; low density	L2-76-136	L-2-76-SC	Dart Core

Appendix H. Sediment and core data within the Tanner Bank survey area.

Latitude	Longitude	Depth	Description	Site	Cruise	Device
32.76167	-119.25167	242	Claystone, silty, micaceous, diatomaceous, calcareous; 5Y5/1; low density	SCA-14	V-1-75-SC	Dart Core
32.73167	-119.07833	440	Siltstone, clayey, diatomaceous, micaceous; 5Y5/1; massive,low density	SCA-171	V-1-75-SC	Dart Core
32.61167	-119.08833	265	Claystone, silty, calcareous; 5Y6/1; low density	SCA-343	V-1-75-SC	Dart Core
32.78000	-119.23333	315	Claystone, silty, pelletal, phosphatic; 5Y4/1 to 5Y6/2; hard, fractured	SCA-5	V-1-75-SC	Dart Core
32.74333	-119.16833	90	Siltstone, clayey, micaceous, dolomitic(?) cement; 5Y7/2; hard, fractured, calcareous	SCA-71	V-1-75-SC	Dart Core
32.76500	-119.30333	474	Claystone, silty, calcareous, diatomaceous; 5GY6/1 to 5GY4/1; indistinctly laminated, minute filled fractures; low density; dip 22 degrees +/-	SCS-119	L-2-74-SC	Dart Core
32.75333	-119.31333	465	Claystone, calcareous, tuffaceous(?), diatomaceous; 5Y8/1 to 5Y4/1; laminated, microfractures; low density; dip 25-27 degrees	SCS-121	L-2-74-SC	Dart Core
32.68333	-119.11167	60	Basalt, vesicular; 5Y4/1; ferromagnesian minerals altered;contains some interstitial augite	SCS-79	L-2-74-SC	Dart Core
32.68833	-119.12000	47	Augite diabase, subophitic; 5Y5/2; contains altered olivine	SCS-80	L-2-74-SC	Dart Core
32.69000	-119.19000	110	Claystone, silty, calcareous; 5Y7/1 and 5GY6/1; laminated; minute filled fractures; phosphorite(?) blebs and streaks; low density; 5 degrees + dip	SCS-89	L-2-74-SC	Dart Core
32.70167	-119.18000	75	Augite olivine basalt, alkaline; 5Y4/1; contains ilmenite and secondary apatite; questionably in place	SCS-91	L-2-74-SC	Dart Core
32.70833	-119.17333	75	Siltstone, clayey, micaceous, calcareous; 5Y6/1; massive,relatively hard	SCS-92	L-2-74-SC	Dart Core
32.74000	-119.14167	100	Claystone, silty, diatomaceous, calcareous; 5Y6/1; massive,faintly mottled, compact; low density	SCS-97	L-2-74-SC	Dart Core
32.75333	-119.13000	352	Claystone, silty, calcareous; 5Y6/1; massive, low density	SCS-99	L-2-74-SC	Dart Core
32.71333	-119.25000	125	Claystone, highly organic, tuffaceous; 5Y4/1; fractured, moderately indurated, low density	LCB-127-2	L-1-74-SC	Dart Core
32.72333	-119.24500	106	Sandstone, feldspathic, fine to coarse-grained, N6 to N7; massive; calcareous cement	LCB-127-3	L-1-74-SC	Dart Core

Appendix H. Continued.

Latitude	Longitude	Depth	Description	Site	Cruise	Device
32.73167	-119.24167	107	Siltstone, clayey, micaceous, burrowed; 5GY/6; massive, indurated	LCB-127-4B	L-1-74-SC	Dart Core
32.73833	-119.23500	111	Claystone, silty, micaceous; 5GY6/1; massive, moderately indurated	LCB-127-5	L-1-74-SC	Dart Core
32.74667	-119.22667	108	Mudstone, micaceous; 5GY6/1; massive, indurated	LCB-127-6	L-1-74-SC	Dart Core
32.75333	-119.22333	125	Diatomite, clayey; 5Y8/1 to 5Y6/1; massive, fractured, moderately indurated, very low density	LCB-127-7	L-1-74-SC	Dart Core
32.63500	-119.22167	195	Claystone, highly organic, bentonitics; 5Y2/1 and 5Y4/1; faintly laminated, moderately indurated	LCB-128-1	L-1-74-SC	Dart Core
32.65000	-119.23167	171	Claystone, organic; 5Y7/2; and 5Y4/1; fractured	LCB-128-3	L-1-74-SC	Dart Core
32.67167	-119.25500	135	Claystone, diatomaceous; N7 to 5Y6/1; laminated, 20 degrees +/- dip; tar-filled fractures	LCB-128-6	L-1-74-SC	Dart Core
32.67667	-119.26333	130	Claystone, highly organic; 5Y6/1 and 5Y6/1; tar-filled fractures	LCB-128-7	L-1-74-SC	Dart Core
32.59833	-119.19333	163	Claystone, organic, 5Y4/1; tar (?)-saturated	LCB-129-6B	L-1-74-SC	Dart Core
32.72500	-119.27670	553	sedimentary (detrital/fragmental or clastic), mudstone (lutite)	64D	CRNR02NH	dredge, rock
32.73000	-119.27670	394	sedimentary (detrital/fragmental or clastic), sandstone/arenite	65D	CRNR02NH	dredge, rock

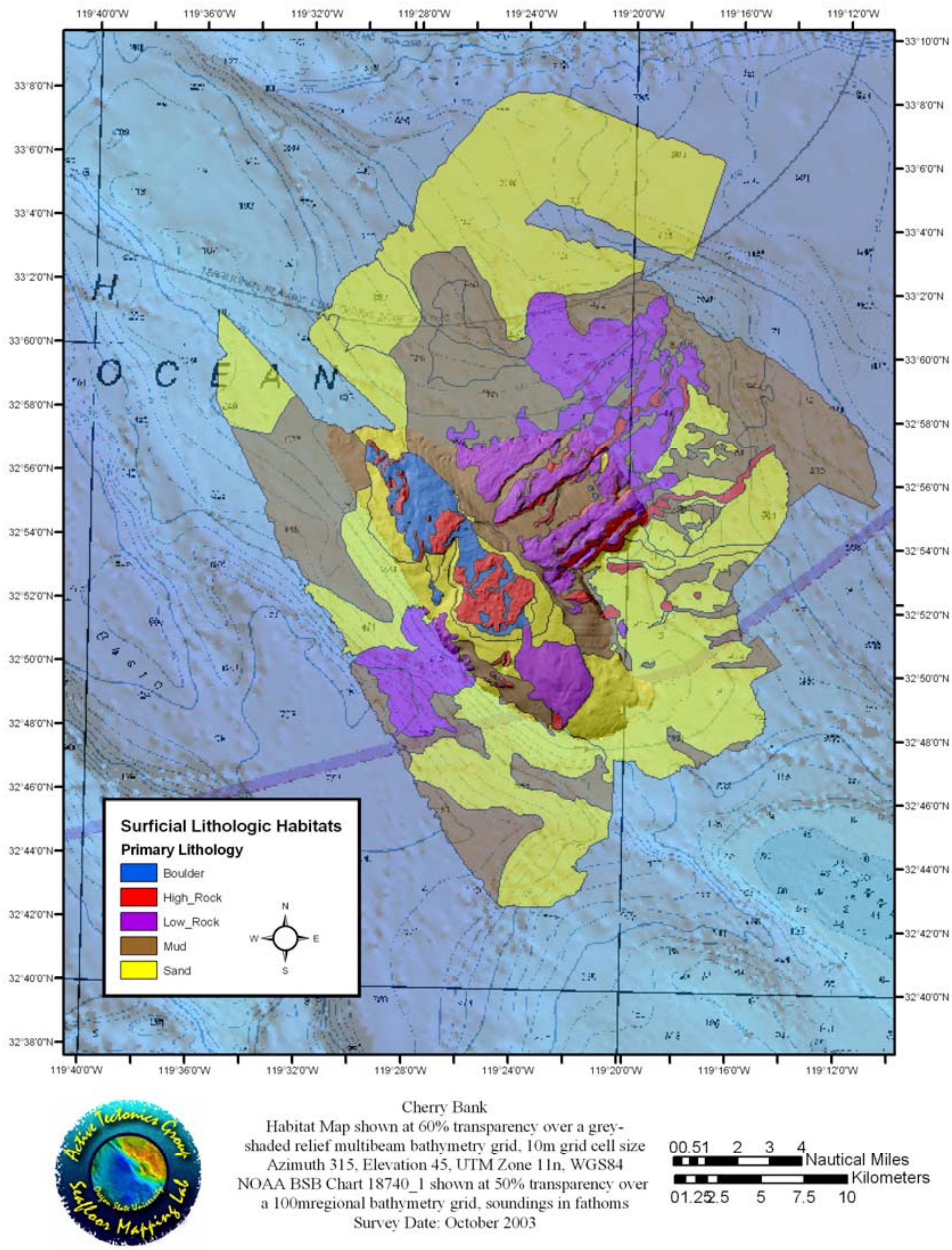
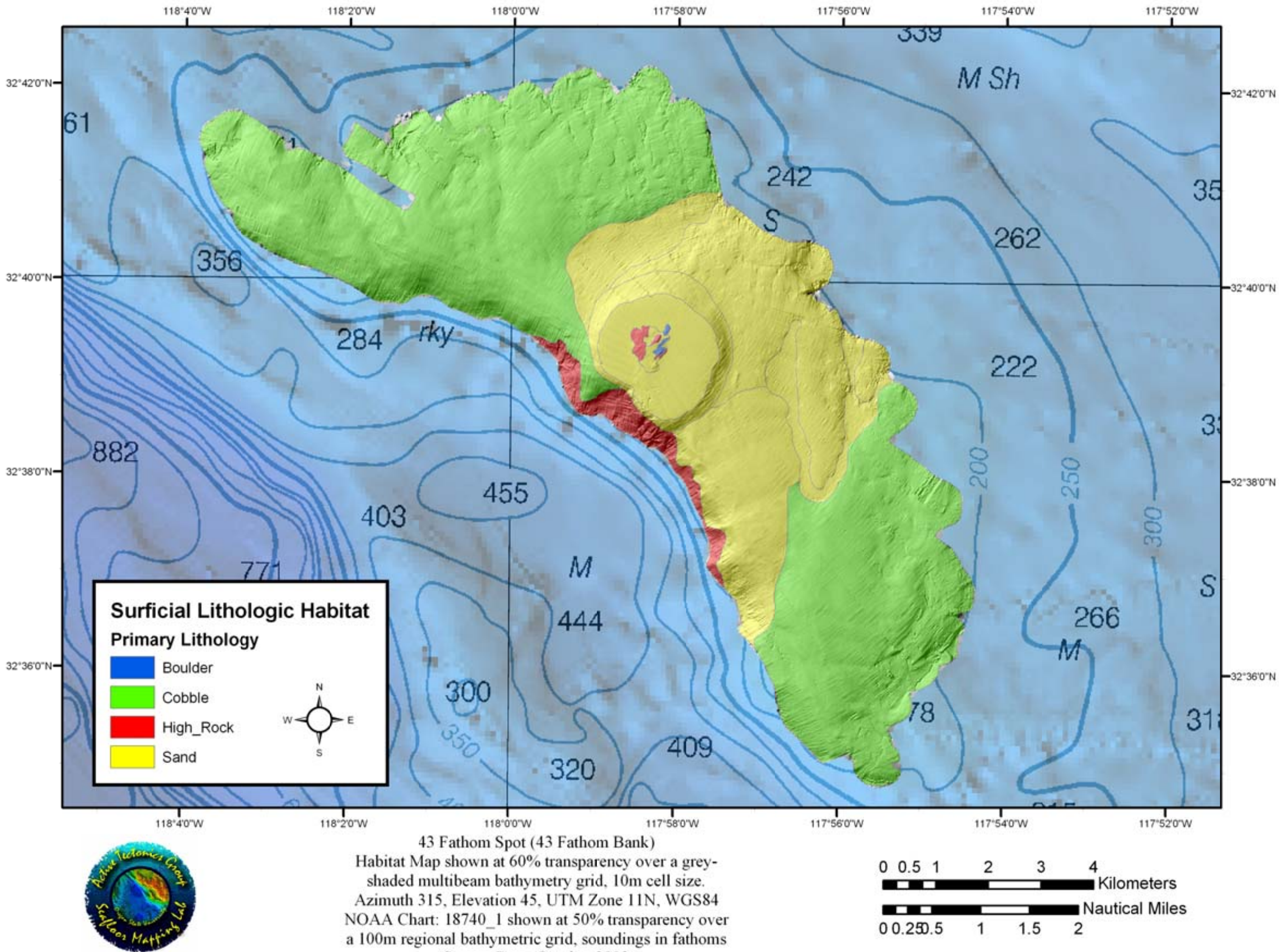


Plate 1. Surficial Geologic Habitat of Cherry Bank, California Continental Borderland.



43 Fathom Spot (43 Fathom Bank)
Habitat Map shown at 60% transparency over a grey-shaded multibeam bathymetry grid, 10m cell size.
Azimuth 315, Elevation 45, UTM Zone 11N, WGS84
NOAA Chart: 18740_1 shown at 50% transparency over a 100m regional bathymetric grid, soundings in fathoms
Survey Date: October 2003

Plate 2. Surficial Geologic Habitat of 43 Fathom Bank, California Continental Borderland.

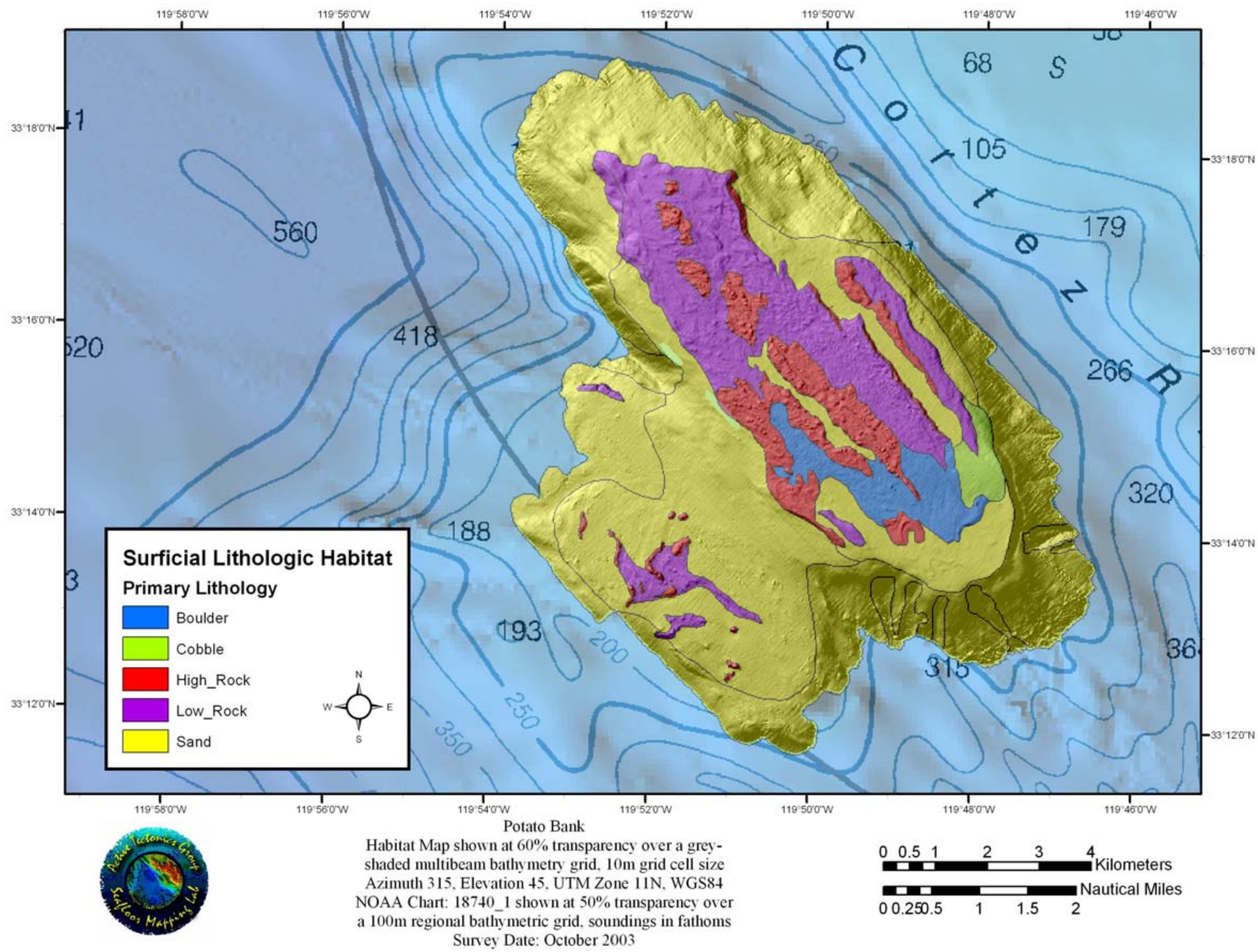
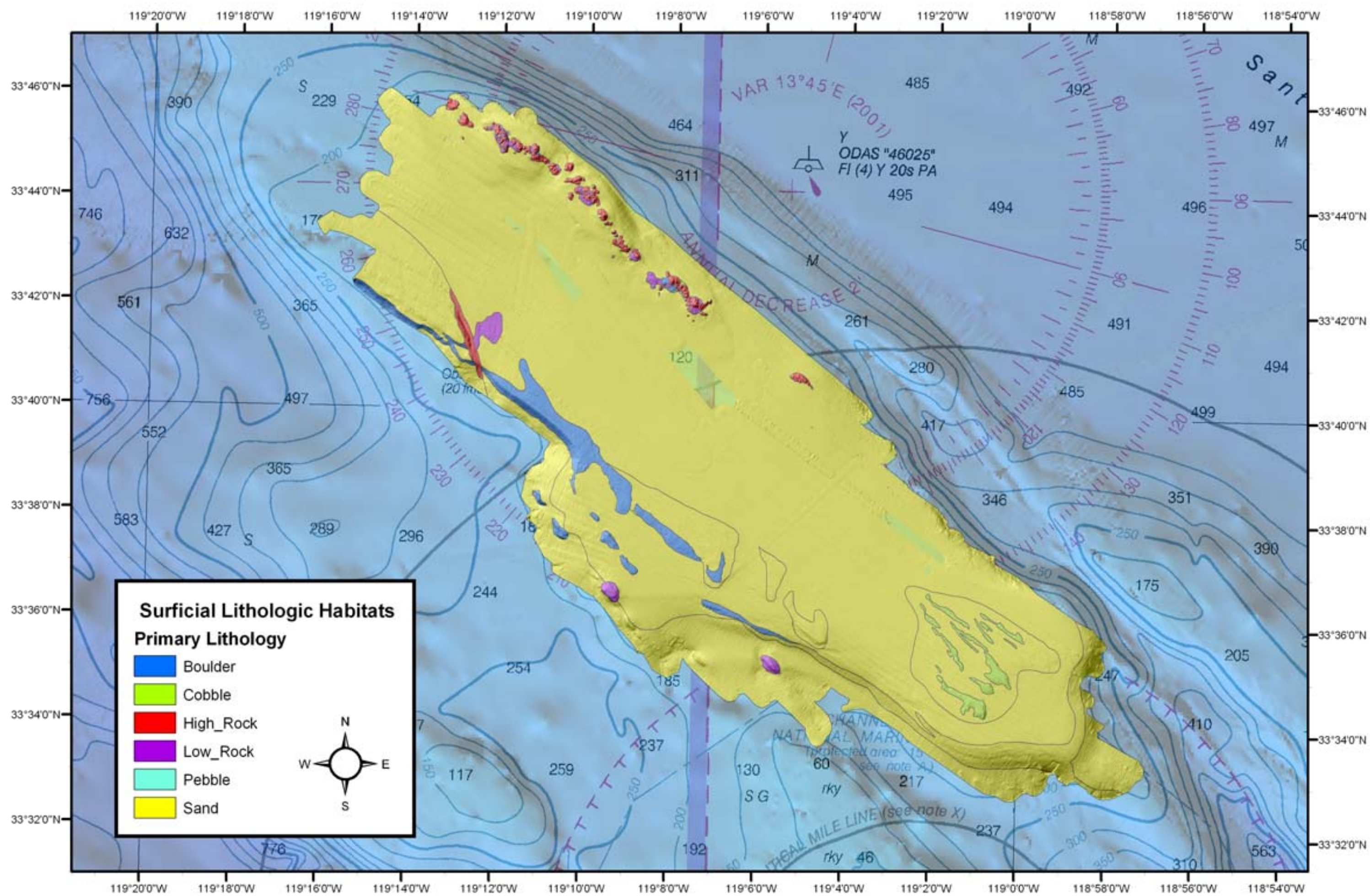
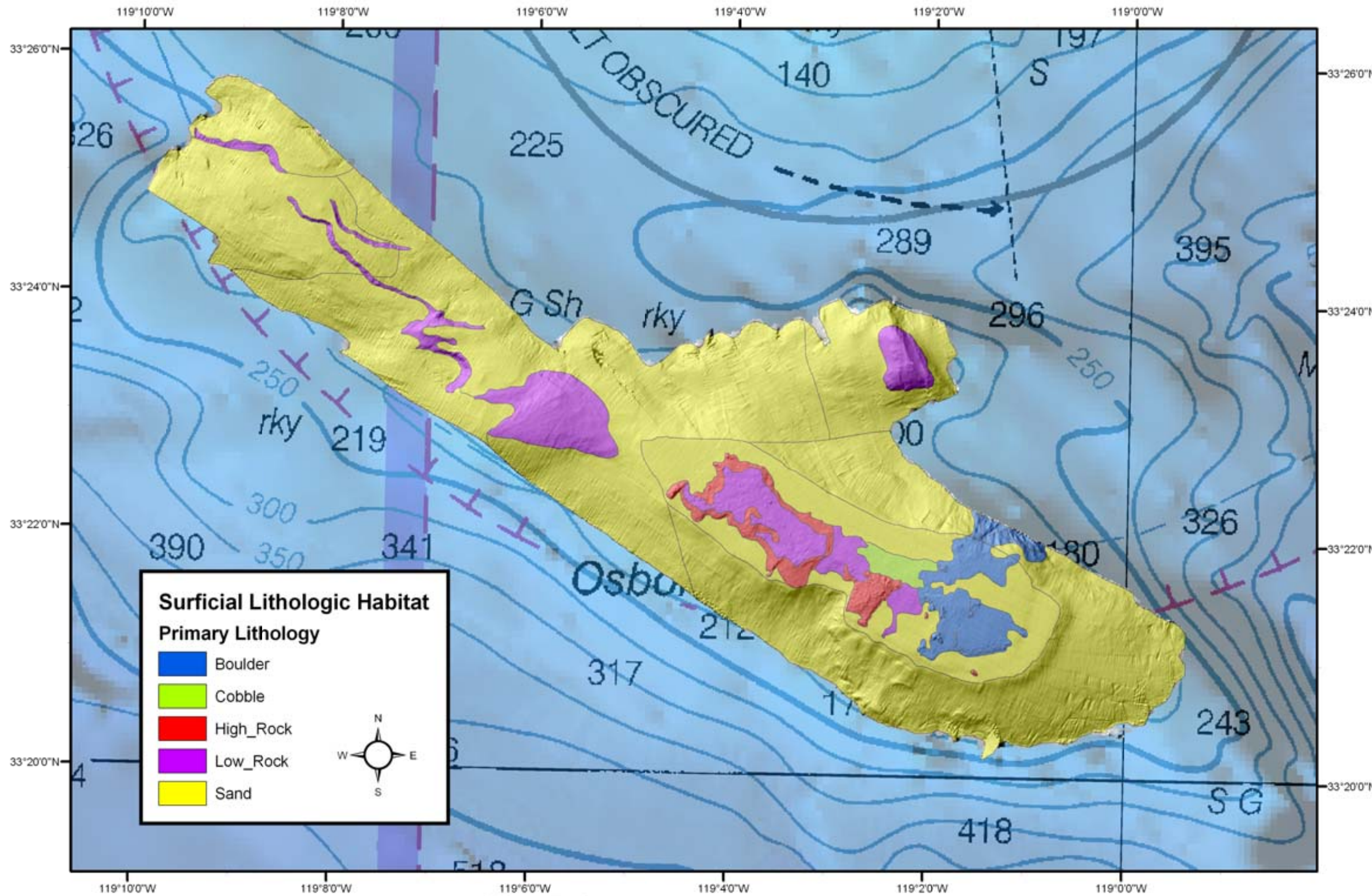


Plate 3. Surficial Geologic Habitat of Potato Bank, California Continental Borderland.



Pilgrim & Kidney Bank
Habitat Map shown at 60% transparency over a
grey-shaded multibeam bathymetry grid, 10m grid cell size
Azimuth 315, Elevation 45, UTM Zone 11N, WGS84
Background Images: NOAA Chart: 18740_1 shown at 50% transparency
over a 100m regional bathymetric image, soundings in fathoms
Survey Date: October 2003

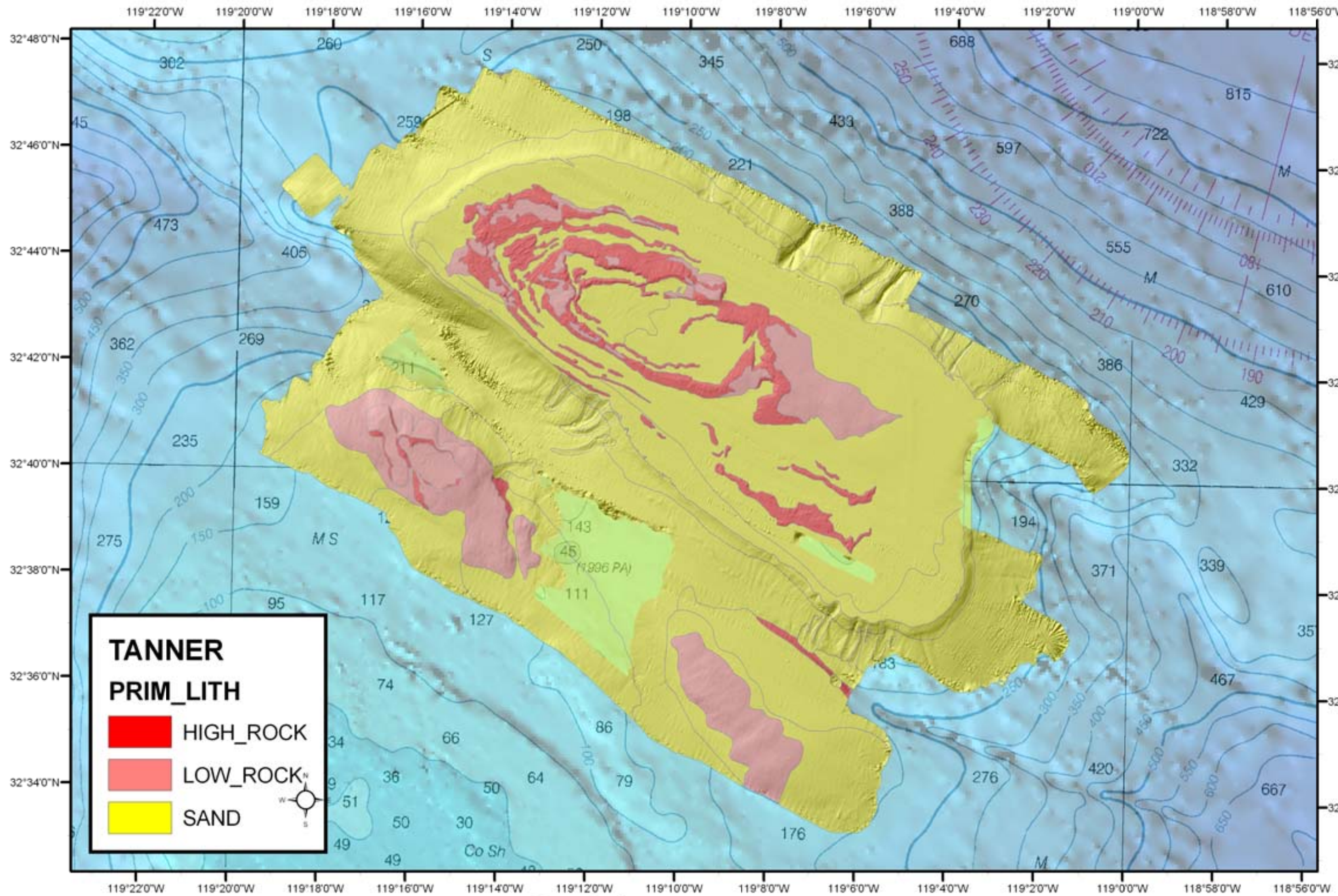
Plate 4. Surficial Geologic Habitat of Pilgrim and Kidney Bank, California Continental Borderland.



Osborne Bank
Habitat Map shown at 60% transparency over a grey-shaded relief multibeam bathymetry grid, 10m grid cell size
Azimuth 315, Elevation 45, UTM Zone 11N, WGS84
NOAA Chart: 18740_1 shown at 50% transparency over a 100m regional bathymetric grid, soundings in fathoms
Survey Date: October 2003

0 0.5 1 2 3 4 Kilometers
0 0.35 0.7 1.4 2.1 2.8 Nautical Miles

Plate 5. Surficial Geologic Habitat of Osborn Bank, California Continental Borderland.



Tanner Bank
Habitat Map shown at 60% transparency over a grey-shaded multibeam bathymetry grid, 10m cell size.
Azimuth 315, Elevation 45, UTM Zone 11N, WGS84
NOAA Chart: 18740_1 shown at 50% transparency over a 100m regional bathymetric grid, soundings in fathoms
Survey Date: October 2005

Plate 6. Surficial Geologic Habitat of Tanner Bank, California Continental Borderland.