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PRELIMINARY GEOLOGIC MAP OF THE PACIFIC PALISADES AREA, CITY OF LOS ANGELES, CALIFORNIA

By John T. McGill

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INTRODUCTION

The map presents basic data on the complex geologic setting of the numerous landslides in the Pacific Palisades area of the City of Los Angeles. It thus complements the previously published report of a special Congressionally authorized study of landslides in the area that was undertaken by the Corps of Engineers in cooperation with the U.S. Geological Survey (U.S. Army Corps of Engineers, 1976). The technical appendix of that report was prepared by the Geological Survey. It consists of a map showing landslides in the Pacific Palisades area (McGill, 1973) and a table giving summary data on each of the 130 individual landslide areas delineated on the map. The cutoff date for information incorporated in the map and table was June 30, 1969, the end of a rainfall year of unusually heavy precipitation and widespread landslide activity. As portrayed on that map, landslides include areas of fresh or relatively unmodified scarps and scars and thus are commonly more extensive than the landslide deposits shown on the present geologic map; landslide scarps are shown and arrows indicate the general direction of movement of the landslides. The table provides information on time and type of movement and kinds of material involved. It also presents pertinent available data on location, dimensions, configuration, volume, and rate of movement; topographic and geologic setting; damages and other effects; remedial measures employed; and seepages, heavy rains, and grading operations.

Engineering data on earth materials and landslides in the Pacific Palisades area are well covered in the voluminous and still very pertinent report of a comprehensive landslide study for the California Department of Public Works by the consulting engineering firm of Moran, Proctor, Mueser & Rutledge (1959). The investigation consisted of a field program of borings, instrumentation, and data collection, a laboratory testing program, and an analytical program leading to conclusions as to landslide causes and recommended remedial measures. Technical data include boring logs, classification and strength tests results, piezometric observations, and measurements of slope indicator movements.

PROCEDURE

Field geologic mapping was done mainly at a scale of 1 in. equals 100 ft (1:1,200) on topographic base maps compiled in 1958 for the California Department of Public Works. No subsurface exploration was undertaken specifically for this investigation. However, a great many temporary excavations and openings made for other purposes were examined, selective use was made of the extensive subsurface data in the report by Moran and others (1959), and numerous boring logs and reports in the files of various local governmental offices were reviewed. Old and recent aerial and ground photographs and topographic maps were especially useful in determining the boundaries of artificial grading and of some landslide deposits.

The geology is shown relative to the 1958 topographic base map (1:4,800 reduction) except for landslide deposits that formed or moved between the date of the aerial photographs used in compiling the base map and June 30, 1969, and that were still present as of the latter date. For those landslide deposits, the boundaries are shown planimetrically as of June 30, 1969, but the contours are not correct. The 1958 base map still provides the most recent large-scale topographic coverage of the entire study area, it comes much closer to portraying the natural setting than a more recent base map would, and its use facilitates comparison of the geologic map with previously published landslide maps on the same base (McGill, 1959; Moran and others, 1959, v. 2; McGill, 1973).

Landslides and artificial grading since June 30, 1969, are not shown on the map, but most have been relatively minor. Landsliding, which occurred mainly during the heavy rains of February-March 1978 and February 1980, did not involve new major slope failures. The principal types of landslides were numerous but small, thin debris slides and debris flows and slow, renewed movement of several preexisting, large, deep-seated rock slumps. Only a few large grading projects have been carried out since June 1969. Most prominent is a fill embankment which extends about half way up the cliffs adjoining Pacific Coast Highway along the central and eastern Huntington Palisades. Canyon bottom fills were constructed in the middle segment of Pulga Canyon, in lower Los Liones Canyon adjoining Paseo Miramar, and in the east tributary to Santa Ynez Canyon near the southern part of Marquez Elementary School playground. Each of these fills serves to buttress slopes that have been subject to landsliding.

ACKNOWLEDGMENTS

Many engineering geologists and engineers in various departments and bureaus of the City of Los Angeles have contributed to this study through helpful discussions and suggestions and by providing access to maps and reports. Deserving of special mention are J. W. Cobarrubias, staff geologist of the Grading Division, Department of Building and Safety, and his predecessor, C. A. Yelverton; and E. R. Reese, geologist in charge, and George Stolt of the Geology and Soils Engineering Section, Street Opening and Widening Division, Department of Public Works. The Board of Education furnished information concerning the sites and grading plans for Palisades High School (constructed 1959-61 in Temescal Canyon south of Sunset Boulevard) and Marquez Elementary School. The California Division of Highways made available historical photographs, landslide data, and construction reports relative to the Pacific Coast Highway.

Several consulting engineering geologists and engineers generously provided information on local investigations made by their firms. I am especially indebted to the late H. R. Johnson for many stimulating discussions at his home and in the field and for contributions of data from his consulting reports and files, which dated back to 1932 for this area. The approximately located trace of the near-vertical branch of the Potrero Canyon fault is based partly on geophysical determinations by Johnson (1932).

The study has greatly benefited from the work and suggestions of R. F. Yerkes and R. H. Campbell of the U.S. Geological Survey, who conducted

geological investigations of the central Santa Monica Mountains west and northwest of the Pacific Palisades area in cooperation with the County of Los Angeles.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

[Measurements were originally made in English units; metric units are mathematical equivalents, rounded to significant figures, and not exact measurements]

af — ARTIFICIAL FILL (HOLOCENE)--Chiefly fill for Pacific Coast Highway (PCH) and adjoining parking areas, other roadways, and canyon bottom developments. Oldest fill is remnant of railroad embankment constructed 1891-93 along base of palisades from Santa Monica to mouth of Potrero Canyon, where stub embankment of granite block rubble marks shore terminus of former Long Wharf. Locally undifferentiated from alluvial, stream-terrace, and colluvial deposits. Generally mapped only where fill area is of substantial size and thickness is more than 5 ft (1.5 m); thickness commonly 10-30 ft (3-9 m), maximum about 75 ft (23 m); thickness of embankment beneath and adjoining PCH generally 10-15 ft (3-4.6 m) and locally as much as 25 ft (7.6 m). Consists chiefly of sand, silt, clay, and pebble- to cobble-size rock fragments. Character varies with source materials, many of which were excavated adjacent to or near fill sites; seaward part of embankment fill adjoining PCH commonly includes landslide debris removed from highway and adjacent uphill slopes, and locally is faced with rubble of rock or concrete fragments as large as 6 ft (1.8 m) for protection against wave erosion; stone groins for beach protection consist chiefly of block rubble of hard, coarse-grained sandstone from outside mapped area. Well compacted to loose; loose rubble on free face of fills. Only one fill placed prior to date of topographic base map was specifically designed as a buttress to control a landslide (McGill, 1973, landslide no. 92)

afh — Hydraulic fill--In lower Santa Ynez Canyon; placed in 1926-28. Material excavated from adjoining area to east. Thickness as much as 30 ft (9 m)

ag — ARTIFICIALLY GRADED LAND (HOLOCENE)--Part fill and part cut; relations too complex or uncertain for fill to be differentiated. Geology largely concealed by construction or plant cover. Fill material mostly obtained from excavations within the same graded area. Thickness of fill generally more than 5 ft (1.5 m) and locally as much as 30 ft (9 m)

Qly — YOUNGER LANDSLIDE DEPOSITS (HOLOCENE)--Landslides known to have been active during historic time. Earliest landslide of record apparently occurred in 1874, but pertinent records generally date back only to the 1920's, when most of the residential subdivision development began. No landslide deposits that formed since

June 30, 1969 are shown. Many younger landslides formed in or included older (prehistoric) landslide deposits. Locally include talus and other colluvial deposits, especially in upper parts adjacent to landslide scarps. Deposits smaller than about 20 ft (6 m) minimum dimension in plan are not shown. Thickness ranges from a few feet (about 1 m) to at least 120 ft (37 m); most small deposits, less than about 100 ft (30 m) maximum dimension in plan, and some medium-size deposits are less than 15 ft (4.6 m) thick; large deposits generally are deep-seated landslides with average maximum thickness greater than about 50 ft (15 m). Lithology is variable and depends on source materials. Principal bedrock map units involved are the Modelo and Topanga Canyon Formations, as is evident from the map distribution of the larger landslides. Shallow slippage has occurred locally in the weathered zone or thin colluvial soil developed on these and other bedrock formations but not mapped separately. Principal surficial map units involved, in addition to older landslide deposits, are nonmarine and marine deposits that overlie the main wave-cut terrace platform. Many landslide deposits include both bedrock and surficial materials. Landsliding commonly resulted in further disruption and weakening of earth materials so that deposits generally are highly susceptible to renewed movement. Loose to poorly indurated except for relatively intact large blocks of bedrock, which can survive in deep-seated slides; porosity and permeability generally high; permanent ground-water level generally is above the sliding surface in massive landslides within older landslide areas (Moran and others, 1959, v. 1, p. 181). Deposits of separate landslides within the same landslide complex are locally differentiated according to relative age by subscripts; 1 is oldest; the later landslides in such a sequence are at least partly within the areas of the earlier landslides. Date in parentheses identifies large landslide that formed since 1958, the date of topographic base map

Qlo OLDER LANDSLIDE DEPOSITS (HOLOCENE AND UPPER PLEISTOCENE)--Prehistoric landslides; no record of historic activity. Most are probably Holocene (approximately the last 10,000 years); some large landslides may date from latest Pleistocene (approximately 10,000-20,000 years B.P.), when sea level was much lower, especially from a period when mean annual rainfall was much greater than at present (Stout, 1977). Locally include talus and other colluvial deposits, especially in upper parts adjacent to landslide scarps. Landslide origin based on geologic evidence and (or) topographic expression, commonly considerably modified by erosion; queried where origin doubtful. Thickness and physical properties generally similar to those of younger landslide deposits, but older deposits tend to be better consolidated. A sample of wood from a stump or burl apparently overridden by the base of an older landslide in lower Temescal Canyon (McGill, 1973, landslide no. 38), and recovered from a depth of 37 ft (11.3 m) in a borehole during landslide remedial work in 1969, has a radiocarbon age of 810±60 years B.P. as determined by a

University of Miami laboratory (D. M. Morton, oral commun., 1980; George Stolt, Los Angeles City Department of Public Works, written commun., 1980)

Qb BEACH DEPOSITS (HOLOCENE)--Generally medium grained sand; pebble to boulder gravel locally at base, especially for about 800 ft (244 m) eastward from mouth of Parker Canyon and 1,600 ft (488 m) eastward from mouth of Santa Ynez Canyon, derived at least partly from adjacent artificial fill. Well-sorted, loose, angular to subangular sand. Thickness probably generally less than 15 ft (4.6 m). Width of beach varies seasonally; probably as much as 50 ft (15 m) greater in summer and fall than in winter

Qal ALLUVIAL DEPOSITS (HOLOCENE AND UPPER PLEISTOCENE)--In active stream channels and beneath adjoining flood plains, locally incised as much as 15 ft (4.6 m). Sand, gravel, and silt; poorly sorted; poorly bedded, lenticular, locally crossbedded; loose to poorly consolidated. Thickness commonly less than 30 ft (9 m), but in lower Santa Monica Canyon may exceed 250 ft (76 m) as result of stream entrenchment during eustatically lowered sea level in latest Pleistocene and early Holocene time. Prior to date of base map, the bottoms of Santa Ynez and Los Liones Canyons were modified by artificial grading and subsequent alluviation such that in parts of those areas it has not been feasible to differentiate between alluvial deposits and artificial fill. Locally undifferentiated from low stream-terrace deposits. As of 1969, the principal streams in Santa Monica, Rustic, Temescal, Santa Ynez, and Los Liones Canyons were confined to flood-control channels and culverts

Qc COLLUVIAL DEPOSITS (HOLOCENE AND UPPER PLEISTOCENE)--Accumulations of surficial material that has moved downslope by gravitational creep and sheetwash or by gravitational falling, rolling, or sliding of rock fragments; locally includes minor landslide deposits. Locally undifferentiated from stream-terrace deposits and artificial fill. Generally on lower part of slope, at base of steep slope, or in gullies; slopes of deposits range from about 20° to at least 45°, but commonly are about 35°. Widely developed, but mapped only where thickness known to be or estimated to be more than 5 ft (1.5 m); thickness generally less than 15 ft (4.6 m). Deposits tend to vary with parent material that underlies slope, but commonly are heterogeneous mixtures of angular to subangular, pebble- to cobble-size rock fragments and silty or clayey sand; unsorted to poorly sorted; loose to poorly indurated; commonly highly permeable. Three areas of pronounced soil creep, evidenced by tilted and overturned trees, are noted near the junction of Los Liones and Santa Ynez Canyons. Colluvial soils on steep slopes are susceptible to shallow slippage and resulting formation of debris flows or debris avalanches during heavy rainfall (Campbell, 1975)

Qt STREAM-TERRACE DEPOSITS (HOLOCENE AND UPPER PLEISTOCENE)--Interbedded gravel, sand, and silt. Thickness locally as great as 50 ft

(15 m). Pale yellowish brown, pale brown, or light to moderate brown; locally olive gray to light olive gray where gravel contains much slate. Generally crudely bedded or crossbedded, lenticular; locally thin bedded (1 in. to 1 ft (2.5-30 cm)); poorly sorted; loose to poorly indurated. Locally include alluvial fan and slopewash deposits from canyon sides. Locally undifferentiated from artificial fill, alluvial, and colluvial deposits. Commonly undifferentiated from unit Qtc where nonmarine deposits underlying stream-terrace surface are higher than altitude of wave-cut platform and marine-terrace deposits; such undifferentiated deposits in lower Santa Monica and Rustic Canyons probably are chiefly stream fill terraces (see map symbols for stream-terrace surfaces in that part of area). Original surfaces of high, extensively developed stream terraces in Pacific Palisades area probably were graded to late Pleistocene eustatic high stands of sea level. Highest extensively developed stream-terrace deposits in Temescal and Pulga Canyons apparently are correlative between the two canyons; upper surface is as much as 180 ft (55 m) above present canyon bottom at mouth of Temescal Canyon. Remnants of upper stream-terrace deposits exposed in side walls of Pulga Canyon north of Sunset Boulevard apparently are correlative with nonmarine cover (Qtc) on lowest or main marine terrace. Some low stream-terrace deposits near canyon mouths may be Holocene

Gravel--Sandy pebble to cobble gravel, commonly with boulders in basal part; boulders as large as 4 ft (1.2 m); rock fragments subrounded to angular, consist mainly of crystalline rocks and sandstone, with lesser amounts of other sedimentary rocks; abundant angular fragments of slate in Santa Monica and Rustic Canyons; commonly underlies finer-grained deposits

Sand--Silty, fine to coarse grained or pebbly

Qtc NONMARINE COVER ON MARINE-TERRACE DEPOSITS OR PLATFORMS (UPPER PLEISTOCENE)--Chiefly alluvial fan deposits; includes locally undifferentiated marine-terrace deposits at base, and talus and other colluvial deposits adjacent to buried sea cliffs. Locally undifferentiated from stream-terrace deposits. Where deposits of alluvial origin directly overlie bedrock, wave-cut platform locally modified by fluvial erosion. Thickness north and west of Potrero Canyon fault (PCF) averages about 40 ft (12 m) and ranges from about 15 ft (4.6 m) in parts of coastal palisades to as much as 100 ft (30.5 m) locally near inner edge of main terrace platform and adjacent to Rustic Canyon; thickness south of PCF exceeds 110 ft (33.5 m), and maximum exposed is 165 ft (50 m) in Huntington Palisades (east of Potrero Canyon mouth). Gravel, sand, silt, and clay; south of PCF, mainly gravel, lesser interbedded silt; north and west of PCF fine-grained deposits commonly are nearest surface. Materials in mass have high coefficient of friction, low cohesion, and relatively high permeability (Moran and others, 1959). Possible weak or incipient near-vertical joints locally in Huntington Palisades, subparallel and normal to cliffs, may contribute to formation of tension cracks, which influence slope stability; soilfalls common along cliffs

Gravel--Pebble to cobble gravel, locally with boulders as large as 5 ft (1.5 m). Pale brown, pale yellowish brown, or light brown to moderate brown; locally moderate reddish brown or grayish red. In Potrero Canyon mouth and for about 1,000 ft (300 m) east, exposed gravels in lower half of section are light bluish gray; mapped by Hoots (1931) as marine deposits, apparently because of their color and the presence of marine fossils in basal gravels of Pleistocene section in canyon mouth; however, the fossils are in marine-terrace deposits (Qtm), and light-bluish-gray gravels are similar to adjoining nonmarine deposits except for the color, which seems to result mainly from a combination of dark-gray slate fragments and white efflorescent coatings of epsomite and gypsum associated with seeps. Massive to irregularly bedded and crossbedded, lenticular. Thickness of beds ranges from a few inches (about 10 cm) to more than 15 ft (4.6 m); commonly 5-10 ft (1.5-3 m). Scour-and-fill deposits locally, including a buried channel entrenched about 50 ft (15 m) below marine-terrace platform about 1,000 ft (300 m) east of Temescal Canyon mouth. Poorly sorted or unsorted rock fragments, in silty sand matrix, consist mainly of angular to subangular clasts of coarse-grained sandstone, rounded to subrounded reworked clasts of crystalline rocks, and, in eastern third of area, angular tabular fragments of dark-gray slate, which locally constitute more than 50 percent of clasts; other sedimentary rock types include shale, siltstone, conglomerate, and algal limestone. Poorly to moderately indurated

Sand--Silty, fine to coarse grained, locally pebbly. Pale brown, pale yellowish brown, or light brown to moderate brown. Massive to poorly bedded and crossbedded, lenticular. Thickness ranges from 1 in. (2.5 cm) to about 25 ft (7.6 m); commonly 5-10 ft (1.5-3 m). Poorly sorted, subangular to angular. Poorly to locally moderately indurated

Silt--Typically fine sandy clayey silt, interbedded with gravel. Best exposed in Huntington Palisades, where several beds can be traced more than 500 ft (152 m). Light olive gray, locally grayish yellow, dark yellowish orange, or moderate brown. Beds generally 1-6 ft (0.3-1.8 m) thick. Basal bed overlying marine-terrace sands immediately east of Potrero Canyon mouth possesses medium to high plasticity (Moran and others, 1959) and contained lower part of slippage surface of famous 1932 landslides (Hill, 1934). Moderately to well consolidated. Persistent seeps of perched water at tops of clayey silt beds are widespread in western Huntington Palisades, mainly at and below elevation of about 100 ft (30 m)

Qtm MARINE-TERRACE DEPOSITS (UPPER PLEISTOCENE)--Sand and gravel, probably beach deposits prograded seaward during emergence of underlying wave-cut platform. All deposits except one associated with lowest and youngest (Pacific Palisades) platform, which Davis (1933) regarded as part of his Dume platform. The exception is a local exposure of possible marine deposits on the next higher platform, immediately west of Pulga Canyon and north of Sunset Boulevard. Marine deposits of second higher terrace (elevation of shoreline angle about 590 ft (180 m)) were well exposed by grading 1,100-1,700 ft (335-518 m) north of north-central edge of mapped area. Elevation of shoreline angle (base of seacliff) of lowest platform ranges from about 175 to 380 ft (53-116 m) as result of tectonic deformation. For elevations of marine-terrace platforms along the Malibu coast to the west, including Pt. Dume, see Birkeland (1972). Thickness ranges from a few inches (about 10 cm) to 28 ft (8.5 m); commonly 10-15 ft (3-4.6 m). Generally overlain by nonmarine cover of alluvial origin. Yellowish gray or grayish orange, to light brown or dark yellowish orange; light brown to moderate brown, thin (0.5-2 in. (1.3-5.1 cm)), subhorizontal bands locally in sand. Commonly massive to poorly bedded and crossbedded. Clean; loose to very poorly cemented; locally basal few inches (about 10 cm) moderately cemented. Highly permeable; seeps locally at basal contact. Outcrop width locally exaggerated on map. Queried where deposits possibly marine

Deposits locally fossiliferous, especially basal fine-grained sands. Long inaccessible locality near head of Potrero Canyon, on lowest terrace platform, contained abundant molluscan fauna referred to late Pleistocene (Woodring _in_ Hoots, 1931, p. 121-122; Valentine, 1956); ratios of amino acids in _Saxidomus nuttalli_ from this fauna permit preliminary age estimate of 120,000-140,000 years B.P. (J. F. Wehmiller, written commun., 1977), based on correlation with analyses of samples from Palos Verdes Sand at San Pedro, and warm-water fauna indicates age probably about 125,000 years B.P. (G. L. Kennedy, written commun., 1977), correlative with oxygen isotope substage 5e (Shackleton and Opdyke, 1973) and highest late Quaternary eustatic sea level (Bloom and others, 1974). Fossils from long inaccessible locality in basal gravel of Pleistocene section south of Potrero Canyon fault (PCF) at Potrero Canyon mouth previously referred to earliest Pleistocene or latest Pliocene (Woodring _in_ Hoots, 1931, p. 120), but stratigraphic and structural relations and review of paleontologic considerations (W. P. Woodring, written commun., 1978) indicate correlation of gravel and overlying clean sand with deposits of late Pleistocene lowest marine terrace north of PCF. Charcoal fragments (carbonized plant material) from sand on west side of Potrero Canyon mouth, south of PCF, analyzed for radiocarbon age determination by U.S. Geological Survey laboratory; age greater than 35,000 years B.P. (Ives and others, 1964, p. 50, lab. sample W-1034)

Sand--Medium to very coarse grained, mica poor, and very fine to fine grained, mica rich. Contains pebbles and cobbles scattered or in thin lenses. Very fine to fine-grained sand mainly in lower part, probably neritic material reworked during emergence (Bradley, 1957). Sand generally moderately to well sorted, angular to subangular, quartzose. Locally laminated or cross-laminated, including black magnetite-rich layers in coarse sand. Locally contains burrows of marine organisms

Gravel--Pebble to boulder gravel, with sand matrix; commonly basal, 1-3 ft (0.3-0.9 m) thick; locally occurs between coarser grained sand and underlying finer grained sand. Moderately to poorly sorted, angular to subrounded clasts as much as 2 ft (0.6 m) long consist of various crystalline and sedimentary rock types, including algal limestone, Modelo shale, and minor slate (at mouth of Potrero Canyon and in Rustic Canyon); some clasts of sedimentary rocks contain pholad borings

BEDROCK UNITS

QTs LOWER PLEISTOCENE OR UPPER PLIOCENE SEDIMENTARY ROCKS--Marine siltstone and very fine grained sandstone. Exposed only in Rustic Canyon, north of Potrero Canyon fault. Maximum exposed thickness probably about 300 ft (90 m). Light olive gray. Generally massive; locally thin bedded, crossbedded or shaly. Soft, poorly indurated. Joints locally well developed, high angle to vertical; spacing as close as 1 ft (0.3 m); rocks locally fractured. Locally highly fossiliferous; macrofossils referred to earliest Pleistocene or latest Pliocene (Hoots, 1931); foraminifera referred to early Pleistocene or late Pliocene, probably very latest Pliocene

Tp PLIOCENE SEDIMENTARY ROCKS (UPPER AND LOWER PLIOCENE)--Marine siltstone, sandstone, and sedimentary breccia. Maximum exposed thickness, in upper Potrero Canyon, about 750 ft (230 m)

Siltstone--Commonly clayey or fine sandy, locally shaly. Generally light olive gray to pale yellowish brown; locally olive gray, greenish gray, or yellowish gray. Massive to thin bedded, locally very thin bedded or laminated. Soft, poorly indurated; moderately plastic where clayey. Biotitic. Locally contains pebble- to cobble-size angular clasts, mainly of Modelo(?) limestone, shale, and mudstone, as scattered fragments or in sedimentary breccia beds 1 in. to 3 ft (2.5 cm to 0.9 m) thick; some clasts bored by pholads. Locally contains very minor limestone beds about 6 in. (15 cm) thick and concretions as long as 2 ft (0.6 m). A few beds of volcanic ash, 0.2-2 in. (0.5-5 cm) thick, exposed in Potrero Canyon. Locally highly fossiliferous. Foraminifera referred to late Pliocene except for collections from south half of Potrero Canyon (Hoots, 1931) and immediately west of canyon mouth, which are referred to early Pliocene. Macrofossils generally fragmental; mollusks from locality near head of Potrero Canyon referred to late Pliocene (Hoots, 1931, locality 61A); fragments of carbonized plant remains, sponge spicules, echinoid spines; rare shark teeth and bracket fungus. Joints locally well developed, commonly nearly vertical and approximately normal to bedding; sheeting joints, moderately steep and subparallel to slope of ground surface; spacing commonly several feet (about 1 m), but locally as close as 1 in. (2.5 cm); rocks locally fractured. Numerous thin debris slides and debris avalanches, especially on steep antidip slopes; local slumps and thin, bedding-plane slides in upper Potrero Canyon

Sandstone--Mainly in Temescal Canyon; mostly silty, very fine to fine grained, grading to or interbedded with siltstone, and otherwise generally similar to the siltstone. Sandstone in exposure inside mouth of Temescal Canyon is fine to very coarse grained, arkosic, white to yellowish gray, massive, friable to loose, angular; locally contains scattered pebble-size angular clasts of Modelo(?) limestone, many bored by pholads; macrofossils referred to San Diego Formation of late or middle Pliocene age (Hoots, 1931), and foraminifera referred to late Pliocene

Sedimentary breccia--Chiefly in lower part of section, especially in basal 30-100 ft (9-30.5 m). Light olive gray to yellowish gray. Massive to very thick bedded; locally contains beds of siltstone or sandstone 2-5 in. (5-13 cm) thick. Generally poorly indurated. Rock fragments mainly pebble to cobble size but locally as much as 6 ft (1.8 m) long, angular, generally in random arrangement, probably mostly from Modelo Formation; largest clasts are sandstone; much limestone and some sandstone bored by pholads; locally abundant shell fragments. Matrix generally siltstone to fine-grained sandstone, locally so sparse that rock resembles intensely brecciated Modelo Formation. Breccia in exposure inside mouth of Temescal Canyon (Hoots, 1931, San Diego Formation) is highly distinctive; rock fragments commonly tabular, consist almost entirely of Modelo(?) limestone; largest blocks, in basal 5 ft (1.5 m) in south limb of syncline, are as much as 3 ft (0.9 m) long and 6 in. (15 cm) thick and subparallel to bedding; locally abundant fragments of large pectens and other mollusks; matrix and interbeds of angular, coarse- to very coarse grained sandstone; mostly hard, well cemented, and resistant to landsliding. Sedimentary breccia probably resulted from submarine slumping near margin of marine basin (Conrey, 1968)

Tm MODELO FORMATION (UPPER MIOCENE) (lower member of Modelo Formation of Hoots, 1931)--Chiefly interbedded shale, siltstone, mudstone, and sandstone; shale generally silty or clayey, commonly diatomaceous, locally siliceous or bituminous; a few thick sandstone units; minor limestone beds, lenses, and concretions. Marine. Maximum exposed thickness, in lower Temescal Canyon, about 800 ft (244 m). Rocks jointed normal to bedding; closely fractured to brecciated; commonly highly deformed or contorted; locally sheared, faulted. Surfaces of fractures and joints commonly coated with gypsum and grayish yellow to moderate yellow jarosite, as determined by X-ray diffraction by C. E. Corbato. Landslides very extensive and commonly deep seated, especially along coastal palisades, where they include largest prehistoric and historic slides in the area

Silty or clayey shale, siltstone, and mudstone--Olive gray, light olive gray, yellowish gray, dark yellowish brown, or pale yellowish brown; unweathered rock dark gray. Laminated to thin bedded; thickness of beds commonly about 1-2 in. (2.5-5 cm); siltstone and mudstone locally massive; shale fissile. Soft to moderately hard. Micaceous, locally bentonitic and plastic. A few very thin beds of volcanic ash. Locally contains foraminifera referred to Mohnian Stage of Kleinpell (1938); fish scales

Diatomaceous shale--Mainly in eastern half of area; white, soft, very thin bedded, 0.5-1 in. (1.3-2.5 cm); contains diatoms referred to Mohnian Stage of Kleinpell (1938)

Siliceous shale--Light brownish gray to white, hard, platy, thinly laminated to thin bedded

Bituminous shale and mudstone--Exposed mainly in local areas on slopes above Pacific Coast Highway between 0.25 and 0.5 mi (0.4 and 0.8 km) east of Sunset Boulevard and at mouth of Temescal Canyon. Dark gray to black, or dark yellowish brown to dusky yellowish brown; laminated to thin bedded; hard and dense where relatively unweathered. Contains asphaltic-base petroleum residues (Hoots, 1931, p. 110). Burned rock locally, chiefly in landslide areas adjacent to Pacific Coast Highway about 2,400 ft (730 m) east of Sunset Boulevard and at mouth of Temescal Canyon; brownish gray or moderate reddish orange; moderate-reddish-brown fracture coating; hard; ignition in some rocks possibly resulted from frictional heat caused by landslide movements (Johnson, 1942)

Sandstone--White to yellowish gray, generally poorly cemented or uncemented, soft, friable, arkosic, biotitic. Interbedded sandstone generally laminated to thin bedded, thickness commonly 2-3 in. (5-7.6 cm), locally cross-laminated; chiefly fine grained but ranges from very fine to very coarse grained. Thick sandstone units range in thickness from 15 to 60 ft (4.6 to 18.3 m), lenticular, massive to thick bedded; chiefly fine to medium grained, locally coarse grained; locally contain shale stringers 3 in. (7.6 cm) to 3 ft (0.9 m) thick. Thickest unit, well exposed inside mouth of Pulga Canyon, contains several beds and lenses of fine pebble conglomerate 4-8 ft (1.2-2.4 m) thick; conglomerate light bluish gray, poorly cemented, with sparse fine-grained sandstone matrix; pebbles average 0.5 in. (1.3 cm) in diameter, consist of dark- to medium-gray porphyries, light-gray quartzite and quartz, granite, and rare tuff

Limestone--Olive gray or light olive gray to light brown or yellowish gray; hard, dense, very fine grained, locally silty; beds and lenses generally laminated to thin bedded; concretions, mainly in western half of area, as much as 3 ft (0.9 m) thick and 10 ft (3.0 m) long

Ti INTRUSIVE IGNEOUS ROCKS (MIDDLE MIOCENE)--Dikes, sills, and irregular bodies of basalt and diabase; one small dike of trachyte(?); commonly emplaced along faults. Most bodies are less than 15 ft (4.6 m) thick, several exceed 100 ft (30.5 m), and the largest may be as much as 200 ft (61 m) thick. Relatively unaltered rocks grayish black to dark olive gray; altered and weathered rocks dark greenish gray, grayish olive, or moderate yellowish brown to dark yellowish orange. Medium to coarse grained, locally vesicular and amygdaloidal, locally contain calcite veins. Fractured to closely fractured, commonly brecciated, and locally sheared, especially along faults. Hard and dense where relatively unaltered; soft where deformed and highly weathered. Intrude rocks of all formations older than Modelo Formation; most of the larger and coarser grained bodies are along Malibu Bowl detachment fault or in Topanga Canyon Formation. Largest body in Pulga Canyon locally contains some undifferentiated, minor, fault-bounded inclusions of sedimentary rocks. Trachyte(?) dike is adjacent to Marquez Elementary School, located on grid line E 4,122,000; rock locally forms buried seacliff at back edge of lowest marine-terrace platform; as much as 20 ft (6.1 m) thick; very pale orange, fine grained, very hard, dense, fractured to brecciated

TOPANGA CANYON FORMATION OF YERKES AND CAMPBELL, 1979 (MIDDLE MIOCENE)--Marine, interbedded siltstone and sandstone, non-marine(?) tuff-bearing conglomerate, and marine sandstone. Maximum exposed thickness unknown, probably greater than 1,600 ft (488 m)

Tti Interbedded siltstone and sandstone--Landslides in present terrain numerous and extensive, including medium to large slumps

Siltstone--Varies from clayey to sandy siltstone and mudstone, commonly shaly; olive gray to light olive gray, dark yellowish brown to pale yellowish brown, or pale brown to light brownish gray; unweathered rock is medium dark gray; fractures commonly coated pale yellowish orange to dark yellowish orange or moderate yellow; thinly laminated to very thin bedded, locally massive; biotitic; fractures commonly coated with gypsum crystals and jarosite; soft to moderately hard, locally brittle; closely fractured to locally brecciated; locally contorted and sheared, especially in clayey beds and along and near faults; contains foraminifera referred to lower part of the Luisian or upper part of the Relizian Stages of Kleinpell (1938); locally abundant fish scales and carbonized plant fragments

Sandstone--Dominantly medium to coarse grained, locally fine grained or pebbly; light gray to yellowish gray; coarser grained beds massive to thin bedded, commonly 2-6 ft (0.6-1.8 m) thick, locally crossbedded, locally graded; feldspathic, subangular to angular grains; finer grained beds very thin bedded to thinly laminated, locally cross-laminated, commonly well sorted, biotitic; soft to moderately hard, locally hard where well cemented (calcareous); jointed and fractured to closely fractured and brecciated, especially near faults

Ttc Tuff-bearing conglomerate--Well exposed in Temescal Canyon north of Sunset Boulevard, especially in cuts immediately north of mapped area; chiefly pebble conglomerate, but ranges to cobble conglomerate; lower contact, with interbedded siltstone and sandstone unit, is locally faulted; very light gray, light bluish gray to bluish white, or yellowish gray, commonly stained dark yellowish orange to light brown or moderate reddish brown to dark reddish brown; thickness of beds commonly 6-8 ft (1.8-2.4 m), locally 1-2 ft (0.3-0.6 m); thin to thick interbeds of coarse- and fine-grained sandstone and siltstone and shale stringers; soft to moderately hard, locally well cemented; very soft and clayey where highly weathered. Pebbles locally comprise as much as 50 percent of rock; round to subangular, average dimension about 1 in. (2.5 cm); predominantly light- to medium-gray porphyries and quartzite; about 10-25 percent and locally as much as 50 percent of pebbles are more or less altered vitric(?) tuff, white, very light gray, or yellowish gray, commonly with dark-yellowish-orange to light-brown exterior or outer part, locally tuff pebbles completely altered to bentonite (clay); other rock types include granitics, metamorphics, and rare boulders of sandstone as large as 2 ft (0.6 m); matrix of conglomerate coarse- to very coarse grained sandstone, clayey where rock highly weathered. Jointed and locally fractured to closely fractured; numerous north-dipping shears in upper Temescal Canyon are approximately normal to bedding and spaced 2-3 ft (0.6-0.9 m) apart. Conglomerate probably at least partly correlative with Fernwood Member of Topanga Canyon Formation (Yerkes and Campbell, 1979); bedded tuff in lower part of that member was possible source of tuff pebbles

Tts Sandstone--Medium to very coarse grained, locally pebbly or conglomeratic; yellowish gray to grayish orange, or pale yellowish orange to moderate yellowish orange; massive to thick bedded, locally crossbedded, locally graded; arkosic, micaceous; subangular to angular grains; moderately to poorly cemented, moderately hard to hard and dense; locally closely jointed and fractured to brecciated, especially near faults; locally contains thin interbeds of laminated mudstone and well-sorted, fine- to medium-grained sandstone; contains molluscan fauna referred to middle or early Miocene; fish scales in fine-grained sandstone

Ts SESPE FORMATION (LOWER MIOCENE, OLIGOCENE, AND UPPER EOCENE)--Nonmarine, probably mostly fluvial, medium- to very coarse grained sandstone and pebbly sandstone. Maximum exposed thickness unknown, probably greater than 1,000 ft (305 m). Pale red to grayish red, light greenish gray to greenish gray, yellowish gray, or white; thick bedded to massive, locally crossbedded; poorly sorted arkose, consists of subangular to angular grains of quartz, feldspar, and rock fragments, commonly with biotite, in a sparse clayey silty matrix; generally moderately to poorly indurated, soft, and friable; locally moderately to highly jointed, with joint spacing commonly 1-4 ft (0.3-1.2 m), and closely fractured to brecciated, especially near faults; contains stringers or lenses as thick as 3 ft (0.9 m) of subrounded to rounded pebbles and cobbles, mainly of quartzite and volcanic porphyries, clasts polished and cracked locally. Landslides most numerous in Pulga Canyon, including medium-size slumps and thin debris slides and debris avalanches

Kt TUNA CANYON FORMATION OF YERKES AND CAMPBELL, 1979 (UPPER CRETACEOUS)--Marine sandstone, siltstone, and minor conglomerate. Maximum exposed thickness unknown, possibly about 700 ft (213 m). Base not exposed. Landslides in sandstone and siltstone, mainly along coastal palisades, include repeated thin failures in Pacific Coast Highway cuts in rocks adjacent to Zuma fault

Sandstone--Medium to very coarse grained, commonly contains small pebbles; light gray to yellowish gray, light olive gray, or light greenish gray; massive to thick bedded, more than 2 ft (0.6 m) thick; generally poorly sorted, but locally graded; angular to subangular grains; arkosic, micaceous, contains dark-gray lithic fragments; moderately well cemented (calcareous) and hard; commonly closely jointed and fractured to brecciated, especially near faults, such that bedding is obscured; contains interbeds as thick as 3 ft (0.9 m) of fine-grained sandstone and laminated siltstone and thin lenses of pebbles and cobbles

Siltstone--Locally moderately fissile, shaly; medium dark gray to medium gray, olive gray to light olive gray; laminated, beds commonly 0.2-0.5 in. (0.5-1.3 cm) thick; locally contains interbedded laminae 0.2-0.5 in. (0.5-1.3 cm) thick of fine-grained sandstone; commonly micaceous; moderately hard to hard; very closely fractured (0.5-2 in. (1.3-5 cm)) to brecciated, especially near faults

Conglomerate--Well exposed along beach at site of former Castle Rock, about 700 ft (210 m) east of western boundary of Los Angeles, and in cut at intersection of Castellammare Drive and Revello Drive, in palisades fronting Castellammare Mesa; chiefly cobble conglomerate, but ranges from pebble to boulder conglomerate; greenish gray or light gray; massive, but contains lenses as thick as 2 ft (0.6 m) of yellowish gray, medium- to coarse-grained arkosic sandstone; moderately well cemented and hard; pebbles, cobbles, and boulders (as much as 2 ft (0.6 m) in maxiumum dimension) are rounded and closely packed, and consist mainly of gray porphyries and quartzites in a matrix of medium- to coarse-grained arkosic sandstone; closely jointed near faults; resistant, stands steeply in natural and cut slopes; widely used as building stone in masonry walls of initial Castellammare development

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