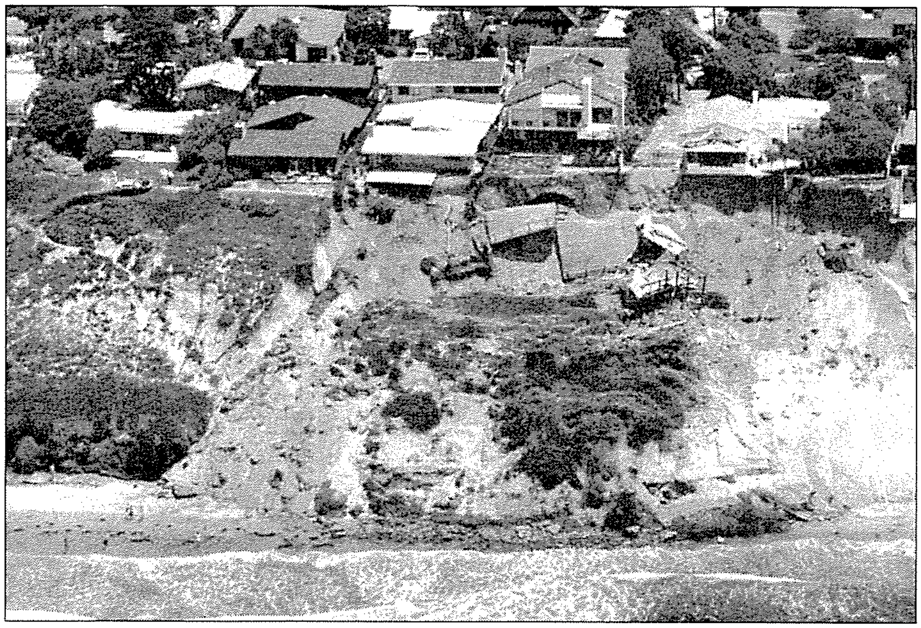
Coastal Processes and Engineering Geology of San Diego, California

SAN DIEGO ASSOCIATION OF GEOLOGISTS

Coastal Processes and Engineering Geology of San Diego, California



Coastal landslide, Leucadia, California, June 2, 1996. Photo by Michael W. Hart (Kendall L. Sherrod, pilot).

Coastal Processes and Engineering Geology of San Diego, California

Editor:

Robert C. Stroh
San Diego Association of Geologists
P.O. Box 191126
San Diego, CA 92159-1126

SAN DIEGO ASSOCIATION OF GEOLOGISTS
www.sandiegogeologists.org

Distributed by Sunbelt Publications
www.sunbeltbooks.com

2001

Coastal Processes and Engineering Geology of San Diego, California

First edition 2001.

Edited by Robert C. Stroh
Book design and composition by W.G. Hample & Associates
Project management by Lowell Lindsay
Printed in the United States of America

Please direct comments and inquiries to:

SDAG
P.O. Box 191126
San Diego, California 92159-1126
www.sandiegogeologists.org/

or the distributor:

Sunbelt Publications
1250 Fayette St.
El Cajon, California 92020
(619) 258-4911, fax: (619) 258-4916
www.sunbeltbooks.com
mail@sunbeltpub.com

07 5 4 3 2

Library of Congress Cataloging-in-Publication Data

Coastal processes and engineering geology of San Diego, California /
editor, Robert C. Stroh -- 1st ed.
p. cm.
ISBN 0-916251-58-6
1. Coast changes--California--San Diego Region. 2. Engineering
geology--California--San Diego Region. I. Stroh, Robert C.
GB458.8.C63 2003
551.45'7'09794985--dc22
2003019312

Front and rear cover: Torrey Pines Cliffs.
Field trip and cover photos by Robert C. Stroh unless noted.
Technical paper photos by authors unless noted.

Contents

SDAG 2001 Officers vi
SDAG 2001 Corporate Sponsors vii

SDAG List of Publications viii

Introduction and Acknowledgments ix
Robert C. Stroh

ANNUAL FIELD TRIP ROAD LOG 1

Day No. 1 Tour — San Ysidro to Lake Jennings 2
Day No. 2 Tour — Lake Jennings to Sunset Cliffs 8

TECHNICAL PAPERS 13

Coastal Landsliding — Leucadia, California 13
William J. Elliott

San Diego Municipal Code: Land Development Code — Coastal Bluffs and Beaches Guidelines 31
The City of San Diego

Conflict in the California Coastal Act: Sand and Seawalls 41
Todd T. Cardiff

Sand Beaches vs. Seawalls — A Geomorphic Perspective 55
Walter F. Crampton

National Marine Fisheries Service Center — Effects of Tectonics and Faulting on Coastal Erosion 65
Walter F. Crampton and Braven R. Smillie

Pump Station 35, Assessing Coastal Stability — A Geomorphic Perspective 75
Gregory A. Spaulding and Walter F. Crampton

The Otay Mesa Lateral Spread 93
Chad W. Warren, W. Lee Vanderhurst, Michael W. Hart

Comparison of Field Descriptions and Quantitative Grain Size Analysis of Common San Diego Stratigraphic Units 105
Derral Van Winkle

Geotechnical Characterization for a 34-Mile-Long Tunnel through the Peninsular Ranges of San Diego County, California 123
M. E. Schmoll, D. J. Young, and D. L. Schug

Geologic Formations of western San Diego County 139
Jeffrey D. Brown

San Diego Association of Geologists

2001 Officers

President
Barbara B. Birnbaum
Consultant

Vice President
Robert C. Stroh
Kleinfelder, Inc.

Secretary
Patrick Brooks
Anteon Corp.

Treasurer
Monte Murbach
Murbach Geotech

Publications Manager
Lowell Lindsay
Sunbelt Publications

Webmaster
Carolyn Glockhoff

SAN DIEGO ASSOCIATION OF GEOLOGISTS
www.sandiegogeologists.org

San Diego Association of Geologists

2001 Corporate Sponsors

Patrick L. Abbott
Bayhawk Ales
Joe Corones
Cynthia Renee Corporation
Earth Consultants International
Dr. Margaret R. Eggers, CHG
William J. Elliot
Environmental Business Solutions
First National Oil, Inc.
Katherine Freese
Geocon, Inc.
Geotechnics, Inc.
Group Delta Consultants, Inc.
Hargis + Associates, Inc.
Rob Hawk, City of San Diego
HP Labs (TEG/Mobile One)
Barbara J. Johnston
Kleinfelder, Inc.
Lejman Geotechnical Group, Inc.
Murbach Geotech
Ninyo & Moore
Donald R. Sorben, R.G.
Southland Geotechnical Consultants
David and Jan Steller
Anne Sturz
Sunbelt Publications — Lowell Lindsay
Testing Engineers — San Diego
Carole L. Ziegler

The generosity of these corporate sponsors allows SDAG to continue to keep membership dues low, sponsor reduced rates for students, produce the monthly newsletter, purchase supplies and host the annual picnic and field trip, produce our geologic guidebooks, and provide scholarships to local geology students. To contact any of the above sponsors, please visit the SDAG website at http://www.sandiegogeologists.org as many of them have direct links.

San Diego Association of Geologists

List of Publications — June 1, 2001

Each of these volumes was prepared in conjunction with the annual field trip and includes self-guiding road logs. Each generally has a combination of papers which discuss general and regional background as well as local topics and research. Many papers are published herein for the first time. Most include maps, diagrams, photos, and a bibliography for further research.

Title	Editor	ISBN, ID#	Specifications	Year	Price each
Geology and Enology of the Temecula Valley, Riverside County This area has an ideal combination of well-drained soils and micro-climate which will interest the geologist, the tourist, and the wine enthusiast. Three sections on Wine and History; Geology; and Road Logs include the Santa Rosa Plateau, Vail Lake, and 1-15 to San Diego.	Barbara Birnbaum, Kerry Cato	0-916251-55-1	190 pgs., 6x9, color maps	2000	$15.00
Water for Southern California: Water Resources Development An historical overview and technical reports for several major projects provide insight to California's most valuable natural resource. Field trips through three counties include the Inland Feeder Project, Diamond Valley Reservoir, Olivenhain Dam, and Padre Dam.	Greg T. Cranham	0-916251-51-9	144 pgs., 6x9	1999	$15.00
Geology and Geothermal Resources of the Imperial and Mexicali Valleys Technical reports and geology road logs along major highways on both sides of the international border provide an introduction to the region with timely emphasis on many scientific and engineering issues associated with renewable energy development.	Lowell Lindsay	0-916251-50-0	192 pgs., 6x9	1998	$15.00
Santa Cruz Island Geology The northern Channel Islands form an east-west mountain chain on the SW border of the Transverse Ranges. Text, maps, and diagrams reveal the geologic story of much of this island and the California bight including the origin of San Diego/Poway cobbles on SW Santa Cruz.	Werner Landry, James Boles	SDAG97	128 pgs., 6x9, color photos	1997	$15.00
Paleontology and Geology of Anza-Borrego Desert State Park A regional overview and ten reports emphasize the fossil history of one of the most complete Mio-Pleistocene sequences in North America. The two mostly 4WD field trips are: Ocotillo to Split Mountain via the Carrizo Badlands; Borrego Springs to the Calcite Mine Scenic Area via Fonts Point. Co-bound vol. 2 includes a geologic and paleontology reference list from 1855 to 1995.	Paul Remeika, Anne Sturz	0-916251-48-9	240 pgs., 8.5x11	1995	$15.00
Geology and Natural History, USMC Camp Pendleton While focused on this 125,000-acre base/environmental preserve, most topics are of general interest including: Luiseño Indians and Spanish contact; endangered coastal bird species; north coastal San Diego geology; local water resource issues.	Phillip S. Rosenberg	SDAG94		1994	$15.00
Natural History of the Coronado Islands, Baja California, Revisited Topics include history, archaeology, vegetation, vertebrate zoology, and geology with three fold-out maps detailing the geology of each of the three islands which lie 15 miles south of Pt. Loma.	Lyne Perry	SDAG92	86 pgs., 8.5x11	1992	$10.00
Environmental Perils, San Diego Region Field trip stops in Mission Valley, Mt. Soledad, Rose Canyon, Torrey Pines, La Jolla, and Pt. Loma address topics including earthquakes, landslides, seacliff erosion, and flood control.	Pat Abbott, Bill Elliott	SDAG91	256 pgs., 8.5x11	1991	$10.00
Geotechnical Engineering Case Histories in S.D. County While liquefaction, subsidence, and soil problems are major challenges for structural development, there are solutions and remedies as exemplified herein.	John H. Hoobs	SDAG90		1990	$10.00
Seismic Risk in the San Diego Region — SCEPP/USGS Workshop Proceedings Papers address issues of seismology and faulting, especially Rose Canyon; the field trip focuses on fault features from La Jolla, U.S.A. to Ensenada, Mexico.	Sue Tanges, Glenn Roquemore	SDAG89		1989	$10.00
Landslides in Crystalline Basement Terrain — San Diego and Riverside Counties The field trip is SDSU to Ocotillo via 1-8, Hwy. S-2 to Warner Springs, Hwy. 76 to Pala, I-15 from Temecula to Welk Resort. Topics include Goat Canyon landslide in ABDSP.	James R. Evans	SDAG88		1988	$10.00

Introduction and Acknowledgments

The San Diego Association of Geologists is pleased to present this field trip and guidebook. This volume presents an annotated road log and research papers discussing topics covered during the field trip along with other topics, both new and old, that are considered of interest to the geologic community.

Numerous colleagues have contributed to this field trip and the associated guidebook. In particular, I relied on several key persons for the successfulness of the field trip. They donated much of their personal time and effort toward making this trip a fun and educational excursion into San Diego's local geology.

Mike Hart, CEG, for giving the grand tour of San Ysidro landslides that can be classified as "classic" examples worthy of a geology textbook, and for his personal guidance and advice along the way.

Lee Vanderhurst, CEG (Geotechnics, Inc.) and Alan Pace, CEG (Golder & Associates) for the tour of the Otay Landfill and their discussion regarding the Otay Lateral Spread. Alan Pace also provided us access and an informative discussion at SDSU regarding the Mission Valley East Light Rail Transit Project. Lee Vanderhurst also led the stop at Santaluz Development, and provided an interesting discussion for the group regarding new interpretations of the geology in that area.

Pete Rutledge, Gary McCall and Les Stark for the tour of the Otay Rock Mountain Quarry. The opportunity to stand in the huge bucket of a loader at the stop could not be resisted.

David Schug, CEG (URS) for the excellent dinner presentation and slide show at the Lake Jennings Campground.

Walter Crampton, RGE (Terracosta Consulting) and Ronald Flick, Ph.D. (Scripps Institute of Oceanography) for their presentation at the end of Scripps Pier. A more appropriate venue to discuss the San Diego coastline and coastal processes could not have been found elsewhere.

Rob Hawk, CEG (City of San Diego, Development Services) for his discussion of the City's Land Development Code for Coastal Bluffs and Beaches.

Monte Murbach and Diane Murbach for setting up the incredibly tasty lunch sandwich buffet both days, and Barbara Birnbaum and Pat Brooks for their assistance and advice in the planning of the event.

September 11, 2001,
is a day we will not forget.
I would like to think that
our participation in this field trip
provided a bit of relief and distraction
during our time of great sorrow.

Robert C. Stroh, CEG
September 2001

Scripps Pier with U.S. flag. Photo by Lisa Guertin

2001 ANNUAL FIELD TRIP ROAD LOG
SEPTEMBER 15 & 16

Field Trip Coordinator: ***Robert C. Stroh***

FIELD TRIP INTRODUCTION

The 2001 San Diego Association of Geologists (SDAG) field trip will revisit San Diego geology. The planned stops will cover a variety of subjects, ranging from world-class landslide deposits in San Ysidro, to newly recognized lateral spread deposits in the Otay area of San Diego. The field trip will visit the Otay Rock Mountain Quarry facility and the Mission Valley East Railway Transit project on the campus of San Diego State University. Other stops will include the newly graded Santaluz project located in the San Dieguito Valley watershed to the east of Rancho Santa Fe, and two coastal stops, the first at Scripps Pier and the other at Sunset Cliffs.

The purpose of this road log is to guide you to our first stop and the following stops of the field trip (see map on this page). This road log includes driving directions between the stops along with approximate mileages, and a summary of each planned stop.

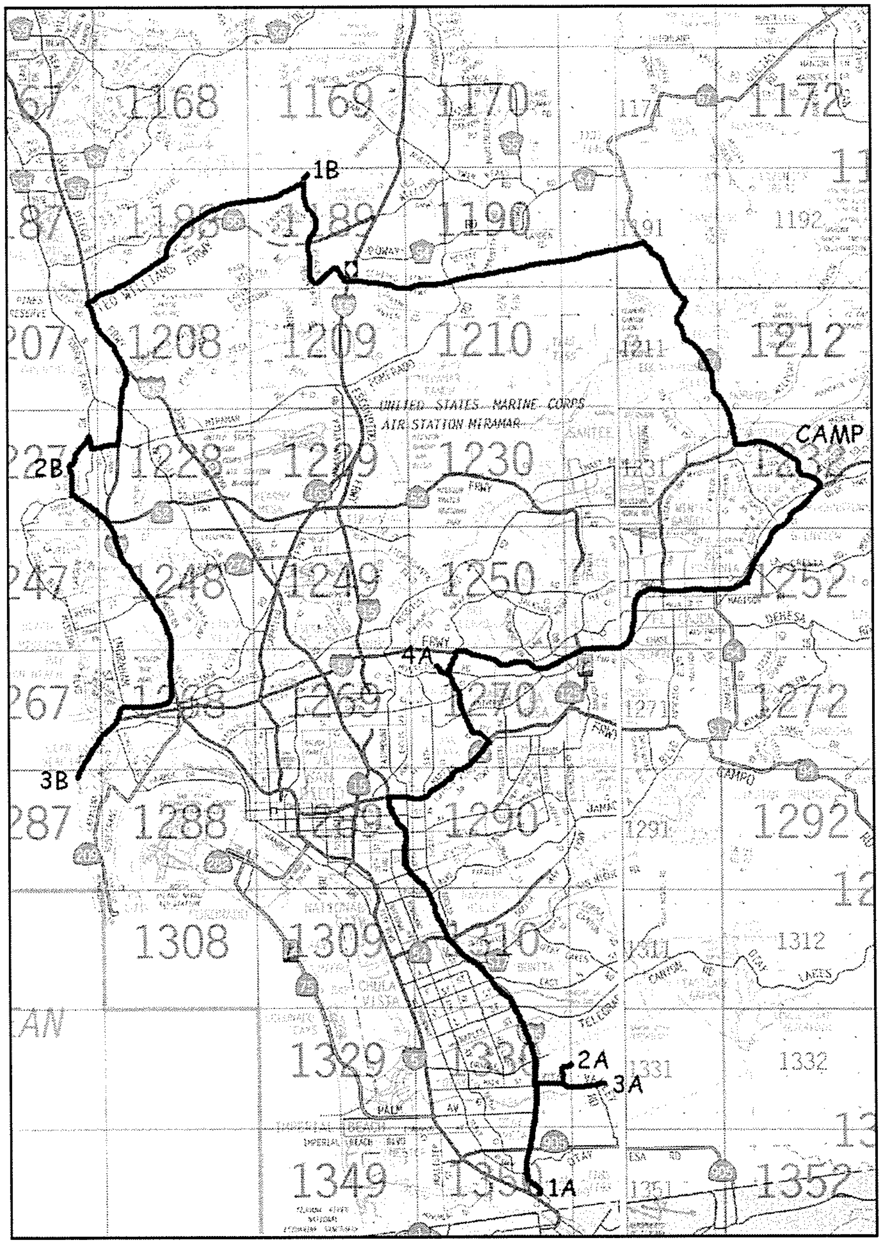
ITINERARY

Day No. 1
San Ysidro to Lake Jennings

Check in at San Ysidro (8:00-9:00); OJ, hot coffee, and bagels supplied by SDAG.

Stop 1A	San Ysidro Landslides — 5 stops (~9:00-11:00); Lunch (~11:00-12:00) — sandwich buffet on the Rim of San Ysidro
Stop 2A	Otay Landfill Lateral Spread Exposure (~12:30-2:00)
Stop 3A	Rock Mountain Quarry Tour (~2:30-3:30)
Stop 4A	SDSU Trolley Tunnel Project Tour (~4:00-5:00)

We arrive at Lake Jennings Campground (~5:30) for catered tri-tip and charbroiled chicken dinner (6:30-8:00). Short slide presentation is given after dinner — Lessons Learned, San Diego Tunneling (~8:00).



Map showing locations of 2001 Field Trip stops.

Day No. 2
Lake Jennings to Sunset Cliffs

Leave campground (~9:00) after having OJ, hot coffee, and bagels supplied by SDAG.

Stop 1B	Santaluz Development (9:30-11:00)
Stop 2B	Scripps Pier Viewpoint — The La Jolla coastline (~12:30-1:30)
	Lunch (~11:30-12:30) sandwich buffet at Scripps Pier
Stop 3B	Sunset Cliffs walking tour (~2:00-4:00)

Road Log

DAY NO. 1 TOUR
SAN YSIDRO TO LAKE JENNINGS

From San Diego starting at the interchange of I-15 and I-8, take I-15 south.

- Traveling south and up the hill out of Mission Valley, near-vertical road cuts on both sides of the freeway generally consist of the San Diego Formation at the upper elevations.
- Stay right on I-15 and then exit right onto southbound I-805.
- Exit San Ysidro Boulevard and turn left at the end of the off-ramp.
- Make a right turn off San Ysidro Boulevard onto Louisiana Avenue and into the parking lot of Longs Drug Store — the registration area.
- Make a left onto San Ysidro Boulevard.
- Make an immediate right onto Bolton Hall Road.
- Make a right onto East Beyer Boulevard.
- Make the first left then an immediate left.
- Make a right up and over the railroad tracks.
- Head up the dirt road and hill toward the top of the mesa.

FIELD TRIP STOP 1A
LANDSLIDES OF THE SAN YSIDRO AREA

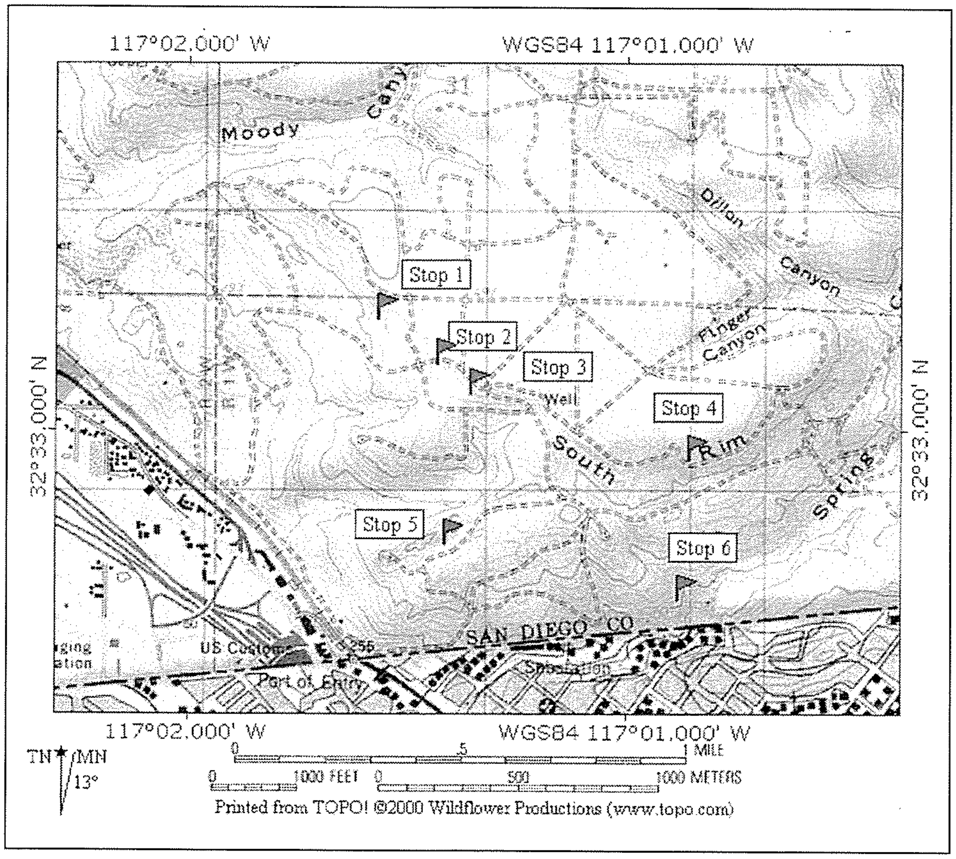
(Consists of 6 Stops total)

Stop Leader:
Mike Hart, Consultant
P.O. Box 261227
San Diego, California 92196
(858) 578-4672

Stop Overview by
Mike Hart

Introduction

Landsliding in San Ysidro was first described by Dennis Hannan (1970) for his Senior Thesis at San Diego State University and was the subject of the first official field trip of the San Diego Association of Geologists (SDAG) in 1973. The first field trip participants stood at the same location we will visit for Stop 1A (see map on previous page), the crown of the San Ysidro Landslide . This landslide is a spectacular example of an ancient (or not so ancient) landslide that was unknown to the geologic community in 1973.



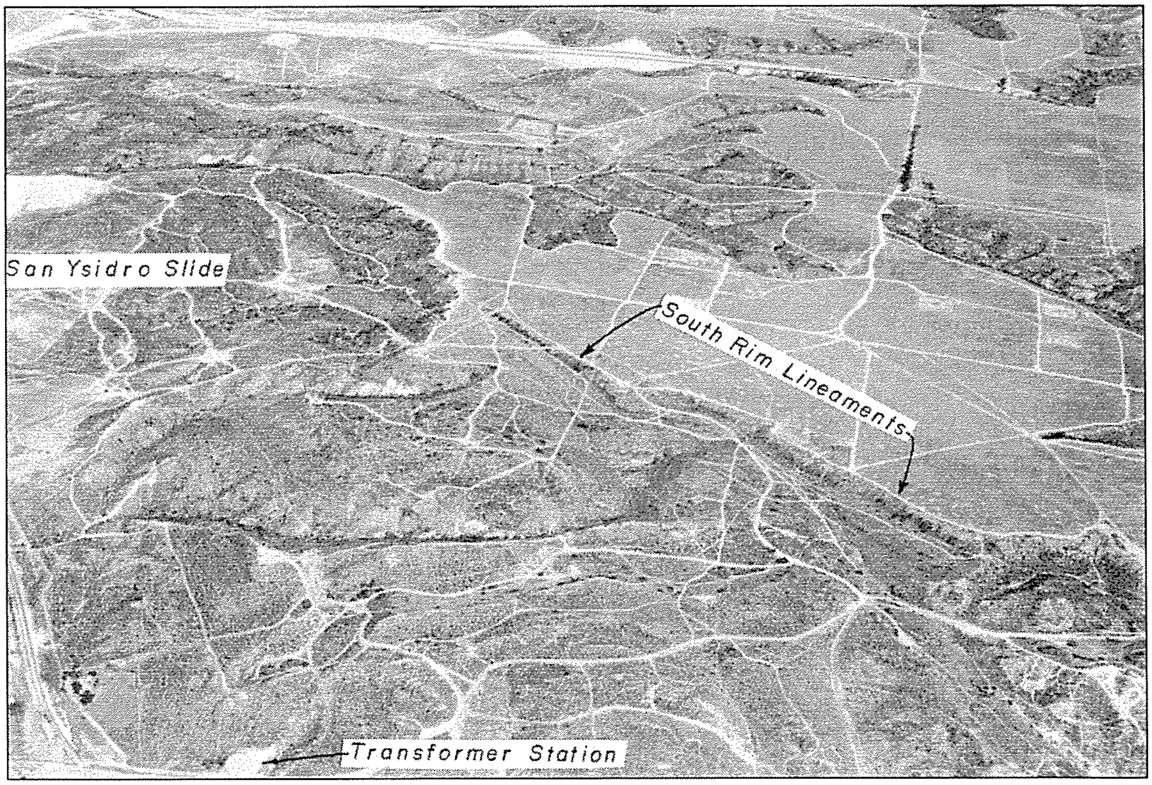
Landslides of San Ysidro, 2001 Field Trip route map.

As described in an earlier SDAG guidebook by Hart (1977), there were also two equally spectacular, very young-looking scarps — the South Rim Lineaments along the western edge of Otay Mesa (see photo below). Although only 1000 to 1500 feet in length and 25 to 30 feet high, their discovery created considerable excitement because the apparent faults displaced Pleistocene marine terrace deposits, which in 1973 would have been a rather unusual phenomenon for San Diego. The scarps were interpreted as fault scarps by Kennedy (1975) and were believed to represent the southernmost manifestation of the La Nacion fault system. There are several problems with this interpretation as discussed below.

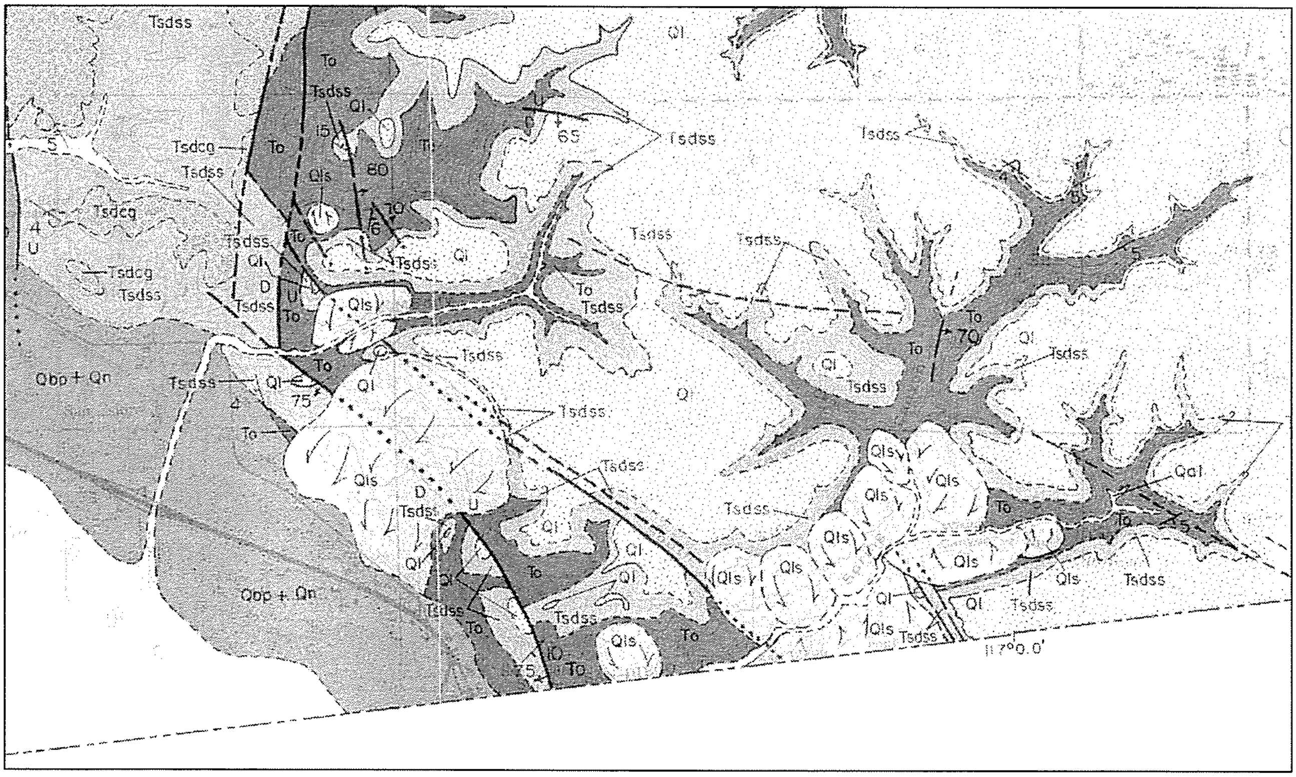
The problem with interpreting the features as fault scarps is that the westernmost scarp dies out in a scissors-like motion prior to reaching the vicinity of the San Ysidro Landslide. The eastern scarp also dies out where it curves abruptly to the west over a distance of several hundred feet and intersects the southern end of the western scarp. We will take a close look at the evidence for and against faulting during Stops 1 through 3.

At Stops 4 through 6 we will examine geomorphic and structural features related to the world-class landsliding along the border. These landslides have occurred within the Oligocene middle member of the Otay Formation and have secondarily involved sediments of the overlying San Diego and Lindavista formations. A geologic map of the area reproduced from Kennedy and Tan (1977) is shown on the next page.

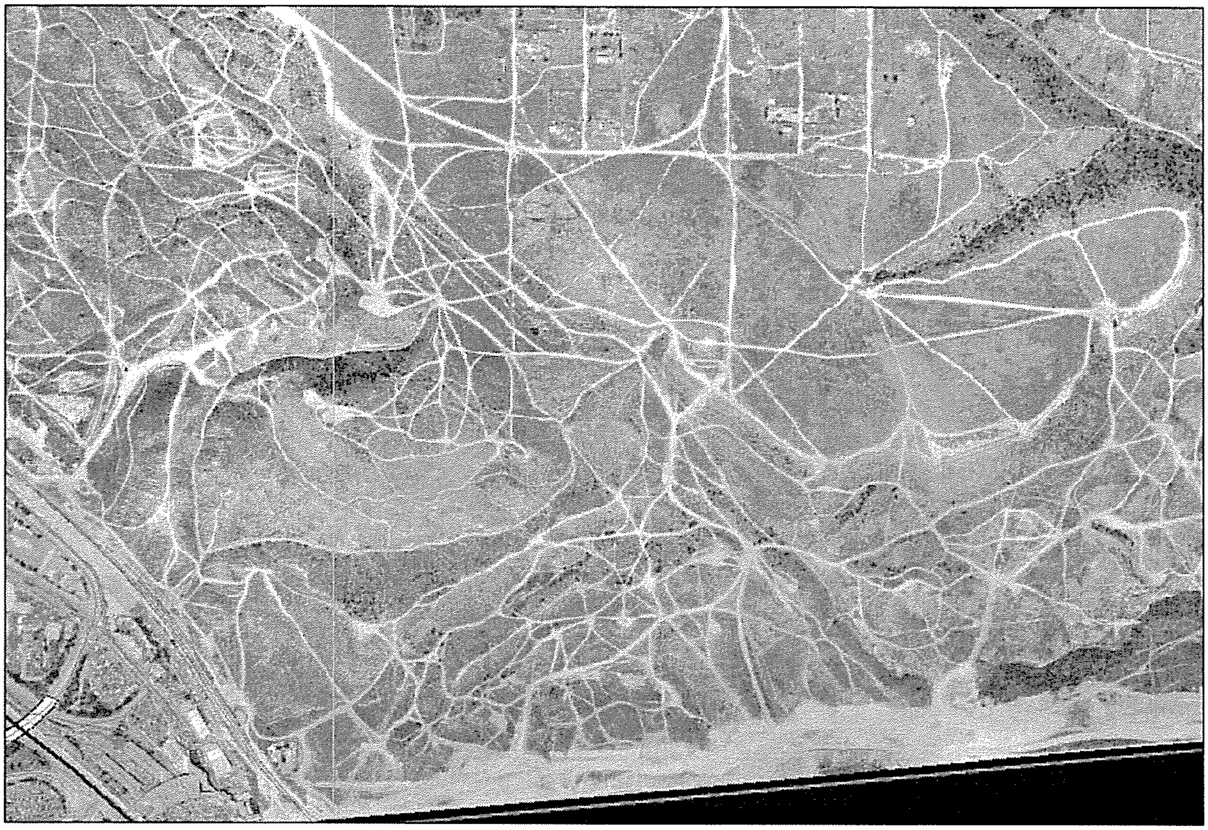
Stop 1 — San Ysidro Landslide Overlook. Approximately 3/4 mile wide and 3000 feet long, this landslide was mapped by Hannan (1970) for his Senior Thesis at SDSU. Below us to the west is an example of classic landslide morphology consisting of a series of tilted blocks capped by Lindavista Conglomerates and intervening graben zones. The well-defined slide morphology attests to the slide's relatively young age. The general lack of closed depressions within the slide mass suggests that this slide is younger than other landslides we will visit to the south that adjoin the U.S./Mexican Border. Recent drilling for geotechnical studies near the railroad tracks at the toe of the slide and immediately north of the four-story structure west of East Beyer Boulevard indicates that the base of the landslide is approximately 90 feet deep (near sea level) at this location and that nearly the entire business district of San Ysidro is underlain by the toe of the landslide.



Low-angle oblique looking northeast. The transformer station in the lower left corner of the photo is no longer present. Shear zones exposed in the cut slope at this location were identified as exposures of the San Ysidro fault by Kennedy (1975).



Geologic map of the Otay Mesa area by Kennedy and Tan (1977).



Aerial photograph of San Ysidro Field Trip Stop area, 1999.

Stop 2. This is a short walk, 200 to 300 feet in length, south of Stop 1 to view the northern end of the westernmost scarps identified as the South Rim Lineaments (see photo on page 3). As may be seen at this location the scarp/lineament dies out before reaching the San Ysidro Landslide. To the south, the scarp increases in height to approximately 25 feet before dying out near the north end of the eastern scarp. While the scarp is approximately on strike with the backscarp of the San Ysidro Landslide, the fact that it dies out before reaching the landslide is evidence that it is not likely related to faulting. Further evidence against faulting as the scarp-forming mechanism will be discussed as we proceed to the north end of the eastern scarp at Stop 3.

Stop 3. The south end of the westernmost lineament and an excellent view of the graben zone of the large landslide whose back scarp is likely represented by the eastern scarp visible to the south. From here we will make a short hike up the hill to the north end of the east lineament to examine geomorphic evidence of the scarp-forming mechanism. Most of the terrain to the southwest and west of the scarps is interpreted as landslide terrain. The base of the slide was recently identified during a geotechnical investigation for a project near the toe of the slide approximately 3500 feet west of here by Geocon, and lies near sea level. From here we will drive south along the base of the east scarp and then follow a jeep trail to the east over the scarp. Turning south at the top of the scarp we will follow the rim of Otay Mesa to a landslide overlook.

Stop 4. Landslide Overlook. From this point we can view classic landslide terrain that extends across the border into Mexico. The relatively small landslide directly below us to the west is a secondary failure that occurred at the headscarp of a much larger landslide that is more than half a mile wide and extends to the bottom of Spring Canyon, the large drainage that approximately parallels the border. From this point we will continue a short distance to the east to observe the extensive and relatively recent landslides that form both sides of Spring Canyon and its tributaries, and then turn back west to Stop 5 at the base of a large closed depression located at the head of another large slide.

Stop 5. A quick stop to view the bottom of a landslide graben zone represented by a large closed depression. This somewhat linear depression has approximately 20 feet of closed drainage and is typical of many of the landslides in this area. Shear zones exposed in a road cut near the toe of this landslide were interpreted as the San Ysidro fault by Kennedy (1975). If a fault is present in this area, it likely underlies the landslide at this location. Some of the major fault-like near-vertical shear zones that can be observed in the new Border Patrol road cut to the south may in fact be faults that have been offset by landsliding. From here we will turn east and head to the toe of the slide to view the basal slip surface and tilted bedding within the body of the slide.

Stop 6. This cut was recently made for the new all-weather Border Patrol road. Basal slip surfaces of the landslide whose pull-apart zone was visited at Stop 5 are visible approximately 15 feet above the road grade. The gouge zone is several inches thick and occurs within a gray bentonitic clay bed. A few feet in elevation above this slip surface, steeply rotated bedding may be observed — further evidence that this shear surface can be attributed to landsliding.

Basal slip surface. Photo by Carole Ziegler.

References

Hannan, D.L., 1970, Engineering Geology of a Landslide area at Otay Mesa, San Diego, and a Landslide in Fanita Corona Subdivision, Santee, California: unpublished Senor Research paper, California State University, San Diego.

Hart, M.W., 1977, Landsliding, an alternative to faulting in San Ysidro, California, in, Farrand, G.T., ed., *Geology of Southwestern San Diego County, California and Northwestern Baja California,* guidebook of the San Diego Association of Geologists.

Kennedy, M.P., 1975, *Character and Recency of faulting, San Diego Metropolitan area*, California, Calif. Div. Mines and Geology Special Report 123, pp. 1-33.

Kennedy, M.P., and Tan, S.S., 1977, Geology of National City, Imperial Beach and Otay Mesa Quadrangles, southern San Diego metropolitan area, California, Calif. Div. of Mines and Geology Map Sheet 29.

From the Longs Drug Store, leave the lot and make a left onto San Ysidro Boulevard.

- Make a right onto the I-805 on-ramp and travel north.
- Travel approximately 2.8 miles north and exit Main Street/Auto Park Drive and make a right on (Otay Valley Road) at the end of the off-ramp.
- Drive approximately 1 mile east and make a left on Maxwell Road.
- Drive to the top of the hill and make a left into the Employee Parking Area for the Otay Landfill.

FIELD TRIP STOP 2A
OTAY LANDFILL —
OBSERVATION OF OTAY LATERAL SPREAD

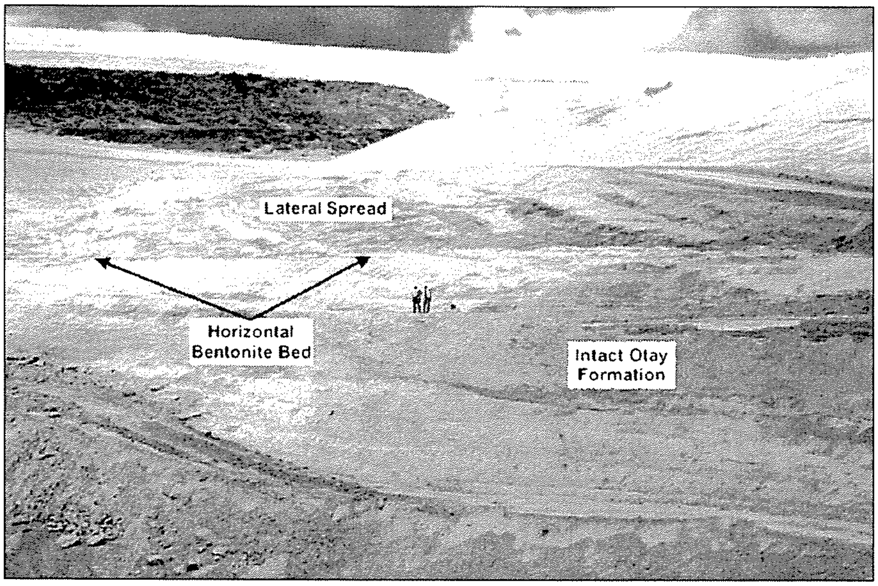
Stop Leaders:
Lee Vanderhurst
Alan Pace

Stop Overview by
Robert Stroh

Previous stockpiling of excavated materials for the Otay Landfill was located a few hundred feet above the basal rupture surface of the Otay Lateral Spread. Subsequently, following continued excavation within the landfill, a failure occurred along the basal rupture surface. From this vantage point, the well-developed basal rupture surface of a small portion of the (OLS) is clearly visible on the northern cut slope of the landfill.

From the Otay Landfill, leave down the hill and make a left onto Otay Valley Road.

- Drive approximately 0.8 mile and make a left onto Heritage.
- Park at the entrance gate to Hanson Chula Vista Plant.



Photograph of the contact between the intact Otay Formation and the Otay Lateral Spread, taken at the Otay Landfill (Locality 7). The flat-lying bentonite bed is clearly visible.

FIELD TRIP STOP 3A
ROCK MOUNTAIN QUARRY TOUR

Stop Leaders:
Pete Rutledge
Gary McCall and Les Stark

Stop Overview by
Pete Rutledge

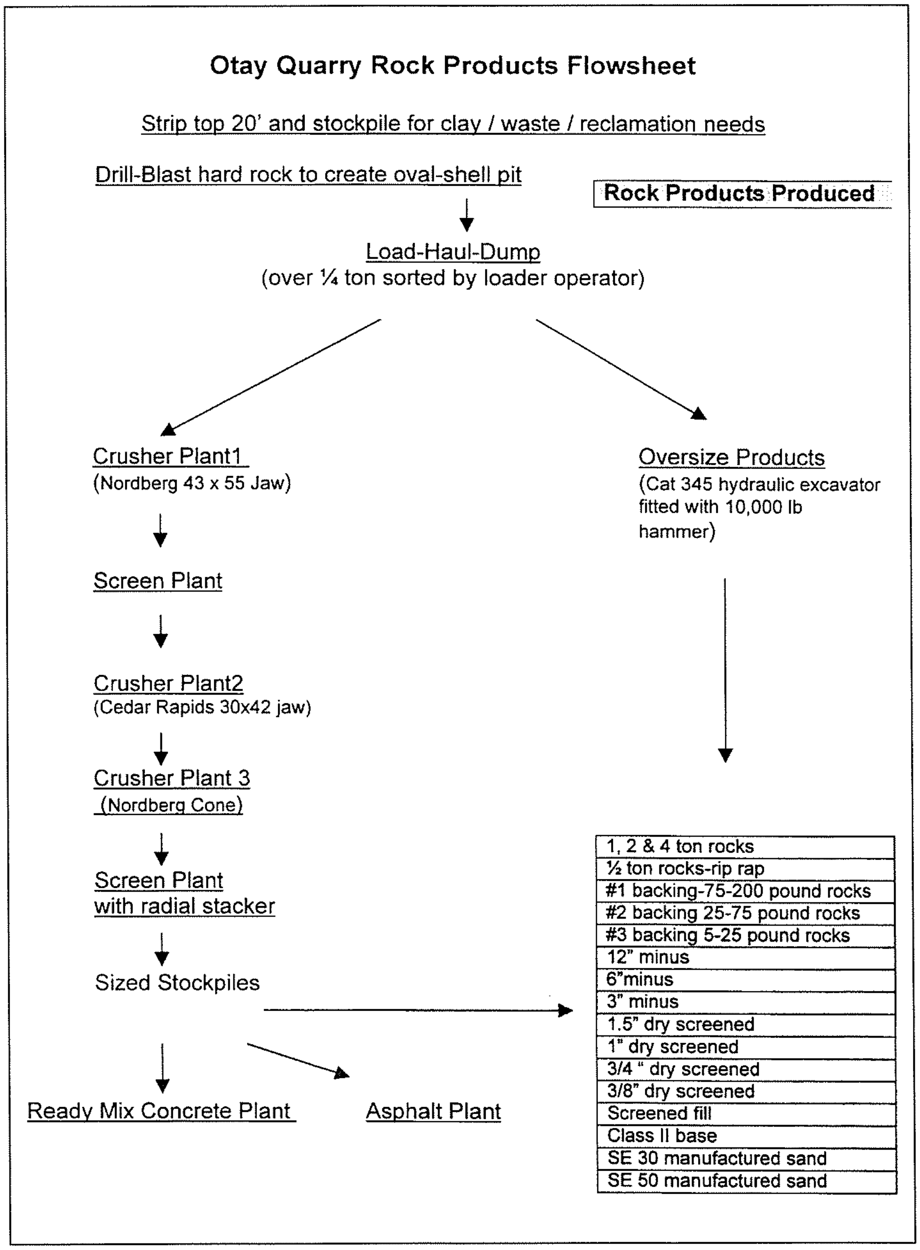
The Otay Rock Quarry is located within the Santiago Peak Volcanics-Metavolcanics (SPV), an ancient island-arc system containing volcanic flows and breccias ranging in composition from andesite to dacite and other. The SPV formation is approximately 170 miles long and 12 miles wide with the Santa Ana Canyon being the northerly boundary in Orange and Riverside counties and the Agua Blanca Fault in Baja being the southerly boundary (Walawender, 2000). The thickness of the SPV formation could easily exceed several hundred feet based upon the surface expression at the top of Rock Mountain minus estimated pit depths (Kennedy, 1977).

SPV rocks at the surface are weathered brown from oxidation within vertical fracture zones and joint sets. Fresh rock is located approximately 20 feet below the surface visible from inside the quarry. It is green-gray, contains white feldspar phenocrysts (1mm) in a crushed/altered aphanitic matrix making it difficult to determine its composition using a hand lens. Its strength is strong to very strong with its hardness being hard to very hard, nonfriable. These properties are very suitable for use as riprap and armor stone, the highest unit value products produced at the mine.

The flowchart on this page illustrates the processes involved in making saleable rock products and was developed with the help of Gary McCall, Otay Area Manager for Hanson Aggregates.

From the Quarry, drive west on Otay Valley Road and exit north onto the on-ramp of I-805.

- Approximately 9.1 miles north on I-805, exit right onto Route 94 East.
- Approximately 4.1 miles east, exit right onto the Broadway/College exit and take College Boulevard north.
- Drive approximately 2.7 miles north on College and make a left onto Montezuma; go two blocks to Campanile Drive, turn right, then go two blocks to Hardy Avenue and turn right.
- Park in the Catholic Newman Center parking area on 5855 Hardy Avenue.



FIELD TRIP STOP 4A
MISSION VALLEY EAST LIGHT RAIL TRANSIT; SDSU STOP

Stop Leader:
Alan Pace

Stop Overview by
Robert Stroh

The Metropolitan Transit Development Board (MTDB) is planning to build a 5.9-mile Mission Valley East Light Rail Transit (LRT) extension from east of Interstate 15 to the City of La Mesa, where it would connect to the existing East LRT Line (now referred to as the Orange Line) near Baltimore Drive. The line would serve four new stations at Grantville, San Diego State University (SDSU), Alvarado Medical Center, and 70th Street, as well as two existing stations at Mission San Diego and Grossmont Center. The proposed project would include elevated, at-grade, and tunnel portions and provide two park-and-ride lots and a new access road between Waring Road and the Grantville Station. The total project capital cost is $361 million (escalated dollars). The project is expected to serve approximately 10,800 daily riders in the corridor by 2015.

Project construction through SDSU is proposed to consist of a combination of cut and cover and excavated tunnel, using the New Australian Tunneling Method (NATM).

From SDSU make a left onto College Avenue and then continue north to east I-8.

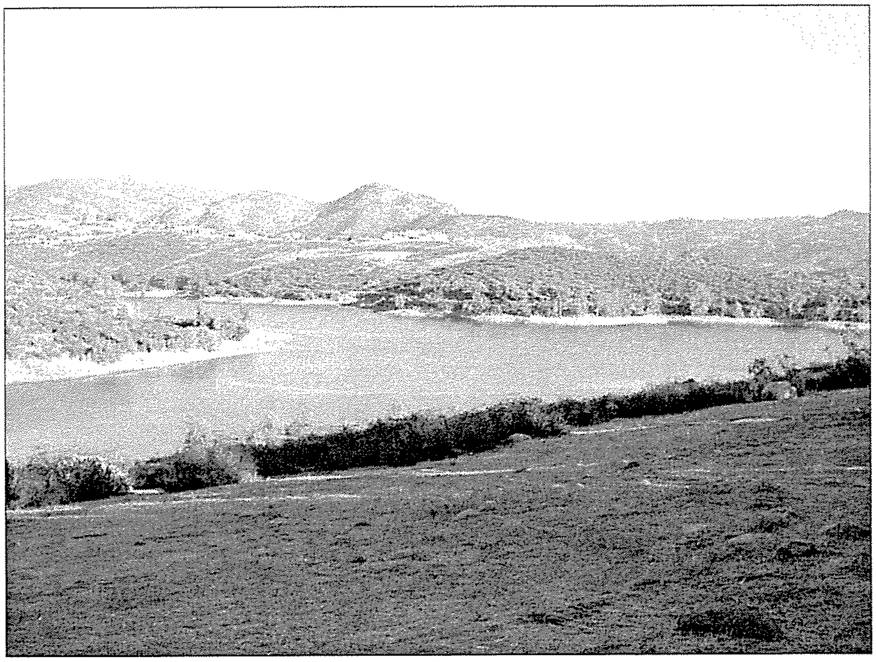
- Drive approximately 13.1 miles on eastbound I-8 and exit onto Lake Jennings Park Road.
- Make a left at the end of the off-ramp, continue approximately half a mile, make a "blind" right into Lake Jennings Regional Park then left toward the campground.

DAY NO. 2 TOUR
LAKE JENNINGS TO SUNSET CLIFFS

Leave Lake Jennings Campground.

- Make a right onto Lake Jennings Park Road.
- Continue approximately 2.1 miles and turn north onto Highway 67.
- Drive north on Highway 67 approximately 7.3 miles and then make a left onto Scripps Poway Parkway.
- Continue west for approximately 9.9 miles and turn right onto Black Mountain Road.
- Heading north on Black Mountain Road, drive approximately 3.5 miles and park where Black Mountain Road and Carmel Valley Road intersect at nearly a right angle.
- From this location the field trip stop is located on the top of the hill to the northwest of here.

Cut and cover portion of the SDSU tunnel alignment. Photo by Robert Stroh.



Lake Jennings Regional Park. Photo by Carole Ziegler.

FIELD TRIP STOP 1B
SANTALUZ

Stop Leader:
Lee Vanderhurst

Stop Overview by
Lee Vanderhurst

The development at the western toe of this hill is called Santaluz. The buried tank reservoir to the east is being constructed by Santaluz and The City of San Diego. We crossed the north-south trending San Diego Aqueduct located on the east side of the hill. To the north, south and west, you can see the dissected Clairemont Terrace underlain by Quaternary and Tertiary sedimentary rocks overlying a high-relief unconformity with Cretaceous sedimentary and Jurassic metamorphic and crystalline rocks. To the east is Black Mountain, which is composed of Santiago Peak Volcanics.

Grading in this area has revealed new data with regard to the Eocene stratigraphy and the Santiago Peak Volcanics.

1. Black Mountain acted as a barrier to the westward flowing Poway Group river system. As a result the Stadium Conglomerate is very thin or nonexistent is this area.
2. The Eocene La Jolla Group stratigraphy described by Kennedy (1975) has been disrupted by extensive lateral changes, likely also a result of the area being in the lee of Black Mountain. There are persistent tongues of Ardath Shale-like and Scripps Formation-like sediments out of place in the stratigraphic section. The vertical and horizontal interfingering make geologic mapping by formation very difficult.
3. Preliminary paleontological evidence suggests that the Mission Valley Formation in this area is much older than previously thought — Unita B Stage rather than Unita C Stage.
4. Gabbro/metavolcanic rock contacts are suggestive of cold intrusion or faulting. There is no stoping or baking along the contacts observed in the Black Mountain Ranch Reservoir excavation.
5. The metavolcanic and crystalline rocks have been metamorphosed following implacement. The only practical way of differentiating between the two rock types in the field is by grain size as there is very little color difference where the rock is fresh.
6. Arsenopyrite is so pervasive as an accessory mineral resulting from metamorphism and intrusive dikes that the spoil from the reservoir was tested for potential arsenic poison levels. The dikes noted in the reservoir excavation trend toward the old abandoned arsenic mine on the north side of Black Mountain.
7. As one walks up to the top of the hill, cobbles and gravels are noticeable on the ground surface. Current interpretation is that these cobbles and gravels are likely a terrace deposit that was previously unmapped. The nearest terrace deposit mapped in the surrounding area is located several hundred feet lower and is that of the Lindavista Formation.

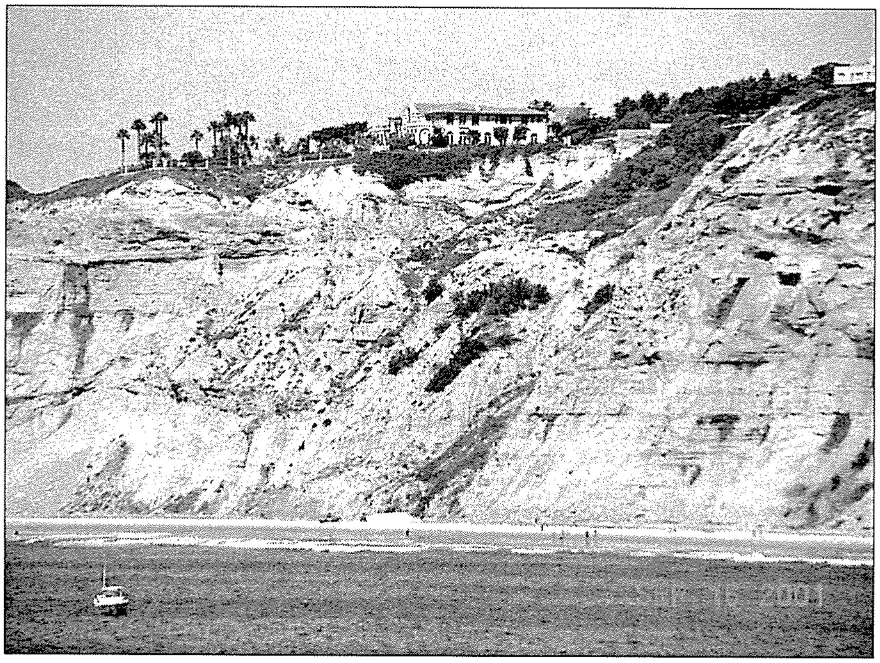
From Black Mountain Road, head west on the new Carmel Valley Road.

- Stay on Carmel Valley Road and at approximately 5.6 miles the road turns into highway.
- Exit to southbound I-5.
- Staying on I-5, continue south for approximately 4.7 miles to the La Jolla Village Drive Exit and exit right.

- Make a right and drive west on La Jolla Village Drive for approximately 1.4 miles then make a left onto La Jolla Shores Drive.
- Continue down La Jolla Shores Drive for approximately 1.1 miles; make a right at the Scripps Naga Entrance and make your way down the hill towards the pier.

FIELD TRIP STOP 2B
SCRIPPS PIER VANTAGE POINT

Stop Leaders:
Walt Crampton
Ron Flick



Seacliff failure north of Scripps Pier at Blacks Beach. Photo by Robert Hawk.

An Introduction to the Shoreline of San Diego
by Reinhard E. Flick, Ph.D.

California Department of Boating and Waterways
Integrative Oceanography Division
Scripps Institution of Oceanography
La Jolla, California 92093-0209

San Diego's Shore and beaches are the region's most important natural assets. As the SANDAG (1993) Shoreline Preservation Strategy says, "When we think of the region's positive image, we most often think of the climate and the shoreline." Beaches are by far the largest tourist attraction. But we also depend on them to buffer homes, businesses and public improvements from ocean waves and flooding. San Diego's coastline contains three littoral cells, or compartments, and offers a wide variety of beach types. But few beaches are wide enough to provide enough expanse for all beach uses, and to defend the back shore against storms. SANDAG estimates that the North County beaches between Oceanside and La Jolla are on average only about half as wide today as they need to be to protect back-shore development and to meet all the recreational demand. By 2040, some beaches will be only 10% or 20% as wide as they will need to be.

What are the factors that make our coast look the way it does? Why are some sand beaches in San Diego so wide and others so narrow? Where does the sand come from and where does it go? How will the coast look in the future? The four most important factors that determine what our beaches look like are: the geological setting, the sand supply, wave action, and human intervention. Geologically, this is a young coast. The major coastal landforms and scenic beauty of San Diego are closely related to the fault systems together with oscillating ocean levels caused by the ice ages. The sand supply to beaches can be narrowed down to four possible sources: offshore areas, the rivers, erosion of seacliffs, and placement by humans. Waves provide nearly all the energy that drives sand motion and coastal erosion in California. The most important sources of waves are swells from distant storms in the North or South Pacific, and seas generated by local wind and storm systems. Humans have had mixed effects on the San Diego coast, as they have on most coasts. Many activities have provided extra sand and stabilizing structures which widened the beaches, while others have interrupted the flow of sand and contributed to beach erosion.

Recent nourishment projects may be the beginning of beach restoration in San Diego, but not the end of beach erosion. Loss of beaches and damage to property will continue intermittently. Losses should be minor until the next really severe winter, when damage to many eroded areas could be catastrophic. Continued human intervention will be necessary if we want to restore and maintain San Diego's beaches. This will have to take the form of sand nourishment and some new or modified hard structures, like jetties, groins or breakwaters. The do-nothing approach is not the most economical. The region has made great progress understanding the problems, and incipient institutional arrangements for solving them now exist, mainly through the State, SANDAG, and the coastal cities. All we need to find is the consensus, the will, and the money.

From Scripps Pier head up the hill back to La Jolla Shores Drive and make a right heading south.

- Approximately 1 mile down the road, make a left onto Torrey Pines Road and head up the hill.
- Stay right and exit Torrey Pines Road onto southbound I-5.
- Exit I-5 south in approximately 5 miles onto Sea World Drive. Make a right at the end of the off-ramp.
- Continue on Sea World Drive for approximately 1.7 miles and staying left, take Sunset Boulevard.
- Continue on Sunset Boulevard over the San Diego River to the intersection of Sunset Boulevard and Osprey and Froude Street, approximately 2.9 miles.

FIELD TRIP STOP 3B
SUNSET CLIFFS

Stop Leaders:
Walt Crampton
Rob Hawk

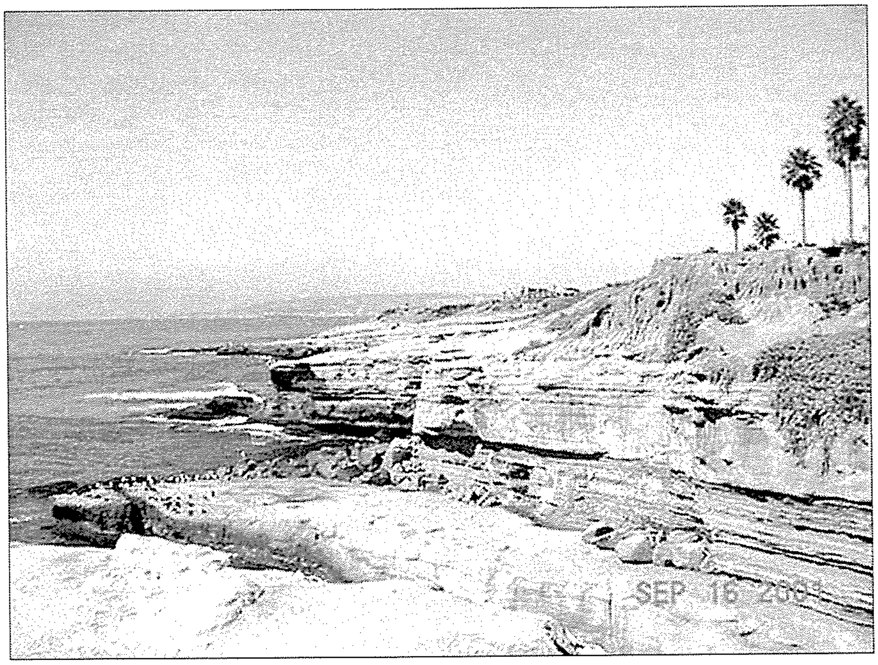
Stop Overview by
Robert Stroh

Seacliff erosion along Sunset Cliffs is well noted at many locations, including this stop. Notable geologic formations located along this portion of the cliffs include the Point Loma Formation, which makes up the lower portions of the cliffs, and the Bay Point Formation, which makes up the upper portions of the cliffs.

The Upper Cretaceous-age rocks of the Point Loma Formation as observed at the stop area generally consist of light brown to light olive-brown, fine- to coarse-grained, moderately to strongly cemented marine sandstones and siltstones. These rocks typically make up the near-vertical portions of the cliffs.

The Pleistocene-age rocks of the Bay Point Formation as observed at the stop area generally consist of reddish brown, fine- to medium-grained, weakly cemented, friable, clayey sandstone. This formation formed as a wave-cut terrace that rests unconformably on the Point Loma Formation in this area.

Sea cave development along with other interesting erosional features can be observed from this vantage area.



Sunset Cliffs. Photo by Robert Hawk.

TECHNICAL PAPERS

Coastal Landsliding — Leucadia, California

William J. Elliott, Consulting Engineering Geologist
P.O. Box 541, Solana Beach, California 92075

ABSTRACT

Prehistoric and recent deep-seated, rotational-slump/block-glide landsliding along the 2.5-mile-long Leucadia coastline is confined to a distance of approximately 0.3 mile, between two north-northeasterly trending faults. These failures have occurred along a black clay seam or seams, interbedded within the lower portions of nearly flat-lying Middle Eocene siltstone. A description of upper and lower seacliff stratigraphy, as well as faulting, provide a basis for understanding and evaluating slope stability along the urbanized edge of this actively eroding coastline.

INTRODUCTION

On the afternoon of June 2, 1996, a catastrophic seacliff landslide occurred in the rear-yards of homes located seaward from 808 through 866 Neptune Avenue, Leucadia, San Diego County, California (Photo 1). An approximately 300-foot-wide, 95-foot-high, section of seacliff slid onto the beach along a thin black clay seam or seams (Photo 2), interbedded within a dark gray sequence of siltstones, claystones, and very fine-grained sandstones. Most recently mapped by Tan and Kennedy (1996) as the Middle Eocene Santiago Formation, this slide-prone facies is informally referred to herein as the "Beacon's siltstone" (Table 1).

A room addition at the rear of 828 Neptune Avenue, and the rear-yard wooden deck of an adjacent residence (836-838 Neptune Avenue) detached, disintegrated, and rode upper Pleistocene terrace deposits and underlying Middle Eocene lower seacliff bedrock sedimentary rocks (Figure 1, Photo 1) down onto the beach below. Gray beach-sand was "bulldozed" toward the ocean for approximately 55 to 65 feet by slide debris moving along the beach-level basal failure surface (cf. June 2, 1996, photo noted in the following paragraph).

Before-, during-, and after-photographs of this event can be seen on the front cover of the San Diego Association of Geologists field trip guidebook of September 1996 (Elliott, 1996). These photographs were taken on November 3, 1991, June 2, 1996, and on June 4, 1996). Landslide repair, as of January 12, 2002, is shown in Photo 4.

Why did this coastal landslide occur where it did, and not somewhere else along this 2.5-mile-long stretch of Leucadia coastline? To answer this question, geologic conditions between the South Carlsbad State Beach parking lot and Moonlight State Beach will be addressed first — from an engineering geologic and slope stability point of view. With this background in mind, the answer to the question should fall logically into place in the final section on slope stability.

GEOLOGIC CONDITIONS

Previous Work

An early account of the geology of San Diego County included a discussion of the Leucadia area by Ellis and Lee (1919, pp. 53-57). Eocene strata in and around Del Mar and Encinitas were described in some detail on page 53. And, on plate 3, Eocene strata in the western part of San Diego County were characterized as "Alternate beds of shale, sandstone, and limestone [Delmar Formation], generally capped by a massive white sandstone [Torrey Sandstone]." Nomenclature in brackets is that of Kennedy and Moore (1971), Kennedy (1975).

Other geologic work of general and historic interest has been published by Jahns (1954, Ch. II, p. 39, pl. 3), Hertlein and Grant (1954, Ch. II, pp. 57-60, fig. 1), Weber (1963, pp. 27-29, pl. 1), Rogers (1966), and Kennedy (1973a, pp. 9-15). A fault map, which included the Leucadia area, was prepared by Hannan (1975, pp. 56-59, including two maps); a landslide hazard map, which included the Leucadia area, was published by Tan and Giffen (1995, pl. 35D).

South of Leucadia. South of Leucadia, Hanna (1926, pp. 207-215 and Geologic Map of La Jolla Quadrangle) mapped and named Eocene strata in the La Jolla 15' quadrangle; from youngest to oldest, these included the: Delmar sand, Torrey sand, and Rose Cañon shale (all members of the La Jolla formation), and the Poway conglomerate.

Kennedy and Moore (1971) redefined Cretaceous and Eocene stratigraphic relationships in the San Diego area and established new formations, complete with type sections. Subsequently, Kennedy (1973b, 1975; and Kennedy and Peterson, 1975) prepared and published geologic maps covering metropolitan San Diego from Solana Beach to Coronado and inland to Rancho Bernardo and La Mesa.

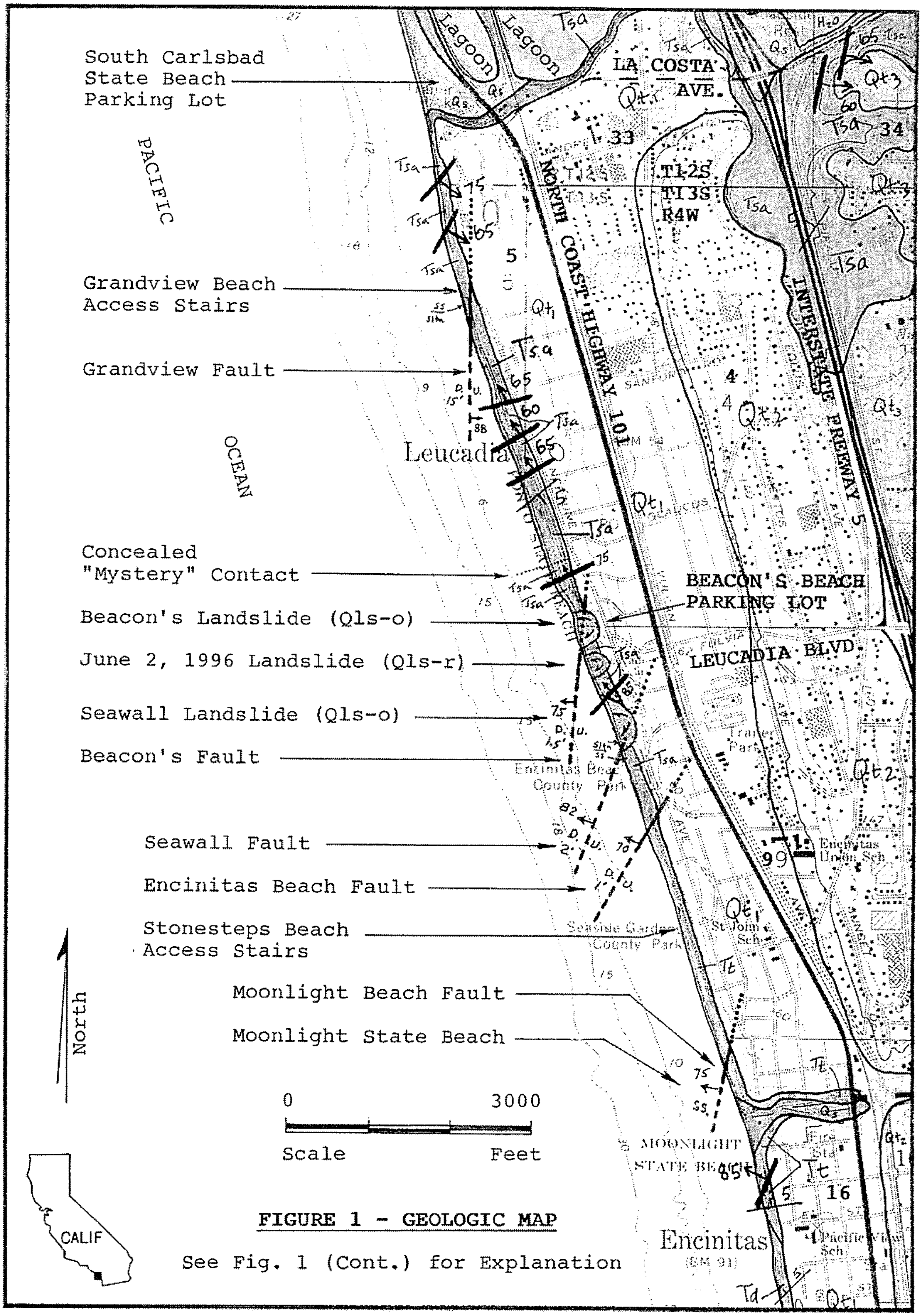


FIGURE 1 - GEOLOGIC MAP

See Fig. 1 (Cont.) for Explanation

FIGURE 1 Continued

EXPLANATION for GEOLOGIC MAP

Qs = Undifferentiated surficial deposits: alluvium, colluvium, beach sand, and artificial fill (Holocene).

Qls-r = Recent landslide (June 2, 1996).

Qls-o = Prehistoric landslides (Holocene / upper Pleistocene).

Qt-1 = Terrace deposits (lowest elevation, youngest) (Bay Point Formation, upper Pleistocene).

Qt-2 = Terrace deposits (Bay Point Formation, upper Pleistocene).

Qt-3 = Terrace Deposits (highest elevation, oldest) (Bay Point Formation, upper Pleistocene).

Tsa = Santiago Formation (Middle Eocene). = Torrey
See Table 1 and text for informal divisions.

Tt = Torrey Sandstone (Middle Eocene).

Td = Delmar Formation (Middle Eocene).


= Geologic contact, dotted where location is concealed or inferred.

= Strike and dip of bedding.

= Strike and dip of fault, dashed where location is approximate, dotted where location is concealed or inferred. U. = Up, D. = Down. SS. = Strike Slip.


= Landslide. Arrows show direction of movement.

Modified after Tan and Kennedy, 1996: California Division of Mines and Geology Open-File Report 96-02.

Base map after: U.S.G.S., Encinitas, California, 7½' topographic quadrangle map, 1968-75.

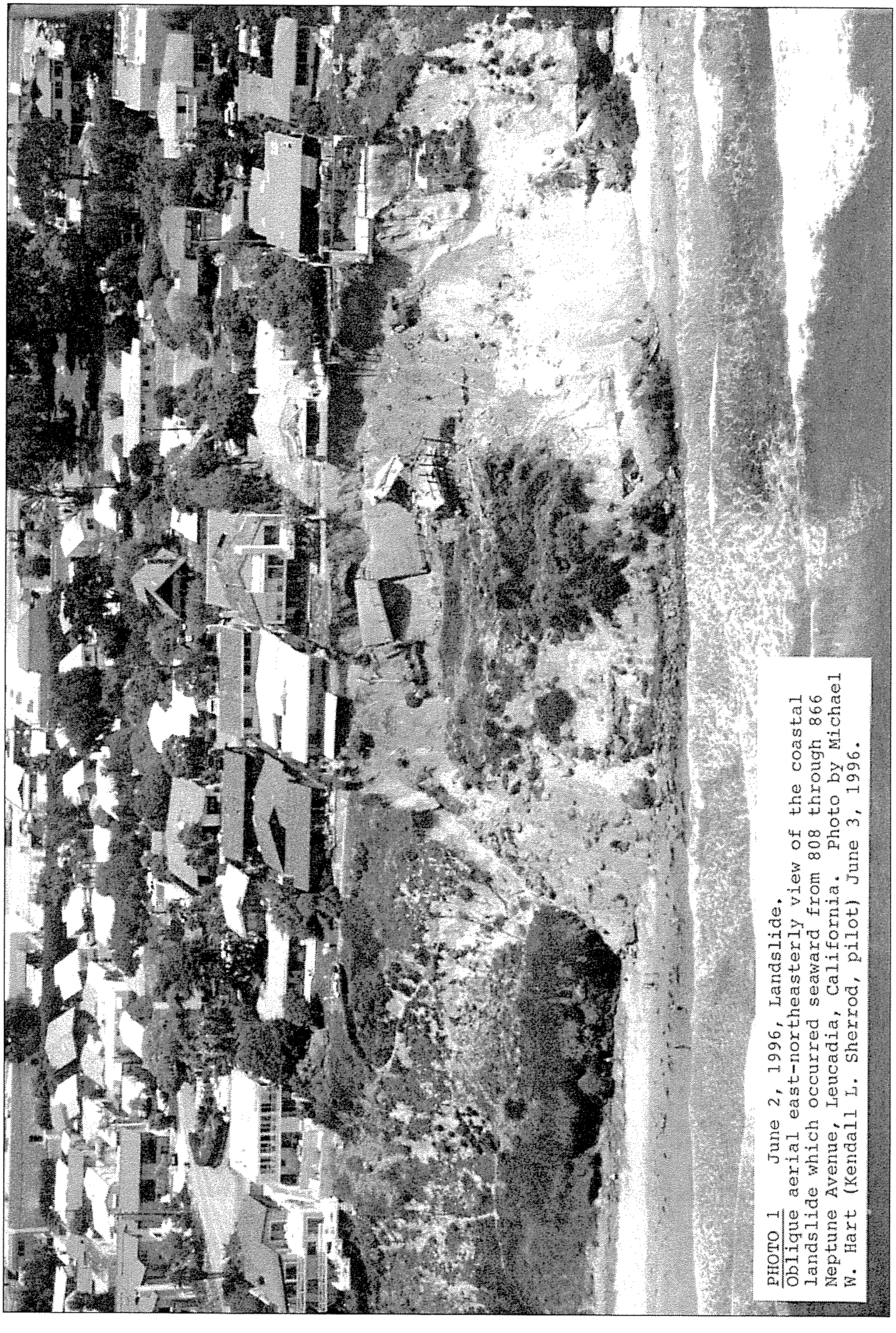


PHOTO 1 June 2, 1996, Landslide.
Oblique aerial east-northeasterly view of the coastal landslide which occurred seaward from 808 through 866 Neptune Avenue, Leucadia, California. Photo by Michael W. Hart (Kendall L. Sherrod, pilot) June 3, 1996.

PHOTO 2 Black Clay Seam.
Approximately one-inch thick black clay seam, located between screwdriver handle and rock hammer head, occurs within the lower portion of the "Beacon's siltstone." See Table 1 and text for informal divisions of Wilson's (1972) Santiago Formation member B. This clay was naturally soft, and easily molded between the thumb and fingers as shown. It is believed to be the clay seam or similar to the clay seam(s) upon which the June 2, 1996, failure, as well as the nearby Beacon's and Seawall prehistoric coastal landslides occurred (Figure 1, Photos 1 and 3). August 10, 1997, photo taken approximately 3140 feet northerly from Stonesteps public beach access stairs (Figure 1).

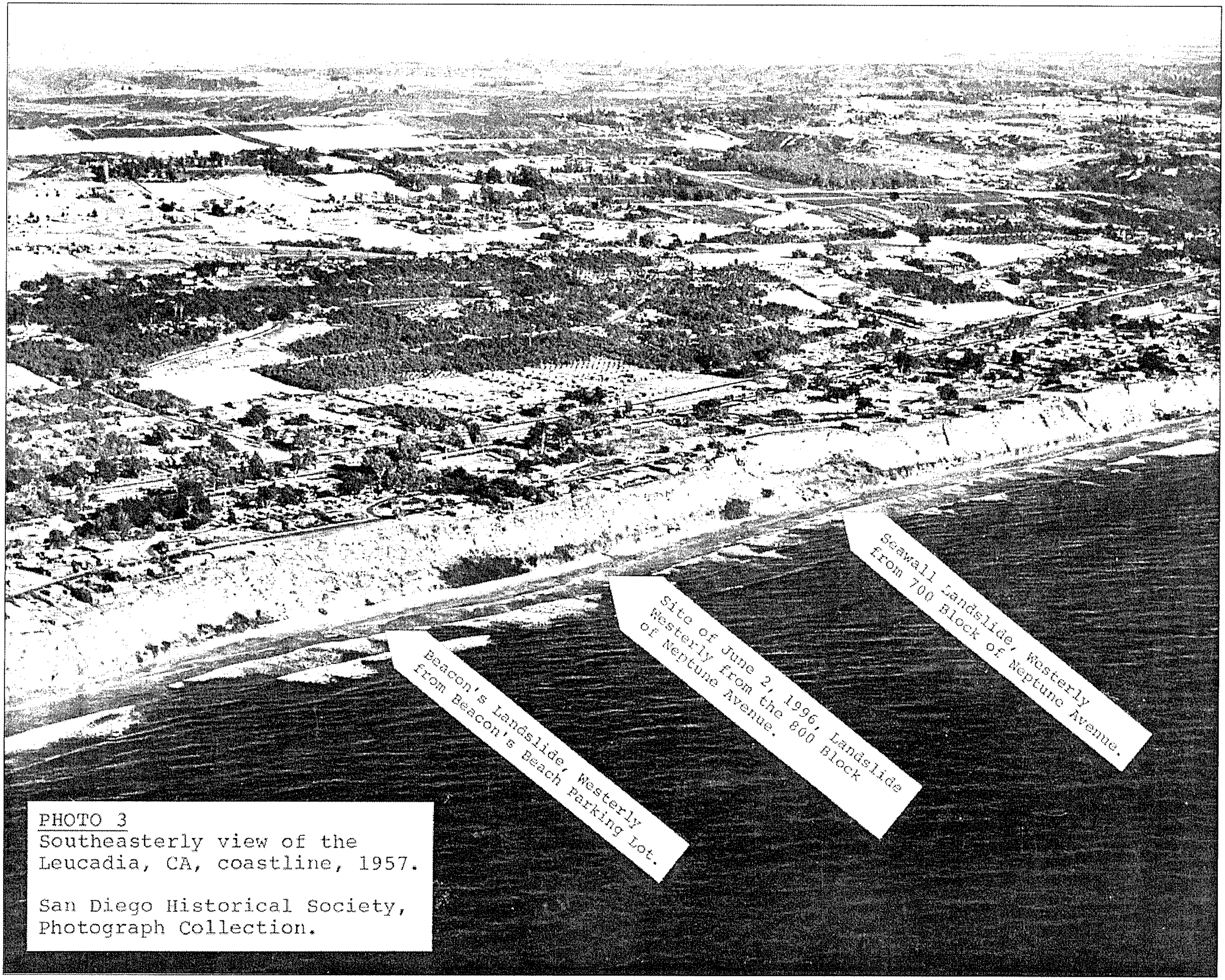


PHOTO 3
Southeasterly view of the Leucadia, CA, coastline, 1957.

San Diego Historical Society, Photograph Collection.

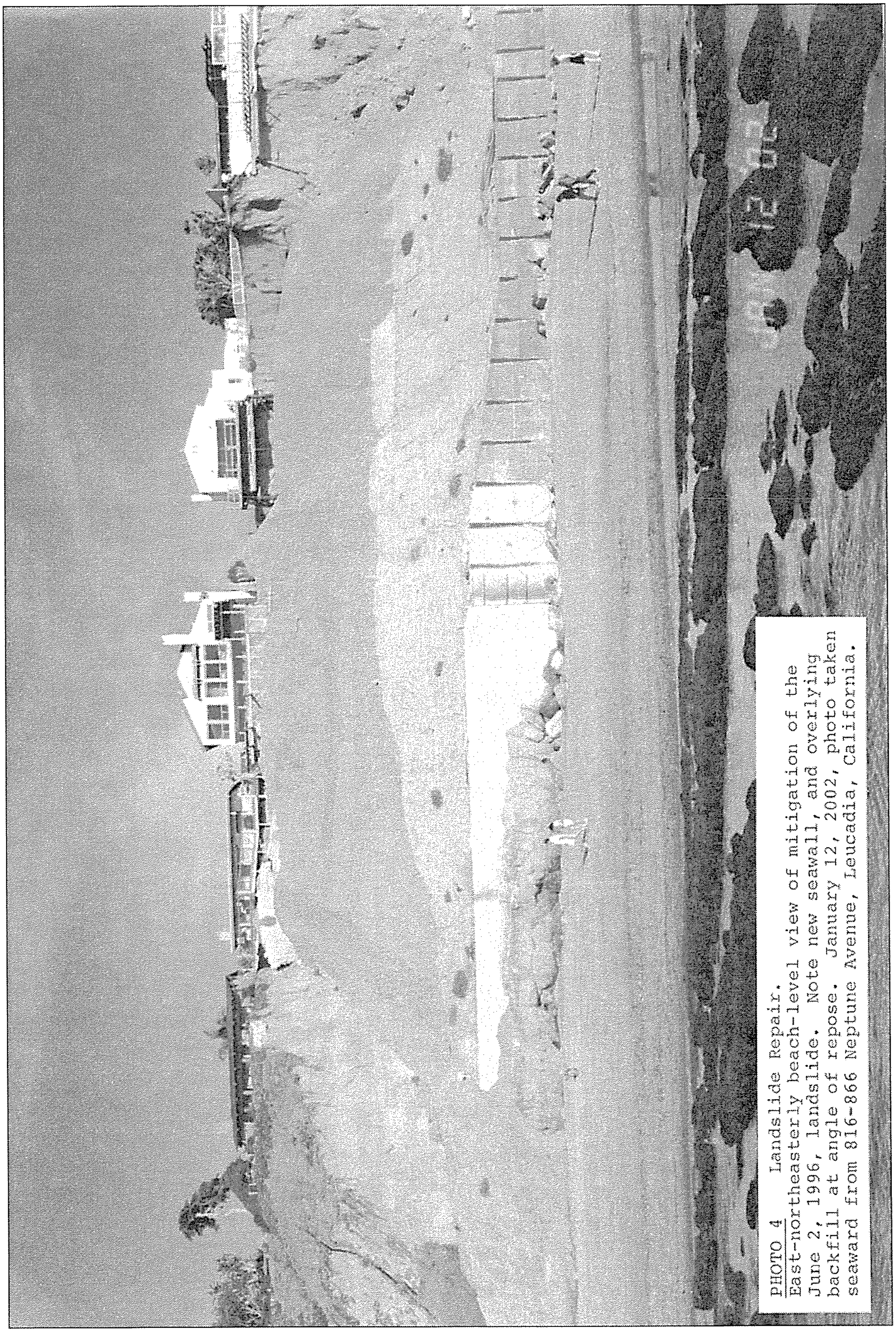


PHOTO 4 Landslide Repair.
East-northeasterly beach-level view of mitigation of the June 2, 1996, landslide. Note new seawall, and overlying backfill at angle of repose. January 12, 2002, photo taken seaward from 816-866 Neptune Avenue, Leucadia, California.

Table 1. Stratigraphic correlation chart for lower seacliff exposures between South Carlsbad State Beach and Moonlight State Beach, Encinitas, California.

Author:	Wilson, 1972	Eisenberg, 1983	Irwin, 1985, 1986	Tan, 1986	Tan and Kennedy, 1996
Coastline identification features, from north to south, are noted in the left-hand column below. Compare with Figure 1, Geologic Map.					
South Carlsbad State Beach					
Private beach access stairs Grandview beach access stairs	Tsb Santiago Formation member B	Lithofacies 5 (Tsc Scripps Formation)	Lithofacies H (no name given)	Tsc Scripps Formation	Tsa Santiago Formation
Grandview fault		(Eisenberg's Grandview fault)			
Low seawalls and private beach access stairs	Tsb Santiago Formation member B	Lithofacies 7 (Ta Ardath Shale)	Lithofacies G (Ta Ardath Shale)	Ta Ardath Shale	Tsa Santiago Formation
Concealed "mystery" contact					
Low seawalls and private beach access stairs Armored Promontory	Tsb Santiago Formation member B	Lithofacies 7 (Ta Ardath Shale)	Lithofacies G (Ta Ardath Shale)	Ta Ardath Shale	Tsa Santiago Formation
Beacon's fault					
Qls-o Qls-r (6-2-1996) Qls-o	Tsb Santiago Formation member B	Lithofacies 7 (Ta Ardath Shale) ---over--- Lithofacies 6 (Tt Torrey Sandstone)	Lithofacies G (Ta Ardath Shale) ---over--- Lithofacies F (Tt Torrey Sandstone)	Ta Ardath Shale	Tsa Santiago Formation ---over--- Tt Torrey Sandstone
Seawall fault					
High seawalls Low seawalls	Tsb Santiago Formation member B	Lithofacies 7 (Ta Ardath Shale) ---over--- Lithofacies 6 (Tt Torrey Sandstone)	Lithofacies G (Ardath shale) ---over--- Lithofacies F (Torrey Sandstone) ---over--- Lithofacies E	Tt Torrey Sandstone	Tt Torrey Sandstone
Encinitas Beach fault	(Wilson's Fault D)	(Eisenberg's Encinitas Beach fault)			
Discontinuous low seawalls Stonesteps beach access stairs Discontinuous low seawalls Moonlight Beach fault	Tt Torrey Sandstone	Lithofacies 6 ---over--- Lithofacies 5 (all Tt Torrey Sandstone)	Lithofacies E (Tt Torrey Sandstone)	Tt Torrey Sandstone	Tt Torrey Sandstone
Moonlight State Beach					

The Grandview, Beacon's, Seawall, and Encinitas Beach faults, as well as the concealed "mystery" contact, provide logical breaks within the lower seacliff bedrock geology. Variables include: rock type/structure, weathering/erosion, physiographic expression, as well as differences in slope stability and landslide susceptibility.

Table 1 (Continued). Stratigraphic correlation chart for lower seacliff exposures between South Carlsbad State Beach and Moonlight State Beach, Encinitas, California.

Author:	This paper*	Description of informal units. See text (Faulting) for units that occur on both sides of fault divisions.
Coastline identification features, from north to south, are noted in the left-hand column below. Compare with Figure 1, Geologic Map.		
South Carlsbad State Beach		
Private beach access stairs Grandview beach access stairs	“Grandview sandstone”	Sandstone. White to light-gray, light greenish gray, and locally pale pink, moderately well consolidated, silty fine-grained sandstone. shark, ray
Grandview fault		
Low seawalls and private beach access stairs	“Jupiter siltstone”	Siltstone. Medium- to dark-gray, greenish gray, and black, well-consolidated, alternating layers and lenses of silty claystone, clayey siltstone, silty very very fine-grained sandstone, and very very fine-grained sandy siltstone. bivalves
Concealed “mystery” contact		
Low seawalls and private beach access stairs Armored Promontory	“Promontory sandstone”	Sandstone. Yellow-brown to olive-brown and greenish brown, well-consolidated, silty very fine-grained sandstone. no foss
Beacon’s fault		
Qls-o Qls-r (6-2-1996) Qls-o	“Beacon’s siltstone”	Siltstone. Medium- to dark-gray, greenish gray, and black, well-consolidated, alternating layers and lenses of silty very fine-grained sandstone, claystone, silty claystone, and clayey very very fine-grained sandy siltstone. Soft, black, “rubbery” clay seams (Photo 2) occur near the base of this unit and provide a basal rupture surface for prehistoric and recent rotational-slump/block-glide landsliding. rich foss, molluscs
Seawall fault		
High seawalls Low seawalls	“Woodley sandstone”	Sandstone. White to light-gray and pale greenish gray to gray-brown, moderately well consolidated, clayey and silty very fine- to fine-grained sandstone. no foss
Encinitas Beach fault		
Discontinuous low seawalls Stonesteps beach access stairs Discontinuous low seawalls Moonlight Beach fault	Torrey Sandstone	Sandstone. Off-white to pale yellow-brown and pale orange-brown, well-consolidated, silty fine- to medium-grained sandstone. no foss
Moonlight State Beach		

* Informal stratigraphic names are suggested herein to identify distinct “mappable” facies within the lower seacliffs between South Carlsbad State Beach and the Encinitas Beach fault. This provides for convenient identification of individual terranes/terrains with differing slope stability and weathering/erosion characteristics.

North of Leucadia. North of Leucadia, Phillips (1941, pp. 34-37 and Geologic Map of the Oceanside Quadrangle) mapped Eocene strata in the Oceanside 15' quadrangle. He followed the stratigraphic nomenclature of Hanna (1926), using the Delmar sand and Torrey sand members of the La Jolla formation south of Batiquitos Lagoon — which included the Leucadia coastline sequence.

Jones (1959, pp. 23-50 and Figure 2 — Geologic Map of the San Luis Rey Quadrangle) mapped Eocene strata in the San Luis Rey 7.5' quadrangle, north of the Leucadia coastline sequence, and followed the same stratigraphic nomenclature as Phillips (1941).

Weber (1982, pp. 16-24, pl. 1) mapped portions of five 7.5' quadrangle maps, including those covering the communities of Carlsbad, Oceanside, Vista, and San Marcos, where he used both La Jolla Group nomenclature (Kennedy and Moore, 1971, p. 713) and Santiago Formation nomenclature (Woodring and Popenoe, 1945; Schoellhammer and others, 1954).

Moyle (1975) mapped undifferentiated Eocene strata on Marine Corps Base Camp Joseph H. Pendleton, following the La Jolla Group nomenclature of Kennedy and Moore (1971, p. 713).

Farther north, in the western Santa Ana Mountains of eastern Orange County, California, Woodring and Popenoe (1945) and Schoellhammer and others (1954) named and mapped, respectively, Eocene strata (Santiago Formation) that appear to be lithologically indistinguishable from Torrey Sandstone (Kennedy and Moore, 1971, pp. 715-16; Kennedy, 1975, pp. 16-18) in the San Diego sequence. Woodring and Popenoe (1945) reported that, "The name Santiago formation is proposed for the Eocene deposits of the northwestern Santa Ana Mountains... Though these Eocene deposits evidently are the equivalent of an undetermined part of the Eocene section in the San Diego district, a local name for them appears to be preferable..."

The Leucadia Coastline. Geologic mapping of the seacliffs along the Leucadia coastline, between the South Carlsbad State Beach parking lot and Moonlight State Beach, has been accomplished by Wilson (1972), Eisenberg (1983), Irwin (1985, 1986), Tan (1986), and Tan and Kennedy (1996). See Table 1.

Work in Progress

It is understood that Dr. Tom Deméré, and his staff at the San Diego Natural History Museum, are planning to document their recent paleontological and stratigraphic work in the Encinitas/Carlsbad/Oceanside area. Publication of this effort is expected within the next few years.

Therefore, in the paragraphs that follow, detailed descriptions of stratigraphic correlations and age relationships have been left for this anticipated new work.

Seacliff Stratigraphy

Seacliffs along the Leucadia shoreline can be subdivided into an upper stratigraphic sequence of upper Pleistocene terrace deposits and a lower stratigraphic sequence of Middle Eocene marine deposits. An unconformity, representing an elevated marine abrasion platform, separates the two sequences.

Upper Seacliff Stratigraphy. Upper seacliff stratigraphy (above about elevation 14 to 30 feet, from north to south, respectively, Eisenberg, 1983, pl. 1) has been mapped variously as: Lindavista Formation (Wilson, 1972, pls. B and C); Bird Rock terrace north of the Encinitas Beach fault and Nestor terrace south of the Encinitas Beach fault (Eisenberg, 1983, pl. 1; Eisenberg and Abbott, 1985, pl. 1); and terrace deposits, Qt-1 (Tan, 1986, pl. 4C; Tan and Kennedy, 1996, pl. 2).

Terrace deposits, as described by Eisenberg (1983, pp. 74-87 and 97-101), consist of a basal sequence of friable laminated "beach" sandstones and an upper sequence of friable to compact cross-bedded to massive "dune" sandstones.

These essentially flat-lying, upper Pleistocene (approximately 80,000 to 125,000 years old; Eisenberg, 1983, pp. 104-105) clastic, nearshore marine and nonmarine sedimentary deposits are typically composed of brown to red-orange brown, thinly to massively bedded and cross-bedded, poorly to moderately consolidated, gravelly silty sandstone.

Terrace deposits fail and retreat landward for a variety of reasons (some unclear), including weathering, erosion, and retreat of underlying lower seacliff Middle Eocene bedrock strata in response to relentless wave attack.

Lower Seacliff Stratigraphy. This consists of Eocene sedimentary rocks that have a rather complex nomenclatural history. Middle Eocene strata in northwestern San Diego County, including Encinitas, Carlsbad and Oceanside, have remained somewhat of a transitional orphan child to the more well-defined and named sequences in Del Mar-La Jolla to the south and in the western Santa Ana Mountains to the north. For example, compare Hanna (1926) / Kennedy (1975) with Woodring and Popenoe (1945) / Schoellhammer and others (1954), respectively.

As pointed out by Young and Berry (1981, pp. 33-35), Eocene sequences are quite different in this transitional region where strata do not simply grade directly and conveniently from one sequence to the other. Other workers, for example, those noted in Table 1, have similarly grappled with the problem of identifiable/mappable units as well as with appropriate nomenclature.

Lower seacliff stratigraphy between the South Carlsbad State Beach parking lot and Moonlight State Beach has been mapped and identified variously by others as shown in Table 1. In this table, lower seacliff stratigraphy is divided into six groups, separated by four faults and one concealed "mystery" contact.

For purposes of this discussion, the geologic nomenclature of Wilson (1972) is followed. The importance of this is that the Encinitas Beach fault separates two distinctly different geologic terranes and physiographic terrains. North of this fault, Santiago Formation (member B of Wilson, 1972) occurs in the lower seacliffs, while to the south, Torrey Sandstone (of Wilson, 1972) is exposed in bold lower seacliff outcrop.

Physiographic reflection of this lithologic change was recorded on a late 19th century coastal topographic survey map (U.S. Coast and Geodetic Survey, 1887). North of the Encinitas Beach fault, closely spaced contour lines are used to depict seacliff topography; to the south, short vertical hachure marks are used to depict a seacliff too steep (at a map scale of 1"=833') to show with contour lines.

Distinctive differences in color have been observed in outcrops of Santiago Formation (member B of Wilson, 1972) and Torrey Sandstone (of Kennedy and Moore, 1971; Kennedy, 1975). Although exceptions do occur, the former tends to be bluish and greenish white and gray in color (cool tones), while the latter tends to be off-white, tan, yellowish and orangish brown (warm tones) in color. Even though generalized, similar observations, were made and/or alluded to by Phillips (1941, p. 35) and by Wilson (1972, pl. C). This marked contrast in appearance is particularly noticeable in the field, north and south of the Encinitas Beach fault (Figure 1).

For convenience, and to facilitate discussion, member B of the Santiago Formation is herein divided into distinctive facies and given informal names as noted in quotes below. From north to south, these informal stratigraphic units are described briefly in the paragraphs that follow. Torrey Sandstone is discussed at the end of this section.

1. *"Grandview sandstone."* Between the South Carlsbad State Beach parking lot and the Grandview fault (Table 1, Figure 1), white to light-gray, light greenish gray, and locally pale pink, moderately well consolidated, silty fine-grained sandstone forms stark near-vertical seacliffs. Close inspection, shows that, thin pink- to rose-colored lenses, and scattered dark pink- and rose-colored claystone clasts are scattered throughout. Bedding in this thinly to massively bedded facies dips approximately 1° to 3° in northerly directions (Eisenberg, 1983, p. 343).

Differential weathering and erosion around small faults and fractures provide texture and relief to the otherwise monotonous, approximately 2550 linear feet of cliff face.

Irwin (1986, pp. 62-64) reported the presence of shark and ray teeth low in the section. He also suggested (p. 68) that these "...teeth also may have been reworked from the lower deposits."

Outcrop and structural/stratigraphic relationships suggest that the thickness is at least 14 feet, but probably does not exceed about 105 feet.

Beach access along this stretch of coastline is via the Grandview public beach access stairs, and a set of private stairs located approximately 900 feet to the north. Except for a lower seacliff concrete face under the Grandview stairs, seawalls are absent.

2. *"Jupiter siltstone."* Between the Grandview fault and the concealed "mystery" contact (Table 1, Figure 1), medium- to dark-gray, greenish gray, and black, well-consolidated, alternating layers and lenses of silty claystone, clayey siltstone, silty very very fine-grained sandstone, and very very fine-grained sandy siltstone, form cavernous and recessive near-vertical and overhanging seacliffs. At least two paper-thin to approximately 3/4-inch thick, soft, gray to gray-brown and olive-brown, "rubbery" clay seams occur in the southernmost exposures of "Jupiter siltstone."

Seitz (1983) reported that hundreds of closely spaced normal faults create planes of weakness along which weathering, erosion, and seacliff retreat occur. By disrupting bedding continuity, this intense faulting may, at least in part, provide a limiting factor to deep-seated slope failures — such as those that have occurred in "Beacon's siltstone" further south.

Bedding planes in this thinly to moderately bedded facies dip approximately 1° to 5° in southerly directions (Wilson, 1972, pl. B; Eisenberg, 1983, p. 342, pl. 3; Tan and Kennedy, 1996, pl. 2). Exceptions do, however, occur. For example, an approximately 1/32- to 1/16-inch thick, soft, olive-brown to gray-brown clay seam occurs approximately 3120 feet south of the Grandview stairs and dips approximately 2° to 4° in a north-northeasterly direction, favorably into slope. This, and other variations like this, are structural, and likely result from intense faulting as described by Seitz (1983).

Several whole and partial clam (bivalve mollusc) shells and impressions were observed at scattered localities in this lower seacliff outcrop.

Outcrop and structural/stratigraphic relationships suggest that the thickness is at least 18 to 20 feet, but probably does not exceed about 60.

Numerous low seawalls and private beach access stairs characterize this approximately 3390-foot-long stretch of Leucadia coastline.

3. *"Promontory sandstone."* Between the concealed "mystery" contact and the Beacon's fault (Table 1, Figure 1), yellow-brown to olive-brown and greenish brown, well-consolidated silty very fine-grained sandstone forms subdued, as well as prominent corrugated (bedding-parallel grooves and ridges) near-vertical seacliffs.

Southerly from the concrete armored promontory (located approximately 3700 to 3900 feet south of the Grandview stairs), bedding planes in this thinly to moderately bedded facies dip approximately 3° to 11° in southerly directions. Differential weathering and erosion along thin, dark, fine-grained interbeds provide a laterally ribbed appearance to this stretch of coastline.

Northerly from the concrete armored promontory exposures are rare and difficult to find. Fossil remains were not found.

Outcrop and structural/stratigraphic relationships suggest that the thickness is at least 19 to 20 feet, but probably does not exceed about 110 feet.

Numerous low seawalls, dense vegetation, and private beach access stairs characterize this approximately 660-foot-long stretch of Leucadia coastline.

4. *"Beacon's siltstone."* Between the Beacon's and Seawall faults (Table 1, Figure 1), medium- to dark-gray, greenish gray, and black, well-consolidated, alternating layers and lenses of silty very fine-grained sandstone, claystone, silty claystone, and clayey very very fine-grained sandy siltstone form near-vertical seacliffs (see Figure 2 on p. 50 of Deméré and Boettcher, 1985). Paper-thin to approximately one-inch thick, soft, black, "rubbery" clay seams (Photo 2) occur near the base of this unit and provide a basal rupture surface for prehistoric and recent rotational-slump/block-glide landsliding.

Bedding planes in this thinly to moderately bedded facies form an approximately east-northeasterly plunging shallow syncline centered approximately in the middle of the recent, June 2, 1996, landslide (cf. "Leucadia syncline" of Eisenberg, 1983, p. 342, pl. 3). Bedding attitudes on the northern limb dip approximately 5° to 10° in an easterly to east-northeasterly direction. While on the southern limb, bedding dips approximately 3° to 7° in a northeasterly direction.

Calcareous cementation of selected layers and lenses, as well as "signature" flying-saucer- and boomerang-shaped, boxwork-decorated concretions provide horizontally ribbed relief to this approximately 1600 feet long stretch of coastline (see Figure 2 on p. 50 of Deméré and Boettcher, 1985).

Portions of this facies are richly fossiliferous and contain well-preserved shells of fossil marine molluscs.

As to age, Wilson (1972, p. 99) concluded that: "These [fossil] collections [along the seacliffs north of Moonlight Beach {at Beacon's Beach} and at Evans Point {located approximately five miles north of Beacon's Beach}] both indicate an upper late Eocene age (upper Tejon...) and hence an age correlation with the marine Mission Valley Formation in the San Diego sequence."

In more recent work, a gravelly fossiliferous layer, located near the base of this unit, was determined by Deméré and Boettcher (1985) to be about 45 to 46.5 million years old. Furthermore, it was provisionally assigned to the Ardath shale (cf. Kennedy and Moore, 1971; Kennedy 1975) which occurs in the La Jolla area of San Diego.

Supported by additional field work, Deméré (personal communication, December 19, 2001) reported that: this fossiliferous bed is now believed to be closer to approximately 42 million years old (based on molluscs), probably a Mission Valley Formation equivalent (cf. Kennedy and Moore, 1971; Kennedy, 1975), and of late Middle Eocene age (Walsh, and others, 1996).

Outcrop and structural/stratigraphic relationships suggest that the thickness is at least 20 feet, but probably does not exceed about 60 feet.

Prehistoric and recent deep-seated rotational-slump/block-glide landsliding, as well as recently constructed low to moderate height seawalls characterize the physiography of this portion of the Leucadia coastline (Photos 1, 3, and 4).

5. *"Woodley sandstone."* Between the Seawall and Encinitas Beach faults (Table 1, Figure 1), white to light-gray and pale greenish gray to gray-brown, moderately well consolidated, clayey and silty very fine- to fine-grained sandstone forms near-vertical to vertical seacliffs.

Bedding inclinations in this thinly to massively bedded and cross-bedded facies are variable, but appear, in general, to dip approximately 6° to 16° in northerly to westerly directions.

Fossil remains were not found. Outcrop and structural/stratigraphic relationships suggest that the thickness is at least 21 feet, but probably does not exceed about 185 feet.

Numerous low and high seawalls, as well as private beach access stairs characterize and almost completely cover this stretch of coastline of approximately 1100 feet in length. Precious few exposures of "Woodley sandstone" remain.

6. *"Torrey Sandstone."* Between the Encinitas Beach fault and Moonlight State Beach (Table 1, Figure 1), off-white to pale yellow-brown and pale orange-brown, well-consolidated, silty fine- to medium-grained sandstone forms stark and distinctly bold near-vertical and vertical seacliffs. Bedding planes in this thinly to massively bedded and cross-bedded formation are nearly flat-lying.

Subtle differences in weathering and erosion result in bumps and hollows which give the seacliff face an irregular wavy and textured appearance. Fossil remains were not found.

Hanna (1926, p. 210) reported that: "The Torrey sand has an exposed thickness between 25 and approximately 200 feet." Wilson (1972, p. 69) reported that: "The Torrey Sandstone thins from south to north...from a thickness of about 180 feet north of San Elijo Lagoon to zero north of Palomar Airport Road."

This approximately 3900-foot-long stretch of coastline is characterized by: scattered discontinuous low seawalls, the Stonesteps stairs, one set of private beach access stairs (approximately 1750 feet south of the Stonesteps stairs), and two stretches of riprap located within the first 950 feet north from Moonlight State Beach.

Faulting

Numerous faults have been identified and mapped along the Leucadia coastline by investigators noted earlier. In addition, Seitz (1983) made a detailed study of more than 100 closely spaced small faults in a portion of the "Jupiter siltstone." From north to south, principal faults, especially those that juxtapose and/or separate major portions of individual facies, are described below.

Grandview fault. The Grandview fault of Eisenberg (1983, p. 128) is located in the lower seacliffs approximately 200 feet south of the Grandview stairs (Figure 1). This fault strikes approximately north-south, and dips approximately 88° east. "Grandview sandstone" on the west is juxtaposed with "Jupiter siltstone" on the east (Table 1).

Irwin (1986, pp. 62-63, Fig. 38; Table 1) reported that his lithofacies G (a portion of which equals the "Jupiter siltstone") underlies his lithofacies H (which equals the "Grandview sandstone") on the west side of the Grandview fault. The contact was reported to be a mostly flat (with local relief up to about a foot or so), sharp, irregular, erosional surface (pp. 62-63). This relationship is presently obscured by approximately 5 to 7 feet of beach sand.

According to Eisenberg (1983, p. 130) "...approximately 15 feet of down-to-the-west [apparent] dip[-slip] separation is present."

Additionally, Eisenberg (1983, p. 128) notes that this fault does not cut overlying upper Pleistocene terrace deposits.

Beacon's fault. The Beacon's fault, alluded to by Eisenberg (1983, p. 126), is located approximately 60 feet north of the seaward projection of the north end of Beacon's Beach parking lot (Figure 1). It was observed to strike approximately N.5°E., and to dip approximately 75° west.

At times when low tides and minimal beach sand coincide, the seaward (southerly) extension of the Beacon's fault is exposed in the abrasion platform where differential weathering and erosion have produced a distinct, low relief, fault-line scarp.

This fault juxtaposes "Promontory sandstone" on the west with "Beacon's siltstone" on the east (Table 1).

En echelon offsets in overlying upper Pleistocene terrace deposits suggest an apparent down-to-the-west sense of dip-slip separation. Therefore, by State definition (Hart and Bryant, 1997, p. 5), the Beacon's fault would be classified as "Quaternary," or "Potentially Active."

Seawall fault. The Seawall fault (Figure 1) is located approximately 40 feet north of the northern end of an approximately 25- to 30-foot-high seawall (composed of distinctive vertical concrete "H" members which retain horizontal wood lagging). This fault strikes approximately N.20°E. and dips approximately 82° west.

The fault offsets the sharp, apparently conformable contact of Irwin's (1985, pp. 44-46; 1986, pp. 50-52, Figures 26, 27, and 33) lithofacies G (a portion of which equals "Beacon's siltstone") over lithofacies F (which equals a portion of the "Woodley sandstone") with approximately 2 feet of down-to-the-west apparent dip-slip separation.

Because of northerly stratigraphic dip, the "Beacon's siltstone" thins to zero under upper Pleistocene terrace deposits a few feet east of the fault. In addition, "Woodley sandstone" disappears below beach level approximately 200 or so feet north of the Seawall fault.

Whether or not this fault cuts overlying upper Pleistocene terrace deposits could not be determined.

Encinitas Beach fault. The Encinitas Beach fault of Eisenberg (1983, pp. 125-132, pl. 1), which is the same as Wilson's fault "D" (1972, p. 117, pl. B), is located approximately 1450 feet north of the Stonesteps stairs (Figure 1). It was observed to strike approximately N.30°E., and to dip approximately 70° west. It juxtaposes "Woodley sandstone" on the west with Torrey Sandstone on the east.

Prior to recent seawall construction, this fault was observed to cut overlying upper Pleistocene terrace deposits with an approximately one foot of down-to-the-west sense of apparent dip-slip separation. Therefore, by State definition (Hart and Bryant, 1997, p. 5), the Encinitas Beach fault would be classified as "Quaternary," or "Potentially Active."

Moonlight Beach fault. The Moonlight Beach fault is located approximately 1700 feet south of the Stonesteps stairs (Figure 1). It was observed to strike approximately N.10°E., and to dip approximately 75° west. Horizontal striae indicate a strike-slip sense of separation. (This is not the same "Moonlight Beach fault" referred to by Eisenberg (1983, p. 37).

Differential weathering and erosion associated with this fault have resulted in a shallow cove in the otherwise nearly straight coastline.

It was not determined whether or not the Moonlight Beach fault cuts overlying upper Pleistocene terrace deposits.

Concealed "Mystery" Contact

The concealed "mystery" contact (Table 1, Figure 1) is located along a stretch of Leucadia coastline, which is covered with seawalls and dense vegetation. This veneered section of approximately 140 feet in length extends from approximately 3560 to 3700 feet south of the Grandview stairs.

For lack of better information, a subtle break in seacliff geomorphology, located approximately 3590 feet south of the Grandview stairs has been provisionally chosen as the approximate location of the concealed "mystery" contact. Here, this break separates "Jupiter siltstone" on the north from "Promontory sandstone" on the south.

As to the nature of the "mystery" contact, the abundance of faulting in this area would suggest a fault contact. On the other hand, a conformable, or nearly conformable, contact is suggested by similarly gently southerly dipping bedding on both sides of the "mystery" contact. Additional information will be required to resolve this dilemma.

SLOPE STABILITY

And now, back to the question, why did the recent landslide (Qls-r), as well as two prehistoric seacliff landslides (Qls-o), occur at the locations shown on the accompanying geologic map (Figure 1), and not elsewhere along the coastline?

Beacon's Fault to Seawall Fault

Geologic observations of the lower seacliffs and the modern bedrock abrasion platform (temporarily exposed during recent winter storms) showed that the slide-prone "Beacon's siltstone" (with its interbedded clay seams exposed near beach level) is bound by two north-northeast trending, near-vertical faults, the Beacon's and Seawall faults (Figure 1).

Exposed briefly during July 1996, the lower seacliff exposure of the Beacon's fault is currently obscured by a sandy talus slope and thick vegetation. The Seawall fault is exposed in the lower seacliff approximately 2550 feet north of the Stonesteps stairs as an approximately eight-foot-wide, near-vertical shear zone.

Relatively large, rotational-slump/block-glide failures along the Leucadia coastline have been historically confined to nearly flat-lying "Beacon's siltstone" exposed between the Beacon's and Seawall faults. The prehistoric Beacon's landslide (Figure 1, Photo 3) is believed to have failed along a clay seam or seams located slightly below beach-level. In contrast, the prehistoric Seawall landslide (Figure 1, Photo 3), failed along a clay seam or seams exposed a few feet above beach-level. Photo 2 shows an approximately one-inch thick, black, soft, clay seam on which, or similar to which, the prehistoric and recent landslides occurred.

The northern end of the Seawall landslide has continued to move over the past several years, as evidenced by shadows cast by the protruding lip of the seaward-creeping clayey basal portion of the slide. More recently, during winter 2002, vegetation (groundcover and brush) has slid off of the leading edge and down onto the sandy beach below.

Photographs of a fresh Beacon's landslide head-scarp, taken by Charles Lough (personal communication, March 28, 2002) on February 20, 1987, show that this coastal landslide too, continues to move — at least episodically. Raveling and small shallow surficial failures occur from time to time as a natural progression of the mass wasting process.

The June 2, 1996, landslide is currently being mitigated with a beach-level seawall and upper slope reconstruction (Photo 4).

North of Beacon's Fault and South of Seawall Fault

North of the Beacon's fault, and south of the Seawall fault, Middle Eocene stratigraphy in the lower seacliffs is noticeably different. "Promontory sandstone," "Jupiter siltstone," and "Grandview sandstone" crop out in the lower seacliffs north of the Beacon's fault, while "Woodley sandstone" and Torrey Sandstone crop out in the lower seacliffs south of the Seawall fault (Table 1, Figure 1).

Although coastal landslides and slope instability problems do occur in these areas, they result from different geological conditions than those noted between the Beacon's and Seawall faults.

For example, typical failures in these lower seacliff sandstones and siltstones are characterized primarily by block falls, and thin seacliff-parallel slabs that peel away along planes of weakness (such as fractures and faults). These failures appear to vary greatly in size and to occur relatively randomly in both time and space. Sadly, a young woman was killed on January 15, 2000, approximately 600 feet south of the Stonesteps stairs when a large thin slab of lower seacliff Torrey Sandstone crushed her as it fell suddenly to the beach.

Seawall Fault to Encinitas Beach Fault

Between the Seawall and Encinitas Beach faults, a number of large (high and low) seawalls, have been constructed to support unstable upper and lower seacliff sedimentary strata. Unfortunately, three construction workers were injured (none fatally) on April 27, 1989, approximately 2370 feet north of the Stonesteps stairs, when a seacliff stabilization project failed — burying them in piles of loose running terrace sand.

South of the Encinitas Beach Fault

South of the Encinitas Beach fault the frequency of fractures in the lower seacliff Torrey Sandstone steadily decreases (spacing increases) over a relatively short distance of approximately 1000 feet, beyond which the formation becomes nearly devoid of fractures and faults, and relatively stable. The death of the young woman described above, however, emphasizes the importance of the word "relatively."

Upper seacliff instability problems in upper Pleistocene sandy terrace deposits have occurred during recent years over a distance of approximately 700 feet south of the Encinitas Beach fault.

North of the Beacon's Fault

Significant historical slope instability problems have occurred for a distance of approximately 1000 feet north of the Beacon's fault. For example, a large (approximately 300-foot-wide) upper seacliff terrace sand failure, located approximately 3580 to 3880 feet south of the Grandview stairs, is clearly distinguishable on an October 1960, San Diego Historical Society oblique aerial photograph.

In addition, immediately adjacent to the north, a set of private beach access stairs was recently lost to what appear to be relatively shallow slope-failures and raveling in the upper seacliff terrace sands. Currently, translucent plastic sheeting covers most of this approximately 75-foot-wide failure, and a sea wall is being constructed at the toe of the seacliff.

Beyond, to the north, noticeably fewer problems appear to be associated with the seemingly more stable lower seacliff sandstones and siltstones, and the overlying upper seacliff upper Pleistocene sandy terrace deposits. A notable local exception, however, occurred on January 30, 1998, during the 1997-98 El Niño Winter storms. Approximately 93 to 153 feet south of the Grandview stairs, an approximately 1- to 5-foot-thick, 8+ foot-high, 60-foot-long, block of "Promontory sandstone" broke away from the cliff face along a coast-parallel fracture and fell harmlessly to the beach.

LANDSLIDE PREDICTION

Could large-scale coastal landsliding along the Leucadia coastline have been predicted?

As to location between the Beacon's and Seawall faults, I believe the answer is yes. For example, between these two faults, the prehistoric Beacon's and Seawall landslides are clearly visible in the field, on topographic maps (U.S. Coast and Geodetic Survey, 1887; U.S. Geological Survey, 1898, 1968-75; San Diego, County of, 1975), and on older aerial photographs (San Diego County of, 1928-29; U.S. Department of Agriculture, 1939, 1953; Photo 3, herein). Additionally, these prehistoric landslides were noted by Wilson (1972, pl. B), Tan (1986, pl. 4C), and Tan and Kennedy (1996, pl. 2).

As to the timing of the occurrence of the June 2, 1996, landslide, or any possible future landsliding between the Beacon's and Seawall faults, I believe that the answer is not likely.

At best, predicting the timing and/or location of coastal slope failures north of the Beacon's fault and/or south of the Seawall fault would likely prove to be a difficult, if not impossible task.

ACKNOWLEDGMENTS

My thanks go to Dr. Tom Deméré for his critical review, constructive criticism, and helpful suggestions for manuscript improvement, and to Walt Crampton and Braven Smillie for stimulating discussions and for sharing copies of 2001 color oblique aerial photographs of the Leucadia coastline.

REFERENCES

Clark, B.L., 1926, The Domengine horizon Middle Eocene of California: University of California Publications, Bulletin of the Department of Geological Sciences, Vol. 16, No. 5, pp. 99-118, issued November 4, 1926. *Note:* For historical interest, it should be pointed out that Clark (1926, pp. 103 and 111) gave Hanna (1926) credit for his work on the Eocene in the La Jolla 15' quadrangle. Clark, however, preceded Hanna in the literature with the names "La Jolla formation" and "Poway conglomerate" by 16 days. Clark's manuscript was issued on November 4, 1926, while Hanna's manuscript was issued on November 20, 1926.

Deméré, T.A., and Boettcher, R.S., 1985, Paleontology and biostratigraphy of Middle Eocene nearshore marine sedimentary rocks, Leucadia, San Diego County, California, in Abbott, P. L., ed., On the manner of deposition of the Eocene strata in northern San Diego County [California]: San Diego Association of Geologists field trip guidebook, April 13, 1985, pp. 49-53.

Eisenberg, L.I., 1985, Depositional processes in the landward part of an Eocene tidal lagoon, northern San Diego County, [California], in Abbott, P. L., ed., On the manner of deposition of the Eocene strata in northern San Diego County [California]: San Diego Association of Geologists field trip guidebook, April 13, 1985, pp. 55-68.

Eisenberg, L.I., 1983, Pleistocene marine terrace and Eocene geology, Encinitas and Rancho Santa Fe quadrangles, San Diego County, California [M.S. thesis]: San Diego State University, 386 p. Approximate geologic map scale 1"=2200'.

Eisenberg, L.I., and Abbott, P.L., 1985, Eocene lithofacies and geologic history, northern San Diego County, [California], in Abbott, P. L., ed., On the manner of deposition of the Eocene strata in northern San Diego County [California]: San Diego Association of Geologists field trip guidebook, April 13, 1985, pp. 19-35.

Elliott, W.J., 1996, Three cover photographs and accompanying one page explanation following guidebook title page, in Munasinghe, T., and Rosenberg, P., eds., Geology and natural resources of coastal San Diego County, California: San Diego Association of Geologists field trip guidebook, September, 1996.

Elliott, W.J., 1997, Sea-cliff landslides — history repeats itself, Leucadia, California 92024 [abs.]: Program with Abstracts, 40th annual meeting, Association of Engineering Geologists, Portland, Oregon, p. 96.

Ellis, A.J., and Lee, C.H., 1919, Geology and ground waters of the western part of San Diego County, California: U.S. Geological Survey Water Supply Paper 446, 321 p. Scale of preliminary geologic map of San Diego County, California 1"=4 miles.

Hanna, M.A., 1926, Geology of the La Jolla quadrangle, California: University of California Publications, Bulletin of the Department of Geological Sciences, Vol. 16, No. 7, pp. 187-246, issued November 20, 1926. Geologic map scale 1"=1 mile.

Hannan, D.L., 1975, Faulting in the Oceanside, Carlsbad, and Vista areas, northern San Diego County, California, in Ross, A., and Dowlen, R.J., eds., Studies on the geology of Camp Pendleton, and western San Diego County, California: San Diego Association of Geologists field trip guidebook, October 1975, pp. 56-59. Two U.S. Geological Survey topographic map sheets, Encinitas, California (1968) and San Luis Rey, California (1968), reduced to a scale of 1"=0.5 mile.

Hart, E.W., and Bryant, W.A., 1997, Fault-rupture hazard zones in California: California Division of Mines and Geology Special Publication 42, 38 pp. Supplements 1 and 2 added 1999.

Hertlein, L.G., and Grant, U.S., 1954, Geology of the Oceanside-San Diego coastal area, Southern California, in Jahns, R. H., ed., Geology of Southern California: California Division of Mines Bulletin 170, Chapter II, pp. 53-63. Geologic map scale 1"=4 miles.

Irwin, R.L., 1985, Eocene lithofacies exposed in sea cliffs from Leucadia to Cardiff-by-the-Sea, San Diego County [California], in Abbott, P. L., ed., On the manner of deposition of the Eocene strata in northern San Diego County [California]: San Diego Association of Geologists field trip guidebook, April 13, 1985, pp. 37-48.

Irwin, R.L., 1986, Eocene lithofacies in the vicinity of Leucadia and Encinitas, San Diego County, California [M.S. thesis]: San Diego State University, 124 p.

Jahns, R.H., 1954, Geology of the Peninsular Range province, Southern California and Baja California, in Jahns, R. H., ed., Geology of Southern California: California Division of Mines Bulletin 170, Chapter II, pp. 29-52, pl. 3. Geologic map scale 1"=6 miles.

Jones, B.F., 1959, Geology of the San Luis Rey quadrangle [M.S. thesis]: University of Southern California, 109 p., geologic map scale 1"=2000'.

Kennedy, M.P., 1973a, Bedrock lithologies, San Diego coastal area, California, in Ross, A., and Dowlen, R.J., eds., Studies on the geology and geologic hazards of the greater San Diego area, California: San Diego Association of Geologists and Association of Engineering Geologists field trip guidebook, May, 1973, pp. 9-15. Geologic map scale approximately 1"=9.8 miles.

Kennedy, M.P., 1973b, Stratigraphy of the San Diego embayment, California [Ph.D. thesis]: University of California, Riverside, 148 p.

Kennedy, M.P., 1975, Geology of the San Diego metropolitan area, California, Section A — western San Diego metropolitan area: California Division of Mines and Geology, Bulletin 200, pp. 9-39. Scale of geologic maps 1"=2000'.

Kennedy, M.P., and Moore, G.W., 1971, Stratigraphic relations of Upper Cretaceous and Eocene formations, San Diego coastal area, California: The American Association of Petroleum Geologists Bulletin, Vol. 55, No. 5, pp. 709-722.

Kennedy, M.P., and Peterson, G.L., 1975, Geology of the San Diego metropolitan area, California, Section B — eastern San Diego metropolitan area: California Division of Mines and Geology, Bulletin 200, pp. 41-56. Scale of geologic maps 1"=2000'.

Moyle, W.R., Jr., 1975, Geologic maps of the eastern and western parts Camp Pendleton, Southern California, in Ross, A., and Dowlen, R.J., eds., Studies on the geology of Camp Pendleton and western San Diego County, California: San Diego Association of Geologists field trip guidebook, U.S. Geological Survey Open-File Report, 2 map sheets, compiled 1973. Geologic map scale 1"=0.9 mile.

Phillips, I.L., 1941, A study of the geology and soils of the Oceanside quadrangle [M.A. thesis]: University of California, 58 p., geologic map scale 1"=1 mile.

Rogers, T.H., compiler, 1966, Geologic map of California, Santa Ana sheet: California Division of Mines and Geology, map scale 1"=4 miles. Map compiled 1965.

San Diego, County of, 1928-29, Stereographic black and white aerial photographs, Nos. 37-E-1, 37-F-1, and 37-F-2, approximate scale 1"=1000', photos flown winter 1928-29.

San Diego, County of, 1975, Topographic survey, Ortho photo base, Sheet Nos. 322-1677, 326-1671, 326-1677, 330-1671, and 334-1671, scale 1"=200', contour interval 5', photos flown September 17, 1975.

San Diego Historical Society, 1957, Black and white oblique aerial photograph (see Photo 3, herein). View is southeasterly of the Leucadia, California coastline. Photo No. S-4130-1.

San Diego Historical Society, 1960, Black and white oblique aerial photograph. View is east-northeasterly of the Leucadia, California coastline (October 1960). Photo No. S-6725-2. (Not reproduced herein.)

Schoellhammer, J.E., Kinney, D.M., Yerkes, R.F., and Vedder, J.G., 1954, Geologic map of the northern Santa Ana Mountains, Orange and Riverside counties, California: U.S. Geological Survey Oil and Gas Investigations Map OM-154, scale 1"=2000', contour interval 20'.

Seitz, G., 1983, Normal faulting associated with major strike-slip faulting in the Leucadia area of San Diego County [California] [Senior Research thesis]: San Diego State University, 32 p.

Tan, S.S., 1986, Landslide hazards in the Encinitas quadrangle, San Diego County, California, Geologic map — Plate 4-C: California Division of Mines and Geology Open-File Report 86-8-LA, 1 p., map scale 1"=2000'.

Tan, S.S., and Giffen, D.G., Landslide hazards in the northern part of the San Diego metropolitan area, San Diego County, California — Plate 35D, Landslide distribution map [U.S. Geological Survey, Encinitas, California, 7.5' topographic quadrangle map]: California Division of Mines and Geology Open-File Report 95-04, 6 p., map scale 1"=2000'.

Tan, S.S., and Kennedy, M.P., 1996, Geologic maps of the northwestern part of San Diego County, California — Plate 2, Geologic map of the Encinitas and Rancho Santa Fe 7.5' quadrangles, San Diego County, California: California Division of Mines and Geology Open-File Report 96-02, 1 p., map scale 1"=2000'.

United States Department of Agriculture, 1939, Stereographic black and white aerial photographs, Nos. AXN-204-72 and 73, flown April 16, 1939, scale 1"=1667'.

United States Department of Agriculture, 1953, Stereographic black and white aerial photographs, Nos. AXN-8M-95 and 96, flown April 11, 1953, scale 1"=1667'.

United States Coast and Geodetic Survey, 1887, Pacific coast topography northward from San Dieguito [River] Valley [to Batiquitos Lagoon], California, surveyed 8-1887, Register No. 1898 [T-1898], original map scale 1:10,000 [1"=833'].

United States Geological Survey, 1898, Oceanside, California, 15' topographic quadrangle map, scale 1"=1 mile, contour interval 25', (surveyed in 1891 and 1898).

United States Geological Survey, 1968-75, Encinitas, California, 7.5' topographic quadrangle map, scale 1"=2000', contour interval 20', photos flown 1947, 1967, and 1975.

Walsh, S.L., Prothero, D.R., and Lundquist, D.J., 1996, Stratigraphy and paleomagnetism of the Middle Eocene Friars Formation and Poway Group, southwestern San Diego County, California, in Prothero, D. R., and Emry, R.J., eds., The terrestrial Eocene-Oligocene transition in North America: Cambridge University Press, pp. 120-151.

Weber, F.H., Jr., 1963, Geology and mineral resources of San Diego County, California: California Division of Mines and Geology, County Report 3, 309 p. Geologic map scale 1"=2 miles.

Weber, F.H., Jr., 1982, Recent slope failures, ancient landslides, and related geology of the north-central coastal area, San Diego County, California: California Division of Mines and Geology, Open-File Report 82-12-LA, 77 p., geologic map scale 1"=2000'.

Wilson, K.L., 1972, Eocene and related geology of a portion of the San Luis Rey and Encinitas quadrangles, [northern] San Diego County, California [M.A. thesis]: University of California, Riverside, 135 p., geologic map scale 1"=2000'.

Woodring, W.P., and Popenoe, W.P., 1945, Paleocene and Eocene stratigraphy of northwestern Santa Ana Mountains, Orange County, California: U.S. Geological Survey Oil and Gas Investigations, Preliminary Chart 12.

Young, J.M., and Berry, R.W., 1981, Tertiary lithostratigraphic variations, Santa Margarita River to Agua Hedionda Lagoon, in Abbott, P. L., and O'Dunn, S., eds., Geologic investigations of the coastal plain, San Diego County, California: San Diego Association of Geologists field trip guidebook, April 25, 1981, pp. 33-51. Geologic map scale 1"=0.58 mile.

SAN DIEGO MUNICIPAL CODE

LAND DEVELOPMENT CODE

Coastal Bluffs and Beaches Guidelines

Adopted September 28, 1999
Amended June 6, 2000

TABLE OF CONTENTS

INTRODUCTION 32

SECTION I: EXPLANATION OF DEFINITIONS 32
- A. Coastal Bluff 32
- B. Sensitive Coastal Bluff 32
- C. Coastal Beach 33
- D. Coastal Bluff Edge 33
- E. Coastal Bluff Face 33

SECTION II: DESCRIPTION OF REGULATIONS 34
- A. 143.0143(a) Development on the Face of a Sensitive Coastal Bluff 34
- B. 143.0143(c) Irrigation on Coastal Bluffs 34
- C. 143.0143(f) Distance from Coastal Bluff Edge of Sensitive Coastal Bluffs 34
- D. 143.0143(g) Erosion Control Measures 35
- E. 143.0143(j) Visual Corridors for Sensitive Coastal Bluffs 35
- F. 143.0143(k) Vertical Public Access Easements for Sensitive Coastal Bluffs 35
- G. 143.0144(a) Development on Coastal Beaches 36
- H. 143.0144(c) Visual Corridors for Coastal Beaches 37
- I. 143.0144(d) and (e) Vertical and Lateral Easements for Coastal Beaches 37

SECTION III: BLUFF MEASUREMENT GUIDELINES 38
- A. Determination of Coastal Bluff Edge for Sensitive Coastal Bluffs 38
  - 1. Simple Bluff 38
  - 2. Step-like Bluff Formation 38
  - 3. Sensitive Coastal Bluff with a Seawall 39
  - 4. Modified Landform 39
  - 5. Sea Caves 39
  - 6. Gullies 40
  - 7. Coastal Canyons 40
- B. Measurement of Distance from Coastal Bluff Edge for Sensitive Coastal Bluffs 40

DIAGRAMS

- Diagram I-1: Coastal Bluff 32
- Diagram I-2: Sensitive Coastal Bluff 33
- Diagram I-3: Coastal Beach 33
- Diagram I-4: Coastal Bluff Face 34
- Diagram III-1: Simple Bluff 38
- Diagram III-2: Step-like Bluff Formation 38
- Diagram III-3: Sensitive Coastal Bluff with a Seawall 39
- Diagram III-4: Modified Landform 39
- Diagram III-5: Sea Caves 39
- Diagram III-6: Gully 40
- Diagram III-7: Coastal Canyon 40
- Diagram III-8: Distance from Coastal Bluff Edge 40

INTRODUCTION

The Coastal Bluffs and Beaches Guidelines are intended to assist in the interpretation and implementation of the development regulations for sensitive coastal bluffs and coastal beaches contained in Chapter 14, Article 3, Division 1, Environmentally Sensitive Lands Regulations. Every development proposed on a sensitive coastal bluff (within 100 feet of the bluff edge) or on a site containing a coastal beach (where the development will be within 100 feet of the beach) will be subject to the Environmentally Sensitive Lands regulations and will be evaluated for conformance with these guidelines as part of the review process for the required Site Development Permit unless the proposed development is exempt from the Environmentally Sensitive Lands Regulations pursuant to Section 143.0110(c). In addition to the findings required for the Site Development Permit, supplemental findings for environmentally sensitive lands must also be made to approve the development. A Coastal Development Permit will be required in addition to the Site Development Permit for all *coastal development* proposed within the Coastal Overlay Zone and which does not qualify for an exemption pursuant to Section 126.0407.

The Coastal Bluffs and Beaches Guidelines are divided into three sections as follows:

Section I: Explanation of Definitions

This section provides additional explanations of the definitions for terms pertaining to coastal bluffs and coastal beaches that are defined in Chapter 11, Article 3, Division 1, Land Development Terms. The distinction between coastal bluffs and sensitive coastal bluffs is clarified.

Section II: Description of Regulations

This section provides detailed explanations for specific regulations contained in the environmentally sensitive lands regulations. The Environmentally Sensitive Lands Regulations must be complied with and the Coastal Bluffs and Beaches Guidelines provide details on the regulations and explanations on how compliance can be achieved.

Section III: Coastal Bluff Measurement Guidelines

This section provides detailed guidelines and illustrations for determining the location of the bluff edge for sensitive coastal bluffs and measuring the required setbacks from the bluff edge.

SECTION I
EXPLANATION OF DEFINITIONS

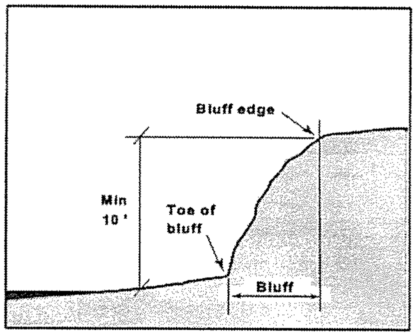
For each of the following terms, the definition is repeated (in italics) from Chapter 11, Article 3, Division 1, Land Development Terms, followed by additional information intended to clarify the definitions. The additional information provided is not part of the definition.

A. Coastal Bluff

Coastal Bluff means an escarpment or steep face of rock, decomposed rock, sediment, or soil resulting from erosion, faulting, or folding of the land mass that has a vertical relief of 10 feet or more and is located in the coastal zone.

A coastal bluff is a naturally formed precipitous landform that generally has a gradient of at least 200 percent (1:2 slope) with a vertical elevation of at least 10 feet. See Diagram I-1. The gradient of a coastal bluff could be less than 200 percent but the vertical elevation must always be at least 10 feet. A coastal bluff is a form of environmentally sensitive lands that is included in the definition of steep hillsides. The coastal bluff includes the bluff face which is all the area between the toe of the bluff and the bluff edge. Steep landforms meeting the criteria of coastal bluffs occur both inside and outside the Coastal Zone. These landforms and all other steep hillsides, both inside and outside the Coastal Zone, are regulated by the steep hillside regulations of the Environmentally Sensitive Lands Regulations (Section 143.0142) and are subject to the Steep Hillside Guidelines.

Diagram I-1: Coastal Bluff.

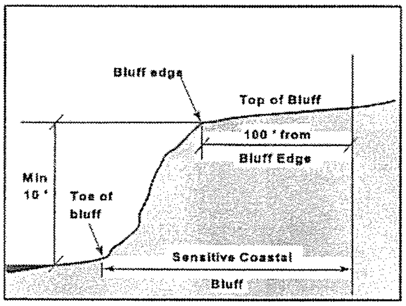


B. Sensitive Coastal Bluff

Sensitive Coastal Bluff means a coastal bluff that is designated within Hazard Category Numbers 41 through 47, inclusive, on the City's Geologic Hazard Maps plus the area of an additional 100-foot landward strip located landward and contiguous to the coastal bluff edge.

Sensitive coastal bluffs are a form of coastal bluffs that are generally located along the shoreline and adjacent to coastal beaches. Sensitive coastal bluffs include the bluff face and the area of the top of bluff located within 100 feet of the bluff edge. See Diagram I-2. Because of their location, sensitive coastal bluffs are regulated differently than other coastal bluffs (or steep hillsides). Although they technically meet the definition of steep hillsides, sensitive coastal bluffs are regulated by a separate regulation section in the Environmentally Sensitive Lands Regulations (Section 143.0143) and are subject to the Coastal Bluffs and Beaches Guidelines.

Diagram I-2: Sensitive Coastal Bluff.

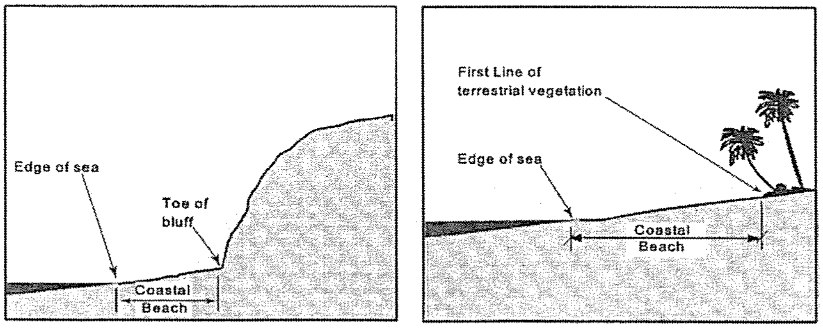


C. Coastal Beach

Coastal Beach means the land between the edge of the sea and the first line of terrestrial vegetation or development or the toe of an adjacent sensitive coastal bluff, whichever is most seaward.

A coastal beach is an environmentally sensitive land that is generally defined as the land lying between the shoreline and the toe of the adjacent sensitive coastal bluff. If a seawall exists, the landward limit of the beach is still the toe of the bluff. The seawall would represent a seaward encroachment onto the beach. If no seawall or bluff exists, the landward limits of the coastal beach shall be the first line of terrestrial vegetation. See Diagram I-3.

Diagram I-3: Coastal Beach.



D. Coastal Bluff Edge

Coastal Bluff Edge means the termination of the top of a sensitive coastal bluff where the downward gradient of the land surface begins to increase more or less continuously until it reaches the general gradient of the coastal bluff face.

The coastal bluff edge is the upper termination of a coastal bluff face where the downward gradient of the top of bluff increases more or less continuously until it reaches the general gradient of the bluff face. When the top edge of the coastal bluff is rounded away from the bluff face as a result of erosional processes related to the presence of the bluff face, the coastal bluff edge shall be defined as that point at the top of bluff nearest the bluff face beyond which the downward gradient of the land surface increases more or less continuously until it reaches the general gradient of the bluff face. If evidence shows that the rounding is a result of geologic processes other than processes related to the presence of the bluff face, the location of the coastal bluff edge shall be determined through consideration of the available geologic data.

In a case where there is a step like feature at the top of the coastal bluff, the landward edge of the topmost riser shall be considered the coastal bluff edge.

The coastal bluff edge is a continuous line across the entire length of the coastal bluff on the premises from which all bluff setbacks shall be measured.

See Section III, part A for details on determining the location of the coastal bluff edge for sensitive coastal bluffs.

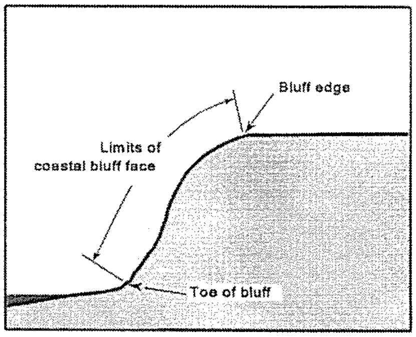
E. Coastal Bluff Face

Coastal Bluff Face means that portion of a sensitive coastal bluff lying between the toe of the existing bluff and the coastal bluff edge.

The coastal bluff face is vertical or contains a relatively steep consistent gradient and may be rounded at the top, adjacent to the coastal bluff edge. When the bluff is rounded at the top as a result of erosional processes due to the presence of the bluff face, the bluff face shall include the rounded portion. The coastal bluff face of a sensitive coastal bluff (at least at the toe of the bluff) is typically subject to marine erosion. See Diagram I-4.

Generally, no development is permitted on the face of a sensitive coastal bluff, except as permitted in Section 143.0143(h) and (i) of the Environmentally Sensitive Lands Regulations.

Diagram I-4: Coastal Bluff Face



SECTION II DESCRIPTION OF REGULATIONS

The regulations for development proposed on a sensitive coastal bluff are located in Section 143.0143. The regulations for development proposed on a site containing a coastal beach are located in Section 143.0144. The following guidelines are intended to aide in the interpretation and implementation of pertinent development regulations in these sections. The numbers referenced for each development regulation refer to the Code section numbers of the Environmentally Sensitive Lands Regulations. The text provided for each regulation does not repeat the Code language but rather restates the regulation with more details and explanations.

A. 143.0143(a) Development on the Face of a Sensitive Coastal Bluff

In general, development is not permitted on the face of a sensitive coastal bluff. Only erosion control facilities, essential public drainage facilities, and public physical beach access facilities are permitted on the face of a sensitive coastal bluff, subject to the regulations in Section 143.0143(g) and (h). Other uses identified in Section 143.0130(a) are permitted on the sensitive coastal bluff, landward of the bluff edge, and only in compliance with the required setbacks from the bluff edge, pursuant to Section 143.0143(f).

Where a stepped bluff landform exists, all of the area of the site that is seaward of the bluff edge (measured at the uppermost riser within the premises) shall be considered the bluff face. This shall include the generally horizontal steps that are below the uppermost riser.

B. 143.0143(c) Irrigation on Coastal Bluffs

Plant material used on or adjacent to coastal bluffs shall be native or naturalized to minimize the need for irrigation beyond initial plant establishment. Permanent irrigation is not permitted on coastal bluffs. Temporary irrigation, consisting of microsprayers and/or drip irrigation, may be permitted on a case-by-case basis as necessary to establish native or naturalized plant materials. Irrigation shall be removed from the bluff upon establishment of the plant materials.

C. 143.0143(f) Distance from Coastal Bluff Edge of Sensitive Coastal Bluffs

Development proposed on a sensitive coastal bluff, including primary and accessory structures, and grading, shall be located at least 40 feet landward from the coastal bluff edge, except as follows:

1. A distance of more than 40 feet from the coastal bluff edge may be required based on current geologic conditions.

2. Development may be located less than 40 feet but not less than 25 feet from the coastal bluff edge if there is evidence in a geology report that the site is stable enough to support the development at the proposed distance and if the development will neither be subject to nor contribute to significant geologic instability or require a shoreline or bluff erosion control device. In determining the stability of the sensitive coastal bluff, consideration shall be given to the rate of bluff retreat to determine whether the proposed development will be impacted within a reasonable economic life-span, taken to be 75 years. If a development is approved with a less-than-40-foot distance to the coastal bluff edge, future erosion control measures are precluded. Air-placed concrete, retaining walls and seawalls will only be permitted when the principal structure, or public improvements not capable of being relocated, are in eminent danger. Less environmentally damaging alternatives that reduce risk and avoid the need to significantly alter the natural landforms of the beach and/or bluff shall be considered as feasible.

[*NOTE: If a seawall (or other stabilization/erosion control measure) has been installed due to excessive erosion on a premises, that premises shall not qualify for a reduction of the required 40-foot distance to the coastal bluff edge. Since the instability of the coastal bluff necessitated the installation of the seawall, the coastal bluff would not be considered stable enough to support development within the 40-foot bluff edge setback.*]

3. A distance of five feet from the coastal bluff edge may be granted for landscape features and accessory structures that are located at grade so that they are not elevated at the base or constructed with a raised floor and are capable of being relocated. Permitted features and structures include landscaping, paved walkways, at-grade decks,

unenclosed patios, open shade structures, lighting standards, fences and walls, seating benches, and signs. A distance of five feet from the coastal bluff edge may not be granted for buildings, garages, carports, pools, spas, and raised decks with load bearing support structures.

4. Open fences may be permitted closer than 5 feet to the coastal bluff edge only if necessary to provide for public safety and to protect resource areas accessible from public right-of-ways or on public parkland.

D. 143.0143(g) Erosion Control Measures

Erosion control measures include, but are not limited to, retaining walls, air-placed concrete, and other structures, devices or methods appropriate for controlling or minimizing erosion of the sensitive coastal bluff. All feasible methods of erosion control shall be considered, including sandbags, revegetation, and drainage diversion and improvements.

Erosion control measures do not include those preventive measures required for soil stabilization or drainage.

Air-placed concrete, retaining walls, and buttress fills shall only be used to protect existing principle structures, or public improvements not capable of being relocated, and if it is determined that no other feasible less impacting method will accomplish the erosion control. Alternatives may include relocation or removal of existing improvements, if feasible, to avoid significant alteration of the bluff. Such measures shall not be used to accommodate proposed development nor to increase the area of the top of bluff. The installation of erosion control measures shall not affect the location of the coastal bluff edge.

E. 143.0143(j) Visual Corridors for Sensitive Coastal Bluffs

A site-specific analysis shall be conducted to determine and quantify the impact of the proposed development upon visual access to the ocean. If a visual corridor is feasible, the appropriate corridor shall be required as a condition of development approval pursuant to Section 132.0403. If there is an existing or potential public view on premises that lie between the shoreline and the first public roadway, but the site is not designated in a land use plan as a view corridor, it is intended that views to the ocean shall be preserved or restored by deed restricting required side yard setback areas to cumulatively form functional view corridors and to prevent a walled effect from development.

If there is an existing or potential pubic view and the site is designated in the applicable land use plan as a view corridor or within a public view-shed, it is intended that such critical views to the ocean be maintained or restored by designing and siting the coastal development in such a manner as to preserve the identified pubic view. Consideration may be given to the development of the adjacent property in determining the appropriate width of the view corridor on the subject premises, so that the overall width of the corridor is at least 10 feet when measured across both properties. Any such required corridor shall be created and approved by the City Manager prior to the commencement of any construction on the premises.

No structures or other obstructions that will impede views shall be installed within the boundaries of any required visual corridor. Open fencing and landscaping may be installed within the view corridor provided such improvements do not significantly obstruct public views to the ocean. Landscaping shall be maintained such that during growing stage and at maturity, it will not encroach into the view corridor or obstruct public views to the ocean.

When remodeling is proposed to an existing structure and the existing development is to be retained which precludes the etablishment of a 10-foot-wide visual corridor, the preservation of any partial existing visual corridor on the premises will be accepted provided that the existing visual corridor is not reduced through the proposed remodeling.

F. 143.0143(k) Vertical Public Access Easements for Sensitive Coastal Bluffs

A site-specific analysis shall be conducted to determine and quantify the impact of the proposed development upon vertical access to the ocean. If the impacts of the proposed development justify in nature and scope the need for such access, the appropriate easements shall be required as a condition of development approval. Any such required easements shall be created and approved by the City Manager prior to the commencement of any construction on the premises.

No structures or other obstructions that will impede access shall be installed within the boundaries of any required vertical access easement. Open fencing and landscaping may be installed within vertical easements provided such improvements do not hinder access or significantly obstruct views to the ocean.

If vertical access is determined to be required on a premises where there is evidence that such access exists, the existing access shall be retained, if feasible, through the easement requirement. If not feasible, an alternative access easement shall be provided on the same premises.

In determining whether the proposed development justifies the need for the requirement of a vertical public access easement, the following factors shall be considered:

- Appropriateness of access
- Privacy rights of landowner
- Existing public access
- Historic public use
- Intensification of land use
- Habitat values of the site
- Topographic constraints of the site
- Fragility of environmentally sensitive lands in the vicinity
- Nature of development in the vicinity
- Development's effect on current and projected demands for access and recreation
- Physical obstructions and the aesthetic, visual or recreational value of public use areas
- Recreational needs of the public
- Impact of development on public's use of beach areas

G. 143.0144(a) Development on Coastal Beaches

Any site that contains any portion of a coastal beach shall be subject to a Site Development Permit unless the proposed development qualifies for an exemption pursuant to Section 143.0110(c). A Coastal Development Permit will be required, regardless of whether a Site Development Permit is required, for all coastal development proposed within the Coastal Overlay Zone and which does not qualify for an exemption pursuant to Section 126.0407. The uses permitted on the coastal beach are only those listed in Section 143.0130(b), all of which are public facilities, with the exception of shoreline protective works. If a privately owned premises contains a coastal beach, the private development shall occur on the portion of the premises that does not contain the coastal beach. If no such area exists or if such area is infeasible for development, a deviation from the Environmentally Sensitive Lands Regulations must be requested with the Site Development Permit. However, deviations from the Environmentally Sensitive Lands Regulations in the Coastal Overlay Zone shall be approved only after the decision maker makes an economically viable use determination and findings pursuant to Section 126.0708(e).

In review of permit applications for shoreline protective works, the City Manager shall determine if the protective device is located on State tidelands or lands subject to the pubic trust, or if it is located on City or publicly owned beach or on private property. The ownership of the beach and location of the protective device will determine whether the Coastal Development Permit is issued by the City or by the Coastal Commission. The Coastal Commission retains Coastal Development Permit authority for development proposed on tidelands, submerged lands or public trust lands; therefore, a mapped representation of the mean high tide line as it currently exists must accompany any permit application for a shoreline protective device.

Where erosion control devices are proposed to encroach upon or affect any portion of property owned by the City of San Diego or other public agency, or on lands subject to the public trust, the applicant shall provide written permission from the City Manager or pubic property owner before approval of any permit. If the protective device encroaches directly on or otherwise affects State tidelands or publicly owned property, the property owner shall be required to compensate for the use of public property and to mitigate the impacts of the protective device on public beaches.

Additionally, Section 143.0144 of these regulations requires that shoreline protective devices incorporate mitigation for adverse impacts on shoreline sand supply. Such impacts include, but are not limited to, loss of the sandy beach on which the structure is located, fixing the back beach, halting the supply of bluff material to the littoral zone, increasing scour and causing changes to the beach immediately seaward of and adjacent to the protective device. The submitted geology report must include site-specific information that will allow the City Manager to determine whether the proposed protective device will have any of these or other adverse effects on shoreline sand supply, use of public beach, the beach area or the bluff landform, wither immediately or over time. The City Manager will consider all feasible design changes that will eliminate or minimize any identified impact from the proposed project. Examples of design changes include, but are not limited to, modifications to the type of structure, relocation of the proposed structure further landward, reducing the size of the extent of the protective device, etc.

Some of the effects which a shoreline protective device may have on natural shoreline processes can be quantified. The Coastal Commission has developed a Beach Sand Mitigation Program within the County of San Diego which includes a methodology by which the following impacts associated with protective devices can be quantified:

1. Loss of beach area on which the structure is located
2. The long-term loss of beach which will result when the back beach location is fixed on an eroding shoreline
3. The amount of material which would have been supplied to the beach if the back beach of bluff were to erode naturally

The methodology is found in the Report on In-Lieu Fee Beach Sand Mitigation Program — San Diego County dated January 1997, available from City staff. The methodology is not applicable to all site conditions, however, in many cases, it can be used to calculate the beach area displaced and the amount of bluff material which does not reach the beach, as a result of a seawall, and to calculate the amount of sand which would be required to replace that lost beach area in the project vicinity. This amount of material is then converted to a fee by multiplying the amount of material times the cost of transporting that material to the beach. To derive these amounts, the methodology uses the information specific to the proposed project, such as the design life and amount of seaward encroachment. Also required is information specific to the project site, such as the height of bluff, width of property, percentage of sand in the bluff material and the predicted rate of erosion that was used to determine the need for protection of the existing principal structure.

The methodology quantifies some of the impacts caused by a protective device in terms of area of beach and volume of sand, but it is not considered the only means to identify impacts to sand supply and required mitigation. Where unavoidable impacts to shoreline sand supply area associated with an approved shoreline protective device, mitigation shall be required, and may include a mitigation fee to be used for beach replenishment within the same littoral cess of the project. The fee shall be roughly proportional to the value of the beach area lost as a result of the approved protective device and shall be used for beach replenishment which is directly related to the impact of the project. When applicable, the above reference methodology may be utilized to calculate the mitigation fee. The fee shall be deposited in the City of San Diego Beach Sand Mitigation Fund held by the San Diego Association of Governments.

H. 143.0144(c) Visual Corridors for Coastal Beaches

A site-specific analysis shall be conducted to determine and quantify the impact of the proposed development upon visual access to the ocean. If a visual corridor is feasible, the appropriate corridor shall be required as a condition of development approval pursuant to Section 132.0403. If there is an existing or potential public view on premises that lie between the shoreline and the first public roadway, but the site is not designated in a land use plan as a view corridor, it is intended that views to the ocean shall be preserved or restored by deed restricting required side yard setback areas to cumulatively form functional view corridors and to prevent a walled effect from development.

If there is an existing or potential public view and the site is designated in the applicable land use plan as a view corridor or within a public view-shed, it is intended that such critical views to the ocean be maintained or restored by designing and siting the coastal development in such a manner as to preserve the identified public view. Consideration may be given to the development of the adjacent property in determining the appropriate width of the view corridor on the subject premises, so that the overall width of the corridor is at least 10 feet when measured across both properties. Any such required corridor shall be created and approved by the City Manager prior to the commencement of any construction on the premises.

No structures or other obstructions that will impede views shall be installed within the boundaries of any required visual corridor. Open fencing and landscaping may be installed within the view corridor provided such improvements do not significantly obstruct public views to the ocean. Landscaping shall be maintained such that during growing stage and at maturity, it will not encroach into the view corridor or obstruct public views to the ocean.

When remodeling is proposed to an existing structure and the existing development is to be retained which precludes the establishment of a 10-foot-wide visual corridor, the preservation of any partial existing visual corridor on the premises will be accepted, provided that the existing visual corridor is not reduced through the proposed remodeling.

I. 143.0144(d) and (e) Vertical and Lateral Easements for Coastal Beaches

A site-specific analysis shall be conducted to determine and quantify the impact of the proposed development upon vertical and lateral access to the ocean. If the impacts of the proposed development justify in nature and scope the need for such access, the appropriate easements shall be required as a condition of development approval. Any such required easements shall be created and approved by the City Manager prior to the commencement of any construction on the premises.

No structures or other obstructions that will impede access shall be installed within the boundaries of any required easement. Open fencing and landscaping may be installed within a vertical easement provided such improvements do not hinder access to the ocean.

If vertical or lateral access is determined to be required on a premises where there is evidence that such access exists, the existing access shall be retained, if feasible, through the easement requirement. If not feasible, an alternative access easement shall be provided on the same premises.

If a beach or headland width is less than 25 feet, the lateral access easement shall include the entire beach or headland area.

In determining whether the proposed development justifies the need for the requirement of a vertical public access easement or a lateral access easement, the following factors shall be considered:

- Appropriateness of access
- Privacy rights of landowner
- Existing public access
- Historic public use
- Intensification of land use
- Habitat values of the site
- Topographic constraints of the site
- Fragility of environmentally sensitive lands in the vicinity
- Nature of development in the vicinity
- Development's effect on current and projected demands for access and recreation
- Physical obstructions and the aesthetic, visual or recreational value of public use areas
- Recreational needs of the public
- Impact of development on public's use of beach areas

SECTION III
BLUFF MEASUREMENT GUIDELINES

The following guidelines provide details on determining the location of the bluff edge for sensitive coastal bluffs and measuring the required bluff edge setback.

A. Determination of Coastal Bluff Edge for Sensitive Coastal Bluffs

The following are examples of typical sensitive coastal bluff configurations with the determination of the coastal bluff edge identified:

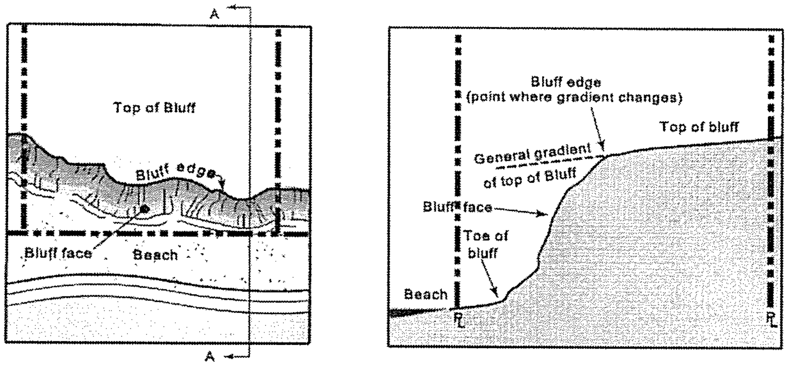
1. Simple Bluff

The coastal bluff edge is a line across the sensitive coastal bluff at the seaward edge of the top of bluff. The line of the coastal bluff edge is formed by measuring the uppermost point of change in gradient at any location on the subject premises. See Diagram III-1.

2. Step-like Bluff Formation

If the sensitive coastal bluff contains a step-like feature, the coastal bluff edge shall be measured at the change in gradient of the uppermost step within the subject premises. See Diagram III-2.

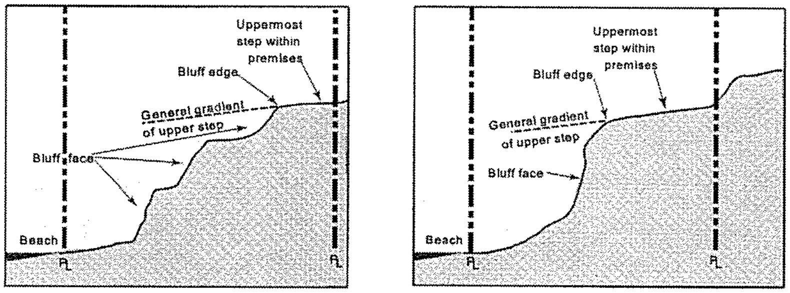
Diagram III-1: Simple Bluff.



Simple Bluff
Plan View

Simple Bluff
Section A-A

Diagram III-2: Step-like Bluff Formation.



Multiple Steps within Premises

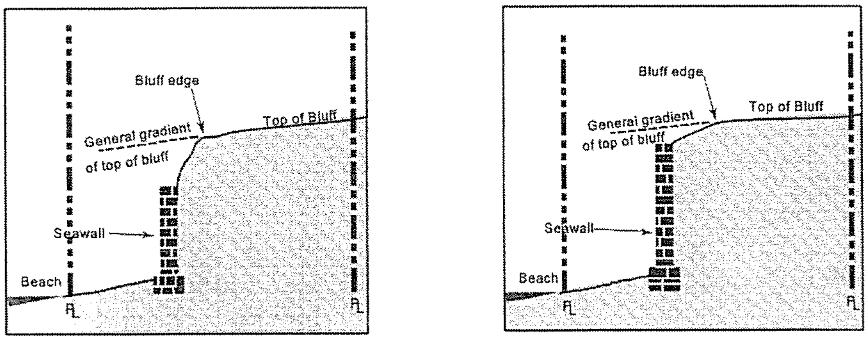
Single Step within Premises

3. Sensitive Coastal Bluff with a Seawall

If the coastal bluff face has been partially altered with the installation of retaining walls, seawalls, or other device, the coastal bluff edge shall be considered the preexisting change in gradient and shall continue to be measured as described in (A), above. That is, the installation of a seawall shall not affect the location of the coastal bluff edge. See Diagram III-3.

[NOTE: If a seawall has been installed on a premises due to excessive erosion, that premises shall not qualify for development at a reduced distance from the coastal bluff edge. Since the instability of the sensitive coastal bluff necessitated the installation of the seawall, the sensitive coastal bluff would not be considered stable enough to support development within the 40-foot distance to the coastal bluff edge.]

Diagram III-3: Sensitive Coastal Bluff with a Seawall.



Seawall with Extreme Gradient Change

Seawall with Gradual Gradient Change

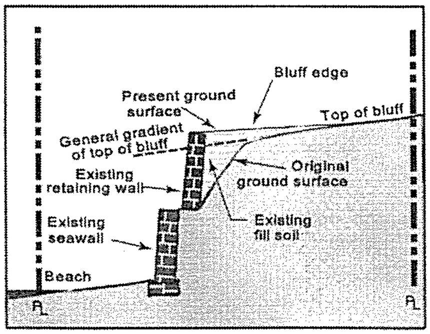
4. Modified Landform

Where a coastal bluff face has been altered by grading and/or retaining wall, the coastal bluff edge shall be determined from the original geometry of the natural ground surface, projected to the present ground surface. See Diagram III-4. This may be determined by geotechnical investigation and/or historic documents such as photographs and maps.

5. Sea Caves

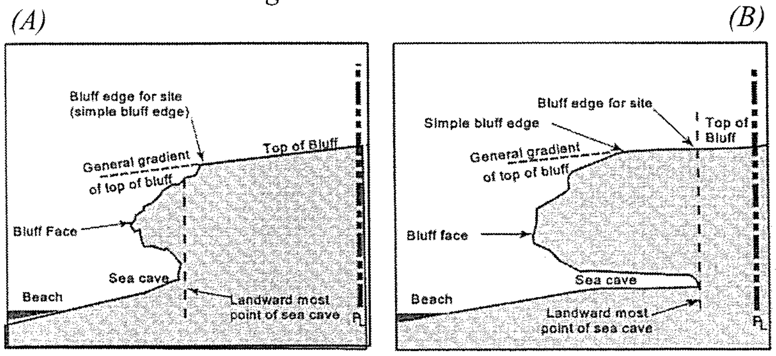
Where a sea cave (a natural cavity or recess beneath the surface of the earth that is formed by or a result of marine erosion) or overhang exists, the coastal bluff edge shall be either the simple bluff edge (See Diagram III-5(A)) or a line following the landward most point of the sea cave projected to the ground surface above (See Diagram III-5(B)), whichever is more landward.

Diagram III-4: Modified Landform.



Modified Landform

Diagram III-5: Sea Caves.



Shallow Sea Cave

Deep Sea Cave

6. Gullies

Where a gully (a small, local erosional feature that results in a minor perturbation of the bluff face) has developed that does not accommodate drainage from off-site, the coastal bluff edge shall follow the landward limits of the gully. See Diagram III-6.

7. Coastal Canyons

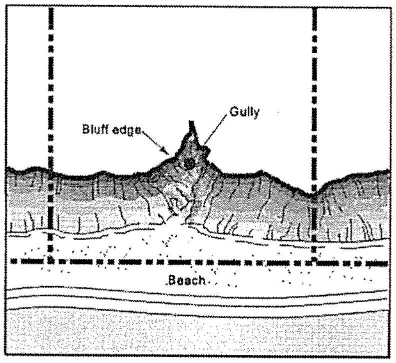
Where a site is bounded on at least one side by a coastal canyon (a large, established regional drainage course that traditionally accepts runoff from off-site), the coastal bluff edge is defined as the portion of the site which drains directly into the ocean. That portion of the site which drains first to the canyon (landward of the drainage divide) is not considered to be a sensitive coastal bluff. See Diagram III-7.

B. Measurement of Distance from Coastal Bluff Edge for Sensitive Coastal Bluffs

The distance from the coastal bluff edge required for development on a sensitive coastal bluff is measured landward and perpendicular to every point along the coastal bluff edge.

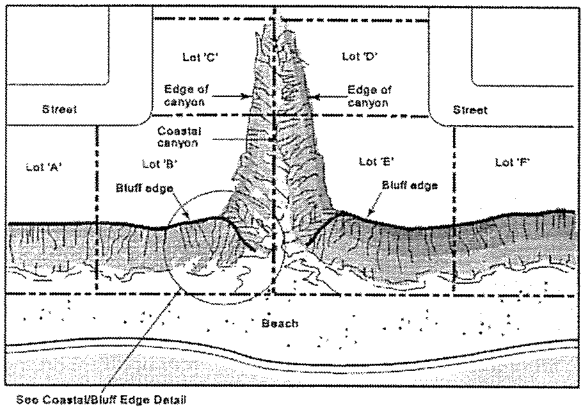
The line of the required distance from the coastal bluff edge will result in a line that is parallel to the coastal bluff edge. See Diagram III-8.

Diagram III-6: Gully.



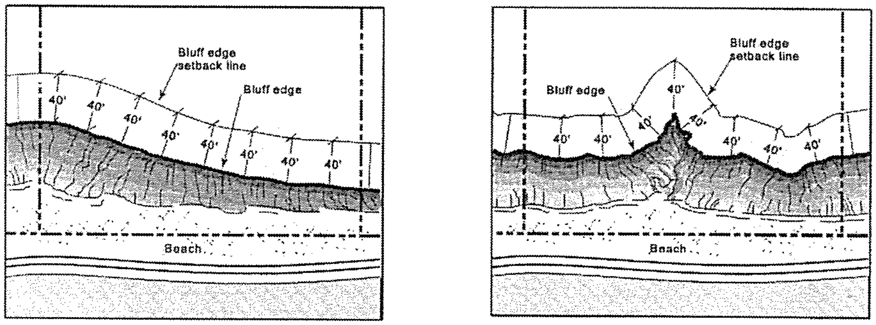
Gully

Diagram III-7: Coastal Canyon.



Coastal Canyon

Diagram III-8: Distance from Coastal Bluff Edge.



Distance from Coastal Bluff Edge

Distance from Coastal Bluff Edge

Conflict in the California Coastal Act: Sand and Seawalls

*Todd T. Cardiff**

INTRODUCTION

> *"Seawalls damage virtually every beach they are built on. If they are built on eroding beaches — and they are rarely built anywhere else — they eventually destroy [the beach]."*[1]

Coastal landowners in California are building seawalls at an alarming rate.[2] Currently, shoreline armoring[3] occupies between 130 and 150 miles of California's 1100-mile coastline.[4] Unfortunately, seawalls have a disastrous effect on the public beach.[5] On an eroding beach, seawalls will eventually destroy the beach, leaving no dry sand area for recreation.[6] Furthermore, beach replenishment projects, the primary method for restoring beaches destroyed by seawalls, are extremely expensive and increase the width of the recreational beach for only a very short time.[7]

Beaches are vital to California's economy, generating fourteen billion tourism dollars per year.[8] From a purely economic viewpoint, California's beaches are considerably more important to the overall economy than the property that shoreline armoring is designed to protect. Shoreline armoring only benefits the incredibly small minority of the population that owns property directly on the coast, while it decreases access to the millions of people who flock to the beach every year.[9]

Coastal property owners claim they have both constitutional and statutory rights to protect their property with shoreline armoring.[10] Under the current interpretation of the Coastal Act,[11] Coastal landowners are permitted to build a seawall if their primary structure is endangered by erosion. However, as this Comment will demonstrate, it was never the Legislature's intent to protect structures built after 1976.

In 1976, when the California legislature passed the Coastal Act, the legislature was aware of the adverse impacts of seawalls.[12] California Coastal Act section 30253 mandates that:

> New development shall . . . [a]ssure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs.[13]

New development must have sufficient setback from the edge of a bluff or high tide line so that a seawall is not needed in the future. Unfortunately, coastal landowners continue to build too close to the shoreline,[14] often intentionally subverting the Coastal Act in exchange for a better view or an increase in the floor area of their coastal home.[15] As the shoreline erodes to within ten or fifteen feet of the house, the coastal homeowner then argues that the Coastal Act guarantees shoreline protection because their home is in imminent danger of destruction from shoreline erosion.[16]

Coastal Act section 30235 states:

> Revetments, breakwaters, groins, harbor channels, seawalls, cliff retaining walls and other shoreline construction that alters natural shoreline processes shall be permitted to protect existing structures . . . in danger from erosion when designed to minimize or mitigate adverse impacts to shoreline sand supply . . .[17]

As Coastal Act section 30235 is currently interpreted, there is a policy conflict between the requirement that all new development have sufficient setback so that shoreline armoring is unnecessary in the future and the policy of protecting existing structures in danger from erosion. The ultimate question in resolving this conflict is: What is the definition of "existing structure"?

This Comment explores the policies and the current conflict with shoreline armoring in California. It begins with a discussion of shoreline processes, explaining the destructive force of shoreline armoring. Next, the conflict between Coastal Act sections 30253 and 30235 is more fully explored, with an eye towards understanding the legislative history and the intent of the legislature. The coastal property owners' claim that building a seawall is a constitutional right is examined by investigating current case law, both within and outside of California. Finally, three options to resolve this conflict are presented: legislative, administrative, and judicial.

---

* J.D. Candidate, April 2002, California Western School of Law; B.A., 1995 California Polytechnic State University at San Luis Obispo; Executive Committee Member, San Diego Chapter of the Surfrider Foundation; Executive Editor, California Western International Law Journal.

SHORELINE PROCESS AND SEAWALLS

Shoreline armoring destroys the beach in three main ways: occupation loss, passive erosion, and active erosion.[18] *Occupation loss* is simply the area of the public beach that is physically occupied by the seawall.[19] *Passive erosion* is the narrowing of the beach in front of a seawall because seawalls fix in place the back end of the beach, preventing the retreat of the bluff or shoreline, while the lower beach continues to erode.[20] *Active erosion* is sand loss caused by waves rebounding off of the seawalls themselves and scouring away the sand.[21]

The first step in understanding the damaging nature of seawalls is to understand fundamental beach processes. Beaches in California are created from sediment transported to the ocean by rivers, streams, and eroding bluffs.[22] Once the sand reaches the coastline, the sand is transported along the coast by side-shore currents, also called the long-shore currents or littoral drift.[23] Beaches are sometimes characterized as rivers of sand because of this constant movement.[24] Unfortunately this river of sand is often cut off at its source by dams, development, flood control projects, and seawalls; and once the sediment does reach the beach, it is often held up by harbors, jetties and groins.[25]

The recreational area of the beach, also called the dry sand area,[26] makes up only a small portion of the total sand at a beach.[27] Ninety percent of the beach is underwater.[28] A beach with an inadequate supply of sand input may experience increased coastal erosion (the shoreline will move back), but the width of the beach, in the long run, will not change.[29] However, if the back part of the beach is fixed by a seawall, the shoreline cannot move back. The sandy beach will continue to erode, and eventually the dry sand area of the beach will disappear.[30] In some cases, seawalls will artificially increase the slope of the beach profile.[31] The importance of this concept cannot be overstated, because it is crucial to an understanding of a number of different cause-and-effect relationships in coastal processes.[32] For example, people are often struck by how temporary the benefits of beach replenishment are.[33] The increases in the beach width may last only one season.[34] A sand-starved beach has a steep profile. When sand is added to the upper beach, the beach simply adjusts, seeking equilibrium and the beach profile is temporarily flattened.[35]

On a natural beach, the sand will act as a shock absorber protecting the shoreline from wave energy.[36] High-energy waves will take a portion of the dry sand area and coastal bluff and redistribute it underwater to form sand bars.[37] These sand bars will cause substantial wave energy to disperse before it reaches the shoreline.[38] In many areas of California, a steep narrow beach will be backed by a cliff, which will be subjected to intense wave energy.[39] Eventually, the cliff will fail, adding more sand to the system and again flattening the beach profile.[40]

On a sand-starved beach backed by seawalls, however, waves break closer to shore and wave energy against the bluff or seawall increases.[41] The land behind the seawall will not erode (which is the purpose of a seawall), yet the shoreline will continue to retreat adjacent to the wall. Studies have shown that the rate of erosion to the shoreline adjacent to a seawall will actually increase due to wave reflection and increased wave energy surrounding a seawall.[42] This has led preeminent coastal geologists to note that once shoreline armoring begins, it seldom stops, because neighboring properties will soon build a seawall to protect their property as well.[43] Furthermore, the increased wave energy rebounding off of seawalls will exacerbate sand loss on an already depleted beach.[44]

In California, the wallification of the coast is reaching epic proportions.[45] In 1990, seawalls armored over 130 miles of shoreline, approximately 12% of California's 1100-mile shoreline,[46] and the wallification of the coast has increased in the last decade.[47] It is estimated that 25% of the total sand supply is contributed by bluff erosion.[48] Even accepting this estimate, armoring 12% of the coast creates a significant cumulative effect on the volume of sand placed into the coastal system.

The ultimate impact of the current shoreline-armoring trend is the loss of the public beach. According to State and Federal law, the beach below the mean high-tide line is owned by the State and held in trust for the people.[49] In many areas of California, the public owns the dry sand area of the beach, but even in areas where dry sand area is privately owned, the public has the right to use the beach for access to the public land.[50] If halting the natural retreat of the coastline narrows the recreational beach and harms public property,[51] should California allow property owners to protect their property at the expense of public property? Should nuisance law prevent the cumulative destruction of public property? Does it make economic sense to favor the protection of private property when public beaches are the most popular tourist destination in the United States,[52] considering the expense of sand replenishment?[53]

HISTORY OF THE CALIFORNIA COASTAL ACT

Legislative Intent

In the late 1960s and early 1970s Californians became increasingly aware of the need for a comprehensive plan to conserve and preserve the State's 1100-mile coastline.[54] In 1970, less than one quarter of California's coast was legally accessible to the public,[55] and coastal land was being subjected to a tremendous amount of public and private development at the expense of long-term conservation.[56] Development interests controlled the majority of California's city and county planning commissions.[57] It was evident that the power to make coastal development decisions needed to be removed from local jurisdictions and vested in a statewide agency.[58] Local control of coastal development decisions, in essence, amounted to uncontrolled development.

Reacting to concerns by environmentalists and the impending Federal Coastal Zone Management Act,[59] the California Legislature introduced six coastal act bills from 1970 to 1971, none of which passed into law.[60] In 1972, frustrated by the inability of the Legislature to pass a strong coastal act bill, conservationists successfully mounted a petition drive to get a coastal initiative on the ballot.[61] Proposition 20, the California Coastal Zone Conservation Act of 1972,[62] passed with over 55% of the vote despite well-funded opposition.[63]

Proposition 20 created one state-level and six regional coastal commission boards to review all coastal development permits. In addition, the coastal commissions were to submit a detailed coastal development plan to the Legislature by December 1, 1975. Most of the policies and suggested language in the California Coastal Plan was adopted as the California Coastal Act of 1976.[64]

The Legislative Record

The legislative record supports the proposition that Coastal Act section 30235 was, in fact, simply a grandfather clause, intended to protect only structures existing before 1976. The legislative record displays this in three main ways. First, the Coastal Act was written by environmentalists and opposed by industry. The intent of the bill can be gleaned from reading the 1975 Coastal Plan from this context. Second, an analysis of the textual evolution of the bill in the legislative record supports the "grandfather clause" contention, because "existing" was intentionally inserted into the final version of the bill. Finally, a comparison of the language of the Coastal Act to the competing coastal act bills, which were not passed into law, demonstrates a fundamentally different approach to shoreline armoring. A thorough analysis of the legislative record leaves little doubt that Coastal Act section 30235 intended to protect only those structures existing at the time of the passage of the Coastal Act.

The Coastal Alliance consisted of a coalition of environmental groups specifically formed to push for comprehensive legislation for the preservation of the California coast.[65] Unfortunately, legislative efforts to pass comprehensive coastal conservation bills were repeatedly killed off in committee by special interest groups.[66] In 1972, frustrated by the lack of success in the legislature, the Coastal Alliance took a strong coastal bill that had died in committee, stripped it of its "compromise" amendments, and presented the bill to the public as Proposition 20.[67] The Coastal Act was a bill written by environmentalists, not developers or legislative representatives.[68]

Proposition 20, the California Coastal Zone Conservation Act of 1972, created one state-level Coastal Commission and six regional Coastal Commissions, which were to oversee development and planning until a comprehensive Coastal Act could be enacted.[69] Additionally, the Coastal Commissions were to "[p]repare a comprehensive, coordinated, enforceable [coastal development] plan for the orderly, long-range conservation and management of the natural resources of the coastal zone,"[70] and "on or before December 1, 1975, . . . submit [the plan] to the legislature for its adoption and implementation."[71] Many of the recommendations and findings included in the 1975 California Coastal Plan were implemented into the California Coastal Act, primarily because the coastal act bill, SB 1277 (Smith-Beilenson), supported by conservationists, was enacted over competing developer-friendly bills.[72] The policies and recommendations of the Coastal Plan and, subsequently, SB 1277 (Coastal Act) were intended to protect natural resources over development.[73]

Legislative Intent as Determined by the 1975 California Coastal Plan

The California Coastal Plan of 1975 (Coastal Plan), mandated by Proposition 20, became the primary basis for SB 1277 (Smith-Beilenson), which was eventually adopted as the Coastal Act of 1976.[74] The importance of the Coastal Plan is explicitly recognized in Coastal Act section 30002(a), which states, "The California Coastal Zone Conservation Commission...has prepared a plan for the orderly, long-range conservation, use and management of the natural, scenic, cultural, recreational, and man-made resources of the coastal zone." Coastal Act section 30002(b) states, "Such plan contains a series of recommendations which require implementation by the Legislature and that some of those recommendations are appropriate for immediate implementation as provided for in this division while others require additional review." It is evident from the language, however, which recommendations contained in the 1975 Coastal Plan required additional legislation for future implementation and which recommendations were codified within the Act.[75] By comparing the language of the Plan with that of the Coastal Act, it is clear that the Plan with regard to bluff setbacks and shoreline protection was codified.

The California Coastal Plan also sheds light on what the Commissioners and Legislature considered important in 1976. The first indication of concern about seawalls appears in the "Major Findings" section of the Plan. The purpose of the Plan is evident from its title: Protect Against Harmful Effects of Seawalls, Breakwaters, and Other Shoreline Structures. It states: "Seawalls, breakwaters, groins, and other structures near the shoreline can detract from the scenic appearance of the oceanfront and can affect the supply of beach sand."[76] The Plan limits the construction of shoreline structures to those necessary to protect existing buildings and public facilities and for beach protection and restoration. Special design considerations were proposed to ensure continued sand supply to beaches, to provide for public access, and to minimize the visual impact of the structures.[77]

This language (as well as other language encompassed in Policy 19 of the Coastal Plan) is very similar to the language encompassed in section 30235. Policy 19 states:

> Revetments, breakwaters, groins, harbor channels, seawalls, cliff retaining walls, and other such construction that alters natural shoreline processes shall be permitted only when designed to eliminate or mitigate adverse impacts on shoreline sand systems and when required (1) to maintain public recreation areas or to serve necessary public service . . . where there is no less environmentally harmful alternative, or (2) to protect principal structures of existing development that are in danger from present erosion where the coastal agency determines that the public interest would be better served by protecting the existing structures than in protecting the natural shoreline process.[78]

Policy 19 is instructive in that it is clearly codified in Coastal Act section 30235.[79] Policy 19 demonstrates that the authors of the Plan were aware of the problems associated with shoreline protection, that protecting private property may be in conflict with the public interest, and that shoreline protection shoul *only* be granted if it was in the public's interest even if the structure already existed prior to the Act! Thus, according to the Coastal Commissioners in 1975, the Coastal Act would grant shoreline protection only if (1) adverse effects were mitigated, (2) it protected an existing structure, *and* (3) it was in the public's interest.

However, assuming that the Commission was unclear with regard to the definition of "existing" within Policy 19, other sections of the Coastal Plan leave little doubt that shoreline protection was not appropriate for development subsequent to the enactment of the Coastal Act. For example, Policy 67, *Geologic Safety Review and Regulation for New Development*, states:

> All *proposed* structures for human occupancy in [an area] of high geologic hazard shall be reviewed and regulated to avoid risk to life and property:
>
> (a) areas of high geologic hazard include seismic hazard areas, . . . unstable bluff and cliff areas, beaches subject to erosion, and others;
>
> . . . .
>
> (g) replacement structures in locations where previous structures have been rendered unfit for human occupancy by geologic instability shall only be permitted if they can successfully withstand the same instability.[80]

Policy 68, *Prevent Public Subsidy for Hazardous Developments*, states:

> It is recommended that State legislation be enacted that if for any reason new structures are built in high geologic areas . . . there shall be no public assistance for such construction or reconstruction and no presumption of public liability for property loss.[81]

Policy 70, *Regulate Bluff and Cliff Developments for Geologic Safety*, states:

> Bluff and cliff developments shall be permitted if design and setbacks are adequate to assure stability and structural integrity for the expected economic lifespan of the development and if the development will neither create nor contribute significantly to erosional problems or geologic instability . . . bluff protection works may be permitted only in accordance with policy 19. With that exception, no new lot shall be created or new structure built that would increase the need for bluff protection works.[82]

Policy 70, which is codified as Coastal Act section 30253, has a very important characteristic: it refers back to policy 19 (codified as section 30235). This demonstrates the Legislature's intent that Coastal Act sections 30235 and 30253 be interpreted together. The practical consequence for coastal landowners is that if they violate the setback requirement under Coastal Act section 30253, they should not be able to argue that they deserve protection under Coastal Act section 30235 (seawalls for existing structures).[83]

Finally there is also substantial evidence in the Coastal Plan, in addition to the specific policy recommendations, that the Commissioners understood the coastal processes, the costs to the public, and the solutions.[84] For example, the plan explicitly states that sand replenishment was very expensive.[85] It is clear that the Commissioners understood the private property rights issues and instead chose to protect public rights.[86] There is little doubt that the authors of the Coastal Plan never intended to permit seawalls for development built after the Coastal Act.

Direct Legislative History Argues Against a Liberal Construction "Existing"

The legislative evolution of the bill that was enacted as the Coastal Act, SB 1277, provides strong evidence that the insertion of "existing" into section 30235 was a distinct policy choice made by the legislature in 1976.[87] Early versions of SB 1277 stated in section 30204 (later renumbered section 30235), "Revetments, breakwaters, groins . . . seawalls, cliff retaining walls and other such construction that alters the natural shoreline process shall be permitted when required to serve coastal-dependent uses or *to protect structures*, developments, beaches, or cliffs in danger from erosion . . . ."[88]

The early version of SB 1277 did not include the word "existing" before "structure" and would have allowed any structure or even "developments, beaches or cliffs in danger from erosion" to have a seawall. However, this was quickly modified in committee. The next version struck the phrase "developments, and cliffs in danger from erosion" from the bill and on January 19, 1976, in what became the final version of section 30235, the word "existing" was inserted before "structures."

To further emphasize the importance of the addition of "existing," the competing bills, which were considered the "developer-friendly" Coastal Act bills,[89] did not add the word "existing" before "structure" and included the protection of cliffs as a legitimate reason to permit seawalls. For example, AB 3875 section 30007 reads, "[S]eawalls . . . shall be permitted when required to serve coastal-related uses or to protect structures, developments, beaches or cliffs in danger from erosion. . ."[90] Obviously the competing coastal act bills could have resulted in the complete armoring of almost the entire California coast and would have entitled any structure in danger from erosion a seawall.

However, SB 1277 was enacted[91] and therefore was the intent of the legislature. The Smith-Beilenson bill (SB 1277) inserted the word "existing" into the Coastal Act in committee, because it intended to distinguish between structures built after 1976 and those structures built before 1976 that warranted protection. To interpret the language otherwise would give effect to versions of coastal act bills that were not enacted.

Textual Analysis Requires that "Existing" be Interpreted as a Grandfather Clause

As already stated, Coastal Act section 30235 is currently interpreted by the Coastal Commission as mandating shoreline armoring when a structure is in danger from erosion, regardless of when the structure was built. While this may seem to be a reasonable interpretation, close textual analysis indicates that the current interpretation does not conform to the intent of the Legislature when writing the Coastal Act.

> Coastal Act section 30235 states:
> Revetments, breakwaters, groins, harbor channels, seawalls, cliff retaining walls, and other such construction that alters natural shoreline processes shall be permitted when required to serve coastal-dependent uses or to protect *existing* structures or public beaches in danger from erosion, and when designed to eliminate or mitigate adverse impacts on local shoreline sand supply. *Existing* marine structures causing water stagnation contributing to pollution problems and fish kills should be phased out or upgraded where feasible.[92]

It is standard in statutory construction that every word is important and is given effect.[93] One could possibly argue that the words "existing structures" were intended to distinguish between protecting empty lots from lots having structures already on them. Such interpretation, however, would not necessitate adding "existing" before "structures." The statute without the modifying adjective "existing" would have this meaning. In other words, the word "structures" precludes protecting future structures, without requiring the word "existing." Taking the prior argument to the extreme, a structure would deserve protection moments after completion; as soon as there were four walls, a roof, and dry paint. Furthermore, the every-completed-structure-is-"existing" interpretation would bring Coastal Act section 30235 into conflict with Coastal Act section 30253.

Coastal Act section 30253(2) states: "[New development shall] neither create nor contribute significantly to erosion . . . or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs."[94] If the interpretation requires protection of structures regardless of when they were built, the setback requirements of Coastal Act section 30253 are meaningless. Coastal landowners would be encouraged to ignore setback requirements, because they were guaranteed a seawall as soon as their "existing" structure was in danger from erosion.

This cannot have been the intention of the drafters of the Coastal Act. The setback requirement for new development is mandatory and unambiguous: "New development *shall* [not] require the construction of protective devices."[95] The only way to keep section 30235 consistent with section 30253 is to distinguish "new development" from "existing." In other words, new development (after 1976) shall not be allowed a seawall; existing development (prior 1976) shall be permitted to have a seawall when in danger from erosion.

Furthermore, Coastal Act section 30007.5 requires "conflicts [within the Coastal Act] be resolved in a manner which on balance is the most protective of significant coastal resources."[96] Coastal Act sections 30235 and 30253 were intended to be interpreted together.[97] But even if they were not part of the same subset of policies, Coastal Act section 30007.5 requires that they be interpreted in a manner most protective of the coastal resource. The only way to bring them out of conflict is to interpret "existing structures" as those structures already existing at the time of the Coastal Act.

Finally, "existing" is used twice in section 30235; once before "structures" and once later in the statute: "[S]eawalls. . .shall be permitted when required . . . to protect *existing* structures. . . . *Existing* marine structures causing water stagnation contributing to pollution problems and fishkills should be phased out or upgraded where feasible."[98] Statutory construction demands, at the very least, consistency within a section.[99] It seems clear the legislature was intending to phase out marine structures presently existing at the time of the passage of the Coastal Act. Any other interpretation would be absurd. Thus, in order to interpret the word "existing" consistently within section 30235, necessitates a grandfather clause interpretation of "existing." The intentional placement of "existing" as a modifying adjective before "structures" must mean existing before 1976 (passage of the Coastal Act). Any other statutory construction would simply not require the word.

In summary, there are three reasons why any textual analysis must come to the conclusion that "existing" must be interpreted as existing at the time of the Coastal Act. First, the alternative interpretation of "existing" would not necessitate the inclusion of the word "existing" in the statute. Second, the alternative interpretation would be inconsistent with other sections of the Coastal Act. Finally, the alternative interpretation would create an inconsistency within Coastal Act section 30235.

CASELAW

Coastal homeowners often believe that they have a Constitutional property right to protect their property from erosion by building a seawall.[100] Any change in current Coastal Act policy with regard to shoreline armoring, or a Coastal Commission decision denying a seawall to a particular property owner, will be challenged as an unconstitutional legislative taking. The preeminent case for legislative takings is *Lucas v. South Carolina Coastal Council*,[101] where the U.S. Supreme Court held that "[compensation is required] where the State seeks to sustain regulation that deprives land of all economically beneficial use."[102] Justice Scalia, writing for the majority, went on to warn, "[A]ny limitation so severe cannot be newly legislated or decreed (without compensation), but must inhere in the title itself, in the restrictions that background principles of the State's law of property and nuisance already place upon land ownership."[103] Thus, any regulation that deprives a landowner of all economically beneficial use of his property, and is not based in a State's background property laws, requires compensation in order to be considered Constitutional.

California has not litigated whether denying a landowner permission to build a seawall amounts to a legislative taking, but indirect case law would seem to indicate that a seawall ban would not be considered a taking. Furthermore, courts in other states have directly held that there is no Constitutional right to build shoreline armoring.[104]

North Carolina, in *Shell Island Homeowners Ass'n v. Tomlinson*,[105] dealt directly with whether a ban on the construction of a "permanent hardened erosion control structure" was Constitutional.[106] In *Shell Island*, the North Carolina Court of Appeals ruled that North Carolina's "hardened structure rule,"[107] which denied permanent shoreline armoring for a hotel, did not amount to a regulatory taking, inverse condemnation, and was not a violation of equal protection or due process.[108] The court noted:

> [P]laintiffs have failed to cite to this Court any persuasive authority for the proposition that a littoral or riparian landowner has a right to erect hardened structures in statutorily designated areas of environmental concern to protect their property from erosion and migration . . . [t]he owner of the riparian land thus loses title to such portions as are so worn or washed away or encroached upon by the water. . . . Its title was divested by "the sledge hammering seas, the inscrutable tides of God."[109]

The court further explained that the "hardened structure rule" was not denial of due process or equal protection, because the right to build a seawall is not a fundamental right under the Constitution, and the hardened structure rule is "clearly rationally related to the legitimate government end."[110] Finally, almost as a side-note regarding *Lucas*, the court found that the regulations were in place when the hotel (the original structure) was permitted, and therefore there was no compensable taking by reason of the regulations.[111]

Oregon took a different tact in defending the Oregon Beach Bill. OAR 736-20-010(6) states, "[P]ermit applications for beachfront protective structures seaward of the beach zone line (the dry sand vegetation line), will be considered only where development existed on January 1, 1977. The proposed project will be evaluated against the applicable criteria included within [the beach bill]."[112]

The Oregon Beach Bill's restriction of seawalls was challenged in *Stevens v. City of Cannon Beach*.[113] The plaintiff, relying on *Lucas*, claimed that the denial of a seawall amounted to a legislative taking because the "ordinance deprive[d] them of all economically viable use of their property."[114] The interesting part of *Stevens* is not simply the fact that the Court rejected the plaintiff's arguments, concluding that there was not a legislative taking, but how the Court reached its conclusion.

In Oregon, the public has a common law and statutory right to use the dry sand area of the beach.[115] The Court explained:

> When plaintiffs took title to their land, they were on notice that exclusive use of the dry sand areas was not part of the "bundle of rights" that they acquired, because public use of dry sand areas "is so notorious that notice of the custom on the part of persons buying land along the shore must be presumed."[116]

The Oregon Supreme Court, applying language from *Lucas*, held that compensation was not required because the "plaintiffs have never had the property interests that they claim were taken by [the regulation]."[117] Thus the Oregon Supreme Court held, even under the strict standards of *Lucas*, that a ban on seawalls did not amount to a legislative taking of property under the U.S. Constitution.

Although there have not been any cases in California that directly deal with the denial of a seawall,[118] case law seems to indicate that there is no Constitutional right to a seawall.[119] For example, in *Whaler's Village Club v. Cal. Coastal Comm'n*,[120] the Court of Appeals stated, "a fundamental right to protect one's property under the [California] Constitution (CAL. CONST., art. 1 sec. 1)[121] is not the equivalent of a vested right to protect property in a particular manner where the method chosen is one that is regulated by government."[122] The Court went on to point out, "It is now a fundamental axiom in the law that one may not do with his property as he pleases; his use is subject to reasonable restraints to avoid societal detriment. . . ."[123]

In *Scott v. City of Del Mar*, the City declared that shoreline armoring encroaching upon the public's land was a nuisance *per se*.[124] The plaintiff refused to remove their encroachments and sought to recover under inverse condemnation when the City forcibly removed the plaintiff's seawall and patio.[125] The Court of Appeals denied relief to the plaintiff and upheld the City's right to legislatively declare seawalls nuisances per se, stating, "Del Mar's abatement of the encroachments [seawalls] on public land was a reasonable exercise of its police power, which does not give rise to an inverse condemnation action."[126]

Unfortunately, in California, the right to build shoreline armoring has not been litigated. Most of the cases have questioned whether the Coastal Commission properly imposed conditions when permitting a seawall.[127] In *Barrie v. Cal. Coastal Comm'n*, the issue was whether the Coastal Commission could compel a homeowner to relocate their seawall that had been built under an emergency permit.[128] Although, the court noted in *Barrie*: "An individual has no vested right to protect property in a particular manner where the method chosen is one that is regulated by [the] government,"[129] the court was not determining whether there was a general right to build a seawall, but only whether there was a vested right to a seawall in the specific location allowed by an emergency permit.[130] The court held that homeowners do not have a vested right to a seawall at a location allowed under an emergency permit.[131]

Similarly, in *Whaler's Village Club v. Cal. Coastal Comm'n*, the court held that there was not a Constitutional right to own property free from regulation, and was simply determining whether the conditions placed on the permit for the seawall were reasonable.[132] The court stated, "The original building permits for construction of residences did not give respondent a preexisting right to unregulated new construction. Moreover, the [Coastal] Commission did not deny them the right to construct a revetment. The question is only the reasonableness of the conditions attached."[133]

Thus the right to protect one's home with a revetment or a seawall has not been decided in California. One could reasonably argue that, according to *Whaler's Village*, there is a right to protect one's home from erosion under the California Constitution,[134] but that right is qualified by regulations on how, when, and where the shoreline armoring will be built.[135] But other language in *Whaler's Village* appears to contradict this line of reasoning: "Respondent's 'right' to construct a new such revetment in a coastal area, an area of public trust, is not a right 'already possessed' or 'legitimately required.' Respondent's use of its property must be subject to 'reasonable restraints to avoid society detriment,'"[136] which would seem to preclude damaging the public's property by building a seawall.

Furthermore, it is clear from *Scott v. City of Del Mar* that seawalls and revetments may be declared a nuisance *per se*.[137] However, in *Scott* the seawalls and revetments were encroaching upon public land.[138] Does legislative power to declare seawalls a nuisance *per se* extend to seawalls and revetments completely on private land?[139] The Supreme Court has upheld ordinances against private land use on the basis of a public nuisance.[140]

It is likely that a policy relying on both the public trust doctrine and nuisance principles to ban seawalls would pass Constitutional muster. The legislative history of the Coastal Act indicates that the legislature was concerned with the considerable adverse impacts of shoreline armoring when Coastal Act section 30235 was being formulated.[141] Furthermore, as demonstrated by the review of cases above, both within California and in other states, protecting one's home with shoreline armoring is not a fundamental, Constitutional right. Finally, the simple fact that other states ban seawalls[142] should indicate that California would have little Constitutional difficulty in either correctly interpreting the Coastal Act or amending the Coastal Act to ban seawalls.

OPTIONS

There are three ways to change the current status quo and prevent the continued wallification of the California coast. The first option is to change the language in the Coastal Act through the legislature. The second option would be for the California Coastal Commission to interpret the Coastal Act as suggested above. The third option is to bring litigation against the Coastal Commission, mandating a correct interpretation of the Coastal Act.

Legislative repair of the Coastal Act would require the substitution of a single word. Changing Coastal Act section 30235 to read, "Seawalls *MAY* be permitted," instead of "*SHALL* be permitted," would give the Coastal Commission discretion in determining whether to permit specific homeowners a seawall. It would be up to the Coastal Commission to determine the merits of the specific seawall application.

A tough discretionary seawall policy would encourage better options such as removal or modification of the structure, better erosion resistant landscaping, and more sensible setbacks. However, it will always be difficult to deny specific homeowners protection in the form of a seawall when they are threatened with the loss of their homes.

Another possible legislative fix would be to simply define "existing." "Existing" could be defined as anything that was built before the passage of the Coastal Act, which would have much the same effect as I have suggested with the reinterpretation. "Existing" could also be defined as anything built before some specific date. Even if "existing" was given a date set after the passage of the Coastal Act, at the very least, there would be some areas spared from the adverse impacts of future seawalls. This option would not help Southern California, which is, at present, extensively developed.

A legislative solution is fraught with pitfalls. First of all, the beach erosion issue is not as clear-cut as it is in some states on the East Coast. The majority of sand on the East Coast is derived from lateral sand transport systems and the large continental shelf.[143] On the West Coast, rivers and streams deliver the majority of the sand.[144] Furthermore there have been some studies suggesting that Pacific storms have become more powerful and now track farther south than in previous decades, which by implication is exacerbating erosion.[145] Finally, on the East Coast, hurricanes periodically destroy large sections of coastal development.[146]

On the West Coast, although large storms do land, they do not have the same force as hurricanes.[147] Coastal destruction from large storms is localized and the dangers of building on the coast seem much more manageable (e.g. the possibility of building a seawall to protect a home).[148] Thus the majority of people in California, who do not live directly on the coast, seem oblivious to the folly of building on the coast and the public costs of shoreline armoring. It will be difficult to gain broad public support to ban seawalls.

Another danger to opening up the Coastal Act to amendment through legislative action is the power of the coastal development interests. Coastal developers and property-rights groups, such as the Pacific Legal Foundation, already have been seeking to weaken the Coastal Act through amendment and the courts.[149] AB 2310 (D-Ducheny) is a prime example of the power of the development interests.[150] AB 2310, as originally drafted, would have denied the Coastal Commission jurisdiction to review wetlands development that had an approved Habitat Conservation Plan.[151] Habitat Conservation Plans would have become a back door to development inconsistent with the Coastal Act. Although AB 2310 was eventually weakened before adoption, it demonstrates the danger of amending the Coastal Act in the face of well-funded and well-connected opposition.

Any amendment that denied protection for coastal landowners would be challenged as an unconstitutional legislative taking. Although the Constitutional challenges may eventually fail, the amendment would be held up indefinitely in court pending challenge. One possible way to avoid Constitutional problems would be to include a compensation clause. However, this would also be fraught with difficulty.[152] What is the worth of a coastal property in danger from erosion? Many coastal lots have extremely large homes worth millions of dollars: would compensation include the fair market value of the home without erosion problems? Ultimately, a compensation scheme may be unworkably expensive and would drain State resources because of lawsuits aimed at increasing the amount of compensation a coastal landowner received from condemnation proceedings.[153]

Finally, finding a State representative to carry a bill is difficult and dangerous for the political career of anyone who undertakes this daunting proposition.[154] The coastal landowners' mantra, "save our homes," clearly carries huge emotional and political appeal.[155] The coastal landowner has the advantage of a simplistic argument that is difficult to counter even for officials who have a deep understanding of the issue.[156] In addition, coastal landowners are wealthy and politically savvy, whereas the general public has little understanding of the issues or the costs involved.

On the other side, beach advocates have a complicated, esoteric argument which does not boil down easily into a slogan. The damage caused by shoreline armoring takes longer to explain and includes a number of side issues that seem to support the coastal landowners' perspective. For example, dams, flood-control works, sand mining, and development in general reduce the sand supply before the sand reaches the coastline.[157] The damage caused by shoreline armoring is gradual in many cases and is not obvious to the casual observer.[158] However, without shoreline armoring, even a sand-starved beach will maintain a recreational beach, because the shoreline will erode.[159] It requires a deep understanding of the issues to understand why shoreline armoring costs more, in the long run, than the worth of the property threatened by erosion.[160] Thus, in my opinion, a legislative fix is clearly unworkable and doomed to failure.

The second option is for the Coastal Commission to reinterpret the Coastal Act. Interpreting "existing" as only allowing protection to those structures built before the Coastal Act, although the correct interpretation, would require an incredible act of bravery on the part of the Coastal Commission. It will always be difficult to deny a homeowner protection when their property is clearly in danger.[161] Furthermore, the controversy over "existing" will continue. For example, does the small beach house that existed at the time of the Coastal Act deserve protection as an "existing structure" after it has been "remodeled" into a mansion? How much of the original structure must be remodeled before a structure is considered "new development"?

One option, which seems to be the current policy of the Coastal Commission, is to require deed restrictions in return for a development permit on a coastal bluff. Common deed restrictions include an admission of the danger of building in a geologically hazardous zone, a release of liability for the Coastal Commission and a promise not to build shoreline protection in the future, in return for a coastal development permit.[162] As of this date, the Coastal Commission has not enforced deed restrictions denying shoreline armoring.[163]

One purpose of deed restrictions is to counter the lack-of-knowledge argument. Although knowledge, or lack thereof, of the true consequences of unwise coastal development is not an element for consideration in a shoreline armoring permit, showing intentional or negligent disregard for coastal hazards may be crucial in the fight to deny shoreline armoring. In other words, knowledge and intent legally have no significance, but may be the critical element in providing courage to the Coastal Commission in denying shoreline armoring.

Presently the coastal landowner provides a sympathetic image to the Coastal Commission by claiming that bluff erosion conditions were unknown at the time of development (i.e., did not violate Coastal Act section 30253 setback provisions). For example, in a recent case in Solana Beach, six property owners claimed that new information, a clean sand lens unknown at the time of building, created the need for immediate shoreline protection.[164] Likewise, in the Cliff's Hotel appeal in Pismo Beach, the Hotel claimed that undiscovered natural springs increased erosion (presumably to counter the accusation that the green, cliff-top lawn was exacerbating erosion).[165] Deed restrictions address this concern by providing constructive knowledge to the coastal landowner that they are taking the risk and encouraging proper setback.

Another way to show constructive knowledge for those properties that do not include deed restrictions would be to investigate other legal instruments for those properties that have been significantly remodeled and sold. California law requires disclosure of geologic conditions upon sale of the house.[166] These documents, while not having a legal bearing regarding shoreline armoring, will have an enormous effect on the sympathy factor for the homeowner. The Coastal Commission, if it accepts the "grandfather clause" interpretation of section 30235, may be less likely to use their discretion to grant a permit when they believe a homeowner intentionally, or negligently, built too close to the bluff edge.

The final option is activist litigation against the Coastal Commission. In essence, coastal advocates must ask the judiciary to correctly interpret section 30235 and order the Coastal Commission to follow the "new" interpretation.

Thus, changing the interpretation of the Coastal Act would require the Coastal Commission to continue to approve permits for shoreline armoring and coastal activists bringing suit against the Coastal Commission seeking a writ of mandamus.[167] This would require certain conditions to correctly target the interpretation of "existing" under the section 30235.[168]

First, the structure would need to be in imminent danger from erosion. There has been no case law that challenges the need for the structure to be in danger from erosion, and the Coastal Commission appears to routinely deny permits for structures not in danger from erosion.[169] A successful case decided on this aspect of section 30235 would have virtually no impact on the current practices, because most homeowners who request a seawall are clearly in danger from erosion. However, the structure should not be in immediate harm sufficient to qualify for an emergency permit.

Second, the property would ideally not include deed restrictions. Although deed restrictions are desirable if the Coastal Commission wishes to deny seawall applications, they essentially are a waiver of one's rights under the Coastal Act.[170] Furthermore, deed restrictions have been upheld in the coastal zone.[171] A successful suit upholding deed restrictions would not have an impact on current shoreline development practices.

A best-case scenario for bringing a lawsuit would be a case where the issue was focused solely on whether the structure could be considered existing. Thus, the facts of the case would ideally include: a primary structure built after 1976, clearly in danger from erosion; no previous shoreline armoring; a design that adequately mitigates adverse impacts; and approval from the Coastal Commission.

This would be the preferable course of action for a number of reasons. First, there is a reasonable possibility that the court will rule that "existing" does in fact indicate an intent to protect only structures built before 1976 and that the Coastal Commission is violating the Coastal Act by approving shoreline armoring for any other structures.

If the court found otherwise, it would not change the current approval practices of the California Coastal Commission. In other words, an adverse ruling only preserves the status quo, although admittedly it would not allow the Coastal Commission to reinterpret the Coastal Act on its own. However, an adverse ruling that "existing" means any primary structure existing at the time of being in danger of erosion would not preclude a legislative fix.

I believe that those who argue that the courts are not an appropriate venue to change the interpretation of section 30235 have not adequately assessed the dangers of a legislative fix, the political climate, or the relatively low risk of litigation on this matter. A worst-case scenario of litigation would expend the time, effort and monetary resources of coastal advocates, but would not preclude other options.

There are other benefits as well. For example, if the Coastal Commission does deny a permit based on the fact that the structure was built after 1976, the Coastal Commission will be defending its interpretation of "existing" from wealthy landowners and private property rights groups. Coastal advocates will not be able to control who the defense attorney will be, nor how passionately the Coastal Commission will defend.[172] Although coastal advocates will be able to intervene as a defendant, there will be less control regarding the narrow issues presented. If the coastal advocate is the plaintiff, the issue going up for review can be intentionally kept narrow and the quality of the lawyer can be controlled.

CONCLUSION

Seawalls protect private property at the expense of the public beach. The purpose of this Comment was two-fold. First, I intended to inform the casual reader about the physical problems associated with seawalls and the current legal considerations regarding shoreline armoring. Second, I intended to provide tools to practitioners, policy makers, and decision-makers who wish to begin charting a course that fully protects the public's beach.

The right to shoreline armoring is a highly contentious issue. Local and state officials often feel compelled to permit seawalls regardless of the adverse impacts. I have heard on multiple occasions Coastal Commissioners lamenting that the law requires them to permit yet another seawall, and in certain circumstances the Commissioner is correct. However, for new development, built after 1976, there is no requirement to permit a seawall under the Coastal Act.

Other states have enacted complete bans on seawalls that have survived constitutional challenges.[173] California case law, although not directly on point, seems to indicate that there is no constitutional right to build a seawall.[174] Therefore any reinterpretation or amendment to section 30235 would likely also survive a legal challenge.

The Coastal Commission is finding it increasingly difficult to find the middle ground. It is impossible to ignore the fact that 150 miles of seawalls is, at the very least, having a disastrous cumulative impact on the availability of the recreational beach. Yet, the emotional appeals of homeowners are also impossible to ignore. Ultimately, compromise is not possible.[175] As Orrin H. Pilkey and Katharine Dixon remind us: "you can have houses or you can have beaches; you cannot have both."[176]

NOTES

1. Cornelia Dean, Against the Tide, The Battle for America's Beaches 53 (1999). Cornelia Dean is the science editor for the *New York Times.*

2. In the last two years seawalls have been permitted to protect fifteen properties in Solana Beach, California. *See, e.g.,* Cal. Coastal Comm'n Application No. 6-99-103 (shoreline armoring permit protecting seven properties, approved Oct. 14, 1999); Application No. 6-99-56 (shoreline armoring permit protecting three properties, approved May 12, 1999); Application No. 6-99-91 (approved Jan. 12, 2000); Application No. 6-00-66 (shoreline protection permit protecting two properties, approved Oct. 10, 2000): Application No. 6-00-36 (shoreline armoring protecting two properties, approved March 13, 2001); *and* Application No. 6-00-138 (shoreline armoring protecting two properties, approved Mar. 13, 2001). *See also* pleadings at 1 Calbeach Advocates v. City of Solana Beach, Case No. GIN010294, (filed Jan. 25, 2001 San Diego Superior Court) (on file with author).

3. "Shoreline armoring" is a generic term for any hardened structure used to protect against wave action, such as seawalls, revetments, riprap, and bulkheads. In this Comment the terms "seawalls" and "shoreline armoring" will be used interchangeably.

4. *See* Surfrider Foundation: State of the Beach 10 (2000) (noting that 1990 statistics showed 130 miles of seawalls in California and that California has experienced two El Niños in the 1990s). *See also* Gary B. Griggs, *Bringing Back the Beaches—A Return to Basics*, *available at* http://www.wetsand.com (last visited Nov. 15, 2000) (noting that approximately 14% of California is armored).

5. *See generally* Dean, *supra* note 1; Orrin H. Pilkey & Katharine L. Dixon, The Corps and the Shore (1996); Wallace Kaufman & Orrin Pilkey, The Beaches are Moving, The Drowning of America's Shoreline (1979) (explaining the adverse impacts of seawalls).

6. Nicholas C. Kraus, *The Effects of Seawalls on the Beach: An Extended Literature Review*, Special Issue, J. Coastal Res., 1, 4 (1988) (However, Kraus disputes whether active erosion is supported by scientific evidence.).

7. *See* San Diego Regional Beach Sand Project Final Environmental Impact Report/Environmental Assessment, State Clearinghouse No. 1999041104 (2000) (The sand replenishment project will add two million cubic yards of sand to San Diego's beaches at a cost of fourteen million dollars. The sand is expected to last one to five years.).

8. Philip King, *Executive Summary of 1999 Report on: The Fiscal Impact of Beaches*, *at* http://userwww.sfsu.edu/~pgking/beaches (last visited Nov. 18, 1999) (report prepared for the California Department of Boating and Waterways).

9. For an excellent documentary film see the video by Eden Productions, Living on the Edge (1998) (available from the Surfrider Foundation *at* http://www.surfrider.org, 122 S. El Camino Real, #67, San Clemente, California 92672).

10. *See* Whaler's Village Club v. Cal. Coastal Comm'n, 173 Cal. App. 3d 240, 252 (1985) (landowners arguing they have a vested right to protect property).

11. Cal. Pub. Res. Code § 30000 et. seq. (2001) [hereinafter Coastal Act § 30000 *et. seq.*].

12. *See* California Coastal Plan 89 (1975). The California Coastal Plan was prepared prior to the coastal act pursuant to Proposition 20 (1972). *See* Cal. Pub. Res. Code § 27320.

13. Coastal Act § 30253 (2001) (emphasis added).

14. *See* Gary Griggs & Lauret Savoy, *Building or Buying on the Coast*, in Living with the California Coast 35, 35 (Gary Griggs & Lauret Savoy eds., 1985).

15. Setbacks from streets and other property lines are fixed. In many areas though, the setback from the bluff's edge is determined by 75-year erosion rates. California Coastal Commission, Periodic Review of the San Luis Obispo County Certified Local Coastal Program, at 269-70 (Prelim. Rep., Feb. 2, 2001), *available at* http://www.coastal.ca.gov/web/recap/rctop.html. By declaring an overly optimistic erosion rate of two to three inches a year, a coastal landowner may build as close as twenty-five feet from the bluff edge. *Id.* at 271. This not only provides a great view, but also allows for an increase in square footage of the house. *See also*, Staff Report, Cal. Coastal Comm'n Amendment Application No 4-83-490-A2, 24 n. 25 (approved Nov. 14, 2001) (noting that the bluff setback was based on an estimated three inches per year erosion rate, but geologists subsequently estimated a buff retreat rate of forty-eight inches per year).

16. *See* Coastal Act § 30235 (2001).

17. *Id.* (emphasis added).

18. Orrin H. Pilkey & Howard L. Wright III, *Seawalls Versus Beaches*, Special Issue 4, J. Coastal Res., 41, 43 (1988). *See also* Video, Living on the Edge (Eden Productions, 1998) (available from the Surfrider Foundation) (Gary Griggs and Scott Jenkins explaining the effects of shoreline armoring).

19. Pilkey & Wright, *supra* note 18, at 43 (asserting that a seawall located on a public beach will naturally prevent use of the beach that it is physically occupying).

20. Dean, *supra* note 1, at 53; Pilkey & Dixon, *supra* note 5, at 40. See *also* Gary B. Griggs, *Bringing Back the Beaches—A Return to Basics*, *available at* http://www.wetsand.com (last visited Nov. 15, 2000).

21. *See* Dean, *supra* note 1, at 53-55; Kaufman & Pilkey, *supra* note 5, at 208; *and* Griggs et. al., *Understanding the Shoreline*, in Living with the California Coast 7, 22 (Gary Griggs & Lauret Savoy eds., 1985) (noting that seawalls block sand supply and cause erosion from wave rebound).

22. Griggs et al., *supra* note 21, at 14. Griggs also notes that in Southern California some beaches are created and maintained by the dredging of harbors. *Id.* at 21-22.

23. *See* Kaufman & Pilkey, *supra* note 5, at 81. Technically, littoral drift is the actual movement of the sand, whereas long shore currents are the side shore currents that cause the littoral drift. Griggs et al., *supra* note 21, at 11.

24. *See* Pilkey & Dixon, *supra* note 5, at 29; Griggs et. al., *supra* note 21, at 15.

25. Katharine E. Stone, *Sand Rights: A Legal System to Protect the "Shores of the Sea,"* Stetson L. Rev. 709, 711-12 (2000).

26. *See, e.g.,* Coastal Act § 30211 (2001) ("Development shall not interfere with the public's right of access . . . including the use of dry sand and rocky coastal beaches to the first line of vegetation").

27. *See* Pilkey & Dixon, *supra* note 5, at 91 (showing a comparison of a sand replenishment to size of shoreface and zone of active sand movement (underwater sand)).

28. *See* Kaufman & Pilkey, *supra* note 5, at 89; Dean, *supra* note 1, at 158; Griggs et al., *supra* note 21, at 11.

29. Aram v. Terchunian, *Permitting Coastal Armoring Structures: Can Seawalls and Beaches Coexist?*, Special Issue 4, J. Coastal Res. 65, 67-68 (1988).

30. Pilkey & Dixon, *supra* note 5, at 40; Kraus, *supra* note 6, at 4.

31. Pilkey & Wright, *supra* note 18, at 59. *Contra* Kraus, *supra* note 6, at 4 (finding no increase in beach slope in front of seawalls, compared to "unstabilized" beaches); *and* Gary B. Griggs & James F. Tait,

The Effects of Coastal Protection Structures on Beaches Along Northern Monterey Bay, California, Seawalls Versus Beaches, Special Issue 4, J. COASTAL RES. 93, 102 (1988) (noting that beach profile in front of seawalls did not change). Griggs, however, notes that seawalls may cause "wave wash or reflection that actually removes sand from the beach in front of a seawall." Griggs et al., *supra* note 21, at 22. A current study by Scott Jenkins, an oceanographer at Scripps Institute of Oceanography has found significant increase in the slope of the beach profile in front of seawalls compared to beaches in front of unprotected cliffs in Solana Beach and Del Mar, California. (Data on file with author).

32. *See* DEAN, *supra* note 1, at 27.

33. *See id.* at 96; KAUFMAN & PILKEY, *supra* note 5, at 216.

34. SAN DIEGO REGIONAL BEACH SAND PROJECT ENVIRONMENTAL IMPACT REPORT/ENVIRONMENTAL ASSESSMENT, State Clearinghouse No. 1999041104, 4.1-5 (2000).

35. *See* DEAN, *supra* note 1, at 96; KAUFMAN & PILKEY, *supra* note 5, at 216. For diagrams of wave and beach profile dynamics *see* KAUFMAN & PILKEY (illustration at 206-07); Griggs et al., *supra* note 21, at 8.

36. Griggs et al., *supra* note 21, at 13.

37. *Id.* at 8.

38. *Id.* Naturally coastal erosion increases during storm events coupled with extreme high tides. *Id.* at 22.

39. *See id.*

40. *Id.;* Nat. Res. Council, MANAGING COASTAL EROSION 24 (1990). Griggs estimates that bluff erosion does not contribute more than 25% of the beach sand. Griggs et al., *supra* note 21, at 15.

41. Terchunian, *supra* note 29, at 67.

42. Griggs & Tait, *supra* note 31, at 101-02.

43. Pilkey & Dixon, *supra* note 5, at 51-53 (noting ten truths about shoreline armoring: (1) Destroys beaches, is ugly and blocks access; (2) There is no need for armoring unless someone builds too close to the shoreline; (3) Small number of people create the need; (4) Once you start you cannot stop; (5) It costs more to save the property than it is worth; (6) Shoreline armoring begets more shoreline armoring; (7) Shoreline armoring grows bigger; (8) Shoreline armoring is a politically difficult issue because of its long-term impacts; (9) Shoreline armoring is a politically difficult issue because no compromise is possible; (10) You can have buildings or you can have beaches; you cannot have both).

44. Active erosion, beach erosion caused by wave rebound, is still highly controversial in the scientific community. *See generally* Krause, *supra* note 5, at 1 (disputing whether beach profile increased because of seawalls). Griggs & Tait, *supra* note 31, at 93 (study noting in northern Monterey, where seasonal beach profile rebounded as quickly with a seawall). *See also* Pilkey & Wright, *supra* note 18, at 59 (explaining the academic debate between active erosion and passive erosion).

45. *See* Video: Eden Productions, LIVING ON THE EDGE (1998) (Mark Massara, Esq., Coastal Director of the Sierra Club, coining the word "wallification").

46. SURFRIDER FOUNDATION, STATE OF THE BEACH 10 (2000) (noting that in 1990 there was 130 miles of shoreline armoring in California).

47. Statistics on shoreline armoring for 1990-1999 are not yet available. It is a reasonable assumption that at least 20 miles of additional shoreline armoring were constructed in the last decade.

48. Griggs et al., *supra* note 21, at 15.

49. Lechuza Villas West v. Cal. Coastal Comm'n, 60 Cal. App. 4th 218, 235 (1997) ("The State owns all tidelands below the ordinary high water mark, and holds such lands in trust for the public") (citations omitted).

50. Coastal Act § 30211 (2001).

51. KAUFMAN & PILKEY, *supra* note 5, at 89.

52. James R. Houston, *International Tourism and U.S. Beaches*, SHORE AND BEACH, Apr. 1996, at 3. *See also, Fun at the Sea: Coastal Tourism, Recreation*, SEA TECH., Oct. 1998, at 3 (noting that 90% of all tourist dollars are spent in Coastal States and 180 million people visit the coast each year).

53. *See* Terry Rodgers, *Deficit May Reduce Beach Sand Project,* SAN DIEGO UNION-TRIB., Feb. 24, 2001, at B5 (noting that San Diego's Association of Governments Sand Replenishment Project will cost over $17 million).

54. *See also* Janet Adams, *Proposition 20—A Citizen's Campaign,* 24 SYRACUSE L. REV. 1019 (1973) (describing the background of the bill that created the coastal act). *See also generally* STANLEY SCOTT, GOVERNING CALIFORNIA'S COAST (1975).

55. *See* SCOTT, *supra* note 54, at 6 (noting that only 260 miles of coast was accessible to the public).

56. *Id.* at 7.

57. *See id.* at 119-24. "California Legislature's Joint Committee on Open Space Land found that 52.9% of city planning commission . . . [and] 62.3 percent of county planning commission members were persons who represented direct or indirect 'beneficial interests.'" *Id.* at 120. "The most corruptive force in government has to do with the use and development of land. The developers and the building industry have been extremely destructive in California . . . local government [has] been corrupted by these developers." *Id.* at 121 (quoting Richard Graves, former executive director of the League of California Cities).

58. *See* Adams, *supra* note 54, at 1023 (recounting why conservationists became frustrated with local government and eventually viewed local government as the enemy); SCOTT, *supra* note 52, at 7-8, ("until Proposition 20 passed, the coast was under the fragmented management of 15 counties, 45 cities, 42 state unites and 70 federal agencies (1972 figures)").

59. SCOTT, *supra* note 54, at 11-12.

60. *Id.* at 14.

61. Adams, *supra* note 54, at 1032; SCOTT, *supra* note 54, at 353-54. The Coastal Alliance and coalition of various environmental groups spearheaded the Proposition 20 initiative drive after legislative efforts to pass a strong coastal bill failed in 1971. *Id.*

62. CAL. PUB. RES. CODE §§ 27000-27650 (1972) *repealed by* Coastal Act of 1976.

63. SCOTT, *supra* note 54, at 357. Opposition included Bechtel Corp., General Electric Co., Southern California Edison Co., Standard Oil Co. of California, Mobil Oil Corp., Gulf Oil Corp., Occidental Petrol Co., Texaco Inc., Irvine Company (developer), Southern Pacific Land Company, Teamsters and the California Real Estate Association (partial list).

64. *See* Coastal Act § 30002 (2001).

65. *See* Adams, *supra* note 54, at 1026.

66. *See id.* at 1029-32 (recounting legislative efforts to pass a coastal bill in 1970-1972).

67. *Id.* at 1033.

68. *See generally* Adams, *supra* note 54, at 1019.

69. CAL. PUB. RES. CODE § 27001(d) (1972) *repealed by* Coastal Act of 1976.

70. CAL. PUB. RES. CODE § 27001(b) (1972) *repealed by* Coastal Act of 1976.

71. CAL. PUB. RES. CODE § 27320(c) (1972) *repealed by* Coastal Act of 1976.

72. SB 1277 (Smith, D-Saratoga) (1976). The competing bills AB 3875 (Keene) and AB 3402 (Cullen) were respectively characterized as a "bulldozer in sheep's clothing" and a "bulldozer without even the sheep's clothing." Press release from the Planning and Conservation League (July 26, 1976) (on file with author).

73. *See, e.g.*, SB 1277 30001 (a) "That the California coastal zone is a distinct and valuable natural resource belonging to all the people and exists as a delicately balanced ecosystem"; *See* California Coastal Plan (1975) at 19 (explaining that property rights are not absolute. . . ." Zoning laws have been upheld by the courts since 1926). *See* Coastal Act § 30007.5 (2001) ("in carrying out the [Coastal Act] . . . conflicts [shall] be resolved in a manner which on balance is the most protective of significant coastal resources.").

74. Coastal Act § 30002 (2001).

75. *See, e.g.*, California Coastal Plan 84 (1975). (Policy 68) ("[I]t is *recommended* that State legislation be enacted to assure that, if for any reason new structures . . . are built in high geologic hazard areas . . . there shall be no public assistance for such construction or reconstruction." (emphasis added)).

76. *Id.* at 18.

77. *Id.* at 45.

78. *Id.*

79. Coastal Act § 30235:

> [s]eawalls . . . and other such construction that alters natural shoreline processes shall be permitted when required to serve coastal-dependent uses or to protect existing structures or public beaches in danger from erosion, and when designed to eliminate or mitigate adverse impacts on local shoreline sand supply.

80. California Coastal Plan at 87-88 (codified as Coastal Act § 30211).

81. *Id.* at 88.

82. *Id.* at 89.

83. *See* Coastal Act § 30007.5 (2001) ("[C]onflicts [within the Coastal Act are to] be resolved in a manner which on balance is the most protective of significant coastal resources.").

84. *See, e.g.*, California Coastal Plan "Bluff Protective works are costly and involve problems. . .these measure can be extremely costly, may be unsightly in the cases of retaining walls, may interfere with access along the shore, may require continual sources of sand for replenishment . . . a decrease in sand supply . . . when artificial protective measures interfere with natural bluff erosion process." *Id.* at 89.

85. *See id.* at 44 (noting that replenishing Doheny State Beach cost over $1 million).

86. *See, e.g.*, Policy 19 (protection of private property would only be allowed when the Commission holds that protecting the existing structure is in the public interest).

87. S.B. 1277 (Ca. 1976).

88. S.B. 1277 (Ca. 1975).

89. *See* Press Release of the Planning and Conservation League, *supra* note 71.

90. A.B. 3875 § 30007 (Ca. 1975).

91. Coastal Act § 30000 et seq.

92. Coastal Act § 30235 (2001) (emphasis added).

93. NORMAN J. SINGER, 2A SUTHERLAND STATUTORY CONSTRUCTION § 46.06, at 119-20 (5th ed. 1992).

94. Coastal Act § 30235(2) (2001).

95. Coastal Act § 30253 (2001) (emphasis added).

96. Coastal Act § 30007.5 (2001).

97. *See* interplay between Coastal Plan policy 19 and policy 70, *supra* pp. 264-66.

98. Coastal Act § 30235 (2001) (emphasis added).

99. *See* SINGER, *supra* note 93, § 46.06, at 120.

100. *See, e.g.*, Whalers Village Club v. Cal. Coastal Comm'n, 173 Cal. App. 3d 240, 252 (1985) (noting that the respondent believes they have a "[Constitutional] right to protect one's home from destruction"). On a personal note, at the many Coastal Commission hearings I have attended, I have yet to meet a coastal homeowner who did not declare they have a Constitutional right to a seawall.

101. *See* Ronald H. Rosenberg, *The Non-Impact of the United States Supreme Court Regulatory Takings Cases on the State Courts: Does the Supreme Court Really Matter?*, 6 FORDHAM ENVTL. L.J. 523, 543 (1995) (calling *Lucas* "the much-heralded [takings] case"). *Lucas* has been discussed or cited in 2525 cases (citation history as of July 5, 2001, in WESTLAW, KC citations).

102. 505 U.S. 1003, 1027 (1992).

103. *Id.* at 1029.

104. *See, e.g.*, Shell Island Homeowners Ass'n v. Tomlinson, 134 N.C. App. 217 (1999); Stevens v. City of Cannon Beach, 317 Or. 131 (1993).

105. Facts at Shell Island Homeowners Ass'n v. Tomlinson, 124 N.C. App. 286 (1999).

106. *Shell Island*, 134 N.C. App. at 220. Plaintiffs argued "[t]he protection of property from erosion is an essential right of property owners." *Id.* at 228.

107. 15A NCAC 7H.0308(a)(1)(B)

> Permanent erosion control structures may cause significant adverse impacts on the value and enjoyment of adjacent properties or public access to and use of the ocean beach, and, therefore, are prohibited. Such structures include, but are not limited to: bulkheads; seawalls; revetments; jetties; groins and breakwaters.

As *cited in Shell Island*, 134 N.C. App. at 219.

108. *Shell Island*, 134 N.C. App. at 231-33.

109. *Id.* at 228 (citations omitted).

110. *Id.* at 233.

111. *Id.* at 231.

112. Stevens v. City of Cannon Beach, 317 Or. 131, 145 (1993).

113. *Id.* at 146.

114. *Id.* at 147.

115. *See id.* at 138 (quoting Thornton v. Hay, 254 Or. 584 (1969)).

116. *Steven*, 317 Or. at 143 (citations omitted).

117. *Id. Stevens* relied heavily on *Lucas*, which held:

> Where the state seeks to sustain regulation that deprives land of all economically beneficial use, we think it may resist compensation only if the logically antecedent inquiry into the nature of the owner's estate shows that the proscribed use interests were not part of his title to begin with.
>
> — *Lucas*, 505 U.S. at 1027.

118. California courts have generally battled over whether the Coastal Commission could enforce conditions, such as mitigation or dedications of easements, in exchange for a seawall. *See* Whaler's Village Club v. Cal. Coastal Comm'n, 173 Cal. App. 3d 240, 261 (1985) (holding that because seawalls were likely to exacerbate erosion of the public beach, a dedication of an easement was an appropriate condition). *Contra* Surfside Colony v. Cal. Coastal Comm'n, 226 Cal. App. 3d 1260 (1991) (holding that there was not a sufficient nexus between the private community's revetment and erosion to the public beach to justify a public access easement).

119. *See* Barrie v. Cal. Coastal Comm'n, 196 Cal. App. 3d 8 (1987).

120. *Whaler's Village*, 173 Cal. App. 3d at 240. (1985).

121. CAL. CONST. art. 1, § 1 ("Inalienable rights: All people are by nature free and independent and have inalienable rights. Among these are enjoying and defending life and liberty, acquiring, possessing, and *protecting property*, and pursuing and obtaining safety, happiness, and privacy.") (emphasis added).

122. *Whaler's Village*, 173 Cal. App. 3d at 252-53. *See also Barrie*, 196 Cal. App. 3d at 18 (holding that there is no vested right in an emergency seawall and upholding *Whaler's Village*).

123. *Whaler's Village*, 173 Cal. App. 3d at 253 (citing People v. Byers, 90 Cal. App. 3d 140, 147-48 (1979); HFH, Ltd. v. Super. Ct., 15 Cal. 3d 508, 515 (1975)).

124. 58 Cal. App. 4th 1296, 1305 (1997). The city declared the encroachments nuisances *per se* because the seawalls increased erosion and they blocked public access. *Id.* at 1306.

125. *Id.* at 1301.

126. *Id.* at 1307. The court also held that diminution in value for removing the seawalls did not amount to a compensable taking. *Id.*

127. *See* Surfside Colony v. Cal. Coastal Comm'n, 226 Cal. App. 3d 1260, 1260 (1991) (holding that there was an insufficient nexus between the city's revetment and erosion to the public beach to justify a public access easement). *Cf. Whaler's Village*, 173 Cal. App. 3d at 261 (holding that because seawalls were likely to exacerbate erosion of the public beach, a dedication of an easement was an appropriate condition).

128. Barrie v. Cal. Coastal Comm'n, 196 Cal. App. 3d 8, 8 (1987).

129. *Id.* at 15 (quoting *Whaler's Village*).

130. The seawall encroached fifteen feet onto public land. *Barrie*, 196 Cal. App. 3d at 13.

131. *Id.* at 18.

132. *Whaler's Village*, 173 Cal. App. 3d at 253-54.

133. *Id.*

134. Cal. Const. art 1, § 1.

135. *Whaler's Village*, 173 Cal. App. 3d at 253-54.

136. *Id.* at 253 (citations omitted).

137. 58 Cal. App. 4th at 1305-06.

138. *Id.* at 1306.

139. *See* Lucas v. South Carolina Coastal Commission, 505 U.S. 1003, 1026 (1992) (warning that "a noxious-use justification [for regulation] cannot be the basis for departing from our categorical rule that total regulatory takings must be compensated").

140. *See, e.g.,* Hadacheck v. Sebastian, 239 U.S. 394 (1915) (prohibiting brickyard in Los Angeles because of noxious fumes); Goldblatt v. Hempstead, 369 U.S. 590 (1962) (prohibiting mining operation that was interfering with water supply).

141. *See* California Coastal Plan 89 (1975).

142. Tina Bernd-Cohen & Melissa Gordon, State Coastal Management Effectiveness in Protecting Beaches, Dunes, Bluffs, Rocky Shores: A National Overview (1998) (Oregon, South Carolina, North Carolina and Maine ban shoreline armoring).

143. Dean, *supra* note 1, at 22.

144. Griggs et al., *supra* note 21, at 14.

145. David E. Graham, *Making Bigger Waves: Stronger Storms Raise Risk for S.D. Coastline*, San Diego Union-Tribune, Feb. 4, 2001, at B1 (citing a study by UCSD's Scripps Institute of Oceanography that waves are larger and more destructive than in the past).

146. *See generally* Dean, *supra* note 1, at 134-54 (recounting damage from numerous hurricanes on the Eastern and Gulf Coasts).

147. Griggs et al., *supra* note 21, at 23.

148. *See generally* Griggs et al., *supra* note 21, at 24 (discussing climate change and the mild climate from 1946 to 1976).

149. *See, e.g.,* Marine Forests Society v. Cal. Coastal Comm'n, No. 00AS00567 (Sacramento Sup. Ct., filed Jan. 31, 2000) (appeal filed May 8, 2001); Terry Rodgers, *Coastal Panel Ruled Unconstitutional: Judge Finds Board Oversteps Authority*, San Diego Union-Tribune, Apr. 27, 2001, at A3.

150. *See* Seema Meeta, *New Wetlands Bill Would Check Bolsa Chica Ruling*, L.A. Times, Feb. 25, 2000, at B14.

151. Terry Rodgers, *Coastal Control is the Subject of Revived Bill*, San Diego Union-Tribune, May 16, 2000, at A3.

152. *See* Gary Griggs & Lauret Savoy, *Shoreline Protection and Engineering*, in Living With the California Coast 46, 74 (Gary Griggs & Lauret Savoy eds., 1985) (noting some of the problems with condemnation or acquisition programs).

153. *But see id.* Griggs notes the limited resources of state and local governments, but ultimately concludes "condemnation may well become an increasingly common control technique." I disagree for the reasons stated above.

154. The Surfrider Foundation has approached a number of coastal state representatives but has not been successful in finding an "author" to carry an anti-seawall bill.

155. At the Coastal Commission hearing on March 13, 2001, a hearing that included three seawall permits, coastal landowners arrived with large buttons exclaiming "Save our Homes."

156. Coastal Commissioner Dentloff commented, "I do not think we [the Coastal Commission] have the guts to tell someone their house is going to fall into the Ocean [and deny a seawall]" (comments during the Coastal Commission hearing March 13, 2001).

157. *See* Stone, *supra* note 25, at 708. Seawalls, however greatly exacerbate erosion on a sand-starved beach. Terchunian, *supra* note 29, at 68.

158. *See* Pilkey & Wright, *supra* note 18, at 44 ("[S]eawall impact on beaches is often a long-term phenomenon").

159. Terchunian, *supra* note 29, at 67-68.

160. Dean, *supra* note 1, at 16 (citing a report by Orrin H. Pilkey and James D. Howard which was submitted to President Reagan in 1982).

161. *See id.* at 68.

162. *See, e.g.,* Coastal Commission Staff Report CDP 6-99-103, noting that some of the properties included deed restrictions specifically denying the ability to build shoreline armoring.

163. *Cf.* Ojavan Investors v. Cal. Coastal Comm'n, 26 Cal. App. 4th 516, 527 (1997) (upholding deed restrictions for transfer development credits).

164. CDP 6-99-103.

165. *See* Staff Report, A-3-PSB-98-049 (Cliff's Hotel Appeal).

166. Cal. Civ. Code § 1102.6 (2001).

167. This concept was formulated through discussions with Doug Ardley, Esq. (Surfer's Environmental Alliance) and Mark Massara, Esq. (Coastal Director of the Sierra Club).

168. A victory or loss on other issues would not have a policy-changing effect.

169. *See, e.g.,* Defendant's Brief at 4, Cliff's Hotel v. Cal. Coastal Comm'n, CV 080283.

170. Ojavan Investors v. Cal. Coastal Comm'n, 26 Cal. App. 4th 516, 527 (1997).

171. *Id.*

172. Ordinarily, the Attorney General defends the Coastal Commission. Sam Overton, Esq., Dan Olivas, Esq., and Jamee Jordan Patterson, Esq. (Deputy Attorneys General covering Central and Southern California) have competently defended the Coastal Commission.

173. *See generally* Shell Island Homeowners Assoc. v. Tomlinson, 134 N.C. App. 217 (1999); Stevens v. City of Cannon Beach, 317 Or. 131 (1993).

174. *See* Whaler's Village Club v. Cal. Coastal Comm'n, 173 Cal. App. 3d 240 (1985); Barrie v. Cal. Coastal Comm'n, 196 Cal. App. 3d 8 (1987); Scott v. City of Del Mar, 58 Cal. App. 4th 1269 (1997).

175. Pilkey & Dixon, *supra* note 5, at 53.

176. *Id.*

Sand Beaches vs. Seawalls — A Geomorphic Perspective

Walter F. Crampton, R.C.E., R.G.E.
TerraCosta Consulting Group, Inc., San Diego, California 92123-4379

ABSTRACT

This presentation provides a geomorphic perspective on the debate concerning the effects of seawalls on beaches. The first consideration is the bedrock shore platform on which the transient beach sands may or may not exist. The shore platform today at the cliff face in the vicinity of Encinitas and Solana Beach is near elevation -1 foot, MSL. The slope of the shore platform represents the ratio of backwearing to downwearing and, thus, in San Diego's North County, backwearing is approximately 60 times that of downwearing of the bedrock foreshore. Thus, 60 feet of seacliff retreat continues to maintain the same shore platform angle, and with an insufficient protective sand beach, 60 feet of coastal erosion merely translates today's problem 60 feet easterly, with an attendant unstable slope and undermined bluff-top improvements.

This paper compares the erosion resistance of North County Eocene-age cliff-forming sediments with those of the Cretaceous Point Loma Formation, and discusses the significance of the elevation of the bedrock shore platform in assessing the seacliff's ability to release sediments and, of course, the corollary debate: sand beaches vs. seawalls — "explain it again, now why aren't there any sand beaches just north of La Jolla Cove?"

Coastal geomorphology includes all factors that contribute to shaping coastal landforms. Coastal erosion and coastal-bluff retreat are caused by both marine and terrestrial processes. Surf action is usually the dominant marine agent producing both hydraulic (wave) impact and abrasion. A basic understanding of the various geomorphic processes is clearly a requisite to assess variations in shoreline erosion. Geomorphic analysis, including coastwide geologic inventory, measurements of offshore bathymetry, and research to determine historic climatic conditions permits assessment of likely future coastal erosion. The relationships between the factors provide the coastal consultant the necessary tools for evaluating future trends in coastal erosion.

Geomorphic Factors that Contribute to Coastal Erosion

Climate. Long-term climatic and short-term meteorologic conditions produce large waves, the energy source causing coastal erosion. Storm conditions may present a variety of wave directions, heights, and frequencies.

Offshore Geology and Wave Energy. The amount of wave energy impacting a seacliff is locally controlled by the offshore seafloor bathymetry of the shore platform, which is influenced by lithology and faulting. The shore platform causes large, deep-water waves to break before reaching the shoreline, thereby attenuating the amount of wave energy ultimately impacting the seacliff. Variations in nearshore bathymetry also refract ocean waves, locally focusing damaging wave energy onto certain coastline segments (Munk and Traylor, 1947; Bradley and Griggs, 1976). Clearly, the presence of nearshore reefs, such as Swami's and Tabletop, shelter portions of the coastline and cause refraction of incoming waves that may result in increased erosion elsewhere along the coast.

Lithology and Structure of Coastal Bluffs. Lithology is the physical character of the rock, which provides the erosion resistance of the rock type. Structural characteristics and associated discontinuities in the rock cause variations in erosion potential for a given rock type. These two factors may vary greatly along a stretch of coast, and are primary factors in site-specific rates of coastal retreat.

Groundwater. The presence of groundwater may significantly impact the stability of certain geologic units and consequently accelerate bluff retreat. Groundwater seepage also tends to weaken intact geologic units (Kuhn and Shepard, 1980) by both chemical solution and by mechanical erosion, thus increasing susceptibility of soils in the bluff face to accelerated marine erosion, and assisting formation of caves along small faults by wave action in the seacliff (Kuhn and Shepard, 1983).

Bluff Geometry. Bluff geometry is the shape of the coastal-bluff profile. Bluff geometry is influenced by marine erosion from coastal processes at the seacliff, and subaerial erosion from terrestrial processes acting on the bluff (Emery and Kuhn, 1982). The rate of marine erosion at the seacliff limits the decline of the bluff caused by subaerial erosion. Because the upper coastal bluffs along San Diego's North County coastline are all subjected to similar terrestrial processes (excluding man's activity), a qualitative assessment of bluff retreat can be made based on variations in bluff geometry along the coastline.

Measurement of Slope Retreat. A classic tenet of geomorphology is that slope angles decrease with the passage of time. Measurement of bluff profiles enables an evaluation of the relative amount and rates of marine and subaerial erosion. The rate of slope decline is nonlinear, consisting of an initial rapid decline, followed by progressively slower decline. Regardless of origin — fault, fluvial, or coastal bluff — all slope decline follows the same rule. The age of the slope can be estimated from the angle of the slope (Wallace, 1977).

As part of the aging process, the near-surface portion of the bluff develops a weathering profile (pedogenic soil profile) that may form on at least part of the slope. The relative development of the weathering profile is thus an indicator of slope age. For coastal bluffs, the rate of marine erosion of the seacliff limits the development of a weathered soil horizon on the upper sloping surface.

Anthropic Influences

Human activity significantly influences shoreline changes, both directly, by erosive activities along the bluff top and seawall building at the base of the bluff, and indirectly, exemplified by the pervasive impact of activities in the upland watersheds, such as periodic burning of surface vegetation by fires, the construction of dams and sand mining.

Until recently, longshore transport annually moved on the order of 200,000 to 300,000 cubic yards of sand through the Oceanside Littoral Cell, which encompasses some 52 miles of coastline terminating at the La Jolla Submarine Canyon (Nordstrom and Inman, 1973; USCOE, 1987, 1991). Under these natural conditions, a relatively persistent sandy beach was maintained since available longshore transport energy was not sufficient to cause a long-term beach deficit. It has been estimated that about 500 to 900 feet of shoreline erosion has occurred in the Encinitas/Solana Beach area in the last 6000 years. This erosion occurred in the presence of beaches maintained by abundant sediment sources from rivers and the coastal bluffs themselves.

Since the 1940s, approximately 40 percent of this sediment-producing watershed has been dammed (Nordstrom and Inman, 1973; COE, 1987, 1991), and concurrently large volumes of river sands have been mined from the lower reaches of North County rivers for use in the construction industry. This human activity in the last 50 years has resulted in a pervasive long-term sediment deficit (Inman, 1976; USCOE, 1991). The current sediment deficit has essentially robbed denuded the shore platform of sand, resulting in an underwater topographic environment somewhat different than what has typically existed in recent geologic times. The lack of sand has created a more severe coastal environment than would normally exist under natural conditions.

CURRENT STATE OF NORTH COUNTY'S BEACHES AND BLUFFS

In addition to recreational opportunities, sand beaches provide natural protection against damage from wave action and flooding. The absence of protective sand beaches also allows the direct impact of breaking waves on coastal bluffs and the accelerated erosion of the bluff. The San Diego Association of Governments (SANDAG) has formed a Shoreline Erosion Committee to address coastal erosion in San Diego County, and has concluded, "The shoreline is a valuable asset to the environment and economy of the San Diego region and the state. It is also considered a resource of significant national significance. The beaches and seacliffs help define this area's quality of life; when we think of the region's positive image, we most often think of the climate and the shoreline." The basic conclusion of SANDAG's Shoreline Preservation Strategy is that a beach building and maintenance program is recommended as the primary shoreline management policy for control of shoreline erosion (SANDAG, 1993).

Throughout the Oceanside Littoral Cell, average beach widths were surveyed, with results reported in the SANDAG study for Solana Beach in 1990 as 80 feet [beach width was defined in the SANDAG study from the MSL contour to the base of the seacliff]. Future projected average beach widths in Solana Beach for the years 2010 and 2040 were 70 feet and 35 feet, respectively [as a point of reference, using the SANDAG definition, the current beach width, measured during our field surveys in mid June 1998, ranged from 0 to 40 feet, with an average width on the order of 20 feet; somewhat less than the year 2040 prediction. Note also that this beach width definition creates a deceptively wide beach, recognizing that beach widths are typically defined as extending out to MHHW or at times to the landward edge of the foreshore. The former results in an average current beach width of 0 to 10 feet, and the latter results in no beach].

The SANDAG study then evaluated the required minimum beach width to protect the coastal bluff, accommodating both seasonal fluctuations and a 100-year storm event. For the Solana Beach coastline, that width was determined to be 232 feet. The SANDAG study further concluded that the required volume of beach fill within the Oceanside Littoral Cell was 25,000,000 cubic yards, with a future annualized renourishment volume of 320,000 cubic yards per year. One of the recommendations contained in the SANDAG Shoreline Preservation Strategy was the need to provide additional beach nourishment to accommodate recreational demand, with the year 2040 total demand requiring an average beach width of 325 feet. Similar data are also available for other North County communities.

Anthropic activities have also locally influenced rates of bluff-top retreat and bluff-slope decline by uncontrolled and concentrated surface drainage, and by surface alterations ranging from early farming to more recent residential bluff-top development (Kuhn and Shepard, 1980; 1985).

In any assessment of future coastal erosion, one must address the impact of human activity, and recognize that the historical database cannot simply be projected into the future without considering human impact.

Human activities in the last 50 years have resulted in the progressive loss of the transient sand beach, primarily from the cumulative effects of sand removal in the urbanizing watershed. This has caused a dramatic increase in the rate of marine erosion not previously observed during man's initial habitation of the North County coastal area.

LONG-TERM SEA LEVEL RISE

Changes in sea level result in significant changes in the shoreline location. Three general sea level conditions are recognized: rising, falling, and stationary. The rising and falling stages result in massive sediment release and transport, while the stationary stage allows time for adjustment and reorganization towards equilibrium. Major changes in sea level during the Quaternary period were caused by worldwide climate fluctuation, resulting in at least 17 glacial and interglacial stages in the last 800,000 years and many before them (Shackleton and Opdyke, 1976). Worldwide sea level rise associated with the melting of glaciers is commonly referred to as "glacio-eustatic" or "true" sea level rise. During the past 200,000 years, eustatic sea level has ranged from about 150 meters below the present-day level, to possibly as high as about 10 meters above the present-day level. If all of the ice presently on earth were to melt, sea level would rise about 78 meters (256 feet) above the present level (Barry, 1981).

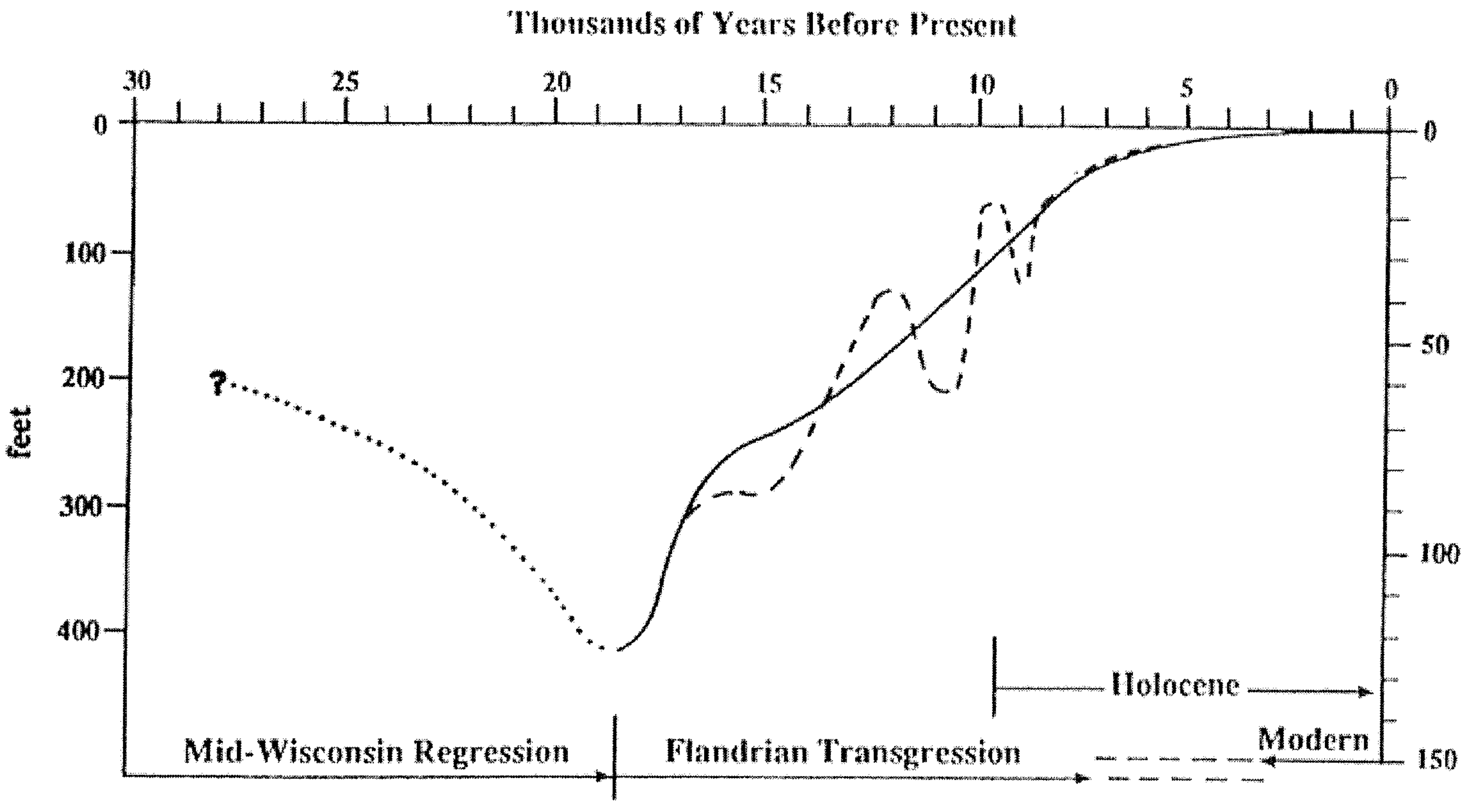
Sea level changes during the last 18,000 years (Figure 1; USCOE, 1991) have resulted in an approximately 400-foot rise in sea level, when relatively cold global climates of the Wisconsin ice age started to become warmer, melting a substantial portion of the continental ice caps (Curray, 1960; 1961). Sea level curves show a relatively rapid rise of about 1 meter per century, from about 18,000 years before present to about 8000 years ago, as indicated in Masters and Fleming (1983). About 8000 years ago, the rate of sea level rise slowed, ultimately to a relatively constant rate of about 10 centimeters per century since about 6000 years ago (Curray, 1960; 1961; 1965). Most researchers agree that, along the southern California coastline, approximately 6000 years ago, the sea level was 12 to 16 feet below its current elevation (Curray, 1960, 1965; Inman and Veeh, 1966). More importantly, the world's coastlines, including that of California, have been shaped largely within this 6000-year period, with the sea at, or within 16 feet of, its present level (Bird, 1985).

Continuous sea level records exist from a tide gauge in San Diego Bay beginning in 1906, and from a gauge at La Jolla beginning in 1924. Figure 2 shows a plot of yearly mean sea level at La Jolla based on data published by the National Ocean Service (NOS). The straight line represents a least-squares fit of the data and indicates a mean rate of sea level rise of 0.64 feet (19.5 centimeters) per century. The shaded areas above the trend line correspond to above-average sea level episodes corresponding to major El Niño events (Quinn, et al., 1978). The highest sea levels in La Jolla were observed on January 29, 1983 (7.71 feet MLLW), and August 8, 1983 (7.81 feet MLLW). These episodes were part of a run of El Niño and storm-influenced extreme events that occurred during the 1982-1983 storm season. [The 8.35-foot extreme tidal level recorded in San Diego Bay during this same period is due to the tidal amplification that occurs within the sheltered bay location.]

When using relatively coarse time scales, say on the order of 100 to 1000 years, given a known rate of sea level rise, in its simplest form, the amount of erosion in a given time is equal to the amount of sea level rise divided by the shore platform slope. This sea level model takes the following form (Marine Board, 1987):

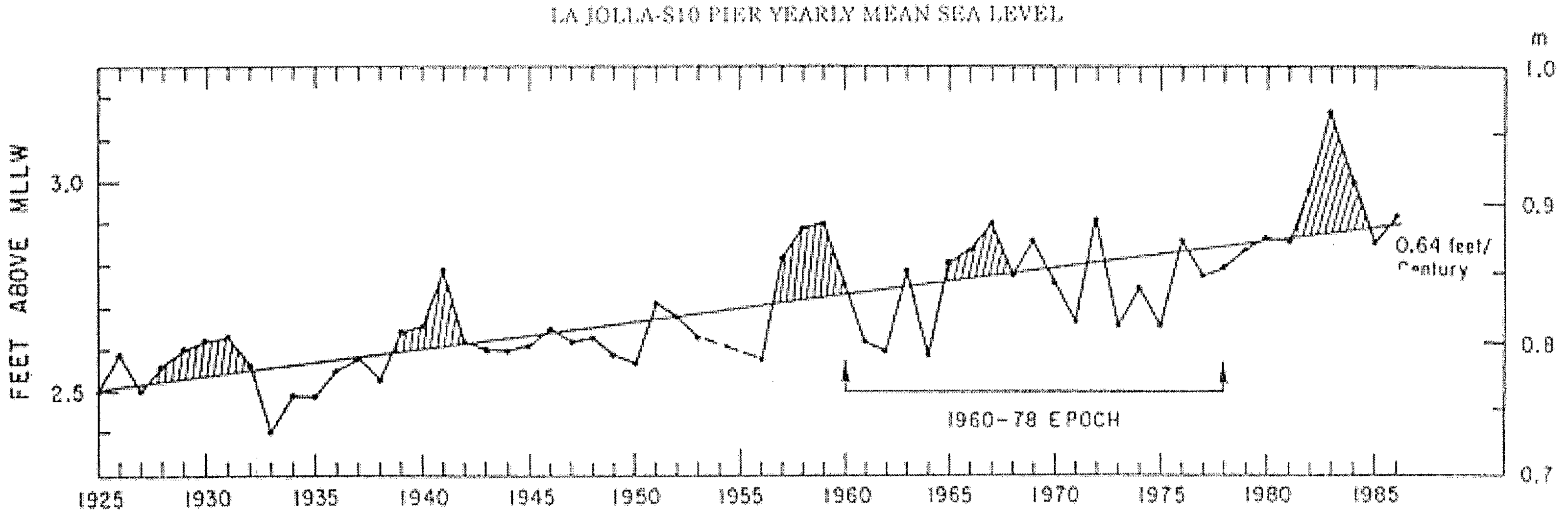
$$dx/dt = (L + E) \,/\, \text{platform gradient}$$

where dx/dt is the horizontal rate of erosion, L is the local tectonic rate of subsidence or uplift, and E is the eustatic sea level rise. With an average platform gradient of 60:1 and a future sea level rise of 10 cm per century, sea level rise alone would result in a retreat of the coastal bluff of approximately 20 feet in the next century. When using the La Jolla sea level rise data of 0.64 feet per century, the sea level rise model would suggest approximately 40 feet of coastal bluff erosion in the next century.



Late Quaternary fluctuations in sealevel. Solid line is the "generalized" sealevel curve (from Curray, 1965); dashed line is detailed curve (from Curray 1960, 1961). Tree ring and Uranium/Thorium dates give greater age than the radiocarbon ages for these curves. Recent studies indicate the glacial maximum was 21,000 ($^{230}Th/^{234}U$) years BP with a sealevel lowering of 121 ± 5 m (400 ± 16 ft) (Fairbanks, 1989; Bard, et al., 1990). *[Reproduced from USCOE, 1991]*

SEA LEVEL CHANGES SINCE THE LAST ICE AGE



Yearly mean sea level observed at La Jolla, 1925-1986. Shaded areas indicate periods of major El Niño episodes associated with heightened sea levels persisting for years. Straight line shows least-square-fit of trend with a slope of 0.64 ft./century.

SEA LEVEL RISE FOR LA JOLLA

SAND BEACHES vs. SEAWALLS - A GEOMORPHIC PERSPECTIVE *Figure No.: 2*

EMPIRICAL AND ANALYTICAL TECHNIQUES

The scientific community has been actively engaged in developing numerical models to assess more contemporary rates of shoreline erosion. Numerical models attempt to address both the landward retreat of the seacliff, and the development of the shore platform. In this simplest expression, predictive cliff-erosion models take the following form (Sunamura, 1977):

$$dx/dt \propto \ln\left(\frac{f_w}{f_r}\right)$$

where dx/dt is the horizontal rate of erosion, f_w is the wave force, and f_r is the rock resistance.

This mathematical model developed by Sunamura basically states the erosion rate is proportional to the natural logarithm of the wave force divided by the rock resistance. A couple of observations are implicit to this equation. First, it is important to recognize that there is a threshold wave force below which no additional erosion can occur, and obviously the wave force that we are interested in is what actually impacts upon the coastal bluff, and this is a function of the presence or absence of the protective sand beach. In other words, a healthy sand beach pushes f_w below its threshold, and thus there is no coastal erosion. The other corollary is that by increasing the rock's resistance, or actually its unconfined compressive strength, there is a corresponding increase in the threshold wave energy necessary to cause erosion.

THE BEDROCK SHORE PLATFORM

The contemporary abrasion surface, or bedrock shore platform, fronting San Diego County's seacliffs also provides a worthwhile geomorphic indicator of the erosion resistance of the coastal bluff. Worldwide, the gradient of the shore platform is a function of the tidal range, with steeper platform gradients occurring in areas where large tidal ranges exist. Along the California coast, platform gradients typically range from about 0.3 degrees to slightly in excess of 1 degree, with flatter platform gradients typically associated with a more erodible seacliff (Trenhaile, 1987). There has also been considerable research on platform downwearing, z, with the rate of downwearing often expressed as a function of seacliff erosion rate times platform gradient (Zenkovich, 1967):

$$dz/dt = dx/dt \cdot \tan m$$

where $\tan m$ is the platform gradient. The elevation of the cliff-platform junction is also a function of the rock strength, with higher rock strengths corresponding to higher cliff-platform junction elevations. Throughout San Diego's North County, where the Eocene-age cliff-forming materials exhibit similar rock strengths, the cliff-platform junction is typically around –1 foot, MSL. However, where Eocene oyster beds are occasionally encountered in the Delmar Formation claystones, these calcium carbonate-rich deposits, with their high unconfined compressive strengths, provide extremely erosion-resistant nearshore reefs with the cliff-platform junction elevation locally as high as +7 feet, MSL [Tabletop Reef], and nearshore elevation differentials as high as 10 feet [measured along the southerly margin of Swami's Reef in 20-foot water depth]. These Eocene-age oyster beds are also responsible for some of North County's best surf breaks, notably Swami's, Cardiff, and Tabletop.

Southerly of the Rose Canyon Fault, the older Point Loma Formation and, locally, the Cabrillo Formation comprise the lower seacliffs. These two geologic units, and particularly the Point Loma Formation, exhibit significant differences in unconfined compressive strength through the stratigraphic section. Along the Point Loma Peninsula, locally highly erodible sections exist, most notably the claystone facies in the vicinity of Del Mar Avenue, where erosion rates exceeded 1.1 feet per year over a 12-year study period in the 1960s and 1970s (City of San Diego, 1976), while in other areas, shales and sandstones with relatively high unconfined compressive strengths produced almost no observable erosion over the past century [southerly of Santa Cruz Avenue, Luscomb's Point and vicinity, and most of the intact non-faulted/fractured sections of coastline extending from the southerly portion of Fort Rosecrans Military Reservation down to the Point Loma Peninsula].

It is of interest to note that along the more erosion-resistant headlands along the southerly portion of the Point Loma Peninsula, the elevation of the cliff-platform junction ranges from –3 to –5 feet, MSL, or several feet lower than the cliff-platform junction elevation of the North County Eocene cliff-forming sediments. It is along these erosion-resistant headlands where the unconfined compressive strengths of these cliff-forming sediments are high enough to resist significant wave forces, where only limited erosion has occurred over the last several thousand years, allowing sea level to rise, invoking more wave energy to assail the coastline and continue the erosion process. One of the best examples of this process can be found at latitude 32°42.1', longitude 117°16.5', about a mile seaward of the Point Loma Peninsula in 100 foot of water depth, where about 10,000 years ago, as sea level was rising at about 1 meter per century, an extremely erosion-resistant section of the Point Loma Formation was encountered in the then-contemporary seacliff, with only minimal erosion occurring until sea level rose to a height of 20 feet above the base of the seacliff, after which time the now very high wave energy, and presumably a change in lithology, allowed fairly rapid seacliff retreat, leaving this now submerged and stranded shoreline. Photo 1 shows this shoreline with a diver for perspective.

What should be obvious to the reader is that a cliff-platform junction elevation of –4 feet, MSL (–1.25 feet, MLLW), precludes essentially any lateral access along the base of the seacliff. This is typical of much of the seacliffs comprising the Point Loma Peninsula. In the absence of sand, a cliff-platform junction elevation of –1 foot, MSL, as exists along much of San Diego's North County, limits lateral access to only during the tidal lows.

LITTORAL ZONE SEDIMENTS

Before anthropic changes in the 20th Century, the coastal bluffs retreated in response to long-term sea level rise since the last glacial maximum. Under pre-anthropic conditions, the littoral sediment budget was primarily supplied by riverine sources, and within the Oceanside Littoral Cell, approximately 10 percent of the sediment budget was supplied by bluff erosion (Griggs and Runyan, in press). Under this natural condition, the available transport capacity from the offshore wave environment would pull sand offshore (not to be confused with seasonal onshore-offshore sand movement) and downcoast, ultimately lost to the littoral system through submarine canyons. Ninety percent of this pre-anthropic sediment budget was provided by subaerial processes and thus responsible for the majority of the transient sand beaches, which overlaid the shore platform and are a significant interest to the beach-going public and the bluff-top property owners alike. It is the presence of these protective transient sand beaches that reduce the wave force, f_w, and thus minimize coastal erosion and even during storm activity, when pulled offshore to form a nearshore bar, would still trip storm waves, again reducing the wave energy actually impacting on the coastal bluff.

The almost total urbanization of the upland watershed, combined with the extensive sand mining within the lower reaches of San Diego County's coastal rivers, has effectively reduced the sediment supply such that the littoral budget is today significantly lower than the available wave-induced transport capacity, resulting in a sand-starved littoral system, particularly within the central portion of the Oceanside Littoral Cell [most notably in the communities of Encinitas and Solana Beach].

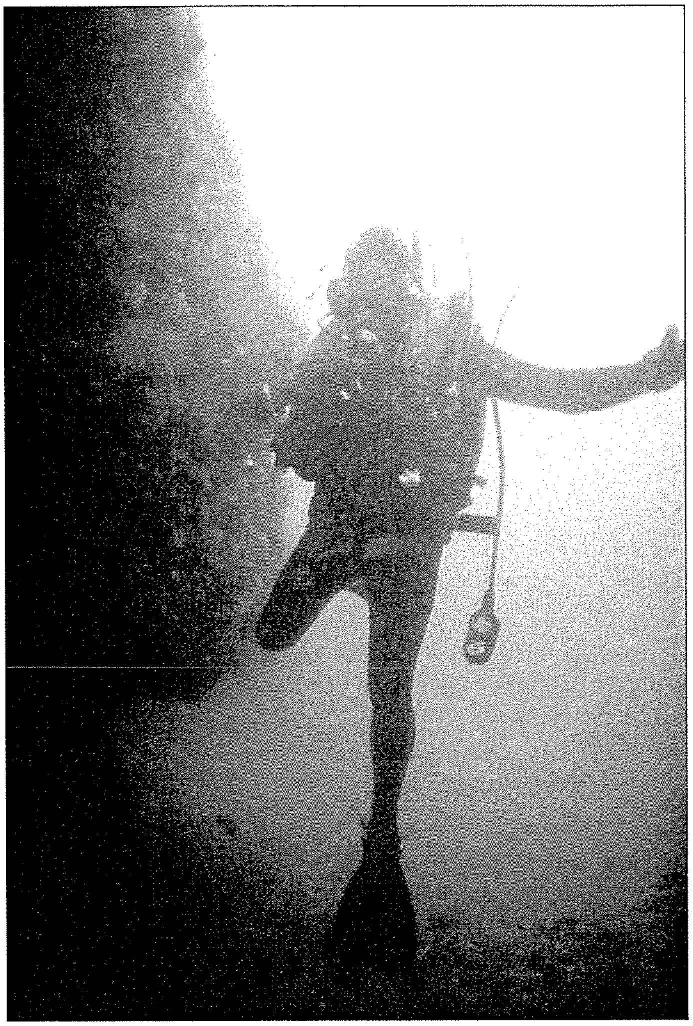


Photo 1. Submerged seacliff off Point Loma at latitude 32°42.1' in 100-foot water depth. Note the notch at the base of the sea cliff and the vertical seacliff that extends about 20 feet in height. Of interest also is the presence of a relic sand beach at the base of the sea cliff extending offshore to in excess of 120-foot water depth (the westerly extent of our underwater examination).

From a beach access/recreational resource perspective, the back berm elevation of a healthy sand beach (even a relatively narrow beach) is around elevation +10 to +12 feet, MSL. In a sand-starved condition, as in San Diego's North County, most notably Solana Beach and Encinitas where the shore platform is now more frequently exposed near elevation –1 foot, there is an essentially total loss of the dry sand beach that at one time provided full-time lateral access and an invaluable recreational resource. This loss of the transient sand beach has occurred almost entirely in the absence of seawalls, with seawall construction only becoming more prevalent since the 1982-83 El Niño storm season in response to man's more pervasive urbanization of the upland watershed, essentially severing this significantly more important subaerial sand source.

Even today, in San Diego's North County, in the absence of any protective sand beaches, thus maximizing f_w, the unconfined compressive strength of the Eocene sediments (f_r) is still high enough to limit sediment release from the seacliff (*dx/dt*) such that sediment contribution from the coastal bluff within the central portion of the Oceanside Littoral Cell amounts to only a few percent of the available transport capacity. Any sediment contribution from the coastal bluffs is immediately carried out of the littoral system.

As with the more erosion-resistant Point Loma shoreline, where the seacliffs provide essentially no source material for the littoral system and a relatively deep foreshore exists, essentially eliminating any lateral access, the North County coastal bluffs, without the benefit of significant subaerial sediment contribution, likewise cannot produce sufficient sediment to meet the available littoral transport capacity generated by the Southern California wave environment. Thus, without human intervention through beach renourishment, seacliff retreat will continue to maintain the same cliff-platform junction elevation and merely translate today's sand-starved shore platform profile landward.

This brings us to the question about the La Jolla Caves along a section of coastline that actually faces north/northeasterly, with a relatively deep cliff-platform junction elevation. We also know that the cliff-forming Point Loma Formation materials are badly faulted along this stretch of shoreline, allowing the formation of the relatively spectacular sea caves, which would presumably reduce the abrasion resistance (f_r) of this cliff-forming geologic unit. It is, however, the orientation of this section of coastline today that provides a reasonable amount of wave sheltering, and hence the significant reduction in f_w, which allows sea level to rise without significant seacliff retreat in the very recent geologic past.

REFERENCES

Barry, R.G., 1981, Trends in snow and ice research, EOS 62, 46, pp. 1139-44.

Bird, Eric C.F., 1985, Coastline changes, a global review: John Wiley & Sons.

Bradley, W.C., and Griggs, G.B., 1976, Form, Genesis and Deformation of Central California Wave-cut Platforms. Geological Society of America Bulletin, Volume 87, pp. 433-449, 16 Figures.

City of San Diego, 1976, Sunset Cliffs, Newport Avenue to Osprey Street, Shoreline Protection Study, Task Force Report.

Curray, J.R., 1965, Late Quaternary history; continental shelves of the United States, pp. 723-735, in Wright, H.E., Jr., and Frey, D.G. (eds), The Quaternary of the United States, Princeton Univ. Press, 922 p.

Curray, J.R., 1960, Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico, pp. 221-266, in Shepard, F.P, Phlefer, F.B., and van Andel, Tj.H. (eds), Recent Sediments, Northwest Gulf of Mexico, 1951-1958, Amer. Assoc. Petroleum Geologists, Tulsa, Oklahoma, 394 p.

Curray, J.R., 1961, Late Quaternary sea level: a discussion. Geological Society of America Bulletin, Vol. 72, pp. 1707-12.

Emery, K.O., and Kuhn, G.G., 1982, "Seacliffs: Their Processes, Profiles and Classifications," Geological Society of America Bulletin, Vol. 93, No. 7, pp. 644-54.

Griggs, Gary, and Runyan, Kiki, in press, Contributions of Coastal Cliff Erosion to the Beach Sand Budget in California and the Effects of Armoring, presented at the 2001 California Shore and Beach Preservation Association Annual Conference, San Diego, California.

Inman, D.L., 1976, Summary Report of Man's Impact on the California Coastal Zone. Prepared for the Department of Navigation and Ocean Development, State of California, 150 p.

Inman, D.L., and Veeh, H.H., 1966, Dating the 10-Fathom Terrace off Hawaii. American Geophysical Union, Trans. 47, 125.

Kennedy, M.P., and Peterson, G.L., 1975, Geology of the San Diego metropolitan Area, California: Del Mar, La Jolla, Point Loma, La Mesa, Poway and SOUTHWEST 3 Escondido 72 minute quadrangles, California Div. of Mines and Geology, Bulletin 200, Sacramento, 56 p. & plates.

Kuhn, G.G., and Shepard, F.P., 1985, Dana Point to the Mexican Border, in Griggs, G.L., and Savoy, L., eds., Living with the California Coast, Duke University Press, Durham, NC, Chapter 18, pp. 344-393.

Kuhn, G.G., and Shepard, F.P., 1983, Beach Processes And Sea Cliff Erosion in San Diego County, California, in Komar, Paul D., ed., CRC Handbook of Coastal Processes and Erosion (Chapter 13), CRC Press, Inc., Boca Raton, FL, pp. 267-284.

Kuhn, G.G., and Shepard, F.P., 1980, Coastal Erosion in San Diego County, California, Proceedings of the Conference: "Coastal Zone '80," American Society of Civil Engineers, pp. 1899-1918.

Marine Board, National Research Council, 1987, Responding to changes in sea level: engineering implications. National Academy Press, Washington, D.C.

Masters, P.M., and Fleming, N.C., 1983, Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves: Academic Press, New York, 641 p.

Munk, W.H., and Traylor, M.A., 1947, "Refraction of Ocean Waves, A Process Linking Underwater Topography To Beach Erosion," Jour. Geol., Vol. 55, No. 1, pp. 1-26.

Nordstrom, C.E., and Inman, D.L., 1973, Beach and Cliff Erosion in San Diego County, California, in Ross, A., and Dowlen, R.J., eds., Studies on the Geology and Geologic Hazards of the Greater San Diego Area, California. Published by San Diego Association of Geologists and the Association of Engineering Geologists, pp. 125-132.

Quinn, W.H., Zopf, D.O., Short, K.S., and Kuo Yang, R.T.W., 1978, Historical trends and statistics of the southern oscillation, El Niño, and Indonesian droughts, Fisheries Bulletin, (76), 663-678.

San Diego Association of Governments, July 1993, Shoreline preservation strategy for the San Diego region.

Shackleton, N.J., and Opdyke, N.D., 1976, Oxygen-isotope and Paleomagnetic Stratigraphy of Pacific Core V28-239, Late Pliocene to Latest Pleistocene, Geological Society of America, Memoir 145.

Sunamura, T., 1977, A Relationship between Wave-Induced Cliff Erosion and Erosive Forces of Wave. J. Geol. 85, pp. 613-18.

Trenhaile, A.S., 1987, The Geomorphology of Rock Coasts, Clarendon Press, Oxford.

U.S. Army Corps of Engineers, 1987, Coastal Cliff Sediments, San Diego Region. Los Angeles District, Coast of California Storm and Tidal Waves Study, CCSTWS 87-2, June 1987, Prepared by Kuhn, Osborne.

U.S. Army Corps of Engineers, 1987, Shoreline movement investigations report, Portuguese Point to the Mexican Border (1852-1982). Los Angeles District, Coast of California Storm and Tidal Waves Study, CCSTWS 87-10, prepared by Kuhn, Osborne.

U.S. Army Corps of Engineers, 1987, Oceanside littoral cell, preliminary sediment budget report, CCSTWS 87-4, prepared by Tekmarine, Inc.

U.S. Army Corps of Engineers, 1991, State of the coast report, San Diego region, CCSTWS, Vol. I — main report, Final — September 1991.

Wallace, R.E., 1977, Profiles and Ages of Young Fault Scarps, North-Central Nevada: Geological Society of America Bulletin, Vol. 88, pp. 1267-1281.

Zenkovich, V.P., 1967, Processes of Coastal Development, Oliver and Boyd, Edinburgh.

National Marine Fisheries Service Center — Effects of Tectonics and Faulting on Coastal Erosion

Walter F. Crampton, R.C.E., R.G.E., and Braven R. Smillie, R.G., C.E.G.
TerraCosta Consulting Group, Inc., San Diego, California 92123-4379

ABSTRACT

The majority of the San Diego County coastline consists of a lower cliff-forming Tertiary or older geologic unit, overlain by the 120,000-year-old Bay Point Formation, which was deposited on the abrasion platform after the 125,000-year-old high still stand, after which sea level receded. The coastline just north of Scripps Pier, however, is somewhat atypical of the San Diego region. Here, tectonic uplift, resulting from movement on the Rose Canyon Fault, has created a 200-foot-high seacliff consisting entirely of Tertiary-age sediments. A northeast-trending splay of the Rose Canyon Fault cutting through this section of coastline further complicates the local coastal bluff profile. This case study discusses the role geologic structure has played in the overall stability of the coastal bluff and its effect on the National Marine Fisheries Service Center. Also discussed is a contemporary assessment of the landslide mapped by Moore in 1973, and published in Bulletin 200.

INTRODUCTION

The Southwest Fisheries Science Center (SWFSC) serves as a headquarters of the National Marine Fisheries Service Southwest Region, and is less than 1/4 mile north of Scripps Institute of Oceanography in La Jolla, California. Figure 1, the Vicinity Map, and Figure 2, the Site Plan, show the general location of the SWFSC complex, and the relationship of the complex to site-area topography and nearby structures, respectively. The stability of the coastal bluff at the subject site has been in question since the early 1960s when the SWFSC complex was designed and constructed.

This case study discusses the role that geologic structure has played in the overall stability of the coastal bluff, the unique structural and geomorphic nature of the site, as compared to the rest of San Diego County coastal bluffs, and the present-day risk to the SWFSC complex posed by bluff-top retreat. Also discussed are the various assessments of both deep-seated and surficial instability of the coastal bluff over the past 40± years, and a brief summary of current alternative recommendations for mitigation of the risk of upper and middle bluff slope failure to the SWFSC complex at this geologically unique site.

SITE AREA GEOLOGIC CONDITIONS

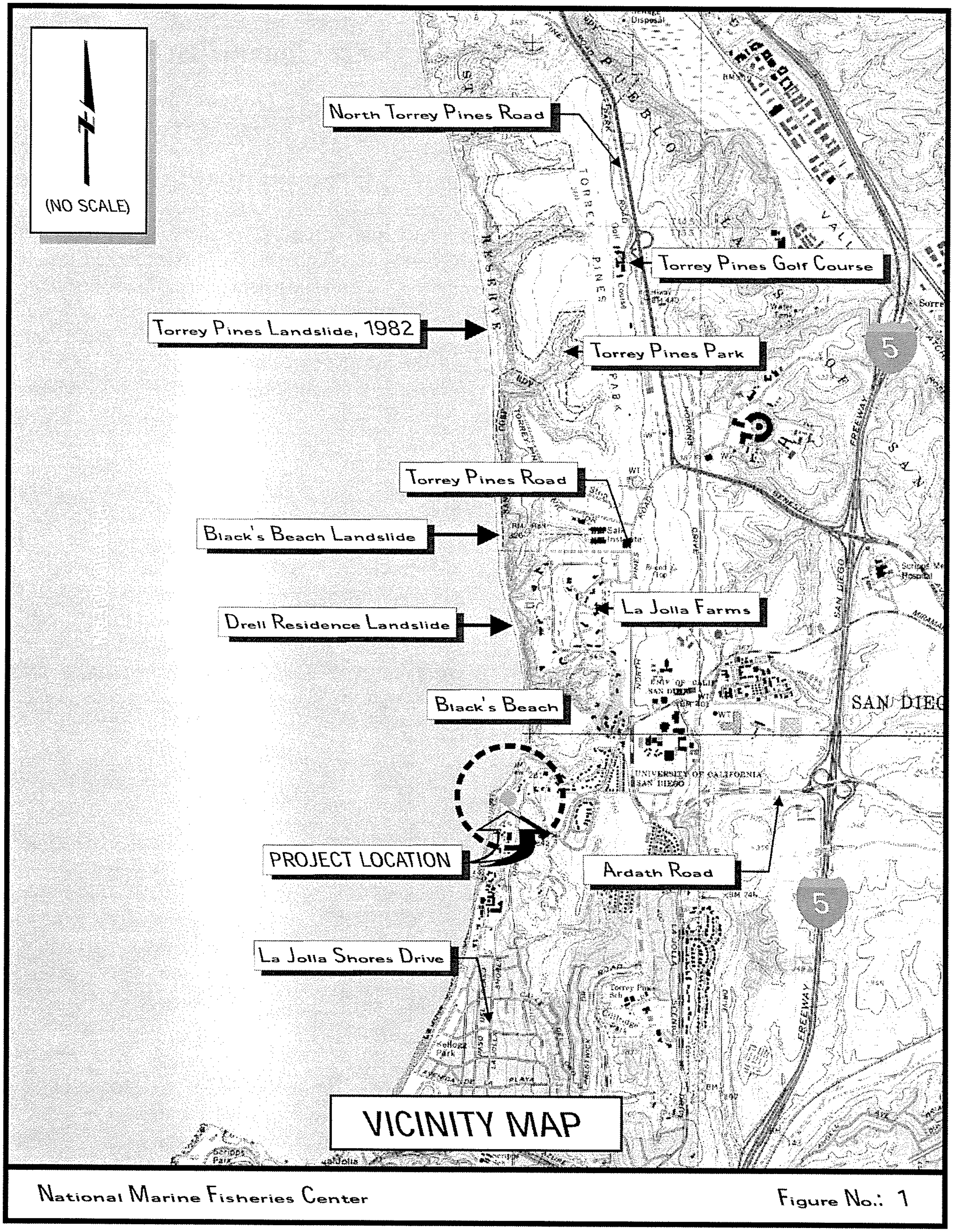
Coastal bluff retreat is a geomorphic process that has operated for millions of years and continues today along most of the San Diego County coastline. Essentially all of the shoreline, from north of Scripps Pier to Torrey Pines State Beach, consists of steep coastal bluffs ranging up to 300 feet in elevation. Numerous steep-sided canyons are incised into the bluff throughout this segment of the coastline.

Stratigraphy

The coastal plain of San Diego county is characterized by thick sequences of interbedded Eocene marine siltstones, claystones, sandstones and conglomerates, which, at the shoreline, are typically capped by late Pleistocene onshore and nearshore terrace deposits. These terrace deposits are absent at the SWFSC site, due to the site area having been elevated by tectonic uplift at the time of terrace deposit deposition. Two Eocene formational units, the Scripps Formation and the Ardath Shale, the principal geologic units exposed in the bluffs at the site, are described below.

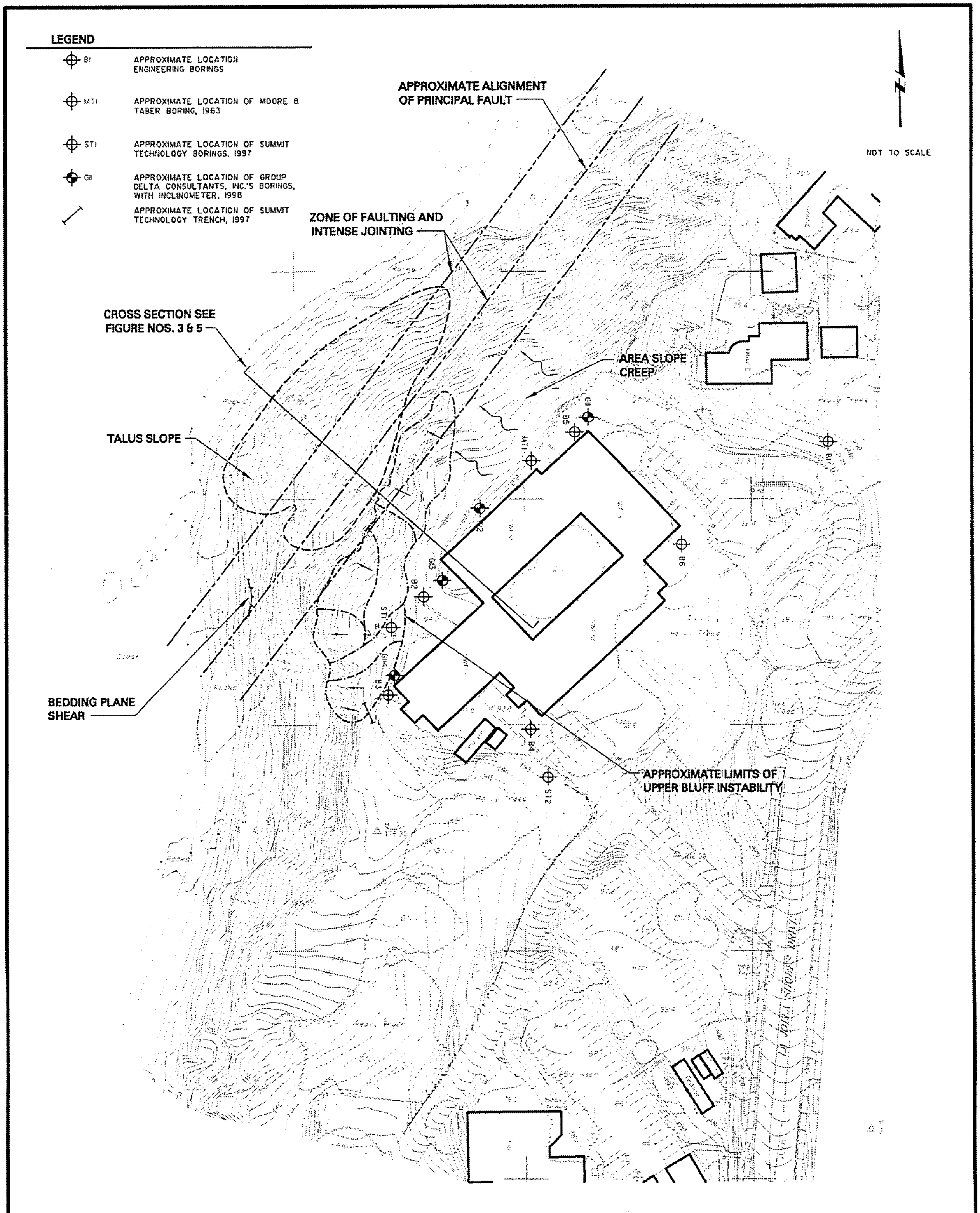
Scripps Formation. The Scripps Formation, as described by Kennedy (1975), underlies much of the area from the middle of Torrey Pines State Park to Scripps Institution of Oceanography. The type section for the Scripps Formation is located on the north side of the mouth of Black's Canyon, approximately 1/2 mile north of the SWFSC. Here it consists of 185 feet of pale yellow-brown, medium-grained sandstone and cobble conglomerate interbeds. Interbeds of clays and siltstones are also exposed in the bluffs in the area of the SWFSC.

Ardath Shale. The Ardath Shale, as described by Kennedy (1975), crops out along the seacliffs from Bathtub Rock in Torrey Pines State Park, south to the pier at Scripps Institution of Oceanography. Along this area of the coastline, the Ardath Shale thins below the Scripps Formation toward the north as it grades into the Torrey Sandstone below. The Ardath Shale is predominantly a weakly fissile, olive-gray shale with concretionary beds containing mollusks and other fossils. Expansive claystones locally comprise as much as 25 percent of the Ardath Shale and landslides are commonly associated with it.



National Marine Fisheries Center

Figure No.: 1



SITE PLAN

NATIONAL MARINE FISHERIES CENTER FIGURE NO. 2

Structure

The northwesterly trending Rose Canyon fault zone (classified as active, and located about a mile to the southwest) juxtaposes the Eocene Ardath shale (northerly, downthrown side of the fault) with the Cretaceous Point Loma Formation (southerly, upthrown side of the fault). Northeast/southwest-trending faults (likely antithetic to the Rose Canyon fault zone) extend through the lower and middle bluff at the site (see Figure 2 — Site Plan, and Figure 3 — Cross Section).

Geologic structure plays a key role in the overall stability of a coastal bluff. The key structural features along this segment of the coastline are the degree of consolidation and cementation, the thickness and arrangement of the geologic units, the strike and dip of bedding and/or zones of discontinuity, and the size, type and distribution of internal structures such as faults, joints, and fractures.

Northeast-trending faulting associated with the Rose Canyon system cuts the bluff on-site (Figure 2). It has been estimated that movement last occurred on these faults during the Miocene epoch when dike rock (a local feature exposed at the toe of the bluff — see Figure 3) was emplaced. Locally, this faulting has fractured the bedrock, as well as tilted and offset the Eocene strata.

Our review of work by others, as well as our own observations, revealed bedding attitudes as steep as 15 degrees to the northwest (out-of-slope), with averages between 8 and 10 degrees. Bedding attitudes were observed to be affected locally by faulting within and adjacent to the bluff face.

Fracturing and jointing of the bedrock have been reported and observed in all of the large-diameter borings and in many of the foundation excavations during the construction of the buildings. The most common attitude of these joints and fractures strikes northwest and dips 60 to 80 degrees southwest. The second most frequent orientation is a northeast-trending strike and a northwest-oriented dip. It is likely that the fractures, many of which are open, are related to faulting and/or the removal of lateral support at the bluff face by erosion.

Individually, none of these structural features appear to play a major role in the overall stability of the coastal bluff. However, combined with external factors, such as the introduction of groundwater or seismic activity, they are key factors in the overall stability of the bluff.

LANDSLIDING AND BLUFF STABILITY

South of Torrey Pines, the cliffs are disturbed locally by extensive deep-seated landslides (Kuhn and Shepard, 1984). The largest of these slides, measuring approximately 1700 feet along the cliff and several hundred feet landward, has been called the Torrey Pines Park Landslide. This landslide was originally mapped by the U.S. Coast Survey in 1889. In 1982, new fractures were observed directly inland from the old landslide in the Torrey Pines Golf Course.

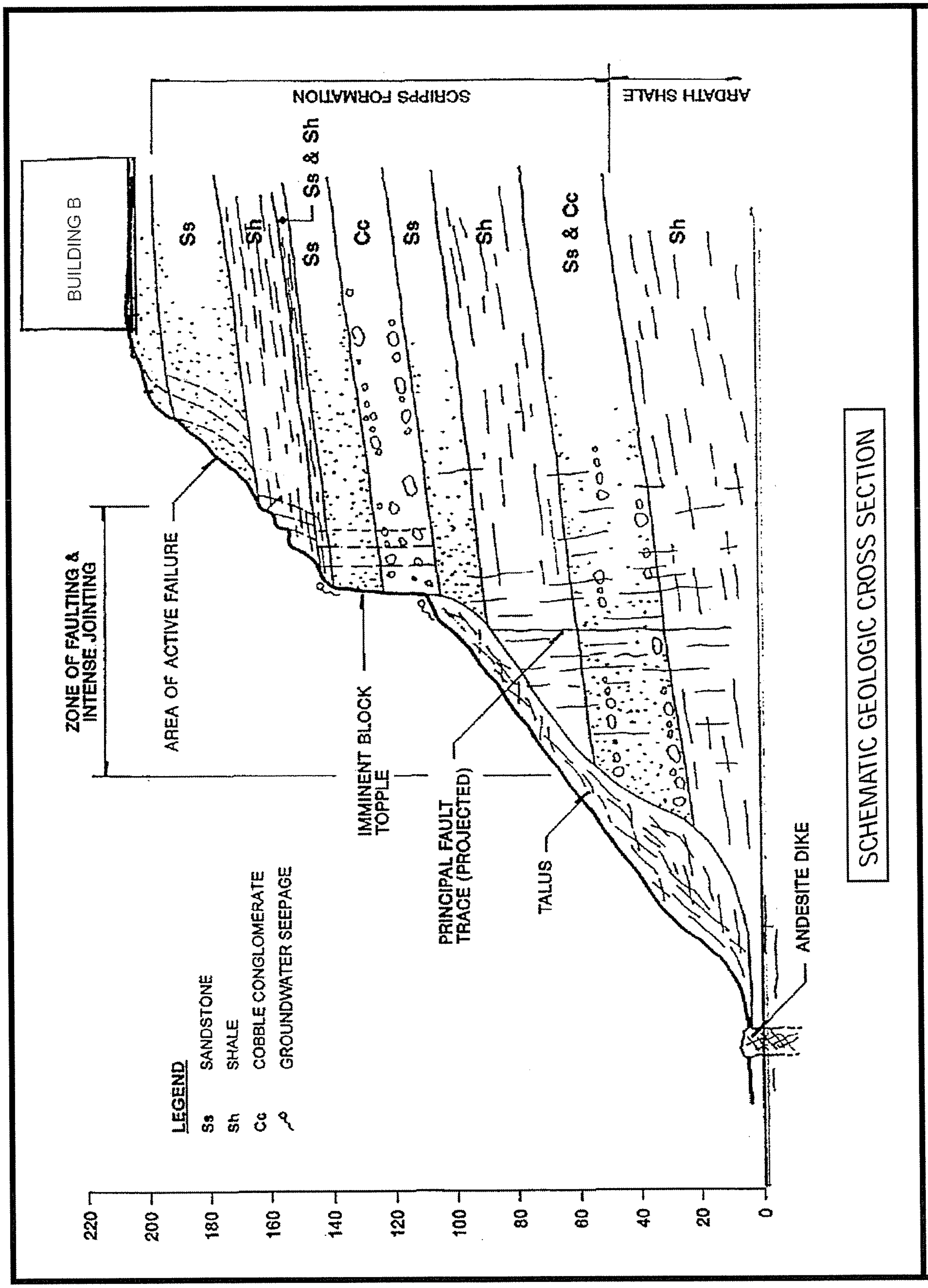
The Black's Beach area has also experienced numerous large landslides. Sumner and Ross (1930) described a failure between 1917 and 1922, with dimensions of 450 feet along the shore by 175 feet in depth, and approximately 200 feet of vertical face. In February 1982, a massive landslide occurred at the same location, measuring approximately 750 feet along the cliff by 280 feet into the cliff (Kuhn and Shepard, 1984). Prior to this movement, groundwater was seen on the cliff face and tensional fractures were noted along the top by San Diego City lifeguards. However, the 1982 failure occurred during a very benign winter, with little rainfall.

Other landslides have been reported in the area of La Jolla Farms. It is speculated that these slides were likely triggered by groundwater introduced by residential landscape irrigation.

Some authors have postulated a potential deep-seated block glide mechanism under the SWFSC complex similar in nature to the Black's Beach and Torrey Pines landslides to the north. During our field investigation, no conclusive evidence was uncovered that would support the existence of a deep-seated slide. In addition, no subsurface soil data within the interior of the bluff is available below elevation 110 feet. Geologic observations on the bluff face found near-horizontal clay seams, clay beds, and seepage locations below elevation 140 feet. None of these were strong enough to confirm the existence of a deep-seated landslide. Firm conclusions from these observed features are not advisable, since most are within or west of the northeast-trending fault zone. For stability, the observations need to be east of the fault zone within the bluff, where the necessary information can only be obtained by drilling. However, a bedding plane shear was uncovered near the base of the bluff (see Figures 2 and 3). It is unknown whether this horizontal shear is related to the fault zone or to deep-seated movement of the coastal bluff. Thus, the potential for a deep-seated instability having a failure mechanism similar to the Black's Beach and Torrey Pines landslides just a short distance to the north can not be ruled out.

Upper-Bluff Stability

The most recent bluff failure on-site, which occurred in late 1997, appears to be confined to the upper third of



SCHEMATIC GEOLOGIC CROSS SECTION

Figure No.: 3

National Marine Fisheries Center

the bluff above approximate elevation 140 feet. Observations made during recent field investigations suggest that the failure may be by block glide mechanism, along adverse, out-of-slope bedding or clay seams between approximate elevations 140 and 190 feet. Fracturing of the siltstone and sandstone beds within this zone, combined with the out-of-slope dip component (estimated at 5 degrees to 10 degrees), allows these blocks to move toward the bluff face. As the blocks move, the fractures are infilled with expansive clayey overburden soils, which, when they become wetted, expand and continue to push the block at an increased rate as it approaches the face of the bluff. As translation along the clayey seams and backward rotation of these blocks continues, the upper weaker materials lose support and fail as a rotational slide or slump-type failure.

A recent, limited test boring program addressed an information gap regarding the depth and extent of fracturing involved in the bluff retreat threatening the corners of two buildings in the complex. Open fractures were observed in two borings, down to elevation 163 feet. Based on interpretation of the recent limited test boring program, the fractured rock involved in the bluff retreat near the building corners extends down to approximate elevation 160 feet. Inclinometers installed in selected test borings were intended to establish the depth and pattern of ground movement; however, no movement has been recorded to date.

Middle-Bluff Stability

The middle portion of the bluff, between approximate elevations 80 and 140 feet, consists of well-indurated, interbedded sandstone and cobble conglomerates. Bluff-parallel fracturing within this zone has created relatively tall columnar features, which, combined with the loss of support of the underlying weaker and more erodible shales, allows these blocks to slump and topple. A number of these columnar blocks are precariously perched and will likely topple in the near future. One of these blocks in particular is estimated to be upwards of 10 feet in thickness and 30 feet in height.

Lower-Bluff Stability

The lower bluff stability is primarily affected by classical marine erosion processes. The lower bluff is protected by a talus slope, which is formed by the soil and block-toppling failures of the upper bluff. This talus slope temporarily protects and buttresses much of the lower slope until removed by erosion. An andesite dike, trending northeast and slightly offshore in the surf zone, partially protects the talus slope from direct wave action. Where unprotected by the talus slope and andesite dike, mechanical erosion processes at the cliff-platform junction backwear the base of the seacliff and downwear the shore platform. The mechanical erosion processes working at the cliff-platform junction include water abrasion, rock abrasion, cavitation, water hammer, air compression in joints, breaking wave shock, and alteration of hydrostatic pressure with the waves and tides. All of these actions are active in the backwearing process. Chemical and salt weathering, as well as slaking and spring sapping, are also erosion processes working on the lower bluff removing support for the middle bluff section.

Groundwater

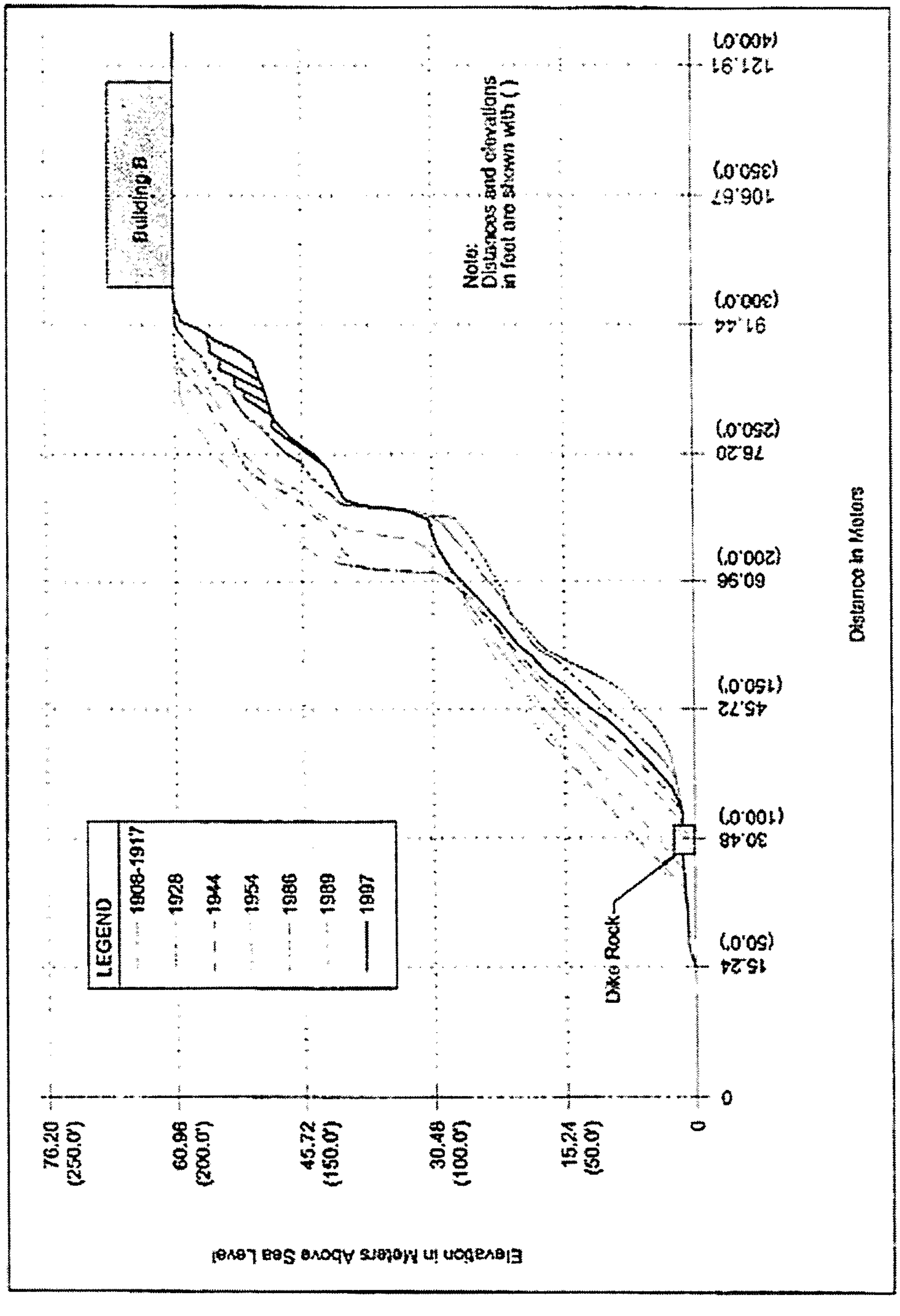
An important contributor to the erosion and decreased stability of coastal bluffs in the area of the SWFSC complex is the flow of groundwater along the contact between interbedded pervious and less pervious Eocene deposits. The likely sources of this groundwater are: 1) natural groundwater migration from highland areas to the north and east, and 2) infiltration by rainfall and residential irrigation water. The volume of groundwater exiting the bluff face in the site area varies from location-to-location, and between seasons, even during drought years.

Since the September 1989 block fall failure, considerable effort has been made by the facilities staff to manage and reduce the amount of irrigation water that is introduced into the coastal bluff locally. Observations made during recent field studies indicate that a large zone of seepage exists in the bluff adjacent to the residential lots north of the SWFSC complex. Consultants agree that groundwater from the north and east is likely migrating down and flowing laterally, as much as several hundred feet, through the more permeable deposits and/or through the fault-controlled joint system that extends northeast toward the adjacent properties. This groundwater causes the clays to swell and increases hydrostatic pressures, which aid in reducing the overall soil and rock strengths. Slope stability analysis has indicated that the stability of the weathered blocks, controlled by bluff-parallel fracturing, is extremely sensitive to groundwater rise.

MARINE EROSION AND BLUFF-TOP RETREAT

From a historical perspective, erosion of the coastal bluff has resulted in approximately 45 feet of bluff-top retreat in the past 90 years, with ongoing marine erosion of the 100-foot-high talus slope significantly affecting the stability of the entire upper bluff (see Figure 4 — reproduced from the 1998 Summit Technology report). The slope

HISTORICAL CLIFF RETREAT



(Reproduced from Summit Technology Consulting Engineers, Inc. PS 1998)

Figure No.: 4

National Marine Fisheries Center

failures at the site are believed to be associated with faulting and/or jointing of the bedrock, combined with marine erosion in the lower bluff. In general, the loss of support caused by erosion and mass wasting of the lower bluff allows the failure to propagate up into the weaker overlying deposits. Sloughing and arcuate surficial failures are common in the upper bluffs where stability is low and where there is a loss of underlying support and/or a lack of protective vegetation.

RECOMMENDED SHORELINE STABILIZATION PROJECT

Stabilization of the upper 70± feet of the coastal bluff was recommended by the use of two free-form structural shotcrete tied-back walls (Figure 5). The upper wall would be 430 feet in length, extending from roughly elevation 167 feet up to the existing bluff top, which ranges from 190 to 215 feet in elevation, with a total upper wall height ranging from 25 to 50 feet. A construction bench was proposed at elevation 165 feet, and after completion of the upper wall, an access road would be pioneered down to a second bench at roughly elevation 137 feet, enabling the construction of a lower, 540±-foot-long, free-form structural tied-back shotcrete wall.

The proposed improvements would also include a 540-foot-long rock revetment at the base of the coastal bluff to essentially arrest ongoing marine erosion that continues to episodically scour the 100±-foot-tall talus slope and undermine the mid-bluff highly fractured columnar bedrock features, thus extending the service life of the lower bench. The rock revetment would have a crown elevation of 25 feet and consist of 4-ton armor stone underlain by half-ton corestone, all constructed at an inclination of 1.5:1. All of the existing debris within the revetment footprint would be temporarily removed and the revetment keyed a minimum of 2 feet into the underlying intact shore platform or bedrock sea floor.

Additionally, horizontal drains (hydro-augers) were recommended to be drilled into the seacliff at various lengths and inclinations, in order to relieve the hydrostatic pressures behind the bluff face, created by the migration of groundwater from off site. Total construction costs for this project were estimated in 1999 to be on the order of $6 million.

REFERENCES

Applied Consultants, Inc., 1989, *Geologic Reconnaissance of Recent Rock Falls West of the Southwest Fisheries Center Building, La Jolla, California*, dated December 12, 1989.

City of San Diego, 1995, *Seismic Safety Study, Geologic Hazards and Faults*, 1995 Edition.

Coastal Consultants, Inc., 1998, [draft] Report on a topographic survey and filling and inspection of landslide cracks, dated December 4, 1998.

Emery, K.O., and Kuhn, G.G., 1982, "Seacliffs: Their Processes, Profiles and Classification," *Geological Society of America Bulletin*, Vol. 93, No. 7, pp. 644-654.

Frank L. Hope & Associates, 1963, Half-size Construction Drawings, Laboratory Building, Bureau of Commercial Fisheries, San Diego, California, dated February 21, 1963.

Group Delta Consultants, Inc., 1999, *Coastal Bluff Stability Study, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, California*, dated February 10, 1999.

Kennedy, M.P., and Peterson, G.L., 1975, *Geology of the San Diego Metropolitan Area, California: Del Mar, La Jolla, Point Loma, La Mesa, Poway, and SW 3 Escondido 72 minute quadrangles*, California Department of Conservation, Division of Mines and Geology, Bulletin 200, Map Scale 1" = 2000'.

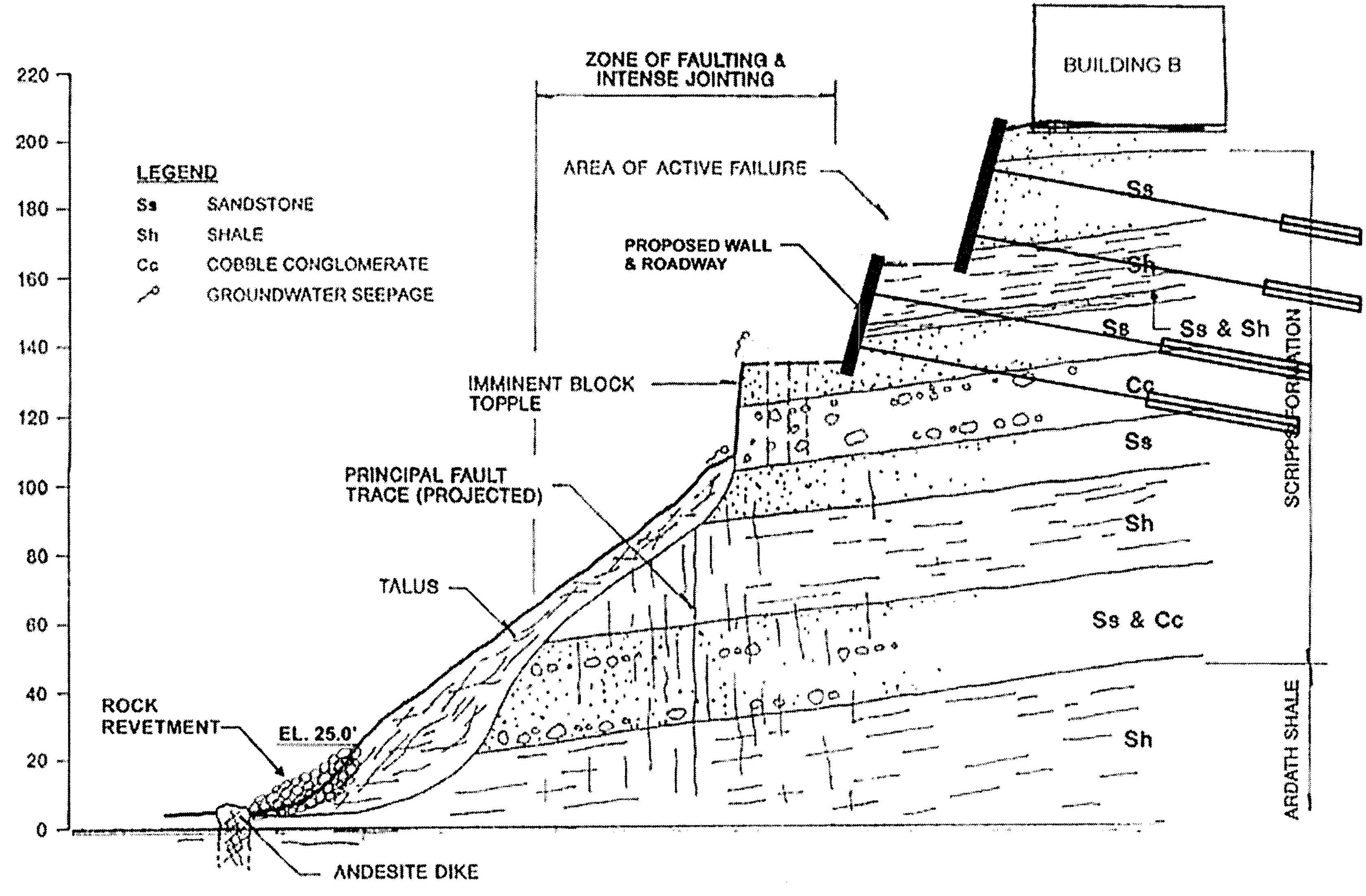
Kuhn, G.G., and Shepard, F.P., 1984, *Sea Cliffs, Beaches, and Coastal Valleys of San Diego County. Some Amazing Histories and Some Horrifying Implications*, University of California Press, Berkeley, California.

Moore, George W., 1973, *National Marine Fisheries Building Landslide, La Jolla, California.*

Summit Technology in association with Kleinfelder, Inc., 1998, *Geological, Geotechnical, and Structural Engineering Report for Southwest Fisheries Science Center, La Jolla, California*, dated April 1998.

Sumner, F.P., and Ross, J.W., 1930, Landslide description. In memorandum to Dr. T.W. Vaughan, S.I.O. Archives.

Trenhaile, A.S., 1987, *The Geomorphology of Rock Coasts*, Clarendon Press, Oxford.



PROPOSED TIEBACK ALTERNATIVE

National Marine Fisheries Center *Figure No.: 5*

Pump Station 35: Assessing Coastal Bluff Stability — A Geomorphic Perspective

Gregory A. Spaulding, R.G., C.E.G., C.H.G., and Walter F. Crampton, R.C.E., R.G.E.
TerraCosta Consulting Group, Inc., San Diego, California 92123-4379

ABSTRACT

As with any coastal bluff development, particularly in California where sufficient bluff-top setbacks are required to obviate the need for future coastal fortification, an accurate assessment of future coastal erosion within the useful life of the structure is critical in the early planning stages of the development. The concept of planned retreat in California and elsewhere significantly increases the responsibility of the geologist in accurately characterizing the extent of future erosion.

This paper provides a case study evaluating the long-term stability of the coastal bluff and the impact of bluff retreat on an existing sewer pump station along the Point Loma Peninsula, which was to be upgraded to provide an additional 50 years of service. The City of San Diego, recognizing that additional coastal fortification would probably not be allowed in the future, determined that, if necessary, the new pump station should be relocated to eliminate this geologic hazard.

Well established geomorphic principles were used in evaluating shoreline erosion and bluff-top retreat, which ultimately led to the conclusion that the coastal bluffs in the site vicinity should not adversely impact the upgraded pump station during its 50-year design life.

INTRODUCTION

Faced with an aging infrastructure, the City of San Diego has recently had to make difficult decisions as to whether or not many of their existing public facilities located on the coastline should be upgraded or abandoned and relocated. Sewer Pump Station No. 35 (SPS35), located on Sunset Cliffs Boulevard at the intersection with Monica Street in the Point Loma area of San Diego, is one such facility. A unique aspect of SPS35, which required serious consideration, is the fact that it is located atop an approximately 50-foot-high coastal bluff. As part of the project, it was necessary to determine the long-term stability of the coastal bluff and be assured that the pump station and related facilities would be capable of providing uninterrupted service to the community over the next 50 years. In this paper, we discuss the methodologies of analysis and the geologist's role to accurately characterize coastal geomorphology and how it is used as a tool for assessing the need for future coastal fortification.

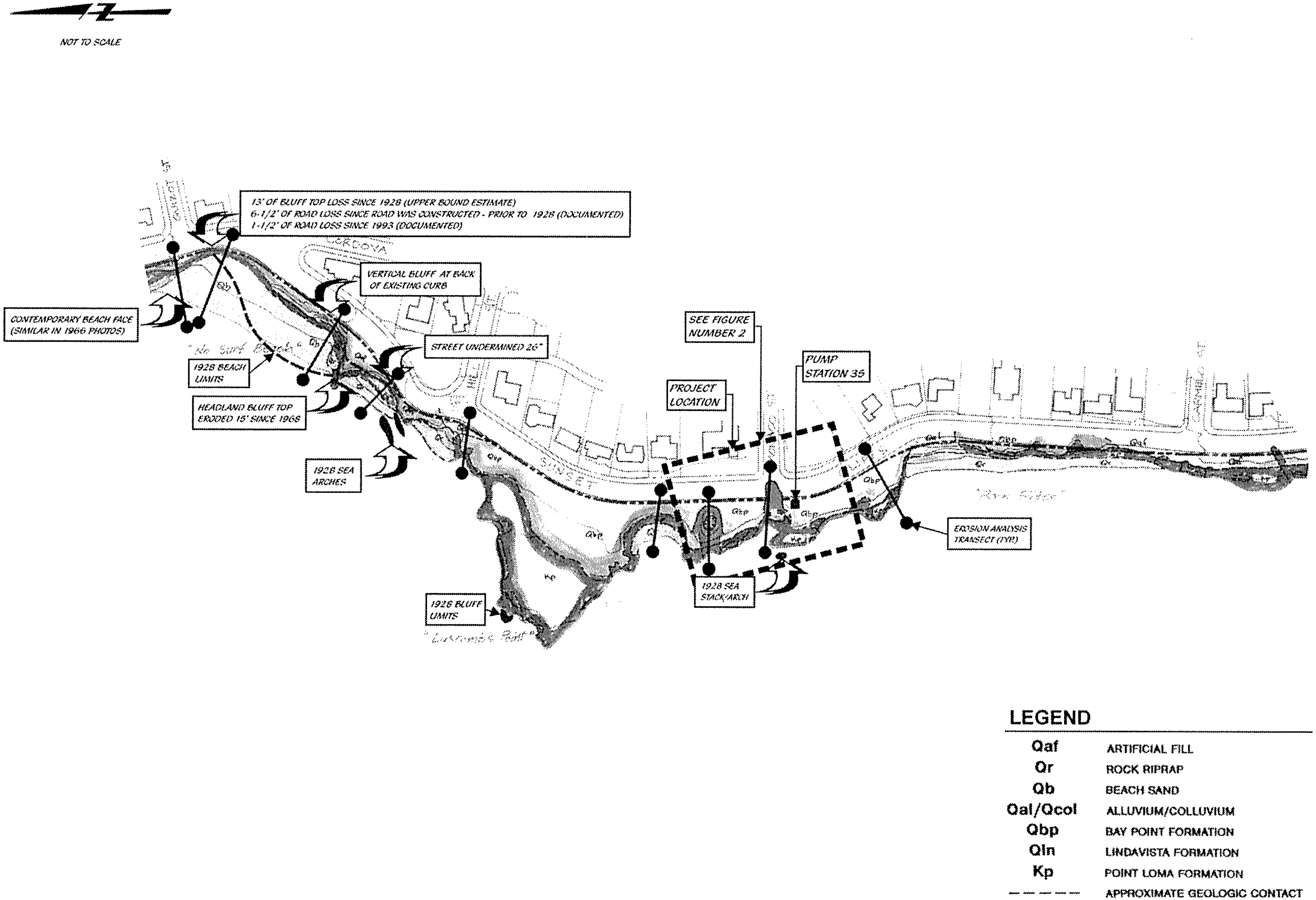
GEOLOGIC AND COASTAL DYNAMICS

One has only to reflect on the changes observed in San Diego's coastline over the past two to three decades to understand that it is a highly dynamic environment along our coastal zone. The effect of anthropic activities, changing climatic cycles, tectonic forces, and the rise in sea level continue to shape our coastline today, as it has during the last 18,000 years.

Figure 1 presents a generalized geologic map of a segment of the coastline along Sunset Cliffs. Aerial and subaerial erosion processes, geologic characteristics of the bedrock and overlying terrace deposits, along with structural weaknesses caused by faulting and jointing, have all worked on the local coastal zone to create the crenulated coastline unique to the Sunset Cliffs area.

GEOLOGIC SETTING

Point Loma is a 6-mile-long promontory extending southward from the lowland adjacent to the mouth of the San Diego River. The Point Loma coastal bluffs are bordered by a narrow wave-cut Quaternary terrace with elevations ranging from 25 to 95 feet MSL. Wave-impact erosion has etched out the less resistant and weakened rock along faults and fractures in the lower coastal bluff, creating numerous shallow coves and sea caves along the Point Loma coastline (Photo 1 and Figure 2). The more resistant Cretaceous rocks of the Point Loma Formation form the lower cliffed section of the coastal bluff and shore platform, which extends seaward. The relatively flat surface of the modern-day abrasion platform is interrupted by isolated erosion-resistant rock, which forms sea stacks and topographic highs. Further seaward, the abrasion platform becomes progressively deeper and locally incised by surge channels that have formed along the trends of major joint sets or faults, which weaken the erosion-resistant rocks of the lower bluff.



GENERALIZED GEOLOGIC MAP

PUMP STATION 35 FIGURE NO.: 1

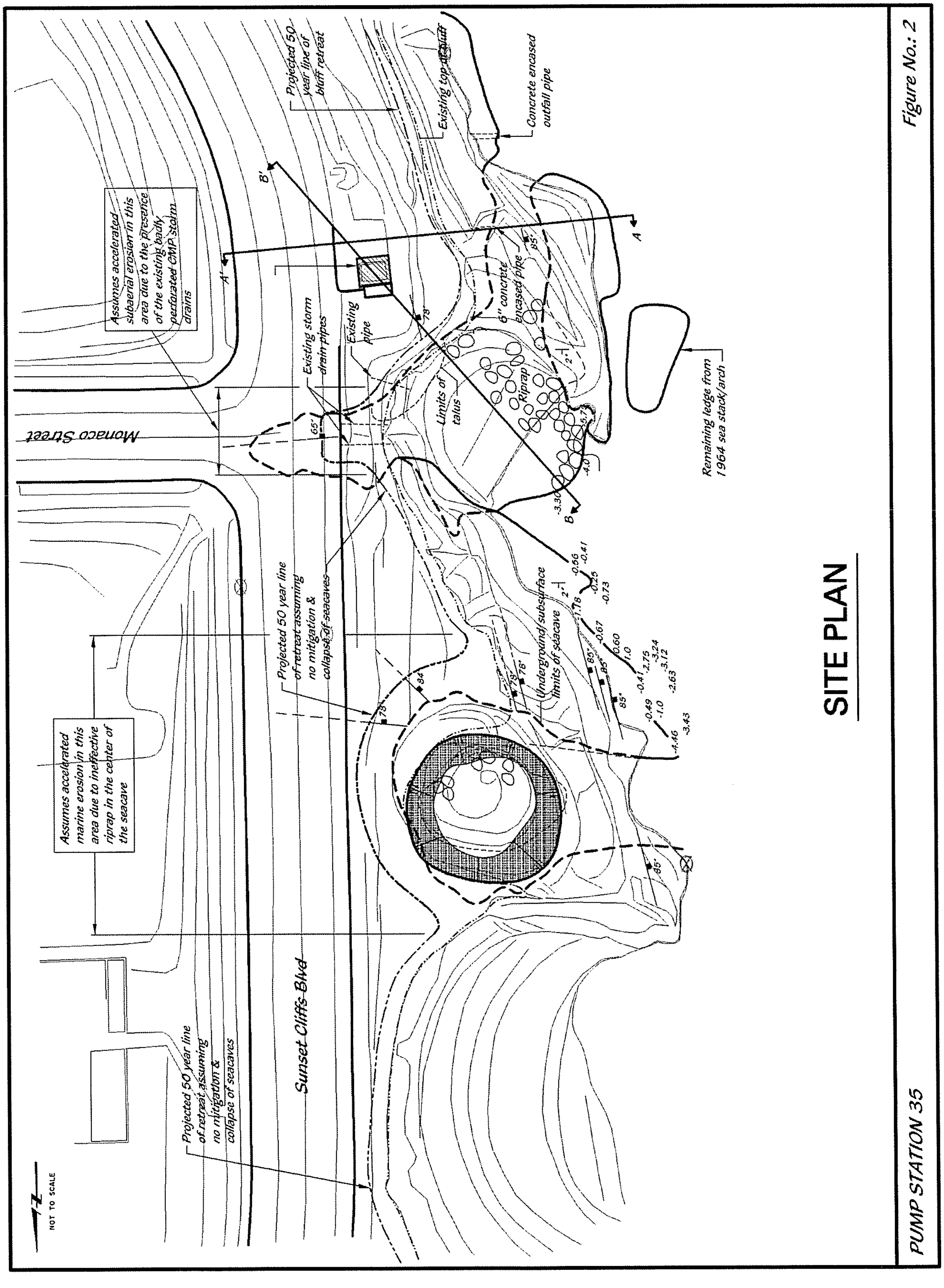

SITE PLAN
PUMP STATION 35
NOT TO SCALE
Sunset Cliffs Blvd
Monaco Street
Assumes accelerated subaerial erosion in this area due to the presence of the existing badly perforated CMP storm drains
Assumes accelerated marine erosion in this area due to ineffective riprap in the center of the seacave
Projected 50 year line of retreat assuming no mitigation & collapse of seacaves
Projected 50 year line of retreat assuming no mitigation & collapse of seacaves
Projected 50 year line of bluff retreat
Existing top of bluff
Concrete encased outfall pipe
Existing storm drain pipes
Existing pipe
6" concrete encased pipe
Limits of talus
Riprap
Remaining ledge from 1964 sea stack/arch
Underground/subsurface limits of seacave
A
A'
B
B'
65°
78°
85°
84
75
2:1
-3.30
-4.0
-5.7
-0.56
-0.41
-0.25
-0.73
-1.78
-0.67
-0.60
-1.0
-0.41
-2.75
-3.24
-3.12
-2.63
-0.49
-1.0
-4.46
-3.43

Figure No.: 2

Photo 1. Point Loma coastline.

The Quaternary Bay Point Formation forms the upper coastal bluff terrace (Figures 3 and 4), and consists mainly of marine and nonmarine, poorly consolidated, fine- and medium-grained, red to pale brown, fossiliferous sandstone. In turn, the Bay Point Formation is capped by geologically recent colluvial soils, topsoils, and artificial fill soils.

COASTAL BLUFF GEOMORPHOLOGY

Terminology

The geomorphology of a typical Point Loma seacliff is shown in Figure 5. Depicted are the shore platform, a lower, near-vertical cliffed surface called the seacliff, and an upper bluff slope generally ranging in inclination between 35 and 80 degrees (measured from the horizontal). Little or no flat area is exposed above the sea surface at the base of the cliff, even at very low tides. The coastal bluff is bounded at its landward edge by the coastal terrace, which at this location extends inland some 1000 feet.

The term "bluff top" (or "top-of-bluff") is an important one, being essential to structure-setback considerations. A simple definition for this term is the boundary between the upper bluff and the coastal terrace. A more rigorous definition of the term, as adopted by the California Coastal Commission, follows (note that the definition uses the terms "cliff" and "bluff" interchangeably):

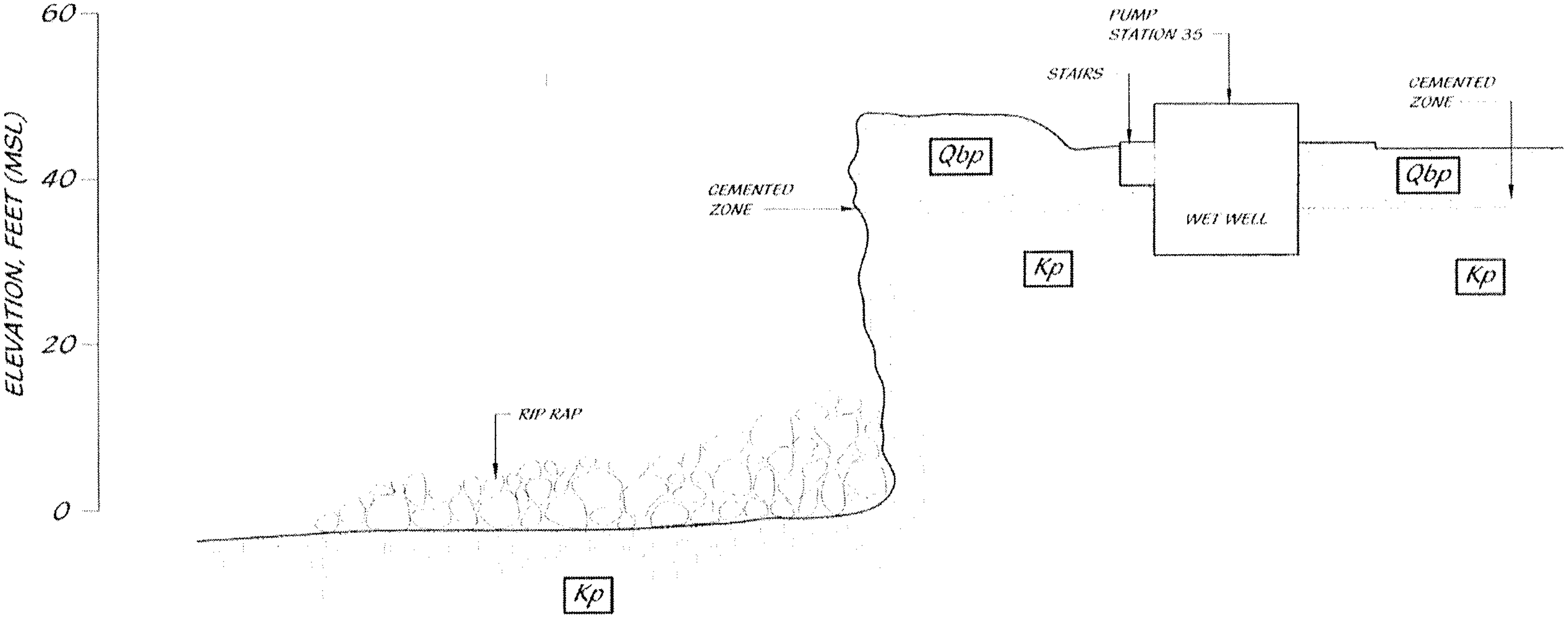
> "A bluff or cliff is a scarp or steep face of rock, decomposed rock, sediment or soil resulting from erosion, faulting, folding or excavation of the land mass. The cliff or bluff may be simple planar or curved surface or it may be steplike in section. For the purposes of these guidelines, 'cliff' or 'bluff' is limited to those features having vertical relief of ten feet or more, and 'seacliff' is a cliff whose toe is or may be subject to marine erosion. 'Bluff edge' or 'cliff edge' is the upper termination of a bluff, cliff or seacliff. When the top edge of the cliff is rounded away from the face of the cliff as a result of erosional processes related to the presence of the steep cliff face, the edge shall be defined as that point nearest the cliff beyond which the downward gradient of the land surface increases more or less continuously until it reaches the general gradient of the cliff. In a case where there is a steplike feature at the top of the cliff face, the landward edge of the topmost riser shall be taken to be the cliff edge."

Offshore from the seacliff is an area of indefinite extent called the nearshore zone (see Figure 5). The bedrock surface in the nearshore zone, which extends out to sea from the base of the seacliff, is the shore platform. Worldwide, the shore platform may vary in inclination from horizontal to a gradient of 3 horizontal to 1 vertical, or $33^{1/3}$ percent (Trenhaile, 1987). Offshore, the gradient of the shore platform is approximated at 1 to 2 percent. The boundary between the seacliff (the lower, vertical and near-vertical section of the bluff) and the shore platform is designated as the cliff-platform junction. At the site, the cliff-platform junction is between elevation –3 and –4 feet, SL.

Within the nearshore zone is a subdivision designated as the inshore zone, beginning where the waves begin to break (Figure 5). This boundary varies with time because the point at which waves begin to break changes dramatically with changes in wave size and tidal level. During low tides, large waves will begin to break far out to sea. During high tide, waves may not break at all or they may break directly on the lower cliff. The foreshore represents that portion of the shore lying between the upper limit of wave wash at high tide and the ordinary low water mark. It is absent at this site.

Classification of Bluff Geometry

Designation of the 50-year line of bluff-top retreat (the desired end result of this study) requires an understanding

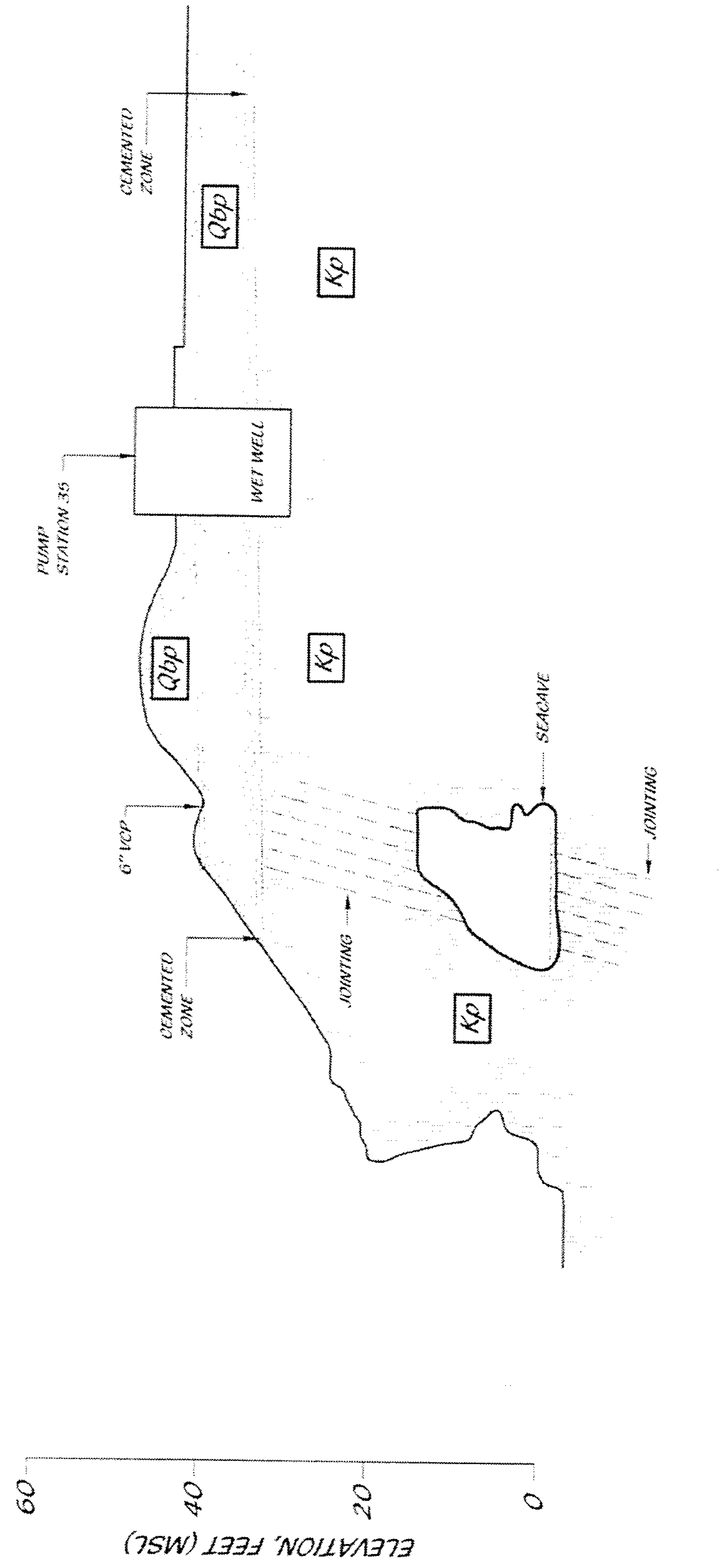


CROSS SECTION B

SCALE: 1"=20' (HORIZ.,VERT.)

PUMP STATION 35

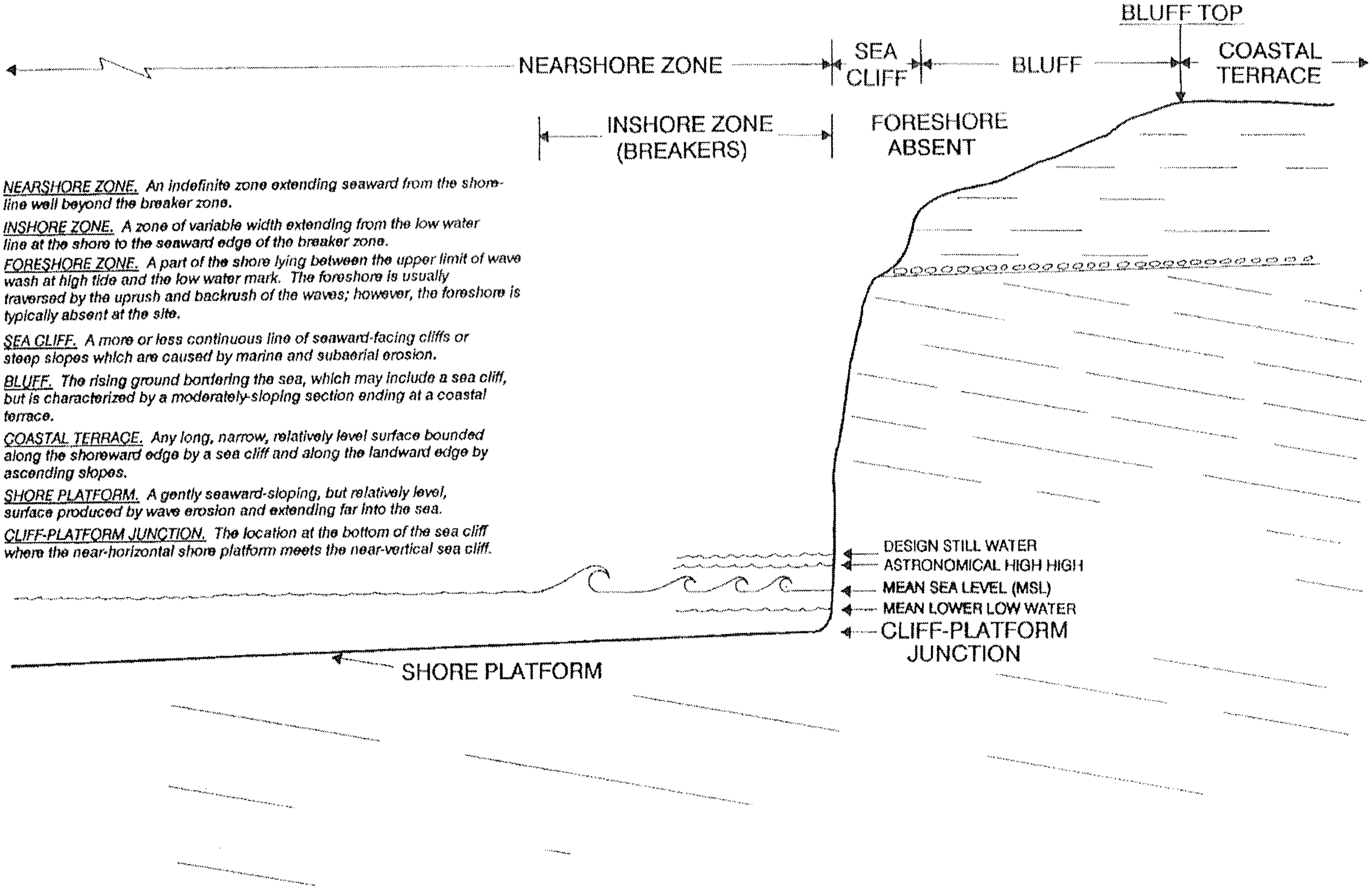
Figure No.: 3



CROSS SECTION A
SCALE: 1"=20' (HORIZ.,VERT.)

Figure No.: 4

PUMP STATION 35



NEARSHORE ZONE. An indefinite zone extending seaward from the shoreline well beyond the breaker zone.

INSHORE ZONE. A zone of variable width extending from the low water line at the shore to the seaward edge of the breaker zone.

FORESHORE ZONE. A part of the shore lying between the upper limit of wave wash at high tide and the low water mark. The foreshore is usually traversed by the uprush and backrush of the waves; however, the foreshore is typically absent at the site.

SEA CLIFF. A more or less continuous line of seaward-facing cliffs or steep slopes which are caused by marine and subaerial erosion.

BLUFF. The rising ground bordering the sea, which may include a sea cliff, but is characterized by a moderately-sloping section ending at a coastal terrace.

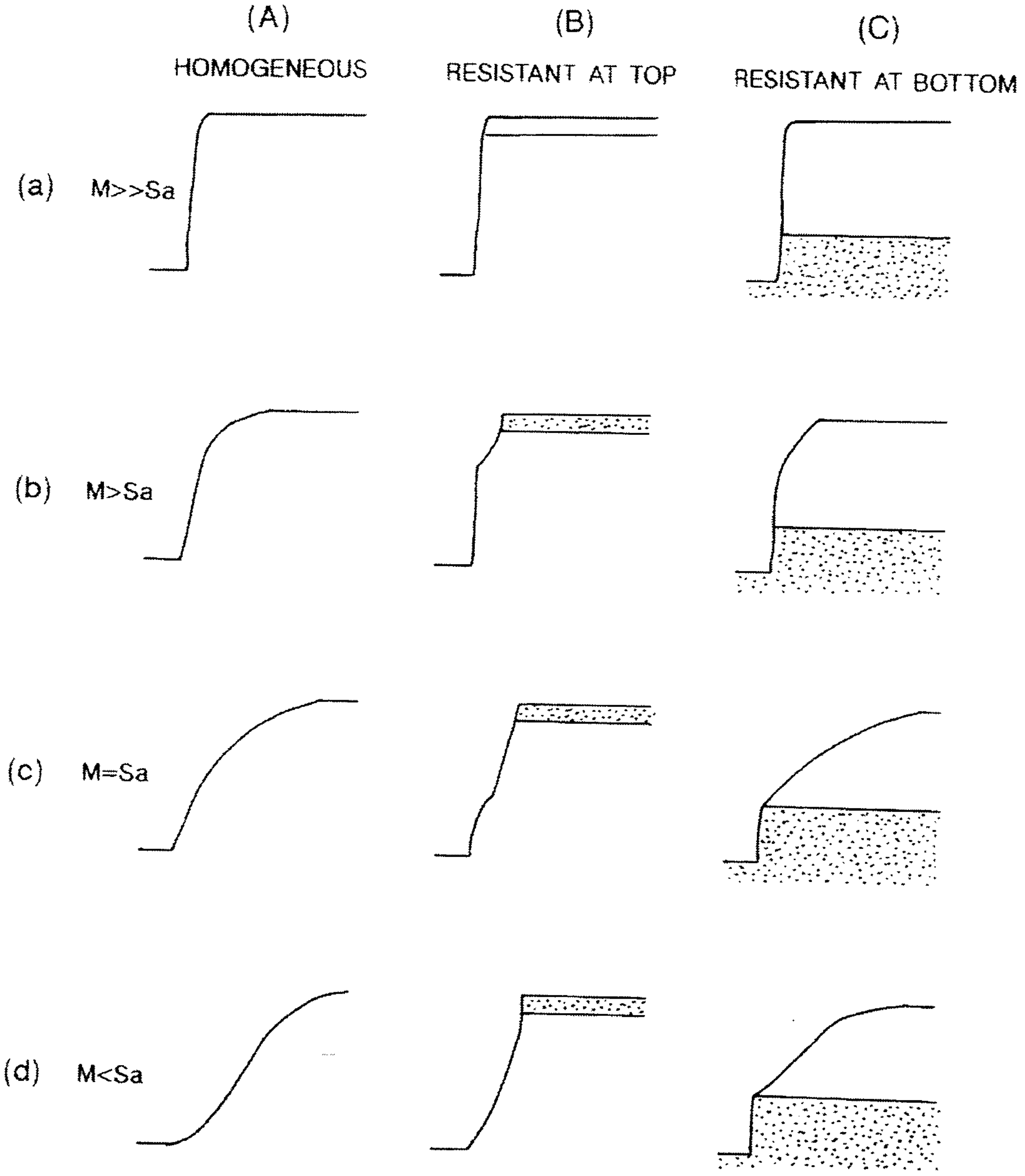
COASTAL TERRACE. Any long, narrow, relatively level surface bounded along the shoreward edge by a sea cliff and along the landward edge by ascending slopes.

SHORE PLATFORM. A gently seaward-sloping, but relatively level, surface produced by wave erosion and extending far into the sea.

CLIFF-PLATFORM JUNCTION. The location at the bottom of the sea cliff where the near-horizontal shore platform meets the near-vertical sea cliff.

TYPICAL COASTAL BLUFF PROFILE (Looking North Up the Coast)

Pump Station 35 *Figure No.: 5*



CLIFF PROFILES ACCORDING TO VARIATIONS IN ROCK RESISTANCE AND IN THE RELATIVE EFFICACY OF MARINE (M) AND SUBAERIAL (Sa) PROCESSES. THE MORE RESISTANT ROCK OUTCROPS ARE SHADED (AFTER EMERY AND KUHN 1982).

MATRIX OF ACTIVE COASTAL BLUFF PROFILES

Pump Station 35 *Figure No.: 6*

of the dynamic relationship between the upper coastal bluff and the seacliff. Emery and Kuhn (1982) developed a global system of classification of coastal bluff profiles, and applied that system to the San Diego County coastline from San Onofre State Park to the southerly tip of Point Loma. On average, the Point Loma area is designated as Type C(d) (see Figure 6).

The letter "C" designates coastal bluffs having a resistant geologic formation at the bottom, and less resistant materials in the upper parts of the bluff. The relative effectiveness of marine erosion of the lower resistant formation compared to subaerial erosion of the upper bluff produces characteristic profiles. Rapid marine erosion compared to subaerial erosion produces a steep cliff whereas slow marine erosion produces a gently sloping upper bluff. The letter "(d)" designates the case of comparatively slow marine erosion.

Local variations in geology along the Point Loma Peninsula have produced a range of profile types characteristic of their resistance to marine erosion and controlled by variations in geologic structure, stratigraphy, and lithology. Jointing and fracturing have encouraged the development of sea caves (eventually becoming coves) with locally weaker (less erosion-resistant) materials contributing to the formation of Type C(a) profiles adjacent to more erosion-resistant headlands with Type C(d) profiles.

The profile of the typical headland within the site vicinity fits classification "C(d)" for which marine erosion is generally somewhat slower than subaerial erosion. In these areas, the profile of the upper bluff indicate that marine erosion at the cliff-platform junction is slow enough to permit rather well developed slope decline to the observed gradients. Along some of the headlands in the site vicinity, a notch has formed just above sea level where wave impact and marine erosion are most severe.

The profile of the typical cove is of Type C(a), having steep cliffs extending up to the bluff top. Undercutting by marine erosion at the base of the cliff is common in this type of bluff profile. This profile indicates that the rate of marine erosion at the cliff-platform junction is much greater than the rate of subaerial erosion of the upper bluff (Figure 6). The upper bluff tends to retreat by collapse of overhangs and block fall along steep joints in order to keep up with the marine erosion. A variable-length transition area exists between the headlands and coves reflective of both Type C(c) and C(b) seacliff profiles.

SHORELINE EROSION

Erosion of the Point Loma coastal bluffs has produced a typical bluff profile. The lower 25 to 30 feet of the bluff is highly resistant to erosion, forming a vertical or near-vertical cliffed section. The upper portion of the bluff has relatively low erosion resistance and forms more gently inclined slopes.

Lower Bluff Erosion

The erosion of the Point Loma Formation in the lower cliffed section of the coastal bluff is due predominantly to marine erosion. Direct wave impact acting on joints and fissures tends to wedge and cleave sections of rock out of the lower seacliff. Where fractures and joints are more prevalent or where shear zones have significantly weakened the rock, surge channels and caves have developed. The site area coastal bluff views presented on Photos 2 and 3 show the effects of marine erosion on the lower bluff under both low tide and high tide conditions.

Upper Bluff Erosion

The upper bluffs, comprised of the less resistant Bay Point Formation sands, are subject to both marine and subaerial processes, including:

- Wave spray and wave splash during high seas or storm events
- The undermining of the underlying cliff-forming Point Loma Formation, and caving of the resultant oversteepened slopes
- Wind, rain, irrigation, and uncontrolled surface runoff, as well as animal burrowing
- Human-induced erosion (cave digging, climbing on the bluffs, and channelized pedestrian traffic across the coastal terrace)

These locally incised erosion features extend seaward to the bluff face. Locally accelerated subaerial erosion also results where terrace deposits have been excavated and the soils utilized for backfill along trenches.

The anthropic (human) activity has significantly affected erosion on the upper bluff. Hikers along the top of the bluff have created footpaths on the upper bluff slope. This tends to denude the upper bluff of any protective vegetation and concentrates surface drainage, which eventually erodes gullies into the soft sediments of the Bay Point Formation. Photos 1 through 4 illustrate the erosion occurring on the bluff slope.

BLUFF-TOP RETREAT

This section documents the technical approach used for estimation of the 50-year bluff retreat line shown on

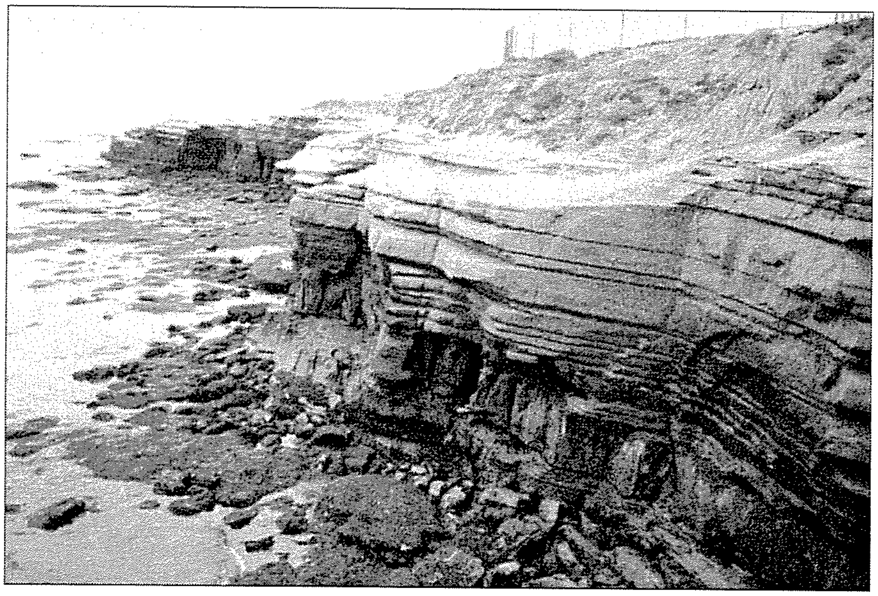


Photo 2. View of bluff looking north at low tide. Note exposed shore platform and erosion along joint/fracture systems.

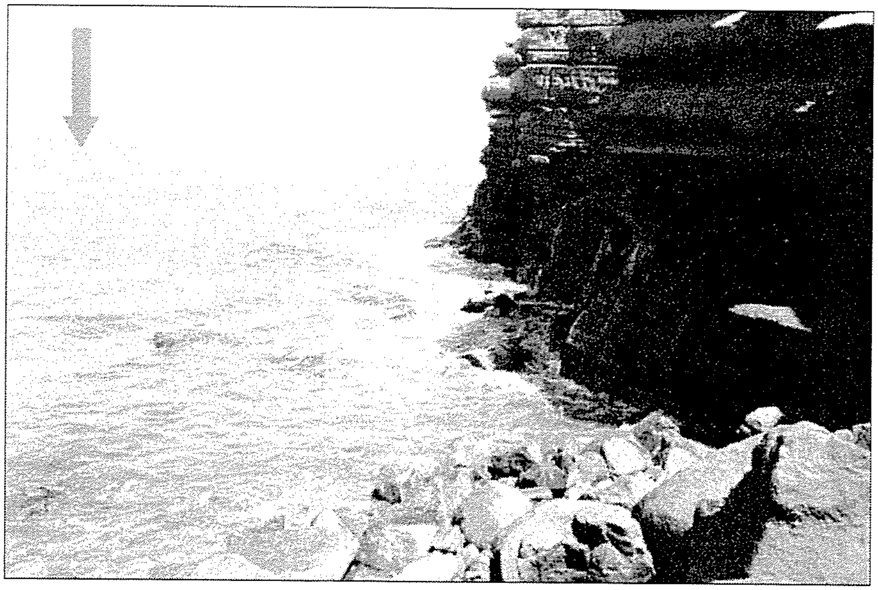


Photo 3. View of bluff looking north at high tide. Lower bluff is exposed to direct wave impact during storms and high tides. Offshore breakers (arrow) result from the wide shore platform which serves to reduce wave energy and protect the lower bluff face, except during storm events and very high tides.

Figure 2, the Site Plan. Our evaluation of bluff retreat is based on two principal factors:

1. Estimation of the amount of marine erosion that should be expected on the shore platform and evaluation of the resulting effect upon erosion of the coastal bluff
2. Estimation of the amount of slope decline that may be expected for the bluff above the elevation of principal influence of marine erosion

Bluff-Top Retreat and Engineering Design

Placement of facilities on the coastal terrace above the bluff must account for changes in the bluff expected during the intended life of the structure. Historically, the typical approach has been to build as close to the bluff as desired, assuming that maintenance and repair would forestall loss of the structure. Another approach has been to estimate the amount of bluff-top retreat expected within the economic life of the structure, and to build behind the influence of retreat.

In coastal engineering, the concept of intended lifetime of a structure has been replaced by required design periods set by regulatory agencies. The California Coastal Commission requires a 75-year period to approximate the useful design life of most structures. The U.S. Army Corps of Engineers requires a 50-year period for this procedure. The City of San Diego requirement for the project site evaluation is also 50 years.

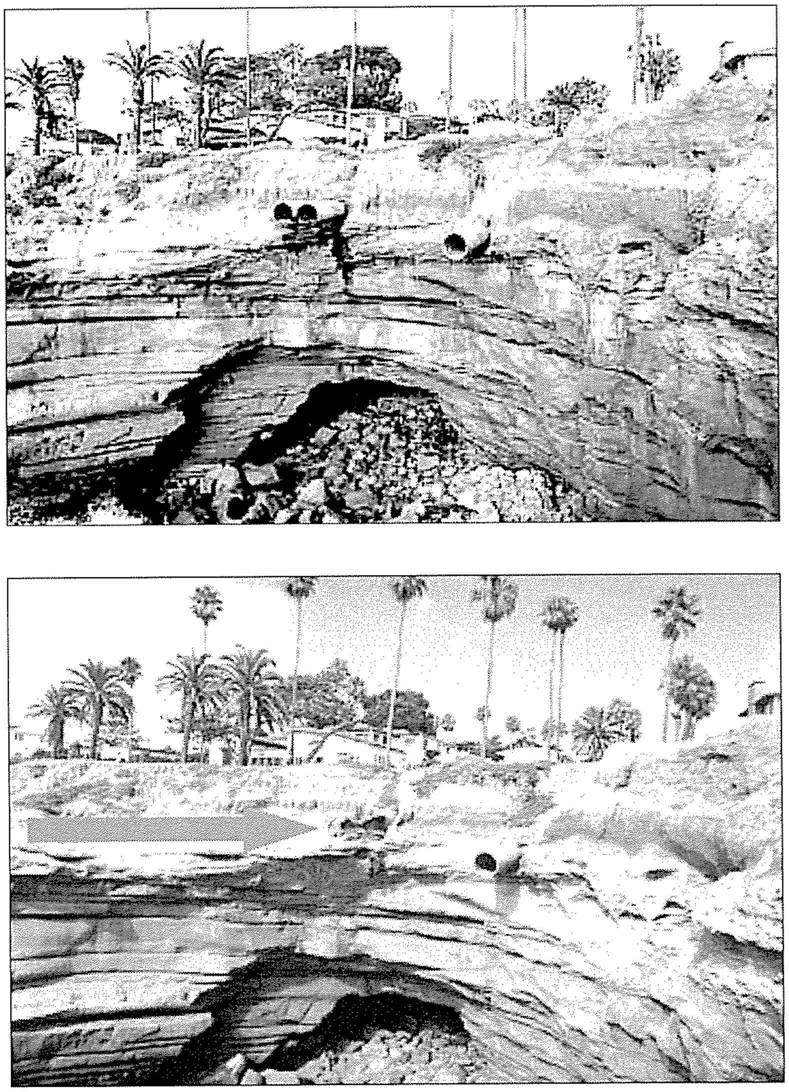
Methodologies of Analyses

In its broadest sense, geomorphology deals with landforms and their evolution over time. Lithology, or the description of the physical character of rocks, can also be used to estimate the relative erosion resistance of the intact, nonfractured rock. Geologic structure, which includes structural discontinuities such as jointing and faults, can be used to estimate variations in erosion resistance within a particular lithologic unit. Coastal processes include waves impacting upon coastal bluffs. This is the basic source of erosive energy, which is modified by the nearshore and offshore bathymetry, and by sea-level elevation relative to the nearshore bathymetry. More recently, natural coastal geomorphic processes have been influenced by anthropic (human) activities.

The methodologies or techniques most useful in the assessment of rates of coastal erosion are divided into five general separate categories:

- Historical analyses
- Geomorphic analyses
- Anthropic influences
- Impact of long-term sea-level change
- Empirical and analytical techniques

Coastal geologists and geomorphologists traditionally employ the first three techniques, often relying on interpretation of maps and aerial photographs. However, such historical data usually cover a short time span and may be limited to small-scale maps and photographs such that significant errors may occur in estimating the amount and rate of shoreline change. If the available maps and photographs cover only a quiescent climatic period, underestimates are likely. The details of each methodology are discussed in the following paragraphs.


March 1993

July 2000

Photo 4. Southerly sea cove looking east toward opening of a smaller extension cave, which trends beneath Monaco Street. Twin 24-inch-diameter corrugated metal pipe (CMP) storm drains (arrow) accommodate street drainage at the Monaco Street street-end. The asbestos concrete pipe (ACP) is reportedly associated with some type of overflow for Pump Station 35. These metal pipes have become very deteriorated, and are exacerbating erosion of the bluff face.

Historical analyses. Historical data often include maps, charts, photographs, survey notes, reports, newspaper clippings, and eyewitness accounts (Fulton, 1981). Useful historical information about coastline changes in San Diego County extends back to the later part of the 19th Century, and reasonably accurate climatological data dates back to the early 1800s. Stereoscopically paired vertical aerial photographs (typically at a scale of 1:24,000) are available from 1928, and good-quality, low-angle oblique photographs (at a scale of 1:2400) date back to 1954. Ground-level, close-up photographs, which are usually the most useful to assess site-specific changes in the coastline, are not abundant, but locally are available from the personal collections of private individuals and from historical societies and museums. Successive ground or aerial photographs, dated drawings, or even paintings that show former coastal configurations, are very useful to assess short-term (historical) rates of erosion (Bird, 1985).

The San Diego County coastline has been portrayed in various maps and charts dating back to the 1800s. A prime source of coastal maps is the National Oceanic and Atmospheric Administration (NOAA), which in cooperation with the Los Angeles District Army Corps of Engineers (USCOE) has produced shoreline-movement maps at a scale of 1:24,000 extending from Portuguese Point (Long Beach) on the north to the Mexican Border on the south (USCOE, 1985; USCOE, 1987). The maps compile coastline data, in part from the U.S. Coast and Geodetic Survey, extending back to 1887 along the coast, and back to the 1850s in the bays, and show gross changes in the shoreline. However, at this scale, erosion amounts of less than 50± feet are not distinguishable.

Considerable work has also been done to evaluate the accuracy of comparing historic and contemporary small-scale mapping (Crowell and others, 1991). In Crowell's study, maps with scales as large as 1:10,000 were considered. A computed erosion rate is based on an apparent map difference (subject to mapping resolution inaccuracies) divided by the time span between maps. A very old map of less accuracy may yield a more accurate erosion-rate estimate than a recent map, because more time allows coastal change to accumulate to detectable amounts. The results of these studies generally indicate that typical resolution of principal identifiable features in mapping performed prior to 1930 may have a horizontal error of 4 meters, indicating that erosion rates estimated by comparison to these maps have a resolution of at best 2 inches per year. Maps produced from 1934 to 1938, using early photogrammetric methods, are highly variable in quality, with horizontal error exceeding 11 meters in some cases, indicating erosion-rate resolutions of at best 9 inches per year. Topographic maps produced through the late 1950s, using more contemporary photogrammetric methods, have horizontal error of about 2.5 meters, yielding potential erosion-rate resolutions of at best 3 inches per year. Since the early 1960s, map quality based on photogrammetric methods has improved to the point where a typical horizontal error would be less than 1.5 meters (5 feet).

Larger-scale topographic maps dating back to the early 1950s are available for most of San Diego County at a scale of 1:2400. These maps were prepared using photogrammetric methods and provide a useful baseline for evaluating coastal erosion during the last 30 to 40 years.

Even comparison of contemporary maps is subject to error, especially when the maps are produced only a few years apart. In general, successive high-resolution photographs showing readily identified coastal features provide the best record of progressive shoreline change.

Geomorphic analyses. Geomorphic analyses include all factors that contribute to shaping coastal landforms. Coastal erosion and coastal-bluff retreat are caused by both marine and terrestrial processes. Surf action is usually the dominant marine agent producing both hydraulic (wave) impact and abrasion. Geomorphic factors that contribute to the assessment of coastal erosion include:

- Climate
- Wave energy
- Lithology and structure of coastal bluffs
- Groundwater
- Bluff geometry
- Measurement of slope retreat

A more detailed discussion of these factors is found in this publication in "Sand Beaches vs. Seawalls — A Geomorphic Perspective" by Crampton.

A basic understanding of the various geomorphic processes is clearly a requisite to assess variations in shoreline erosion. Geomorphic analysis, including coastwide geologic inventory, measurements of offshore bathymetry, and research to determine historic climatic conditions permits assessment of likely future coastal erosion. The relationships between the various types of information should be evaluated by the coastal consultant in estimating prudent and reasonable erosion rates.

Anthropic influences. Human activity significantly influences shoreline changes, both directly, by erosive activities along the bluff top and coastal fortification at the base of the bluff, and indirectly, exemplified by the pervasive impact of activities in the upland watersheds, such as periodic loss of surface vegetation by fires, the construction of dams, and sand mining. Pedestrian foot traffic atop and on the face of the coastal bluffs can also significantly channelize runoff and accelerate locally incised gully and rill erosion.

In any assessment of future coastal erosion, one must address the impact of human activity, and recognize that the historical database cannot simply be projected into the future without considering human impact. For a more detailed discussion, see "Sand Beaches vs. Seawalls — A Geomorphic Perspective," by Crampton.

Impact of long-term sea-level change — and — ***Empirical and analytical techniques.*** An entirely independent method of assessing the rate of coastal erosion is to consider long-term (geologic) sea-level change, which is the major factor determining coastal evolution (Emery and Aubrey, 1991). The companion paper by Crampton discusses the significance of sea level rise and the effects of direct wave impact on the coastal bluffs. In addition, empirical and analytical techniques assessing shoreline erosion are also discussed.

Estimating Rate of Bluff-Top Retreat

The rate of bluff-top retreat has been estimated from both historical and geomorphic techniques, with consideration given to anthropic influences, long-term sea level rise, and the recognition that the cliff-forming materials comprising the headlands have significantly higher rock strengths than the cliff-forming materials exposed within the coves. The rate of marine erosion for the coves has been estimated as a reasonable multiple of the rate for the seacliff along the main coastline alignment and from comparison of aerial photographs taken as early as 1928, with various photographic sets extending through the present. As a practical matter, within the site vicinity, and specifically with reference to the cove just seaward of Monaco Street and the partially collapsed sea cave just to the north, in reviewing aerial photographs flown since 1928, as well as oblique aerial photographs of the coastline dating back to 1954, there is a general lack of observable marine erosion, discounting the localized loss of erosion-resistant stacks, arches, and other isolated detached coastal features. Given the resolution of vertical aerial photographs, general bluff-top retreat within the site vicinity over the last 70 years has been less than 5 feet. This is also important in view of the significant storm periods this section of coastline has weathered, including those that occurred in 1969, 1978-79, and 1983-84, the January 1988 storm, and the most recent 1997-98 El Niño storm season.

Probably the most recognizable indicator of coastal erosion in the site vicinity is the gradual seacliff retreat encroaching upon Sunset Cliffs Boulevard in the vicinity of Guizot Street. This section of coastline, and particularly from Froude Street to Guizot Street, has experienced some recognizable coastal bluff retreat, and it was likely responsible for the Corps of Engineers shoreline erosion study conducted in 1960 and the federally funded rock revetments placed in this area in 1971.

Of importance is the recognition that Sunset Cliffs Boulevard was constructed along this section of coastline prior to 1928, and in the 1928 aerial photographs, the street edge in the vicinity of Guizot Street is right adjacent the vertical seacliff. The original 1928 roadway edge is still visible today, just northerly of Guizot Street, where 6.5 feet of encroachment into the travelway can be measured, setting a lower limit on 70 years of marine erosion in this area. In viewing the 1928 photographs, one might also conclude that an upper limit of bluff-top retreat may be as much as 13 feet in this area, suggesting an annualized erosion rate of from 1 to 2 inches per year.

The Guizot Street street-end coastal bluff area is also important from a geomorphic perspective, as it represents a Type C(a) profile and hence an area along this section of coastline exhibiting the highest rate of marine erosion, considerably higher than that in the vicinity of Monaco Street.

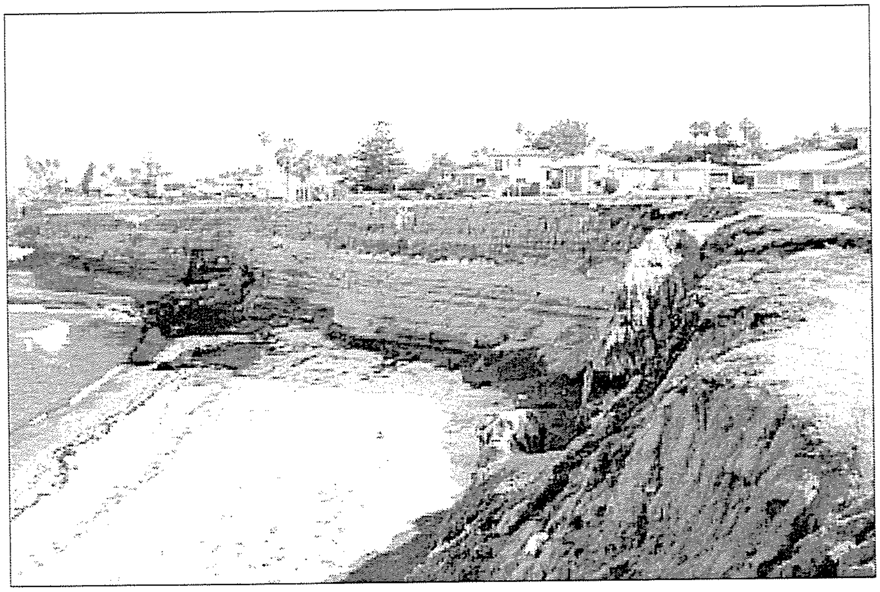
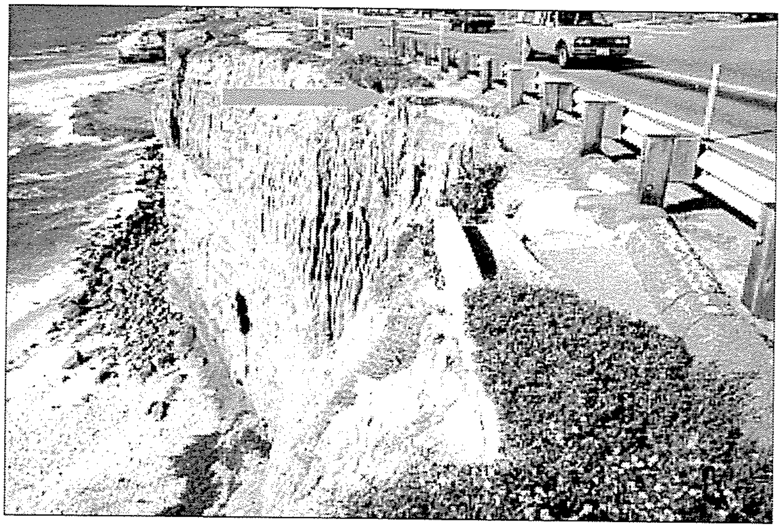


Photo 5. Overall view of vertical bluff at Guizot Street (bluff profile Type Ca). This locality has experienced the highest rate of marine erosion in the general project site area, estimated at 1.5 inches per year over the past 50 years.

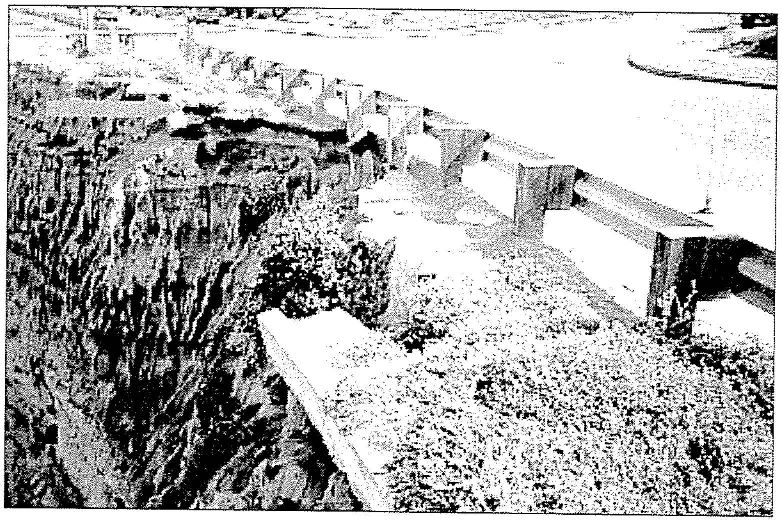
Photo 5 shows the Guizot Street street-end section of coastline exhibiting the Type C(a) profile, where ongoing coastal bluff erosion is encroaching upon and threatening Sunset Cliffs Boulevard. Also evident in this photo is the rock revetment placed at the base of the seacliff as part of the 1971 Corps of Engineers project. As this photo suggests, the Corps project did not actually extend the rock revetment to the extreme southerly edge of this cliffed portion of coastline, but stopped the southerly edge of the revetment a short distance northerly of the Guizot Street street-end.

Photo 6 shows an additional close-up of the Guizot Street street-end in 1993 and again in August 2000, when an additional 1.5 foot of subaerial erosion has locally encroached further into the Sunset Cliffs roadway (an annualized rate of 2.6 inches per year). However, this localized erosion appears to have been the result of uncontrolled surface drainage discharging off the roadway surface and locally incising this gully into the upper terrace deposits and asphalt pavement.

Photos 7a through 7d provide an interesting perspective on coastal erosion closer to the site vicinity, specifically Luscomb's Point located about 700 feet northerly of the pump station. The first three photographs have been reproduced from Kuhn and Shepard's *Sea Cliffs, Beaches, and Coastal Valleys of San Diego County: Some Amazing Histories and Some Horrifying Implications* (1984), showing only minor changes in the coastline between Hill Street and Luscomb's Point taken from the small headland located midway between Guizot and Hill Streets. The fourth



1993



2000

Photo 6. Photos taken in 1993 and 2000 at Guizot Street and Sunset Cliffs Boulevard. Approximately 1.5 feet of upper bluff loss was documented during this period. Measurements from this old roadway curbline (arrows) indicate that 6.5 feet of the old roadway have been lost since 1928 (year of the earliest available aerial photographs showing the old roadway intact). Review of the 1928 photos suggests upper bound bluff-top loss on the order of 13 feet. This results in an annualized bluff-top erosion rate ranging from 1 to 2 inches per year.

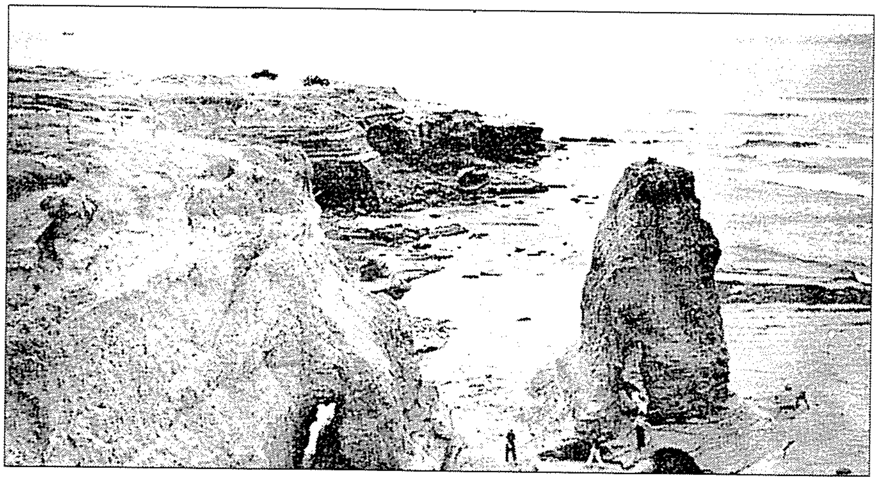


Photo 7a. View of sea arches at Sunset Cliffs, 1938. Note that one arch is formed in the center of a sea stack and the other is connected to the mainland cliff. Photo: F. Shepard.

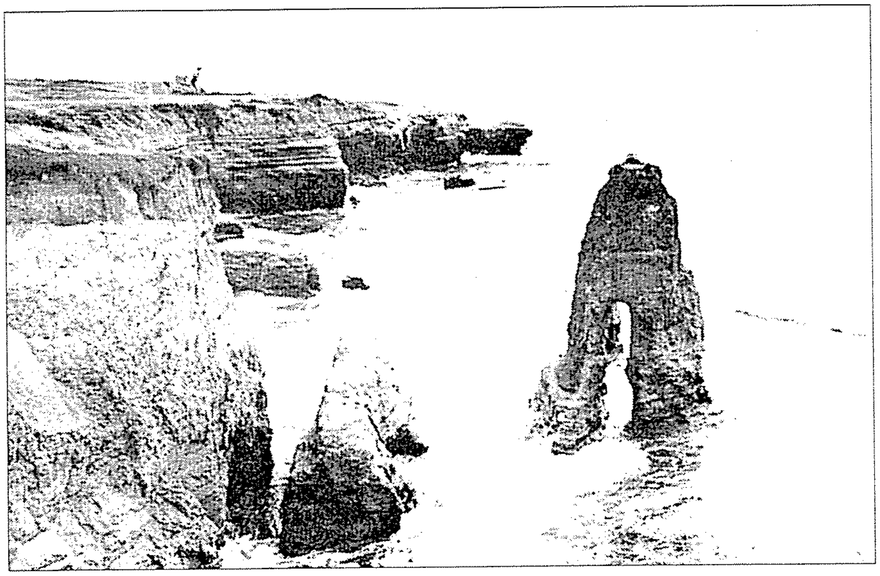


Photo 7b. View of same site as that in 7a, 1946. Note that the arch previously connected to the mainland has collapsed. Photo: F. Shepard.

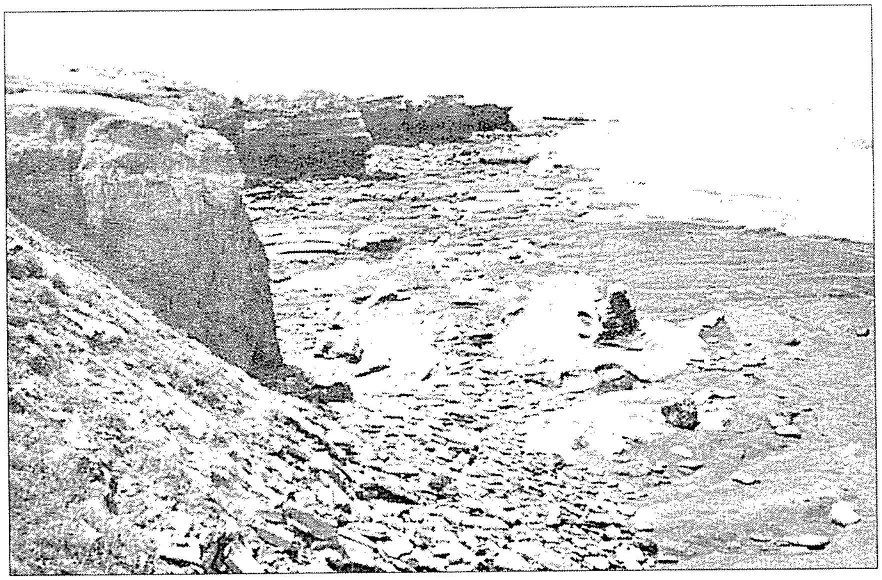


Photo 7c. View of same site as that in 7a and 7b, 1968. Note that only a small pedestal remains to mark the site of the arch. The isolated rock near the cliff has also disappeared. Photo: F. Shepard.

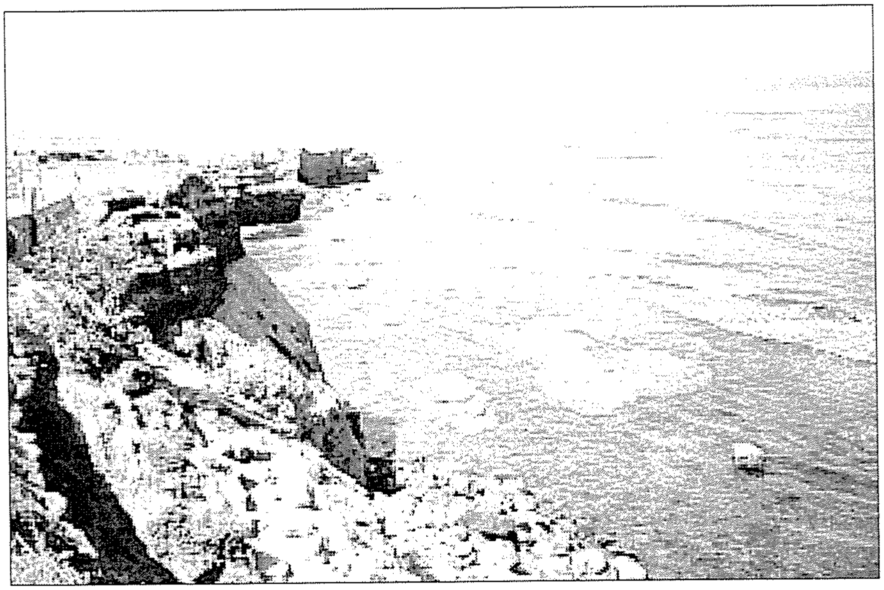


Photo 7d. Photos 7a, 7b, and 7c, reproduced from Sea Cliffs, Beaches, and Coastal Valleys of San Diego County: Some Amazing Histories and Some Horrifying Implications *(Kuhn and Shepard, 1984), looking to the southwest toward Luscomb's Point, illustrate the process of marine erosion affecting this section of coastline. This photo, taken August 8, 2000, has a photo perspective offset approximately 15 feet from the previous three photos, indicating 15 feet of erosion of the small headland between Guizot and Hill streets (see Figure 1).*

photo in the set, taken in August 2000, places the location of the photo perspective approximately 15 feet landward due to the more recent loss of this previous headland, but more importantly, the bulk of Luscomb's Point and the exposed shore platform, for all intents and purposes, remains intact.

Given the measurable 70-year coastal bluff erosion record in the vicinity of Guizot Street, and recognizing this represents a Type C(a) profile compared to the Type C(d) profile seaward of SPS 35, along with its Type C(a) profiles for the adjacent cove seaward of Monaco Street and partially collapsed sea cave just to the north, we have assigned an annualized erosion rate for the Type C(a) profiles of 1.5 inches per year, and for the Type C(d) profiles at half this value, or 3/4 inch per year. We have also assumed the immediate collapse of the southerly trending sea cave just westerly of SPS 35, allocating this erosion rate from the existing artificial seacliff edge formed by this southerly trending sea cave. As a practical matter, this sea cave may well maintain its integrity for the next 50 years, thereby resulting in an eroded bluff-top profile considerably more seaward than that depicted on Figure 2.

Although these erosion rates may, at first glance, appear to be somewhat low, they do reflect the past 70 years of record at Guizot Street in an area where admittedly more erosion is occurring, due primarily to a difference in lithology, with the Guizot Street bluffs consisting of a poorly bedded, highly fractured arkosic sandstone and shale, while the Luscomb's Point Monaco Street coastal bluffs consist of a well-indurated, arkosic sandstone sandwiched between thinly laminated clay shale beds, all of which are highly resistant to erosion.

This 70-year period of record has also witnessed numerous intense coastal storms, a recorded rise in sea level on the order of 10 cm, a coastline essentially void of any fluctuations in protective sand beaches (more prevalent in San Diego's North County), and, most importantly, the presence of a rock revetment placed in the adjacent cove in 1971, significantly reducing the rate of marine erosion, at least in this area along both joint fracture pattern axes.

Given this preceding discussion, if one were to summarily increase the annualized erosion rates to something on the order of 4 inches per year, more consistent with the Eocene cliff-forming units prevalent in San Diego's North County, maximum 50-year projected bluff-top locations would still be upwards of 10 feet seaward of SPS 35. Recognizing that the unconfined compressive strength, and hence the erosion resistance of the Cretaceous sediments, is from 2 to 5 times stronger than the North County Eocene sediments, one must conclude that an annualized erosion rate of say 4 inches per year is overly conservative.

DISCUSSIONS AND CONCLUSIONS

Our geologic assessment indicates that the bluffs in the site vicinity have been relatively stable over the past 72+ years, and that, assuming climatic conditions remain essentially the same for the next 50 years (until the year 2050), coastal bluff erosion should not adversely impact the upgraded pump station during its design life. Moreover, our geologic mapping in the site vicinity confirmed the absence of voids or loose, incompetent bearing materials in the seacliffs around the SPS 35 site.

Although of no impact to SPS 35, the partially collapsed sea cave to the north may be experiencing some level of increased marine erosion, and hence bluff-top retreat, due to the ineffective placement of a small amount of riprap as part of the 1971 Corps of Engineers project. It appeared that the limited rock, essentially located within the center of this sea cave, allowed and encouraged circular scouring action around the perimeter of the sea cave, more so than what would occur without the riprap or were it more strategically placed. Consideration should be given to rearranging the existing rock in this sea cave or, if possible, placing additional rock and/or closure of the mouth of the sea cave to minimize long-term encroachment and the eventual undermining of Sunset Cliffs Boulevard.

The existing storm drains accommodating storm water from the inlet located on the west side of the intersection of Sunset Cliffs Boulevard and Monaco Street were badly perforated. If not replaced, increased subaerial erosion will occur in this area as degradation of these storm drains continue, eventually undermining Sunset Cliffs Boulevard.

As part of the original grading on the site, a berm was constructed near the top of the bluff in an effort to direct surface drainage away from the bluff top. Over the years, foot traffic and animal activity have locally worn down this berm, causing localized uncontrolled discharges over the bluff top and associated gully-induced erosion.

As part of this study, an invaluable and recoverable baseline survey of both the coastal bluff and the various geomorphic features that are shaping this coastal bluff has been developed. Although relatively slow, progressive shoreline retreat in this area is expected, future surveys, particularly in the vicinity of the partially collapsed sea cave to the north and in the storm drain off the Monaco Street street-end, may help justify future warranted improvement projects in these areas to forestall the eventual undermining of Sunset Cliffs Boulevard.

It should be noted that the growth of these sea caves occurs along the structural weaknesses in the cliff-forming Point Loma Formation, and the rehabilitation of these geologic anomalies can easily be accommodated by infilling the sea caves and/or joints and fractures in the rock with an erodible grout having similar strengths to that of the more massive adjacent bedrock material. This remedial-type stabilization work significantly reduces the rate of marine erosion, and future consideration may be given to yet additional stabilization of these areas at some time in the future. The resource and regulatory agencies recognize the inherent value of sea cave infills. However, a long-term monitoring program helps validate the justification and/or need for any future work within the coastal zone.

REFERENCES

Bird, E.C.F., 1985, Coastline Changes — A Global Review, John Wiley and Sons, 219 p.

Crowell, M., Leatherman, S.P., and Buckley, M.K., 1991, Historical Shoreline Change: Error Analysis and Mapping Accuracy. Journal of Coastal Research, 7 (3), 839-852. Ft. Lauderdale, Florida.

Emery, K.O., and Kuhn, G.G., 1982, "Seacliffs: Their Processes, Profiles and Classifications," Geological Society of America Bulletin, Vol. 93, No. 7, pp. 644-654.

Emery, K.O., and Aubrey, D.G., 1991, Sea Levels, Land Levels, and Tide Gauges: Springer-Verlag Publishers, New York, NY, 237 p., 113 figures.

Fulton, K., 1981, A Manual for Researching Historical Coastal Erosion, Report No. T-CSGCP-003, University of California, Santa Cruz, Writing Program, published by California Sea Grant College Program, 56 p.

Kuhn, G.G., and Shepard, F.P., 1984, Sea Cliffs, Beaches, and Coastal Valleys of San Diego County, California, University of California Press, 193 p.

Trenhaile, A.S., 1987, The Geomorphology of Rock Coasts, Clarendon Press, Oxford.

U.S. Army Corps of Engineers, 1987, Coast of California, Storm and Tidal Waves Study — Coastal Cliff Sediments, San Diego region, 21 sections, plates.

U.S. Army Corps of Engineers, 1985, Coast of California, Storm and Tidal Waves Study — Shoreline Movement Data Report, Portuguese Point to Mexican border (1852-1982), 48 p., appendix.

U.S. Army Corps of Engineers, 1928, Aerial Photographs Nos. 66-E1 & F1 (B&W), flown 1928.

The Otay Mesa Lateral Spread

Chad W. Warren, W. Lee Vanderhurst, Michael W. Hart

ABSTRACT

Recent grading in a subdivision in southwest San Diego County created multiple exposures of a pre-late Pliocene lateral spread within the Oligocene Otay Formation. Isolated exposures of deformed sedimentary rock have been observed north and south of the subdivision but were identified as Quaternary landslides or faulted Tertiary formations. Outcrop evidence now suggests that a single lateral spread covering approximately 124 km^2 occurred between 1.5 and 28 Ma. The debris appears above a continuous bentonitic claystone layer within the Otay Formation. Large, intact to moderately fractured and tilted blocks of interbedded sandstone and siltstone are bound by steeply dipping faults that terminate on the bentonite. The bedding varies from massive to horizontal in some blocks, to dipping 30 to 50 degrees southeast in others. The late Pliocene to early Pleistocene San Diego Formation was deposited on a planar wave-cut terrace that caps the debris.

High-angle shearing in the Otay Lateral Spread may be misinterpreted as faulting using shallow trenching techniques. The lateral spread is located on the eastern margin of the La Nacion fault zone, which is characterized by north-south trending, steeply dipping normal faults similar to those bounding the lateral spread blocks. Evaluation of faulting in areas suspected to be within the lateral spread should include deep borings to determine if the basal bentonite bed has been displaced.

The Otay Lateral Spread (OLS) debris contains a well-developed basal rupture surface, discontinuous and unpredictably oriented internal shears and fractures within large blocks of debris that will impact slope stability. Since much of the structure cannot be evaluated completely by preliminary investigations, in-grading mapping and engineering analysis are necessary to provide appropriate recommendations for stabilization.

INTRODUCTION

The southwestern portion of San Diego County is an area that has seen tremendous growth in the past 20 years (Figure 1). It is this growth that has shed new light on the

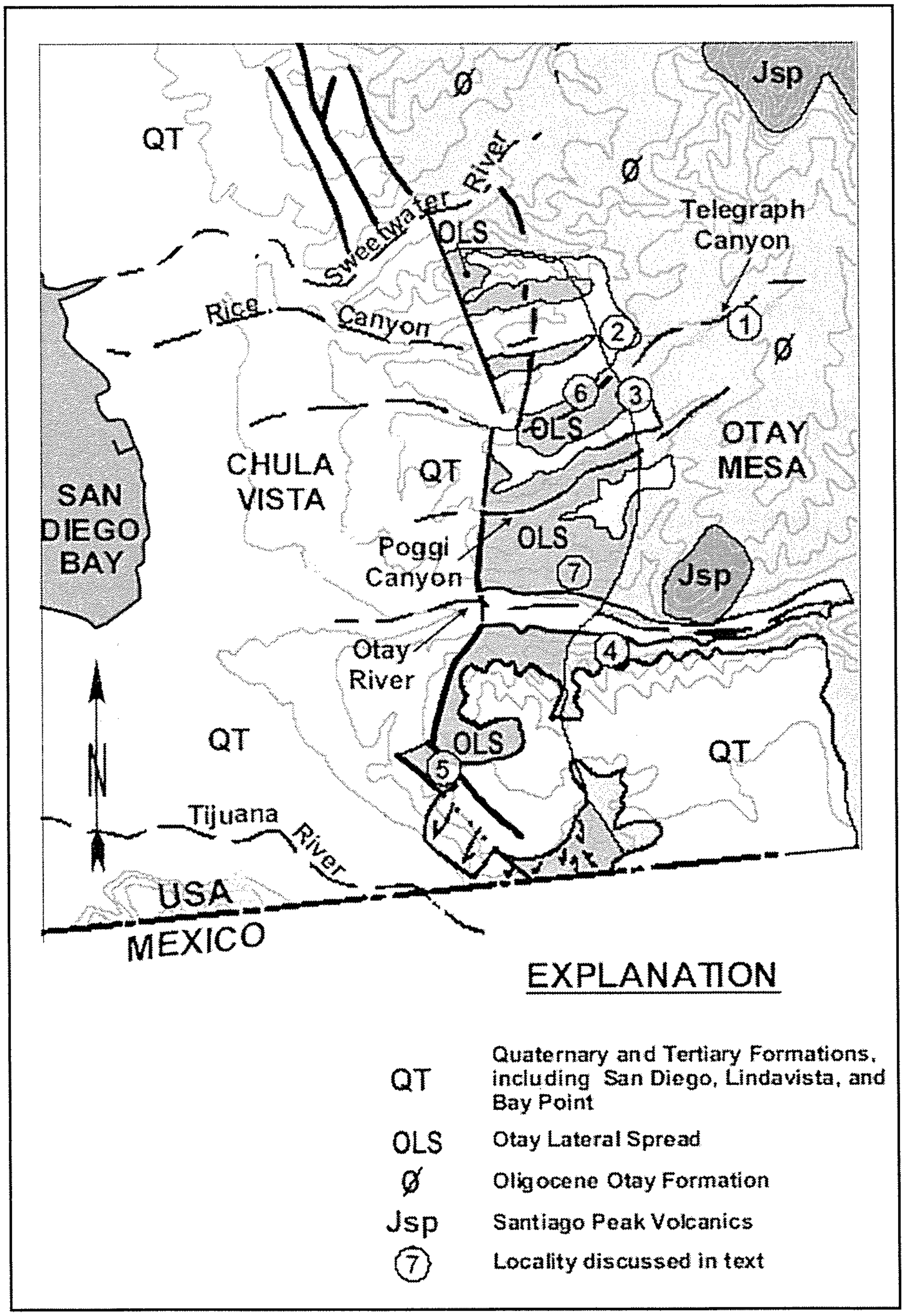


Figure 1. Geologic Map of southwest San Diego County.

geology of this area of the county. Large residential developments including Eastlake (Locality 1), Rancho Del Rey (Locality 2), and Otay Ranch (Locality 3), and the major roads associated with these developments have provided geologists countless new outcrops. Without these artificial outcrops, the mid-Cenozoic geology of the area would never have been well understood.

The natural topography in southwestern San Diego County consists primarily of gently rolling hills dissected by numerous westward-draining canyons, as shown in the photograph in Figure 2. Alluvial deposits within the canyons are relatively thick, and a shallow mantle of colluvium covers the hillsides. There are typically few naturally occurring outcrops. Prior to development, knowledge of the geology (Figure 1) was based on isolated roadcut exposures, particularly Chester Grade (Locality 4), and in open pit bentonite mines. Beginning in the late 1980s and early 1990s, residential developments began moving further eastward and southward from Interstate 805. These developments were generally limited to the ridge and/or mesa tops and canyon bottoms and as such, earthwork was relatively minimal. More recent grading beginning in the mid- to late 1990s began to expose more geology as developments utilized as much land as possible.

Figure 2. Photograph of the Otay Mesa/Chula Vista area, showing the gently rolling hills typical of the undeveloped portions of the region. View is to the southwest along Salt Creek toward Otay Valley. Note lack of outcrops.

Features in sedimentary rock that are now attributed to the OLS were observed in southwest San Diego County as early as 1988. These features included locally faulted clay bodies exhibiting structure resembling soft-sediment deformation, oversized flame structures, and rip up clasts. These deformation features were often thought to be associated with the nearby La Nacion fault, or soft-sediment deformation that occurred during or shortly after deposition. A 1988 geotechnical investigation in San Ysidro (San Diego Geotechnical Consultants, Inc.) concluded that syndepositional landsliding or deformation due to faulting on the La Nacion fault was responsible for unusual geologic structure observed near San Ysidro (Locality 5). Mike Hart (personal communication) and Dick Berry (1999) observed 3- to 8-meter-high apparent flame structures in bentonite within cut slopes along Telegraph Canyon Road near the intersection with Otay Lakes Road during the widening of Telegraph Canyon Road in the early 1990s (Locality 6). Berry (1999) was of the opinion that the flame structures were caused during deposition due the weight of overburden and poor consolidation of the bentonite (ash) and sediments.

During the grading of Rancho Del Rey (Locality 2), located roughly between the Sweetwater River valley and Telegraph Canyon in 1985 to 1989, abundant intrusive, diapir-like bodies of bentonite were observed at the lower elevations of the site (Richard Cerrutti, George Copenhaver, Pat Thomas, Brad Riney, personal communication). North-south trending, linear, clay-filled shears were also observed. The shears were continuous over several hundred meters and were concluded to be inactive traces of the La Nacion fault. Exposures in the Otay Landfill (Locality 7) showed a sheared bentonite clay layer forming a classic decollement with tilted and deformed bedding overlying horizontal, undeformed sediments (Hart, 1999). By 1993, geotechnical consultants working in the area universally acknowledged the presence of some type of intra-formational landslide or landslide-like feature within the pre-Pliocene sediments. However, the geometry or genesis of the feature was not known.

In 1995, development began south of Telegraph Canyon. Geotechnical investigations conducted for the new development did not encounter anything extraordinary other than the presence of a single persistent bentonite clay bed. Within the first week of grading, it was apparent that the geology above the clay layer was substantially different than below, similar to the exposures in the Otay Landfill. Initially, detachment or thrust faulting was hypothesized as a possible cause of the deformation. As grading proceeded, the eastern limits of the decollement were exposed as well as a 250-meter-long cross-section through the axis of the now apparent, lateral spread.

GEOLOGIC SETTING OF SOUTHWEST SAN DIEGO COUNTY

In general, the geology of southwest San Diego County consists of nearly flat-lying sequences of marine and nonmarine Tertiary and Quaternary age sedimentary rocks unconformably overlying Jurassic metamorphic and volcanic rocks (summarized best in Walsh and Deméré, 1991). Figure 3, a schematic, east-west section through southwest San Diego County, shows the stratigraphic and spatial relationship between the units. The basement consists of a complex mix of Jurassic to Cretaceous volcanic rocks known as the Santiago Peak Volcanics (Larson, 1948, Fife, et al., 1967, Herzig and Kimbrough, 1991). A high-relief nonconformity separates the overlying Tertiary sedimentary rocks from the basement. The Tertiary sediments are divided into the middle Eocene Mission Valley and Sweetwater Formations (Walsh and Deméré, 1991), the late Oligocene Otay Formation (Deméré, 1988), the late Pliocene to early Pleistocene San Diego Formation (Hertlein and Grant, 1944, Deméré, 1982), and the Pleistocene Lindavista Formation (Kennedy and Tan, 1977). The OLS debris is observed only in the Otay Formation.

In general, the sedimentary units have a gentle regional dip to the southwest. A north-south trending buttress unconformity is present where the Pliocene shoreline was cut into the Otay Formation, and the San Diego Formation was subsequently deposited against this near-vertical feature. The major structural feature in the area is the La Nacion fault, which is composed of anastomosing, near-vertical, down-to-the-west normal faults. The La Nacion appears to have formed in response to motion on the Rose Canyon fault zone further to the west (Marshall, 1989).

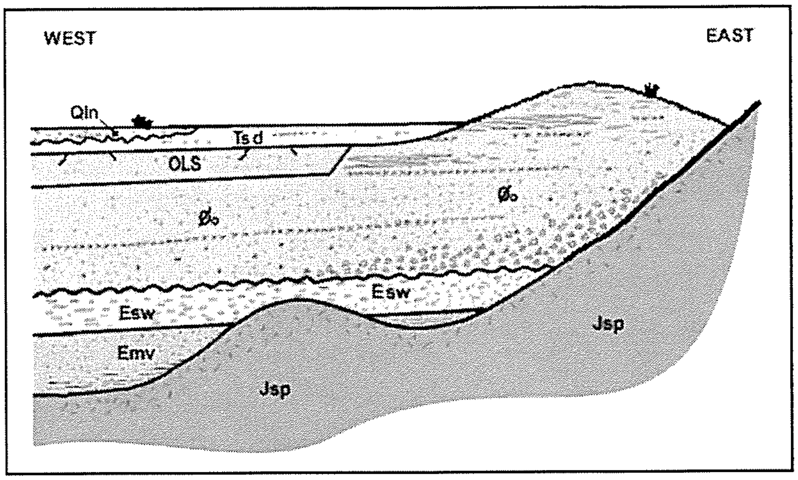


Figure 3. Generalized geologic cross-section of southwest San Diego County. Jsp, *Santiago Peak Volcanics;* Emv, *Mission Valley Formation;* Esw, *Sweetwater Formation;* Oo, *Otay Formation;* OLS, *Otay Lateral Spread;* Tsd, *San Diego Formation;* Qln, *Lindavista Formation.*

Tsd
Tmv

OTAY FORMATION

Lithology

The Otay Formation is thought to be a fluvial deposit, consisting of a basal conglomerate, middle gritstone, and upper sandstone-mudstone with regionally continuous bentonite claystone beds throughout (Walsh and Deméré, 1991). As a whole, the Otay Formation fines upward and westward (distally), as depicted in Figure 3. The 12-meter-thick basal conglomerate is made up of gravel, cobble and boulder conglomerates with a coarse sandstone (gritstone) matrix. Clasts within the conglomerate are both metavolcanic and granitic in origin. The middle gritstone unit consists coarse to gravelly sandstone and is roughly 16 meters thick. Lithic fragments are typically quartz, feldspar, and plutonic rocks, with lesser amounts of metavolcanic rock fragments. Rare beds of bluish gray bentonite claystone are also present. The upper sandstone-mudstone unit is characterized by massive beds of light brown and light gray sandstone with thinner interbeds of reddish brown to green to olive siltstone and claystone. The uppermost sections of the Otay Formation contain distinct red, green, and brown claystone and siltstone beds dubbed the "Christmas Beds." The upper sandstone unit is at least 35 meters thick as the top has been eroded.

Bentonite

The existence of bentonite claystone in the Chula Vista area has been known since the beginning of the 1900s. This material was mined from the Otay Formation between 1917 and 1957 for use as a cleaning and de-colorizing agent for petroleum (Cleveland, 1960). It has also been used as a drilling fluid, and in impermeable membrane applications. Otay Bentonite is a Clay Minerals Society Source Clay, consisting almost entirely of mixed-layered illite-smectite (Berry, 1999). Argon/argon dating of a bentonite bed within the upper sandstone-mudstone unit of the Otay Formation indicated an age of 28.86 Ma (Walsh and Deméré, 1991), corresponding to Late Oligocene. The generally accepted theory for the formation of bentonite is the deposition of volcanic ash in seawater. The "...general consensus is that primary waxy bentonites result from the fall of (probably hot) volcanic ash directly into water that is at least brackish… The alteration takes place in a matter of hours or days and the resulting deposit of pure, unconsolidated bentonite must be left undisturbed for a longer time until it develops its coherent waxy character," Berry (1999). The observed geology associated with the bentonite in the Otay Formation is somewhat at odds with the aqueous origin of the clay. Sedimentary structure, lithology and paleontology within the Otay Formation indicate a fluvial system with freshwater fauna as opposed to estuarine or shallow marine environments.

Although bentonite layers occur throughout the Otay Formation, they appear most frequently and most continuously in the upper sandstone-mudstone member. The most persistent layer occurs at elevation 360 feet near the intersection of Paseo Ranchero and Telegraph Canyon Road. Cleveland (1960) also reported this layer in Otay Valley. The bentonite is pink to white in color, waxy in texture and ranges from brittle to remolded in consistency. The bentonite ranges from several centimeters to two meters in thickness and is typically associated with dark red, thinly stratified clay. The red clay is usually 1 to 2 meters thick above and locally below the bentonite. The bentonite dips 1 to 2 degrees to the west-southwest. Another continuous layer of bentonite was observed at elevation 585 feet near the intersection of La Media and East Palomar Street. This higher bed is associated with thinly bedded red, green, and white "Christmas Beds" claystone. Both beds appear to be primary bentonites (Berry, 1999).

OTAY LATERAL SPREAD

A lateral spread is defined as "lateral movements in a fractured mass of rock or soil, which results from liquefaction or plastic flow of subjacent materials", (AGI, 1980). Lateral spreads in bedrock typically involve the fracturing and extension of coherent upper units on a liquefied or plastic basal surface (Varnes, 1978). These features generally develop on gentle slopes, between 0.3 and 3 degrees. During movement, the lateral spread will typically break up internally, forming numerous fissures and scarps. Lateral spreads can occur on all scales, however, the size of these features can be tremendous, extending up to many kilometers (Varnes, 1978). Additionally, as observed in actual lateral spreads in Russia and Libya, the cracks between the coherent blocks of bedrock were filled with soft material squeezed up from below or detritus from above (Varnes, 1978). Most lateral spreads are thought to be triggered by a seismic event, though it is not a requirement. Many are caused by exposure of a free face such as a cliff or riverbank.

General Description

The sedimentology/sedimentological structure of the Otay Lateral Spread deposit observed in the Chula Vista area is variable, however, it is in accordance with the defining characteristics of a lateral spread. The best exposure to date was located in a 700-meter-long, continuous buttress backcut along the south wall of Poggi Canyon (Figures 4, 5, and 6). In general, the debris consists of relatively discrete blocks of sandstone, siltstone and claystone separated by steeply dipping shear zones (Figure 5). The entire mass mobilized on the lower bentonite layer observed at elevation 360 feet in the vicinity of Paseo Ranchero.

Internal Blocks. The internal blocks average 10 meters in height, 50 to 100 meters in width (east-west), and several hundred meters in length (north-south). Some blocks are composed of relatively undisturbed massive sandstone whereas others consist of highly fractured and sheared mixtures of claystone, sandstone and bentonite (Figure 6). Several blocks near the head of the lateral spread exhibit steeply dipping, backward rotated bedding (Figure 7). In all cases, the blocks are relatively well lithified or healed with carbonate cement. The blocks often contain odd shaped bodies of bentonite (Figure 8) varying from 1 to several meters in length. These features are usually internally sheared and are probably the result of fragments of plastic bentonite being peeled from the basal rupture surface and dragged into the debris during the initial failure. Wherever thin bedding has been preserved in the blocks, it is abruptly truncated at the basal rupture with no indication of soft sediment deformation or dragging (Figures 9 and 10).

Boundary Shear Zones. The shear zones between the blocks trend north-south (normal to the westward direction of movement) and are traceable over hundreds of meters. The shear range from several centimeters to several meters in width and are composed of sheared claystone with polished shear surfaces. The claystone is locally soft and remolded. Where the steeply dipping shear zones intersect the low angle basal failure surface, the bentonite is often dragged up into the zone in diapir-like intrusive bodies (Figure 5) or as elongated fragments.

Basal Rupture. The basal rupture clearly occurred on or within a thick continuous bentonite clay bed. The bentonite ranges from 10 centimeters to 2 meters thick with the variations due to deformation during movement of the overlying debris. The upper portions of the basal rupture often exhibit soft sediment or plastic deformation in the form of dike-like intrusive bodies into the overlying debris or complex recumbent drag folds (Figure 11). Residual

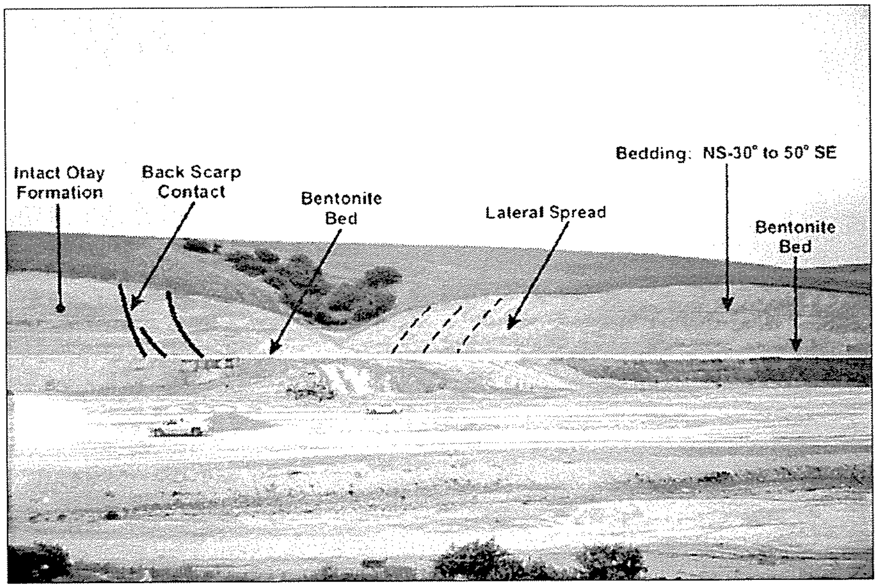


Figure 4. Photograph of a portion of a buttress backcut slope along Poggi Canyon, looking south. Note the back scarp contact between the intact Otay Formation and the Otay Lateral Spread deposit, and the backward rotated bedding emphasized by the dashed lines. Of particular interest is the lack of topographic expression of this contact.

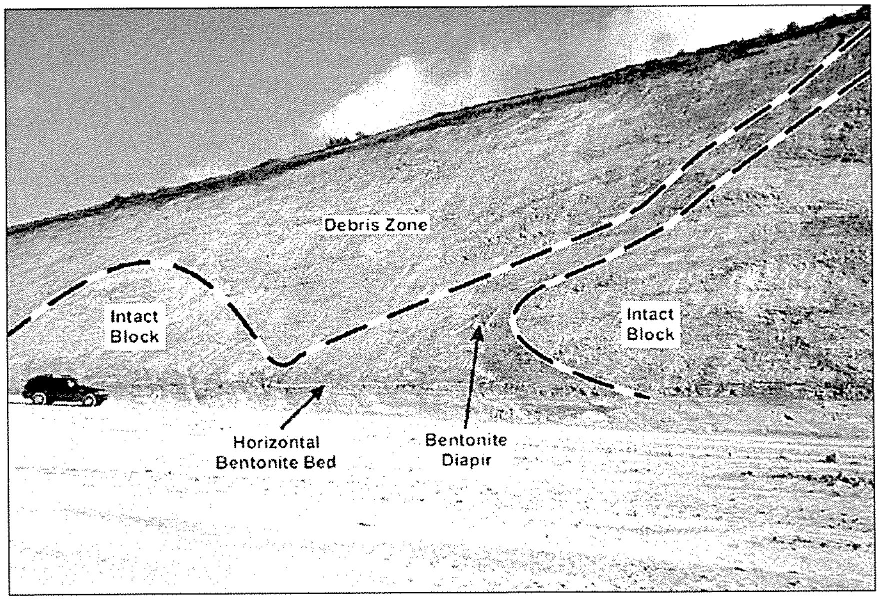


Figure 5. Photograph of a portion of a buttress backcut along Poggi Canyon, west of Figure 4. Note the intact blocks of sandstone separated by the bentonite diapir and zone of disturbed sandstone, siltstone, and claystone. The horizontal bentonite bed is clearly visible.

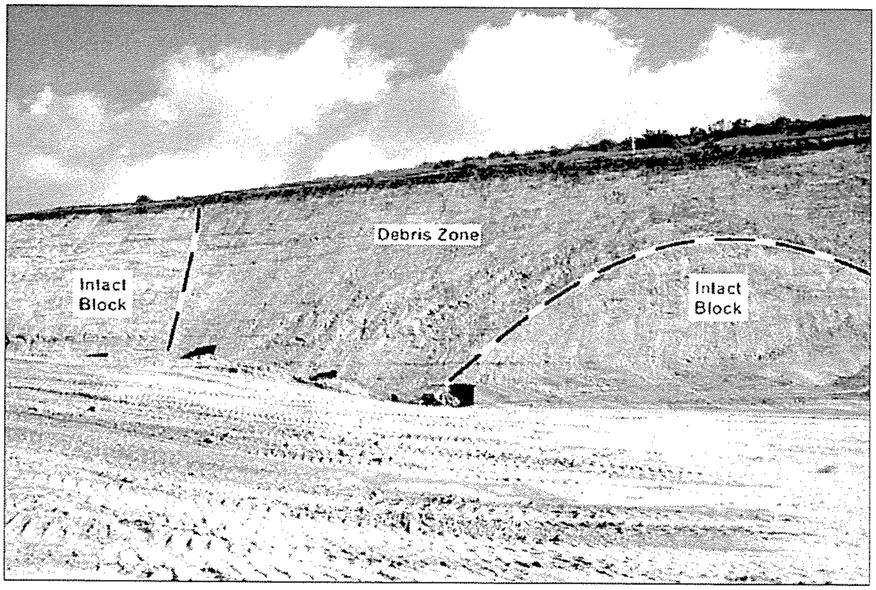


Figure 6. Photograph of a portion of a buttress backcut along the south side of Poggi Canyon east of Figure 5. Note the sheared and fractured debris zone.

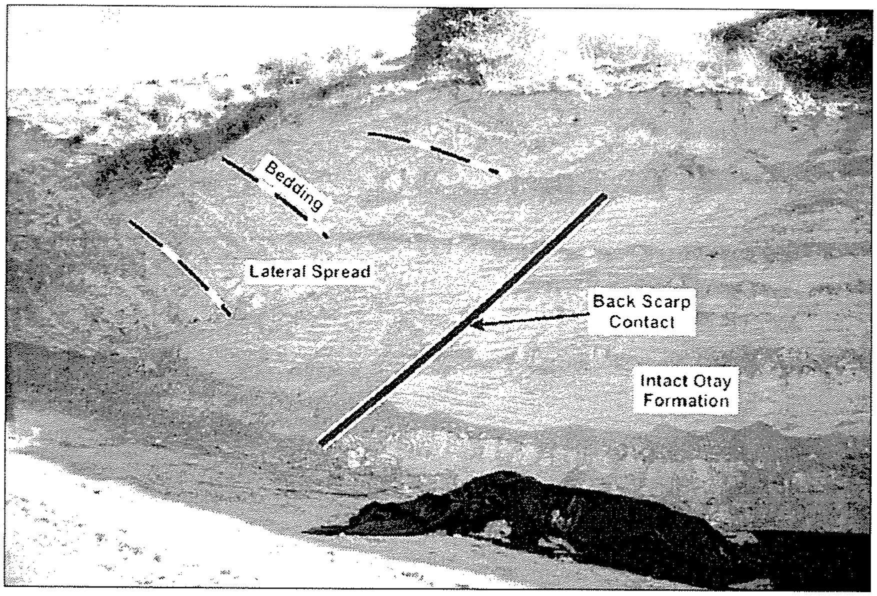


Figure 7. Photograph of back scarp contact on the north side of Poggi Canyon, looking northeast. Note the massive to flat-lying bedding of the intact Otay Formation, and the southeast dipping bedding of the Otay Lateral Spread.

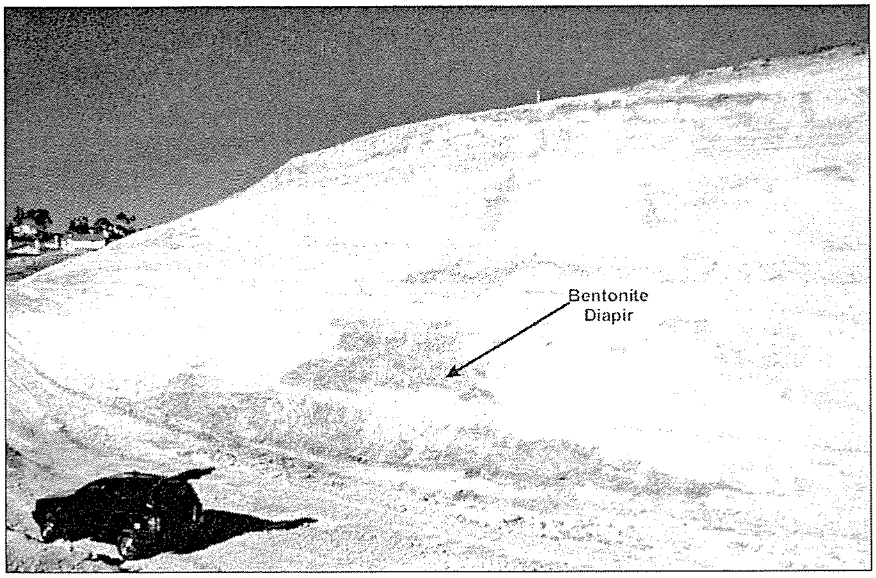


Figure 8. Photograph of a large diapir of bentonite.

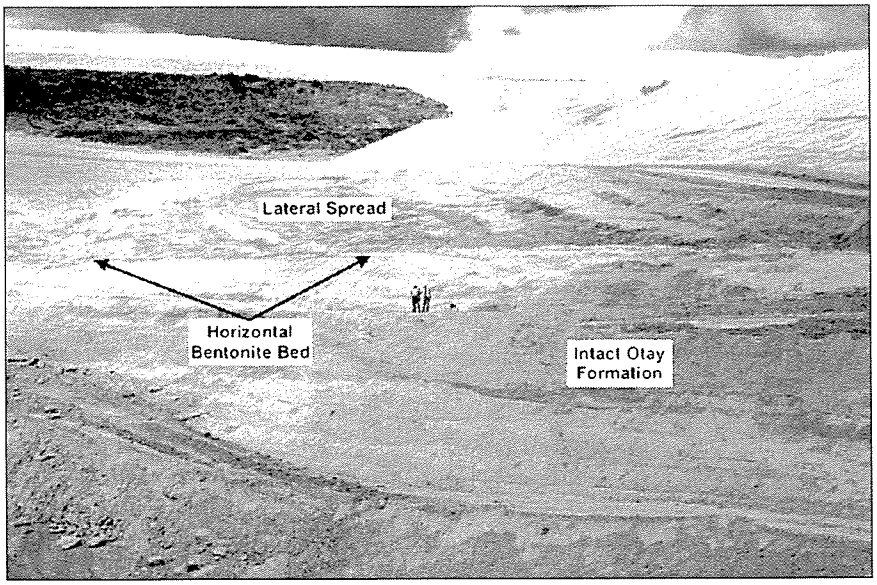


Figure 9. Photograph of the contact between the intact Otay Formation and the Otay Lateral Spread, taken at the Otay Landfill (Locality 7). The flat-lying bentonite bed is clearly visible.

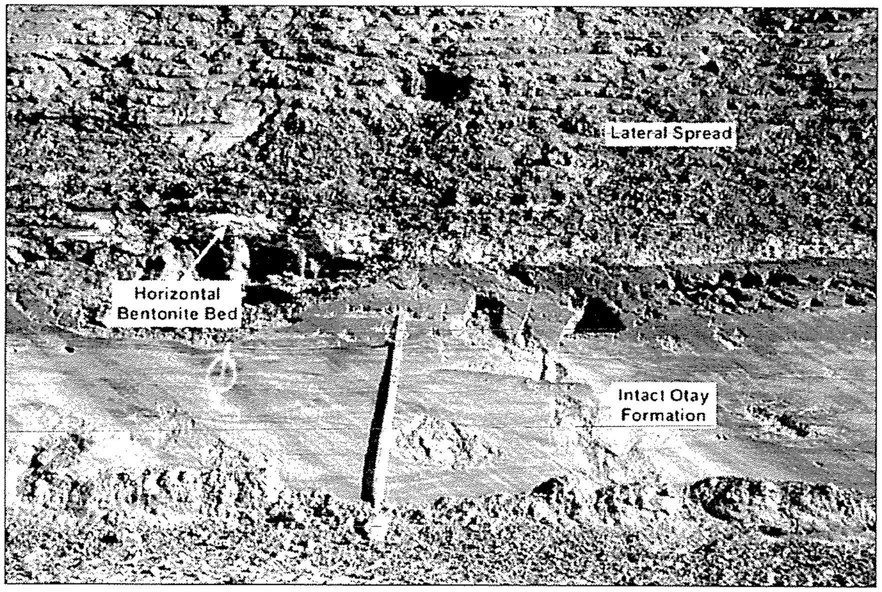


Figure 10. Close-up photograph of the contact between the intact Otay Formation and the Otay Lateral Spread in Poggi Canyon. The flat-lying bentonite bed is clearly visible. Note the "punky" appearance of the OLS sediments. The striations in the lower portion of the photograph were caused by grading equipment.

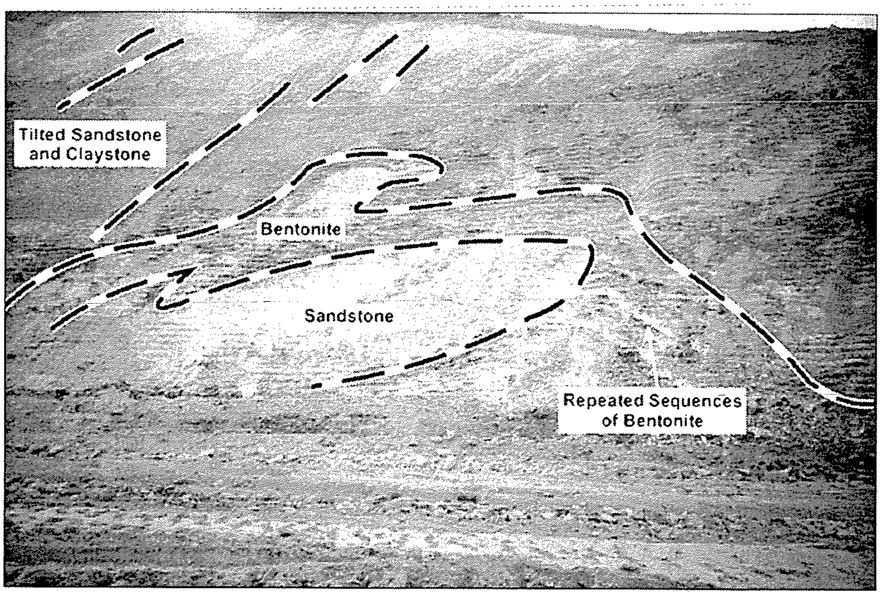


Figure 11. Photograph of a buttress backcut slope along the south side of Telegraph Canyon Road just east of Paseo Ranchero. The bentonite has been squeezed up into the debris and folded into a complex recumbent structure.

shear tests (using a direct shear) for this material yield average angles of internal friction of 8 degrees and cohesion of 0 psf.

Head/Graben. The head of the OLS is marked by a clear, steeply dipping fault-like shear separating highly deformed and broken debris from massive, undisturbed Otay Formation sandstone (Figures 4 and 7). Adjacent to the back scarp, the graben debris is composed of highly chaotic bedding with no discernible preferred orientation. However, as you traverse westerly from the back scarp toward the distal portion of the lateral spread, the bedding takes on a uniform orientation, striking a few degrees east or west of north, and dipping approximately 30 to 50 degrees to the east (backward rotation). The bedding observed in the graben is composed of alternating green, red and white claystone and a thin bentonite that correlates well with the "Christmas Beds" found approximately 60 meters higher in the Otay Formation section. This band of "uniformly disturbed beds" is roughly 50 meters wide and extends over 1.6 kilometers in a north-south direction.

Lateral Limits

The eastern limits of the OLS are well documented between Telegraph and Poggi Canyons in the Otay Ranch area (Figure 1). The exposures in the Otay Landfill extend a minimum eastern limit to the north side of Otay Valley. Observations in a residential subdivision on the south side of Otay Valley (Randy Wagner, personal communication), and recent cut-slope exposures near the Border Patrol Headquarters are the basis for extrapolation of the spread southward. The southern limits are unknown, but exposures near San Ysidro suggest the lateral spread extends at least to the United States/Republic of Mexico border. The western limits are defined by the La Nacion fault based on exposures west of Paseo Ranchero where the fault juxtaposes lateral spread debris against the down-dropped San Diego Formation (Pat Thomas, personal communication). The northern limits are more difficult to establish as they are based on recollections of geologists working the area during development construction in the 1980s. The OLS extends at least to the northern boundary of the Rancho Del Rey subdivision. Unusual sedimentary structure was described by Dennis Hannan working along the south side of the Sweetwater River Valley in the 1970s (personal communication) that may suggest the debris extends this far northward.

Stratigraphy

The top of the OLS was removed by erosion prior to the deposition of the San Diego Formation. The unconformity between the Otay Formation and the San Diego Formation clearly separates undisturbed San Diego Formation from the underlying OLS debris (Figure 12). This brackets the youngest age of the lateral spread to late Pliocene. The basal rupture is within the Otay Formation, thereby bracketing the lower boundary to late Oligocene. We suggest that the OLS likely occurred sometime after deposition of the Otay Formation. The presence of the "Christmas Beds" in the graben indicates the failure must have occurred after the deposition of at least 60 meters of Otay Formation above the basal bentonite. The lack of soft sediment deformation in the OLS debris indicates that the Otay Formation had to have been somewhat consolidated or lithified prior to initiation of the lateral spread. Finally, a significant amount (at least 60 meters) of erosion or faulting must have occurred prior to the failure to expose the basal bentonite (Figure 13b) and destabilize the mass.

FAILURE MECHANISM

As defined by Varnes (1978), lateral spreads are generally thought to be triggered by seismic events, causing liquefaction or plastic flow of subjacent materials and allowing lateral movement. The basal bentonite exhibits extremely low shear strength, is highly plastic and acts as an aquitard creating a perched water table. Creation of a high seabluff along a paleo-coastline west of the OLS debris would likely have occurred to complete the requirements for failure (Figure 13b). Using these parameters, approximated back-calculations of stability indicate that seismically induced ground acceleration of only 0.12 g could have mobilized the mass. We have discounted the possibility that the failure is the result of retrograde landsliding because of the size of the feature preserved, the lack of evidence of erosion within the debris, and the 700-meter-long, continuous exposure of debris that had to have occurred as a single event.

GEOTECHNICAL IMPACTS

The areas underlain by the OLS are currently being developed or are in the path of future development. While the western limits of the feature are buttressed by the down-faulted San Diego, Lindavista, and Bay Point Formations west of the La Nacion fault zone, large internal units of the debris exposed in slopes and valleys are not. One of the identifying features of natural slopes underlain by the OLS is the presence of relatively recent large scale, deep-seated landslides. The highly disturbed nature of the debris along with weak basal bentonite may be responsible for the large

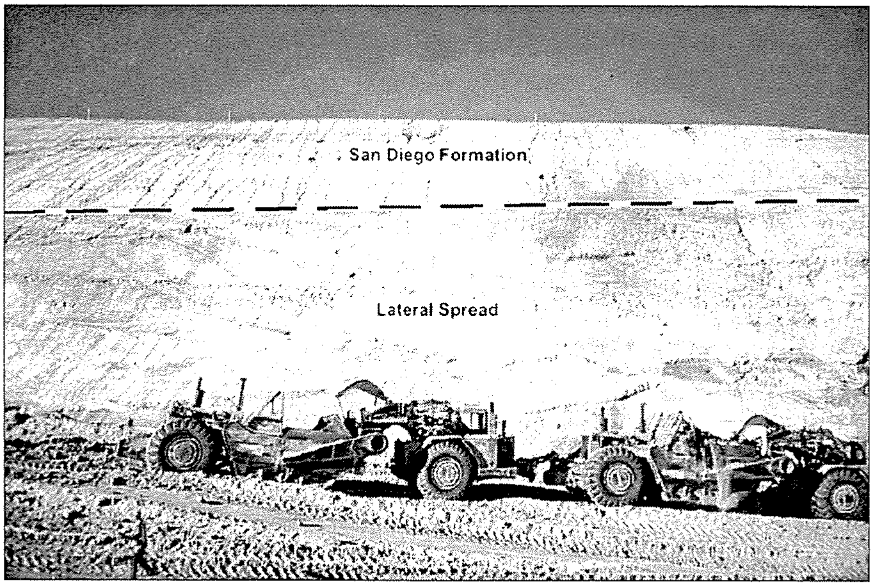


Figure 12. Photograph of a buttress backcut slope along the west side of Paseo Ranchero. The chaotic bedding of the OLS is clearly truncated by the San Diego Formation.

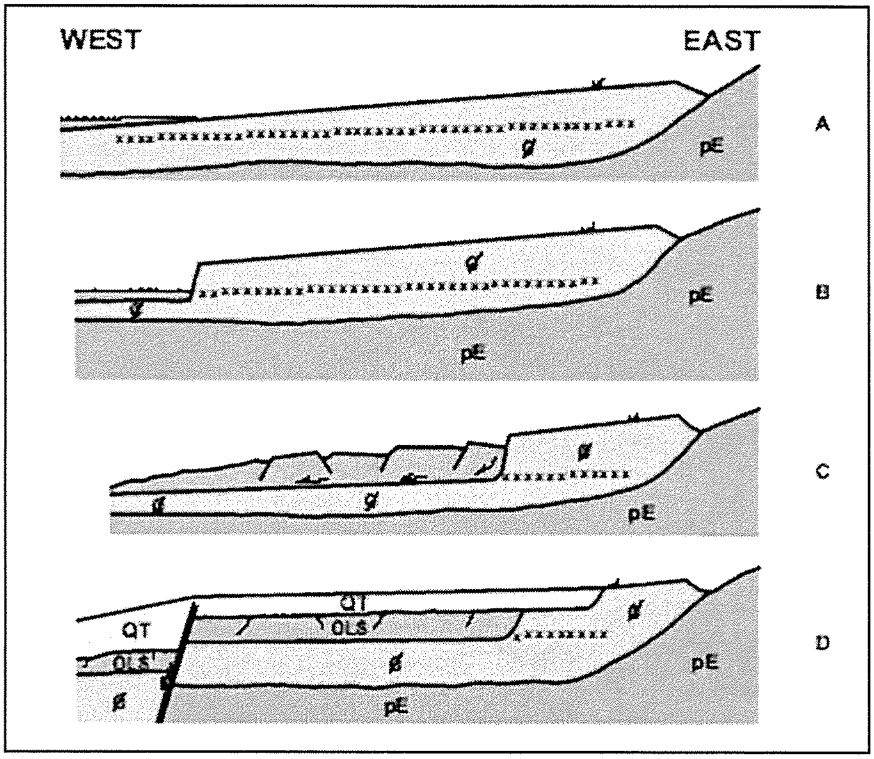


Figure 13. Idealized sequence of events, beginning in the late Oligocene (A) and leading up to the present day (D).

number of ancient landslides seen along the south side of Otay Valley and Smuggler's Gulch along the U.S./Mexico border.

In graded slopes, the same factors affect stability. The typical method of evaluating slope stability for future grading is to drill large (1-meter) diameter borings in areas where the slopes will be cut. The boring is entered by the geologist and logged for potentially unstable geologic structure. If the boring is not drilled precisely in a shear zone separating the intact blocks within the debris, the potentially destabilizing effect on east or west facing slopes will not be recognized (Figure 14). This geologic misinterpretation will have an obvious effect on project design and construction.

The shear zones are also composed of irregular bodies of highly expansive bentonite and other clays. Large irregular bodies of bentonite are also associated with the shear zones. If a shear zone is located beneath a structure or shallow fill, there is a potential for damaging heave once the clays become wet from irrigation. The shear zones are also fault-like in appearance and may be misidentified as strands of the La Nacion fault.

To avoid the potential hazards of grading in the OLS, careful exploration is not our only tool. In grading mapping by qualified geologists will be needed to identify the presence of the debris and to map the hazardous features. Only then will the geotechnical engineers have the three-dimensional model necessary to conduct a realistic analysis of stability.

CONCLUSIONS

Evidence of mass-wasting is very rare in the geologic record. The Otay Lateral Spread is special because of the excellent preservation of all but the toe of the debris over a 124 square kilometer area. The presence of the feature was not previously recognized because there were no geomorphic features or sufficient outcrops to suggest its existence.

There are several lessons to be learned from the Otay Lateral Spread by the geotechnical consulting industry. The sharing of geologic information within the geotechnical community is extremely important. If not in formal papers or presentations, then at least, by discussion. Geology is not limited by property or subdivision boundaries. We owe our clients the most complete geologic characterization of the site that we can put together. That most certainly includes geologic data from adjacent sites. The "big picture" is still important. Finally, we cannot be lulled into a false sense of security with regard to our investigative reports. It is a very humbling experience to watch all of

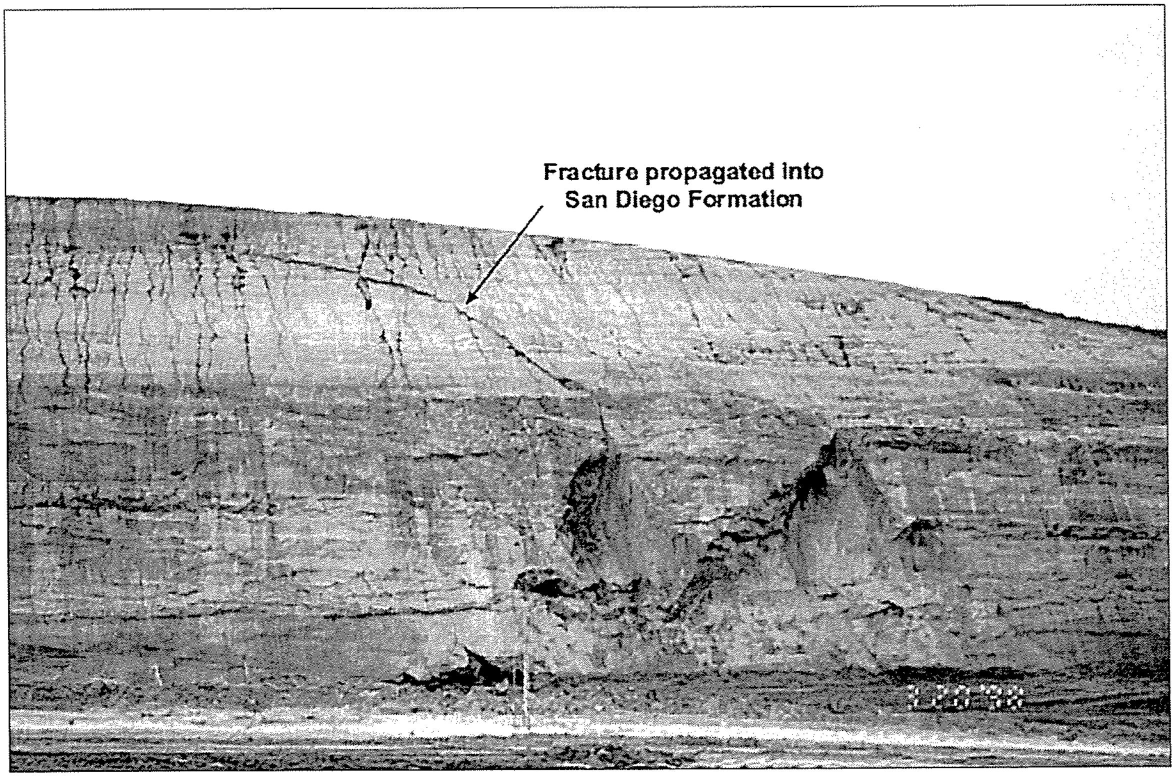


Figure 14. Photograph of a construction failure in progress. The fracture propagated up into the San Diego Formation from the OLS, requiring large amounts of additional earthwork and stabilization efforts.

your carefully selected assumptions evaporate during mapping of the first canyon clean-out. We (and that means engineers too) need to react quickly and professionally to changes observed during grading. That requires careful mapping in the field and analysis of that data throughout the grading process.

ACKNOWLEDGMENTS

This paper would not have been possible without the hard work of countless geologists working in the southwest San Diego County area over the past 20 years. We would like to especially thank Dick Berry, Richard Cerrutti, George Copenhaver, Tom Deméré and the crew at the San Diego Natural History Museum, "Wild" Bill Elliott, Jim Sanders, Dave Evans, Gordon Gastil, Dennis Hannan, Brad Riney, Pat Thomas, and Randy Wagner. Ultimately, though, we have to thank the people that paid for the scrapers and cats, not to mention our salaries, The McMillin Companies, the Otay Ranch Company, Sunbow, and the County of San Diego. Last but not least, the unknown planners or engineers that decided Paseo Ranchero had to go "straight through" rather than "up and over."

REFERENCES

AGI, 1980, Glossary of Geology, Second Edition: American Geologic Institute, Falls Church, Virginia.

Abbott, P.L., 1999, The Rise and Fall of San Diego: Sunbelt Publications, San Diego, California.

Berry, R.W., 1999, Eocene and Oligocene Otay-Type Waxy Bentonites of San Diego County and Baja California: Chemistry, Mineralogy, Petrology and Plate Tectonic Implications: Clays and Clay Minerals, Vol. 47, No. 1, pp. 70-83.

Cleveland, G.B., 1960, Geology of the Otay Bentonite Deposit, San Diego County, California: California Division of Mines Special Report 64, 16 p.

Deméré, T.A., 1983, The Neogene San Diego Basin: A Review of the Marine Pliocene San Diego Formation, in Larue, D.K., and Steel, R.J., editors, Cenozoic marine Sedimentation, Pacific Margin, U.S.A.: Pacific Section, Society of Economic Paleontologists and Mineralogists, Vol. 28, pp. 187-195.

Deméré, T.A., 1988, Early Arikareean (late Oligocene) Vertebrate Fossils and Biostratigraphic Correlations of the Otay Formation at EastLake, San Diego County, California, in Filewicz, M.V., and Squires, R.L., editors, Paleogene Stratigraphy, West Coast of North America: Pacific Section, Society of Economic Paleontologists and Mineralogists, Vol. 58, pp. 35-44.

Fife, D.L., Minch, J.A., and Crampton, P.J., 1967, Late Jurassic age of the Santiago Peak Volcanics, California: Geological Society of America, Vol. 78, pp. 299-303.

Hart, M.W., 1999.

Hertlein, L.G., and Grant, U.S., IV, 1944, The Geology and Paleontology of the Marine Pliocene of San Diego, California, part 1, Geology. Memoir II. San Diego Society of Natural History, 72 p. and 18 plates.

Herzig, C.T., and Kimbrough, D.L., 1991, Early Cretaceous Zircon Ages Prove a Non-Accretionary Origin for the Santiago Peak Volcanics, northern Santa Ana Mountains, California: Geological Society of America Cordilleran Section Meeting Abstract with Programs, Vol. 35, p. 35.

Kennedy, M.P., and Tan, S.S., 1977, Geology of National City, Imperial Beach, and Otay Mesa Quadrangles, Southern San Diego Metropolitan Area, California: California Division of Mines and Geology. Map Sheet 29.

Larsen, E.S., Jr., 1948, Batholith and Associated Rocks of Corona, Elsinore, and San Luis Rey Quadrangles, Southern California: Geological Society of America Mem. 29, 182 p.

Marshall, M., 1989, Detailed Gravity Studies and the Tectonics of the Rose Canyon–Point Loma–La Nacion Fault System, San Diego, California, in Roquemore, G, and, Tanges, S., editors, The Seismic Risk in the San Diego Region: Special Focus on the Rose Canyon Fault System — Proceedings.

San Diego Geotechnical Consultants, Inc., 1988, Geotechnical Investigation, Beyer Hill Park Apartments, San Ysidro, California: June 8.

Varnes, D.J., 1978, Slope Movement Types and Processes, in Krizek, R.J., and Schuster, R.L., editors, Landslides, Analysis and Control: National Academy of Sciences, Special Report 176, pp. 11-33.

Walsh, S.L., and Deméré, T.A., 1991, Age and Stratigraphy of the Sweetwater and Otay Formations, San Diego County, California, in Abbott, P.L., and May, J.A, editors, Eocene Geologic History, San Diego Region: Pacific Section, Society of Economic Paleontologists and Mineralogists, Vol. 68, pp. 131-148.

Comparison of Field Descriptions and Quantitative Grain Size Analysis of Common San Diego Stratigraphic Units

***Derral Van Winkle**, Brown and Caldwell*

ABSTRACT

A study was conducted to examine differences between quantitative results from grain size analysis and field descriptions by professional geologists of some common San Diego area formations.

Geologists from several different consulting firms and with differing years of experience were asked to do "field descriptions" of six samples from different San Diego area formations. Field descriptions were limited to identifying the mean grain size, sorting, and roundness of each sample. The field descriptions were then prepared for statistical analysis by assigning a phi, sigma, or rho value for mean grain size, sorting, and roundness, respectively based on the description the geologist provided. Statistical analysis was conducted on these results and the results were compared with results from the grain size characterization.

Quantitative analysis was conducted on each sample using mechanical sieve and pipette analysis. Quantitative descriptions of grain size and sorting were determined using the results from this sieve analyses, including values for the mean grain size (in phi) and sorting (in sigma).

The quantitative grain size and sorting calculation results were then compared with the distribution obtained based on the field descriptions. Additionally, roundness description variation was examined based on the spread of different values obtained from the field descriptions. Finally, correlations between years of experience and description accuracy were examined.

Significant differences do exist between the geologist's descriptions and quantitative sieve analysis in some cases but not all. Descriptions for mean grain size often differed, but were inconsistently biased either high or low, even though most field geologists are used to providing descriptions using the Unified Soil Classification System versus using the Wentworth System that the sieve results were based upon. In most cases sorting descriptions were biased towards a tighter spread by a factor of at least 1.0 sigma. Roundness descriptions varied considerably from geologist to geologist. In addition, no significant trends could be deduced from the data such as correlation with better description matches with years of experience or classification system use.

INTRODUCTION

This paper has been prepared to discuss the findings of an experiment that compares the visual qualitative descriptions of soil samples by different geologists with the quantitative results obtained from mechanical procedures such as sieving and pipette analysis.

The purpose of the experiment is to examine whether significant differences exist between the results of professional geologists using qualitative field description methods for grain size and sorting, and the quantitative results obtained from mechanical particle size differentiation through sieving and pipette analysis. Additionally, qualitative descriptions from the geologists for roundness are compared for variability within each sample. The working hypotheses for this experiment are as follows:

1. Significant differences will exist between the geologists qualitative descriptions and the quantitative results from mechanical analysis, both for mean grain size and sorting.

2. Significant difference will exist within the descriptions of roundness for a particular sample.

3. Deviation from the quantitative grain size analysis will be a function of years of experience.

PROCEDURES

This section summarizes the procedures used to conduct the experiment. Detailed descriptions of the procedures employed can be found in textbooks or in standards established by such organizations as the American Society for Testing and Materials (ASTM), the American Geologic Institute (AGI), or the American Petroleum Institute (API). Two general approaches to determining the experimental parameters were used in the experiment: geologist visual descriptions of mean grain size, sorting, and roundness, and quantitative results for mean grain size and roundness from mechanical procedures described below.

Visual Descriptions

Ten geologists working in different capacities at consulting firms in San Diego were given six samples to describe for mean grain size, sorting, and roundness. The only instructions given to the geologists were that they should describe the samples as they would on any professional job, but that only mean grain size, sorting, and particle shape should be described. Samples were submitted to each geologist as they might from a field drilling project, i.e., in a jar as close as possible to original condition (moisture content was maintained).

The descriptions were prepared for quantitative comparison with the results from sieve and pipette analysis by assigning a phi (ø), sigma (graphical inclusive standard deviation or phi standard deviation), or rho value to each geologist's description and then calculating an average (mean) and standard deviation for the probability distribution obtained from each parameter in a sample. The value assigned for each parameter was determined by using the middle of the range for each category corresponding to the description. For example, if a mean grain size was described as fine sand, it was assigned 2.5 ø, which is the center range for the Wentworth size class for fine sand. Sorting and grain roundness descriptions were handled similarly, using the ranges for different classification as presented in Boggs (1995, after Folk, 1974). The statistical values were then used to calculate a probability distribution, which approximates the variability in the six geologist's descriptions for that sample. Table 1 summarizes the results of the geologist descriptions and the statistical analysis of these data.

Sieve and Pipette Analysis

Mechanical sieving and pipette analyses were conducted on the samples to determine the grain size and sorting characteristics of each sample quantitatively. Thirteen sieves ranging from a U.S. Standard sieve size 4 to 230 were used to separate the different fractions of gravel- and sand-size particles. These raw data are included in Table A-1 and A-2 in Appendix A. The fraction left from this dry sieving was then used for pipette analysis.

Pipette analysis was conducted by collecting the leftover from the mechanical sieve analysis and using it as the aliquot for the pipette analysis. No pipette analysis was conducted for Samples 5 or 6, where it appeared that adequate amounts were retained prior to the silt and clay grain sizes to facilitate obtaining the ø95 value from the graph. The procedure followed was obtained from a laboratory procedures manual from Royse (1970).

RESULTS

Figure 1 shows the grain size distributions for all samples. Figures A-1 through A-6 in Appendix A exhibit the cumulative percentage retained curve, and the histograms of percentage retained for each grain size category. Supporting data for these figures are found in Tables A-1 and A-2 in Appendix A.

Figures 2 through 7 contain the results from geologist descriptions and subsequent statistical analysis, and the mean results from sieve and pipette analysis. Figure 8 exhibits the variation in roundness for each sample plotted together for comparison. Table 2 contains the summary of statistical calculations for the sieve analysis using formulas for calculating grain size statistical parameters using graphical methods (Boggs, 1995). These data were obtained graphically from the curves included on Figures A-1 though A-6. The results of this statistical analysis also are plotted as vertical lines on Figures 2 through 7. As seen in Table 2, no statistical analysis was conducted on Sample 5 due to the high amount of retained mass within the first sieve category, which creates a condition whereby not all parameters required for the calculation can be obtained from the graph (e.g., ø95). Hence, only qualitative discussion and comparison can be attempted with results for this sample.

DISCUSSION

As seen in Figure 1, the experiment was designed to have some grain size and sorting differences to the samples. The samples do not exhibit as much variation as was desired at the initiation of the experiment, but do exhibit enough for a fair test of descriptive field techniques.

As observed in the histograms presented on Figures A-1 through A-6, most of the samples exhibit a normal or slightly skewed normal distribution. Samples 3 and 5 (Figures 4 and 6, respectively) are slightly different and appear to exhibit a bimodal distribution. The distribution for both of these samples appears to be spread over greater grain size than other samples. Note with the Sample 5 the influence of pebble and cobble-size particles on the distribution. Approximately 64 percent of the total sample mass was retained in this size range.

Table 2 presents the results from calculations for statistical analysis using data obtained graphically from Figures 2 through 7. Note that mean grain sizes for the particles vary between 1.6 and 3.8 ø or very fine to medium sand. Sigma values vary between 1.2 and 2.0 ø, suggesting a particle size distribution that is poorly sorted for all samples. Note that for Sample 5, which exhibits the poorest sorting, no calculation could be made because graphical analysis could not be performed due to poor particle distribution throughout a range of grain sizes.

The statistical results from Table 1 are shown on Figures 2 through 7. Some variation is observed in these plots regarding the geologist's descriptions versus the calculated mean grain size for each sample. In some cases the geologist's mean is a coarser description than that determined by the sieve analysis, for other samples it is a finer description. In two cases, Samples 2 and 6 (Figures 3 and 7, respectively), the descriptions are very close to that calculated by the mechanical grain size analysis. It appears, based on the mean grain size descriptions and the spread shown grain size histograms in Appendix A, that some correlation exists between how closely the described mean grain size agrees with sieve analysis results and the sorting of the sample. For example, Sample 2 (Figure 3) shows that the described mean grain size agrees fairly closely with that found through sieve analysis. Examination of Figure A-2 shows that this sample has a relatively tight grain size distribution with the median grain size accounting for almost 30 percent of the sample by weight. Contrast results from sample 2 with those from Sample 4, which has a relatively large spread of different grain sizes (Figure A-4) and hence relatively poor agreement between described mean grain size and that quantified from sieve results. Sample 4 also exhibits a significant range of variation in descriptions.

One puzzling aspect of this result is that in all cases, the geologists surveyed in this experiment are used to and have been trained using the Unified Soil Classification System (USCS) for describing soil and particle size. The USCS uses sizes for each grain designation that generally are coarser than the Wentworth class system, which would suggest that the geologist's descriptions should be consistently coarser. However, this trend is only observed for two samples, and again, nothing is characteristic about these two samples that would appear to bias the results. In one case the sample (Sample 3) appears to contain mainly silt-size particles; and the grain size analysis suggests that a large portion is silt; however, the sorting on this sample spreads it over several orders or phi, so the mean grain size is in the fine sand range. The other sample (Sample 1) is wet and hence may have caused some misjudgment by the geologist. In general, the spread in grain-size descriptions within each sample varies over approximately 3ø or more, or, for example, very fine sand to coarse sand, which suggests a great degree of inconsistency in the descriptions. As observed in Table 1, no correlation is apparent between the grain-size descriptions and their closeness to the calculated values and years of experience.

Sorting data exhibit a trend towards describing samples as better sorted than the quantitative analysis of mechanical sieving would suggest. This is consistently demonstrated throughout the descriptions as seen on Figures 2 through 7, although the mean geologist descriptions for Sample 4 and Sample 6 are closer to the calculated sieve analysis result. As observed with variations in the mean grain size description, descriptions of sorting are exhibit a sigma value spread of 2 to 3 ø or more, or roughly equivalent of a range from very poorly sorted to well sorted. Only one sample, Sample 2, exhibits a relatively tight range of sorting description, which probably reflects the relatively narrow range of grain size for this sample as shown on Figure A-2. Again, as observed in Table 1, no correlation was observed between years of experience, and trends observed in the data. In general, however, some correlation is observed between sorting and the spread in grain size descriptions.

Figure 8 shows the results from the descriptions for roundness. Note that in most cases (except Sample 4) the range of roundness is approximately 4 or 5 rho scale units. This corresponds with a range of very angular to subround. This suggests that field descriptions of roundness are subject to variations due to the characteristics that stick out to each geologist's eye; hence, roundness, especially on fine grained materials, should not be considered a diagnostic tool for a sample if based on a field description.

SUMMARY AND CONCLUSIONS

An experiment was conducted in order to test several hypotheses. These hypotheses include:

- Do significant differences exist between the geologist's qualitative descriptions and the quantitative results from mechanical analysis, for both for mean grain size and sorting?

- Do significant differences exist between the descriptions of roundness for a particular sample?

- Finally, is deviation from the quantitative grain size analysis a function of years of experience?

Significant differences do appear to exist between geologist descriptions and quantitative sieve analysis in some cases but not all. Descriptions for mean grain size often differed, but were inconsistently biased either high or low, even though most field geologists are used to providing descriptions using the Unified Soil Classification System versus using the Wentworth System that the sieve results were based upon. In most cases sorting descriptions were biased towards a better or tighter sorting description by a factor of at least 1.0 sigma. Roundness descriptions varied considerably from geologist to geologist. With all of these trends, significant variation exists between the geologists descriptions, indicating that, whenever possible, field visual observations should be supplemented with grain size analysis. Finally, no significant trends could be deduced from the data such as correlation with years of experience or classification system use. Perhaps the variation within the descriptions is a multivariate function depending on the moisture content, familiarity with grain sizes (i.e., recent practice), and sorting in the sample.

REFERENCES

Boggs, S., Jr., 1995, Principles of Sedimentology and Stratigraphy, Second Edition: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 774 p.

Folk, R.L., 1974, Petrology of Sedimentary Rocks: Hemphill, Austin, Texas, 182 p.

Kennedy, J.B., and Neville, A.M., 1976, Basic Statistical Methods for Engineers and Scientists, Second Edition: Harper & Row, Publishers, New York, 490 p.

Royse, 1970, Introduction to Sedimentology Analysis: Arizona State University.

Appendix A
Raw Data from Sieve and Pipette Analysis

Table 1. Sample Desriptions and Calculations from Geologists.

Geologist	Yrs Experience	Sample 1						Sample 2					
		Grain Size Description	Avg Phi (ϕ)	Sorting Desciption	Avg Sigma (in ϕ)	Roundness Desciption	Avg Rho	Grain Size Description	Avg Phi (ϕ)	Sorting Desciption	Avg Sigma (in ϕ)	Roundness Desciption	Avg Rho
Geologist 1	3	Fine Sand	2.5	Well	0.42	Subangular	2.5	Fine Sand	2.5	Well	0.42	Subround	3.5
Geologist 2	7	Fine Sand	2.5	Well	0.42	Subround	3.5	Fine Sand	2.5	Well	0.42	Subround	3.5
Geologist 3	18	Fine Sand	2.5	Poor	1.5	None		Fine Sand	2.5	Well	0.42	Subround	3.5
Geologist 4	15	V. Fine Sand	3.5	Well	0.42	Round	4.5	V.fine Sand	3.5	Well	0.42	Rounded	4.5
Geologist 5	11	V. Fine Sand	3.5	Moderate	0.85	Subangular	2.5	Med. Sand	1.5	Moderate	0.85	Subround	3.5
Geologist 6	5	Fine Sand	2.5	Well	0.42	Subround	3.5	Med. Sand	1.5	Well	0.42	Rounded	4.5
Geologist 7	7	V. Fine Sand	3.5	Well	0.42	Round	4.5	Med. Sand	1.5	Well	0.42	Rounded	4.5
Geologist 8	8	V. Fine Sand	3.5	Well	0.42	Subangular	2.5	Fine Sand	2.5	Well	0.42	Subround	3.5
Geologist 9	4	Fine Sand	2.5	Well	0.42	Subround	3.5	Fine Sand	2.5	Well	0.42	Subangular	2.5
Geologist 10	2	Silt	5.0	Well	0.42	Angular	1.5	Fine Sand	2.5	Well	0.42	Subangular	2.5
Statistical Calculations													
	Mean		3.2		0.57		3.17		2.30		0.46		3.60
	Std Dev		0.82		0.35		1.00		0.63		0.14		0.74
	2*Std Dev		1.64		0.71		2.00		1.26		0.27		1.48
	3*Std Dev		2.45		1.06		3.00		1.90		0.41		2.21
	4*Std Dev		3.27		1.41		4.00		2.53		0.54		2.95
Probability Distribution		$x = \mu \pm \sigma$	P(x)[a]	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)
		-0.1	0.0002	-0.8	0.0004	-0.8	0.00013	-0.2	0.0002	-0.1	0.001	0.6	0.0002
		0.7	0.0054	-0.5	0.0125	0.2	0.00443	0.4	0.0070	0.1	0.033	1.4	0.0060
		1.5	0.0660	-0.1	0.1528	1.2	0.05399	1.0	0.0854	0.2	0.397	2.1	0.0732
		2.3	0.2957	0.2	0.6849	2.2	0.24197	1.7	0.3826	0.3	1.779	2.9	0.3279
		3.2	0.4876	0.6	1.1292	3.2	0.39894	2.3	0.6308	0.5	2.934	3.6	0.5407
		4.0	0.2957	0.9	0.6849	4.2	0.24197	2.9	0.3826	0.6	1.779	4.3	0.3279
		4.8	0.0660	1.3	0.1528	5.2	0.05399	3.6	0.0854	0.7	0.397	5.1	0.0732
		5.6	0.0054	1.6	0.0125	6.2	0.00443	4.2	0.0070	0.9	0.033	5.8	0.0060
		6.4	0.0002	2.0	0.0004	7.2	0.00013	4.8	0.0002	1.0	0.001	6.6	0.0002

(a) - Probability distribution calculated using formula 9-16 in Kennedy and Neville (1976)

Table 1. Sample Desriptions and Calculations from Geologists.

Geologist	Yrs Experience	Sample 3						Sample 4					
		Grain Size Description	Avg Phi (ϕ)	Sorting Desciption	Avg Sigma (in ϕ)	Roundness Desciption	Avg Rho	Grain Size Description	Avg Phi (ϕ)	Sorting Desciption	Avg Signa (in ϕ)	Roundness Desciption	Avg Rho
Geologist 1	3	Silt	5	None		None		Fine Sand	2.5	Poorly	1.5	Subround	3.5
Geologist 2	7	Clay	8	Well	0.42	subangular (sand frac)	2.5	Fine Sand	2.5	well	0.42	Angular	1.5
Geologist 3	18	Clay	8	Poor	1.5	Subround (sand Frac)	3.5	Fine Sand	2.5	Moderate	0.85	Subangular	2.5
Geologist 4	15	Medium Silt	6	Moderate	0.85	Round	4.5	Fine Sand	2.5	Moderate	0.85	Round	4.5
Geologist 5	11	Silt	5	Poor	1.5	Subround (sand Frac)	3.5	Medium Sand	1.5	Moderate	0.85	Round	4.5
Geologist 6	5	Fine Sand	2.5	Poor	1.5	Subangular (sand frac)	2.5	Coarse Sand	0.5	Poorly	1.5	Subround	3.5
Geologist 7	7	Silt	5	Well	0.42	Round	4.5	Medium Sand	1.5	Moderate	0.85	Round	4.5
Geologist 8	8	V.fine Sand	3.5	Well	0.42	subangular (sand frac)	2.5	Fine Sand	2.5	well	0.42	Subangular	2.5
Geologist 9	4	Fine Sand	2.5	Well	0.42	Subround (sand Frac)	3.5	Fine Sand	2.5	well	0.42	Subround	3.5
Geologist 10	2	Fine Gravel		Poor	1.5	Subround (sand Frac)	3.5	Fine Sand	2.5	Poorly	1.5	Subround	3.5
Statistical Calculations													
	Mean		5.06		0.95		3.39		2.10		0.92		3.40
	Std Dev		2.05		0.54		0.78		0.70		0.44		0.99
	2*Std Dev		4.11		1.08		1.56		1.40		0.89		1.99
	3*Std Dev		6.16		1.62		2.35		2.10		1.33		2.98
	4*Std Dev		8.21		2.16		3.13		2.80		1.78		3.98
Probability Distribution		$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)
		-3.2	0.000065	-1.2	0.000	0.3	0.0002	-0.7	0.0002	-0.9	0.0003	-0.6	0.0001
		-1.1	0.0022	-0.7	0.008	1.0	0.0057	0.0	0.0063	-0.4	0.0100	0.4	0.0045
		0.9	0.0263	-0.1	0.100	1.8	0.0691	0.7	0.0772	0.0	0.1215	1.4	0.0543
		3.0	0.1179	0.4	0.447	2.6	0.3095	1.4	0.3461	0.5	0.5443	2.4	0.2433
		5.1	0.19431	0.9	0.737	3.4	0.5103	2.1	0.5706	0.9	0.8974	3.4	0.4012
		7.1	0.1179	1.5	0.447	4.2	0.3095	2.8	0.3461	1.4	0.5443	4.4	0.2433
		9.2	0.0263	2.0	0.100	5.0	0.0691	3.5	0.0772	1.8	0.1215	5.4	0.0543
		11.2	0.0022	2.6	0.008	5.7	0.0057	4.2	0.0063	2.2	0.0100	6.4	0.0045
		13.3	0.000065	3.1	0.000	6.5	0.0002	4.9	0.0002	2.7	0.0003	7.4	0.0001

Table 1. Sample Desriptions and Calculations from Geologists.

Geologist	Yrs Experience	Sample 5						Sample 6					
		Grain Size Description	Avg Phi (ϕ)	Sorting Desciption	Avg Sigma (in ϕ)	Roundness Desciption	Avg Rho	Grain Size Description	Avg Phi (ϕ)	Sorting Desciption	Avg Sigma (in ϕ)	Roundness Desciption	Avg Rho
Geologist 1	3	Coarse Sand	0.5	Poor	1.5	Subround	3.5	Medium Sand	1.5	Poor	1.5	Angular	1.5
Geologist 2	7	Coarse Gravel	-6	well (matirx)	0.42	subround	3.5	Fine Sand	2.5	Well	0.42	Angular	1.5
Geologist 3	18	Fine Sand	2.5	Poor	1.5	Subround	3.5	Medium Sand	1.5	Poor	1.5	Subangular	2.5
Geologist 4	15	Medium Sand	1.5	Poor	1.5	Subround	3.5	Fine Sand	2.5	Moderate	0.85	Subround	3.5
Geologist 5	11	Coarse Sand	0.5	Extremely Poor	4	Round	4.5	Coarse Sand	0.5	Poor	1.5	Subround	3.5
Geologist 6	5	Medium Sand	1.5	Poor	1.5	subangular	2.5	Medium Sand	1.5	Poor	1.5	Subround	3.5
Geologist 7	7	Coarse Sand	0.5	Poor	1.5	Subround	3.5	Coarse Sand	0.5	Moderate	0.85	Angular	1.5
Geologist 8	8	Fine Sand	2.5	Extremely Poor	4	Subangular	2.5	Coarse Sand	0.5	Poor	1.5	Subround	3.5
Geologist 9	4	Fine Sand	2.5	Moderate	0.85	Subrouund	3.5	Fine Sand	2.5	Well	0.42	Subangular	2.5
Geologist 10	2	Coarse Sand	0.5	Poor	1.5	Round	4.5	Fine Gravel		Well	0.42	Angular	1.5
Statistical Calculations													
	Mean		0.65		1.83		3.50		1.50		1.05		2.50
	Std Dev		2.49		1.20		0.67		0.87		0.50		0.94
	2*Std Dev		4.99		2.41		1.33		1.73		1.01		1.89
	3*Std Dev		7.48		3.61		2.00		2.60		1.51		2.83
	4*Std Dev		9.98		4.81		2.67		3.46		2.01		3.77
Probability Distribution		$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)	$x = \mu \pm \sigma$	P(x)
		-9.3	0.0001	-3.0	0.0001	0.8	0.00020	-2.0	0.0002	-1.0	0.00027	-1.3	0.0001
		-6.8	0.0018	-1.8	0.0037	1.5	0.00665	-1.1	0.0051	-0.5	0.00880	-0.3	0.0047
		-4.3	0.0216	-0.6	0.0449	2.2	0.08099	-0.2	0.0623	0.0	0.10720	0.6	0.0573
		-1.8	0.0970	0.6	0.2012	2.8	0.36296	0.6	0.2794	0.5	0.48043	1.6	0.2566
		0.7	0.1599	1.8	0.3317	3.5	0.59841	1.5	0.4607	1.0	0.79209	2.5	0.4231
		3.1	0.0970	3.0	0.2012	4.2	0.36296	2.4	0.2794	1.5	0.48043	3.4	0.2566
		5.6	0.0216	4.2	0.0449	4.8	0.08099	3.2	0.0623	2.1	0.10720	4.4	0.0573
		8.1	0.0018	5.4	0.0037	5.5	0.00665	4.1	0.0051	2.6	0.00880	5.3	0.0047
		10.6	0.0001	6.6	0.0001	6.2	0.00020	5.0	0.0002	3.1	0.00027	6.3	0.0001

Table 2. Summary Statistics from Sieve Analysis.

Phi	Sample 1			Sample 2			Sample 3			Sample 4			Sample 6		
	Data	Mean (Phi)	Standard Dev. (Phi)	Data	Mean (Phi)	Standard Dev. (Phi)	Data	Mean (Phi)	Standard Dev. (Phi)	Data	Mean (Phi)	Standard Dev. (Phi)	Data	Mean (Phi)	Standard Dev. (Phi)
σ_5	1.3	3.8	1.7	-0.35	2.4	1.4	-0.7	2.3	2.0	1.63	3.1	1.1	-1.38	1.6	1.2
σ_{16}	2.6			1.3			0.13			2.38			0.55		
σ_{50}	3.47			2.56			2.38			3.0			1.63		
σ_{84}	5.3			3.38			4.33			4.06			2.5		
σ_{95}	8.35			5.75			5.88			6.26			3		

Table A-1. Raw Data from Sieve and Pipette Analysis.

Sieve No	Phi (ϕ)	a				Sample 2				Sample 3			
		Mass Retained (gm)	Cumulative Mass Retained (gm)	Percent Retained	Cumulative Percent Retained	Mass Retained (gm)	Cumulative Mass Retained (gm)	Percent Retained	Cumulative Percent Retained	Mass Retained (gm)	Cumulative Mass Retained (gm)	Percent Retained	Cumulative Percent Retained
N/A	-4 to -6												
N/A	-2 to -4												
5	-2.0					0.7	0.7	0.8	0.8	0.0	0	0.0	0.0
8	-1.3					0.1	0.8	0.1	0.9	0.4	0.4	0.4	0.4
10	-1.0					1.6	2.4	1.8	2.6	1.6	2	1.8	2.2
14	-0.5					1.6	4	1.8	4.4	5.1	7.1	5.6	7.8
18	0.0	0.7	0.7	0.3	0.3	2.4	6.4	2.6	7.0	5.4	12.5	5.9	13.7
25	0.5	1.3	2.0	0.6	1.0	2.8	9.2	3.1	10.1	8.3	20.8	9.1	22.8
35	1.0	3.0	5.0	1.4	2.4	3.1	12.3	3.4	13.5	7.0	27.8	7.7	30.4
45	1.5	4.3	9.3	2.0	4.4	3.9	16.2	4.3	17.7	6.1	33.9	6.7	37.1
60	2.0	5.4	14.7	2.6	7.0	5.8	22	6.4	24.1	5.9	39.8	6.5	43.6
80	2.5	14.4	29.1	6.9	13.9	18.4	40.4	20.2	44.2	7.8	47.6	8.5	52.1
120	3.0	30.4	59.5	14.5	28.3	26.3	66.7	28.8	73.1	9.7	57.3	10.6	62.8
170	3.5	45.5	105.0	21.7	50.0	11.2	77.9	12.3	85.3	10.1	67.4	11.1	73.8
230	4.0	34.5	139.5	16.4	66.4	4.2	82.1	4.6	89.9	5.8	73.2	6.4	80.2
Pan	<4.0	70.5	210.0	33.6	100.0	9.2	91.3	10.08	100.0	18.1	91.3	19.82	100.0
		210.0				91.3				91.3			
Pipette Analysis	5	28.25	167.8	13.5	79.9	4.12	86.2	4.5	94.4	11.4	84.6	12.5	92.7
	6	20.95	188.7	10.0	89.9	0.93	87.2	1.0	95.5	2.6	87.2	2.9	95.6
	7	5.81	194.5	2.8	92.6	0.50	87.7	0.6	96.0	1.4	88.7	1.6	97.1
	8	4.52	199.0	2.2	94.8	0.47	88.1	0.5	96.5	1.5	90.1	1.6	98.7
	9	1.32	200.4	0.6	95.4	0.25	88.4	0.3	96.8	1.1	91.2	1.2	99.9
	10												

Table A-1. Raw Data from Sieve and Pipette Analysis.

Sieve No	Phi (ϕ)	Sample 4				Sample 5				Sample 6			
		Mass Retained (gm)	Cumulative Mass Retained (gm)	Percent Retained	Cumulative Percent Retained	Mass Retained (gm)	Cumulative Mass Retained (gm)	Percent Retained	Cumulative Percent Retained	Mass Retained (gm)	Cumulative Mass Retained (gm)	Percent Retained	Cumulative Percent Retained
N/A	-4 to -6												
N/A	-2 to -4					180	180	62.9	62.9				
5	-2.0	0	0	0.0	0.0	16.1	196.1	5.6	68.5	3.5	3.5	3.7	3.7
8	-1.3	0.1	0.1	0.1	0.1	0.9	197	0.3	68.8	1.3	4.8	1.4	5.0
10	-1.0	0.1	0.2	0.1	0.2	3.5	200.5	1.2	70.0	2.5	7.3	2.6	7.6
14	-0.5	0.2	0.4	0.2	0.4	1.8	202.3	0.6	70.7	1.6	8.9	1.7	9.3
18	0.0	0.8	1.2	0.9	1.3	2.4	204.7	0.8	71.5	2	10.9	2.1	11.4
25	0.5	0.9	2.1	1.0	2.3	4.4	209.1	1.5	73.0	3.4	14.3	3.6	15.0
35	1.0	1.1	3.2	1.2	3.5	16.1	225.2	5.6	78.7	10.5	24.8	11.0	25.9
45	1.5	1.2	4.4	1.3	4.8	20.6	245.8	7.2	85.9	19.2	44	20.1	46.0
60	2.0	2.4	6.8	2.6	7.4	13	258.8	4.5	90.4	18.1	62.1	18.9	65.0
80	2.5	11.9	18.7	13.0	20.4	10.3	269.1	3.6	94.0	19.6	81.7	20.5	85.5
120	3.0	27.3	46	29.8	50.2	6.2	275.3	2.2	96.2	9	90.7	9.4	94.9
170	3.5	21.1	67.1	23.0	73.3	3.9	279.2	1.4	97.5	1.3	92	1.4	96.2
230	4.0	9.2	76.3	10.0	83.3	1.8	281	0.6	98.1	0.5	92.5	0.5	96.8
Pan	<4.0	15.3	91.6	16.7	100.0	5.3	286.3	1.9	100.0	3.1	95.6	3.2	100.0
		91.6				286.3	572.6			95.6			
Pipette Analysis	5	9.2	85.5	10.0	93.3	Not Analyzed				Not Analyzed			
	6	1.7	87.2	1.9	95.2								
	7	0.2	87.4	0.2	95.4								
	8	0.2	87.6	0.3	95.7								
	9												
	10	0.3	87.9	0.3	96.0								

Table A-2. Raw Data from Pipette Analysis.

Sample ID	Time after Start	Volume removed	Mass Beaker Start	Mass Beaker End	Mass Sed + Dispersant	Mass Sediment Passing in 20 mL	Mass Retained	Conversion to Amt in 1 L	Fraction Used of Total	Conversion to Total Mass Retained for Sample
	(min)	(mL)	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)		(gm)
Sample 1	1 min	20	28.4504	28.689	0.2386	0.1358	0.0638	3.1900	0.1129	28.25
	2 min 59 sec	20	28.8572	29.032	0.1748	0.0720	0.0473	2.3660	0.1129	20.95
	11 min 59 sec	20	30.0522	30.1694	0.1172	0.0247	0.0118	0.6556	0.1129	5.81
	47 min 51 sec	20	29.9768	30.0822	0.1054	0.0129	0.0092	0.5100	0.1129	4.52
	3 hr 12 min	20	26.3492	26.4557	0.1065	0.0037	0.0030	0.1490	0.1129	1.32
	8 hr 58 min	20	29.6701	29.7839	0.1138	0.0007				
Sample 2	1 min	20	28.1668	28.3675	0.2007	0.0979	0.0667	3.3360	0.8092	4.12
	2 min 59 sec	20	29.1294	29.2531	0.1237	0.0312	0.0135	0.7511	0.8092	0.93
	11 min 59 sec	20	29.7728	29.8727	0.0999	0.0177	0.0065	0.4075	0.8092	0.50
	47 min 51 sec	20	29.4626	29.5714	0.1088	0.0111	0.0072	0.3805	0.8092	0.47
	3 hr 12 min	20	27.2962	27.3952	0.0990	0.0039	0.0038	0.2054	0.8092	0.25
	8 hr 58 min	20	29.7454	29.8406	0.0952	0.0001				
Sample 3	1 min	20	29.3564	29.6337	0.2773	0.1745	0.0970	4.8500	0.4250	11.41
	2 min 59 sec	20	29.9786	30.1589	0.1803	0.0775	0.0224	1.1200	0.4250	2.64
	11 min 59 sec	20	29.4954	29.6533	0.1579	0.0551	0.0122	0.6100	0.4250	1.44
	47 min 51 sec	20	29.8644	30.0101	0.1457	0.0429	0.0124	0.6200	0.4250	1.46
	3 hr 12 min	20	30.1358	30.2691	0.1333	0.0305	0.0091	0.4550	0.4250	1.07
	8 hr 58 min	20	29.916	30.0402	0.1242	0.0214				
Sample 4	1 min	20	29.6701	29.9259	0.2558	0.1119	0.0933	4.6659	0.5090	9.17
	2 min 59 sec	20	29.1294	29.2302	0.1008	0.0186	0.0140	0.8756	0.5090	1.72
	11 min 59 sec	20	29.7728	29.8673	0.0945	0.0045	0.0019	0.1103	0.5090	0.22
	47 min 51 sec	20	29.4626	29.5526	0.0900	0.0026	0.0021	0.1253	0.5090	0.25
	3 hr 12 min	20	27.2962	27.3815	0.0853	0.0005	0.0021	0.1291	0.5090	0.25
	25 hr 43 min	20	29.7454	29.826	0.0806	-0.0016	-----	-----	-----	-----
Sample 5	Not Analyzed	-----	-----	-----	-----	-----	-----	-----	-----	-----
Sample 6	Not Analyzed	-----	-----	-----	-----	-----	-----	-----	-----	-----

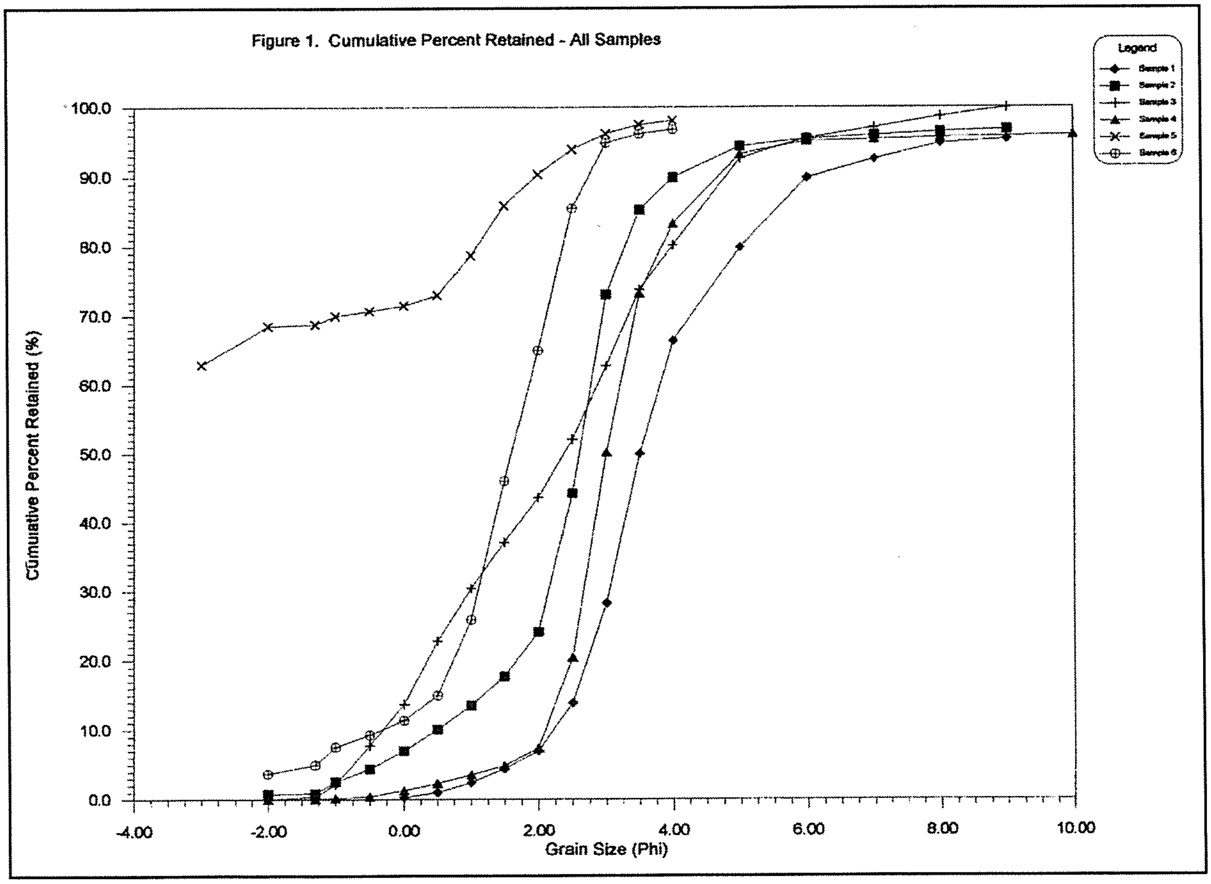


Figure 1. Cumulative Percent Retained - All Samples

Figure 2. Plot of Grain Size, Sorting, and Roundness Variations in Descriptions and Calculated Values for Grain Size and Sorting from Sieve Curves - Sample 1.

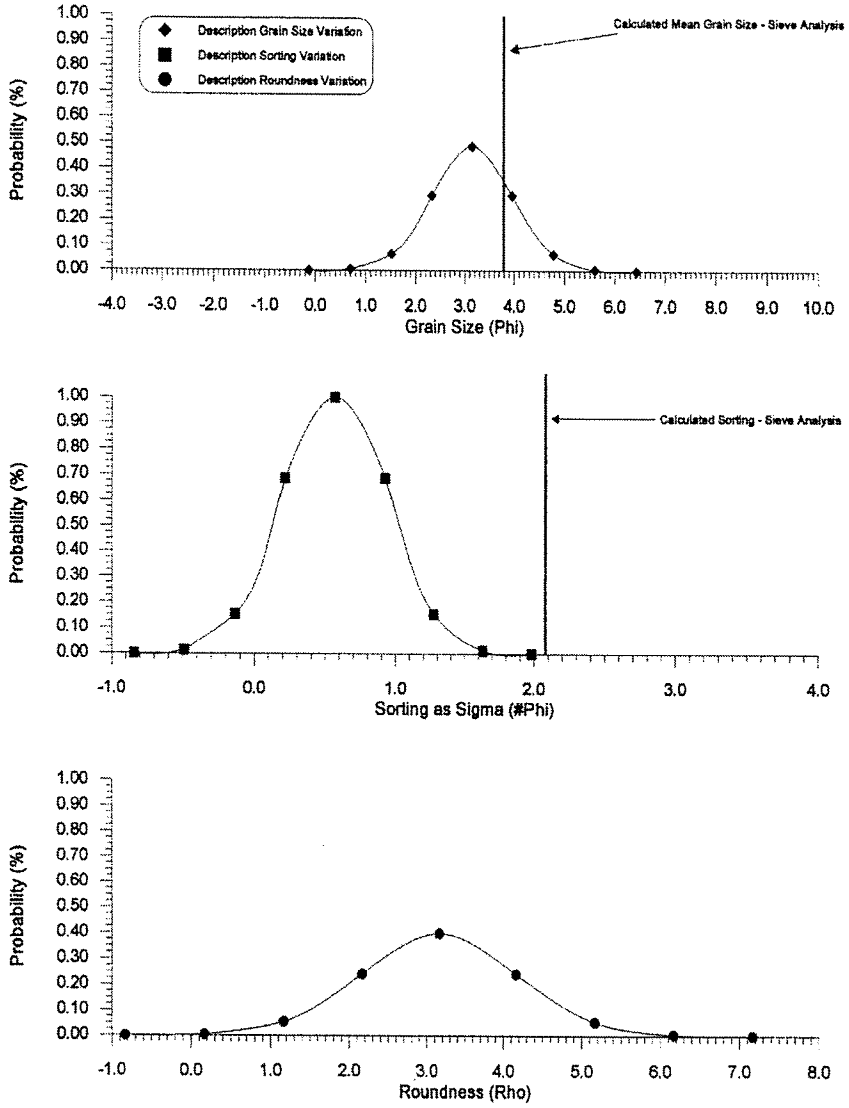


Figure 3. Plot of Grain Size, Sorting, and Roundness Variations in Descriptions and Calculated Values for Grain Size and Sorting from Sieve Curves - Sample 2.

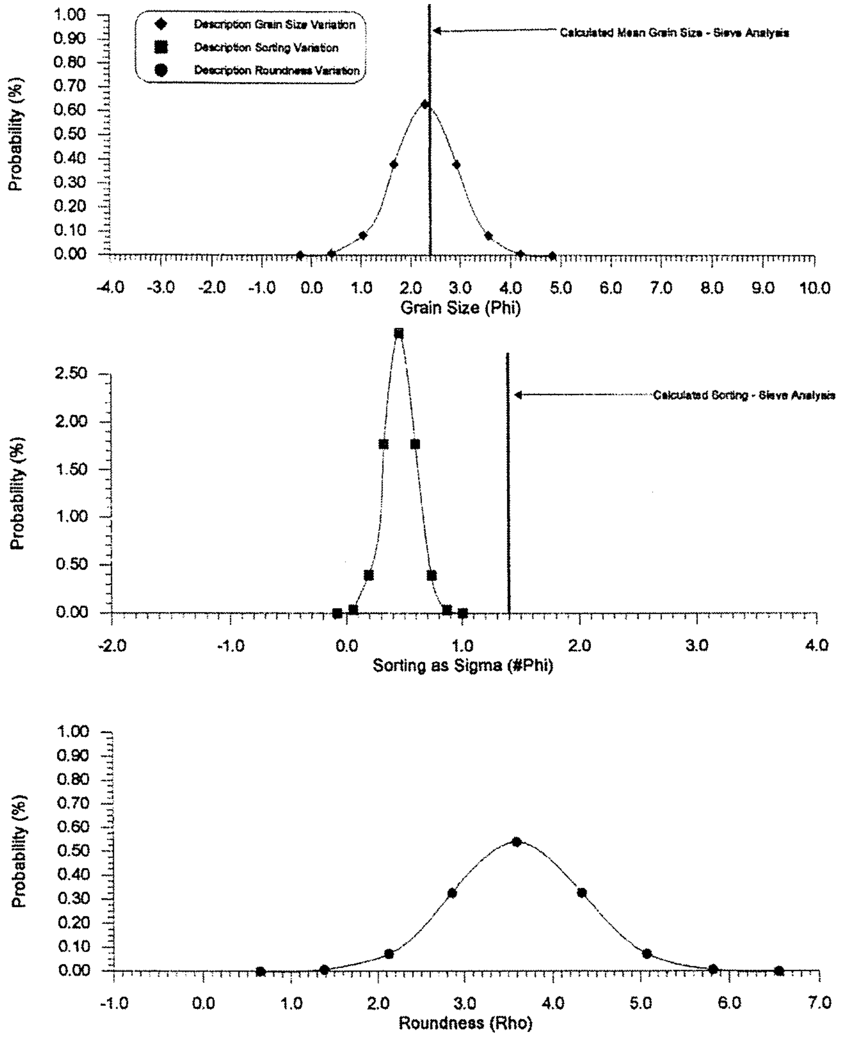


Figure 4. Plot of Grain Size, Sorting, and Roundness Variations in Descriptions and Calculated Values for Grain Size and Sorting from Sieve Curves - Sample 3.

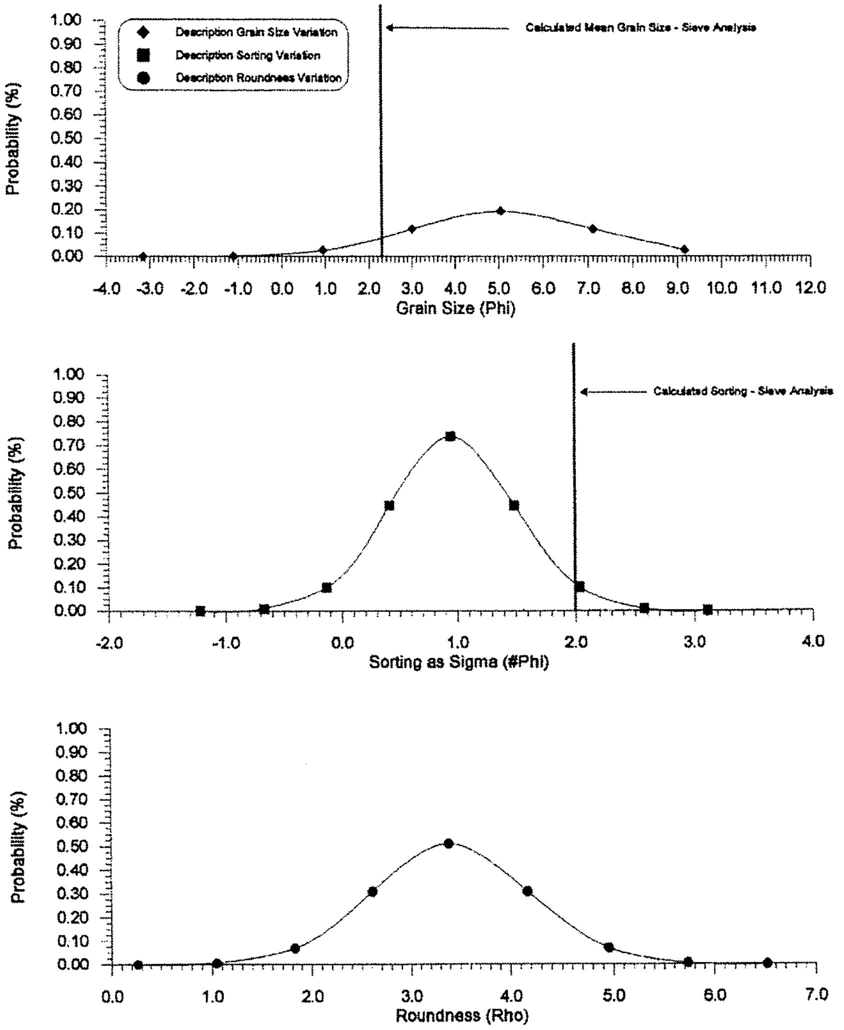


Figure 5. Plot of Grain Size, Sorting, and Roundness Variations in Descriptions and Calculated Values for Grain Size and Sorting from Sieve Curves - Sample 4.

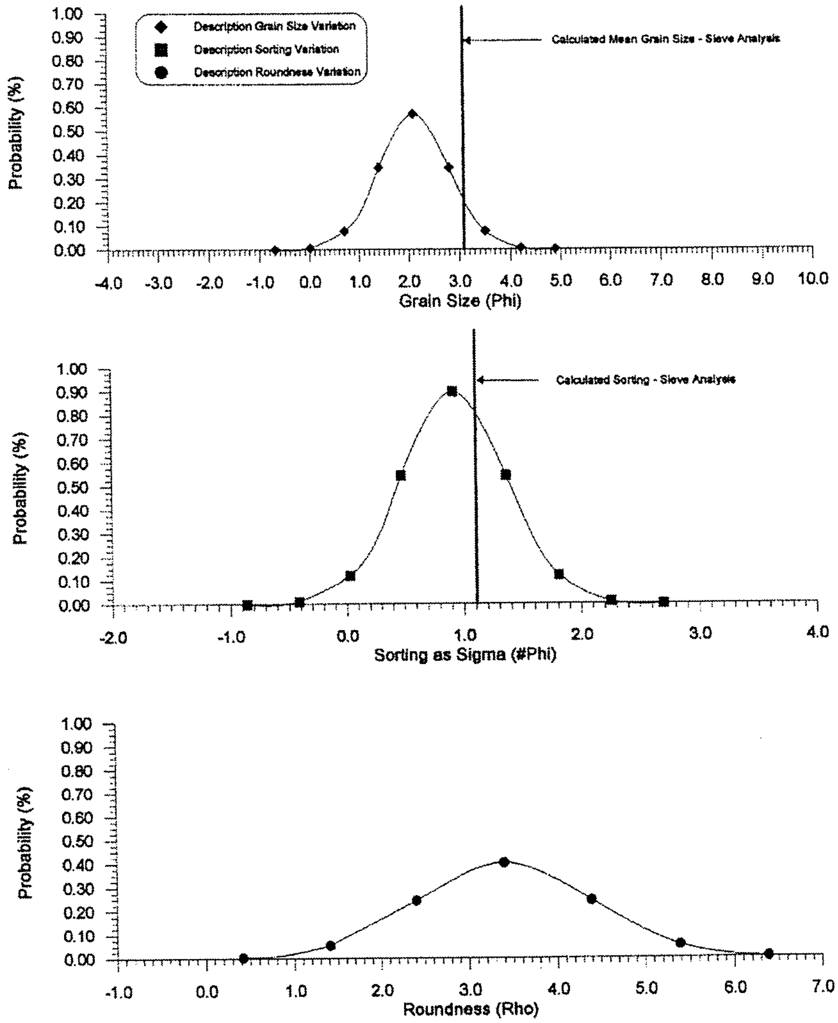
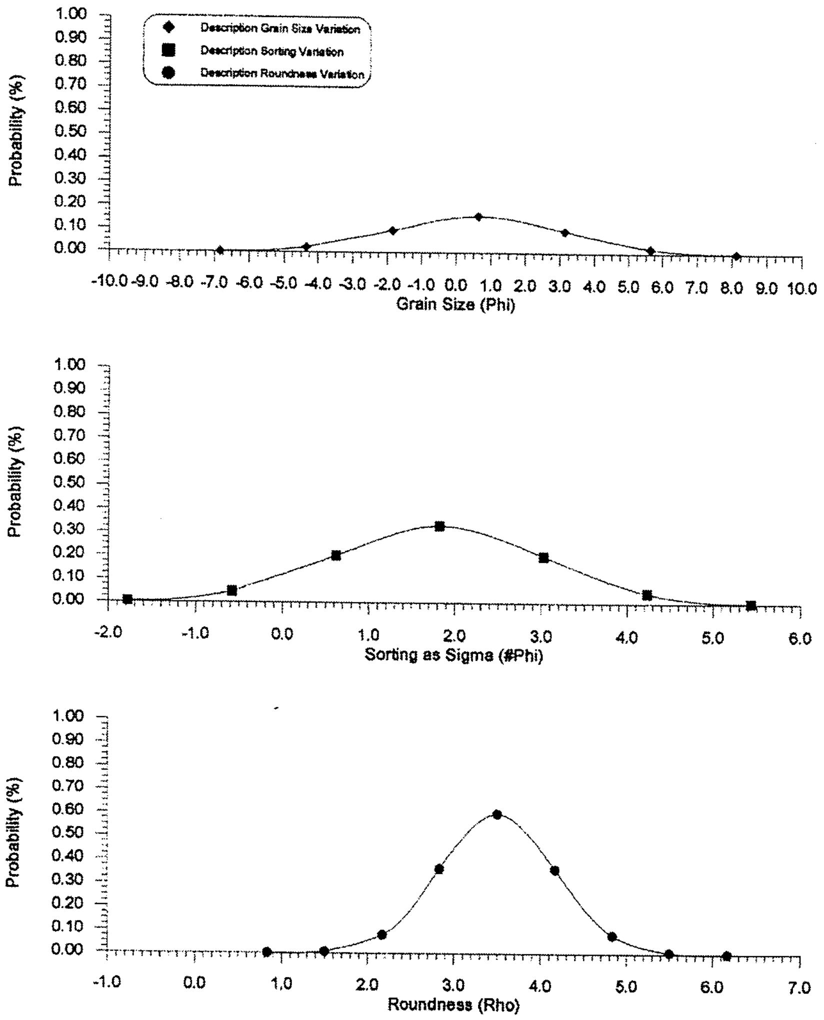


Figure 6. Plot of Grain Size, Sorting, and Roundness Variations in Descriptions and Calculated Values for Grain Size and Sorting from Sieve Curves - Sample 5.



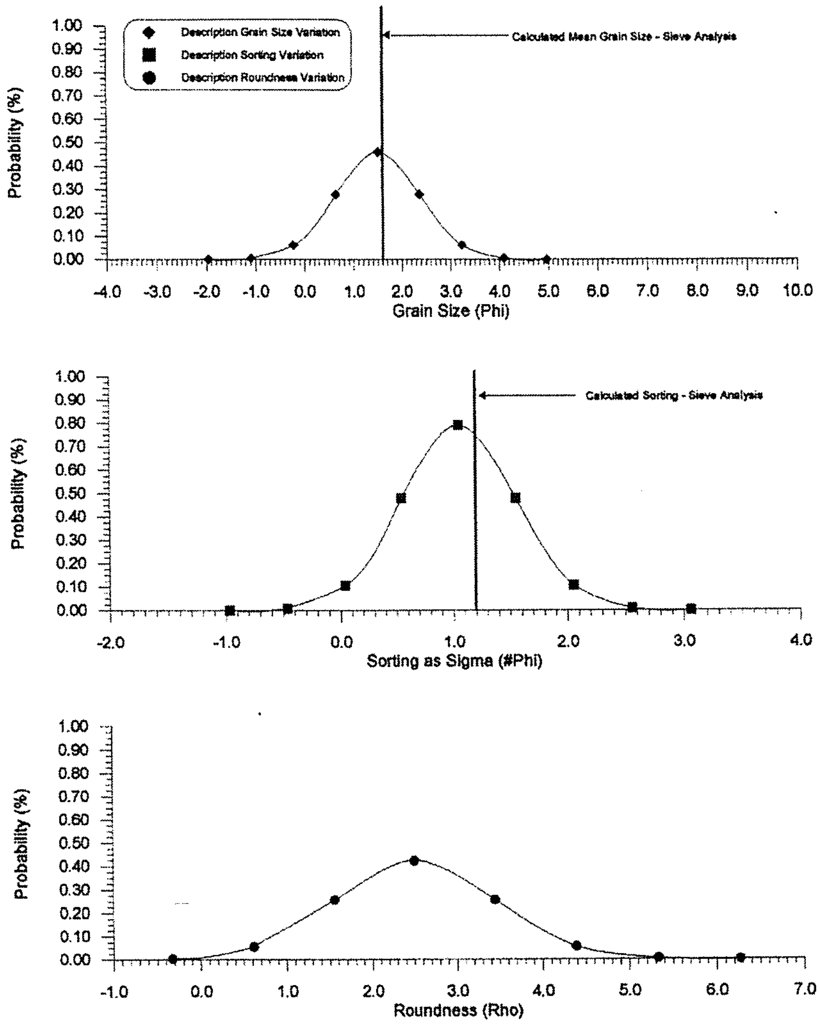


Figure 7. Plot of Grain Size, Sorting, and Roundness Variations in Descriptions and Calculated Values for Grain Size and Sorting from Sieve Curves - Sample 6.

Figure 8. All Roundness Variations from Descriptions.

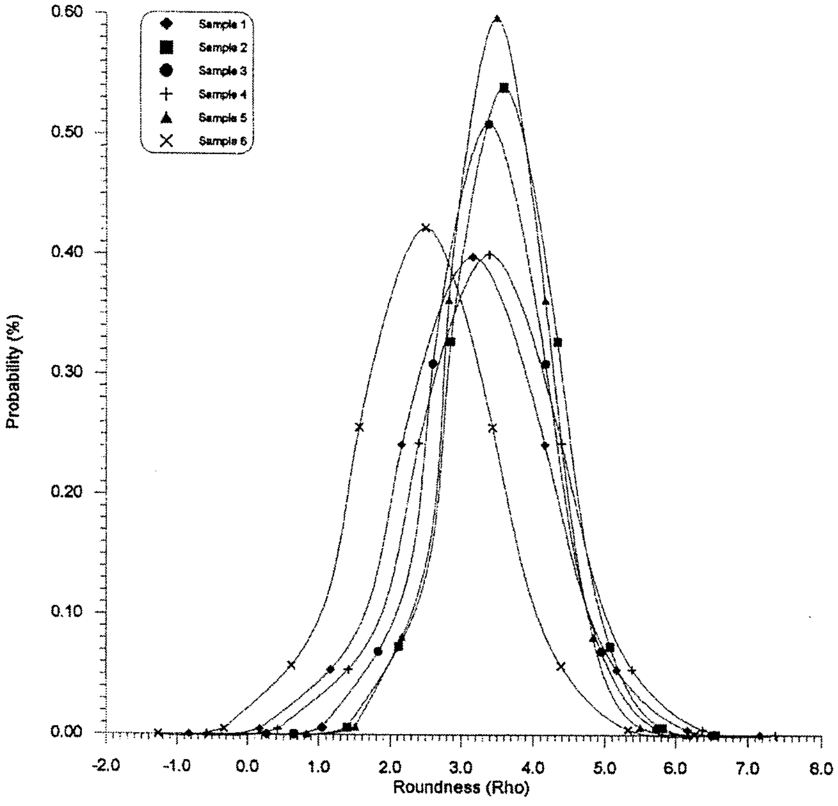


Figure A-1. Cumulative Percent Retained and Histogram of Percent Retained per Phi Size
Sample 1

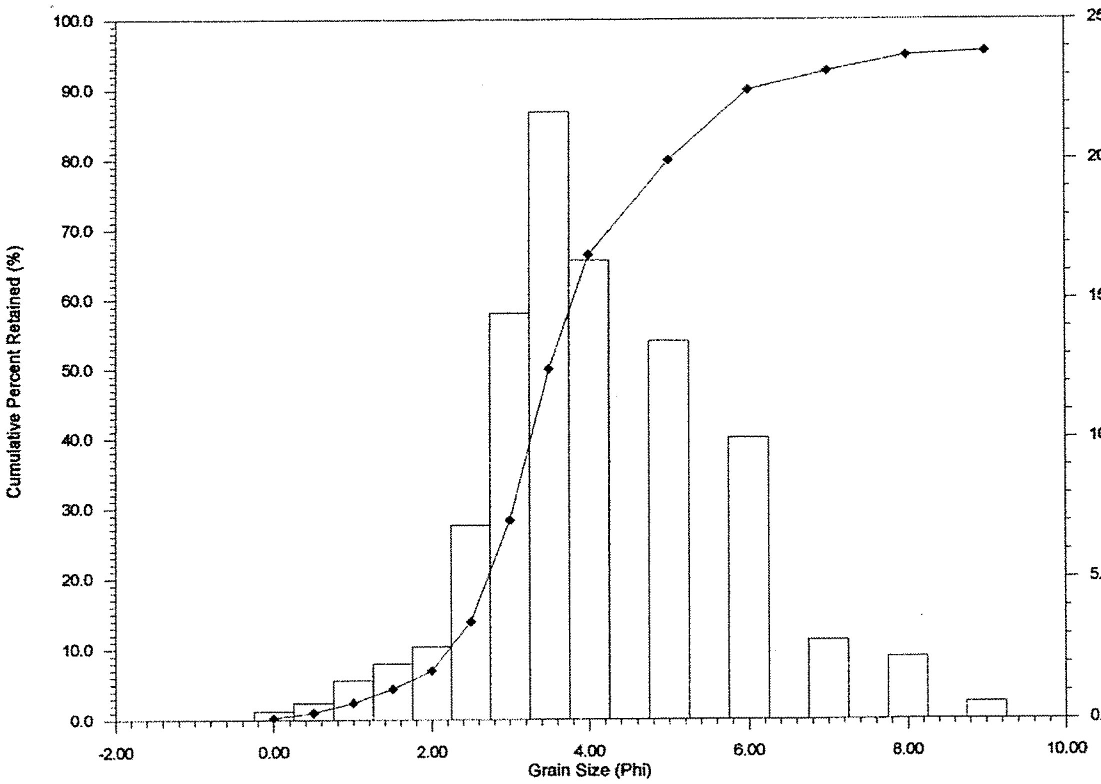


Figure A-2. Cumulative Percent Retained and Histogram of Percent Retained per Phi Size
Sample 2

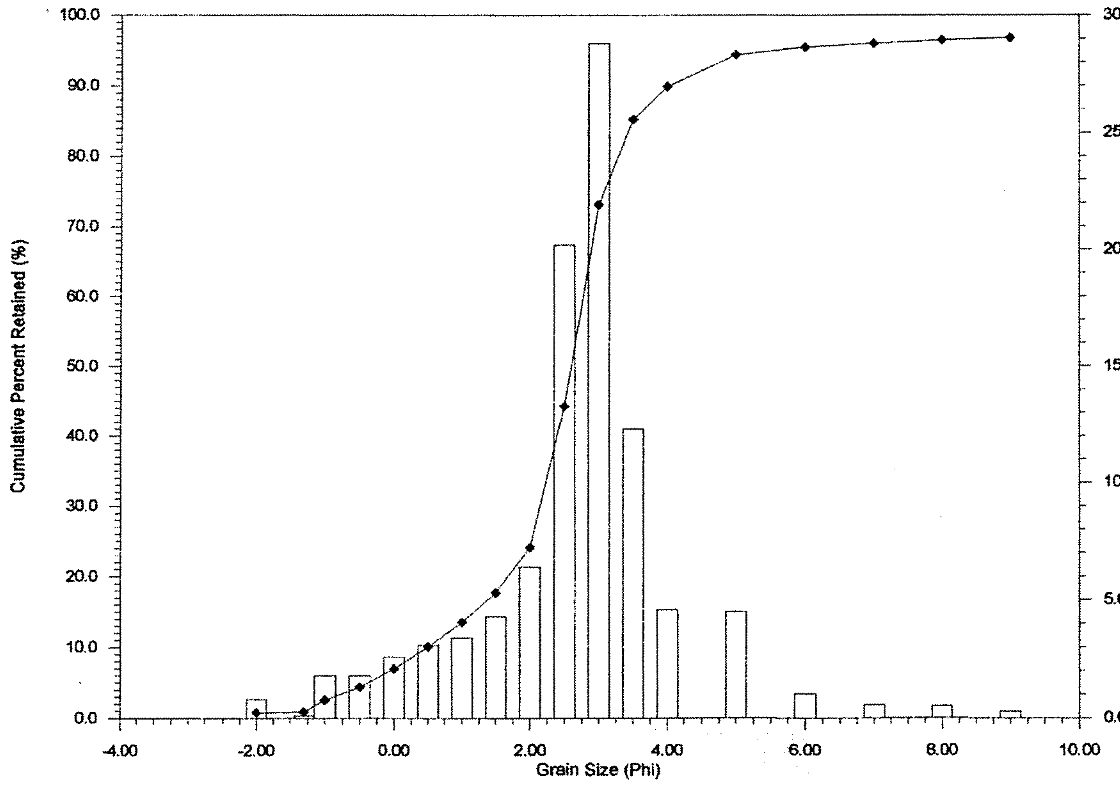


Figure A-3. Cumulative Percent Retained and Histogram of Percent Retained per Phi Size
Sample 3

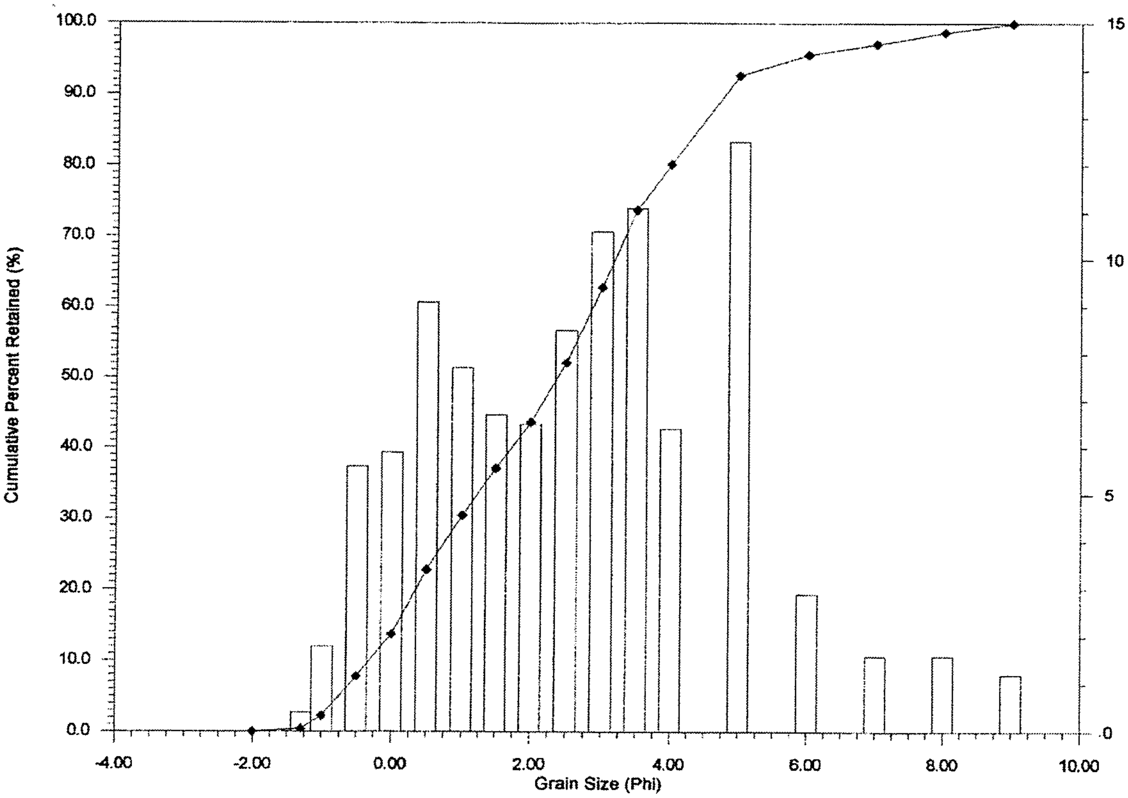


Figure A-4. Cumulative Percent Retained and Histogram of Percent Retained per Phi Size
Sample 4

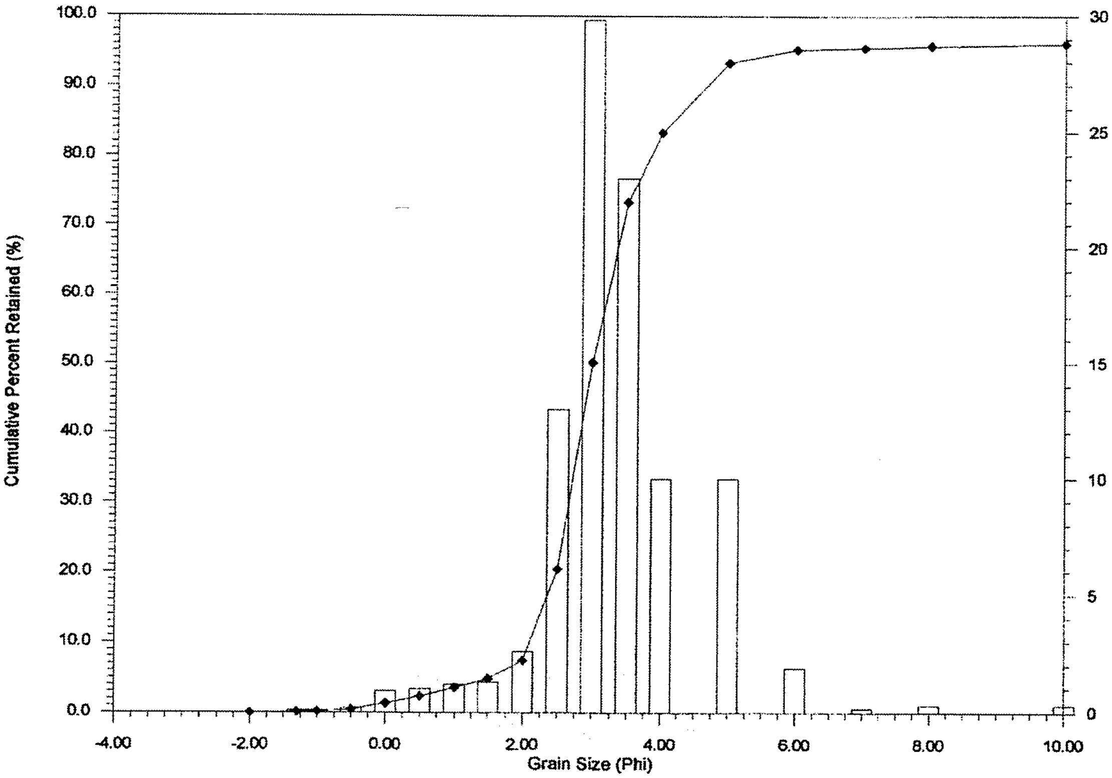


Figure A-5. Cumulative Percent Retained and Histogram of Percent Retained per Phi Size
Sample 5

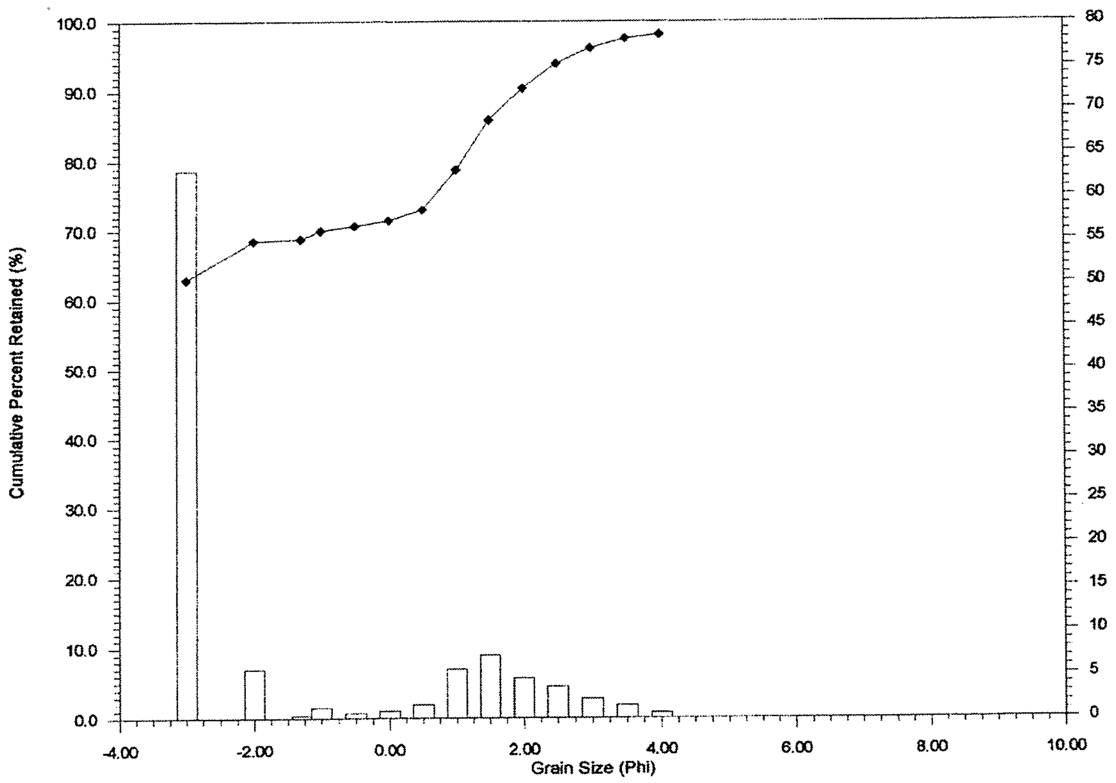
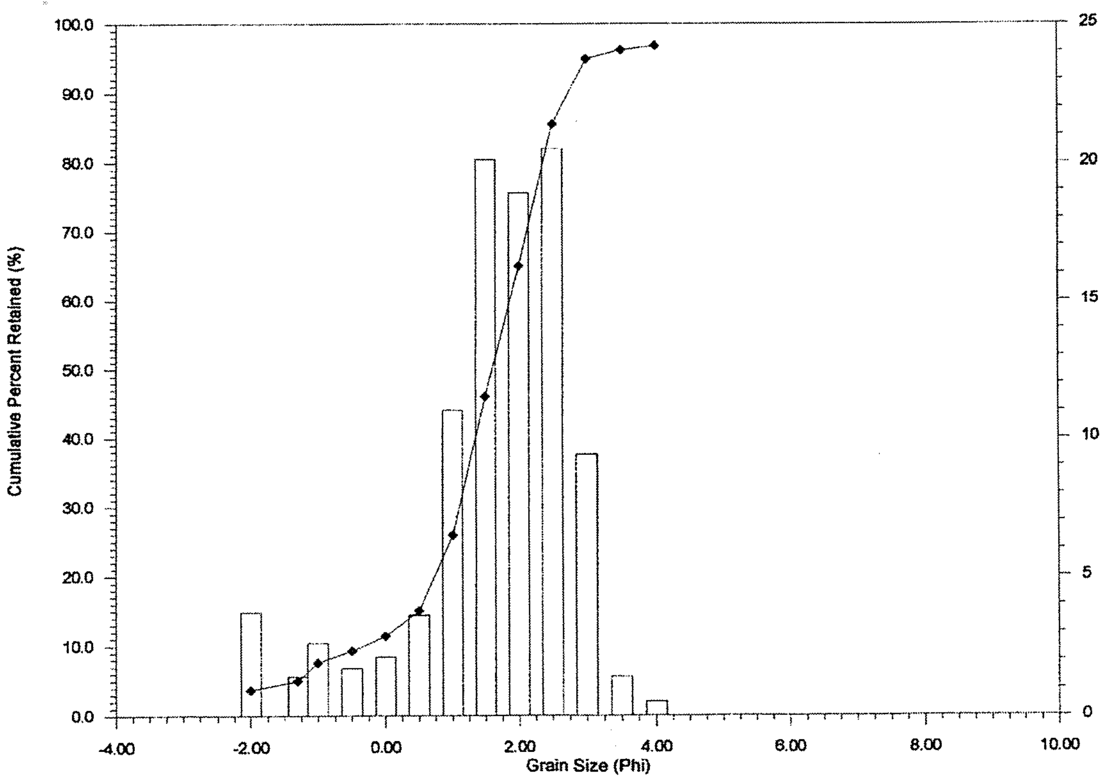


Figure A-6. Cumulative Percent Retained and Historgram of Percent Retained per Phi Size
Sample 6



Geotechnical Characterization for a 34-Mile-Long Tunnel through the Peninsular Ranges of San Diego County, California

M. E. Schmoll and D. J. Young, URS Corporation, Oakland, California
D. L. Schug, URS Corporation, San Diego, California

ABSTRACT

The San Diego County Water Authority is completing feasibility-level planning studies for a new water conveyance system to transport Colorado River water from the Imperial Valley to San Diego. The geologic and geotechnical conditions of two alternative pipeline routes have been evaluated by URS Corporation consisting of large diameter open-cut pipelines and tunnels. One route would lift water 3800 feet in elevation over the Peninsular Ranges while the other route includes a 34-mile-long tunnel through the mountains, resulting in a lift of only 1500 feet.

The 34-mile-long tunnel would pass through the hard crystalline granitic and metamorphic rocks of Mesozoic age collectively known as the Peninsular Ranges Batholith. Key geotechnical design issues for the tunnel, which has up to 4900 feet of cover, include the potential for high pressure, high volume groundwater inflows and the potential surface dewatering related impacts, high ambient temperatures at tunnel depth due to the natural geothermal gradient and high in situ stress requiring special ground support. Major challenges for the project included the prediction of the rock mass conditions at tunnel depth utilizing core borings that were typically less than 300 feet in depth and the development of a groundwater model to estimate the length of pre-excavation grouting to mitigate impacts to the groundwater resources and for constructability.

PROJECT DESCRIPTION

The San Diego County Water Authority (Authority) is studying the feasibility of constructing a water conveyance facility between Imperial Valley and San Vicente Reservoir in San Diego County. The water currently delivered by the Authority is imported to southern California through the State Water Project facilities and the Colorado River Aqueduct to Riverside County and is then transported via large diameter pipelines operated by the Metropolitan Water District of Southern California and the Authority to San Diego County. More than 90 percent of San Diego County's water needs are delivered through the aqueducts. The Authority is studying options to diversify its water supply to ensure reliability and to meet the region's future needs.

Two alternative alignments (designated the 5A and 5C alignments) are being considered as shown on Figure 1. These two alignments were screened out of several alternatives alignments identified in a previous conceptual study completed in 1996. The 1996 study did not include any subsurface investigations.

Both alignments begin at Drop No. 1 on the All-American Canal and end at the San Vicente Reservoir near the eastern margin of the San Diego metropolitan area. The first approximate 46 miles of both alignments would

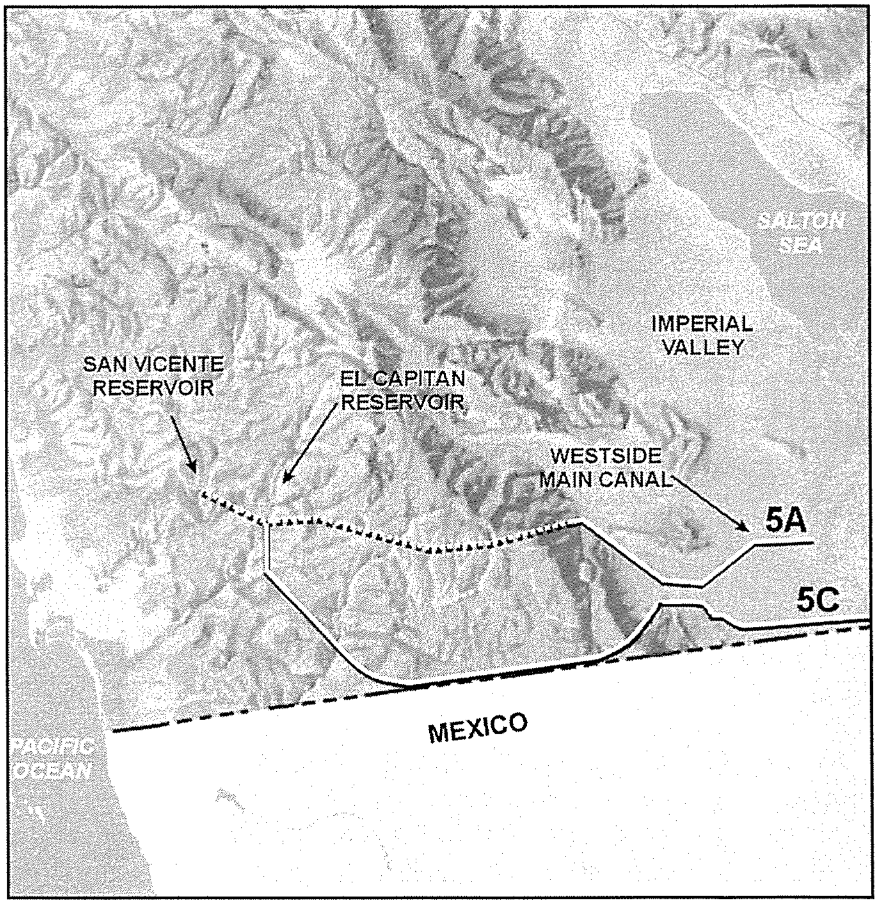


Figure 1. Project Location Map

consist of a new gravity flow concrete-lined canal parallel to the existing All-American Canal, which parallels the U.S./Mexico border. An additional 12 miles of concrete-lined canal parallel to the north-south trending Westside Main Canal would be required for the 5C alignment. From a new forebay pump station adjacent to either the Westside Main Canal for the 5A alignment or the All-American Canal for the 5C alignment, the conveyance system would enter a pressurized pipeline/tunnel to the terminus point at San Vicente Reservoir. The pressurized section of the 5A alignment would involve predominantly tunnel construction, whereas the pressurized section 5C alignment would use predominantly open-trenched construction. Both alignments share two common tunnel segments totaling about 7 miles in length between a portal just upstream of El Capitan Reservoir to San Vicente Reservoir (see Figure 1). The total lengths of the 5A and 5C alignments are approximately 129 and 139 miles, respectively including canals. Only the pressurized portions of the alignments were evaluated as part of the geotechnical evaluations by URS Corporation. The results of these evaluations were then used by the Authority's consultant, Black & Veatch to update the conceptual cost estimates developed during the 1996 study. Water transfer volumes of 300,000 acre feet/year (AF/yr), 400,000 AF/yr and 500,000 AF/yr were evaluated.

The key geologic and land use criteria used to lay out the alignments in the 1996 study include the following:

1. Avoid crossing active faults in tunnel.
2. Avoid areas of known geothermal activity in tunnel.
3. Avoid Indian Reservations and Federal Wilderness areas.
4. Minimize impacts to the groundwater resources.
5. Minimize surface disruptions in Forest Service and BLM lands.
6. Minimize impacts to environmentally sensitive areas.

The pressurized section of the 5A "tunnel" alignment starts at about elevation -30 feet at a new forebay at the Westside Main Canal and extends westward in a cut-and-cover pipeline approximately 30 miles to the eastern front of the Peninsular Ranges in the Anza-Borrego Desert. Two pumping stations would be required between the forebay and the tunnel portal to lift the water a total of 1500 feet. The pipeline would then enter a tunnel at about elevation 970 feet and extend for approximately 34 miles before portaling out into a short cut-and-cover segment across a canyon just upstream of El Capitan Reservoir. The pipeline then enters a tunnel again for about 3.5 miles to a 0.5 mile cut-and-cover segment across the San Diego River Valley where it would again enter a tunnel again for about 3.6 miles to the end point at San Vicente Reservoir at an elevation of about 700 feet.

Alignment Consideration

During the 1996 study the 34-mile 5A tunnel alignment included four deep construction shafts spaced at about 6 to 7 mile intervals. These shafts were included to provide multiple points of access to the deep tunnel to keep individual tunnel drives less than about 7 miles in length. However, the cost estimate for the 1996 study showed that these deep shafts (up to 3600 feet deep) were about one-third of the total tunnel construction cost and took up to 3 years of time to construct. Preliminary evaluations at the start of the current study showed that at least two of the construction shafts could be eliminated by doing longer tunnel drives. Only two shafts were considered for the current study; a 3080-foot-deep shaft and a 1600-foot-deep shaft at the approximate one-third points along the tunnel alignment. Alternatives to the shafts were also evaluated including the construction of decline tunnels from the ground surface to tunnel depth. However, the length of the declines were several miles long since the cover remains consistently high north and south of the alignment and the cost of these decline tunnels were considered to be more than the cost of the shafts.

Once the tunnel cost and schedule estimates for the project were underway, it became evident that a tunnel mined from the east portal would reach the 3080-foot-deep shaft before the shaft could be excavated to the tunnel depth. Similarly, a tunnel drive starting at the west portal would also nearly reach the 1600-foot-deep shaft before this shaft could reach tunnel depth. Another issue that became apparent as the cost estimates were developed was related to the cost of pumping tunnel groundwater inflows out of the deep shafts. The power requirements and size of the piping to lift the groundwater (estimated to be up to 18,000 gpm) out of the shafts were viewed as a major obstacle. Based on these issues, inquiries were made to TBM manufactures and reviews were made of similar tunnel case histories as to the maximum feasible length of a tunnel drive from a single portal access point. Elimination of the shafts would result in two long drives for the 34-mile tunnel; one heading east from the portal near El Capitan Reservoir and one heading west from the Anza-Borrego portal.

There were no apparent reasons why tunnel drives of this length could not be completed as long as the ventilation requirements could be maintained, the tunnel muck could be efficiently removed from the heading and groundwater inflows could be removed from the tunnel. Based on these considerations, it was decided to eliminate the two remaining construction shafts and plan the construction of the long 5A tunnel from the two portals. To accommodate the muck removal and ventilation requirements, the size of the tunnel excavation was increased to 15-foot diameter to allow for a conveyor belt muck removal system and to accommodate the large piping for removal of groundwater. Revisions to the tunnel grade were also made so that both tunnel segments are mined upgrade to facilitate removal of the groundwater from the tunnel heading. A permanent vent shaft would also be required at the middle high point of the tunnel to provide passive venting during filling and draining of the tunnel. This vent shaft could be constructed with raised-bore methods.

Regional Geology and Seismicity

The 5A alignment extends across two major physiographic and geologic provinces: 1) the Peninsular Ranges of southern and Baja California, and 2) the Salton Trough within the Imperial Valley. The Peninsular Ranges are comprised of igneous and metamorphic rock of Mesozoic age collectively known as the Peninsular Ranges Batholith (PRB). The Salton Trough is a deep sedimentary basin containing Tertiary and Quaternary age sedimentary deposits. The 34-mile-long 5A tunnel is entirely within the rocks of the PRB.

The rock units making up the PRB comprise a westward tilted block, which is bounded along its eastern edge by the active Elsinore fault. The east portal of the 5A tunnel is located west of the Elsinore fault. There are no major active faults cutting the PRB to the west of the Elsinore fault, therefore the PRB block has been tectonically stable as the terrain is not extensively faulted, especially compared to the Salton Trough (which contains the active San Jacinto and San Andreas Fault systems).

The igneous rocks within the PRB consist of several plutons, or large rock bodies with similar minerology and cooling history. Within the 5A alignment, the rocks comprising these plutons are largely of granitic composition with the predominant minerals consisting of quartz and feldspar, with lesser biotite, hornblende and pyroxene. From east to west, mapped granitic plutons along the 5A tunnel include the: La Posta Pluton, Cibbett Flat Pluton, Pine Valley Monzogranite, and the Alpine Tonalite as shown on Figure 2. Several gabbro plutons would also be encountered in the tunnel. The gabbro is devoid of quartz and consists chiefly of plagioclase feldspar, pyroxene and olivine. Gabbro plutons along the 5A tunnel include Guatay Peak, Poser Mountain, and Viejas Mountain.

Portions of the 5A tunnel will pass through metamorphic rocks of the Julian Schist. These rocks pre-date the PRB, and represent ancient sedimentary rocks disrupted and metamorphosed by emplacement of the plutonic rocks. The Julian Schist contains an assemblage of metamorphic rocks ranging from mostly quartzite and gneiss in the western PRB, with marble and schist making up a large percentage in the eastern PRB. The more extensive exposures of the Julian Schist are assumed to have near-vertical boundaries and extend to the tunnel depth based on the vertical contacts observed at the ground surface; smaller, less extensive surface outcrops of the Julian Schist may not extend to the depth of the tunnel.

The portion of the tunnel between the Cibbett Flat and Pine Valley Plutons would pass through a belt of granitic rocks with metamorphic texture described as the Cuyamaca-Laguna Mountain Shear Zone (CLMSZ) (Walawender, 2000). The rocks within the CLMSZ are interpreted to have experienced ductile deformation, rather than brittle crustal faulting. Therefore, the rock mass within the CLMSZ is not anticipated to be highly fractured or sheared as would be expected within a brittle fault zone.

The 5A tunnel will intersect several regional linear landforms recognizable on very high altitude photographs. These regional lineament features are thought to be expressions of rock foliation, fracture zones and inactive faults that likely extend to tunnel depth. The major regional lineaments crossing the tunnel are likely to represent highly fractured and sheared rock and potential sources of groundwater inflow to the tunnel.

GEOTECHNICAL INVESTIGATIONS

Geotechnical investigations completed to provided a preliminary characterization of the ground conditions along the 5A tunnel included the following:

1. Review of previous investigations and relevant tunnel construction case histories
2. Review of remote sensing data and aerial photographs
3. Geologic mapping
4. Rock core borings
5. Hydraulic conductivity (packer) testing
6. Down-hole geophysical surveys
7. Laboratory testing

A total of 12 HQ-wireline core borings were completed along the 5A tunnel alignment to investigate the rock mass conditions and to obtain samples for laboratory testing. The inclination of the borings ranged from 60 to 90 degrees (from horizontal). The borings were completed at portal locations and along the tunnel alignment in an effort to obtain representative rock samples of the major plutons. The depths of the borings were typically 200 to 300 feet, or at least 100 feet into the unweathered rock. However, one boring was drilled to(a depth of 1000 feet into the CLMSZ and one boring was drilled to a depth of 1750 feet in a relatively low cover area, reaching tunnel depth. All borings were completed as open-hole piezometers and were monitored over a period of about 6 months before being abandoned by backfilling them with cement grout.

Hydraulic conductivity (packer) testing was completed in all core borings at approximate 20-foot intervals for the entire length of the boring below the weathered rock. The packer testing was completed using either a single packer as the boring was advanced, or more typically using a double straddle packer at the completion of drilling. A pressure transducer was used monitor water pressure within the packer test zone to eliminate the need to calculate friction losses and to insure the packers were sealed. A total of 214 packer tests were completed in the 12 core borings. Hydraulic jacking tests were also performed in the low tunnel cover areas near the portals to evaluate in situ stress conditions and for making estimates of the required length of steel lining.

Down-hole geophysical surveys were conducted in all the core borings. The surveys included continuous optical televiewer logging to characterize the in situ frequency and orientation of rock discontinuities such as rock foliation, fractures and shear zones. Temperature logging was also completed in the two deep core borings to measure the local geothermal gradient.

Laboratory testing on the recovered rock core samples included point load testing at approximate 10-foot intervals, unconfined compression tests and microscopic petrographic (thin section) examinations. Representative samples from each of the major rock types were also sent to the Earth Mechanics Institute at the Colorado School of Mines for TBM performance testing, which included Brazillian Tensile strength, Punch Penetration Response, Cerchar Abrasivity Index, unconfined compression and petrographic analysis.

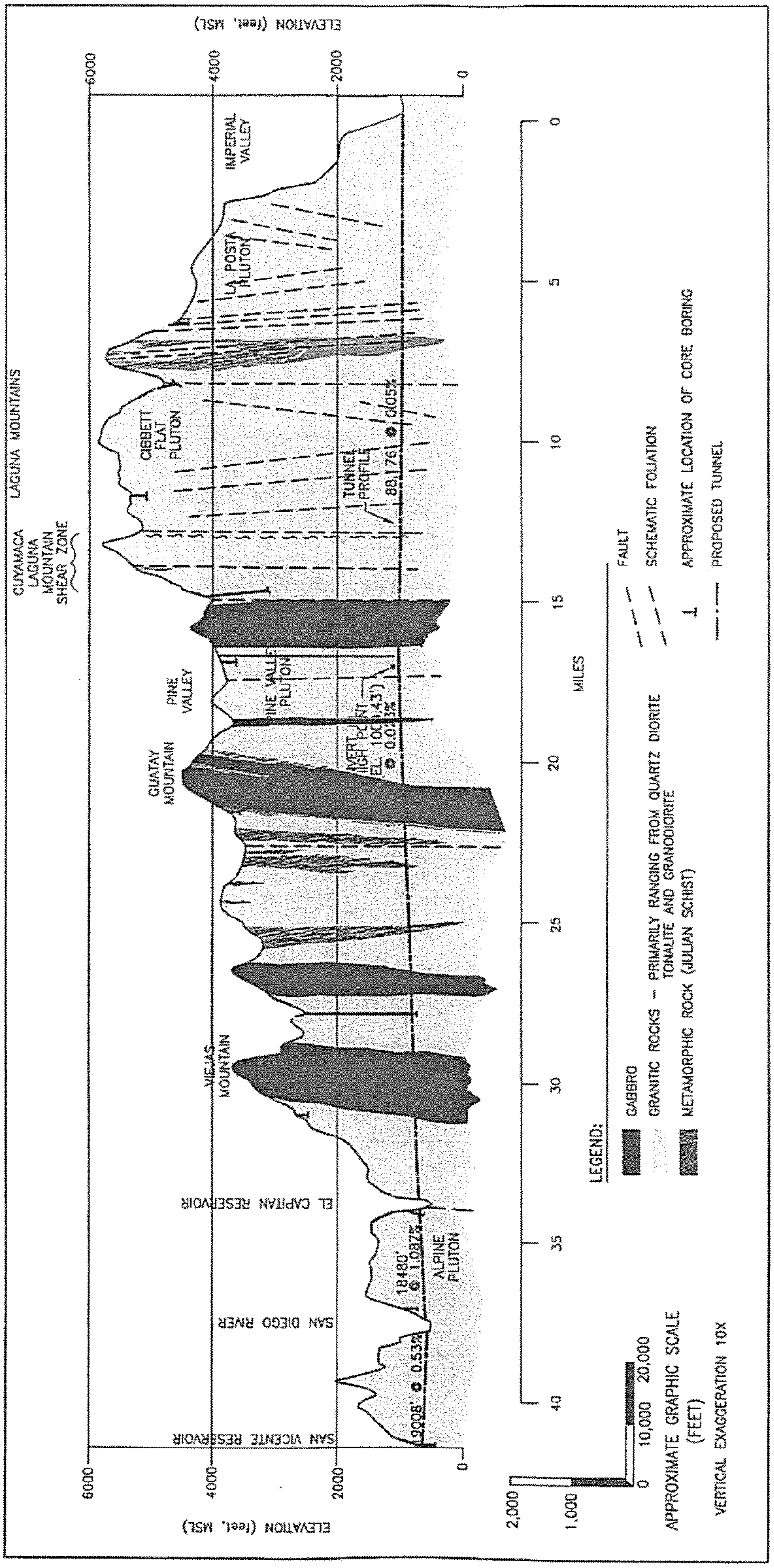


Figure 2. Geologic Profile along 5A Tunnel.

GROUND CHARACTERIZATION

Approach to Characterization

The goal of the ground characterization program was to subdivide the range of anticipated conditions along the project alignment into segments with uniform characteristics related to penetration rate, tunnel stability, and groundwater inflow. Criteria for subdividing the tunnel included the plutons identified by surface mapping or subdivision by rock type or minerology. Rock strength data showed less scatter when grouped by rock type than by pluton, so the alignment was divided into 20 segments (18 tunnel segments) based on rock type as shown on Table 1. The next step in the characterization process involved summarizing rock, discontinuities and groundwater properties and design values for evaluating tunneling requirements in each of the 18 tunnel segments. Because groundwater inflow, rock quality and rock stress conditions are related to cover, this data was summarized for each segment in Table 1.

Igneous rocks were named according to the International Union of Geological Sciences (IUGS) classification scheme. If significant metamorphic texture was present, a metamorphic rock name was used, following metamorphic rock name convention published by Compton (1985).

Rock and discontinuity properties were assigned to each segment including: rock type, lineaments crossed, rock strength (point load, UCS, Brazilian Tensile, Punch Penetration), Cerchar Abrasivity, percent hard minerals, fracture frequency, degree of foliation and the orientation of predominate joint sets relative to the tunnel drive.

Rock Mass Properties

Rock Types. Based on visual and laboratory analysis of core samples from the borings and results of the geologic mapping, six predominant igneous rock types and one metamorphic rock type were identified along the tunnel alignment. The rock types are:

1. Granodiorite
2. Mafic tonalite
3. Tonalite
4. Monzogranite
5. Gabbro
6. Diorite
7. Gneiss as the metamorphic rock type

All of the crystalline rocks are strong to very strong and contain relatively high percentages of quartz with the exception of the gabbro and diorite, which contained little or no quartz. Quartz content for the rocks ranged from about 15% for the mafic tonalite to 33% for the monzogranite.

Surface Weathering. One of the key challenges for the project included the prediction of the rock mass conditions at tunnel depth utilizing core borings that were typically less than 300 feet in depth. The depth of rock mass weathering ranged from a little as 15 feet to as much as 175 feet with an average depth of 40 to 60 feet.

Rock Strength. Below the weathered zone the rock generally appeared uniform in strength and degree of weathering except within shear zones. The unconfined compressive strength of the rocks ranged from a low of about 10,000 psi to over 44,000 psi. Figure 3 shows the range and average unconfined compressive strength of rocks tested.

In order to evaluate rock strength verses depth and whether potential stress relief during coring could have disturbed the samples, the stress-strain curves obtained during unconfined compressive strength testing were reviewed and the results of the point load tests were plotted for the 1000 and 1750-foot-deep borings. Figure 4 shows the point load index verses depth for the 1750 boring. Based on this plot and a review of the unconfined compression tests completed at various depths in this boring, there does not appear to be any noticeable stress relief of the core nor a change in rock strength with depth.

Rock Mass Discontinuities and Permeability. Although all of the borings were drilled at least 100 feet into the unweathered rock, the rock mass was often moderately fractured to the bottom of the shallow borings, even when located away from known lineaments and shear zones. The 1000-foot-deep boring was drilled into the Cuyamaca-Laguna Mountain Shear Zone and thus the degree of rock fracturing remained relatively constant for the entire length of this boring. However, the 1750-foot-deep boring was drilled away from known shear zones and is thought to be more representative of the rock mass conditions that will be encountered along the majority of the tunnel alignment. To evaluate the degree of fracturing verses depth, the fracture frequency (number of recorded naturally occurring fractures per foot of core) were plotted for the deep boring as shown on Figure 5. Even though unweathered rock was encountered at a depth of 45 feet in this boring, the rock remained relatively fractured to a depth of about 200 to 250 feet. Below this depth the rock was relatively unfractured except for within a minor shear encountered at 1450 feet.

Table 1. 5A Tunnel Corridor Summary

Segment	Length (miles)	No. of Lineaments	Rock Name	Approximate Tunnel Elevation (feet)	Ground Cover Elevation (feet)			Average Groundwater Elevation in Borehole (feet)	Average Tunnel Depth Below Groundwater (feet)
					Maximum	Minimum	Average		
1A	2.3	5 minor	Granodiorite	1000	2900	1000	2000	1980	980
1B	4.3	15 minor	Granodiorite	1000	4550	2900	4000	3980	2980
1C	1.0	5 minor	Granodiorite	1000	5700	4550	5100	5080	4080
2	0.8	2 major 1 minor	Gneiss	950	5700	4750	5300	5280	4330
3	6.1	4 major 14 minor	Mafic Tonalite	900	5800	4750	5400	5350	4450
4	0.9	3 minor	Tonalite	900	4900	4000	4500	4490	3590
5	0.2	1 minor 1 major	Mixed Monzogranite and Mafic Tonalite (1/2 of each)	900	4100	4100	4100	4090	3190
6	1.1	4 minor 1 major	Gabbro	900	4300	4000	4200	4170	3270
7	2.6	4 minor 1 major	Tonalite	900	4000	3700	3900	3880	2980
8	1.3	1 minor	Mixed Gabbro, Tonalite, and Gneiss (1/3 of each)	900	4500	3900	4200	4130	3230
9	1.1	none	Gabbro	880	4500	4000	4300	4230	3350
10	4.8	8 minor 2 major	Mixed Gneiss and Granodiorite (1/2 of each)	850	3900	3200	3500	3450	2600
11	0.9	none	Gabbro	850	3600	3200	3500	3460	2610
12	1.0	1 minor	Mixed Granodiorite, Tonalite, and Diorite (1/3 of each)	830	3100	2500	2800	2760	1930
13	2.0	4 minor	Gabbro	830	3600	2500	3200	3160	2330
14A	1.8	2 minor	Tonalite	800	3400	1900	2800	2760	1960
14B	1.8	1 major	Tonalite	800	1900	1100	1500	1460	660
15	0.1		OPEN CUT PIPELINE	800	1100	1100	1100	1060	260
16	3.5	10 minor	Tonalite	700	1500	1700	1300	1250	550
17	0.5		OPEN CUT PIPELINE	600	700	600	600	560	–40
18	0.6	1 minor	Tonalite	620	1400	600	1000	950	330
19	0.5	1 minor	Gneiss	650	1400	1200	1300	1250	600
20	2.5	10 minor	Tonalite	700	2000	1000	1500	1450	750

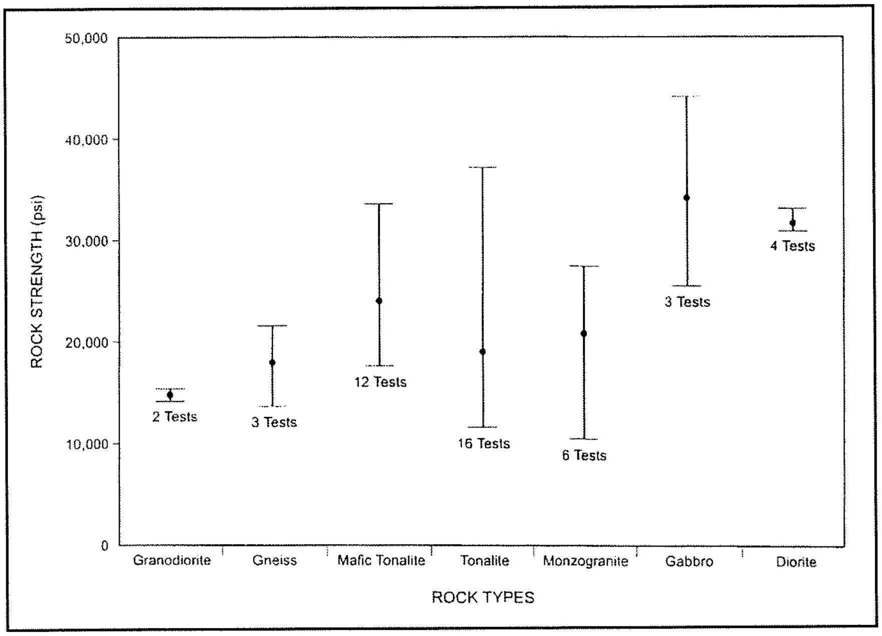


Figure 3. Rock Strength by Rock Type.

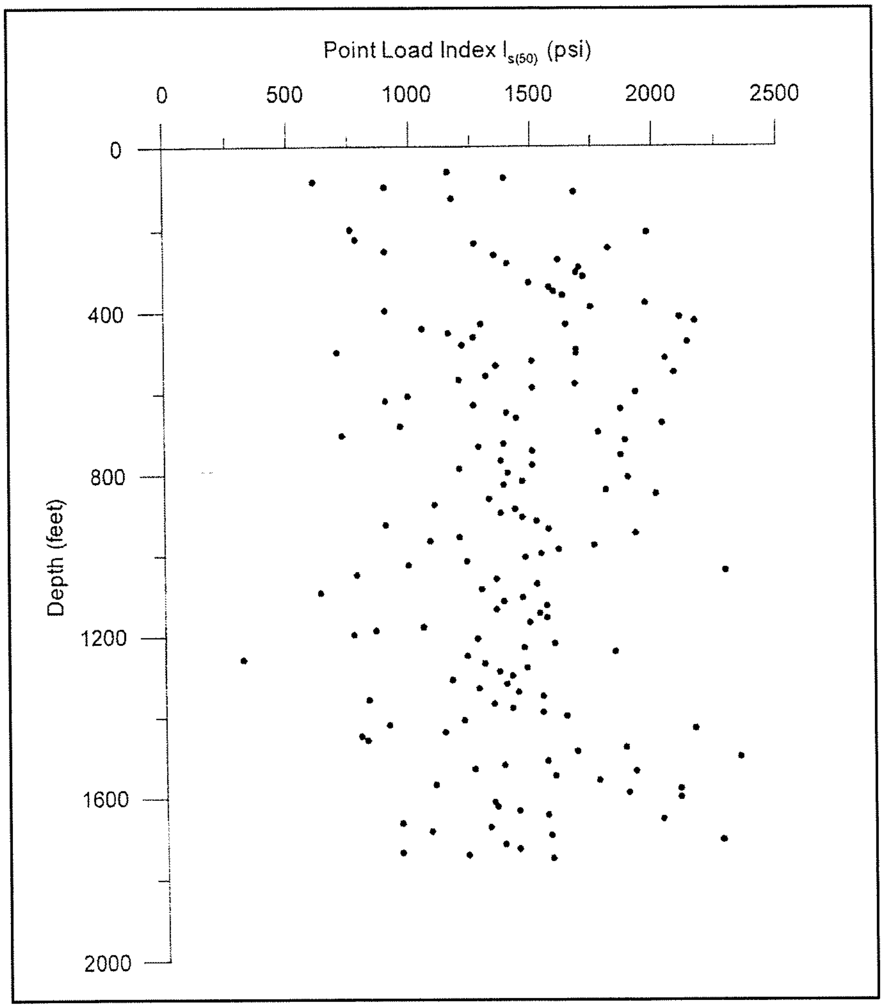


Figure 4. Point Load Index vs. Depth for 1750-foot Boring.

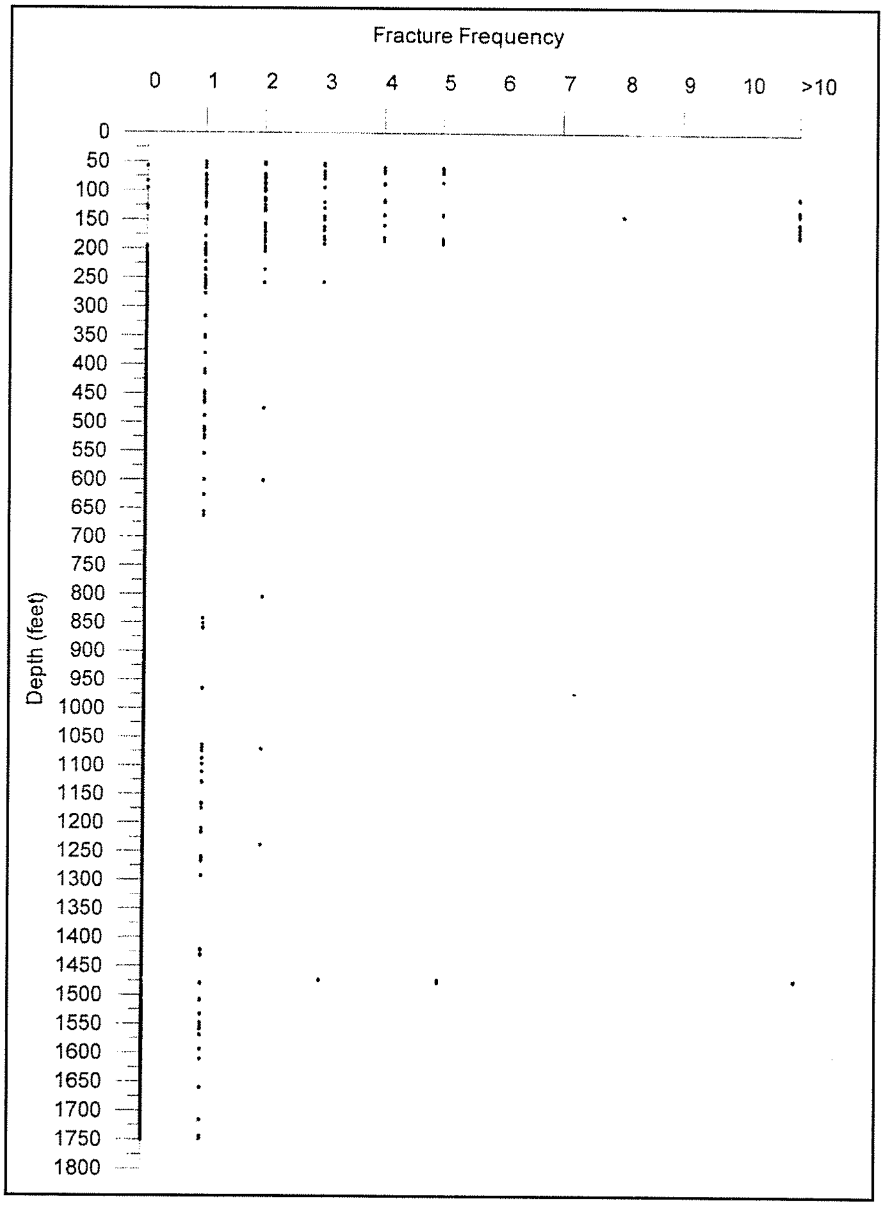


Figure 5. Fracture Frequency vs. Depth for 1650-foot Boring.

Another indication that the rock mass is generally more fractured in the upper 200 to 300 feet than would be expected at a tunnel depth of over 1000 feet was obtained from packer testing. Groundwater at tunnel depth exists only in the open fractures of the essentially impermeable hard igneous and metamorphic rocks. In order for groundwater to flow in the hard rock mass, the fractures in which water is present must be open and interconnected. The degree of fracturing (fracture frequency) and openness of the fractures are generally expected to be higher near the ground surface and to decrease with depth. As a result, most groundwater and groundwater flow is expected to be perched in the more highly fractured near-surface rock mass.

Results of the packer testing in the borings generally confirm these observations. A histogram showing the distribution of the 214 permeability values measured in all of the borings combined is shown on Figure 6. This plot shows that about 63 percent of the rock mass had a permeability of 1 x 10^{-7} cm/sec or less. A similar plot for the 1750-foot-deep boring shown on Figure 7 showed that 87 percent of the rock mass had a permeability of 1 x 10^{-7} cm/sec or less. The permeability distribution and the degree of rock fracturing from the 1750-foot-deep boring is thought to be more representative of the overall rock mass excluding lineaments and major shear zones, which were not encountered in the preliminary drilling program. The number and magnitude of faults or shear zones shown on

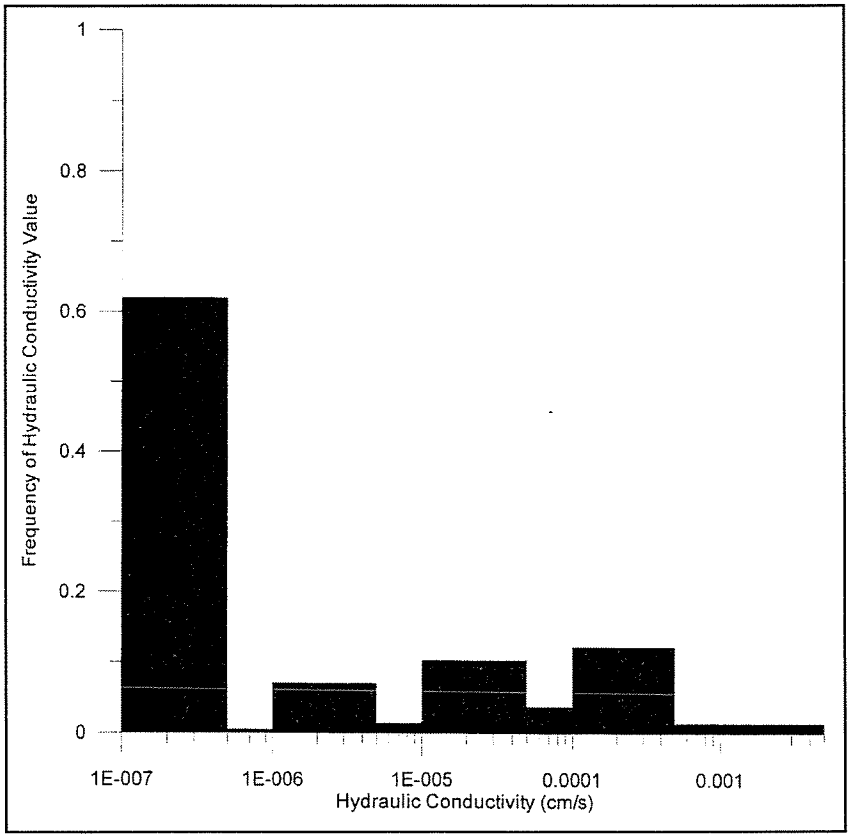


Figure 6. Packer Test Results From All Core Borings.

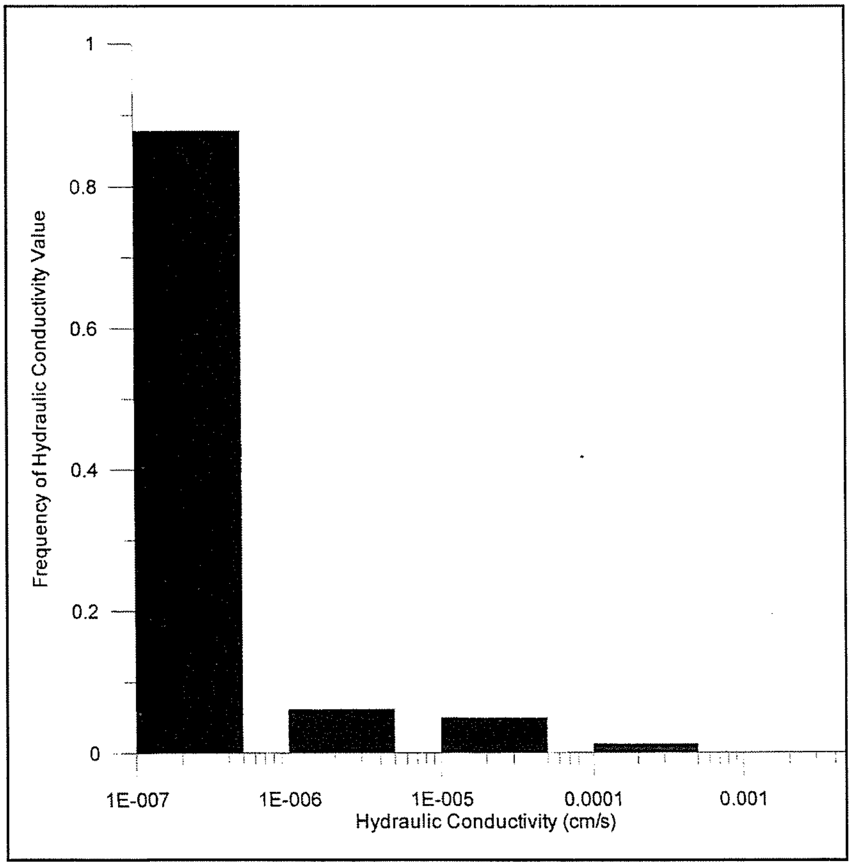


Figure 7. Packer Test Results From 1750-foot Boring.

Table 1 were assumed to be represented by the lineaments mapped from the satellite and aerial photographs. The minor lineaments were assumed to be 50 feet in width and the major lineaments were assumed to be 300 feet in width based on a comparison of similar lineaments encountered in previously constructed tunnels in granitic rock terrain (MK, 1992 and WC, 1997).

Hot Water, High Rock Temperatures. Hot springs and wells that encounter hot water are present throughout southern California. Hot water and associated high ground temperatures present a significant hazard to tunneling at the depths contemplated. The Phase I study identified tunnel alignments using avoidance of hot springs and active faults as a routing criterion. The avoidance of active fault zones in the tunnel sections is significant because within the PRB, there is a general correlation between hot springs and thermal wells with active faults and zones of seismicity (Gastil and Bertine, 1986). As a result, the 5A corridor does not cross near known mapped thermal springs or thermal wells and crosses the active Elsinore-Laguna Salada fault zone in pipeline.

Water temperatures were measured over the length of two of the deeper borings, C5A-9A (total depth 1000 feet) and C5A-13 (total depth 1750 feet). The temperature measurements were taken several days after completion of drilling to allow the hole to stabilize. The measured water temperatures are considered to be representative of the rock temperature also. Temperatures in C5A-9A ranged from 16.6° to 20.5° C (62° to 70° F) at depths ranging from 94 feet to 921 feet. In C5A-13 temperatures ranged from 19°C to 26.8°C (66° to 80° F) at depths of 100 feet to 1740 feet. In both cases temperature increased uniformly with depth. These temperature ranges represent relatively low gradients of 0.0047° C (0.0085° F) per foot, or approximately 1° C per 210 feet (1° F per 118 feet). Assuming a surface temperature of 14° C (57° F) at the highest elevation area along the 5A alignment where the tunnel cover is about 4900 feet would suggest a maximum temperature at tunnel depth of approximately 37° C (99° F). This is a relatively high temperature for workers to be exposed to since the humidity in the tunnel will be very high.

Radon Gas. Significant levels of radon gas were encountered in groundwater samples with measured levels of 9180 and 989 pCi/L from Borings C5A-9A and C5A-13, respectively. Maximum levels of groundwater radon concentration recorded in the samples were over 2 times the safe drinking water level developed by the National Research Council committee. The safe drinking water level was calculated on the basis of water-to-air transfer because the inhalation pathway dominates other means of ingestion or absorption contributing to overall cancer risk from radon exposure (Hopke et al. 2000). Ventilation airflow rates within the tunnel during construction would need to be several times larger than that of residential indoor air to eliminate the potential for a radon gas hazard. Given the standard means of ventilation typically used in tunneling projects, a protective exposure level for workers should be obtained; however, air monitoring for radon gas levels will likely be required during tunnel construction as well as worker radiation monitoring.

Rock Mass Classification

The rock mass was evaluated in terms of the RMR system (Bieniawski, 1989), and the Q-system (Barton et. al., 1974) and basic classification values were assigned to each core run. Following more detailed evaluation of in-situ conditions at tunnel depth, the Q-system ratings were modified to reflect in-situ stress conditions. The Q-system was used to divide the range of anticipated conditions into the following categories: massive, moderately blocky or schistose rock, blocky and seamy rock, and fault zones. The distributions of Q values from the boreholes were used to estimate the probability of occurrence of each ground category. A description of each ground category is provided in Table 2. The propensity for overbreak and rock stress problems are predicted based on relevant project experience and the Q-system rating.

Anticipated Tunneling Conditions

Anticipated rock conditions were evaluated based on results of rock mass classification, using boring log and cover depth information, as well as reviewing geologic mapping, air photo studies, petrographic examination, laboratory testing and groundwater inflow evaluations.

Based on the rock mass classification discussed above, and allowing for encountering faults associated with air photo lineaments, the tunnels are anticipated to encounter 82% massive to moderately jointed or schistose rock, 11% blocky and seamy rock and 7% fault or shear zones. Tunneling in massive to moderately jointed or schistose rock under the proposed 1100 to 4900 feet of maximum cover raises the potential for encountering spalling conditions (Proctor and White, 1968). An evaluation of the potential for spalling is included below. Blocky and seamy rock (Q less than 4) will be associated with frequent rockfall in the TBM area as discussed by Barton (Barton, 1990). An irregular tunnel perimeter will result. Faults and shears may be charged with water and exhibit low stand-up time resulting in face instability and overbreak above the cutterhead.

Table 2. Summary of Ground Categories — 5A Tunnel

Ground Category	Description	Rock Mass Quality (Q)
Massive, Moderately Blocky, Schistose	Strong, fresh rock with or without foliation, joint spacing 1 to 2 feet. Joint surfaces may be locally slightly altered. Occasional thin shears or seams (less than 6 inches wide) may be intercepted. Spalling expected in some areas.	>4
Blocky and Seamy	Srong, fresh rock with joint spacing 0.5 to 2 feet. Joint surfaces may be weathered or altered with some slickensides or opening. Occasional shears or seams (less than 10 feet wide) may be intercepted, requiring supplemental support.	0.1–4
Wide Faults and Shears	Zones greater than 10 feet wide, consisting of rock ranging from highly fractured to sheared or crushed, with variable degrees of decomposition. Rock mass immediately adjacent to shear or fault zones anticipated to be blocky to seamy for tens of feet.	<0.1

Ravelling and squeezing conditions may be associated with fault zones as well. Probe drilling and formation grouting will result in an improvement in ground behavior prior to excavation.

Groundwater Characterization

Groundwater is an important resource in eastern San Diego County. Except for the western one-third of the 5A alignment, imported water is not available and water for agricultural and domestic use comes entirely from surface storage and groundwater wells. The surface and groundwater resources are also an important natural resource on the U.S. Forest Service, BLM and Anza-Borrego Desert State Park lands overlying the tunnel. Nearly the entire 5A tunnel will be constructed below the groundwater table. Estimates of groundwater inflows to the tunnel excavations are needed to: (1) evaluate safety and working conditions during tunnel construction; (2) evaluate portal or shaft discharge quantities and the need for tunnel grouting or watertight linings; and (3) evaluate the interaction between the tunnel and the groundwater regime.

Groundwater modeling was conducted to investigate these issues: the peak inflow of groundwater to the tunnel heading, the peak cumulative inflow to the tunnels during construction, the steady-state cumulative inflow under long term conditions, and the impact of the tunnel inflows on the overlying groundwater elevations. Several different approaches were used to calculate the rate of groundwater discharge into the tunnels.

In order to make estimates of groundwater inflow into the tunnel during and after construction and to evaluate the potential impact to the groundwater level, a numerical model was developed by Dr. David Huntley at San Diego State University. Using the information obtained from the field investigation (including results of packer tests, rock core fracture frequency, downhole optical logs and groundwater level measurements in the piezometers), a conceptual geologic model was developed and used in the numerical model. Several scenarios were assumed and the results compared to tunnel groundwater inflows in previously constructed tunnels in similar geologic environments including the Metropolitan Water District's San Jacinto (MWD, 1940) and the San Bernardino tunnel (DWR, 1967) in southern California and the Manapouri tailrace tunnels in New Zealand (WC, 1997). The numerical model was then refined using the results and interpretations of the field data combined with observed case history inflows to make estimated inflows for the proposed tunnel.

Some of the key elements and criteria used to estimate the groundwater inflows in the model were that:

1. The groundwater inflows would be mitigated to a point that the groundwater table above the tunnel alignment would not be lowered more than 1 foot on average, during and following construction.
2. During tunneling, two probe holes would be advanced in front of the TBM, and all significant fault and shear zones that produce water would be grouted to a permeability of 3×10^{-5} cm/sec.

The model showed that small volume groundwater inflows into the tunnel segments with low cover (less than 1000 feet) had a significant impact on the groundwater table. For example a groundwater inflow in excess of 0.08 gallons per minute per foot (gpm/ft) of tunnel would result in a lowering of the groundwater level. In contrast, groundwater inflow into a tunnel with 3000 feet of cover would need to exceed 20 gpm/ft of tunnel before having an impact of the groundwater level due to the much larger storage and recharge area above the tunnel. Because of this sensitivity, the two tunnel segments between the west portal of the 34-mile tunnel and San Vicente Reservoir

(Segments 16 and 18 through 20 from Table 1) were planned to use precast, gasketed segments, since it was not considered feasible to control groundwater inflows with grouting alone to maintain the criteria of 1-foot maximum drawdown of the groundwater level. However, the use of gasketed segments was not considered feasible for the deeper 34-mile tunnel segment since the gaskets and strength of the segments cannot withstand the high hydrostatic heads. Groundwater inflows into this tunnel would need to be controlled by pre-excavation grouting; however, realistic grouting closure criteria can be established based on a packer test permeability of 3×10^{-5} cm/sec.

Refinements to the model were made including a reduction of the total available hydraulic head at tunnel depth based on review of the initial head flow pressures measured in the San Jacinto tunnel and the Manapouri tailrace tunnels, which were generally about half the total available head.

To make a comparison of the numerical model inflow quantities, a semi-empirical groundwater inflow method developed by Heuer (1995) was used, using the results of the packer test permeability distribution for the 1750-foot-deep boring (Figure 7). This method essentially confirmed predicted inflows except under very high head situations (over 3500 feet), where the project estimates exceeded estimates based on Heuer by a factor of three (1995).

The groundwater inflow quantities estimated by the model after grouting of the lineaments and an additional 3 to 4 percent of the tunnel length to prevent impacts to the groundwater resources resulted in a maximum cumulative inflow of 18,000 gpm for eastern segment and 15,000 gpm for the western segment. The predicted amount of grouting using ordinary Portland cement resulted in a grouted length of 5900 feet for the eastern segment and 5100 feet for the western segment, or about 8 to 10 percent of the total tunnel length. Use of high-early and micro-fine cements were also evaluated.

Anticipated Spalling Conditions

Spalling ground can occur when in-situ stress concentrations around the tunnel perimeter exceed the strength of the rock mass. Goodman (1989) suggests that where the major in-situ stress exceeds 25 percent of the rock unconfined compressive strength (or compressive strength divided by in-situ stress is less than 4), cracking and spalling that results in overbreak can occur. Implicit in the Strength Reduction Factor of Barton et al, (1974) is a threshold of 5, below which mild to heavy spalling or rock burst is said to occur. While Goodman and Barton are relatively consistent on prediction of spalling, other case histories suggest different relationships between rock strength and in-situ stress.

The potential for spalling ground was evaluated by comparing the average rock unconfined compressive strength in each tunnel segment to the estimated overburden pressure.

One possible explanation for the seemingly wide variation in the occurrence of spalling is the effect of lateral in-situ stress. When the in-situ lateral stress is the same as the in-situ vertical stress, the stress concentration around a circular opening in an elastic medium is twice the in-situ stress (Hoek and Brown, 1982). However, if the lateral stress differs from the vertical stress, the maximum stress concentrations in the tunnel perimeter increase sharply. Table 3 summarizes the maximum stress concentration in the tunnel perimeter as a function of the ratio of vertical to horizontal stress.

A second explanation that is likely to complement the first is anisotropic rock strength and the effects of partially healed discontinuities on rock mass strength. At the first Manapouri Tailrace tunnel the spalling behavior was reportedly observed when the strike of rock mass discontinuities and/or foliation aligned sub-parallel with the tunnel excavation (WC, 1997) which demonstrates a relationship between anisotropic rock mass strength and spalling. Selection of rock samples for laboratory testing of intact rock strength is by necessity biased toward higher intact rock strength. For comparison, consider the rock strength test cases summarized in Table 4. Based on this summary the strength of nearly intact rock can be 34-38% lower than intact rock.

In-situ stress conditions are difficult to predict without in-situ testing; however, Hoek and Brown (1982) provide a chart for estimating the ratio of vertical to lateral stresses (K_0) that is based on stress measurements obtained from the United States and abroad. Considering depths ranging from 3000 to 5000 feet, their work indicates that K_0 typically ranges between 0.5 and 1.5 with and average of 1.0. This would generally support the use of the vertical overburden stress for evaluating spalling ground conditions.

Cover over the proposed tunnel ranges from negligible at the portals to a maximum of about 4900 feet within Segment 3. Assuming an average total unit weight of 175 pcf, this results in a maximum estimated overburden pressure of about 5950 psi. Assuming that the 25 percent rule is an appropriate indicator of spalling conditions, a tunnel excavation would be susceptible to spalling with rock unconfined compressive strengths less than 24,000 psi. Over

Table 3. Maximum Stress Concentration in Tunnel Perimeter
Northern Alignments Geological Study

K[1]	Maximum Stress Concentration in Circular Tunnel Perimeter[2]
0	3
0.5	2.5
1	2
1.5	3.5
2	5

Notes:

[1] $K = \frac{\text{Lateral in Situ Stress}}{\text{Vertical in Situ Stress}}$

[2] Stress concentration values represent factors applied to vertical in-situ stress, which is normally estimated as the product of the depth of cover and average rock unit weight. These values apply to elastic, isotropic conditions around a circular tunnel and are developed using either the Kirsch equations or the principle of superposition based on 2-dimensional boundary element modeling of stresses around a circular opening as presented in Hoek & Brown, 1982.

Table 4. Effects of Geologic Structure on UCS Results[1]
Northern Alignments Geological Study

				UCS[2] (psi)	
Case	Rock Type	Boring	Depth (feet bgs)	Structurally Controlled Failure[3]	Intact Rock Strength
1	Monzogranite	C5A-9A	910.7-914.2	11,000 12,800	17,900
2	Gneiss	C5A-12	201.0-202.7	17,100 9,400	21,500

Notes

[1] Data from Table 2A of GDR.

[2] Only test results from CSM are shown.

[3] Structurally controlled failures of Case 1 resulted in a 34% decrease in strength over the intact rock strength. For Case 2, decrease in strength was 38%.

60% of the samples tested had strength lower than this value. Based on this assumption, it was determined that there is a potential for spalling ground conditions in segments 1B, 1C, 2, 3, 4, 7 and 8. Consistent with the Barton relative stress classification, these areas typically exhibit a ratio of rock compressive strength to in-situ stress ranging between 2.5 and 5. Where spalling conditions are expected along these segments, overburden heights above the tunnel range between 2800 and 4900 feet. This condition is present over 15+ miles of the tunnel alignment; hence, it is considered critical with respect to primary support and lining requirements and hydraulic roughness.

Estimated TBM Performance

Instantaneous penetration rates were estimated for each segment by Dr. Levent Ozdemir of the Earth Mechanics Institute, of the Colorado School of Mines (CSM). Penetration rate estimates were based on a summary of rock and geologic properties for each tunnel segment. A final comparison was made to check the CSM results with historical instantaneous penetration rate data obtained from completed tunnel projects in California and abroad.

Table 5. Norwegian Institute of Technology Joint Classification

NTH Joint Class	Distance Between Joints (cm/inches)
0	—
0-I	160/63
I	80/31
I-II	40/16
II	20/8
III	10/4
IV	5/2

Penetration rates estimated by the CSM Method are a function of tunnel geometry, rock mass characteristics and machine parameters. Tunnel geometry parameters are the tunnel diameter and the tunnel axis orientation. Rock mass characteristics include the rock strength and hardness properties, degree of fracturing and orientation, and foliation. Machine parameters involve the TBM diameter, cutter diameter and spacing, net thrust per cutter, cutterhead RPM, number of cutters and installed cutterhead power.

The assumed tunnel diameter for this project is 15 feet. This diameter has been selected to accommodate plant and equipment in the tunnel necessary for the long tunnel drives envisioned. This excavation size ensures the necessary hydraulic requirements are achieved even if thick linings are deemed necessary. The tunnel axis orientation with respect to joint orientation can have an impact on penetration rate. Tunnel drive orientation along the project varies. In general, the tunnel drive direction for the 5A corridor is east-west. The orientation measured by azimuth, ranges between 248 degrees (segment 1) to 305 degrees (segments 17, 18, 19 and 20).

The degree and orientation of jointing was characterized using the Norwegian Institute of Technology (NTH, 1994) system as presented in Table 5. No distinction between joints and fissures was attempted because joint persistence data was not available from core logs.

The joint orientation with respect to the tunnel axis orientation is expressed as the alpha angle (a):

a = arcsin (sin a f * sin(a t - a s))
where: a s = strike angle of each joint set
a t = dip angle of each joint set
a f = tunnel axis orientation

The alpha angle is the minimum angle between the tunnel axis and a normal to the discontinuity plane. This angle is independent of the tunnel drive direction. Joint orientation for each segment was identified by plotting borehole and surface mapping data on stereoplots. Major joint sets were determined along with their strike and dip angles. Where multiple joint sets were identified, an average alpha angle was computed for the tunnel segment.

The CSM model employs a variety of laboratory tests to estimate rock drillability (nonfractured rock) or the "basic" TBM penetration rate. These laboratory tests include unconfined compressive strength, tensile strength, punch penetration and point load index. All of these tests were conducted on select rock core samples obtained during the field investigation. Estimated "basic" rates are then adjusted to account for joint effects using the NTH joint classification and foliation.

Two machine specifications were developed for the CSM model: a "standard" TBM and a "high power" TBM. Both assumed a 15-foot (4.54 m) TBM diameter with 33 cutters spaced at 3.2 inches (81 mm). Assumed cutter diameter for the standard and high power TBM's was 17 inches (432 mm) and 19 inches (483 mm), respectively. The standard TBM has an operating thrust per cutter of 55 kips (245 kn) with a cutter head rotational speed of 12.5 rpm. The high power TBM employs an operating thrust per cutter of 70 kips with a rotational speed of 13.3 rpm. Installed power for the standard and high power TBM's was assumed to be 2532 and 2954 hp, respectively. Certain advances in cutter and TBM technology between the time of the study and envisioned construction timeframe were anticipated for the high-powered TBM.

The instantaneous penetration rate, typically expressed in inches per cutterhead revolution, is dependent upon the "basic" penetration rate, joint effects and equivalent thrust per cutter. The net penetration rate, expressed in feet per hour, is a function of instantaneous penetration rate and the cutterhead RPM:

$I = i_o * RPM * 60$ (feet/hour)

where: i_o = instantaneous penetration rate (inches/revolution)

To identify a range in penetration rates for each segment and TBM, CSM developed models for the worst-case, best-case and most likely scenarios. Maximum and minimum rates for the standard TBM ranged between 2.9 feet/hour for gabbro and 19.9 feet/hour for granodiorite, gneiss and tonalite. Maximum and minimum rates for the high power TBM ranged between 4.4 feet/hour for gabbro and 19.9 feet/hour for granodiorite, gneiss and tonalite. Weighted averages for the overall project penetration rate were estimated to range between 9.9 and 16.9 feet/hour for the standard TBM and between 14.9 and 18.5 feet/hour for the high power TBM. Overall average penetration rates for the most likely scenario were 13.1 feet/hour (0.21 feet/rev) for the standard TBM and 17.4 feet/hour (0.26 inches/rev) for the high power TBM.

Comparison between CSM Method and Case Histories

The estimated TBM penetration rates developed using the CSM Method were compared to actual rates obtained at relatively recent projects in California. This comparison provides a way to confirm that recommended penetration rates are consistent with actual TBM performance at similar projects and that reasonable construction costs and schedules can be developed.

One project considered to be relatively similar and in near proximity to the 5A tunnel is the Cowles Mountain Tunnel located in San Diego. The Cowles Mountain Tunnel involved an 11.25-foot-diameter tunnel constructed in very strong granitic rocks including granodiorite, monzogranite and tonalite. An average unconfined compressive strength of about 40 ksi was reported for these rock types as compared to the average of about 22 ksi for the rock types obtained for the 5A tunnel. Typical joint spacing observed during the construction of the Cowles Mountain Tunnel was approximately 1 to 2 feet, which compares favorably with those assumed for the 5A tunnel. Cutter diameter was 17 inches with an average thrust per cutter of about 55 kips. Reported instantaneous penetration rates ranged between 0.08 to 0.16 inches/rev with and average of about 0.12 inches/rev. The average penetration rate is considerably lower than the average rate estimated for the 5A tunnel (0.21 in/rev — standard TBM); however, the average rock compressive strength at Cowles Mountain was nearly double.

Numerous TBM tunnel projects located in the Sierra Nevada Mountains can be compared and contrasted with the 5A tunnel project. These projects include Grizzly Power, Kerchoff 2, Calaveras-North Forks and Sandbar. Most of these tunnels were constructed in granodiorites and/or gabbro with average unconfined compressive strengths on the order of 20 ksi, which is comparable to the 5A tunnel average strength. In contrast to the 5A tunnel, joint spacing is typically about 5 to 10 feet in the Sierra Nevada's; hence, the NTH joint classification is 0 to I. Assuming similar rock strength and hardness, the low degree of fracturing would tend to result in lower penetration rates when compared to a typical joint class of I to II for the 5A tunnel. Reported instantaneous penetration rates for these projects ranged between 0.16 to 0.18 inches/rev. Thrust per cutter was typically 45 to 50 kips for these projects; hence, it can be assumed that a 55 kip/cutter (5A tunnel) thrust would result in higher penetration rates that approach 0.20 inches/rev.

In summary, CSM's average estimated TBM penetration rates (standard TBM) compare favorably with those obtained at completed projects when rock mass and machine parameter variables are considered. Based on an overall review of the estimated rates, it was recommended that the average rates developed for the standard TBM be used for determining construction costs and schedules. Although some new TBMs are being fitted with front-loading 19-inch cutters, their performance is relatively unproven compared to 17-inch cutter machines. The improvements in performance offered by a high-powered TBM equipped with 19 inch cutters should be considered in evaluating project cost contingencies.

CONCLUSIONS

Construction of the 34-mile-long 5A tunnel is geotechnically feasible on the basis of the limited geologic and hydrogeologic data collected during the study. The tunnel will encounter hard, massive, abrasive granitic and metamorphic rocks with zones of highly fractured and sheared ground that will likely produce high volume, high pressure groundwater inflows.

As currently envisioned, this tunnel would be constructed from two separate headings each 17 miles in length. Tunnel drives of this length from a single heading, combined with the high cover (up to 4900 feet with an average of nearly 3000 feet) have not been constructed to date. Key geologic issues that impact the cost and construction schedule of this long tunnel include:

1. Potentially high rock temperatures due to the earth's natural geothermal gradient

2. High in-situ stresses requiring additional ground support
3. Several significant lineaments (fault zones) which must be crossed requiring pre-excavation grouting and support
4. Potentially high pressure/high volume groundwater inflows requiring pre-excavation grouting to reduce flows to a manageable level

Future design-level studies will be needed to better characterize the rock and groundwater conditions at the depth of the tunnel including ground temperatures at tunnel depth, in situ stress conditions, degree of rock fracturing, rock mass permeability and rock strength.

ACKNOWLEDGMENTS

The authors wish to thank the San Diego County Water Authority, and Richard Pyle, Project Manager and Bill Busch, Senior Right of Way Agent for their cooperation and assistance during the course of this study. Thanks are also due to the individuals who provided technical support during the project including P.E. Sperry, G. Korbin, J. Kaneshiro, T. Brekke, M. Walawender, D. Huntley and L.Ozdemir.

URS geologists involved with geologic mapping, core logging and field testing included Alex Greene and Mike Hatch (San Diego office), Tom Kolbe (Oakland office), Chris Goetz and Martin Siem (Santa Ana office). Southland Geotechnical (Sue Tanges, Glen Roweder, Gene Custenborder, and Daryl Streiff) assisted during the field investigation, and helped handle a lot of core.

REFERENCES

Barton, N., Lien, R. and Lunde, J., 1974, Engineering classification of rock masses for the design of tunnel support: rock mechanics, Vol. 6, No. 4, 1974, pp. 189-236.

Barton, N., 2000, *TBM Tunneling in Jointed and Faulted Rock*, Balkema, Rotterdam.

Bieniawski, Z.T., 1989, Engineering rock mass classification, John Wiley and sons, New York.

Black & Veatch, 1996, Feasibility Level Engineering for Facilities to Transfer Water from the Imperial Irrigation District, prepared for San Diego County Water Authority.

Compton, R.R., 1985, Geology in the field, John Wiley and sons, New York.

Gastil, G., and Bertine, K., 1986, Correlation between Seismicity and the Distribution of Thermal and Carbonate Water in Southern and Baja California, United States and Mexico. Geology, v. 14, pp. 287-290.

Goodman, R.E., 1989, Introduction to Rock Mechanics, Second Edition, John Wiley and Sons, New York.

Heuer, R.E., 1995, Estimating rock tunnel water inflow, in Williamson, G.E. and Gowring, I.M., eds., Proceeding of the Rapid Excavation and Tunneling Conference, San Francisco, June.

Hoek, E. and Brown, E.T., 1982, "Underground Excavations in Rock," Institute of Mining and Metallurgy, London. Second Edition.

Hopke, P.K. et al. 2000. Health Risks Due to Radon in Drinking Water. *Environmental Science and Technology*. Vol. 34, No. 6.

Morrison Knudsen Corporation, 1992, Geologic field mapping sheets for Cowles Mountain Tunnel, Contract 412, Prepared for San Diego County Water Authority, 49 p.

NTH, 1994, Hard Rock Tunnel Boring, Project Report I-94, University of Trondheim, The Norwegian Institute of Technology.

Proctor, R.V., and White, T.L., 1968, Rock Tunneling with Steal Supports, with an introduction to Tunnel Geology by Karl Terzaghi, Commercial Shearing, Inc., Youngstown Ohio, revised.

Walawender, M., 2000, The Peninsular Ranges — A geological guide to San Diego's back country, Kendall-Hunt Publishing.

Woodward-Clyde, 1997, Second Manapouri Tailrace Tunnel, Geotechnical Baseline Report, Vol. 4 of 6, prepared for Electricity Corporation of New Zealand.

Geologic Formations of Western San Diego County

Jeffrey D. Brown, R.G., C.E.G, *GEI Consultants, Inc.*
2141 Palomar Airport Road, Suite 160, Carlsbad, California 92209-1424
jbrown@geiconsultants.com

INTRODUCTION

Published geologic literature provides a wide range of information about the geologic formations common to San Diego County. Such studies range from specific to broad in scope, but most often focus on a specific portion of the county, a general age or type of rock, or a particular formation or group of formations. This article condenses general information about the origin, distribution, and characteristics of rock formations of western San Diego County from the literature and personal experience into an abridged, phrased format. The intent of this exercise was to provide a tool for quick reference on local geological conditions by geologists, engineers and other investigators.

GEOLOGIC UNITS

183-163 Mya (Jurassic)

Bedford Canyon Formation (northwestern County)/ Julian Schist (central and southeastern County): marine, continental margin deposits; shale, siltstone and claystone with quartz sandstone, metamorphosed to quartz-mica schist with quartzite interlayers; low pressure-high temperature metamorphism; named for type-section in Orange County; covers 280 square miles of San Diego County with rock bodies 10s of square feet to many square miles (includes hybrids); bounded by batholithic rocks; trends north to northwest; 1000s of feet thick; increased metamorphism and possibly younger to older from west to east. Source: Weber, 1963.

Angular Unconformity

151-117 Mya (Late Jurassic to Early Cretaceous)

Santiago Peak Volcanics: low-grade metamorphosed volcanics and volcaniclastics; basalt to rhyolite in composition but predominantly dacite and andesite; traditionally late Jurassic (≈**150 Mya**); recent work in Orange County (type-section in Santa Ana Mountains) shows early Cretaceous (**128-117 Mya**); formed in volcanic coastal area east of subduction zone; western exposures typically mudstones, angular sandstones and gravel (breccia) deposits eroded from western flanks of volcanoes and deposited in marine, continental margin environments (includes submarine gravity flows); eastern exposures primarily andesitic lava flows and volcaniclastics; moderate pressure-low temperature metamorphism (greenschist facies: pyroxenes to chlorite) during prebatholithic deformation; outcrops from east Orange County to central Baja; covers 170 square miles, most from U.S. Border to La Mesa; possibly 1000s of feet thick: dated Late Jurassic (**151-142 Mya** based on fossils) in Los Penasquitos Canyon where formation is locally tilted 48° to west. Sources: Abbott, 1999; Gray, et al., 2002; Adams and Walawender, 1982; Kennedy and Peterson, 1975; Weber, 1963.

Intrusion

105-95 Mya (Early to Late Cretaceous)

Peninsular Ranges Batholith outcrops from Riverside to tip of Baja (1000 miles); up to 70 miles wide in San Diego County; covers 1900 square miles (about 40% of County); emplaced every few million years as distinct units after preceding unit had crystallized; sequence of gabbro through tonalite and granodiorite to granite, with tonalite and granodiorite most common. Sources: Weber, 1963; Tan and Kennedy, 1996.

San Marcos Gabbro: covers 160 square miles in County, primarily in bodies of 1 to 5 square miles, but up to 25 square miles; generally southwest of Elsinore Fault Zone.

Granitic Rocks: covers 1700 square miles in County, from 100s of square feet to 10s of square miles in area.

Green Valley Tonalite: medium to dark gray, lacks abundant streaked inclusions; found in west County area.

Bonsall Tonalite: light to dark gray, abundant hornblende inclusions; widespread throughout County.

Lakeview Mountain Tonalite: light gray, lacks abundant inclusions; typically found in mid-east and southeast County areas.

Lake Wolford Leucogranodiorite: light gray, fine-grained; found primarily between Lake Wolford and Escondido.

Woodson Mountain Granodiorite: pale brownish gray, coarse-grained, much has gneissic or banded structure; found in west County along with Green Valley Tonalite.

Indian Mountain Leucogranodiorite: light gray, fine-grained; found along sides of San Luis Rey River southwest of Pala.

Escondido Creek Leucogranodiorite: light gray, fine-grained, with inclusions of tonalite; found as small bodies southwest and west of Escondido.

Hybrid Gneisses and Associated Quartz Diorite and Granodiorite: injection gneisses and banded gneisses (migmatites) and mixed metamorphic and granitic rocks; texture suggests partly derived from Julian Schist in Santa Ysabel-Julian area; found in northwest trending belt from Jacumba to Palomar Mountains; portions dated **96 Mya**. Source: Weber, 1963.

Nonconformity

90-72 Mya (Late Cretaceous)

Lusardi Formation: alluvial fan deposit; reddish brown, locally derived cobble and boulder conglomerate with muddy sandstone interlayers; clasts up to 30 feet; outcrops in east Carlsbad, Rancho Santa Fe, east Poway (Poway Grade), northeast of San Vicente Reservoir and Alpine; exposed thickness up to 400 feet, estimated up to 1250 feet thick from well data; estimated **90-75 Mya** (based on Point Loma Formation). Sources: Abbott, 1999; Kennedy and Peterson, 1975; Tan and Kennedy, 1996.

Unconformity

Point Loma Formation: marine shelf and submarine fan deposits; interbedded, fine-grained yellowish sandstone and olive-gray clay shale; outcrops in Point Loma, south and central La Jolla coastal and south Carlsbad (El Camino Real); estimated thickness 1000 feet; dated **76-72 Mya**; sea caves readily form along fracture planes on seacliff exposures. Sources: Abbott, 1999; Kennedy and Peterson, 1975; Tan and Kennedy, 1996.

Conformity

Cabrillo Formation: submarine fan deposit; yellowish, locally derived cobble and boulder conglomerate with sandstone interlayers; clasts up to 10 feet; outcrops in Point Loma and along La Jolla coastline (False Point to Bird Rock); 560 feet thick at False Point; estimated **76-72 Mya** (based on Point Loma Formation). Sources: Abbott, 1999; Kennedy and Peterson, 1975.

Unconformity

70-55 Mya (Paleocene to Early Eocene)

Paleosols (Ancient Soils): ancient soils developed through physical (mechanical) and chemical disintegration of exposed rock mass during time of reduced or no sedimentation; mechanical weathering (ex. thermal expansion and contraction, water freeze-expansion, root wedging) and chemical weathering (ex. dissolution, leaching, alteration) to form an A-Horizon (zone of soluble mineral leaching and organic material), a B-Horizon (zone of clay and precipitate accumulation), and a C-Horizon (partially decomposed parent material); thick, well-developed paleosols formed in the tropical climatic conditions (average annual temperature: 73°F; average annual precipitation 63 inches) believed to exist in this area during Paleocene; distinct buried clay soil profile found on Santiago Peak Volcanics, Point Loma Formation and Mount Soledad Formation; clays (A- and B-Horizons) up to 15 feet in thickness and locally mined; cobbles and boulders of conglomerates remain only as ghosted relicts in paleosols; paleosols on granitics beneath Eocene sediments locally 20 or more feet in thickness; greenish gray, intensely weathered-to-clay granitics informally termed "frock" (Friars rock) because of similarity to Friars Formation claystones; clayey paleosols, particularly along sloping igneous/sedimentary rock contact, can provide a plane-of-weakness to promote landsliding. Sources: Abbott, 1999; Weber, 1963.

Unconformity

50-44 Mya (Early to Middle Eocene)

The ancient Ballena River brought rhyolite-gravel ("Poway" clasts) from area of what is presently Sonora, Mexico; sediments deposited into alluvial fan-submarine canyon-submarine fan complex extending for miles offshore; remnants of submarine fan facies outcrops as far west as northern Channel Islands; displacement of segments of depositional system caused by large-scale lateral faulting and opening of Gulf of California; remaining Ballena River deposits outcrop discontinuously over 16 miles in a west-southwest trend from Whale Peak (west of San Ysabel Valley) to San Vicente Reservoir; river was up to two miles in width through Peninsular Ranges; alluvial fan deposits over 650 feet in thickness in Sycamore Canyon area test borings; remnant volume of alluvial fan estimated at 6.4 cubic miles (16.5 km^3) in studies using a maximum thickness of only 360 feet thickness; progressive-regressive (changing sea level) shoreline during deposition of fan and peripheral environments caused migration of depositional facies. Sources: Abbott, 1999; Simpson and Abbott, 1996.

La Jolla Group:

Mount Soledad Formation: submarine fan deposits; yellowish, distally derived cobble conglomerate with minor sandstone interlayers; outcrops around perimeter of Mount Soledad with conglomerates more inland; 225 feet thick at type section; estimated **50-49 Mya** (based on Ardath Shale). Source: Kennedy and Peterson, 1975.

Conformity

Delmar Formation: lagoonal deposit; yellowish green sandy claystone interbedded with medium-gray coarse-grained sandstone; clays are expansive and landslide-prone; outcrops from Soledad Valley to Encinitas; grades vertically into Friars Formation from Los Penasquitos Canyon to La Zanja Canyon and vertically and horizontally into the Santiago Formation in Encinitas; estimated to be 200 feet thick at type section; dated **49-47 Mya**. Sources: Kennedy and Peterson, 1975; Tan and Kennedy, 1996.

Conformity

Torrey Sandstone: tidal flat and beach deposits; white to pale brown, medium to coarse-grained sandstone interbedded with medium-gray coarse-grained sandstone; outcrops from Torrey Pines Golf Course to Encinitas; grades vertically and horizontally into the Santiago Formation in Encinitas; estimated to be 200 feet thick; estimated **49-47 Mya** (based on Ardath Shale and Delmar Formation). Sources: Abbott, 1999; Kennedy and Peterson, 1975; Tan and Kennedy, 1996.

Conformity

Ardath Shale: continental shelf deposits; olive-gray (unweathered) to yellowish brown (weathered), weakly fissile silty shale with thin beds of medium-grained sandstone; some expansive clays and landslide-prone; estimated to be 230 feet thick at type section; outcrops from Mission Bay to Torrey Pines State Park; correlates with the middle part of the Santiago Formation; dated **49-45 Mya**. Sources: Abbott, 1999; Kennedy and Peterson, 1975.

Conformity

Scripps Formation: beach-bar deposit, pale yellowish brown, medium-grained sandstone with some cobble-conglomerate interbeds; outcrops from Mission Valley to Carmel Valley; grades into the Torrey Sandstone near Carmel Valley and correlates with the middle part of the Santiago Formation; estimated to be 180 feet thick at type section; estimated **47-44 Mya** (based on Ardath Shale). Sources: Abbott, 1999; Kennedy and Peterson, 1975; Tan and Kennedy, 1996.

Conformity

Friars Formation: nonmarine and lagoonal deposits; Tf yellowish green to gray, medium-grained sandstone with claystone interbeds and cobble conglomerate lenses increasing to east; clays expansive and landslide-prone; outcrops from Mission Valley to Carmel Valley; estimated to be 160 feet thick; estimated **47-44 Mya** (based on Ardath Shale). Sources: Abbott, 1999; Kennedy and Peterson, 1975; Tan and Kennedy, 1996.

Conformity

Santiago Formation (North County equivalent of La Jolla Group)

Sources: Cranham et al., 1994; Tan and Kennedy, 1996.

Lower Member (A): intertidal mudflat and subtidal sand bar deposits; interbedded, very light gray medium- to coarse-grained arkosic sandstone and greenish gray silty sandstone and claystone; claystones are landslide-prone; estimated up to 100 feet thick from Encinitas to Oceanside and up to 1300 feet thick in northern Camp Pendleton; approximately equivalent to Delmar Formation; age estimated **49-47 Mya** (based on Delmar Formation).

Middle Member (B): fluvial, coastal river deposits; light tan coarse-grained arkosic sandstone with lenses of small gravels and interbedded with reddish brown siltstone and claystone; claystones are landslide-prone; estimated up to 200 feet thick from Encinitas to Oceanside and up to 700 feet thick in northern Camp Pendleton; approximately equivalent to Torrey Sandstone; age estimated **49-47 Mya** (based on Torrey Sandstone).

Upper Member (C): shallow marine shelf deposits; interbedded grayish to greenish brown siltstone and gray to grayish brown claystone with some whitish to greenish gray fine- to medium-grained calcareous arkose and subarkose; also rare light gray to white, very fine-grained tuff beds; claystones are landslide-prone; estimated up to 200 feet thick from Encinitas to Oceanside and up to 1900 feet thick in northern Camp Pendleton; approximately equivalent to Ardath Shale; age estimated **49-45 Mya** (based on Ardath Shale).

Conformity

45-37 Mya (Late Eocene)

Poway Group:

Stadium Conglomerate: fluvial/deltaic deposits; massive cobble conglomerate with yellowish brown sandstone as matrix and thin interlayers; outcrops from Chollas Lake (Highway 94) to Fairbanks Ranch (width of fan delta at least 20 miles); estimated more than 450 feet thick; estimated **45-43 Mya** (based on Mission Valley Formation). Sources: Kennedy and Peterson, 1975; Kennedy and Tan, 1977; Tan and Kennedy, 1996.

Conformity

Tmv

Mission Valley Formation: nearshore (littoral) marine deposits, light olive gray to light gray, fine- to medium-grained sandstone with cobble conglomerate interbeds (up to 30% of total mass, increasing in frequency to the east), and interbeds of dark gray claystone (about 20%); clays are expansive and landslide-prone; outcrops from Otay Valley (east of La Nacion Fault) to Rancho Bernardo; estimated up to 200 feet thick; dated **44-42 Mya**. Sources: Kennedy and Peterson, 1975; Kennedy and Tan, 1977; Tan and Kennedy, 1996.

Conformity

Pomerado Conglomerate: fluvial/deltaic deposits; massive cobble conglomerate with yellowish brown sandstone as matrix and as typically thin interlayers); outcrops from Mission Gorge to Beeler Canyon (south edge of Poway); estimated up to 180 feet thick including Miramar Sandstone Member (up to 30 feet thick); estimated **43-42 Mya** (based on Mission Valley Formation). Source: Kennedy and Peterson, 1975.

Conformity

Sweetwater Formation: fluvial channel and floodplain deposits; stacked, fining upward sequences of coarse-grained arkosic sandstones and pebble gritstone grading upward into light brown siltstones and pale reddish brown sandy mudstones; outcrops from Highway 94 to south of the border, east of La Nacion Fault to Otay Lakes; estimated to be up to 130 feet thick; dated **42-37 Mya**. Source: Walsh and Deméré, 1991.

Periodic Volcanism

37?-11 Mya (Oligocene to Miocene)

Dacite/Andesite Volcanic Plugs: volcanic rock masses that cooled and hardened within a near-surface feeder pipe of an ancient volcano, now exposed by erosion; volcanic plugs identified at Cerro de la Calavera (northeast Carlsbad), Morro Hill (extreme northern tip of Oceanside), and an unnamed hill north of Horno

Summit in Camp Pendleton; small remnants of lava flows and pyroclastic deposits recognized overlying remnants of Santiago Formation up to 1 km to the south and southeast of Morro Hill; large andesite dike north of Scripps Institute pier dated at **11 Mya**; volcanics plugs, if Oligocene, possible source for volcanic ash layers in Otay Formation. Sources: Abbott, 1999; Tan and Kennedy, 1996; Elliot, 1985; Kennedy and Peterson, 1975.

Unconformity

30-28 Mya (Oligocene)

Otay Formation: alluvial fan deposits, facies (east to west) of angular (breccia) cobble conglomerate with light brown, medium to coarse-grained sandstone matrix (165 feet thick), white to light gray angular sand and pebble gritstone (130 feet thick) and brown, sandy claystone (115 feet thick) with interbeds (less than centimeter to more than one meter thick) of pink bentonite clays (weathered and chemically altered deposits of volcanic ash) and with interbeds of coarse, well-sorted sandstone (intrafan stream channel deposits); retrogradational depositional system, possibly formed during sea-level recovery from dramatic drop in late Oligocene; bentonite clays highly expansive, landslide prone; outcrops from Highway 94 to south of the border, east of La Nacion Fault, up through Proctor Valley to Jamul, easternmost exposures cap ridges 5 mi. southeast of Jamul; estimated to be up to 410 feet thick; dated **30-28 Mya**. Sources: Cleveland, 1960; Kennedy and Tan, 1977; Walsh and Deméré, 1991.

Unconformity

17-14 Mya (Miocene)

San Onofre Breccia: alluvial fan and fan delta deposits; coarsening upward sequence of coarse sandstone to muddy pebble to boulder conglomerate; clast types typically from metamorphic suite including glaucophane schist, greenschist, actinolite schist, amphibolite, serpentinite, quartzite; clasts typically up to 30 feet in size; slide blocks of schist exposed up to 0.6 mi. in length within Camp Pendleton; material shed from offshore islands composed of Catalina Schist (e.g. Santa Catalina Island); Catalina Schist formed in high pressure-low temperature shallow early-subduction setting; islands formed by extensional faulting; outcrops as far south as Oceanside Boulevard at Interstate 5; estimated to be up to 4500 feet thick in Camp Pendleton; dated **17-14 Mya**. Sources: Abbott, 1999; Cranham et al., 1994; Tan and Kennedy, 1996.

Unconformity

3-1.5 Mya (Pliocene to Early Pleistocene)

Tsd

San Diego Formation (southwestern County)/San Mateo Formation (coastal North County): shallow marine and nonmarine deposits; lower portion yellowish brown, fine-grained sandstone (deposited in shallow seawater); upper section light reddish brown, medium to coarse-grained sandstone and interbedded conglomerates (alluvial delta/fan deposit); San Diego Formation outcrops from south of International Border to southern La Jolla; estimated up to 280 feet thick; San Mateo Formation outcrops as far south as Highway 76 (Mission Avenue) at Interstate 5; estimated to be up to 450 feet thick near San Onofre (Camp Pendleton); dated **3-1.5 Mya**. Sources: Abbott, 1999; Cranham et al., 1994; Kennedy and Peterson, 1975; Kennedy and Tan, 1977; Tan and Kennedy, 1996.

Unconformity (locally conformable)

1.5-0.7 Mya (Early Pleistocene)

Lindavista Formation

Sources: Abbott, 1999; Tan and Kennedy, 1996; Kennedy and Tan, 1977; Kennedy and Peterson, 1975.

Terrace Facies: shallow marine and nonmarine (talus and slopewash) terrace deposits; deposited on currently raised 10 km-wide wavecut platform; typically consolidated, light brown to reddish brown, clean to silty, medium- to coarse-grained sand and gravels (typically derived from Poway Group) with localized interbeds of clayey sand and sandy clay (localized back-beach lagoonal deposits); characterized by ferruginous cementation (primarily hematite) which provides color and resistant nature; known for its cemented hardpan located below the B soil horizon; typically found from about 300 to 500 feet in elevation; mapped capping ridges from International Border to northern Carlsbad; the dominant near-surface geologic formation from East San Diego north to Kearny Mesa; up to 65 feet thick but generally less than 50 feet in thickness; dated **1.5-0.7 Mya**.

Beach Ridge Facies: primarily wind-blown and wave (swash zone) deposition, back-beach dunes at hesitation points (stillstands) of the regressing sea; generally cleaner sands and rare gravels; characterized by ferruginous cementation (primarily hematite) and ironstone concretions; typically about one-half km wide and 5 to 50 feet in height; forms prominent ridges paralleling coast along Clairemont, La Jolla, and Kearny Mesa; dated **1.5-0.7 Mya**.

Unconformity

0.8-0.01Mya (Late Pleistocene)

"Normal Heights Mudstone": tidal flat or lagoon deposit; medium gray, highly expansive, gypsiferous sandy clay; deposited on erosional surface of Lindavista Formation; basal contact elevations 290 to 390 ft; overlies Lindavista Formation from Highway 163 east to 54th Street and Interstate 8 south to about Morley Field (approximately 7.5 square miles); mudstone up to 13 feet thick; estimated **0.8-0.5 Mya** (based on correlated marine terraces). Source: Reed, 1991.

Unconformity

Bay Point Formation: shallow marine and nonmarine (talus and slopewash) deposits; deposited on currently raised wavecut platforms; typically poorly consolidated, light brown fine- to medium-grained, clean, silty and clayey sand with few interbeds of sandy clay; includes most terrace deposits found up to 200 feet in elevation: remnants overlying most coastal and near coastal areas; also found along margins of San Diego and Mission Bay and mouth of major river valleys (e.g. San Diego River, Soledad Valley, Penasquitos Canyon, Carmel Valley, San Dieguito Valley; uninvestigated maximum thickness, but on the order of 100 feet or more; dated **0.13-0.08 Mya**. Sources: Kennedy and Peterson, 1975; Kennedy and Tan, 1977; Tan and Kennedy, 1996.

River Terrace Deposits: fluvial terrace deposits; deposited on upstream terraces cut along edges of river/stream valleys when waters flowed above current levels (wetter climate, before uplift, or during higher sea levels); unconsolidated, light brown to reddish brown coarse sands and gravels; typically thin (less than 30 feet) remnants found along banks of most large stream and river valleys (Otay River north to Santa Margarita River); estimated **0.05-0.01 Mya**. Sources: Kennedy and Peterson, 1975; Kennedy and Tan, 1977.

Unconformity

0.01 Mya-Present (Holocene)

Natural Overburden Deposits: color and grain size related to source area, depositional environment and distance of transport.

Alluvium: fluvial deposits; detrital material deposited by action of rivers or streams; found underlying floodplain of most stream and river valleys; primarily unconsolidated sand and silt, sometimes with gravel and clay (overbank deposits); thickness typically related to valley width, ranging from a couple feet to over 200 feet.

Slopewash: terrestrial deposit; detrital material washed downslope by sheetflow; found on lower hillside areas and accumulates at the base of hillsides; often interfingered with alluvium on margins of stream/river valleys; poorly consolidated sand, silt and clay mix, sometimes with gravel; typically less than 30 feet in thickness.

Colluvium: terrestrial deposit; consists of weathered rock debris, which has moved downslope generally by creep; primarily unconsolidated sand, gravel and rock fragments; typically less than 30 feet in thickness.

Beach Deposits: nearshore marine (littoral) deposits; deposited by longshore drift and alluvial discharge from major stream courses; primarily unconsolidated sand and silt, locally underlain by cobble (shingle) beach; thickness seasonally variable, typically less than 25 feet.

Man-Placed Overburden Deposits

Fill: terrestrial and nearshore bay (reclaimed land) environments; all types of earth materials, typically generated from local sources; most placed for human development; compacted, uncompacted and hydraulic fills; thicknesses to 150 feet or more for deep canyon fills.

SOURCES

Abbott, Patrick L., 1999, *The Rise and Fall of San Diego*, Sunbelt Publications, San Diego, California.

Adams, Mark A., and Walawender, Michael J., 1982, **Structure and Stratigraphy of the Santiago Peak Volcanics East of Rancho Santa Fe, California**, in Abbott, Patrick L. (ed.), *Geologic Studies in San Diego*, Annual Field Trip Guidebook, San Diego Association of Geologists.

Cleveland, George, B., 1960, *Geology of the Otay Bentonite Deposit, San Diego County, California*, Special Report 64, California Division of Mines and Geology.

Cranham, Greg T., Camilleri, Phyllis A., and Jaffe, Glenn R., 1994, **Geologic Overview of the San Onofre Mountains, Camp Pendleton Marine Corps Base, San Diego County, California**, in Rosenberg, Phillip S. (ed.), *Geology and Natural History, Camp Pendleton United States Marine Corps Base, San Diego County, California*, Annual Field Trip Guidebook, San Diego Association of Geologists.

Elliot, William J., 1985, **Geology of the Morro Hill Area, Northwestern San Diego County, California**, in *On the Matter of Deposition of the Eocene Strata in Northern San Diego County*, Annual Field Trip Guidebook, San Diego Association of Geologists.

Gray, C.H., Jr., Morton, Douglas M., and Weber, F.H., Jr., 2002, *Geologic Map of the Corona South 7.5' Quadrangle, Riverside and Orange Counties, California*, Open File Report OF-02-021, U.S. Geological Survey.

Kennedy, Michael P., and Peterson, Gary L., 1975, *Geology of the San Diego Metropolitan Area, California*, Bulletin 200, California Division of Mines and Geology.

Kennedy, Michael P., and Tan, Siang S., 1977, *Geology of National City, Imperial Beach and Otay Mesa Quadrangles, Southern San Diego Metropolitan Area, California*, Map Sheet 29, California Division of Mines and Geology.

Reed, Leslie D., 1991, Normal Heights Mudstones: **A new Upper Pleistocene Marine Sedimentary Unit, San Diego, California**, in Hoobs, John H. (ed.), *Geotechnical Engineering Case Studies in San Diego County*, San Diego Association of Geologists.

Simpson, Gary S., and Abbott, Patrick L., 1996, **Volume of the Eocene Poway Alluvial Fan**, in Munasinghe, T., and Rosenberg, P. (eds.), *Geology and Natural Resources of Coastal San Diego County, California*, 1996 Annual Field Trip Guidebook, San Diego Association of Geologists.

Tan, Siang S., and Kennedy, Michael P., 1996, *Geologic Maps of the Northwestern Part of San Diego County, California*, Open File Report 96-02, California Division of Mines and Geology.

Walsh, Stephen L., and Deméré, Thomas A., 1991, **Age and Stratigraphy of the Sweetwater and Otay Formations, San Diego County, California**, in Abbott, P.L., and May, J.A. (eds.), *Eocene Geologic History, San Diego Region*, Guidebook 68, The Pacific Section of the Society of Economic Paleontologists and Mineralogists (SEPM).

Weber, F. Harold, Jr., 1963, *Geology and Mineral Resources of San Diego County, California*, County Report 3, California Division of Mines and Geology.

THE COASTAL GEOLOGY OF SAN DIEGO is explored in this guidebook, published for the San Diego Association of Geologists (SDAG) 2001 annual field trip under the supervision of Robert C. Stroh. Self-guiding road logs range throughout the coastal plain from San Ysidro to Sunset Cliffs/Point Loma via Otay Mesa, SDSU, Lake Jennings, Black Mountain, and the Torrey Pines/La Jolla coastline. Technical papers focus on coastal processes and engineering geology including landslides, beach erosion and bluff retreat, stratigraphy of western San Diego County, and geotechnical issues in the Peninsular Ranges.

ISBN # 0-916251-58-6

9 780916 251581

$25.00