Onshore and Offshore Geologic Map of the Coal Oil Point Area, Southern California

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Introduction

Geologic maps that span the shoreline and include both onshore and offshore areas are potentially valuable tools that can lead to a more in depth understanding of coastal environments. Such maps can contribute to the understanding of shoreline change, geologic hazards, both offshore and along-shore sediment and pollutant transport. They are also useful in assessing geologic and biologic resources. Several intermediate-scale (1:100,000) geologic maps that include both onshore and offshore areas (herein called onshore-offshore geologic maps) have been produced of areas along the California coast (see Saucedo and others, 2003; Kennedy and others, 2007; Kennedy and Tan, 2008), but few large-scale (1:24,000) maps have been produced that can address local coastal issues.

A cooperative project between Federal and State agencies and universities has produced an onshore-offshore geologic map at 1:24,000 scale of the Coal Oil Point area and part of the Santa Barbara Channel, southern California (fig. 1). As part of the project, the U.S. Geological Survey (USGS) and the California Geological Survey (CGS) hosted a workshop (May 2nd and 3rd, 2007) for producers and users of coastal map products (see *list of participants*) to develop a consensus on the content and format of onshore-offshore geologic maps (and accompanying GIS files) so that they have relevance for coastal-zone management. The USGS and CGS are working to develop coastal maps that combine geospatial information from offshore and onshore and serve as an important tool for addressing a broad range of coastal-zone management issues. The workshop was divided into sessions for presentations and discussion of bathymetry and topography, geology, and habitat products and needs of end users. During the workshop, participants reviewed existing maps and discussed their merits and shortcomings.

Figure 1. Location of Coal Oil Point onshore-offshore geologic mapping.

This report addresses a number of items discussed in the workshop and details the onshore and offshore geologic map of the Coal Oil Point area. Results from this report directly address issues raised in the California Ocean Protection Act (COPA) Five Year Strategic Plan. For example, one of the guiding principles of the COPA five-year strategic plan is to “Recognize the interconnectedness of the land and the sea, supporting sustainable uses of the coast and ensuring the health of ecosystems”. Results from this USGS report directly connect the land and sea with the creation of both a seamless onshore and offshore digital terrain model (DTM) and geologic map. One of the priority goals (and objectives) of the COPA plan is to “monitor and map the ocean environment to provide data about conditions and trends.” Maps within this report provide land and sea geologic information for mapping and monitoring nearshore sediment processes, pollution transport, and sea-level rise and fall.

Geologic Maps

General Features of Geologic Maps

Geologic maps show the distribution, nature, and age relations of bedrock units; surficial deposits (for example, sand along beaches and rivers), geologic structures such as faults and folds; and, in some cases, mineral deposits. Geologic maps are commonly used by scientists, planners, and decisionmakers in both government and industry to evaluate geologic hazards; to assess known and potential energy, mineral, and water resources; and to guide land-use policies.

Geologic maps are often shown overprinted on topographic maps, which include contour lines (lines that link points of equal elevation) to show the shape of any part of the Earth's surface. Geologic maps are not the same as substrate maps, which may superficially resemble geologic maps because they show the surface distribution of bedrock and surficial deposits (for example, gravel, sand, and mud). However, unlike geologic maps, substrate maps do not distinguish different bedrock units from each other, do not show the geologic ages of the bedrock units, and do not depict geologic structures.

Onshore Geologic Maps

Onshore geologic maps are prepared using detailed observations of rocks at many outcrops, usually by one or several geologists traveling on foot and assisted by motor vehicles, boats, or aircraft. At each outcrop, many different kinds of information are gathered and recorded, including (1) color, composition, texture, and structure of the rock or surficial deposit; (2) detailed measurements of the orientations of features such as sedimentary layering, fractures, faults, and folds; and (3) details that might reveal the age of the rock, such as fossils from sedimentary rocks or samples of igneous rocks that can be isotopically dated in the laboratory. These outcrop observations are often supplemented by examination and interpretation of vertical aerial photographs.

Most geologic maps use colored polygons to show the distribution of different kinds of bedrock and surficial deposits (fig. 2). Each color represents a different geologic unit, and each unit is also labeled with letter symbols that contain information about the age of the unit and its lithology; for example, the symbol “Qls” might be used for landslide deposits of Quaternary age, whereas the symbol "Tms" might be used for a sandstone unit that was deposited during the Miocene Epoch of the Tertiary Period.

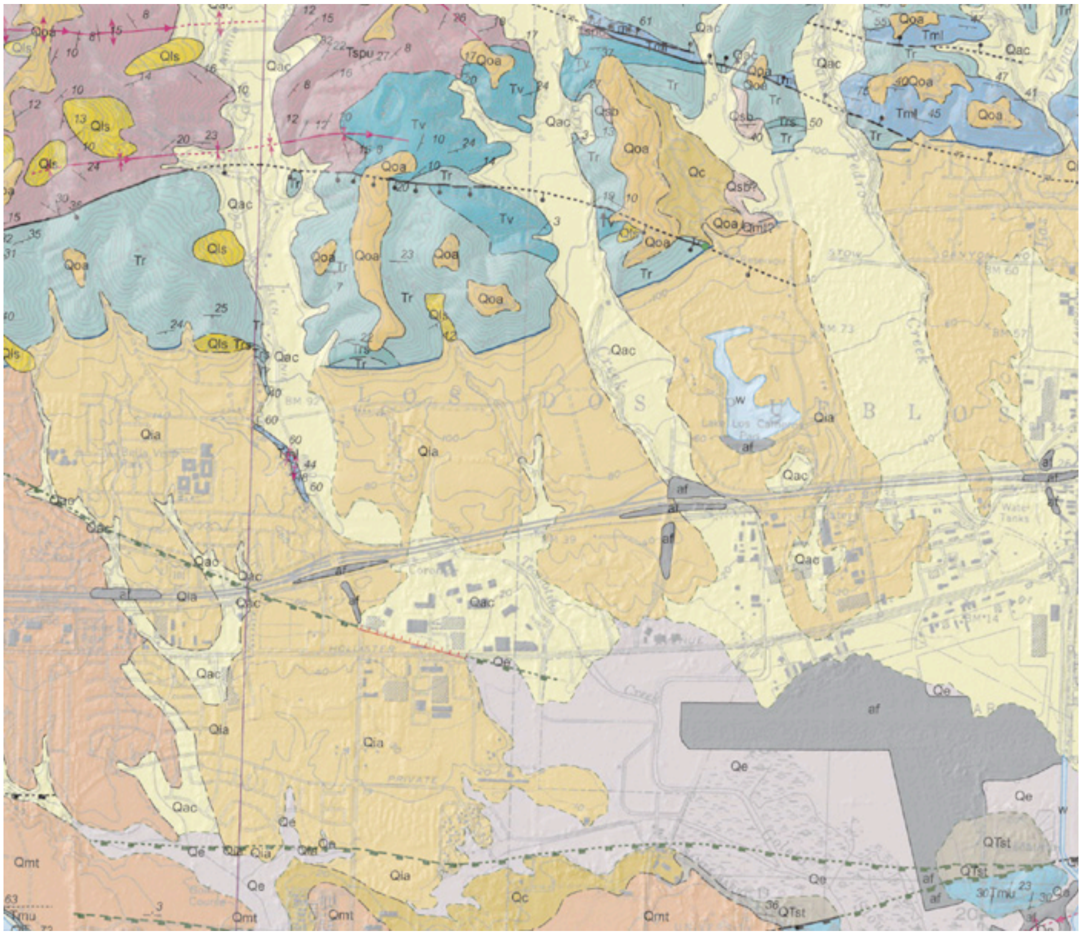

Figure 2. Example of a geologic map with different colored polygons representing different bedrock or suficial deposits (from Minor and others, 2009).

The boundary between two different rock units is called a contact and is shown on the geologic map as a line. On most geologic maps, thick lines are used to show faults, whereas thin lines are used to show both depositional and intrusive contacts. A contact that is located accurately is shown on the map as a solid line, but a contact that is located only approximately (perhaps because it is partly hidden by soil or vegetation) is shown as a dashed line. A contact between two bedrock units that is completely covered by surficial deposits is shown as a dotted line. Other lines that appear on geologic maps show the crests of folds and the locations of cross sections and these are usually labeled with symbols to distinguish them from contact lines. A wide variety of other kinds of symbols are used to show additional geologic features such as oil and gas seeps, occurrences of fossils, and places where a geologist has measured the orientation of layering in sedimentary rocks, or the orientation of structural features such as faults and joints.

Geologic maps are available for much of the onshore western United States at a variety of scales. In coastal central and southern California, for example, published geologic maps are available for most areas at a scale of 1:24,000, which is suitable for most scientific, industrial, and government purposes. These maps, however, vary considerably in the degree to which they show geologic details as well as the accuracy of locations; many published onshore geologic maps are generalized and, therefore, of reconnaissance quality only. In much of coastal California, new and detailed mapping of both bedrock and Quaternary units is still needed to (1) adequately identify and evaluate geologic hazards such as landslides, liquefaction, seismic shaking, and surface-fault rupture; (2) assess known and potential energy, mineral, and water resources; and (3) provide detailed and reliable information for use in preparing and implementing land-use policies.

Offshore Geologic Maps

Few geologic maps at a scale of 1:24,000 are available for offshore areas, largely because direct observation of geologic materials on the seafloor is difficult and costly. However, along some parts of the coast, modern marine geophysical techniques such as multibeam sonar and bathymetric lidar have been used to collect remarkably detailed bathymetric data. Also, many multibeam and bathymetric side-scan systems collect co-registered acoustic backscatter that can be used in conjunction with the bathymetry data and seafloor video or sediment samples to create substrate maps that show the distribution of bedrock, sand, and mud. Some seafloor video shows physical characteristics that allow preliminary interpretations of rock type, such as conglomerate, sandstone, or volcanic rock. These images however, provide no information on the ages of the rocks.

Information on the lithologies and ages of rocks on the seafloor can only be obtained by direct observation, sampling, and analysis of rocks from outcrops that occur on and beneath the seafloor. Samples from the bottom of the sea are usually obtained from dredge hauls and shallow cores, and less often from boreholes and by direct acquisition by human divers or remotely controlled vehicles. Photographs and videos of the seafloor can provide information on the nature, thickness, and distribution of surficial sediments and, in areas of bedrock outcrop, the character and general orientation of layering, faults, and fractures. Seismic-reflection profiling is generally easier to obtain offshore than onshore and can reveal sediment thickness as well as the locations, geometries, and relative ages of unconformities, faults, and folds. Acquisition and modeling of gravity and magnetic data can provide important insights into geologic structure in areas where geologic units differ from each other in density and magnetic properties.

Combined Onshore and Offshore Geologic Maps

The preparation of truly seamless onshore-offshore geologic maps presents several challenges. The shoreline is nearly always an abrupt seam because, as a fundamental boundary between the terrestrial and marine realms, the shoreline marks an abrupt and dramatic change in depositional processes and surficial deposits. In coastal California, for example, Quaternary surficial deposits in onshore areas are created and modified by terrestrial processes such as rivers and blowing wind, whereas Quaternary surficial deposits in nearby offshore areas are created and modified by marine processes such as waves, tidal currents, and longshore drift.

In some coastal areas, the same bedrock geologic units and structures that have been identified and mapped onshore may continue into the offshore. Nevertheless, detailed geologic observations are usually easier to make on land than on the seafloor, and most onshore-offshore geologic maps will show more geologic detail (for example, more measurements on the orientation of sedimentary layering, as well as more faults and folds) onshore than offshore. An additional challenge is posed by the way that certain rock units are distinguished from each other. For example, the Monterey and Sisquoc Formations near Santa Barbara, California, are mudstone units that are distinguished from each other on the basis of subtle changes in texture, mineralogy, and fossil content; such features are easily observed in onshore outcrops but are much more difficult to observe in offshore outcrops. Therefore, on combined onshore and offshore geologic maps, it may be necessary to depict fewer, more generalized bedrock units in the offshore.

In many places along the California, Oregon, and Washington coasts - for example, in parts of Sonoma, San Mateo, and Santa Barbara Counties, California - the location of the shoreline is coincident with, or in close proximity to, faults that are poorly understood because their position in the surf zone makes them difficult to study. Closely coordinated mapping efforts by teams of geologists and geophysicists working both onshore and offshore could provide a better understanding of the structural and tectonic significance of these faults and their seismic-hazard potential.

Coal Oil Point Geologic Mapping

In an effort to resolve the challenges of producing an onshore-offshore geologic map, a 1:24,000 scale geologic map was created for the Coal Oil Point area and part of the Santa Barbara Channel. This area was chosen due to its unique setting and the existence of many of the data sets needed to produce this map. The Coal Oil Point area includes coastal cliff erosion near Isla Vista between Coal Oil and Goleta Points, a number of faults that trend across the land-sea boundary, an offshore region with some of the highest hydrocarbon seepage rates along the West Coast, and a large active submarine landslide located about three nautical miles offshore that has the potential to generate tsunamis. This area was also chosen because detailed, onshore 1:24,000-scale geologic mapping was recently completed along the Santa Barbara coastal plain and mountains (Minor and others, 2009).

Offshore Mapping

The offshore geologic interpretations are based on several data sets including, bathymetry, acoustic backscatter, seismic profiles, seafloor video, photographs, and sediment samples. A seamless topographic-bathymetric digital terrain model (DTM) at 10-m resolution was used as a base map for the interpretations. The bathymetry was compiled from a number of surveys that were collected over a period of 25 years by various institutions (fig. 3).

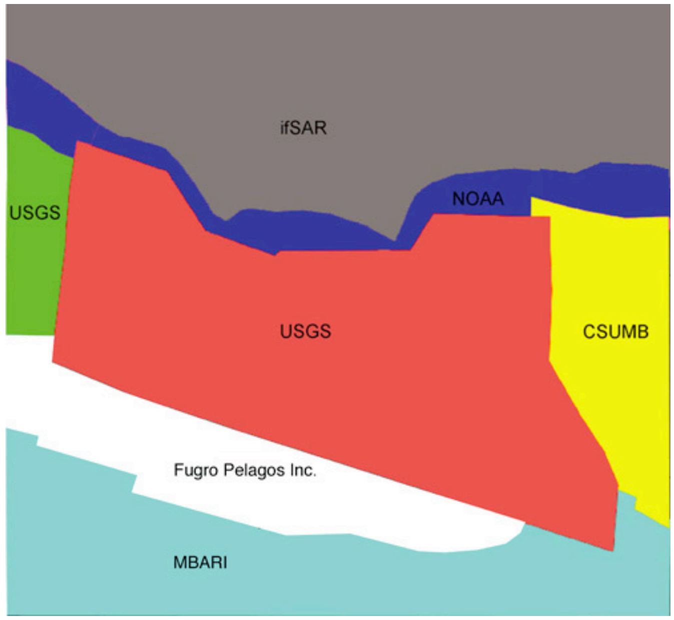

Figure 3. Areas surveyed offshore the Coal Oil Point region by institution. USGS-U.S. Geological Survey; CSUMB-California State University, Monterey Bay; NOAA-National Oceanographic and Atmospheric Administration; MBARI-Monterey Bay Aquarium Research Institute.

Different mapping systems were used including pole-mounted bathymetric side scan systems, pole-mounted multibeam echosounders, hull-mounted multibeam echosounders, and single-beam echosounders. The surveys (table 1) mapped at various resolutions (2 m to over 10 m) and the soundings were referenced to different vertical datums (for example, MLLW and NAVD88). As part of this project, all of the surveys were projected to a common horizontal datum (NAD83) using standard GIS transformations and a common vertical datum (NAVD88) using NOAA's VDatum tool. The topography was compiled from publicly available ifSAR data (table 1).

Table 1. Original Bathymetric and Topographic Datasets used to create the bathy-topo digital terrain model.

Institution	Year	Original Horizontal / Vertical Datum	Original Resolution	Source
U.S. Geological Survey	2007	WGS84 / NAVD88	2-m	This report (partial, 10-m data)
U.S. Geological Survey	2006	WGS84 / MLLW	2-m	This report (10-m data)
California State Univ. - Monterey Bay	2007	WGS84 / NAVD88	2-m	http://seafloor.csumb.edu/
Monterey Bay Aquarium Research Institute	1998	WGS84 / NAVD88	10-m	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
Fugro Pelagos Inc.	2008	NAD83 / NAVD88	5-m	http://seafloor.csumb.edu/
National Oceanographic and Atmospheric Admin. (NOAA) - Survey H10165	1985	NAD83 / MLLW	varies	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
National Oceanographic and Atmospheric Admin. (NOAA)	2002/2003	WGS84 / NAVD88	3-m	http://www.csc.noaa.gov/digitalcoast/

Depth offsets did occur between overlapping bathymetric data sets (table 2) even though they were projected to common horizontal and vertical datums. There may be a number of reasons for these depth offsets that include different sonar systems mapping at different frequencies and resolutions; errors in horizontal and vertical datum transformations; and errors measuring vertical and horizontal offsets between the sonar head, GPS, and vehicle-motion unit aboard the survey vessels.

Table 2. Measured statistics of overlapping bathymetric datasets. USGS, U.S. Geological Survey; CSUMB, California State University, Monterey Bay; MBARI, Monterey Bay Aquarium Research Institute; NOAA, National Oceanic and Atmospheric Administration; Fugro, Fugro Pelagos Inc.

Surveys	Mean Difference (meters)	Standard Deviation (meters)
USGS2006 – USGS2007	0.13	0.55
USGS2006 - CSUMB	0.48	0.28
USGS - MBARI	0.35	0.51
USGS – NOAA (H10165)	0.46	1.2
Fugro - MBARI	0.4	0.8

Once all of the data sets were transformed to a common datum, the higher resolution multibeam and bathymetric side-scan surveys as well as the ifSAR DEM were de-sampled to 10-m resolution grids. Initially, in the nearshore area (surf zone), there was a 50 m to more than 200 m gap between the shallowest soundings of the NOAA single-beam survey and the ifSAR DEM. To fill this gap, the nearshore portion of the DEM was converted to a point coverage and exported as an XYZ file. This XYZ data was merged with the NOAA single-beam soundings (XYZ), as well as a digital coastline (0-m depth). A 10-m surface was created from the new merged XYZ file using a GIS spline procedure. This procedure creates a surface that closely passes through each XYZ point (depth, coastline, and elevation).

All of the 10-m grids including the bathymetric surveys, nearshore spline surface, and DEM were merged into one nearly seamless 10-m onshore-offshore DTM using a GIS “merge” function (fig. 4). Bathy-topo profiles (fig. 5) show a relatively smooth transition between the land-seafloor interface as well as between the different bathymetric data sets.

Since this seamless bathymetric-topographic DTM was created for this project, other similar DTMs have been made public in and around this region including NOAA’s 10-m Inundation Model (Carignan and others, 2009), as well as Barnard and Hoover (2010).

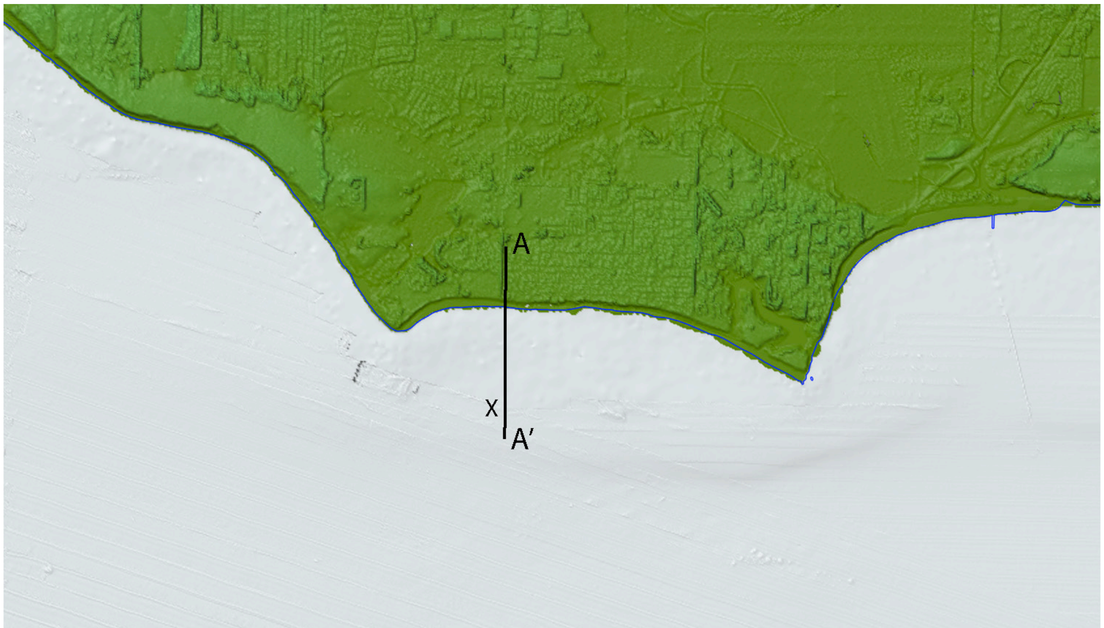

Figure 4. Close-up map view of the onshore-offshore DTM near the Isla Vista area. The green area shows land, while the blue area shows the seafloor. Line A-A' shows the location of the bathy-topo profile in fig 5 while "X" shows the transition between two bathymetric datasets.

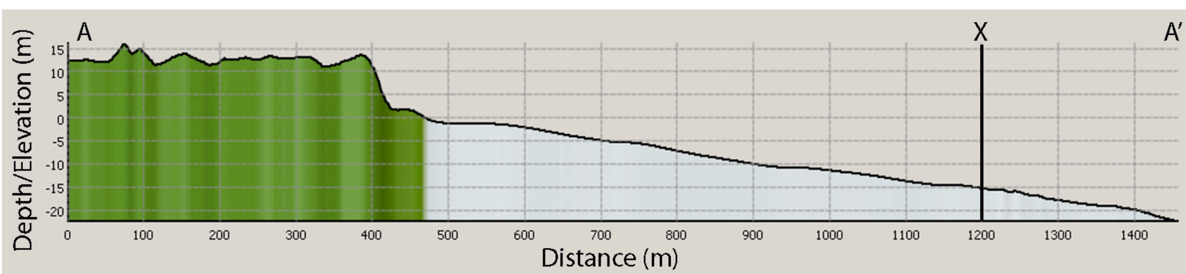

Figure 5. Profile A-A' across the land - seafloor interface near Isla Vista. The profile crosses onshore 10-m ifSAR DEM, nearshore gridded NOAA single-beam bathymetry, and offshore USGS bathymetric sidescan bathymetry. The black vertical line (X) in the profile shows the location of the transition between bathymetric datasets. See Figure 4 for the profile location.

Offshore Seismic Profiling

In July of 2007 seismic sub-bottom profiles using Huntec and Chirp systems were collected within the Santa Barbara Channel (Sliter and others, 2008). Four profiles were collected within this study area orientated perpendicular to shore and show folded bedrock exposed at the seafloor (location A, fig. 6), as well as sediment covering folded bedrock (location B, fig. 6). Gas bubbles are also seen in the water column above active hydrocarbon seeps. These profiles along with the high-resolution bathymetry and backscatter data help define the distribution and characteristics of bedrock units exposed on the seafloor as well as the distribution and thickness of unconsolidated marine sediments.

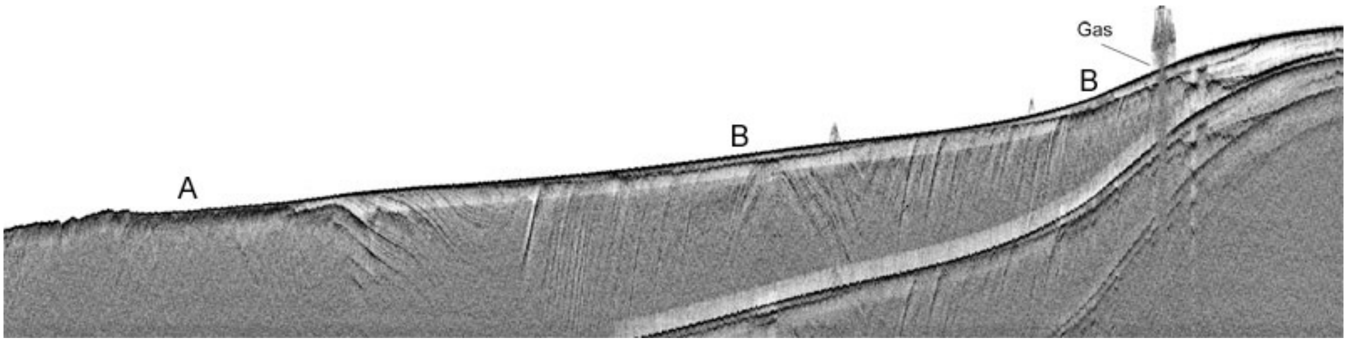

Figure 6. Seismic profile collected just east of Coal Oil Point, California showing folded bedrock, sediment, and gas seeps.

Offshore Ground-Truthing

To obtain visual geologic observations of the seafloor (such as rock or sediment) to relate to the remotely collected multibeam and bathymetric side-scan data, the USGS collected seafloor video from a towed camera sled. The sled is approximately 2 m by 0.5 m and houses a downward-looking video camera, a forward-looking video camera, and a downward-looking high-definition video camera (fig. 7). Paired lasers associated with each video camera are spaced 16 cm apart and provide scale.

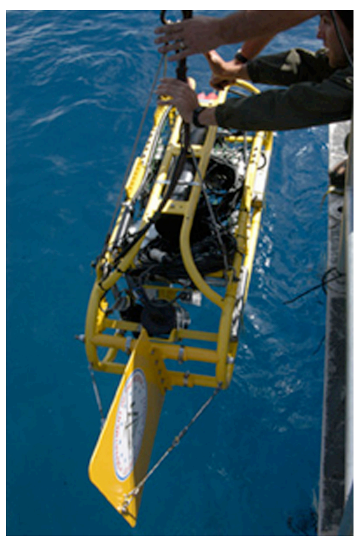

Figure 7. USGS towed camera sled.

Both the downward- and forward-looking regular video cameras had a real-time feed up to the ship where the video could be observed as well as recorded onto miniDV tapes (fig. 8). From the streaming video, observations, such as geologic composition and biologic cover were recorded over a 10-second period, every minute using programmable keypads (fig. 8). Each observation was stamped with a time and geographic coordinates both at the beginning and end of the observation. The output from the keypads is a comma delimited text file that can be quickly converted to a GIS shapefile and overlayed on the sonar data to help with interpretations.

Figure 8. Video screens aboard the ship showing real-time seafloor video. Insert figure shows one of the programmable keypads.

Offshore Sediment Samples

While no sediment samples were collected in the study area for this project, existing sample information (texture) was obtained from the usSEABED database (Reid and others, 2006).

Onshore and Offshore Geologic Map

The extent of the onshore-offshore geologic map of this report is the same size and shape as a typical USGS 7.5 minute quadrangle. However, an existing quadrangle (Dos Pueblos Canyon or Goleta) was not used because they mainly include the land areas with very little offshore region. Therefore, a base for the map area was generated centered on Isla Vista with approximately equal land and offshore coverage.

The offshore geologic interpretations were based on the swath bathymetry, acoustic backscatter, seismic profiles, sediment samples, and seafloor video and photography. In GIS software ArcMap, bathymetric and acoustic backscatter maps were created at 1:24,000 scale and exported as Adobe Illustrator files. Geologic interpretations including geologic unit polygons, contacts, and folds were digitized using Adobe Illustrator and then imported back into the GIS software. The polygons, contacts, and folds were converted to shapefiles to merge with the onshore geology of Minor and others, 2009. All files, both onshore and offshore, were projected to UTM zone 11 WGS84 coordinates.

The onshore geology is described in detail in Minor and others (2009), and includes sedimentary rocks of Oligocene to Holocene age. The offshore geologic units are of Miocene age and younger, and include the Miocene Monterey Formation (Tm), upper Miocene and lower Pliocene Sisquoc Formation (Tsq), and younger Pliocene marine sediments. In the nearshore, these units can be recognized when contiguous with units identified onshore and in some cases confirmed with paleontological ages from dartcore samples. Onshore, the Monterey Formation is divided into lower, middle and upper units (Tml, Tmm, and Tmu), but these are not easily recognizable in the offshore so there the Monterey Formation (Tm) is not subdivided. Further offshore, a large bedrock outcrop on the mid to outer shelf is known from dartcore sampling to include the Monterey and Sisquoc Formations as well as younger marine sediments that contain microfossils of Repettian age, but these data are not detailed enough to permit subdivision of these units so they are mapped as undivided Miocene and Pliocene rocks (Tmp).

These Miocene and Pliocene rocks are warped into asymmetric folds that trend generally east-west, roughly parallel to the coastline. At least some of these folds probably root into blind faults at depth. Presumably, these rocks underlie the entire offshore shelf and slope region, but they are in most places covered by unconsolidated marine sediments consisting of sand, silt, and mud of Holocene (and possibly older) age (Qms), which is as much as 10 m thick in places. In addition, small deposits of unconsolidated marine gravel (Qmg), and a 1- to 2-m-thick unit of sedimentary rocks, at least in part consisting of cobble conglomerate (Qys) occur on the shelf.

Numerous asphalt deposits (Qas) associated with hydrocarbon seeps and gas vents occur onshore and were confirmed in the offshore with seafloor video. Many are too small to be shown on the map but the larger deposits cover as much as several hundred square meters. Asphalt occurrences are often localized along bedrock structures such as faults or the crests of antiforms. These deposits appear as bathymetric features that appear similar to bedrock outcrops but are distinguished from them by having low acoustic backscatter.

The head of the Goleta slide complex is located along the shelf edge in the southwest quadrant of the study area and is divided into five sub-units using the classification of Greene and others (2006).

Conclusion

Onshore geologic maps are used by scientists and planners to evaluate geologic hazards; to assess known and potential energy, mineral, and water resources; and to guide land-use policy. Combined onshore-offshore geologic maps have the added benefit of addressing local coastal issues including shoreline changes, coastal geologic hazards such as submarine landslides, both offshore and along-shore sediment and pollutant transport, and to assess nearshore geologic and biologic resources.

Offshore geologic mapping is complicated by the fact that geologists can rarely view *in situ* geologic units. Most offshore mapping is completed using remotely sensed information. The Coal Oil Point offshore geologic interpretations were based on swath bathymetry data, acoustic backscatter data, seismic profiles, sediment samples, as well as seafloor video and photography. The offshore region is composed of Holocene aged marine sediment and Pliocene and Miocene bedrock outcrops of the Monterey Formation, Sisquoc Formation, and marine sedimentary rocks containing Repettian-age fossils. The offshore area also includes faults and folds that trend mainly east-west and a few of these extend onshore.

The Coal Oil Point onshore-offshore geologic map and DTM will help local coastal managers and researchers better understand coastal issues including shoreline erosion near Isla Vista, nearshore hydrocarbon seeps, tsunami potential from the nearby Goleta slide complex, and alongshore sediment and pollutant transport along the northern Santa Barbara Channel.

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