A GEOPHYSICAL APPROACH TO CLASSIFYING MARINE BENTHIC HABITATS: MONTEREY BAY AS A MODEL

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Introduction

Remote sensing and large-scale mapping of potential habitat for benthic organisms contribute to a more efficient use of manned submersibles and remotely operated vehicles (ROV) during *in situ* seafloor investigations. Because many benthic habitats are defined by their geology (along with depth, chemistry and other attributes), geophysical techniques are critical in determining habitat structure and lithology (rock type). Such geological descriptions then can be applied to associated biological communities.

Until recently, assessment of benthic marine habitats and their biological assemblages largely has been limited to subtidal (< ca. 30 m) *in situ* observations. Increased availability and use of underwater video systems on ROVs, submersibles, and sleds have made fine-scale surveys in deep water more commonplace, thereby expanding our understanding of the processes that help define these communities and the spatial scale at which these processes operate. With the support of the West Coast National Undersea Research Center, a cooperative project between geologists and fishery biologists was recently undertaken in Monterey Bay (Yoklavich et al. 1994). In this paper, we discuss the geophysical procedures used to map seafloor geology, and their potential for describing relatively deep (> 50 m), marine benthic habitats for fishes. We propose a classification of benthic habitats that is applicable to the rockfish assemblages being studied in the Monterey Bay area and suggest this classification be developed as a model for characterizing benthic habitats elsewhere.

Marine geophysical methodologies used to investigate benthic habitats of Monterey Bay include side-scan sonar and seismic reflection profiling. These techniques use sound sources of different frequencies to produce images of surface and subsurface features. Reflected sound waves are recorded as seafloor images in plane, areal, and cross-section views. Resultant maps of morphology, textures, and structure can be related to lithology.

Side-Scan Sonar

Side-scan images are created by reflections of sound waves from the seafloor surface. The transceiver (sound source) is towed from a ship at a constant height above the seafloor; height above seafloor is related to desired swath width. Very high frequency (~ 100 kHz) sound emanates from both sides of the source and sweeps the seafloor with a swath width of up to 1 km. Generally, closely spaced ship track lines assure sufficient overlap to mosaic the images or sonographs.

Two side-scan systems (EG&G Seafloor Mapping System and a Klein System) were used in Monterey Bay, each with a 100 kHz sound source. Each side of the swath varied from 300 to 500 m. In steep terrain, such as along the walls of submarine canyons, only one channel (side) of the "fish" received usable echoes; under these circumstances, close spacing of track lines was necessary to achieve adequate overlap for mosaics. Seafloor morphology is imaged on a sonograph that resembles the negative of a black-and-white photograph (Figure 1). Strong reflection and shadows create an image from which we distinguish features, such as bedrock outcrops, muds, sands, gravel, landslide scarps, and debris, faults, folds, and often general lithologies; i.e., granite, volcanic rock, or bedded sedimentary rock. These images are used to identify likely fish habitats that can be examined more closely with *in situ* equipment.

Seismic Reflection Profiling

Seismic reflections also can be used to map subsurface stratigraphy and structure. We have used this technique to supplement our interpretations of side-scan sonographs. These systems have high resolution (images as small as 0.5 m), shallow penetration (less than 500 m), and generally use a high frequency (~ 1,000–1,500 Hz) sparker- or transducer-type sound source towed by the survey vessel at the sea surface. A short (< 10 m) hydrophone streamer also is towed behind the vessel (~ 1 m beneath the sea surface) to receive echoes from subsurface features.

Seismic reflection profiles are time-distance graphs, that when corrected for true velocity of sound through the water column and seafloor, depict a geologic cross section of the stratigraphy along the survey vessel's track. From this we can identify subsurface structures that influence seafloor morphology associated with likely habitats.

Geologic Setting of Monterey Bay

Monterey Bay is a nearly crescentic bay that indents an otherwise straight coastline by about 10 km (Figure 2). The floor of the bay is generally flat, ranging in water depth from 0 m at the shoreline to 100 m near its outer margin. A major submarine canyon system bifurcates the bay producing deep incisions that disrupt the generally flat nature of the seafloor. The Monterey Canyon system is composed of three canyons: Monterey Canyon proper and 2 tributaries and Carmel and Soquel Canyons (Figure 3). Monterey Canyon extends from near the shoreline at Moss Landing and is the primary conduit for transporting sediments from the shelf to abyssal depths. Soquel Canyon cuts the northern Monterey Bay shelf, is far removed from the shoreline, and appears not to be active as far as transporting sediment to

Monterey Canyon. Carmel Canyon is eroded along the Palo Colorado-San Gregorio fault zone that trends northwest-southeast along the western margin of the bay.

Monterey Bay lies in a very active geologic and tectonic setting. It is situated between the seismically active San Andreas and Palo Colorado-San Gregorio fault zones, and its geomorphology is the direct result of tectonic processes along the transform and oblique convergent boundary between the North American-Pacific Plates (Greene 1990). Additionally, the Monterey Bay fault zone trends northwest through the bay from the Monterey bight and merges with the Palo Colorado-San Gregorio fault zone just northwest of Santa Cruz. Movement along faults within the Monterey Bay fault zone is actively deforming the seafloor in Monterey Bay today (Figure 2).

The oblique convergence of the Pacific Plate against the North American Plate, and motion within the San Andreas fault system have created areas of compression and tension (Greene 1990). This fault motion has transported and slivered a granitic basement block (the Salinian Block) into the Monterey Bay region from the block's origin further to the south (Page 1970; Greene 1990). During the transport of the Salinian Block in the past 27 million years, submergence (tension) below and emergence (compression) above sea level resulted in deposition of Tertiary marine sediment and erosion of previously deposited sediment. Additionally, large-scale erosion of the submarine canyon has created a region of extremely diverse and complex geomorphology and lithology.

Due to its dynamic Cenozoic tectonic history, lithologies are represented by igneous intrusions, volcanism, deep- and shallow-water sedimentation, carbonate buildup, and wind-driven deposition. In addition, extremely diverse physiographic provinces exist within Monterey Bay, ranging from flat Continental Shelf, steep Continental Slope and Rise, and steep-walled canyon environments, to shallow seafloor with bedrock banks and knolls (Greene and Hicks 1990; Greene et al. 1993; Orange et al. 1993). The variety in geologic composition makes Monterey Bay an excellent region for characterizing benthic habitats.

Monterey Bay: A Model for Classifying Benthic Marine Habitats

We are in the process of using the Monterey Bay as a model to characterize benthic habitats for commercially and recreationally important species of fishes. These habitats can be categorized on the basis of depth, geology, physiography and geomorphology, slope or inclination, substratum morphology, structure, texture, and associated biotic communities. All habitat categories can be modified by terminology that is applicable across many higher levels of classification. Many habitats can be described as a mosaic of several subcategories. Our main objective is to develop a common framework based on geologic descriptors and processes from which biologists and ecologists can describe, visualize, and interpret functional assemblages of marine benthic organisms and their habitats. A classification system of geologic characteristics of the seafloor specific to biological applications will assist in identifying benthic habitats and is essential in evaluating marine coastal resources. Our habitat classification scheme is modified from those developed for shallow-water estuarine and marine systems (Cowardin et al. 1979; Dethier 1992).

<u>System</u> (based on salinity; proximity to seafloor):
- *Marine Benthic*

<u>Subsystem</u> (based on physiography; depth):

- ***Shelf***
  - *Intertidal (salt spray to extreme low water)*
  - *Subtidal (0–30 m)*
  - *Intermediate (30–100 m [location of shelf break])*

- ***Slope***
  - *Upper (100 m [location of shelf break]–500 m)*
  - *Intermediate (500–1,000 m)*
  - *Lower (1,000+ m)*

- ***Submarine Canyons***
  - *Head (10–100 m)*
  - *Upper (100–300 m)*
  - *Middle (300–500 m)*
  - *Lower (500–1,000+ m)*

<u>Class</u> (based on bottom morphology):

Bars
Sediment waves
Banks
Caves, crevices (ragged features)
Sinks
Debris field, slump, block glide, rockfalls
Grooves, channels (smooth features)
Ledges
Vertical wall
Pinnacles
Mounds, buildups, crusts (> 3 m in size)
Slabs
Reefs (carbonate features)
  biogenic
  nonbiogenic
Scarps, scars
Terraces
Vents
Artificial structures (wrecks, breakwaters, piers)

<u>SubClass</u> (based on substratum textures):

Organic debris (coquina, shell hash, drift algae)
Mud (clay to silt; < 0.06 mm)
Sand (0.06–2 mm)
Gravel
Pebble (2–64 mm)

<u>SubClass</u> (based on substratum textures [continued]):

Cobble (64–256 mm)
Boulder (0.25–3.0 m)
Bedrock
- *Igneous (granitic, volcanic)*
- *Metamorphic*
- *Sedimentary*

<u>SubClass</u> (based on slope):

Flat (0–5°)
Sloping (5–30°)
Steeply sloping (30–45°)
Vertical (45–90°)
Overhang (>90°)

<u>Modifiers</u>

- for bottom morphology

regular
irregular (continuous, non-uniform bottom with local relief 1–10 m)
hummocky (uniform bottom w/ mounds/depressions 0–3 m)
structure (fractured, faulted, folded)
friable
outcrop (amount of exposure)
bedding
massive

- for bottom deposition

consolidation (unconsolidated, semi-consolidated, well-consolidated)
erodability (uniform, differential)
sediment cover
- *dusting (<1 cm)*
- *thin (1-5 cm)*
- *thick (>5 cm)*

- for bottom texture

voids (percentage volume occupied by clasts or rock)
sorting
packing
density
- *occasional (random occurrence of feature; e.g., boulder)*
- *scattered (feature covers 10–50% of area)*
- *contiguous (features are close to touching)*
- *pavement (features are touching everywhere)*

lithification
jointing
clast (rock) roundness
clast shape

Modifiers

- ***for bottom texture*** *(continued)*
    - *blocky*
    - *lensoidal*
    - *boitroidal (e.g., pillow lava)*
    - *needle-like*
    - *angular*

- ***for physical processes***
    - *currents*
        - *winnowing*
        - *scouring or lag deposits*
        - *sediment trail*
    - *wave activity*
    - *upwelling*
    - *seismic*

- ***for chemical processes***
    - *vent chemistry (sulfur, methane, freshwater,* CO_2*)*
    - *cementation*
    - *weathering or oxidation (fresh to highly weathered)*

- ***for biological processes***
    - *bioturbation (tracks, trails, burrows, excavation)*
    - *cover of encrusting organisms*
        - *continuous (> 70%)*
        - *patchy (20–70% cover)*
        - *little to no cover (< 20%)*
    - *communities (examples of conspicuous species)*
        - Metridium sp.
        - *crinoids*
        - *vase sponges*
        - *coraline algae*
        - *kelp understory*
        - *sea grasses*
        - *kelp forest*

Examples of Marine Benthic Habitats in Monterey Bay

While a variety of benthic habitats exist in Monterey Bay, we will only describe 2 of these in this paper. Soquel Canyon and Portuguese Ledge represent 2 end members consisting of a deep (~ 300 m) habitat with steep relief and a shallow (~ 100 m) habitat of low relief or generally flat (Yoklavich et al. 1992; Greene and Sullivan 1993; Greene et al. 1994; Yoklavich et al. this publication).

Soquel Canyon

Soquel Canyon is a dormant, submarine canyon that appears to not be actively eroding today (Figure 3). The last erosion event was during the Pleistocene, when sea level was lower and the San Lorenzo River drained from the southern Santa Cruz Mountains onto the exposed northern bay floor. At this time, undercutting of the walls of the canyon caused extensive landslides; one near the mouth of the canyon blocked the canyon axis and caused ponding of sediment upcanyon. Our area of interest is in the headward part of the canyon, between 100 and 300 m. Here, the canyon cuts the generally flat-lying beds of the Pliocene Purisima Formation, a shallow-water marine deposit consisting of interlayered sandstone, mudstone, and shell hash (coquina).

Side-Scan Sonar. Side-scan sonographs collected along the headward part of Soquel Canyon show an area of steep relief with morphology varying from gentle slopes ($\sim 30°$) to near-vertical cliffs. Arcuate slump scarps were imaged along the upper walls of the canyon, and extensive slump-debris fields composed of large (meters in dimensions) angular to subrounded blocks to small boulders were found concentrated at the base of the walls and out into the canyon axis (Figure 1). Most of the canyon was so steep that only one channel (side) could be used to receive reflected signals. Using a 600-m swath width (300 m per channel), a mosaic was constructed that imaged the slump features and outcrops of well-layered sedimentary rocks.

Seismic Reflection Profiles. Seismic reflection profiles show the subsurface structure of the canyon to be locally faulted and to have a fairly thick (<100 m), flat-lying, well-layered sedimentary section. Well- defined reflectors continue beneath the canyon axis, indicating the canyon is located completely within the Purisima Formation. However, shoreward of the head, beneath the shallow (>100 m) seafloor, folds, faults, and apparent gas-charged zones suggest that Soquel Canyon may be structurally controlled, and erosion may have been precipitated through fluid flow and gas venting (Figure 4).

Submersible Dives. DSV *Delta* submersible dives confirmed the existence of slump scarps, landslide debris, and exposures of well-layered, friable, differentially eroded sedimentary rocks. Rocky outcrops of differentially eroded beds provide overhangs and caves that attract rockfishes (Figure 5). Boulder landslide debris also provide suitable habitat for rockfishes. More gently inclined (20–30°) slopes, covered with mud and organic detritus, occur in between slump scarps and bedrock exposures. Blocky landslide debris composed of scattered boulders interspersed with highly bioturbated muds occur at the base of the canyon walls and in the axis of the canyon.

Habitat Characterization. Based on the habitat characterization scheme above and interpretation of the geophysical data collected in Soquel Canyon, along with submersible observations, we characterize this habitat as follows:

> Upper submarine canyon (100-300 m), steeply sloping (30-45°) walls, locally including vertical walls (80–90°), with landslide (slump scarps and debris field) morphology and well-bedded, friable, differentially eroded outcrops of sandstone, mudstone, and coquina. Differentially eroded beds along the canyon walls form overhangs ($>90°$) and crevices. Landslide debris produces irregular seafloor conditions consisting of scattered, blocky boulders of sandstone interspersed with a fairly bioturbated mud seafloor.

Lithology, geomorphology, depth range, and other physical conditions in Soquel Canyon provide suitable habitat for many species of rockfishes. Further analyses of the geophysical, geological, and biological data will provide specific associations of rockfish assemblages and their microhabitat.

Portuguese Ledge

Portuguese Ledge is a basement and bedrock outcrop that rises several meters above the flat, sandy seafloor of the southern Monterey Bay shelf (Figure 3). The shelf is a wave-planed surface that represents the latest sea-level rise and advancement to the present day shoreline. Due to the resistant nature of Portuguese Ledge rocks (granite and shales) and movement along the Monterey Bay fault zone that resulted in uplift (through compression), the rocky bank remains exposed today and exhibits a faulted, flat-topped to gently irregular surface. This bank lies in water depths of ~ 100 m and is composed of Cretaceous granitic basement rocks of the Salinian block and diatomaceous mudstones (shales) and radiolaria chert of the Miocene Monterey Formation.

Side-Scan Sonar. Due to the relatively subtle relief of Portuguese Ledge when compared to Soquel Canyon, a 1-km (500 m/channel) side-scan sonar swath width with 100% overlap resulted in a fairly complete mosaic of the bank. From the sonographs, rectangular basement and bedrock outcrop appear to be bounded in many places by linear scarps, possibly formed from both faulting and erosion (Figure 6). These scarps generally rise ~ 1 m above the surrounding flat, sandy seafloor. The surface of the bank varies from repetitively bedded, gently to steeply dipping shales to massive granitic rocks textured with crosscutting joint sets. The surface of the bank is generally flat, but locally the surface can be defined as gently irregular.

Seismic Reflection Profiles. Seismic reflection profiles collected across Portuguese Ledge exhibited gently to steeply dipping sedimentary rocks and faulted basement. From the seismic reflection profiles, many of the steep scarps identified in the sonographs appear to be controlled by faults. Seismic reflection profiles collected adjacent to the bank show faulted sedimentary rocks that have been deformed from movement within the Monterey Bay fault zone.

Submersible Dives. Observations from the DSV *Delta* submersible confirmed that Portuguese Ledge is composed of granitic basement rocks and shales of the Monterey Formation. The rocky outcrops of meter-high granitic scarps and exposed folded and faulted sedimentary rocks form habitats suitable to diverse rockfishes.

Habitat Characterization. Using the habitat characterization scheme above, as well as geophysical interpretations and submersible observations, we define the Portuguese Ledge habitats as follows:

> Intermediate shelf (30–100 m) with a massive granite and bedded shale bank, lightly grooved with a flat to gently irregular surface. Some margins of the bank are faulted and form meter-high scarps. The granite surface is fractured from crosscutting joint sets. The bank is surrounded by sands and gravel that have been deposited in a strong current regime.

Conclusions

Geophysical techniques that define large-scale, marine benthic features are extremely valuable in selecting and targeting habitats for further submersible and ROV observations. Interpretations of side-scan sonar and seismic reflection data were used to locate dive sites in Soquel Canyon and Portuguese Ledge areas of Monterey Bay. Submersible observations confirmed the habitat characterization as initially described by geophysical interpretations. We suspect that similar habitats exist elsewhere and that characterization studies underway in Monterey Bay can be used as models for describing habitats outside the Monterey Bay region.

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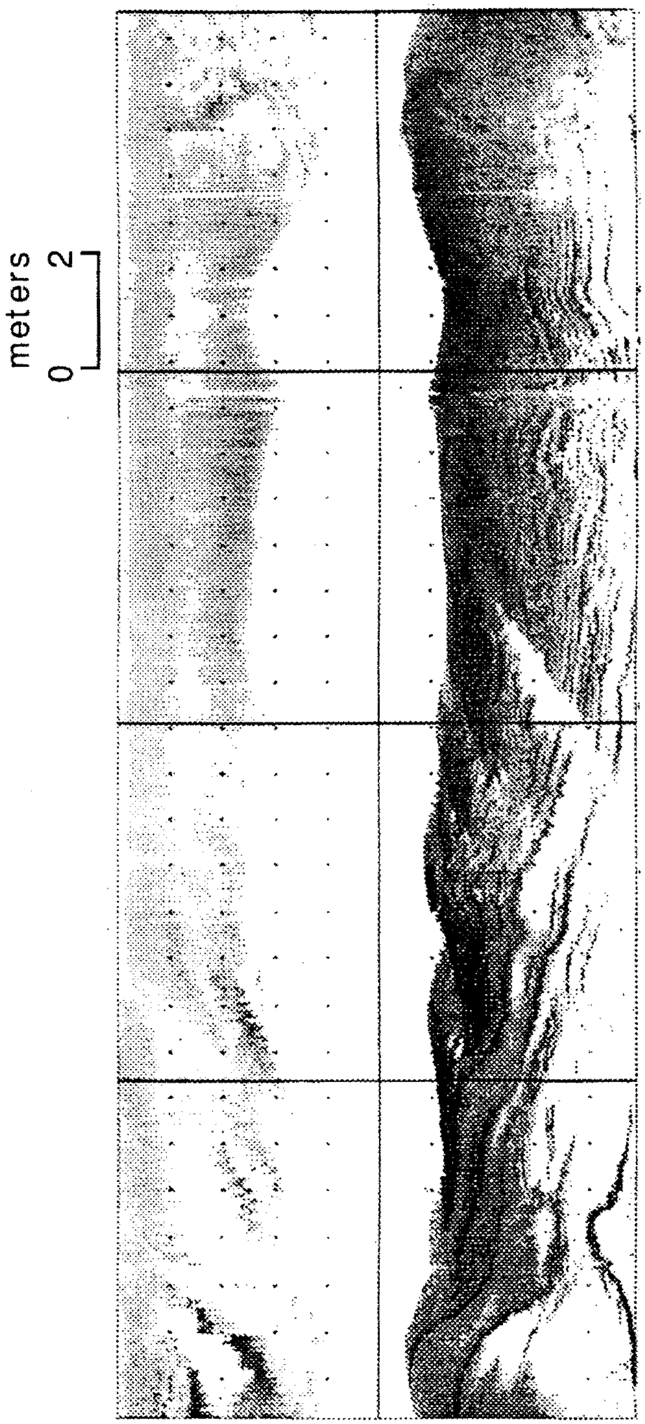


Figure 1. Side-scan sonograph showing imaged seafloor morphology along the eastern wall of Soquel Canyon.

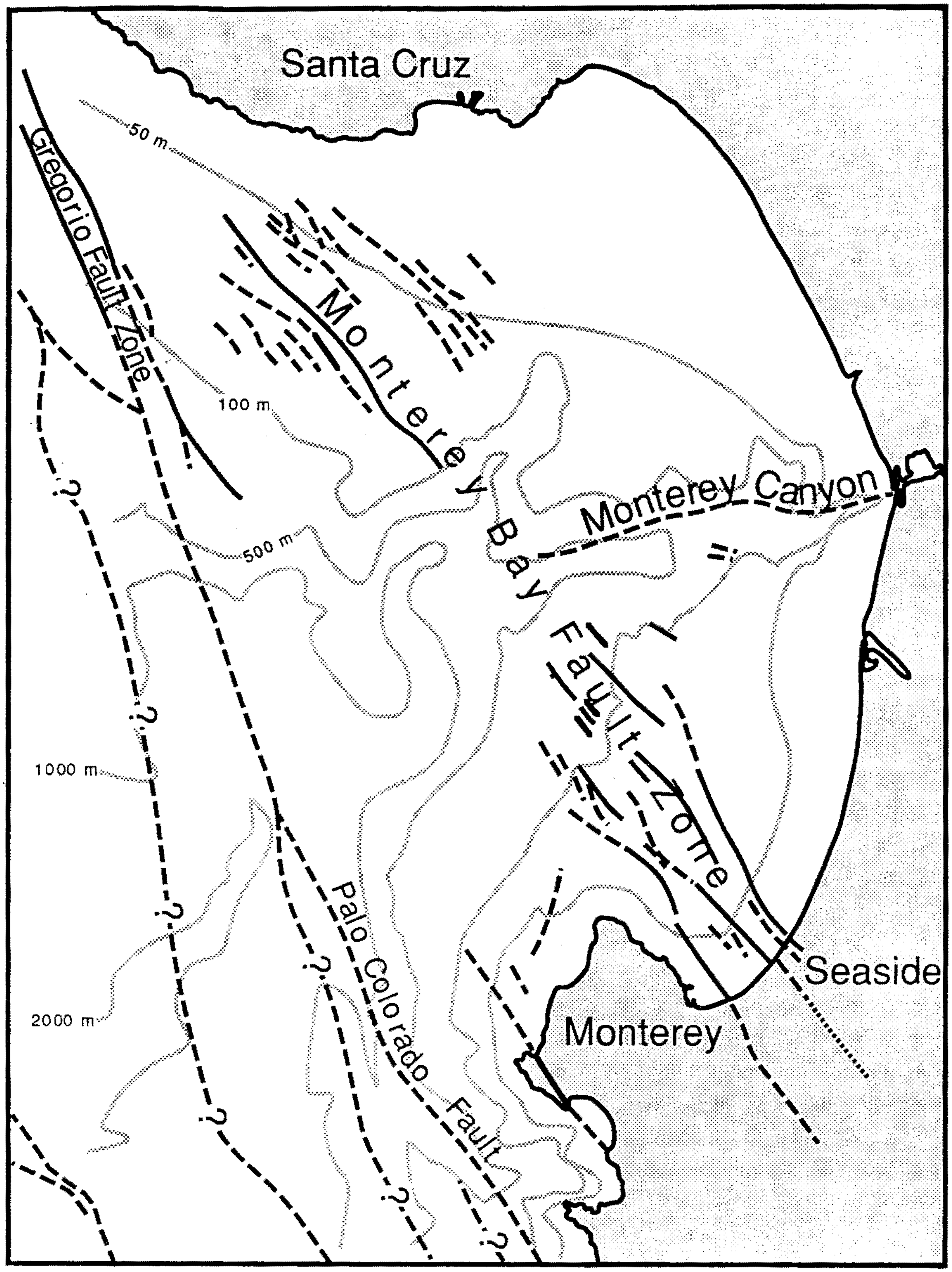


Figure 2. Faults and major physiographic features of the Monterey Bay region.

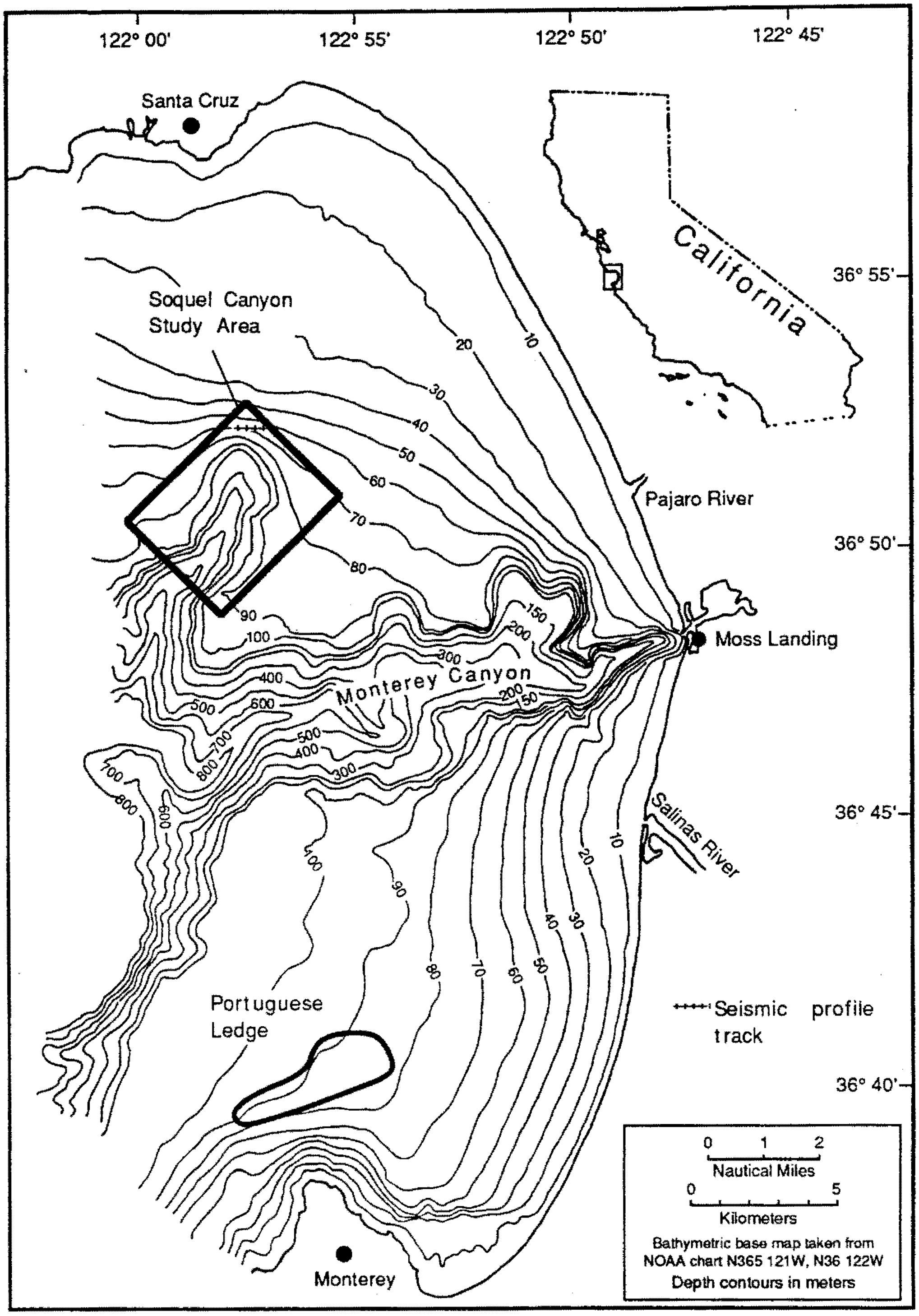


Figure 3. Locations of the Soquel Canyon and Portuguese Ledge marine benthic habitats of the Monterey Bay area.

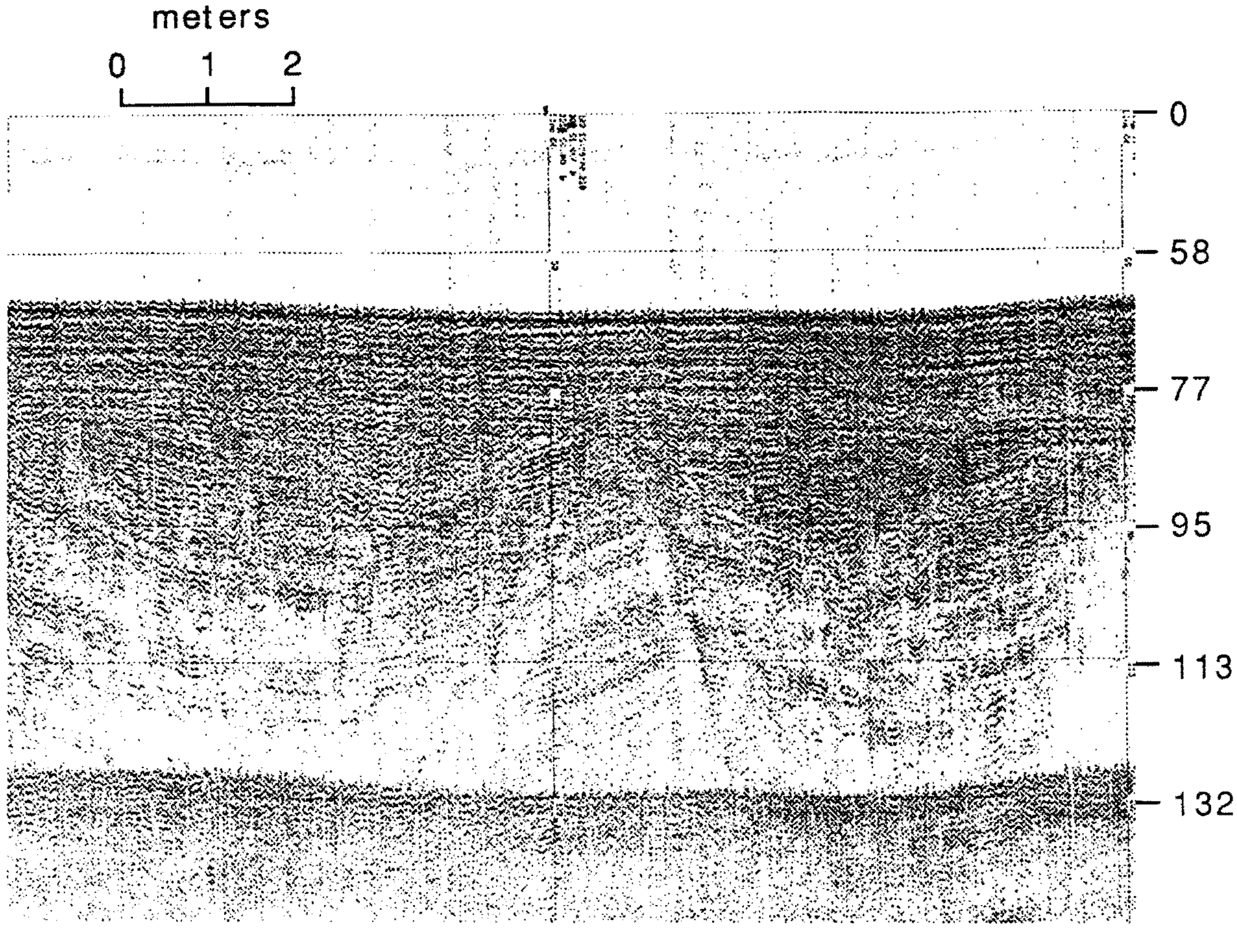


Figure 4. Seismic-reflection profile across headward part of Soquel Canyon, showing folds, faults and gas-charged sediments (see Figure 3 for location).

Figure 5. Photo taken from DSV *Delta* submersible showing differentially eroded beds of the Purisima Formation in Soquel Canyon and adult greenspotted rockfish (*Sebastes chlorostictus*).

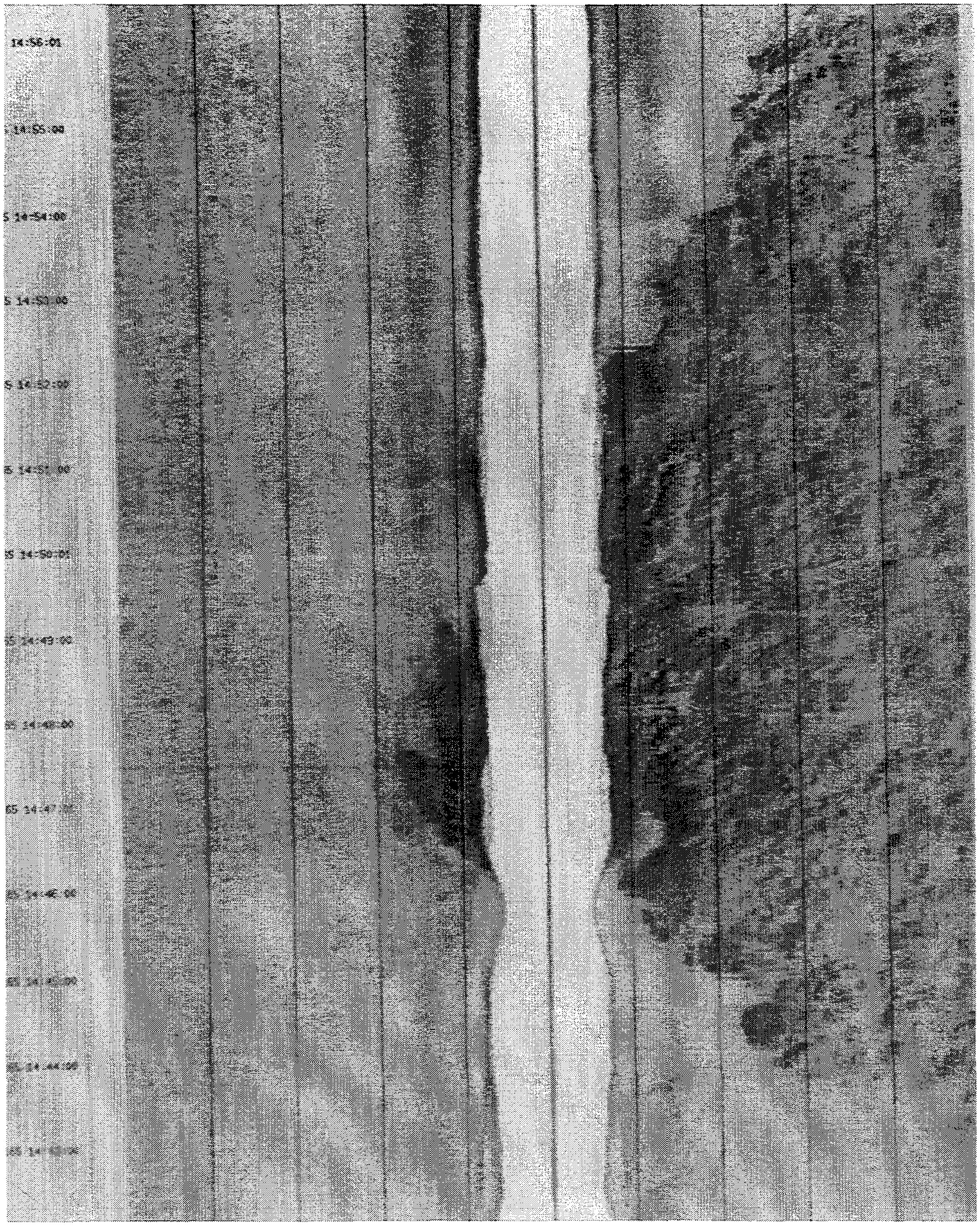
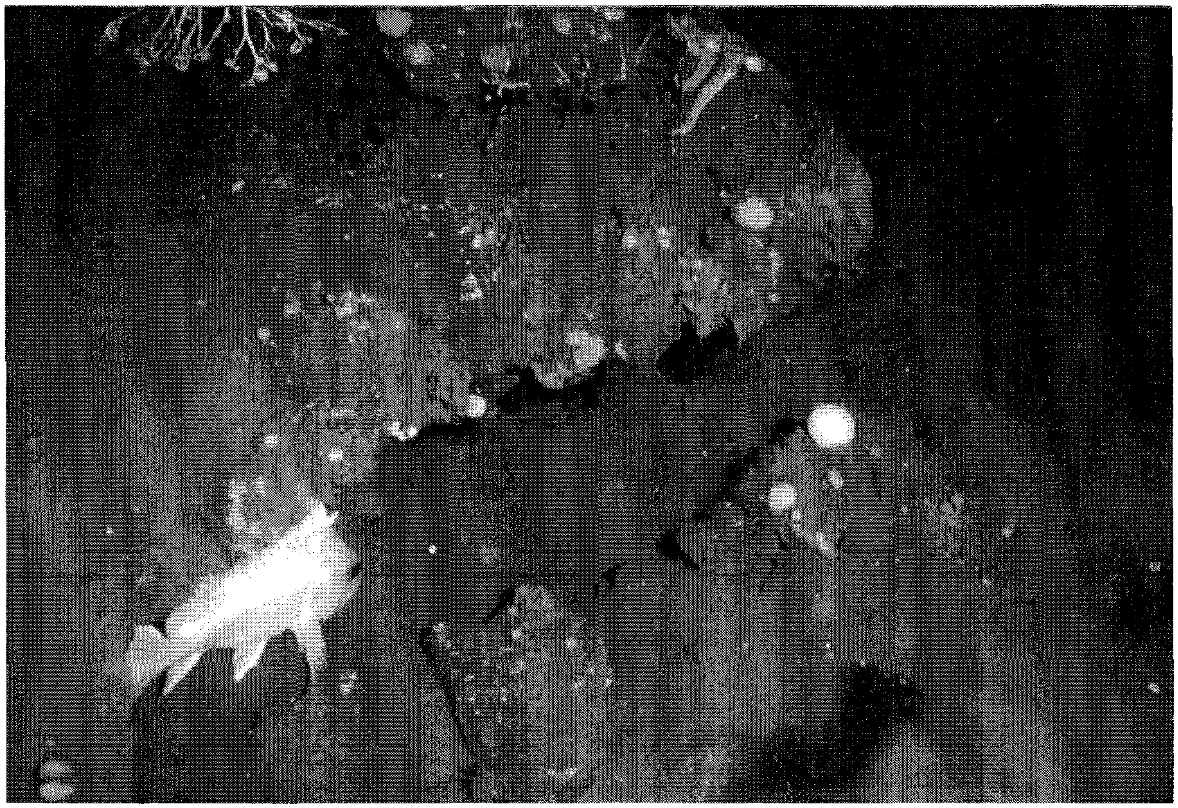


Figure 6. Side-scan sonograph across Portuguese Ledge showing cracks and crevices in granitic rocks.

WORKSHOP PROCEEDINGS

Applications of Side-Scan Sonar and Laser-Line Systems in Fisheries Research

Coast Bastion Inn
Nanaimo, British Columbia, Canada
January 20, 1994



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Alaska Department of Fish and Game
Commercial Fisheries Management
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Juneau, Alaska

March 1995

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PREFACE

The collection of abstracts in this volume represents the proceedings of a workshop held on January 20, 1994, at the Coast Bastion Inn, Nanaimo, British Columbia, Canada, directly following the 8th Western Groundfish Conference. Funding for the workshop was provided by the West Coast National Undersea Research Center, and sponsorship was provided by the Alaska Department of Fish and Game. The moderators gratefully acknowledge the following persons for their help during the workshop and their associated activities: Dr. Ray Highsmith and David Doudna, WCNURC, Greg Cailliet, Rick Starr, Jan Straley, and Mary Yoklavich. The moderators would also like to thank the organizing committee of the 8th Western Groundfish Conference from the Pacific Biological Station, Department of Fisheries and Oceans, for their support of our workshop: Rick Stanley, Lynne Yamanaka, Debra Murie, Max Stocker, Judy Stolz, Carol Roy, and Bruce Leaman.

The workshop's primary purpose was to bring together marine fishery biologists, marine geologists, and technology representatives to discuss the availability, applications, and limitations of side-scan sonar and laser-line technologies as it relates to the investigation of marine fish habitats. A total of 14 presentations were made. In all, we received abstracts and extended abstracts for 13 of the presentations: 3 related to fisheries applications, 3 related to geology and fish habitats, and 7 that were more technology related. The intent of publishing these abstracts is to provide the reader with a source for locating more detailed information on the successful application of side-scan and laser-line technology in fisheries research.

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