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

by Scott A. Minor, Karl S. Kellogg, Richard G. Stanley, Paul Stone,
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DESCRIPTION OF MAP UNITS

af **Artificial fill (Holocene)—**Mappable areas of fill used for construction of 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 black clay and silt deposited in brackish-water environment. Contain a high percentage of decomposed terrestrial organic matter. Form areas of flat topography that are largely covered by vegetation and urban development and were mapped primarily by means of air photographs and digital elevation models

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)

Qdf **Debris-flow deposits (Holocene and/or upper Pleistocene)—**Massive, weakly consolidated, coarse-grained, poorly sorted, generally matrix-supported rock-debris breccia. Two separate debris-flow deposits are identified in central part of map area: the Mission deposit (Selting and Urban, *in* Gurrola and others, 2001) near confluence of Mission and Rattlesnake Canyons, and a smaller deposit at head of Cieneguitas Creek. Mission deposit 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 exposed in Santa Ynez Mountains. 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 up floor of Rattlesnake Canyon to inferred source of debris flow in large landslide deposit (Qls) at Skofield Park. Estimated average thickness 9 m; estimated volume 9.1 x 10^6 m^3. Age is inferred to be less than 45 ka based on local tectonic and geomorphic constraints (Selting and Urban, *in* Gurrola and others, 2001). Deposit in upper Cieneguitas Creek is composed of sandstone and mudstone debris derived from upper unit of Sespe Formation (Tspu). Youthful geomorphic expression of Cieneguitas Creek deposit suggests that this deposit is Holocene in age. Estimated thickness less than 5 m

Qac **Alluvium and colluvium (Holocene and upper Pleistocene)—**Unconsolidated to weakly consolidated silt, sand, and gravel deposits of modern drainages, alluvial fans, and floodplains inferred to underlie much of Goleta-Santa Barbara urban area. Where exposed, alluvium is composed of poorly to moderately sorted silt, sand, and pebble to boulder gravel traversed by narrow channels too small to map separately. 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. Commonly contains poorly to moderately developed soil profile in upper part. Exposed thickness 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; rock clasts and fine-grained material are mixed by downslope movement. Contains angular pebbles, cobbles, and boulders derived from weathering of bedrock. Includes sheetwash and some 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. Commonly contains poorly to moderately developed soil profile in upper part. Smaller colluvial deposits are unmapped, particularly where thin and discontinuous. Maximum thickness 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 zone commonly identifiable. Rincon Shale, relatively fine grained sequences in Sespe Formation, and middle shale unit of Monterey Formation (Tmm) 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 calcite. Contains embedded pebbles as long as about 5 cm. Mapped in two small areas in western part of map area. At one locality just north of Cathedral Oaks Road, 0.5 km northeast of intersection with Los Carneros Road, calcite forms layers as thick as about 10 cm within soil that also occur as 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 and probably resulted from now-inactive spring activity

Qia **Intermediate alluvial deposits (upper Pleistocene)—**Orange-brown to tan, weakly consolidated, stratified silt, sand, and cobble conglomerate. Well-rounded clasts, rarely longer than 10 cm, include Eocene marine sandstone, sandstone from the Sespe Formation, and rare volcanic and granitic rocks derived from conglomerates of the basal Sespe Formation. Forms low, rounded, dissected terraces that, in the Goleta area, are as high as about 15 m above the coastal piedmont surface. Average clast size decreases to south, away from source in the Santa Ynez Mountains. Unit is lower topographically than adjacent older alluvial deposits (Qoa), implying that it is younger, and generally contains smaller clasts. 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 sequence 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 these exposures 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 sequence typically includes nonmarine eolian sand or sandstone and silt or siltstone, moderately 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 in central part of map area, and are inferred to underlie the broad, elevated, locally dissected coastal mesas that extend inland from cliffs. Flights of multiple marine terraces are locally preserved along 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 not certain 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 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 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). Marine terraces preserved in Hope Ranch, La Mesa, and Santa Barbara Cemetery areas range in age from 58 ka to 105 ka and mostly correlate to oxygen isotope stage 5 sea-level high stands.

Marine terrace deposits of this report were previously mapped as older alluvium (Dibblee, 1966) or older dissected surficial sediments (Dibblee, 1986a, 1987). 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 sandstone and sand, pebbly sandstone and sand, silty to sandy pebble-cobble-boulder gravel, conglomerate, and breccia, and rare interbeds and partings of sandy to pebbly 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 marine sandstone typically forms thick (>3 m), sheet-like, clast-supported beds probably deposited by debris flows.

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. Farther south, unit is deformed and uplifted by youthful folds and faults to form rounded hills and ridges, including Mission Ridge in northern Santa Barbara. Finer-grained, medial and distal facies commonly erode into badlands topography. Large areas of urban development 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) 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 Casitas Formation of Upson (1951) mapped east of map area (Dibblee, 1966, 1986a, b). More commonly, however, older alluvial deposits unconformably overlie Santa Barbara Formation with as much as 30^{o} of angular discordance. One such small, isolated deposit located just north of Lavigia Fault and west of Las Positas Road is questionably mapped as older alluvial deposits (Qoa?) due to its possible correlation with marine terrace deposits (Qmt?) mapped at the same elevation about 0.7 km to the east. Most older alluvial deposits of this report were previously mapped as fanglomerate (Dibblee, 1966) or older dissected surficial sediments (Dibblee, 1986a, 1987).

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 (Tm). 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 they overlie 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 pale-tan and -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. Light-gray sandstone, weakly to strongly cemented with carbonate and exhibiting “curb-and-gutter” concretions commonly parallel or subparallel to bedding, is present locally. 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.

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. Other than small, isolated exposure questionably assigned to Santa Barbara Formation in Mission Ridge area (Qsb?), trace of this unconformity marks northernmost known extent of unit in map area. Presence of shelf molluscan fossils and lack of shoreface fossils in northern exposures of formation, however, suggests that original depositional basin extended farther north than present limit of exposure. 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 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). 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)

Unnamed sedimentary rocks east of Goleta Pier (Pleistocene and Pliocene?)—Conglomerate, sandstone, siltstone, and mudstone exposed along coast 1.5 to 3.5 km east of Goleta Pier, previously mapped as parts of an unnamed unit (Upson, 1951), Pico Formation (Dibblee, 1966), and Santa Barbara Formation (Dibblee, 1987). 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 while 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. The fauna is distinguishable from the Santa Barbara Formation fauna only by the presence of shallow water, open coast taxa and coarser sediments. The common occurrence of the Pismo clam (*Tivela stultorum* Mawe), for example, suggests much shallower water depths than faunas from the Santa Barbara Formation. Collections from this unit are very similar to the Santa Barbara Formation and are probably of similar age, but, in part, represent shallower water and different environments. A single shark tooth (*Carcharinus*) was identified by J.D. Stewart (Los Angeles County Museum of Natural History)

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 because of contrasting bedding attitudes on either side; 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. were observed in field during the present study. Modern representatives of these taxa co-occur 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 because Sisquoc strata near the contact are vertical to very steeply dipping and strongly fractured. 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. 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).

Seacliffs 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 on Mescalitan Island north of More Ranch Fault are assigned to siltstone unit because they are lithologically similar to exposures east of Goleta Pier, and because one sample yielded a benthic foraminiferal assemblage indicative of Wheelerian stage and upper bathyal to upper middle bathyal water depths (R.S. Boettcher, written commun., 2001). Similar strata exposed further west between South and North More Ranch Faults are questionably assigned to unit as they await micropaleontologic identification

Tsq **Sisquoc Formation (Pliocene and upper Miocene)—**Laminated diatomaceous mudstone, subordinate shale and dolomite, and local conglomerate. Mudstone and shale are white weathering, gray to brown on freshly broken surfaces, and nonresistant, and contain zones of fractures lined with moderate to abundant jarosite. Mudstone is soft to moderately hard; shale ranges from soft to hard and brittle. Both mudstone and shale are of low density and range from noncalcareous to strongly calcareous. 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, and sponge spicules are common to abundant, particularly along surfaces broken parallel to stratification. Most mudstone and shale beds are moderately to strongly laminated but some are massive. 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.

Dolomite constitutes less than one percent of 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. Fish fragments and poorly preserved microfossils, including foraminifers, are common.

Conglomerate consists mainly of angular clasts of laminated mudstone, shale, 5–10 percent dolomite, and subordinate black phosphorite that appear to have been derived from the underlying Monterey Formation. Clasts range from granules to bounders; most are smaller than 30 cm but clasts up to 1 m across are common; largest clasts are more than 2 m across. Largest blocks in most outcrops are composed of hard, laminated dolomite. Most 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, many large, elongate clasts are oriented parallel or subparallel to stratification. In many places clasts are tightly packed with little or no matrix, which, where present, is massive mudstone. Conglomerate beds are easily recognized in fresh exposures along sea cliffs but are difficult to recognize in weathered exposures; some outcrops that previously were described as massive mudstone are conglomeratic. Good exposures of conglomerate are in sea cliffs about 3.5–4 km east of Goleta pier and along coast between Goleta Point and Goleta Beach County Park.

Lower part of Sisquoc Formation contains diatoms of the *Thalassiosira hyalinopsis* Assemblage Zone (late Miocene, about 5.9–6.2 Ma) and 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). Contact between Sisquoc Formation and underlying Monterey Formation is sharp and apparently conformable, and is placed at base of stratigraphically lowest thick bed of conglomerate; this lithologic change appears to coincide with boundary between *T. miocenica/N. miocenica* Assemblage Zone and underlying *Rouxia californica* Partial Range Zone (late Miocene, about 6.7–7.6 Ma) (J.A. Barron, oral and written communs., 2001). Previously, contact between Sisquoc and Monterey Formations in Santa Barbara coastal area was described as ranging from sharp and disconformable to “somewhat gradational” to a “slight angular unconformity” (Dibblee, 1966, p. 51). Part of Sisquoc Formation in adjacent Dos Pueblos quadrangle to west is of early Pliocene age (Arends and Blake, 1986; Blake, 1994, p. 19).

Most rocks mapped as Sisquoc Formation in this study previously were mapped as Monterey Formation (Upson, 1951), Santa Margarita shale (Bailey, 1952; Dibblee, 1966), Sisquoc Formation (Dibblee, 1966), and Sisquoc Shale (Dibblee, 1987). In area between Goleta Pier and Hope Ranch, some rocks previously mapped as Monterey Shale (Dibblee, 1966) and Monterey Formation (Dibblee, 1987) are herein included in the Sisquoc Formation. Thickness of Sisquoc Formation in this 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). According to Dibblee (1966, p. 51), Sisquoc is at least 250–300 m thick in Goleta Pier area

Tm **Monterey Formation (Miocene)**—Predominantly thin-bedded to laminated, light-colored siliceous and calcareous mudstone and shale. Well exposed and relatively unweathered along coastline where formation is divided into three subunits, the upper siliceous, middle shale, and lower calcareous units. Elsewhere, formation generally is poorly exposed and highly weathered, with many original lithologic details obscured; in most of these areas formation is undivided. Undivided Monterey mudstone and shale typically are very light gray to light brownish gray, well stratified, platy to fissile, soft, and low in density. As seen with hand lens and in thin section, many samples variably contain diatoms, planktic and benthic foraminifers, fish scales, and scattered silt. Thin sections show larger bioclasts and mineral grains suspended in a very fine grained matrix ranging from recognizable diatomaceous and other biogenic debris to microcrystalline siliceous material of unknown origin. Some samples are calcareous.

Locally, at or near base of formation, is a white fine-grained vitric tuff composed largely of glass shards and minor pumice along with scattered plagioclase, sanidine(?), and quartz. Dibblee (1966) considered this tuff to mark base of Monterey Formation. However, we observed the tuff at only two localities in map area and were unable to use it as a mapping horizon. Instead, we mapped lower contact of Monterey at lithologic transition from relatively massive to poorly stratified, predominantly argillaceous Rincon Shale to overlying, much better stratified, siliceous and calcareous mudstone and shale. In most places this contact is approximately located because of poor exposure. Tuff exposed at Lauro Canyon Dam apparently is underlain by at least a few meters of siliceous shale typical of Monterey Formation, and thus does not appear to mark exact base of Monterey.

In foothills of Santa Ynez Mountains in Santa Barbara quadrangle, bedding attitudes in Monterey Formation are highly variable, due at least in part to folding. Outcrop-scale folds, some overturned, are observed in several places, and Dibblee (1966) interpreted Monterey in one such area in Sycamore Canyon to be folded by a map-scale syncline. At present, however, our structural data from these rocks are insufficient to support the mapping of any map-scale folds or to determine the facing direction of beds at most localities. All Monterey bedding attitudes in the map area are attributed as normal (i.e., upright) even though some may be overturned.

Monterey Formation exposed near Lauro Canyon Dam ranges in age from lower to middle Miocene based on one sample in lowermost exposed beds (apparently about 1 m below tuff) that yielded a benthic foraminiferal assemblage of probable Saucesian age, and two samples higher in unit (across fault from the probable Saucesian sample) that yielded benthic foraminiferal assemblages of Relizian to Luisian ages (R.S. Boettcher, written commun., 2001). These assemblages indicate lower middle bathyal water depths. Other outcrops of undivided Monterey Formation in map area have not been sampled paleontologically.

Tuff at or near base of formation also is undated, but may correlate with dated tuffs at or near Monterey-Rincon contact in several nearby areas. These include tuffs (1) near Summerland, 2 km east of map area (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); (2) near Naples, 5 km west of map area ($^{40}Ar/^{39}Ar$ single-crystal laser-fusion age on sanidine of 18.42 ± 0.06 Ma; Stanley and others,1996); and (3) at

Tranquillon Mountain, 65 km west of map area ($^{40}Ar/^{39}Ar$ single-crystal laser-fusion age on sanidine of 17.80 ± 0.05 Ma; Stanley and others, 1996).

Tmu **Upper siliceous unit (upper Miocene)—**Diatomaceous mudstone and shale with subordinate dolomite and porcelanite, generally well laminated and thin to thick bedded. Mudstone and shale generally weather white 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 than dolomite and porcelanite, low-density, and locally exhibit numerous fractures associated with abundant jarosite and goethite(?). Reaction in dilute HCl ranges from weak to strong, indicating 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. Laminations generally 0.5–10 mm thick are defined by color banding ranging from nearly white to dark gray-brown, variations in 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 mudstone and shale exhibit hydrocarbon staining and a strong oily odor.

Unit contains about 5–10 percent dolomite that occurs as ellipsoidal to spheroidal concretions, generally 10–50 cm thick and less than 2.5 m long, usually oriented parallel to stratification, and laterally persistent beds about 10 cm to 1 m thick. Dolomite is very hard and brittle, relatively resistant, brown to gray on fresh surfaces, generally weathering white with a slight orange or yellow cast, high-density, and aphanitic to sugary. Reaction in dilute HCl ranges from none to weak. Laminations 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 but generally poorly preserved. In many places dolomite is strongly fractured; some fractures are filled by white mineral of unknown composition, while others are filled by asphalt. In places dolomite is so pervasively fractured that it resembles breccia. Some concretions are strongly fractured only along their margins.

Unit contains less than one percent porcelanite that forms isolated, resistant beds 5–50 cm thick. Porcelanite is hard and brittle, white-weathering, gray to brown on fresh surfaces, generally noncalcareous, and exhibits conchoidal fracture and porcelaneous luster; generally well laminated; contains abundant but poorly preserved microfossils, including foraminifers. Present only in stratigraphically lower part of unit where it is interstratified with diatomaceous mudstone and shale that contain abundant, well-preserved diatoms with opaline luster.

Age is late Miocene on the basis of: (1) benthic foraminiferal assemblages that probably represent upper part of Mohnian stage of Kleinpell (1938, 1980) and upper bathyal to upper middle bathyal water depths (R.S. Boettcher, written commun., 2001); (2) calcareous nannofossils of late Miocene age that could not be assigned to a specific zone (S.A. Kling, Micropaleo Consultants, written communs., 2001); and (3) 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). Unit rests conformably and sharply on middle shale unit (Tmm); contact between these units is exposed in 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.

Well exposed along sea cliffs in southern part of Goleta quadrangle, where it forms bright, white-weathering dip slopes. Small landslides, mainly rock falls, are common along these slopes, but unit appears to be generally more resistant to erosion and less susceptible to landsliding than underlying middle shale unit.

In sea cliff exposure about 5.2 km east of Goleta Pier, unit consists of shale, mudstone, and dolomite that are unusually hard, exhibit complicated outcrop-scale folding, and are strongly fractured. Some rocks at this locality have a brecciated appearance because of pervasive fractures. Many fractures are partly or completely filled by asphaltic material that smells strongly of oil. These rocks may represent a fractured petroleum reservoir that formed at depth and was subsequently exhumed by uplift and erosion.

Rocks assigned to upper siliceous unit previously were mapped as Monterey shale (Upson, 1951), upper Monterey Shale (Dibblee, 1966), and upper shale unit of Monterey Formation (Dibblee, 1987). Unit may be partly correlative with siliceous shale and upper calcareous and transition members of Monterey Formation defined by Hornafius (1994b, p. 10). Thickness of unit could not be determined accurately owing to structural complications and because sea cliff exposures are at low angles to strike of bedding, but is estimated to be no less than 45 m and may be as much as 250 m

Tmm **Middle shale unit (upper and middle Miocene)—**Shale, mudstone, porcelanite, and subordinate dolomite, 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. 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 1 m thick or more. Bedding is defined mainly by variations in texture, color, and resistance to weathering, which in turn are probably related to variations in composition. In places, shale and mudstone contain abundant microfossils visible with hand lens, including foraminifers and fish scales. Cream- to white-colored phosphatic nodules and laminae generally 1–10 mm thick are locally abundant, particularly in darker-colored, less-resistant horizons. Local interbeds of dolomite up to 50 cm thick are similar in lithology to dolomite in upper diatomaceous unit.

Porcelanite is generally hard and brittle, relatively resistant to erosion, white-weathering, brown on freshly-broken surfaces, and exhibits conchoidal fracture and porcelaneous luster. Beds range from a few centimeters to about 30 cm thick and are well laminated. Some beds contain abundant foraminifers and fish scales visible with hand lens. Porcelanite beds east of Arroyo Burro Beach are in opal-CT diagenetic stage, whereas silica in the associated organic-rich mudstone has remained in opal-A diagenetic stage (Eichhubl and Behl, 1998, p. 86). In places, porcelanite is strongly fractured; fractures are partly or completely filled by dark-colored, solid asphaltic material with a strong oily odor. In some outcrops intense fracturing imparts a brecciated appearance.

In places, this and underlying lower calcareous unit exhibit abundant and complex outcrop-scale folding, faulting, fracturing, and vein-filling. These features are particularly well exposed east of Arroyo Burro Beach and are discussed in detail by Hornafius (1994a), Eichhubl and Behl (1998), Eichhubl and Boles (1998, 2000), and Gross and others (1998).

Unit age is late and middle Miocene based on microfossils. A sample from uppermost part of unit about 5.4 km east of Goleta Pier yielded benthic foraminifers indicative of Mohnian, possibly upper Mohnian, stage of Kleinpell (1938, 1980) and probable upper middle bathyal water depths (R.S. Boettcher, written commun., 2001). Samples from 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), boundary between Mohnian and Luisian benthic foraminiferal stages is in lowermost part of unit about 2.1 km east of Arroyo Burro Beach Park parking lot.

Most rocks mapped as middle shale unit in this report were mapped as Monterey shale by Upson (1951), upper Monterey Shale by Dibblee (1966), and upper shale unit of Monterey Formation by Dibblee (1986, 1987. Some rocks herein assigned to middle shale unit in area between Arroyo Burro and Santa Barbara Point were mapped as lower shale unit of Monterey Formation by Dibblee (1986). Middle shale unit of this report apparently includes all of middle shale and massive chert members and part or all of upper chert member of Hornafius (1994a, p. 121–122). Thickness of unit cannot be determined accurately owing to structural complications and the fact that many exposures are at low angles to bedding, but is estimated to be about 120–180 m.

West of Arroyo Burro, 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). Landslide areas are characterized by irregular, hummocky topography that includes well-defined benches. Numerous buildings and roads are present in this area, and there have been many attempts to control sliding and wave-aided erosion of the sea cliffs with walls, terraces, and systems of pipes

Tml **Lower calcareous unit (middle and lower Miocene)—**Calcareous, siliceous, and phosphatic mudstone and shale, with subordinate porcelanite, dolomite, 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 generally well stratified and occur in laterally persistent beds about 3–30 cm thick; some beds are as thick as 50 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. Horizons of mudstone with abundant phosphatic nodules and laminae are thicker and more frequent in upper part of unit, and in places are as thick as 5 m. These horizons 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 yellowish gray to orangish gray and light orange, and is gray to grayish 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; some beds and concretions are as thick as 1 m. 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.

Porcelanite is hard, brittle, resistant, exhibits conchoidal fracture, weathers light gray to white, and is gray to brown on freshly broken surfaces. Porcelanite constitutes less than 1 percent of unit and occurs as massive to well-laminated beds about 5–20 cm thick that increase in thickness and frequency upward in the unit. Some beds react strongly with dilute HCl and contain abundant calcareous foraminifers. Porcelanite beds east of Arroyo Burro Beach are in opal-CT diagenetic stage as shown by x-ray diffraction (R.J. Behl, cited by Hornafius, 1994b, p. 8).

A 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. Glauconitic sandstone horizon is hard and more resistant to weathering than the underlying and overlying horizons of calcareous mudstone. Sandstone weathers tan to orange tan, is brown to tan on freshly broken surfaces, and consists of at least three amalgamated beds separated by irregular, sharp, erosional surfaces. All three beds are bioturbated and normally graded from medium-grained sandstone at base to fine-grained, silty sandstone at top. Lower contact of horizon with underlying calcareous mudstone is sharp and exhibits about 10 cm of erosional relief. Upper part of horizon grades upward into the overlying calcareous mudstone.

Laterally persistent, recessive beds of tuff about 1–10 cm thick constitute much less than 1 percent of unit. Tuffs weather orangish to yellowish gray, are gray to greenish-gray on freshly broken surfaces, and appear to range from vitric to crystal-vitric with crystals of biotite and feldspar. Lower contacts of tuff beds are generally sharp and apparently erosional; 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.

Sharp, laterally persistent surfaces of discontinuity that may represent slump scars or erosional surfaces are present locally in upper part of unit. One such surface exposed in sea cliff about 2 km west of Santa Barbara Point is overlain by well-stratified mudstone and shale that dip southwestward about 5–20 degrees steeper than lithologically similar strata below surface. This relation is tentatively interpreted as having formed by downslope movement of coherent blocks of strata on a glide plane during or shortly after deposition.

Unit age is middle and early Miocene based on microfossils. Samples near Santa Barbara Point yielded benthic foraminiferal assemblages indicative of 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). Lowest part of unit is not exposed in Santa Barbara Point area but probably includes strata of Saucesian age, based on comparison with more complete exposures of Monterey Formation in nearby areas including Naples (Blake, 1994; Hornafius, 1994b) and Summerland (Turner, 1970).

Unit is well exposed along coast from Santa Barbara Point westward to near lighthouse, but generally is poorly exposed elsewhere in map area. Along coast, unit forms steep, light-colored sea cliffs with numerous small rock falls; in places, erosion of these cliffs has undermined buildings, fences, and other structures, and local property owners have attempted to control erosion by constructing walls and other devices. Strata mapped as lower calcareous unit in this report previously were mapped as Monterey shale by Upson (1951), lower Monterey Shale by Dibblee (1966), and lower shale unit of Monterey Formation by Dibblee (1986). Unit is correlative with most or all of lower calcareous shale member of Hornafius (1994a, p. 121–122; 1994b, p. 6). Along sea cliff north and northeast of Santa Barbara Point, Dibblee (1966, 1986) mapped a depositional contact between lower Monterey Formation and underlying Rincon Shale, but this contact, along with lower part of Monterey and upper part of Rincon, are no longer exposed. Because of poor exposure and complicated structure, thickness of lower calcareous unit cannot not be determined, but it may be similar to that of lower calcareous shale unit of Hornafius (1994b, p. 4–5) at Naples Beach (about 250 m)

Tr **Rincon Shale (lower Miocene)—**Brown, gray-brown, and gray, massive to poorly bedded mudstone, shale, siliceous shale, and gray-brown to yellow-brown dolomite; poorly exposed in most places. In outcrop, mudstone and shale are hard and characteristically display conchoidal fracture; dull, yellow jarosite commonly coats cracks. Thin bedding and lamination in mudstone and shale are defined by subtle variations in texture and color and commonly are visible only in slightly weathered outcrops where defined by parallel fractures. Thin sections show that the mudstone and shale are composed dominantly of clay with 5–10 percent silt and very fine sand. Dolomite is aphanitic, hard and resistant, and contains abundant fish scales and bones; it comprises about 5 percent of the unit and occurs throughout the section in layers as thick as about 60 cm and in lenses or elliptical masses as thick as about 1.5 m with shortest axis perpendicular to stratification. Where exposed, dolomitic layers and lenses define stratification.

A thick (as much as 40 m) siliceous shale interval about 60 m below top of Rincon Shale is differentiated in westernmost part of map area (unit Trs). Interval consists of pale-gray and light-tan, thin-bedded, hard, siliceous shale that resembles basal Monterey Shale.

Unit was deposited in a bathyal marine environment and contains abundant foraminifers; it typically contains 1–5 percent total organic carbon and is a potential source rock of oil and gas (Stanley and others, 1992). Unit age is based on evidence from Tajiguas landfill 25 km west of map area, where benthic foraminifers, planktic foraminifers, and calcareous nannofossils indicate that entire formation is of early Miocene age rather than Oligocene and Miocene as previously reported (Stanley and others, 1992, 1994).

Rincon rests conformably on Vaqueros Formation and is conformably overlain by Monterey Formation. As mapped in this study, Rincon is about

400 m thick at Carneros and Vegas Creeks in Goleta quadrangle and about 430–460 m thick in Santa Barbara quadrangle.

Rincon Shale is highly susceptible to landsliding and other forms of downslope movement; unit commonly forms smooth, dark slopes mantled with fine-grained colluvium and soil. Some such slopes mapped as Rincon Shale in this study were shown as landslides by Bezore and Wills (2000), as in Sycamore Canyon area where significant and locally damaging downslope movement of sediment derived from Rincon has occurred.

Tv **Vaqueros Formation (upper Oligocene)**—Tan, yellowish-tan, yellowish-gray, and greenish-gray, weakly to moderately indurated, feldspathic sandstone. Locally forms ridges; commonly weathers to light-tan rounded sandstone outcrops and a distinctive, light-tan sandy soil. Sandstone is primarily medium to coarse grained and massive to thick bedded, but becomes finer grained upsection. Upper part contains well defined, thin siltstone interbeds. Sandstone in upper third of unit typically is mottled tan and greenish gray; lower two-thirds is yellowish-tan with abundant orange 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. Either at base of unit or as much as 5 m above base is a 50–150-cm-thick, well-indurated, gray conglomerate containing abundant pelecypod shell fragments, rounded chert clasts, and subangular graywacke clasts as long as about 1 cm. Chert and graywacke are thought to be derived from outcrops of Franciscan Complex to north (Rigsby, 1998). Lower contact with Sespe Formation is sharp, which Howard (1995) considered to be an erosional disconformity throughout the map area, but Rigsby (1998) interpreted a transition of the contact to conformable east of Lauro Canyon.

Unit was deposited in a shallow marine environment; massive nature of sandstone is due to bioturbation, which can be observed in many places. Late Oligocene age is inferred from stratigraphic position of unit between Sespe Formation and Rincon Shale, which at Tajiguas landfill 25 km west of map area contains earliest Miocene microfossils in its lower part (Stanley and others, 1994) and the base of which is considered coincident with 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 50 km west of map area, consistent with late Oligocene age. Unit is about 90 to 115 m thick where exposed in map area, comparable to regional thickness of about 100 m reported by Dibblee (1982)

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. 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 one place in the central part of map area the lower two units pinch out such that the upper Sespe rests directly on rocks of the underlying Coldwater Sandstone (Tcw). Overall thickness of Sespe Formation increases eastward from about 700 m near the northwestern corner of map area to about 1300 m north of Santa Barbara.

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, or 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.

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). Unit 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. Upper unit averages about 1,100 m thick in Santa Barbara quadrangle and thins westward into Goleta quadrangle, where it is about 470 m thick along Old San Marcos Pass Road. Unit was previously mapped as part of the Sespe Formation by Upson (1951), Lian (1954), and Dibblee (1966, 1986b, 1987)

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, from less than 200 m near northwest corner of map area to 335 m near northeast corner, 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, 1986b, 1987), and as red to gray conglomerate and arkosic sandstone of the Sespe Formation by Dibblee (1987)

Tspl **Lower conglomerate and sandstone unit (upper Oligocene and 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 to buff massive, commonly oyster-shell-bearing sandstone of the underlying Coldwater Sandstone (Tcw).

The lower conglomerate and sandstone unit generally increases in thickness eastward along strike from where it pinches out just west of the map area in Glen Annie Canyon to a maximum of about 170 m north of Santa Barbara; farther eastward unit gradually thins to 100 m at the east edge of map area; unit also pinches out along a short strike distance across the boundary between the Goleta and Santa Barbara 7 ½' quadrangles. 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. Thus, it appears that the lower Sespe transition into the Gaviota is confined to a small area where the lower conglomerate and sandstone unit pinches out just west of the map area. 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, 1986b, 1987), as the lower member of the Sespe Formation by Lian (1954), and as pink to white sandstone and red claystone of the Sespe Formation by Dibblee (1986b, 1987)

Tcw **Coldwater Sandstone (upper and/or middle Eocene)—**Shallow-marine sandstone with minor amounts of mudstone. Consists dominantly of light-yellowish-brown, light-brownish-gray, and light-brown, mostly massive to thick-bedded, medium- to coarse-grained, feldspathic to arkosic sandstone, interbedded with minor dark-brown mudstone and fine-grained argillaceous sandstone. Medium- to coarse-grained sandstone beds are less than 1 m to more than 10 m thick, and range from internally unstratified to pervasively plane- and cross-laminated. In thin section, these sandstones consist dominantly of well-sorted quartz, less abundant feldspar, and subordinate lithic grains (felsic volcanic rock, micaceous schist, argillite?, chert?) in a silty argillaceous matrix; detrital biotite and muscovite are common in some samples. Mudstone and fine-grained sandstone units are generally thinner than the medium- to coarse-grained sandstone units and locally contain abundant oyster shells and shell fragments. In Goleta quadrangle, ferruginous leaf and wood impressions occur about 400 m below top of formation. Unit is about 750 to 1,000 m thick in region (Dibblee, 1982), but only upper part is present in map area. Age of unit is not tightly constrained in map area; regionally, age of Coldwater has been variably considered late and (or) middle Eocene (Kleinpell and Weaver, 1963; Dibblee, 1966; Howard, 1995; Campion and others, 1996; Prothero, 2001) on basis of paleontologic, magnetostratigraphic, and sequence stratigraphic correlations. As mapped, uppermost part of unit near northwest corner of map area may include eastward terminating beds of the Gaviota Formation, whose sandstone beds closely resemble those 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 (1986b, 1987)

INTRODUCTION

This report presents a new geologic digital map of the Santa Barbara coastal plain area at a compilation scale of 1:24,000 (one inch on the map = 2,000 feet on the ground) and with a horizontal positional accuracy 20 m or better. *(Note: This map is not intended to be displayed at scales larger than 1:24,000.)* This preliminary map depicts the distribution of bedrock units and surficial deposits and associated deformation underlying and adjacent to the coastal plain within the contiguous Santa Barbara and Goleta 7.5' quadrangles. A final version (2007 approximate publication date) will extend the mapping westward into the adjoining Dos Pueblos Canyon quadrangle and eastward into the Carpinteria quadrangle (fig. 2). 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, Stanley, Stone, and Powell) and the tectonic geomorphology research group at the University of California at Santa Barbara (Gurrola and Selting). C.L. Powell, II, performed all new fossil identifications and interpretations reported herein. T.R. Brandt designed and edited the GIS database, performed database integration, and created the digital cartography for the map layout. The digital geologic database for this map is available on the Internet at: http://geology.cr.usgs.gov/pub/open-file-reports/ofr-02-0136/.

The Santa Barbara coastal plain is located in the western Transverse Ranges physiographic province along a west-trending segment of the southern California coastline about 100 km (62 mi) northwest of Los Angeles (Fig. 1). The coastal plain region, which extends from the Santa Ynez Mountains on the north to the Santa Barbara Channel on the south, is underlain by numerous active and potentially active folds and partly buried thrust faults of the Santa Barbara fold and fault belt (Fig. 2) (Keller and Gurrola, 2000; Gurrola and others, 2001). 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 and Goleta. Also, young landslide deposits along the steep lower 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.

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 1950's 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. This landmark effort provided unprecedented geologic map coverage of the Goleta half of the map area at a scale of 1:62,500 and of the Santa Barbara half at a scale of 1:31,680. Hoover (1978) mapped the geology of the Santa Barbara half of the map area at a scale of 1:1000 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 state-of-knowledge geologic maps of the Santa Barbara and Goleta 7 ½' quadrangles (Dibblee, 1986b, 1987) at a scale of 1:24,000. These latter two maps have provided us with valuable background information, and have served as a foundation, for our present mapping efforts. Recently, the 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).

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 strong, protracted deformation that includes folding, thrust and reverse 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 Eocene to Oligocene sedimentary rocks that form a mostly southward-dipping and laterally continuous sequence along the south flank of the Santa Ynez Mountains. Less resistant, deformed, Miocene and Pliocene(?) sedimentary rocks are exposed in the lower Santa Ynez foothills and in the coastal hills and sea cliffs farther south. 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.

The following depositional and deformational history is inferred from the mapped sedimentary rocks and deposits. The Tertiary sedimentary rocks record a transition from shallow-marine deposition (unit Tcw) to nonmarine fluvial deposition (units Tspl, Tspm, and Tspu), followed by a return to shallow- (unit Tv) and, eventually, bathyal- (units 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 between the lower (unit Tspl) and middle (unit Tspm) units of the Sespe Formation 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 temporarily disrupted during the Pliocene and (or) early Pleistocene, probably due to tectonism accompanied by uplift and erosion, as evidenced by a locally pronounced erosional and angular unconformity that separates the Sisquoc (unit Tsq) and older formations from the overlying marine Santa Barbara Formation (unit Qsb) and partly coeval, unnamed sedimentary rocks (units QTst, Qss, and Qcg).

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 marine shelf that may have been transected by several submarine canyons. Sometime during the middle Pleistocene tectonic uplift of the Santa Ynez Mountains commenced, resulting in the initial development of a piedmont alluvial fan system (unit Qoa) that encroached upon the Santa Barbara marine depositional shelf from the north. Eventually, marine-shelf sedimentation ended throughout the coastal plain region as it was replaced by nonmarine alluvial and fluvial deposition (units Qoa and Qia) concomitant with initial transpressional faulting, folding, and uplift in the Santa Barbara fold and fault belt (Gurrola and others, 2001). Strong contractional deformation continued into the late Pleistocene in the coastal plain area, resulting in the episodic uplift and warping of wave-cut marine platforms and capping marine-to-nonmarine terrace deposits (unit Qmt). Alluvial and colluvial deposition (units Qa, Qac, Qc, and Qce) continued into the Holocene on broad low-lying, possibly downwarped (Keller and Gurrola, 2000; Gurrola and others, 2001) floodplains underlying downtown Santa Barbara and the Goleta Valley and elsewhere along major stream canyons. This sedimentation was locally accompanied by the deposition of estuarine deposits (Qe) in low coastal areas by a combination of subsidence and (or) 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 have been and are 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).

Structurally, the Santa Barbara coastal plain area is dominated by the Santa Barbara fold and fault belt, an east-west-trending zone of Quaternary, partly active folds and blind and exposed reverse and thrust faults (Keller and Gurrola, 2000; Gurrola and others, 2001). The dominant trend of individual structures within the belt is west-northwest -- slightly oblique to the overall trend of the fold and fault belt. A conspicuous exception, however, is the More Ranch fault system, which strikes east-northeast across the fold and fault belt at a high angle to the dominant structural grain. Based on a limited number of observations made at rare fault-plane exposures, most of the map-scale faults in the coastal plain area are moderately to steeply dipping and have most recently experienced reverse or reverse-oblique slip. Multiple sets of slip lineations, including strike-slip and, rarely, normal-slip striae, are commonly preserved on the fault planes, however, indicating that many of the faults have a varied, complex movement history.

Several folds within the older alluvial deposits (Qoa) have 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). The most dramatic example of such a geomorphic-structural correlation is Mission Ridge just north of downtown Santa Barbara, which is coincident with an anticline that is paired on its north side with a syncline that roughly follows a linear valley containing Sheffield Reservoir and Mountain and Stanwood Drives. Such anticlines and synclines, which are geomorphically and structurally well expressed in Pleistocene deposits but which commonly have poor structural definition in underlying, discordant bedrock units, are mapped as upwarps and downwarps, respectively. 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 the Mission Ridge fault and resulting in progressive westward deflection of Mission Creek. Several fold axes on the coastal plain are parallel to adjacent fault traces, and in such cases the fold on the apparent upthrown, hanging-wall side of the fault is typically an asymmetric anticline whose steeper limb faces the fault. Nearly all of these asymmetric anticlines in the map area have northward vergence. Examples of such anticline-fault associations include the eastern strand of the Foothill fault in the northeastern part of Goleta Valley as well as along the entire mapped, 6-km-long trace of the Lavigia fault in the coastal hills in the Hope Ranch–La Mesa area. Such structural geometry is consistent with fault-propagation folding (Gurrola and others, 2001) and, together with the previously described evidence of dominant reverse fault slip, implies that faults in the map area have accommodated significant contractional strain during the Pleistocene. The Lavigia fault 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, including the Mission Ridge anticlinal upwarp (Gurrola and others, 2001). The northward vergence of the majority of folds in the coastal plain area suggests that most associated blind reverse-thrust faults are dominantly southward dipping similar to the exposed faults and, thus, have accommodated northward tectonic transport of their hanging-wall blocks (Keller and others, 1999; Gurrola and others, 2001).

Most of the structures in the fold and fault belt deform deposits as young as middle to late Pleistocene (i.e., Qoa), but many of the west-northwest-striking faults in the northwest part of the map area do not cut older alluvial deposits (Qoa) or they offset such deposits a significantly lesser amount than the underlying bedrock units. These relations, and a moderate angular discordance that locally exists between the middle Pleistocene Santa Barbara Formation (Qsb) and overlying older alluvial deposits (Qoa), 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. One or more of these earlier deformational episodes may have been coeval with the formation of numerous northwest-trending folds and faults in the Monterey Formation (Tm) along the sea cliffs between Santa Barbara Point and Arroyo Burro; these structures clearly predate unconformably overlying, cliff-capping marine terrace deposits (Qmt). Possible age-equivalent (pre-Qoa) folds also deform the Monterey in Sycamore Canyon area in the east part of the map area. 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, and 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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