GEOLOGIC SETTING AND ACTIVITY OF FAULTS IN THE SAN FERNANDO AREA, CALIFORNIA

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U.S. GEOLOGICAL SURVEY

With a section on

SEISMOLOGICAL ENVIRONMENT

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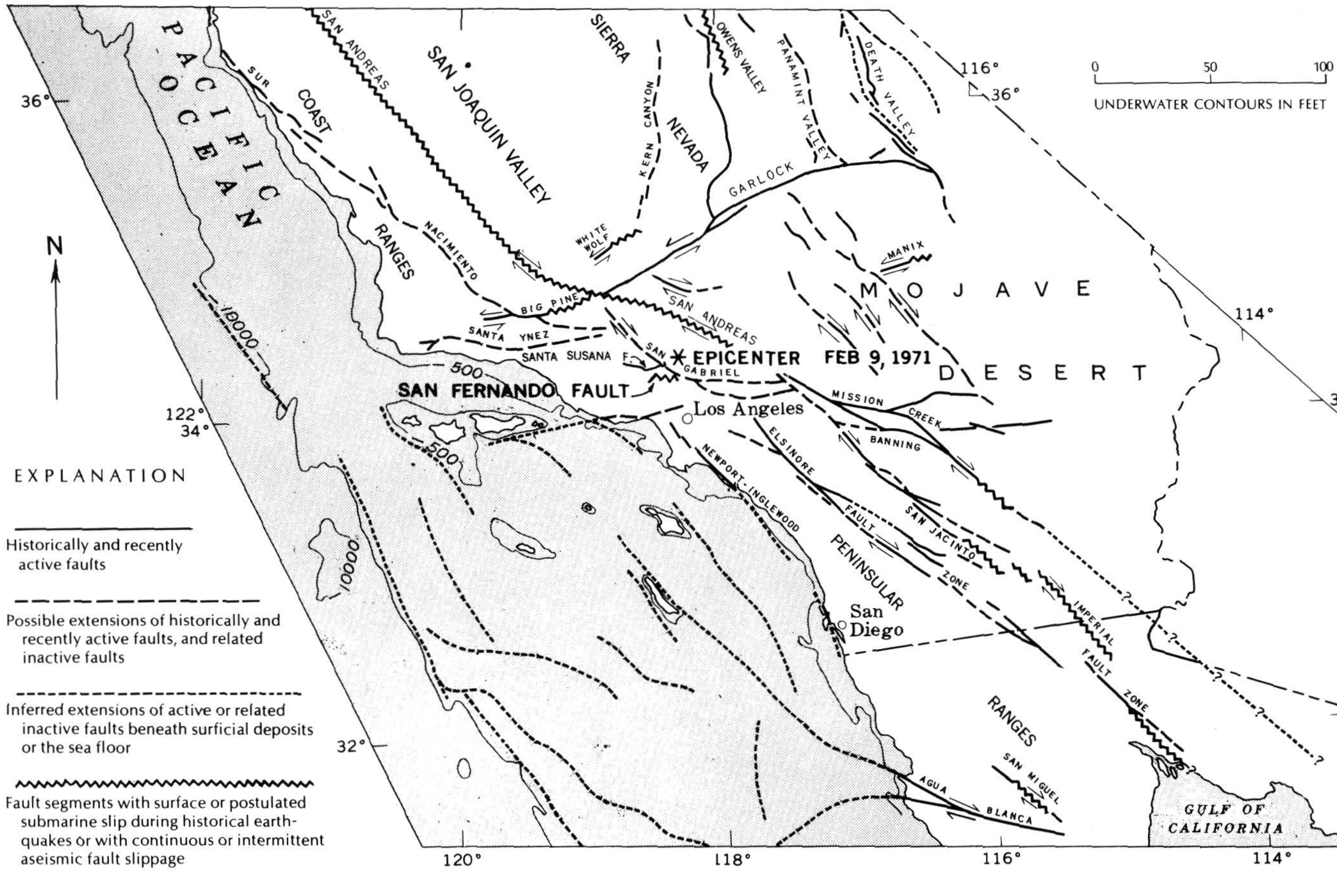
The faulting associated with the San Fernando earthquake of February 9, 1971, occurred in the Transverse Ranges structural province, a region noted for its strong and relatively young tectonic deformation. This is, however, the first example of historic surface faulting within the interior of that province.

The Transverse Ranges structural province trends eastward across southern California (across the center of fig. 1) and constitutes a region of late Cenozoic north-south shortening that lies athwart the northwesterly regional trend of the dominant San Andreas fault system. In the past 30 million years the San Andreas fault, master fault of the system, has undergone about 200 km of right-lateral strike slip in southern California (Crowell, 1962). During historic time, surface faulting in southern California has largely been confined to this and related right-lateral strike slip faults in the San Andreas system. Notable exceptions are the historic ruptures of the east- and northeast-trending White Wolf and possibly Big Pine faults, and now the 1971 San Fernando faulting, all of which have displayed at least some component of left-lateral strike slip (fig. 1).

The Transverse Ranges province consists of numerous east-trending mountain ranges and valleys typified by late Cenozoic structural deformation and strike slip, reverse, and thrust faults of similar trend (Bailey and Jahns, 1954; Jennings and Strand, 1969). The most spectacular development of the structure of this province is in the Ventura Basin, where an immense Cenozoic syncline that includes a thickness of 1,500 m of marine Pleistocene sediments has both limbs overturned and overridden by thrusts (Bailey and Jahns, 1954, p. 92–96). Very young deformation in the Transverse Ranges is not restricted to the Ventura Basin, however, and late Quaternary faulting is known to occur from near Point Conception eastward to the San Andreas fault.

The February 9, 1971, faulting broke the ground surface near the north margin of the San Fernando Valley opposite the "great bend" in the San Andreas fault south of the San Joaquin Valley (fig. 1). The geometry of the crustal blocks in this region is such that the Transverse Ranges structural block southwest of the San Andreas fault is constrained and compressed against the bend as the block moves northwestward along the fault. During the past 5 to 10 million years' this compressive deformation has thrust the mountain blocks up over adjacent valleys to the south. The movement has occurred along north-dipping reverse or thrust-fault systems such as the Sierra Madre and Santa Susana, which trend west and northwest along the southern margins of the mountain blocks. The most impressive product of this uplift is the bold southern front of the San Gabriel Mountains, which stands some 1,500 m above the San Fernando and Los Angeles areas to the south. Additional horizontal shortening and uplift of one of the blocks occurred along the ruptures that accompanied the San Fernando earthquake.

Although segments of the surface traces of many of the Transverse Ranges faults have been mapped and interpreted in the context of regional structural history, the abundant but relatively unobtrusive evi-



MAJOR HISTORICALLY AND RECENTLY ACTIVE FAULTS OF THE SOUTHERN CALIFORNIA REGION

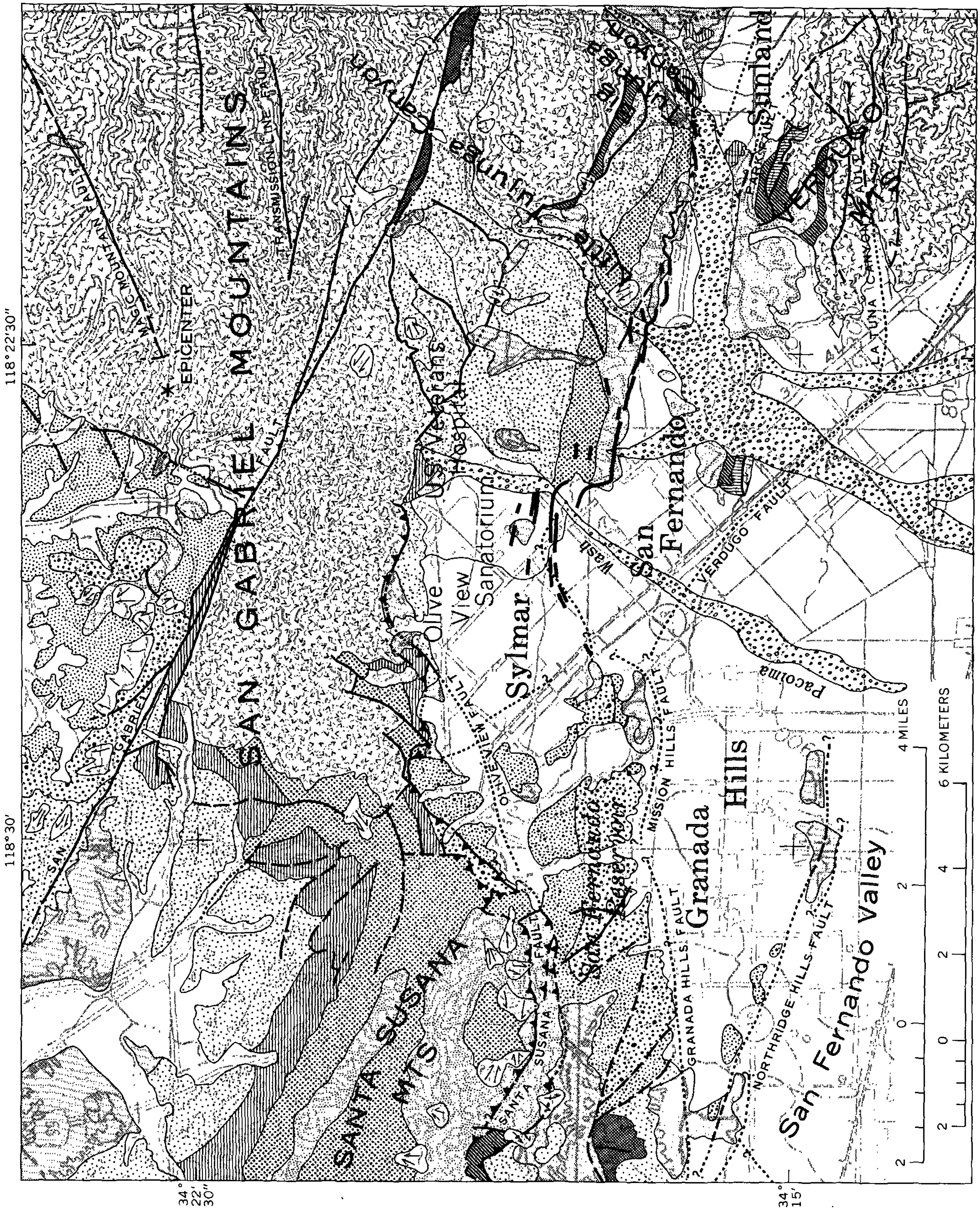
FIGURE 1.—Major historically and recently active faults of the southern California region.

dence of their recent geologic activity has not been widely recognized or appreciated. Study of the 1971 San Fernando faulting should reinforce our confidence in using this geologic data to evaluate the future behavior of faults.

SEISMOLOGICAL ENVIRONMENT

In the years prior to 1971, the area of the San Fernando earthquake had been one of low to moderate seismic activity—not unlike that of many other parts of California. Indeed, the 1934–63 strain-release maps (Allen and others, 1965) indicated that the northern San Fernando Valley was seismically less active than most other parts of the greater Los Angeles area. Certainly there was nothing in the very recent seismic history to suggest that this area, more than any other area, was particularly likely to experience a magnitude 6.6 earthquake. It must be kept in mind, however, that an earthquake of at least this magnitude occurs somewhere in the southern California region on the average of about once every 4 years (Allen and others, 1965), and in this sense the earthquake itself was no great surprise. An earthquake of about this same magnitude occurred in 1968 in the Borrego Mountain area 220 km southeast of Los Angeles, but damage was small because—unlike the 1971 event—it occurred in a remote location.

Between 1934 and 1971, which is the interval during which epicentral locations of southern California earthquakes have been listed by the California Institute of Technology, only about 10 earthquakes of magnitude 3.0 and greater occurred within the area that corresponds to the epicentral region of the San Fernando earthquake. None of these was large, although a few were felt locally, such as the magnitude 4.0 shock of August 30, 1964, that was centered under southern San Fernando. Previous to 1934, two shocks are of special interest: the magnitude 5.2 earthquake of August 30, 1930, was probably much closer to San Fernando than the original assignment of the epicenter location in Santa Monica Bay suggests, and it is particularly noteworthy because it caused some minor damage to


SAN GABRIEL MOUNTAINS
EPICENTER
MAGIC MOUNTAIN FAULT
TRANSMISSION LINE FAULT
SAN GABRIEL FAULT
SANTA SUSANA MTS
SANTA SUSANA FAULT
U.S. Veterans Hospital
Olive View Sanatorium
Sylmar
San Fernando
Pacoima Wash
Sunland
Little Tujunga Canyon
OLIVE VIEW FAULT
MISSION HILLS FAULT
GRANADA HILLS FAULT
NORTHRIDGE HILLS FAULT
VERDUGO FAULT
LA TUNA CANYON FAULT
Verdugo Mts
San Fernando Reservoir
Granada Hills
San Fernando Valley
118°30′
118°22′30″
34°22′30″
34°15′
4 MILES
6 KILOMETERS

EXPLANATION

QUATERNARY

Upper Pleistocene and Holocene

Qc | Qa

Alluvial deposits

Qc, deposits in active stream channels; unconsolidated gravel, sand, silt, and clay

Qa, unconsolidated gravel, sand, silt, and clay; commonly overlain by soil

Qt

Stream terrace deposits

Slightly consolidated gravel, sand, silt and clay

UNCONFORMITY

QUATERNARY AND TERTIARY

Pliocene and lower Pleistocene

QTs | Qs | Tsr

Saugus Formation

QTs, north and east part of map: slightly to moderately consolidated coarse-grained sandstone, conglomerate, and mudstone

Qs, southwest part of map: slightly consolidated conglomerate and coarse-grained sandstone

Tsr, Sunshine Ranch Member, of Pliocene age, in west part of map; siltstone with interbedded sandstone and conglomerate; locally interfingers with upper part of Pico Formation

TERTIARY

Pliocene

Tp

Pico Formation

Marine; soft siltstone, mudstone, and fine-grained sandstone with interbedded coarse-grained sandstone and resistant pebble conglomerate; upper part interfingers with Saugus Formation and lower part with Towsley Formation

Upper Miocene and lower Pliocene

Tto

Towsley Formation

Soft siltstone and mudstone with interbedded moderately indurated, sandstone and conglomerate; basal conglomerate in west center of map is well indurated and contains boulders and blocks of locally-derived basement rocks; upper part interfingers with Pico Formation in northwest part of map

Upper Miocene

Tm

Modelo Formation

Siltstone, soft mudstone, and siliceous shale, minor interbedded sandstone

Upper Miocene

UNCONFORMITY

Tmc

Mint Canyon Formation

Present only north of San Gabriel fault; continental, soft, poorly to well-consolidated sediments; upper part conglomerate and coarse-grained sandstone, mudstone, and tuff; lower part poorly sorted conglomerate with interbedded coarse-grained sandstone, siltstone, and mudstone; coarse basal conglomerate consists of angular fragments of underlying basement rocks

UNCONFORMITY

Middle Miocene

Tt

Topanga Formation

Sandstone and cobble-boulder conglomerate, poorly sorted, massive, commonly well indurated

UNCONFORMITY

Tv

Volcanic rocks

Basaltic flows, tuff breccias, and flow breccias, hard and dense to soft, vesicular, and amygdaloidal

CRETACEOUS AND TERTIARY

Upper Cretaceous and Paleocene

Tk

Undifferentiated lower Tertiary and Upper Cretaceous rocks

Chiefly sandstone, siltstone, and pebble conglomerate commonly referred to Martinez and Chico Formations; commonly well indurated and resistant. Crops out in Simi Hills in west part of map and slivers along San Gabriel fault

UNCONFORMITY

PRECAMBRIAN TO MESOZOIC

bc

Basement complex

Igneous and meta-igneous rocks, commonly dense and crystalline. North of San Gabriel fault, chiefly gabbro, anorthosite, and granodiorite; south of San Gabriel fault, chiefly granodiorite and diorite gneiss

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Contact

High-angle fault — Thrust fault

Faults

Dashed where approximately located or inferred; dotted where concealed; queried where doubtful

Tectonic ruptures associated with earthquake of February 9, 1971

Landslide

Only selected large landslides shown; arrows indicate general direction of movement

Geology compiled by R.F. Yerkes and C.M. Wentworth, 1971

FIGURE 2.—Generalized geologic map of the San Fernando area, Los Angeles County, Calif. (Van Norman Lakes are called San Fernando Lakes on this map base.)

both Chatsworth Dam and Lower Van Norman Dam. Of much greater significance in terms of its similarity to the recent San Fernando earthquake is the so-called Pico Canyon earthquake of 1893; Pico Canyon is only 5 km west of Newhall, which was very heavily shaken by both the 1893 and the 1971 events. Townley and Allen's (1939) description suggests a magnitude of about 6, inasmuch as the shock was described as heavy in Mojave, Ventura, and San Bernardino, and was felt in San Diego. Numerous landslides and fissures were reported in the Newhall area, and aftershocks continued for some time. The contemporary report that "landslides from every peak in sight came tumbling down with huge boulders; the mountains appeared as if myriads of volcanoes had burst forth" might well have applied to the 1971 event in addition. It seems probable that the 1893 earthquake originated slightly west of the 1971 epicenter, but it certainly indicates that moderate earthquakes of this size are no stranger to the region.

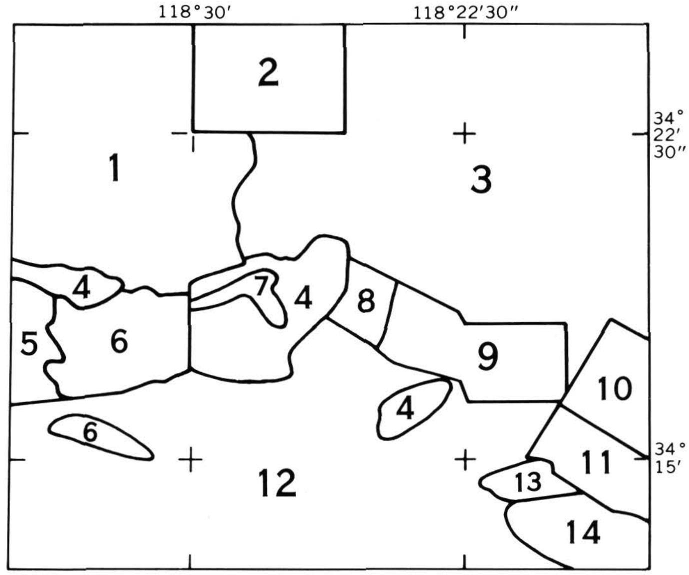

FIGURE 3.—Index to geologic map sources. 1, Winterer and Durham (1962); 2, R. B. Saul, 1970, California Division of Mines and Geology, work in progress; 3, Oakeshott (1958); 4, T. W. Dibblee, Jr., unpublished data; 5, Bishop (1950); 6, R. B. Saul, 1968, California Division of Mines and Geology, work in progress; 7, Merifield (1958); 8, Metropolitan Water District, 1968, unpublished geologic map L–1078; 9, Metropolitan Water District, 1968, unpublished geologic map B–20262; 10, Metropolitan Water District, 1968, unpublished geologic map L–1084; 11, Metropolitan Water District, 1968, unpublished geologic map L–1079; 12, R. F. Yerkes and C. W. Wentworth, generalized from California State Water Rights Board (1962), Corbato (1963), and Holmes (1919); 13, Johnston (1938); 14, C. W. Jennings and R. B. Saul, 1969, California Division of Mines and Geology, unpublished data. The unpublished maps of the Metropolitan Water District of Southern California are on file with the California Division of Mines and Geology.

STRATIGRAPHY

The San Fernando Valley is in the southeastern part of the Ventura Basin area, and its sedimentary rocks are similar to those described in the northwest by Winterer and Durham (1962). Oakeshott (1958) provides a description of the units at the north side of the valley, in the area of the main shock, aftershocks, and surface faulting that accompanied the earthquake.

In the central Transverse Ranges the crystalline basement rocks are overlain with great unconformity by Cretaceous and younger sedimentary rocks many thousands of meters thick. The San Fernando Valley itself (figs. 2, 3) is an asymmetric synclinorium developed chiefly in Miocene and younger rocks that have been deformed by late Cenozoic folding and faulting, especially at the northern margin by thrusting along the Santa Susana fault and its eastward equivalents. Based on a gravity-density model, Corbato (1963) estimates that approximately 4,500 m of sedimentary rocks are present in the central part of the valley.

None of the late Cenozoic sedimentary rocks are particularly hard, and the Saugus Formation especially is only partially indurated and difficult to distinguish from alluvium in drill holes.

Precambrian to Cretaceous crystalline rocks of the basement complex are exposed in the San Gabriel Mountains in the northeast part of the map area and in the Verdugo Mountains in the southeast corner. These dense metamorphic and igneous rocks constitute the terrane on which the sedimentary sequence was deposited. Cretaceous and lower Tertiary sedimentary strata are only exposed locally along the Santa Susana and San Gabriel faults, although to the west and south of figure 2 they crop out extensively. Within the map area south of the San Gabriel fault, the oldest sedimentary rocks overlying the basement are the middle Miocene Topanga Formation, which includes about 300 m of conglomerate, marine sandstone, and volcanic rocks.

As much as 1,500 m of marine upper Miocene Modelo Formation is exposed along the foothills of the San Gabriel and Verdugo Mountains, in the Mission Hills, and in the Santa Susana Mountains. The Modelo is overlain by, and locally interfingers with, the Towsley Formation of late Miocene–early Pliocene age. The Towsley ranges in thickness from zero where it is overlapped by the Pico Formation just south of the San Gabriel fault zone to about 750 m in the east and west central parts of the map area.

The Pico grades upward and laterally into the late Pliocene–early Pleistocene Saugus Formation, a shallow marine to brackish-water unit that rims the north side of the San Fernando Valley. The Saugus Formation thickens westward from essentially zero at Big Tujunga Canyon to about 1,950 m at Lopez Canyon east of Pacoima Wash. An exploratory well drilled north of the Olive View fault and about 1½ km west of Olive View Sanitorium penetrated a minimum stratigraphic thickness of 1,200 m of Saugus Formation, and the California State Water Rights Board report (1962, v. I., p. 52) states that the formation exceeds 1,800 m in thickness in the syncline near Sylmar.

The "middle Pleistocene" Pacoima Formation of Oakeshott (1958) has been combined with the Saugus Formation on the map (fig. 2). This deformed fanglomerate-breccia unit is exposed north of Sylmar, where it unconformably overlies the Saugus and is unconformably truncated by stream-terrace and alluvial deposits.

Uplifted erosional remnants of stream-terrace gravel and sand are widely distributed in the San Fernando area, but only a few are shown on the generalized map. No direct evidence for the age of these deposits is available, although a late Pleistocene age is inferred on the basis of their stratigraphic position, lack of deformation, and unconformable relations with the underlying Saugus Formation. Oakeshott (1958) was able to distinguish five stages of terrace formation along Pacoima Wash and two in the Lopez-Kagel Canyon area 6½ km northeast of San Fernando. Some of the late Quaternary history of the mountain blocks can be obtained from such geomorphic features.

UNCONSOLIDATED SEDIMENTS

The relatively flat surface of San Fernando Valley is underlain by unconsolidated sand, gravel, and finer sediment ranging in thickness from zero at the valley edges to greater than 200 m in the east-central part of the valley near the south margin of figure 2. In the Sylmar area, alluvium is perhaps 6 m thick, except along Pacoima Wash (California State Water Rights Board, 1962).

Sediment west of Van Norman Lakes and along the southern part of the valley has been supplied by streams draining areas of sedimentary rocks, with the result that alluvium in these areas consists predominantly of clay. In contrast, larger streams at the north margin of the valley east of the Lakes drain crystalline rocks of high relief and have produced deposits of coarser materials with abundant gravel.

Additional information concerning the alluvial deposits in San Fernando Valley is available from California State Water Rights Board (1962): plate 6 (v. I) of that report shows contours on the base of the valley fill, or water-bearing sediments, and plate 30 shows ground-water contours as of 1958. The agricultural soil map of Holmes (1919) is also useful.

EVIDENCE FOR LATE QUATERNARY FAULTING

A number of faults in the San Fernando area follow prominent topographic breaks at the boundaries between the alluvial valleys and the adjacent hills and mountains. This relationship, combined with stratigraphic evidence, indicates that these faults were active in late Quaternary time and that they followed the general tectonic patterns established in late Tertiary time. The immediately available evidence concerning the late Quaternary history of these faults is cited in a following section on structure. This evidence is critical to the evaluation of possible future movements on these faults.

Unfortunately, the geologic record of the late Quaternary, which is the past few hundred thousand years of earth history, is incomplete and difficult to interpret. Few of the alluvial deposits that constitute the sole stratigraphic record of late Quaternary time in the San Fernando area are even approximately dated at present, and their stratigraphic relations are poorly known and difficult to decipher. Topographic features produced by faulting of the ground surface constitute the only other direct record of late Quaternary faulting but are often difficult to interpret. Most can form in more than one way, and their durability in various geologic and climatic situations, although relatively short in geologic time, is poorly understood.

Where late Quaternary faults are buried or obscured by alluvium, subsurface information is needed to evaluate their history. Particularly useful are data on the effects of such faults on the movement of ground water. These effects are essentially of two kinds: (1) clayey gouge seams can form along such faults, even in alluvium, and partly or completely block passage of water across them, or (2) faulting can also produce a step in the bedrock surface beneath the alluvium, which will impose a barrier to ground-water movements if the general direction of such movement is toward the upthrown block or the development of a ground-water cascade if the direction is opposite. Although such steps could be formed by erosion or faulting prior to burial by alluvium, well-defined steps of significant length are more likely to form by postalluvium faulting. Erosion of a channel through a fault-gouge barrier could also result in the formation of a ground-water cascade. All hydrologic evidence cited in the following pages comes from a valuable study of ground water in the San Fernando Valley by the California State Water Rights Board (1962).

The age of the San Fernando Valley alluvium that is involved in faulting is unknown in detail. These deposits, however, are sufficiently young that it is prudent to consider any fault that has an observable effect on the movement of shallow ground water in the San Fernando Valley to have been active in late Quaternary time.

STRUCTURE

The structure of the San Fernando Valley area is dominated by two intersecting regional fault systems: the northwest-trending San Andreas system of right-lateral strike-slip faults, which includes the San Gabriel fault, and the east-trending system of north-dipping reverse and thrust faults along which much of the uplift of individual ranges has been accomplished. Among the latter are the Santa Susana–Sierra Madre trend and faults within the San Fernando Valley.

Although the older geologic history of the San Fernando Valley area is dominated by the San Gabriel fault zone, the present-day structure of the northern margin of the valley has been greatly modified by overthrusting on the north-dipping reverse faults. Uplift along these faults has created the large residual gravity gradients mapped by Corbato (1963, map 3) and are shown in figure 4 of this report. All of the foregoing fault trends exhibit evidence of late Quaternary displacement.

SAN GABRIEL FAULT

The San Gabriel fault resembles the San Andreas in many ways. It consists of a zone of imbricate steeply north-dipping faults and is characterized by deflected drainage courses, strike valleys, notched ridges, and largely dissimilar geology on opposite sides (Oakeshott, 1958).

The work of Crowell (1950, 1952, and 1962) indicates that the fault absorbed about 30 km of right strike slip and locally as much as 4.3 km of dip slip during Pliocene time. Oakeshott (1958) cites evidence for 2.5 to 6.5 km of right slip along the fault zone in late Pliocene-Quaternary time and shows the "middle Pleistocene" Pacoima Formation to be

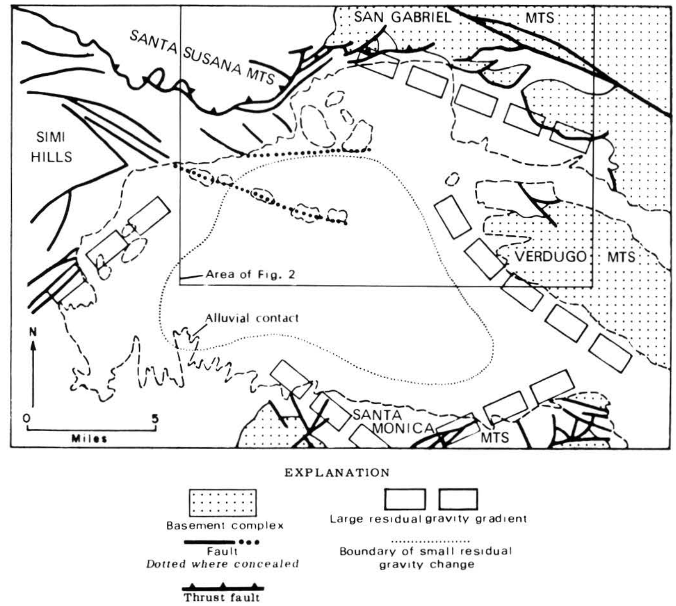

FIGURE 4.—Structure map of the San Fernando Valley area modified from Corbato (1963, fig. 7).

offset in an area northwest of figure 2. Late Quaternary stream-terrace deposits appear to be unaffected by the San Gabriel fault, although none lies completely across the fault zone. The displacement of Pleistocene deposits and deflected drainages along the fault warrant attention to the possibility of renewed movement along this fault.

SANTA SUSANA FAULT

The Santa Susana is a long east-trending fault zone characterized by low-angle thrusting, a sinuous trace, and a gentle north dip. Estimates of horizontal shortening and vertical separation across it range upward from 2.4 km (Hazzard, 1944; Oakeshott, 1958).

In the Santa Susana Mountains at the west side of figure 2, the fault consists of two parallel strands about 0.5 km apart. The northern strand is entirely within Tertiary rocks, whereas the southern strand forms a thrust contact on which Miocene strata on the north overrode Quaternary terrace deposits on the south (Bishop, 1950, p. 93–94).

More recent work east of Bishop's area by R. B. Saul (fig. 3) suggests that landsliding might account for some of Bishop's observations. In any case, late Quaternary faulting has occurred on the south face of the Santa Susana Mountains because the west-trending Devonshire fault of Bishop (1950) moved both during and after accumulation of the terrace deposits.

The two western traces of the Santa Susana fault merge northwest of Sylmar and continue eastward to form a series of northeast-trending faults along which rocks of the basement complex have been thrust over sedimentary units as young as the Pliocene-Pleistocene Saugus Formation and the "middle Pleistocene" Pacoima Formation. The terrace deposits, however, do not appear to be affected (Oakeshott, 1958).

GRANADA HILLS-MISSION HILLS TREND

This trend of faults is a largely buried system of east-trending range-front faults along which the southeastern Santa Susana Mountains and the Mission Hills have been uplifted.

Existence of the Granada Hills fault is based on the straight south margin of the adjacent mountains, which suggests that the inferred fault had late Quaternary displacement.

The existence of the Mission Hills fault was postulated by Oakeshott (1958, p. 94, pls. 1 and 2) on the basis of topography, a geologic section in a test well, and analogy with faults in the mountains north of Sylmar.

The San Fernando fault zone, as used in this report, is defined as the zone of tectonic surface rupture of the 1971 San Fernando earthquake. It consists of the Mission Wells, Sylmar, and Tujunga fault segments and other scattered minor faults.

The Mission Wells and Sylmar segments extend generally eastward from the Granada Hills–Mission Hills trend and closely coincide with the surface trace of a known impediment to southward movement of ground water. This ground-water anomaly is shown in figure 2 as a northeast- and east-trending queried fault crossing the neck in the alluvial surface south of Sylmar. It is marked by a 15-m difference in ground-water levels, higher on the north, with ground-water cascades flowing southward through alluviated erosional notches at its east and west ends. Ground water north of the anomaly occurs in confined aquifers in steeply north-dipping Saugus strata that are truncated and covered by a thin veneer of alluvium; south of the anomaly ground water is unconfined and occurs in coarse alluvial gravels.

The California State Water Rights Board report (1962) relates the Sylmar ground-water anomaly to impermeable strata in the north-dipping Towsley (= Repetto in their report) and Saugus Formations. The trace of the ground-water anomaly, however, is at an oblique angle to the strike of beds in the Saugus-Towsley; this angle suggests that a structural discontinuity such as a fault could more reasonably explain it.

The ground-water anomaly is here concluded to be the product of a reverse fault that has raised northward-dipping Saugus Formation in the Little Tujunga syncline against alluvial gravels on the south, with progressive erosional planation maintaining only a thin veneer of alluvium over the Saugus strata in the rising northern fault block. Gouge along such a fault could account for the impediment to ground-water flow, and vertical displacement along it could account for the different thicknesses of alluvium north and south of the ground-water anomaly. Together, these factors could produce the resultant differences in ground-water habit across the anomaly. M. M. Clark has observed a rather subtle south-facing topographic escarpment, on aerial photographs taken in 1952, that extends nearly continuously along the approximate trace of the ground-water anomaly and which is thought to be a result of the latest movements on the fault postulated to have caused the anomaly. (See the section on "Surface faulting" by the U.S. Geological Survey staff in this report.)

The zone of faulting that approximately follows the base of the western San Gabriel Mountains eastward from San Fernando along the north side of Tujunga Valley is called the Tujunga segment of the San Fernando fault zone in this report.[1] Kamb and others (this report) note that the Tujunga fault segment as thus defined differs from that of Hill (1930) for a postulated fault in the central alluviated part of the Tujunga Valley and suggest that the older definition by Hill be dropped.

A number of unnamed fault traces had been mapped along the Tujunga fault segment prior to the new 1971 surface ruptures. One of these faults just west of Oliver Canyon dips northward 60° and thrusts Miocene strata southward over upper Pleistocene terrace deposits (Oakeshott, 1958). At the mouth of Little Tujunga Canyon a ground-water cascade of perhaps 30 m, which suggests late Quaternary displacement, is nearly coincident with the site of a 1971 rupture.

VERDUGO FAULT

The Verdugo fault lies at the southwest foot of the Verdugo Mountains (fig. 2, and Jennings and Strand, 1969) and is probably responsible for the 1,000 m of relief between the mountain crest and the base of the alluvial fill to the south. This conclu-

[1] R. J. Proctor of the Los Angeles Metropolitan Water District reports that tectonic ruptures associated with the February 9 earthquake roughly follow a north-dipping thrust fault which he had previously mapped and which he has named Lakeview fault. The scarps in Schwartz and Oliver Canyons coincide with this fault, which would be synonomous with the Tujunga fault segment as used in this report.

sion is supported by the steep residual gravity gradient found by Corbato (1963, map 3; fig. 4 of this paper) to extend along this trend from Burbank to west of the Pacoima Hills. The steep southwest face of the mountains, the presence of faulted stream-terrace deposits north of Burbank (California State Water Rights Board report, v.II., p. A-23) and a ground-water cascade at the mouth of Verdugo Wash led Wentworth, Ziony, and Buchanan (1970, pl. 1) to conclude that the southeastern end of the Verdugo fault had undergone late Quaternary displacement. Between the Verdugo Mountains and the Pacoima Hills, clayey gouge seams have been formed by fault movement in the alluvial fill along the trend of the Verdugo fault, and the resultant ground-water impediment has been used as the trace for the fault in figure 2. Topographic and gravity evidence for the Verdugo fault are lacking between the Pacoima Hills and the Mission Hills. Limited information indicates, however, that ground-water levels northeast of a reasonable extension of the fault are more than 60 m higher than southwest of it and therefore that a major ground-water cascade occurs there.

NORTHRIDGE HILLS FAULT

The Northridge Hills fault trends southeastward from the southeastern Santa Susana Mountains across the valley floor along the south side of the Northridge Hills. The eastward extent of the fault is unknown, although its easternmost topographic expression appears almost halfway across the valley. The fault forms a distinct though discontinuous topographic feature along its mapped length in the valley and is inferred to displace older late Quaternary deposits (Qt in fig. 2) and to raise Saugus Formation into low hills along its central part. Late Quaternary displacement on the Northridge Hills fault may be considerable, for cross sections in the California State Water Rights Board report (1962) show the base of the alluvium to be faulted downward by as much as about 300 m on its southwest side.

CHATSWORTH FAULT

Corbato (1963, map 3; and fig. 4 of this paper) shows a steep gravity gradient extending northeastward across the west end of the San Fernando Valley, which coincides in position with the northeastward trend of faults that juxtapose upper Miocene Modelo Formation against Cretaceous rocks at and southwest of Chatsworth Reservoir (Jennings and Strand, 1969). The bedrock surface beneath the valley alluvium has been dropped down on the southeast side to produce a 25-m ground-water cascade within the alluvium. Additional evidence of late Quaternary displacement may exist in the form of faulted terrace deposits at the northeast end of Chatsworth Reservoir (Conrad, 1949).

ACTIVITY OF FAULTS

A fault is active if, because of its present tectonic setting, it can undergo movement from time to time in the immediate geologic future. This active state exists independently of the geologists' ability to recognize it. A number of characteristics have been used to identify active faults, such as historic seismicity or surface faulting, crustal strain, geologically recent displacement inferred from topography or stratigraphy, or physical connection with a known active fault. Not enough is known, however, of the behavior of faults to assure successful discrimination of all active faults by such characteristics.

Of the faults discussed above, only the San Andreas fault and the San Fernando fault zone are known to be active on the basis of earthquakes or historic surface faulting, and the San Fernando fault was discovered to be active only when it ruptured the ground surface on February 9, 1971. It is evident, however, that more faults in the San Fernando Valley area may be active today than are now recognized. Study of the topographic and stratigraphic records of the past histories of these faults, in concert with studies of earthquake activity and crustal strain, can lead to important insights into their possible activity.

Agreement does not currently exist on the length of fault history that should be used in evaluating the future behavior of faults. The commonly used cutoff of 10,000 years (beginning of Holocene time) seems too short in the light of surface faulting in 1952 along the White Wolf fault, which was not previously recognized as an active fault and exhibited no obvious evidence of late Quaternary activity other than defining a steep mountain front (Oakeshott, 1955; Dibblee, 1955). The White Wolf experience, combined with the likelihood that only some fraction of the past movements of a fault will actually be evident in the geologic record, led Wentworth, Ziony, and Buchanan (1970) to suggest (p. 13 and 15) that faults with evidence of Holocene displacement probably should be considered active for most purposes and that it may be desirable to consider faults with late Quaternary displacement as active, at least for land uses requiring relatively high safety factors.

The addition of the 1971 San Fernando event to the experience of the 1952 White Wolf event strengthens the conclusion that, in the absence of proof to the contrary, demonstrated late Quaternary movement should be considered evidence that a fault is probably active. Thus, we would tentatively conclude that all the faults described above that have had late Quaternary displacement are probably active. Further work will be required to test and corroborate the conclusions of late Quaternary displacement and to evaluate the movement rates and characteristics of these faults.

In view of the foregoing, the location of the 1971 San Fernando faulting should not have come as a complete surprise because preearthquake information was sufficient to suggest the existence of faults having late Quaternary displacement along or near the positions of the main traces of the February 1971 ruptures. It would not, however, have been possible to predict, on the basis of present knowledge, that the next surface faulting in Southern California, or even in the San Fernando area, would occur either where or when it did.

CONCLUSIONS

The San Fernando Valley area is underlain by a depositional basin that dates from Miocene time and is bordered by pre-Cenozoic crystalline basement rocks. The basement rocks are unconformably overlain by an Upper Cretaceous-Cenozoic sequence of clastic sedimentary rocks that has been deformed by north-south compression, producing east-west folds and causing thrust faulting during late Cenozoic time along the southern margins of the mountain ranges. The thrust faulting—and the February 1971 rupturing—are continuations of long-established tectonic processes that have resulted in uplift of the mountainous parts of the Transverse Ranges.

The faulting of February 9, 1971, near San Fernando occurred on faults not previously recognized as active, although sufficient evidence was available to suggest that there had been movements along their main traces in late Quaternary time. The topographic and stratigraphic record of late Quaternary fault movements, including their effect on groundwater flow, must be given greater scrutiny, because late Quaternary displacement appears to be a sufficient criterion for probable activity of a fault in this area. Numerous faults in the San Fernando Valley area exhibit some evidence of late Quaternary displacement and in the light of the San Fernando faulting should be considered probably active until investigated in detail with both geologic and geophysical techniques.

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