CABRILLO Project

Re-discovering the Southern California Coast

The CABRILLO Project (Southern **CA**lifornia **B**ight **R**egional **I**nvestigations **L**ife, **L**and, and **O**cean) of the U.S. Geological Survey addresses complex oceanographic and hazard issues that affect Southern California coastal communities.

The offshore area is geologically active resulting in the potential for earthquakes, underwater mass-wasting events (submarine landslides and slumps), and tsunamis. The geology of the seafloor along the coast and continental shelf of Southern California provides diverse habitats that include rich fisheries, kelp forests, marine mammals, and many other niches and biological guilds. Both human and non-human inhabitants are at risk from pollution of the coastal ocean and from the degradation of fresh-water sources as a result of salt-water intrusion. In addition, the coastal ocean is a resource for economic development (shipping), communication (trans-oceanic cables), fishing, recreation, and tourism. The CABRILLO project provides USGS scientists with an interdisciplinary framework in which these complex coastal issues can be studied.

CABRILLO efforts currently focus on six component tasks and a regional synthesis:

- **CASA - Salt Water Intrusion** investigates offshore-onshore components of salt-water intrusion into coastal aquifers by developing 2D and 3D stratigraphic models of potential salt-water infiltration.
- **Océano - Contaminant Processes** studies ocean contaminants, their distribution along the coastal region and the processes by which they are transported.
- **Playa - Coastal Change** addresses issues of coastal change, including beach loss, shoreline retreat, and the processes that impact coastal stability.
- **Tierra - Geologic Hazards** investigates geologic hazards associated with submarine landslides, earthquakes, and

tsunamis.
- **Vida - Benthic Habitats** concerns the relationship between sea-floor rock and sediment and benthic habitats.
- **Región - Regional Synthesis** provides a regional synthesis of Southern California's coastal and marine geology, the impact of man on the environment and the impact of the natural environment on man.

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Southern California Salt-Water Intrusion

CASA (**C**oastal **A**quifers **S**tratgraphic **A**rchitecture) is one of six tasks in the CABRILLO Project of the U.S. Geological Survey's Coastal and Marine Geology Team. CASA addresses issues of salt-water intrusion into coastal aquifers. These efforts currently focus on the Greater Los Angeles area, including the cities of Los Angeles, Long Beach, and San Pedro.

CASA - A Multi-Faceted Effort

CASA is a multi-faceted task. USGS scientists are working in collaboration with other Federal and State agencies as well as regional, county, and local water managers to better understand the pathways of salt-water intrusion into fresh-water aquifers. USGS efforts involve both the Water Resources and Geologic disciplines. The latter includes the FOQUS-LA Project, a component of the USGS Earthquake Hazards Program, and CASA is a component of the CABRILLO Project (Southern California Bight Regional Investigations-Life, Land, and Ocean) that concerns coastal and marine geology. CASA spearheads studies of the seafloor and sub-seafloor marine geology to better understand fluid migration and constraints on the geologic modeling of ground-water flow.

Accomplishments and Current Work:

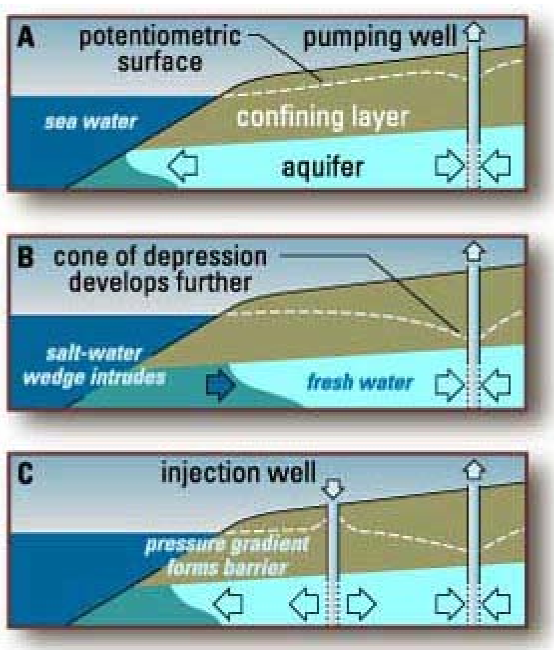
- **Borings:** CASA has completed three 425-m deep (1400 feet) continuous-recovery bore holes, and plans to integrate interpretations with onshore and offshore borehole geophysical logs in the near future.
- **Geochemical Studies:** CASA intends to correlate the chemistry of the existing chemical database and pore water extracted from the new boreholes with the chemistry and mineralogy of their associated solids.
- **Seismic Lines:** CASA has collected Geopulse, multi-channel minisparker, and sleeve-gun seismic-reflection data from the San Pedro mainland and LA and Long Beach harbors. Currently, interpretation of this seismic-reflection data is taking place.
- **Modeling:** CASA will continue developing a data model to integrate map, borehole, geophysical, and seismic data into a

3D-database system that is web accessible.

[REPORTS](#)

What is Salt-Water Intrusion?

The diagram below illustrates the concept of salt-water intrusion into fresh-water aquifers. As fresh-water is pumped from a confined aquifer, an aquifer that is overlain by a confining layer, the pressure gradient forms a slight depression in the potentiometric surface (A). Increased pumping can cause an even greater cone of depression, and the gradient that formerly held salt-water at bay reverses, resulting in invasion of the aquifer (B). Coastal barriers can help to stem this invasion; these consist of sets of closely spaced injection wells that inject high-quality fresh water into the ground, creating a hydraulic pressure ridge (C). In the Los Angeles Basin, these barriers are not completely effective; salt water continues to leak through locally, affecting water quality. New studies indicate that the geology that controls flow paths is much more complex than recognized previously.



How Can We Contain Salt-Water Intrusion?

Understanding the potential pathways for salt-water movement is crucial for stemming the inflow of marine salt water. Part of CASA's success has been the interpretation of integrated geophysical, petrophysical, and surficial data collected off the Los Angeles and San Pedro continental shelves.

Glossary of Hydrological Terms

Aquifer. A body of rock or sediment that contains abundant fresh water in a network of connected pores (small intergranular spaces) or fractures. Aquifers generally are characterized by the amount of pore space that they contain (porosity) and the capacity for water to pass through interconnected pore networks (permeability). [Return to text passage]

Cone of Depression. The depressed shape of the water table around a well after active pumping. The water table adjacent to the well is drawn down by the water removal.

Confined Aquifer. An aquifer that is bounded above and below by impermeable layers of rock or sediment.

Confining Layer. A geologic unit which is relatively impermeable, such as clay or rock, and does not yield usable quantities of water. Confining layers, also referred to as aquitards, restrict the movement of ground water into and out of adjacent aquifers.

Potentiometric Surface. A pressure level in a confined aquifer, defined by the level to which water rises in wells.

Unconfined Aquifer. An aquifer that is not bounded by impermeable strata. It is simply the zone of saturation in water-bearing rock strata, with no impermeable overburden and recharge generally accomplished by water precolating down from above.

Water Table. The upper surface of groundwater; that contact zone between the zone of saturation and aeration in an unconfined aquifer.

Southern California Contaminant Processes

Océano addresses oceanographic and contaminant-related studies in southern California.

The Océano project is comprised of the following three topics:

- **Mechanisms & Processes**
- **Toxicants**
- **Hydrocarbon Seeps**

The main study area for the Océano project extends from Pt. Arguello down to the California-Mexico border (Figure 1).

Figure 1

Human and environmental health are the overriding issues addressed in the Océano task. These issues are of critical importance in the coastal region of the Southern California Borderland (SCB), which borders the second largest urban-population center in the U.S. The SCB is unique among the continental margins of the U.S. Within the SCB, the abundance of natural contaminants may actually be as significant as anthropogenic sources. We presently do not fully know the quantitative contributions of contaminants from the various anthropogenic input sources, such as streams, surface runoff in urban areas, sewage outfalls, wind-blown debris, and natural input sources such as seepage along faults and organic matter-rich sediments. Quantifying the natural sources of contaminants is essential for determining the scope of the contaminants problem; the mass balance of contaminants; regional contaminant patterns; and the locations of hot-spots that may need attention in terms of analyzing biota for toxicants; those hot-spots may be regions of potential risk for human health through bio-accumulation and bio-magnification of toxicants in the food web.

Accomplishments and Current Work:

Cruises: Océano has completed numerous cruises throughout 2001-2003 to deploy and recover instruments, as well as take numerous sediment samples

- **Moorings/Tripods:** Océano has successfully deployed and recovered over 24 oceanographic moorings and tripods, obtaining quality data of currents, waves, winds, temperature, salinity, water clarity, and sediments
- **Cores:** Océano has collected over 200 sediment cores
- **Photographs:** Océano has taken approximately 100 bottom photographs and performed about 70 hours of camera tows
- **Geophysics:** Measurements of currents taken over the central portion of the San Pedro shelf and over the Palos Verdes peninsula will be shared by Océano in a data cooperative with a number of collaborators
- **Dating of Core Contaminants:** Océano is using sediment cores to yield sediment budgets and estimates of sediment flux for both the late Holocene and the last 100 years.
- **Modeling:** Océano is modeling sediment transport processes and helping to predict how sediment conditions will change with time as the influence of human activities changes. Also, a regional sediment transport model will be developed that will incorporate all sedimentological and oceanographic data and will allow planners to forecast future seabed conditions given variable input parameters.
- **Publications:** A special issue of Continental Shelf Research has been printed that presents the results of Océano's stuidies on the Palos Verdes margin. Also, a dedicated issue of Marine Environmental Research has been produced that resents the results of our recently completed collaborative, multidisciplinary studies in Santa Monica Bay.

For more information on the Océano, Contaminant Processes Task, use the following links:

Digital Data **Reports** **What's New** **Related Links**

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Southern California Coastal Change

The southern California coast is complex and varied, exhibiting a wide variety of coastal landforms and subject to a number of natural hazards. In places, the coast is strongly influenced by human activities. High population densities and threatened natural resources characterize much of the coast. Beach loss, cliff retreat, and coastal erosion are widespread and locally severe within the region and there have been few region-wide studies to assess coastal change in southern California.

This landslide closed Highway 1 and damaged homes near Mailbu during the El Niño winter of 1998.

Photo taken by: Bruce Richmond,
USGS. 3/12/98, near Malibu, CA.

The primary issues are the loss of critical coastal habitats and recreational resources, and damage to private property and public infrastructure caused by coastal change. The main goal of this task is to better understand the causes and processes of long-term coastal change in the California Bight.

The overall objectives are three-fold: 1) Document the regional geologic changes that have occurred along the coast, 2) Conduct research to improve our understanding of the processes and causes driving coastal change at critical sites, and 3) Provide useful and high-quality data to coastal scientists, managers, planners, and engineers for better management of coastal resources.

COASTAL PROCESSES

DIGITAL DATA
[page size >60KB]

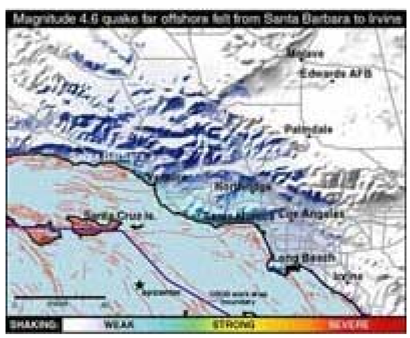
DIGITAL PHOTOS

RELATED LINKS

Southern California Geologic Hazards

The overarching goal for this effort is to identify the active fault systems in the southern California coastal zone, including the continental shelf and adjacent deep basins, that pose the greatest potential seismic hazards for the most populated urban corridor along the U.S. Pacific margin. The history of fault movements as well as the current strain building along the active faults must be determined to evaluate the hazard potential.

See Tierra: Digital Data [*page size >60KB*], Digital Photos [*page size >60KB*], Reports, What's New, and Permit Documents



[Click on Thumbnail to view Full Image]

This figure demonstrates the need for work done by the CABRILLO Project to understand offshore earthquake hazards. Early in 2002, a small magnitude 4.6 earthquake centered 40 miles offshore caused shaking of coastal southern California that was felt from Santa Barbara to Irvine. There are many faults (in red) much closer to shore, some of which may have the potential to produce devastating earthquakes of magnitude 6 or greater.

In addition, the history of submarine landslide generation related to earthquake ground motion is critical to determine the potential for the generation of tsunamis that could devastate the coastal area.

[Click on Thumbnail to view Full Image]

Accomplishments and Current Work:

- **Seismic Lines:** Tierra has performed geophysical and side-looking-sonar surveys. In addition to sidescan-sonar images, the surveys have obtained high-resolution multichannel, chirp sonar, and Huntec deep-tow boomer data as well
- **Cores:** Sediment coring has provided samples for dating to determine the age of fault movements, as well as provides age control for the high-resolution stratigraphic analysis, as well as providing material for radiocarbon dating
- **Dating:** Tierra is using radiocarbon dating of cores for age identification of faults and landslides

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Southern California Benthic Habitats

Vida is one of six tasks in the CABRILLO Project of the U.S. Geological Survey's Coastal and Marine Geology Team. Vida addresses relationships between the sea-floor geology and benthic habitats.

The main study area for the Vida project includes the Southern California coast and the Channel Islands.

[Click on above image for full view]

Gopher Rockfish - These fish can reach a length of up to 15.5 inches and can live for up to 13 years.
[learn more about rockfish]

Vida

The nearshore benthic habitat of the Southern California coast and Channel Islands supports a diversity of marine life that are commercially, recreationally, and intrinsically valuable. Some of these resources are known to be endangered including a variety of rockfish and the White Abalone. State and National agencies have been mandated to preserve and enhance these resources and require detailed habitat characterization in order to do so. This project will characterize and map the benthic habitat in areas that have been selected because they have been set aside as National Sanctuaries or State Preserves, or are areas of ongoing or planned fish population studies.

[Photos courtesy of the Channel Islands National Marine Sanctuary web site.]

Species of importance in Southern California.
White Abalone and Rockfish.

Read more on Nearshore Benthic Habitat Mapping of the Southern California Coast and Channel Islands

DIGITAL DATA

REPORTS

WHAT'S NEW

RELATED LINKS

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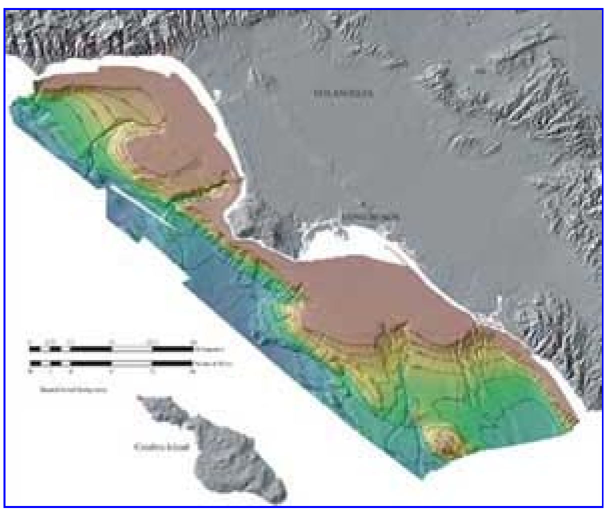
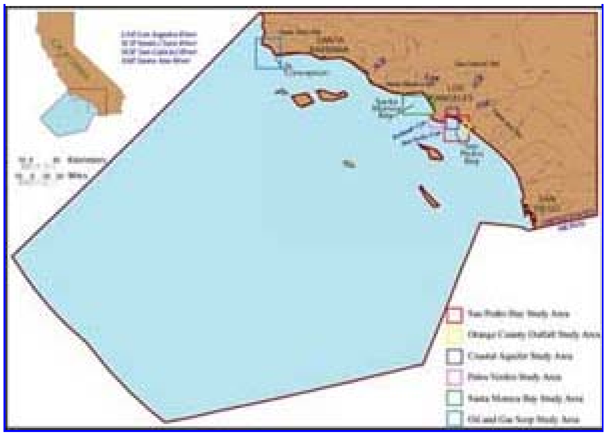
CABRILLO Southern California Regional Synthesis

A deeper understanding of the interrelationships between oceans, coastal aquifers, tectonics, human populations, and natural forces provides for successful management of southern California's resources and hazards. The Regional Synthesis task in an integrated scientific study of physical processes, water chemistry, sediment transport, coastal aquifers, earthquakes, and biohabitats. This type of study is required in the understanding of how natural and anthropogenic changes have affected coastal ecosystems in the past, and how these changes continue to affect our resources.



Click on image above for full-scale map

With new multibeam technology, scientists are able to 'drain the water' from the ocean using digital technology. The image above shows the shelf and slope deposits of the Santa Monica and San Pedro Bays offshore Los Angeles. The flat, tan areas are the shelf deposits (shelf break ~100 meters), grading into the yellow-to-green slope deposits (400-600 meters) and finally the blue basins (600-800 meters).



Click on image above for full-scale map

The regional synthesis offshore study area for Southern California extends from just north of Pt. Arguello to the Mexican border, and from the coast to the 200-mile limit of the EEZ (Exclusive Economic Zone) (See boundary and selected study areas on the above map.)

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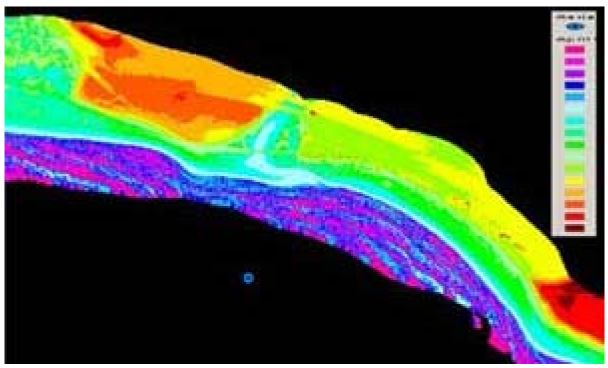

NASA's Airborne Topographic Mapper (ATM) record April 1998.

Below is a list of Southern California digital data that are available for each task.

CASA: Salt Water Intrusion Digital Data not available

Océano: Contaminant Processes Digital Data

Playa: Coastal Change Digital Data

Tierra: Geologic Hazards Digital Data

Vida: Benthic Habitats Digital Data

Región: Regional Synthesis Digital Data not available

Coastal and Marine Geology: INFOBANK Digital Data

Digital Photos

Digital Photos

Southern California coastline following the 1997-1998 El Niño weather events. [Above photo taken by Bruce Richmond, USGS, March 12, 1998.]

Below is a list of Southern California digital photos that are available for each task.

CASA: Salt Water Intrusion Digital Photos not available

Océano: Contaminant Processes Digital Photos not available

Playa: Coastal Change Digital Photos

Tierra: Geologic Hazards Digital Photos

Vida: Benthic Habitats Digital Photos not available

Región: Regional Synthesis Digital Data not available

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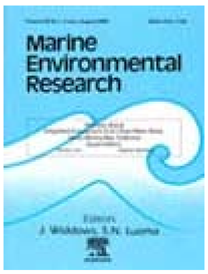

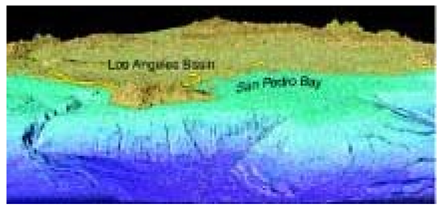

Below are a list of Open File Reports, Publications, and Digital Data Series (DDS) maps.

CASA: Salt Water Intrusion Reports

Océano: Contaminant Processes Reports

Playa: Coastal Change Reports not available

Tierra: Geologic Hazards Reports

Vida: Benthic Habitats Reports

Región: Regional Synthesis Reports not available

Digital Data Series - DDS:
Dartnell, Peter, and Gardner, James V., 1999, Sea-Floor Images and Data from Multibeam Surveys in San Francisco Bay, Southern California, Hawaii, the Gulf of Mexico, and Lake Tahoe, California-Nevada, DDS-55 http://geopubs.wr.usgs.gov/dds/dds-55/.

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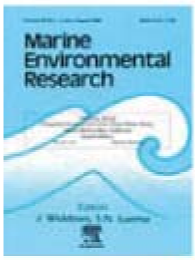

Below are links to New Science developments in Southern California that are available for each task. Last update: 2005

CASA: Salt Water Intrusion not available

Océano: Contaminant Processes What's New

Playa: Coastal Change not available

Tierra: Geologic Hazards What's New

Vida: Benthic Habitats What's New

Región: Regional Synthesis not available

Coastal and Marine Geology: Sound Waves newsletter

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Meet the Scientists

Meet the Scientists

Below are links to Scientists who play vital roles in each task.

CASA: Salt Water Intrusion Scientists

Océano: Contaminant Processes Scientists

Playa: Coastal Change Scientists

Tierra: Geologic Hazards Scientists

Vida: Benthic Habitats Scientists

Región: Regional Synthesis

Scientist's Last Names Listed Alphabetically:

NAME	TITLE / TASK
Barnhardt, Walter	Research Geologist, Playa
Borden, John	Electronics Technician, Océano
Boyle, Michael E.	Marine Electronics Technician, Océano
Carkin, Bradley	Geologist, CASA
Childs, Jon	Geophysicist, CASA
Cochrane, Guy	Marine Geophysicist, Vida Task Leader
Degnan, Carolyn	Geophysicist, CASA
Denny, Jane	Geologist
Edwards, Brian	Research Geologist, CASA Task Leader, Océano
Faunt, Claudia	Hydrologist, CASA
Ferreira, Joanne	Geophysicist, Océano
Fisher, Michael	Geophysicist, Tierra
Gonzales, David	Electronics Technician, Océano
Gutmacher, Chris	Geologist, Tierra Task Leader

Hanes, Daniel	Oceanographer, Océano
Hanson, Randall	Hydrologist, CASA
Hein, James	Research Geologist, CASA, Océano
Hibbeler, Lori	GIS/Web Development for Océano and CABRILLO
Kooker, Lawrence	Marine Electronics Technician, Océano
Kvenvolden, Keith	Emeritus Research Geologist, Océano
Lacy, Jessie	Research Oceanographer, Océano
Land, Michael	Hydrologist, CASA
Lee, Homa	Research Civil Engineer, CABRILLO Project Leader, Océano Task Leader
Lightsom, Fran	Oceanographer, Océano
Lopez, Michelle	Physical Science Technician, CASA, Océano
Martini, Marinna	Electronics Engineer, Océano
McGann, Mary	Research Geologist, Tierra
McIntyre, Brandie	Physical Science Technician, Océano
Noble, Marlene	Research Oceanographer, Océano
Normark, Bill *in memoriam*	Research Geologist, Tierra Task Leader
Olson, Walter	Marine Mechanical Technician, Océano
Orzech, Kevin	Geologist, Océano
O'Toole, Kevin	Supervising Marine Mechanical Technician, Océano
Payne, Fred	Marine Electronics Technician, Océano
Reichard, Eric	Hydrologist, CASA
Reiss, Carol	Geologist, Región, Data
Reiss, Thomas	Oceanographer, Océano
Richmond, Bruce	Research Geologist, Playa Task Leader
Rosenbauer, Bob	Geologist, CASA, Océano
Ryan, Holly	Research Geologist, Océano
Sherwood, Chris	Research Oceanographer, Océano
Sliter, Ray	Geophysicist, Océano
Storlazzi, Curt	Research Geologist, Océano
Swarzenski, Peter	Oceanographer, CASA
Warrick, Jon	PostDoc, Océano
Williams, Hal	Marine Mechanical Technician, Océano
Wong, Florence	Research Geologist, Región, Data
Xu, Jingping	Oceanographer, Océano

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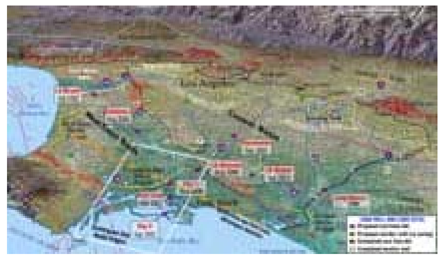


Below are relevant Southern California links that are available for each task.

Océano: Contaminant Processes Related Links

Playa: Coastal Change Related Links

Vida: Benthic Habitats Related Links

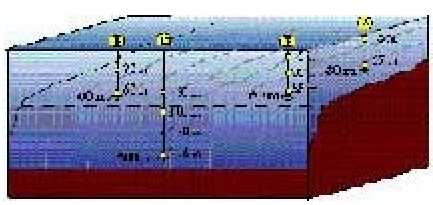
Reports

Edwards, Brian, and Evans, Kevin, 2002, Saltwater Intrusion in Los Angeles Area Coastal Aquifers--the Marine Connection: USGS Fact Sheet 030-02, http://geopubs.wr.usgs.gov/fact-sheet/fs030-02/.

Mechanisms & Processes

One major focus of Océano is to develop an improved understanding of the sediment and pollutant transport processes near major metropolitan areas. Waste products from both population and Southern California industry are released into the coastal waters, where they interact with and are transported with the bottom sediment. Understanding the geologic processes that modify, transport, and re-deposit the polluted sediment is essential if forecasting of future trends and design of remediation projects is to be accomplished.

Sediment Transport Poster by; Marlene Noble, Jingping Xu, Homa Lee, Kevin Orzech, and Juliet Kinney. (525 kb) pdf file



Circulation patterns on the Palos Verdes Shelf

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Toxicants

Human and environmental health are overriding issues addressed within Toxicants. These issues are of critical importance in the coastal region of the Southern California Borderland (SCB), which is the second largest urban-population center in the U.S. The SCB is unique among the continental margins of the U.S. One of our main objectives is to determine the natural sources and fluxes of toxicants versus those of anthropogenic origin. This objective is vital to land-use issues in the SCB, including: harbors, recreation, fishing, commerce, extraction of energy resources, and for remediation of pollution. It is also important to study the biota living in areas of natural toxicant accumulation to learn if they have developed biochemical strategies that allow them to live in such stressed environments; biochemicals that may be useful to industry and in medicine.

OCÉANO CABRILLO
Contaminant Processes

Hydrocarbon Seeps Page

A major component of Océano includes hydrocarbon seep studies. A significant quantity of oil exists in the Southern California coastal region due to various natural and anthropogenic causes. Assessment of the interrelations among oil seeps, tarballs, and produced crude oils is important in understanding the sources and distribution of these occurences. It is also an important element in the quality of beaches in southern California.

Casmailia Beach is located just north of Pt. Conception. It was selected as one of the sampling locations for the collection of tarballs.

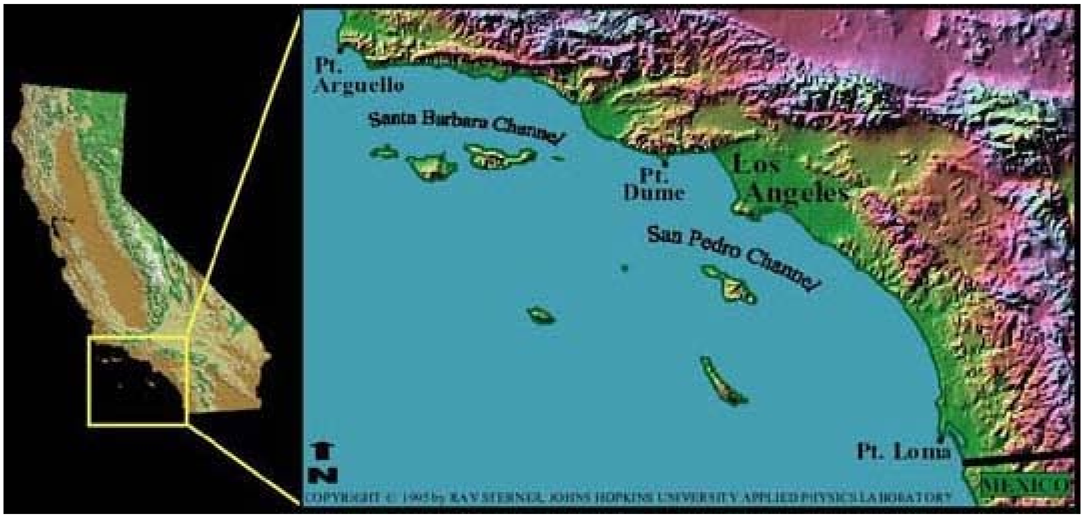
In studying hydrocarbon seeps, field studies comprised of various sampling methods and seismic surveys have taken place. Sampling methods have included the collection of tarballs from beaches for geochemical analyses, as well as the collection of produced crude oil samples from oil production platforms. These samples will provide for scientists to assess the sources of tarballs on the California coast, as well as differentiate produced crude oil from crude oil released from natural seepage. Seismic recordings allow for the detection of where these natural seeps occur.

Below is a list of relevant links:

Kvenvolden, Keith, and Lorenson, Tom. USGS Sound Waves Article. September 2001. Beginning the Search for Offshore Oil Seeps Near Point Conception, California. (http://soundwaves.usgs.gov/2001/09/fieldwork2.html)

Normark, Bill, Fisher, Michael, Gutmacher, Christina, Sliter, Ray, Hibbeler, Lori, Feingold, Beth, and Reid, Jane, 2002, Cruise Report for A1-02-SC, Southern California CABRILLO Project: U.S. Geological Survey Open-File Report 03-110, http://geopubs.wr.usgs.gov/open-file/of03-110/.

Océano Site Map



The map above shows the study area for the Océano project. It includes the coastal areas just north of Pt. Arguello, south to the California-Mexico border.

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Downloadable Arc Files and Metadata for Southern California Field Activities can be found at:

1992 Southern California Field Activity
(http://walrus.wr.usgs.gov/infobank/v/v192sc/html/v-1-92-sc.nav.html)

1997 Southern California Field Activities
(http://walrus.wr.usgs.gov/infobank/s/s197sc/html/s-1-97-sc.nav.html)

1998 Southern California Field Activity
(http://walrus.wr.usgs.gov/infobank/a/a198sc/html/a-1-98-sc.nav.html)

1999 Southern California Field Activity
(http://walrus.wr.usgs.gov/infobank/o/o199sc/html/o-1-99-sc.nav.html)

2000 Southern California Field Activity
(http://walrus.wr.usgs.gov/infobank/a/a100sc/html/a-1-00-sc.nav.html)

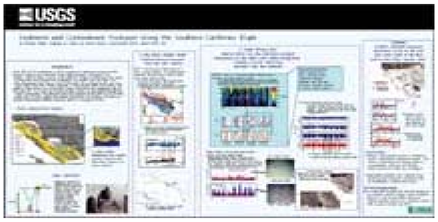
2002 Southern California Field Activity
(http://walrus.wr.usgs.gov/infobank/a/a102sc/html/a-1-02-sc.nav.html)

2003 Southern California Field Activity
(http://walrus.wr.usgs.gov/infobank/a/a103sc/html/a-1-03-sc.nav.html)

Additional Southern California Field Activities can be found HERE
(http://walrus.wr.usgs.gov/infobank/programs/html/regions2idshtml/sc_ids.html)

2002 Program Planning Posters:

Evaluating Changing Sediment Contamination Conditions, Santa Monica Bay by; Homa Lee, Steven Weisberg, Steven Bay, Clark Alexander, Brian Edwards, Eddie Zeng, Masahiro Dojiri, Marlene Noble, and Megan McQuarrie. (18MB) pdf file



Sediment Transport Poster by; Marlene Noble, Jingping Xu, Homa Lee, Kevin Orzech, and Juliet Kinney. (43MB) pdf file.

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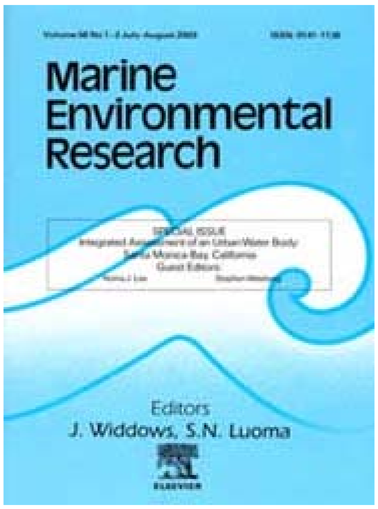
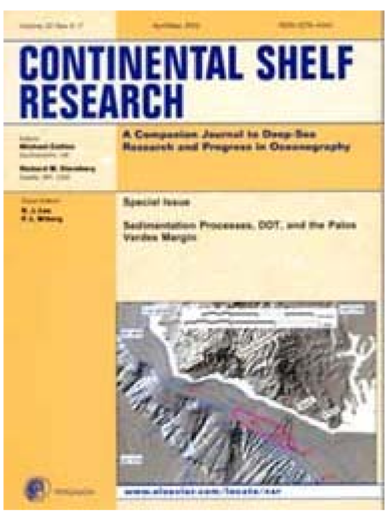


Marine Environmental Research
July-August 2003
Special Issue: Integrated Assessment of an Urban Water Body: Santa Monica Bay, California.



Continental Shelf Research
April/May 2002
Special Issue: Sedimentation Processes, DDT, and the Palos Verdes Margin

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Studies of Polluted Sediment Offshore Los Angeles:

- Understanding the Urban Influences on Santa Monica Bay, CA
- Pollution and Waste Disposal, Los Angeles Shelf
- Distribution and Fate of Contaminated Sea-floor Sediment on the Offshore Los Angeles

Bacterial Contamination at Huntington Beach, California:

- Fact Sheet - Is It From a Local Offshore Wastewater Outfall?
- Executive Summary
- Final Report

Further Studies of the Palos Verdes Region

- Fecal Pellets in Effluent-Affected Sediment on Palos Verdes Margin
- Contaminated, Effluent-Affected Sediment on the Continental Margin near Los Angeles, California
- Statistical Characterization of Current and Wave Patterns on Southern California Shelf off Palos Verdes

Alexander, C., Sommerfield, C., and Lee, H., 2000, Dispersal and Accumulation of Modern Sediments on the Santa Monica Shelf and Slope: Presented at the 2000 Southern California Academy of Sciences Meeting, Los Angeles, CA.

Drake, et al., 1997, The Fate of Contaminated Sediment on the Palos Verdes Shelf, California: Linked Earth systems; congress program and abstracts; Vol. 1, p. 48, 1995.

Hein, James R., and Dowling, Jennifer S., 2001, Clay Mineral Content of Continental Shelf and River Sediments, Southern California: U.S. Geological Survey Open-File Report 01-077, http://geopubs.wr.usgs.gov/open-file/of01-077/.

Wong, Florence, 2001, Heavy Minerals from the Palos Verdes Margin, Southern California: Data and Factor Analysis: U.S.Geological Survey Open-File Report 01-153, http://geopubs.wr.usgs.gov/open-file/of01-153/.

More Océano Reports

What's New

July-August 2003

- Marine Environmental Research Special Issue: Integrated Assessment of an Urban Water Body: Santa Monica Bay, California

March 2003

- Bacterial Contamination at Huntington Beach, California - Is It From a Local Offshore Wasterwater Outfall?

Related Links and Coordinating Partners

Below is a list of partner organizations and cooperating federal, state, and local government agencies:

Bureau of Sanitation, City of Los Angeles
(http://www.lacitysan.org/index.htm)

Bureau of Ocean Energy Management (BOEM)
(http://www.boem.gov/)

Skidaway Institute of Oceanography
(http://www.skio.usg.edu/)

Southern California Coastal Water Research Project (SCCWRP)
(http://www.sccwrp.org)

Woods Hole Oceanographic Institution
(http://www.whoi.edu)

Coastal Processes

[Example Photos provided in the links below]

Coastal hazards that impact the Southern California coast with direct human consequences include: cliff and bluff retreat, shoreline erosion and beach loss, and inundation from large waves, extreme storms, tsunamis, sea-level rise, and subsidence.

In addition to these natural hazards, large segments of the Southern California coast have been impacted by extensive human activities such as: harbor construction, dredge operations, and dam building; which traps sediment and deprives the coast of beach sand. Engineering structures which modify local sediment transport processes include breakwaters, groins, seawalls/ revetments, and cliff stabilization.

Digital Data

An Introduction to LIDAR:
LIght **D**etection **A**nd **R**anging

During late summer 1997, a plan was formulated to determine the magnitude, spatial patterns, and causative processes of El Niño-induced change along the west coast of the United States. The agencies responsible for this plan include; Wallops Flight Facility at the National Aeronautics and Space Administration (NASA), Coastal Services Center at the National Oceanic and Atmospheric Association (NOAA), and the Coastal and Marine Program at the United States Geological Survey (USGS). A key element of the plan was to survey 1200 km of representative reaches of the west coast both prior to and following the El Niño winter storms using scanning airborne laser altimetry, a technology that has only recently been applied to coastal change research.

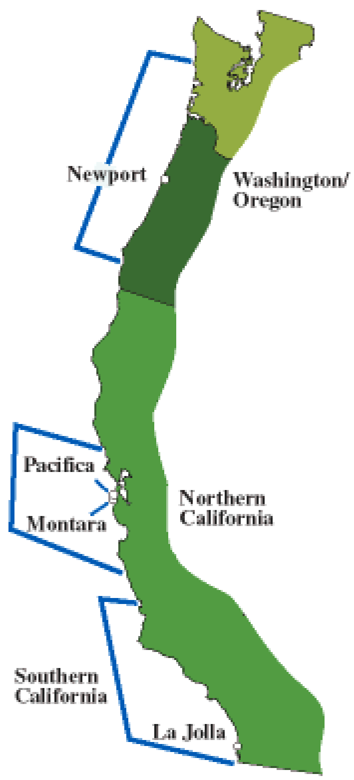

Figure 1 (above)**:** Extent of airborne scanning laser (LIDAR) surveys along the west coast of the United States during October 1997 and April 1998.

NASA's Airborne Topographic Mapper (ATM)

NASA's Airborne Topographic Mapper (ATM) is an example of a scanning airborne laser altimetry system. The ATM can survey beach topography along hundreds of kilometers of coast in a single day with data densities that cannot be achieved with traditional survey technologies . For each pass along the coast, the ATM lidar scanned a 375-m wide swath along the aircraft flight line.

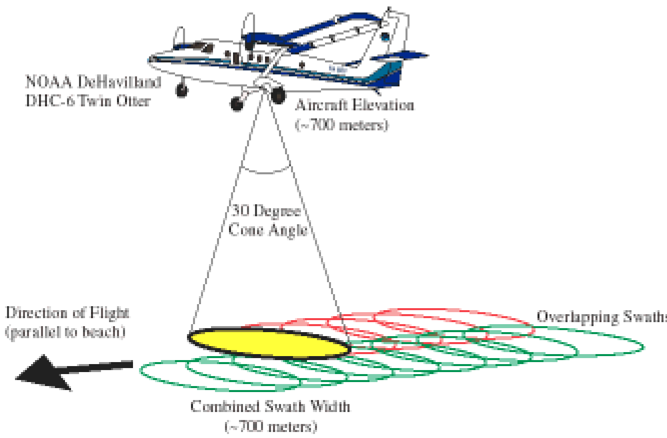

Figure 2: Diagram showing the elliptical scan pattern of NASA's ATM operated from a NOAA Twin Otter.

For most of the 1997-1998 study area, four overlapping passes were flown yielding a typical surveyed swath ~700 m wide with laser spot elevations every 3 square meters. The aircraft pitch, roll, and heading were obtained with an inertial navigation system and the positioning of the aircraft was determined using kinematic Global Positioning System (GPS) techniques.
[For more details see Playa's Related Links Page]

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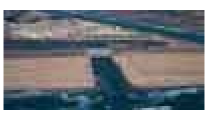
Click on the following links for a quick demonstration on how LIDAR can be used to investigate coastal change in Southern California:

 Engineered Outlet to a Coastal Wetland

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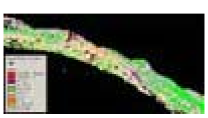
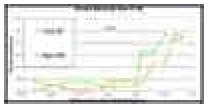
 ATM recorded for October of 1997

 ATM recorded for April of 1998

 Grid for April 98

 Calculation Grid for October 1997/April 1998

 Eroded and Accreted Beach Erosion Cross Sections

Digital Photos

ALL PHOTOS TAKEN AFTER 1997-1998 EL NIÑO WEATHER EVENTS

[click on images below to see enlarged view]

Bluff Failure

Bluff Failure

Beach Erosion

Bluff Failure

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Related Links and Coordinating Partners

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USGS Hurricane and Extreme Storm Impact Studies - (http://coastal.er.usgs.gov/hurricanes/)

Coastal and Nearshore Mapping with Scanning Airborne Laser (Lidar)
(http://coastal.er.usgs.gov/lidar)

USGS Oblique Aerial Photography - Coastal Erosion from El-Niño Winter Storms
(http://coastal.er.usgs.gov/response/)

NOAA - USGS Lidar
(http://www.csc.noaa.gov/digitalcoast/dataregistry/#/usgs-lidar)

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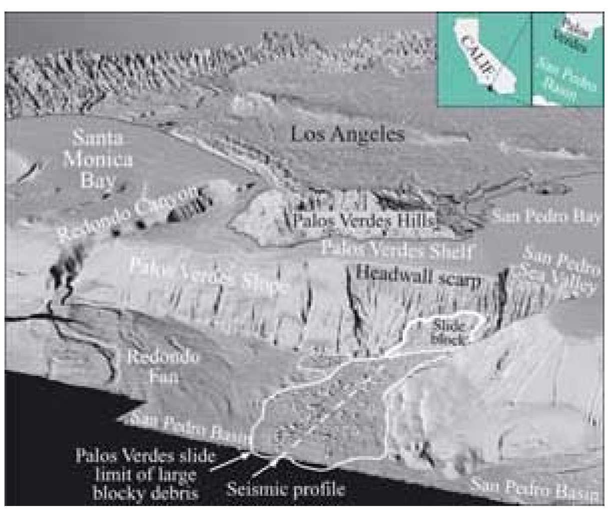
[*Click on image above for larger view*]
This image shows the overlapping areas that were surveyed during cruises to collect seismic-reflection data for the Tierra part of the CABRILLO project. Click on the image above for further details.

Coming Soon!
Core location map for Tierra. Strategically placed cores help researchers to correlate sediment layers across large areas, calculate the rate of sedimentation, and get a handle on timing of fault and landslide movements.



[*Click on image above for larger view*]
Multibeam shaded-relief oblique view of the Palos Verdes submarine debris avalanche from Dartnell and Gardner (1999). Click on the

image above for further details.

[*Click on image above for larger view*]
Downslope deep-tow boomer seismic-reflection profile across the Palos Verdes debris avalanche. Location of profile is shown in the shaded relief view above this image. Click on the profile image immediately above for further detail.

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[*Click on image above for larger view*]
Side-by-side vans on fantail of the ship Auriga, from geophysical cruise A-1-00-SC. Click on the image above for further details.

[*Click on image above for larger view*]
Vans and winches on fantail of the ship Auriga, from sampling cruise A-1-03-SC. Click on the image above for further details.

[*Click on image above for larger view*]
Rigging piston core during sunset on cruise A-1-03-SC.

[*Click on image above for larger view*]
Collecting acoustic data in the acquisition van, aboard the ship Auriga in 2002. Click on the image above for further details.

[*Click on image above for larger view*]
Typical setup of navigation area in the acquisition van. Click on the image above for further details.

[*Click on image above for larger view*]
Four yellow towfish used on geophysical cruise, A-1-02-SC. Click on the image above for further details.

Reports

Tierra Reports are listed in reverse-time order, in several groups as follows:
A. **Sound Waves articles** (USGS Coastal Science Monthly Newsletter)
B. Open-File Reports
C. Published abstracts of presentations at scientific meetings
D. Papers in scientific journals, or other USGS publications

Sound Waves articles:

USGS Scientists Discover Gas Hydrate in Southern California During Cruise to Study Offshore Landslides, Earthquake Hazards, and Pollution, November **2003**, by Cathy Frazee, Homa Lee, Bill Normark, and Brian Edwards

Survey of Offshore Hazards in Southern California, August **2002**, by Michael A. Fisher, Christina E. Gutmacher, and Helen Gibbons

Southern California Earthquake Hazards, August **1999**, by Bill Normark

Sediment Sampling Off Southern California, August **1999**, by Homa Lee

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Open-File Reports:

Ross, S.L., D.M. Boore, M.A. Fisher, A.D. Frankel, E.L. Geist, K.W. Hudnut, R.E. Kayen, H.J. Lee, W.R. Normark, and F.L. Wong, **2004**, Comments on Potential Geologic and Seismic Hazards Affecting Coastal Ventura County, California: U.S. Geological Survey OFR 2004-1286, 20p.

Wolf, S.C. and Gutmacher, C.E., **2004**, Geologic and Bathymetric Reconnaissance Overview of the San Pedro Shelf Region, Southern California: U.S. Geological Survey Open-File Report 2004-1049, 7 sheets, scales range from 1:43,000 to 1:174,000.
http://pubs.usgs.gov/of/2004/1049/

Normark, W.R., Fisher, M.A., Gutmacher, C.E., Sliter, R., Hibbeler, L., Feingold, B. and Reid, J.A., **2003**, Cruise Report for A1-02-SC: Southern California CABRILLO project, Earthquake Hazards Task: U.S. Geological Survey Open-File Report 03-110, 68 p.

Gutmacher, C.E., W.R. Normark, S.L. Ross, B.D. Edwards, P. Hart, B. Cooper, J. Childs and J.A. Reid, **2000**, Cruise report for A1-00-SC Southern California Earthquake Hazards Project, Part A, U.S. Geological Survey Open-File Report 00-516, 51 p.

Childs, J.R., W.R. Normark, and M.A. Fisher, **1999**, Permit application and approval chronology for a small airgun survey offshore southern California, June 1999, U.S. Geological Survey Open File Report 99-572 (web publication only).

Normark, W.R., J.A. Reid, R.W. Sliter, D.J. Holton, C.E. Gutmacher, M.A. Fisher, and J.C. Childs, **1999**, Cruise report for O1-99-SC Southern California earthquake hazards project, U.S. Geological Survey Open-File Report 99-560, 55 p.

Normark, W.R., Bohannon, R.G., Sliter, R., Dunhill, G., Scholl, D.W., Laursen, J., Reid, J.A., and Holton, D., **1999**, Cruise report for A1-98-SC Southern California earthquake hazards project, U.S. Geological Survey Open-File Report 99-152, 52 p.

Clarke, S.H. and Kennedy, M.P., **1998**, Analysis of late Quaternary faulting in the Los Angeles Harbor area and hazard to the Vincent Thomas Bridge, California Dept. of Conservation, Division of Mines and Geology Open-File Report 98-01, 50 p., 10 figures, 5 plates.

Normark, W.R. and Piper, D.J.W., **1998**, Preliminary Evaluation of Recent Movement on Structures Within the Santa Monica Basin, Offshore Southern California, U.S. Geological Survey Open-File Report 98-518, 47 p.

Kennedy, M.P. and Clarke, S.H., **1997**, Analysis of late Quaternary faulting in San Diego Bay and hazard to the Coronado Bridge, California Dept. of Conservation, Division of Mines and Geology Open-File Report 97-10A, 59 p., 18 figures, 3 plates.

Kennedy, M.P. and Clarke, S. H., **1997**, Age of faulting in San Diego Bay in the vicinity of the Coronado Bridge - An addendum to - Analysis of late Quaternary faulting in San Diego Bay and hazard to the Coronado Bridge, California Dept. of Conservation, Division of Mines and Geology Open-File Report 97-10B, 110 p., 12 figures, 2 plates.

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Published abstracts from scientific meetings:

Covault, J.A., W.R. Normark, and S.A. Graham, **2005**, Sea-level and tectonic controls on late Quaternary sedimentation in San Diego Trough, offshore California: Geol. Soc. Amer. Cordilleran Section/Pacific Section American Association of Petroleum Geologists Meeting, San Jose, Official Program, p. 34.

Nicholson, C., C. Sorlien, S. Hopkins, J. Kennett, W. Normark, R. Sliter, and M. Fisher, **2005**, High-Resolution Stratigraphy and the Evolution of an Active Fault-Related Fold in 3D, Santa Barbara Channel, California: SCEC Annual Meeting, Sept. 2005, Proceedings and Abstracts, p. 159-160.

Normark, W.R., C.E. Gutmacher, and R. Sliter, **2005**, Natural hydrocarbon seeps on the inner shelf off Pt. Conception and western Santa Barbara Channel, California: Geol. Soc. Amer. Cordilleran Section/Pacific Section American Assoc. of Petroleum Geologists Meeting, San Jose, Official Program, p. 96-97.

Normark, W.R., D.J.W. Piper, and R. Sliter, **2005**, Late Quaternary turbidite systems in Santa Monica Basin, offshore California: Geol. Soc. Amer. Cordilleran Section/Pacific Section American Association of Petroleum Geologists Meeting, San Jose, Official Program, p. 34.

Ryan, H.F., J.E. Conrad, and R.W. Sliter, **2005**, Quaternary Faulting in the Inner Southern California Borderland, Offshore San Diego County, California: SCEC Annual Meeting, Sept. 2005, Proceedings and Abstracts, p. 177-178.

Conrad, J., R. Sliter, and H. Ryan, **2004**, Characteristics of the Southern Part of the Palos Verdes Fault from High Resolution and Multichannel Seismic Reflection Data: SCEC Annual Meeting, Sept. 2004, Proceedings and Abstracts, p. 86-87.

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Fisher, M.A., W.R. Normark, H.G. Greene, H.J. Lee, and R. Sliter, **2004**, Evaluating the Tsunamigenic Potential of Submarine Landslides Below Santa Barbara Channel, Southern California: Seismological Soc. of Amer. Annual meeting. Seismological Research Letters, v. 75, p. 290.

Hein, J.R., Normark, W.R., Lorenson, T.D., Powell, C.L. II, and McIntyre, B.R., **2004,** Methanogenic carbonates collected with gas hydrate from a mud volcano offshore Southern California: Abstracts with Program of the 32nd International Geological Congress, 20-28 August, Florence Italy, part 2, p. 1250-1251.

Hopkins, S.E., C.C. Sorlien, C. Nicholson, J.P. Kennett, W.R. Normark, M.A. Fisher and R.W. Sliter, **2004**, A Test for Extending the High-Resolution Global Climate Record in Santa Barbara Basin: Eos Trans. AGU, 85(47), Fall Meet. Suppl., Abstract GC51D-1078.

Lee, H.J., W.R. Normark, M.A. Fisher, H.G. Greene, R.E. Kayen, P. Dartnell and J. Locat, **2004**, Size and Age Characteristics for West Coast Tsunamigenic Landslides: Eos Trans. AGU, 85(47), Fall Meet. Suppl., Abstract OS22B-05.

Normark, W.R., S. Baher, and R. Sliter, **2004**, Late Quaternary Deformation in Santa Monica Basin Deposits Adjacent to Santa Cruz-Catalina Ridge, Offshore Southern California: SCEC Annual Meeting, Sept. 2004, Proceedings and Abstracts, p. 137.

Normark, W.R., M. McGann, and R. Sliter, **2004**, Sediment accumulation rates of late Quaternary deposits in San Pedro Basin, the Gulf of Santa Catalina, and San Diego Trough, offshore southern California: Eos Trans. AGU, 85(47), Fall Meet. Suppl., Abstract OS33B-0587.

Ryan, H., R. Sliter, and J. Conrad, **2004**, New Fault Map of the Inner Southern California Borderland Offshore San Diego and Orange Counties, California: SCEC Annual Meeting, Sept. 2004, Proceedings and Abstracts, p. 155-156.

Sorlien, C., K. Broderick, L. Seeber, B. Normark, M. Fisher, R. Sliter, and M. Kamerling, **2004**, The complete Palos Verdes Anticlinorium and Offshore Evidence for the Compton Blind Fault Beneath it: SCEC Annual Meeting, Sept. 2004, Proceedings and Abstracts, p. 164.

Baher, S., Fuis, G., Normark, W.R., Sliter, R., **2003**, Estimating Earthquake Hazards in the San Pedro Shelf Region, Southern California: Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract S52H-07.

Baher, S., G. Fuis, R. Sliter, and B. Normark, **2003**, Estimating Earthquake Hazard in the San Pedro Shelf Region, Southern California: SCEC Annual Meeting, Sept. 2003, Proceedings and Abstracts, p. 64.

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Broderick, K., C. Sorlien, B. Luyendyk, M. Kamerling, R. Sliter, M. Fisher, B. Normark, N. Seeber, **2003**, Blind Thrust Faulting and Shelf-Slope Deformation in Eastern Santa Monica Bay, California: SCEC Annual Meeting, Sept. 2003, Proceedings and Abstracts, p. 70.

Erohina, T., W.R. Normark, R.W. Sliter, **2003**, Acoustic Facies of Late Quaternary Channel and Overbank Systems, Gulf of Santa

Catalina, California Borderland: Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract OS52B-0917.

Fisher, M.A., Normark, W.R., and Langenheim, V.E., **2003**, Geologic structure of the San Pedro shelf region, southern California: Pacific Section Amer. Assoc. Petrol. Geologists, May 2003, Conference Program and Abstracts, p. 65 (invited).

Fisher, M.A., W.R. Normark, H.G. Greene, H.J. Lee, and R. Sliter, **2003**, Geology of Submarine Landslides Below Western Santa Barbara Channel, California: SCEC Annual Meeting, Sept. 2003, Proceedings and Abstracts, p. 84-85.

Greene, H.G., M. Fisher, N. Maher, and W. Normark, **2003**, Dating One Slide Event of the Complex Compound Goleta Submarine Landslide, Santa Barbara Basin, California USA: Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract OS31A-03 (invited).

Hart, P.E., J.R. Childs, and W. Normark, **2003**, New Access to Proprietary Marine Seismic Reflection Data along the U.S. West Coast: SCEC Annual Meeting, Sept. 2003, Proceedings and Abstracts, p. 94-95.

Lee, H.J., W.R. Normark, M.A. Fisher, H.G. Greene, B.D. Edwards, and J. Locat, **2003**, Ages of Potentially Tsunamigenic Landslides in Southern California: Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract OS31A-02.

Normark, W. R., **2003**, Geohazards of the southern California offshore area: out of sight, out of mind?: Geol. Assoc. Canada-Mineral. Assoc. Canada-Soc. Econ. Geologists Joint Annual Meeting, Abstract Vol. 28, cd-rom, Abstract No. 783 (invited keynote address for geohazards session of the Geological Assoc. of Canada meeting).

Normark, W.R. and M. McGann, **2003**, Developing a High-Resolution Stratigraphic Framework for Estimating Age of Fault Movement and Landslides in the California Continental Borderland: SCEC Annual Meeting, Sept. 2003, Proceedings and Abstracts, p. 121-122.

Normark, W.R., H.J. Lee, B.D. Edwards, and Shipboard Scientific Staff USGS Cruise A1-03-SC, **2003**, Hydrate Discovery in Santa Monica Basin Offshore California: SCEC Annual Meeting, Sept. 2003, Proceedings and Abstracts, p. 121.

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Normark, W.R., J.R. Hein, C.L Powell II, T.D. Lorenson, H.J. Lee, and B.D. Edwards, **2003**, Methane Hydrate Recovered From A Mud

Volcano in Santa Monica Basin, Offshore Southern California: Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract OS51B-0855.

Piper, D.J.W., W.R. Normark, and M. McGann, **2003**, Variations in accumulation rate of late Quaternary turbidite deposits in Santa Monica Basin, offshore southern California: Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract OS52B-0916.

Ryan, H. F., Sliter, R., and Normark, W. R., **2003**, Recent faulting in the Gulf of Santa Catalina from San Diego to Dana Point, California: Pacific Section Amer. Assoc. Petrol. Geologists, May 2003, Conference Program and Abstracts, p. 87 (invited).

Ryan, H., R. Sliter, and B. Normark, **2003**, Revisiting the Offshore Connection Between the Newport-Inglewood and Rose Canyon Fault Zones: SCEC Annual Meeting, Sept. 2003, Proceedings and Abstracts, p. 135-136.

Sliter, R.W. and H. F. Ryan, **2003**, Possible Connections Between the Coronado Bank Fault Zone and the Newport-Inglewood, Rose Canyon, and Palos Verdes Fault Zones Offshore San Diego County, California: Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract T51D-0193.

Sorlien, C., Broderick, K., Kamerling, M., Fisher, M., Normark, W. R., Sliter, R., and Seeber, L., **2003**, Structure and kinematics beneath Santa Monica Bay, California: Pacific Section Amer. Assoc. Petrol. Geologists, May 2003, Conference Program and Abstracts, p. 90.

Fisher, M.A., Normark, W.R., Langenheim, V.E., Calvert, A.J., Sliter, R.W., Sorlien, C.S., Nicholson, C., **2002**, Marine geology of the San Pedro continental shelf and initial results from seismic reflection data obtained in Santa Barbara Channel: Eos Trans. AGU, 83(47), Fall Meet. Suppl., Abstract T71E-1218. ALSO presented at SCEC Annual Meeting, Sept. 2002, Proceedings and Abstracts, p. 69-70.

Kennedy, M.P., Tan, S.S., and Clarke, S.H., **2002**, Geologic map and digital data base of the Oceanside 30'x60' quadrangle, California: Geol. Soc. America Annual Mtg. Abstracts with Program, v. 34, no. 6, p. 125.

Normark, W. R., McGann, M., and Sliter, R., **2002**, Emplacement of the 7,500 yr B.P. Palos Verdes submarine debris avalanche, southern California: Eos Trans. AGU, 83(47), Fall Meet. Suppl., Abstract T71E-1219.

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What's New

Subsequent work on the hydrate discovery, 2003-2005:

Geology journal paper, in press

International Geological Congress (IGC) meeting poster, 2004

American Geophysical Union (AGU) meeting poster, 2003

Soundwaves (USGS Coastal Science Monthly Newsletter), 2003

July 2003

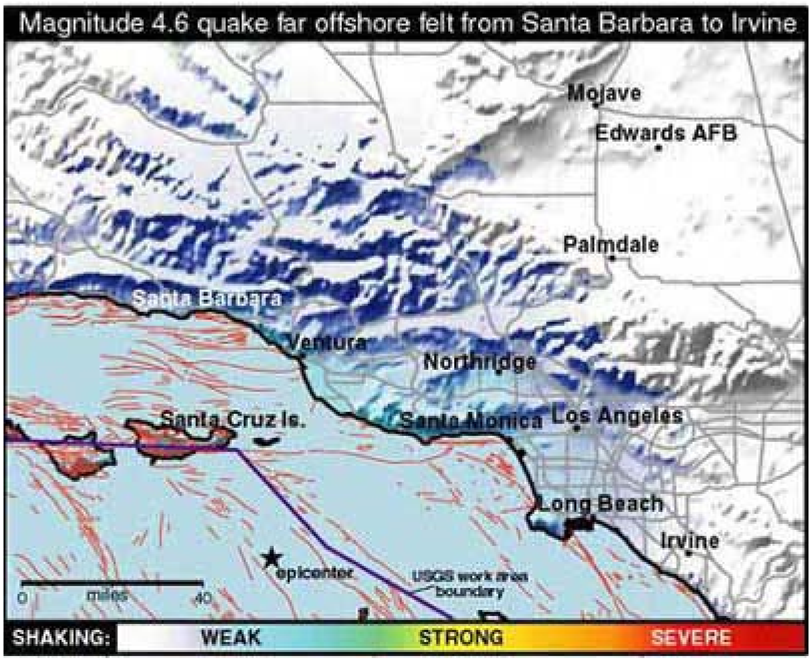
Follow link for details about the July 2003 **Methane Hydrate Discovery!**

Permit Documents

[*The following links will EXIT the CABRILLO site*]

We use remote sensing with sound to map offshore faults. Under the Marine Mammal Protection Act we are required to have permits to make that sound, both from the US government and from the State of California Coastal Commission and State Lands Commission. For details on the permit process, see this report.

Shake Map



This figure demonstrates the need for work done by the CABRILLO Project to understand offshore earthquake hazards. Early in 2002, a small magnitude 4.6 earthquake centered 40 miles offshore caused shaking of coastal southern California that was felt from Santa Barbara to Irvine. There are many faults (in red) much closer to shore that, in all likelihood, have the potential to produce devastating magnitude 6 to 7 earthquakes.

Map references:
Earthquake Hazards Program (http:www.trinet.org/shake/12659440/intensity.html)

Vedder, J.G., Crouch, J.K., and Junger, A., 1987, Geologic map of the outer-southern California continental margin -- Area 3 of 7, In Greene, H.G. and Kennedy, M.P., eds, 1987, California continental margin geologic map series: Sacramento, CA (California Division of Mines and Geology), scale 1:250,000.

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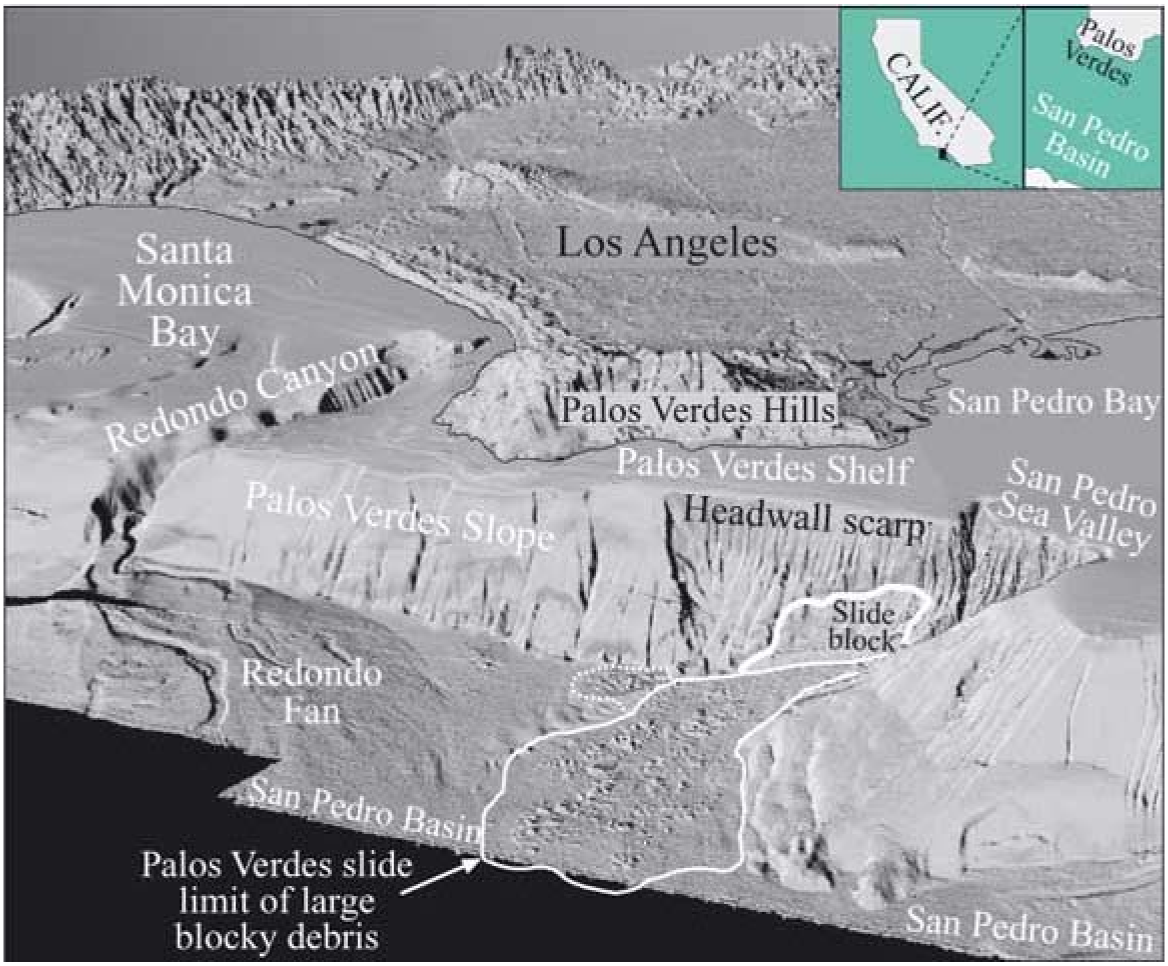
Submarine Landslide



In addition, the history of submarine landslide generation related to earthquake ground motion is critical to determine the potential for the generation of tsunamis that could devastate the coastal area.

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The colored regions on the map indicate areas mapped around the Northern Channel Islands.

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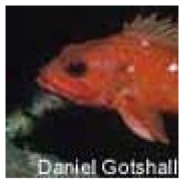
Rockfish



Click on each rockfish thumbnail for a larger view.

Concern for rockfish species has been voiced by fishers, managers, and scientists alike, and while the particular species, amount of decline, and areas affected can be debated, there is no debating the question that a problem does indeed exist. Serious exploitation of rockfish began in the late 1960s with removals by foreign vessels and continues to the present with removals by the domestic fleet. Significant declines have been observed in bocaccio rockfish populations, most likely as a result of variations in the marine environment, which can strongly affect the survival of young fish, as well as overexploitation. These factors have conspired to reduce population levels to the point that they are now listed on the IUCN's (World Conservation Union) Red List of "critically endangered" species. The criteria for this listing require an 80 percent reduction in the population over the last ten years or three generations . Estimates current levels of total and spawning biomass for bocaccio to be at eight percent and six percent of historic apex levels respectively. The most recent stock assessment for bocaccio indicates their current level to be at two to four percent of historic levels (NMFS 1998 Triennial Survey Data). Substantial declines can be seen in the estimates of current total and spawning biomass levels for black, yellowtail, widow, Pacific ocean perch, and canary rockfish as well as others. In the 1998 National Marine Fisheries Service report to congress on the overfishing status of commercially fished species the designation of yellowtail rockfish has changed from approaching an overfished condition to a stable status. This rapid change in status for yellowtail rockfish is very indicative of the lack of data we have for many species. (Pacific Marine Conservation Council and other sources)

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White Abalone

Click on abalone thumbnail for enlarged image

In 2001, white abalone, Haliotis sorensoni, became the first marine invertebrate to be listed as an endangered species. A submarine survey of rocky reefs for white abalone at offshore islands and banks in southern California found white abalone at densities three orders of magnitude (ie., 1000 times) lower than historically reported. Using the abundance of abalone at different locations and the amount of potentially suitable habitat at these locations, the investigators conservatively estimated that 3,000 individuals (or < 2.3 metric tons) remain in California (most on the offshore banks) compared with the total combined commercial landing of >280 metric tons. An estimate of the number of white abalone in Mexico (based on rough estimates of suitable habitat) only added another 200-2,000 animals to the total abundance for the species. Abalone were associated with Laminaria farlowii (an alga) and occurred on relatively large rocks (with a variety of algal/invertebrate cover), usually near the rock-sand interface. The investigators were able to collect several white abalone and hold them in captivity until they were ready to spawn. Spawning resulted in settled juveniles that are presently under culture.

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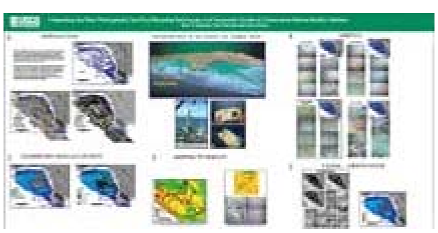
Digital Data

[*The link listed below will exit the Vida site*]

Cochrane, Guy R., Nasby, Nicole M., Reid, Jane A., Waltenberger, Lee, Kristen M., 2003, Nearshore Benthic Habitat GIS for the Channel Islands National Marine Sactuary and Southern California State Fisheries Reserves Volume 1: U.S. Geological Survey Open-File Report 03-85, http://geopubs.wr.usgs.gov/open-file/of03-85/.

2002 Program Planning Poster:



Habitat Poster by; Brian D. Edwards, Peter Dartnell, and Henry Chezar. (41MB) pdf file.

[PDFs require Acrobat Reader, Download free Acrobat Reader here]

Reports

[Note: All of the following links will EXIT THIS SITE]

Cochrane, Guy R., and Lafferty, Kevin D., 2000, Activities and Preliminary Results of Nearshore Benthic Habitat Mapping in Southern California, 1998: U.S. Geological Survey Open-File Report 00-321. http://geopubs.wr.usgs.gov/open-file/of00-321/

Cochrane, Guy R., Nasby, Nicole M., Reid, Jane A., Waltenberger, Ben, and Lee, Kristen M. Nearshore Benthic Habitat GIS for the Channel Islands National Marine Sactuary and Southern California State Fisheries Reserves Volume 1: U.S. Geological Survey Open-File Report 03-85. http://geopubs.wr.usgs.gov/open-file/of03-85/

1999, Sustainable Seas Submersible Project: Alolkoy, Vol.12, n.1. http://walrus.wr.usgs.gov/nearshorehab/sse.html

What's New

[Note: All of the following links will EXIT THIS SITE]

March, 2003

- Nearshore Benthic Habitat GIS for the Channel Islands National Marine Sactuary and Southern California State Fisheries Reserves Volume 1

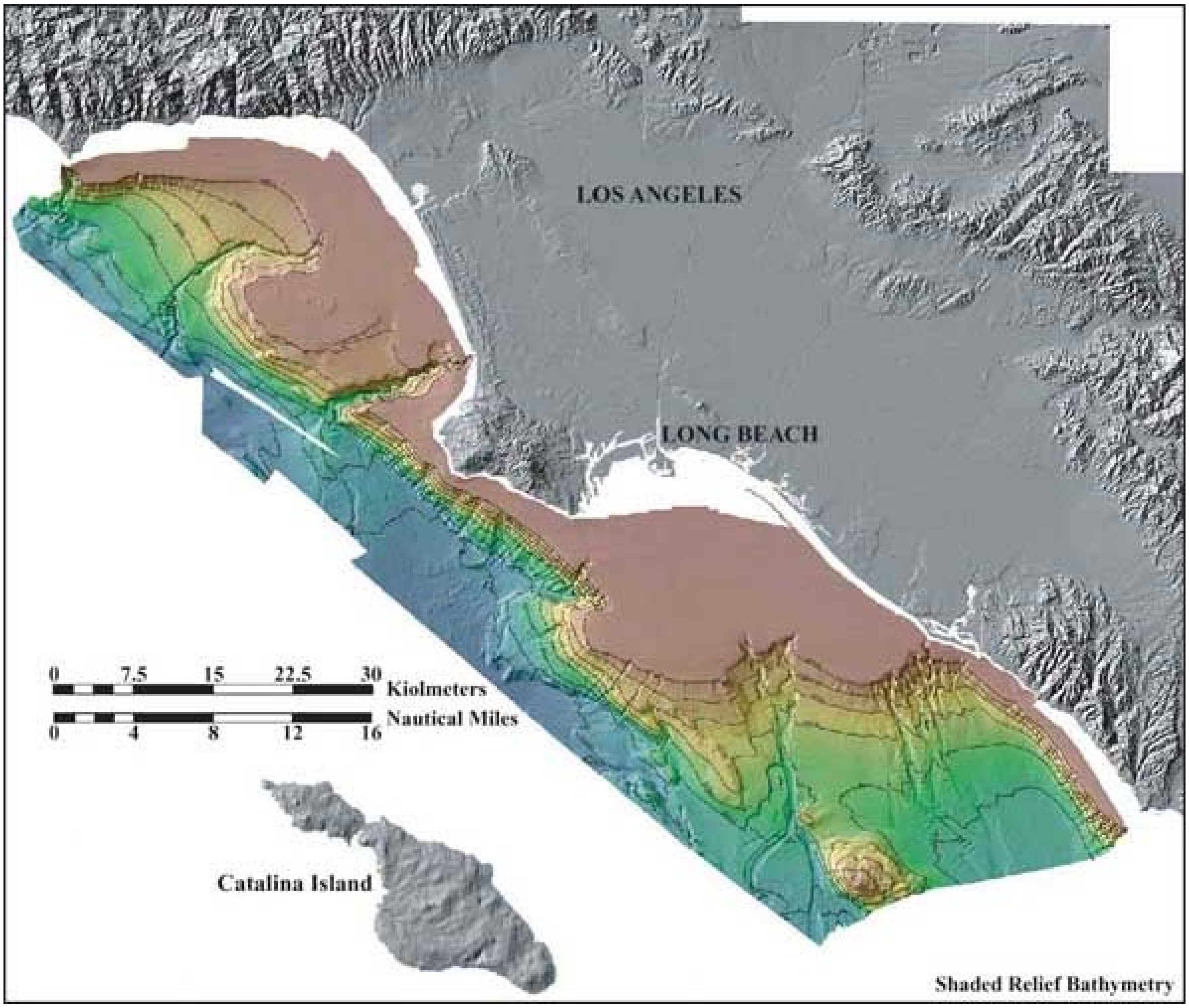
Related Links and Coordinating Partners

Below is a list of related links:

usSEABED: sediment facies map

Nearshore Benthic Habitat Project (http://walrus.wr.usgs.gov/nearshorehab/)

Multibeam Technology



The regional synthesis offshore study area for Southern California extends from just north of Pt Arguello to the Mexican border. This shaded relief bathymetry map extends throughout the regional synthesis study area.

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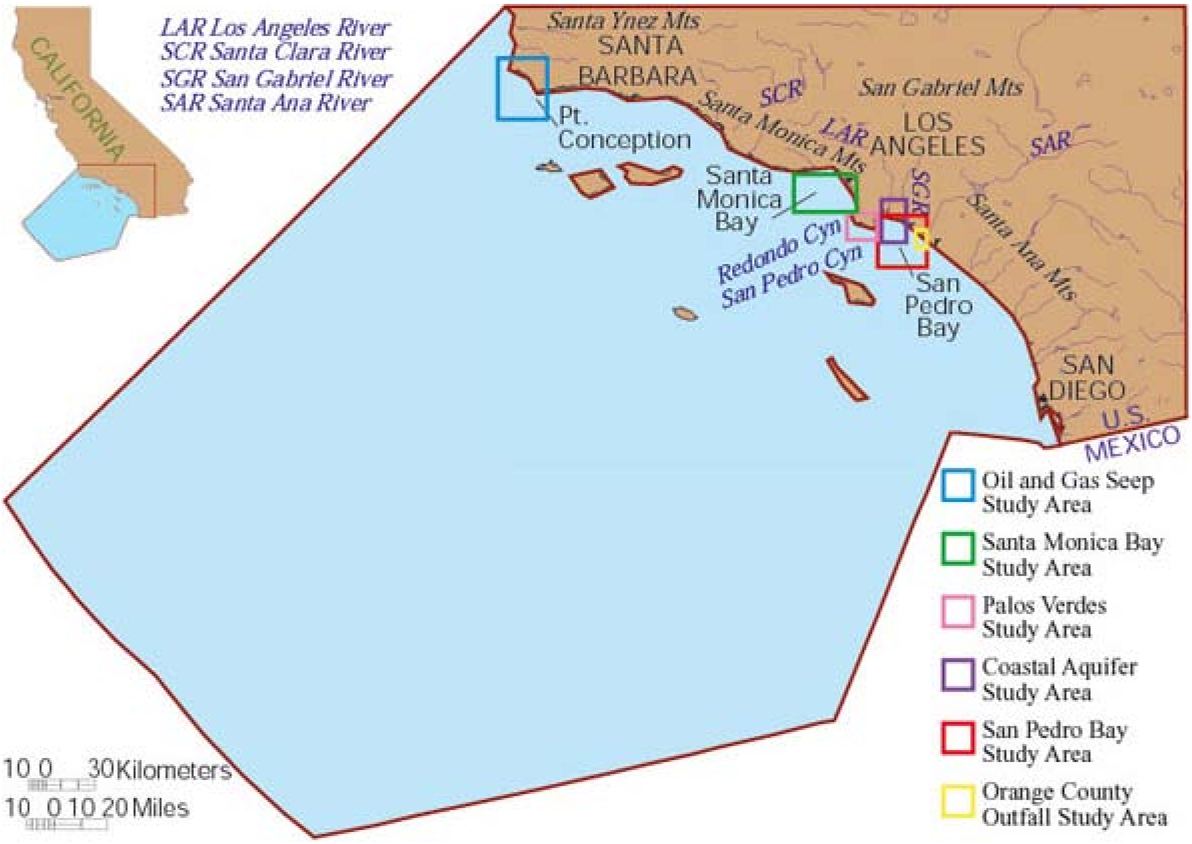
Región EEZ Map



The regional synthesis offshore study area for Southern California extends from just north of Pt Arguello to the Mexican border, and from the coast to the 200-mile limit of the Exclusive Economic Zone (EEZ).

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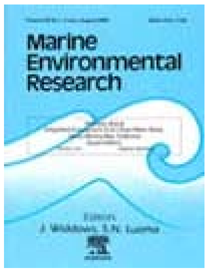

Marine Environmental Research Special Issue Integrated Assessment of an Urban Water Body: Santa Monica Bay, California

Volume 56 No 1-2 July-August 2003
Guest Editors: Homa J. Lee and Stephen Weisberg

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Modern sedimentary processes in the Santa Monica, California, continental margin: sediment accumulation, mixing, and budget
C.R. Alexander, & C. Venherm (USA)

Water quality impacts of stormwater discharges to Santa Monica Bay
S. Bay, B.H. Jones, K. Schiff, & L. Washburn (USA)

Impacts of stormwater discharges on the nearshore benthic environment of Santa Monica Bay
K. Schiff, & S. Bay (USA)

Retrospective evaluation of shoreline water quality along Santa Monica Bay beaches
K.C. Schiff, J. Morton, & S.B. Weisberg (USA)

Temporal and spatial distributions of contaminants in sediments of Santa Monica Bay, California
S.M. Bay, E.Y. Zeng, T.D. Lorenson, K. Tran, & C. Alexander (USA)

Toxicity assessment of sediment cores from Santa Monica Bay
D.Greenstein, S. Bay, A. Jirik, J. Brown, & C. Alexander (USA)

Foraminiferal response to pollution and abatement in Santa Monica Bay
M. McGann (USA)

To **View Abstracts** go to ScienceDirect. Search for Marine Environmental Research, select Volume 56, then select Issues 1-2.

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Continental Shelf Research Special Issue Sedimentation Processes, DDT, and the Palos Verdes Margin

Volume 22 Nos 6-7 April/May 2002
Editors: Michael Collins and Richard W. Sternberg
Guest Editors: Homa J. Lee and P.L. Wiberg

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p,p′-DDE bioaccumulation in femail sea lions of the California Channel Islands
J.P. Connolly and D. Glaser

A model of *p,p′*-DDE and total PCB bioaccumulation in birds from the Southern California Bight
D. Glaser and J.P. Connolly

Organic matter diagenesis in the sediments of the San Pedro Shelf along a transect affected by sewage effluent
W.M. Berelson, K. Johnson, K. Coale and H.-C. Li

To **View Abstracts** go to ScienceDirect. Search for Continental Shelf Research, select Volume 22, then select Issues 6-7.

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L.A. Reports

Studies of Polluted Sediment Offshore Los Angeles:
Marine sediment on the continental shelf south of Los Angeles is contaminated with DDT and PCBs from historic sewage discharges. This effluent-affected sediment body, which has been the subject of litigation, adversely affects natural resources. USGS scientists, working in cooperation with the National Oceanic and Atmospheric Administration and the Department of Justice, in addition to the National Park Service, the Fish and Wildlife Service, and the State of California, completed a major study to delineate the present distrubution and character of the effluent-affected sediment body and to model its natural recovery. This study showed that the sediment contains in excess of 100 tons of DDT and that surface concentrations of DDT will remain above 1 part per million well into the 21st century and possibly beyond.
Refer to the three web sites listed below to learn more about the polluted sediment studies in the offshore region of Los Angeles;

Lee, Homa J., McQuarrie, Megan, and Hibbeler, Lori, 2002, Tracking Contaminants in Santa Monica Bay, Offshore of Greater Los Angeles: U.S. Geological Survey Fact Sheet 155-02, http://pubs.usgs.gov/fs/2002/fs155-02/

Lee, Homa J., 1998, Pollution and Waste Disposal, Los Angeles Shelf

Lee, Homa J., 2001, Distrubution and Fate of Contaminated Sea-floor Sediment on the Offshore Los Angeles

Huntington Beach, California:
During the summers of 1999 and 2000, beaches at Huntington Beach, California, were repeatedly closed to swimming because of high bacteria levels in the surf zone. The city's beaches are a major recreational and commercial resource, normally attracting millions of visitors each summer. One possible source of the bacterial contamination was the Orange County Sanitation District's sewage outfall, which discharges treated wastewater 4.5 miles offshore at a depth of 200 feet. Scientists from the U.S. Geological Survey and cooperating oraganizations have been investigating whether ocean currents and waves transport the wasterwater to the beaches. These studies indicate that bacteria from the outfall are not a significant source of the beach contamination.

Xu, Jingping, Noble, Marlene, Rosenfeld, Leslie, Largier, John, Hamilton, Peter, and Jones, Burt, 2003, Bacterial Contamination at Huntington Beach, California - Is It From a Local Offshore Wastewater Outfall?: U.S. Geological Survey Fact Sheet 024-03, http://geopubs.wr.usgs.gov/fact-sheet/fs024-03/.

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Noble, Marlene, and Xu, Jingping, eds., 2004, Huntington Beach Shoreline Contamination Investigation, Phase III, Final Report: Coastal circulation and transport patterns: the likelihood of OCSD's plume impacting Huntington Beach shoreline: U.S. Geological Survey Open-File Report 2004-1019 [available on the World Wide Web at http://pubs.usgs.gov/of/2004/1019/].

Additional Reports

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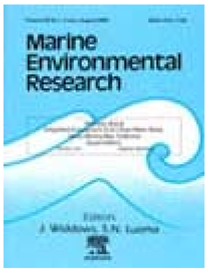

Marine Environmental Research Special Issue Integrated Assessment of an Urban Water Body: Santa Monica Bay, California

Volume 56 No 1-2 July-August 2003
Guest Editors: Homa J. Lee and Stephen Weisberg

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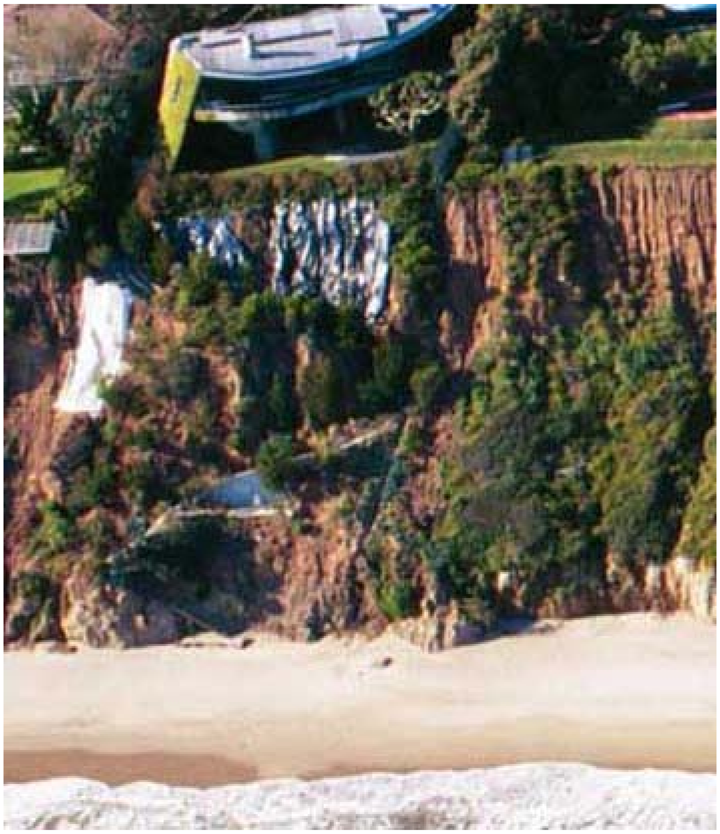
Bluff Retreat



Homes threatened by bluff failure. Located between Santa Barbara and Los Angeles, just north of Pt. Dume. April 1998. [Photos taken from a NOAA Twin Otter aircraft flying at 500 feet and 130 knots are from URL: http://coastal.er.usgs.gov/response/]

Accelerated bluff failure caused by the established drainage channel at top of bluff, on the

Palos Verdes Peninsula, North of Los Angeles. April 1998. [Photos taken from a NOAA Twin Otter aircraft flying at 500 feet and 130 knots are from URL: http://coastal.er.usgs.gov/response/]

BACK

Shoreline Erosion

October 1997

April 1998

Huntington Beach in a wide, pre-winter state (left) and in a narrower, post-winter state (right). Is the change in beach width a strictly seasonal phenomena, or are there long term changes as well? Only a regional analysis over time will provide the information needed to make a determination. [Photos taken from a NOAA Twin Otter aircraft flying at 500 feet and 130 knots are from URL: http://coastal.er.usgs.gov/response/]

BACK

Breakwater

Breakwaters create safe harbors but can also trap sediment moving along the coast. Long Beach Harbor, April, 1998

Coastal lagoons fronted by barrier spits typically have entrances that migrate through time. Here, the entrance has been fixed by jetty construction. Carlsbad, CA, April 1998.

[Photos taken from a NOAA Twin Otter aircraft flying at 500 feet and 130 knots, are from URL: http://coastal.er.usgs.gov/response/]

BACK

Groin

This curved groin was constructed in San Diego, near Coronado, to make the beach larger in front of this hotel, which starves the beach to the right. [Photo taken in April, 1998, from a NOAA Twin Otter aircraft flying at 500 feet and 130 knots are from URL: http://coastal.er.usgs.gov/response/]

BACK

CABRILLO
LifeLandOcean

Seawall

A revetment constructed from boulders protects a waste treatment facillity between Santa Barbara and Los Angeles, near Pt. Mugu. April 1998. [Photos taken from a NOAA Twin Otter aircraft flying at 500 feet and 130 knots are from URL: http://coastal.er.usgs.gov/response/]

BACK

Cliff Stabilization

Almost every home along this stretch of northern San Diego (La Jolla) has engineered cliff stabilization preventing further failure. April 1998. [Photos taken from a NOAA Twin Otter aircraft flying at 500 feet and 130 knotsare from URL: http://coastal.er.usgs.gov/response/]

BACK

Outlet

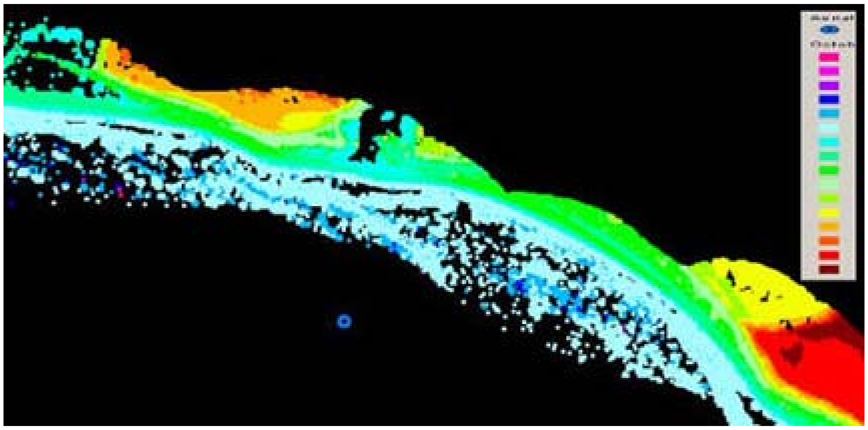
An engineered outlet to a coastal wetland in October of 1997.

The same location on the left, imaged in April of 1998.

Location of images is just North of Newport Beach, near Los Angeles, CA. [Photos taken from a NOAA Twin Otter aircraft flying at 500 feet and 130 knots are from URL: http://coastal.er.usgs.gov/response/]

BACK

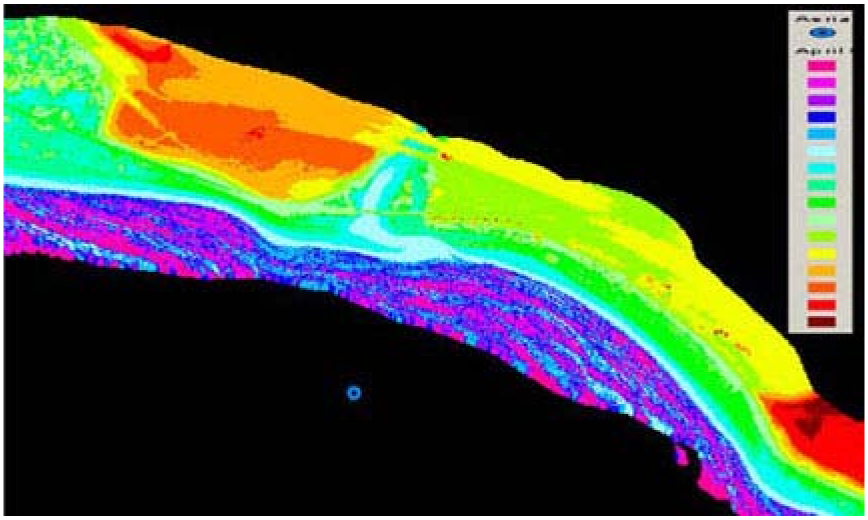
ATM Oct '97



The blue dot offshore is the location of the aircraft when it captured the images above. This image is what the ATM recorded for October of 1997. The colors in the legend correspond to elevations for each returned laser signal (i.e. each dot).

BACK

ATM Apr '98

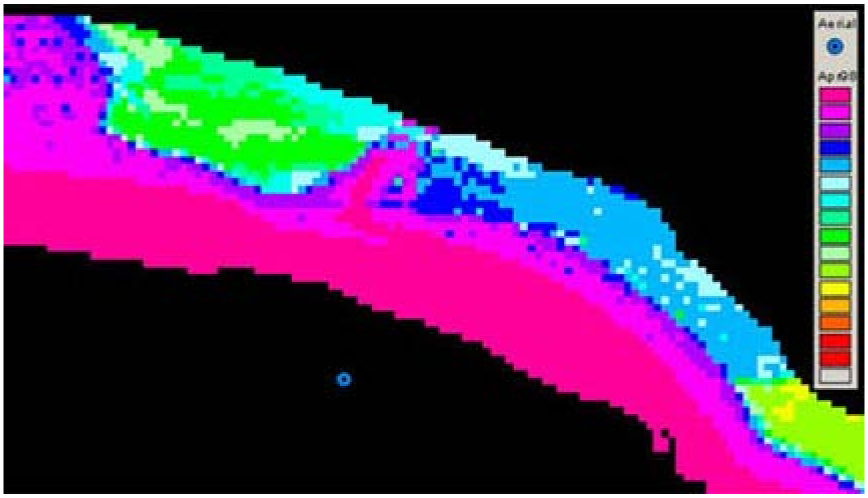


This image is what the ATM recorded in April 1998. The reason that the October image has fewer points is most likely due to surface water interference with the LIDAR sensor.

BACK

USGS
science for a changing world

Grid Apr '98

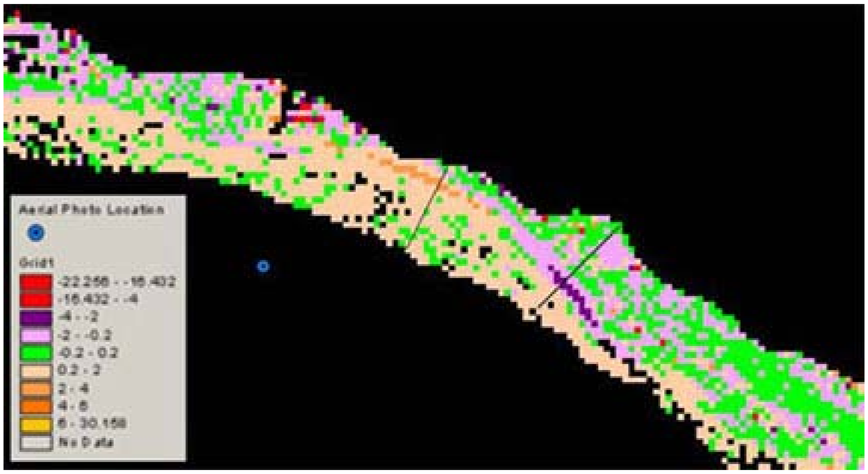


This is the grid for April 1998. In order to make any calculations, the GPS point data has to be converted to a grid format. In this case, the GPS point data is resampled to about two meters per pixel. Each of these pixels is an average of a few GPS points.

BACK

CABRILLO
LifeLandOcean

Calculation Grid

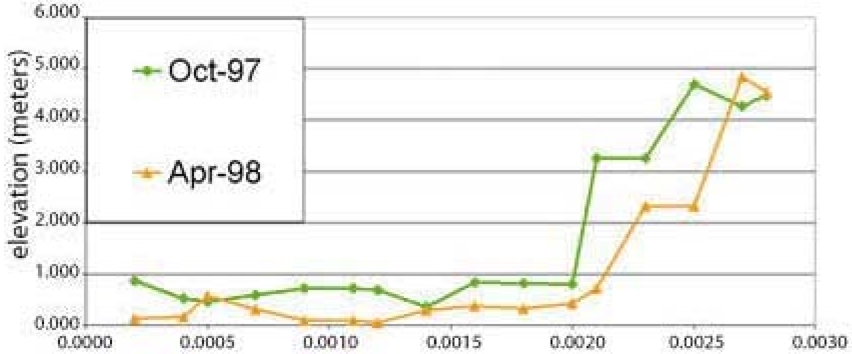


The April grid (refer to Digital Data page) was then subtracted from the October grid to produce this calculation grid where the negative values, represented by the red and purple cells, show accretion, and the positive values, represented by the orange and yellow cells, show erosion. The green cells show areas that changed by less than a half meter, which is a resonable error buffer. The black lines are where cross sections were taken to show the change in graphical format (see graphs on digital data page).

BACK

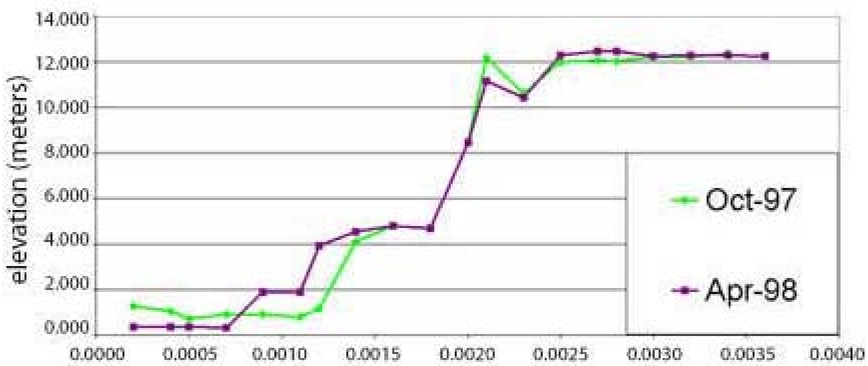
Cross Sections

Eroded Beach: El Niño 97-98



Distance from water (decimal degrees)

Accreted Beach: El Niño 97-98



Distance from water (decimal degrees)

BACK

Bluff Failure

Photo taken by Bruce Richmond, USGS, March 12, 1998, near San Clemente, CA.

BACK

Bluff Failure II

Photo taken by Bruce Richmond, USGS, March 12, 1998.

BACK

Erosion


Photo taken by Bruce Richmond, USGS, March 12, 1998

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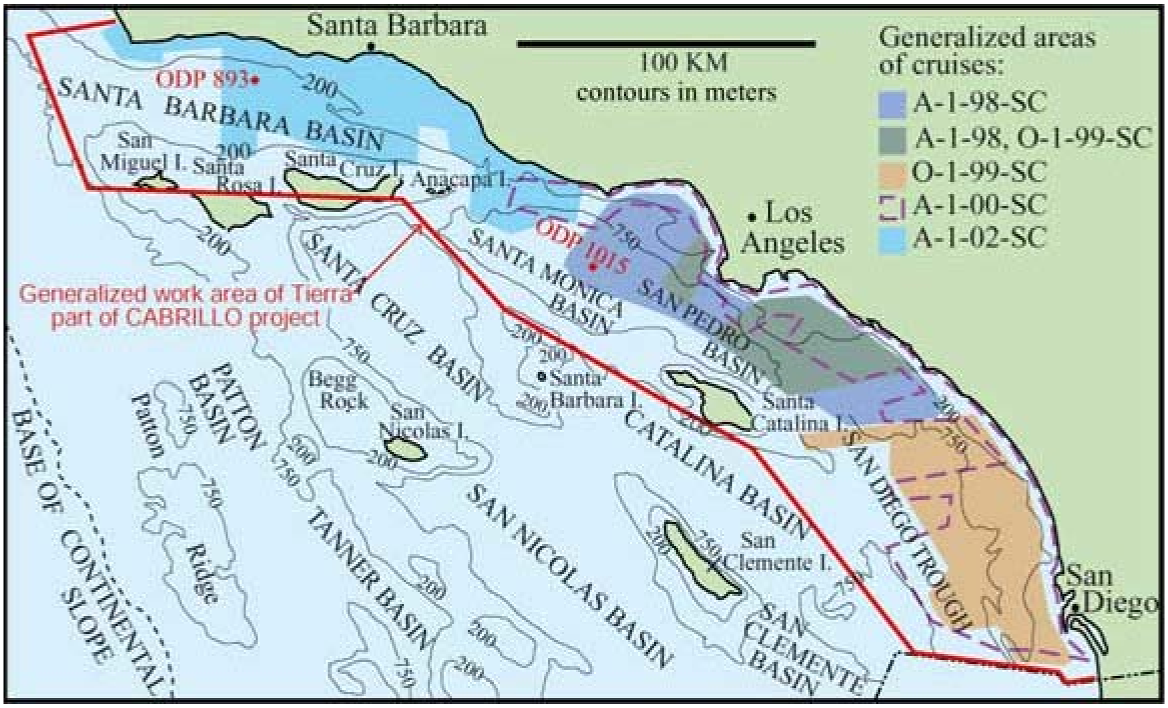
Bluff Failure III

Photo taken by Bruce Richmond, USGS, March 12, 1998.

BACK

Work Area



This image shows the overlapping areas that were surveyed during cruises to collect seismic-reflection data for the Tierra part of the CABRILLO project. The cruise in 2000 had permits to collect data within the State's 3-mile limit, so it served two purposes: collect data nearshore, as well as add necessary trackline density to some areas covered on previous cruises. For more information about each cruise listed on the map, navigate by cruise id starting at the following web address: http://walrus.wr.usgs.gov/infobank/programs/html/ids2idshtml/a_ids.html

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Associated Field Activity Links:

A-1-98-SC (*http://walrus.wr.usgs.gov/infobank/a/a198sc/html/a-1-98-sc.meta.html*)

A-1-00-SC (*http://walrus.wr.usgs.gov/infobank/a/a100sc/html/a-1-00-sc.meta.html*)

A-1-02-SC (*http://walrus.wr.usgs.gov/infobank/a/a102sc/html/a-1-02-sc.meta.html*)

O-1-99-SC (*http://walrus.wr.usgs.gov/infobank/o/o199sc/html/o-1-99-sc.meta.html*)

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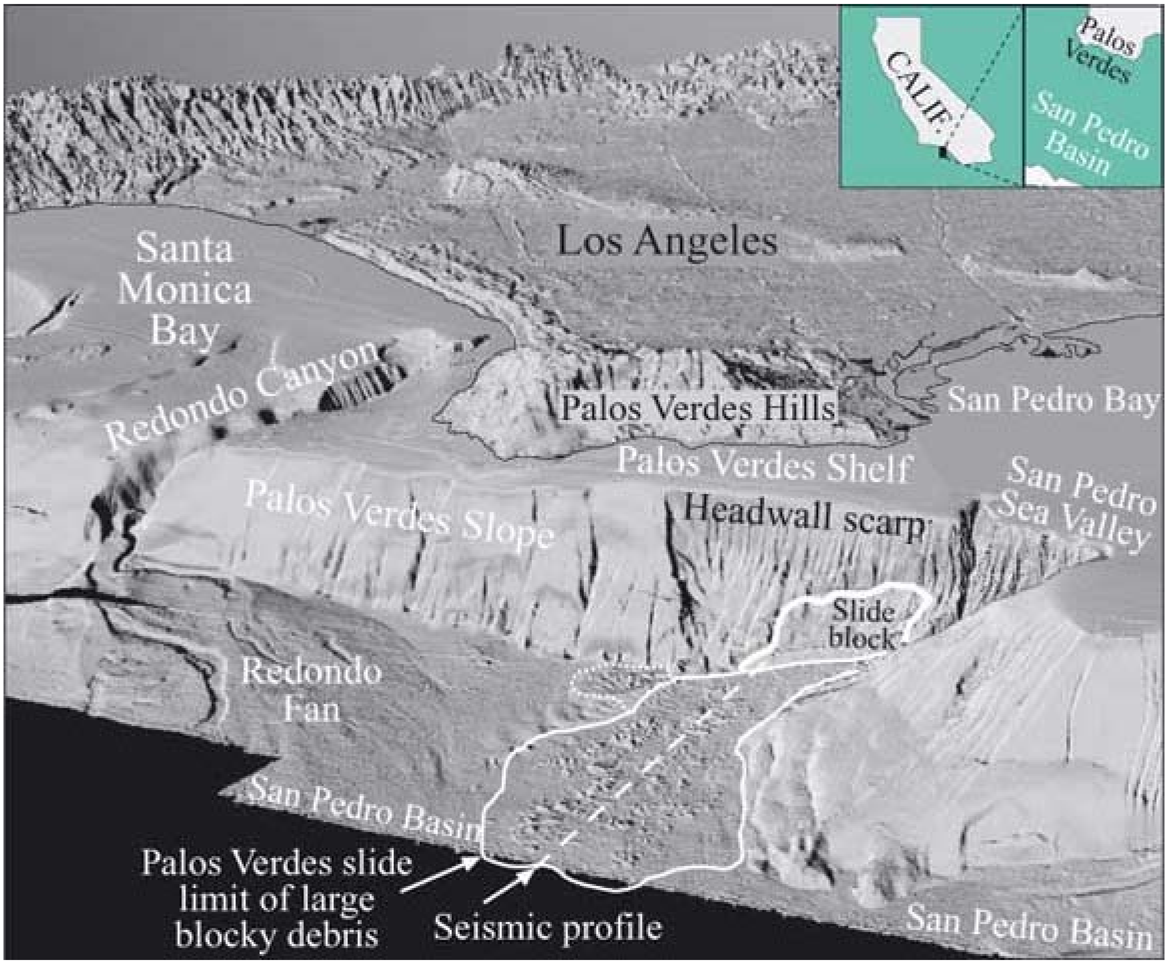
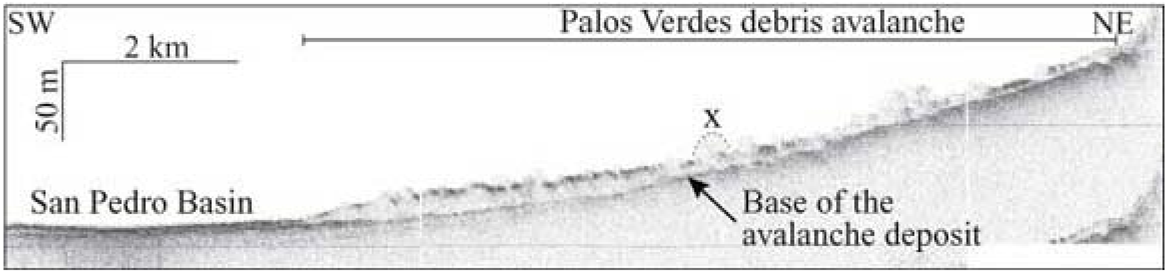
Palos Verdes Debris



Multibeam shaded-relief oblique view of the Palos Verdes submarine debris avalanche from Dartnell and Gardner (1999). Outline of Palos Verdes debris avalanche is based on seismic-reflection profile and multibeam data.

BACK

Palos Verdes Profile



Downslope deep-tow boomer seismic-reflection profile across the Palos Verdes debris avalanche. Note the landslide block marked with an X. Its cross-section on this profile is about 20m tall by 350m long. This block, which is well over 6 stories high and longer than 3 football fields, has been carried a minimum of 5 kilometers (3miles) in the debris avalanche.

BACK

Auriga Fantail

Side-by-side vans on fantail of the ship Auriga, from geophysical cruise A-1-00-SC. The van to the left houses Electronics shop and space for data processing. Electronics Technicians Larry Kooker (standing) and Dave Gonzales confer over repair of the mini-sparker. Right-hand van contains the computer stations for underway watch during data collection. Mechanical Technician Kevin O'Toole stands by the winch, ready to raise or lower the Huntec towfish so that it does not run into the seafloor.

Notice also the catamaran sled for towing Geopulse boomer (cylindrical white floats in foreground), and the yellow cable of the multi-channel seismic-reflection streamer on the winch to the left.

Auriga Sample

BACK

Piston Core

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Acquisition Van

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Navigation

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Towfish

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Abstracts

Covault et al, 2005, Cordilleran GSA oral presentation:
Sea-level and tectonic controls on late Quaternary sedimentation in San Diego Trough, offshore California

Abstract:
High-resolution deep-tow boomer seismic-reflection data are used to characterize late Quaternary (< 50 Ka) deposition in San Diego Trough, a structurally active basin located in the California Continental Borderland. Four modern submarine canyon-channel systems feed sediment into San Diego Trough: Newport, Oceanside, Carlsbad, and La Jolla, from north to south. Newport Canyon, which is more than 50 km north of San Diego Trough, contributes sediment longitudinally, whereas the other three systems are lateral sources. Contrary to typical depositional models in which coarse clastic supply dominates submarine fan deposition during marine lowstand, our examination of deposition in San Diego Trough during Holocene transgression reveals that two of the four canyons remain active. As sea level rose, Oceanside and Carlsbad Canyons were stranded on the outer shelf, deprived of littoral sediment. At present only Newport and La Jolla Canyons have their heads on the inner shelf and continue to feed sediment to their submarine turbidite channel extensions. Within San Diego Trough, all channels extending from these canyons have low relief levees. The juxtaposition of Newport and La Jolla Canyon sediment persisted throughout the latest Quaternary. Displacements along strike-slip faults and related pull-apart depressions and uplifted ridges considerably affected the sediment dispersal of the Newport and Carlsbad canyon-channel systems contributing sediment to San Diego Trough. Deformation approximately 40 km south of Newport Canyon ultimately led to the deflection of Newport channel 20 km to the west. This deflection resulted in Newport channel feeding northern San Diego Trough. Along the eastern side of San Diego Trough, anticlinal folding along a strand of the Coronado Bank fault resulted in blocking progradation of Carlsbad submarine fan and redirecting its sediment to the mid La Jolla Fan area. Late Quaternary deposition in San Diego Trough reveals a complex interplay of river- and littoral drift-fed canyon-channel systems prograding into an elongate structurally active deepwater basin.

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Nicholson et al, 2005, SCEC poster:
High-Resolution Stratigraphy and the Evolution of an Active Fault-Related Fold in 3D, Santa Barbara Channel, California

Abstract:
As part of a global climate study investigating the sedimentary record of Santa Barbara Basin, grids of high-resolution MMS analog, industry multichannel, and 2D high-resolution seismic reflection data (collected in separate cruises by the USGS and UCSB in 2002) are being used to correlate dated reference horizons from ODP Site 893 across the basin to the Mid-Channel Trend. The Mid-Channel Trend is an active oblique fold related to the offshore Oak Ridge fault system. Continuous late-Quaternary strata deposited in the deep paIeo-bathymetric basin were uplifted and folded across this Mid-Channel anticline. Extrapolation of available age data suggest that strata as old as ~450 ka (OIS 12) appear to be exposed at the seafloor where they are now accessible to piston coring. The mapped horizons (dated at ~110 ka and ~160 ka, and including sequence boundaries interpolated at ~320 ka, ~420 ka, and ~475 ka) provide the basis for modeling the evolution of the structure and stratigraphy in 3D, and to precisely locate suitable core sites. In late August 2005, gravity and piston cores-together with deep-towed chirp data-will be taken using the R/V Melville to survey and sample these horizons and their intervening sequences where they are expected to crop out over the Mid-Channel Trend. Subsequent analyses of the cores and chirp data will be used to verify the predicted outcrop pattern and the basin-wide sequence stratigraphic interpretation. Thus, in addition to its contributions to Quaternary climate history, this project will help document the nature, geometry and evolution of the Mid-Channel anticline, its relation to the oblique Oak Ridge fault, and the local interaction between tectonics, climate, and sea-level change. To date, our results show that the Mid-Channel Trend has propagated from east to west as previously proposed. South of Santa Barbara harbor, folding on the anticline began about 1 Ma, while 10 km farther west, folding began after ~475 ka. Our sequence of multiple mapped reference horizons documents a fairly complicated process of how slip on the deep fault system is transformed at shallow levels into fold growth as different strands and back-thrusts become active. The active offshore Oak Ridge fault is thus mostly blind, despite offsetting the unconformity created during the Last Glacial Maximum.

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Normark et al, 2005, Cordilleran GSA poster:
Natural hydrocarbon seeps on the inner shelf off Pt. Conception and western Santa Barbara Channel, California

Abstract:
A study of natural oil and gas seeps on the inner shelf of the western Santa Barbara Channel and at the southern end of the Santa Maria Basin, offshore California, was conducted in collaboration with the Minerals Management Service (MMS). The goal was to establish the geologic framework for, and to document the locations of, active seeps. The area surveyed forms a broad V-shaped swath 3 to 5-km wide both north and east of Pt. Conception. Each side of the V is about 15-km long, covering water depths between 40-150 m. Sidescan sonar with a resolution of 50-cm along-track, and 17-cm across-track, was collected throughout. For most of the survey, a chirp sonar system provided high-definition profiles of the underlying geology and seep structures. While seeps are found in areas of bare rock outcrop, eroded during the last sea-level transgression, many active seeps occur on mounds, which previous MMS work indicates are formed by tar residue and sand. These mounds range from a few meters across to large accumulations that can exceed a kilometer in width and 5 m height. We recognize them primarily just west of Pt. Conception, where they cover an irregular area of approximately 5 km^2. Overall, a total of more than 100 likely active seeps were identified that are the targets for ongoing collection of gas and tar samples. This mapping activity is in support of an effort to establish chemical correlations between offshore active seeps and coastal oil residues as well as to measure the rate of natural seepage at individual sites that can be used to assess regional rates.

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Normark et al, 2005, Cordilleran GSA presentation:
Late Quaternary turbidite systems in Santa Monica Basin, offshore California

Abstract:
Santa Monica Basin is a tectonically active depression that is filling more rapidly than other offshore basins in the California Continental Borderland. Sediment accumulation rates during the last glacial maximum exceed $4m/10^3$ yr, which is about an order of magnitude greater than for other basins. Four main submarine canyons feed sediment to the basin --- from west to east, Hueneme, Mugu, Dume and Santa Monica Canyons. An extensive multichannel and single-channel seismic-reflection profiling data set allows evaluation of the relative contribution of sediment from these four sources since about Marine Isotope Stage 12. In addition, high-resolution deep-tow boomer profiles, and recently available radiocarbon ages for sediment cores including those at ODP Site 1015, provide an opportunity to construct a detailed stratigraphic evolution of deep-water depositional systems in the basin during the last 30 ka. The dominant source for sediment in the Santa Monica Basin is the Santa Clara River and adjacent drainages, which feed both Hueneme and

Mugu Canyons as well as three smaller delta-edge canyons between them. These canyons feed channel-levee complexes featuring high (>50-m relief) muddy levees and sandy floors. In contrast, Dume Canyon receives sediment from littoral drift and feeds a small channel with low (15-m relief) sandier levees; the sandy, prograding wedges of Dume Fan are generally buried by sediment coming from the Santa Clara river delta via Hueneme Canyon. Santa Monica Canyon, which is the longest canyon feeding the basin, has apparently not been a major conduit and its associated fan has the most limited expression of any of the turbidite systems in the basin. Rivers crossing the present Los Angeles Basin area appear to preferentially feed sediment farther south toward the Long Beach shelf area.

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Ryan et al, 2005, SCEC poster:
Quaternary Faulting in the Inner Southern California Borderland, Offshore San Diego County, California

Abstract:
Multichannel 2D seismic reflection (MCS) data collected by Western Geophysical in 1975 and recently made publicly available combined with high-resolution MCS, single-channel Huntec and Geopulse profiles collected by the USGS in 1999 and 2000 are used to address two key questions pertaining to offshore faulting in the southern California Borderland: 1) has the Oceanside detachment fault been reactivated as a thrust fault during the Quaternary, and 2) is the Palos Verdes fault zone continuous with the Coronado Bank fault zone south of La Jolla fan valley (LJFV)? The Oceanside detachment fault is best imaged north of San Mateo Point, where it dips landward (eastward), and prominent folds deform hanging wall rocks. However, the age of these folds is unknown. In some areas they appear to be onlapped by flat-lying basin sediment. South of San Mateo point, the Oceanside detachment is not as well defined in the MCS data, however, a prominent strike-slip fault, the San Onofre-Oceanside fault (after Fischer and Mills, 1991), is observed near the base of the continental slope. Near the southern termination of this fault offshore of Carlsbad, there is another zone of folding near the base of the slope. This zone of folding is coincident with the intersection of a narrow subsurface ridge that trends at a high angle and interacts with the margin. Recent motion of the Oceanside detachment as a thrust fault therefore appears to be limited to the area between Dana and San Mateo Points, and offshore of Carlsbad.

The Coronado Bank fault zone (CBFZ) has generally been mapped as a steeply dipping, NW-trending zone consisting of multiple strands that extend from south of the border to offshore of San Mateo Point. South of LJFV, the CBFZ is primarily transtensional and appears to terminate at the LJFV in a series of horsetail splays. Whether the CBFZ continues north of LJFV is problematic. North of

the LJFV, the CBFZ forms a positive flower structure that can be mapped at least as far north as Oceanside. However, north of Oceanside, the fault zone is more discontinuous than to the south and in places, there is no strong physiographic expression of faulting. This contrasts with the Palos Verdes fault zone north of Lasuen Knoll, which shows clear evidence for recent faulting. Therefore, although the northern segment of the CBFZ may connect with the Palos Verdes fault zone, it does not appear to have a similar style of deformation and suggests that some of the net slip between LJFZ and Lasuen Knoll may be transferred to faults other than the CBFZ.

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Conrad et al, 2004, SCEC poster:
Characteristics of the Southern Part of the Palos Verdes Fault from High Resolution and Multichannel Seismic Reflection Data

Abstract:
The southern part of the Palos Verdes fault system (PVF) comprises a semi-continuous series of fault segments with various deformation styles extending from the Palos Verdes Peninsula to the Coronado Bank fault zone north of La Jolla Fan Valley (LJFV). South of the Palos Verdes Peninsula, multichannel seismic (MCS) data show that the PVF consists primarily of a single, well-defined fault trace trending about N30°W, which extends from the San Pedro shelf to the southern part of Lasuen Knoll (LK). In places, the fault branches into two or three strands near the surface. It is difficult to map the PVF system south of LK where it appears to merge into a diffuse zone of transtentional faults. The transition between the PVF and the Coronado Bank fault zone (CBF) occurs between LK and LJFV. Scant data coverage precludes identification of a clear, through-going fault trace, although we are able to map several short fault segments along strike of both the PVF and CBF. A positive flower structure comprised of three closely spaced parallel fault strands are mapped for 16 km north of LJFV. These strands trend N40°W along a bathymetric ridge. LJFV appears to mark a significant structural boundary, as fault traces cannot be confidently mapped across the canyon axis into the main CBF zone.

High-resolution seismic reflection data (Huntec) are interpreted to determine the recency of faulting of the PVF-CBF fault system. The PVF does not appear to be active beneath the San Pedro shelf or along the northern and western edge of LK (although this could reflect rapid reworking of surface traces in shallow water on San Pedro shelf and obscuration by slumps and/or channel features to the south). The only evidence of active slip is found along the southwestern edge of LK just north of where the fault merges into a broad transtensional zone. Recent offset on this segment of the PVF appears to die out south of LK, perhaps being transferred to smaller faults in the extensional zone and/or an active fault strand mapped east of the main strand of the PVF, which has a more westerly trend.

Another anomalous 20-km-long single active fault strand is imaged on Huntec data about 10 km southeast of the main PVF strand. This fault trends more northerly than the PVF zone, actively cutting through young basin sediments with the eastern side down. The faults imaged in the PVF-CBF transition zone immediately north of La Jolla Canyon are most likely active as they offset the seafloor.

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Fisher et al, 2004, SSA poster:
Evaluating the Tsunamigenic Potential of Submarine Landslides Below Santa Barbara Channel, Southern California

Abstract:
Seismic-reflection, multibeam bathymetric, and chronostratigraphic data reveal the generation, timing, and emplacement processes of large landslides along the north side the Santa Barbara Channel, southern California. Age control from ODP Site 893 together with seismic-reflection data indicate that over the past 250 ka landslides have occurred consistently along one segment of the shelf break. These landslides directly underlie or make up the Goleta landslide complex, the largest in the region. Thrust-faulted, Miocene and older rocks are thought to underlie the part of the shelf break that spawned the landslide complex. What appears to be a talus deposit along the downthrown (south) side of these deep faults dates from about 350-250 ka. These observations indicate that the part of the shelf break that produced the Goleta landslide complex has shed mass-wasting debris into the basin for much of the late Quaternary.

Seismic-reflection data indicate that a shelf-edge delta of probable Quaternary age was the source material for the Goleta landslide. This landslide includes three main lobes. High-resolution seismic-reflection data and age dates from ODP Site 893 reveal that undeformed shallow sediment covering the northwest lobe dates from about 5-6 ka, suggesting that material making up the toe of this lobe was emplaced before about 6 ka ago. In contrast, high-resolution seismic-reflection data over the southeastern lobe show that the shallowest sediment in the lobe is deformed, perhaps meaning that this lobe is very young.

The Goleta landslide complex does not represent a single or even several sediment failures, isolated in time, but instead the complex is made up of deposits from a sequence of mass failures that occurred over a relatively long time period (about 300 ka). For the region of the Santa Barbara Channel, the tsunami hazard from submarine landslides should be evaluated with this in mind.

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Hein et al, IGC poster:
Methanogenic carbonates collected with gas hydrate from a mud volcano offshore Southern California

Abstract:
In July 2003, a 2.1 m piston core from 813 m water depth near the summit of a mud volcano located 24 km off shore of Los Angeles, California, contained gas hydrate in its lower 0.5 m. Bivalve mollusk shells and methanogenic carbonate occur above the hydrate in olive-green silty mud. Two types of methanogenic carbonate are present: (1) massive, recrystallized nodular masses of calcite, with an outer mm-thick sugary patina; and (2) a bivalve coquina with carbonate cement. Shells of living and dead *Lucinoma aequizonatum* (thick walled) and *Vesicomya elongata* (thin walled) were recovered, both of which are characteristic of methane-seep environments. *L. aequizonatum* also occurs in sulfide-rich habitats. Carbon isotope values (-46 to -58‰) clearly indicate that the oxidation of biogenic methane was the source of the carbonate carbon. Carbon isotopes (-17 to -19‰) from shells of both clam species also indicate a carbon source from oxidized methane, or possibly oxidized organic matter. This is the first reported occurrence of such ^{12}C-rich shells from living clams. Strontium isotopes indicate that the Sr in both the carbonate calcite and aragonite shells was derived from seawater. Calculated temperatures of 2.5 to 10.0° C (assuming seawater $\delta^{18}O$) for calcite and aragonite formation indicate that they were not in equilibrium with the bottom-water temperature of 6.5° C. Six additional sediment cores obtained within 15 m of the hydrate-bearing core contained olive-brown silty mud with variable amounts of bivalve shells and methanogenic carbonate fragments, but no gas hydrate. Methane is the dominant gas collected, with minor hydrogen sulfide and trace amounts of heavier hydrocarbon gases. Sediment gas chemistry infers that the gas hydrate is a Structure I hydrate, although the hydrate was not preserved and analyzed directly. The above characteristics indicate a cold-seep environment with methane likely venting at the seafloor. The mud volcano, 300 m in diameter at the base, exhibits no structure on either deep-tow boomer or single-channel air-gun profiles, most likely because of its high gas content and sediment deformation. This diapiric structure cuts through well-bedded sediment in an area transitional between strike-slip motion along basin-slope faults and convergent motion farther north. The source of the gas forming the hydrate appears to be collecting in beds as shallow as 200 m below the regional seafloor.

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Hopkins et al, 2004, AGU poster:
A Test for Extending the High-Resolution Global Climate Record in Santa Barbara Basin

Abstract:
ODP Site 893 in Santa Barbara Basin recovered high-resolution

global climate data extending back to ~160 ka at 200 m sub-seafloor. Safety concerns though have prevented deeper drilling at this site. Santa Barbara Basin is, however, tectonically active. As a result, continuous late-Quaternary strata deposited in the deep paleo-bathymetric basin were uplifted and folded across the Mid-Channel Trend, and strata as old as ~450 ka (OIS 12) appear to be exposed at the seafloor where they are now accessible to piston coring. This project will test the accessibility along the anticline of these older stratigraphic sequences through detailed basin correlation of high-resolution seismic stratigraphy and subsequent coring. In preparation for coring in summer 2005, grids of high-resolution MMS analog, industry multichannel, and 2D USGS high-resolution seismic reflection data (collected in 2002) are being used to correlate dated reference horizons at ~120 ka, ~160 ka and ~1 Ma along with several intervening seismic sequence boundaries across the Mid-Channel Trend. Results provide the basis for modeling the structure and stratigraphy in 3D, and to precisely locate suitable sites for coring. Subsequent core analyses will be used to verify the predicted outcrop pattern and basin-wide sequence stratigraphic interpretation. Thus, in addition to its contributions to Quaternary climate history, this project will help document the nature and evolution of the Mid-Channel anticline, and the local interaction between tectonics, climate, and sea-level change. To date, our results show that the Mid-Channel Trend has propagated from east to west as previously proposed. South of Santa Barbara harbor, folding on the anticline began about 1 Ma, while 10 km farther west, folding began after ~450 ka. Furthermore, our results confirm that older strata (extending back to inferred OIS 12) of the paleo-Santa Barbara Basin have been folded, and are present at or near the seafloor.

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Lee et al, 2004, AGU poster:
Size and Age Characteristics for West Coast Tsunamigenic Landslides

Abstract:
Multibeam bathymetric imagery is now available for a number of well-defined submarine landslide deposits along the west coast of the United States. Several of these landslides are known to have caused damaging tsunamis and others are of sufficient size to have generated tsunamis when they occurred, assuming that their motion was rapid. These failures are located off Palos Verdes Peninsula, California, and within Santa Barbara Channel, California, Commencement Bay, Washington, Resurrection Bay, Alaska, and Port Valdez, Alaska. For two of these failures, ages were determined by identifying acoustic reflectors in the vicinity of the failed masses that either clearly postdate or predate the landslide events. The ages of the reflectors are determined by tracing them to the locations of nearby ODP borings or to piston cores dated using radiocarbon methods. Three of the landslides produced tsunamis during historic

time (post 1750 AD) so the ages are well constrained. High-resolution subbottom reflection profiles also allow us to estimate the dimensions of the failed masses. Although the examples selected clearly do not represent all scales of tsunamigenic west coast landslides, this information is useful in providing input to statistically based models of landslide-induced tsunamis.

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Normark et al, 2004, SCEC poster:
Late Quaternary Deformation in Santa Monica Basin Deposits Adjacent to Santa Cruz-Catalina Ridge, Offshore Southern California

Abstract:
High sedimentation rates in Santa Monica Basin provide an ideal opportunity to document tectonic activity during the last 100 ka offshore Los Angeles, California. The history of sedimentation has been documented with high-resolution deep-tow boomer profiles and with both multichannel and single-channel seismic-reflection profiles, which have been used to map 15 nearly basin-wide reflecting horizons. The initial results for sediment-accumulation rates obtained from cores recovered at Ocean Drilling Program (ODP) Site 1015 on the floor of Santa Monica Basin indicated a Holocene rate of nearly 3 m/ka, which is the highest yet documented for southern California deep-water basins. A more detailed determination of the sedimentation-accumulation rate in the basin allows improved age assignments for the high-resolution seismic stratigraphy, which in turn, results in better control on the timing of deformation within the basin. New radiocarbon dates obtained from sediment recovered at ODP Site 1015 provide stratigraphic age control for the upper 12 reflectors back to 32 ka at ~100 meters below the sea floor (mbsf). Ages estimated for the three deepest reflectors (140 to 220 mbsf) are based on extrapolation of rates for the dated sequence between 75 and 100 mbsf. The bulk of the sediment fill in Santa Monica Basin is from the Santa Clara River delta. The frequency of turbidite deposits at ODP 1015 is roughly equivalent to the frequency of 100-year storm events in southern California and more work is needed to attempt using the turbidite record to develop a paleoseismic record for the basin.

The Santa Cruz-Catalina Ridge (SC-CR) forms the southwestern margin of Santa Monica Basin. Deformation of basin-fill sediment adjacent to the SC-CR is limited to the northwestern corner of the basin in the area of convergence between thrusting to the north and strike-slip along the southwestern margin of the basin. Here, turbidite deposits of Hueneme Fan show local evidence for flexure of sediment horizons as young as 6 ka with minor fault offsets as recently as 1.5 ka. Larger scale anticlinal folding (~5 km width and >100 m of relief) of the basin fill is observed for strata older than ~65 ka, and faulting within (and assumed to be subparallel to the

trend of) the anticline continued until sometime between 13 and 20 ka. To the south, the flat-lying turbidite fill of the basin onlaps both the SC-CR and Redondo Knoll with no evidence for disruption or folding post 75 ka. This suggests that recent faulting along the trend of the SC-CR must occur within the ridge itself except in the northwest corner of the basin. Very limited data from the sediment fill of Catalina Basin, which is adjacent to the SC-CR on the southwest side, shows little deformation within the basin fill and only minor westward tilting during the latest Quaternary.

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Normark et al, 2004, AGU poster:
Sediment accumulation rates of late Quaternary deposits in San Pedro Basin, the Gulf of Santa Catalina, and San Diego Trough, offshore southern California

Abstract:
A multiyear program of seismic-reflection profiling and sediment coring has focused on understanding the history of late Quaternary sedimentation within the inner basins of the California Borderland. The objective of this study has been to develop a high-resolution seismic stratigraphy primarily for the Last Glacial Maximum and the Holocene that can be used to understand depositional processes, sediment budgets, and deformation within the basins. The Santa Barbara and Santa Monica Basins in the northern Borderland are closed basins and both were cored during the Ocean Drilling Program (ODP) in support of paleoclimatic studies. In contrast, the inner basins in the southern Borderland that are the focus of this report are open-ended basins that have not been the subject of scientific drilling. We present the preliminary results of sediment coring at 21 sites in San Pedro Basin, the Gulf of Santa Catalina, and San Diego Trough. Initial estimates of sediment-accumulation rates for these basins are based on 48 previously unpublished radiocarbon dates. During the Holocene, average sediment-accumulation rates are generally less than 0.5 m/ky on the basin floors where turbidite deposition locally continued at reduced rates from those of the OIS 2-lowstand interval. This rate is nearly an order of magnitude less than was documented for the Holocene by ODP coring at Site 1015 in Santa Monica Basin reflecting, in part, the loss of sediment in the non-closed basins. Background hemipelagic rates range from 0.01 to 0.1 m/ky, with the lowest rates on mid-basin highs, e.g., Lasuen Knoll. More dating is currently underway for some of the core sites to determine the rate of change in sediment accumulation during the Holocene.

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Ryan et al, 2004, SCEC poster:
New Fault Map of the Inner Southern California Borderland Offshore San Diego and Orange Counties, California

Abstract:
We present a new fault map of the offshore southern California borderlands south of Newport Beach, CA. Major faults remapped from west to east include the San Diego Trough fault (SDTF), Coronado Bank fault (CBF), a prominent fault zone located near the base of the continental slope, and offshore segments of the Newport-Inglewood (NIF) and Rose Canyon (RCF) faults. Our interpretations are based on high-resolution, multichannel (MCS), Huntec and Geopulse seismic reflection profiles collected by the USGS from 1998-2000. The Huntec and Geopulse data are used to identify the most recently active segments of the fault zones. In addition, deep penetration MCS data collected by Western Geophysical in 1974-75 and Jebco in 1988 are utilized to determine the primary fault traces within multi-stranded fault zones and the attitude of faults at depth.

From the Mexican border north to the La Jolla fan valley (LJFV), the San Diego Trough fault is composed of one or two well-defined linear fault strands that cut through the center of the San Diego Trough and trend N30°W. North of the LJFV, the fault zone steps west and is composed of up to 4 fault strands. The Coronado Bank fault zone is a complex feature with multiple fault strands that can only be mapped over relatively short distances (generally less than 10 km). South of LJFV, the CBF zone is primarily transtentional; we mapped two pull-apart basins within the fault zone. The CBF is difficult to map northward across the LJFV, however, the two westernmost strands may continue north of the fan valley. The CBF zone north of the LJFV forms a positive flower structure that can be mapped at least as far north as Oceanside. An unnamed fault zone near the base of the continental slope (600-700m water depth) is imaged discontinuously from about 10 km north of LJFV to offshore of Dana Point. This fault zone changes in style of deformation along strike, with segments of the fault zone exhibiting compression as evidenced by prominent folds imaged in the deep penetration MCS data. The age of these compressional features is unclear as in places the folds are cut by younger near-vertical faults. The multi-stranded RCF and NIF generally follow the shelf break between La Jolla and Newport Beach. The transition between these fault zones is associated with a prominent active anticline at mid-slope (300-400 m) depths, suggesting a left step in slip between these two fault zones.

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Sorlein et al, 2004, SCEC poster:
The complete Palos Verdes Anticlinorium and Offshore Evidence for the Compton Blind Fault Beneath it

Abstract:
The Palos Verdes anticlinorium is part of a NW-SE-trending >130 km-long Inner Borderland contractional belt. The top of its southwest limb coincides with the shelf break, and its offshore northwest plunge is transitional between Borderland and E-W structure of the western Transverse Ranges. The Compton blind thrust ramp was imaged and inferred to explain the southwest flank of Los Angeles basin (Shaw and Suppe, 1996). A SW-directed tectonic wedge continues southwest of the ramp on published cross sections. A SW-dipping backthrust that forms the roof of this wedge was called upon to explain uplift of the onshore Palos Verdes anticlinorium. Our mapping shows that the anticlinorium continues beneath the offshore Shelf Projection for 30 km to the northwest, reaching beyond Santa Monica Canyon. The southwest limb of the anticlinorium is a continuous, linear structure for 45 km, and is responsible for the offshore San Pedro escarpment. A SSW-facing escarpment continues another 10 km south of a right step at San Pedro Sea Valley. This escarpment separates the anticlinorium from the more subdued expression of 5 km-wavelength folds farther southeast. Short-wavelength (1 to 2 km) folds, some with seafloor expression, are superimposed on the northwest 30 km of the anticlinorium. Five km wavelength folds beneath San Pedro shelf overprint the larger anticlinorium. The Palos Verdes anticlinorium, especially its southwest limb, is continuous for 45 km, with an additional 10 km of broad uplift of southern San Pedro Shelf.

We interpret the SW-dipping fold limb to be a forelimb above NE-dipping blind thrust or oblique thrust faults. These offshore faults project in 3D into the SCEC Community Fault Model (CFM) representation of the Compton Thrust ramp, at least for the northwest 30 km of the structure. Horizontal-axis rotation (progressive tilting) of an upward-widening zone absorbs thrust slip; slip on the blind faults gradually decreases updip as it is transformed into folding. Significant SW-dipping roof thrusts are not needed in this model. The NNE-dipping backlimb is also progressively tilting along at least 10 km of the northwest plunge of the anticlinorium, suggesting a listric area on the underlying fault. Activity along the northwest offshore anticlinorium is suggested by the following observations: (1) the floor of Santa Monica Canyon and early Holocene strata farther northwest are warped; (2) post-50 ka strata are deformed above the tips of the blind faults; (3) Palos Verdes Hills are uplifting; (4) the Shelf Projection has eroded, and the wavecut platform is shallower than low eustatic sealevels, suggesting rock uplift, above an inferred subsiding base level. Area balancing in cross-section yields up to 1.7 km of blind thrust slip beneath the Shelf Projection in the last ~2.5 M.Y., or more if sediment compaction and pressure solution are significant.

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Baher et al, 2003, AGU poster:

Estimating Earthquake Hazards in the San Pedro Shelf Region, Southern California

Abstract:
The San Pedro Shelf (SPS) region of the inner California Borderland offshore southern California poses a significant seismic hazard to the contiguous Los Angeles Area, as a consequence of late Cenozoic compressional reactivation of mid-Cenozoic extensional faults. The extent of the hazard, however, is poorly understood because of the complexity of fault geometries and uncertainties in earthquake locations. The major faults in the region include the Palos Verdes, THUMS Huntington Beach and the Newport-Inglewood fault zones.

We report here the analysis and interpretation of wide-angle seismic-reflection and refraction data recorded as part of the Los Angeles Region Seismic Experiment line 1 (LARSE 1), multichannel seismic (MCS) reflection data obtained by the USGS (1998-2000) and industry borehole stratigraphy. The onshore-offshore velocity model, which is based on forward modeling of the refracted P-wave arrival times, is used to depth migrate the LARSE 1 section.

Borehole stratigraphy allows correlation of the onshore and offshore velocity models because state regulations prevent collection of deep-penetration acoustic data nearshore (within 3 mi.). Our refraction study is an extension of ten Brink et al., 2000 tomographic inversion of LARSE I data. They found high velocities (>6 km/sec) at about ~3.5 km depth from the Catalina Fault (CF) to the SPS. We find these velocities, shallower (around 2 km depth) beneath the Catalina Ridge (CR) and SPS, but at a depth 2.5-3.0 km elsewhere in the study region. This change in velocity structure can provide additional constraints for the tectonic processes of this region.

The structural horizons observed in the LARSE 1 reflection data are tied to adjacent MCS lines. We find localized folding and faulting at depth (~2 km) southwest of the CR and on the SPS slope. Quasi-laminar beds, possible of pelagic origin follow the contours of earlier folded (wavelength ~1 km) and faulted Cenozoic sedimentary and volcanic rocks. Depth to basement, where observed, is approx. 1.7 km. beneath the base then shallows to approx. 1 km at the top of the SPS. This corresponds to the results obtained by Fisher et al. (in press) and Wright (1991). The pattern of faulting changes from southwest to the northeast. West of CF, faulting is confined to the pelagic and older units. Closely spaced faulting (~0.75 km) is prominent between CF and Avalon Knoll (AV), while generally more widely spaced faults (~5 km) with localized fracture zones is observed from AV to the SPS. The SPS is dominated by major faults such as the Cabrillo, Palos Verdes, THUMS Huntington Be ach and Newport-Inglewood fault zones. The Cabrillo and Palos Verdes fault are major stratigraphic discontinuity with laminar beds (~30 cm) adjacent to gently folded sediments (wavelength ~1.5 km). There is evidence of recent displacement on the Cabrillo fault.

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Baher et al, 2003, SCEC poster:
Estimating Earthquake Hazard in the San Pedro Shelf Region, Southern California

Abstract:
The San Pedro Shelf lies within the inner Continental Borderland region in southern California. This offshore region poses significant seismic hazard to contiguous Los Angeles Area, owing to late Cenozoic compressional reactivation of mid Cenozoic extensional faults. This hazard, however is poorly understood due to complexity of fault geometries and uncertainties in earthquake locations. The faults that posed the most significant hazard in the offshore include the Palos Verdes, THUMS-Huntington Beach, and Newport Inglewood fault zones. The recorded seismicity in this region is diffuse, even for those events associated with main-shock sequences, which could in part be due to asymmetrical station locations that results in large uncertainties in event locations. Initial findings show that the Palos Verdes fault consists of several strands that define the western border of the Wilmington Graben. Previous studies of this fault show a slip rate of 2.7-3.0 mm/yr that could generate a 7.0-7.2 event every 400-900 years.

We report here the analysis and interpretation of wide-angle seismic reflection and refraction data recorded as part of the Los Angeles Region Seismic Experiment line 1 (LARSE 1), multichannel seismic (MCS) reflection data recorded by the USGS (1998-2000) and industry borehole stratigraphy. An onshore-offshore velocity was developed by forward modeling of the refracted P arrival times and this model was used to depth migrate the LARSE 1 seismic line. The structural horizons were mapped and tied to nearby marine reflection lines. Borehole stratigraphy connects the onshore to the offshore velocity models due to restrictions on data nearshore data collection. A velocity step from 3.5 to 5.0 km/sec is observed at shallow depths (1.5-2.5 km) beneath the inner borderland. This step is interpreted as the contact between Cenozoic sedimentary (and volcanic) rocks and the Catalina schist. In the contact ramps downward to the east across the Palos Verdes fault and is consistent with a 1-km down-to-east basement offset shown by Wright (1991).

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Broderick et al, 2003, SCEC poster:
Blind Thrust Faulting and Shelf-Slope Deformation in Eastern Santa Monica Bay, California

Abstract:
We used industry and USGS multichannel seismic-reflection data to extend our mapping of the Shelf Projection blind fault and associated

deformed strata across the Shelf Projection anticlinorium in eastern Santa Monica Bay. The thrust-reactivated eastern segment of the blind fault, which strikes approximately N55W, is subparallel to the axial trace of the Shelf Projection anticlinorium and dips gently northeast beneath a broad shelf-edge fold. Contraction of the Shelf Projection anticlinorium results from a restraining left step between the northwest-striking, right-lateral San Pedro Basin and Palos Verdes faults, such that slip is absorbed in folding of the hanging-wall above the blind thrust. Digital structure-contour maps of the top-Miocene unconformity and an upper Pliocene "Repetto" horizon indicate at least late Pliocene deformation, while young strata (<60 ka) correlated from ODP Site 1015 are deformed in the Shelf Projection anticlinorium's south limb. The blind fault continues southeast to dip beneath the southwest-dipping fold limb of the San Pedro escarpment, offshore west of the Palos Verdes peninsula. When viewed obliquely down dip using 3D visualization, the Shelf Projection blind fault projects directly into the Compton-Los Alamitos thrust ramp beneath Los Angeles basin. If the two thrust segments are linked, then slip on the upper part of this combined fault system may be absorbed by folding of the overlaying San Pedro escarpment. Furthermore, assuming the Shelf Projection/Compton-Los Alamitos fault system is active, then earthquake hazard models for the Los Angeles metropolitan area must be reevaluated to account for increased fault surface area.

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Erohina et al, 2003, AGU poster:
Acoustic Facies of Late Quaternary Channel and Overbank Systems - Gulf of Santa Catalina, California Borderland

Abstract:
The Gulf of Santa Catalina is a deepwater (>300m) basin that lies offshore between Long Beach and Dana Point California. Deep-tow Huntec boomer data from the northern gulf cover a complex channel system consisting of a series of slope gullies euphemistically known as the Newport Canyon. The boomer data have a vertical resolution of 50 cm and the system works effectively for imaging sandy turbidite deposits. A preliminary evaluation of the seismic-reflection data, together with available multibeam bathymetry, provides a better understanding of when different parts of the Newport channel system were active.

Three distinct acoustic facies characterize the late Quaternary turbidite sequence of the Newport channel system: an acoustically transparent facies, a high-amplitude discontinuous facies, and a moderate-amplitude sinusoidal facies. The acoustically transparent facies drapes the sea floor on both overbank deposits and some channel floors. Commonly the overbank areas on the west sides of channels preserve the thickest transparent sediment cover. The seismic characteristic of this facies is consistent with a mud-rich

deposit but the thickness variation appears to rule out a simple hemipelagic deposit.

The high-amplitude discontinuous facies is associated with depressions in the sea floor. These features include active channels, large-scale scours and channel remnants. The moderate-amplitude sinusoidal facies is typical for large amplitude sediment waves.

The sediment waves interpreted from the boomer data are not everywhere coincident with the scale of those visible on the multibeam bathymetry. The sediment waves migrate upslope and away from the channel axes. This wave growth pattern is probably related to flows that are substantially thicker than the channel relief and is similar to wave forms found on sediment drifts in the deep ocean.

A second channel system similar to the Newport system, associated with the San Gabriel Canyon approximately 9 km to the west, provides additional insight to the depositional processes in the Gulf of Santa Catalina. This system has been strongly affected by the Palos Verdes fault and, therefore, the channel activity is less likely to be autocyclic in nature.

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Fisher et al, 2003, AAPG oral presentation:
Geologic Structure of the San Pedro Shelf Region, Southern California

Abstract:
An integrated interpretation of marine seismic-reflection and aeromagnetic data as well as multibeam bathymetry shows the complex Pleistocene history of rocks beneath the San Pedro shelf, west of Los Angeles. Prominent structures include the nearshore Wilmington graben, the Palos Verdes Fault Zone, and numerous faults below the west part of the shelf and slope. For subsurface depths less than 2 km, the Palos Verdes Fault Zone can be divided into three segments. Under the shelf, the northwest segment includes several fault strands that dip steeply west. Under the slope, the middle fault segment comprises several normal faults, most of which dip east. Near Lasuen Knoll, the southeast fault segment, includes thrust and reverse faults, many of which dip east. Apparently fresh seafloor scarps along the Palos Verdes Fault zone near the base of this knoll indicate recent fault movement. Possible wavecut terraces and sediment core samples that contain fossils of Quaternary outer-shelf fauna indicate that this knoll was subaerial and has rapidly subsided several hundred meters. Models of aeromagnetic data measured over the west San Pedro shelf indicate a large magnetic rock body that is probably middle Miocene basalt. Sedimentary rocks over the basalt are tightly folded, whereas folds in sedimentary rocks east of the basalt have much longer wavelengths. This difference

probably resulted because the basalt was more competent during deformation than the sedimentary rocks.

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Fisher et al, 2003, SCEC poster:
Geology of Submarine Landslides Below Western Santa Barbara Channel, California

Abstract:
Submarine landslides under the western Santa Barbara channel may contribute to the regional hazard from tsunamis, like the tsunami that reportedly followed the 1812 Santa Barbara earthquake. Multibeam bathymetry shows that the Goleta landslide, the largest one in the area, consists of two main lobes that extend 10-15 km southwestward across the lower slope and basin floor. High-resolution seismic-reflection data show what appear to be older mass-wasted deposits that underlie the Goleta landslide. These older deposits are late Pleistocene, on the basis of biostratigraphic data from drilling at ODP Site 146-893, which is located about 1 km southwest of the toe of the Goleta landslide. Drilling data indicate that some of the underlying mass-wasting deposits are at least as old as 164 ka, the maximum age obtained from drilled rock and sediment. Thus the Goleta landslide does not represent a single failure, isolated in time, but instead it represents the latest in a series of sediment failures.

Chirp seismic-reflection data obtained over the ODP drill site and the toe of the Goleta landslide show that a thin (0.01 s, about 8 m) sediment layer covers the landslide, and on seismic-reflection sections, this layer appears similar to the shallowest sediment drilled at the ODP site. If the two sediment layers correlate, then the landslide is covered by sediment that is between 3 ka and 6 ka old, indicating a minimum age range for the landslide. The top of oxygen-isotope stage 4 in the ODP hole corresponds in two-way traveltime with the base of a band of high-amplitude reflections. These reflections can be correlated through the basin fill that surrounds the Goleta landslide, but disrupted reflections from sediment underlying this landslide makes this correlation tenuous. High-resolution seismic reflection data show that sedimentary rocks under the shelf edge dip south toward the channel and that the headwall of the slide cuts downward into these rocks. A rotated, apparently intact block of these rocks underlies a narrow seafloor ridge that extends along most of the length of the headwall. The headwall of the Gaviota submarine landslide developed directly over a shallow anticline, and both features formed along the North Channel Fault. A series of seafloor cracks and pockmarks, evident in multibeam bathymetry, connect eastward with the headwall of the Goleta landslide and show possible future sites for submarine failures.

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Greene et al, 2003, AGU poster:
Dating One Slide Event of the Complex Compound Goleta Submarine Landslide, Santa Barbara Basin, California USA

Abstract:
Dating of submarine sediment slumps and slides is fraught with problems, especially those taking place during the past several thousand years. However, we need to develop accurate dating techniques so as to improve our ability to assess the periodicity of, and the actual risk from, these events. The large (130 km^2) Goleta landslide located off Coal Oil Point near the town of Goleta, California measures 14.6-km long, extends from 90 m to nearly 574 m below sea level, and is 10.5 km wide. The slide is complex, and includes both buried slump blocks and mudflows, with a surface expression of three distinct segments of failures. Each segment is composed of a distinct head scarp, down-dropped head block, and a slide debris lobe. We estimate that at least 1.75 km3 of surface material represents the most recent displaced events of this slide.

Dating of the more recent failures of this slide has been speculative and based on modeling and estimated sediment cover on one of the head scars. The most recent event is thought to be the cause of the reported tsunamis of 1812. However, sophisticated dating of the slide has yet to be done. Recent interpretation of newly acquired seismic reflection profiles indicates that the head slump block of the eastern segment of the slide dammed sediment behind it after it came to rest at the base of the head scarp. We calculated that about 64 m of sediment was dammed behind the block, based on a measured two-way travel time through the sediment pond of 0.075 sec. and an assumed velocity of ~1680 m/sec. Using a sedimentation rate of 1.73 m/Ka to 2.5 m/Ka, the range of sedimentation rates determined by other investigators for the mid- to lower shelf areas of the western Santa Barbara Basin, the time required for deposition would be 37-25.6 Ka. Therefore, if the sedimentation rates are correct and that the ponded sediment represent nothing but normal sedimentation devoid of sloughing or debris flows down the slope, the maximum age of when the block came to rest in its present position would be 37-25.6 Ka. However, given the tectonic dynamics of the area and the instability of the slope in this part of the Santa Barbara Basin, the likelihood of deposits derived from mass movement filling the depression behind the slump block is high, thus suggesting a possible younger age for the failure.

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Hart et al, 2003, SCEC poster:
New Access to Proprietary Marine Seismic Reflection Data along the U.S. West Coast

Abstract:
High-quality seismic reflection data are essential to geological investigation of the offshore. Over the past thirty years the USGS has acquired approximately 12,000 km of 2D data off the west coast of the United States. During this same period the petroleum exploration industry acquired probably 30 to 50 times that amount. To date, these data have been proprietary and available for publishable research only with significant restrictions. Although the commercial value of these data has diminished as a result of technological advances and offshore development moratoria, these data continue to have great relevance value to current and future scientific research efforts. The value and risk of loss of these data was recently the subject of a National Research Council report "Geoscience Data and Collections: National sources in Peril" by the Committee on the Preservation of Geoscience Data and Collections, Committee on Earth Resources.

Recently, two companies with perhaps the largest holdings of proprietary data off the US west coast, WesternGeco and ChevronTexaco, have offered to transfer more than 250,000 km to the USGS for the purpose of making those data publicly available for research and educational purposes. Extension of these offers to include data offshore Alaska and the east coast of the U.S. is under discussion. The data being offered are for the most part conventional 2D multichannel airgun seismic reflection acquired and processed according to standards of the mid 1970's and early 1980's. The data commonly were acquired using a 5-to-25 element tuned airgun source totaling 1,000 to 3,000 cubic inches; 24-fold to 48-fold stacking; 25-to-50 meter CDP interval; 6 second recording with 4 msec sampling; processed through stack and post-stack migration. The surveys were generally limited to the continental shelf, extending up to 150 miles offshore southern California. line spacing is dense off southern California, and becomes sparser to the north.

Cataloging, documenting, reformatting, and providing access to these data will require a multi-year effort. Tens of thousands of digital 9-track tapes will be transferred to modern media, and auxiliary data (such as observer logs and processed film records) will be scanned. The available processed data (post-stack and migration) for all the data sets will be reformatted and cataloged on-line. However, a much larger quantity of data (25- to 50-times greater) exists in the form of original field recordings (pre-stack) for each data set. While these pre-stack field data are also extremely valuable, the resources required to capture and subsequently reprocess these data are correspondingly large. A prioritization strategy for salvage of the pre-stack data must be developed.

The USGS has several partners in this effort, including NSF (Earthscope), Institute for Crustal Studies at UC Santa Barbara, the IRIS Data Management Center, University of Southern California, and Minerals Management Service. The ultimate objective is the creation of a comprehensive geophysical data repository accessible on-line, with a graphical search and retrieval interface that would be available to teachers and researchers.

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Lee et al, 2003 AGU poster:
Ages of Potentially Tsunamigenic Landslides in Southern California

Abstract:
The innermost basin slopes of the Southern California Borderland contain numerous large-scale submarine landslides. Many of these are of sufficient size to have generated tsunamis when they occurred, assuming that the imaged deposits represent a single failure and that their motion was rapid. We have obtained high resolution subbottom profiles of five well-defined slope failures. These failures are located off the Palos Verdes Peninsula, within Santa Monica Bay, and within the Santa Barbara Channel. A landslide motion and tsunami generation model for one of the landslides shows that it likely generated a tsunami with a source height of at least 8 m. For four of the failures, ages were determined by identifying acoustic reflectors in the vicinity of the failed masses that either clearly postdate or predate the landslide events. The ages of the reflectors are determined by using seismic-reflection profiles to correlate with dated sections at ODP sites or by directly da ting the slide masses with piston cores. In the case of the most recent failure in the Santa Barbara Channel, post-failure sediment deposited on the scar of the landslide was sampled completely with a gravity corer, and the age was estimated based on a representative sedimentation rate. Our assessment shows that three of the four older landslides are approximately 10,000 years old and that the Palos Verdes event was about 7,500 years ago. However, the most recent failure may be as young as 200 years. Such a landslide might have generated a tsunami such as was observed by early Spanish settlers during the 1812 earthquake.

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Normark, 2003, GAC invited keynote address:
Geohazards of the southern California offshore area: out of sight, out of mind?

Abstract:
The California Borderland offshore southern California is a tectonically active area of basins and ridges that exceeds 150-km in width and includes part of the wide distributed boundary between the Pacific and North American plates. Intensive, on-land earthquake hazard research over the last few decades has shown that only about 80% of the strain associated with plate movement is recorded in onshore areas. Since 1997, the Coastal and Marine Geology Program of the USGS has been conducting marine surveys to assess

geohazards of the inner Borderland basins. The seaward limit of the survey is roughly estimated to include faults that could cause damage to the adjacent onshore infrastructure at earthquake magnitudes of 6.5 and higher. The study extends from the city of Santa Barbara in the north to the US-Mexican border south of San Diego, along the most densely populated coastal corridor on the west coast that represents a major component of the earthquake risk for the en tire United States.

The first phase of the geohazard research involved imaging the offshore structures to determine the length and sense of motion on active faults and folds using high-resolution multichannel and boomer seismic-reflection profiles. The techniques available for this phase of the research were restricted by State and Federal regulations and resulted in cruise operations that involved more marine mammal observers than geoscientists on board the ships and, in addition, precluded work inside the three-mile limit (albeit closest to the populace at risk). The current phase of the geohazard assessment is to determine the recency of deformation and, where possible, recurrence intervals on active faults. This activity involves establishing a detailed sequence stratigraphy for the last 10 ka using piston cores and the two existing ODP boreholes. The final phase of the geohazard evaluation will be a collaboration with the academic community to deploy an offshore strain monitoring program that is needed to fully evaluate the geohazards within the inner Borderland.

Our evaluation to date suggests that the area west of Los Angeles shows the most recent and recurring deformation where strike-slip shearing common in the southern part of the study area transforms into compressional structures offshore Malibu and Santa Barbara to the northwest. The largest submarine landslide in the area lies offshore from the Los Angeles/Long Beach harbors and occurred 7500 ka B.P., much older than previously thought.

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Normark and McGann, 2003, SCEC poster:
Developing a High-Resolution Stratigraphic Framework for Estimating Age of Fault Movement and Landslides in the California Continental Borderland

Abstract:
One goal of the offshore earthquake hazard study in the California Borderland is to date the recency of movement on faults and folds and age of major landslide failures. The approach has been to identify active structures and landslides using high-resolution Huntec boomer or chirp-sonar data to image the structural detail (to 50 cm resolution) in the upper 20 to 80 m of sediment. These high-resolution profiles are then used to identify sites that can be sampled using standard (wire-line) piston coring to obtain material for AMS radiocarbon dating. This approach to deciphering fault history has

been euphemistically referred to as "acoustic trenching."

The initial attempts in our study focused on the Santa Monica Basin and the Gulf of Santa Catalina using cores obtained in 1998 and 1999, respectively. A total of 18 cores were recovered from 17 sites. In addition, for Santa Monica Basin, 11 radiocarbon dates were obtained from ODP Site 1015 that provide age control for a basin-wide stratigraphic framework based on Huntec boomer records. Preliminary results from the dating document Holocene displacement as young as 3 ka on base-of-slope faults along the southwestern margin of Santa Monica Basin. In addition, two small landslides at the base of slope in the eastern end of the basin both occurred about 10 ka. To the south in San Pedro Basin, the Palos Verdes debris avalanche is the largest Holocene mass failure recognized to date in the inner Borderland and is dated at about 7.5 ka. South of the Long Beach shelf, attempts to date recent offset on the Palos Verdes fault system have been inconclusive as a result of mas s-wasted deposits of older sediment covering the youngest offset horizons.

Additional sampling, including 27 piston cores, in July 2003 will be used to extend the analysis to other basins of the inner Borderland.

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Normark et al, 2003, SCEC poster:
Hydrate Discovery in Santa Monica Basin Offshore California

Abstract:
During a sediment-sampling cruise in late July 2003, a short piston core from near the summit of a mud diapir in Santa Monica Basin recovered gas hydrate at a water depth of 813 m. The discovery core was 2.1 m long and apparently stopped in the hydrate as evidenced by chunks of ice at the bottom of the core. Violent degassing of the core section between 162 and 212 cm resulted in spontaneous extrusion of the sample in the ship laboratory. Fresh mussel shells recovered from the top of the core indicate that the diapir is a site of active methane venting. The existence of hydrate at such a shallow depth in the sediment was unexpected and a decision was made to return to the site later in the cruise. Subsequent sampling with piston, gravity, and box corers (the latter included a Benthos (TM) bottom-trip camera) failed to sample more hydrate but did recover additional cold-seep fauna as well as fragments of indurated sediment. GPS positioning of the vessel allowed placement of all sample sites within a 15 m radius of the discovery core location, i.e., within about a 700 m^2 area) near the summit of the diapir. Within that area, the character of core samples varied from only rock fragments in one core to over 2.4 m of sediment in another core.

The mud diapir is about 300 m in diameter at the base and narrows to less than 100 m across the gently sloping summit. The diapir is internally structureless on both high resolution deep-tow boomer and

single-channel air-gun profiles (most likely as a result of the gas content and sediment deformation) and has extruded through well-bedded sediment on the lower slope of the basin producing as much as 30 m of bathymetric relief. The diapir is located about 24 km west-southwest of Redondo Beach, in an area where strike-slip motion along the San Pedro Basin fault zone to the south is replaced by convergent motion to the north. The intruded turbidite and lower slope sediment is correlated with latest Pleistocene and Holocene age deposits drilled at ODP Site 1015. The source horizon for the gas in the hydrate may be as shallow as 200 m below the regional seafloor based on the presence of a strong and irregular reflection interval observed on a 40 cu. in. sleeve-gun profile.

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Normark et al, 2003, AGU poster:
Methane Hydrate Recovered From A Mud Volcano in Santa Monica Basin, Offshore Southern California

Abstract:
In July 2003, a short (2.1 m), piston core from the summit of a mud volcano recovered methane hydrate at a water depth of 813 m in Santa Monica Basin. The discovery core penetrated into in the hydrate as evidenced by chunks of ice and violent degassing of the core section between 162 and 212 cm depth. The core consists of shell hash and carbonate clasts (to 7-cm long) in silty mud. The methanogenic carbonates are of two types: massive, recrystallized nodular masses with an outer mm-thick sugary patina and a bivalve coquina with carbonate cement. Living clams including the genus *Vesicomya*, commonly found at cold-seep sites elsewhere, were recovered from the top of the core. Further sampling attempts using piston, gravity, and box corers, all of which were obtained within 15 m of the discovery core, recovered olive-brown silty mud with variable amounts of whole and fragmented bivalve shells and methanogenic carbonate fragments characteristic of cold-seep environments. Gases collected in cores adjacent to the discovery core contain elevated amounts of methane and trace amounts of heavier hydrocarbon gases, indicating some component from thermogenic sources. Hydrogen sulfide was also detected in these sediment samples. Vertical channels in one core may have served as fluid pathways. The existence of hydrate at such a shallow depth in the sediment was unexpected, however, the presence of *Vesicomya* and hydrogen sulfide indicate that the mud volcano is a site of active methane venting.

The mud volcano, which is about 24 km west-southwest of Redondo Beach, is about 300 m in diameter at the base. No internal structure is resolved on either high resolution deep-tow boomer or single-channel air-gun profiles, most likely as a result of the gas content and sediment deformation. The diapiric structure has ascended through well-bedded sediment on the lower slope of the basin,

producing as much as 30 m of bathymetric relief. It is located in an area where strike-slip motion along the San Pedro Basin fault zone to the south is replaced by convergent motion to the north. The source horizon for the gas in the hydrate is unknown but appears to be collecting in beds as shallow as 200 m below the regional seafloor based on the presence of a strong and irregular reflection interval.

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Piper et al, 2003, AGU poster:
Variations in accumulation rate of late Quaternary turbidite deposits in Santa Monica Basin, offshore southern California

Abstract:
The Santa Monica Basin off southern California provides an ideal setting to study the effects of sea-level change and turbidity current initiation styles on turbidite depositional processes along a narrow continental margin. It is the perfect sink: all sediment delivered through multiple submarine canyons along its northern margin remains within the basin, except for quantifiable advection of shelf mud to the south. High-resolution deep-tow boomer data, which provides stratigraphic detail (to 50-cm resolution) for the upper 20 to 80 m of basin fill, permits mapping of a series of reflectors across the basin floor and onto the lower basin slopes. Age control for the upper basin fill at ODP Site 1015 is provided by 11 new radiocarbon dates, back to 31 ka (radiocarbon years) at 98 m. The average sediment-accumulation rate during the Holocene of 2.4 m/ka is about half the peak lowstand accumulation rate of 4.7 m/ka. During oxygen isotope stage 3, the accumulation rate wa s 2.5 m/ka (based on two dates), comparable to the Holocene rate. Additional dates from samples taken with conventional piston cores on the basin slopes confirm age assignments and stratigraphic correlation based on the boomer data. Basin floor reflectors in the turbidite fill can be traced from ODP Site 1015 to as much as 40 m above the floor of the basin at both the western and southeastern margins. Intervals of thick sands on the basin floor have correlative fine-grained turbidites on the basin margins, whereas intervals with only thin sands on the basin floor lack identifiable turbidites. Volume estimates of sediment accumulation can thus be made for individual time slices, allowing identification of periods of shelf trapping (e.g., 7.5-4 ka), preferential mid-fan deposition from high-density turbidity currents (e.g., 4-1.5 ka) and preferential basin-plain deposition from thick turbulent flows (e.g., 1.5-0 ka).

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Ryan et al, 2003, AAPG oral presentation:

Recent faulting in the Gulf of Santa Catalina from San Diego to Dana Point, California

Abstract:
The inner continental borderland offshore of southern California is complexly deformed by a number of faults that generally trend in a northwest direction. We have analyzed multichannel (MCS) and high resolution seismic-reflection data recently acquired by the USGS, combined with JEBCO and Western Geophysical industry MCS data, to compile a revised fault map for the area from offshore San Diego to Dana Point. The major fault zones we mapped include 1) the Coronado Bank fault zone and its northward extension and possible connection to the Palos Verdes Fault, 2) an unnamed fault zone at the base of the slope that extends discontinuously from La Jolla Canyon to near Dana Point, and 3) the offshore connection of the Rose Canyon fault zone (mapped onshore at La Jolla Canyon) with the Newport Inglewood fault zone, which trends offshore at Newport Beach. All of the fault zones we mapped are multi-stranded, discontinuous with respect to offset of the seafloor, and show signi ficant along-strike variability. The number of fault strands, width of the fault zone and the sense of offset on an individual strand commonly change along strike. As imaged on the high-resolution data, there is a spatially coherent pattern of recent fault slip on parallel faults. The orientation, distribution, and style of deformation of the various fault splays that compose the major fault zones suggest that the faults may be interconnected, resulting in a complex pattern of slip transfer between individual strands.

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Ryan et al, 2003, SCEC poster:
Revisiting the Offshore Connection Between the Newport-Inglewood and Rose Canyon Fault Zones

Abstract:
We have interpreted very high-resolution seismic-reflection data collected by the U.S. Geological Survey in 2000 to reexamine the relationship between the Newport-Inglewood (NI) and Rose Canyon (RC) fault zones (FZ) in the offshore between Newport and La Jolla submarine canyons. The NI-RCFZ is multistranded and generally tends follow the shelf break at about 100 m water depth. We have divided the offshore portion of the fault zones into 3 distinct segments: from Newport Beach south to Dana Point, from Dana Point to Carlsbad Canyon, and between Carlsbad and La Jolla Canyons. The 'North Branch' strand of the NIFZ can be traced from on land at Newport Beach to almost as far south as Dana Point. On the shelf, this strand is generally buried by sediment of probable Holocene age. However, another sub-parallel fault strand is discontinuously imaged seaward of the shelf break and appears, in places, to offset gullies imaged on sidescan sonar data. It is difficult to trace fa ult strands across Dana Point in part because there is

limited data in this area. Shelf sediment thins across Dana Point, which is the location where the San Joaquin Hills anticline plunges offshore (Grant et al., 1999).

From Dana Point south, the NIFZ is composed of up to 4 strands that are mapped near the shelf break. South of San Mateo Point, which lies about 12 km southeast of Dana Point, some of the strands appear to deform the sea floor. In addition, on many profiles shallow reflections are obscured in the vicinity of the fault zone, suggesting the presence of gas. Immediately north of La Jolla Canyon, the RCFZ follows the shelf break, which has a more northerly trend than the shelf break north of Carlsbad Canyon. We have mapped at bast 5 fault strands of the RCFZ; these strands commonly appear as terrace-like features. Locally, there are pronounced bathymetric features associated with the RCFZ. The transition between the NI and RC fault zones occurs in the region between Del Mar and Oceanside. This segment shows the most significant deformation of the sea floor, particularly near Carlsbad Canyon at mid-slope water depths of about 300 m. Here, a prominent anticline is mapped that offsets the sea floor about 60 m; its relief at the sea floor decreases to the northwest and southeast, but it is still observable over a distance of almost 15 km. The RCFZ merges into the more westerly trending transition zone at Carlsbad Canyon. The transition zone is linearly aligned with the segment of the NIFZ north of Dana Point, which suggests that the NI and RCFZ are connected at depth.

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Sliter and Ryan, 2003, AGU poster:
Possible Connections Between the Coronado Bank Fault Zone and the Newport-Inglewood, Rose Canyon, and Palos Verdes Fault Zones Offshore San Diego County, California

Abstract:
High-resolution multichannel seismic-reflection and deep-tow Huntec data collected by the USGS were interpreted to map the Coronado Bank fault zone (CBFZ) offshore San Diego County, California. The CBFZ is comprised of several major strands (eastern, central, western) that change in both orientation and degree of deformation along strike. Between Coronado Bank and San Diego, the CBFZ trends N25W and occupies a narrow 7 km zone. Immediately north of La Jolla submarine canyon (LJSC), the easternmost strand changes orientation to almost due north and appears to be offset in a right-lateral sense across the canyon axis. The strand merges with a prominent fault that follows the base of the continental slope in about 600 m water depth. The central portion of the CBFZ is mapped as a negative flower structure and deforms seafloor sediment as far north as 15 km north of LJSC. Farther north, this structure is buried by more than 400 m of basin sediment. Along the eastern edge of the Coronado Bank, the western portion of the CBFZ is characterized by high angle normal faults that dip to the

east. North of the Coronado Bank, the western segment follows the western edge of a basement high; it cuts through horizontal basin reflectors and in places deforms the seafloor. We mapped an additional splay of the CBFZ that trends N40W; it is only observed north and west of LJSC.

Although the predominant trend of the CBFZ is about N40W, along strike deviations from this orientation of some of the strands indicate that these strands connect with other offshore fault zones in the area. Based on the limited data available, the trend of the CBFZ south of Coronado Bank suggests that it might connect with the Rose Canyon fault zone (RCFZ) that has been mapped in San Diego Bay. North of Coronado Bank, the CBFZ is a much broader fault zone (about 25 km wide) composed of diverging fault strands. The westernmost strand may merge with the western strand of the Palos Verdes fault zone (PVFZ) south of Lasuen Knoll. The eastern strand trends toward the Newport-Inglewood fault zone (NIFZ) as imaged offshore near Dana Point. These connections suggest that the CBFZ is linked at depth with other prominent fault zones to the north (PVFZ and NIFZ) as well as to the south (RCFZ).

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Sorlien et al, 2003, AAPG oral presentation:
Structure and kinematics beneath Santa Monica Bay, California

Abstract:
West-striking seafloor faults and underlying blind thrust faults separate the Santa Monica Mountains (north) from northwest-striking right-lateral faults beneath Santa Monica Bay to the south. The moderately north-dipping Santa Monica-Dume fault (SMDF) is continuous for 75 km and links to the Malibu Coast fault. We model 4 to 7 km of post-~4 Ma left-lateral slip on the SMDF. An east-west-elongate basin extends 75 km offshore south of the SMDF. Assuming an unconformity beneath lower Pliocene strata formed near sea level, it has since subsided between 1.5 and 4 km. This foreland subsidence is synchronous with folding and basin inversion north of the SMDF. A blind fault dips north beneath this basin and the SMDF, and is interpreted as a Miocene detachment. This structure, which we call the Shelf Projection blind fault, has been mapped along 50 km of its strike using seismic reflection data. A thrust-reactivated segment of this fault located offshore of Manhattan Beach i s overlain by the 20 by 20 km Shelf Projection anticlinorium. Folding is post-Miocene, and the south limb of this anticlinorium deforms the youngest strata. This contraction is due to a left restraining step between the NW-striking right-lateral Palos Verdes and San Pedro basin faults. Assuming a local 40-50 degree north-northeast dip beneath its imaged uppermost part, the Shelf Projection blind fault projects into nodal planes of the 1979 and 1989 M5 reverse-slip earthquakes. It continues southeast beneath a broad southwest-dipping fold limb along the San Pedro escarpment.

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Abstracts

Fisher et al, 2002, AGU and SCEC posters:
Marine geology of the San Pedro continental shelf and initial results from seismic reflection data obtained in Santa Barbara Channel

Abstract:
The San Pedro continental shelf is cut by several large faults; chief among them is the Palos Verdes fault, which extends for nearly 100 km across the region. Research into the earthquake hazards posed by the Palos Verdes and other offshore faults is based primarily on small-airgun, multichannel, seismic-reflection data that were migrated and converted to depth sections. These data were interpreted together with the results of modeling aeromagnetic and gravity data and tomographic analysis of LARSE deep-penetration, seismic-reflection data. Our research shows that south of the Palos Verdes Peninsula and west of the Palos Verdes fault, rocks of middle Miocene through Pliocene age, at least 2 km thick, are folded into a large anticline and syncline--the Shelf Projection anticlinorium of Nardin and Henyey [1978]--that diverge to the northwest from the Palos Verdes fault. Aeromagnetic data show a 120-nT positive anomaly over the western limb of the syncline. Modeling of this anomaly suggests the presence of a large body of probable middle Miocene basalt. Isostatic gravity values, however, do not reveal a large dense body, perhaps owing to widely spaced measurements. Even so, we propose that a mass of basalt, more competent than the encasing sedimentary rocks, controlled the location and development of sub-shelf folds and of thrust faults that deform rocks farther west, below the continental slope. This basalt, then, appears to have played an important role in establishing the earthquake potential of faults near the San Pedro shelf. During June 2002, seismic-reflection data, of several different resolutions, were collected by the USGS in the Santa Barbara Channel. These data will be used to support research into earthquake hazards and the generation of submarine landslides, like the large Goleta slide below the northwestern part of the channel. In a collaborative effort, geologists at U.C. Santa Barbara will use these data to evaluate the in teraction between climate, sedimentation and tectonics. These new seismic-reflection data confirm that rocks of probable late Pleistocene age crop out along the Mid-Channel Trend, a series of anticlines developed adjacent to the

Oak Ridge fault. These rocks are attractive targets for sampling to obtain dates of fault movement, fold development and paleoclimatic events. Seismic-reflection data were collected across the active Oak Ridge reverse fault, near where it crosses the shoreline at Ventura.

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Kennedy et al, 2002, GSA poster:
Geologic map and digital data base of the Oceanside 30'x60' quadrangle, California

Abstract:
The Oceanside 1:100,000-scale quadrangle lies between 33° and 33°30'N latitude and 117° and 118°W longitude. It underlies a rapidly urbanizing part of southern California. The area is tectonically and seismically active and is dissected by four major, northwest trending, oblique right slip, Pacific/North American Plate boundary fault zones. They include the Elsinore Fault Zone in the northeastern corner of the quadrangle, the Newport-Inglewood Fault Zone in the center of the quadrangle (origin of the 1933, M=6.3, Long Beach earthquake), the Coronado Bank Fault in the near offshore region and the San Diego Trough Fault Zone in the southwestern corner of the quadrangle (origin of the 1986, ML=5.3, Oceanside earthquake). Landslides are abundant in the western and offshore parts of the quadrangle. Also, seismic hazards are numerous throughout the area. A tsunami hazard exists along the coastal margin.

The quadrangle is underlain by a thick sequence of forearc and forearc-basin Jurassic and Cretaceous (mostly low grade greenschist facies but partly unmetamorphosed) andesitic flows, sedimentary and volcaniclastic breccias and marine metasedimentary rocks that have been intruded in their older part by the southern California batholith. The batholith is Cretaceous in age and in part coeval with the forearc and forearc-basin rocks. The batholithic rocks are mostly tonalite and granodiorite with less common gabbro, diorite, monzogranite and granite. Pegmatite dikes are common in these intrusive rocks. The western part of the quadrangle is underlain by a relatively thick (>1000m) succession of Upper Cretaceous, Tertiary and Quaternary sedimentary and volcanic rocks that unconformably overlie the older plutonic and forearc basement rock sequence. These rocks consist chiefly of beds of marine, paralic, and nonmarine claystone, siltstone, sandstone and conglomerate and minor flows consisting mostly of Neogene basalt. Many cycles of uplift, erosion, subsidence and deposition since the Late Mesozoic have created the complexity of the existing stratigraphic and structural settings.

Fractured and deeply weathered bedrock associated with K/T boundary subareal extremes mantles much of the interior highlands and particularly the steep slopes adjacent to and southwest of the Elsinore Fault Zone.

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Normark et al, 2002, AGU poster:
Emplacement of the 7,500 yr B.P. Palos Verdes submarine debris avalanche, southern California

Abstract:
The Palos Verdes debris avalanche in San Pedro Basin offshore southern California is the largest volume late Quaternary mass-wasted deposit known from the inner California Borderland basins. Closely spaced, high-resolution deep-tow boomer profiles of the Palos Verdes debris avalanche collected in 1998 and 2000 show that it fills a turbidite leveed channel that extends from San Pedro Sea Valley. The bulk of the avalanche deposit, which is about 14 km long, appears to have resulted from a single failure on the adjacent slope because no internal stratigraphy was observed. Blocks as large as 40 m high have been transported onto the gently sloping basin floor. The volume of the debris avalanche deposit is between one and two cubic kilometers. The total volume of sediment that failed on the adjacent slope is difficult to estimate because of the unknown extent of a muddy debris flow on the basin floor that is coeval with the avalanche. The Palos Verdes deposit has been used to model tsunami generation in recent studies attempting to quantify local coastal hazards. Earlier studies speculated that the slope failure and the resulting deposit occurred less than a thousand years ago, well after sea level reached its present position. Radiocarbon dates from two piston-cores obtained near the distal toe of the avalanche deposit, however, indicate that the main failure occurred about 7,500 yr B.P. Subsequently, one or more smaller failures resulting in muddy debris flows have occurred as sea level rose during the mid to late Holocene.

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Sorlien et al, 2002, SCEC poster:
A blind fault beneath Santa Monica Bay

Abstract:
We used industry seismic reflection data to map a blind N-dipping low-angle fault beneath central and eastern Santa Monica Bay, along 50 km of its strike. This fault could be called the tip of the Santa Monica Mountains thrust, the Shelf Projection thrust, or the San Pedro escarpment thrust. We interpret it to be a basal Miocene detachment associated with clockwise vertical-axis rotation of the Santa Monica Mountains. It is located south of and beneath the Santa Monica-Dume fault. Several contractional structures indicate that it has been reactivated, with different structural styles for each. The western part, south and southwest of Pt. Dume, has been only

slightly reactivated near its upper tip by post-Miocene folding. However, its downdip projection merges with or intersects the moderately-dipping Santa Monica-Dume fault. Any active folding of the Santa Monica Mountains anticlinorium absorbs a deep thrust slip component on these faults. The central part of the fault is overlain by the 10x15 km WNW-trending Shelf Projection anticlinorium, located off of Manhattan Beach. We are investigating whether Pliocene-early Quaternary folding of this structure continues through late Quaternary time. The M5.0 1979 and 1989 earthquakes are spatially associated with this fold. The fault, or linked system of faults, then bends to the southeast, where its tip is beneath the base of San Pedro escarpment. The San Pedro escarpment is a dip slope associated with a SW-dipping fold limb, where the seafloor is almost as steep as the underlying strata. Further investigation is required to see whether this fault tip is associated with the Compton-Los Alamitos thrust of Shaw and Suppe (1996). It is possible that deformation above the Compton-Los Alamitos has changed with time as the tip of the reactivation propagated offshore. Contraction near this tip may now absorb thrust slip at the expense of the onshore fold, without need for a change in slip rate on the deep blind fault. Quantifying contraction across the San Pedro escarpment and the Shelf Projection anticlinorium is needed to evaluate rates of slip on the newly mapped blind fault.

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Bohannon, 2001, AGU poster:
Quaternary Tectonic Evolution of the Coastal Belt Southwest of Los Angeles Basin

Abstract:
Modern geologic hazards in the coastal belt southwest of Los Angeles Basin are intimately tied to its Quaternary tectonic evolution. Models describing tectonism during this period fall into at least three classes depending on what type of feature is showcased. 1.) Fold-and-thrust belt models feature blind thrusts, 2.) convergent-flake-tectonic models emphasize rigid upper-crustal blocks that interact above a mobile middle crust, and 3.) strike-slip models center on the interaction of blocks bounded by vertical faults with lateral offsets. High-resolution, multi-channel, seismic-reflection data, collected in a network of lines offshore, image numerous structures and tectonic features that have geometric characteristics that can be used to support each of the models, depending upon where one looks. Numerous folded uplifts and reverse faults are consistent with fold-and-thrust models. Some of the broad, deep basins might be best explained by convergent-flake tectonics. Complex vertical fault zones separating blocks with different seismic stratigraphy suggest strike-slip. In addition, large normal faults and deep fault-bounded basins are widespread, but are not explained well by any of the models. One aspect of local tectonic history, not considered by any models, is a major reversal of the regional

physiography that occurred during the Quaternary. Los Angeles Basin (LAB), which is now sub aerial, was mid-bathyal in the Pliocene whereas Santa Monica and San Pedro (SM/SP) Basins, which are presently mid-bathyal, were shallow to sub aerial. The physiographic reversal resulted from a combination of folding and uplift in the Palos Verdes/Santa Monica areas, which impounded sediment causing LAB to fill, and extensional faulting and rapid subsidence nearby in SM/SP Basins. These seemingly opposed tectonic styles can be easily documented with seismic data, but these styles are thought to be incompatible in most models.

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Fisher et al, 2001, AGU poster:
Geology of the Continental Margin Beneath Santa Monica Bay, Southern California, from Small-Airgun Seismic-Reflection Data

Abstract:
Small-airgun, multichannel-seismic-reflection (MCS) data collected in Santa Monica Bay reveal the geologic structure of the continental shelf and of the adjacent basin slope and deep-water basins. The Palos Verdes fault under the northern, shallow part of the bay cannot be identified in seismic-reflection data, even though many studies suggest its presence. This fault neither offsets the seafloor nor cuts through an undeformed sediment apron. Other major faults, such as the east-west Dume fault under the northern part of Santa Monica Bay, show evidence for recent activity. Tomographic-velocity data, derived from arrivals along the LARSE, deep-crustal MCS streamer, show that metamorphic rocks, probably the Catalina schist, underlie Santa Monica Bay and the deep-water Santa Monica basin to the south. The Santa Monica canyon marks a significant change in deformation of the lower slope of the Santa Monica Basin. North and northwest of this canyon, the slope is underlain by a little-deformed sediment apron; the main apron structures are two anticlines that extend toward Point Dume and are cored by reverse or thrust faults. Southeast of the canyon, lower-slope rocks are deformed by a complex zone of strike-slip, normal and reverse faults. The San Pedro bathymetric escarpment rises abruptly along the southeast side of Santa Monica Canyon. Structures underpinning this escarpment steepen progressively southeastward; they cut downward into basement rocks, and merge with the San Pedro Basin fault zone, which is nearly vertical and possibly strike-slip. The escarpment and its attendant structures extend for 60 km along the margin, separating the continental shelf from the mid-bathyal Santa Monica and San Pedro basins. The Santa Monica Basin, the more extensive of the two, contains about 1.5 km of turbidite fill that is deformed only near the northern basin margin. Data from ODP site 1015 indicate that this fill is most likely no older than Quaternary, and possibly no older than 600 ka. To the south, the San Pedro basin is a narrow graben that widens to the southeast. Locally near the Redondo Canyon and Palos Verdes Peninsula, graben rocks are deformed by

reverse faults and folds.

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Sliter et al, 2001, AGU poster:
Does recent deformation at the base of slope provide evidence of a connection between the Newport-Inglewood and the Rose Canyon fault zones offshore southern California?

Abstract:
The possible offshore connection of the Newport-Inglewood fault zone (NIFZ) and the Rose Canyon fault zone (RCFZ) between Newport Beach and La Jolla, California is important to the assessment of earthquake hazards in southern California. One or more strands of the NIFZ head offshore near Newport Beach; the RCFZ heads offshore and offsets the Scripps submarine canyon near La Jolla. Many workers have proposed that the faults are connected by a complex zone of faulting along the continental shelf, with the main deformation occurring near the shelf edge. However, fault strands mapped on the shelf north of Oceanside do not disturb the seafloor.

The USGS collected high-resolution (35 in^3 GI gun, 250 m 24-channel streamer) multichannel seismic reflection (MCS) data in 1998 and 1999, and high-resolution Geopulse (boomer) data over the shelf and slope in 2000. We observe sediments at the seafloor deformed near the base of the slope at water depths of about 700 m on MCS data between Dana Point and Oceanside. Between Oceanside and Carlsbad, at about 300 m water depth, we observe folding of the seafloor. The boomer data show recent faulting on the shelf (< 100 m water depth) associated with the Rose Canyon fault from Carlsbad to La Jolla. We interpret the base of the slope faulting to be related to a strand of the NIFZ. This strand may connect with the RCFZ by a left step near Carlsbad, as evidenced by recent folding of the seafloor.

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Bohannon and Gardner, 2000, AGU oral presentation:
Submarine Landslides of San Pedro Sea Valley, Southwest Los Angeles Basin

Abstract:
The coastal infrastructure of the southern greater Los Angeles metropolitan area would be profoundly affected by a large tsunami of local derivation. Submarine slope failures and active faults, either of which could potentially generate a large tsunami, are both known on the shelf and slope near Long Beach. This paper examines features

suspected of being large slope failures on the San Pedro Escarpment and on the basin slope adjacent to the San Pedro shelf using detailed bathymetry and seismic profiles. The southeastern part of the escarpment has had a long history of slope failure. The most recent of these, the valley failure scar, is over 4.5 km long, might be less than 500 years old, and involved over 0.34 km^3 of material, which now litters the adjacent basin floor. Other smaller deposits from other nearby failures are also present, as are buried wedges of allochthonous debris which indicate that slope failure has been occurring locally throughout the Holocene and much of the late Pleistocene. Slope failures have occurred in response to continual uplift of the Palos Verdes anticlinorium during that same period. A large feature on the basin slope south of the San Pedro Shelf, called the lower-slope structure, has many morphologic characteristics of a slope failure, but is probably an incipient uplift of tectonic origin. Although it has a distinct upper slope break that resembles a headwall-breakaway and it appears to have a rumpled toe that overrides basin sediment, seismic profiles indicate that it is a deeply rooted structure. The apparent breakaway is merely a sharp change in slope caused by folding and the toe is a series of normal faults with intermediate west dips. The entire structure is underlain by a shallow basement core. The valley failure scar is a likely candidate for failure-related tsunamogenisis because it started in shallow water, evolved on low-drag bedding planes, had a long slide path, and involved high-strength li thified material. The lower-slope structure may have seismic tsunomogenic potential. Since all features are pre-historic, the ancient record in and around Long Beach should be examined for evidence of local tsunami activity.

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Reid et al, 2000, AGU poster:
Multibeam Image and New High-Resolution Seismic Reflection Profiles Confirm Recent Deformation in the Loma Sea Valley, Offshore San Diego

Abstract:
Recently acquired multibeam images of the Loma Sea Valley, offshore San Diego, illuminate the effects of recent faulting and folding on the seafloor as evidenced by newly acquired multi-channel airgun and Huntec high-resolution seismic-reflection profiles. The Loma Sea Valley lies between the northern extension of Coronado Bank and the Point Loma peninsula of San Diego, and the valley is underlain by multi-strand faults that are considered part of the Palos Verdes Hills-Coronado Bank (PV-CB) fault system. The seismic-reflection profiles show a group of separate fault strands that cut the mid-slope region and trend north-northwest parallel to the valley axis and Coronado Bank. Some of these strands extend to and cut the sea floor, appearing as lineations in the high-resolution multibeam bathymetric data and affecting the seabed morphology, forming lows and controlling drainage. A separate fault strand on the

lower slope trends parallel and adjacent to the valley axis and is evident as a lineation in the multibeam bathymetry for at least six kilometers. These fault strands appear on the seismic-reflection profiles as vertical to steeply dipping and some show complex changes in deformation style and character along strike, in some cases suggesting differential block movement along individual fault segments. This multi-strand fault zone, about 5-km wide, is subparallel to the better-known Rose Canyon Fault system that transects nearby downtown San Diego. Both the Rose Canyon fault and Loma Sea Valley segment of the PV-CB system are part of the West Coast's distributed shear fault systems making up the Pacific/North American plate boundary. These seismic-reflection profiles, along with the multibeam bathymetric data, suggest that faults within the Loma Sea Valley area may pose a hazard to western San Diego of the same magnitude as faults in the Rose Canyon system.

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Simila et al, 2000, AAPG poster:
The Los Angeles Region Seismic Experiment, Phase II (LARSE II); a survey to identify major faults and seismic hazards beneath a large metropolitan area

Abstract:
A number of institutions, including the U.S. Geological Survey and the Southern California Earthquake Center, collaborated in a seismic-imaging survey known as the Los Angeles Region Seismic Experiment, Phase II (LARSE II). This survey included an active and passive component and was concentrated along a 100 km-long corridor extending from Santa Monica Bay northward to the western Mojave Desert, crossing the Santa Monica Mountains, the San Fernando Valley (Northridge epicentral area), the Santa Susana Mountains, and the western Transverse Ranges. In the active component, 1400 seismographs were deployed at 100 m spacing along the main corridor, with shot points approximately 1000 m apart; with additional cross-lines. Chief imaging targets included the Santa Monica, San Gabriel, and San Andreas faults, blind thrust faults (e.g., Northridge fault), and the depths and shapes of the sedimentary basins in the San Fernando Valley and Santa Monica areas. Preliminary analysis indicates good data quality and energy transmission. Small shots (5-20 lbs) in the San Fernando Valley were recorded 50-80 km away in the Tehachapis.

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Holton et al, 1999, AGU poster:
Holocene deformation in the Santa Monica Basin, offshore

southern California

Abstract:
The upper 200 meters of slope sediment and basin-floor turbidites in the Santa Monica Basin were surveyed by the Canadian Geological Survey in 1992 and the U.S. Geological Survey in 1998 using high resolution deep-tow boomer (~100 m penetration) and multichannel airgun seismic-reflection systems (~1000 m penetration). This cooperative study establishes a basin-wide seismic-stratigraphic framework, which can be used to establish the character of deformation, especially in the vicinity of previously mapped faults near the basin margins. Constraints on the timing of deformation are tied to recognizing disruption of key stratigraphic marker horizons within the sediment fill. We have assigned tentative age ranges to the key horizons using preliminary drilling results, from ODP Leg 167 at site 1015, that indicate an early to mid Holocene sedimentation rate approaching 3 meters per thousand years (Shipboard Scientific Party, 1997). With the high resolution (~0.5 meter) capa bilities of the deep-tow boomer system, we are able to infer dates for a suite of key reflectors in the upper 50 meters of sediment. Deformation features such as slumps, growth folds, and fault offsets that disrupt Holocene sediment are common near all margins of the Santa Monica Basin. Estimates for the time of deformation, based on the high sedimentation rate in the basin, indicate widespread tectonic activity over the last 12 ka. Some offsets on the eastern slope reach the sea floor, but timing of motion on these features is not well constrained because the rate of late Holocene slope deposition is less certain than on the basin floor.

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Marlow et al, 1999, GSA poster:
Palos Verdes Fault Complex: An Example of Fault Segmentation in Offshore Southern California

Abstract:
Recently acquired high-resolution multibeam bathymetric imagery reveals several linear ruptures in the sea floor on the upper continental slope southeast of Palos Verdes Peninsula. High-resolution multichannel and boomer seismic-reflection profiles show that these linear ruptures are the surficial expressions of Holocene faults with vertical to steep dips. One prominent fault, which lies about 10 km to the west of the mapped trace of the Palos Verdes Fault, can be traced on the multibeam imagery for 14 km between the shelf edge and the base of the continental slope. The fault trace is informally called the Avalon Knoll fault for the nearby geographic feature of that name. The reflection profiles show that the Avalon Knoll fault is part of a northwest oriented complex of faults and anticlinal uplifts that are evident as scarps and bathymetric highs on the multibeam imagery. The Palos Verdes Fault bounds this complex on the east and can be discontinuously traced on the multibeam

imagery and geophysical profiles from Lasuen Knoll to the shelf edge. Folding coincident with the Palos-Verdes Fault alternates in intensity and bathymetric expression on either side of the Palos Verdes Fault between Lasuen Knoll and the shelf edge, suggesting that a scissoring of tectonic blocks occurs along the fault trace. The multibeam-bathymetric imagery allows the ready identification of previously unmapped fault traces that rupture the sea floor. The imagery also shows offset slope drainage systems that would not be evident on a grid of geophysical profiles alone. The imagery data are a valuable tool for delineating offshore earthquake hazards through recognition of the length of offset sea floor, and these offsets can be confirmed by carefully sited, high-resolution seismic-reflection profiles.

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Normark et al, 1999, AGU poster:
Evidence for a buried gas-hydrate mound in turbidite fill of the Gulf of Santa Catalina, offshore southern California

Abstract:
The possible presence of a buried gas-hydrate mound in turbidite deposits offshore Oceanside, California is indicated by an anomalous column of concave-upward reflections capped by a convex-upward reflection that has been observed in two multichannel seismic-reflection profiles across the basin floor in 850 m water depth. The column of anomalous reflections is about one kilometer wide and extends from about 45 m below the sea floor (mbsf) in the otherwise flat-lying sediment to a depth of at least 200 mbsf. This distinct column of convex/concave reflections generally resembles velocity-amplitude structures (VAMPs) described from the deep Bering Sea (Scholl and Cooper, 1978). In the Bering Sea examples, VAMPs are caused by a localized gas-hydrate layer, which causes a velocity pull-up near the base of the hydrate stability zone. The hydrate overlies a column of free gas that results in a velocity push-down (i.e., concave-upward reflections). The reflection geometry of the acoustic anomaly observed offshore southern California cannot be interpreted as a VAMP because: (1) the relief (in two-way travel time) of the concave-upward reflections is too great to result from a low-velocity free-gas zone; and (2) based on nearby observations of heat flow and bottom-water temperature, the base of the methane gas-hydrate stability zone is at least 700 mbsf. The southern California feature occurs above a diapiric structure that intrudes the flat-lying basin-plain turbidites. A probable explanation for this acoustic anomaly is a buried mound of sediment containing gas hydrate and, possibly, authigenic carbonate. The convex-upward reflection is the upper surface of this buried mound, which formed by gas/fluid migration above the diapir, and the concave reflections might record collapse of the diapiric crestal zone. Similar, but less striking, examples of possible lens-shaped gas-hydrate accumulations are observed on nearby multichannel seismic-reflecti

on profiles.

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Bohannon, 1998, GSA oral presentation:
Tertiary tectonic evolution of the inner continental borderland, California

Abstract:
The inner continental borderland offshore of Los Angeles and San Diego has been likened to large metamorphic core-complex, based on data and interpretations derived from multi-channel seismic-reflection, seismic-refraction, and regional geologic studies. Neogene sedimentary rocks overlie a basement of Catalina Schist that has been intruded by Miocene plutons throughout this unique belt. The belt of schist is separated on its west side from the gently deformed late Cretaceous and Paleogene sedimentary rocks of the Nicolas fore-arc belt by faults with steep west dips and pronounced normal separations. On its east side the schist belt is bounded by a large detachment fault that dips gently to the east beneath the west edge of the Peninsular Ranges belt at the coastline near Oceanside. The Catalina Schist was uplifted from middle crustal depths and exposed during a major event of extensional tectonism that started in the early Miocene in conjunction with about 10° of clockwise rotation of the western Transverse Ranges belt. Part of the uplift of the Catalina Schist could have occurred on the detachment fault, but mostly it is thought to have occurred on the steep faults that bound the west edge of the schist belt. A large amount of uplift is required and it probably involved strong footwall flexural deformation in the wake of the translating and rotating western Transverse Ranges and Nicolas fore-arc belts. Extension, accompanied by probable large amounts of right slip, continued in the borderland region during and after the middle Miocene. The later stage of extension was accompanied by rapid clockwise rotation of the western Transverse Ranges of at least 90°. Most of the borderland, including the belt of schist that was uplifted in the early Miocene, was further deformed into numerous basins and ridges during this stage of oblique extension. The primary driving force for the deformation is thought to have been derived from the rapid northwest motion of the Pacific plate after it had become coupled to the Farallon plate system which had previously been subducted beneath the borderland.

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Bohannon et al, 1998, AGU poster:
Seismic hazard potential of offshore Los Angeles Basin based on high-resolution, multibeam bathymetry and close-spaced, seismic-reflection profiles

Abstract:
Young structures and mass flows on the offshore margin of Los Angeles Basin might produce nearshore earthquakes or tsunamis that could pose a hazard to the nearby urban corridor. These features are delineated on detailed bathymetry, backscatter maps, and high-resolution seismic-reflection profiles. Simrad EM1000 and EM 300 high-frequency, multi-beam data provide new base maps for much of the area. A Huntec deep-tow boomer obtained high-resolution (0.4m), vertical-incidence, sub-bottom profiles to depths corresponding to 25-125 milliseconds (TWTT). A 24 channel-seismic-reflection system acquired data to depths corresponding to at least 1 second (TWTT) using a 35 cu. in. gas-injector airgun. Close line spacing for the seismic-reflection data enabled tracing structures through the area. Numerous large folds that appear to be actively growing are aligned parallel to the base of the slope that forms the west-southwest edge of the Santa Monica shelf. These folds, particula rly the anticlinal structures, are bathymetrically expressed in the seafloor relief and their growth history is delineated by flanking unconformities and stratigraphic pinch-outs. Many of the anticlines are bounded on at least one side by short fault segments that offset some of the youngest reflectors. Some of the flanking faults break through to the seafloor. The steep west-southwest flank of the Palos Verdes uplift has been the source of numerous, large mass flow deposits that cover extensive areas in San Pedro Basin. Many of these mass flow deposits are probably Holocene in age and if they prove to have occurred catastrophically, they may have generated tsunamis. Our data suggest the strong possibility for continued mass wasting on these steep slopes. Numerous northwest-oriented active fault traces, including the previously documented Palos Verdes fault, are evident in our data on the Long Beach shelf and slope. These faults are associated with the growth and development of a large complex of submarine canyons at the shelf edge, the Lasuen Knoll anticline, and numerous unnamed ridges. Although seismicity is relatively low in this part of the California Continental Borderland, the number and variety of active structures that are evident in our dataset suggest that this region might have a high potential for seismic hazards.

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Clarke et al, 1998, GSA poster:
Kinematics of the Palos Verdes fault zone in Los Angeles Harbor, California, from multidisciplinary studies

Abstract:
Recent high and very-high resolution seismic-reflection profiling in the Los Angeles Harbor main channel provides evidence of a structural transition along the Palos Verdes fault zone, from a regime of right-oblique slip (SW-side up) that extends southeastward from the Palos Verdes Hills, to predominantly right slip to the south in the Los Angeles outer harbor and on the San Pedro shelf. In the

Southwest Slip, at the northern end of our study area, a reflector tentatively correlated to the unconformity between the Lakewood and San Pedro Formations (estimated age 400-650ka), shows a vertical separation of about 40m across a narrow, sharply defined zone. This implies a minimum Quaternary vertical separation rate of about 0.06-0.10 mm/yr, which is only about 20-25% of the uplift rate estimated from marine terraces in adjacent San Pedro. At Vincent Thomas Bridge, only 800m to the south, vertical separation of the Lakewood-San Pedro contact is reduced to ~18-21m across a ~400m wide fault zone. Recent strike-slip activity appears confined to the westernmost part of the zone, whereas most vertical offset of the Lakewood-San Pedro contact occurs to the east. Although not resolved in the seismic records, logs of boreholes recently drilled beneath the bridge suggest that as much as 10m of vertical separation may have occurred in Holocene time. In these newly drilled holes, paleontological analysis, combined with ^{14}C and amino-acid dating of recently acquired samples will establish stratigraphic control across the fault zone, enhance interpretations of the seismic records, and provide detailed constraints on timing and strain partitioning along the Palos Verdes fault in the Los Angeles Harbor.

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Kennedy et al, 1998, GSA poster:
Holocene faulting on the Rose Canyon fault zone, San Diego Bay, California

Abstract:
An important charge of the Southern California Areal Mapping Project (SCAMP) is geologic mapping and assessment of geologic hazards of the southern California continental margin. The recently completed multidisciplinary SCAMP study of the Rose Canyon fault zone, in San Diego Bay, has proven to be important in evaluating the safety of the Coronado Bridge.Sub-bottom seismic reflection profiling surveys controlled by precision GPS navigation, coupled with coring, radiocarbon dating, aminostratigraphy and molluscan biostratigraphy have been used to unravel the geometry and Holocene/Pleistocene fault history of a portion of the Rose Canyon fault zone in the vicinity of the Coronado Bridge.

Sub-bottom seismic reflection profiling surveys controlled by precision GPS navigation, coupled with coring, radiocarbon dating, aminostratigraphy and molluscan biostratigraphy have been used to unravel the geometry and Holocene/Pleistocene fault history of a portion of the Rose Canyon fault zone in the vicinity of the Coronado Bridge.

A network of approximately 500 line-km of closely spaced (~50 m), orthogonally positioned (sub-meter accuracy), high- and very-high resolution reflection seismic lines were used to develop a detailed model of the fault geometry of the central portion of San Diego Bay.

Molluscan shell material collected from a series of coreholes drilled adjacent to the youngest observed faults were dated and used to establish the Holocene/Pleistocene boundary in the vicinity of the Coronado Bridge. The Holocene sediments consist of a fine-grained, estuarine sequence that is approximately 6,500 yrs old at its base. The youngest dated materials that are faulted are 4435+/-115 yrs, although faults occur higher in the section in stratigraphically younger deposits.

The Holocene fault geometry of the bay is characterized by small-scale detachment faults in a predominately strike-slip environment. Four prominent Holocene northeast-trending, normal faults that are an integral part of the detachment fault system are of special concern in that they underlie piers 1, 5, 14 and 17 of the Coronado Bridge.

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Normark et al, 1998, AAPG poster
Depositional architecture and outcrop-scale acoustic facies analysis for Hueneme and Dume fans, Santa Monica Basin, California

Abstract:
Fifteen widely correlatable key seismic reflectors provide a stratigraphic framework for interpreting Quaternary turbidite systems in Santa Monica Basin. Eight acoustic facies are distinguished with deep-tow boomer seismic-reflection profiles, which have a vertical resolution of a few tens of centimeters and acoustic penetration of 20 to 50 m. Acoustic facies, which are correlated with available core data, and reflector geometry have been integrated to define six architectural elements together with a number of subelements that are of a scale that can be recognized in outcrops of ancient turbidites on land. On Hueneme Fan, two distinct overbank elements record construction and partial erosion of laterally confined secondary levees. Near the termination of fan channels on the upper midfan, sandy facies form compensation cycles. The middle fan comprises three main subelements: sandy channel-fill, low-gradient sandy lobes, and a scoured-lobe subelement formed of alternating sand and mud filling erosional depressions. The site of thickest lobe sediment accumulation shifts from one part of the fan surface to another through time, i.e., compensation cycles. The lower fan comprises main sheet-like alternations (locally gently lensing) of sand and mud. The Santa Clara River delta is the dominant source for Hueneme Fan, for which changes in facies distribution reflect variations in the rate at which sea level rose since the last glacial maximum. The smaller Dume Fan, which is composed of coarser sediment supplied through littoral drift, has steeper gradients, less prominent levees, and displays fewer subelements than Hueneme Fan.

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ten Brink et al, 1998, AGU:
The thermal structure of California

Abstract:
The thermal and magmatic history of coastal California is generally interpreted as a consequence of asthenospheric upwelling beneath part of the forearc where the subducted lithosphere was removed in the wake of the northward migration of the Mendocino Triple Junction (MTJ). We suggest that, with the exception of the Inner California Borderland (ICB), the magmatic and thermal history of coastal California does not require asthenospheric upwelling and can simply be explained by thermal re-equilibration following cessation of subduction of young oceanic lithosphere. Geothermal gradients in the forearc and underlying oceanic crust are suppressed during subduction because of the cooling effect of the downgoing slab. When subduction stops, the geothermal gradient returns to normal bringing the temperatures in the now-fossil ocean crust to 600-750°C for parameters typical to coastal California (20-30 km thick forearc, 10-4 Ma subducting slab, 15° subduction angle, and 40 km/my subduction rate). The recovery of the thermal gradient results in a rapid increase of surface heat flow to 60-77 mW/m2, which is consistent with observations. The recovery of the thermal gradient can also generate some partial melting in the fossil ocean crust at 25-35 km depths. Amphibolite dehydration-melting can take place at temperatures as low as 630°C and pressures of 8 kbar (~25 km). This partial melting of the ocean crust could produce the minor calcalkaline Neogene volcanism in coastal California which followed the northward migration of the MTJ. The isotopic and trace-element signatures of the volcanic rocks are indicative of crustal anatexis. A recent seismic survey close to the MTJ indicates the presence of melt lenses at the base of a high velocity crustal layer, which is consistent with crustal anatexis occurring presently. Basal layers of high crustal velocities, interpreted as fossil oceanic crust, are observed under northern and ce ntral California, but not under the ICB. The ICB underwent considerable extension in the mid-Miocene. The heat flow in the ICB is indeed still high (67-89 mW/m2), consistent with high subcrustal temperatures. Volcanism here is more voluminous, its composition is indicative of a greater melting depth, and its isotopic and trace-element contents are closer to that of MORB. The ICB therefore is suggested to be the only coastal California region underlain by asthenospheric upwelling following the cessation of subduction. A consequence of the proposed thermal structure is a progressive shallowing of the brittle-ductile transition (except for the ICB) from near the base of the forearc at the end of subduction to 1315 km depth at present, which is consistent with the observed epicentral depths.

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ten Brink et al, 1998, AGU oral presentation:
Crustal structure of the Inner California Borderland: Evidence for modern deformation and for a Miocene metamorphic core complex

Abstract:
Wide-angle seismic reflection and refraction data along two lines crossing the Inner California Borderland (ICB) indicate a seismic velocity structure which is remarkably similar to that of metamorphic core complexes in the Basin and Range Province. The lines collected as part of the 1994 LARSE experiment trend roughly north-south from San Clemente Ridge to Long Beach and Santa Monica, respectively. The data support Crouch and Suppe's (1993) model for the origin of the ICB as an autochthonous highly-extended region, which was possibly formed during the Miocene by the rotation of the Transverse Ranges and by the rifting along what was then the North American-Pacific plate boundary. Lateral velocity heterogeneities in the vicinity of known faults are confined to the upper 5 km of the crust. The lower crustal velocity is laterally homogenous within the limits of our resolution and possibly consists entirely of quartz-rich Catalina Schist. The Moho is subhorizontal and i s located at a depth of 19-22 km. Thickening of the crust occurs beneath the continental shelves of Santa Monica Bay and Long Beach and marks the northern and eastern boundaries of the ICB. These data, and coincident MCS reflection data, also indicate modern compressional or transpressional deformation between the coast and the southwestern edge of Catalina Ridge. Both the Palos Verdes and the San Pedro Basin faults appear to change their sense of motion between the two profiles. The Palos Verdes fault terminates at a shallow depth (2-3 km) against a basement (?) high, whereas the San Pedro Basin Fault extends to a depth of at least 5 km within the crust. Finally, our data provide no evidence for underplated oceanic crust under the ICB, contrary to seismic observations from other parts of coastal California. The absence of this layer may be a local phenomenon caused by a slab gap under the ICB or representative of southern California as a whole. We construct a hypothetical g eothermal gradient for the ICB, which is in agreement with geochemical constraints, present heat flow, and the origin of the province as a metamorphic core complex. We use it to show that the shallow depth of earthquake epicenters beneath the ICB relative to onshore southern California is due to the felsic crustal composition, and not to the thermal gradient.

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Clarke et al, 1997, GSA poster:
Seismic-reflection study of the Palos Verdes fault zone in the vicinity of the Los Angeles Harbor, California

Abstract:
Approximately 150 line-km of digitally-recorded, single-channel 350

Joule ORE Geopulse data and 50 line-km of 24 channel MCS data using a 16 in^3 airgun source were collected from the San Pedro and Long Beach Channels, and from the Los Angeles outer harbor during mid 1996. Data collection was conducted jointly by the California Division of Mines and Geology and the U.S. Geological Survey, and was funded by the California Department of Transportation to study the Palos Verdes fault zone pursuant to seismic retrofit of the Vincent Thomas Bridge. Single-channel data provide 1-2 m resolution at shallow depths beneath the floor of the channels, whereas the MCS data provide 2-10 m resolution to maximum depths of about 500 milliseconds (~450 m).

Maximum age of faulting in the vicinity of the Vincent Thomas Bridge was largely constrained by disruption of the contact (ca. 600-650 ka) between the Lakewood and San Pedro Formations. One kilometer north-northwest of the bridge, the fault is a discrete rupture that cuts Holocene strata and extends to the channel floor. Beneath the bridge, the fault appears as a 400 m-wide zone of disruption containing multiple traces that closely approach or cut the channel floor. This may reflect bifurcation or a right-step of the fault zone. Data from this area are consistent with an upwardly anastomosing fault that may be resolved at depths greater than we have imaged as a negative flower structure resulting from divergent wrench faulting. In the Los Angeles outer harbor, faults in our date approach, but do not cut, strata assigned by McNeilan and others (1996) to the 8-10 ka "transgressive marine section", and would thus be assigned a late Quaternary age.

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Kennedy and Clarke, 1997, GSA poster:
An analysis of the Rose Canyon fault zone in San Diego Bay, California

Abstract:
Approximately 350 line-km of digitally-recorded, single-channel 350 Joule ORE Geopulse date and 130 line-km of 24 channel MCS data using a 16 in^3 airgun source were collected in San Diego Bay during early-mid 1996. Data collection was conducted jointly by the California Division of Mines and Geology and the U.S. Geological Survey, and was funded by the California Department of Transportation to study the Rose Canyon fault zone pursuant to seismic retrofit of the Coronado Bridge. Single-channel data provide 1-2 m resolution to depths of about 120 milliseconds (~110 m) beneath the floor of the bay, whereas the MCS data provide 2-10 m resolution to depths of about 500 ms (~450 m). Together, these data have enabled us to examine the architecture of faulting in the bay in great detail.

San Diego Bay in the vicinity of the Coronado Bridge is characterized by small-scale detachment faulting in a predominantly

strike-slip environment. A series of northeast-trending normal faults together form a graben that is centered along the axis of the bay. These normal faults appear to have formed in a tensional environment that is bounded by north-to-northwest-trending right-lateral strike-slip faults of the greater Rose Canyon fault zone that lie along both the eastern and western margins of the bay. Major faults mapped in San Diego Bay extend upward to near the floor of the bay (to within about 5-15 ms of the seafloor) in youthful water-saturated sediment. As the Mount Soledad strand of the Rose Canyon fault zone is known to cut Holocene deposits onland in the San Diego area, and based on the close upward proximity of faults mapped in this study to the bay floor in the vicinity of the Coronado Bridge, we consider these faults to be of probable Holocene age.

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Klitgord and Brocher, 1996, AGU:
Oblique-slip deformation in the San Pedro Basin offshore Southern California region

Abstract:
Multichannel seismic-reflection profiles acquired offshore Los Angeles during the 1994 LARSE experiment and in 1990 with the RV LEE imaged the zone of active deformation within the San Pedro Basin and along the eastern edge of Santa Monica Basin. This zone of deformation is bound on the west by the San Pedro Basin fault, an oblique-slip fault with a significant normal dip-slip component (over 500m) down thrown to the east. The San Pedro Basin fault coincides with the western limit of a dense distribution of small to moderate magnitude (Mw 3-5) earthquakes that extends east across the Palos Verdes and Newport-Inglewood fault zones. Redondo and Avalon knolls are located on the footwall (west side) of the San Pedro Basin fault and are overlain by thin (<500m), moderately deformed Pleistocene to Recent turbidites. In contrast, a thicker section (up to 1000m) of more intensely folded and faulted Pleistocene to Recent turbidites are found on the hanging wall to the east . Isopach and fault-offset (vertical) records for the Pleistocene to Recent strata in the deep water east of the San Pedro Basin fault are used to investigate how deformation has been partitioned across this part of the oblique-slip fault system. At present the most intense folding and dip-slip faulting are located about 6 km east of the San Pedro Basin fault in a zone a few km wide. A narrower 1-km wide zone of chaotic faulting but only minimal strata offset is found about 6 km further east near the shelf edge and may coincide with a region dominated by strike-slip faulting. This change in deformation character across the basin is interpreted to indicate that the proportion of dip-slip to strike-slip faulting increases to the west across the oblique-slip fault zone.

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Papers in Scientific Journals

Hein et al, in press, Geology paper:
Methanogenic calcite, ^{13}C-depleted bivalve shells, and gas hydrate from a mud volcano offshore southern California

Abstract:
Methane and hydrogen sulfide vent from a cold seep above a shallowly buried methane hydrate in a mud volcano located 24 km offshore southern California in 800 m water. Bivalves, authigenic calcite, and methane hydrate were recovered in a 2.1 m piston core. Aragonite shells of two bivalve species are unusually depleted in ^{13}C (to -19‰ $\delta^{13}C$), the most ^{13}C-depleted shells of marine macrofauna yet discovered. Carbon isotopes for both living and dead specimens indicate that they used in part C derived from anaerobically oxidized methane (AOM) to construct their shells. Although the ^{13}C values are highly variable, most fall within the range -12 to -19‰. This variability may be diagnostic for identifying cold-seep/hydrate systems in the geologic record. Authigenic calcite is abundant in the cores down to about 1.5 m subbottom, the top of the methane hydrate. The calcite is depleted in ^{13}C ($\delta^{13}C$ = -46 to -58‰) indicating that C produced by the AOM was the main source. Likely methane sources include a geologic hydrocarbon reservoir from Miocene source rocks, and biogenic and thermogenic degradation of organic matter in basin sediments. Oxygen isotopes indicate that most calcite formed out of isotopic equilibrium with ambient bottom water, under the influence of gas hydrate dissociation and strong methane flux. High concentrations of Ag, Hg, Cd, Tl, and other elements in mud volcano sediment may indicate leaching of basement rocks by fluid circulating along an underlying fault, which also allows for a high flux of fossil methane to the seep/hydrate site.

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Baher et al, 2005, BSSA paper:
Upper-Crustal Structure of the Inner Continental Borderland near Long Beach, California

Abstract:
A new *P*-wave velocity/structural model for the inner Continental Borderland (ICB) region was developed for the area near Long Beach, California. It combines controlled-source seismic reflection and refraction data collected during the 1994 Los Angeles Region Seismic Experiment (LARSE), multichannel seismic reflection data collected by the U.S. Geological Survey (1998-2000), and nearshore borehole stratigraphy. Based on lateral velocity contrasts and stratigraphic variation determined from borehole data, we are able to locate major faults such as the Cabrillo, Palos Verdes, THUMS-Huntington Beach, and Newport Inglewood fault zones, along with minor faults such as the slope fault, Avalon knoll, and several other yet unnamed faults. Catalog seismicity (1975-2002) plotted on our preferred velocity/structural model shows recent seismicity is located on 16 out of our 24 faults, providing evidence for continuing concern with respect to the existing seismic-hazard estimates.

Forward modeling of *P*-wave arrival times on the LARSE line 1 resulted in a four-layer model that better resolves the stratigraphy and geologic structures of the ICB and also provides tighter constraints on the upper-crustal velocity structure than previous modeling of the LARSE data. There is a correlation between the structural horizons identified in the reflection data with the velocity interfaces determined from forward modeling of refraction data. The strongest correlation is between the base of velocity layer 1 of the refraction model and the base of the planar sediment beneath the shelf and slope determined by the reflection model. Layers 2 and 3 of the velocity model loosely correlate with the diffractive crust layer, locally interpreted as Catalina Schist.

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Fisher et al, 2005, BSSA paper:
Neotectonics of the Offshore Oak Ridge Fault near Ventura, Southern California

Abstract:
The Oak Ridge fault is a large-offset, south-dipping reverse fault that forms the south boundary of the Ventura Basin in southern California. Previous research indicates that the Oak Ridge fault south of the town of Ventura has been inactive since 200-400 ka ago and that the fault tip is buried by ~1km of Quaternary sediment. However, very high-resolution and medium-resolution seismic reßection data presented here show a south-dipping fault, on strike with the Oak Ridge fault, that is truncated at 80 m depth by an unconformity that is probably at the base of late Pleistocene and Holocene sediment. Furthermore, if vertically aligned features in seismic reßection data are eroded remnants of fault scarps, then a subsidiary fault within the Oak Ridge system deforms the shallowest imaged sediment layers. We propose that this subsidiary fault has mainly left-slip offset. These observations of Holocene slip on the

Oak Ridge fault system suggest that revision of the earthquake hazard for the densely populated Santa Clara River valley and the Oxnard coastal plain may be needed.

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Bohannon et al, 2004, Tectonics paper:
Holocene to Pliocene tectonic evolution of the region offshore of the Los Angeles urban corridor, southern California

Abstract:
Quaternary tectonism in the coastal belt of the Los Angeles urban corridor is diverse. In this paper we report the results of studies of multibeam bathymetry and a network of seismic reflection profiles that have been aimed at deciphering the diverse tectonism and at evaluating the relevance of published explanations of the region's tectonic history. Rapid uplift, subsidence in basins, folds and thrusts, extensional faulting, and strike-slip faulting have all been active at one place or another throughout the Quaternary Period. The tectonic strain is reflected in the modern physiography at all scales. Los Angeles (LA) Basin has filled from a deep submarine basin to its present condition with sediment impounded behind a large sill formed behind uplifts near the present shoreline. Newport trough to the south-southeast of LA Basin also accumulated a large volume of sediment, but remained at midbathyal depths throughout the Period. There is little or no evidence of Quaternary extensional tectonism in either basin although as much as 6 km of subsidence, which mainly occurred by sagging, has been recorded in places since the middle Miocene. The uplifts include folded and thrust faulted terranes in the Palos Verdes Hills and the shelves of Santa Monica and San Pedro Bays. The uplifted areas have been shortened in a southwest-northeast direction by 10% or slightly more, and some folds are reflected in the bathymetry. Two large adjacent midbathyal basins, Santa Monica and San Pedro, show strong evidence of subsidence and slight west-northwest extension (10%) during the same time folding was taking place in the uplifts. The tectonic boundaries between uplifts and basins are folded, normal faulted, reverse-faulted, and strike-slip faulted depending on location. The rapid Quaternary uplift and subsidence, along with the filling of LA Basin, have produced a reversal in the regional physiography. In the early Pliocene, LA Basin was a submarine deep, Palos Verdes and the shelves comprised a northeast basin slope, and the present offshore basins and Catalina Island formed an emergent or shallowly submerged shelf. Since extensional, compressional, and lateral strains are all locally in evidence, simple notions that this part of southern California underwent a change from Miocene transtension to Quaternary transpression fail to explain our observations.

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Fisher et al, 2004, BSSA paper:
The Offshore Palos Verdes Fault Zone Near San Pedro, Southern California

Abstract:
High-resolution seismic-reflection data are combined with a variety of other geophysical and geological data to interpret the offshore structure and earthquake hazards of the San Pedro shelf, near Los Angeles, California. Prominent structures investigated include the Wilmington graben, the Palos Verdes fault zone, various faults below the west part of the San Pedro shelf and slope, and the deep-water San Pedro basin. The structure of the Palos Verdes fault zone changes markedly along strike southeastward across the San Pedro shelf and slope. Under the north part of the shelf, this fault zone includes several strands, with the main strand dipping west. Under the slope, the main fault strands exhibit normal separation and mostly dip east. To the southeast near Lasuen Knoll, the Palos Verdes fault zone locally is low angle, but elsewhere near this knoll, the fault dips steeply. Fresh seafloor scarps near Lasuen Knoll indicate recent fault movement. We explain the observed structural variation along the Palos Verdes fault zone as the result of changes in strike and fault geometry along a master right-lateral strike-slip fault at depth. Complicated movement along this deep fault zone is suggested by the possible wavecut terraces on Lasuen Knoll, which indicate subaerial exposure during the last sealevel lowstand and subsequent subsidence of the knoll. Modeling of aeromagnetic data indicates a large magnetic body under the west part of the San Pedro shelf and upper slope. We interpret this body to be thick basalt of probable Miocene age. This basalt mass appears to have affected the pattern of rock deformation, perhaps because the basalt was more competent during deformation than the sedimentary rocks that encased the basalt. West of the Palos Verdes fault zone, other northwest-striking faults deform the outer shelf and slope. Evidence for recent movement along these faults is equivocal, because we lack age dates on deformed or offset sediment.

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Greene et al, 2004, Canadian Geotech. paper:
Types and mechanisms of mass-wasting events that shape the California continental margin, USA

Abstract:
Multibeam bathymetric and seismic reflection profile data collected along selected parts of the California continental margin indicate that mass wasting is a significant process that has shaped the seafloor in the past and is presently active today. A variety of mass movement features mapped along the margin indicate that many different triggering mechanisms are at work to produce landslides. Some of these mass-wasting features cover extensive areas such as the 130

km^2 Goleta landslide in the Santa Barbara Basin a complex compound slide that has been produced from different types of movements and mechanisms occurring at different times throughout its failure history. Potential triggering mechanisms for submarine landslides include fluid flow, tectonic oversteepening of slopes, earthquakes, sediment and rock undercutting in submarine canyons, sediment accumulations reaching the angle of repose, and terrestrial input from subarial mass-movement features. Many of these slides appear capable of producing a tsunami.

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Lee et al, 2004, OTC paper:
Timing and Extent of Submarine Landslides in Southern California

Abstract:
Submarine landslide deposits occur in many locations throughout the Southern California Borderland and indicate the potential for continued slope failure. Future landslide activity may constitute a direct hazard to offshore facilities and an indirect hazard to coastal communities through landslide-induced tsunamis. Evaluating the risk of these hazards requires information on the scale of landslides that can occur and their recurrence rate. In this study, five mass transport complexes are described and volumes are estimated. Two of these complexes, the Palos Verdes debris avalanche and the Goleta slide contain the remains of many past events. Using dated cores and tracing stratigraphy to nearby ODP borings, we have estimated ages of the most recent failures in the five complexes and some of the ages of earlier failures in the Goleta slide. These results show that the volumes of the failed masses vary over several orders of magnitude with the largest of the masses having volumes on the order of 0.5 km^3. The ages of the failures range from a few hundred years to over 100,000 years. The two complexes that show repeated failure represent the largest landslides we evaluated and probably are the largest complexes on the mainland slope in Southern California. We estimate that these large failures on the mainland slope probably reoccur with an interval that has an order of magnitude of 10,000 years.

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Normark et al, 2004, S. Coast Geol. Soc. paper:
Late Quaternary sedimentation and deformation in Santa Monica and Catalina Basins, offshore southern California

Abstract:
The late Pleistocene history of sedimentation in Santa Monica Basin

has been documented using seismic-reflection profiles with ground truth provided by drilling at Ocean Drilling Program (ODP) Site 1015 on the basin floor. High-resolution deep-tow boomer profiles together with both multichannel and single-channel seismic-reflection data provide a framework of 15 key horizons in the upper 200 m of basin fill. The uppermost 12 key reflectors, many of which have been traced across much of the basin in the upper 100 m of sediment fill, have been correlated with the sequence cored at ODP Site 1015. Recently completed radiocarbon dating of samples from Site 1015 on the floor of Santa Monica Basin confirmed a Holocene rate of nearly 3 m/ky, which is the highest yet documented for southern California deep-water basins and only slightly lower than the peak rate during sea-level lowstand. The radiocarbon dates provide stratigraphic age control for the upper 12 key reflectors back to 32 ka at ~100 meters below the sea floor (mbsf). The dated stratigraphic sequence is used to evaluate deformation along the linear southwestern margin of Santa Monica Basin that is formed by the Santa Cruz-Catalina Ridge (SC-CR). In the northwestern corner of the basin, turbidite deposits of Hueneme Fan show local evidence for flexure of sediment horizons as young as 6 ka with minor fault offsets as recently as 1.5 ka. Larger scale anticlinal folding (~5 km width and >100 m of relief) of the basin fill is observed for strata older than ~65 ka. Farther south in the basin, however, much of the western as well as the southern margin of Santa Monica Basin shows limited evidence for tectonic activity affecting the basin fill during the last 100 ka.

The Santa Cruz-Catalina Ridge (SC-CR) separates Santa Monica Basin and the Catalina Basin to the west. There is limited seismic-reflection data for study of the sediment fill of Catalina Basin compared to Santa Monica Basin. The effects of sea level on sources for sediment entering the San Gabriel Canyon system on the Long Beach shelf control the largest sediment inputs to Catalina Basin. We use sediment accumulation rates determined from 20 recently obtained piston cores in San Pedro Basin, the Gulf of Santa Catalina, and San Diego Trough as an analog for the rate of sediment input to Catalina Basin. Deformation within the Catalina Basin fill during the latest (<300 ky) Quaternary is recorded by successive tilting and fault offsets of deposits primarily deposited during lowstands of sea level.

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Normark et al, 2004, Marine Geology paper:
Age of Palos Verdes submarine debris avalanche, southern California

Abstract:
The Palos Verdes debris avalanche is the largest, by volume, late Quaternary mass-wasted deposit recognized from the inner California Borderland basins. Early workers speculated that the

sediment failure giving rise to the deposit is young, taking place well after sea level reached its present position. A newly acquired, closely-spaced grid of high-resolution, deep-tow boomer profiles of the debris avalanche shows that the Palos Verdes debris avalanche fills a turbidite leveed channel that extends seaward from San Pedro Sea Valley, with the bulk of the avalanche deposit appearing to result from a single failure on the adjacent slope. Radiocarbon dates from piston-cored sediment samples acquired near the distal edge of the avalanche deposit indicate that the main failure took place about 7500 yr BP.

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Fisher et al, 2003, BSSA paper:
Geology of the Continental Margin Beneath Santa Monica Bay, Southern California, from Seismic-Reflection Data

Abstract:
We interpret seismic-reflection data, which were collected in Santa Monica Bay using a 70 in^3 generator-injector airgun, to show the geologic structure of the continental shelf and slope and of the deep-water, Santa Monica and San Pedro basins. The goal of this research is to investigate the earthquake hazard posed to urban areas by offshore faults. These data reveal that northwest of the Palos Verdes Peninsula, the Palos Verdes fault neither offsets the seafloor nor cuts through an undeformed sediment apron that postdates the last sea level rise. Other evidence indicates that this fault extends northwest beneath the shelf in the deep subsurface. Other major faults in the study area, such as the Dume and San Pedro Basin faults, were active recently, as indicated by an arched seafloor and offset shallow sediment. Rocks under the lower continental slope are deformed to differing degrees on opposite sides of Santa Monica Canyon. Northwest of this canyon, the continental slope is underlain by a little-deformed sediment apron; the main structures that deform this apron are two lower-slope anticlines that extend toward Point Dume and are cored by faults showing reverse or thrust separation. Southeast of Santa Monica Canyon, lower-slope rocks are deformed by a complex arrangement of strike-slip, normal and reverse faults. The San Pedro Escarpment rises abruptly along the southeast side of Santa Monica Canyon. Reverse faults and folds underpinning this escarpment steepen progressively southeastward. Locally they form flower structures and cut downward into basement rocks. These faults merge downward with the San Pedro Basin fault zone, which is nearly vertical and strike-slip. The escarpment and its attendant structures diverge from this strike-slip fault zone and extend for 60 km along the margin, separating the continental shelf from the deep-water basins. The deep-water Santa Monica Basin has large extent but is filled with only a thin (less than 1.5 km) section of what are probably post-Miocene rocks and sediment. Extrapolating ages obtained from ODP site 1015 indicates that this sedimentary cover is Quaternary, possibly no older than 600 ka. Folds and faults along the

base of the San Pedro escarpment began to form during 8 ka to 13 ka ago. Refraction-velocity data show that high-velocity rocks, probably the Catalina schist or Miocene volcanic rocks, underlie the sedimentary section. The San Pedro basin developed along a strike-slip fault, widens to the southeast, and is deformed by faults having apparent reverse separation and by folds near Redondo Canyon and the Palos Verdes Peninsula.

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Normark et al, 2002, Marine Geology paper:
Variability in form and growth of sediment waves on turbidite channel levees

Abstract:
Fine-grained sediment waves have been observed in many modern turbidite systems, generally restricted to the overbank depositional element. Sediment waves developed on six submarine fan systems are compared using high-resolution seismic-reflection profiles, sediment core samples (including ODP drilling), multibeam bathymetry, 3D seismic-reflection imaging (including examples of buried features), and direct measurements of turbidity currents that overflow their channels. These submarine fan examples extend over more than three orders of magnitude in physical scale. The presence or absence of sediment waves is not simply a matter of either the size of the turbidite channel-levee systems or the dominant initiation process for the turbidity currents that overflow the channels to form the wave fields. Both sediment-core data and seismic-reflection profiles document the upslope migration of the wave forms, with thicker and coarser beds deposited on the up-current flank of the waves. Some wave fields are orthogonal to channel trend and were initiated by large flows whose direction was controlled by upflow morphology, whereas fields subparallel to channel levees resulted from local spillover. In highly meandering systems, sediment waves may mimic meander planform. Larger sediment waves form on channel-levee systems with thicker overflow of turbidity currents, but available data indicate that sediment waves can be maintained during conditions of relatively thin overflow. Coarser-grained units in sediment waves are typically laminated and thin-bedded sand as much as several centimetres thick, but sand beds as thick as several tens of centimetres have been documented from both modem and buried systems. Current production of hydrocarbons from sediment-wave deposits suggests that it is important to develop criteria for recognising this overbank element in outcrop exposures and borehole data, where the wavelength of typical waves (several kilometres) generally exceeds outcrop scales and wave heights, which are reduced as a result of consolidation during burial, may be too subtle to recognise.

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Kennedy and Clarke, 2001, Calif. Geol. paper:
Late Quaternary faulting in San Diego Bay and hazard to the Coronado Bridge

Abstract:
Southern California is transected by numerous pervasive northwest-trending Quaternary fault zones. Together they form the broad transform-fault boundary along which the Pacific and North America crustal plates move irregularly past one another in a right-lateral sense at a rate of about 5 centimeters (cm)/year. The city of San Diego, which lies adjacent to the Pacific Ocean in the southwestern-most corner of California, is cut by one such fault zone-- the Rose Canyon Fault Zone. Oblique movement on faults within the Rose Canyon Fault Zone has, over time, led to the development of San Diego Bay, which separates the metropolitan area of San Diego from Coronado and North Island.

The Coronado Bridge spans San Diego Bay and connects the cities of San Diego and Coronado. The bridge is supported by 32 piers, 21 of which (piers 3-23) rest on footings anchored in the bay floor and rise above mean sea level to elevations ranging from 5 meters (m) at Coronado to more than 75 m in the main channel of the bay near San Diego. A principal concern regarding the bridge's earthquake safety involves its proximity, especially of its foundation piers, to potential shallow fault rupture. Our objectives in this study were 1) to identify and accurately locate Holocene faults (those younger than about 12,000 yrs); and 2) to determine the time of most recent movement on these faults and therefore their potential hazard to the Coronado Bridge.

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Piper and Normark, 2001, AAPG Bulletin paper:
Sandy fans --- from Amazon to Hueneme and beyond

Abstract:
Most submarine fans are supplied with both sand and mud, but these become segregated during transport, typically with the sand becoming concentrated in channels and channel-termination lobes. New data from high-resolution seismic reflection surveys and Deep Sea Drilling Project (DSDP)/Ocean Drilling Program (ODP) wells from a variety of fans allow a synthesis o the architecture of those submarine fans that have important sand deposits. By analyzing architectural elements, we can better understand issues important for petroleum geology, such as the reservoir properties of the sand bodies and their lateral continuity and vertical connectivity. Our analysis of fan architecture is based principally on the Amazon and Hueneme fans, generally perceived to be classic examples of muddy

and sandy systems, respectively. We recognize depositional elements, for example, channel deposits, levees, and lobes, from seismic reflection data and document sediment character in different elements from DSDP/ODP drill cores. We show the utility for petroleum geology of evaluating sandy and muddy elements rather than characterizing entire fans as sand rich or mud rich. We suggest that fan classification should include evaluation of source-sediment volumes and grain size, as well as the probable processes of turbidity-current initiation, because these factors control the character of fan elements and their response to changes in sea level, sediment supply, and autocyclic changes in channel pattern. Basin morphology, controlled by tectonics, influences overall geometry, as well as the balance between aggradation and progradation.

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Marlow et al, 2000, Geology paper:
Using high-resolution multibeam bathymetry to identify seafloor surface rupture along the Palos Verdes fault complex in offshore southern California

Abstract:
Recently acquired high-resolution multibeam bathymetric data reveal several linear traces that are the surficial expressions of seafloor rupture of Holocene faults on the upper continental slope southeast of the Palos Verdes Peninsula. High-resolution multichannel and boomer seismic-reflection profiles show that these linear ruptures are the surficial expressions of Holocene faults with vertical to steep dips. The most prominent fault on the multibeam bathymetry is about 10 km to the west of the mapped trace of the Palos Verdes fault and extends for at least 14 km between the shelf edge and the base of the continental slope. This fault is informally called the Avalon Knoll fault for the nearby geographic feature of that name. Seismic-reflection profiles show that the Avalon Knoll fault is part of a northwest–trending complex of faults and anticlinal uplifts that are evident as scarps and bathymetric highs on the multibeam bathymetry. This fault complex may extend onshore and contribute to the missing balance of Quaternary uplift determined for the Palos Verdes Hills and not accounted for by vertical uplift along the onshore Palos Verdes fault. We investigate the extent of the newly located offshore Avalon Knoll fault and use this mapped fault length to estimate likely minimum magnitudes for events along this fault.

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ten Brink et al, 2000, JGR paper:
Geophysical evidence for the evolution of the California Inner Continental Borderland as a metamorphic core complex

Abstract:
We use new seismic and gravity data collected during the 1994 Los Angeles Region Seismic Experiment (LARSE) to discuss the origin of the California Inner Continental Borderland (ICB) as an extended terrain possibly in a metamorphic core complex mode. The data provide detailed crustal structure of the Borderland and its transition to mainland southern California. Using tomographic inversion as well as traditional forward ray tracing to model the wide-angle seismic data, we find little or no sediments, low (²6.6 km/s) P wave velocity extending down to the crust-mantle boundary, and a thin crust (19 to 23 km thick). Coincident multichannel seismic reflection data show a reflective lower crust under Catalina Ridge. Contrary to other parts of coastal California, we do not find evidence for an underplated fossil oceanic layer at the base of the crust. Coincident gravity data suggest an abrupt increase in crustal thickness under the shelf edge, which represents the transition to the western Transverse Ranges. On the shelf the Palos Verdes Fault merges downward into a landward dipping surface which separates "basement" from low-velocity sediments, but interpretation of this surface as a detachment fault is inconclusive. The seismic velocity structure is interpreted to represent Catalina Schist rocks extending from top to bottom of the crust. This interpretation is compatible with a model for the origin of the ICB as an autochthonous formerly hot highly extended region that was filled with the exhumed metamorphic rocks. The basin and ridge topography and the protracted volcanism probably represent continued extension as a wide rift until ~13 m.y. ago. Subduction of the young and hot Monterey and Arguello microplates under the Continental Borderland, followed by rotation and translation of the western Transverse Ranges, may have provided the necessary thermomechanical conditions for this extension and crustal inflow.

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Piper et al, 1999, Sedimentology paper:
Outcrop-scale acoustic facies analysis and latest Quaternary development of Hueneme and Dume submarine fans, offshore California

Abstract:
The uppermost Quaternary deposits of the Hueneme and Dume submarine fans in the Santa Monica Basin have been investigated using a closed-spaced grid of boomer seismic-reflection profiles, which give vertical resolution of a few tens of centimetres with acoustic penetration to 50 m. Acoustic facies integrated with geometry define six architectural elements, some with discrete subelements that are of a scale that can be recognized in outcrops of ancient turbidite systems. In the Santa Monica Basin, the relationship of these elements to fan morphology, stratigraphy and sediment source is precisely known.

The width of upper Hueneme fan valley has been reduced from 5 km

since the last glacial maximum to 1 km at present by construction of laterally confined sandy levees within the main valley. The middle fan comprises three main subelements: thick sand deposits at the termination of the fan valley, low-gradient sandy lobes typically 5 km long and <10 m thick, and scoured lobes formed of alternating sand and mud beds with many erosional depressions. The site of thickest lobe sediment accumulation shifts through time, with each sand bed deposited in a previous bathymetric low (i.e. compensation cycles). The lower fan and basin plain consists of sheet-like alternations of sand and mud with shallow channels and lenses.

Variations in the rate of late Quaternary sea level rise initiated changes in sediment facies distribution. At lowstand, and during the approximately 11 ka stillstand in sea level, the Hueneme Fan was fed largely by hyperpycnal flow from the Santa Clara River delta, depositing high sediment waves on the right hand levee and thick sandy lobes on the middle fan. At highstand of sea level, most turbidity currents were generated by failure of silty prodelta muds. In contrast, the smaller Dume Fan was apparently always fed from littoral drift of sand through a single-canyon point source.

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Bohannon and Geist, 1998, GSA Bulletin paper:
Upper crustal structure and Neogene tectonic development of the California Continental Borderland

Abstract:
Multichannel seismic-reflection data, sonobuoy seismic-refraction data, and regional geology are used to define the upper crustal structure of the southern California continental borderland and to delineate the characteristics of the main lithotectonic belts of the region. The Catalina Schist belt is separated on its west side from the gently deformed Nicolas forearc belt by faults that have steep west dips and pronounced normal separations. On its east side the schist belt is bounded by a large detachment fault that dips gently to the east beneath the west edge of the Peninsular Ranges belt at the coastline near Oceanside. The Catalina Schist was uplifted from middle crustal depths and exposed during a major event of extensional tectonism that started in early Miocene time in conjunction with about 10° of clockwise rotation of the western Transverse Ranges belt. Part of the uplift of the Catalina Schist could have occurred on the detachment fault, but it is thought to have mostly occurred on the steep faults that bound the west edge of the schist belt. A large amount of uplift is required, and it probably involved strong footwall flexural deformation in the wake of the translating and rotating western Transverse Ranges and Nicolas forearc belts. Extension, accompanied by probable large amounts of right slip, continued in the borderland region during and after middle Miocene time. The later stage of extension was accompanied by rapid clockwise rotation of the western Transverse Ranges of at least

90°. Most of the borderland, including the belt of schist that was uplifted in early Miocene time, was further deformed into numerous basins and ridges during this stage of oblique extension. The primary driving force for the deformation is thought to have been derived from the rapid northwest motion of the Pacific plate after it had become coupled to the Farallon plate system, which had previously been subducted beneath the borderland.

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Normark et al, 1998, Sedimentology paper:
Sea level controls on the textural characteristics and depositional architecture of the Hueneme and associated submarine fan systems, Santa Monica Basin, California

Abstract:
Hueneme and Dume submarine fans in Santa Monica Basin consist of sandy channel and muddy levee facies on the upper fan, lenticular sand sheets on the middle fan, and thinly bedded turbidite and hemipelagic facies elsewhere. Fifteen widely correlatable key seismic reflections in high-resolution airgun and deep-towed boomer profiles subdivide the fan and basin deposits into time-slices that show different thickness and seismic-facies distributions, inferred to result from changes in Quaternary sea level and sediment supply. At times of low sea level, highly efficient turbidity currents generated by hyperpycnal flows or sediment failures at river deltas carry sand well out onto the middle-fan area. Thick, muddy flows formed rapidly prograding high levees mainly on the western (right-hand) side of three valleys that fed Hueneme fan at different times; the most recently active of the lowstand fan valleys, Hueneme fan valley, now heads in Hueneme Canyon. At times of high sea level, fans receive sand from submarine canyons that intercept littoral-drift cells and mixed sediment from earthquake-triggered slumps. Turbidity currents are confined to thalweg channels in fan valleys and to steep, small, basin-margin fans like Dume fan. Mud is effectively separated from sand at high sea level and moves basinward across the shelf in plumes and in storm-generated lutite flows, contributing to a basin-floor blanket that is locally thicker than contemporary fan deposits and that onlaps older fans at the basin margin. The infilling of Santa Monica Basin has involved both fan and basin-floor aggradation accompanied by landward and basinward facies shifts. Progradation was restricted to the downslope growth of high muddy levees and the periodic basinward advance of the toe of the steeper and sandier Dume fan. Although the region is tectonically active, major sedimentation changes can be related to eustatic sea-level changes. The primary controls on facies shifts and fan growth appear to be an interplay of texture of source sediment, the efficiency with which turbidity currents transport sand, and the effects of delta distributary switching, all of which reflect sea-level changes.

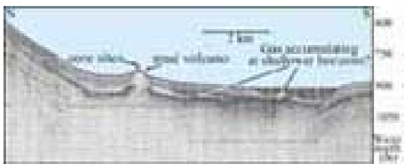
Methane Hydrate

In addition to naturally occurring oil and gas seeps in the Santa Barbara Channel, north of Los Angeles, methane and hydrogen sulfide gases are actively discharging at the crest of a mud volcano only 24 kilometers west-southwest of Redondo Beach, California. The mud volcano is 30m high and its top is about the size of a football field. It formed as gas-charged sediment from depth squeezed up to the sea floor, probably along an active fault at the edge of the offshore Santa Monica Basin. The top of the mud volcano is about 800m below the sea surface, and at this depth the water pressure is 80 times the atmospheric pressure at sea level. As a result, water and methane gas at this pressure "freezes" to form what is termed a methane hydrate. The hydrate ice becomes incorporated in the surrounding ocean-floor sediment. The photo of a cross-section of a sediment core (see below) reveals the rapidly disassociating chunk of hydrate (methane ice).

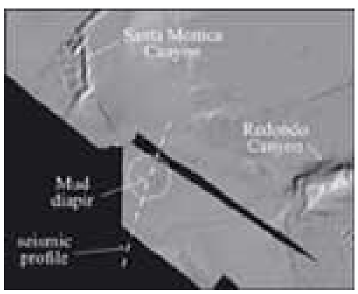
Photo of the bottom of the deepest section (212 cm below the sea floor) of the discovery piston core showing the methane hydrate (white chunks) as it disassociated. Sediment pushed out of the liner by degassing of the core section is caught in the plastic bag. The core liner was cut in 50 cm sections on deck, but by the time this lowermost section was finished degassing, much of the mud was extruded leaving carbonate clasts behind.

When the core was opened on the deck of the research ship, the intense "rotten egg" smell of the hydrogen sulfide, which is incorporated in the hydrate ice along with the methane, together with the hissing and sizzling sounds of the vaporizing gas, made everyone scramble to make sure there were no sources that might ignite the gases, all the while gasping for fresh air. The map below shows where the mud volcano lies in relation to the Southern California coast, and the seismic-reflection profile gives an idea of its size and shape.

The core sample is the only proven occurrence of methane gas hydrate between the continental shelf off Northern California and the Gulf of California, Mexico.



Seismic profile on the left collected in 1992. Click on image for further details.



Shaded-relief image from multibeam sonar showing the mud volcano as a small circular bump on the sea floor. Click on image to the left for further details.

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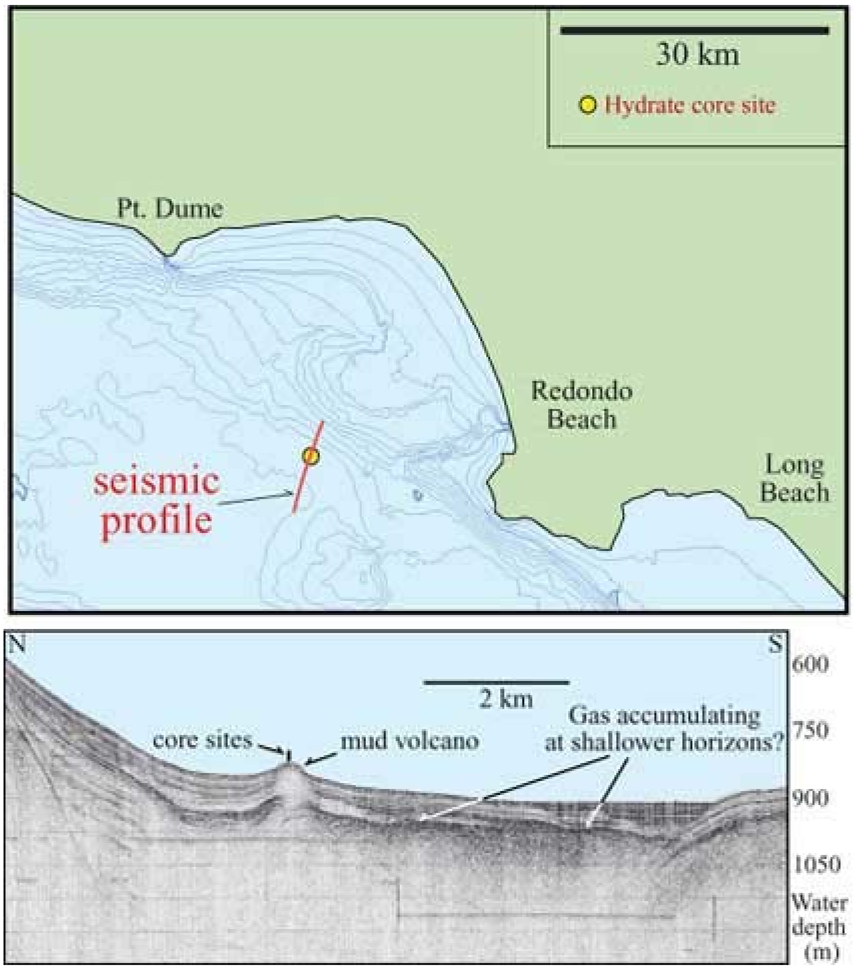
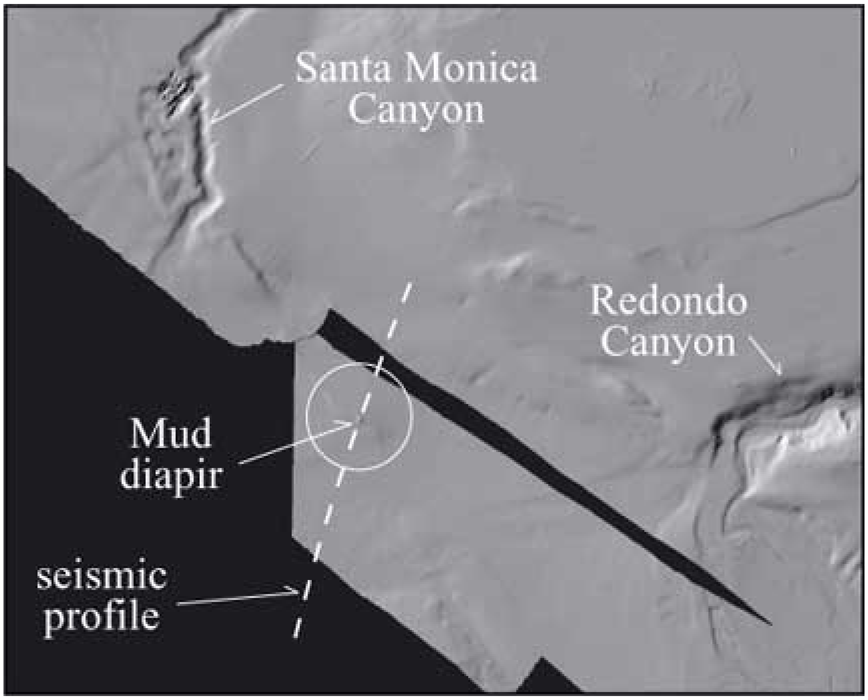
Profile


30 km
Hydrate core site
Pt. Dume
Redondo
Beach
Long
Beach
seismic
profile
N
S
2 km
core sites
mud volcano
Gas accumulating
at shallower horizons?
600
750
900
1050
Water
depth
(m)

Shaded Relief



Shaded-relief image from multibeam sonar showing the mud volcano as a small circular bump on the sea floor. White circle also encloses two small compressional ridges that flank the mud volcano to the northwest and southeast.

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