AN ABSTRACT OF THE THESIS OF

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Abstract approved: Signature redacted for privacy.

Dr. Robert S. Yeats

Surface and subsurface data are combined to determine the structure of the western half of the Simi fault system in the Las Posas and Camarillo Hills area. Cretaceous (?) to Eocene sedimentary rocks, present only in the subsurface, are overlain by late Eocene to early Miocene nonmarine stata (Sespe Formation) and middle Miocene volcanics and sedimentary rocks (Conejo Volcanics and Topanga Formation undifferentiated), in part exposed in the Las Posas Hills. Late Miocene marine beds (Modelo Formation) are present in the subsurface in the Camarillo Hills and may crop out in the eastern Santa Rosa Valley. These rocks are overlain unconformably by marine Pliocene-Pleistocene beds (Saugus Formation), older and younger Quaternary alluvium, and alluvial fan deposits. Normal faults cause the Sespe to subside towards a thick volcanic pile, built up in the Conejo Hills in the middle Miocene. Volcanic rocks butt-ressed against and later overtopped these Sespe subsidence structures.

Reverse faults in the Oxnard plain and the left-lateral Somis fault are truncated by the unconformity at the base of the Saugus. Miocene and older strata were broadly folded in the Las Posas anticline and Santa Rosa syncline prior to deposition of the Saugus Formation and displacement on the Simi fault zone. The Bailey fault, a northwest-trending range-front fault, shows reverse separation, commonly follows Sespe subsidence structures and north-dipping normal faults which cut the Sespe. The Camarillo Hills anticline, Springville dome and post-Saugus Las Posas anticline appear to be pressure ridges adjacent to the Simi fault system on the north. Older alluvium deposits are uplifted and warped. The Camarillo fault cut and warped older alluvium.

Surface and Subsurface Geology of the Camarillo and Las Posas Hills area, Ventura County, California

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INTRODUCTION

Regional Setting

The Las Posas and Camarillo Hills are located in southern Ventura County, California, at the east end of the Oxnard plain, twenty miles east of the city of Ventura and fifty miles northwest of Los Angeles. The study area extends from the city of Moorpark west to the city of Camarillo and is bordered by State Highway 118, Beardsley Avenue, Highway 101, Pleasant Valley, and Santa Rosa Valley (index map, Figure 1). The area is located in the south-central Ventura basin, part of the western Transverse Ranges.

The western Transverse Ranges are a west-trending geomorphic province in southern California bounded on the north by the Santa Ynez fault, on the east by the San Bernardino Mountains, on the south by the Anacapa-Malibu Coast fault and on the west by the Pacific Ocean (Figure 2). Near the western boundary, the west trends of this region merge with northwest structural trends of the Santa Maria Basin (Willingham, 1979).

The Ventura basin, including its offshore continuation in the Santa Barbara Channel, is the dominant structural element of the western Transverse Ranges. The basin is filled with a Cenozoic

Figure 1. Sketch map of western half of Simi fault system. Faults, shown in heavy lines, from Jennings (1977). Uplands include hilly areas underlain by Miocene to Quaternary formations, including older alluvium.

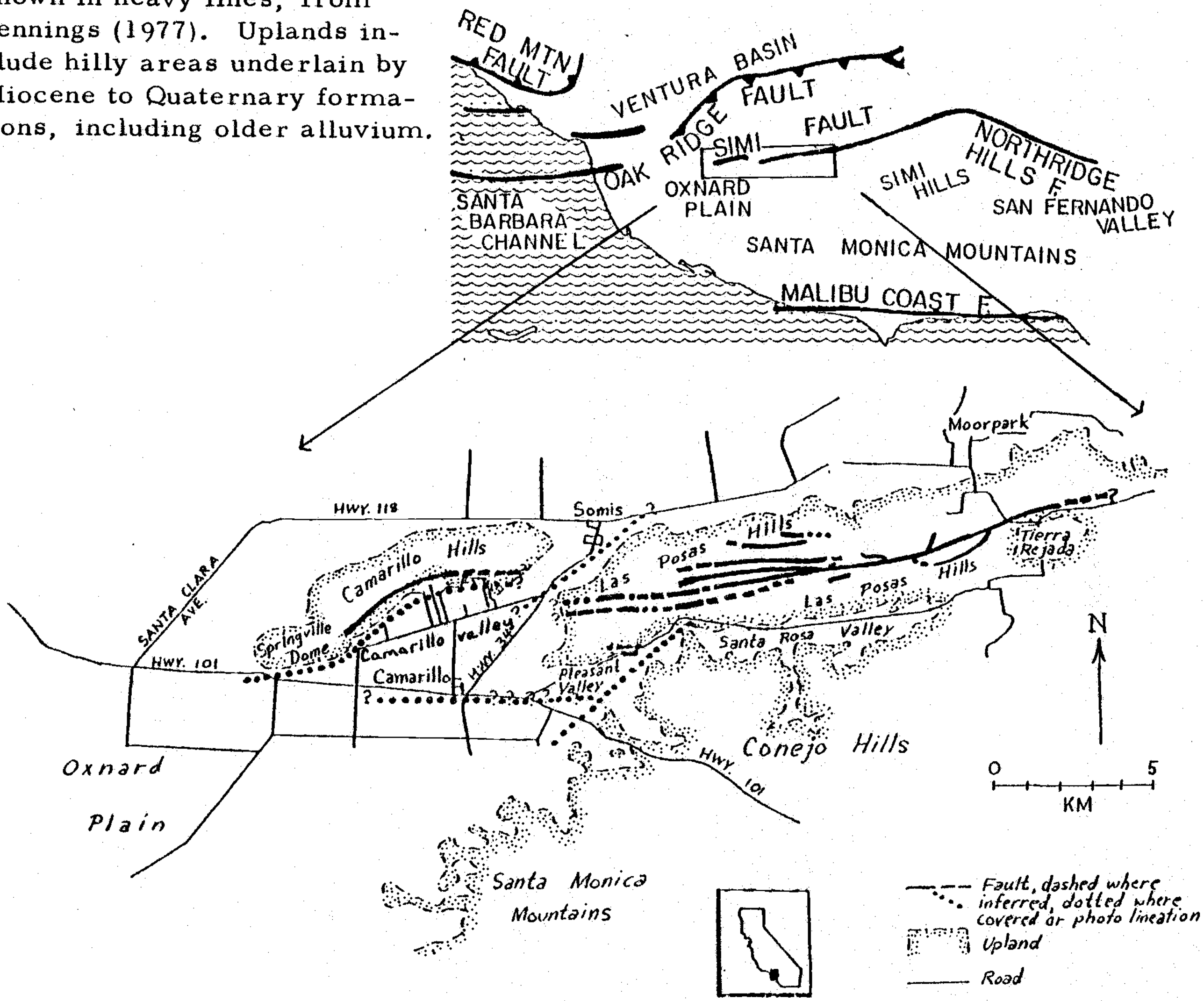
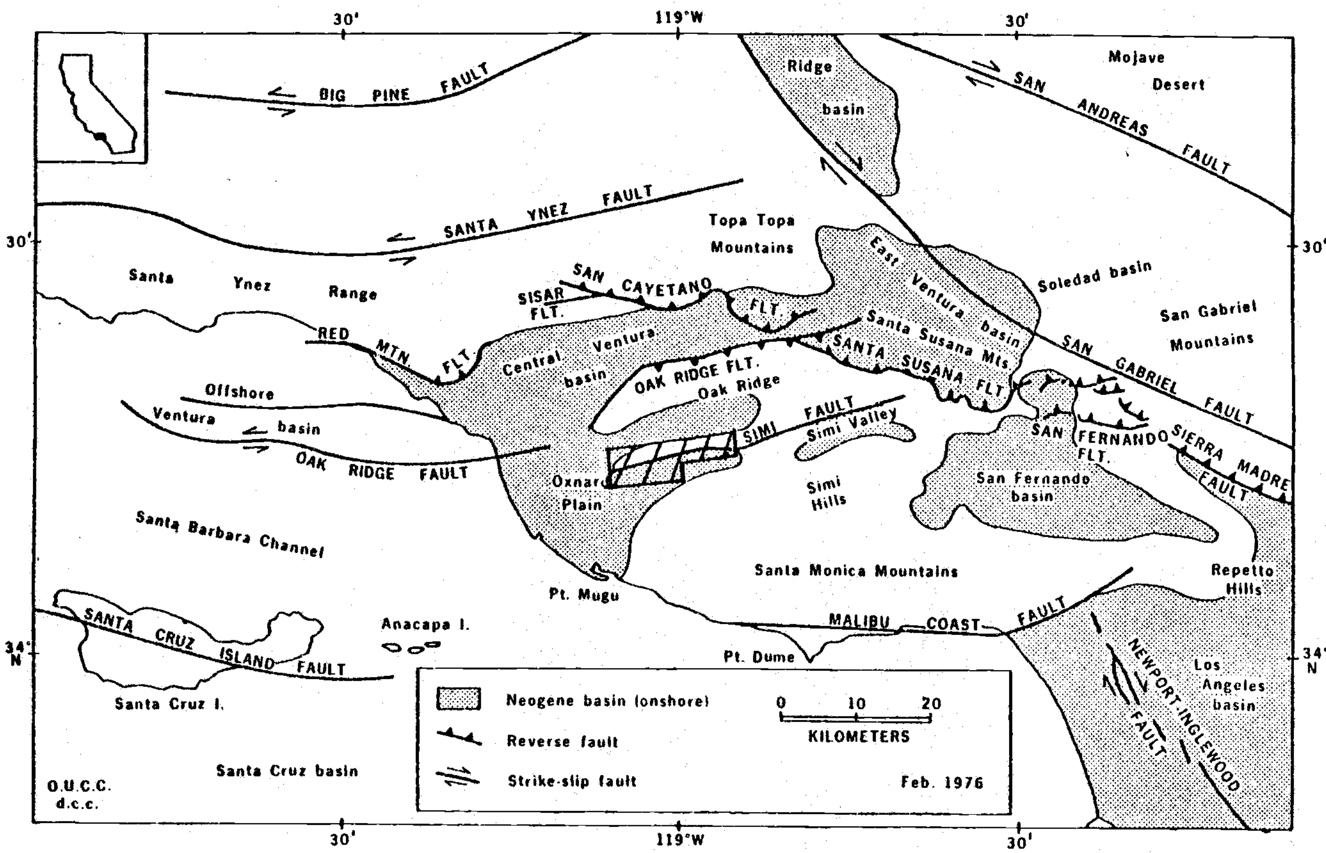


Figure 2: Tectonic map of Transverse Ranges



Tectonic map of the central Transverse Ranges showing onshore Neogene basins and lowlands (shaded) and major Neogene faults (heavy lines). Base map from Jennings (1973). Illustration from Yeats (1976). Field area cross-hatched.

sedimentary sequence estimated to be more than 12 km thick (Nagle and Parker, 1971). Major east-trending reverse faults reflect regional north-south compression in the basin. One of these reverse faults, the Oak Ridge fault, shows a left-lateral component of offset (Yeats, 1976).

The Simi fault system extends from the Simi Valley west to the Oxnard plain. The western half of this fault, extending from Moorpark to Camarillo, was examined in this study. The fault exhibits reverse separation with the north side up. In the Camarillo Hills, it has two main strands, which are together called the Springville fault zone. In the Las Posas Hills, there are two strands in the western portion of the hills, but to the east, the fault zone is composed of one main strand with several discontinuous traces to the north. The possibility of a lateral component of offset is discussed in this report.

Limited exposures of Sespe Formation of late Eocene to early Miocene age, and Conejo Volcanics and Topanga Formation of Miocene age are found in the uplands of the Las Posas Hills. These deposits are unconformably overlain by the Plio-Pleistocene Saugus Formation. In the Camarillo Hills, only Saugus Formation crops out. Throughout the study area, the Saugus is overlain locally by older and younger alluvium.

Objectives of Study

The Las Posas and Camarillo Hills area is rapidly undergoing urbanization. It is important to understand the geologic nature of the young faults that cut through these populated areas. The first objective of this study is to determine the geometry, age, and motion of the Simi fault system. Secondly, I wanted to determine if the Simi fault system is active and constitutes a seismic or ground-rupture hazard to the surrounding communities. The third objective is to see how this fault fits in with the regional tectonics of the Transverse Ranges.

Methods of Study

Surface exposures, especially in the Camarillo Hills, are poor because of extensive cultivation and urbanization. However, a detailed structural analysis of the fault zone can be made using subsurface oil- and water-well data, and engineering geology studies.

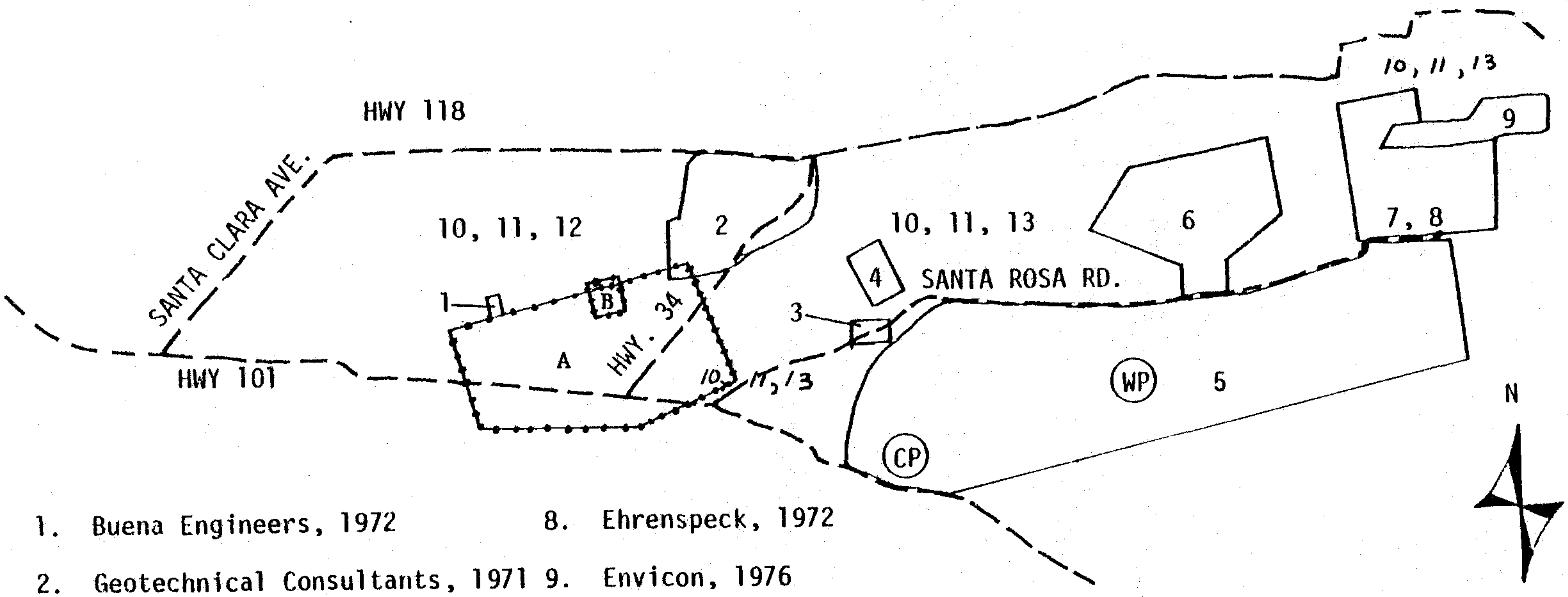
The California Division of Oil and Gas (DOG) provided electric logs, directional surveys, and core and sidewall sample descriptions for the 74 wells drilled by the petroleum industry in the area. Additional information, such as paleontology reports and dipmeter logs, was provided by private operators upon request. The Ventura County Public Works Agency granted access to water well lithology descriptions, and several geologic consulting firms provided engineering geology reports. Cross sections and contour maps constructed at key horizons helped to determine the subsurface geology. Canter (1974) and Ricketts and Whaley (1975) describe in detail those techniques of subsurface structural geology used in this study.

Outside the study area, I examined exposures of those units present in the area only in the subsurface in order to familiarize myself with subsurface formations as well as the regional geologic relationships.

The surface geologic map (Plate I) consists of a compilation of previous work together with my own field check of faults and formation contacts during the summer of 1978. Previous work includes unpublished master's theses by Pasta (1958) and Williams (1977), mapping by Bailey (1951), and several detailed mapping projects done by local geologic consultants for major housing developments in the study area (such as Stone, 1969, Geotechnical Consultants, 1971). An index to sources used is shown in Figure 3.

I reinterpreted as landslides several areas in the Las Posas Hills which had been mapped as bedrock. Strikes and dips for these areas were not included in the compilation. Since mapping in the Las Posas Hills was done by using float and limited exposures, formation contacts as mapped are not precise. Subsurface dips in the Saugus were obtained through several engineering studies which included bucket auger holes and deep trenches.

Figure 3: Source Index for Geologic Map (Plate I) and Location Map



1. Buena Engineers, 1972
2. Geotechnical Consultants, 1971
3. Geolabs, 1978
4. Tierra Tech Testing Laboratory, 1978
5. Williams, 1977
6. Stone and Associates, 1969
7. Trefzger, 1957
8. Ehrenspeck, 1972
9. Envicon, 1976
10. Bailey, 1951
11. Pasta, 1958
12. McCoy and Sarna-Wojcicki, 1979
13. Weber and others, 1975

0 5 KM

Paleomagnetism sampling locations of Kamerling and Luyendyk (1979):
CP: Camarillo Park
WP: Wildwood Park

A Location of air photo shown in Figure 12.
B Location of air photo shown in Figure 13.

Through the use of the Fairchild air photo collection of Whittier College, photos taken from 1927 to 1971 were examined to locate and confirm formational and fault contacts. Because these photos were taken before urbanization, photo lineaments and drainage patterns, unaffected by cultural changes, can be recognized. These air photos were compared with a set flown for the USGS in 1974.

The geologic map (Plate I) reflects this compilation modified by my own field work and air photo interpretation.

Previous Work

The geology of the Las Posas and Camarillo Hills area was first mapped by Kew (1924) as part of a regional study of the Ventura basin. He defined the major units exposed (Saugus and Sespe Formation, and Miocene intrusive and extrusive andesites and basalts), and he mapped the trace of the Simi fault.

Bailey (1951) mapped in greater detail in the study area as part of a regional geologic map of the Ventura basin. He defined the Springville and Camarillo faults, and he extended and named Kew's trace of the Simi fault westward to the western end of the Las Posas Hills. He also recognized a set of discontinuous fault traces in the central Las Posas Hills. Pasta (1958) mapped the Simi fault from Camarillo to the Simi Hills as part of a master's thesis. Williams (1977) and Ehrenspeck (1972) mapped the volcanic rocks in the Conejo

Hills and Tierra Rejada. McCoy and Sarna-Wojcicki (1978), using the Ventura County soil survey (Edwards and others, 1970), divided the post-Saugus deposits into younger and older alluvial sequences.

Detailed geologic investigations were done by engineering consulting firms for specific housing tracts in the Camarillo and Las Posas Hills. These include reports on Rancho Santa Rosa in the eastern Las Posas Hills by Stone and Associates (1969), Kaiser-Aetna properties near Somis by Geotechnical Consultants (1971), and eastern Camarillo housing tracts by Tierra Tech Testing Laboratory (1978). Because the Saugus Formation and older alluvium are major ground water aquifers, the distribution of these units has been studied extensively through the use of water well information. In 1953, the California State Water Resources Board defined and described the Pleasant Valley and Santa Rosa ground water basins. Geologic cross sections included with this study were the first to show the Bailey fault. Further investigations by Mukae (1974), Mukae and Turner (1975), and Turner (1975), showed the effects of the Bailey, Camarillo, Springville, and Simi faults on the ground-water system. The Ventura County Public Works Agency published a biennial report summarizing hydrologic data of Ventura County, including ground water basins of the study area (Goulet and Nowak, 1978).

The stratigraphy of the marine Pleistocene rocks of the Las Posas Hills was studied by Pressler (1929), who named and defined the Las Posas Formation, called Saugus in this report. Oligocene megafauna described by Stock (1932) from Kew's Quarry in the Las Posas Hills provide an age constraint ot the Sespe Formation as defined by Bailey (1947).

STRATIGRAPHY

Oligocene to Recent strata are exposed in the Camarillo and Las Posas Hills area. Cretaceous (?) to middle Eocene rocks have been drilled in the subsurface.

Cretaceous (?) to Eocene Pre-Sespe strata are conformably overlain by the nonmarine Sespe Formation. Late Eocene to early Miocene Sespe is unconformably overlain by the middle Miocene Conejo Volcanics and Topanga Formation undifferentiated. The volcanics and Topanga sandstone are unconformably overlain and onlapped from the west by marine Modelo strata. The late Miocene Modelo Formation is unconformably overlain by the Pliocene-Pleistocene marine Saugus Formation. The Saugus is unconformably overlain by older and younger alluvium and by alluvial fan deposits.

Formations are described from subsurface well descriptions and from surface exposures.

Pre-Sespe Strata, undifferentiated

The Sespe Formation in the Camarillo and Las Posas Hills is underlain by marine siltstone, sandstone and conglomerate. These rocks do not crop out in the study area and have been defined previously on the basis of their lithologic descriptions and paleontologic data from 24 wells that reach pre-Sespe strata. These include siltstone of middle Eocene age designated as Llajas Formation by well operators, as well as strata of possible Cretaceous age. It is not yet possible to subdivide the pre-Sespe rocks in the area and these rocks are called pre-Sespe strata undifferentiated in this report.

The Sespe is underlain by roughly equivalent amounts of siltstone and sandstone with minor conglomeratic interbeds. The dark grey, calcareous siltstone is medium- to fine-grained and contains abundant worm borings, pyrite, and fragments of carbonaceous material and megafossils. The light grey, calcareous, silty sandstone is medium- to fine-grained, well cemented and biotite-rich. In Exxon Berylwood D-2 (19-2N-21W), 2200 feet below the base of the Conejo Volcanics and Topanga Formation (no Sespe is present in this well), 150 feet of conglomerate in a hard, tight sand matrix was penetrated. These rocks were considered the basal Llajas conglomerate by the operator. In Sun-Standard Ferrell #1 (14-2N-20W), 3,950 feet of siltstone, sandstone and conglomerate were drilled below the base of the Sespe Formation. However this well may have a repeated pre-Sespe section due to reverse faulting (cf. Cross Section C-C', Plate XI). The fault may be located within this siltstone-sandstone sequence such that an indeterminate amount has been repeated in the well. Below this 3950 foot thick sequence are 900 feet of light to dark grey, silty sandstone, locally well-cemented and containing abundant biotite and interstitial clay.

Interbeds of both dark grey, calcareous, micromicaceous siltstone and claystone are common. The operator reports this basal 900 feet of section to be Cretaceous in age.

Microfaunal dating places most of the pre-Sespe strata in the middle and lower Eocene, which would make it correlative with the Llajas Formation (McMasters, 1933), the type locality of which is northwest of Las Llajas Canyon on the northwest side of the Simi Valley (cf. Cushman and McMasters, 1936). Many of the faunal zones were defined according to Laiming (1943). Zones B-1 and B-2 correlate to the Llajas Formation. McMasters (1933) felt that the lower Llajas is correlative with the Meganos Formation of Kew (1924), and therefore the Llajas Formation would also contain zone B-3 of Laiming (1943). In Texaco Miketta (21-2N-21W), lower Eocene to Paleocene fauna were identified at 7080 feet subsea. In Lloyd Livingston #4 (31-2N-21W), R. S. Yeats (personal commun., 1979) tentatively recognized 500 feet of Santa Susana Shale, 150 feet of "Martinez" (?) and 500 feet of Cretaceous (?) sandstone beneath 1300 feet of Llajas Formation. These correlations were based on faunal assemblages. (See Plate VI for a summary of the paleontologic data on the pre-Sespe.)

The contact between the Sespe and pre-Sespe strata appears to be concordant (Plate VI). Correlation of intra-Eocene and intra-Sespe markers (Plate VI) shows that Sespe and pre-Sespe strata have the same angle of dip. There is no truncation of pre-Sespe beds at the contact with the Sespe (Cross Section A-A', Plate X).

In the subsurface, the Sespe-pre-Sespe contact was picked on the basis of a lithologic change from grey fossiliferous siltstone to red and green, unfossiliferous, silty sandstone of the Sespe. The contact is well defined in the Continental Berylwood #1 well (18-2N-21W) where grey-green, silty Sespe sandstone rests on dark grey, laminated Eocene silty shale. The Berylwood well also has an electric log allowing the lithologic data to be referred to a diagnostic electric log horizon. (See Plate VI.) The contact is located at a specific sharp amplitude increase upward in both resistivity and SP on the electric log. In other wells, where lithologic and paleontologic data are less precise in defining the contact, the contact is based upon electric log correlation with Continental Berylwood #1.

Sespe Formation

Watts (1897) named the Sespe Formation for exposures in lower Sespe Creek north of Fillmore. Kew (1924) correlated the Sespe Formation to the study area. In 1947, Bailey described the Sespe Formation as the nonmarine redbed facies of the Ventura basin overlying marine Eocene strata and underlying the marine Vaqueros Formation of early Miocene (now considered Oligocene) age. In the study area, the Sespe is found extensively in the subsurface and crops out locally in the uplands of the Las Posas Hills near the Simi fault.

The Sespe is easily recognized in the field and in the subsurface by its characteristic red and green color. At the surface, the formation consists of mottled maroon and green, micaceous sandy claystone and siltstone. Interbeds of grey-green, medium- to coarse-grained, pebbly sandstone containing abundant biotite, interstitial clay, green siltstone fragments, and varicolored grains are common. Minor amounts of conglomerate are present.

In the subsurface, these same rock types are found, locally intruded by Miocene basalt. The electric log characteristics of the Sespe, low amplitude SP and resistivity with irregular jagged peaks, contrast markedly to the blocky, high SP and resistivity of electric logs of Topanga sandstone (Cross Section E-E', Plate XII). Intra-Sespe correlation has been done through the use of electric log markers (Plate VI). Markers can be correlated among wells on the north side of the Simi fault system and within the Oxnard plain south of the fault, but are only tentatively correlated across the Simi fault. Markers north of the fault are labeled SA-SO whereas those so south of the fault are labeled SO-S12.

A late Oligocene (Whitneyan) vertebrate fauna was collected at Kew's Quarry in the Las Posas Hills (cf. Plate I) by Stock (1932). This collection was made approximately 500 feet below the base of the overlying middle Miocene Topanga Formation and 2,500-3,000 feet above the top of the marine Eocene as determined from the nearby Shell Everett wells (Bailey, 1947). Sespe exposures at other localities in the Ventura basin contain vertebrate fossil assemblages ranging in age from Uintan (late Eocene) to Arikareean (early Miocene) (Savage and Downs, 1954; Durham and others, 1954).

The Sespe varies in thickness from 6500 feet in the northwest Camarillo Hills to zero in both the Texaco Miketta (21-2N-20W) and Exxon Berylwood D-2 (19-2N-20W) wells (Plate VIII). This rapid thinning is due to truncation of the Sespe at the contact with the Conejo Volcanics-Topanga Formation by erosion and by normal faulting. Eocene sedimentary rocks are also locally truncated by Conejo Volcanics and Topanga as shown in Plate VI.

The contact between the Sespe and pre-Sespe strata appears to be concordant (Plate VI). In Shell Everett #1 (14-2N-20W), however, an unconformity was described at this contact from core samples. It is a wavy contact between green, coarse-grained quartzose sandstone above and dark grey, laminated, fine- to coarse-grained biotite-rich sandstone below. This well was drilled prior to the use of electric logs, so a subsurface correlation of Pre-Sespe strata cannot be done. However the amount of erosion represented by this unconformity is probably minimal since nearby wells appear to show a conformable Sespe- pre-Sespe contact.

There is a pronounced angular discordance from 5° to 80°

between the Sespe Formation and overlying Conejo Volcanics and Topanga Formation. The contact is an erosional unconformity where the angular discordance is low. Where the angle is high, the contact is a fault scarp related to subsidence of the Sespe Formation. This is further discussed below under Sespe subsidence structures.

Conejo Volcanics and Topanga Formation, undifferentiated

The Topanga Formation was named by Kew (1924) for well-bedded sandstone and conglomerate in Topanga Canyon near Calabasas Peak in the Santa Monica Mountains. Susuki (1952) recognized a series of intercalated basalts in the type section. Durrell (1954) defined three members of the Topanga Formation in the Santa Monica Mountains, a lower marine sandstone and siltstone of Relizian age (foraminiferal zone of Kleinpell, 1938), a middle member of basalt, andesite, and dacite with interbedded sandstone, and an upper marine sandstone and siltstone member of Luisian age (foraminiferal zone of Kleinpell, 1938).

In 1924, Taliaferro named the Conejo Volcanics for the volcanic and intrusive rocks in the western Santa Monica Mountains and Conejo Hills. He recognized that the volcanic rocks interfinger with middle Miocene sedimentary rocks of the Topanga Formation. The sequence of volcanic and sedimentary rocks dips northward 15 to 32° from Point Mugu north to Santa Rosa Valley such that the Conejo Hills is the northernmost major exposure of this series. In the Conejo Hills, a thick volcanic sequence of submarine to subaerial basalt flows is exposed in a north-dipping homocline (Figure 11, Williams, 1977).

The Topanga Formation and Conejo Volcanics have not been differentiated in the study area. In the Las Posas Hills, Topanga sandstone and Conejo Volcanics are present in limited exposure. Brown and grey silty sandstone, commonly ashy and containing tar, dark brown to grey, laminated shale with fish scales and carbonaceous material, and less-common white, quartzose sandstone are interbedded with tuff, agglomerate and volcanics composed of weathered to fresh, fractured, mica-rich basalt, andesite, and dacite. Basalt flows and intrusive cross-cutting dikes are common. Basalt amygdules are calcite-filled. Williams (1977) reported a succession in the Conejo Hills of submarine pillow basalt, hyaloclastic pillow breccia and autoclastic breccia grading upward to a subaerial sequence of basalt and andesite flows, laharic breccia, and pyroclastic deposits.

In the subsurface, the unit consists of light green, fine- to coarse-grained, arkosic, thin-bedded, silty sandstone commonly containing interstitial clay, fish scales, and oil stains. Minor amounts of grey, subangular clasts and green, thin, sandy siltstone are present. Thick sequences of light to dark green, vesicular, mica- and pyrite-rich volcanics are interbedded throughout the unit. The volcanics include tuffs, agglomerates, basalt flows and numerous intrusions. The volcanics have a low resistivity and spontaneous potential (S. P.) on electric logs, and the sands have a high resistivity and S. P. with a characteristic blocky form. The basal part of the unit is a sequence of interbedded sandstones and volcanics. This is commonly overlain by a thick volcanic sequence (Cross Section E-E', Plate XII). The interbedded nature of the sandstone and basalt, abrupt facies changes, and the presence of cross-cutting and concordant basaltic intrusions make it difficult to separate the two units. Therefore, in this report, the volcanic and sedimentary rocks are considered as one unit.

Fish scales and carbonaceous material are common throughout the unit. Originally considered middle Miocene in age by Taliaferro (1924) in the Conejo Hills, subsurface samples yield microfauna varying from specifically, the Relizian and Saucesian Stages of Kleinpell (1938) in ARCO McFarland #1 (13-2N-21W) to generally, middle Miocene in age in Texaco Miketta #1 (21-2N-20W).

Kamerling and Luyendyk (1977) sampled volcanics for paleomagnetic studies from Camarillo Park (CP) and Wildwood Park (WP) in the Conejo Hills. (See Figure 3 for locations.) They reported a clockwise rotation of 70° since middle Miocene time and possibly 10° of northward transport. Their data however, are based primarily on samples from Anacapa Island, Point Mugu and Encinal Canyon. Only one sample from a dike at Camarillo Park was used and two flow samples and four dike samples were from Wildwood Park. Six other samples from Wildwood Park were not used because they appeared to have a secondary chemical remanence. Stable directions were found for these samples but they did not fit in with the 70° of clockwise rotation seen in the other samples. The age of this rotation of the Conejo Hills and Santa Monica Mountains has a significant effect on understanding the geologic history of the Las Posas Hills area. This will be discussed under lateral offset.

The thickness of the volcanics shows an abrupt increase near the Simi fault zone in the Las Posas Hills (Cross Section J-J', Plate XVI). To the west in the Camarillo Hills, this zone of abrupt thickening corresponds to a pre-Topanga and Conejo Volcanics scarp in the Sespe Formation; this scarp is present in the Oxnard plain. It is penetrated by the Southern California Petroleum-Hartman well south of Oxnard (AAPG regional cross section, Paschall and others, 1956). To the northwest of this feature, a thick sequence of Sespe, and pre-Sespe marine strata (minimum 6,500 feet) and a thin sequence of volcanics (800 feet) are present. To the southeast, a minimum of 11,000 feet of volcanics and Topanga Formation pond against this Sespe scarp. In the AAPG regional cross section (Paschall and others, 1956), this scarp is shown as a purely erosional feature.

However, an erosional scarp of over 11,000 feet height and overall 35° slope should have developed side canyons and a youthful dendritic drainage. Extensive well control in the Oxnard field shows the scarp to be relatively smooth, uncut by side canyons (R. S. Yeats, personal commun., 1978). Thus, the scarp may be in part controlled by faulting. This feature is discussed in more detail in the structure section of this report.

The Conejo Volcanics-Topanga Formation undifferentiated overlies the Sespe Formation in a marked angular unconformity (Cross Section G-G', Plate XIV). It in turn is overlain unconformably by the Modelo Formation to the west and the Saugus Formation to the east (Plate III).

Modelo Formation

The Modelo Formation was originally described by Eldridge and Arnold (1907) in Hopper and Modelo Canyons in the eastern Ventura basin. They defined four units, two sandstone members separated by two siliceous shale members. Kew (1924) correlated the Modelo into the study area. Because the unit is present mainly in the subsurface in the study area, it is defined on the basis of lithology from well descriptions and electric log character. In its type locality the Modelo contains proximal fan turbidites interbedded with siliceous shales. In the Camarillo Hills, the Modelo is composed of siliceous claystone and clayey siltstone and represents a different facies of the Modelo from that deposited in the type locality.

The Modelo is present in the subsurface only in the western part of the study area. It thins eastward and is overlapped by Saugus at the east end of the Camarillo Hills (Plate VII). Kew (1924) correlated a small outcrop of diatomaceous shale and claystone west of Tierra Rejada with the Modelo Formation. The strata graded upward from a series of tuff, sandstone and conglomerate. Isolated outcrops of Modelo were mapped in the eastern Las Posas Hills (west of Tierra Rejada) by Stone and Associates (1969), who did detailed geologic mapping for the Rancho Santa Rosa housing development.

There is no evidence of Modelo strata in the subsurface in this area but well data are limited there. The correlation of these outcrops is questionable. These isolated remnants of Modelo may have been preserved during the formation of the Santa Rosa syncline. However, these outcrops may be part of the Conejo Volcanics-Topanga Formation undifferentiated.

The Modelo in core descriptions consists mainly of brown siliceous claystone and micaceous clayey siltstone. Both are highly fractured and brittle, commonly calcareous, laminated, and tar soaked. Olive brown, brittle, cherty shale and grey, fine- to medium-grained, thin sands are common. Thin limestone interbeds may cause the characteristic spikes (high resistivity peaks) on electric logs of the unit. Regan and Hughes (1949) in a study of a lithologically similar sequence in the Santa Maria basin found that high resistivity values were caused by rock fractures and that high SP values were caused by more calcareous interbeds.

Paleontologic information from Union Janss #1 (22-2N-21W) date the Modelo as late Miocene (Mohnian Stage of Kleinpell, 1938). Data from the Mobil Franco Western-Standard Del Tio well (21-2N-21W) place the lower 100 feet of the Modelo in the middle Miocene Luisian Stage of Kleinpell (1938). These stages are based on benthic foraminiferal correlations which may be time-transgressive (Crouch and others, 1979).

In the western Las Posas Hills, paleontologic information from the Topanga Formation in Burmah-Texaco Berylwood #3 (21-2N-20W) and Texaco Miketta #1 (21-2N-20W) indicate a transitional microfauna between the Mohnian and Luisian Stages of Kleinpell (1938). This implies a time-transgressive relationship between the two formations. Alternatively, the faunas in the Modelo and Conejo Volcanics-Topanga Formation are not distinctive enough to be distinguished, or there was contamination of the well samples during drilling.

The Modelo varies in thickness from 1380 feet in Shell Brother #1 (16-2N-21W) to zero in the eastern Camarillo Hills (see Plate VII which shows isopach and zero lines of the Modelo). The Modelo unconformably overlies the Conejo Volcanics-Topanga Formation unit. Intra-Modelo electric log markers in Cross Section D-D' (Plate XI) delineate an onlap relationship. Hoots (1931) described this unconformity in the eastern Santa Monica Mountains, where Modelo, with Mohnian Stage microfossils, rests on rocks as old as Jurassic. The Modelo is overlain with angular unconformity by the Saugus Formation.

Saugus Formation

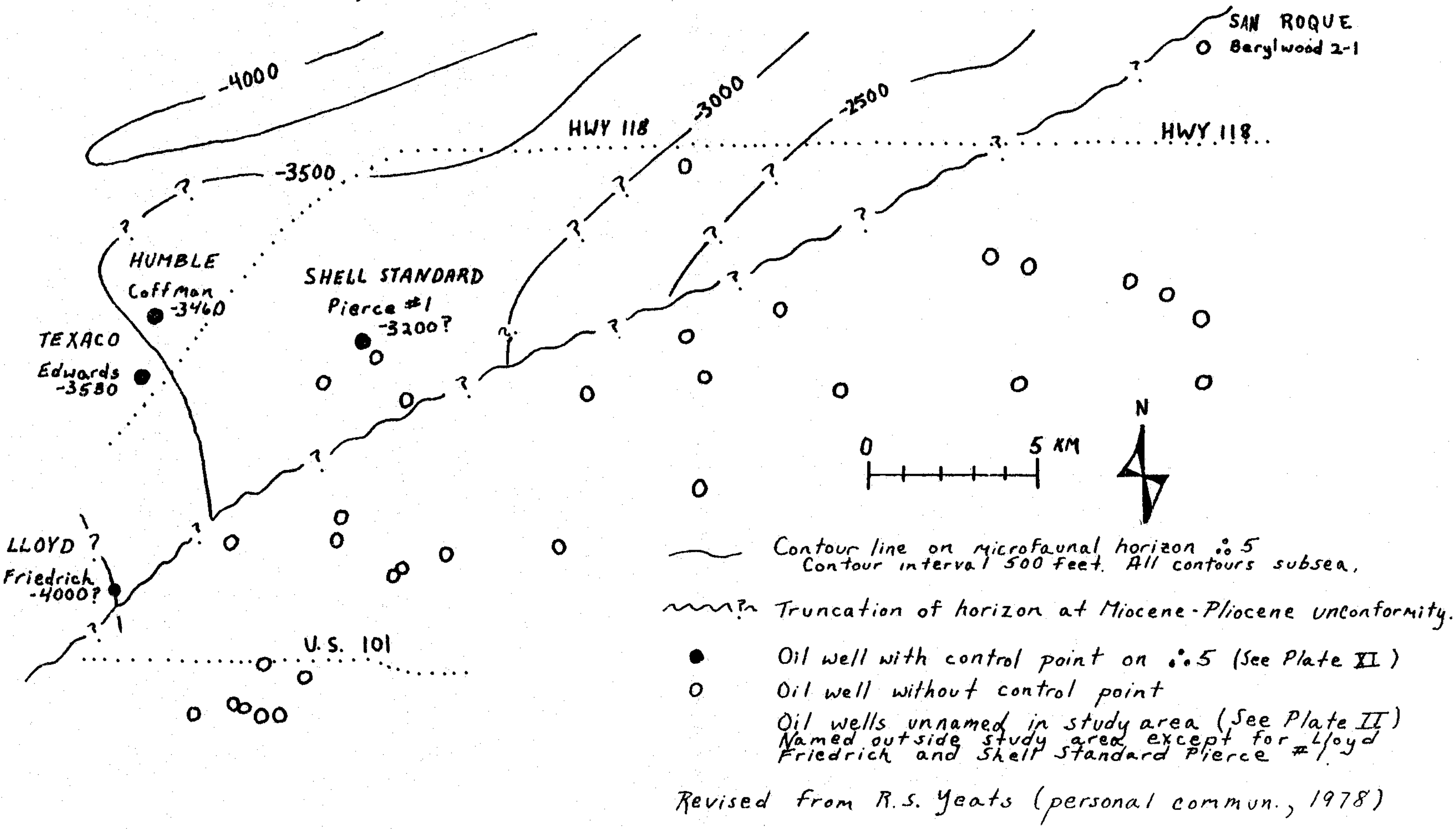
Hershey (1902) first defined the Saugus Formation at Soledad Canyon near the town of Saugus, California. Kew (1924) mapped Saugus in the study area. Pressler (1929) redefined it as the Las Posas Formation based on its marine character in contrast to the predominantly nonmarine Saugus at the type locality. In 1943, Bailey, also recognizing the marine nature of these rocks, called the unit San Pedro after Arnold's (1903) original definition of the southern California marine Pleistocene in the Los Angeles basin. Saugus is used by Yeats (1977) to refer to shallow marine and nonmarine clastic deposits overlying the Fernando in the Ventura basin and overlain by older alluvium, fans, and marine terraces. The San Pedro of the Los Angeles basin probably never extended continuously across the Santa Monica Mountains. The Las Posas is a local name used in the Las Posas Hills for strata with no clearly defined stratigraphic relationship with the Fernando Formation. I am returning to the term

Saugus as originally used by Kew because it more clearly describes the lithologic and stratigraphic nature of the marine Pleistocene rocks in the study area. Defining these rocks as Saugus provides greater consistency in the stratigraphic nomenclature of the Ventura basin because neither a locally restrictive term (Las Posas) or a regionally generalized one (San Pedro) is used.

The contact between the Saugus Formation and Fernando Formation in the Oxnard Plain is marked by a siltstone unit which comprises the uppermost member of the Fernando. (See Cross Section C-C', Figure 2 of Yeats, 1976, for illustration of this relationship.) In the study area, this siltstone unit is not present, probably due to a facies change southeastward to sandstone. There is no diagnostic break in the electric log characteristics between the Saugus and Fernando; and paleontological data do not allow the exact location of this contact in the study area.

Yeats (personal commun., 1979) mapped microfaunal marker ∴5 in the northwest Oxnard plain (Figure 4), using well data and unpublished industry seismic data. At Balcolm Canyon and on the flanks of the Ventura anticline, microfaunal marker ∴5 is stratigraphically just above the Bailey ash bed (Blackie and Yeats, 1976; Yeats, 1977), dated at 1.2 ± 0.2 million years (Izett and others, 1974). The change in the facies between the central Ventura basin and the Camarillo and Las Posas Hills prevents marker ∴5 from being

Figure 4. Structure contours and termination of microfaunal horizon 5, just above 1.2 m.y. ash bed.



easily correlated to the edge of the area. Furthermore, electric log correlation south from the Oak Ridge fault is difficult near the area. Accordingly, control of points in two wells (Figure 4) are of questionable reliability but seismic correlation with areas to the northwest in which marker 5 is more clearly identifiable indicate these control points are approximately correct.

In the western end of the Camarillo Hills, this marker is located at 3200 feet below sea level in Shell Standard Pierce #1 (20-2N-21W). There are 700 feet of sedimentary rocks below this marker and above the unconformity at the base of the Saugus Formation.

Because the contact between the Fernando and Saugus Formation cannot be picked accurately, the rocks above the unconformity at the base of the Saugus are designated as Saugus. However, it should be noted that the basal portions of the unit in the western part of the study area are laterally equivalent to beds mapped as Fernando Formation to the north.

The Saugus crops out in both the Camarillo and Las Posas Hills. It is composed of loosely consolidated, tan to yellow conglomerate, fine- to medium-grained sandstone, and silty mudstone. The formation is in part lenticular and poorly bedded, and it contains thin calcareous sandstone layers. Shallow marine fossils are abundant in the Las Posas Hills whereas they are scarce in the Camarillo Hills, except for a hard fossiliferous layer near the top of the Saugus.

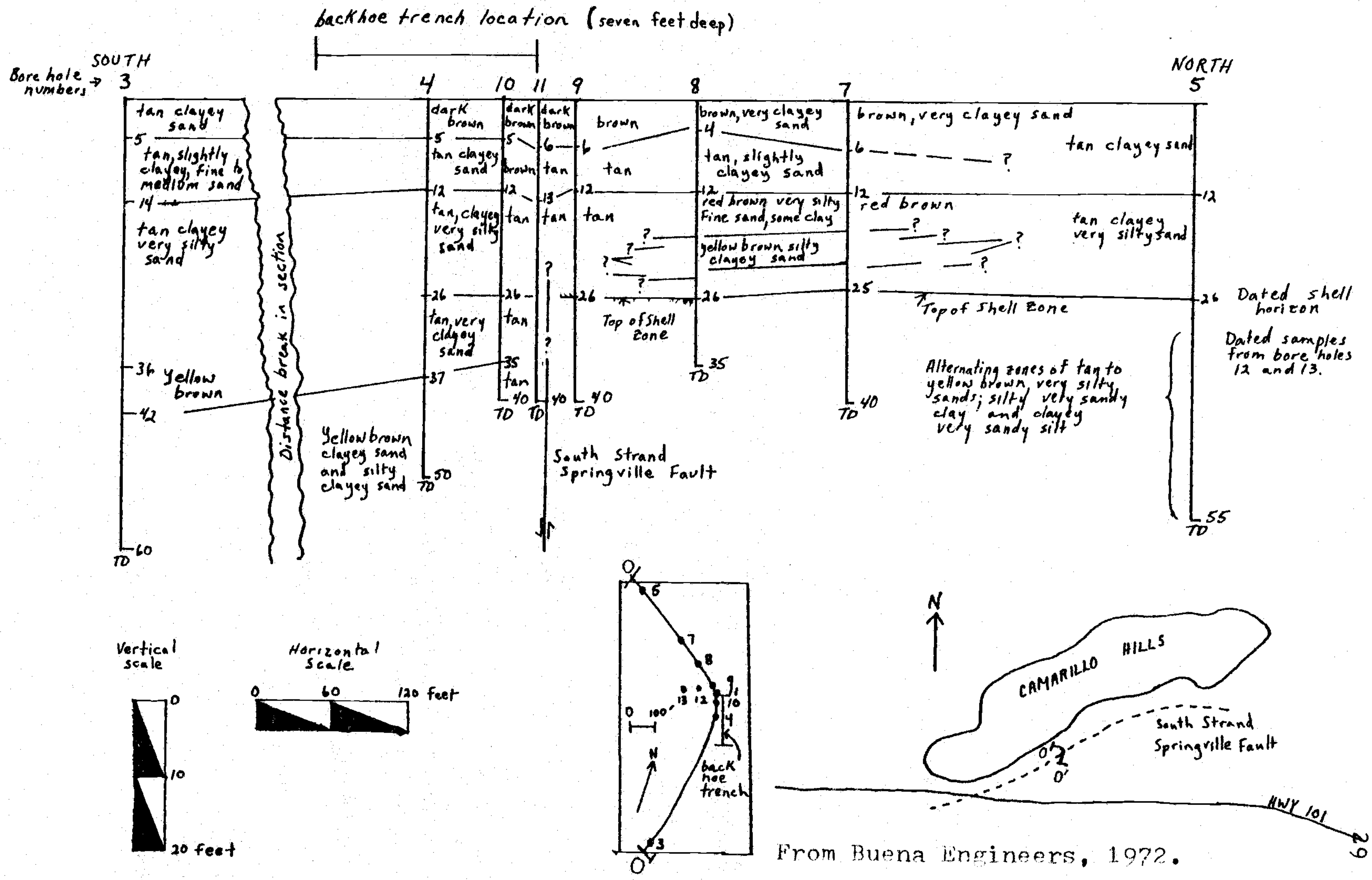
Pressler (1929) concluded that the Saugus in this area is marine.

The Fox Canyon member (Pasta, 1958) consists of fine- to medium-grained sandstone with stringers of gravel. It is in the middle of the sequence, and it constitutes a major aquifer in the Oxnard plain and Pleasant Valley basins. Turner (1975) dated the Fox Canyon aquifer as early Pleistocene, deposited in a shallow marine environment.

Above the unconformity at the base of the Saugus Formation, a tar sand is seen in some wells near the Oxnard plain. Dosch (1966) outlined the distribution of tar sands in the Oxnard field. The Vaca tar sand has been traced northward to the Camarillo Hills by Yeats (unpublished data); it is locally present in the Springville dome. These tar sands are lithologically similar to grey Saugus sands. The sands became oil soaked when in contact with the underlying Miocene oil-bearing fractured cherts and volcanics (Yeats, personal commun., 1978).

Fossil remains of *Equus* were found by Pressler (1929) at the eastern end of the Las Posas Hills (fossil locality shown on geologic map, Plate I) demonstrate a Pleistocene age for the Saugus Formation. In northwest Camarillo (Cross Section A-A' on Plate X), borings were drilled to determine the location of the south strand of the Springville fault (Figure 5). A shell bed found in two bore holes, at 22 and 24 foot depths respectively, yielded a minimum age of 240,000 years as based on uranium series dating of the shell fragments by

Figure 5. Converse Ranch cross section of boreholes. Numbers indicate depth in hole measured in feet.



From Buena Engineers, 1972.

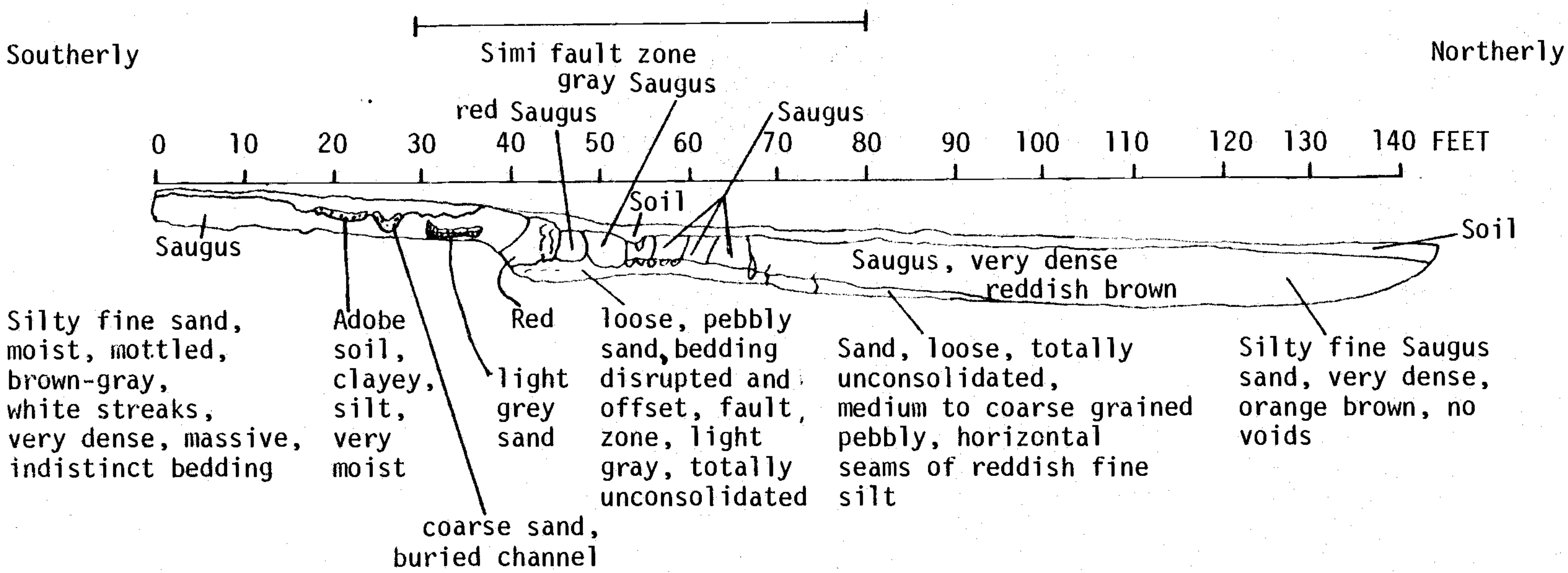
M. Kimmel of the University of Southern California. Appendix I gives a description of the technique used for this dating. The two bore holes were on the north side of the fault and borings on the south side of the fault did not encounter this shell bed within a depth of sixty feet. Because this is a minimum age, it provides no information on the age of the Springville fault. Saugus deposition ceased as recently as 0.2 million years ago in the Ventura area (Yerkes and Lee, 1979).

In the Camarillo Hills, the Saugus is 600 feet thick. The unit thickens westward into the Oxnard Plain where it is 5000 feet thick. In the Las Posas Hills, the Saugus is 200 feet thick on the north flank of the hills. In the uplands, the unit is locally completely eroded, and older rocks are exposed.

The Saugus is unconformably overlain by older alluvium and younger alluvium. The Saugus is differentiated from the older and younger alluvium by an angular unconformity with the overlying sediments, the presence of marine fossils and the semi-consolidated nature of the Saugus versus the unconsolidated alluvial sediments. Although local conditions can vary considerably, the Saugus normally exhibits a higher degree of compaction, a higher density, and a greater direct shear strength than the overlying older or younger alluvium. Trenching along Santa Rosa road and across the south strand of the Simi fault shows this relationship (Figures 6-9).

Figure 6: Trench Log T1, Tract 2910

Note: orientation as given in report.

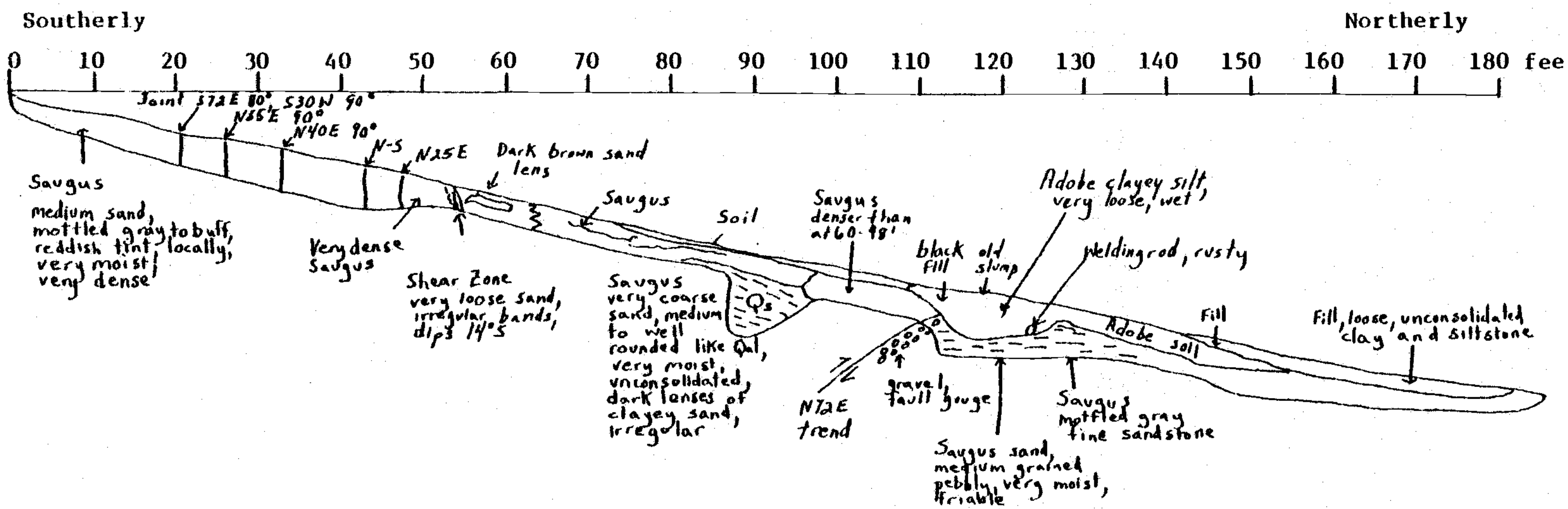


LOCATION ON PLATE I

from Tierra Tech Testing Laboratory, 1978

Figure 7. Trench log T2, Tract 2910.

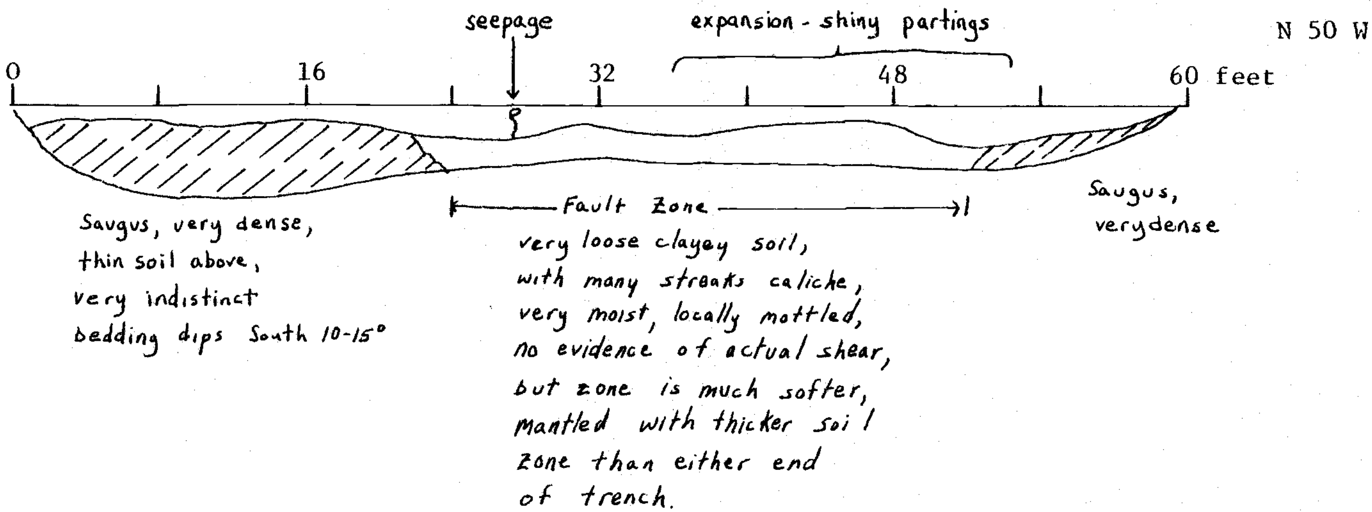
Note: orientation as given in report



Location on Plate I.

From Tierra Tech Testing laboratory, 1978.

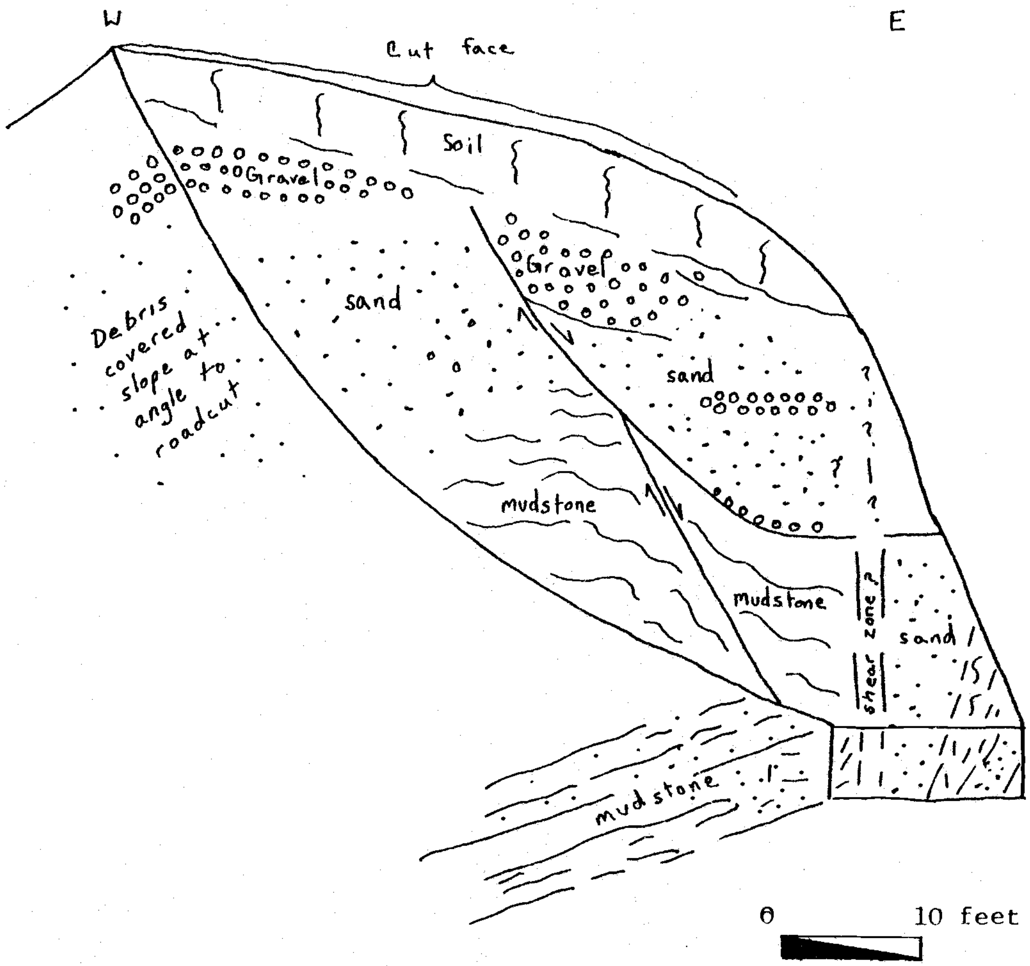
Figure 8. Trench log T3, Tract 2930.



Location on Plate I.

From Tierra Tech Testing laboratory, 1978.

Figure 9. Trench log of roadcut on Santa Rosa Road.



Location on Plate I. Sketch done by Geolabs, 1978.

Saugus unconformably overlies the Miocene Modelo Formation. This angular unconformity is best seen in Cross Section D-D' (Plate XI). Eastward, the Modelo is overlapped by the Saugus such that the Saugus rests unconformably on Conejo Volcanics and Topanga Formation (Cross Section E-E', Plate XII). In the Las Posas Hills, the Saugus lies unconformably on the Conejo Volcanics and Topanga Formation as well as on the Sespe Formation. This reflects a pre-Saugus erosion of the Conejo Volcanics-Topanga Formation unit and the Sespe Formation due to folding with subsequent deposition of Saugus Formation over this fold.

Older Alluvium

Uplifted and commonly warped late Pleistocene alluvium is composed of gravel, sand, silt and clay with soil zones showing "B" horizon development (McCoy and Sarna-Wojcicki, 1979). The sediments are light colored, cross-bedded and unconsolidated. Scour and fill channel structures are common. Low dips on bedding planes are seen. The older alluvium is differentiated from the Saugus by its lack of consolidation, absence of marine fossils, and an angular unconformity between the underlying Saugus and overlying older alluvium which can be seen in backhoe trenches. It is difficult to lithologically separate the older and younger alluvium. However, the older alluvium is located on uplifted surfaces and shows a "B" soil horizon development whereas the younger alluvium is present in the lowlands and shows no "B" horizon development.

This older alluvium comprises undulating surfaces of low relief in the Las Posas Hills and caps most of the Camarillo Hills. This unit may have been continuous over the entire Camarillo Hills prior to uplift of the Camarillo anticline and Springville dome and dissection by erosion. Deformation of these surfaces implies late Quaternary movement in this area.

In the north-central Las Posas Hills, faults A and B of the Simi fault zone were mapped by Bailey (1951) in strata mapped by him as San Pedro (Saugus of this report). These sediments are mapped as older alluvium in this report. These faults are not seen as lineations on air photos in areas of older alluvium and are dotted and queried across this area. Subsurface control on the fault is lacking in this region.

Alluvial Fan Deposits

These deposits consist of loose, medium- to fine-grained, permeable sand and silt. Drainage patterns from old air photos show anastomosing streams typical of alluvial fans. The fans built out onto the valley floors as the Camarillo and Las Posas Hills were uplifted along the Simi fault system. Because there is still a topographic break due to faulting and uplift between the steep south-facing slopes of these hills and the adjacent gently sloping valleys, these fans are assumed to be still active. However, urbanization has disrupted their natural drainage patterns as seen on 1927 air photos. The alluvial fan deposits are younger than the older alluvium because the fan deposits were shed off of the uplifting Camarillo and Las Posas Hills. Older alluvium was deposited on these hills before uplift occurred. The fan deposits are equivalent in age to the young alluvium.

Landslides

These features are recognized on the basis of topographic expression (i.e. an arcuate scarp face and lobate slide debris) as well as by the hummocky appearance of the ground within the slide area. Air photo interpretation and detailed engineering reports were used in examination of these features.

The slides occur mainly on the north-facing slopes of the Camarillo and Las Posas Hills. The ages of these slides vary; several are now completely revegetated, whereas others have not yet been modified. A large scarp at the northwest corner of the Las Posas Hills has been modified by vegetation but is still easily recognizable. This slide may have occurred due to undercutting of the toe of the slope by Arroyo Las Posas.

Younger Alluvium

This alluvium is composed of light tan to yellow, coarse- to fine-grained gravel, sand, silt, and clay. The sediments are unconsolidated, clayey and light colored. McCoy and Sarna-Wojcicki (1979) classify this alluvium as those sediments whose soil zones have not yet developed a "B" horizon. The alluvium is differentiated from the Saugus by an absence of marine fossils, unconsolidated nature, its low angle of dip of bedding and the unconformity between the two units. It is located in the lowlands and includes both flood plain deposits and those sediments now being deposited in stream channels.

STRUCTURE

Introduction

In the Camarillo and Las Posas Hills area, normal faults developed in the Sespe Formation prior to deposition of the Conejo Volcanics and Topanga Formation. During deposition of the volcanics, Sespe subsidence structures formed. An angular unconformity separates the Modelo Formation from older rocks. Reverse faults (Borchard Thrust and Fault E) cut the Modelo but are truncated at the unconformity at the base of the Saugus Formation. This unconformity also truncates the left lateral Somis fault. The Las Posas anticline and Santa Rosa syncline developed before deposition of the Saugus. Reverse movement along the Simi fault system occurred before and after the end of Saugus deposition, forming the Springville dome, Camarillo anticline and post-Saugus Las Posas anticline adjacent to the fault system. The Bailey fault may cut the Saugus Formation or it may be a pre-Saugus fault. The Camarillo fault cuts older alluvium.

The relationship between structure and stratigraphy is discussed under geologic history.

Faults

Sespe Subsidence Structures

Intra-Sespe correlation (Plate VI) in the Oxnard field shows several normal faults that cut Sespe and older rocks, yet are truncated by the unconformity at the top of the Sespe (Faults F, H, I, Cross Sections A-A' and B-B', Plate X). North of the Simi fault system, other normal faults are located in both the Camarillo and Las Posas Hills (Cross Sections D-D', E-E', G-G', Plates XI, XII and XIV, respectively). These faults in the Camarillo and Las Posas Hills are unnamed, and their orientation and continuity are queried. Because a fault rarely is recognized in more than one well, the dip of the fault plane cannot be determined. However, these faults are commonly constrained to a steep dip (Cross Section D-D', Plate XI).

In Cross Sections F-F', H-H' and J-J' (Plates XIII, XV, and XVI respectively), the south strand of the Springville fault zone and the north strand of the Simi fault zone reactivated north-dipping normal faults, moving along the same fault plane. Restoration of the offset due to reverse faulting in these cross sections reveals older normal faults with 650 feet of stratigraphic offset in Cross Section J-J', 780 feet in Cross Section H-H' and up to 1300 feet of offset in Cross Section F-F'.

The normal faulting of the Sespe Formation is analogous to that at South Mountain. There, numerous normal faults, dipping 50-60° north and south, are seen in roadcut exposures of the Sespe Formation and in the subsurface (Yeats, 1965). The formation of these normal faults has been related to the Miocene encounter between the North American continent and the East Pacific Rise (Yeats, 1971).

In the Oxnard plain, the fault scarp of one of these normal faults has been preserved. A northeast-trending scarp cut in the Sespe Formation and older strata (Paschall and others, 1956) slopes about 35° to the southeast and is composed of about 6000 feet of Sespe and at least 500 feet of Llajas Formation and older rocks. It is capped by 800 feet of Conejo Volcanics. Well control is to a depth of 10,000 feet subsea. To the southeast of this scarp, 3000 feet of Conejo Volcanics and a minimum of 8000 feet of Topanga Formation buttress against this feature in the south-central Oxnard plain. Well control is to a depth of 12,600 feet subsea. Dosch and Mitchell (1964) in their study of the Oxnard oil field interpret the northeast-trending scarp as a purely erosional surface offset by a series of high-angle reverse faults (cf. Cross Section E-F, Dosch and Mitchell, 1964).

R. S. Yeats mapped this scarp in the subsurface of the Oxnard field, using extensive oil-well data. He determined that the scarp is probably not erosional because it is too straight and not indented by dendritic drainage. It may have formed as a subsidence-related structure due to normal faulting during deposition of the Conejo Volcanics and Topanga Formation (R. S. Yeats, personal commun., 1978). If formed in this way, the scarp would never have existed as a free-standing topographic feature of high relief and would not have developed erosional channels in its face. A low-angle detachment fault, as postulated by Campbell and others (1966) in the central

Santa Monica Mountains, could also form this type of scarp.

In the study area, similar scarps are found. They are harder to map because they are disrupted by the Simi fault system. The scarps are preserved remnants of normal faults in the Sespe Formation.

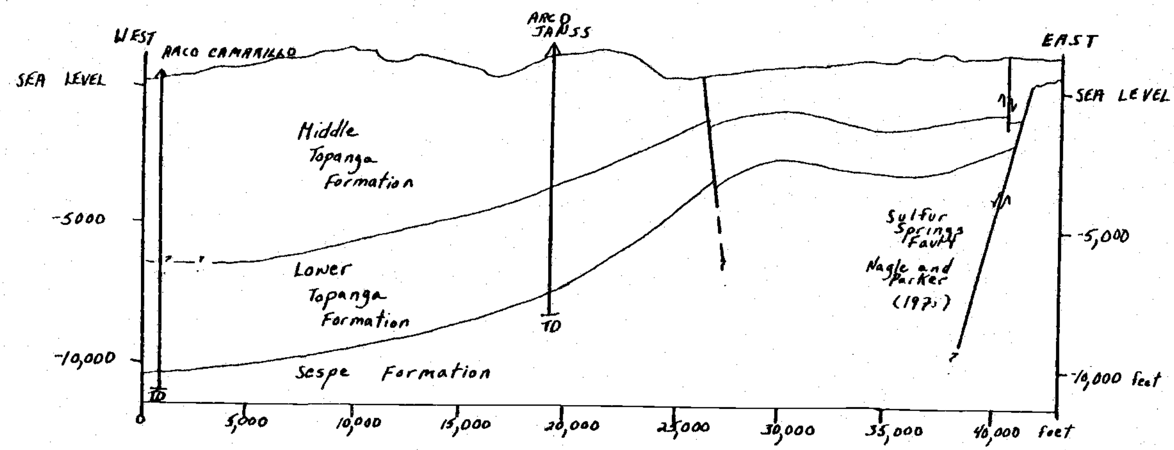
In the western Camarillo Hills, a northeast-trending scarp is seen in Cross Section D-D' (Plate XI) between the Mobil-Franco Western-Shell-Standard Del Tio well (21-2N-21W) and the Mobil-Shell-Standard Pierce #2 well (20-2N-21W). This scarp slopes 50° to the southeast.

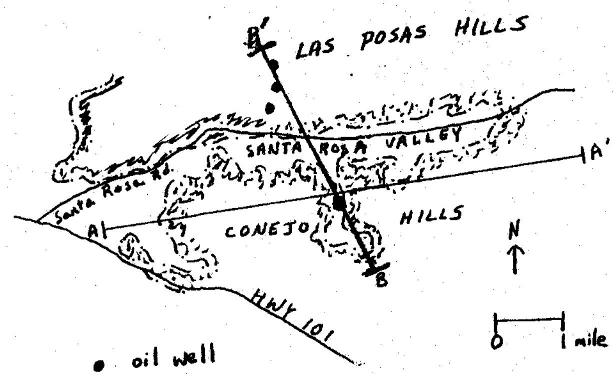
Contours on the base of the Conejo Volcanics and Topanga Formation (Plate IV) and Cross Sections F-F' and H-H' (Plates XIII and XV respectively) reveal an east-trending, south-dipping scarp in the central Camarillo Hills.

In the western Las Posas Hills, an east-trending scarp seen in Cross Section J-J' (Plate XVI) consists of 4700 feet of Sespe resting conformably on Eocene rocks. Unconformably overlying the Sespe are 1930 feet of volcanics and Topanga sandstone. In the Texaco Miketta #1 well (21-2N-20W), a sequence of 6100 feet of volcanics and Topanga sandstone lie unconformably on Eocene rocks. This sequence buttresses against the scarp lying to the north.

McIvor (1955) postulated a north-trending, westward-dipping, Sespe scarp in the eastern Conejo Hills (Figure 11A). This was later

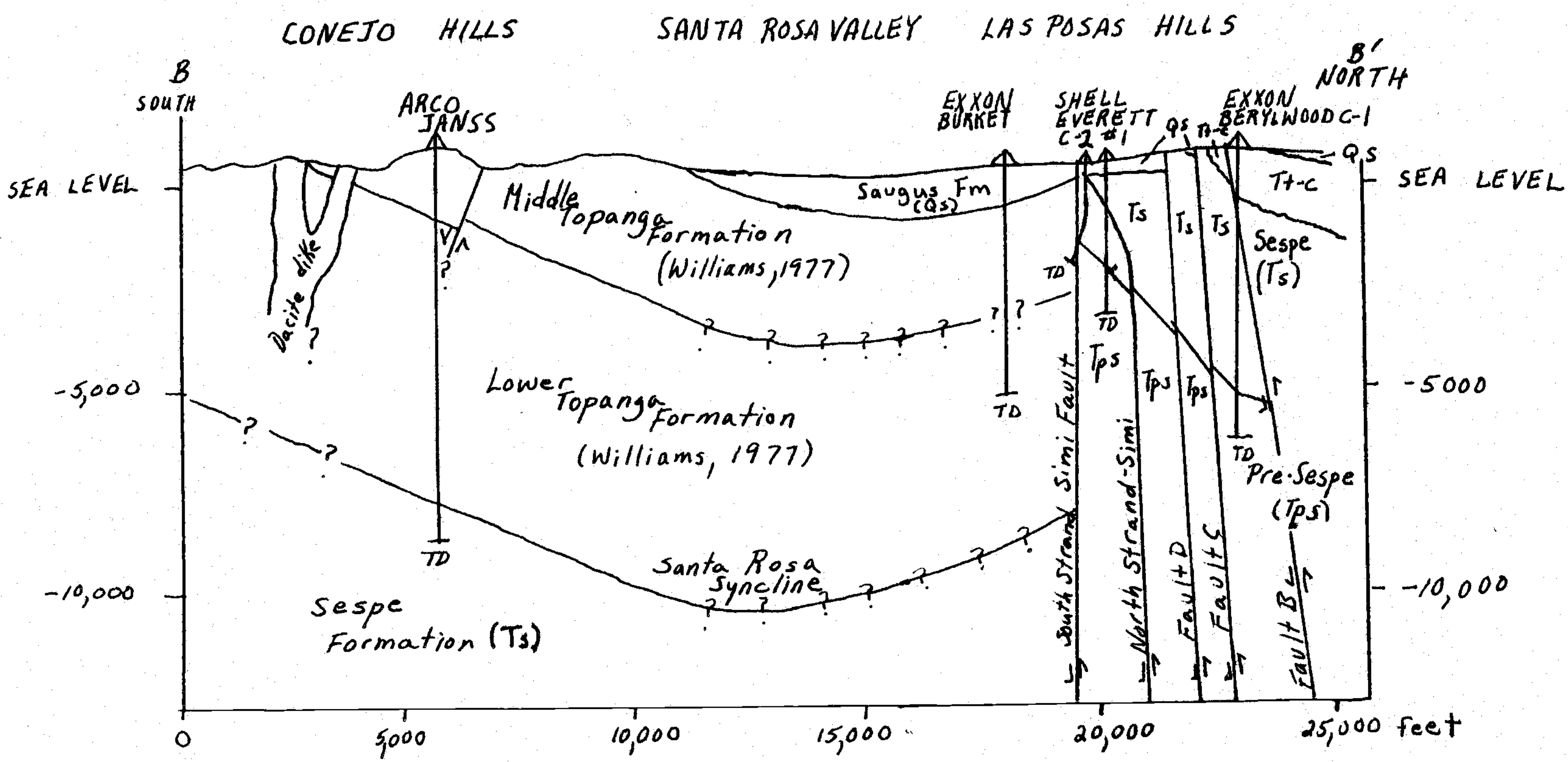
Figure 10A. West-East Cross Section of Conejo Hills.





Adapted from Williams, 1977.

Figure 10B. South-North Cross Section of Conejo Hills.



named the Sulphur Springs Fault by Nagle and Parker (1971).

The most likely explanation for these scarps in the study area is that they are formed by subsidence towards a volcanic center in the Conejo Hills. Their spatial arrangement suggests a series of faults curving around the perimeter of the Conejo Hills. Each fault downdrops the block closest to this thick pile. In Cross Section E-E' (Plate XII), the Sespe Formation in the relatively upthrown block between Union Janss #2 (22-2N-21W) and Union Tassano (23-2N-21W) is back tilted and Sespe beds locally dip more steeply away from the Conejo Hills.

Back tilting of the Sespe, fault blocks downdropped toward the volcanic pile and the curved spatial arrangement of these faults are characteristic of subsidence structures (Williams, 1941). The combination of Sespe normal faults with eroded fault scarps and preserved fault scarps form what I am calling Sespe subsidence structures. Figure 18 outlines the formation of these structures.

During the Miocene, intersection of the East Pacific Rise with the continent was accompanied by extensional tectonism in the Ventura basin (Yeats, 1971), forming normal faults. Submarine volcanism centered in the Conejo Hills built up a thick sequence of volcanics and interbedded sandstone. The Sespe rocks surrounding this area subsided along south-dipping normal faults towards this volcanic pile. Volcanism and subsidence were contemporaneous during the buildup of the volcanic pile in the Conejo Hills. Several of the fault scarps were preserved as volcanics ponded against them from the south. However, volcanism outlasted subsidence such that fault scarps to the north were eroded, and basalt flows overtopped the scarps and flowed out to the north and west over the tops of these eroded scarps (Figure 18, b, c and d).

After formation of the Sespe subsidence structures and deposition of the Conejo Volcanics and Topanga Formation, submarine or subaerial erosion occurred. There is an angular discordance of 9° between the overlying Modelo Formation and the underlying Conejo Volcanics and Topanga Formation (Cross Section D-D', Plate XI).

Pre-Saugus Reverse Faults

The Borchard thrust was mapped by R. S. Yeats (personal commun., 1978) in the northeast section of the Oxnard plain. The Borchard wells in Section 31 T2N-R21W (DOG map 204, 1978) critically define the thrust because of a repeat of the Modelo-Conejo Volcanics contact in Lloyd Borchard #6. Using Yeats' data, the Borchard thrust is extrapolated from Section 31 into the study area, where it is permissive but not critically defined (Cross Sections A-A' and B-B', Plate X). This high-angle reverse fault offsets intra-Modelo markers 250 feet and dips steeply north. The fault is truncated by the unconformity at the base of the Saugus Formation.

In the Oxnard plain, Chevron McGrath 11 (29-2N-21W) is cut by a high-angle reverse fault at 6246 feet subsea. The fault, shown in Cross Section B-B' (Plate X) as fault E, cause a repetition of 470 feet of Sespe and 330 feet of volcanics. Repetition of the Sespe is confirmed by intra-Sespe correlation. Marker S2 has been recognized in the upthrown block north of Fault E. The fault also juxtaposes 370 feet of Modelo and 3190 feet of volcanics to the north against 490 f eet of Modelo and 3980 feet of volcanics to the south. The dip of the fault plane is constrained to 70-85° because the fault does not cut Lloyd McGrath 2 and 3. Dosch and Mitchell (1964) recognized this high-angle reverse fault in their study of the Oxnard oil field.

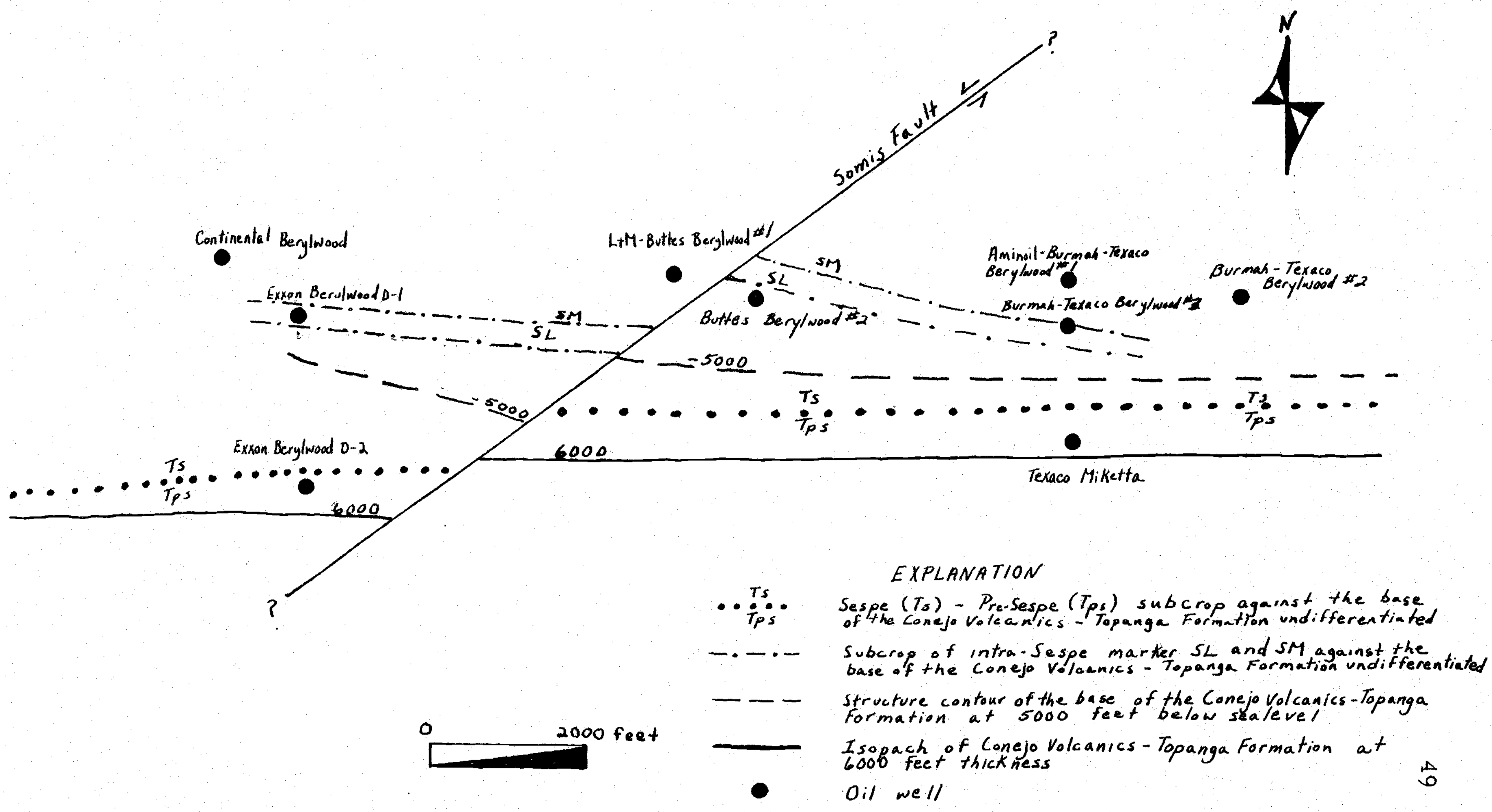
Both of these reverse faults are truncated by the angular unconformity at the base of the Saugus Formation. The Modelo dips 18° to the northwest and the Saugus dips 10° to the west. In the study area, the faults are post-Modelo and pre-Saugus in age. Throughout the Ventura basin an angular unconformity exists between the Miocene Modelo Formation and the overlying Pliocene-Pleistocene strata. The faults could be pre-Pliocene in age because the Saugus (Pleistocene) and Fernando (Pliocene) Formations are conformable throughout much of the Oxnard plain west and northwest of the study area. But, at several localities south of the Oak Ridge fault, there is an angular unconformity between the upper Fernando and siltstones of the lower Fernando (Yeats, 1976). This angular unconformity is defined by wells at the west end of Oak Ridge (Cross Section B-B' of Yeats, 1976) and at the Fernando basin margin northwest of the study area where upper Fernando turbidites overlie lower Fernando siltstone with angular unconformity (R. S. Yeats, personal commun., 1979). The lower Fernando siltstone pinches out, and the Fernando turbidites are overlapped by Saugus west of the study area such that the unconformity at the base of the Saugus in the Camarillo Hills represents both the unconformity at the top of the Modelo and the intra-Fernando unconformity. Thus the reverse faults in the Oxnard plain could be truncated by either of these two unconformities.

Somis Fault

The Somis fault was first mapped by Bailey (1951) as a northeast-trending normal fault with the east side up, separating the Camarillo and Las Posas Hills. The surface trace is concealed by alluvium of Arroyo Las Posas. The fault is seen in the subsurface between L & M Buttes Berylwood #1 (17-2N-20W) and Buttes Berylwood #2 (17-2N-20W) in Cross Section G-G' (Plate XIV). In this section, the fault juxtaposes 4460 feet of Sespe and 2580 feet of volcanics on the west against 4050 feet of Sespe and 2900 feet of volcanics on the east. There is 350 feet of separation of the top Sespe unconformity and 100 feet of separation of the intra-Sespe markers.

Because the fault does not cut any well in the study area, the

Figure 11. Evidence for left lateral movement on the Somis fault.



dip of the fault plane is indeterminate. But the dip is constrained by the L & M Berylwood #1 and Buttes Berylwood #2 wells to nearly vertical (Cross Section G-G', Plate XIV).

The Somis fault either shows a sequence of east-side-up, then east-side-down faulting, or it demonstrates lateral offset. The first hypothesis is necessary to explain the relative east side up displacement of intra-Sespe markers and the east side down displacement of the unconformity.

Five lines of evidence support the concept of left lateral strike-slip movement on the fault (Figure 10). First, the subcrop of the base of the Sespe against the Conejo Volcanics is offset (Plate IV), and structure contours on the base of the Conejo Volcanics and Topanga Formation are also offset left laterally (Plate IV). Isopachs of the volcanics and Topanga sandstone (Plate VIII) and the Sespe Formation (Plate IX) show left lateral offset. Finally the subcrop of intra-Sespe markers against the fault are offset left-laterally (Figure 10).

The actual amount of offset is difficult to determine because faulting along the Simi fault system disrupts the original thickness relationships between the Sespe and volcanics. Also only two wells are close enough to the fault and deep enough to provide accurate data on the amount of fault displacement. An estimate of fault offset is roughly 1500 feet (457 m) ± 200 feet (60 m), which is purely strike slip movement.

The Somis fault does not cut the Saugus Formation, and it is truncated by the unconformity at the base of the Saugus. Fault movement occurred after deposition of the Conejo Volcanics and Topanga Formation but prior to the formation of the unconformity at the base of the Saugus Formation.

Simi Fault System

The Simi fault system is the east-trending series of faults in the Las Posas and Camarillo Hills. It is composed of the Simi and Springville fault zones.

Kew (1924) first mapped the Simi fault in the Simi Valley. He also mapped one trace of a north-dipping reverse fault in the eastern Las Posas Hills. Bailey (1951) extended the Simi fault westward from the Simi Valley into the Las Posas Hills, where he mapped and named one main strand. In the central part of the hills, Bailey mapped several discontinuous strands north of the main Simi fault trace. Trefzger (1957) and Ehrenspeck (1972) confirmed Bailey's extension of the Simi fault in Tierra Rejada Valley. Pasta (1958) showed that the main strand splits into two strands in the western Las Posas Hills. Recent trenching by Tierra Tech Testing Laboratory (1978) (T1, T2 and T3 on Plate I, and Figures 6, 7, and 8) confirmed the presence of two strands. Detailed geologic mapping by Stone and Associates (1969) traced the fault and several splays in the eastern Las Posas Hills in Sections 17-20, T2N, R19W (Plate I). Preliminary Report 14 (1973) and several other publications refer to the fault zone in the Las Posas Hills as the Simi-Santa Rosa fault or the Santa Rosa fault due to its proximity to the Santa Rosa Valley. Envicon (1976) described in detail the roadcut on State Highway 23 which exposed the fault plane (east of the old alluvium outcrop at the east edge of Plate I).

One trace of the Springville fault was mapped by Bailey (1951) at the south trace of the Camarillo Hills. Pasta (1958) mapped a second concealed trace of the fault in the alluvial fan deposits south of the Camarillo Hills. This second trace was confirmed by both ground water studies (Turner, 1975) and engineering geologic reports (Buena Engineers, 1973).

Both the fault sets in the Las Posas and Camarillo Hills were formed contemporaneously and are en echelon strands of the same fault system. In this report, the term "Simi fault system" is used to refer to the entire complex of east-trending reverse faults in the Camarillo and Las Posas Hills. The term "fault zone" refers to a particular set of related faults in either the Camarillo or Las Posas Hills. Because the fault zone in the Las Posas Hills is the mapped extension of the Simi fault in the Simi Valley (Bailey, 1951; Envicon, 1976), I use the term "Simi fault" zone for these faults in Las Posas Hills rather than the hyphenated "Simi-Santa Rosa fault" or "Santa Rosa fault" as have previous authors.

Simi Fault Zone. The Simi fault zone is composed of one main strand in the eastern Las Posas Hills. In the central part of the hills, the main strand bifurcates into two branches, a north and a south strand, and the fault zone contains four discontinuous fault traces to the north of the main fault trace. In the western Las Posas Hills, a north and a south strand are recognized.

In the eastern Las Posas Hills, the fault dips 75° to the north, showing reverse displacement with the north side up. In Cross Section M-M' (Plate XVII), the fault cuts the north-dipping limb of the Las Posas anticline. The Sespe Formation shows a projected separation of 3600 feet.

Near the water tank at the end of Presilla Road (on Plate I, the intersection of the Simi fault and the east boundary of Section 17-T2N-R19W), the fault separates north-dipping strata on the north from south-dipping strata. This relationship is seen in Cross Section K-K' (Plate XVI) in the central Las Posas Hills, along with numerous discontinuous fault traces (Faults A, B, C, and D) to the north of the main strand of the Simi fault (Plates XVI and XVII). The evidence for these faults is seen in the surficial geology, and the dip of the respective fault planes is in general unknown. However, Fault D does show a fault plane dip of 70°N from surface exposures mapped by Bailey (1951). Formation contacts across this faulted section are extrapolated from oil-well data in the cross sections.

Two main strands of the Simi fault cut the Shell Everett #C-2 well (14-2N-20W) (Cross Section K-K', Plate XVI). In this well, the vertical south strand brings 1, 365 feet of Sespe and at least 55 feet of pre-Sespe strata on the north against more than 1, 700 feet of Conejo Volcanics and Topanga sandstone on the south. The north strand cuts both the Shell Everett #C-2 and Shell Everett #1 (14-2N-20W) wells. This strand dips 60° near the surface, but apparently steepens at depth because it does not cut Exxon Berylwood #C-1 (14-2N-20W).

In Cross Section K-K', the north and south strand appear to merge near the surface and only one fault trace is seen at the surface. To the east, the north strand, which shows 150 feet of separation of the base of the Saugus Formation, based on the repetition of the Saugus-Sespe contact in Shell Everett #C-2, dies out and in Cross Section L-L' (Plate XVII) one main strand is recognized.

In the western Las Posas Hills, a north and a south strand can be recognized. A fault zone (19-50 feet wide) rather than a distinct fault plane was seen in trenches across the south strand (Figures 6 and 8). The north strand dips steeply north (Figure 7), and in Trench 2 the fault was logged with the south side up relative to the north. However, in Cross Section J-J' (Plate XVI), the north side is up relative to the south, which is consistent with fault motion along the rest of the Simi fault system. The true relationship (north side up) may have been obscured in Trench 2 by an old slump seen at the surface.

In Cross Section J-J', the north strand dips 65° north, causes 650 feet of offset and follows the same fault plane as a normal fault in the Sespe Formation. The south strand is located 1500 feet south of the north strand along Cross Section J-J'. The dip of the fault plane is unknown but assuming it is similar to the north strand, then the fault would cut the volcanics and Topanga sandstone in Texaco Miketta #1 (21-2N-20W). With two strands cutting the Sespe subsidence structure, the Sespe fault scarp would be perpendicular to intra-Sespe markers. With only the north strand, the fault scarp would dip in the same direction as intra-Sespe markers which is not feasible for subsidence structures. The amount of separation on both fault strands is confined by the scarp slope of the Sespe subsidence structure and is not based on any direct well data.

To the east of the study area (east of the older alluvium surface at the east edge of Plate I), the Simi fault was exposed in a roadcut during construction of State Highway 23. The fault dips 70° with Sespe strata tightly folded into an anticline and overturned on the north, faulted against Conejo Volcanics on the south side of the fault (Envicon, 1976). The fault zone is composed of gouge and highly sheared fragments of both Sespe and volcanics. A fault-polished chert pebble with many re-healed shears was found in the fault zone.

Initial movement on the Simi fault zone occurred prior to the formation of the unconformity at the base of the Saugus Formation as well as after Saugus deposition. This relationship is seen in Cross Section K-K' (Plate XVI). Restoration of the unconformity at the base of the Saugus shows that the Simi fault juxtaposes a thick section of Conejo Volcanics and Topanga Formation on the south against a sequence of Sespe and pre-Sespe strata on the north. This implies pre-Saugus movement on the north strand of the Simi fault.

Saugus Formation is also faulted. Pressler (1929), upon recognizing a sequence 30 feet thick of rocks containing Santa Barbara fauna below 100 feet of Saugus (his Las Posas Formation) in the Las Posas Hills, believed that the strata deposited there was the middle and basal members of the formation. In his stratigraphic analysis, he recognized upper Saugus (his Las Posas) in the Camarillo Hills. Although faulting probably occurred during as well as after all of the Saugus was deposited (as recently as 0.2 million years ago in the Ventura area according to Yerkes and Lee, 1979), in the Las Posas Hills there is evidence for only basal and middle Saugus being faulted. since no upper Saugus beds are found in this area. The older alluvium and alluvial fan deposits are unfaulted.

Springville Fault Zone. The Springville fault zone is located at the southern edge of the Camarillo Hills. It consists of two north-dipping strands.

The south strand is concealed by alluvial fan and old alluvium deposits. This fault cuts Texaco Converse #1 (22-2N-21W) at 5150 feet subsea (Cross Section F-F', Plate XIII) and dips 78°N; to the east, the fault cuts Union Tassano #1 (23-2N-21W) at 2530 feet subsea (Cross Section E-E', Plate XII) dipping 55°N. The south strand shows 900 feet of displacement in Cross Section F-F' and 250 feet in Cross Section E-E'. In Cross Sections F-F' and H-H' (Plates XIII and XV respectively), the south fault strand follows the same fault plane as a north-dipping normal fault in the Sespe Formation, as based on the offset of intra-Sespe markers, as shown in Cross Section F-F'. These normal faults were formed during a period of extension associated with Miocene volcanism.

On the Converse Ranch (0-0' section line on Plate I and shown in Figure 5), auger holes were drilled to determine the location of the south strand of the Springville fault. A shell bed was recognized at 25 feet depth in bore holes 5, 7, 8, and 9 which was not found in holes 3, 4, 10, and 11. This located the fault trace in the thirty-foot interval between bore holes 9 and 11. A backhoe trench south of the fault showed undisturbed sediments to the seven-foot depth of the trench. However this trench does not appear to cross the fault. In the cross section of the bore holes (Figure 5), a change in the soil sequence occurs at 12-14 feet. This may represent the youngest disturbed sediments in the fault zone. The shell bed found at 25 feet depth yielded a minimum age of 240, 000 years using uranium series dating methods. (See Appendix I.) This shell bed was not found on the south side of the fault to a depth of 60'. Thus the Springville fault here shows a minimum of 35 feet of separation. The disturbed sediments above the dated shell horizon (from 12-14 feet to 25 feet) may be part of the Saugus Formation, but an absence of marine fossils or any evidence of consolidation or bedding dip leaves this question unanswered. Thus the fault cuts strata older than 240, 000 years, but no estimate of the age of the youngest strata cut by the fault can be made.

The north strand of the Springville fault trends east-west, produces locally a steepening and overturning of beds, and forms a fault scarp 20 feet high at the base of the Camarillo Hills. The surface trace dies out to the west near the Springville dome, and to the east, it is covered by alluvium of Arroyo Las Posas and alluvial fan deposits on the eastern front of the Camarillo Hills.

In the subsurface, the north strand is not clearly defined and two possible orientations of the fault are permissible. Bailey (1951) first mapped a reverse fault in ARCO McFarland #1 (13-2N-21W) which cuts the well at -382 feet subsea with a repeat of 76 feet of Saugus grey sandstone and 36 feet of Modelo siliceous claystone (Cross Section G-G', Plate XIV). In the Oak Ridge McFarland well (13-2N-21W), 600 feet of Modelo are present which may contain a repetition of 300 feet of Modelo. However this well has no electric log, and the location of a fault in this well cannot be determined.

Using these points to contour the fault indicates an 18° dip of the fault plane (Plate V). Bailey (Cross Section H-H', 1951) showed a 20° dip of the fault plane based on a test pit across the north strand of the Springville fault. This evidence for a low-angle reverse fault however does have an alternate explanation. The thick Modelo in the Oak Ridge McFarland well could be accommodated on the Modelo isopach map without a fault repeat. The grey sandstone in Arco McFarland could be an intra-Modelo sandstone and not a repeat of the Saugus Formation.

If the north strand is a low-angle reverse fault, it also would cut several other wells in the Camarillo Hills. Repeats of the Saugus Formation may occur in Union Janss #1 (22-2N-21W), Union Janss #2 (12-2N-21W), Continental Janss #3 (22-2N-21W), and Continental Berylwood #1 (18-2N-20W). But these repeats are questionable because in the first three wells, the Saugus Formation increases in thickness westward (Cross Section E-E', Plate XII). It is difficult to determine if a thicker Saugus section is due to a depositional relationship or a fault repeat. This low-angle reverse fault appears to die out in the volcanics because wells to the north (Mobil-Franco Western-Security First National Bank, 15-2N-21W) and to the west (Mobil-Franco-Western-Standard Del Tio, 21-2N-21W) are not cut by the fault.

Because a reverse fault is seen directly in only one well and is missing in other wells where it should be found, the low angle of dip on the north strand cannot be confirmed and is proposed as Alternative A for the orientation of the north strand.

A second alternative, B, for the orientation of the north strand is a steeply-dipping reverse fault. The south strand of the Springville fault is well-documented in the subsurface to be dipping 55-78° north. Although a steeply-dipping north strand would not cut any of the wells in the study area, this configuration of two high-angle reverse faults comprising the Springville fault zone is in greater accord with relationships in the Simi fault zone to the east. Pasta (1958) believed that both strands were near vertical, although he did not give his evidence. The Springville fault zone is a ground water barrier at the base of the Camarillo Hills (Turner, 1975), and a high angle fault is a better explanation for this barrier to water flow.

Both alternatives are possible with the available data. Instead of making an arbitrary decision, both solutions are presented in this study. Cross Sections E-E', F-F', G-G', H-H' (Plates XII, XIII, XIV, and XV, respectively) and the derivative maps (Plates III, IV, VII, VIII, and IX) show the two alternate fault orientations. The low-angle reverse fault is contoured (Plate V) based on an interpretation of data from 6 wells, and only one well cut is clearly defined by the data. Because no wells are cut by the high-angle reverse fault, this alternate orientation cannot be contoured.

In the central Camarillo Hills, the east-trending Springville fault zone parallels an east-trending Sespe subsidence structure. The south strand cuts the Sespe Formation along the fault plane of a normal Sespe fault formed in the Miocene (Cross Sections F-F' and H-H', Plates XIII and XV respectively). Near the Springville dome, the south strand cuts across all previous structural trends (Plate III). The south strand of the Springville fault cannot be traced southwest of the Springville dome. There is no subsurface evidence for the fault in the Oxnard plain, and the fault appears to die out southwest of the Springville dome.

The Camarillo Hills anticline and Springville dome are bounded on the south by the Springville fault zone. The folds formed contemporaneously with the reverse fault.

The Springville fault zone cuts the Saugus Formation and older rocks in the Camarillo Hills. Pressler (1929) felt that these were upper Saugus (his Las Posas) deposits. Therefore, faulting occurred after Saugus deposition which ended as recently as 0.2 million years ago in the Ventura area (Yerkes and Lee, 1979). Older alluvium is not cut by either strand of the fault, and therefore faulting ended before deposition of the older alluvium.

The Springville fault zone and Simi fault zone are both part of the west-trending Simi fault system. The fault zones parallel for some distance subsurface structural trends of Sespe subsidence features. The two fault zones are *en echelon*, right-stepped segments of the fault system. The Somis fault may be the zone of weakness which controlled the position of this en echelon step.

Possible Lateral Offset on the Simi Fault System. Truex (1976) suggested that right lateral offset on the Simi (Las Posas fault) caused the westward movement of the Santa Monica Mountains block. Clockwise rotation of this block is suggested by the paleomagnetic results of Kamerling and Luyendyk (1979), implying left slip on bounding faults. Left lateral offset as a component of fault offset has been documented by Yeats (1976) along the Oak Ridge fault, which is the northern boundary of the Oak Ridge-Malibu Coast fault block.

In the Camarillo and Las Posas Hills, no direct evidence supporting left-lateral offset on the Simi fault system was found. This may be due to a lack of data south of the Simi fault system.

An indirect line of evidence for lateral Simi fault movement stems from correlation of intra-Sespe markers. Correlation of intra-Sespe markers north of the Simi fault system is fairly consistent (Plate VI). Markers can be traced 12 miles from the eastern Las Posas Hills across the western Camarillo Hills. In the Oxnard plain, south of the Simi fault system, a consistent set of intra-Sespe markers can also be correlated. However, it is difficult to correlate these two sets of markers across the Simi fault system. Only limited correlation is possible between Reserve Shumate-Sumpf #1 (28-2N-21W) and Chevron McGrath 11 #1 (29-2N-21W) which are only one mile apart.

If these rocks can be correlated for 12 miles on the north side of the fault, they should correlate the one mile across the fault. If lateral offset has occurred, then the rocks which are now one mile apart across the fault in which the Reserve Shumate-Sumpf #1 and Chevron McGrath 11 #1 wells may have originally been deposited many miles apart and therefore, correlation would be much more difficult. This suggests that lateral offset may have occurred, although the direction of slip, right or left is ambiguous.

Assuming left-slip, rocks south of the fault in the Las Posas Hills would correlate with rocks north of the fault further west. Because there are no deep wells adjacent to and south of the fault in the Las Posas Hills, a correlation could not be made. Assuming right slip, I tried to correlate Chevron McGrath 11 #1 (29-2N-21W) with those wells north of the fault which bottomed in Sespe. However, none of the wells seemed to correlate with the McGrath well.

Isopach of the Conejo Volcanics and Topanga Formation (Plate VIII) as well as the zero line of the Modelo Formation (Plate VII) show an abrupt change across the Simi fault zone. This is due to pre-Saugus/post-Modelo movement on the Simi fault. However, I cannot determine if movement along the fault included a lateral component of offset. Reverse faulting with subsequent erosion could by itself cause the isopach relationships seen.

Point-to-point offset cannot be demonstrated because of a lack of oil-well data south of the Simi fault system. The fault is not found in the Oxnard oil field but could conceivably extend north of the field and south of the Santa Clare Avenue field. Therefore, no definitive statement can be made on the lateral component of offset along the Simi fault system.

Camarillo Valley Lineation. The Camarillo valley lineation is the northeast-trending lineation seen in the 1927 and 1931 air photos of the city of Camarillo (Figures 12 and 13). This feature is marked by an abrupt tonal difference on the air photos, and it is the boundary between the alluvial fan coming off the Springville fault zone and the flood plain deposits of the Camarillo valley floor.

Texturally, the feature separates Holocene soils of coarse-grained alluvial fan material on the north from fine-grained alluvium on the south (McCoy and Sarna-Wojcicki, 1979). The lineation separates 2-9% slopes on the fan surface from 0-2% slopes on the flood plain.

Drainage patterns in the 1927 air photos show alluvial fan material ponding against the north side of the feature. The lineation truncates Calleguas Creek drainage patterns such as a stream meander seen in Figure 13 (locality B). Streams coming off the alluvial fan from the north abruptly swing to the southwest after crossing this boundary. The lineation does not have the lobate form characteristic of the toe of an alluvial fan. Instead, this toe appears to be truncated

65

Figure 12. Camarillo Valley.

A-A') Camarillo valley lineation

B) Calleguas Creek meander

C-C') Camarillo fault scarp

Photos K-18, L-15 Set C104

Flown 1927

Location of photos in Figure 3.

0 1500 feet

Figure 13. Detail of Camarillo valley lineation.

A-A') Camarillo valley lineation

B) Truncated stream meander

Location of photo in Figure 3.

Photo 41, Set C1910

Flown 1931

0 1000 feet

by the younger alluvium.

Preliminary Report 14 (Weber and others, 1973) shows this feature as a questionable concealed fault, and the Seismic Hazards Study (Weber and others, 1975) shows this feature as the buried trace of the Simi fault. Although the geomorphology suggests some type of truncation at this feature, I hesitate to call this lineation an extension of the Simi fault zone of the Las Posas Hills. An alternative hypothesis to a buried fault is that the lineation is the edge of a floodplain, and the truncation is due to stream erosion.

There is no definite subsurface evidence for a fault controlling the Camarillo valley lineation. In the area between the south strand of the Springville fault and the Camarillo fault, only four oil wells have been drilled. Three are located just north of the Camarillo fault and the fourth, Southern California Drilling W.P.D. #2 (26-2N-21W), was drilled in 1937 to a depth of 3,086 feet. In this well, volcanics were encountered at 1515 feet (1390 feet subsea), and no electric log was taken. This lack of data in the area of the Camarillo valley lineation does not allow a subsurface interpretation of this feature. Cross Section F-F' (Plate XIII) shows the location of the lineation. No ground water barrier is associated with this feature (Turner, 1975). However, geomorphic features seen in Figure 12 suggest that this lineation does have some effect on drainage systems in the area.

Further investigation of this feature is needed in the form of trenching or shallow seismic profiles to determine the true geologic nature of this lineation.

Bailey Fault

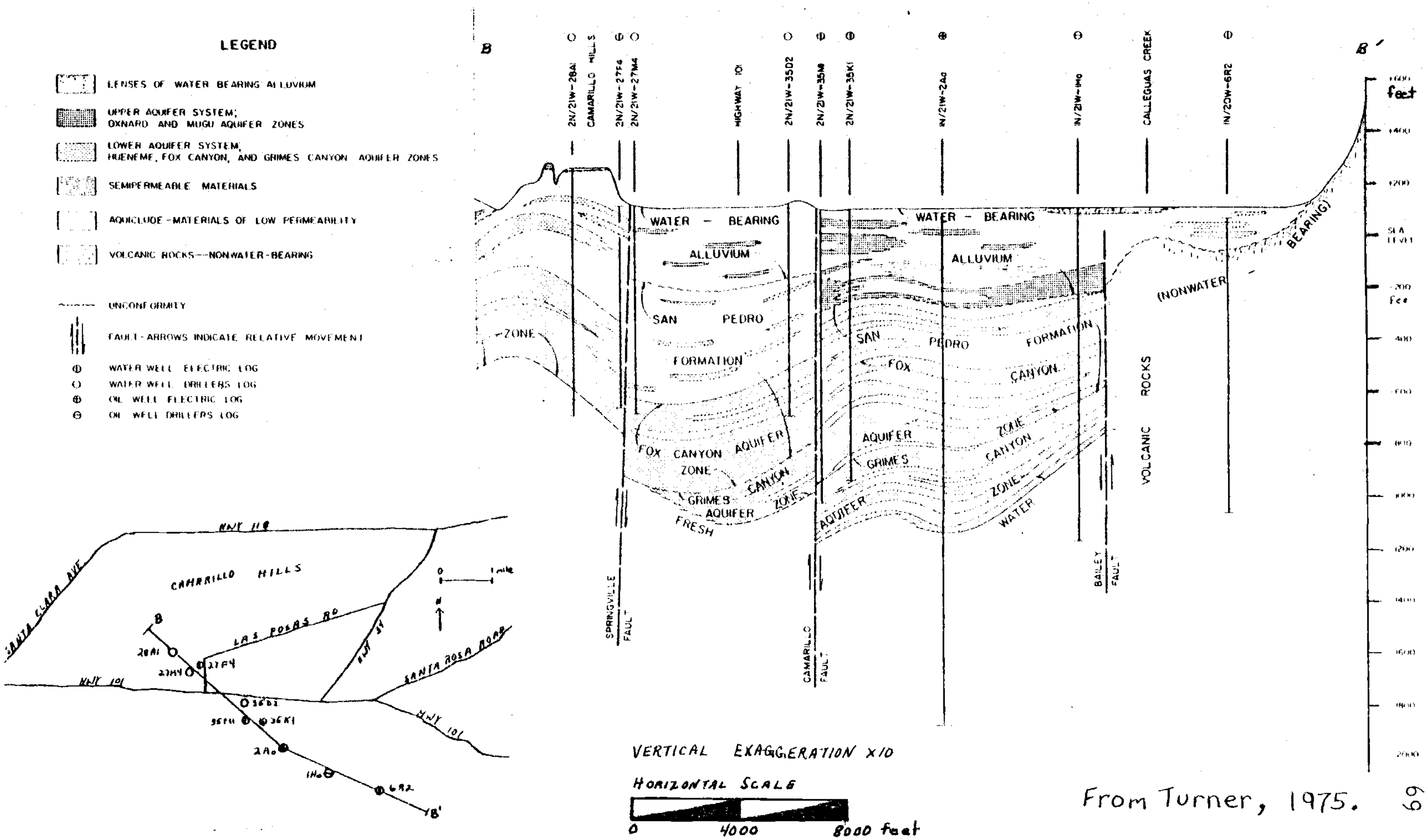
The Bailey fault was first mapped by Bailey (1951) at the embayed northwest-facing front of the Santa Monica Mountains.

In the study area, the fault trends northeast through Pleasant Valley and dies out in Santa Rosa Valley. The location of the fault is based on ground-water studies. Turner (1975) interpreted the Bailey fault as vertical, displacing Saugus (his San Pedro Formation) and the younger water-bearing alluvium (Figure 14) with 550' of vertical separation.

Cross Section I-I' (Plate XVI), using both oil- and water-well data, neither confirms nor denies the presence of the Bailey fault. The best evidence for the fault in this area is found in the geohydrology study of Mukae (1974). Contours of the base of the effective ground water reservoir in Pleasant Valley (Figure 15) shows that the water level is 600 feet higher on the east side of the Bailey fault, and the content of total dissolved solids in the water is much more variable east of the fault.

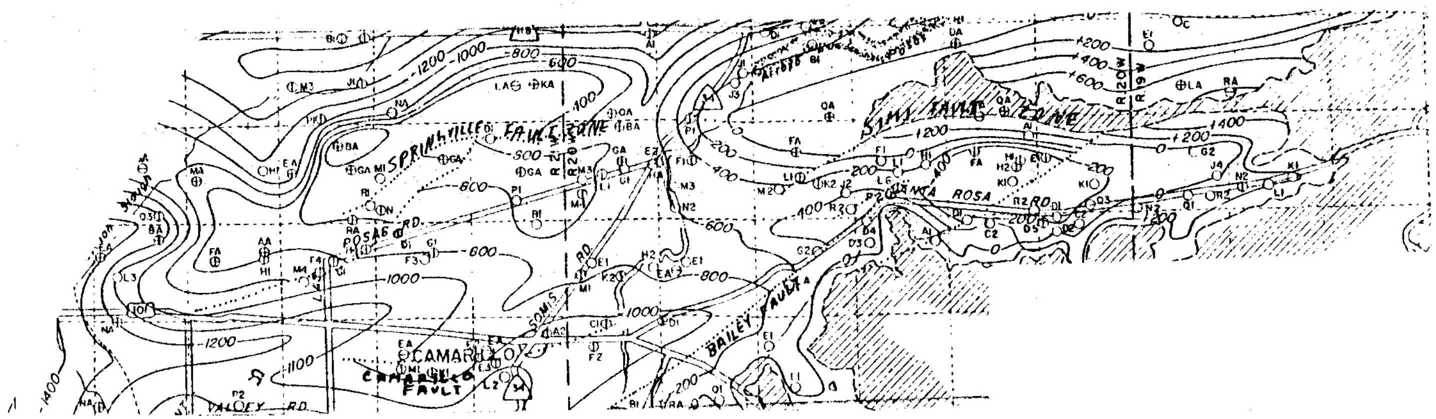
Turner's Cross Section (Figure 14) shows a buttressing of Saugus (San Pedro Formation) against the Bailey fault and an offset of lenses of water-bearing alluvium. However, the west-facing Santa Monica

Figure 14. Cross section of Camarillo, using water well data.



From Turner, 1975.

Figure 15. Base of effective ground water reservoir.



Contours on effective base of ground water reservoir. Dotted lines are faults, shaded area area is Pre-Saugus outcrop. From Turner, 1975. θ or ⊕ oil well 0 or 0 water well

Mountains range front is highly dissected and embayed rather than sharp and linear; the range front would be a Class 2 or 3 terrain as defined by Bull and McFadden (1977) which is inactive to moderately active tectonically. This implies that the major movement along the Bailey fault which uplifted the Santa Monica Mountains block, may have occurred as long ago as the time of the formation of the unconformity at the base of the Saugus Formation. In Figure 14, Cross Section B-B' (Turner, 1975) can be explained by 1) pre-Saugus Bailey fault movement with subsequent buttressing of the Saugus and water-bearing alluvium against the fault scarp; 2) post-Saugus Bailey fault movement with Saugus faulted against volcanics and a buttressing of water-bearing alluvium against the fault scarp; or 3) Bailey fault movement after deposition of the lower beds of water-bearing alluvium. No fault scarps or air photo lineations are recognized in the alluvium of Pleasant Valley along the trace of the Bailey fault. One would expect to see these features if the water-bearing alluvium was offset. Bull and McFadden's geomorphic classification of the western front of the Santa Monica Mountains would suggest that faulting predated deposition of the Saugus Formation or post-Saugus alluvium. The age of the Bailey fault cannot be conclusively determined, although movement along the fault after deposition of the water-bearing alluvium seems unlikely.

Along Santa Rosa Road, recent excavation for a new housing site exposed a fault in the roadcut. (See Figure 9 and Plate I for location.) The fault, logged by Geolabs (1978), cuts mudstone, sandstone, and gravel of the Saugus Formation. It does not offset the top 1-2 feet of soil and gravel deposits.

The fault strikes east-west and dips 80-90° to the north. Due to its proximity to the inferred trace of the Bailey fault, this was considered to be a possible extension or the real trace of the Bailey fault. Further investigations by Geolabs (1978) could not satisfactorily answer this question. The strike of the fault appears to follow the Simi fault zone and not the northeast trend of the Bailey fault. This however, does not rule out the possibility that the fault along Santa Rosa Road may be a splay from the Bailey fault.

Camarillo Fault

The east-trending Camarillo fault is located on the south side of a narrow, west-trending ridge south of downtown Camarillo. Bailey (1951) first mapped this fault with north-side-up displacement. Turner (1975) estimated 150 feet of separation of the Grimes Canyon and Fox Canyon aquifers across the fault. His Cross Section B-B' (Figure 14) shows offset of the Saugus (San Pedro) Formation and the water-bearing alluvium unconformably overlying it.

Cross Section F-F' (Plate XIII) neither confirms nor denies the existence of the Camarillo fault. Due to limited oil-well data in the area, the 150 feet of stratigraphic separation and the depiction of a vertical fault plane are taken from Turner (1975).

The Camarillo fault uplifted an old alluvium surface in a pressure ridge to the north of the fault (Plate I; Figure 12). The fault scarp is 40 feet high at the eastern end of the uplift and 10 feet at the western end where a northward plunging anticline is located in older alluvium. The decreasing height of the fault scarp and the presence of the anticline to the west suggest that the fault dies out westward, and deformation occurred by anticlinal folding instead of faulting.

The Camarillo fault acts as a barrier to ground water movement. Local drawdown of pumping wells does not extend across the fault, and ground water levels are higher on the north side of the fault (Mukae and Turner, 1975). They infer that the fault may have undergone late Quaternary movement.

The Camarillo fault has been extended eastward from the Southern Pacific Railroad to Pleasant Valley on the basis of lineations seen on 1927 and 1931 air photos in Calleguas Creek and the presence of an uplifted surface of old alluvium on trend with the fault and lineations, on which Camarillo High School is located (Plate I). This surface, although topographically lower than the one to the west, has the same steep south-facing and gentle north-facing slopes. Considering these surface and near surface relationships, contours on the base of the Saugus Formation can be drawn to show an anticline extending along the length of the Camarillo fault with the contours offset by the fault.

During faulting and the formation of the pressure ridge to the north, Calleguas Creek was able to maintain its southerly course and cut through the ridge. Development of a flood plain of Calleguas Creek eroded the pressure ridge. The east-facing slope of the ridge on which downtown Camarillo is located is a cut bank, formed by an old meander of Calleguas Creek. (The meander is shown in Figure 12). The old alluvial surface at the high school is interpreted as an isolated remnant of the pressure ridge on which downtown Camarillo is located.

The Camarillo fault cut and uplifted older alluvium, and therefore faulting post-dates deposition. Trenching is necessary to determine if younger alluvium is also offset and if the fault is presently active.

Folds

Las Posas Anticline

In the Las Posas Hills, Bailey (1951) recognized a large anticline in the subsurface. He mapped its surface trace in the western Las Posas Hills in the Saugus Formation, as Kew had in 1924. Subsurface analysis shows that the anticline had two stages of growth in the Las Posas Hills, a pre-Saugus fold which uplifted and exposed Sespe Formation in the central and eastern part of the hills and a post-Saugus fold in the central and western part of the hills the trace of which was mapped by Kew (1924), Bailey (1951) and Pasta (1958).

The pre-Saugus Las Posas anticline trends east-west, roughly parallel to the main strand of the Simi fault. The crest of the anticline is disrupted in the central part of the Las Posas Hills by discontinuous fault segments of the Simi fault zone. Structure controus on the base of the Saugus Formation (Plate III) and the base of the Conejo Volcanics-Topanga Formation (Plate IV) show that these horizons are folded in the central and eastern Las Posas Hills along the anticline. The isopach of the Conejo Volcanics and Topanga Formation (Plate VIII) shows the subcrop of the contact of the Sespe Formation with the Conejo Volcanics and Topanga Formation against the base of the Saugus Formation. The map pattern of this contact demonstrates the erosion of volcanics and Topanga sandstone prior to Saugus deposition due to uplift of the Las Posas anticline. Paleogeology on the base of the Saugus Formation is shown on Plate VII.

The anticline did not have much topographic relief. Saugus Formation onlapped the fold from the north (Bailey, 1951) and the south (Cross Section K-K', Plate XVI) and completely covered the structure.

After Saugus deposition, the anticline was cut by movement along the Simi fault zone. The fault cuts the north-dipping limb of the fold in the eastern Las Posas Hills (Cross Section M-M', Plate

XVII), and the south-dipping limb in the central part of the hills where the crest of the fold is disrupted by movement along Faults A, B, C and D. At depth, the Simi fault zone cuts the north-dipping limb of the anticline in the central and western Las Posas Hills (Cross Section J-J', Plate XVI). The Las Posas anticline was formed prior to faulting, and the fault cut across the pre-Saugus fold at depth.

Movement along the Simi fault zone in the central and western Las Posas Hills was accompanied by folding of the Saugus Formation north of the fault zone. The axis of this Saugus fold was mapped by Kew (1924), Bailey (1951) and Pasta (1958). I have extended the fold axis eastward on the basis of surface dips in the Saugus Formation. The axis intersects the main strand of the Simi fault in the central Las Posas Hills. The post-Saugus folding of the Las Posas anticline is contemporaneous with the formation of the Camarillo Hills anticline and the Springville dome. The present topography of the Las Posas Hills is a result of uplift and continued folding in the area after the deposition of older alluvial deposits.

Santa Rosa Syncline

Bailey (1951) mapped and named the Santa Rosa syncline in the central Santa Rosa valley. This broad structure downwarps Conejo Volcanics and Topanga Formation and Saugus Formation. It is concealed by alluvial fan deposits and older alluvium.

The syncline is identified by the surface geology and descriptions from water wells in Santa Rosa valley. No oil wells have been drilled in the valley. Contours on the base of the Saugus Formation (Plate III) clearly delineate the fold.

The 20-30° north-dipping homocline of the Conejo Hills forms the south limb of the syncline (Figure 11). The north limb is cut by the main strand of the Simi fault, where south-dipping beds are locally steepened.

The Santa Rosa syncline formed in conjunction with the Las Posas anticline before Saugus deposition. Conejo Volcanics and Topanga Formation and possible Modelo strata were preserved in the syncline in the eastern Santa Rosa Valley. Saugus deposits then filled in the synclinal basin. After Saugus deposition, movement along the Simi fault zone disrupted the shared south-dipping limb of the pre-Saugus Las Posas anticline and Santa Rosa syncline. Saugus deposits were folded in the eastern Santa Rosa Valley during faulting. Older alluvium was folded in Santa Rosa Valley after surface faulting had ceased.

Camarillo Hills Anticline

The Camarillo Hills anticline was mapped by Kew (1924) along the east-trending crest of the Camarillo Hills. Bailey mapped the fold with a westward plunge in 1951.

The limbs of the broad symmetrical fold dip 20°. The south limb is steepened locally along the north strand of the Springville fault. In the subsurface, the base of the Saugus Formation and the base of the Conejo Volcanics and Topanga Formation are folded by the anticline, as demonstrated by structure contours (Plates III and IV).

The Saugus Formation onlaps the unconformity at the top of the Modelo Formation from the west in the Oxnard plain and western Camarillo Hills (Cross Sections A-A' and C-C', Plates X and XI respectively). But the Saugus is of uniform thickness over the Camarillo Hills anticline (Cross Sections D-D' and F-F', Plates XI and XIII respectively). Older alluvium surfaces are uplifted and warped on the top of the Camarillo Hills. Younger alluvium is not affected by folding.

The Camarillo Hills anticline is bounded on the south by the Springville fault zone. The anticline formed in response to reverse faulting with the north side up relative to the south along the Springville fault zone, which began to form after the end of Saugus deposition. After faulting, older alluvium was deposited in the Camarillo Hills and was then later uplifted.

Springville Dome

Kew (1924) mapped a westward-plunging anticline in the southwestern segment of the Camarillo Hills. Bailey (1951) also mapped an eastward plunge on this fold and named this west-trending structure the Springville dome. The broad, flat-topped, anticline involves an uplifted surface underlain by older alluvium and exposes Saugus Formation on its flanks. The limbs of the anticline dip 20° with the Saugus more steeply dipping than the gently-folded older alluvium. The Springville dome affects structure contours on both the base of the Saugus Formation (Plate III) and the base Conejo Volcanics and Topanga Formation (Plate IV). The Saugus is of uniform thickness across the dome (Cross Section C-C', Plate XI), and the crest of this flat-topped hill is composed of a thin capping of old alluvium. Thus the Springville dome, like the Camarillo Hills anticline, formed after Saugus deposition. A small west-trending syncline is located between the two anticlines the Springville dome formed in response to reverse faulting along the south strand of the Springville fault, which bounds the anticline on the south.

Warped Older Alluvium

Older alluvium (as mapped and defined by McCoy and Sarna-Wojcicki, 1979) throughout the study area is uplifted, dissected, and commonly warped. Bailey (1951) mapped several broad folds in the older alluvium (Quaternary terrace deposits) in the Las Posas and Camarillo Hills area. Several folds are present in the southwestern extension of the Las Posas Hills.

The Camarillo fault uplifts a surface of old alluvium and tilts this surface to the north. At the western end of the fault, a northwest-plunging asymmetric anticline is present. Structure contours on the base of the Saugus Formation (Plate III) reflect these broad folds in the Camarillo valley. Deformation of these surfaces indicates the youthful nature of the tectonism.

After Saugus deposition, the region had low relief, and the older alluvium was deposited in a nearly continuous sheet over the area. The central Las Posas anticline had some topographic relief, and older alluvium was deposited only on its flanks. As the region was deformed, these surfaces were uplifted and gently warped.

The older alluvium deposits were warped by the continued folding in the Camarillo and Las Posas Hills. The Simi fault system may have been active at depth, causing the surface warping without ground rupture. Older alluvium was also folded in Santa Rosa Valley and the west side of Pleasant Valley. This folding may also have been related to the Simi fault system at depth, or it could be a result of regional north-south compression.

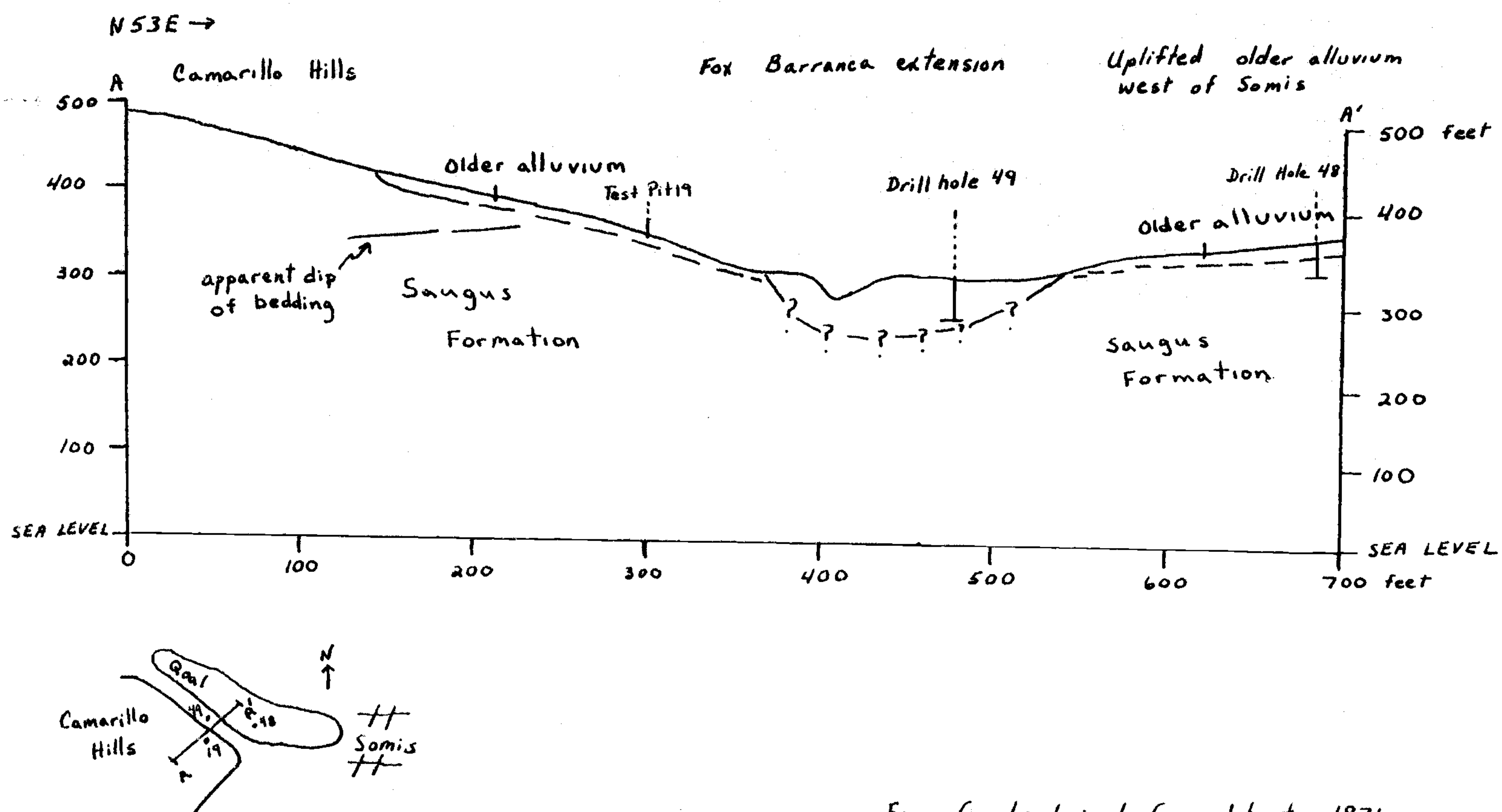
GEOMORPHOLOGY

Examination of air photos from the Fairchild Collection of Whittier College taken in 1927, 1931, 1935, 1938, and 1941 helped work out the geomorphology of the area. Drainage patterns mapped on Plate I are based on these old air photos.

At the eastern end of the Camarillo Hills, an uplifted surface underlain by old alluvium is located between the town of Somis and Fox Barranca. It is separated from the main portion of the hills by a narrow valley, the southeastern projection of Fox Barranca, which does not contain a major stream and is now a wind gap. The wind gap contains over 50 feet of alluvium which rests unconformably on Saugus (Figure 16) (Geotechnical Consultants, 1971). A stream channel ten feet deep entrenched in the alluvium, is eroding headward to the northwest with a drainage divide within the wind gap. The old alluvium (Qoal) surface to the east is only a thin capping of sediments over Saugus Formation.

The 1927 air photos show that the main channel of the Fox Barranca formerly flowed through this wind gap between the Camarillo Hills and the uplifted surface to the east. As the Camarillo Hills anticline formed and the thin capping of older alluvium was uplifted, the ancestral Fox Barranca stream was able to maintain its course and cut a narrow canyon in older alluvium and Saugus Formation. The

Figure 16. Cross Section of eastern Camarillo Hills.



From Geotechnical Consultants, 1971.

old alluvial surface to the east is, therefore, the eastern end of the Camarillo Hills anticline. The thick section of alluvium in the valley may represent a period of subsidence when deposition in the valley occurred or the 50 feet of alluvium may represent the active bedload of the Fox Barranca stream during major floods. Fox Barranca is now diverted artificially east of the old alluvial surface through the town of Somis.

A predominant southwest-flowing drainage is seen northeast of downtown Camarillo (Plate I and Figure 13). This pattern is disrupted by the uplifted old alluvium surface to the north of the Camarillo fault. The uplift of this surface caused the drainage of Arroyo Las Posas and Calleguas Creek to bifurcate around this feature. Calleguas Creek was able to maintain its southerly course and cut through the old alluvium as it was being uplifted. Development of a flood plain along Calleguas Creek further eroded the old alluvial surface. Figure 13 shows an old stream meander immediately to the east of the uplifted surface. Presently, a remnant of this surface, now occupied by Camarillo High School, is isolated in the southwest part of Pleasant Valley separated from its much larger extension in downtown Camarillo by the flood plain of Calleguas Creek. Old air photos show west-southwest drainage patterns between the Camarillo valley lineation and the city of Camarillo (Figure 12). This drainage has been abandoned in favor of Calleguas Creek. The present gradient in the Calleguas Creek floodplain is steeper than that south of the Camarillo valley lineation, favoring abandonment of the Camarillo valley drainage. This change in gradient may have been caused by slight uplift of the area south of the Camarillo valley lineation with respect to Pleasant Valley as the Camarillo Hills and the pressure ridge in downtown Camarillo were uplifted.

At the western end of the Springville dome, the 1927 and 1931 air photos show an odd, circular drainage pattern in the alluvium. (See drainage pattern southeast of the intersection of Central Avenue and Beardsley Road, Plate I). There is no topographic rise in the center of this feature. This may be caused by the west-trending nose of the Springville dome anticline, although the axis would be offset northward. It may also be evidence of early human habitation.

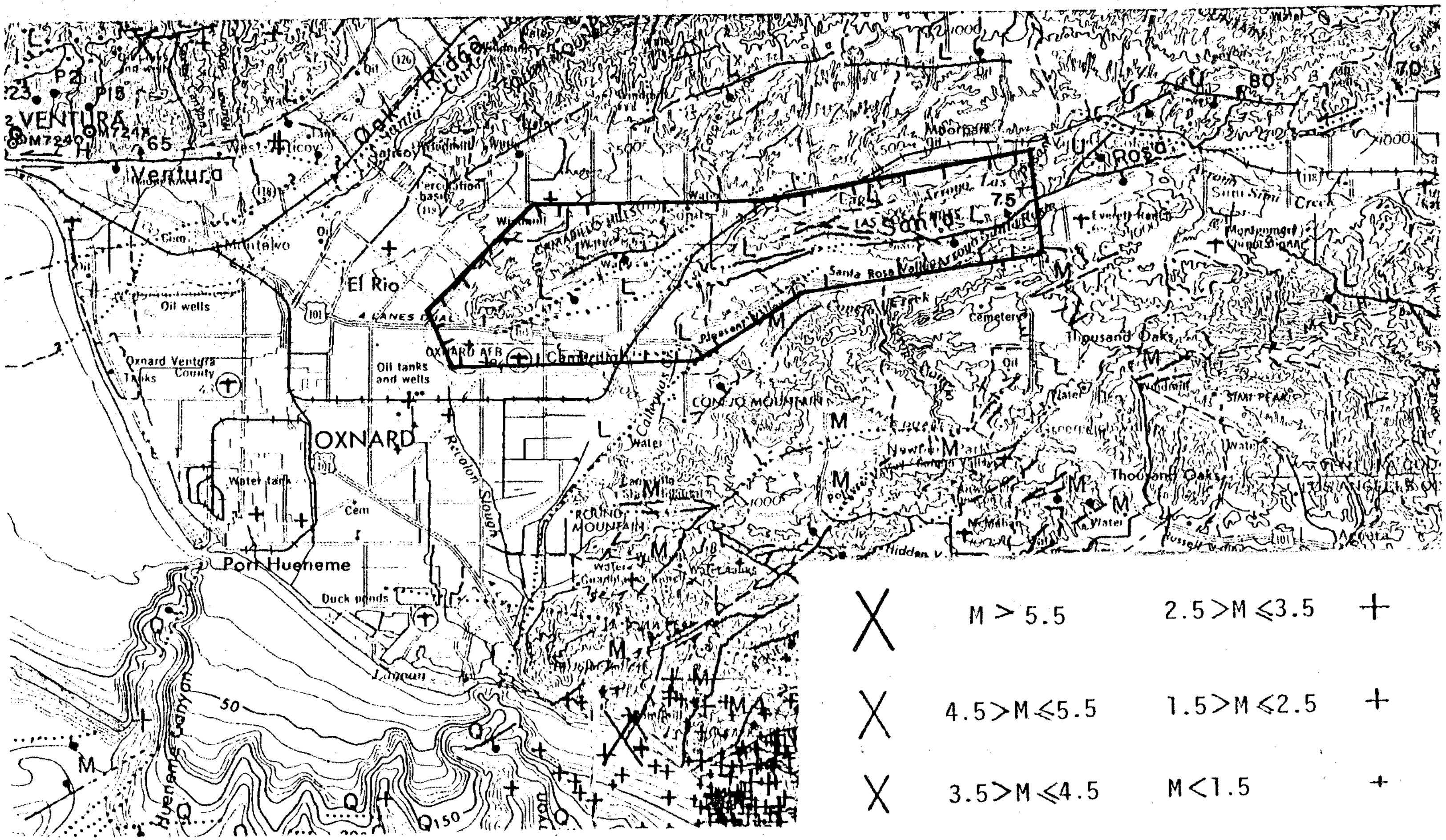
SEISMICITY

The Camarillo-Las Posas Hills area has been aseismic since detailed recording of seismic events began in 1932. From the period 1932-1974, no earthquakes have been located along the trace of the western half of the Simi fault system. However, a magnitude 3.1 event occurred along the eastern half of the trace of the fault (Latitude 34° 16.6', Longitude 118°49.2') on November 28, 1969. The epicenter was at a 10 km depth. The California Institute of Technology-Seismology Laboratory is presently determining the focal mechanism of this event.

Yerkes and Lee (1979) mapped epicenters in the western Transverse Ranges from 1970-1975 (Figure 17). Although no events were located on the Simi fault (their Santa Rosa fault as shown on Figure 17), seven events were present in the Oxnard Plain on a westerly projection of the south strand of the Springville fault. This set of events trends northeast-southwest towards the Hueneme submarine canyon (Green, 1978). This submarine canyon may be fault-controlled as is the Mugu Canyon. The events range in magnitude from less than 1.5 to 2.5.

This set of events may be related to the abrupt southeastward increase in thickness of the Conejo Volcanics. Isopachs of the Conejo Volcanics show a steep gradient parallel to the epicenter mapped by Yerkes and Lee (1979). Because this structural feature is pre-Pliocene in age, the distribution of earthquakes may reflect only the structural anisotropy of this isopach gradient.

Figure 17: Earthquake epicenters 1970-1975.



Study area enclosed. From Yerkes and Lee, 1979.

SEISMIC AND GROUND RUPTURE HAZARDS

Active geologic structures constitute two types of hazards to the local inhabitants; a ground rupture hazard where surface materials are disrupted by movement along a fault surface and a seismic hazard where an earthquake and related ground shaking are caused by fault movement at depth. The potential hazard of faults in the study area can be classified in this manner.

Those faults that have not moved since the formation of the unconformity at the base of the Saugus Formation are considered inactive and do not present a hazard to the general public. These include the normal faults in the Sespe Formation, the Somis fault and the reverse faults in the Oxnard plain.

Those faults that do cut the Saugus Formation are potentially active and present a potential hazard. The Simi and Springville fault zones cut the Saugus Formation but do not cut the older and younger alluvial deposits. These deposits are uplifted and warped which may indicate that the Simi fault system is active at depth even though faulting does not reach the surface. Therefore, the Springville and Simi fault zones would represent more of a seismic hazard than a ground rupture hazard.

The Camarillo fault cuts and warps older alluvium. Ground rupture could occur along this fault with any subsequent fault movement. The fault may also indicate a seismic hazard because movement of the fault at depth could produce an earthquake. The Camarillo fault is the youngest fault in the study area and therefore has the greatest potential for fault activity.

The potential hazard of the Bailey fault is speculative because the age of the last fault movement is unsure. If the age of fault movement is pre-Saugus, it does not present a seismic or ground water hazard. If it is post-Saugus, it would present a seismic hazard. Because there is no evidence for faulting of surficial materials in Pleasant Valley, it appears the Bailey fault does not indicate a ground rupture hazard.

The Springville, Camarillo and Bailey faults are each no more than 10 km long. If this represents the maximum length at depth of earthquake generation, this would minimize the seismic moment of an earthquake which activated one of these faults along its entire length. In contrast, the Simi fault east of Calleguas Creek is relatively continuous and extends east, beyond the area. It is 30 to 40 km long. The seismic moment of an earthquake which activated the Simi fault along its entire length of 30-40 km would be several times that of an earthquake along one of the western faults.

The observation that the Simi fault system dies out west of Springville dome, together with mapping to the east, indicates that total displacement would indicate a westward decrease of seismic moment or a westward increase in recurrence interval or both. If the moment history of the fault indicates the fault is propagating westward with time, as is suggested by the features of the pressure ridges at the west, it may constitute a greater seismic hazard. Data are inadequate to resolve the problem.

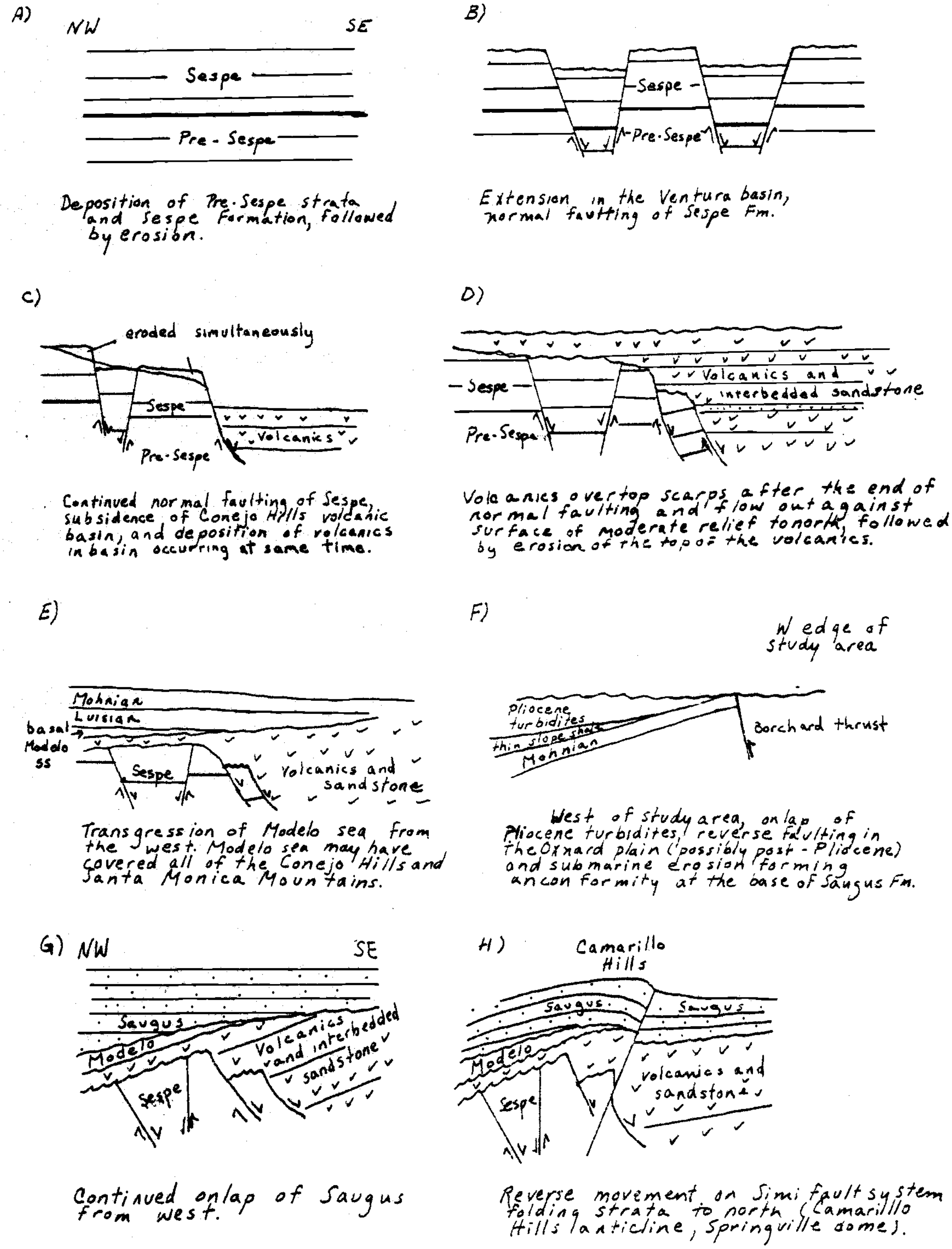
GEOLOGIC HISTORY

The oldest rocks recognized in the Las Posas and Camarillo Hills are a sequence of pre-Sespe marine siltstone and sandstone. The oldest rocks drilled are sandstone thought to be Cretaceous in age. Eocene strata in the southern Ventura basin were deposited in a regressive, marine environment (Sage, 1975; Howell, 1974), although evidence for this has not been found in the study area. During the middle Eocene, dark grey, carbonaceous siltstone was deposited near shore on a broad, low-relief shelf, which received a high influx of terrigenous sediment rich in organic matter.

This regression culminated with the deposition of the nonmarine Sespe Formation of late Eocene to early Miocene age. The continental, alluvial fan deposits of the Sespe Formation were derived from braided streams which were tributaries to a main westward-flowing river (McCracken, 1972). The study area is part of the finer grained Sespe deposits of the Poway fan with northwest-trending paleocurrents, as suggested by Yeats and others (1974).

In the Big Mountain area, northeast of the study area and in the Santa Monica Mountains, south of the area, the Sespe is overlain unconformably by lower Miocene sandstone and siltstone of shallow marine facies; this is referred to as the Vaqueros Formation. This formation has not been recognized in the study area, despite

Figure 18. Geologic evolution of the Camarillo Hills and the Las Posas Hills.



identification in the AAPG regional cross section across the Oxnard plain (Paschall and others, 1956).

In the early and middle Miocene, Topanga marine sandstone was deposited on the Sespe in the Santa Monica Mountains southeast of the study area. Miocene volcanism was initiated in the Santa Monica Mountains at the time of the encounter of the East Pacific Rise and the North American continent and extension occurred in the Ventura basin, forming normal faults. Extensive amounts of submarine basalts were extruded from one or more local centers in the Conejo Hills. The thick localized volcanic pile caused subsidence of the surrounding Sespe Formation along south-dipping normal faults. Some northward and westward tilting of the Sespe occurred due to rotational movement of the down-dropped fault blocks. Many of the normal fault scarps were affected by either subaerial or submarine erosion. Several submarine scarps, closer to the volcanic pile, were preserved. Conejo Volcanics and Topanga sandstone buttressed against the submarine fault scarps, filling in the downthrown sides of the scarps as subsidence continued. As volcanism continued, the volcanic center in the Conejo Hills became emergent. Basalt flows capped the eroded fault scarps. These were subaerial flows in the Conejo Hills (Williams, 1977) and the upper parts of the fault scarps may have been emergent. However, the Conejo Hills volcanics may have been seamounts in a Topanga sea. The flows extended in thin sheets across the region and were diverted around topographic highs such as South Mountain (R. S. Yeats, personal commun., 1979). Minor subaerial or submarine erosion of the volcanics occurred before the transgression of the Modelo sea.

There is no evidence for the clockwise rotation of the Conejo Hills during the Miocene as suggested by paleomagnetic data (Kamerling and Luyendyk, 1979) found in this area. However, this hypothesis cannot be disproven by the present study.

During the Mohnian (late Miocene), a deep water marine environment extended probably across the entire Santa Monica Mountains and Conejo Hills (Hoots, 1931). Siliceous claystone, chert and thin beds of limestone were deposited on a relatively stable structural shelf.

A major period of deformation and a marine regression occurred after Modelo deposition. In the Oxnard plain, reverse faulting along the Borchard Thrust and Fault E took place prior to the deposition of the Saugus. Left lateral movement occurred along the Somis fault. Large-scale movement along the Bailey fault downdropped rocks in the Oxnard plain. Subsequent uplift of the Santa Monica Mountains to the south caused an erosion of the Miocene and older rocks in the area, and led to a regional northwest tilt of the strata. The unconformity at the top of the Modelo Formation was produced by submarine erosion on a steep paleoslope (Yeats, 1965).

Northwest of the study area, a slope shale and Pliocene turbidites onlap this unconformity. Another unconformity is developed between these turbidites and upper Fernando deposits. In the study area, the unconformity at the base of the Saugus represents both these periods of erosion. Reverse movement occurred on the Simi fault zone accompanied by the formation of the Las Posas anticline and Santa Rosa syncline before the Saugus was deposited. Erosion along the anticlinal crest exposed Sespe Formation in the central and eastern Las Posas Hills and remnants of possible Modelo strata are preserved in the Santa Rosa syncline at the east end of Santa Rosa valley.

With the influx of coarse clastic Saugus sedimentation, the paleoslope represented by this unconformity was buried under Saugus sandstone and mudstone. These shallow marine deposits onlapped the study area from the west and onlapped, then buried, the emergent Las Posas anticline.

When Saugus deposition ceased, possibly as recently as 0.2 million years ago, the area had low relief with a slight topographic high in the Las Posas Hills. Reverse faulting along the Simi and Springville fault zones locally deformed Saugus beds into anticlines sub-parallel to the fault. The faults are parallel to the subsidence structures in the Sespe in the western Las Posas Hills and the central Camarillo Hills and commonly follow the fault plane of a Sespe normal fault. Near the Springville dome, the fault cuts across older structures. The Camarillo Hills anticline, Springville dome and the post Saugus Las Posas anticline formed in response to reverse faulting along the Springville and Simi fault zones.

Older alluvium was deposited in broad river systems over the study area, onlapping the topographic high in the Las Posas Hills. Continued deformation in the Camarillo and Las Posas Hills uplifted and warped the older alluvium deposits, producing the present topography. The Simi and Springville fault zones may have been active at depth, causing uplift but not faulting surface deposits.

The Camarillo fault uplifted and folded an older alluvium surface. As the Camarillo fault moved, the pressure ridge to the north was eroded by the antecedent Calleguas Creek. Younger alluvium was then deposited in the lowlands. This alluvium may be cut by the Camarillo fault.

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APPENDIX

APPENDIX I

Letter from Margaret Kimmel, University of Southern California to Buena Engineers

Regarding the analysis of the fossil shells received Dec. 11, 1973 the following results were obtained:

$U^{234}/U^{232} = 0.67 \pm .03$

$U^{234}/U^{238} = 1.34 \pm .06$

$U = 2.44 \pm .12$ ppm

$Th^{230}/Th^{228} = 0.65 \pm .04$

$Th^{232}/Th^{228} = 0.034 \pm .01$

$Th = .37 \pm .10$ ppm

$Th^{230}/U^{234} = 1.02 \pm .08$ (age = > 240, 000 yrs.)

The Th^{230}/U^{234} age which has been derived is based on the theory that thorium (and protactinium) isotopes are initially absent in a sample and that time progresses Th^{230} will grow in due to the decay of its parent U^{234} until it is finally in equilibrium with it, that is, the Th^{230}/U^{234} ratio equals 1.00, which takes 600, 000 years. All samples older than 600, 000 years would thus have a ratio of 1.00 no matter what their age. The equation which relates the age of the sample to its Th^{230}/U^{234} ratio is given below:

$$Th^{230}/U^{234} = U^{238}/U^{234}\,(1-e^{-\lambda_{Th^{230}}t}) + (1-U^{238}/U^{234})$$

$$\left(\frac{\lambda_{Th^{230}}}{\lambda_{Th^{230}}-\lambda_{U^{234}}}\right)(1-e^{(-\lambda_{Th^{230}}+\lambda_{U^{234}})t})$$

where t = age of the sample

$\lambda\, U^{234}$, Th^{230} are the respective decay constants

Th^{230}/U^{234}, U^{238}/U^{234} are activity ratios

In order for the age to be valid, the thorium (and protactinium) content of the sample must be zero or negligibly small. A good indication of this is the Th^{232} content. The Th^{230}/Th^{232} ratio should be at least twenty and thorium content less than 0.5 ppm to yield reliable ages. In addition, no thorium, uranium, or protactinium should have entered or left the system. (Closed system) This is more difficult to ascertain, since uranium concentrations are so variable. Anomalously high or low contents and U^{234}/U^{230} ratios (differing by an order of magnitude from 2 ppm and 1.2 respectively) indicate open systems.

When the two independent age determinations based on Th^{230}/U^{234} and Pa^{231}/U^{235} agree with each other (concordancy) then that age must be assumed correct, since it would be a very fortuitous set of circumstances where an open system would yield the same thorium and protactinium ages. The same is true of Th^{230}/U^{234} and Pa^{231}/U^{235} ratios of 1.00.

The determinations of the various isotopic ratios is accomplished by alpha spectrometry for uranium and thorium and by alpha and beta counting for Pa^{231} and its yield tracer Pa^{233}. 4.689 dpm of U^{232} and Th^{228} (isotopes which do not occur in nature) were added to 1.736 grams of cleaned sample, along with 1.30 grams Pa^{233} tracer. The sample was dissolved and the isotopes separated on anion and cation exchange columns. Each solution was then purified and extracted into thenoyltrifluoroacetone in benzene and plated onto a stainless steel planchet for counting. Ratios are determined by counting the dpm's in a twenty channel envelope at the appropriate energy for the alpha decay of each isotope in question. Pa^{231} is determined by calculating the percent yield of the tracer by beta counting, then counting alpha disintegrations of Pa^{231} and correcting for the yield.

Errors in ratios and age estimates are based on counting errors and represent 1 standard deviation. The Th^{230}/U^{234} ratio of 1.02 could be in fact as low as 0.94 (240,000 yrs. old). Theoretically, the Th^{230}/U^{234} ratio cannot exceed 1.00 unless the sample has been altered. Dr. T. L. Ku of the University of Southern California was also consulted in this analysis and concurred that within experimental error, the ratio is a reliable indication of the true age of the sample. Thus, the conclusion that we can draw from the analysis is that the sample is at least 240,000 years old or more.