# TECHNICAL REPORT AND EVALUATION GUIDELINES

# GEOLOGY AND GEOHAZARDS
## MASTER ENVIRONMENTAL ASSESSMENT

*Prepared for:*

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# LIMITATIONS

Services performed by URS have been conducted in a manner consistent with the level of care and skill ordinarily exercised by other professional consultants under similar circumstances. No other representations, either expressed or implied, and no warranty or guarantee is included or intended in this report. URS Corporation collected, mapped, and documented existing geologic information and assisted in the production of this document. Opinions relating to environmental, geologic, and geotechnical conditions are based on limited data and actual conditions may vary from those encountered at the times and locations where the data were obtained, despite the use of due professional care.

This document reflects a peer review process by the local geological community and review and direction from the city of Santa Barbara.

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## SECTION 1.0 INTRODUCTION

This report has been prepared pursuant to an April 2006 contract between URS and the city of Santa Barbara (the City) Community Development Department in order to update the city-wide Master Environmental Assessment (MEA) geospatial information to characterize current environmental conditions in the City. Geological research and changes in engineering and building codes and standard practices with respect to the fields of geotechnical engineering and engineering geology have occurred since the original City geology and geohazard maps were produced by Hoover (1978).

The City MEA update of geology and geohazards information includes: 1) the generation of new maps depicting geologic and seismic conditions and hazard zoning, 2) automated version of mapped information as part of the City Geographic Information System (GIS), and 3) this technical report, which includes the description of how the maps were produced, and evaluation guidelines for using the new MEA geology and geohazard maps. It is the intent of these new MEA geology and geohazard maps and this accompanying technical report to provide users of the maps with an understanding of current geologic conditions and standard procedures for evaluation of geologic and geohazard investigations within the City and its Sphere of Influence.

The 10 geology and geohazards maps are:

- Map 1 Geology
- Map 2 Soils
- Map 3 Potential Fault Hazard Zones
- Map 4 Peak Ground Acceleration
- Map 5 Potential Liquefaction Hazard Zones
- Map 6 Slope Failure Hazard Zones
- Map 7 Expansive Soils Hazard Zones
- Map 8 Erosion Potential Hazard Zones
- Map 9 Radon Hazard Zones
- Map 10 75-Year Sea Cliff Retreat Line

The methodology for the generation of the new and revised geology and geohazard maps is described under sections for each map. In general, previously published data and maps that have undergone rigorous scientific scrutiny and are readily available were utilized and adapted to the map scale of 1:18,000. All of the maps obtained for use as baseline information were digitized as necessary, edited or refined as appropriate, and made available in a Geographic Information System (GIS) format.

The purpose of the geohazards maps and this report is to provide guidance and information regarding how the mapped categories should be used in project reviews and associated impact analyses. This report also outlines what additional technical analysis may be needed, general formats for recommended reports, and the general professional qualifications of individuals to complete the analyses. Additionally, general types of mitigation measures are outlined for each type of condition or hazard.

It is recommended that locations and proposed improvements for development projects be reviewed with these MEA geology and geohazard maps early in the project planning stages so that appropriate investigative requirements and mitigation measures can be identified prior to completing major project planning or design tasks. The purpose of these MEA geology and geohazard maps is to screen out unnecessary technical reports for areas not needing them, and identify any potential hazards that would need to be addressed with further investigation and/or project design measures. In consideration of potential problems that are likely to affect sites and possible scenarios for proposed projects, early identification of site hazards can greatly reduce project costs, allow for better location or design of projects, or allow for project stakeholders to identify whether a given project is feasible considering potentially encountered hazards.

## 1.1 QUALIFIED PROFESSIONALS FOR INVESTIGATION, REPORTING, AND REVIEW OF GEOLOGIC HAZARDS

All geology, engineering geology, or geotechnical engineering reports prepared or other professional activities conducted as a requirement of fulfilling hazard investigation, evaluation, and mitigation related to the geologic hazards identified herein, need to be conducted in accordance with all applicable laws and/or regulations. The guidelines presented herein are not intended to supersede any applicable laws and/or regulations.

All geology, engineering geology, geotechnical engineering, or other related professional practice conducted during any phase of the investigation, evaluation, analyses, report preparation, or review of such professional services or documents need to be performed either directly or under the direct supervision of the appropriately California licensed professional as identified in the California Code of Regulations.

## 2.0 GEOLOGY

### 2.1 MAP 1: GEOLOGY

Regional and local geologic maps that include areas of the City and its Sphere of Influence have been prepared by various geologists (Dibblee 1986; Olson 1982; Hoover 1978; Upson 1951). Changes in geologic maps produced of the region have occurred throughout the years and, in particular, are reflected in recently produced geologic maps (Minor et al. 2006; USGS 2006; Gurrola 2006; Urban 2004). These changes on geologic maps reflect the renaming and remapped boundaries of geologic formations and units, as well as the depiction of structural features that were not recognized by earlier geologists.

The combination of recent research and geologic mapping of the Santa Barbara region has, in some locations, changed the mapped locations of various geologic formations or units and features, and the renaming of geologic units has occurred. For instance, the geologic unit fanglomerate (Qog), depicted on the City geologic map by earlier workers (Dibblee 1986; Olson 1982; Hoover 1978; Upson 1951), is no longer used in modern geologic maps (Minor et al. 2006; USGS 2006; Urban 2004; Gurrola 2006). In addition, additional geologic features and units have been identified that are not depicted on the maps produced by earlier workers (Dibblee 1986; Olson 1982; Hoover 1978; Upson, 1951); they are now depicted on current geologic maps (Minor et al. 2006; USGS 2006; Urban 2004; Gurrola 2006).

The U.S. Geological Survey (USGS) has recently produced a Preliminary Geologic Map of the Santa Barbara Coastal Plain (Minor et al. 2006; USGS 2006) that includes portions of the City of Santa Barbara and its Sphere of Influence. An updated and finalized geologic map of the Santa Barbara coastal plain is anticipated to be released in the near future by the USGS, however it is understood that the portions of the preliminary geologic map completed for the areas of interest to the City are in a final format, and modifications to the new release will include additional mapped areas beyond the area of the City's interest (personal comm., Minor 2006).

The Preliminary Geologic Map of the Santa Barbara Coastal Plain (Minor et al. 2006; USGS 2006) serves as the base geologic map for the City and its Sphere of Influence. Some modifications to the USGS' geologic map were accomplished where more detailed geologic mapping better defined geologic contacts and where readily available additional geologic information was available. The Geology Map is accompanied with a legend that depicts symbols and respective descriptions used on the Geology Map and the names of geologic formations and units. A description of the geology of the Santa Barbara Coastal Plain and lithologic descriptions is provided from the United States Geological Survey Open-File Report 02-136 (Minor et al. 2006; USGS 2006). Minor modifications to the USGS Open-File Report 02-136 have been made to the lithologic descriptions to allow for appropriate description of the geologic units found only within the limits of the City and its Sphere of

Influence's boundaries, including the change of description of the debris flow deposits (Qdf) (Minor et al. 2006), and the addition of the geologic unit, Mission diamicton (Qmd), as reported by (Urban 2004). The geologic summary and lithologic descriptions are provided in Appendix A.

## 2.2 GEOLOGY MAP GUIDELINES

The Geology Map of the City of Santa Barbara and its Sphere of Influence (Geology Map) is for use by planners, engineers, geologists, and the general public as a base geologic map for project locations submitted to the City for review. The Geology Map can also be used to identify general geologic conditions for use in community planning and for geological and engineering investigation and design considerations.

# 3.0 SOILS

## 3.1 MAP 2: SOILS

The United States Department of Agriculture (USDA) – National Resource Conservation Service (NRCS) Soil Survey maps depicting the areas of the City of Santa Barbara and its Sphere of Influence were used to generate soil maps of the project area. Also, readily available GIS-formatted and mapped soils were obtained within the area of interest from the USDA Soil Survey Geographic Database (SSURGO). Mapped soils were then overlain onto a topographic contour map (2 ft. to 20 ft. contours) from the County of Santa Barbara Flood Control topographic maps. The USDA NRCS soil maps depict the areal extent of mapped soils according to soil type, and the GIS based soil map has attribute data pertinent to land use planning. These data include, but are not limited to, shrink-swell potential, erosive potential, runoff potential, and drainage potential.

Approximately 105 soils were mapped within the City of Santa Barbara and its Sphere of Influence by the USDA NRCS. The names of soils are listed on Map 3 (Legend) that accompanies this report. Detailed descriptions of individual soils, soil profiles, and soil horizons are available in the USDA NRCS Soil Survey of Southern Santa Barbara County.

As part of the generation of the soil map for the City, an analysis of the soil types was performed to evaluate problematic and/or hazardous soil conditions. Both an Expansive Soils Hazard Zones Map (Map 7) and an Erosion Potential Hazard Zones Map (Map 8) were produced from evaluation of the USDA NRCS mapped soils. These maps are discussed in Sections 9.0 and 10.0.

## 3.2 SOILS MAP GUIDELINES

The Soils Map of the City of Santa Barbara and its Sphere of Influence is for use by planners, engineers, geologists, and the general public as a base soils map for depicting project locations submitted to the City for review. The Soils Map can be used to identify general soil conditions at a project site and the surrounding area for use in community planning efforts and geological and engineering investigation and design considerations.

## 4.0 FAULTS

## 4.1 MAP 3: POTENTIAL FAULT HAZARD ZONES

The tectonic setting of the Santa Barbara area along with the structural history of the region is described in detail in Appendix A. No faults designated as active under the Alquist-Priolo Act exist in the City or its sphere of influence. As such, specific Alquist-Priolo regulations requiring development setback from designated faults do not apply to faults within the city of Santa Barbara at this time.

However, several documented faults do exist. Fault locations depicted on the Geologic Map (Map 1) are derived from the USGS' geologic map (Minor et al. 2006; USGS 2006). Faults depicted on Map 3 have been evaluated with geologic criteria to identify those faults that pose potential surface deformation hazard resultant from fault rupture. The faults depicted on the City geologic map were evaluated for activity by reviewing geologic literature and discussing research findings with geologic researchers who have worked in the region. Based on the geologic mapping efforts of the USGS and recent researchers (Minor et al. 2006; Gurrola 2006; Urban 2004) and the identification of new faults and fault strands that were previously unrecognized and have not been thoroughly evaluated for fault activity by fault trenching studies, fault activity is largely inferred by investigators from geologic relationships and geomorphologic expression.

In addition, some newly mapped faults and associated fault strands were not evaluated for fault activity by researchers. However, based on geologic relationships and the general geologic setting, and consistent with California Geological Survey Special Publication 42, it is presumed the faults and fault strands within the same fault system have the same fault activity rating.

### 4.1.1 Potential Fault Hazard Categories

Consistent with California Geological Survey (CGS) nomenclature and local studies, Map 3 presents the following three categories of potential fault hazard zones, for the purpose of determining whether to request technical reports for development proposals:

1. **Apparently Active Fault Hazard Zone (Color Orange)** – This designation refers to potential fault locations that are considered Holocene Active (surface displacement within approximately the last 11,000 years). Historic period (approximately last 200

years) surface rupture or surface deformation due to faulting has not been documented in the City of Santa Barbara or its Sphere of Influence.[1]

2. **Potentially Active Fault Hazard Zone (Color Green)** – This designation refers to potential fault locations that have experienced displacement within late Quaternary time, approximately the last 700,000 years.
3. **Potentially Active Fault Hazard Zone (Color Purple)** – This classification refers to potential fault locations demonstrating older activity, those which have experienced displacement within Quaternary time, approximately the last 1,600,000 years.

Potential fault hazard zones are identified on either side of inferred fault locations. These zones identify areas where development proposals considered by the City may be subject to requirements for site-specific geotechnical studies.

There is no regulatory requirement to identify such zones or for a specified width for such zones around faults that are not designated as active under the Alquist-Priolo Act. However, the City requires that fault investigations and reporting will be required for projects that lie within fault hazard zones established by a width of 400 feet (200 feet on either side of a fault). This zone width has been used by the City for the past 25 years, and is used on the updated potential fault hazard zone maps.

Given that definitive information on faults is limited in many areas, applicants with projects located outside but near a potential fault hazard zone may also want to consult a California-licensed Certified Engineering Geologist in deciding whether it is advisable to conduct geotechnical studies for the project. To help applicants and their consultants evaluate this issue, fault hazard zones are surrounded by a 100-foot buffer where additional consultation is recommended (Please note for clarification that under City of Santa Barbara CEQA evaluation guidelines: the advisory buffer area does not equate to a potentially significant fault hazard zone; a site's location within the advisory buffer area does not mean that there is a potentially significant fault hazard, and, absent other site-specific information, the fault hazard within the buffer area will be deemed less than significant for purposes of CEQA review.).

### 4.1.2 Other Mapped Features

Map 3 also depicts surface warps that could potentially indicate near-surface faulting in the area. There is no regulatory requirement to identify fault hazard zones around these features. Applicants with projects located within 300 feet of surface warps may want to consider

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[1] Note that Jennings (1994) considers Holocene Active faults to represent movement within the last 10,000 years. The slightly more conservative definition of 11,000 years has been chosen to be consistent with the Alquist-Priolo Earthquake Fault Zoning Act.

consulting with a California-licensed Certified Engineering Geologist to decide whether it is advisable to conduct geotechnical studies for the project. (Please note for clarification that under City of Santa Barbara CEQA evaluation guidelines these areas do not equate to a potentially significant fault hazard zone; a site's location within these areas does not mean that there is a potentially significant fault hazard, and, absent other site-specific information, the fault hazard within these areas will be deemed less than significant for purposes of CEQA review.)

## 4.2 POTENTIAL FAULT HAZARD ZONE MAP GUIDELINES

The Potential Fault Hazard Zones Map (Geohazards Map 3 of 10) depicts areas that are potentially susceptible to fault-related surface deformation within the City and its Sphere of Influence. The Map 3 zones identify areas where additional fault studies are required for review of some types of proposed development projects. Many common types of projects are exempt from fault-related studies consistent with applicable laws, regulations and codes. As such, not all projects that are within a potential fault hazard zone will be required to have studies conducted as part of the permitting process. For example, an alteration or addition to a single family residence is exempt from such studies unless the addition exceeds 50 percent of the value of the structure.

### 4.2.1 Technical Report Guidelines

The following are guidelines for the requirement of technical studies of proposed development projects, based on site location within the mapped zones, and the proposed type of land use. Table 4-1 summarizes required studies by mapped zone, type of proposed land use, and timing of reports. Fault investigations are to be performed and reports prepared by a California licensed Certified Engineering Geologist. The report format and content should be in general accordance with the California Board for Geologists and Geophysicists adopted guidelines for fault investigation reports (Appendix B). Information required pursuant to these guidelines is submitted with the discretionary project application and before the application is deemed complete for processing, as the information may be relevant to the project's California Environmental Quality Act (CEQA) determination.

1. **Location Outside Mapped Zones.** If a proposed project site is located outside of a mapped Potential Fault Hazard Zone, a geotechnical study will not be required by the City. However, given that definitive information on faults is limited in many areas, applicants with projects located outside but near a potential fault hazard zone may also want to consult a California-licensed Certified Engineering Geologist in deciding whether it is advisable to conduct geotechnical studies for the project.
2. **Exempt Projects.** Projects within a mapped Potential Fault Hazard Zone that do not require geotechnical reports include minor projects and the types of projects that are exempted from fault studies under the Alquist-Priolo Act and California Geological Survey Special Publication 42. Minor projects involve small additions to habitable structures and accessory structures with no substantially increased exposure to risk, such as swimming pools and garage additions. Exempt projects include:

    a. Single-family wood- or steel-frame dwellings to be built on parcels with prior acceptable geologic reports

b. Fewer than four single-family wood- or steel-frame dwellings not exceeding two stories (including mobile homes with body width exceeding eight feet)

c. Conversion of an existing apartment complex into a condominium

d. Alterations or additions to structures not exceeding 50 percent of the value of the existing structure

3. **Screening Level Analysis.** As shown on Table 4-1 for specified non-exempt types of projects located within a mapped Potential Fault Hazard Zone, a qualitative site-specific screening-level investigation is required to address potential for surface deformation related to faulting on the site and potential mitigation as appropriate.

   A qualitative evaluation typically involves review of available data, air photo interpretation, and geologic reconnaissance, and may include the results of previous geologic evaluation(s) at or near the project site, with demonstration that the geologic site conditions are similar to and representative of the project site.

   If the proposed project site does not demonstrate fault surface deformation potential as part of this screening study, the results of the study are submitted with the project discretionary application. If fault surface deformation potential is identified on the project site, additional evaluation is performed per Guideline 3 and submitted with the project discretionary application.

4. **Site Investigation.** As shown on Table 4-1 for specified types of projects within specified Potential Fault Hazard Zones, or if the screening-level analysis required pursuant to Guideline 2 above identifies the potential for fault surface deformation hazard at the project site, site-specific fault deformation surface hazard analysis is required in accordance with procedures outlined in California Geological Survey Special Note 49: Guidelines for Fault Investigation, the California Board of Geologists and Geophysicists Guidelines for Fault Investigations, and Evaluating the Hazard of the Surface Fault Rupture (Bryant 1998). [Note: This reference is also incorporated in Appendix C of CGS Special Publication 42, Fault-Rupture Hazard Zones in California (Hart and Bryant 1999).] These procedures include field investigation, laboratory testing, and geologic analysis. The study report is submitted with the project discretionary application.

### 4.2.2 Mitigation Measures

Appropriate mitigation measures for fault surface deformation hazard are variable depending on site conditions and the nature of the proposed project. Often, the most appropriate solution can involve a combination of mitigation measures. Mitigation measures may include, but are not limited to:

- Hazard avoidance

## TABLE 4-1
## REPORTS REQUIRED FOR PROJECT PROPOSALS WITHIN POTENTIAL FAULT HAZARD ZONES

| Potential Fault Hazard Zone | Proposed Development | Studies Required | Timing |
|---|---|---|---|
| Higher (Orange)<br>(Apparently Active)<br>≤11,000 years | • Minor Improvements and Exempt Projects[1] | No Report[3] | - - - - - - - - - - |
| | • Non-Exempt Single Family Residential[1] | Screening Level[4] | Discretionary |
| | • Non-Exempt Multiple Single Family Residential Units or Multi-Family Residential[1] | Screening Level[4] | Discretionary |
| | • Commercial/Industrial[1] | Site Investigation[5] | Discretionary |
| | • Essential Facility[2] | Site Investigation[5] | Discretionary |
| Medium (Green)<br>(Potentially Active)<br>≤700,000 years | • Minor Improvements[1] | No Report[3] | - - - - - - - - - - |
| | • Non-Exempt Single Family Residential[1] | Screening Level[4] | Discretionary |
| | • Non-Exempt Multiple Single Family Residential Units or Multi-Family Residential[1] | Screening Level[4] | Discretionary |
| | • Commercial/Industrial[1] | Screening Level[4] | Discretionary |
| | • Essential Facility[2] | Site Investigation[5] | Discretionary |
| Lower (Purple)<br>(Potentially Active)<br>≤1,600,000 years | • Minor Improvements[1] | No Report[3] | - - - - - - - - - - |
| | • Single Family Residential[1] | No Report[3] | - - - - - - - - - - |
| | • Multiple Single Family Residential Units or Multi-Family Residential[1] | No Report[3] | - - - - - - - - - - |
| | • Commercial/Industrial[1] | No Report[3] | - - - - - - - - - - |
| | • Essential Facility[2] | Site Investigation[5] | Discretionary |

[1] e.g., Minor improvements involve small additions to habitable structures and accessory structures involving no substantially increased exposure to risk, such as swimming pools, garage additions. Exemptions include single-family dwellings on sites with prior acceptable geologic studies; fewer than four single-family dwellings (or mobile homes of eight-foot width) not exceeding two stories; conversion of apartments to condominiums; and alterations or additions to structures not exceeding 50 percent of the value of the existing structure.

[2] e.g., hospital, school.

[3] No report required as part of the discretionary application required, low-exposure level and/or land use.

[4] Screening Level: Typically involves review of available data, air photo interpretation, geologic reconnaissance; if results are unfavorable, site investigation is required.

[5] Site Investigation: Follow CGS Special Note 49 including field investigation, laboratory testing, and geologic analysis.

- Appropriate site layout of planned improvements with established setbacks (typically 50 feet) from discrete fault surface rupture, or setbacks as recommended by the geologist to mitigate surface warping hazard
- Structural engineering to accommodate acceptable levels of discrete movements or surface warping

## 5.0 GROUND ACCELERATION

### 5.1 MAP 4: PEAK GROUND ACCELERATION

Substantial research in the fields of seismicity and seismic ground motions has occurred over the last 30 years. As a result, the findings of this research have led to changes and refinements in the International Building Code (IBC) and California Building Code (CBC). The CBC details seismic design requirements for general structures within the State of California and identifies that the design life of structures be able to accommodate seismic ground motions generated from a Design Basis Earthquake (DBE), defined as the earthquake with a 10 percent chance of exceedence within a period of 50 years.

It should be noted that structures that are identified as Essential Facilities according to the California Code of Regulations (CCR) Title 24 are required to be evaluated for structural collapse according to the ground motions produced from an earthquake occurrence with a 10 percent chance of exceedence within a 100-year period. Essential Facilities, as defined by CCR Title 24, include facilities such as public schools, hospitals, police stations, and fire stations. The Peak Ground Acceleration Map depicts only ground accelerations anticipated for a DBE and therefore the map does not include anticipated ground accelerations utilized for planning and design purposes of Essential Facilities according to CCR Title 24 criteria. The Probabilistic Seismic Hazard Assessment (PSHA) and Model for the State of California developed by the California Geological Survey (CGS) and the USGS (CGS 1996; updated 2002; revised 2003) was utilized to develop the Peak Ground Acceleration Map of the City of Santa Barbara and its Sphere of Influence. The CGS Probabilistic Seismic Hazard Map utilizes State of California accepted seismic parameters of faults for seismic evaluation. A grid of the City and its Sphere of Influence was generated with 0.5-mile spacing to coincide with the resolution of the State of California PSHA Model. The latitude and longitude coordinates at each grid intersection were identified in a GIS environment. Peak ground acceleration (PGA) anticipated to occur with a 10 percent chance of exceedence within 50 years were identified at these points from the CGS interactive website. PGAs are reported by the CGS database for alluvium, soft bedrock, and hard bedrock conditions.

To identify the appropriate PGA at each respective grid point, the geologic material at each grid point was determined according to the Geologic Map of the City and its Sphere of Influence. Alluvium PGAs were prescribed to grid points on geologic units with alluvial characteristics. Soft bedrock PGAs were prescribed to all grid points lying on geologic units that are identified as bedrock. For the generation of the map, hard bedrock PGAs were not used when geologic units of bedrock formations were mapped at the surface because this analysis assumes that either a mantle of sediments and/or a weathered soft rock zone with shear wave velocities correlative to alluvial sediment velocity exist near the surface, as is the case for most mapped locations within the City and its Sphere of Influence. Seismic ground motion maps were then generated by contouring, at 0.01g increments, the PGA ground motion data relative to percent of gravity (g).

Any map developed on any regional scale cannot replace the requirements for site-specific seismic investigations, and any PGA maps developed for the MEA should only be utilized for reviewing anticipated relative ground motions for design basis earthquakes in a region.

Ground motions at a given site are typically calculated using one of two approaches or techniques: a deterministic approach or a probabilistic approach. A deterministic approach is normally used in areas with sparse instrumental history/seismograph data and represents a "worst case" scenario, assuming that the largest seismic event capable of occurring will occur on the nearest "Capable" seismic source at its closest proximity to the site. A probabilistic approach is followed in situations where there is a long historic instrumental record and usually produces a less conservative, more realistic PGA. Both techniques are described in CGS *Special Publication 117, Guidelines for Evaluating and Mitigating Seismic Hazards in California*.

## 5.2 PEAK GROUND ACCELERATION MAP GUIDELINES

The Peak Ground Acceleration Map (PGAM) (Geohazards Map 4 of 10) uses contour lines to depict anticipated values of Peak Ground Acceleration (PGA) (ten percent chance of exceedence in 50 years) within the City and its Sphere of Influence. The ground accelerations depicted on the PGAM should only be used in preliminary site assessments or planning efforts.

### 5.2.1 Technical Report Guidelines

Site-specific peak ground accelerations and structural analysis for seismic groundshaking is required for projects consistent with Building Division and Building Code requirements, for submittal with Building Permit application. See Table 5-1.

**TABLE 5-1**
**REPORTS REQUIRED TO EVALUATE PEAK GROUND ACCELERATION**

| Ground Acceleration Zoning | Proposed Development | Studies Required | Timing |
|---|---|---|---|
| All areas within the City and Its Sphere of Influence | • Minor Improvements[1] | Site Specific PGA Determination[3] | Building Permit |
| | • Single Family Residential | Site Specific PGA Determination[3] | Building Permit |
| | • Multiple Single Family Residential Units or Multi-Family Residential | Site Specific PGA Determination[3] | Building Permit |
| | • Commercial/Industrial | Site Specific PGA Determination[3] | Building Permit |
| | • Essential Facility[2] | Site Specific PGA Determination[3] | Building Permit |

[1] e.g., swimming pool, garage addition, or any non-habitable structure or improvement.

[2] e.g., hospital, school.

[3] Site specific PGA determination analysis by seismologist or engineering geologist followed by structural analysis by a structural engineer as required by the CCR and City Building Division. Studies shall be performed in accordance with the California Building Code as adopted by the California Code of Regulations Title 24 and applicable sections of the Seismic Hazards Mapping Act and California Geological Survey Special Publication 117.

### 5.2.2 Mitigation

Appropriate mitigation measures for strong ground motion hazard are variable depending on site conditions and the nature of the proposed project. The most appropriate solution may involve a combination of mitigation measures. Mitigation measures can include, but are not limited to:

- Hazard avoidance

- Appropriate site layout of project elements onto geologic materials anticipated to receive less severe ground motions relative to other areas on a project site
- Specific foundation and/or structure design

## 6.0 LIQUEFACTION

### 6.1 MAP 5: POTENTIAL LIQUEFACTION HAZARD ZONES

The investigation and evaluation of liquefaction hazard has, like seismic investigation and evaluation, undergone changes in the last 30 years. The evaluation of liquefaction hazard can be categorized into two methods: 1) quantitative, and 2) qualitative. Local groundwater data is not readily available in a format that would produce a quantitative liquefaction hazard analysis on a regional scale of the City and its Sphere of Influence; a qualitative hazard evaluation was therefore performed.

The identification of potentially liquefiable materials is generally dependent upon three considerations: 1) a site being able to experience threshold ground accelerations, 2) the presence of potentially liquefiable materials, and 3) the presence or potential presence of groundwater within potentially liquefiable materials. Based on known seismic hazards to the region and the PGA map generated as part of the MEA update, strong ground motions that are likely to exceed liquefaction thresholds are anticipated to be experienced within the City and its Sphere of Influence. Potentially liquefiable materials, or generally granular materials, were identified within the study area from the mapped extents of geologic units and soils identified on the Geology and Soils maps (Maps 1 and 2). The liquefaction hazard zones were identified based on evaluation of geologic materials, areas of known depth to groundwater less than 60 feet, presumed areas where temporary water zones may develop (due to severe rainstorm events) in liquefiable-type (granular) geologic materials that are less than 60 feet below the ground surface, and areas identified to be susceptible to liquefaction by previous project studies.

The identification of liquefaction hazard zones based on these criteria, as applicable, is in general accordance with the California Seismic Hazards Mapping Act, CGS *Special Publication 117: Guidelines for Evaluating and Mitigating Seismic Hazards in California*, the *Recommended Procedures for Implementation of Division of Mines and Geology* (now CGS) *Special Publication 117: Guidelines for Analyzing and Mitigating Liquefaction in California* (Southern California Earthquake Center 1999), and CGS *Special Publication 118: Recommended Criteria for Delineating Seismic Hazard Zones in California* (1999). These referenced documents are publications developed for implementing and meeting the requirements of the California Seismic Hazards Mapping Act.

## 6.2 POTENTIAL LIQUEFACTION HAZARD ZONES MAP GUIDELINES

The Potential Liquefaction Hazard Zone map (Geohazards Map 5 of 10) depicts areas that are potentially susceptible to liquefaction within the City and its sphere of influence. The Liquefaction Hazard Zone Map (Map 5) is used to identify areas where proposed development projects may be subject to liquefaction hazards.

### 6.2.1 Technical Report Guidelines

Studies required to evaluate the potential consequences of liquefaction are necessarily a function of: 1) level of identified liquefaction hazard, and 2) land usage (i.e., type of development). A matrix that indicates required studies related to liquefaction hazard and proposed land usage is presented on Table 6-1. A geotechnical study must be prepared either by a Professional Engineer (PE) or a Certified Engineering Geologist competent in the field of liquefaction, and the study must provide specific recommended mitigation measures to adequately address the hazard for the proposed project. The following are technical report guidelines for mapped Potential Liquefaction Hazard Zones.

1. **Outside Potential Liquefaction Zone.** If a proposed project site is located outside of a mapped Potential Liquefaction Hazard Zone, a geotechnical report addressing liquefaction hazard will not be required by the City.
2. **Groundwater Depth of 60 Feet or Greater.** If groundwater data for a project site is provided which shows that depth to groundwater is 60 feet or more, then it is presumed that no liquefaction hazard exists and no site investigation is required.
3. **Site Investigation.** For projects located on sites within High Potential Liquefaction Hazard Zone, a full site investigation with recommended mitigation is required prior to discretionary permit application for any new construction. For projects located on sites within the Moderate Potential Liquefaction Hazard Zone, a full site investigation is required with a Building Permit application for new construction, except for minor projects or residential projects for which prior geologic studies have been prepared. For projects located on sites within the Low Potential Liquefaction Hazard Zone, no site investigation is required for most projects, except large public buildings or essential facilities require a full site investigation submitted with a Building Permit application.

### 6.2.2 Mitigation Measures

Liquefaction is a mitigable condition through site and structural design. Most often, it is treated through overexcavation and recompaction of liquefiable soils along with proper foundation design. The most appropriate solution may involve a combination of mitigation measures. In accordance with CGS Special Publication 117, Chapter 6, mitigation measures can include, but are not limited to:

## TABLE 6-1
## REPORTS REQUIRED TO EVALUATE LIQUEFACTION HAZARD ZONING

| Liquefaction Zoning | Proposed Development | Studies Required | Timing |
|---|---|---|---|
| Low Hazard | • Minor Improvements[1, 4] | No Report[4] | - - - - - - - - - - |
| | • Single Family Residential[4] | No Report [4] | - - - - - - - - - - |
| | • Multiple Single Family Residential Units or Multi-Family Residential[4] | No Report[4] | - - - - - - - - - - |
| | • Commercial/Industrial, large public facilities[2] | Site Investigation | Building Permit |
| | • Essential Facility[3] | Site Investigation | Building Permit |
| Moderate Hazard | • Minor Improvements[1, 4] | Site Investigation | Building Permit |
| | • Single Family Residential[2] | Site Investigation | Building Permit |
| | • Multiple Single Family Residential Units or Multi-Family Residential[2] | Site Investigation | Building Permit |
| | • Commercial/Industrial[2] | Site Investigation | Building Permit |
| | • Essential Facility[3] | Site Investigation | Discretionary |
| High Hazard | • Minor Improvements[1, 4] | Site Investigation | Building Permit |
| | • Single Family Residential[4] | Site Investigation | Building Permit |
| | • Multiple Single Family Residential Units or Multi-Family Residential[4] | Screening Level[4] | Discretionary |
| | • Commercial/Industrial[2] | Screening Level[4] | Discretionary |
| | • Essential Facility[3] | Screening Level[4] | Discretionary |

[1] e.g., Minor improvements involve small additions to habitable structures and accessory structures, such as swimming pools and garage additions.

[2] Site Investigation is required for large, public buildings.

[3] e.g., hospital, school.

[4] The California Building Code may require studies either not required by or in addition to those studies required by the City of Santa Barbara Community Development Department.

[5] Studies shall be performed in accordance with the California Building Code as adopted by the California Code of Regulations Title 24 and applicable sections of the Seismic Hazards Mapping Act and California Geological Survey Special Publication 117.

[6] The State Department of Architecture may require the investigation of all geologic hazards for essential facilities during the discretionary permitting phase.

- Hazard avoidance
- Excavation and removal or recompaction of potentially liquefiable soils
- In-situ ground densification
- Specific foundation and/or structure design

- Edge containment structures
- Site drainage to lower the groundwater table

## 7.0 SLOPE FAILURE

### 7.1 MAP 6: SLOPE FAILURE HAZARD ZONES

The evaluation of slope stability at pertinent sites is critical for the safety and integrity of people and projects. Many methods for evaluating regional slope stability and identifying areas requiring detailed site slope stability investigations are available. The mapped slope failures (landslides) depicted on the Slope Failure Hazard Zones Map of the City of Santa Barbara and its Sphere of Influence (SFHZ Map 6) were compiled from slope failures identified by the USGS (Minor et al. 2006), Urban (2004), and the CGS (Bezore and Wills 2000). The CGS Landslide Hazard Maps of Southeastern Santa Barbara County (Bezore and Wills 2000) utilized the material and types of movement classification scheme presented by Cruden and Varnes (1996) and slope movement classification of Keaton and DeGraff (1996). The slope failures mapped by Urban (2004) were ascribed material and types of movement classification symbols used by the CGS, as derived from the classification scheme presented by Cruden and Varnes (1996). USGS (Minor et al. 2006) mapped slope failures were not differentiated into specific types of slope movement and materials and were, therefore, not prescribed specific landslide classification symbols. Slope failures mapped by Urban (2004) and the USGS (Minor et al. 2006) were not ascribed activity classification as information regarding activity ratings were not readily available for these mapped slope failures.

The CGS Landslide Hazard Maps of Southeastern Santa Barbara County, Plates 1A and 1B (Bezore and Wills 2000) were used to identify areas of varying landslide potential (slope instability) within the project area. In addition, landslides mapped by the USGS (2006) and Urban (2004) were included on the Slope Failure Hazard Zones Map of the City of Santa Barbara and Its Sphere of Influence.

The principal factors that were considered in determining the ratings shown on this map are:

- The broad apparent stability characteristics of geological materials underlying the slopes and adjacent lower-lying areas, as expressed in their natural exposures and their observed responses to alteration by the activities of man. For example, slopes that exhibit abundant evidence of landsliding or downslope creep of the soil are considered oversteepened relative to the strength of the materials that underlie them.
- Steepness of slopes, whether or not landsliding is apparent upon them.
- The presence of active or intermittent natural influences that tend to cause slope failure. These include gravity, fluvial processes, and the tendency of certain soils to shrink and swell under varying moisture conditions.

For further information regarding how the CGS developed the landslide potential areas, the reader is referred to the CGS Landslide Hazard Maps of Southeastern Santa Barbara County (Bezore and Wills 2000).

### 7.1.1 Mapped Categories of Landslide Potential

The SFHZ Map (Map 6) depicts areas within four (4) categories of landslide potential, described below (from Bezore and Wills 2000).

- ***AREA 1 – Very Low Landslide Potential.*** *Landslides and other features related to slope instability are very rare to non-existent within this area. Included within this area are topographically low-lying valley bottoms and alleviated floodplains. Part of the area may be underlain by material that lacks the strength to support steep slopes (such as unconsolidated alluvium) but occupies a relatively stable position due to the flatness of the slope. Land within Area 1 will probably remain relatively stable unless the topography is radically modified.*
- ***AREA 2 – Low Landslide Potential.*** *This area includes gentle to moderate slopes underlain by relatively competent material or colluvium that is considered unlikely to remobilize under natural conditions. The stability of slopes within Area 2 may change radically in response to modification of the adjacent terrain.*
- ***AREA 3 – Moderate Landslide Potential.*** *Slopes within this area are at or near their stability limits due to weaker materials, steeper slopes, or a combination of these factors. Although most slopes within Area 3 do not currently contain landslide deposits, the materials that underlie them can be expected to fail, locally, when modified because they are close to their stability limits.*
- ***AREA 4 – High Landslide Potential.*** [Area 4, depicted on the SFHZ Map (Map 6) corresponds to Area 4.2, as depicted on the CGS Landslide Hazard Maps of Southeastern Santa Barbara County (Bezore and Wills 2000).] *This area is characterized by steep slopes and includes most landslides in upslope areas, whether apparently active at present or not, and slopes upon which there is substantial evidence of downslope creep of surface materials. Landslide density is greater than elsewhere in the study area, with landslides being common to very common, as well as closely spaced. Landslides range from small and shallow to very large. Earthflows are the most common type of failure, but slides of intact bedrock are also common. The combination of predominantly gentler and lower relief terrain, abundant landslides, and large landslide size indicates that the bedrock units in these areas are generally softer, weaker, less resistant to erosion and less stable than in other mapped areas. Slopes in Area 4 are considered to be naturally unstable and subject to failure even in the absence of the activities of man. Slope instability results from the weakness of rocks in what is only moderately steep terrain.*

### 7.1.2 Mapping Notes

The following important notes are stated in the CGS Landslide Hazard Maps of Southeastern Santa Barbara County (Bezore and Wills 2000) with respect to the evaluation and utilization of the landslide potential areas:

- ***Note 1.*** *The boundaries of the areas were determined by combining observations shown on the accompanying map (objective data), with judgments and interpretations (subjective data) drawn from the experience of the authors (S. Bezore and C.J. Wills) with the field area at the time the map was made.*
- ***Note 2.*** *It is possible that modifications to the landscape by the activities of man may significantly alter the relative stability of slopes in specific areas. Thus, the relative landslide susceptibility of these areas may change in the future.*
- ***Note 3.*** *This map identifies potential landslide source areas only. No attempt has been made to map the potential for downslope areas to be inundated by debris flow, rock falls, or other types of landslides.*
- ***Note 4.*** *This map is based on judgments that are interpretative and apply generally to large areas. Therefore, within each area conditions may range, locally, through all levels of susceptibility. Hence, small, unmapped landslides may exist, locally, within Area 1 and there may be, locally, relatively stable sites within Area 4.*
- ***Note 5.*** *The delineation of the various areas of susceptibility is limited by the scale of the map.*

The four-value scale used on this map indicates the comparative capacity of slopes to resist failure by landsliding.

## 7.2 SLOPE FAILURE HAZARD ZONES MAP GUIDELINES

The Slope Failure Hazard Zones Map (Geohazards Map 6 of 10) depicts areas that are potentially susceptible to landslides and slope stability hazards within the City and its Sphere of Influence. The SFHZ Map is used by planners and the public to identify areas where proposed development projects may be subject to landslides and slope stability hazards. It must be recognized that the evaluation of slope stability hazards may not be limited to only those hazards that are present within a project boundary. Slope stability hazard evaluations, as described below, should also review and consider off-site slope stability hazards that could affect the project site from hazards such as the runout of landslides, debris flows, etc, and the subsequent inundation of a project site from off-site slope failures.

A matrix that indicates required studies related to slope failure and proposed land usage is presented in Table 7-1.

### 7.2.1 Technical Report Guidelines

The evaluation of landslide and slope stability hazards at a site should include not only natural slopes and conditions but also any proposed modifications of slopes for the proposed project.

Slope stability hazard evaluation must be performed and reports prepared by a California licensed Geotechnical Engineer or Certified Engineering Geologist. The format and content of reports should be in general accordance with the California Board for Geologists and Geophysicists adopted guidelines for engineering geology reports or the acceptable format and content of geotechnical reports, the CBC, and CGS Special Publication 117 and the SCEC Recommended Procedures for Implementation of CGS *Special Publication 117: Guidelines for Analyzing and Mitigating Landslide Hazards in California* (Appendix B). In accordance with the CCR Title 24, site-specific geotechnical and/or engineering geology investigations shall be performed to evaluate slope stability hazards for project layout and design purposes. Procedures for analysis of static slope stability, including site investigations, geologic studies, sampling, laboratory testing, and engineering calculations, are described in Blake, et al. 2002. Chapter 11 of that document describes several analyses for the evaluation of dynamic slope stability in accordance with CGS Special Publication 117.

1. **Outside Hazard Zones, or Zones 1 and 2 – Low Slope Stability Hazard**. If a proposed project site is located outside of a mapped Landslide and Slope Stability Potential Hazard Zone or within Areas 1 or 2, a landslide and slope stability hazard geotechnical study will not be required for most types of projects as shown on Table 7-1, unless the project would introduce a slope stability hazard to the site due to major excavations or creation of substantial fill slopes. In that event, a geotechnical report would be required with a building permit application. For essential facilities such as schools and hospitals, a site

## TABLE 7-1
## REPORTS REQUIRED TO EVALUATE SLOPE FAILURE HAZARD

| Slope Failure Zoning | Proposed Development | Studies Required | Timing |
|---|---|---|---|
| Within Areas 1 or 2 or outside of zoned areas | • Minor Improvements[1] | No Report, or Site Investigation if major excavation or fill slopes created.[2, 4] | Building Permit (if any) |
| | • Single Family Residential | As above | As above |
| | • Multiple Single Family Residential Units or Multi-Family Residential | As above | As above |
| | • Commercial/Industrial | As above | As above |
| | • Essential Facility[3] | As above | Discretionary |
| Inside or adjacent to Mapped Zone Areas 3 and 4 | • Minor Improvements[1] | Site Investigation[2, 5] | Building Permit |
| | • Single Family Residential | Site Investigation[2, 5] | Building Permit |
| | • Multiple Single Family Residential Units or Multi-Family Residential | Site Investigation[2, 5] | Discretionary |
| | • Commercial/Industrial | Site Investigation[2, 5] | Discretionary |
| | • Essential Facility[3] | Site Investigation[2, 5] | Discretionary |
| If landslide and/or slope stability hazards identified by above investigations | • Minor Improvements[1] | Site Investigation[2, 5] | Building Permit |
| | • Single Family Residential | Site Investigation[2, 5] | Building Permit |
| | • Multiple Single Family Residential Units or Multi-Family Residential | Site Investigation[2, 5] | Discretionary |
| | • Commercial/Industrial | Site Investigation[2, 5] | Discretionary |
| | • Essential Facility[3] | Site Investigation[2, 5] | Discretionary |

[1] Minor Improvements e.g., swimming pool, garage addition, or any non-habitable structure or improvement.

[2] Any studies would be conducted in accordance with the applicable sections of the California Building Code, Seismic Hazards Mapping Act, and California Geological Survey Special Publication 117.

[3] e.g., hospital, school.

[4] No report required for projects with low exposure to hazards, unless man-made improvements or project elements introduce slope stability hazards to a project site. The California Building Code may require studies either not required by or in addition to those studies required by the City of Santa Barbara Community Development Department.

[5] Site Investigation: Follow CGS Special Publication 117, the Southern California Earthquake Center's Guidelines for Implementing CGS Special Publication 117, and applicable sections of the California Building Code including as needed, field investigation, laboratory testing, geologic analysis, and applicable engineering analysis.

specific geotechnical analysis is recommended as part of an overall geologic study at the discretionary permit application stage.

2. **Zones 3 and 4 – Moderate or High Slope Stability Hazard.** For proposed projects located within the mapped Landslide and Slope Stability Potential Hazard Zone Areas 3 or 4, a site-specific geotechnical report for landslide and slope stability hazard potential is

submitted to identify the site's landslide and slope stability hazard potential and measures, if applicable, to mitigate the hazard. For minor improvements or single-family dwellings, a geotechnical report is submitted with building permit application. For multiple-family residential, commercial/industrial, or essential facilities, a geotechnical report is submitted with a discretionary application.

### 7.2.2 Mitigation

Appropriate mitigation measures for landslide and slope stability hazard are variable depending on site conditions and the nature of the proposed project. Appropriate solutions may often involve a combination of mitigation measures. Mitigation measures can include, but are not limited to:

- Hazard avoidance
- Dewatering of slopes and controlling site drainage
- Geotechnical engineering design including, but not limited to, mechanically stabilized earth retaining walls, reinforced slopes, buttress fill, soil nails, rock nails, rock nets or drapery, retaining walls, soldier pier walls
- Engineered landscaping

# 8.0 EXPANSIVE SOILS

## 8.1 MAP 7: EXPANSIVE SOILS HAZARD ZONES

URS utilized the USDA – NRCS Soil Survey maps and attribute data of mapped soils to identify each respective soil's expansive potential and present the attributes in a map format. The map is presented as Map 7, Expansive Soils Hazard Map (ESHZ Map) of the City of Santa Barbara and its Sphere of Influence. USDA – NRCS mapped soil profiles (depths from 0 to 6 feet bgs) were reviewed. The expansive soil hazard zones were categorized based on the ratings of shrink-swell potential identified by the USDA – NRCS for soil horizons. The hazard ratings identified include: very low, low, moderate, and high. The higher the hazard rating, the more shrink-swell potential a soil may exhibit and, therefore, the greater expansive soil hazard exists.

The expansive potential of soils is variable and dependent upon the type of soil and soil horizon (location within a soil profile) of interest. The highest, or worst, expansive soil potential rating identified by the USDA – NRCS for each soil unit was selected for hazard zonation. For instance, if a 6-foot-thick soil profile contained a soil horizon with ratings of "low to high" shrink-swell potential, then the mapped soil was included within the "high" expansive potential hazard zone.

## 8.2 EXPANSIVE SOILS HAZARD ZONES MAP GUIDELINES

The ESHZ map, (Geohazards Map 7 of 10) depicts various soils' expansive potential within the City and its Sphere of Influence. The ESHZ Map (Map 7) is used to identify areas where proposed development projects may be subject to expansive soils hazards.

### 8.2.1 Technical Report Guidelines

A matrix that indicates required studies related to expansive soils hazards and proposed land usage is presented in Table 8-1.

**TABLE 8-1**
**REPORTS REQUIRED TO EVALUATE EXPANSIVE SOILS HAZARD**

| Expansive Soils Zoning | Proposed Development | Studies Required | Timing |
|---|---|---|---|
| "Very low" to "low" rating | • Minor Improvements[1] | No Report[3] | - - - - - - - - - - |
| | • Single Family Residential | No Report[3] | - - - - - - - - - - |
| | • Multiple Single Family Residential Units or Multi-Family Residential | No Report[3] | - - - - - - - - - - |
| | • Commercial/Industrial | No Report[3] | - - - - - - - - - - |
| | • Essential Facility[2] | Site Investigation recommended[3, 4, 5,6] | Discretionary |
| "Moderate" to "high" rating | • Minor Improvements[1] | Site Investigation[5] | Building Permit |
| | • Single Family Residential | Site Investigation[5] | Building Permit |
| | • Multiple Single Family Residential Units or Multi-Family Residential | Site Investigation[5] | Building Permit |
| | • Commercial/Industrial | Site Investigation[5] | Building Permit |
| | • Essential Facility[2] | Site Investigation[5] | Discretionary |

[1] e.g., swimming pool, garage addition, or any non-inhabitable structure or improvement that does not provide life-line services.

[2] e.g., hospital, school.

[3] No report required by the City.

[4] The State Department of Architecture requires investigation of all geological hazards for essential facilities in accordance with Title 24 of the California Code of Regulations and California Geological Survey Special Note 48.

[5] Site Investigation: Follow CCR Title 24 and applicable sections of the California Building Code including field investigation, laboratory testing, geologic analysis, and applicable engineering analysis.

[6] The California Building Code may require studies either not required by or in addition to those studies required by the City of Santa Barbara Community Development Department.

The expansive soils hazard report and findings are performed and reports prepared by a California licensed Professional Engineer with satisfactory experience in soils engineering, Geotechnical Engineer, or Certified Engineering Geologist. The format and content of reports should be in general accordance with the California Board for Geologists and Geophysicists adopted guidelines for engineering geology reports or the acceptable format and content of geotechnical reports, and with appropriate sections of the CBC (Appendix B).

1. **Very Low or Low Potential Expansive Soils Hazard Zone.** If a proposed project site is located in a mapped Expansive Soils Potential Hazard Zone of "very low" or "low," an expansive soils hazard technical study is not required for most project types as identified in Table 8-1. For essential facilities, such as schools and hospitals, a site specific geotechnical analysis is recommended as part of an overall geologic study at the discretionary permit application stage.
2. **Moderate or High Potential Expansive Soils Hazard Zone.** For proposed projects located within the mapped Expansive Soils Potential Hazard Zones "moderate" or "high," a site-specific investigation for expansive soils is performed to identify expansive soils hazard potential. The site-specific investigation is conducted in accordance with the CCR Title 24, and the most recent edition of the Uniform Building Code and California Building Code.

   The determination of site expansive soil hazard and appropriate design mitigation is mandated by the CCR Title 24. Expansive soil hazard is generally mitigable by appropriate project-specific engineering. For essential facilities, expansive soil hazard investigations are submitted with a discretionary permit application. For other types of land uses, expansive soil hazard investigations are submitted with a building permit application, although they can be conducted voluntarily during the early phases of project planning process at the project proponent's discretion.

### 8.2.2 Mitigation

Appropriate mitigation measures for expansive soil hazards are variable, depending on site conditions and the nature of the proposed project. Often, the most appropriate solution can involve a combination of mitigation measures. Mitigation measures can include, but are not limited to:

- Hazard avoidance
- Appropriate site layout of project elements onto geologic materials that have less expansive soil hazard relative to other areas on a project site
- Control of site drainage and the conveyance of runoff away from foundation elements
- Specific foundation and/or structure design such as reinforced foundations or pre-stressed concrete slabs

## 9.0 EROSION

### 9.1 MAP 8: EROSION POTENTIAL HAZARD ZONES

URS utilized the USDA – NRCS Soil Survey maps and attribute data of mapped soils to identify each respective soil's erosion potential and present the attributes in a map format and presented as Map 8, Erosion Potential in the City of Santa Barbara and its Sphere of Influence (EPHZ Map). USDA – NRCS mapped soil profiles (depths from 0 to 6 feet bgs) were reviewed and evaluated for erosion potential. The erosion potential hazard zones were categorized based on review of the USDA – NRCS' evaluation and categorization of each soil unit's erosive potential. The hazard ratings identified include: slight, moderate, high, and very high. The higher the hazard rating designated on the EPHZ Map, the more likely encountered soils are susceptible to erosion and, therefore, a greater erosion hazard exists.

## 9.2 EROSION POTENTIAL HAZARD ZONES MAP GUIDELINES

The Erosion Potential Hazard Zones Map (Map 8) is used to identify areas where proposed development projects may be subject to erosive soils hazards, and the guidelines identify required geotechnical reports for specified types of development within the various hazard levels and timing reports in conjunction with permitting. See Table 9-1.

### TABLE 9-1
### REPORTS REQUIRED TO EVALUATE EROSION POTENTIAL HAZARD

| Erosion Potential Zoning | Proposed Development | Studies Required | Timing |
|---|---|---|---|
| Slight Erosion Potential | • All developments | No Report[2] | Building Permit |
| Moderate Erosion | • Creation of steep fill slopes | Site Investigation[3, 5] | Building Permit |
| High, or Very High Potential | • Minor Improvements[1] | Site Investigation[3, 5] | Building Permit |
| | • Single Family Residential | Site Investigation[3, 5] | Building Permit |
| | • Multiple Single Family Residential Units or Multi-Family Residential | Site Investigation[3, 5] | Building Permit |
| | • Commercial/Industrial | Site Investigation[3, 5] | Building Permit |
| | • Essential Facility[4] | Site Investigation[3, 5] | Building Permit |

[1] e.g., swimming pool, garage addition, or any non-habitable structure or improvement.

[2] No report required by the City. The California Building Code and/or the California regional water Quality Control Board may require stormwater pollution mitigation for some projects.

[3] Studies are to be conducted in accordance with the applicable sections of the California Building Code and with California Regional Water Quality Control Board (CRWQCB) regulations; minimum size of project or area of ground disturbance, as defined by the CRWQCB applies.

[4] e.g., hospital, school.

[5] Site Investigation: Evaluate on-site soils for erosion potential, comments on erosion potential of soils and general mitigation measures to mitigate soil erosion and minimize potential for releases to waterways (Note that a Storm Water Pollution Prevention Plan may also be required, as specified by the California Regional Water Quality Control Board.).

1. **Site Location Outside Potential Hazard Zones or "Slight" Erosion Potential.** No report is required.
2. **"Moderate" Potential Erosion Hazard Zone.** Projects that include creation of steep fill slopes may induce more active erosion, and require submittal of a full site investigation with a grading/building permit application.
3. **"High" or "Very High" Potential Erosion Hazard Zones.** For proposed projects located within the High, or Very High Erosion Potential Hazard zones, a site-specific soil report is submitted with application for grading/building permits. Within these areas, gullying and sedimentation may be more active in winter months, and steep slopes are

likely to erode if vegetation is stripped and not replanted before rains. Seacliff areas are also subject to erosion.

Reports prepared to address erosion potential hazards should evaluate the on-site soils for erosion potential with consideration to both the final project improvements and interim construction measures necessary to complete the project. The report should comment on the erosion potential of soils and general mitigation measures to control erosion during both the construction of the project and the final project design. In accordance with general engineering practice to prevent storm water pollution, a storm water pollution prevention plan or recommendations should be included as part of the geotechnical recommendations for small projects that appropriately mitigates potential erosion during project construction. Larger projects, as defined by California Regional Water Quality Control Board regulations, may require submittal of a separate Storm Water Pollution Prevention Plan as part of a building permit application. Mitigation measures for construction and final design will be shown on project plans.

Erosive soils evaluation should be performed and reports prepared by a California licensed Professional Engineer with satisfactory experience in soils engineering, Geotechnical Engineer, or Certified Engineering Geologist. The format and content of report should be in general accordance with the California Board for Geologists and Geophysicists adopted guidelines for engineering geology reports or the acceptable format and content of geotechnical reports, and with appropriate sections of the CBC (Appendix B).

### 9.2.1 Mitigation Measures

Appropriate mitigation measures for erosive soils depend on site conditions and the nature of the proposed project. Appropriate solutions may involve a combination of mitigation measures. General mitigation measures include, but are not limited to:

- Excavation and removal or recompaction (densification of loose granular soil) of erosive soils
- Engineering slopes and grades
- Landscaping
- Use of geotextiles

Implementation of Best Management Practices (BMPs) as identified in a SWPPP during the project construction phase for storm water pollution prevention, which include, but are not limited to:

- Straw wattles, hay bales, filter fabric, silt fencing, sand and/or gravel bags, gravel beds for site ingress and egress

# 10.0 RADON

## 10.1 MAP 9: RADON HAZARD ZONES

URS used the Radon Zone Map for Santa Barbara County (Churchill 1995) to generate the GIS-based Radon Hazard Zones Map for the City. On the Radon Hazard Map, hazard zones are identified according to three levels: 1) high potential for indoor radon levels above 4 pico-curies per liter (pCi/L), 2) moderate potential for indoor radon levels from 2 to 4 pCi/L, and 3) low potential for indoor radon levels below 2 pCi/L (all areas outside moderate and high zones). The radon hazard designations utilized by the CGS are based on the criteria that the California Department of Health Services (CDHS) and the United States Environmental Protection Agency (EPA) have identified—that indoor radon levels above 4 pCi/L pose hazardous conditions to humans. Based on the Geology and Soils Maps prepared by URS for the City, additional areas in geologic units with Rincon and Monterey formations were mapped outside of the radon hazard zones identified by the CGS, were included as “high” hazard level zones.

The Radon Hazard Zones Map (Map 9) shows the areas of Santa Barbara and its Sphere of Influence that have moderate and high radon potentials. The moderate and high radon potentials are typically associated with geologic units of the Rincon and Monterey formations and soils derived from these formations. The moderate and high radon potentials are mostly concentrated on the northern (canyon outfall) margin of Santa Barbara and on the southern margin of Santa Barbara near the Pacific Ocean. Higher water tables and low permeability probably reduce the radon potentials along most of the ocean coastline. Appendix C contains further information and useful facts about radon.

## 10.2 RADON HAZARD ZONES MAP GUIDELINES

The Radon Hazard Zones (RHZ) Map, (Geohazards Map 9 of 10) is used to identify areas where proposed and existing development projects may be subject to radon hazards.

### 10.2.1 Technical Report Guidelines

A matrix that indicates required studies related to radon hazards and proposed land use is presented in Table 10-1. Evaluation of radon hazards can be conducted either by a Professional Geologist or a Certified Engineering Geologist. A Professional Engineer competent in the field of radon hazard mitigation may identify engineering controls to mitigate radon hazards.

**TABLE 10-1**
**REPORTS REQUIRED DUE TO RADON ZONING**
**AND PROPOSED LAND USAGE**

| Radon Zoning | Proposed Development | Studies Required | Timing |
|---|---|---|---|
| Low Hazard Zone (includes all areas mapped outside Moderate and High Hazard zones) | • Minor Improvements[1] | No Report[2] | - - - - - - - - - - |
| | • Single Family Residential | No Report[2] | - - - - - - - - - - |
| | • Multiple Single Family Residential Units or Multi-Family Residential | No Report[2] | - - - - - - - - - - |
| | • Commercial/Industrial | No Report[2] | - - - - - - - - - - |
| | • Essential Facility[3] | No Report[2, 5] | - - - - - - - - - - |
| Moderate and High Hazard Zones | • Minor Improvements[1] | No Report[2] | - - - - - - - - - - |
| | • Single Family Residential | Engineered Controls[4] | Building Permit |
| | • Multiple Single Family Residential Units or Multi-Family Residential | Engineered Controls[4] | Building Permit |
| | • Commercial/Industrial | Engineered Controls[4] | Building Permit |
| | • Essential Facility[3] | Engineered Controls[4] | Building Permit [5] |

[1] e.g., swimming pool, garage addition, or any non-habitable structure or improvement.

[2] No report required by the City. However, for essential facilities regardless of location, the State Department of Architecture requires radon hazard evaluation per Title 24 of the California Code of Regulations and California Geological Survey Special Note 48.

[3] e.g., hospital, school.

[4] Because site investigations and evaluation of radon hazard may be more costly than simply incorporating radon mitigation measures into project design, final project plans are submitted with engineered controls to mitigate radon hazard for appropriate structures.

[5] The State Department of Architecture requires earlier investigation of all geological hazards for essential facilities in accordance with Title 24 of the California Code of Regulations and California Geological Survey Special Note 48.

1. **Low Hazard Zone.** Radon hazard mitigation measures will not be required.
2. **Moderate or High Hazard Level.** Because the detailed investigation and evaluation of radon hazard is generally more costly than simply incorporating radon mitigation measures into project design, final project plans submitted with a building permit application are to include engineered controls to mitigate radon hazard for appropriate structures.

### 10.2.2 Mitigation Measures

Appropriate mitigation measures for radon hazard are variable depending on site conditions and the nature of the proposed project. Appropriate solutions may involve a combination of mitigation measures. Radon hazard mitigation measures include, but are not limited to:

- Avoidance of the hazard
- Limiting the types of land use or development to outdoor activities
- Specific foundation and/or structure design including, but not limited to:
  - Sub-slab (or sub-membrane) depressurization (SSD) systems
  - Mechanical barriers (sealing and caulking foundations cracks)
  - Improved location and sealing of air handling ducts

Air-handling systems that utilize sub-floor or sub-slab return air ducts should be avoided because of their tendency to “mine” radon-laden air through cracks and leaks that commonly develop. All air returns should be well sealed and air handling systems balanced so that radon suction points are not created in parts of the house that develop negative air pressures relative to other areas.

For retrofitting existing houses with elevated radon levels, sealing of all foundation and floor-slab cracks, pipe penetrations, and any other soil-gas access points such as crawl spaces and utility channels is a good first step that often reduces radon levels adequately. Perimeter slab cracks along foundation walls are common leakage zones. When greater reductions in radon level are required, sub-slab ventilation is commonly the method of choice. SSD systems can be installed in discrete locations of existing houses to depressurize and ventilate the sub-slab and crawl-space areas.

## 11.0 SEA CLIFF RETREAT

### 11.1 MAP 10: 75-YEAR SEA CLIFF RETREAT LINE

An updated Sea Cliff Retreat Line (SCRL) is mapped, based on anticipated sea cliff erosion over a 75-year period, for sea cliffs located within the City and its Sphere of Influence.

Section 30253 of the Coastal Act requires that new development shall:

1. Minimize risks to life and property in areas of high geologic, flood, and fire hazard.
2. Assure 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.

The methodology outlined by Johnsson (2002) was generally utilized for the generation of a SCRL, including steps to identify the top bluff edge; identify the general global stability conditions; and identify long-term erosion rates over a period of at least 50 years, evaluate short-term or episodic erosion rates; and apply a safety factor for setbacks if necessary.

Research findings of sea cliff erosion rates provided by Norris (1986) were utilized, and coastal bluff stability was qualitatively evaluated to develop a sea cliff retreat line. Norris (1986) evaluated coastal erosion rates over a 70-year period and determined long-term erosion rates and short-term episodic rates along the entire Santa Barbara coastline The highest erosion or retreat rate documented by Norris (1986, personal communication 2006) for sea cliffs within the project boundaries was approximately 12 inches per year. However, long-term erosion rates are on average 8 inches per year. The sea cliff erosion rate findings by Norris identified that sea cliff erosion is not steady state and can be highly variable throughout time. For instance, a high erosion rate of 12 inches per year may be followed by a period of time with a much lower sea cliff erosion rate. The global slope stability of sea cliffs along the Santa Barbara coastline was qualitatively evaluated at select locations along the project area coastline. The evaluation also was based on professional and research experience and a review of literature of mapped landslides along the Santa Barbara coastline. Mapped landslides generally have landslide toes at or near the base of the sea cliff and the headscarps are generally found near the top bluff edge. For the purposes of establishing a SCRL and based on a regional geologic evaluation of bluff stability conditions, it is assumed that global slope instability exists from the toe of the sea cliff to the top outer bluff edge. Large coastal bluff failures are often located within this zone. Detailed quantitative global slope stability evaluation was beyond the scope of this study to identify a regional SCRL. Site-specific quantitative evaluations may find that global slope stability may be less than or greater than the assumed global bluff instability zone identified in this study.

The SCRL depicted on Map 10, 75-Year Sea Cliff Retreat Line Map of the City of Santa Barbara and its Sphere of Influence (SCRL Map) was identified using the following methodology:

- The top bluff edges of sea cliffs were identified by reviewing aerial photos and 2- to 5-foot contour elevation data in the areas of interest. The top bluff edge was digitized in a GIS environment and is depicted as a green line on the SCRL Map.
- Based on the evaluation described above, global slope instability was presumed from the top edge of the bluff towards the ocean with the exception of select locations where global bluff instability has been historically observed to extend landward of the top outer edge of the bluff, e.g. Shoreline Park.
- Additional sea cliff setback due to the effect of erosion on the sea cliff was calculated by multiplying the design life (75 years) by the identified documented highest episodic erosion rate (12 inches per year).

Because rates of sea cliff erosion may translate along the coast (rate of erosion moves from littoral cell to another), the highest (most conservative) documented rate of sea cliff erosion (12 inches per year) has been utilized for generating the sea cliff retreat line..

The identified SCRL is depicted as a red line on the SCRL Map.

## 11.2 75-YEAR SEA CLIFF RETREAT LINE MAP GUIDELINES

The 75-Year Sea Cliff Retreat Line Map (Geohazards Map 10 of 10) depicts areas that are subject to regulation under Section 30253 of the Coastal Act within the City and its Sphere of Influence. The SCRL Map is used to identify areas where proposed development projects may be subject to coastal bluff retreat that may threaten the design life of the project or planned project elements may contribute to coastal bluff retreat processes.

### 11.2.1 Technical Studies

A matrix indicating required studies related to sea cliff retreat hazards and proposed land usage is presented in Table 11-1.

### TABLE 11-1
### REPORTS REQUIRED TO EVALUATE 75-YEAR SEA CLIFF RETREAT ZONE AND PROPOSED LAND USE

| Sea Cliff Retreat Zone | Proposed Development | Studies Required | Timing |
|---|---|---|---|
| Landward of mapped SCRL, or more than 50 feet from top outer edge of bluff, whichever is greater | • Minor Improvements[1] | No Report | - - - - - - - - - - - - |
| | • Single Family Residential | No Report | - - - - - - - - - - - - |
| | • Multiple Single Family Residential Units or Multi-Family Residential | No Report | - - - - - - - - - - - - |
| | • Commercial/Industrial | No Report | - - - - - - - - - - - - |
| | • Essential Facility[2] | No Report[3] | - - - - - - - - - - - - |
| Seaward of mapped SCRL or within 50 feet from top outer edge of bluff, whichever is greater | • Minor Improvements[1] | Site Investigation[4] | Building Permit |
| | • Single Family Residential | Site Investigation[4] | Discretionary |
| | • Multiple Single Family Residential Units or Multi-Family Residential | Site Investigation[4] | Discretionary |
| | • Commercial/Industrial | Site Investigation[4] | Discretionary |
| | • Essential Facility[2.] | Site Investigation[4] | Discretionary |

[1] e.g., swimming pool, garage addition, or any non-inhabitable structure or improvement that does not provide life-line services.

[2] e.g., hospital, school

[3] No report required by the City. However, the State Department of Architecture requires investigation of all geological hazards for essential facilities regardless of location in accordance with Title 24 of the California Code of Regulations and California Geological Survey Special Note 48.

[4] Site Investigation: May include results of previous sea cliff retreat evaluations at project site, available data, aerial photography, field investigation, laboratory testing, engineering analysis, and other such data as may be needed on a site-specific and project-specific basis to address cliff retreat issues.

A Sea Cliff Retreat evaluation should be performed and reports prepared by a California licensed Geotechnical Engineer and Certified Engineering Geologist. Each licensed professional should conduct the sea cliff retreat evaluation within their respective areas of expertise. The Certified Engineering Geologist may conduct all aspects of the investigation relating to the evaluation of geologic processes affecting sea cliff retreat and bluff stability and may conduct stability analyses of the bluff. The Geotechnical Engineer may conduct portions of the investigation relating to the global bluff stability evaluation. The format and content of reports should be in general accordance with the California Board for Geologists and Geophysicists adopted guidelines for engineering geology reports or the acceptable format and content of geotechnical reports, and with appropriate investigation following the evaluation procedures set forth by Johnsson (2002) (Appendix B).

1. **Landward of Sea Cliff Retreat Line.** If habitable structures or improvements are proposed landward of the SCRL or more than 50 feet from the top outer edge of bluff, whichever is greater, a sea cliff retreat evaluation geotechnical study is not required.
2. **Seaward of Sea Cliff Retreat Line.** If habitable structures or improvements projects are proposed oceanward of the mapped SCRL or within 50 feet of the top outer edge of bluff, whichever is greater, a site-specific investigation for sea cliff retreat is performed to identify the detailed SCRL for the project site area.

   Data submitted as part of the sea cliff retreat evaluation may include: a) the results of previous sea cliff retreat evaluation(s) at the project site, b) sea cliff retreat evaluation(s) in close proximity to the project site, with demonstration that the geologic site conditions and the identified nearby sea cliff retreat rate are similar and extractable to the project site, or c) other such data as may be determined on a project-specific basis and acceptable to the City. These procedures include appropriate historical data and aerial photography, field investigation, laboratory testing, and engineering analysis.

### 11.2.2 Mitigation

Appropriate mitigation measures must be in accordance with the Coastal Act, and mitigation measures suggested here are not intended to preclude or supersede requirements of the Coastal Act. Acceptable mitigation measures for sea cliff retreat are variable depending on site conditions and the nature of the proposed project. The most appropriate solution may involve a combination of mitigation measures. Mitigation measures may include, but are not limited to:

- Avoidance of sea cliff retreat hazard – by not locating planned improvements oceanward of the identified SCRL that would be in conflict with the intent of the Coastal Act
- Control site drainage, including requirements set forth by the Coastal Act, to minimize subsurface flow through geologic materials

- Engineering design of foundation and structural project elements that would extend to suitable depth(s), be of suitable strength to not be compromised, and would support the applicable structure(s) in the event that sea cliff failure or retreat encroached upon the foundation and structure

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# APPENDIX A GEOLOGY OF THE SANTA BARBARA COASTAL PLAIN

The following lithologic descriptions, previous mapping and geologic summary sections are from the United States Geological Survey Open-File Report 02-136 (Minor et al. 2006; USGS 2006). Minor modifications to the USGS Open-File Report 02-136 have been made including the description of the debris flow deposits (Qdf), the addition of the geologic unit, Mission diamicton (Qmd), as reported by (Urban 2004).

## Geologic Map of the Santa Barbara Coastal Plain Area, Santa Barbara County, California

### Version 2.0

**By Scott A. Minor, Karl S. Kellogg, Richard G. Stanley,**
**Larry D. Gurrola, Edward A. Keller, and Theodore R. Brandt**

## DESCRIPTION OF MAP UNITS

af **Artificial fill (Holocene)—**Mappable areas of fill used for construction of highways, roads, buildings, harbor facilities, and dams.

Qa **Active channel alluvium (Holocene)—**Unconsolidated sediments, primarily pebble to boulder gravel, in floors and banks of modern stream channels. Commonly incised as much as 5 m into alluvial deposits of associated floodplain (Qac). Thickness variable.

Qb **Beach deposits (Holocene)—**Unconsolidated beach sediment, mostly fine- to medium-grained, well sorted, clean, light-grayish-tan sand composed predominantly of quartz, feldspar, and lithic grains. Includes subordinate shell fragments, plant remains, and human litter.

Qe **Estuarine deposits (Holocene)—**Dark-brown and dark-gray laminated clay, silt, and subordinate sand deposited in brackish-water environment. Contain a high percentage of decomposed terrestrial organic matter. Form areas of flat, low-lying topography that are largely covered by marshy vegetation or urban development and were mapped primarily by means of air photographs and digital elevation models. Estuarine deposits mapped in coastal areas beneath and surrounding Devereaux and Goleta Sloughs, lower downtown Santa Barbara, Andre Clark Bird Refuge, and El Estero. Maximum thickness of deposits estimated to be no more than 15 m.

Qas **Asphalt deposits (Holocene)**—Accumulations of black, tar-like asphalt that represent weathered and biodegraded oil derived from nearby natural seeps. Varies from moderately hard to very hard and brittle; freshly broken pieces emit a strong oily odor. Primarily form low mounds 1–10 m across and 1–3 m thick and drape-like accumulations on the sea cliff 1–5 m across and 1–5 m high; such deposits are depicted on map by point symbols. Also form sheet deposits of undetermined thickness that extend laterally for tens of meters. Locally contain shells, angular fragments of older asphalt, and rock fragments. Commonly overlie beach sand and older landslide deposits derived from erosion of the modern sea cliff; commonly overlain by very young beach sand and landslide deposits. Exposed surfaces of some accumulations are overgrown by intertidal organisms and terrestrial vegetation. Typically spatially associated with asphalt-filled fractures in Pleistocene sandstone unit (Qss) and Pleistocene and Pliocene siltstone unit (Qst).

Qmd **Mission Diamicton (Holocene)—**Massive, weakly consolidated, coarse-grained, poorly sorted, generally matrix-supported. The Mission Diamicton contains abundant boulders as large as 5 m in diameter and exhibits a large range in grain size (boulder to clay); clasts mostly consist of tan to gray sandstone derived from Coldwater Sandstone (Tcw) and older Eocene units. Most boulders in the Mission deposit are subangular to subrounded and lack weathering rinds or oxidation staining. Majority of deposit is ungraded but examples of crude normal and reverse grading are observed locally. Deposit can be traced from the debris flow fan near the Santa Barbara Mission and Rocky Nook Park through Rattlesnake Canyon to the source in a large landslide deposit and landslide complex (Qls) at Skofield Park. Deposit has an estimated average thickness of 8.7 m and an estimated volume of 9.2 x $10^6$ $m^3$ (Urban 2004). Age is inferred to be less than 1000 years largely based on two $^{14}C$ dates on charcoal (1460 + 40 and 1000 + 40 yr BP, (as reported by J.P. McGeehin, USGS, written commun. 2003 from field study and samples collected by Urban 2004) (Urban 2004). Youthful, lobate geomorphic expression of most deposits agrees with Holocene age carbon dating results.

Qac **Alluvium and colluvium (Holocene and upper Pleistocene)—**Unconsolidated to weakly consolidated silt, sand, and gravel deposits of modern drainages, alluvial fans, and floodplains. Deposits inferred to underlie much of the Goleta, Santa Barbara, Montecito, and Carpinteria urbanized areas and many of the larger broad canyon floors in the western half of the map area. Where exposed, alluvium is composed of poorly to moderately sorted silt, sand, and pebble to boulder gravel that commonly occupy paleochannels. Flanking colluvial deposits are composed primarily of poorly sorted, angular clasts, with longest axis typically as great as 1 m, in a fine-grained matrix derived from weathering of bedrock and transported directly downslope. Geomorphic surfaces underlain by alluvium and colluvium commonly contain poorly to moderately developed soil profiles and exhibit weak to moderate erosional dissection. Exposed thickness of alluvial and colluvial deposits generally less than 10 m.

Qc **Colluvium (Holocene and upper Pleistocene)—**Unconsolidated to weakly indurated, mostly non-stratified, dark-brown to light-gray-brown deposits that mantle gentle to moderate slopes. Consists of angular to subrounded pebbles, cobbles, and boulders mixed with fine-grained material, mostly derived from weathering and down-slope movement of nearby bedrock. Includes sheetwash deposits and some small landslide deposits on slopes, minor alluvium in small channels, and deposits of wind-blown sand, silt, and minor clay in areas of open gentle slopes. Colluvial deposits commonly capped by poorly to moderately developed soil profiles. Smaller colluvial deposits are not mapped, particularly where thin and discontinuous. Maximum thickness of colluvial deposits probably less than 15 m.

Qls **Landslide deposits (Holocene and Pleistocene)—**Deposits of diverse slope-movement processes including earth slides, earth flows, rock slides, debris slides and rock slumps (Bezore and Wills 2000; terminology of Cruden and Varnes 1996). Deposits range from poorly sorted, disrupted mixtures of rock fragments and soil to relatively intact bedrock slump blocks. Surfaces of deposits commonly hummocky; relatively steep breakaway zones commonly identifiable. Rincon Shale (Tr), middle shale unit of Monterey Formation (Tmm), and relatively fine grained intervals in the Sespe Formation (Tspu, Tspm, Tspl) and Coldwater Sandstone (Tcw) are particularly susceptible to sliding (mostly by earth flow), although slides have occurred in most units where oversteepening has destabilized slopes. Largest landslide deposits may be as thick as 60 m.

Qtc **Travertine and/or caliche deposits (Holocene? and Pleistocene?)—**White, massive, low-density, locally vuggy deposits of very fine-grained, micritic carbonate. Contains embedded pebbles as long as about 5 cm. Mapped in three small areas in central part of map area. At one locality just north of Cathedral Oaks Road, 0.5 km northeast of intersection with Los Carneros Road, carbonate forms layers as thick as about 10 cm within soil that also comprises numerous float blocks scattered on hillside. This deposit may be either travertine precipitated from an ancient fault-related(?) carbonate-rich spring or pedogenic caliche. Just west of Fairview Avenue, 0.5 km north of Cathedral Oaks Road, travertine forms globular masses as thick as 0.5 m that probably resulted from now-inactive spring activity. Small resistant outcrop about 0.75 km southeast of Lauro Canyon Dam just north of Foothill Road consists of white chalky, flaggy micritic carbonate that may have precipitated along fault that thrusts lower calcareous unit of the Monterey Formation (Tml) over older alluvial deposits (Qoa).

Qia **Intermediate alluvial deposits (upper Pleistocene)—**Orange-brown to tan, weakly consolidated, stratified silt, sand, and pebble, cobble, and rare boulder gravel. Well-rounded clasts, rarely longer than 10 cm, include Eocene marine sandstone, sandstone from the Sespe Formation, and rare reworked, rounded cobbles and pebbles derived from conglomerates of the Sespe Formation. Forms low, rounded, moderately dissected terraces that, in the Goleta area, are as high as about 15 m above the modern coastal piedmont surface. Average clast size decreases to south, away from sources in the Santa Ynez Mountains.

Extensive intermediate alluvial deposits in the Montecito area and north of Carpinteria were primarily deposited on piedmont alluvial fans. North and west of Goleta, where northern edge of unit coincides with a possible older, elevated shore line angle, unit may include older marine terrace deposits (Qmt). Farther west intermediate alluvial deposits grade laterally into a coastal strip of marine terraces (Qmt) such that mapped contact separating two units between Glen Annie Road and Bell Canyon is not well constrained and very approximately located. Intermediate alluvial deposits are topographically lower and, thus, younger than adjacent older alluvial deposits (Qoa), and generally contain smaller clasts, but in some areas of map unit may be temporally equivalent to older alluvial deposits (Qoa) mapped in other areas.

Late Pleistocene age of unit mainly based on lateral correlation with relatively well-dated marine terrace deposits (Qmt) and late Pleistocene age of underlying older alluvial deposits (Qoa).

Unit was previously mapped as fanglomerate, older alluvium, and alluvium (Dibblee 1966) and older dissected surficial sediments (Dibblee 1986a, 1986b, 1987a, 1987b). Base of unit not exposed; thickness probably locally greater than 20 m.

Qmt **Marine terrace deposits (upper Pleistocene)—**Mostly pale- to medium-tan, -brown, and -gray, weakly to moderately consolidated, crudely to moderately bedded, pebble-cobble gravel and conglomerate, pebbly to conglomeratic sand and sandstone, and silt and siltstone. Deposits unconformably overlie eroded bedrock or older sediments on elevated marine wave-cut abrasion platforms. Lower part of marine terrace sequences typically consists of a thin ($\leq$1 m-thick) basal layer of fossiliferous cobble to pebble gravel or conglomerate that grades upward into laminated to massive beach(?) sand or sandstone and, locally, estuarine organic-rich clay and silt. Basal gravel and conglomerate clasts commonly exhibit mollusk (pholad) borings that rarely contain pholad shells. An open coast invertebrate fauna of at least 125 taxa, including 102 mollusks and 18 foraminifers has been collected from the lowermost emergent terrace of this unit near Goleta (Wright 1972; C.L. Powell II unpub. data). The mollusks from this terrace inhabited an exposed rocky and sandy shore from intertidal to inner sublittoral depths (0-9 m) (Valentine 1961; Wright 1972). Among the fauna is the rare fossil solitary coral *Balanophyllia elegans* (Verrill) (Gurrola and others 2001). Upper part of terrace sequences typically includes nonmarine eolian sand or sandstone and silt or siltstone, stratified fluvial or alluvial pebble-cobble gravel or conglomerate, and (or) colluvial deposits.

Marine terrace deposits are best exposed in upper parts of sea cliffs that span nearly continuously the western two-thirds of map area and intermittently the eastern third. Also, the deposits are inferred to underlie the elevated, locally dissected coastal mesas that extend inland from the sea cliffs and, in western Goleta Valley, may extend beneath the broad area of moderately dissected terraces mapped as intermediate alluvial deposits (Qia). Flights of multiple marine terraces are locally preserved along the coast and are bounded along their back edges by shoreline angles that mark bases of adjacent terrace-riser scarps. In the Hope Ranch area on either side of southern Las Palmas Drive and in the La Mesa area as many as four terrace surfaces are preserved ranging in elevation from lower than 30 m to as high as 90 m (100-300 ft). Additionally in the La Mesa area, some terrace deposits and beveled surfaces have elevations as great as 120 m (400 ft), but it is uncertain if these deposits (mapped as

Qmt?) are of marine origin. Elevation of first emergent marine terrace in Isla Vista area is about 10 m (30-40 ft).

Marine terrace basal abrasion surfaces in map area probably formed during interglacial sea-level high stands, whereas the overlying terrace deposits most likely accumulated during marine regressions resulting from eustatic drops in sea level and (or) tectonic uplift (Rockwell and others 1992; Muhs and others 1992; Keller and Gurrola 2000; Gurrola and others 2001). Emergent marine terraces in Ellwood, Isla Vista, and More Mesa areas are dated at approximately 45 ka and correlated to oxygen isotope stage 3 sea-level high stand, based on integrated results from uranium-series analysis of marine terrace corals, $^{14}$C ages of terrace shells and detrital charcoal, optically stimulated luminescence of terrace sands, and oxygen isotopic signatures of terrace mollusks (Keller and Gurrola 2000; Gurrola and others 2001). The marine terrace present southeast of Carpinteria has a similar 45 ka – stage 3 approximate age (Wehmiller and others). Marine terraces preserved in Hope Ranch, La Mesa, Santa Barbara Cemetery, Summerland, and Loon Point areas range in age from 58 ka to 105 ka and mostly correlate to oxygen isotope stage 5 sea-level high stands (Gurrola and others 2001). Dibblee (1966) reported the presence of a jaw bone of a late Pleistocene mammoth (*Archidiscodon imperator*) in alluvium within marine terrace deposits near the western edge of the map area.

Alluvial deposits typically present in upper part of marine terrace sequences probably correlate with intermediate (Qia) and older (Qoa) alluvial deposits. Marine terrace deposits of this report were previously mapped as terrace deposits (Upson 1951; Lian 1954), Carpinteria formation (Lian 1954), older alluvium (Dibblee 1966), and older dissected surficial sediments (Dibblee 1986a, 1986b, 1987a, 1987b). Maximum exposed thickness about 20 m.

Qoa **Older alluvial deposits (upper and middle Pleistocene)—**Tan, brown, pale-gray, pale-tan, and reddish-brown, moderately consolidated, crudely stratified, poorly sorted, clayey to silty sand and sandstone, pebbly sand and sandstone, silty to sandy pebble-cobble-boulder gravel and conglomerate, and breccia, and rare interbeds and partings of sandy to pebbly clay, silt, and mudstone. Sand and sandstone are locally cross laminated. Gravel and conglomerate typically occupy paleochannels or form lenticular beds, and contain subrounded clasts composed primarily of sandstone derived from Eocene formations exposed in Santa Ynez Mountains. Clasts commonly are imbricated. Southwest of La Cumbre Junior High School, lowermost beds contain clasts of siliceous shale and chert possibly derived from Monterey Formation (Tm). Breccia composed of subangular clasts mainly of Eocene sandstone typically forms thick (>3 m), sheet-like, clast-supported beds probably deposited by debris flows. Most older alluvial deposits are poorly to moderately consolidated, but alluvium in Mission Ridge area is locally indurated and cemented near basal contact with rocks of the Monterey Formation.

Along front of Santa Ynez Mountains, unit typically forms dissected, gently south sloping terraces and interfluvial caps, as much as 100 m above modern stream level, interpreted as erosional remnants of old alluvial fans. Clast size generally decreases and sorting increases away from mountain front; coarse breccia deposits, restricted to northern, proximal parts of fan remnants along mountain flanks, include blocks several meters in diameter. Finer-grained, medial and distal facies commonly erode into badlands topography. On coastal plain unit is deformed and uplifted by youthful upwarps, folds, and faults and forms rounded hills and ridges, including Mission Ridge in northern Santa Barbara and lower hills in northern Goleta Valley, Montecito, and near Summerland. Some low-lying areas of urban development, including much of downtown Santa Barbara, are inferred to be underlain by Qoa on the basis of geomorphology; such areas are slightly higher in elevation and exhibit greater erosional dissection than adjacent areas of presumably younger deposits (Qac, Qe, Qia) and were mapped primarily by means of air photographs and digital elevation models.

In most places, older alluvial deposits overlie Tertiary bedrock units with marked angular discordance. Locally in central part of map area near Highway 101, older alluvial deposits are interstratified with and conformably overlie sandstone of Santa Barbara Formation (Qsb). These deposits may be correlative with sediments of the Casitas Formation (Qca) mapped in eastern part of map area, which they closely resemble. More commonly, however, older alluvial deposits unconformably overlie Santa Barbara Formation with as much as 30$^{o}$ of angular discordance. Most older alluvial deposits of this report were previously mapped as older alluvium (Upson 1951), dissected and faulted fanglomerate (Lian 1954), alluvium (Lian 1954), fanglomerate (Dibblee 1966), and older dissected surficial sediments (Dibblee 1986a, 1986b, 1987a, 1987b).

Unit age is bracketed by underlying and interstratified middle Pleistocene Santa Barbara Formation (Qsb), and by elevated upper Pleistocene marine terrace deposits (Qmt) into which distal facies of older alluvial deposits appear to grade. Maximum exposed thickness is approximately 35 m, but thickness probably is much greater in subsurface under coastal plain.

Qbx **Shale-clast sedimentary breccia (middle Pleistocene)—**Breccia and conglomerate composed dominantly of clasts of white, beige, and pale-gray shale and mudstone derived from the Monterey Formation. Clasts are matrix- and clast-supported, angular to subangular, and as much as 20 cm long. Deposits are crudely to moderately stratified. Breccia exposed only on eastern Mission Ridge at base of older alluvial deposits (Qoa) where it directly overlies rocks of the Monterey Formation. Breccia inferred to be primarily locally derived paleo colluvium. Unit thickness locally exceeds 10 m.

Qsb **Santa Barbara Formation (middle Pleistocene)—**Mostly pale-gray and cream-colored (fresh) to buff, pale-tan, and pale-yellow (weathered), friable, fine- to medium-grained sandstone and pebbly sandstone; marine. Sandstone ranges from bioturbated and massive to crudely or moderately tabular-bedded and planar- to cross-laminated. Pale-gray sandstone weakly to strongly cemented with carbonate is present locally, which exhibits "curb-and-gutter" concretions commonly subparallel to bedding. Pebble- and rare cobble-bearing conglomeratic sandstone lenses and intervals contain generally well rounded polymict clasts that include siliceous shale possibly derived from Monterey Formation (Tm), sandstone possibly derived from Eocene formations exposed in Santa Ynez Mountains, and intermediate-to-silicic volcanic rocks. Conglomeratic layers become more common up section in exposures near Highway 101 in central part of map area. Partings, interbeds, and thin-bedded intervals of gray and pale-greenish-gray, laminated shale, siltstone, and silty to clayey fine-grained sandstone are subordinate; these commonly contain layers rich in shell hash and locally are stained with rusty-orange iron oxide. Diverse marine invertebrate assemblages of mollusks, bryozoans, and foraminifers are concentrated in multiple stratigraphic intervals, ranging in thickness from less than 1 m to several tens of meters, distributed throughout all but uppermost, conglomeratic parts of unit. Typically, shells are disarticulated, fragmented, and concentrated in planar horizons and lenses in both sandstone and finer grained intervals. Unit includes rare whitish beds of calcareous coquina, 0.5 to about 3 m thick and composed almost entirely of shell and (or) bryozoan fragments, and thin layers rich in carbonaceous (fossil plant?) fragments.

Unit typically is poorly exposed and forms subdued rounded hills except where strongly cemented, in which case it forms resistant cliffs; silt- and clay-rich intervals locally erode into badlands topography. Maximum exposed thickness is approximately 300 m. Type section of formation is west of Santa Barbara City College, just east of "Airway Beacon" on hill 406 (Dibblee 1966, 1986b). This section, which exposes a fossiliferous stratigraphic interval about 40 m thick, is fairly representative of finer-grained, thinly bedded intervals of Santa Barbara Formation, but not of the friable, massive to crudely stratified sandstone that characterizes most of unit in map area.

An isolated eastern sea-cliff exposure of probable Santa Barbara Formation exists in the footwall block of the Loon Point fault east of Summerland, consisting of marine(?) pale greenish-gray, laminated to massive and bioturbated, interbedded siltstone, sandstone, and conglomeratic sandstone. Nonmarine sediments of the Casitas Formation (Qca) are thrust over the Santa Barbara deposits in the fault exposure, implying that the exposed Santa Barbara interval is younger than the structurally overlying Casitas. This age relation may reflect local interfingering of the two formations in the uppermost part of the Santa Barbara Formation.

A slight to moderate angular unconformity separates Santa Barbara Formation from underlying Miocene and older units (Tspu, Tv, Tr, and Tml) along west-northwest-trending belt of discontinuous exposures extending from Santa Barbara Harbor to foothills northwest of Goleta. Surface trace of this unconformity marks approximate northern limit of unit in central map area, but presence of shelf molluscan fossils and lack of shoreface fossils in northern exposures of formation suggests that original depositional basin extended farther north than present limit of exposure (cf., Dibblee 1966). In La Mesa area west of Lavigia Hill, formation is inferred to onlap a buttress unconformity underlain by more steeply tilted strata (dips $20^{o}$ and greater) of Rincon Shale (Tr) and Monterey Formation (Tml). Upper contact of Santa Barbara Formation with younger sedimentary units is generally unconformable and discordant but is locally gradational with conglomerates and gravels mapped as older alluvial deposits (Qoa) and possibly correlative with the Casitas Formation (Qca). Nonfossiliferous, cross-laminated sand deposits that underlie marine terrace deposits (Qmt) at the mouth of La Honda Valley (near Santa Barbara City College) are questionably assigned to the Santa Barbara (Qsb?).

Molluscan fossils from Santa Barbara Formation examined by us characteristically include bivalves *Chlamys* spp., *Cyclocardia occidentalis* (Conrad), *C. californica* (Dall), *Humilaria perlaminosa* (Conrad), *Lucinoma annulatum* (Reeve), *Patinopecten caurinus* (Gould), *Pecten bellus* (Conrad), and gastropods *Amphissa reticulata* (Dall), *Boreotrophon* spp., *Crepidula princeps* (Conrad), *Olivella biplicata* (Sowerby), *Neptunea tabulata* (Baird), and *Turritella cooperi* Carpenter. The molluscan faunas are consistent with deposition at shelf water depths and a possible late Pliocene to middle Pleistocene age. In addition, a few mollusks known to be no younger than Pliocene, including bivalves *Dendostrea? vespertina* (Conrad) and *Patinopecten healeyi* (Arnold) and gastropod *Nassarius grammatus* (Dall), have been reported from formation (Addicott 1965; Los Angeles County Museum of Natural History collections), but these occurrences need to be confirmed by further study. Previously, Dibblee (1966) presented a list of molluscan fossils from formation interpreted to indicate a late Pliocene(?) to early Pleistocene age.

Middle Pleistocene age provisionally assigned to Santa Barbara Formation in this report is based mainly on reconnaissance paleomagnetic data indicating that formation is of normal polarity and thus no older than 790 ka (Keller and Gurrola 2000; Gurrola and others 2001). Middle Pleistocene age also is consistent with (1) a reported amino-acid racemization age of 500–600 ka for formation near Santa Barbara Hospital (Wehmiller 1992), (2) strontium isotope data suggesting an age of 400–900 ka for formation near Santa Barbara Harbor (Patterson and others 1990), and (3) a shift from predominantly dextral to sinistral coiling in planktic foraminifer *Neogloboquadrina pachyderma*, indicating an age of about 600 ka, within formation near Santa Barbara Harbor (Patterson and others 1990).

Unit was previously mapped as Santa Barbara Formation by Upson (1951) and Dibblee (1966, 1986b, 1987b).

**Unnamed sedimentary rocks east of Goleta Pier (Pleistocene and Pliocene?)**—Marine conglomerate, sandstone, siltstone, and mudstone exposed along coast 1.5 to 3.5 km east of Goleta Pier, previously mapped as unnamed upper Pliocene formation (Upson 1951), Pico

Formation (Dibblee 1966), and Santa Barbara Formation (Dibblee 1987b). In this study, mapped as three unnamed, lithologically distinct units.

Qcg **Conglomeratic unit (middle Pleistocene?)**—Conglomerate, sandstone, siltstone, and mudstone. Conglomerate is mostly clast supported and consists of angular to rounded granules, pebbles, cobbles, and boulders in a poorly sorted, friable to hard sandy and silty matrix; where hard, matrix is calcareous. Clasts larger than 20 cm commonly are oriented parallel to bedding. Conglomerate beds typically are lenticular and range in thickness from a few centimeters to about 5 m. Some conglomerate beds exhibit inverse-to-normal grading; others exhibit complex, lenticular internal stratification marked by variations in clast size. Bases of most conglomerate beds are sharp, irregular, and erosional. Weak clast imbrication in two beds suggests paleoflow generally to west, southwest, and south. Clasts in lower parts of unit are mainly mudstone, shale, porcelanite, dolomite, and subordinate black phosphorite inferred to be derived from Sisquoc and Monterey Formations; clasts higher in unit additionally include abundant fine- to coarse-grained sandstone possibly derived from Paleogene and Mesozoic strata in the Santa Ynez Mountains. Benthic foraminifers and calcareous nannofossils from one dark-brown mudstone clast indicate derivation from middle or lower parts of the Monterey Formation (Tmm or Tml) (R.S. Boettcher and S.A. Kling, Micropaleo Consultants, written commun. 2001). Largest clasts are angular to subrounded boulders of dolomite as much as 1.2 m long; most clasts larger than 10 cm are mudstone, shale, and dolomite. Clasts also include minor gray chert, red quartzite, and gabbro or diorite derived from unknown sources; black, glassy chert possibly derived from the Monterey Formation; and angular, irregularly shaped clasts of bioturbated fine-grained sandstone and siltstone possibly derived from the associated sandstone and (or) siltstone units (Qss, QTst).

Unit also includes: 1) bioturbated siltstone and sandstone; 2) laminated, fine- to coarse-grained sandstone; and 3) thin-bedded sandstone and mudstone. Bioturbated siltstone and poorly sorted, very fine to fine-grained sandstone are friable to moderately hard, brown to gray and blue-gray on freshly broken surfaces, weather gray to tan with some orange and yellow mottling, and occur in beds ranging in thickness from a few centimeters to more than 2 m. Some beds contain scattered granules, pebbles, and cobbles, thin lenses of conglomerate, and molluscan shells and shell fragments. Fractures commonly are partly filled by jarosite. Bioturbation is defined by textural and color mottling and by knobby, irregular weathering surfaces.

Laminated, fine- to coarse-grained sandstone is gray on fresh surfaces, weathers light brown to tan, is poorly to well sorted, and ranges from friable to hard. Hard sandstone is variably calcareous and forms prominent ledges. Occurs as lenses within conglomerate and laterally persistent beds less than 50 cm to 5 m thick. Most beds are amalgamated; some amalgamation horizons are marked by thin gray-brown clay-rich horizons up to 3 cm thick. Some beds exhibit normal grading from pebbly and granular sandstone at base to fine sandstone at top. Sedimentary structures include plane lamination, ripple cross lamination, convolute lamination, and low-angle scour and fill; basal bed surfaces commonly are erosional. Granules, pebbles, and cobbles of mudstone and dolomite apparently derived from Sisquoc and (or) Monterey Formations are common as scattered clasts and in lenses of conglomerate.

Intervals of thin-bedded sandstone and mudstone are poorly exposed and generally 1–5 m thick. Sandstone is friable, very fine to fine-grained, generally well sorted, and weathers white to light brown. Sandstone beds are 5–20 cm thick and interstratified with beds of mudstone 1–3 cm thick. Many sandstone beds exhibit irregular, gradational, and apparently bioturbated contacts with underlying and overlying mudstone beds; some have abrupt erosional lower contacts. Sedimentary structures include plane lamination, ripple cross lamination, and convolute lamination. Some sandstone beds exhibit partial Bouma sequences and may represent Tb, Tac, and Tbc turbidites. Local observations on ripple cross laminations suggest paleoflow generally to the west and southwest. Mudstone is gray to brown, clayey and silty, bioturbated, and generally harder and more consolidated than interlayered sandstone.

Unit is inferred to have been deposited in a submarine canyon or channel eroded into underlying units. Exposed width of channel is about 610 m. Eastern contact of unit with Sisquoc Formation (Tsq) is a west-dipping buttress unconformity; western contact with underlying sandstone unit (Qss) is an east-dipping buttress unconformity. Both contacts are abrupt, irregular, and clearly erosional. Unit is unconformably overlain by marine terrace deposits. Base of unit in thickest, axial part of channel is not exposed; minimum thickness of unit in this area is 33 m. Preliminary evidence suggests that much of the conglomerate was deposited by submarine debris flows and/or high-density turbidity currents, whereas much of the sandstone and siltstone may have been deposited by low-density turbidity currents.

Locally abundant marine fossils in conglomerate and sandstone intervals consist mainly of mollusks and arthropods. A list of mollusks identified by W.P. Woodring and reported by Upson (1951) and Dibblee (1966) were interpreted as being late Pliocene(?) to early Pleistocene, but our reinterpretation of this list supplemented with museum and recent collections have found no Pliocene indicators. A single shark tooth (*Carcharinus*) was identified by J.D. Stewart (Los Angeles County Museum of Natural History) The fauna are distinguishable from the Santa Barbara Formation fauna only by the presence of shallow water, open coast taxa and coarser sediments, and the two units are probably of similar age.

Qss **Sandstone unit (middle Pleistocene?)**—Laminated and bioturbated feldspathic sandstone, siltstone, and subordinate mudstone and conglomerate. Lower part of unit consists mainly of couplets of laminated sandstone and bioturbated sandstone and siltstone 30-100 cm thick. Laminated sandstone is gray, weathers light gray to light brown, and ranges from fine to coarse grained and moderately to well sorted; some beds contain scattered granules, pebbles, and cobbles consisting of clasts of mudstone, shale, and dolomite derived from the

Sisquoc and (or) Monterey Formations, in addition to scattered, poorly preserved molluscan shells and shell fragments. Planar to gently undulatory laminations mostly 0.5–1 cm thick are defined by variations in grain size and color banding and in places resembles hummocky cross-stratification. Convolute laminations are present locally. Lower contacts of laminated sandstone beds are abrupt and in places clearly scoured into the underlying bioturbated beds with up to 5 cm erosional relief. Bioturbated sandstone and siltstone is fine to medium grained, moderately to poorly sorted, gray to brown on freshly broken surfaces, weathers light brown, and is generally softer and less resistant than the laminated sandstone. Bioturbation is defined by textural and color mottling; individual burrows are well preserved in some beds and exhibit vertical, horizontal, and oblique orientations. Where weathered, both laminated and bioturbated beds are soft and friable and contain abundant jarosite along fractures.

Poorly exposed intervals of white- to tan- weathering and friable to well-consolidated sandstone overlie laminated sandstone beds. Beds are 5–100 cm thick but generally less than 50 cm thick; most are lenticular. Some beds appear to be massive but others exhibit planar and (or) convolute lamination.

Conglomerate constitutes 1–2 percent of unit and occurs mainly as lenses 10–50 cm thick and less than 5 m in lateral extent. Most clasts are angular to subrounded granules and pebbles less than 5 cm long, although some are as long as 30–50 cm. Most clasts are laminated shale, mudstone, porcelanite, and dolomite derived from the Sisquoc and (or) Monterey Formations. Benthic foraminifers from one mudstone clast indicate derivation from lower part of the Monterey Formation (Tml) (R.S. Boettcher and S.A. Kling, written commun. 2001).

Contact with siltstone unit (QTst) is covered by vegetation and soil but is inferred to be a fault; depositional base of unit is not exposed, and stratigraphic relation with siltstone unit is uncertain. Exposed thickness of sandstone unit is 45–60 m. Preliminary work suggests that unit may have been deposited below fair-weather wave base on a storm-dominated marine shelf, perhaps at water depths of 10–100 m.

Age of sandstone unit is uncertain owing to lack of age-diagnostic fossils. Pleistocene age is probable on basis of general lithologic resemblance of conglomerate, sandstone, and siltstone in unit to strata of better-dated siltstone and conglomeratic units (QTst, Qcg).

QTst **Siltstone unit (lower Pleistocene and/or upper Pliocene)**—Siltstone, mudstone, and silty, very fine to fine-grained sandstone; moderately hard, dark gray-brown to brown on freshly broken surfaces, weathering light brown to gray, massive and extensively bioturbated. Stratification is generally indistinct and, where visible, poorly defined by subtle variations in color, resistance to weathering, and types and relative abundance of trace fossils; individual beds generally range from about 10 cm to 1 m or more in thickness. Siltstone and sandstone appear to be feldspathic and in places contain abundant mica and (or) fragments of land plants. Pebbles and granules of rock fragments are uncommon and include dolomite derived from the Sisquoc and (or) Monterey Formations and porphyritic dacitic rock of unknown derivation. Scattered, poorly preserved mollusk shells and shell fragments suggest shelf deposition, or possibly deeper. The bivalve mollusk *Cylocardia* sp., and gastropods *Amphissa reticulata* Dall, *Antiplanes* sp., and *Exilioidea* sp. are present in unit. Modern representatives of these taxa coexist in the Southern California Bight at water depths between about 60 and 200 m. They are not age diagnostic. Microfossils are abundant in the unit and include benthic foraminifers, ostracodes, and sponge spicules. Jarosite and gypsum are locally abundant along fractures. Locally, unit is cut by asphalt-filled fractures, some of which may represent exhumed conduits or "feeder dikes" in which oil migrating from source rocks at depth reached the surface and created accumulations of asphalt (Qas).

Contact with Sisquoc Formation (Tsq) is covered by landslide deposits and asphalt (Qas) but may be a fault. Depositional base of siltstone unit is not exposed, but regional discordance between gently dipping beds of unit and more steeply dipping beds of older Sisquoc Formation suggests an unconformable relation. Unit is unconformably overlain by marine terrace deposits (Qmt). Exposed thickness is about 45 m.

Contains benthic foraminiferal assemblages indicative of Wheelerian stage (of Natland 1952, and Kleinpell 1980) and upper to middle bathyal water depths (R.S. Boettcher, written commun. 2001). Wheelerian stage is considered latest Pliocene and early Pleistocene in age (McDougall and Lagoe 1993, p. 7; K. McDougall, written commun. 2001).

Sea cliffs formed by unit about 2.1 km east of Goleta Pier are actively eroding; some man-made structures along the tops of the cliffs have been undermined by erosion and appear to be in danger of falling. In places, outcrops of unit are partly covered by sea walls and retaining walls.

Poorly exposed strata north of More Ranch fault on Mescalitan Island and further west between South and North More Ranch Faults are assigned to siltstone unit because they are lithologically similar to exposures east of Goleta Pier, and because samples yielded benthic foraminiferal assemblages indicative of Wheelerian stage and upper bathyal to upper middle bathyal water depths (R.S. Boettcher, written commun. 2001; 2002).

Tsq **Sisquoc Formation (Pliocene and upper Miocene)**—Diatomaceous mudstone and shale, conglomerate, and subordinate dolomite; marine. Diatomaceous mudstone and shale are tan to white weathering, gray to brown on freshly broken surfaces, and contain zones of fractures lined with moderate to abundant jarosite and gypsum. Mudstone is generally soft to moderately hard; shale ranges from soft to hard and brittle. Both mudstone and shale are generally of low density. Reaction in dilute hydrochloric acid (HCl) ranges from weak to strong, indicating the presence of varying amounts of carbonate minerals. Foraminifers, diatoms and diatom debris (in some cases with opaline luster), fish fragments, radiolarians, sponge spicules, and molluscan shells and shell fragments are common to abundant, particularly along surfaces that are broken parallel to stratification. Most mudstone and shale beds are moderately to strongly laminated but some are massive and bioturbated. Laminations generally are 0.5–10.0 mm thick and are defined by light and dark color bands and variations in the types and abundance of microfossils and microfossil debris. Some cream-colored laminae may be phosphatic. Laminations within some beds are deformed into soft-sediment folds with amplitudes and wavelengths of a few centimeters to a few tens of centimeters. In places, such as the Goleta Point area, strongly fractured mudstone exhibits hydrocarbon staining and an oily odor. At Coal Oil Point, mudstone and shale within the stratigraphically lowest 80-100 m of the Sisquoc Formation are hard, brittle, and porcelanitic.

Dolomite constitutes less than one percent of the formation and forms laterally persistent beds generally less than 30 cm thick but ranging up to 100 cm thick, and ellipsoidal to spheroidal concretions up to about 100 cm in longest dimension. Dolomite is very hard, gray on freshly broken surfaces, weathers white to light orange or light brown, and is aphanitic to sugary. Some is strongly calcareous. Laminations, mostly 1–10 mm thick but as much as 20 mm thick, are defined by alternating light and dark color banding and by subtle variations in texture. Some distinctive cream-colored laminations may be phosphatic. In some beds, the laminations are involved in small-scale, disharmonic folds with wavelengths and amplitudes of a few centimeters to tens of centimeters that are interpreted to reflect soft-sediment deformation. Fish fragments and poorly preserved microfossils, including foraminifers, are common.

Conglomerate consists mainly of angular to subrounded clasts of mudstone, shale, dolomite, porcelanite, and phosphorite that appear to have been derived from the underlying Monterey Formation. Clasts range from granules to boulders; most are smaller than 30 cm but blocks up to 1 m across are common and the largest blocks are more than 10 m across. In most outcrops, the largest blocks are composed of hard, laminated dolomite or porcelanite, whereas shale and mudstone blocks are generally smaller. Most conglomerate beds are about 10 cm to 5 m thick and some may be as thick as 10–20 m. Laminated clasts typically are oriented at various angles to each other and bedding. However, some large, elongate clasts are oriented parallel or subparallel to stratification. In many places the clasts are tightly packed together; the matrix between the clasts, where present, is massive, diatomaceous mudstone. Conglomerate beds are easily recognized in fresh exposures along sea cliffs but are difficult to recognize in weathered or strongly fractured exposures. Conglomerate is well exposed in sea cliffs about 3.5–4 km east of Goleta Pier, in sea cliffs between Goleta Point and Goleta Beach County Park, in sea cliffs and the intertidal zone from Coal Oil Point to Isla Vista, and in sea cliffs between Dos Pueblos Canyon and Eagle Canyon. Conglomerate is present but poorly exposed in sea cliffs east of Bell Canyon and in sea cliffs between Ellwood and Coal Oil Point.

Samples from the lower part of the Sisquoc Formation in coastal outcrops near the mouth of Dos Pueblos Canyon, east of the mouth of Eagle Canyon, and near Goleta Pier contain diatoms of the *Thalassiosira miocenica*/ *Nitzschia miocenica* Assemblage Zone (late Miocene, about 6.2–6.7 Ma) (J.A. Barron, U.S. Geological Survey, oral and written communs. 2001, 2002). Samples from the upper part of the Sisquoc Formation at Rocky Nook Park and from a coastal exposure near the University of California, Santa Barbara, yielded diatoms of the *Thalassiosira oestrupii* Zone (early Pliocene, younger than 5.5 Ma) (J.A. Barron, U.S. Geological Survey, oral and written communs. 2002, 2005). Diatoms of early Pliocene age have been previously reported from the upper part of the Sisquoc Formation in coastal exposures southeast of Dos Pueblos Canyon (Arends and Blake 1986; Blake 1994, p. 19). At several localities in the Goleta quadrangle, the contact between the Sisquoc Formation and the underlying Monterey Formation is abrupt and is placed at the base of the stratigraphically lowest thick bed of conglomerate; this lithologic change appears to coincide with boundary between *T. miocenica*/*N. miocenica* Assemblage Zone and the underlying *Rouxia californica* Partial Range Zone (late Miocene, about 6.7–7.6 Ma) (J.A. Barron, personal commun. 2001) and is interpreted herein as a regional unconformity.

In sea cliff exposures about 300-750 m west of the mouth of Eagle Canyon, the Sisquoc Formation rests in angular unconformity on the middle unit of the Monterey Formation (unit Tmm), consists mainly of boulder conglomerate, and apparently represents the fill of a large channel or submarine canyon that was incised into the Monterey Formation prior to deposition of the Sisquoc Formation at that locality (Hornafius 1994b, p. 10-11). In an exposure in the sea cliff about 600 m southeast of the mouth of Dos Pueblos Canyon, the unconformable contact between the Sisquoc Formation and the underlying, unnamed upper Miocene mudstone unit (Tu) is exposed and is marked by an abrupt change from dark-colored strata (mainly shale, mudstone, porcelanite, and phosphatic pebble conglomerate) of unit Tu to overlying, lighter-colored strata (mainly conglomerate and diatomaceous mudstone) of the Sisquoc Formation. This contact was previously interpreted as the boundary between the Sisquoc and Monterey Formations (Hornafius (1994a, fig. 10, p. 119) and has also been interpreted as a regionally significant sequence boundary within the Sisquoc Formation (the “surface at 1282 feet” of Bohacs and Schwalbach 1994, p. 93).

Most rocks mapped in this study as Sisquoc Formation were previously mapped as Monterey Formation (Upson 1951), unnamed upper Pliocene formation (Upson 1951), Santa Margarita shale (Bailey 1952; Dibblee 1966), Sisquoc Formation (Dibblee 1966), and Sisquoc Shale (Dibblee 1987a, 1987b). Some rocks previously mapped as Monterey Shale (Dibblee 1966) and Monterey Formation (Dibblee 1986b, 1987a, 1987b) are herein included in the Sisquoc Formation. Thickness of the Sisquoc Formation in map area is uncertain because the upper part of the unit was removed by erosion prior to deposition of the overlying Santa Barbara Formation (Qsb), unnamed sedimentary rocks east of Goleta Pier (Qcg, Qss, and QTst), and marine terrace deposits (Qmt). The Sisquoc is at least 250–300 m thick in the Goleta Pier area (Dibblee 1966, p. 51) and at least 140 m thick along the coast southeast of Dos Pueblos

Canyon. In certain coastal areas, most notably Isla Vista, wave-aided erosion of sea cliffs underlain by the Sisquoc Formation has undermined buildings and exposed parts of their foundations.

Tm **Monterey Formation (Miocene)**—Predominantly well-bedded, siliceous and calcareous mudstone and shale; marine. The Monterey Formation is well exposed and relatively unweathered along extensive stretches of sea cliffs in the western half of the map area and along the sea cliff southeast of Carpinteria; the Monterey generally is poorly exposed and highly weathered, with many original lithologic details obscured, where it crops out inland in low hills north of Goleta and in the La Mesa, Hope Ranch, and Mission Ridge areas. The Monterey Formation is of Miocene age on the basis of abundant biostratigraphic data from microfossils (Dibblee 1966; Ingle 1980, and references therein; Arends and Blake 1986; Barron 1986; DePaolo and Finger 1991; Blake 1994; Hornafius 1994a, 1994b, and references therein). The Monterey Formation is about 370-390 m thick near the mouth of Dos Pueblos Canyon; elsewhere in the map area, the thickness of the Monterey Formation cannot be determined from outcrops because of poor exposure, complicated structure, and erosion. The Monterey Formation is divided into three subunits.

Tmu **Upper siliceous unit (upper Miocene)**—East of Eagle Canyon, the upper siliceous unit consists mainly of diatomaceous mudstone and shale with subordinate dolomite and porcelanite. Mudstone and shale generally weather white to tan but have a slight red to orange cast in places where hydrocarbon staining is present, are generally brown to gray on fresh surfaces, soft to moderately hard, less resistant to weathering than dolomite and porcelanite, low-density, and locally exhibit numerous fractures coated with abundant jarosite and goethite(?). Variable reactions to dilute HCl indicates the presence of varying amounts of carbonate minerals. Microfossils are abundant, generally well preserved, and include diatoms, foraminifers, and fish fragments; in places, freshly broken surfaces of diatomaceous mudstone reveal many diatom tests with opaline luster. Mudstone and shale are generally thin to thick bedded and well laminated; the laminations are generally 0.5–20 mm thick and are defined by color banding ranging from nearly white to dark gray-brown, variations in the types and abundance of microfossils, and parallel alignment of flat particles, mainly fish scales and diatom tests. Some beds include cream-colored phosphatic laminations and (or) oblate phosphatic nodules as much as 1 cm thick and 5 cm long, with the longest dimension usually parallel to bedding. In places, the mudstone and shale exhibit hydrocarbon staining and a strong oily odor.

Dolomite constitutes about 5-10 percent of the unit and occurs as concretions and beds. The concretions are ellipsoidal to spheroidal, generally 10–50 cm thick and less than 2.5 m long, and usually oriented with the long axis parallel to stratification. The beds are generally laterally persistent and mostly about 10-100 cm thick but in places are more than 200 cm thick. Dolomite is very hard and brittle, relatively resistant, brown to gray on fresh surfaces, generally weathers white with a slight orange or yellow cast, and aphanitic to sugary in texture. Reaction of the dolomite in dilute HCl ranges from none to weak. Laminations in the dolomite are common and resemble those in the associated mudstone and shale. In some cases, laminations in dolomitic concretions pass laterally into mudstone and shale. Microfossils, including foraminifers and fish fragments, are abundant in the dolomite but generally poorly preserved. In many places, the dolomite is strongly fractured and in some exposures brecciated; some fractures are filled by white minerals of unknown composition, whereas other fractures are filled by hydrocarbons.

East of Eagle Canyon and north of the Isla Vista fault, porcelanite is present only in the stratigraphically lower part of the upper siliceous unit and occurs as isolated, resistant beds about 5-50 cm thick that are sporadically interstratified with diatomaceous mudstone and shale. The porcelanite is hard and brittle, gray to brown on fresh surfaces, weathers tan to white, is generally noncalcareous, and exhibits conchoidal fracture and porcelaneous luster. The porcelanite is generally well laminated and contains abundant but poorly preserved microfossils, including foraminifers. In places, the porcelanite is strongly fractured and stained by hydrocarbons.

West of Eagle Canyon, the upper siliceous unit consists mainly of thin-bedded, siliceous mudstone and shale, porcelanite, and subordinate dolomite. The mudstone and shale are hard, brittle, thin-bedded, brown on fresh surfaces, weather light brown, contain fish fragments and poorly preserved diatoms, occur in beds generally about 5-30 cm thick, and usually react weakly or not at all with dilute HCl. Porcelanite is hard and brittle, commonly highly fractured, dark gray to brown on fresh surfaces, weathers gray and light brown to white, exhibits conchoidal fracture, and occurs in beds that are generally 5-20 cm thick and slightly more resistant than mudstone and shale. Dolomite is generally very hard and more resistant to weathering than porcelanite, mudstone, and shale. Dolomite weathers orange- to yellow-brown, is gray brown on fresh surfaces, generally exhibits a weak reaction in dilute HCl, and occurs as concretions and as beds that are well-laminated and generally about 30-50 cm thick.

Published biostratigraphic studies of coastal outcrops near Dos Pueblos Canyon indicate that the upper siliceous unit in that area contains diatoms and benthic foraminiferal assemblages of late Miocene age (Arends and Blake 1986; Barron 1986; Hornafius 1994a, 1994b; Blake 1994). Farther east, samples from coastal outcrops of the upper siliceous unit near the mouth of Bell Canyon, near Ellwood, and near Goleta Pier yielded benthic foraminiferal assemblages that probably represent the upper part of the Mohnian stage of Kleinpell (1938, 1980) and upper bathyal to upper middle bathyal water depths (R.S. Boettcher, written commun. 2001; K.A. McDougall, written commun. 2004), and diatom assemblages of the *Rouxia californica* Partial Range Zone, *Thalassiosira antiqua* Zone, and *Denticulopsis hustedtii* Zone, all of late Miocene age (Barron 1986; J.A. Barron, written communs. 2001-2005). Within the City of Santa Barbara, samples of the upper siliceous unit from road cuts and natural outcrops in the vicinities of Franceschi Park, Sycamore Canyon, and Lou Dillon

Lane yielded diatoms of the middle late Miocene, lowermost part of the *Thalassiosira antiqua* Zone (ca. 8.5 Ma), the late Miocene *Denticulopsis hustedtii* Zone (=*D. katayamae* Zone) (8.6-9.2 Ma), and the early late Miocene *Denticulopsis dimorpha* Zone (9.2-9.9 Ma) (J.A. Barron, written communs. 2003-2005). The available data imply that the base of the upper siliceous unit increases in age from west to east, from about 8.0-8.5 Ma in the vicinity of Dos Pueblos Canyon (Hornafius 1994a) to about 9.2-9.9 Ma or older near Franceschi Park.

The upper siliceous unit rests conformably and sharply on the middle shale unit (Tmm). The contact between the two units is well exposed in the sea cliff about 5.4 km east of Goleta Pier and is placed at base of a prominent 40-cm-thick dolomite bed that overlies a prominent horizon of dark platy phosphatic shale that is highest known occurrence of phosphatic shale in Monterey Formation in this area. In the sea cliff south of Ellwood, the contact between the upper and middle units is placed at the base of a prominent, white-weathering, 200-cm-thick dolomite bed that separates white weathering diatomaceous mudstone of the upper siliceous unit from underlying, darker-colored, diatomaceous and phosphatic mudstone, porcelanite, and dolomite of the middle shale unit. In the sea cliff near Dos Pueblos Canyon, the contact between the upper siliceous and middle shale units is placed at a prominent change in lithology marked by an abrupt increase in the frequency and thickness of porcelanite beds.

Rocks assigned herein to the upper siliceous unit previously were mapped as Monterey shale (Upson 1951; Lian 1954), upper Monterey Shale (Dibblee 1966), lower shale unit of the Monterey Formation (Dibblee 1986b), upper shale unit of the Monterey Formation (Dibblee 1986b, 1987a, 1987b), and Sisquoc Shale (Dibblee 1987a). The thickness of the upper siliceous unit appears to increase eastward from about 50-60 m near Dos Pueblos Canyon to about 160-180 m near Ellwood and about 250 m in the vicinity of Goleta Pier. The upper siliceous unit is well exposed along sea cliffs in the Dos Pueblos and Goleta quadrangles, where it generally forms bright, white-weathering dip slopes; small landslides and rock falls are common along these slopes, but the upper siliceous unit appears to be generally more resistant to erosion and less susceptible to landsliding than the underlying middle shale unit. In inland upland areas, the upper siliceous unit is generally poorly exposed and mostly covered by colluvium and dense vegetation.

In the intertidal zone at Coal Oil Point, thin-bedded strata consisting mainly of hard, siliceous shale, porcelanite, and dolomite are visible during low tides. These strata are herein questionably assigned to the upper siliceous unit of the Monterey Formation (Tmu) but, alternatively, may instead be correlative with the unnamed mudstone unit (Tu).

Tmm **Middle shale unit (upper and middle Miocene)**—Shale, mudstone, dolomite, porcelanite, phosphorite, and subordinate tuff, typically exposed in white-weathering dip slopes along sea cliffs. Shale and mudstone are variable in outcrop appearance and contain varying proportions of siliceous, calcareous, phosphatic, organic, and argillaceous components; some are highly calcareous and react vigorously in dilute HCl, whereas some dark-colored, apparently organic-rich shales react weakly or not at all. Siliceous and calcareous shale and mudstone typically are hard and brittle, often but not always fissile to platy weathering, and relatively resistant to weathering; phosphatic, organic-rich, and clay-rich shales and mudstones are generally less hard and less resistant, and range from hackly to fissile weathering. Shale and mudstone generally weather white to tan; some phosphatic-and organic-rich shales and mudstones weather reddish-brown. Shale and mudstone of all compositions are brown to dark brown on fresh surfaces, and commonly are well laminated and thin to medium bedded; most beds are less than 30 cm thick, but some are 100 cm thick or more. Bedding is defined mainly by variations in texture, color, and resistance to weathering, which in turn may reflect variations in composition. Most beds are laminated; in places, the laminations show subtle low-angle truncations that probably represent scour-and-fill processes on the sea floor and can be used as top-bottom indicators. Most laminae are planar and parallel to each other but some horizons exhibit small-scale, disharmonic and isoclinal folds that probably represent soft-sediment deformation. In places, shale and mudstone contain abundant microfossils visible with hand lens, including foraminifers and fish scales. Diatoms are visible in the upper part of the unit at certain localities, including coastal exposures near Ellwood. In places, foraminifers are concentrated in sandy-textured lenses; these lenses fill shallow scours that truncate lamination in the underlying strata and thereby aid in determining the direction of stratigraphic top. Cream- to white-colored phosphatic laminae, generally 1–10 mm thick, and phosphatic nodules up to 5 cm across, are locally abundant in the shale and mudstone, particularly in darker-colored, less-resistant horizons. Interbeds and concretions of dolomite range in thickness from a few cm to about 300 cm thick and are similar in lithology to dolomite in the upper siliceous unit.

Porcelanite is generally hard and brittle, relatively resistant to erosion, weathers tan or gray to nearly white, is dark gray or dark brown to black on freshly broken surfaces, shows conchoidal fracture and porcelaneous luster, and exhibits a variable reaction with dilute HCl ranging from none to very strong. Most beds are well-laminated and, where outcrops are large, laterally persistent for tens to hundreds of meters along strike; beds range from a few cm to about 40 cm thick but some beds are more than 100 cm thick. Laminae of black, glassy chert occur in places, including coastal exposures southwest of Ellwood. Some beds contain abundant foraminifers and fish scales that are visible with a hand lens. In some inland exposures the foraminifers have been removed by dissolution, leaving behind small holes that preserve the shapes of the foraminifers. In places, porcelanite is strongly fractured, and the fractures are partly or completely filled by dark-colored asphaltic material with a strong oily odor. In some outcrops, the intense fracturing imparts a brecciated appearance. In western sea cliff exposures the relative proportion of porcelanite in the middle shale unit increases westward and generally up section, from about 5 percent near Tecolote Canyon to nearly 50 percent west of Eagle Canyon.

Phosphatic hardgrounds and conglomerate in the middle shale unit are well exposed in the sea cliff near the mouth of Dos Pueblos Canyon and are described in detail by Garrison and others (1994) and Föllmi and others (2005). A poorly exposed occurrence of phosphatic conglomerate associated with porcelanite and shale was noted in a road cut in Sycamore Canyon.

Tuff is present sporadically as single, laterally persistent beds, generally 1-5 cm thick but in places as thick as 25 cm, that range from soft and friable to hard, and that weather to a variety of colors including orange, green, cream, gray, and white. The tuff is generally aphanitic but in places exhibits a silty to very fine sandy texture and contains crystals of biotite(?).

Published biostratigraphic studies of assemblages of diatoms and foraminifers, summarized by Hornafius (1994a, 1994b), show that the middle shale unit along the coast near Dos Pueblos Canyon was deposited about 14.5-8.0 Ma. Samples from outcrops of the middle shale unit along the coast from near Eagle Canyon to near Tecolote Canyon yielded benthic foraminiferal assemblages indicative of the Mohnian stage of Kleinpell (1938, 1980) and upper bathyal to middle bathyal water depths, and calcareous nannofossils of probable late Miocene age that could not be assigned to specific zones (R.S. Boettcher and S.A. Kling, written communs. 2002). Samples from sea cliff exposures of the middle shale unit on the north side of the More Ranch fault, about 1.1 km southeast of the mouth of Tecolote Canyon, yielded benthic foraminiferal assemblages indicative of the Mohnian stage of Kleinpell (1938, 1980) and upper middle bathyal to lower middle bathyal water depths, and calcareous nannofossils of the probable CN5a zone of middle Miocene age (R.S. Boettcher, S.A. Kling, and K.A. McDougall, written communs. 2003, 2004). Samples of the middle shale unit from coastal exposures southwest of Ellwood yielded benthic foraminiferal assemblages indicative of the Mohnian stage of Kleinpell (1938, 1980) and upper middle bathyal water depths, and calcareous nannofossils of probable late Miocene age that could not be assigned to specific zones (R.S. Boettcher and S.A. Kling, written communs. 2003). A sample from the uppermost part of the middle shale unit about 5.4 km east of Goleta Pier yielded benthic foraminifers indicative of the Mohnian, possibly upper Mohnian, stage of Kleinpell (1938, 1980) and probable upper middle bathyal water depths (R.S. Boettcher, written commun. 2001). Samples from the Hope Ranch and Arroyo Burro areas yielded lower Mohnian benthic foraminifers suggestive of middle bathyal water depths, as well as calcareous nannofossils of probable late Miocene age (R.S. Boettcher and S.A. Kling, written communs. 2001).

According to Hornafius (1994a, p. 123), the boundary between the Mohnian and Luisian benthic foraminiferal stages exposed in the sea cliff about 2.1 km east of the Arroyo Burro Beach Park parking lot is associated with a prominent, white-weathering dolomite bed in the lowermost part of the unit. A few meters to the east of this locality and slightly down-section, the conformable contact between the middle shale unit and the underlying lower calcareous unit is placed at the base of a prominent, thick interval of porcelanite (the "massive chert member" of Hornafius 1994a, p. 120-123). Elsewhere in the map area, the depositional contact between the middle shale and lower calcareous units is not exposed.

Rocks mapped as middle shale unit in this report were previously mapped as Monterey shale (Upson 1951; Lian 1954), upper Monterey Shale (Dibblee 1966), lower Monterey Shale (Dibblee 1966), lower shale unit of Monterey Formation (Dibblee 1986b, 1987a), upper shale unit of Monterey Formation (Dibblee 1986b, 1987a, 1987b), and Sisquoc Shale (Dibblee 1987a). The middle shale unit of this report apparently includes all of the middle shale and massive chert members and part or all of upper chert member of Hornafius (1994a, p. 121–122). The thickness of the middle shale unit along the coast near Dos Pueblos Canyon is about 70-75 m; elsewhere in the map area, the thickness of the unit cannot be determined accurately owing to structural complications and the fact that many exposures are at low angles to bedding. The thickness in these areas is estimated to be about 120–180 m.

In coastal exposures in the Goleta and Santa Barbara quadrangles, the middle shale unit is involved in several large landslides, many of which comprise large translated and partly rotated blocks of intact bedrock in which remnants of pre-landslide stratigraphy and structure are preserved (see also Bezore and Wills 2000). Upland exposures of the middle shale unit, limited to lower Sycamore Canyon, are very poor and the unit is mostly covered by colluvium and vegetation.

Tml **Lower calcareous unit (middle and lower Miocene)**—Calcareous, siliceous, and phosphatic mudstone and shale, with subordinate dolomite, porcelanite, breccia, glauconitic sandstone, and tuff. Mudstone and shale range from moderately hard to very hard, weather white to tan, and are brown to gray brown on fresh surfaces. Mudstone and shale are well stratified and occur in laterally persistent beds generally about 3–30 cm thick, but some beds are as thick as 100 cm. Beds vary considerably in relative resistance to weathering. Reaction in dilute HCl also is variable but moderate to strong in most beds, indicating that they are moderately to highly calcareous. Most beds exhibit laminations ranging from 0.5 to 10 mm thick and defined by subtle variations in color and texture; some beds are massive to bioturbated. Microfossils are abundant and consist mainly of calcareous foraminifers and fish fragments. Some beds appear to be composed of more than 50 percent bioclastic debris. In places, white- to cream-colored phosphatic nodules and laminae are abundant, generally about 1–10 mm thick and 5–25 cm in longest dimension, which is always parallel to stratification. Intervals of mudstone with abundant phosphatic nodules and laminae are thicker and more frequent in the upper part of the unit, and in places are as thick as 5 m. These intervals weather white to tan, are dark gray to brown on fresh surfaces, and generally are less resistant to weathering than calcareous and siliceous mudstones.

Dolomite is very hard, resistant, weathers yellow-gray to orange-gray and light orange, and is gray to gray-brown on freshly broken surfaces. Dolomite constitutes less than 5 percent of the unit and generally occurs as beds and concretions about 10–50 cm thick, but some beds are as thick as 200 cm. Concretions are ellipsoidal to irregular in shape and about 1–2 m in longest dimension, which is usually parallel to stratification. Most dolomite reacts slowly with dilute HCl, but some weathered dolomite reacts strongly. Dolomite beds are often strongly fractured; veins of white to gray calcite are common and some veins are oil stained.

Porcelanite is hard, brittle, resistant, exhibits conchoidal fracture, weathers light gray to white, and is gray to brown on freshly broken surfaces. Porcelanite occurs sporadically in the unit as massive to well-laminated beds about 5–20 cm thick that increase in thickness and frequency upward in the unit. The relative amount of porcelanite in most outcrops is generally less than one percent but in some outcrops is as much as 25 percent. In sea-cliff outcrops, some beds of porcelanite react strongly with dilute HCl and contain abundant calcareous foraminifers. Lenses of black, glassy chert occur at places, for example in sea cliffs near Elwood and in sea cliffs east of the mouth of Carpinteria Creek. In some inland exposures, porcelanite contains small holes created by dissolution of calcareous foraminifers.

At places along the sea cliffs—for example, west of the mouth of Gato Canyon, between the mouths of Las Varas and Dos Pueblos Canyons, and east of the mouth of Carpinteria Creek—the lower calcareous unit includes intervals about 1-30 m thick in which beds are gently to moderately folded, faulted, and stretched (for example, see Hornafius 1994a, p. 118, fig. 10c); these intervals exhibit outcrop-scale, disharmonic folds with wavelengths and amplitudes of 1-10 meters, discontinuous faults with small offsets, and beds that are stretched and thinned. Much of this deformation may have formed during down-slope, gravity-driven slumping of soft to partly lithified sediment shortly after deposition. In some areas, for example near the mouth of Dos Pueblos Canyon and east of the mouth of Carpinteria Creek, the slumped intervals are associated with layers of breccia that range in thickness from less than 1 m to about 45 m and consist of angular to subrounded clasts, generally about 1-100 cm in longest dimension but in places as large as 30 m, of mudstone, shale, dolomite, and porcelanite. In most exposures of breccia, the blocks form a clast-supported framework, and the matrix between blocks is gray to gray brown mudstone. Some breccia intervals, however, are matrix-rich and have a mélange-like appearance in which the blocks are separated from one another by mudstone matrix. The specific processes that deposited the breccias are unclear but may have included catastrophic, gravity-driven events such as debris flows, underwater rock falls, sediment gravity flows, and down slope slumping in a submarine slope environment (Garrison and others 1989).

Sandstone constitutes much less than one percent of the lower calcareous unit; a single horizon of glauconitic, medium- to fine-grained sandstone about 40–50 cm thick was found in the intertidal zone about 0.25 km southwest of Santa Barbara Point. The glauconitic sandstone horizon is hard and more resistant to weathering than the underlying and overlying horizons of calcareous mudstone. The sandstone weathers tan to orange tan, is brown to tan on freshly broken surfaces, and consists of at least three amalgamated beds that are normally graded from medium-grained sandstone at the base to fine-grained, silty sandstone at the top. The lower contact of the lowest sandstone bed with the underlying calcareous mudstone is sharp and exhibits about 10 cm of erosional relief. The upper part of the uppermost sandstone bed is bioturbated and grades upward into the overlying calcareous mudstone.

Tuff constitutes much less than one percent of the unit. Tuff weathers orange-gray to yellow-gray, is gray to greenish-gray on freshly broken surfaces, and ranges from vitric to crystal-vitric with crystals of biotite and feldspar. Tuff generally occurs as laterally persistent, recessive beds about 1–10 cm thick; the lower contacts of the beds are generally sharp and apparently erosional, whereas the upper contacts are generally bioturbated and gradational into overlying calcareous mudstones. Some crystal-bearing beds of tuff are well laminated and appear to be normally graded.

Samples of mudstone from outcrops of the lower calcareous unit near the mouth of Gato Canyon yielded benthic foraminiferal assemblages indicative of the Saucesian stage of Kleinpell (1938, 1980) and lower middle bathyal to lower bathyal water depths, and calcareous nannofossils of early middle to early Miocene zones CN3 to CN1 (R.S. Boettcher and S.A. Kling, written communs. 2003). Abundant biostratigraphic, paleomagnetic, and strontium-isotopic data indicate that the lower calcareous unit near the mouth of Dos Pueblos Canyon is of early middle to early Miocene age (DePaolo and Finger 1991; Blake 1994; Hornafius 1994a, 1994b). Samples of mudstone and shale from the lower calcareous unit in the sea cliff southeast of the mouth of Bell Canyon yielded benthic foraminifers indicative of the Relizian and Luisian stages of Kleinpell (1938, 1980) and lower middle bathyal to upper middle bathyal water depths (R.S. Boettcher, written commun. 2002; K.A. McDougall, written commun. 2004) and calcareous nannofossils of middle Miocene zone CN5A (S.A. Kling, written commun. 2002). Samples of mudstone from the lower calcareous unit near Santa Barbara Point yielded benthic foraminiferal assemblages indicative of the Relizian and Luisian stages of Kleinpell (1938, 1980) and lower middle bathyal to lower bathyal water depths, calcareous nannofossils of early middle Miocene zone CN 4, and apparently reworked lower Miocene or upper Oligocene calcareous nannofossils (R.S. Boettcher and S.A. Kling, written commun. 2001). Samples of mudstone and shale from the lower calcareous unit in the sea cliff southeast of the mouth of Carpinteria Creek yielded benthic foraminifers indicative of the Relizian and Saucesian stages of Kleinpell (1938, 1980) and lower middle bathyal to upper middle bathyal water depths, and calcareous nannofossils of early middle to early Miocene zones CN4 to CN1 (R.S. Boettcher and S.A. Kling, written communs. 2002, 2003).

The conformable contact between the lower calcareous unit and the underlying Rincon Shale is well-exposed in the sea cliff near the mouth of Las Varas Canyon and is placed at the abrupt lithologic transition from well-bedded, siliceous and calcareous mudstone and shale (typical of the lower calcareous unit) to the underlying massive mudstone (typical of the

Rincon Shale). In most of the map area, however, the contact between the lower calcareous unit and the Rincon Shale is faulted or not exposed.

Strata mapped as the lower calcareous unit in this report were previously mapped as Monterey shale by Upson (1951) and Lian (1954), lower Monterey Shale by Dibblee (1966), lower shale unit of Monterey Formation by Dibblee (1986b, 1987a, 1987b), and upper shale unit of Monterey Formation by Dibblee (1986a, 1987a). The lower calcareous unit of this report is correlative with most or the entire lower calcareous shale member of Hornafius (1994a, p. 121-122; 1994b, p. 6). The lower calcareous unit is about 250 m thick near the mouth of Dos Pueblos Canyon (Hornafius 1994b, p. 4–5). Elsewhere in the map area, the thickness of the unit cannot be reliably determined because of poor exposure and (or) complicated structure. The lower calcareous unit is well exposed along the coast but generally is poorly exposed inland. It is the only subunit of the Monterey Formation exposed in upland areas except on Mission Ridge, where it is accompanied by middle and upper Monterey subunits. Along the coast, the lower calcareous unit generally forms steep, light-colored sea cliffs with numerous small rock falls; in places, erosion of these cliffs has undermined buildings, fences, and other man-made structures.

Tr **Rincon Shale (lower Miocene)**—Primarily massive and thick-bedded marine mudstone, with subordinate dolomite, siliceous shale, sandstone, and tuff; marine. More than 90 percent of the Rincon Shale is composed of mudstone that is gray to gray-brown on freshly broken surfaces, weathers light brown, is generally hard to moderately hard, and generally shows a moderate to weak reaction in dilute HCl. At places, the mudstone contains abundant microfossils including calcareous foraminifers and fish scales. Mudstone is generally massive and bioturbated; some burrows in mudstone are filled by glauconitic(?) fine sandstone, for example in intertidal outcrops west of Las Varas Canyon. Mudstone is thick to very thick bedded, with beds generally 30-200 cm thick. Typical hackly fractures in mudstone commonly contain yellow jarosite.

Dolomite is hard, resistant to weathering, gray to gray brown on freshly broken surfaces, weathers orange to yellow orange, has aphanitic to sugary texture, and reacts slowly or not at all in dilute HCl. Dolomite forms laminated to massive, laterally persistent beds as thick as 100 cm, and also spheroidal to ellipsoidal concretions that range in size from a few centimeters to nearly 3 m across. The long axes of the dolomite concretions commonly are parallel to stratification.

Sandstone is uncommon and occurs as sparse interbeds within thick sequences of mudstone. The sandstone is medium to fine grained, quartzofeldspathic, and friable. Sandstone beds are generally 5-10 cm thick and laterally persistent across most outcrops; exhibit sharp and irregular lower contacts that probably represent filled scours in the underlying mudstone; and have gradational, bioturbated upper contacts with the overlying mudstone.

White-weathering tuff in the upper part of the Rincon Shale is exposed at several localities including the sea cliff near the mouth of Las Varas Canyon, along Mission Creek in Rocky Nook Park, in Sycamore Canyon, and road cuts in Summerland and along Conejo Drive in Santa Barbara. The tuff ranges from soft and friable to moderately indurated, consists mainly of glass shards, and in places contains fish scales as well as pumice and crystals of feldspar, quartz, and biotite. The tuff is massive to well-laminated and its apparent thickness ranges from at least 4 m at Rocky Nook Park to nearly 10 m in Sycamore Canyon. Dibblee (1966, p. 46) apparently considered these widely separated outcrops of tuff to represent a single stratigraphic horizon that marks the base of the Monterey Formation. However, we mapped the boundary between the Rincon Shale and Monterey Formation at the lithologic transition from relatively massive and poorly bedded, predominantly argillaceous mudstone (typical of the Rincon Shale), to overlying, well-bedded, siliceous and calcareous mudstone and shale (typical of the Monterey Formation). In many places this contact is approximately located because of poor exposure. However, tuff exposed near the mouth of Las Varas Canyon is clearly at least 8 m (Hornafius 1994, p. 6) stratigraphically below the change in lithology and is, thus, included in the Rincon Shale. In places, the tuff may be entirely within the Monterey Formation; for example, tuff exposed near Lauro Canyon Dam appears to be underlain by siliceous shale typical of the Monterey Formation. Outcrop quality and available age control are insufficient to demonstrate whether the widely separated outcrops of tuff represent a single stratigraphic horizon that was deposited during a single event or, alternatively, several closely spaced stratigraphic horizons that were deposited during multiple events. Within the map area, a sample of tuff from a road cut in Summerland yielded a preliminary $^{40}Ar/^{39}Ar$ incremental heating age on plagioclase of 17.2-17.3 Ma (R.J. Fleck, U.S. Geological Survey, personal commun. 2005). Previously, samples of tuff from Summerland yielded K-Ar ages on plagioclase of 16.5 ± 0.6 Ma and 17.2 ± 0.5 Ma (Turner 1970, corrected for changes in decay constants using method of Dalrymple 1979), and a sample of tuff from near the mouth of Las Varas Canyon yielded a $^{40}Ar/^{39}Ar$ single-crystal laser-fusion age on sanidine of 18.42 ± 0.06 Ma (Stanley and others 1996). Samples of tuff from Lauro Canyon Dam, Rocky Nook Park, and Conejo Drive in Santa Barbara are undated but are petrographically and geochemically indistinguishable from each other (A.M. Sarna-Wojcicki, written commun. 2002) and probably were derived from the same eruptive source.

Unit was previously mapped as Rincon Formation by Lian (1954) and as Rincon Shale by Upson (1951) and Dibblee (1986a, 1986b, 1987a, 1987b).

The age of the Rincon Shale is early Miocene on the basis of abundant biostratigraphic evidence from a measured stratigraphic section in Cañada de la Pila, about 15 km west of the map area (Stanley and others 1992, 1994) and isotopic ages of tuffs, as noted above. Also, the base of the Rincon Shale is considered to be coincident with the Oligocene-Miocene boundary (D. Bukry, oral commun. 1994). The Rincon Shale rests abruptly and conformably on the late Oligocene Vaqueros Formation and is conformably overlain by the early and middle Miocene Monterey Formation. The Rincon Shale is about 449 m thick at Cañada de la Pila (Stanley and others 1992), about 400 m thick at Carneros and Las Vegas Creeks in the Goleta quadrangle, and about 430-460 m thick in the Santa Barbara quadrangle. The Rincon Shale is generally poorly exposed and covered by vegetation, and it is susceptible to landsliding (Bezore and Wills 2000), for example in the Sycamore Canyon area where significant and locally damaging down slope movement of Rincon debris has occurred. Along the coast, the Rincon Shale is well-exposed in sea cliffs but is generally less resistant to erosion than rocks of the Monterey Formation.

Trs **Siliceous shale interval within Rincon Shale (lower Miocene)**—Siliceous shale is pale-gray and light-tan on freshly broken surfaces, weathers white to pale-gray, thin-bedded, and hard. Unit is slightly more resistant than surrounding Rincon mudstones and resembles siliceous shale intervals within Monterey Formation. Where siliceous interval is differentiated in western part of map area unit is about 60 m stratigraphically below top of Rincon Shale and has a thickness of 35 to 45 m.

Tv **Vaqueros Formation (upper Oligocene)**—Tan, yellowish-tan, yellowish-gray, and greenish-gray, weakly to moderately indurated, quartzofeldspathic sandstone; marine. Unit is moderately to strongly resistant to erosion and locally forms prominent ledges, cliffs and ridges; commonly weathers to light-tan rounded sandstone outcrops and distinctive, light-tan sandy soils; weathered surfaces locally exhibit tufoni cavities. Sandstone is primarily massive to thick bedded and medium to coarse grained, but becomes finer grained up section; massive sandstone is mostly bioturbated. Some sandstone intervals are very coarse grained and pebbly and others are rich in shell fragments. Sandstone locally contains planar to cross laminations and rare thin (5-15 mm) partings of gray siltstone and mudstone. Uppermost part contains well-defined, thin-laminated sandstone, siltstone, and mudstone interbeds. Sandstone in upper third of unit typically is mottled tan and greenish gray; underlying sandstone has abundant orange to red staining and mottling. Fractures commonly contain iron-oxide minerals. In thin section, sandstone consists primarily of quartz and subordinate feldspar and lithic grains (mostly chert and felsic volcanic rock) in an argillaceous matrix or calcite cement. Typically at base of unit but as much as 5 m stratigraphically above is a distinctive 50–150-cm-thick, well-indurated and flaggy, thinly bedded and laminated, light-gray, calcareous conglomerate containing abundant pelecypod shell fragments, rounded chert pebbles, and subangular graywacke clasts as long as about 1 cm; chert and graywacke are thought to be derived from the north from Franciscan Complex terrane (Rigsby 1998).

Lower contact with Sespe Formation is sharp and typically defined by abrupt change from thick tan-yellow sandstone and basal gray shell-rich conglomerate of the Vaqueros to underlying interbedded light- greenish-gray, tabular sandstone and maroon to olive-gray mudstone of the Sespe. Howard (1995) considered the lower Vaqueros contact to be an erosional disconformity throughout the map area, but Rigsby (1998) interpreted a transition of the contact to conformable east of Lauro Canyon.

Late Oligocene age is inferred from stratigraphic position of unit between the late Oligocene Sespe Formation and early Miocene Rincon Shale. Also, the base of the overlying Rincon Shale is considered to be coincident with the Oligocene-Miocene boundary (D. Bukry, oral commun. 1994). Rigsby (1998) reported a strontium isotope date of 24 ± 1 Ma from oyster shells in Vaqueros Formation in Hollister Ranch area 40 km west of map area, consistent with late Oligocene age.

Unit was previously mapped as basal Vaqueros formation by Arnold (1907), Vaqueros sandstone by Upson (1951) and Lian (1954), and Vaqueros Sandstone by Dibblee (1966, 1986a, 1986b, 1987a, 1987b). In the map area unit gradually decreases in thickness eastward, from over 150 m in the Dos Pueblos Canyon area to about 75 m in the Summerland area; a regional thickness of about 100 m was reported by Dibblee (1982).

Tspu, Tspm, Tspl **Sespe Formation (upper Oligocene and upper Eocene)—** Predominantly maroon, reddish-brown, and greenish- to pinkish-gray sandstone, mudstone, and conglomerate; nonmarine. Sespe Formation is poorly to moderately exposed primarily in northern part of map area in foothills flanking Santa Ynez Mountains and in uplands north of Summerland and Carpinteria. In map area Sespe Formation divided into an upper sandstone and mudstone unit, middle conglomerate and sandstone unit, and lower conglomerate and sandstone unit. The upper unit comprises well over half of the total thickness of formation, and in a few places in the central and western parts of map area the lower two units pinch out such that the upper Sespe rests directly on rocks of the underlying Coldwater Sandstone. Overall thickness of Sespe Formation increases eastward from about 700 m near Tecolote Canyon to over 1500 m in the Summerland area.

Age of Sespe Formation in Santa Barbara area is considered late Eocene and late Oligocene by Howard (1995), with an intraformational unconformity representing much or all of early Oligocene time. This unconformity (erosional disconformity) coincides with the mapped contact separating the lower conglomerate and sandstone unit (Tspl) from the middle conglomerate and sandstone unit (Tspm). Rocks below unconformity have been interpreted as part of a late Eocene fluvial sequence composed of clastic detritus derived primarily from bedrock now in the Mojave Desert, whereas overlying rocks have been interpreted as part of a late Oligocene fluvial sequence containing chert, graywacke, and other clasts derived from Franciscan Complex source terrane (Howard 1995).

Tspu **Upper sandstone and mudstone unit (upper Oligocene)**—Sandstone, siltstone, and mudstone interbedded in proportions that vary both laterally and through the section; sandstone to mudstone-siltstone ratio in a given exposure typically ranges from 5:1 to 1:5. Sandstone-rich units are commonly broadly lenticular and thin to thick bedded, and in some places they appear to occupy paleochannels. Sandstone beds are as thick as 10 m but mostly less than 2 m. Sandstone is mostly fine to medium grained, silty, and feldspathic to arkosic. On weathered surfaces sandstones display various shades of maroon, buff, pale green, tan, and gray. Laminations are typically well developed, ranging from planar to cross and trough geometries. Sandstone is friable to well indurated and typically forms resistant tabular, flaggy, or ledgy outcrops. Small pebbly lenses are locally present in sandstone beds, and some thin (≤ 1 m thick) intervals, commonly near the base of beds, contain subrounded mudstone rip-up clasts as long as 30 cm.

Mudstone is typically silty to sandy and locally grades into siltstone and, rarely, fine-grained sandstone. Mudstone and siltstone are typically maroon, reddish maroon, and brownish maroon, but in some places they are pale green or olive green. Mudstone is thin to very thin bedded and commonly laminated. Intervals of nearly pure mudstone range from less than 10 cm to at least 10 m thick. Mudstone and siltstone bedding planes commonly contain mud cracks and ripple marks. Mudstone exhibits hackly to spheroidal fracturing on weathered surfaces. Most mudstone-rich intervals are poorly exposed and form gentle slopes.

Upper Sespe unit is prone to landsliding particularly on steeper slopes along the lower flanks of the Santa Ynez Mountains as evidenced by numerous slumps and lesser debris-flow deposits in such areas.

Environment of deposition of Sespe upper sandstone and mudstone unit, which is equivalent to lithofacies D of Howard (1995), has been interpreted as progressing upward from braided to meandering river channels and interchannels (Howard 1995). Late Oligocene age of upper unit is based on Arikareean vertebrate fossils reported from the underlying middle unit in the map area (Weaver and Kleinpell 1963; Howard 1995) and on the Miocene-Oligocene boundary recognized at the base of the Rincon Shale (Tr) farther up section (D. Bukry, oral commun. 1994). Upper unit thickens eastward across map area from about 500 m thick in the Eagle Canyon area to more than 1,000 m north of Summerland. Unit was previously mapped as part of the Sespe Formation by Upson (1951), Lian (1954), and Dibblee (1966, 1986a, 1986b, 1987a, 1987b).

Tspm **Middle conglomerate and sandstone unit (upper Oligocene)**—Conglomerate, sandstone, and mudstone interbedded in proportions that vary both laterally and through the section; relative proportion of conglomerate increases down section towards base of unit, but conglomerate is strongly subordinate to sandstone and mudstone in some intervals. Conglomeratic depositional units range from laterally extensive to narrowly lenticular and thin to thick bedded (as thick as 15 m), and in some places they appear to occupy paleochannels. Conglomerate and conglomeratic sandstone typically contain subangular to well-rounded pebbles and cobbles supported in a medium- to coarse-grained sandy matrix. Clasts are polymict and include abundant chert and lithic sandstone derived from Franciscan Complex terrane, arkosic sandstone derived from Coldwater Sandstone, and quartzitic, metamorphic, and granitoid rocks derived from Mojave Desert terrane (Howard 1995). Sandstone is mostly medium to coarse grained, pebbly, silty, and feldspathic to lithic; rare sandstone beds are arkosic. On weathered surfaces conglomerates and sandstones display various shades of maroon and, less commonly, tan and pale greenish gray. Laminations are common particularly in sandstones, ranging from planar to cross and trough geometries. Some sandstone bedding planes exhibit fossil worm burrows. Commonly conglomerates and sandstones are moderately indurated and resistant and form tabular, flaggy, or ledgy outcrops.

Mudstone is typically silty to sandy and locally grades into siltstone and, more rarely, fine-grained sandstone. Mudstone is thin to very thin bedded and commonly laminated. Ripple marks are common. Mudstone-rich intervals range in thickness from thin partings to 20 m. Mudstone is maroon, maroonish red, reddish brown, and, rarely, pale greenish-gray and exhibits hackly to spheroidal fracturing on weathered surfaces. Most mudstone-rich intervals are poorly exposed and form gentle slopes.

Upper contact of middle unit mapped at stratigraphically highest conglomerate bed. Disconformity at base of middle unit commonly expressed by 3-10-m-thick interval of conspicuous deep-reddish-brown, massive-to-bedded, silty to sandy claystone and mudstone containing rare thin sandstone interbeds and lenses. Basal reddish claystone and mudstone interval interpreted to be paleosol that formed during early Oligocene hiatus of Sespe sedimentation that preceded deposition of the middle unit.

Middle conglomerate and sandstone unit is primarily equivalent to Sespe lithofacies C of Howard (1995). Late Oligocene age of unit is based on Arikareean vertebrate fossils (*Sespia nitida* Leidy) that were reported from the unit above unconformity along San Marcos Pass highway and in Sycamore Canyon (Weaver and Kleinpell 1963; Howard 1995). Unit moderately susceptible to landsliding particularly on steeper slopes along the lower flanks of the Santa Ynez Mountains as evidenced by several slumps in such areas. Middle unit generally increases in thickness eastward in map area from where it pinches out in Tecolote Canyon to about 200 m in San Pedro Canyon, to 335 m in Sycamore Canyon, to almost 450 m north of Carpinteria, but unit locally pinches out over a strike distance of more than 1.8 km in the north-central part of area. Unit was previously mapped as part of the Sespe Formation by Upson (1951), Lian (1954), and Dibblee (1966, 1986a, 1986b, 1987a, 1987b), and as red to gray conglomerate and arkosic sandstone of the Sespe Formation by Dibblee (1987b).

Tspl **Lower conglomerate and sandstone unit (upper Eocene)**—Conglomerate, conglomeratic sandstone, sandstone, mudstone, and minor shale interbedded in proportions that vary both laterally and through the section. Conglomeratic depositional units range from laterally extensive to narrowly lenticular and medium to thick bedded (as thick as 15 m), and in some places they appear to occupy paleochannels. Conglomerate and conglomeratic sandstone typically contain pebbles and cobbles as much as 50 cm in diameter supported in a medium-grained to very coarse-grained sandstone, locally grussy, matrix. Clasts are polymict and include abundant subrounded to well-rounded quartzitic, granitoid, metamorphic, and volcanic clasts derived from Mojave Desert terrane and lesser subangular to subrounded arkosic sandstone clasts and rare oyster-shell fragments and shale clasts derived from Coldwater Sandstone (Tcw) (Howard 1995). Sandstone is mostly medium to very coarse grained, pebbly, and arkosic to feldspathic. On weathered surfaces conglomerates and sandstones mostly exhibit distinctive shades of salmon gray, reddish gray, pale-pinkish gray, and tan, but some beds are pale gray, maroon, or brown; reddish-brown iron-oxide staining is locally prevalent. Laminations are very common particularly in sandstones, ranging from planar to cross and trough geometries. Conglomerates and sandstones are moderately to well indurated, resistant, and form flaggy, blocky, and ledgy outcrops and hogbacks.

Mudstone is typically silty to sandy and locally grades into siltstone and, more rarely, fine-grained sandstone. In some places intervals of fissile shale are present. Mudstone is thin to very thin bedded and commonly laminated. Mudstone-rich intervals range in thickness from thin partings to 5 m. Mudstone is maroon, maroonish red, gray, greenish-gray, and reddish brown and exhibits hackly to spheroidal fracturing on weathered surfaces. Most mudstone-rich intervals are poorly exposed and form gentle slopes.

Disconformable upper contact of lower conglomerate and sandstone unit mapped at top of 3-10-m-thick interval of conspicuous deep-reddish-brown, massive-to-bedded, silty to sandy claystone and mudstone, which is interpreted to be paleosol that formed during early Oligocene hiatus of Sespe sedimentation that preceded deposition of the middle unit. Basal, mostly conformable, contact of lower unit mapped at generally sharp change from pinkish- and reddish-gray laminated sandstone and conglomerate to pale yellow-tan to buff, massive, commonly oyster-shell-bearing sandstone of the underlying Coldwater Sandstone (Tcw). Locally in eastern map area lower contact is gradational, expressed by a thin (< 10 m) to thick (> 10 m) interval of Coldwater-like sandstone containing Sespe-like maroon mudstone and siltstone interbeds; in such areas basal Sespe contact mapped at top of uppermost Coldwater sandstone bed.

The lower conglomerate and sandstone unit generally increases in thickness eastward along strike in map area from where it pinches out in Glen Annie Canyon to about 170 m north of Santa Barbara; farther eastward unit gradually thins to 100 m north of Montecito but then locally thickens to more than 250 m north of Carpinteria; unit also pinches out along a short strike distance near Barger Canyon in north-central map area. Overall grain size of lower unit becomes finer in northwest part of map area, and at Bartlett Canyon lower unit has been interpreted to grade westward into marine sandstone of the late Eocene (Refugian) Gaviota Formation (Weaver and Kleinpell 1963; Howard 1995). However, correlation of lower Sespe beds with Gaviota in this area is dubious due to fault complications (as noted in Weaver and Kleinpell 1963) and because clear marine, fossil-bearing interbeds were not observed within the lower unit during our present mapping. Possibly the lower Sespe transition into the Gaviota is confined to the small area where the lower conglomerate and sandstone unit pinches out in Glen Annie Canyon. The lower unit is primarily equivalent to Sespe lithofacies A of Howard (1995). Unit was previously mapped as part of the Sespe Formation by Upson (1951) and Dibblee (1966, 1986a, 1986b, 1987a, 1987b), as the lower member of the Sespe Formation by Lian (1954), and as red to pink (or pink to white) sandstone and red claystone of the Sespe Formation by Dibblee (1986a, 1986b, 1987b).

Tcw **Coldwater Sandstone (upper and/or middle Eocene)**—Sandstone with subordinate interbeds and thin intervals of siltstone, shale, and mudstone; shallow marine. Sandstone is mostly fine- to medium-grained, arkosic to quartzofeldspathic, locally silty to clayey or micaceous, and locally weakly cemented with calcium carbonate. Sandstone forms thin, tabular beds as well as medium to thick beds, some of which are massive and bioturbated whereas others contain planar, wavy, or cross laminations. Thin siltstone and shale partings are rare in the sandstones. Sandstone is typically pale gray and greenish gray on fresh surfaces and weathers to distinctive, pale shades of buff, yellowish-tan, tan, and brown. Some beds and intervals as thick as 3 m especially in the upper part of the unit contain rare to conspicuously abundant oyster shells and shell fragments (*Ostrea idriaensis*, Weaver and Kleinpell 1963), and numerous other fossil mollusks have been previously identified throughout the unit (e.g., Weaver and Kleinpell 1963). Other beds and intervals contain rare to abundant ferruginous(?) fossil wood fragments that commonly contrast visually with the surrounding rock due to their dark-gray to reddish-brown color. Local lenses and intervals as thick as 25 m of conglomeratic sandstone are present in the uppermost Coldwater near its contact with the overlying lower unit of the Sespe Formation (Tspl). Evidence of localized soft-sediment deformation is provided by contorted and disrupted layering in some sandstone beds. Sandstone beds and sandstone-rich intervals typically crop out as resistant, blocky ledges and cliffs and form prominent hogbacks where steeply dipping.

Siltstone, shale, and mudstone form interbeds as thin as 1 cm and bedded intervals as thick as 5 m. These fine-grained rocks mostly exhibit pale to dark shades of gray, olive-gray, and greenish-gray. Commonly shale is fissile and mudstone exhibits hackly fractures. Some siltstone beds are micaceous and contain wood fragments. Siltstones and finer-grained rocks of the Coldwater are considerably less resistant than the sandstones and tend to be more poorly exposed.

Some siltstone and mudstone intervals in uppermost part of unit in eastern part of map area are maroon, suggesting that contact with overlying nonmarine beds of the Sespe Formation becomes gradational to the east. In such areas upper Coldwater contact is mapped at top of uppermost Coldwater-like sandstone bed.

Unit is about 750 to 1,000 m thick in region (Dibblee 1982), but only upper part is included in map area. Unit as a whole is resistant to erosion as evidenced by the elevated, rugged ridges, spurs, and hogbacks it forms on the steep, southern flank of the Santa Ynez Mountains. Several large landslide deposits in the Coldwater in this area indicate the units' susceptibility to slope failure. Age of unit is not tightly constrained in map area; regionally, age of Coldwater has been variably considered late and (or) middle Eocene (Narizian)

(Kleinpell and Weaver 1963; Dibblee 1966; Howard 1995; Campion and others 1996; Prothero 2001) on basis of paleontologic, magnetostratigraphic, and sequence stratigraphic correlations. Uppermost part of map unit in northwest part of map area may include eastward-terminating sandstone-rich beds of the marine late Eocene (Refugian) Gaviota Formation that closely resemble sandstones of the underlying Coldwater (Weaver and Kleinpell 1963; Dibblee 1966, 1987). Unit was previously mapped as Tejon Formation by Upson (1951), as “Coldwater” Sandstone by Dibblee (1966), and as Coldwater Sandstone by Lian (1954) and Dibblee (1986a, 1986b, 1987a, 1987b).

# APPENDIX A GEOLOGY OF THE SANTA BARBARA COASTAL PLAIN

## A.1 INTRODUCTION

This report presents a newly revised and expanded digital geologic map of the Santa Barbara coastal plain area at a compilation scale of 1:24,000. The map depicts the distribution of bedrock units and surficial deposits and associated deformation underlying and adjacent to the coastal plain within the contiguous Dos Pueblos Canyon, Goleta, Santa Barbara, and Carpinteria 7.5' quadrangles (Figure 2). The new map supersedes an earlier preliminary geologic map of the central part of the coastal plain (Minor and others 2002) that provided coastal coverage only within the Goleta and Santa Barbara quadrangles. The mapping presented here results from the collaborative efforts of geologists with the U.S. Geological Survey Southern California Areal Mapping Project (SCAMP) (Minor, Kellogg, and Stanley) and the tectonic geomorphology research group at the University of California at Santa Barbara (Gurrola and Keller). T.R. Brandt assisted in the design and editing of the GIS database and performed database integration. The digital geologic database for this map is available on the Internet at: http://geology.cr.usgs.gov/pub/xxxxx/xxxx.

The Santa Barbara coastal plain is located in the western Transverse Ranges physiographic province along an east-west-trending segment of the southern California coastline about 100 km (62 mi) northwest of Los Angeles (Figure 1). The coastal plain extends from the Santa Ynez Mountains on the north to the Santa Barbara Channel on the south, obtains a maximum width of about 5 km near the cities of Santa Barbara and Goleta, and thins to 1 km or less several kilometers west of Goleta and just east of Carpinteria (Figures 2 and 3). The coastal plain surface is locally disrupted by numerous mesas and hills (Figure 3) that are geomorphic expressions of potentially active folds and partly buried oblique and reverse faults of the Santa Barbara fold and fault belt that transects the coastal plain (SBFFB, Figure 2) (Keller and Gurrola 2000; Gurrola and others 2001). [Note: Although Keller and Gurrola (2000) and Gurrola and others (2001) named the structural belt the “Santa Barbara Fold Belt,” we refer to it as a “fold and fault belt” due to the common presence of both surficial folds and faults along it.] Strong earthquakes that occurred in the region in 1925 (6.8 magnitude) and 1978 (5.1 magnitude) are evidence that such structures pose a significant earthquake hazard to the approximately 200,000 people living within the major coastal population centers of Santa Barbara, Goleta, and Carpinteria. Also, numerous Quaternary landslide deposits along the steep southern flank of the Santa Ynez Mountains indicate the potential for continued slope failures and mass movements that may threaten urbanized parts of the coastal plain. Deformed sedimentary rocks in the subsurface of the coastal plain and the adjacent Santa Barbara Channel contain deposits of oil and gas, some of which are currently being extracted. Shallow, localized sedimentary aquifers underlying the coastal plain provide limited amounts of water for the urban areas, but the quality of some of this groundwater is compromised by coastal salt-water contamination. The present map compilation provides a set of uniform geologic digital coverages that can be used for analysis and prediction of these and other geologic hazards and resources in the coastal plain region.

## A.2 PREVIOUS MAPPING

The earliest detailed, larger-scale (i.e., greater than 1:100,000) geologic mapping in the map area was conducted in the early 1950s by Upson (1951), who mapped in reconnaissance the coastal plain region at a scale of 1:31,680 as part of a water resource study, and by Lian (1954), who mapped the eastern Mission Ridge – Montecito area at a scale of 1:62,500. Thomas W. Dibblee, Jr. (1966) produced the first comprehensive, detailed geologic maps of the Santa Barbara coastal plain region. These maps provided unprecedented geologic coverage of the west half of the map area at a scale of 1:62,500 and of the east half at a scale of 1:31,680. Hoover (1978) mapped the geology of the city of Santa Barbara at a scale of 1:12,000 as part of a masters thesis effort to evaluate geologic hazards in the Santa Barbara area. As an aid to constructing subsurface geologic interpretations of the coastal plain region, Olson (1982) produced a 1:24,000-scale geologic map compilation of the area that was largely based on the previous mapping listed above. The Thomas Dibblee Foundation published geologic maps of the Carpinteria, Santa Barbara, Dos Pueblos, and Goleta 7.5' quadrangles (Dibblee 1986a, 1986b, 1987a, 1987b) at a scale of 1:24,000. This strip of four contiguous maps provided us with valuable background information, and has served as a foundation, for our present mapping efforts. The California Geological Survey (formerly California Division of Mines and Geology) produced 1:24,000-scale landslide inventory and landslide potential maps of the Santa Barbara coastal plain region (Bezore and Wills 2000). Finally, our recent preliminary geologic map of the central part of the coastal plain (Goleta and Santa Barbara quadrangles) (Minor and others 2002) provided an initial revised geologic depiction of the coastal region and formed a framework for producing the present map.

## A.3 GEOLOGIC SUMMARY

Rocks of the western Transverse Ranges consist mainly of variably deformed marine and nonmarine sedimentary rocks that range in age from Jurassic to Quaternary (about 200 Ma to 10 ka). These strata record a long history of continental-margin sedimentation, and deposits as young as middle Pleistocene (about 500 ka) have sustained considerable protracted deformation that includes folding, faulting, and significant clockwise vertical-axis rotations of crustal blocks (e.g., Dibblee 1966, 1982; Namson and Davis 1988; Luyendyk 1991). In the map area the oldest stratigraphic units consist of resistant, southward-dipping to overturned, Eocene sedimentary rocks along the south flank of the Santa Ynez Mountains uplift, which form a backdrop of prominent hogbacks and cuestas to the Santa Barbara coastal plain. Less resistant but similarly deformed, Oligocene through Pleistocene sedimentary rocks and deposits are exposed in the lower Santa Ynez foothills and in the coastal hills and sea cliffs farther south. Late Pleistocene and Holocene surficial deposits directly underlie much of the low-lying coastal plain area, and similar-aged alluvial and landslide deposits are locally present along the lower flanks of the Santa Ynez Mountains.

### A.3.1 Depositional History

The following brief summary of the depositional history of the map area is inferred from the sedimentary rocks and deposits investigated in this report. The mapped Tertiary sedimentary rocks record a transition from shallow-marine deposition (unit Tcw) to nonmarine fluvial deposition (Tspl, Tspm, Tspu), followed by a return to shallow- (Tv) and, eventually, bathyal- (Tr, Tm, and Tsq) marine deposition. Sedimentation during this period was not continuous, but instead was interrupted locally by several brief periods of nondeposition, and one possible depositional hiatus in the Sespe Formation (between Tspl and Tspm) may have lasted for more than 7 m.y. during much or all of the early Oligocene (Howard 1995). Marine sedimentation in the map area was episodically disrupted during the Miocene, Pliocene, and possibly early Pleistocene, probably due to local tectonic deformation (see below) accompanied by uplift, erosion, and sudden submarine slumps and debris flows of coarse detritus. Stratigraphic evidence of such disruptions in the western coastal map area include: 1) locally pronounced late Miocene erosional disconformities at the base of the unnamed mudstone unit (Tu) and the base of the Sisquoc Formation (Tsq); 2) presence of large angular (olistostromal?) blocks and boulders derived from the Monterey Formation (Tm) in upper Miocene and Pliocene Sisquoc conglomerates; and 3) a Pliocene to early Pleistocene angular unconformity that separates marine deposits of the Santa Barbara Formation (Qsb) and partly coeval, unnamed sedimentary rocks east of Goleta Pier (QTst, Qss, Qcg) from underlying rocks of the Sisquoc and older formations.

Widespread shallow marine deposition resumed most likely in the middle Pleistocene when sand-rich sediment of the Santa Barbara Formation and possibly coeval units (Qsb, Qss, and Qcg) was deposited on a southward-deepening and -thickening marine shelf that may have been transected by several submarine canyons. Sometime during the middle Pleistocene major tectonic uplift of the Santa Ynez Mountains commenced, resulting in the initial development of a piedmont alluvial fan and fluvial system that encroached upon the Santa Barbara marine depositional shelf from the north. Units initially deposited on this new piedmont included the Casitas Formation (Qca) and the older alluvial deposits (Qoa). Eventually, marine sedimentation ended throughout the coastal plain area and was entirely replaced by nonmarine alluvial and fluvial deposition (upper Qca, Qoa, and Qia) concomitant with pronounced transpressional and transrotational faulting, folding, and uplift in the Santa Barbara fold and fault belt (see structural description below) (Gurrola and others 2001). Beginning at about 105 ka, and possibly much earlier, terrace basal abrasion surfaces were cut by wave action along the coast during multiple interglacial sea-level high stands, with accumulation of overlying marine terrace (Qmt) and alluvial (Qoa and Qia) deposits during subsequent marine regressions resulting from eustatic drops in sea level and (or) tectonic uplift (Rockwell and others 1992; Muhs and others 1992; Keller and Gurrola 2000; Gurrola and others 2001). Alluvial and colluvial deposition (Qa, Qac, and Qc) continued into the Holocene on broad low-lying, possibly downwarped (Keller and Gurrola 2000; Gurrola and others 2001) floodplains underlying Goleta Valley, downtown Santa Barbara, Montecito, the

Carpinteria area, and elsewhere along major stream canyons. This sedimentation was locally accompanied by the deposition of estuarine deposits (Qe) in low coastal areas owing to local subsidence and possibly sea-level rise. During times of heavy precipitation in the late Pleistocene and Holocene relatively steeply sloping areas in the map area underlain by clay-rich sedimentary rocks were, and continue to be, prone to landsliding and/or debris flows. Deposits resulting from such slope failures (units Qls and Qdf) include the large Mission debris flow, which was deposited on a now-urbanized part of the coastal plain in the central part of the map area (Selting and Urban, *in* Gurrola and others 2001; Urban 2004).

### A.3.2 Structural Framework and History

Structurally, the Santa Barbara coastal plain area is dominated by the Santa Barbara fold and fault belt (SBFFB) (Keller and Gurrola 2000; Gurrola and others 2001), an east-west-trending zone of potentially active folds and partly blind oblique-slip reverse and thrust faults (Figures 2 and 4, orange faults and purple fold/warp axes). The dominant trend of individual structures within the belt is west-northwest, which is slightly oblique to the trend of the overall fold and fault belt (Figures 2 and 4). A conspicuous exception, however, is the More Ranch fault system, which strikes east-northeast undisrupted for ~20 km obliquely ($40^o$ to $60^o$ angle) across the dominant west-northwest structural grain of the fold and fault belt. Besides the More Ranch fault system, the other major through-going fault system on the coastal plain is the west-northwest-trending Mission Ridge fault system, which consists of the sinistral-slip Arroyo Parida fault located on the north side of the lower ridge north of Carpinteria and the oblique reverse-slip Mission Ridge fault zone north of Montecito and Santa Barbara (Keller and Gurrola 2000; Gurrola and others 2001). Although the Arroyo Parida fault is sinistrally offset 1 km east of Montecito from the Mission Ridge fault zone by the inferred concealed Fernald Point fault (Figure 4), Keller and Gurrola (2000) and Gurrola and others (2001) recognized the potential for the entire Mission Ridge fault system to rupture in a future large seismic event. Most of the structures underlying the coastal lowlands deform Quaternary deposits (Figure 4, orange faults and purple fold axes), but the structural belt continues northwest into older Tertiary rocks along the south flank of the Santa Ynez Mountains. Although many of the faults and some of the folds in these Tertiary rocks strike and trend subparallel to structures to the southeast on the coastal plain, the range of orientations is much greater in the older rocks, with several structures having north-northwest trends (Figure 4). The SBFFB is superimposed on the regionally extensive south-dipping flank of the Santa Ynez Mountains uplift, which is grossly homoclinal but in detail characterized by overturned strata with steep to moderate dips east of lower San Roque Canyon (north of Santa Barbara) and upright, moderately south dipping strata west of the canyon. The overturned section continues for more than 50 km to the east as far as Ojai and has been variously called the Matilija overturn or Montecito overturn (Dickinson 1969; Dibblee 1982). The westward transition between overturned and upright stratal dips in the map area is fairly abrupt and may be structurally accommodated largely by a zone of northeast-striking sinistral-oblique faults that branch off the More Ranch fault to the southwest and that may have acted as tear faults.

As part of our geologic mapping efforts to document the structural geology of the coastal plain area, we collected kinematic data (slip-surface orientation and slickenline rake measurements and slip-sense determinations) from 192 smaller-displacement (<5 m) fault surfaces and 40 larger-displacement (5 to >100 m) fault surfaces exposed in the map area within sedimentary rocks and deposits ranging in age from middle Eocene (Tcw) to late Pleistocene (Qia and Qmt). (Note: Slip measurements taken at exposures of larger-displacement faults are shown on the cartographic representation of the map, whereas all of the kinematic data, including those from smaller-displacement minor faults, are embedded as "point" data in the geologic map data base.) Kinematic data collected along faults in the older Tertiary rocks where the SBFFB continues northwest into the south flank of the Santa Ynez Mountains reveal a protracted history of faulting in the area leading up to the Quaternary deformation that is best expressed on the coastal plain below. West-northwest- to northwest-striking faults cutting rocks as young as Monterey Formation (Tm, Tml) in the northwest part of the map area exhibit multiple generations of slickenlines indicating older normal- and oblique normal-slip movement and younger oblique strike-slip movement (Figure 4). Oblique-slip faults in this area commonly restore to nearly pure normal-slip or strike-slip faults by back tilting bedding to horizontal, suggesting that much of the folding and associated reverse faulting in the SBFFB were preceded by normal- and strike-slip faulting. Opposing senses of normal stratigraphic offset on some adjacent mapped faults in the northwest area suggest that subparallel horst and grabens dominated the older structural landscape of the region, and explain the apparent opposing strike-slip offsets of similarly striking faults north and northwest of Goleta. In the Miocene and older rocks, individual west-northwest- to north-northwest-striking fault surfaces show kinematic evidence of both dextral and sinistral strike-slip movement, and in most cases cross cutting relations of slickenlines indicate that dextral slip postdates sinistral slip. In some areas, reverse faults contain multiple generations of slickenlines that exhibit progressive shifts in rake. Faults in deformed middle and late Pleistocene marine and alluvial sediments exposed on the coastal plain (Qsb, Qmt, Qoa, and Qia) lack evidence of early normal slip, but otherwise have strike-slip histories similar to faults in the older rocks and show abundant evidence of late reverse and oblique reverse movement. North-northwest-trending folds that are oblique to folds in younger deposits on the coastal plain are restricted to Tertiary rocks in the northwest map area and along the sea cliffs southwest of Santa Barbara and Goleta. All of these observations are consistent with previous tectonic models constrained by paleomagnetic data that invoke large (up to ~$90^o$), Neogene, clockwise vertical-axis rotations of crustal fault blocks in the WTR accompanied by a gradual change from transtensional to transpressional fault kinematics (e.g., Luyendyk 1991). Furthermore, the considerable components of strike slip observed on oblique-reverse Quaternary faults on the coastal plain suggest that significant clockwise rotation of crustal fault blocks may be continuing today.

On the coastal plain, several folds within the older and intermediate alluvial (Qoa and Qia) and marine terrace (Qmt) deposits have subtle to strong geomorphic expression that is consistent with a youthful age of deformation; commonly anticlines are coincident with elongate ridges or hills whereas synclines coincide with valleys or swales (Keller and others 1999; Gurrola and others 2001). One of the most dramatic examples of such a geomorphic-structural correlation is western Mission Ridge just north of downtown Santa Barbara, which is coincident with an anticline that is paired on its north side with an inferred syncline that roughly follows a linear valley containing the old Sheffield Reservoir site and Mountain Drive (Figure 4). Another is the Loon Point anticline that directly underlies a small hill where it is spectacularly exposed in a sea cliff east of Summerland. Such anticlines and synclines, which are geomorphically and structurally well expressed in Pleistocene alluvial deposits but which commonly have poor structural definition in underlying, discordant bedrock units, are mapped as upwarps and downwarps, respectively (Figure 4, purple fold axes). On the basis of several lines of geomorphic evidence Keller and others (1999) inferred that the Mission Ridge upwarp is a fault-related fold that has propagated westward, reflecting westward propagation of a blind strand of the Mission Ridge fault zone and resulting in progressive westward deflection of Mission Creek. The Lavigia fault, located in the coastal hills in the Hope Ranch–La Mesa area southwest of Santa Barbara, is inferred to become blind along its easternmost 2 km where its surface expression consists of a closely spaced anticline-syncline pair. Similar blind reverse and thrust faults are inferred to underlie many of the folds in the map area (Gurrola and others 2001). Several fold axes on the coastal plain are parallel to adjacent traces of faults that have broken through to the surface, and in such cases the fold on the apparent upthrown, hanging-wall side of the fault is typically an asymmetric anticline whose steeper limb dips towards the fault trace. The faults commonly dip gently to steeply in an opposite directions to the vergences of the adjacent folds. Such structural geometry is consistent with fault-propagation folding (Suppe 1985). Examples of such anticline-fault associations include those along the Loon Point fault, the eastern strand of the Foothill Road fault in the northeastern part of Goleta Valley, and the 6-km-long surface trace of the Lavigia fault. The majority of folds in the coastal plain area have northward vergence, suggesting that most associated blind reverse-thrust faults are dominantly southward dipping similar to the exposed faults and, thus, have accommodated northward components of tectonic transport of their hanging-wall blocks. The above structural observations, together with the previously described evidence of dominantly oblique-reverse slip along faults cutting Quaternary deposits in the map area (Figure 4), implies that structures on the coastal plain have accommodated significant transpressional strain during the middle to late Pleistocene, possibly accompanied by clockwise rotation of crustal fault blocks.

A moderate angular discordance that locally exists between the middle Pleistocene Santa Barbara Formation (Qsb) and overlying older alluvial deposits (Qoa) in the western part of the map area indicate that pre-Qoa, possibly middle Pleistocene, deformation occurred locally along structures that were partly reactivated later in the Pleistocene. The erosional angular unconformity that separates the Sisquoc Formation (Tsq) and older units from the Santa Barbara Formation and partly coeval deposits (QTst, Qss, and Qcg) suggests that significant uplift and deformation occurred in the coastal area in the Pliocene. Strong transpressional (and transrotational?) deformation continued into the late Pleistocene in the coastal plain area, resulting in the episodic uplift, warping, and faulting of wave-cut marine platforms and capping marine terrace (Qmt) and alluvial deposits (Qia). Nevertheless, the late Pleistocene marine terrace deposits (Qmt), although uplifted and locally warped or gently folded, are clearly not as strongly deformed as the older Pleistocene deposits and underlying bedrock. No significant deformation has been recognized in the mapped Holocene deposits despite the historic earthquake activity in the region. Collectively, these various structural age relations imply that deformation in the coastal plain area was most pronounced during the Pliocene and/or Pleistocene prior to formation of the marine terraces in the late Pleistocene.

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# GUIDELINES FOR ENGINEERING GEOLOGIC REPORTS

## GENERAL INFORMATION

These guidelines suggest a format for reports. They do not include complete listings of techniques or topics, nor should all techniques described be used or all topics listed be dealt with in every project.

These guidelines are informational and are not regulations. Language used has been carefully gleaned of mandatory requirements. The guidelines have no force of law and do not set standards of practice. To be enforceable, the guidelines would have to be adopted as regulations in accordance with the Administrative Procedures Act.

On January 23, 1986, the Board of Registration for Geologists and Geophysicists (Board) passed the following resolution:

**"The Guidelines have been adopted as useful information documents. Not having been adopted as regulations in accordance with the Administrative Procedures Act, the Guidelines are not legally enforceable."**

These guidelines have their roots in eight California Division of Mines and Geology notes, that were published in California Geology during 1973-75. The four guidelines that evolved through the Technical Advisory Committee for the Board of Registration from 1983 to 1989 are:

Guidelines for Engineering Geologic Reports.
Geologic Guidelines for Earthquake and/or Fault Hazard Reports.
Guidelines for Geophysical Reports.
Guidelines for Groundwater Investigation Reports.

## I. INTRODUCTION

These guidelines have been prepared by the Technical Advisory Committee of the Board and adopted by the Board on April 18, 1998 to assist those involved in preparing or reviewing engineering geologic reports. The guidelines present general procedures suggested for use by geologists carrying out engineering geologic studies and, while they do not constitute a complete listing of all techniques for such studies, they do include most major topics. In the broad sense, nearly all engineering projects requiring geologic input are also engineering geology projects. Most of these involve identifying and evaluating geologic hazards, using the various exploration tools available today, as applicable, and developing appropriate mitigation measures, if necessary. Projects may include on-land and offshore structures, large excavations, buried tanks and disposal sites for hazardous, designated and nonhazardous wastes. Groundwater and its relationship to other site characteristics is an integral part of engineering geology. Additionally, past uses of a site are becoming increasingly important in evaluating its applicability for a new use.

Engineering geology reports would be expected to be prepared by or under the direct supervision of a certified engineering geologist. Clear descriptions of work and unambiguous presentations of results are encouraged. If the report falls within the scope of the Geologist and Geophysicist Act (Business and Professions Code, Chapter 12.5), it must be signed by the responsible professional(s). If such reports include significant geophysical information, they should be cosigned by a registered geophysicist, or the signed geophysical report may be appended to the geological report. It is important that reports that present conclusions or recommendations based in part on field sampling or field or laboratory testing include the test results with adequate descriptions of the methods employed, and with specific reference to standard sampling, preservation, and testing methods, where appropriate. Where necessary, technical terms will need to be defined.

The following is a suggested guide or format for engineering geologic reports. These reports may be prepared for projects ranging in size from a single lot to the master plan for large acreage, in scope from a single family residence to large engineering structures and for sites in all manner of geologic terrain. Because of this diversity, the order, format and scope of the reports is flexible to allow tailoring to the geologic conditions and intended use of the site. The format is intended to be relatively complete; not all items will be applicable to small projects or low-risk sites. In addition, some items may be covered in separate reports by geotechnical engineers, geophysicists, or structural engineers.

## II. REPORT CONTENT

### A. Purpose and Scope of the Investigation

Includes a brief description of proposed or existing site use; may also include a description of limitations of the work and authorization to perform the work. The design lifespan of the proposed project should be implicitly stated.

### B. Regional Geologic Setting

May include reference to geologic province and location with respect to major structural features.

### C. Site Description and Conditions

Includes information on geologic units, landforms, graded and filled areas, vegetation, existing structures, etc., that may affect the choice of investigative methods and the interpretation of data.

### D. Description of the Investigation

1. Review of the regional and site geology, and land-use history, based primarily on existing maps and technical literature.

a. Geologic hazards that could affect the planned use of the site.

(1) Significant historic earthquakes in the region.

(2) Fault traces that may affect the site. Is the site within an earthquake fault zone?

(3) Secondary earthquake effects, such as ground breakage in the vicinity of the site, seismically-induced landslides, differential tilting and liquefaction.

(4) Regional effects, such as subsidence, uplift, etc.

(5) Landslides or other earth movements at the site and vicinity.

(6) Soil and rock properties such as high moisture content, low density, swelling, cementation, weathering, fracturing, etc.

b. Other geologic conditions that could affect the planned use of the site.

(1) Soil thickness, types, and relationship to bedrock.

(2) Excavatability of rock materials.

(3) Depth to and characteristics of subsurface water.

c. Conditions imposed on the site by past uses, such as buried objects, contaminated soils, groundwater, or adjacent structures, etc.

2. Interpretation of aerial photographs and other remotely sensed images relative to topography, vegetation, or any other features related to geologic hazards and past site use.

3. Surface investigation.

a. Mapping of the site geology and vicinity; identification and description of geologic units, soil and rock types, and features that could be related to geologic hazards and the proposed use and constructability of the site. A clear distinction should be made on the map and within the report between observed and inferred geologic features and relationships.

b. Evaluation of surface-water conditions, including quality, flood potential in relation to site conditions, geomorphology and drainage within or affecting the subject area.

4. Subsurface investigation.

a. Trenching and any other excavation (with appropriate logging and documentation) to permit detailed and direct observation of continuously exposed geologic units and features.

b. Borings drilled, test pits excavated, and groundwater monitoring wells installed to permit the collection of data needed to evaluate the depth and types of materials and subsurface water. Data points sufficient in number and adequately spaced will permit valid correlations and interpretations.

c. Geophysical surveys conducted to facilitate the evaluation of the types of site materials and their physical properties, groundwater conditions and any other pertinent site conditions. The types of equipment and techniques used, such as seismic refraction, magnetic, electric resistivity, seismic reflection and gravity, and the name of the geophysicist responsible for the work.

5. Special methods (used when special conditions permit or critical structures demand a more intensive investigation).

   a. Aerial reconnaissance overflights, including special photography.

   b. Geodetic measurements, radiometric analysis, age dating, etc.

## E. Results of Investigation

Describes the results of the investigation outlined in Section IV above. The actual data or processed data upon which interpretations are based should be included in the report to permit technical reviewers to make their own assessments regarding reliability and interpretation.

## F. Conclusion

Relative to the intended land use or development (made in conjunction with the geotechnical engineering study). Includes a statement concerning the degree of confidence in and limitations of the data and conclusions, as well as disclosure of known or suspected potentially hazardous geologic processes affecting the project area.

1. Presence or absence of active or potentially active faulting at the site or in the vicinity, and the potential for renewed fault activity.

2. Effects on the site from ground shaking.

3. Potential for secondary effects from earthquakes, such as ground cracking, landsliding, and liquefaction.

4. Potential for subsidence or other regional effects.

5. The presence of creep or landsliding; and possible future mass movements.
6. Soil and rock conditions, such as swelling soils that could affect site use.
7. The presence of and possible effects from any other soil and rock defects.
8. Excavation methods.
9. Presence of contamination or any other man-imposed condition.
10. Potential for earthquake-induced flooding, including tsunamis and seiches.
11. Potential for volcanic hazards.
12. Conformance with local, state and federal statutory and regulatory requirements.

## G. <u>Recommendations</u>

1. Effect of fault locations on proposed structures at the site. Federal, state, or local law may dictate minimum standards.
2. Placement of structures to best take advantage of geologic conditions.
3. Methodology for excavating and moving materials.
4. Means of correcting site defects, such as buttressing landslides, installing special drainage devices, etc.
5. Correcting contamination or other man-induced site defects.
6. Other recommendations as appropriate for the proposed project.

## H. <u>References</u>

1. Literature and records cited and reviewed.
2. Aerial photographs or images interpreted, listing the type, scale, source, and index numbers, etc.
3. Compiled data, maps, or plates included or referenced.
4. Other sources of information, including well records, personal communications, or other data sources.

## I. <u>Illustrations</u>

1. Location map to identify the site locality, geographic features, or major regional geologic features.

2. Site development map, at an appropriate scale, to show the site boundaries, existing and proposed structures, graded areas, streets, and locations of exploratory trenches, borings, wells, geophysical traverses, and other data.

3. Geologic map to show the areal distribution of geologic units, faults and other structures, geomorphic features, aerial photo features noted, along with surface water bodies and springs. The geologic map may be combined with the location and site development maps.

4. Geologic cross sections illustrating significant or appropriate geologic features.

5. Logs of exploratory trenches and borings to show the details of observed features and conditions.

6. Geophysical data and the geologic interpretations of those data.

7. Other, as appropriate.

### J. Supporting Data Not Already Provided

1. Non-confidential water well data (including bore-hole logs).

### K. Signature and Registration Number of the Responsible Professional(s)

1. Registered Geologist, Certified Engineering Geologist.

## SELECTED REFERENCES

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# GEOLOGIC GUIDELINES FOR EARTHQUAKE AND/OR FAULT HAZARD REPORTS

## GENERAL INFORMATION

These guidelines describe the scope of work normally done and suggest a format for reports. They do not include complete listings of techniques or topics, nor should all techniques described be used or all topics listed be dealt with in every project.

These guidelines are informational and are not regulations. Language used has been carefully gleaned of mandatory requirements. The guidelines have no force of law and do not set standards of practice. To be enforceable, the guidelines would have to be adopted as regulations in accordance with the Administrative Procedures Act.

On January 23, 1986, the Board of Registration for Geologists and Geophysicists (Board) passed the following resolution:

**"The Guidelines have been adopted as useful information documents. Not having been adopted as regulations in accordance with the Administrative Procedures Act, the Guidelines are not legally enforceable."**

These guidelines have their roots in eight California Division of Mines and Geology notes, that were published in *California Geology* during 1973-75. The four guidelines that evolved through the Technical Advisory Committee for the Board from 1983 to 1989 are:

Guidelines for Engineering Geologic Reports.
Geologic Guidelines for Earthquake and/or Fault Hazard Reports.
Guidelines for Geophysical Reports.
Guidelines for Groundwater Investigation Reports.

## I. INTRODUCTION

These guidelines are prepared by the Technical Advisory Committee of the Board and adopted by the Board on April 18, 1998 to assist those involved in preparing and reviewing earthquake and fault hazard reports. The guidelines describe the general procedures used by geologists carrying out earthquake and fault hazard studies and, while they do not constitute a complete listing of all techniques in such studies, they do attempt to include all major topics.

The investigation of sites for potential earthquake hazards, including possible surface fault rupture, is a difficult geologic task. The professional performing or supervising each investigation has a responsibility to determine what is appropriate and necessary in each case, and so does the professional who reviews each report.

Many active faults are complex, consisting of multiple breaks. Yet the evidence for identifying active fault traces is generally subtle or obscure and the distinction between recently active and long-inactive faults may be difficult to make. Because of the complexity of evaluating surface and near-surface faults and because of the infinite variety of site conditions, no single investigative method will be the best at every site; indeed, the most useful technique at one site may be inappropriate for another site.

Geologic reports prepared using these guidelines would be expected to be done by or under the direct supervision of registered geologists. Clear descriptions of work and unambiguous presentations of results are encouraged. If the report falls within the scope of the Geologist and Geophysicist Act (Business and Professions Code, Chapter 12.5), the report must be signed by the responsible professional(s). It is important that reports that present conclusions or recommendations based in part on field sampling or field or laboratory testing of samples include the test results with adequate descriptions of the methods employed, and with specific reference to standard sampling and testing methods, where appropriate. Where necessary, technical terms (such as active fault, maximum earthquake, etc.) will need to be defined.

The following is a suggested guide or format for earthquake and fault hazard reports. These reports may be prepared for projects ranging in size from a single lot to a master plan for large acreage, in scope from a single family residence to large engineered structures, and from sites located on an active fault to sites a substantial distance from the nearest known active fault. Because of this wide variation, flexibility in the order, format, and scope of the reports will allow tailoring to the seismic and geologic conditions and intended use of the site. The format is intended to be relatively complete, and not all items will be applicable to small projects or low risk sites. In addition, some items may be covered in separate reports by geotechnical engineers, geophysicists, or structural engineers.

## II. REPORT CONTENTS

### A. Purpose and Scope of the Investigation

Includes a brief description of proposed or existing site use; may also include a description of limitations of the work and authorization to perform the work. The design lifespan of the proposed project should be implicitly stated.

### B. Regional Geologic Setting

May include reference to geologic province and location with respect to major structural features.

### C. Site Description and Conditions

Includes information on geologic units, landforms, graded and filled areas, vegetation, existing structures, etc., that may affect the choice of investigative methods and the interpretation of data.

## D. **Description of the Investigation**

1. Review of the region's seismic or earthquake history, based primarily on existing maps and technical literature.

    a. Significant earthquakes during historic time and epicenter locations and magnitudes in the vicinity of the site.

    b. Location of fault traces that may affect the site, including maps of fault breaks and a discussion of the tectonics and other relationships of significance to the proposed construction.

    c. Location and chronology of other earthquake-induced features such as landsliding, lurching, settlement and liquefaction, accompanied by:

        (1) Map showing the location of these features relative to the proposed project.

        (2) Description of the disturbed zone for each feature.

        (3) Estimate of the amount of disturbance relative to bedrock and surficial materials.

2. Interpretation of aerial photographs and other remotely sensed images relative to fault-related topography, vegetation, and soil contrasts, and other lineaments of possible fault origin.

3. Surface investigation.

    a. Mapping of geologic units and structures, topographic features, deformation of man made structures, etc., both on and beyond the site (sag ponds, spring alignments, offset bedding and man made features, disrupted drainage systems, offset ridges, faceted spurs, dissected alluvial fans, scarps, landslide alignments, vegetation patterns).

    b. Review of local groundwater data (water-level fluctuations, groundwater impediments, water quality variations, or anomalies indicating possible faults).

    c. Description of the distribution, depth, thickness, and nature of the various earth materials, including subsurface water, which may affect the seismic response and damage potential at the site.

4. Subsurface investigation.

a. Trenching and any other excavation (with appropriate logging and documentation, including method of cleaning wall) to permit the detailed and direct observation of continuously exposed geologic units and features. This would include trenching done across any known active faults and suspicious zones to determine the location and recency of movement, the width of disturbance, the physical condition of fault zone materials, the type of displacement, the geometry of fault features, and recurrence interval, if known.

b. Borings drilled and test pits excavated to permit the collection of data needed to evaluate the depth and types of materials and groundwater and to verify fault-plane geometry. Data points sufficient in number and adequately spaced will permit valid correlations and interpretations.

c. Geophysical surveys conducted to facilitate the evaluation of the types of site materials and their physical properties, groundwater conditions, and fault displacements, including a description of the types of equipment and techniques used, such a seismic refraction, magnetic, electrical resistivity, seismic refraction, magnetic, electrical resistivity, seismic reflection, and gravity.

5. Other special methods (used when special conditions permit or critical structures demand a more intensive investigation).

   a. Aerial reconnaissance overflights, including special photography.

   b. Geodetic and strain measurements, microseismicity monitoring, or other monitoring techniques.

   c. Radiometric analysis (e.g., C14, K-Ar), stratigraphic correlation (fossils, mineralogy), soil profile development, paleomagnetism, or other age-dating techniques to identify the age of faulted or unfaulted units or surfaces.

## E. <u>Conclusions</u>

1. Regarding areas of high risk and potential hazards relative to the intended land use or development (made in conjunction with the geotechncial engineering study) and a statement of the degree of confidence in, and limitations of, the data and conclusions.

   a. Presence or absence (including location and age) of active or potentially active faults on or adjacent to the site or in the region of the site if they could affect it (through ground shaking).

   b. Types and probability of, or relative potential for, future surface displacement within or immediately adjacent to the site, including the direction of relative displacement and the maximum possible displacement.

   c. Secondary effects, such as: liquefaction of sediments and soils, shallow ground rupture, settlement of soils, earthquake-induced landslides, and lurching.

d. Estimates of maximum earthquake, upper bound earthquake, or other definitions of earthquakes if required by statute or regulation for the specific type of project.

## F. Recommendations

1. Mitigative measures that provide appropriate protection of the health, safety and welfare of the public.
2. Effect of fault locations on proposed structures at the site. Federal, state and local law may dictate minimum standards.
3. Risk evaluations, if appropriate, relative to the proposed development.
4. Other recommendations as appropriate for the proposed project.

## G. References

1. Literature and records cited and reviewed.
2. Aerial photographs or images interpreted, listing the type, scale, source, index numbers, etc.
3. Compiled data, maps, or plates included or referenced.
4. Other sources of information, including well records, personal communications, or other data sources.

## H. Illustrations

1. Location map to identify the site locality, significant faults, fault strain and/or creep, geographic features, seismic epicenters, and other pertinent data.
2. Site development map, at an appropriate scale, to show the site boundaries, existing and proposed structures, graded areas, streets, exploratory trenches, borings, geophysical traverses, and other data.
3. Geologic map to show the distribution of geologic units (if more than one), faults and other structures, geomorphic features, aerial photo lineaments, and springs. The geologic map may be combined with the location and site development maps. A clear distinction should be made on the map and within the report between observed and inferred geologic features and relationships.
4. Geologic cross-sections illustrating displacement and/or rupture, if needed to

provide a three-dimensional picture.

5. Logs of exploratory trenches and borings to show the details of observed features and conditions.

6. Geophysical data and the geologic interpretations of those data.

## I. Supporting data not already provided

1. Water well data.

## J. Signature and registration number of the responsible professional(s)

1. Registered Geologist, Certified Engineering Geologist.

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# APPENDIX C USEFUL FACTS ABOUT RADON

Naturally occurring radon (Rn-222) poses a serious public health problem, causing about 21,000 lung cancer deaths per year in the United States among both smokers and non-smokers. Radon is an inert, gaseous radioactive decay product of uranium, which occurs naturally in virtually all soil and rocks. However, uranium is more concentrated in some regions than others because of their geologic differences. Radon is similarly enhanced in the same regions as uranium because its short half life (3.8 days) causes it to disappear except to the extent that it is continually replenished by uranium decay.

Radon is too dilute to see, smell, or detect chemically, occurring at less than a ten-billionth of a part per billion ($< 10^{-10}$ nanograms per liter of air) outdoors, and at about 3 to 30 times higher levels indoors. Radon is only detectable from the radiation it emits upon decay, which is measured in pico-curies per liter of air. One pCi of radon corresponds to 2.22 radon decays per minute. Indoor radon averages 1.3 pCi/L in U.S. homes and about 0.4 pCi/L outdoors.

The well-known risk of radon-related lung cancer is proportional to inhaled airborne radon concentrations, which are dominated by indoor radon. Most indoor radon seeps from underlying soil and rocks. The radon enters indoors by diffusion and airflow through foundation pores, cracks, and openings. It accumulates indoors because it is not able to disperse as readily as in outdoor air where turbulence disperses most radon to decay at higher altitudes. Radon causes lung cancer by chronic alpha irradiation of sensitive lung tissues primarily by radon’s solid polonium decay products that are continually deposited in the lungs as radon decays.

Typically, regional radon potentials increase with both radon sources (elevated uranium mineral concentrations) and radon mobility (permeable soils). Therefore, areas with permeable (sandy, well-drained) soils tend to have higher radon potential for a given radon source than impermeable (high-clay, saturated) soils. Increasing the drainage of the top few meters of otherwise permeable soil can increase the local radon potential by allowing radon to move from a larger volume of uranium-mineralized soil around the building foundation.

High-radon homes tend to cluster geographically on uranium- and radium-mineralized soils that produce higher amounts of radon. An EPA map of radon zones shows which U.S. counties have the highest radon levels. In California, Santa Barbara and Ventura counties have the highest radon potential (Zone 1), counties in the northern and southern extremities of California have the lowest (Zone 3), and most central counties have moderate radon potential (Zone 2). EPA respectively defines radon potentials in Zones 1, 2, and 3 as greater than 4 pCi/L, from 2 to 4 pCi/L, and less than 2 pCi/L of radon in indoor air. The EPA recommends 4 pCi/L as the threshold above which homeowners should fix existing homes to reduce the risks from indoor radon (USEPA 2005).

Although radon maps cannot identify specific lots where radon problems will occur, they show major trends that are valuable in land-use planning to avoid long-term health effects.

For example, regions with uniformly low radon potentials have little chance of hosting a high-radon building and thus need few precautions. Regions with high radon potential have a higher chance of containing high-radon buildings, however, and builders should incorporate radon-protective features or in extreme cases, even limit land uses to outdoor activities or low-occupancy commercial or industrial uses. Attention should be given to uranium- or radium-mineralized formations, mine wastes, gravelly and sandy materials in sedimentary and glacial deposits, well-drained sloped or re-contoured lands, and shallow faulted, fractured, or cavernous rock systems.

Differences in house characteristics cause additional variations in indoor radon besides those caused by soil radon potential. The house differences include radon entry pathways such as foundation or slab cracks, sumps, and plumbing penetrations. They also include varying air pressure gradients that draw soil gas into basements or crawl spaces. Therefore, soil radon potential maps do not replace the need for indoor radon tests in occupied houses.

Radon-resistant designs, construction features, and mitigation are effective in maintaining levels below 4 pCi/L in nearly all areas of moderate and high radon potential. The EPA recommends incorporating radon-resistant features in all areas of high radon potential. The most cost-effective time for building the features is during initial construction. Their cost during new construction (about $100 to $500) is much less than the cost of retrofit radon controls (typically $800 to $2,500) (USEPA 2001).

Pre-construction soil testing of site-specific radon potential is often unreliable in predicting indoor radon levels because of site preparation impacts and unknown indoor pressures and soil-gas entry routes. Furthermore, the costs of pre-construction soil testing are commonly greater than the cost of building in a passive radon control system. The passive radon control system typically reduces radon levels by about 50 percent, which is valuable in reducing radiogenic lung cancer risks by 50 percent, even if the reduction is from nearly 4 pCi/L to nearly 2 pCi/L. There is no recognized risk-free threshold for radon levels (National Research Council 1999). The passive radon control system has additional value in reducing moisture and other soil gases from entering the home, thereby reducing molds, mildews, methane, pesticide gases, and other common indoor pollutants.