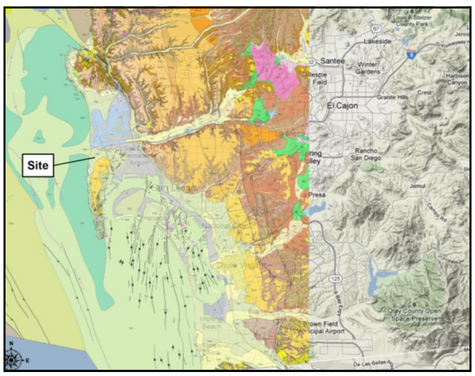
Geotechnical Desktop Study
Ocean Beach Community Plan Update
Programmatic EIR
San Diego, California



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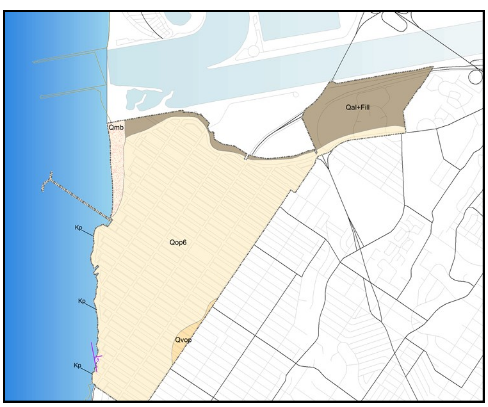

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The Bodhi Group Inc.
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February 2013
Project No. 9066001

The Bodhi Group

The Bodhi Group

Revised February 2013
Project No. 9066001

Mr. Brian Mooney
Senior Sustainability Specialist
Chambers Group, Inc.
9909 Huennekens Street, Suite 206
San Diego, CA 92121

Subject: Final Geotechnical Desktop Study
Ocean Beach Community Plan Update
Programmatic Environmental Impact Report
San Diego, California

Dear Mr. Mooney:

Please find attached the geotechnical desktop study in support of the Ocean Beach Community Plan Update Programmatic EIR. Our study summarizes the regional and local geology and focuses on the geologic hazards within the Community Plan area. We have included a map of the area geology and a geologic hazards map. This revised draft report addresses comments received from the City of San Diego on our draft report dated November 2012.

We appreciate this opportunity to provide our professional services. If you have any questions or require additional services, please do not hesitate to contact us.

Sincerely,

THE BODHI GROUP INC

W. Lee Vanderhurst, P.G., C.E.G.
Engineering Geologist

Sree Gopinath, P.E.
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1. INTRODUCTION

This report presents the results of our "desktop" evaluation of the geology underlying the Ocean Beach Community Plan area (Site, shown on Figure OBGEO – 1). The purpose of our evaluation was to identify geologic conditions or hazards that might affect the proposed Ocean Beach Community Plan Update.

For this study, we reviewed relevant published geologic maps, State issued geologic hazard maps, the City of San Diego Seismic Safety Study Geologic Hazard and Fault maps, and the City of San Diego Guidelines for Geotechnical Reports. The relevant geologic hazards listed in the "Guidelines for Geologic/Seismic Consideration in Environmental Impact Reports," California Geological Survey (California Division of Mines and Geology) Note 46 and "Guidelines for Preparing Geologic Reports for Regional-Scale Environmental and Resource Management Planning," California Geological Survey (California Division of Mines and Geology) Note 52, are addressed. The study focused on the geologic hazards within the Site consistent with the geologic hazard categories identified in the San Diego Seismic Safety Study maps.

We have included a map of the Site geology showing distribution of surficial deposits and geologic units (Figure OBGEO – 2). A separate geohazards map is presented as Figure OBGEO – 3 identifying areas susceptible to the potential geologic hazards described in this report, including but not limited to areas prone to soil liquefaction, and other relevant hazards. As required by our contracted scope, the figures are presented with a scale of 1"=800'. Also, in accordance with our scope, we are transmitting this report in electronic Portable Document Format, the text as a Word file, and the shapefiles by email.

2. SITE DESCRIPTION

The Site is located in the western central portion of the City of San Diego, at the northern end of Point Loma (Figure OBGEO – 1). The Site is bound to the east by Froude Street, to the south by Adair Street, to the west by the Pacific Ocean and to the north by the San Diego River. The southwestern edge of the area is characterized by steep ocean bluffs up to 20-feet high. West of Point Loma Avenue, the Site is relatively flat ranging from nearly sea level to 60 feet above sea level. The Site rises gently east of Ebers Street between Newport Avenue and Pescadero Avenue. The northern portion of the Site is located in a portion of the San Diego River basin that has been filled to create level parks and building areas. The Site is occupied by residential and commercial buildings, paved and unpaved streets, parks, schools and other public buildings. Structures are generally less than 3 stories high and are of light construction.

3. PROPOSED UPDATE TO THE COMMUNITY PLAN

The Update would rezone 99 parcels (approximately 21 acres) from residential single unit zones with a minimum of 5,000-square feet lots (RS-1-7) to residential multiple units with a maximum density of 1 dwelling unit for each 3,000 square feet lot area (RM-1-1). The existing zone allows for single dwelling unit (du) density of 9/du per acre for a maximum build out of approximately 189 units. The Update would change the zoning to allow up to 15/du per acre and would result in the maximum build out of approximately 315 units, or a net increase of 126 dwelling units. In total, the Update could accommodate an additional 1,399 dwelling units (Cecilia Gallardo, 2011). The goals of the plan are as follows:

- Maintain the low-medium density residential nature of neighborhoods in Ocean Beach.
- Encourage sensitive development and small-scale character for mixed-use residential/commercial development within commercial districts.

- Support transitional housing uses in Ocean Beach.
- Provide housing for all economic levels.
- Protect and enhance commercial areas.
- Maintain, protect, enhance, and expand park facilities, open spaces, and institutional uses for the benefit of residents and future generations.

4. GEOLOGY

The Ocean Beach Community Plan area is located within the Peninsular Ranges Geomorphic Province of California. This province is characterized by rugged north-south trending mountains separated by subparallel faults, and a coastal plain of subdued landforms underlain by Mesozoic and Cenozoic sedimentary formations. The Site is located within coastal plain portion of the province. The Site is underlain at depth by the Cretaceous Point Loma Formation, Pleistocene Very Old Paralic sediments in the low hills and Old Paralic Unit 6 in the flat lying central portion of the area. Quaternary beach sand, alluvium and fill overlie the older sediments along the northern and northwestern margins of the area. The regional geology showing mapped geology in the Site vicinity is shown on Figure OBGEO – 1, modified from Kennedy and Tan (2008). The distribution of geologic units at the Site is shown on Figure OBGEO – 2.

Southern California is dominated by right-lateral active faulting and San Diego is no exception. The Rose Canyon fault is located 6 kilometers east of Ocean Beach (Figure OBGEO – 1). The fault is responsible for lifting Mount Soledad and creating the basin known today as San Diego Bay. There are two large active faults off shore from Ocean Beach; the Coronado Banks and San Diego Trough. There are no known active faults (faults that show evidence of movement in the last 11,000 years) at the Site. The nearest Quaternary fault (a fault that shows evidence of movement in the last 2.5million years, but not in the last 11,000 years) is the Point Loma fault (Figure OBGEO – 3).

Groundwater conditions at the Site are highly variable. Throughout most of the central and northern portions of the Site, the groundwater is controlled by sea level and the flood level of the San Diego River. To the south and east, groundwater is controlled by the relatively impermeable Point Loma Formation. Groundwater, primarily from local irrigation, percolates downward through the Very Old Paralic sediments and Old Paralic Unit 6 sediments and becomes perched on the Point Loma Formation. Due to the gentle westward tilt of the old wave cut terrace, the groundwater eventually migrates to the coastal bluffs where it can be observed as seeps in the cliff faces. Geologic units that underlie the Site, from oldest to youngest, are described below.

4.1. Point Loma Formation (Map Symbol - Kpl)

The Cretaceous Point Loma Formation is anticipated to underlie the Site at depth and is exposed in the coastal bluffs from the Ocean Beach Pier to the southern boundary of the Site (Figure OBGEO – 2). The Point Loma Formation is composed of very dense marine sandstone and very hard clay and siltstone. The formation has a gentle north east dip which is generally favorable for slope stability. However, the formation is jointed and contains numerous steeply dipping inactive faults that can erode when attacked by waves in coastal bluffs. The Point Loma Formation is overlain by the mid to late Pleistocene Old Paralic Unit 6 sediments.

4.2. Quaternary Very Old Paralic Deposits (Map Symbol - Qvop)

Early to middle Pleistocene estuarine, beach, alluvial and colluvial deposits overlies the Point Loma Formation in the gentle hills east of Ebers Street (Figure OBGEO – 2). These sediments were deposited on a wave cut terrace cut into the Point Loma Formation. This formation was formerly mapped as the Linda Vista Formation and is composed of reddish brown poorly indurated sandstone, mudstone and conglomerate. The Very Old Paralic deposits are relatively incompressible and perform well in slopes protected from erosion. Where unprotected, these sediments are susceptible to erosion.

4.3. Old Paralic Unit 6 (Map Symbol - Qop6)

Late to middle Pleistocene estuarine, alluvial and colluvial deposits overlie the Point Loma Formation throughout most of the Site (Figure OBGEO – 2). Unit 6 is composed of poorly bedded, dense clayey sand, clay and conglomerate. The sediments are relatively incompressible under light building loads and are not susceptible to slope instabilities if exposed in low (10 feet or less) slopes inclined no steeper than 2:1 (horizontal to vertical). Where unprotected, slopes in this unit are susceptible to erosion.

4.4. Holocene Marine Beach Sand (Map Symbol Qmb)

Unconsolidated medium to fine grained sand has been deposited along the beach between the Ocean Beach Pier and the south jetty of the San Diego River. The sand is susceptible to erosion due to waves or running water.

4.5. Alluvium and Fill (Map Symbol Qal + Fill)

Alluvium associated with the San Diego River is located between West Point Loma Boulevard and the San Diego River Jetty. The alluvial sediment is composed of unconsolidated and predominately silty fine sand. The alluvial sediments are mixed with unconsolidated fills dredged during the channelization of the San Diego River and fills placed for building pads.

5. GEOLOGIC HAZARDS

According to the City of San Diego Seismic Safety Study (1995), the Site is susceptible to a number of geologic hazards. The geohazards map (Figure OBGEO – 3) depicts the various hazards and their anticipated locations. The geologic hazard boundaries nearly always coincide with geologic unit contacts. The number designations on the map correspond to designations from the City of San Diego Seismic Safety Study. In addition to the hazards identified in the City of San Diego Seismic Safety Study, seismic shaking from earthquakes and tsunami inundation have been included as geologic hazards that should be considered for the Site.

5.1. Seismicity and Ground Motion

The Site will be subject to hazards caused by ground shaking during seismic events on regional active faults. Figure OBGEO – 4 shows the locations of known active faults within 100 kilometers of the Site. The centroid of the Site is located at about latitude 32.7452º north and longitude 117.2468º west in the North American Datum of 1983 in decimal degree coordinates. Commercially-available computer software was used to evaluate potential seismicity at the Site. These programs determine the distance between the Site centroid and known faults. Table 1 summarizes the properties of these faults based on the program EQFAULT and supporting documentation (Blake, 2000). EQFAULT was used to perform a deterministic seismic analysis of known active faults within 100 kilometers of the Site.

Deterministic analysis is conducted by assuming that each fault will rupture at the nearest distance to the Site. The results do not have substantial statistical significance, but they are useful for indicating the relative contribution of each of the nearby faults to the total seismic risk at the Site.

The program FRISKSP was also used to perform a probabilistic seismic hazard analysis for the Site. The analysis was conducted using the characteristic earthquake distribution of Youngs and Coppersmith (1985). Based on the results of our probabilistic analyses, the peak ground accelerations with a 2, 5 and 10 percent probability of being exceeded in a 50 year period are 0.55g, 0.41g and 0.31g, respectively. The identified levels of risk are often referred to as the Maximum Considered, Upper Bound and Design Basis Earthquakes, respectively. By comparison, the California Building Code (United States Geological Survey [USGS] Seismic Hazard Curves and Uniform Response Spectra) indicates that the Peak Ground Acceleration for the Site is 0.39g.

The program EQSEARCH (Blake, 2000) was used to evaluate historical seismicity. The results of EQSEARCH indicate that 19 historical earthquakes of magnitude 5.0 or greater have occurred within 100 km of the Site in the last 206 years. These earthquakes were estimated to have produced peak ground accelerations (PGA) of up to roughly 0.23g at the Site.

5.2. Surface Rupture

Surface rupture is the result of movement on an active fault reaching the surface. Figure OBGEO – 4 shows the Site in relation to known active faults in the region. The nearest previously mapped named fault to the site is the Point Loma fault located in the northeastern portion of the Site, roughly underlying Nimitz Boulevard (Figures OBGEO – 2 and 3). The Point Loma fault has geomorphic expression and is reported to offset geologic units of Pleistocene age, but is not known to offset sediments or soils of Holocene age. As a result, the fault is considered potentially active fault and the City of San Diego will require additional investigation for structures constructed within the fault buffer zone. The nearest known active fault is the Rose Canyon fault zone, which is located about 6 kilometers east of the Site based on City of San Diego (1995) fault maps. There are no known active faults underlying, or projecting toward the Site. The Site is not located within an Alquist-Priolo Earthquake Fault Zone. In our opinion, the probability of surface rupture due to faulting beneath the Site is negligible.

5.3. Liquefaction (Geologic Hazard Map Symbol 31)

Liquefaction is a process in which soil grains in saturated sand or silt deposits lose contact due to earthquakes or other sources of ground shaking. The soil deposit temporarily behaves as a viscous fluid; pore pressures rise, and the strength of the deposit is greatly diminished. Liquefaction is often accompanied by sand boils, lateral spread, and post-liquefaction settlement as the pore pressures dissipate. Liquefiable soils typically consist of cohesionless sands and silts that are loose to medium dense, and saturated. To liquefy, soils must be subjected to ground shaking of sufficient magnitude and duration. The geologic conditions susceptible to liquefaction at the Site are in the low lying areas north of West Point Loma Boulevard. Ground failure and lateral spreading could occur in the residential area in the northeast corner of the planning area if the ground was not sufficiently prepared prior to grading and construction of buildings.

5.4. Stable Beach Sand (Geologic Hazard Map Symbol 48)

Beach sand is relatively stable but is subject to rapid erosion due to storm waves, flooding and tsunamis. The beach at Ocean Beach is somewhat protected from long shore currents by the South Mission Bay Jetty. Annual sand movement is generally onshore during the summer months and off shore during the winter months. The beach is replenished periodically by floods in the San Diego River. These factors have created a relatively stable over-all sand budget. Localized erosion and flooding do occur during winter storms when the sand has migrated off-shore. The combination of storm waves, storm surge and high tides have and will continue to flood the low lying areas of Ocean Beach immediately adjacent to the beach. If global sea levels rise in the future, flooding may become more frequent.

5.5. Coastal Bluff Retreat (Geologic Map Symbol 43)

Coastal bluff erosion and subsequent retreat in the Sunset Cliffs area of Point Loma are well documented. The main factors causing bluff erosion are geologic structure and sea level. Wave action attacks weak points (faults, fractures, and joints) in the Point Loma Formation causing localized increased erosion. Over time, the erosion grows to the point where the overlying Old Paralic Unit 6 sediments are undercut and fail resulting in a landward migration of the bluff top. Where the Point Loma Formation has not been affected by faulting, fracturing, or jointing, bluffs are quite stable. Sea level affects wave attack by controlling how and where waves break. At higher levels (such as high tide) waves can beat against the bluffs without breaking. This causes a piston-like action on the bedrock and is much more damaging than waves that have broken further to sea. Sea levels have been documented to have risen 10 centimeters in the last 70 years (Spaulding and Crampton, 2001). If this trend continues, the forces acting on the bluffs will increase as well.

Retreat rates are highly variable. When failures do occur, they are episodic and often catastrophic. An annualized rate of 0.75 to 1.5 inches has been shown for parts of the Sunset Cliffs just south of the Site (Spaulding and Crampton, 2001). It should be noted that the mode of failure consists of an initial collapse that causes retreat measured in feet followed by years of quiescence.

5.6. Stable Geology (Geologic Hazards Map Symbol 52)

A majority of the Site is designated as having a low risk for geologic hazards (Figure OBGEO –3). The area with map symbol 52 has low topographic relief, which minimizes slope stability hazards or erosion. However, slopes steeper than 2:1 (horizontal : vertical) and higher than 8 feet may be subject to erosion, or instability due to adverse drainage or geologic structure and will require specific geotechnical investigation to evaluate slope stability The soils underlying this area are relatively well consolidated and are not typically subject to settlement, subsidence, or liquefaction.

5.7. Tsunami Inundation, Flooding

The California Geologic Survey issued tsunami inundation maps for the coastal portions of California in 2009 (CGS, 2009). The inundation line for the La Jolla 7.5 Minute Quadrangle has been reproduced on the geohazards map (Figure OBGEO – 3). The line is based on an elevation where a reasonable estimated event may extend. Source events include nearby offshore faults, submarine landslides and distant (worldwide) seismic sources. There is no probability assigned to this run-up line. FEMA does not show the Site within a 100 year flood zone.

6. CONCLUSIONS

Based on the results of our study, it is our opinion that none of the proposed Updates to the Ocean Beach Community Plan will have direct or indirect significant environmental effects with regard to geologic hazards. Liquefaction and flood prone areas should continue to be used for parks and open spaces. More intense use of these areas, such as new structures, will require additional geotechnical investigation to provide mitigation measures. We recommend that the following items be considered in the updated plan.

6.1. General Development and Construction

Development and new construction should conform to the standards and conditions set forth by the City of San Diego. Conformance will mitigate seismic shaking hazards, liquefaction and slope stability hazards to currently accepted levels. Additions to existing structures should also follow the standards and conditions set forth by the City of San Diego.

6.2. Tsunami Inundation

Emergency exit signs should be posted in the tsunami inundation area. Emergency personnel (police, fire and lifeguards) should be aware of the inundation area and have plans for evacuation in the event of a tsunami.

6.3. Coastal Bluff Erosion

Development or new construction should be in accordance with Coastal Bluffs and Beach Guidelines (City of San Diego, 2000) and should include a specific geotechnical investigation of the coastal bluffs both on and off the property that might affect the stability of new construction. The coastal bluffs in Ocean Beach are considered Sensitive Coastal Bluffs and therefore encompass property within 100 feet of the bluff edge. Construction within that area is subject to the Coastal Bluffs and Beach Guidelines. The Guidelines recommend a 40-foot setback from the bluff edge for grading and construction of primary and accessory buildings. If geotechnical analysis can demonstrate stable conditions, then smaller setbacks may be permitted. Seismic loading should be considered in stability calculations within the Old Paralic Unit 6 soils.

7. LIMITATIONS

This report was prepared in general accordance with current regulatory guidelines and the standard-of-care exercised by professionals preparing similar documents in the project area. No warranty, expressed or implied, is made regarding the professional opinions presented in this document. Variations in Site conditions will exist and conditions not observed or described in this document could be encountered during subsequent activities and site work. Please also note that this document did not include an evaluation of environmental hazards.

The conclusions, opinions, and recommendations as presented in this document, are based on a desktop analysis of data, some of which were obtained by others. The data, as a whole, support the conclusions and recommendations presented in the report.

Site conditions will change with time as a result of natural processes and the activities of man at the Site or nearby sites. In addition, changes to the applicable laws, regulations, codes, and standards of practice may occur due to government action or the broadening of knowledge. The findings of this document may, therefore, be invalidated over time, in part or in whole.

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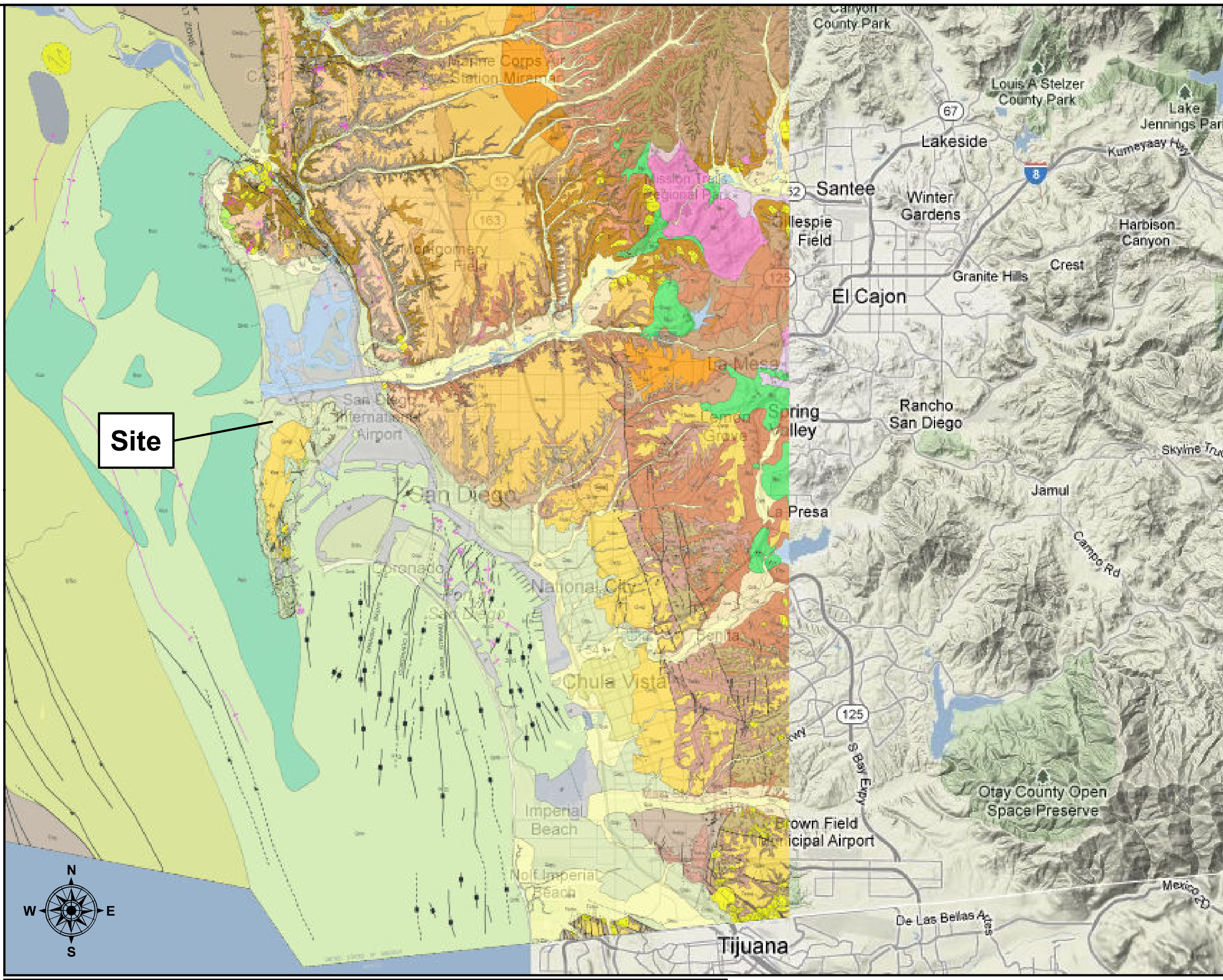
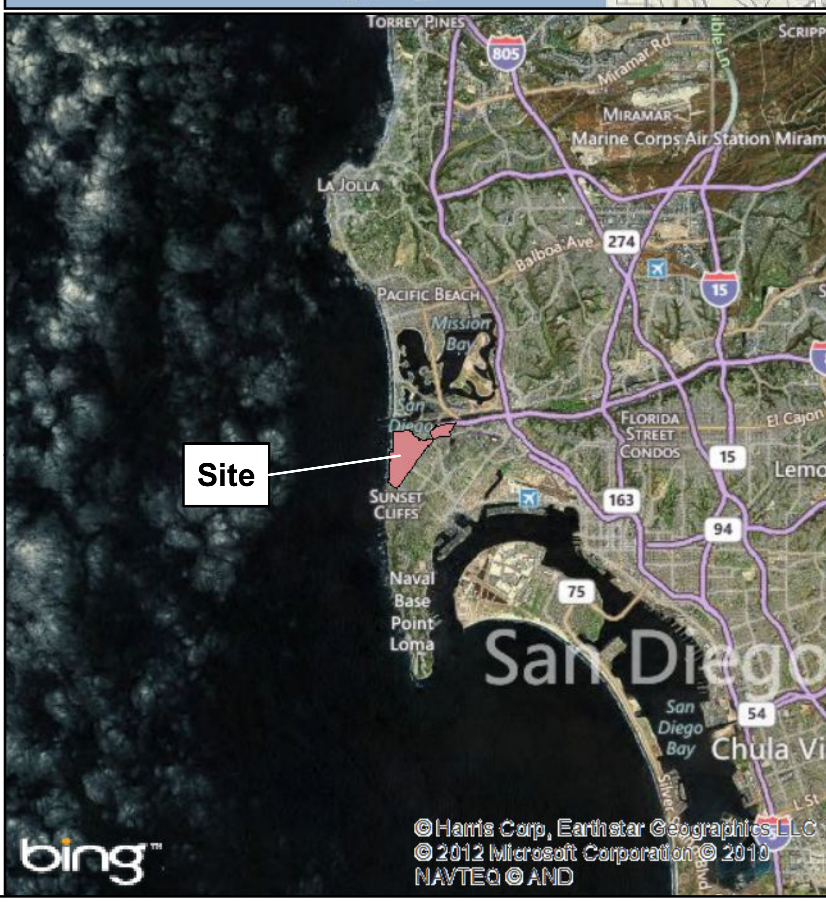
Figures





Note: The maps are not to scale.
Explanation of the geology features in the regional geology map is provided as an attachment to the report.

Source: State of California, Department of Conservation
Geology Map of the San Diego Quadrangle
quake.ca.gov/gmaps/RGM/sandiego/sandiego.html

THE CITY OF SAN DIEGO
Ocean Beach Community Plan
DRAFT
Regional Geology and Site Vicinity Map

Figure OBGEO-1

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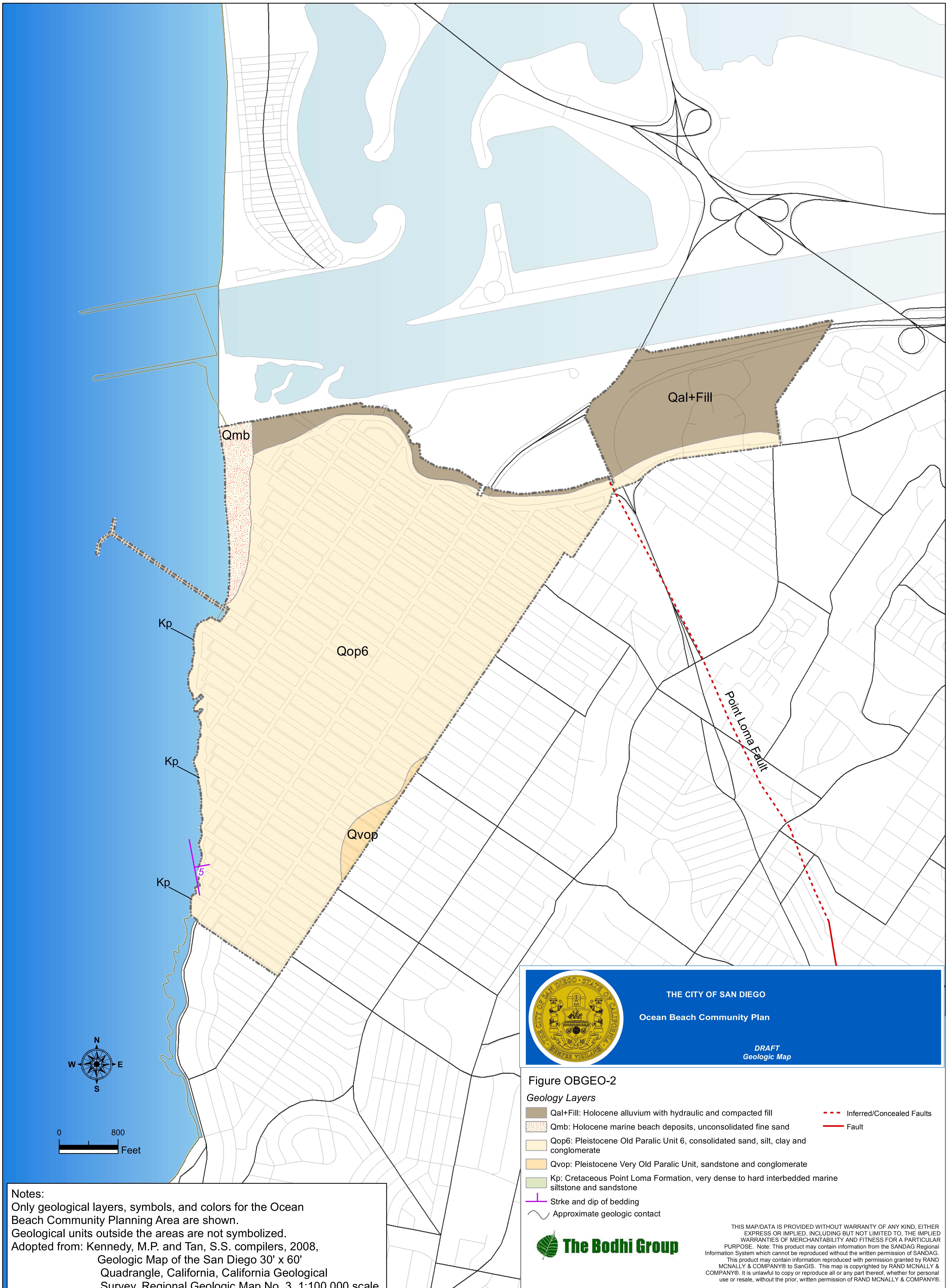
Qal+Fill
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THE CITY OF SAN DIEGO
Ocean Beach Community Plan
DRAFT
Geologic Map
Figure OBGEO-2
Geology Layers
Qal+Fill: Holocene alluvium with hydraulic and compacted fill
Qmb: Holocene marine beach deposits, unconsolidated fine sand
Qop6: Pleistocene Old Paralic Unit 6, consolidated sand, silt, clay and conglomerate
Qvop: Pleistocene Very Old Paralic Unit, sandstone and conglomerate
Kp: Cretaceous Point Loma Formation, very dense to hard interbedded marine siltstone and sandstone
Strke and dip of bedding
Approximate geologic contact
Inferred/Concealed Faults
Fault
The Bodhi Group
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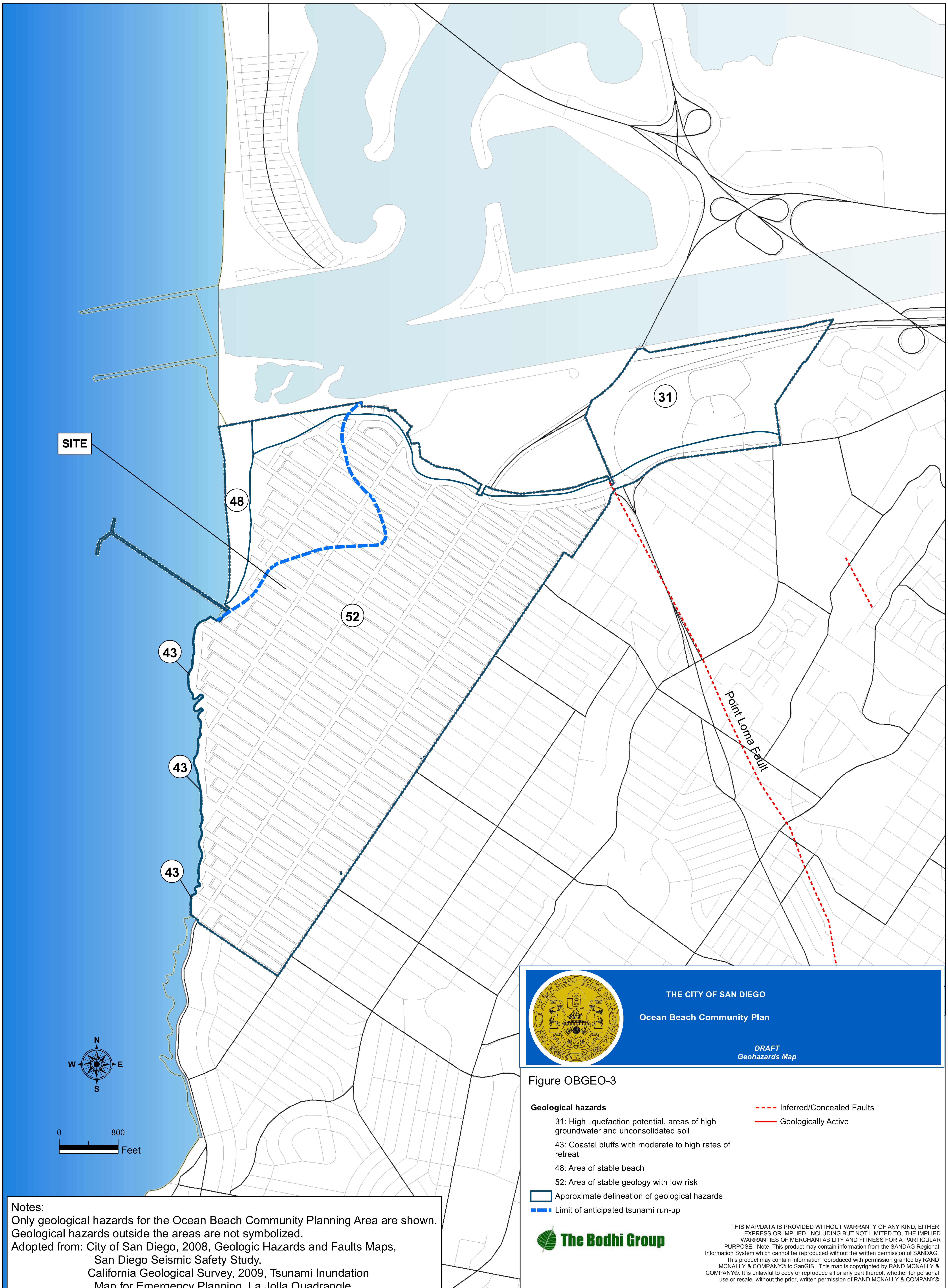
Notes:
Only geological layers, symbols, and colors for the Ocean Beach Community Planning Area are shown.
Geological units outside the areas are not symbolized.
Adopted from: Kennedy, M.P. and Tan, S.S. compilers, 2008, Geologic Map of the San Diego 30' x 60' Quadrangle, California, California Geological Survey, Regional Geologic Map No. 3, 1:100,000 scale.



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THE CITY OF SAN DIEGO
Ocean Beach Community Plan
DRAFT
Geohazards Map
Figure OBGEO-3
Geological hazards
31: High liquefaction potential, areas of high groundwater and unconsolidated soil
43: Coastal bluffs with moderate to high rates of retreat
48: Area of stable beach
52: Area of stable geology with low risk
Approximate delineation of geological hazards
Limit of anticipated tsunami run-up
Inferred/Concealed Faults
Geologically Active
The Bodhi Group
Notes:
Only geological hazards for the Ocean Beach Community Planning Area are shown.
Geological hazards outside the areas are not symbolized.
Adopted from: City of San Diego, 2008, Geologic Hazards and Faults Maps,
San Diego Seismic Safety Study.
California Geological Survey, 2009, Tsunami Inundation
Map for Emergency Planning, La Jolla Quadrangle.
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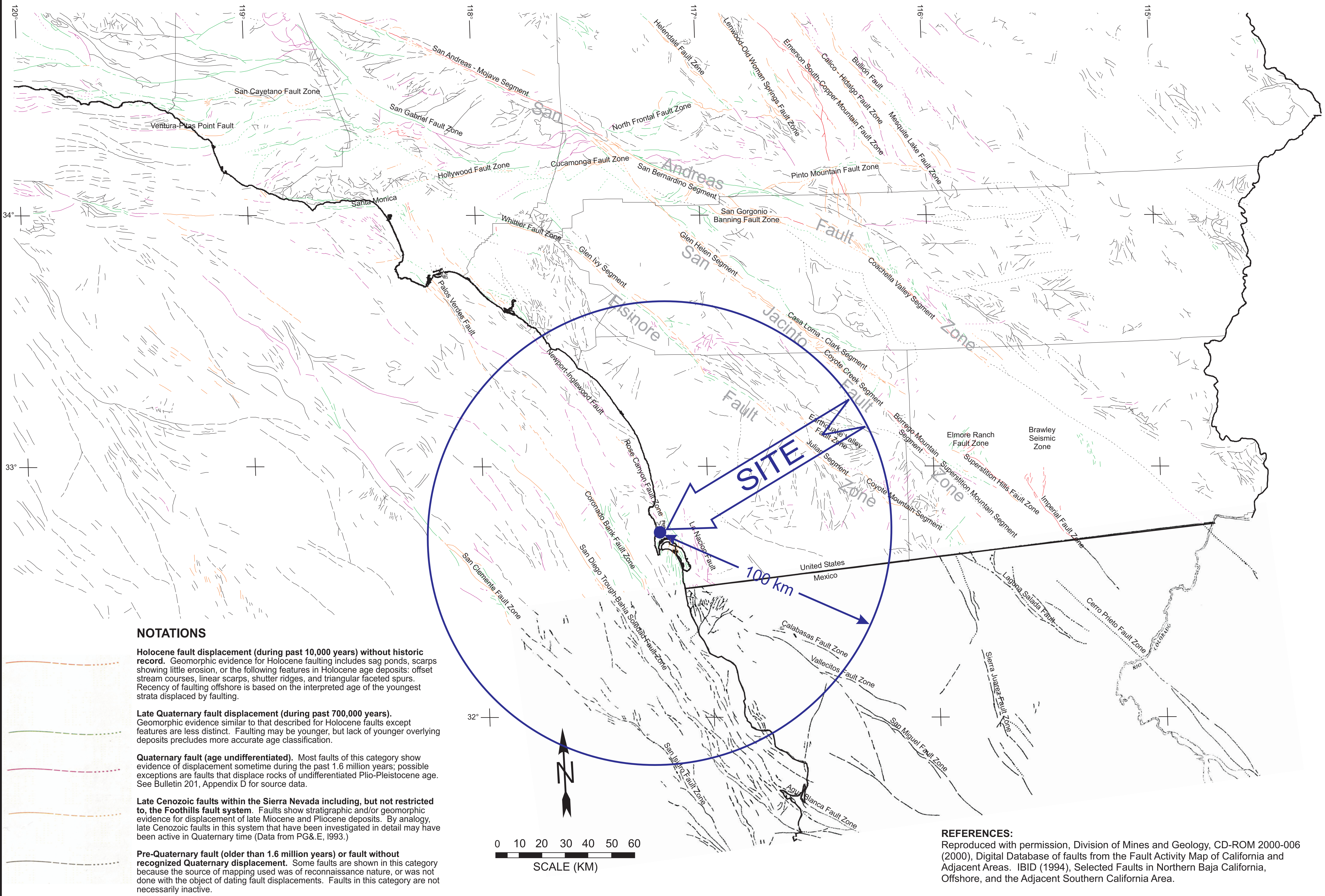
Figure OBGEO - 4

FAULT LOCATION MAP



NOTATIONS

Holocene fault displacement (during past 10,000 years) without historic record. Geomorphic evidence for Holocene faulting includes sag ponds, scarps showing little erosion, or the following features in Holocene age deposits: offset stream courses, linear scarps, shutter ridges, and triangular faceted spurs. Recency of faulting offshore is based on the interpreted age of the youngest strata displaced by faulting.

Late Quaternary fault displacement (during past 700,000 years). Geomorphic evidence similar to that described for Holocene faults except features are less distinct. Faulting may be younger, but lack of younger overlying deposits precludes more accurate age classification.

Quaternary fault (age undifferentiated). Most faults of this category show evidence of displacement sometime during the past 1.6 million years; possible exceptions are faults that displace rocks of undifferentiated Plio-Pleistocene age. See Bulletin 201, Appendix D for source data.

Late Cenozoic faults within the Sierra Nevada including, but not restricted to, the Foothills fault system. Faults show stratigraphic and/or geomorphic evidence for displacement of late Miocene and Pliocene deposits. By analogy, late Cenozoic faults in this system that have been investigated in detail may have been active in Quaternary time (Data from PG&E, l993.)

Pre-Quaternary fault (older than 1.6 million years) or fault without recognized Quaternary displacement. Some faults are shown in this category because the source of mapping used was of reconnaissance nature, or was not done with the object of dating fault displacements. Faults in this category are not necessarily inactive.

REFERENCES:

Reproduced with permission, Division of Mines and Geology, CD-ROM 2000-006 (2000), Digital Database of faults from the Fault Activity Map of California and Adjacent Areas. IBID (1994), Selected Faults in Northern Baja California, Offshore, and the Adjacent Southern California Area.

The Bodhi Group

Tables

FAULT[1]	DISTANCE TO SITE [KM]	ESTIMATED PEAK GROUND ACCELERATION[2]	MAXIMUM EARTHQUAKE MAGNITUDE[3,5]	ESTIMATED FAULT AREA[4] [CM^2]	SHEAR MODULUS[4] [$DYNE/CM^2$]	ESTIMATED SLIP RATE[4] [MM/YEAR]
Rose Canyon	6	0.41	7.2	9.10E+12	3.30E+11	1.5
Coronado Bank	15	0.31	7.6	2.41E+13	3.30E+11	3.0
San Diego Trough	32	0.20	7.7	3.00E+13	3.30E+11	2.0
Newport-Inglewood (Offshore)	49	0.09	7.1	8.58E+12	3.30E+11	1.5
San Clemente	62	0.13	8.1	6.00E+13	3.30E+11	4.0
Elsinore (Julian)	69	0.06	7.1	1.14E+13	3.30E+11	5.0
Elsinore (Temecula)	74	0.05	6.8	6.45E+12	3.30E+11	5.0
Earthquake Valley	79	0.03	6.5	3.00E+12	3.30E+11	2.0
Elsinore (Coyote Mountain)	86	0.04	6.8	5.85E+12	3.30E+11	4.0
Palos Verdes	88	0.05	7.3	1.25E+13	3.30E+11	3.0
San Joaquin Hills	98	0.03	6.6	4.30E+12	3.60E+11	0.5

1. Fault activity determined by Blake (2000), CDMG (1992), Wesnousky (1986), and Jennings (1994).
2. Median peak horizontal ground accelerations (in g's) from Sadigh et al (1997) for Rock Sites for the Maximum Earthquake Magnitude.
3. Moment magnitudes determined from CDMG (2003), Blake (2000), Wesnousky (1986) and Anderson (1984).
4. Estimated fault areas, shear moduli, and slip rates after fault data for EQFAULT and FRISKSP, Blake (2000).
5. The Maximum Earthquake Magnitude is the estimated median moment magnitude that appears capable of occuring given rupture of the entire estimated fault area.

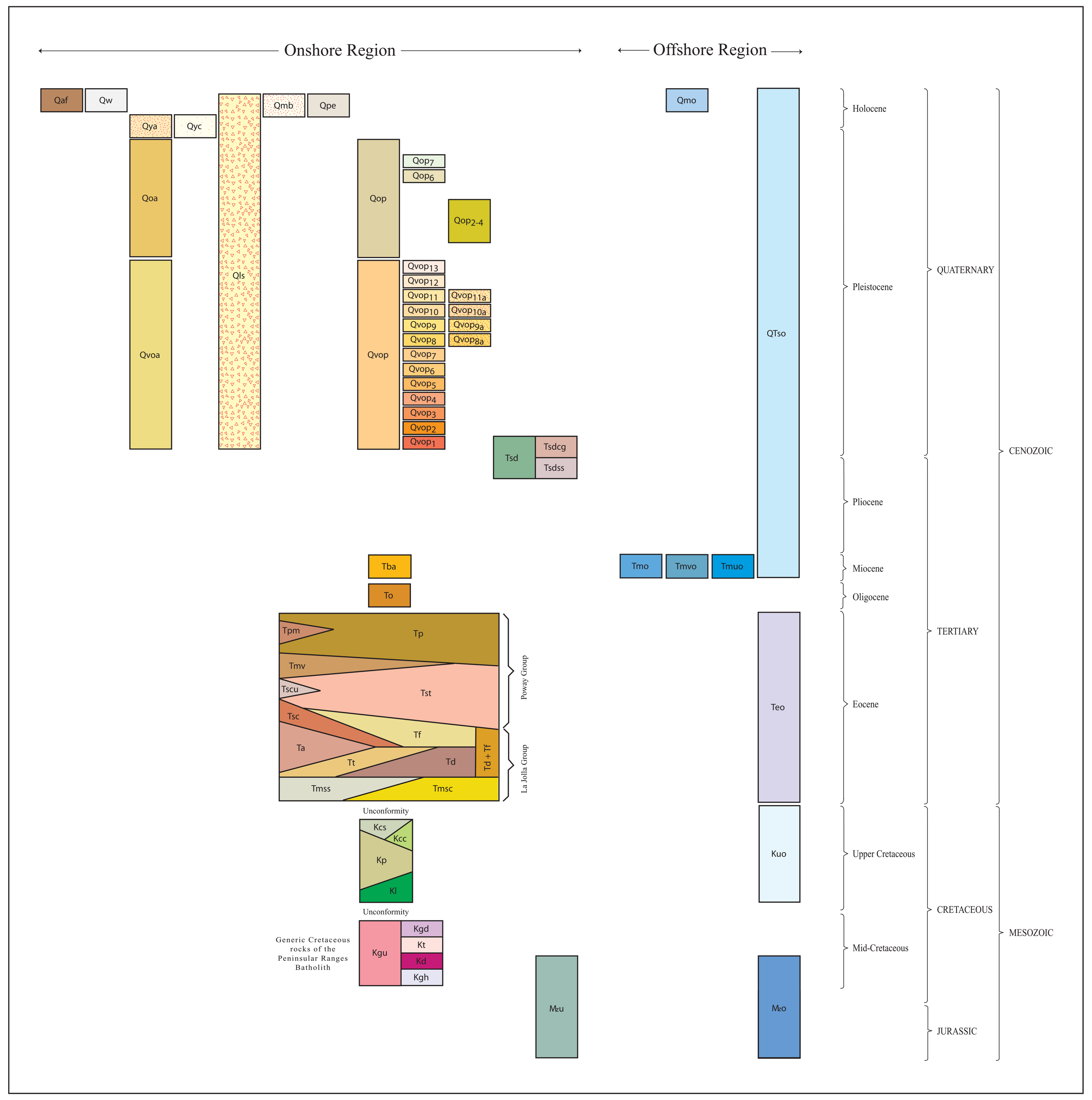
DETERMINISTIC SEISMIC HAZARD ANALYSIS

TABLE 1

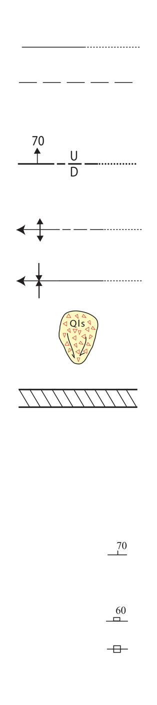
Appendix A

Correlation of Map Units and Description of Map Units for the Geologic Map of the San Diego 30' x 60' Quadrangle, California (Kennedy and Tan, 2008)

CORRELATION OF MAP UNITS



ONSHORE MAP SYMBOLS



Contact—Contact between geologic units; dotted where concealed.

Contact—Contact between paralic deposits and their associated marine abrasion platforms. This contact is approximate and generally buried by 1-5 m of marine and/or nonmarine sediment.

Fault—Solid where accurately located; dashed where approximately located; dotted where concealed. U = upthrown block, D = downthrown block. Arrow and number indicate direction and angle of dip of fault plane.

Anticline—Solid where accurately located; dashed where approximately located; dotted where concealed. Arrow indicates direction of axial plunge.

Syncline—Solid where accurately located; dotted where concealed. Arrow indicates direction of axial plunge.

Landslide—Arrows indicate principal direction of movement.

Fault Zone—Area of extensively sheared rock within a zone defined by multiple faults.

Strike and dip of beds

Inclined

Strike and dip of igneous joints

Inclined

Vertical

Strike and dip of metamorphic foliation

Inclined

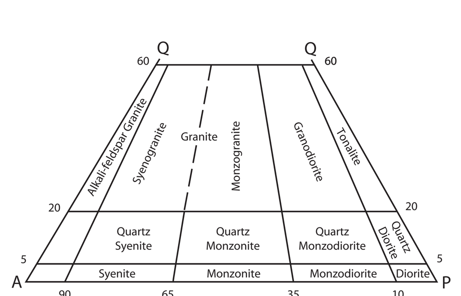


Figure 1. Classification of plutonic rock types (from IUGA, 1973, and Streckeisen, 1973). A, alkali feldspar; P, plagioclase feldspar; Q, quartz.

OFFSHORE MAP SYMBOLS

Contact

Contact—All contacts are extrapolated from a combination of seismic reflection data, samples and bathymetry, and are approximate in location.

Fault

Fault—Solid where well defined; dashed where inferred. Where fault offsets sea floor, age symbol is shown on bar on downthrown side. Where age was determined, age symbol is shown beside fault and relative offset if known is shown by "D" and "U" on downthrown and upthrown sides. Ages of faults are indicated as follows.

cuts strata of Holocene age
cuts strata of Quaternary age
cuts strata of Miocene age or older
cuts strata of late Tertiary and Quaternary age

Fault Zone—Area of extensively sheared rock within a zone defined by multiple faults.

Folds

Anticline—Solid where well defined, dashed where inferred.

Syncline—Solid where well defined, dashed where inferred.

Landslides

Creep—Dashed where inferred.

Creep (noted on single survey line)—Arrow indicates apparent direction of sediment movement.

Slump—Dashed where inferred, queried where uncertain. Arrows indicate direction of movement.

Erosional scarp—Solid where well defined, dashed where inferred. Generally associated with active channels.

Channels and levees

Active Channel—Dash-dot line marks axis, arrow indicates direction of paleo-sediment transport.

Levees—Dashed where inferred.

Correlation of Map Units and Description of Map Units
for the

Geologic Map of the San Diego 30' X 60' Quadrangle, California

Compiled by
Michael P. Kennedy and Siang S. Tan

2005

Digital Preparation by
Kelly R. Bovard[1], Anne G. Garcia[1] and Diane Burns[1]

1. U.S. Geological Survey, Department of Earth Sciences, University of California, Riverside

DESCRIPTION OF MAP UNITS

MODERN SURFICIAL DEPOSITS—Sediment that has been recently transported and deposited in channel and washes, on surfaces of alluvial fans and alluvial plains, and on hill slopes and in artificial fills. Soil-profile development is non-existent. Includes:

Qaf **Artificial fill (late Holocene)—**Deposits of fill resulting from human construction, mining, or quarrying activities; includes compacted engineered and non compacted non engineered fill. Some large deposits are mapped, but in some areas no deposits are shown

Qw **Wash deposits (late Holocene)—**Unconsolidated bouldery to sandy alluvium of active and recently active washes

Qls **Landslide deposits undivided (Holocene and Pleistocene)—**Highly fragmented to largely coherent landslide deposits. Unconsolidated to moderately well consolidated. Most mapped landslides contain scarp area as well as slide deposit. Many Pleistocene age landslides were reactivated in part or entirely during late Holocene

Qmb **Marine beach deposits (late Holocene)—**Unconsolidated beach deposits consisting mostly of fine- and medium-grained sand

Qpe **Paralic estuarine deposits (late Holocene)—**Unconsolidated estuarine deposits. Composed mostly of fine-grained sand and clay

Qmo **Undivided marine deposits in offshore region (late Holocene)—**Unconsolidated, often ponded, marine sediments. Composed mostly of very fine- to medium-grained sand and silt

YOUNG SURFICIAL DEPOSITS—Sedimentary units that are slightly consolidated to cemented and slightly to moderately dissected. Alluvial fan deposits typically have high coarse-fine clast ratios. Young surficial units have upper surfaces that are capped by slight to moderately developed pedogenic-soil profiles. Includes:

Qya **Young alluvial flood plain deposits (Holocene and late Pleistocene)—**Mostly poorly consolidated, poorly sorted, permeable flood plain deposits

Qyc **Young colluvial deposits (Holocene and late Pleistocene)—**Mostly poorly consolidated and poorly sorted sand and silt slope wash deposits

OLD SURFICIAL DEPOSITS—Sediments that are moderately consolidated and slightly to moderately dissected. Older surficial deposits have upper surfaces that are capped by moderate to well-developed pedogenic soils. Includes:

Qoa **Old alluvial flood plain deposits undivided (late to middle Pleistocene)—**Fluvial sediments deposited on canyon floors. Consists of moderately well consolidated, poorly sorted, permeable, commonly slightly dissected gravel, sand, silt, and clay-bearing alluvium

Qop **Old paralic deposits undivided (late to middle Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the now emergent wave cut abrasion platforms preserved by regional uplift. Where more than one number is shown (e.g., Qop_{2-4}), those deposits are undivided (Fig. 3). Includes:

Qop_7 **Old paralic deposits, Unit 7 (late to middle Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 9-11 m Bird Rock terrace (Fig. 3)

Qop_6 **Old paralic deposits, Unit 6 (late to middle Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 22-23 m Nestor terrace (Fig. 3)

Qop_{2-4} **Old paralic deposits, Units 2-4 undivided (late to middle Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. In much of the area marine terraces and their paralic deposits can not be divided as they merge with and are alternately covered by one another. Their physical and temporal relationships are diagramatically illustrated in Figure 3

VERY OLD SURFICIAL UNITS—Sediments that are slightly to well consolidated to indurated, and moderately to well dissected. Upper surfaces are capped by moderate to well-developed pedogenic soils. Includes:

Qvoa **Very old alluvial flood plain deposits undivided (middle to early Pleistocene)—**Fluvial sediments deposited on canyon floors. Consists of moderately to well-indurated, reddish-brown, mostly very dissected gravel, sand, silt, and clay-bearing alluvium

Qvop **Very old paralic deposits undivided (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the now emergent wave cut abrasion platforms preserved by regional uplift. Includes:

$Qvop_{13}$ **Very old paralic deposits, Unit 13 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 67-69 m San Elijo terrace (Fig. 3)

$Qvop_{12}$ **Very old paralic deposits, Unit 12 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 83-85 m Fire Mountain terrace (Fig. 3)

$Qvop_{11}$ **Very old paralic deposits, Unit 11 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 92-94 m Clairemont terrace (Fig. 3)

$Qvop_{11a}$ **Very old paralic deposits, Unit 11a (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, dune and back beach "beach ridge" deposits composed of cross-bedded sandstone. The ridge is a conspicuous linear topographic high that has formed along a strand line, on and as a part of $Qvop_{11}$

$Qvop_{10}$ **Very old paralic deposits, Unit 10 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 104-106 m Tecolote terrace (Fig. 3)

$Qvop_{10a}$ **Very old paralic deposits, Unit 10a (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, dune and back beach "beach ridge" deposits composed of cross-bedded sandstone. The ridge is a conspicuous linear topographic high that has formed along a strand line, on and as a part of $Qvop_{10}$

$Qvop_9$ **Very old paralic deposits, Unit 9 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 113-115 m Linda Vista terrace (Fig. 3)

$Qvop_{9a}$ **Very old paralic deposits, Unit 9a (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, dune and back beach "beach ridge" deposits composed of cross-bedded sandstone. The ridge is a conspicuous linear topographic high that has formed along a strand line, on and as a part of $Qvop_9$

$Qvop_8$ **Very old paralic deposits, Unit 8 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 123-125 m Tierra Santa terrace (Fig. 3)

$Qvop_{8a}$ **Very old paralic deposits, Unit 8 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, dune and back beach "beach ridge" deposits composed of cross-bedded sandstone. The ridge is a conspicuous linear topographic high that has formed along a strand line, on and as a part of $Qvop_8$

$Qvop_7$ **Very old paralic deposits, Unit 7 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 129-131 m Mira Mesa terrace (Fig. 3)

$Qvop_6$ **Very old paralic deposits, Unit 6 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 139 m Black Mountain terrace (Fig. 3)

$Qvop_5$ **Very old paralic deposits, Unit 5 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 153-157 m Rifle Range terrace (Fig. 3)

$Qvop_4$ **Very old paralic deposits, Unit 4 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 170-174 m Aqueduct terrace (Fig. 3)

$Qvop_3$ **Very old paralic deposits, Unit 3 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 181-185 m Aliso Canyon terrace (Fig. 3)

$Qvop_2$ **Very old paralic deposits, Unit 2 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 190-194 m Flores Hill terrace (Fig. 3)

$Qvop_1$ **Very old paralic deposits, Unit 1 (middle to early Pleistocene)—**Mostly poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 201-205 m Eagle Loft terrace (Fig. 3)

QTso **Undivided sediments and sedimentary rocks in offshore region (Holocene, Pleistocene, Pliocene and Miocene)—**Mostly unconsolidated and poorly consolidated Pleistocene sand, silt and clay deposits that mantle the modern seafloor. Includes unmapped sandstone, siltstone, conglomerate and breccia

SEDIMENTARY AND VOLCANIC BEDROCK UNITS

Tsdcg / Tsdss **San Diego Formation (early Pleistocene and late Pliocene)—**Predominantly yellowish-brown and gray, fine- to medium-grained, poorly indurated fossiliferous marine sandstone (Tsdss) and reddish-brown, transitional marine and nonmarine pebble and cobble conglomerate (Tsdcg). In part of the area the sandstone and conglomerate are undivided (Tsd). The San Diego Formation consists of approximately 75 m of marine and 9 m of nonmarine sedimentary rocks (Demere, 1983). These rocks and their associated marine fossils were first described by Dall (1898) and given the name "San Diego Beds." The name San Diego Formation was given to these rocks in an extensive biostratigraphic study by Arnold (1903). Several comprehensive studies of the marine invertebrate fossil faunas of the San Diego Formation have been published subsequently by Grant and Gale (1931) and Hertlein and Grant (1944, 1960, 1972). Most recently Demere (1982, 1983) presents a concise discussion on the history of work, geologic setting, biostratigraphy and age of the San Diego Formation

Tba **Basaltic-andesite Dike (Miocene)—**Black, fine-grained, massive, very fresh, basaltic-andesite dike located approximately 600 m north of the Scripps Institution of Oceanography pier. A whole-rock potassium-argon analysis of this rock, which shows some evidence of wall rock assimilation, gave an age of 11 Ma (J.W. Hawkins, written communication 1972)

Tmo **Undivided sedimentary rocks in offshore region (Miocene)—**Mostly, well consolidated, bedded sandstone and siltstone

Tmvo **Undivided volcanic rocks in offshore region (Miocene)—**Mostly dark-gray and black basaltic rock

Tmvso **Undivided volcanic and sedimentary rocks in offshore region (Miocene)—**Tmo or Tmvo

To **Otay Formation (late Oligocene)—**The Otay Formation consists of light-gray and light-brown, medium- and coarse-grained, nonmarine arkosic sandstone intertongued with light-brown siltstone and light-gray claystone. Much of the claystone is composed of light-gray bentonite in beds up to 1 m in thickness. A rich vertebrate fossil assemblage from the Otay Formation yields an Arikareean North American mammal "age" (Walsh and Demere, 1991). An isotopic ($^{40}Ar/^{39}Ar$) date of 28.86 Ma from a bentonite bed within the upper part of the Otay Formation has been provided by J.D. Obradovich of the U.S. Geological Survey and reported in Berry (1991). Berry (1991) provides an excellent summary of the bentonite clay deposits of the Otay Formation

Tp / Tpm **Pomerado Conglomerate (middle Eocene)—**The Pomerado Conglomerate is composed of a massive cobble conglomerate with a dark yellowish-brown coarse-grained sandstone matrix (Tp) and an intervening, 10 m thick, light-olive-gray, soft and friable, fine- to medium-grained sandstone tongue designated the Miramar Sandstone Member of the Pomerado Conglomerate (Tpm). The Pomerado Conglomerate is the uppermost formation of the Poway Group, and has a thickness of 56 meters at its type section. Sandstone beds within the Pomerado Conglomerate and Miramar Sandstone Member contain a middle Eocene (late Uintan) vertebrate fossil assemblage (Walsh and others, 1996). The Pomerado Conglomerate was named for exposures located in a divide between Carroll Canyon and Poway Valley along Pomerado Road (Peterson and Kennedy, 1974). The Miramar Sandstone Member is 10 m thick at its type section in the vicinity of Miramar Reservoir where it is lithologically nearly identical to the Mission Valley Formation but is stratigraphically higher and wholly contained within the Pomerado Conglomerate (Peterson and Kennedy, 1974)

Tmv **Mission Valley Formation (middle Eocene)—**Predominantly light-olive-gray, soft and friable, fine- to medium- grained marine and nonmarine sandstone containing cobble conglomerate tongues. Contains a diverse late Uintan mammal fauna (Walsh and others, 1996) and a robust molluscan fauna assigned to the Tejon stage (Givens and Kennedy, 1979). A bentonite bed within the upper part of the Mission Valley Formation yielded a single crystal $^{40}Ar/^{39}Ar$ date of 42.83 ± 0.24 Ma (reported in Walsh and others, 1996). The Mission Valley Formation has a maximum thickness of 60 m and was named for exposures along the south wall of Mission Valley on the west side of State Highway 163 (Kennedy and Moore, 1971)

Tst **Stadium Conglomerate (middle Eocene)—**Massive cobble conglomerate with a dark yellowish-brown, coarse-grained sandstone matrix. The formation consists predominantly (up to 85%) of slightly metamorphosed rhyolitic to dacitic volcanic and volcaniclastic rocks and up to 20% percent quartzite. It yields an early and late Uintan vertebrate assemblage (Walsh and others, 1996) and Tejon stage mollusks (Givens and Kennedy, 1979). The Stadium Conglomerate is 50 m thick at its type section, located between the La Jolla and La Mesa quadrangles along the northern wall of Mission Valley near the San Diego Stadium (Kennedy and Moore, 1971)

Tf **Friars Formation (middle Eocene)—**Mostly yellowish-gray, medium-grained, massive, poorly indurated nonmarine and lagoonal sandstone and claystone with tongues of cobble conglomerate. It contains an early Uintan vertebrate assemblage (Walsh and others, 1996) and was named for exposures along the north side of Mission Valley near Friars Road (Kennedy and Moore, 1971). The Friars Formation reaches a maximum thickness of 50 m between Mission Valley and Carmel Valley

Tscu / Tsc **Scripps Formation (middle Eocene)—**The Scripps Formation (Tsc) is mostly pale yellowish-brown, medium-grained sandstone containing occasional cobble-conglomerate interbeds. It contains a middle Eocene Molluscan fauna (Givens and Kennedy, 1979). The Scripps Formation is 56 m thick at its type section which is 1 km north of Scripps Pier, on the north side of the mouth of Blacks Canyon (Kennedy and Moore, 1971). Both the basal contact with the Ardath Shale and the upper contact with the Friars Formation are conformable. In upper Carroll Canyon a tongue of the Scripps Formation (Tscu) exists above an intervening part of the Stadium Conglomerate. This "upper" tongue is difficult to separate from the main body of the Scripps Formation where the Statium Conglomerate is absent

Ta **Ardath Shale (middle Eocene)—**Mostly uniform, weakly fissile olive-gray silty shale. The upper part contains thin beds of medium-grained sandstone, similar to thicker ones in the overlying Scripps Formation, and concretionary beds with molluscan fossils. The type section of the Ardath Shale is on the east side of Rose Canyon, 800 m south of the Ardath Road intersection with Interstate 5 (Kennedy and Moore, 1971)

Tt **Torrey Sandstone (middle Eocene)—**White to light-brown, medium- to coarse-grained, moderately well indurated, massive and broadly cross-bedded, arkosic sandstone. This unit is the Torrey Sand Member of Hanna (1926) and was named for exposures at Torrey Pines State Park. It is now considered a formation of the La Jolla Group (Kennedy and Moore, 1971)

Td **Delmar Formation (middle Eocene)—**Dusky yellowish-green, sandy, claystone interbedded with medium-gray, coarse-grained, sandstone. This unit is the Delmar Sand Member of Hanna (1926) and was named for exposures in the sea cliffs at Del Mar. It is now considered a formation of the La Jolla Group (Kennedy and Moore, 1971)

Td + Tf **Delmar Formation and Friars Formation undivided (middle Eocene)—**In the upper reaches of La Zanja, McGonigle and Penasquitos Canyons the Delmar and Friars Formations are undivided

Tmss / Tmsc **Mount Soledad Formation (middle Eocene)—**The Mount Soledad Formation consists of a massive, reddish-brown, cobble conglomerate (Tmsc) and light-brown, medium-grained sandstone (Tmss). The Mount Soledad Formation (part of the Rose Canyon Shale Member of Hanna, 1926) was named for exposures that crop out around the Mount Soledad anticline in La Jolla and is a formation of the La Jolla Group (Kennedy and Moore, 1971)

Teo **Undivided Eocene rocks in the offshore area (Eocene)—**Mostly, well indurated, massive arkosic sandstone. Also includes interbeds of claystone, siltstone and conglomerate

Kcs / Kcc **Cabrillo Formation (Upper Cretaceous)—**Mostly massive medium-grained sandstone (Kcs) and cross-bedded cobble conglomerate containing fresh locally derived plutonic and metavolcanic clasts (Kcc). Named for exposures at the southern tip of the Point Loma Peninsula near Cabrillo National Monument and assigned to the upper part of the Rosario Group (Kennedy and Moore, 1971). The Cabrillo Formation conformably overlies massive sandstone and siltstone of the Point Loma Formation. Lower Maestrichtian forams have been found about 30 m below the base of the Cabrillo Formation in siltstone of the Point Loma Formation (Sliter, 1968), and a fossil clam collected on the east flank of Mount Soledad from 2 m below the overlying Eocene unconformity has been identified as "Pharella" alta (Gabb) and assigned to the Maestrichtian (L.R. Saul, written commun., 1969). The Cabrillo Formation is correlative in part to the Williams Formation in the Santa Ana Mountains (Popenoe and others, 1960). Arthur and others (1979) and Nilsen and Abbott (1979) provide a detailed description of these rocks

Kp **Point Loma Formation (Upper Cretaceous)—**Mostly interbedded, fine-grained, dusky-yellow sandstone and olive-gray siltstone. Named for exposures in the sea cliffs along the west side of the Point Loma Peninsula and assigned to the intermediate part of the Rosario Group (Kennedy and Moore, 1971). Contains calcareous nannoplankton of Upper Cretaceous (Campanian and Maestrichtian) age. The Point Loma Formation is correlative in part to the Williams Formation in the Santa Ana Mountains (Popenoe and others, 1960; Bukry and Kennedy, 1969). Arthur and others (1979) and Nilsen and Abbott (1979) provide a detailed description of these rocks

Kl **Lusardi Formation (Upper Cretaceous)—**Reddish-brown cobble and boulder conglomerate with occasional thin lenses of medium-grained sandstone. Named by Nordstrom (1970) for exposures in Lusardi Creek in the Rancho Santa Fe quadrangle and later assigned to the basal part of the Rosario Group by Kennedy and Moore (1971). The Lusardi Formation is correlated with the Trabuco Formation in the Santa Ana Mountains (Nordstrom, 1970)

Kuo **Undivided rocks of the Rosario Group in the offshore area (Upper Cretaceous)—**Undivided rocks of the Rosario Group that occur beneath the sea floor offshore from La Jolla and Point Loma

CRETACEOUS ROCKS OF THE PENINSULAR RANGES BATHOLITH

Kgu **Granodiorite and tonalite undivided (mid-Cretaceous)—**Mostly leucocratic, fine- medium- and coarse-grained granodiorite and tonalite with minor amounts of leucocratic granophyre and dark-gray to black gabbro and diorite

Kgd **Granodiorite undivided (mid-Cretaceous)—**Mostly medium- to coarse-grained, leucocratic, hornblende-biotite granodiorite. Contains some medium- and fine-grained leucocratic tonalite

Kt **Tonalite undivided (mid-Cretaceous)—**Mostly massive, coarse-grained, light-gray, hornblende-biotite tonalite. Contains some medium-grained, leucocratic granodiorite

Kd **Diorite undivided (mid-Cretaceous)—**Mostly massive, medium- to coarse-grained, dark-gray hornblende diorite and quartz-bearing diorite

Kgh **Hypabyssal rocks undivided (mid-Cretaceous)—**Mostly hornblende tonalite and leucocratic granophyre

JURASSIC AND CRETACEOUS METAMORPHOSED AND UNMETAMORPHOSED VOLCANIC AND SEDIMENTARY ROCKS

Mzu **Metasedimentary and metavolcanic rocks undivided (Mesozoic)—**Low-grade (greenschist facies) metasedimentary rocks (conglomerate, sandstone and siltstone) interlayered and mixed with metavolcanic rocks consisting of flows, tuffs and volcaniclastic breccia

Mzo **Undivided metamorphic rocks in the offshore area (Mesozoic)—**Mostly massive, low grade, metavolcanic and metasedimentary rocks. Correlative in large part with rocks designated Mzu onshore

GEOLOGIC SUMMARY

The San Diego 30' X 60' quadrangle was prepared by the Department of Conservation, California Geological Survey pursuant to a U.S. Geological Survey STATEMAP cooperative mapping award (# 1434-94-A-1224). It is a product of the Southern California Areal Mapping Project (SCAMP), a cooperative U.S. Geological Survey-California Geological Survey mapping project, http://scamp.wr.usgs.gov/. This map is a compilation of published geological mapping (Fig. 1). The published mapping has been modified only to the extent necessary to integrate variables in nomenclature and scale. The onshore part of the map was digitized at a scale of 1:24,000 and the offshore part has been enlarged from 1:250,000. The quadrangle is between 32.5˚ and 33.0˚ N. latitude and 117.0˚ and 118.0˚ W. longitude. It encompasses the greater San Diego area, the second largest metropolitan area of California.

The area is tectonically active and is dissected by four major northwest-trending, oblique right slip faults that lie within the western part of the Pacific/North American Plate boundary. They include the Rose Canyon-Newport-Inglewood Fault Zone along the coastal margin, the Palos Verdes-Coronado Bank Fault Zone on the inner shelf, the San Diego Trough Fault Zone (origin of the 1986, ML=5.3, Oceanside earthquake) in the central offshore and the San Clemente Fault Zone on the outer offshore margin. Within the greater San Diego metropolitan area, the Rose Canyon Fault Zone as depicted by Kennedy and others (1975), Moore and Kennedy (1975), Kennedy and Welday (1980), Clarke and others (1987), Treiman (1993) and Kennedy and Clarke (2001) includes the Mount Soledad, Old Town, Point Loma, Silver Strand, Coronado and Spanish Bight faults. The Rose Canyon Fault Zone displaces Holocene sediment in Rose Canyon 7 km north of San Diego Bay where a late Pleistocene slip rate of 1-2 mm/yr has been estimated (Lindvall and Rockwell, 1995). A study of the recency and character of faulting in the greater San Diego metropolitan area suggests a long-term Tertiary slip rate for the Rose Canyon Fault Zone of about 1-2 mm/yr (Kennedy and others, 1975). Although there is significant late Quaternary deformation in the San Diego region the seismicity is relatively low (Simons, 1977).

The San Diego quadrangle is underlain by a thick sequence (>5 km) of Mesozoic fore-arc and fore-arc basin andesitic flows and coarse-grained volcaniclastic breccias that have been in large part metamorphosed to low-grade greenshist facies and are pervasively penetratively deformed. However, in the upper part of the section these rocks are not metamorphosed and are only moderately deformed. Marine sedimentary interbeds in Penasquitos Canyon, near Del Mar, contain the fossil Buchia piochii, which indicates a Late Jurassic (Tithonian) age for these strata (Fife and others, 1967; Jones and Miller, 1982). Zircon U/Pb ages from the metavolcanic rocks are reported to range from 137 Ma to 119 Ma (Anderson, 1991) indicating that they are coeval with the surrounding plutonic rocks of the western Peninsular Ranges batholith. The batholithic rocks are mostly granodiorite and tonalite and based on U-Pb isotopic ages range from 140 Ma to 105 Ma (Silver and Chappell, 1988). Much of the basement rock has been deeply weathered and altered. The weathered bedrock and Quaternary alluvial deposits derived from them contain expansible clays, mostly smectite.

The western part of the quadrangle is underlain by a relatively thick (>1,000 m) succession of Upper Cretaceous, Tertiary and Quaternary sedimentary rocks that unconformably overlie basement rocks. They consist of marine, paralic, and continental claystone, siltstone, sandstone and conglomerate. The Upper Cretaceous rocks are composed of marine turbidites and continental fan deposits assigned to the Rosario Group (Kennedy and Moore, 1971). The Lusardi Formation, the basal formation of the Rosario Group is a nonmarine boulder fanglomerate deposited along the western margin of a tectonic highland upon a deeply weathered surface of the older Cretaceous and Jurassic plutonic and metamorphic basement rocks. Clasts within the Lusardi Formation are composed exclusively of these weathered basement rocks. The Lusardi Formation is overlain by the Point Loma Formation, the middle part of the Rosario Group. It is composed mostly of marine sandstone, siltstone and conglomerate sequences that together form massive turbidite deposits. The Point Loma Formation is Campanian and Maestrichtian in age (Sliter, 1968; Bukry and Kennedy, 1969) and underlies most of the Point Loma Peninsula and the hills southeast of La Jolla. It is conformably overlain by the uppermost part of the Rosario Group, marine sandstone and conglomerate of the Maestrichtian (Sliter, 1968; Bukry and Kennedy, 1969) Cabrillo Formation. Following the deposition of the Rosario Group, the San Diego coastal margin underwent uplift and erosion until the middle Eocene when nine partially intertonguing middle and upper Eocene sequences composed of siltstone, sandstone, and conglomerate were deposited during several major transgressive-regressive cycles. The succession is over 700 meters thick and grades from nonmarine fan and dune deposits on the east through lagoonal and nearshore beach and beach-bar deposits to marine continental shelf deposits on the west near the present-day coastline. The age and environmental interpretation of the Eocene sequence is based on the mapped distribution of lithofacies coupled with the presence of a pelagic fossil calcareous nannoplankton flora in the continental shelf facies (e.g., Bukry and Kennedy, 1969), a shallow water molluscan fauna in the nearshore facies (e.g., Givens and Kennedy, 1979), and a fossil terrestrial vertebrate mammal fauna in the paralic facies (e.g., Golz, 1973). Cross bedding, cobble imbrications, paleo-stream gradients and clast petrology indicate a local eastern source for these rocks. The nonmarine facies of the Eocene formations are typically well indurated and cemented whereas the lagoonal facies are soft and friable. The nearshore facies are well indurated, well sorted, and locally concretionary. The marine deposits are typically fine-grained, indurated, and cemented. Following the deposition of Eocene rocks the San Diego margin was again elevated and eroded. During the Oligocene, continental and shallow water lagoonal deposits of the Otay Formation, were deposited. The Otay Formation is light-gray and light- brown, medium- and coarse-grained, arkosic sandstone intertongued with light-brown siltstone and light-gray claystone. Much of the claystone is composed of light-gray bentonite in beds up to 1 m in thickness. Following Oligocene time the San Diego coastal margin underwent uplift and extensive erosion. The next major marine transgression did not occur until Pliocene time when the strata of the San Diego Formation were deposited. The San Diego Formation rests unconformably upon Oligocene, Eocene and Upper Cretaceous beds across its outcrop from Pacific Beach to the International border with Mexico. The San Diego Formation is late Pliocene in age and contains a rich molluscan fauna (e.g., Arnold, 1903; Demere, 1983). It consists mostly of yellowish-brown and gray, fine- to medium-grained, marine sandstone and reddish-brown, transitional marine and nonmarine pebble and cobble conglomerate. Following the deposition of the San Diego Formation and continuing to the present time, the San Diego coastal margin has undergone relatively steady uplift (Fig. 2). A series of continually evolving marine abrasion platforms have been carved and uplifted during this time and are manifest in the marine terraces and their deposits that are ubiquitous to the San Diego coastal region. The deposits consist of nearshore marine, beach, estuarine, lagoonal and continental dune facies that were deposited across a marine/nonmarine transition zone and along a coastal strandline. Changes in sea level coupled with regional uplift give rise to the preservation and/or obliteration of both the abrasion platforms and their overlying deposits (e.g. Lajoie, and others, 1991; Kern and Rockwell, 1992; Kern, 1996a, 1996b).

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INDEX MAP

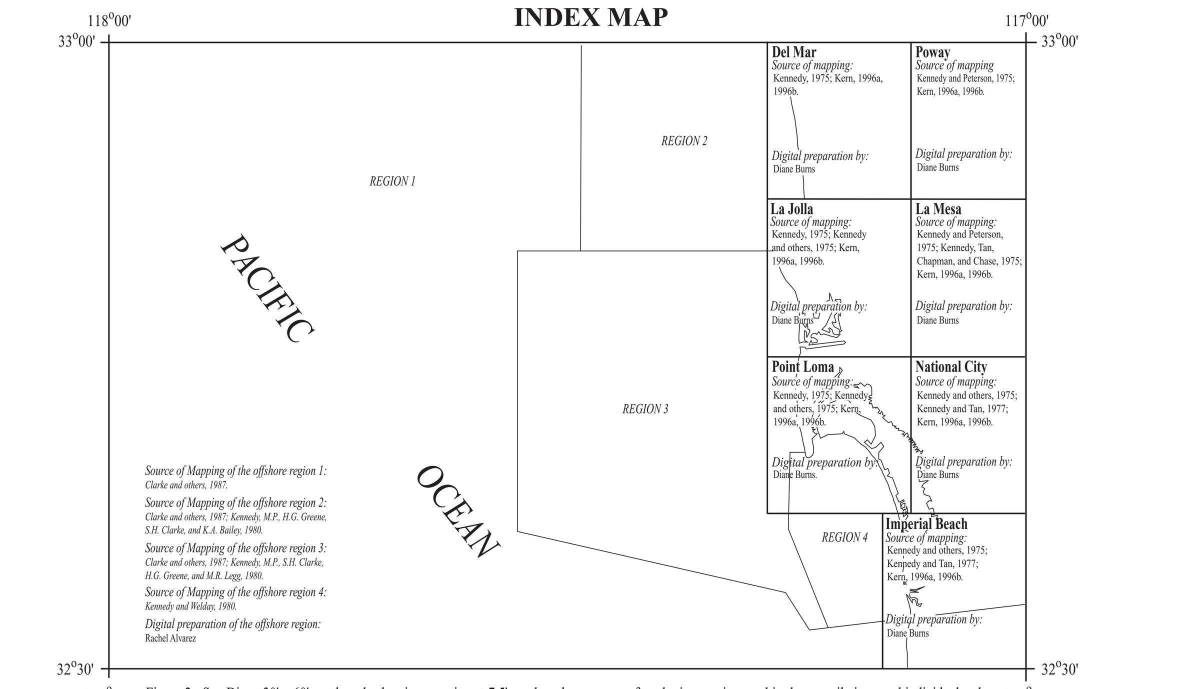

Figure 2. San Diego 30' x 60' quadrangle showing constituent 7.5' quadrangles, sources of geologic mapping used in the compilation, and individuals who digitized the geologic mapping.

CHRONOLOGY OF MARINE TERRACES AND THEIR DEPOSITS

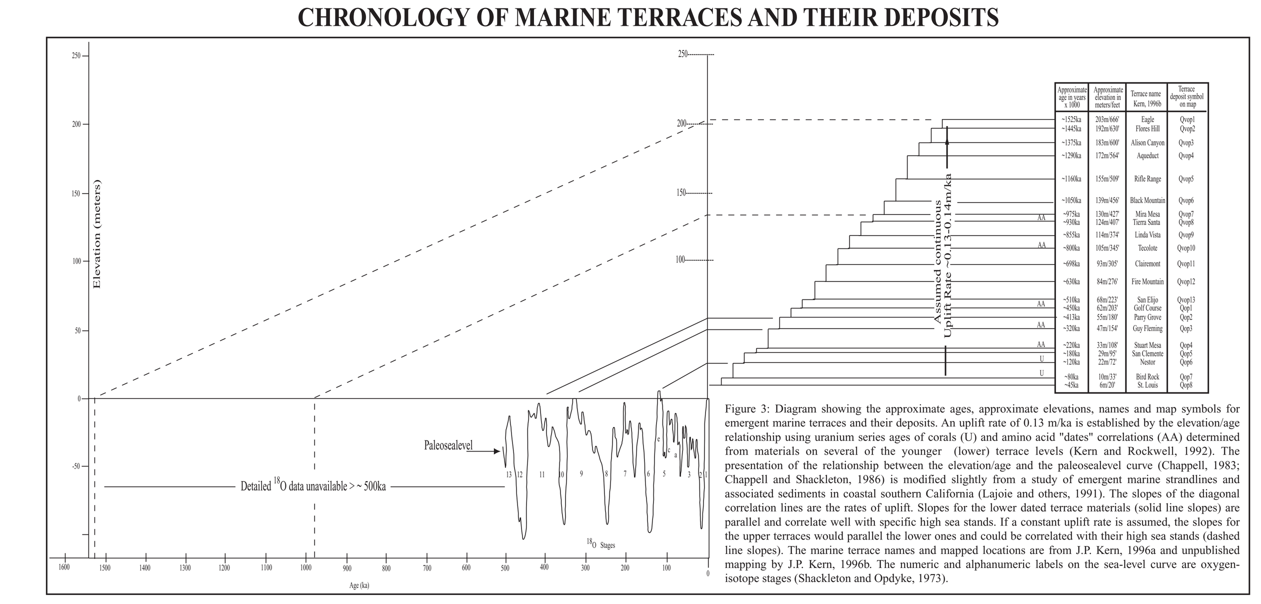

Figure 3: Diagram showing the approximate ages, approximate elevations, names and map symbols for emergent marine terraces and their deposits. An uplift rate of 0.13 m/ka is established by the elevation/age relationship using uranium series ages of corals (U) and amino acid "dates" correlations (AA) determined from materials on several of the younger (lower) terrace levels (Kern and Rockwell, 1992). The presentation of the relationship between the elevation/age and the paleosealevel curve (Chappell, 1983; Chappell and Shackleton, 1986) is modified slightly from a study of emergent marine strandlines and associated sediments in coastal southern California (Lajoie and others, 1991). The slope of the diagonal correlation lines are the rates of uplift. Slopes for the lower dated terrace materials (solid line) slopes are parallel and correlate well with specific high sea stands. If a constant uplift rate is assumed, the slopes for the upper terraces would parallel the lower ones and could be correlated with their high sea stands (dashed line slopes). The marine terrace names and mapped locations are from J.P. Kern, 1996a and unpublished mapping by J.P. Kern, 1996b. The numeric and alphanumeric labels on the sea-level curve are oxygen-isotope stages (Shackleton and Opdyke, 1973).

Preliminary Geologic Map available from:
http://www.conservation.ca.gov/cgs/rghm/rgm/preliminary_geologic_maps.htm

Prepared in cooperation with the U.S. Geological Survey,
Southern California Areal Mapping Project